Dormont Park PassivHaus

Phase 2 study
In-use and post-occupancy

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InnovateUK project number	450097
Project author	Glasgow School of Art, Mackintosh Environmental Architecture Research Unit (MEARU) for Dormont Estate
Report date	2015
[1]InnovateUK Evaluator	N/A

No of dwellings	**Location**	**Type**	**Constructed**
Four	Lockerbie	Semi-detached	2011

Areas	**Construction form**	**SAP v9.81 rating**	**Certification level**
2-bed units: 87 m^2 3-bed units: 103 m^2	Off-site timber frame	2-bed units: 93 (A) 3-bed units: 92 (A)	PassivHaus

Background to evaluation

The development studied involved eight new build-houses, comprising four 2-bed and four 3-bed 2-storey, semi-detached dwellings designed to the PassivHaus standard. The BPE study was undertaken on four dwellings: two 2-bed cottages and two 3-bed cottages. The design and procurement processes were regarded as exemplary. The BPE monitoring involved non-invasive testing of the building fabric to provide an indication of construction quality. Each dwelling underwent two air permeability tests while *in situ* U-value tests were undertaken to the roof and wall in one dwelling Thermographic surveys were undertaken in all dwellings.

Design energy assessment	**In-use energy assessment (SAP)**	**Sub-system breakdown**
Yes (details in Figure 2.7, p.9)	Yes (details in Figure 2.7, p.9)	Partial

Space heating was achieved through mechanical ventilation with heat recovery (MVHR), and water heating by wood stove and solar thermal systems. SAP predictions were said to be fairly accurate for energy consumption, but not for energy costs, which were between 3 and 4 times higher, due mainly to inaccurate unit costs within SAP. The most difficult aspect on site was achieving the required level of airtightness. The plumbing and electrical works were contractor design packages and proved the most problematic post-completion. Apart from issues associated with occupants' understanding of the active services, the main issue for occupants was overheating.

Occupant survey type	**Survey sample**	**Structured interview**
BUS domestic	7 of 8 (87% response rate)	Yes (plus occupant diaries)

Overall, the houses were well received. The only significant issue for occupants appeared to be overheating in the summer. Note: Researchers and students should be wary of the data interpretations from the BUS survey, as there appears to be some misunderstanding of the statistical data that was derived from very small (local) samples. The local responses from each survey respondent are more insightful than the BUS scores aggregated from the individual dwellings (i.e. from local, specific contexts). The reported contradictions between the averaged scores and individual free-text responses therefore need to be read with some caution.

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Acronyms

AASHP	Air to Air Source Heat Pump
ACH	Air Changes per Hour
ATTMA	Air Tightness Testing and Measurement Association
BPE	Building Performance Evaluation
GSA	Glasgow School of Art
HA	Housing Association
HFP	Heat Flux Plate
IAQ	Indoor Air Quality
LCH	Low Carbon Homes
MEARU	Mackintosh Environmental Architecture Research Unit
MVHR	Mechanical Ventilation and Heat Recovery
NHBC	National House Building Council
PH	Passivhaus
PHPP	Passivhaus Planning Package
PoE	Post Occupancy Evaluation
RH	Relative Humidity
SPHC	Scottish Passive House Centre
STS	Solar Thermal System
VOC	Volatile Organic Compounds

1 Introduction and overview

1.1 The Dormont Park Passivhaus Development

The Dormont Estate is situated close to Lockerbie in rural Dumfriesshire. It has 400 hectares of farmland and 100 hectares of woodland, salmon fishing on the River Annan and 12 houses and cottages for rent. In July 2011 8no newbuild houses were added to this total, comprising 4no 2-bed and 4no 3-bed 2-storey, semi-detached houses designed using traditional features around a communal court. The rural setting and in particular the existing traditional sandstone cottages next to the site, required a sensitive design which blended in well and respected the scale, details and colours of the existing buildings.

Figure 1.1: View of the new development from the East, showing four dwellings each side of a shared, landscaped area and existing sandstone properties beyond, within a rural setting.

Beautiful though rural Annandale may be, its two principal drawbacks are that it is a part of a low wage economy and it is not on the mains gas grid. Taken together these lead to high levels of fuel poverty. By offering homes that need no heating to local households in priority need, on long term leases at affordable rents, the development at Dormont Park sought to address these two issues head-on. The new houses were designed to the German Passivhaus standard due to the Estate's conviction that this was the best approach to reduce fuel poverty and ensure high quality, comfortable low energy buildings optimising the benefits of renewables within the wider remit of rural sustainability and the oncoming requirements for zero carbon construction in 2016. The houses were all oriented due south with south facing main living spaces to allow large areas of glazing for solar gain.

The project was part of the Scottish Government's Rural Homes for Rent pilot programme, which was aimed at levering private investment to deliver affordable housing in rural areas. The scheme provided partial grant funding for the project, however the funding limits did not make provision for any extra costs of delivering homes to Passive House standards. It became a fundamental part of the project brief to deliver the houses within normal commercial budgets.

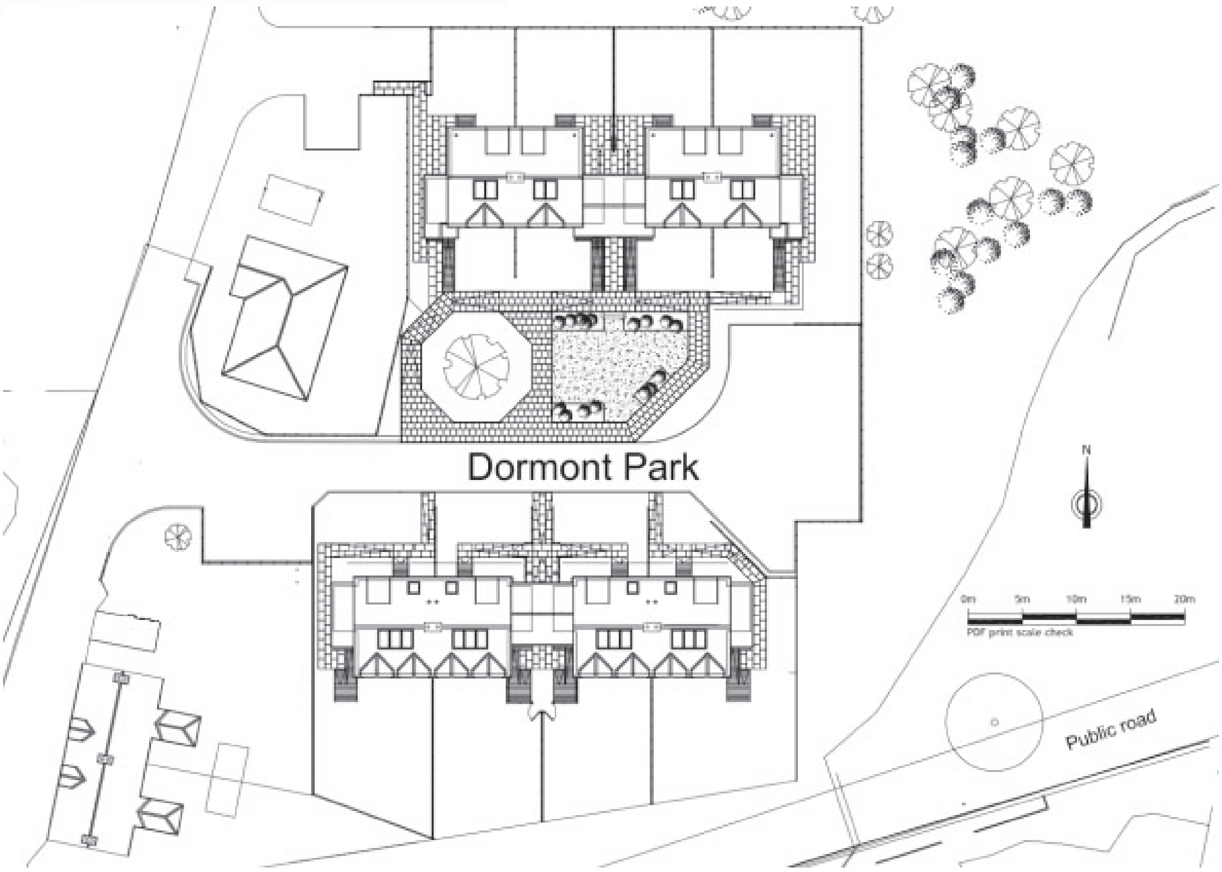


Figure 1.2: Site Plan of the new development showing the three existing cottages to the left and 8no new build homes. Living Spaces for both rows of four face South.

1.2 The BPE Project

The BPE study was undertaken on four of the total of eight dwellings. The chosen dwellings included 2no 2-bed cottages ('DA1' and 'DA2') and 2no 3-bed cottages ('DB1' and 'DB2') which can be seen in the site plan above. Each house is constructed using an identical construction methodology.

The project offered the opportunity to study a number of issues, including the effect of different occupancies on identically built houses, how close in a rural setting the development could get to becoming 'zero carbon', the success or otherwise of the Passivhaus approach, and of the active and renewable energy tactics chosen as well as the success or otherwise of the use of offsite construction.

This study examines the relationships between design intentions and predictions, impacts of the procurement process, users' experiences and perceptions of the design, and metered environmental and energy performance. Occupant engagement, in the form of diaries, and the testing of improved occupant guidance were included as part of the project.

The project team consisted of:

Dormont Estate	Jamie Carruthers Cathy Duff	Based at Dormont and acting as the project lead, DE provided support with contacting residents, arranging visit times and undertook some survey work.
Mackintosh Environmental Architecture Research Unit (MEARU)	Tim Sharpe	Based at the Mackintosh School of Architecture in Glasgow MEARU was the academic subcontractor to DE. MEARU undertook testing, survey work, and environmental and energy

	Donald Shearer Chris Morgan	monitoring analysis through sub-contracts to T-mac and Orsis, and report writing.

Figure 1.3: BPE project team

The key facts for the development are as follows:

Name of Project	Dormont Park Passivhaus
Address	Dormont Estate, Lockerbie, Dumfriesshire, DG11 1DJ, Scotland
TSB Reference	450097
Occupation Date	Practical Completion July 2011
Procurement Method	**Design & Build (CCG Construction)** **Planning / Building Control Approval by White Hill Design Studio (Project Architect: David Major)**
Unit Types	4no Semi-detached pairs. 4no 2-bed units, 4no 3-bed units Units studied were 2no of each.
Floor Area	**2-bed Units: 87 sq.m,** **3-bed Units: 103 sq/m**
(Design) SAP Rating	**2-bed Units:** 93 A (SAP Version 9.81) **3-bed Units:** 92 A (SAP Version 9.81)
Occupancy Patterns	Various
Fabric: U value (W/m2K) **Fabric build-up** **(Design Values)**	Roof: 0.1 – pitched, mineral wool between timber rafters, rigid PUR board beneath Wall: 0.1 – mineral wool between timber studs, PUR board internally Floor: 0.1 – 200mm rigid XPS over RC slab Windows: 0.8 – gas filled TG timber frame Doors: 0.8 – timber with TG panels
Service Strategy	Passivhaus levels of fabric performance: insulation, thermal bridging and airtightness Space heating by Post-heater on MVHR, also towel rails and wood stove (indirect) Water heating by Wood Stove and Solar Thermal system, immerser back-up Ventilation: MVHR with pre- and post-heater (electric and water heated respectively)
Key Features	8-unit Passivhaus development, Offsite timber frame construction, nominal renewables-only space and water heating by wood stove and solar thermal, MVHR

Figure 1.4: Project key Facts

At the outset of the project a number of questions were posed. Here we briefly note these with brief findings. Fuller discussions on each finding can be found later in the report.

The proposal acknowledged that Passivhaus could make a major contribution towards UK and Scottish government targets for reducing carbon dioxide emissions, but that the understanding of the application and performance of such high standards is still in its infancy in the UK. The study has shown that in general the Passivhaus approach has been very successful in enabling the reduction of energy consumption and carbon emissions, notwithstanding minor concerns along the way.

There was an interest in the use of wood stoves and solar thermal in meeting the residual energy input requirements in relation both to the rural setting, maintenance requirements and low carbon agenda overall. By using timber from the Estate and simple solar thermal, there is no doubt the project has responded well to its rural setting and the active systems in strategic terms have been a success, also in terms of a genuine low carbon approach. However, the procurement of the active systems has proved one of the least successful aspects, leading to a lack of clarity and understanding from all parties, including occupants.

There was an interest to investigate the environmental conditions resulting from the Passivhaus and low carbon approach, with a desire to ensure that these were not sacrificed on the altar of energy efficiency. In general, the environmental conditions have been shown to be very good, with the only significant concern being the prevalence of overheating in warmer weather.

With identically constructed and oriented homes there was an opportunity to investigate the influence of occupant behaviour on energy consumption, building performance and the user experience. There is no doubt that the occupants have significantly affected the overall energy consumption and performance of the buildings with a correspondence between those who could 'engage' with the ideas behind the low energy approach and the various active systems and those who could not.

There was also an interest in the efficacy of the off-site construction method chosen in respect of the low energy and high performance requirements. In general, the off-site construction was a success, although the concerns surrounding the airtightness and minor concerns of in-situ U values show that there are still lessons to be learnt.

The findings noted above represent the major findings of the study, while a full list of findings and conclusions can be found at the end of each chapter and in Chapters 9 and 10.

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

2.1 Context and Amenities

The development site lies in rural Dumfries and Galloway, just to the North of the small village of Dalton which is within walking distance, around 10 miles East of Dumfries and 5 miles South of Lockerbie. The site itself sits within the Dormont Estate and is only accessible via a minor country road. All the usual amenities are available in the two nearby towns by car and all those living in the area travel largely by car.

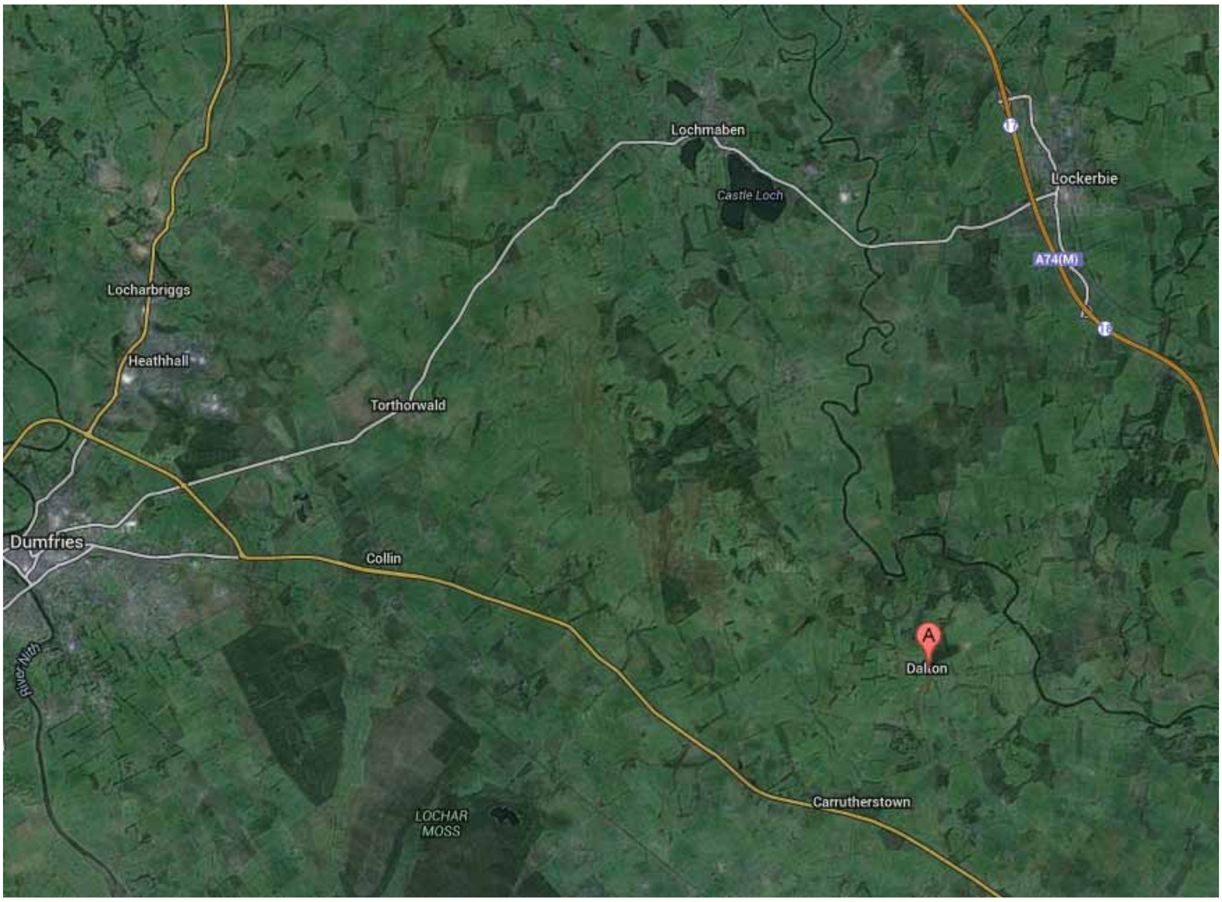


Figure 2.1: The Dormont Park Passivhaus Project lies just to the North of the village of Dalton (red pin) in a rural area 10 miles east of Dumfries and 5 miles South of Lockerbie.

The main West Coast train line runs through Lockerbie with direct access to Glasgow and Edinburgh to the North and Manchester and London to the South. A single bus visits the nearby village of Dalton once a day and another service runs between nearby Carrutherstown and Dumfries, but again, once a day only, so bus travel is not practical on a day-by-day basis and the bus service is little used. The 'Annandale Way' – a major public walkway passes through the middle of the Estate.

2.2 Design Intentions and Process

Dormont Estate has been renting houses and cottages on the estate for many years. These were, by and large, traditional one or two storey stone and slate houses built pre-1919. Since the 1980s, efforts have been ongoing to improve the energy efficiency of the dwellings, with a recent emphasis on renewable generation as well. The Rural Homes for Rent Grant Scheme changed the economics of potential new development in rural areas and Dormont Estate seized the opportunity, developing at the same time, their interest in, and commitment to homeworking, energy efficiency and the use of renewable energy. This developed over time into proposals to aim for Passivhaus certification and use both solar thermal and biomass, sourced from the Estate itself.

Architects White Hill Design Studio had been commissioned back in April 2007 to start drawing up plans for the proposed site in anticipation of possible grant availability so when, in October 2008, the Estate was invited by Scottish Government to submit a detailed application plans were well advanced.

Financial analysis had to be undertaken for the Grant scheme and also for the Lender. The Rural Homes for Rent grant scheme provided partial funding for the project however the funding limits made no provision for the extra costs of delivering homes to Passive House standards. It therefore became a fundamental part of the project brief to deliver the houses within a normal commercial budget, significantly reducing the average square meter build costs from previous Passive House projects.

The Passive House standard cut no ice with the planners and because there was no certainty that the scheme would get approval at all, it was not cost-effective to bring in a certified Passive House designer in the early stages of the design. The early design had to develop with a careful eye on the key principles of Passive House design but without the advantage of running the changes and developments to the design past a certified Passive House Designer. So it was not until the revised planning application was being considered that the design team was complemented by the appointment of the Scottish Passive House Centre which was asked to use the Passive House Planning Package (PHPP) software to fine tune the design prior to construction to ensure each house met the requirement for Passivhaus Certification.

The Planning process was complicated by issues to do with access but eventually permission was granted in October 2010.

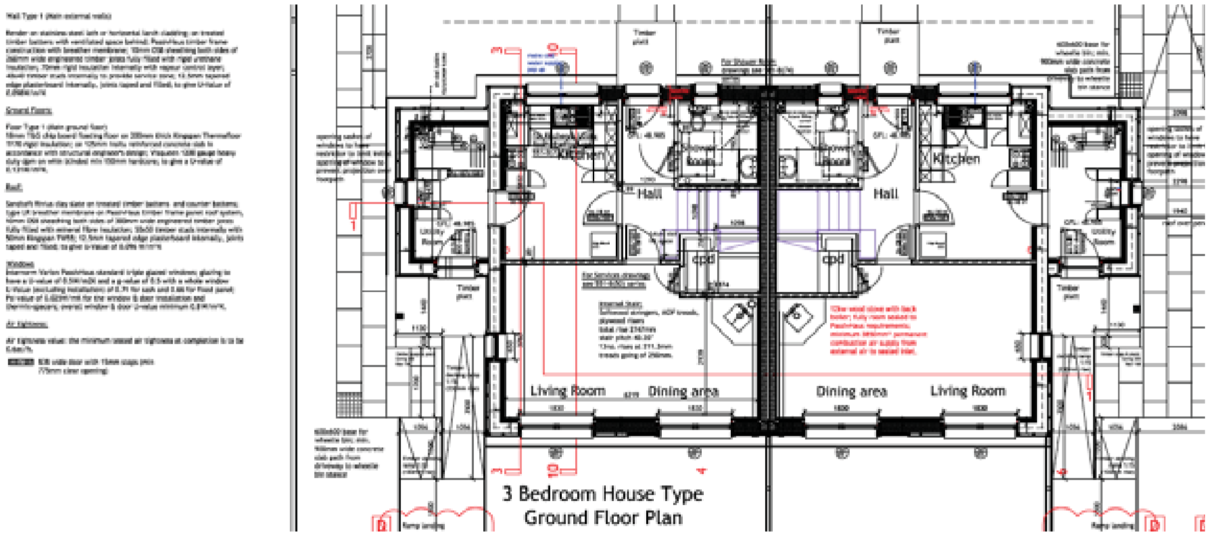


Figure 2.2: 3-bed House Ground Floor Plan BW Drawings by White Hill Design Studio showing updated specification agreed with the SPHC.

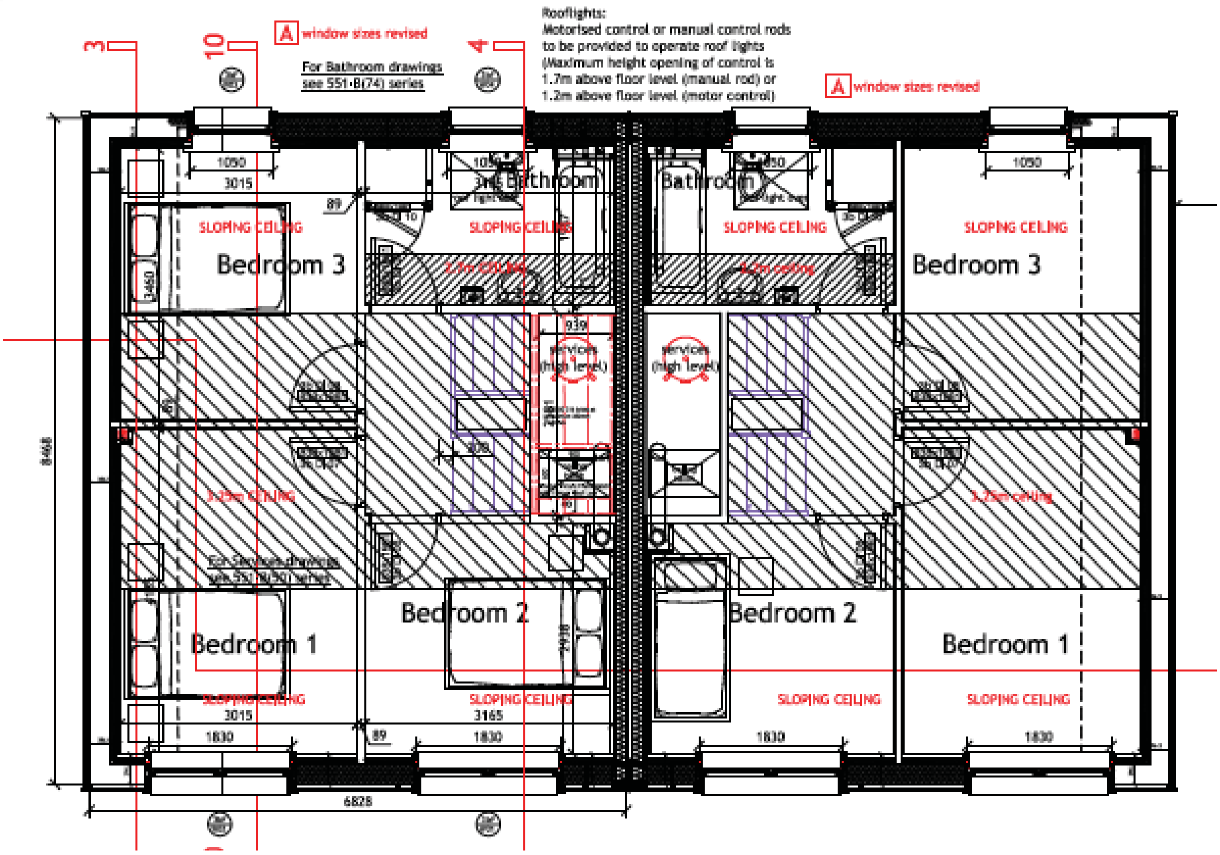


Figure 2.3: Corresponding 3-bed House First Floor Plan BW Drawings

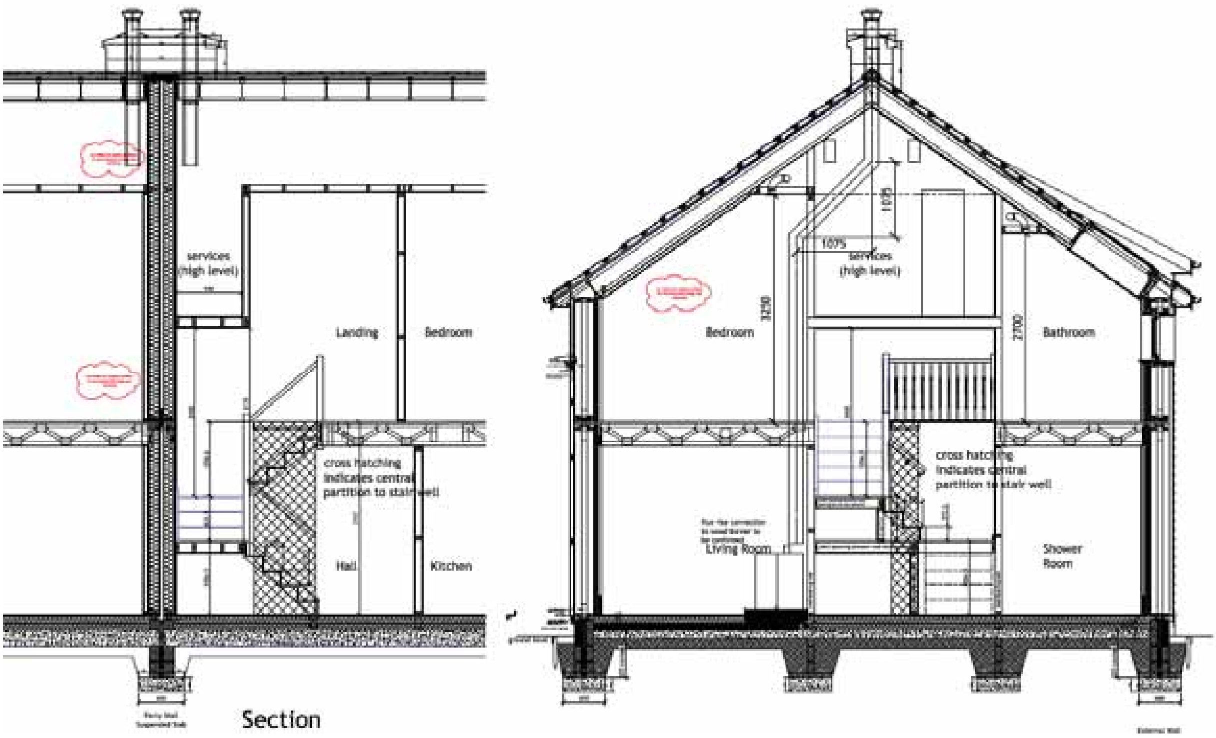


Figure 2.4: North and South Elevations of the 3-bed houses.

Figure 2.5: Building warrant stage North and South Elevations of the 3-bed houses.

The above **Architect's Drawings**, along with other Building Warrant stage drawings, are in **appendix folder 2.1**.

Once the SPHC were on board, Building Warrant drawings could be completed with greater reassurance of the likelihood of Passivhaus certification. In the event there were no significant changes between the Planning and Building warrant drawings in terms of fabric or services performance. This can be traced to the Passivhaus clarity of guidance on building performance and the Architect's accurate interpretation of these requirements.

2.3 SAP Assessment

The Standard Assessment Procedure (SAP) is a prediction tool used to assess and compare the energy and environmental performance of dwellings. Its purpose is to provide accurate, reliable and above all comparable assessments of dwelling energy performances that are needed to underpin energy and environmental policy initiatives. SAP calculations are a requisite component of the Building warrant submission and as such tend to be accurate in relation to the design status at that stage.

SAP works by assessing how much energy a dwelling will consume, when delivering a defined level of comfort and service provision. The assessment is based on standardised assumptions for occupancy and behaviour input by a trained user, but ignore climatic location. This enables a like-for-like comparison of dwelling performance. Related factors, such as fuel costs and emissions of carbon dioxide (CO2), can be determined from the assessment.

SAP quantifies a dwelling's performance in terms of: energy use per unit floor area, a fuel-cost-based energy efficiency rating (the SAP Rating) and emissions of CO2 (the Environmental Impact Rating). These indicators of performance are based on estimates of annual energy consumption for the provision of space heating, domestic hot water, lighting and ventilation. Other SAP outputs include an estimate of appliance energy use, the potential for overheating in summer and the resultant cooling load. The SAP calculations reviewed for this BPE study are summarised in table 2.1.

The original as designed Standard Assessment Procedure (SAP) sheets are attached in Appendix 2.2. An excerpt is shown below.

The SAP sheets were undertaken after the SPHC had become involved and basic U values and services arrangements had been agreed, and because there was little deviation between these and the as-built details, there is no discernible discrepancy between the SAP calculation inputs and the houses as built.

3. Heat losses and heat loss perimeter

	Net area (m²)		U-value		AxU (W/K)	
Doors	3.78	x	0.80	=	3.02	(26)
Windows*	21.13	x	0.78	=	16.38	(27)
Rooflights*	0.81	x	1.05	=	0.85	(27)
Ground floor	54.52	x	0.10	=	5.45	(28)
Walls	68.09	x	0.10	=	6.81	(29)
Roof	66.46	x	0.10	=	6.65	(30)
Total area of elements	214.79 (32)					

**for windows and rooflights, use effective window U-value calculated as given in paragraph 3.2*

Fabric heat loss	(26) + (27) + (28) + (29) + (30) =	39.16	(33)
Thermal bridges - calculated using Appendix K *if details of thermal bridging are not known calculate y x (32) [see Appendix K] and enter in (34)*		2.15	(34)
Total fabric heat loss	(33) + (34) =	41.31	(35)
Ventilation heat loss	(25) x 0.33 x (6) =	12.34	(36)
Heat loss coefficient	(35) + (36) =	53.65	(37)
Heat loss parameter (HLP), W/m²K	(37) ÷ (5) =	0.52	(38)

Figure 2.6: Excerpt from the SAP calculation for House DB1 showing the heat loss part of the calculation.

As discussed in the following section, there is in fact a discrepancy between the insitu tested U values of the wall and roof panels, but this is a discrepancy between reality and design intention, not between any stage in the design and construction phase.

In terms of the physical construction of the houses, the SAP calculation therefore is based on accurate data and as can be seen in the table below, the predicted energy consumption rates are close to the average energy consumption rates for all four houses. There are however discrepancies between predictions and reality on an individual building basis. Whilst there are likely to be a myriad of reasons for this, in this case, the two largest components of this gap are occupant behaviour and the inaccuracies of some results of the monitoring.

Dwelling	SAP Energy Efficiency Rating	SAP Environmental Impact CO2 Rating	SAP Prediction: Space Heating kWh/m²/yr	Actual Space Heating kWh/m²/yr*	SAP Prediction: Primary Energy Use kWh/m²/yr	Actual Primary Energy Use kWh/m²/yr (2013)
DA1	93A	97A	11.21	35.80*	56	76.96
DA2	93A	97A	11.21	3.65*	56	38.08
DB1	92A	96A	10.75	8.16*	56	61.01
DB2	92A	96A	10.84	4.97*	57	46.59
Average			11.00	13.15*	56.25	55.66

Figure 2.7: SAP calculation results for all four houses compared to actual results for 2013.

*** Actual space heating results gained through monitoring should be treated with caution, as these are difficult to separate from other loads and are therefore estimated.**

The space heating figures however are only indicative and cannot be taken as accurate. They are derived from incorporating 10% of the total electrical consumption as an allowance of the contribution to space heating from such incidental gains, 10% of the biomass consumption (Manufacturer's stated percentage of direct room output for stoves compared to hot water provision) and the hot water flow results to the MVHR post-heater.

However the two post-heater flow results for DA1 and DA2 are suspect, rendering the final figures equally suspect.

There are other problems with trying to establish a reliable space heating demand that can be directly compared with the SAP prediction. One is differentiating between space and water heating when considering the service arrangements at Dormont. Another is that it is impossible to clarify what level of heat input contributes to overheating, where the SAP prediction is based on achieving a standardised comfort level.

Considering the relative accuracy of the SAP calculation, it is interesting to note the annual energy cost predictions which are £21.44 for space heating (using wood) for both 2-bed houses and £24.31 for the 3-bed houses. Overall energy costs, including water heating and all electricity are predicted to be £108.65 for the 2-bed houses and £129.58 for the 3-bed houses.

These costs are far lower than the reality, and appear to be based on unrealistically low predictions of timber and electricity costs per kWh: £2.20 and £7.12 respectively. The above cost predictions can be compared to anecdotal timber costs (from the Estate) of approx. 1 bag at £60.00 per annum and annual electricity bills (for DB2) of around £500.00, i.e. between 3x and 4x higher than predicted.

2.4 Tender Stage / Final Specification

With debt finance in principle approved in May 2010 work started on the contractor selection process. The Estate was aware that this was a pioneering scheme in Scotland. Only a few individual houses had been built to Passive House standard so there were no contractors in Scotland who had delivered a multi-unit Passive House scheme. However, a number of timber kit manufacturers had recently invested in advance timber kit production lines and had been developing timber kit detailing to limit thermal bridging and achieve Passive House levels of insulation and air tightness. Project information, explaining that the development was to comprise 8 new houses to be built to certified Passivhaus standard, was sent to 13 construction companies with a pre-qualification questionnaire. Five companies emerged from this process that the Estate believed had the understanding and competence required and tender documents were subsequently sent out in July 2010 for return in August. It should be noted that Planning permission was not finally gained until October of that year.

The contract had to be procured through normal competitive tendering. However the advanced requirements of the Passive House standards meant that the tender package had to ensure a competitive price but allow the tenderers flexibility to propose alternative cost efficient solutions. This was done by including the key Passive House elements of the houses as a performance specification. The houses were tendered on a timber kit engineered I-beam construction with insulation levels based on the PHPP check by the Scottish Passive House Centre. A small amount of value engineering was required to bring the price in line with the contract budget and the contract was awarded to CCG (Scotland) Ltd based in Cambuslang, Glasgow with their off-site manufacturing division CCG OSM providing the design and detailing of the timber kit with their IQ system.

CCG were engaged as Main Contractors, taking responsibility for all aspects of the build process including co-ordination of trades, while SPHC remained in an advisory role throughout and undertook all necessary testing and paperwork to ensure the buildings were certified.

The two changes noted were a small reduction in the overall size of the buildings – occasioned by the need to reduce costs once tendered prices had been received, and the addition of the 70mm rigid insulation layer internal to the main insulated frame structure. This was required in order to comply fully with the requirements of Passivhaus and can be seen in the detail below.

The 2-bed houses have an internal area of 83.7 sqm, while the 3-bed houses have an internal area of 102.7 m2. Rooms downstairs have a consistent ceiling height of 2.4m, while upstairs heights vary due to the 'cathedral ceilings' while in the 3-bed houses, there is an attic which restricts the highest ceiling height to 3m.

All the Dormont Park houses are built with an off site manufactured timber frame system. The external walls have a core structure of 260mm wide SpaceStud framing. The SpaceStud system has two solid section timbers connected by spacer clips providing an efficient way to provide thick insulation layers and limit thermal bridging compared to solid timber. The SpaceStuds are faced both sides with 9mm OSB sheathing and the void fully filled with mineral fibre insulation. There is an additional layer of 70mm rigid insulation board on the inner face secured with timber battens providing the service void. The airtight layer of ProClima Intello membrane is installed to the internal face of the rigid insulation. The walls are finished internally with plasterboard. The external wall U-value was calculated to be 0.095 W/m2K. The external cladding of larch boards or render on backing boards is fixed with battens to the external face of the timber kit (not shown).

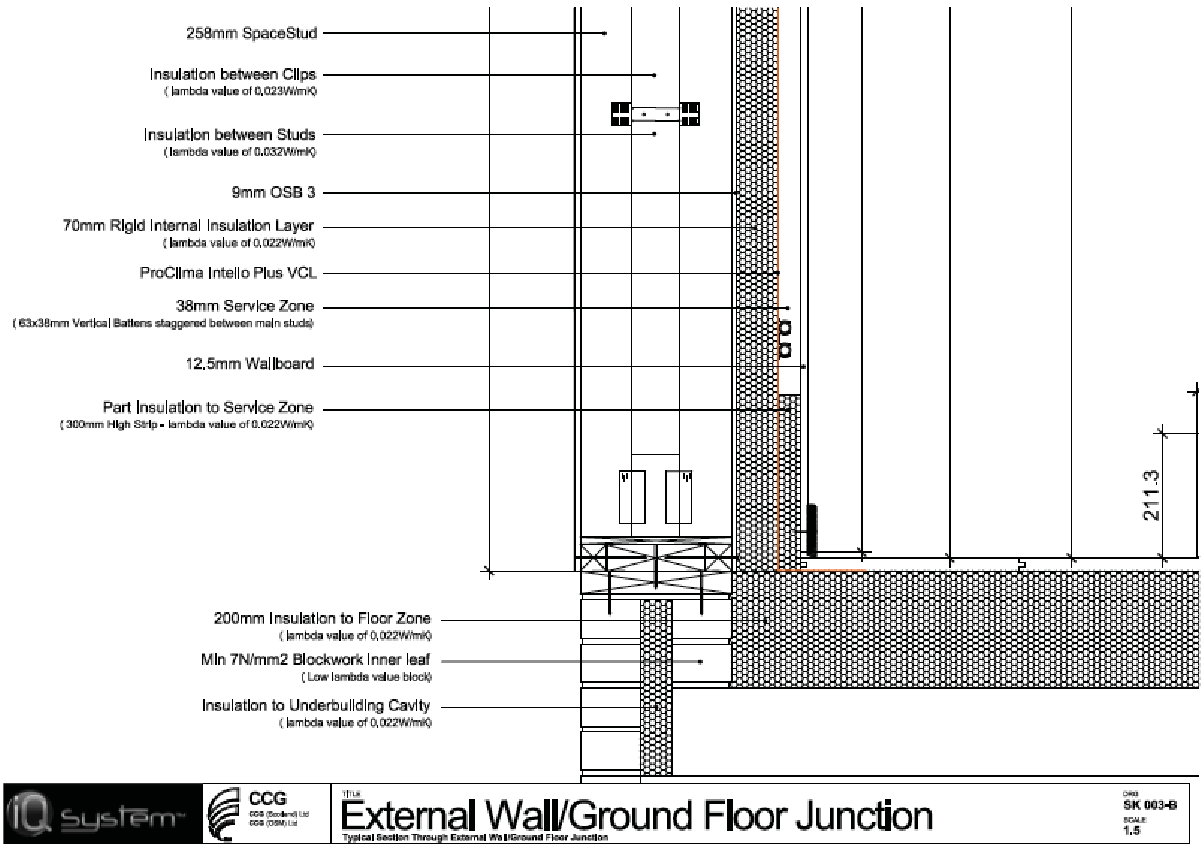


Figure 2.8: CCG OSM iQ system external wall / ground floor junction detail.

The roof structure is constructed of 300mm deep engineered joists, sheathed both sides with 9mm OSB and fully filled with mineral fibre insulation. A layer of 55mm rigid insulation is fixed to the inner face with the air tight membrane behind the service zone and plasterboard ceiling. The roof U-value was calculated to be 0.118 W/m2K. The roof is clad with Sandtoft Rivius clay slate on battens and a vapour control layer.

The ground floors are 22mm chipboard flooring on 200mm rigid insulation on a concrete slab. The ground floor U-value is 0.111 W/m2K. The first floor was constructed using lattice joists which provided sufficient space for the MVHR pipework. Windows and doors were supplied by Internorm with the composite timber aluminium triple glazed windows achieving a U-value of 0.74 W/m2K.

The above **CCG OSM iQ System Drawing**, along with others, is in **appendix folder 2.3**.

2.5 Construction Phase

With Planning finally gained in October 2010, work started on site in glorious weather in November but December brought some of the fiercest winter conditions the region had ever known with prolonged periods when temperatures were as low as -18^{o}C. By the time the first panels arrived in February the ice and snow had turned to rain which presented a rather different challenge. However, work proceeded quickly and, by May 2011, all 8 houses had met the requisite air-tightness level for certified Passivhaus standard. Practical completion was achieved in early July and within 3 weeks 7 of the 8 houses were occupied.

Figure 2.9: Construction phase: offsite manufactured panel being hoisted into position.

The project was characterised by an unusually close and good working relationship between the Client, Design Team and Contractor who adopted a strong design input post-tender stage and became the effective Designer for details at least. There also appears to have been an admirable lack of 'blame culture'.

This can be largely attributed to the adoption of the Passivhaus standard as the goal for all involved. This target sits astride all aspects of the development and is not 'owned' by one of those involved but all. This common purpose, being both a design and a performance target integrated all stages of the process meant that it was not a case of the Architect "doing his bit, then leaving it to the Builder" since the requirements of Passivhaus, particularly with airtightness fall equally upon wider design and narrower detail issues. Coupled with this clarity was the explicit acknowledgement that no-one involved had been through the process of delivering a Passivhaus development before so there was a steep learning curve and degree of tolerance on all sides when things were harder to achieve than initially assumed.

The only significant problem that arose during construction was the difficulty in achieving the requisite level of airtightness. This issue is discussed further in Section 3. Although not a problem on site as such, a subsequent problem was related to the difficulty occupants had in understanding and using the various active services, particularly the plumbing and the associated controls. It is worth noting therefore that the plumbing and electrics packages were left as Contractor-design elements and were not finalised until well into the build process. There are important lessons to be learnt from this in terms of either including the services as part of a detailed package of specification / details, or by ensuring that the Contractor has the relevant experience / expertise to design and install services to a Passivhaus standard. It is also important that the Installer is able to produce clear and accurate "as-built" drawings and is able to adequately explain the systems to the incoming occupants.

Figure 2.10: Achieving the required level of airtightness proved to be the most difficult part of the site works. Image shows a proprietary grommet and taping to seal one of the air ducts as it passes through the wall.

2.6 Handover

By all accounts the handover process was well managed with a concerted effort by both Client and Contractor to impart sufficient information to the new occupants. The **document** handed over to incoming occupants upon entry is enclosed within the **appendix folder 2.4**, along with a brief document that records the handover between the Contractor's service personnel to the on-going local maintenance service personnel.

From the perspective of the Occupants, the two main issues have been the difficulty in understanding and using the various active services, discussed in Section 6, and the overheating. This is discussed further in Section 8.

Photographic Surveys of the four monitored dwelling are located in **appendix 2.5**. A small selection of images is shown below.

Figure 2.11: Panoramic view of all four 2-bed houses which face South into the communal court.

Figure 2.12: Panoramic view of all four 3-bed houses whose South facades (shown) lead out into their own private gardens.

Figure 2.13: View of DA1 Living Room showing stairs, hallway and large windows facing South into the communal court.

Figure 2.14: View of DB1 North-facing Kitchen looking through into the Utility Room (where the MVHR Unit is located)

Figure 2.15: View of DA2 Rear bedroom with high sloping ceilings. Access to lights, air grilles and the attic hatch is difficult.

2.7 Conclusions and key findings for this section

- An initial interest in energy efficiency developed into a commitment to Passivhaus and this set the basic parameters for the whole design and construction process
- Overall the design and procurement process can be seen as exemplary.
- Initial designs were undertaken without input from SPHC, but turned out to be adequate as no significant alterations were made once SPHC came on board
- SAP predictions were fairly accurate for energy consumption, but not for energy costs, which were between 3x and 4x higher, due mainly to inaccurate unit costs within SAP
- The development had to be achieved within conventional cost parameters, the success of the project shows that both innovative and rigorously low energy projects can be delivered without excessive on-costs.
- The build process was characterised by very good working relationships between Client, Design team and Contractor. This was achieved by a mutual recognition that this was to be a learning experience for all involved, and due to the Passivhaus requirements which drove the entire exercise and were ‘owned’ by all parties.
- The most difficult aspect on site was achieving the required level of airtightness.
- The plumbing and electrical works were Contractor-design packages and have proved the most problematic post completion.
- The handover procedures by Client and Contractor were exemplary.
- Apart from issues associated with understanding of the active services, the main issue for occupants has been overheating.

3 Fabric testing (methodology approach)

The BPE monitoring mandated non-invasive testing of the building fabric to provide an indication of construction quality and to identify whether specified design targets were met. Each dwelling underwent two air permeability tests while insitu U value tests were undertaken to the roof and wall in one dwelling only as construction was the same across all properties. Thermographic surveys were also undertaken in all dwellings.

3.1 In-situ U Value Testing

The purpose of these tests is to establish 'real' rather than predicted U-values for the construction, and where these differ sufficiently, input revised figures into the SAP calculations, TSB Dwelling Characteristics Forms and other documents to establish a more accurate 'in-use' energy efficiency assessment of the development.

In this development of 8 No. houses, a standard roof, wall and floor construction were used throughout so a single dwelling was used to provide representative figures for the whole development.

The methodology used for all testing and analysis was as the test procedures set out in ISO 9869:1994 and Hukseflux HFP01 / HFP03 manual version 1014 and TRSYS01 manual version 0810 both of which describe thermal resistance testing procedures in accordance with ISO 9869, ASTM C1046 and ASTM 1155 standards. Refer http://www.hukseflux.com for further details.

An insitu U value test was undertaken between 26th February and 21st March 2013. Hukseflux measuring kit was installed to measure a typical roof section and typical wall section. The chosen area was a North facing (minimal interference from direct sunshine) upstairs bedroom in Cottage DA2 which the single occupant uses as her main bedroom.

Externally, 4 No. tinytag dataloggers were securely affixed to the building, ensuring that no damage was done to the construction. One pair was attached to the verge tiles of the dormer whilst another was securely fixed to the top of the cladding boards in a location corresponding to the wall sensors internally. Pairs were used with each pair containing a lead logger and a spare in case of failure of the first logger. Internally, temperature sensors and flux plates were installed to locations on the wall and ceiling. Care was taken internally to ensure that the kit itself was installed in such a way as to be unobtrusive internally. This reduced disruption to the occupant but also minimised the risk of the equipment being accidentally dislodged or damaged. Images of both external and internal installations are shown below.

The results of this first test showed that whilst the roof appeared to be per the design intent, the result for the wall was well outwith the design intent. This may have been because the sensor was positioned too close to the top of the wall and was measuring the wall head construction (solid timber) rather than a more representative section of the wall.

Figure 3.1: Internal and External views of the insitu U value test kit installed for the first test.

The test was therefore retaken using Hukseflux measuring kit between 28th November and 13th December 2013. The installation was generally the same as before except that we lowered the wall sensor and flux plate to take account of the timberwork at the wall head. The thermocouples supplied as part of the TRSYS01 kit were not used externally for the same reasons as before. Moreover in both cases air temperature rather than surface temperature was recorded for calculation purposes as noted in the ISO 9869 methodology.

A **full raw data set** is provided in .xls format in **Appendix Folder 3.1**, along with the **reports** themselves. The results of the second monitoring period are presented in the table below.

CONSTRUCTION ELEMENT	SAMPLE PERIOD	SAMPLE DURATION	DESIGN U-VALUE	MEASURED U-VALUE
DA2 External (N) Wall	28.11.13 @ 12.00 - 13.12.12 @ 11.50	359 hours	0.1W/m^{2}K	**0.12W/m^{2}K**
DA2 Roof (North facing)	28.11.13 @ 12.00 - 13.12.12 @ 11.50	359 hours	0.1W/m^{2}K	**0.12W/m^{2}K**

Figure 3.2: Results table of Insitu Testing of U-values (Test 2) at Cottage DA2 28 November to 13 December '13

The results appear to indicate that both elements are performing broadly as intended. However, the measured values do not take account of the thermal bridging because they are taken as far as ascertainable at points to avoid any timber structure. The thermal bridging would have been factored into the design figure of 0.1 W/m^{2}K, and so the figures are higher (worse) than immediately apparent.

This discrepancy is noted within the Hukseflux analysis spreadsheet used to derive the above results where the deviation between modelled (predicted) and measured figures are shown to be 28.6% for the wall and 34.4% for the roof. The predicted figures for both wall and roof without thermal bridging ought to be around 0.08 W/m^{2}K and in this context it is clear that the measured figures are not as good as first appears.

This drop in performance may be due to a number of factors such as local poor workmanship or misleading declared lambda values, but the discrepancy is still relatively small and performance overall is relatively good.

Figure 3.3: Internal view of the Hukseflux installation for the second test. Note the position of the wall plate, which is lower than in the first test.

3.2 Thermography Testing

Thermographic imagery was captured on two occasions during the project. First, during the initial airtightness testing on the 28th September 2012, and second as a stand-alone exercise in February 2013.

In the first exercise, the thermography was being used to help trace air leakage and in this capacity, the main leaks discovered were around the lower corner of the Utility Room doors and also from the wood stove flues.

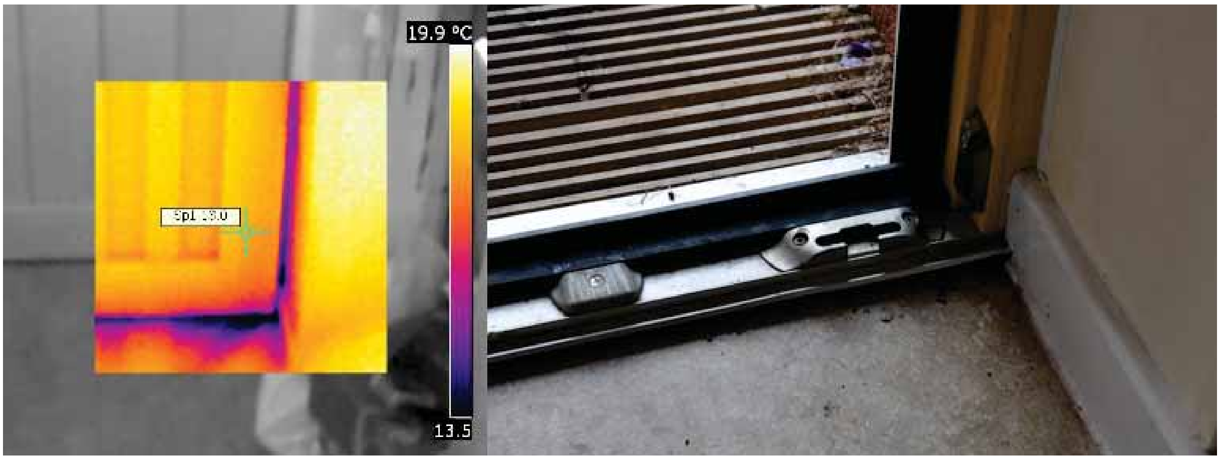


Figure 3.4: Air leakage at the Rear doors in several of the cottages could be seen when de-pressurised.

The main **thermographic survey** was conducted on 26th February 2013 between 7.20pm and 10.30pm, with a clear sky. The day had been sunny so exactly two hours were left after sundown (c. 5.20pm). A FLIR 360 camera was used. The testing was undertaken by C Morgan (non-member of UKTA) in accordance with the requirements of TSB monitoring protocol, BPE IP1/06 and BSRIA 39/2011. The full report is in **Appendix Folder 3.2**.

It was not possible to gain admission to DA1 at that time, but all other properties were surveyed both internally and externally. The table below gives an indication of some of the areas surveyed and issues raised.

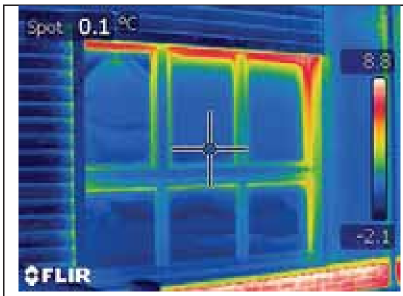
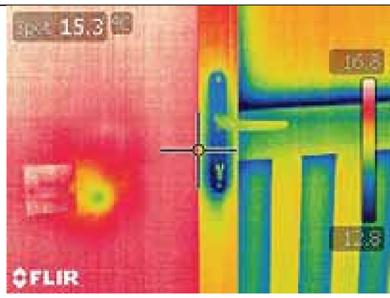
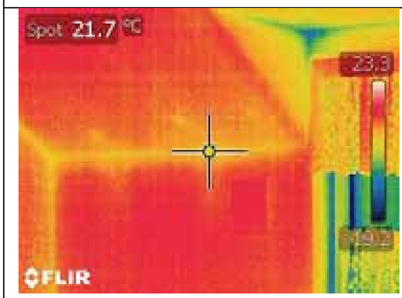
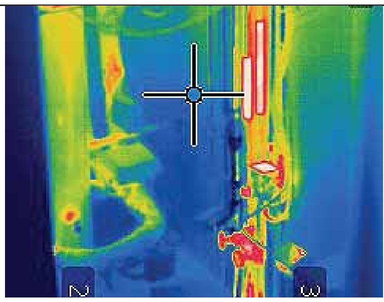
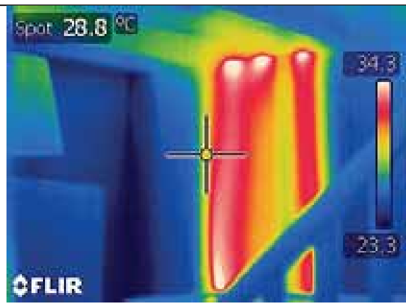
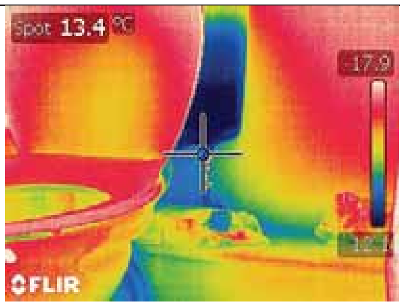
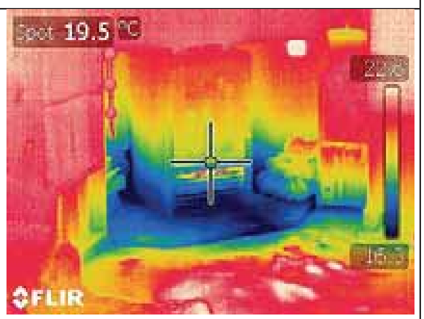
		
External. DA1 Living Room Window. Increased heat loss around window heads, and apparent heat loss (but more likely retained warmth) along base brick course.	Internal. DA2 Utility Door. Excessive heat loss around leading edge of door at base. Apparently explained by incorrect hinges currently fitted	Internal. DA2 Entrance. Cold patch by light switch linked to wiring for door bell – there was a corresponding 'warm' patch externally. Presumably an air gap caused by creating the hole for the wiring
		
Internal. DA2 Main Bedroom. Showing minimal heat loss at exposed gable wall / roof junction and also at dormer.	Internal. DA2 Cylinder Cupboard Showing exposed uninsulated water pipework	Internal. DB1 Stairwell Showing significant heat gain from uninsulated hot water pipes within bathroom / stairwell partition.
		
Internal. DB2 Utility Door from Kitchen. Showing significant difference in temperature (8^{o}C) between Kitchen and utility (which is within same thermal envelope)	Internal. DB2 GF Toilet Cistern. Drop in surface temperature to exposed cistern (condensation evident) after toilet flushing. Passivhaus best practice promotes use of concealed & insulated cisterns.	Internal. DB2 Wood Stove and Hearth. Taken at request of Occupant who suspected hearth area to be colder, shown to be correct, likely cause being the cooling effect of uninsulated air intake duct

Figure 3.5: Table of various thermographic images showing range of issues.

The thermographic survey highlighted a number of common issues in construction; the air leakage associated with doors and windows and services penetrations, but overall confirmed a high level of thermal effectiveness and consistency across all four dwellings, as evidenced in the central left image in the table above. At no point did we discover areas of wall, floor or ceiling that would be likely to drop below surface temperatures of around 13^{o}C and thus present a risk of condensation and mould forming assuming the basic heating and ventilating functions of the building are maintained.

Important anomalies however were discovered included the cooling effect of the uninsulated combustion air pipe as it rose from the rear of the hearth to the underside of the stove, and the cooling effect of the toilet cisterns creating a condensation issue. This has led to problems in other monitored properties by MEARU. However, the most important discovery was certainly the significant effect of the decision not to insulate the hot water pipes, as evidenced in the image centre right. This is discussed later in Section 6.

The principle challenge, or risk of the work was choosing a suitable day for the work. In the event, it was not ideal having been a sunny day and clear sky, leading both to warmth built up by thermally massive items (such as the brick base courses) giving misleading readings, and the problems associated with reflectivity of items to a cold, clear sky. External readings were minimised but the image shown above was representative of the warmer brick base on all properties and on all sides (including North facing) so worthy of mention.

3.3 Air Leakage Testing

In April 2011, the eight houses at Dormont were pressure tested by BR Testing of Blackburn, Lancs, employed by SPHC, and all found to be within the 0.6 ach required for Passivhaus certification. The houses were all certified as Passivhaus some time thereafter.

The air leakage tests undertaken at the beginning of the project gave markedly different figures however. The air change rates being 2.42, 2.13, 2.43 and 2.21 for each house respectively. These results are approximately 4x those recorded at the time of completion and 4x the necessary airtightness for Passivhaus certification. Areas of weakness identified at the time included the rear doors, stove flue as well as other service penetrations.

During the project it became clear that the initial tests by BR Testing had been undertaken using 'co-pressurisation' (of adjacent properties) while the MEARU testing by Elite Energy had been carried out using a standard process. In order to understand the possible influence of this variable, the second and final testing undertaken in August 2014 included both procedures. The results are given below and the **full reports** are included in **Appendix folder 3.3.**

PROPERTY	ACH REQUIRED FOR PHI	ACH @ COMPLETION (CO-PRESSURISED)	ACH BY MEARU (1) STANDARD	ACH BY MEARU (2) (CO-PRESSURISED)	ACH BY MEARU (2) STANDARD
DA1	0.6	0.581	2.410	1.78	**1.88**
DA2	0.6	0.515	2.125	1.58	**1.64**
DB1	0.6	0.501	2.495	1.59	**1.66**
DB2	0.6	0.530	2.210	1.38	**1.55**
Average	**0.6**	**0.532**	**2.310**	**1.583**	**1.683**

Figure 3.6: Air Change Rates per Hour (ACH) (Also known as n50) Results of 4no airtightness tests at Dormont.

The second test report highlighted the contribution to leaks from the combustion air supply pipes into the rear of the wood stoves, along with doors and service penetrations.

Without disruptive testing, it has not been possible to establish reasons for the dramatic, and consistent drop in performance. It is possible that it relates to a comprehensive failure of tapes or other seals used. In conversation, the initial tester from BR Testing made an off-the-cuff remark that it was unlikely that airtightness levels would remain as good, which would support the theory that poor quality 'patching' was undertaken to get the right results in the short term. It was also noted that the testers had to return to the site on several occasions - certainly more than had been anticipated – and this may have played a part in all involved seeking a short-term solution.

Figure 3.7: View of the combustion air supply pipe located behind the wood stoves. Air leakage was found at the junction between the pipe and the adjacent brickwork.

The two sets of tests undertaken on behalf of MEARU identified a limited range of air leakage points; the doors, service penetrations and the stove flue and combustion air supply pipe associated with the wood stove, pictured above. Whilst it is possible that the stove flue has opened up slightly since being installed, and there is some evidence that the rear doors to the properties have become less tight in the intervening period, none of these areas have evidently failed to such an extent that it explains the discrepancy in figures.

Two further possible reasons for the discrepancies have been investigated, but both are related to methods of testing, rather than 'physical' reasons associated with the houses themselves.

The first is the fact that the compliant tests made at completion used 'co-pressurisation' to achieve the results, whereby adjacent properties are simultaneously pressurised (or de-pressurised). This tactic effectively removes anomalies caused by air leakage in party walls and is used in some cases.

It is justified by some on the basis that adjacent properties are likely to be similarly heated, so leakage between properties is of little significance in terms of energy loss, and there is an argument that air leakage is closely associated with wind pressure and other induced air and temperature pressures across the external envelope, so the performance of the party walls is of little interest. However, the method is not deemed acceptable by the Air Tightness and Testing Measurement Authority (ATTMA), the governing testing authority, and leakage between the properties would be a concern for fire separation for example.

MEARU's first tests were undertaken without co-pressurisation so this could have been a potential reason for the differences. For this reason, the second tests undertaken in August 2014 used both methods and co-pressurisation gave on average 6.3% lower ('more airtight') results than standard testing.

Figure 3.8: View of cottage DA2 (to left) and its neighbour under co-pressurisation, whereby both adjoining properties are pressurised, or de-pressurised.

A second anomaly was that the initial tests for MEARU undertaken by Elite Energy comprised de-pressurisation only, whilst it is generally accepted – and is a TSB requirement - that an average of both pressurisation and de-pressurisation should be the measurement used. For the second set of tests, both were carried out and an average used as the stated result.

In every case during the second tests, the result under de-pressurisation was greater than that achieved using pressurisation. The smallest discrepancy was 1.9% while the largest was 20.8%, with an average discrepancy of 7.9%. Whilst this would go some way to describing the higher figures obtained by the 2012 tests, it clearly cannot account for the whole of the difference.

In conclusion, there is no apparent construction issue that would lead to the consistent and significant loss in airtightness evidenced between the tests undertaken at completion, and those undertaken 18 months later. In addition, whilst discrepancies have been created by two separate anomalies in the testing methodologies used, neither could account for the differences in the pre- and post-completion tests.

3.4 Conclusions and key findings for this section

- Insitu measured U value results for the construction were higher (worse) than the design intent figures by a factor of 28.6% for the wall and 34.4% for the roof.
- Thermographic inspection showed the basic fabric to be consistently thermally effective and in keeping with Passivhaus requirements.
- However, a number of avoidable anomalies were discovered including cooling effects of air leakage from doors and windows, uninsulated combustion air supply ducts and toilet cisterns, as well as heating effects of uninsulated hot water pipes.
- Whilst airtightness testing arranged by the Contractor as part of the construction process indicated air leakage rates consistent with Passivhaus requirements, both sets of air leakage tests conducted subsequently as part of this study gave results considerably higher (worse) than these and it has not been possible to establish the reasons for this discrepancy.
- Differences in the methods of measuring air leakage have been shown to account for some differences in the results, but cannot account for the whole discrepancy.
- Whilst the values are within the air permeability requirement for use of MVHR systems, they are well outside the standards required for Passivhaus and given the relative important of air tightness in the context of the fabric performance, will contribute to increased energy consumption.

4 Key findings from the design and delivery team walkthrough

4.1 Introduction

A semi-structured interview, developed from TSB Guidance documentation, took place at Dormont on the 28th January 2013. Present were Jamie Carruthers and Cathy Duff from Dormont Estate (Clients), David Major from White Hill Design Studio(Architect), Stephen Good from CCG (Contractor) as well as Tim Sharpe and Chris Morgan from MEARU. There was a good degree of consensus about the process and its successes and challenges.

The main objective of the process was to develop an understanding of whether design changes (if any) had been made to the original design intent and if so at what stage changes had been made, why these had been made, who made the change and to understand the main challenges in delivering the project. As built drawings and operation and maintenance manuals (where available) were used as aids. The **Notes from the meeting** are contained in **Appendix Folder 4.1.**

Design Intent

From the point at which drawings were first started, it was the explicit intention of the Client to pursue a Passivhaus development. Unlike aspirations such as being 'sustainable' or 'energy efficient' the Passivhaus intention is fairly prescriptive, at least in terms of performance, so it was relatively easy for the Architect, and later for Contractors to work to this overarching imperative. The Client had other aspirations linked to providing good quality, affordable housing in rural areas and a sense of place tied to existing buildings which are not so related to the monitoring process.

The other explicit design intention was to incorporate renewables in the best fit to the prevailing context. An early scoping study established that the best fit was likely to be solar thermal with wood stoves using the Estate's timber and this remained the case. In every sense the delivered buildings realised the initial aspirations.

Project Delivery

The design did not change through the Planning or Building warrant process. Once CCG were appointed a process of value engineering took place, in concert with a migration of the details to the CCG system and the overview of the SPHC who ensured the Passivhaus requirements were being met. These changes were, briefly:

- A slight reduction in house size to meet budget constraints
- Migration from a nominal RTC timber frame system to the iQ system developed by CCG (but fundamentally similar timber frame concept)
- Addition of internal insulation layer to satisfy U-value requirements for Passivhaus
- Not able to use local timber for cladding or frame
- Clarification of services design by Contractor via Contractor-design packages for electrical and plumbing works

None of the above changes altered the fundamentals of achieving Passivhaus, or of using renewables. In comparison to some of the design changes enforced on other projects, this was an almost painless process with no serious casualties. None of those involved expressed frustration or disappointment at the changes since it was simply a case of needing to meet Passivhaus requirements within the budget, and all involved were signed up equally to the cause.

Timescales were tight, but no-one commented on these being an issue. The weather worsened as the panels came on site, but although this was commented upon, it was not felt to have a significant difference to the project. What was agreed upon generally was that the airtightness was difficult to achieve. The Contractor noted that the Ground Floor / wall detail was a problem but also that the dormers presented a problem and the tapes specified were not universally liked. The Contractor confirmed that in subsequent projects, they have used different tapes.

Apart from the airtightness, almost all of the problems experienced both during the build process and post-completion have been associated with the active systems, particularly the plumbing and the controls. It is worth noting therefore that the plumbing and electrics packages were left as Contractor-design elements and were not finalised until well into the build process. The insulation of water pipes was not carried out, the plumber reasoning that heat lost would be to the house and it was agreed at the time that this was acceptable.

The handover process was by all accounts well managed. Two documents handed over to Occupants are enclosed in the Design Team Interview Folder. CCG provided manuals and Manufacturer's literature as part of the H&S File while the Estate produced a handbook. The plumbers and electricians both undertook a walkthrough with both occupants and local Plumbers / Electricians who were to take over the maintenance burdens for the Estate. The Estate Manager is on hand for all day-today- queries.

There were a number of issues early on as occupants got to know the active systems and as problems with those systems became apparent. Most problems were resolved within a few months, but long standing issues include the Occupant of DA1 remaining disinclined to use her wood stove, preferring instead to use the immerser, while confusion as to the nature of the post-heater in the ventilation system persisted as well. These are more fully described in Section 6.2.

All involved agreed that the performance based criteria of the Passivhaus approach helped bring clarity of purpose to the project, all appreciated the lack of 'blame culture' that prevailed on the project and all agreed that the early involvement in the Contractor in design helped avoid alterations and cost uncertainty on site.

The main feeling in the meeting regarding lessons learnt was that more time should be spent early in the process ensuring airtightness detailing was robust, while CCG have brought in measures for subsequent projects such as the use of in-house pressure testing devices to ensure buildings are ready before engaging independent testers, along with the instigation of airtightness 'champions' on each site.

4.2 Conclusions and key findings for this section

- The aspiration to provide Passivhaus-certified and affordable housing was met.
- The use of the Passivhaus performance criteria was useful in clarifying the requirements for everyone in the design and delivery team.
- The lack of 'blame culture' was widely appreciated – it was accepted that the project was on a learning curve and the some errors could therefore be anticipated.

- The main lesson learnt was to allow more time for airtightness detailing. The Contractor has subsequently invested in in-house testing kit and espouses the use of an 'Airtightness Champion' on subsequent jobs.

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

The handover to occupants was discussed in Chapter 2. This section discusses the variety of occupant engagement exercises conducted over the monitoring period. These comprise the Basic Occupancy Surveys and Walkthrough Interviews early in the process, followed by the introduction of the Quickstart Guides and BUS Survey which was carried out by Dormont Estate. MEARU also introduced Occupant Diaries in order to acquire a finer grain of detail of occupant behaviour and compare this to the monitoring data collected at the same time.

5.1 Basic Occupancy Surveys

The basic surveys were conducted in January 2013 to establish the basic data of the household occupancy numbers and patterns. One of the unusual aspects that came to light in this process related to sleeping arrangements. Both of the three-bedroom houses are occupied by families with three children. In DB1 the couple choose to sleep on a sofa-bed in the Living Room while the children have a bedroom each. More unusually still, the single parent in DB2 slept in the cupboard under the stairs leaving the Living Room free and a bedroom each for the children. The significance of this being that conventional assumptions could not be made about the main bedroom having one or both parents, for CO_2, temperature and humidity readings. The **Surveys** are contained in **Appendix Folder 5.1.**

1. Household Details

1.1	How long have you lived in your current home?	1	Years	6	Months
1.2	How many people in your household?			5	People
1.3	Number of occupants in each age group				

Under 5	6 – 15	16 – 25	26 – 35	36 – 45	46 – 55	56 – 65	Over 65
	2	1		2			

1.4 Please indicate what times your home is typically occupied during the week and by whom

	Morning		Lunch		Afternoon		Evening		Night	
Adults	Morning		Lunch		Afternoon		Evening	X	Night	X
Children	Morning		Lunch		Afternoon		Evening	X	Night	X

1.5 Please indicate what times your home is typically occupied during the weekend and by whom

	Morning		Lunch		Afternoon		Evening		Night	
Adults	Morning	X	Lunch	X	Afternoon	X	Evening	X	Night	X
Children	Morning	X	Lunch	X	Afternoon	X	Evening	X	Night	X

1.6 Please indicate hours used and activities that take place.

Room	Occupant(s)	Cooking/Eating	Relaxing	Sleeping	Socialising	Working /Homework	Other
Living Room			X	X COUPLE IN SOFA / BED	X		
Dining Room							
Kitchen		X	X		X	X KIDS	
Bathroom							
Bedroom 1				X	X		

Figure 5.1: Basic Occupancy Survey excerpt from DB1.

5.2 Occupant Interviews

Semi-structured interviews were held with all the occupants. The **questionnaires** are contained in **Appendix Folder 5.2**. Due to the length of time since occupants moved in it was clearly not possible to observe hand-over processes but these were discussed in the interviews, and occupants were asked to show key features and use of controls. In all of the four households interviewed, there is no doubt that occupants are very satisfied with the buildings. There are niggles, as discussed below, but that should not deflect too much praise away from the way the buildings have been delivered.

Whilst awareness of the importance of handover is rapidly increasing, and some of what was done at Dormont can be seen as inadequate in this light, the handover process was otherwise exemplary, with time taken by the Client, Contractors involved and written guides provided to everyone. Refer also to Chapter 2 for further discussion on this subject.

Equally worthy of praise is the commitment to ongoing management and maintenance. The Estate Manager is always nearby and extremely helpful and knowledgeable. This means that even though there have been a number of teething problems, they have always been dealt with promptly and this clearly resonates with the Tenants who reported feeling both reassured that problems are taken seriously and quickly resolved. Importantly, though this is perhaps more subjective, both this confidence in having problems listened to and resolved, and the overall contentment with the houses appears to have led to a rather more mature attitude where occupants acknowledge that an innovative project like this has teething problems.

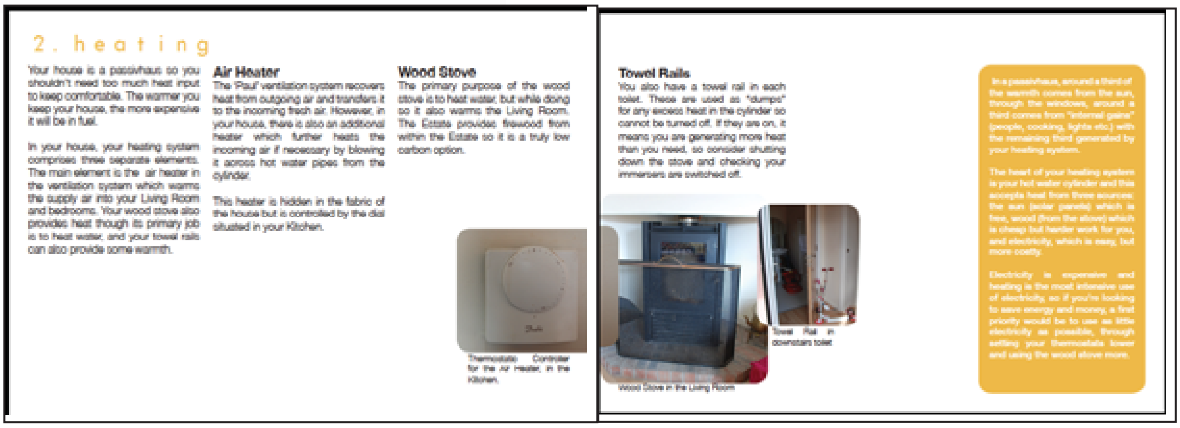
Across all four households, it was consistently reported that the bedrooms upstairs, mainly those facing South, overheat in the warmer months. From a user experience perspective, this was the only consistent, significant and ongoing criticism of the buildings by the occupants. This is described in greater detail in Chapter 7.

Arguably the other consistent concern was the overall confusion surrounding the correct operation of the various services. In most cases, occupants reported an initial period of around 6 months during which they were not clear how to manage the property. Each accepted that some of the technology was new to them, but (with one exception – DA1) agreed that it wasn't too hard and that they are now satisfied that they operate their building efficiently. The initial period of confusion was exacerbated by the fact that the Design Team and Client also clearly did not know how best to operate the systems and as reported elsewhere a number of fairly significant interventions had to be made, with the plumbing system in the main, to ensure a safe and efficient working system. These issues are described more fully in Section 6.2.

While it was clear that people knew that the MVHR (affectionately known by some as 'Paul') was responsible for keeping the house warm, there was apparent confusion about the role of the MVHR in keeping the houses cool in Summer. Some tenants maintain the MVHR on during the summer, others turn it off (conceiving of it as a heating system), but regardless, a number of occupants keep their windows open at night in bedrooms.

5.3 Quickstart Guides

Individual Quickstart Guides were developed through October 2013 and handed over to the Occupants on the 8th November, at the beginning of the second heating season, along with a discussion as to their potential role not only in helping Occupants to fully understand their home and services, but also to hopefully nudge them towards more efficient use and greater comfort. A **pdf copy of each guide** can be found within **Appendix Folder 5.3.**



2. heating

Your house is a passivhaus so you shouldn't need too much heat input to keep comfortable. The warmer you keep your house, the more expensive it will be in fuel.

In your house, your heating system comprises three separate elements. The main element is the air heater in the ventilation system which warms the supply air into your Living Room and bedrooms. Your wood stove also provides heat though its primary job is to heat water, and your towel rails can also provide some warmth.

Air Heater
The 'Paul' ventilation system recovers heat from outgoing air and transfers it to the incoming fresh air. However, in your house, there is also an additional heater which further heats the incoming air if necessary by blowing it across hot water pipes from the cylinder.

This heater is hidden in the fabric of the house but is controlled by the dial situated in your Kitchen.

Wood Stove
The primary purpose of the wood stove is to heat water, but while doing so it also warms the Living Room. The Estate provides firewood from within the Estate so it is a truly low carbon option.

Thermostatic Controller for the Air Heater, in the Kitchen.

Towel Rails
You also have a towel rail in each toilet. These are used as "dumps" for any excess heat in the cylinder so cannot be turned off. If they are on, it means you are generating more heat than you need, so consider shutting down the stove and checking your immersers are switched off.

Wood Stove in the Living Room

Towel Rail in downstairs toilet

In a passivhaus, around a third of the warmth comes from the sun, through the windows, around a third comes from "internal gains" (people, cooking, lights etc.) with the remaining third generated by your heating system.

The heart of your heating system is your hot water cylinder and this accepts heat from three sources: the sun (solar panels) which is free, wood (from the stove) which is cheap but harder work for you, and electricity, which is easy, but more costly.

Electricity is expensive and heating is the most intensive use of electricity, so if you're looking to save energy and money, a first priority would be to use as little electricity as possible, through setting your thermostats lower and using the wood stove more.

Figure 5.2: Examples pages from a Quickstart Guide given to occupants.

5.4 Building Use Studies (BUS)

BUS is an established method of evaluating occupant satisfaction and for benchmarking buildings against a large database of details for similar buildings across a development. This survey formed a mandatory requirement of the study and it was undertaken during October 2013. This time of year was selected as it was considered to be more neutral in terms of climate which would have reduced potential for influencing respondents' comments.

One week before the planned survey a letter was posted to each address in the development to request participation in a doorstep survey. A consent form was included in the letter which was subsequently collected from willing participants prior to the survey. The survey was undertaken by the Estate Manager and it is possible that occupants were reluctant to be as critical as they might to an independent person. Unlike larger scale RSL Tenants, the relationship between Tenants and Landlord on the Estate is close, and there is a degree of respect and deference toward the Landlord which might preclude more critical or negative comment.

After the survey, the responses were entered into the standard BUS spreadsheet template and emailed to Arup for analysis. This allowed the results for this development to be benchmarked against other BUS responses. As part of the analysis, Arup provide a web link to a standard report while the **quantitative and qualitative results** are summarised in two appendices which can be found in **Appendix Folder 5.4.**

In total, 7 of the 8 householders participated in the survey and the basic data is summarised below.

Question	Value	No. responses	Percentage
Age	1. Under 30	2	28
	2. 30 or over	5	71
Sex	1. Male	1	14
	2. Female	6	85
Time lived here	1. Less than one year	0	0
	2. One year or more	7	100
Other people 18 years or over	1no.	4	100
Other people under 18	1no.	1	25
	2no.	2	50
	3no.	1	25
Are you normally at home…?	1. Most of the time	4	57
	2. Evenings and weekends only	3	42
	3. Other	0	0
Dwelling Type	1. Detached House	0	0

	2. Semi-detached house	7	100
	3. Flat	0	0
	4. Terraced house	0	0
	5. Other	0	0
Occupancy Type	1. Tenancy	7	100
	2. Owner Occupier	0	0
Has living here changed your lifestyle?	1. Yes	5	71
	2. No	2	28

Figure 5.3: BUS basic data on householders surveyed.

The Survey consists of a range of questions which require the respondents to answer based on a performance scale of 1-7. The questions were designed to evaluate the dwelling design, needs of the occupants, comfort, indoor air quality, control, noise, lighting, health, lifestyle and utilities. The results were grouped into the following categories:

- Data set scoring better than Benchmark and scale midpoint (Green Square);
- Data set scoring between the Benchmark and the scale midpoint (Amber Circle) ;
- Data set scoring poorer than Benchmark and scale midpoint (Red Diamond).

The summary below shows that the majority of the variables were ranked higher than average (green squares), showing clearly that people were happy with the development overall.

Green Squares	**Amber Circles**	**Red Diamonds**
Issues scoring better than the benchmark and scale midpoint	Issues scoring between the benchmark and the scale midpoint	Issues scoring poorer than benchmark and scale midpoint
• Air In Summer: Fresh/Stuffy • Air In Summer: Odourless/Smelly • Air In Summer: Overall • Air In Winter Overall • Air In Winter: Fresh/Stuffy • Air In Winter: Odourless/Smelly • Appearance From The Outside • Comfort: Overall • Control Over Cooling • Control Over Heating • Control Over Lighting • Control Over Noise • Control Over Ventilation • Design • Health (Perceived) • Layout • Lighting: Artificial Light • Lighting: Natural Light • Location • Needs • Noise From Neighbours • Noise: Noise From Other People • Noise: Noise From Outside • Noise: Overall • Space • Temperature In Winter: Overall • Temperature In Winter: Stable/Varies • Utilities Costs For Electricity • Utilities Costs For Heating	• Lighting: Overall • Temperature In Summer: Overall • Temperature In Summer: Stable/Varies	• Air In Summer: Dry/Humid • Air In Summer: Still/Draughty • Air In Winter: Dry/Humid • Air In Winter: Still/Draughty • Storage • Temperature In Summer: Hot/Cold • Temperature In Winter: Hot/Cold

Figure 5.4: High level feedback from occupants indicating general satisfaction with the development.

Overall, it is clear that the houses have been very well received. The only significant issue for occupants appears to be the overheating in the summer. The summary results noted above give an overview of the responses but can be a little misleading and as such require a little more investigation.

Whilst the summer temperature appears as an amber 'warning' in the overall summary, the responses to the more detailed questions about summer temperature are more concerning and indicate a serious, rather than mild issue. The concern appears across all houses with comments such as: *"Too hot in summer", "Gets too warm upstairs especially difficult at night. House is hotter in the day", "Upstairs gets too warm. Always has windows open."*

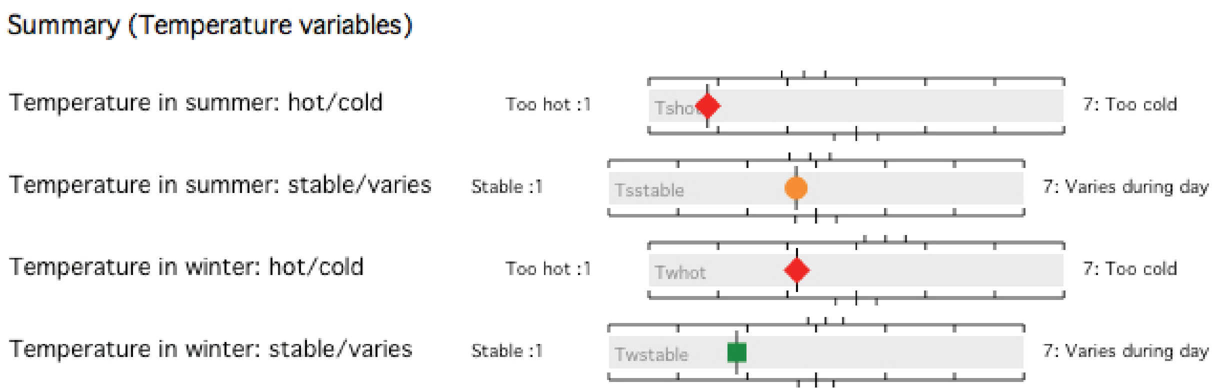


Figure 5.5: Bus Survey analysis: Summary of temperature variables.

Most occupants appear to open windows on a regular basis, which they say controls the issue: *"Can get hot in the summer especially at night, tenant just opens the windows which soon cools." "Windows upstairs always open as too hot."* All comments came before the improvement works to the pipework in the cupboards and the re-wiring of the MVHR post-heater so things should improve in this regard. The two results tables below indicate both the acknowledgement of the problem, and the fact that it is being managed.

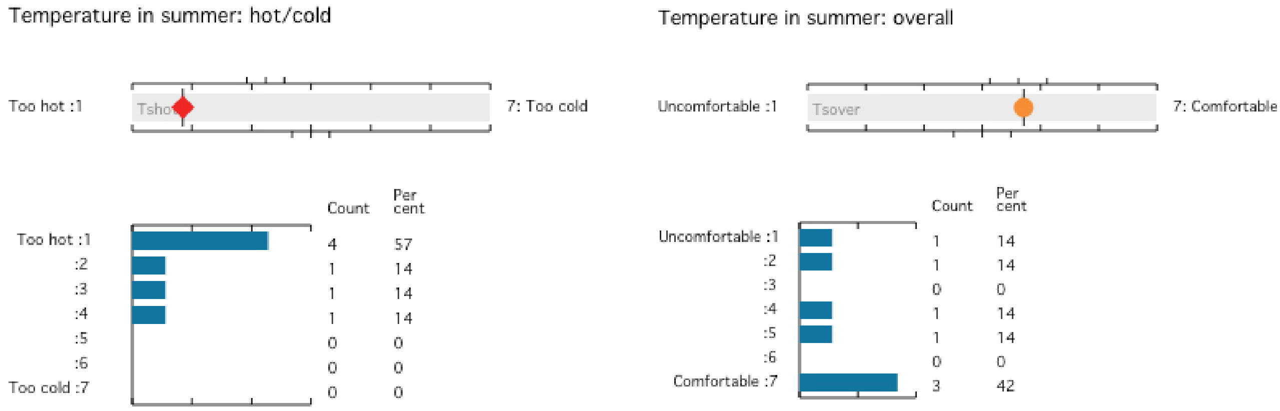


Figure 5.6: Bus Survey analysis: Varying responses to issues of summer temperature.

Whilst the overall summary shows no concerns with air quality, at first glance, the Summary of Air quality shows a different picture, with several red diamonds indicating a potential problem (Figure 5.7 below). This is probably due to the nature of the questions that ask whether the air is 'still' or 'draughty' which are at opposite ends of the scale. Since the houses are, in common with all Passivhaus projects, draught-free, the occupants have opted to mark their responses as far away from 'draughty' as they can, resulting in a potentially misleading diagnosis. Comments such as *"Used to a cold drafty (sic) house"* and *"Can be stuffy but nearly always has a window open"* indicate an awareness of the lack of air movement, while one occupant noted an awareness of air movement caused by the supply air grilles: *"Blast of cold air from vents felt when sitting in living room".*

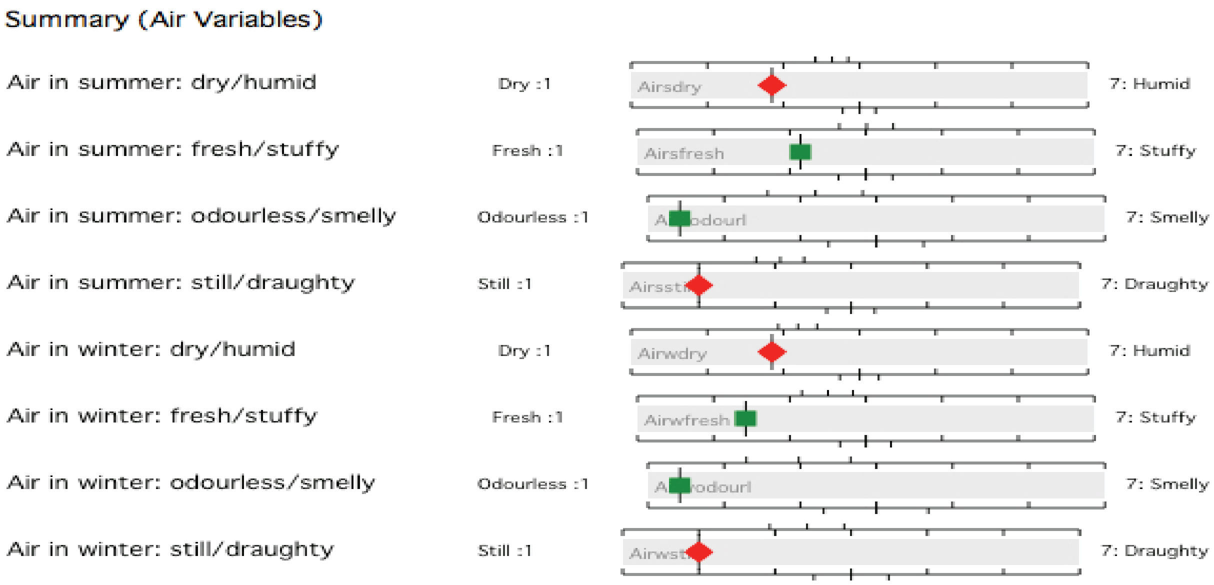


Figure 5.7: BUS Methodology: Summary of Air Variables.

On the overall summary, there appeared to be an issue with lighting. A look at the Lighting Summary itself (below) suggests otherwise:

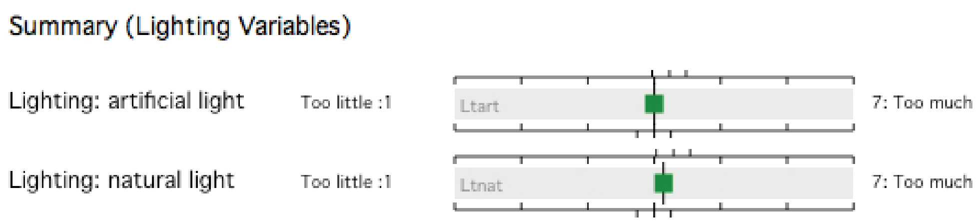


Figure 5.8: BUS Methodology: Summary of Light Variables.

There is a potentially misleading aspect to the BUS methodology here in that the Lighting result (amber) shown in the Overall Summary is not a higher order summary of the two Lighting results (green) shown above, but the answer to a separate question posed by the survey. The breakdown indicates that whilst there is widespread satisfaction with the light levels, there are individual instances of dissatisfaction. This is picked up by the range of quotes, such as "The amount of natural light makes you feel better", "Big windows give lots of light.", "Generally dark house, lights are not strong enough.", "Utility room a little dark. 3 pin bulbs very expensive to replace - not lasting", "Do not like the light fittings are unable to reach the upstairs fittings".

The comments provide a slightly different picture again which is of general satisfaction with the levels of natural light, but dissatisfaction with both the location of ceiling fitments, the price of the specialist bulbs and the fact that they have not lasted as long as they should.

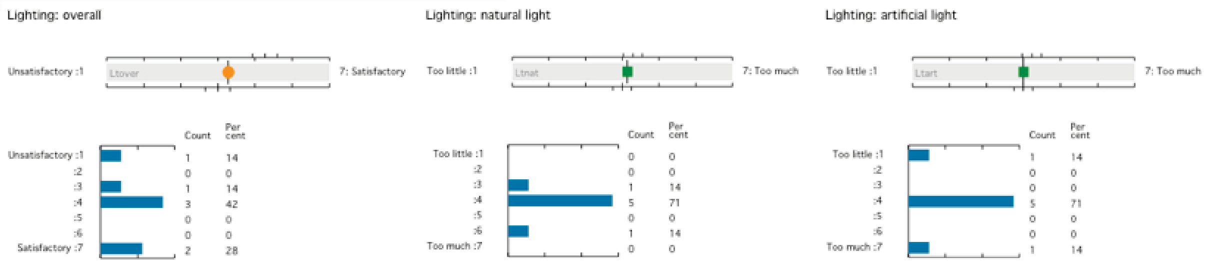


Figure 5.9: BUS Methodology: Breakdown of Lighting Feedback

All aspects of noise feedback indicated a high level of satisfaction, although again the detail can be picked up in comments such as *"Because windows have to be open there is an external noise level but not high. Some internal noise between bedrooms", "Can hear next door especially as windows in both houses are open a lot", Windows open so always external noise though not unpleasant."* These comments show both an acceptance of the noise through the development and an awareness that this is largely due to the need for windows to be kept open (due to the high temperatures). This highlights the potential 'knock-on' effects of the thermal design.

The breakdown of the Health (perceived) result indicates a broad range of responses, although the accompanying comments convey an overwhelmingly positive appreciation: *"Have always has chilblains until moved here", "Helped allergies, very healthy house." "It is a warm comfortable, light, nice environment being stress free good for personal wellbeing".*

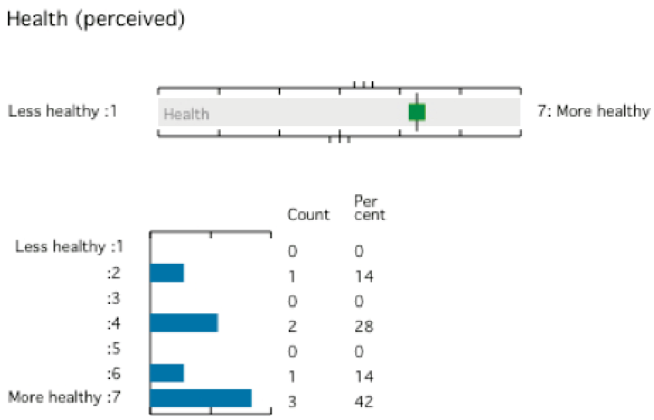


Figure 5.10: BUS Methodology: Breakdown of Health (perceived) Responses

The variable, Design / Needs summary suggests a broadly positive response, see below. This is supplemented by a number of positive comments: *"Facilities are more than good enough", "Internal layout very easy to live in with generous space plenty big enough for a family", "Loves the staircase and the light airy feel of the house", "Whole house works very well."*

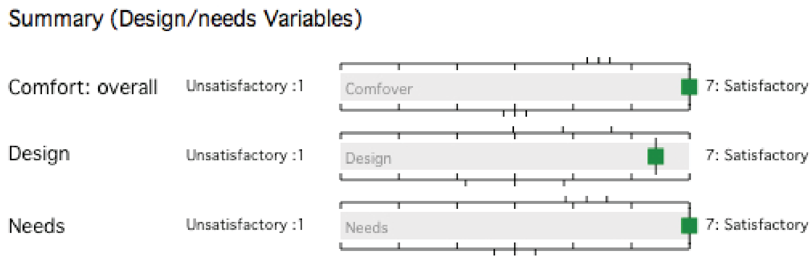


Figure 5.11: BUS Survey: Summary of Comfort, Design and Needs Variables.

At the same time, a number of problems were highlighted; *"Lots of problems (teething problems with plumbing and heating)", "Not enough kitchen storage", "The decking ramp at the front door is dangerous when wet or icy, needs a handrail", "Not keen on stairs going straight from living room or door to downstairs cloakroom open to front door", "Never enough space coming from larger family home", "Not enough storage space, no loft space."*

The variation of responses highlights that you can never satisfy everyone all of the time, although a consistent problem mentioned was lack of storage, particularly in relation to the fact that none of the houses have an attic. The last word on this section should however go the following quote:

"(Its) always good to get home when we've been away"

To end this section, it is perhaps worth noting that MEARU have developed some reservations about the BUS methodology when used in domestic situations, which are noted briefly below.

The first relates to sample size. The BUS was developed primarily as a tool for non-domestic buildings, such as offices and schools and therefore relies on a reasonably large sample size. This sample can also be relatively easily accessed through a workplace, where occupants may be employees. In this project however the sample size is smaller (a total of 7 dwellings), with different house arrangements and different circumstances in each.

A second concern relates to semantics. In places, it would seem that the semantics used are not well suited to domestic surveys and served to cause confusion and, in this instance, provide negative outcomes when this may not have been the perception of the respondents. Thus qualities such as 'still' or 'dry' air may have pejorative resonance with occupants of an office building. For housing tenants these qualities are the opposites of 'draughty' and 'damp', which in the context of social housing in Scotland are all too familiar concepts, so describing a building as still and dry may be considered an excellent thing. Similarly, for some occupants 'fresh' has associations with temperature ('its a bit fresh today'). Some items may be confused with other elements, for example 'cooling' and 'ventilation'.

There is also the issue of prior experience. In other interviews and discussions with occupants, frequent reference is made to occupants' prior housing experience, meaning comments can often be positive *in relation* to previous properties which, if older, are likely to be colder etc. A more longitudinal approach to satisfaction may therefore be more appropriate.

5.5 Occupant Diaries

It was an intention of MEARU to undertake occupant diaries in order to corroborate monitoring data and investigate occupancy behaviour and conditions at a greater level of detail across all projects.

A standard form was developed in which the building and room use of individual occupants was mapped throughout the week with specific reference to bedrooms, bathroom, cooking and laundry. The detailed data from the occupant diaries showed the daily routine for each occupant, by room and when at home over 7 days. The information sought included:

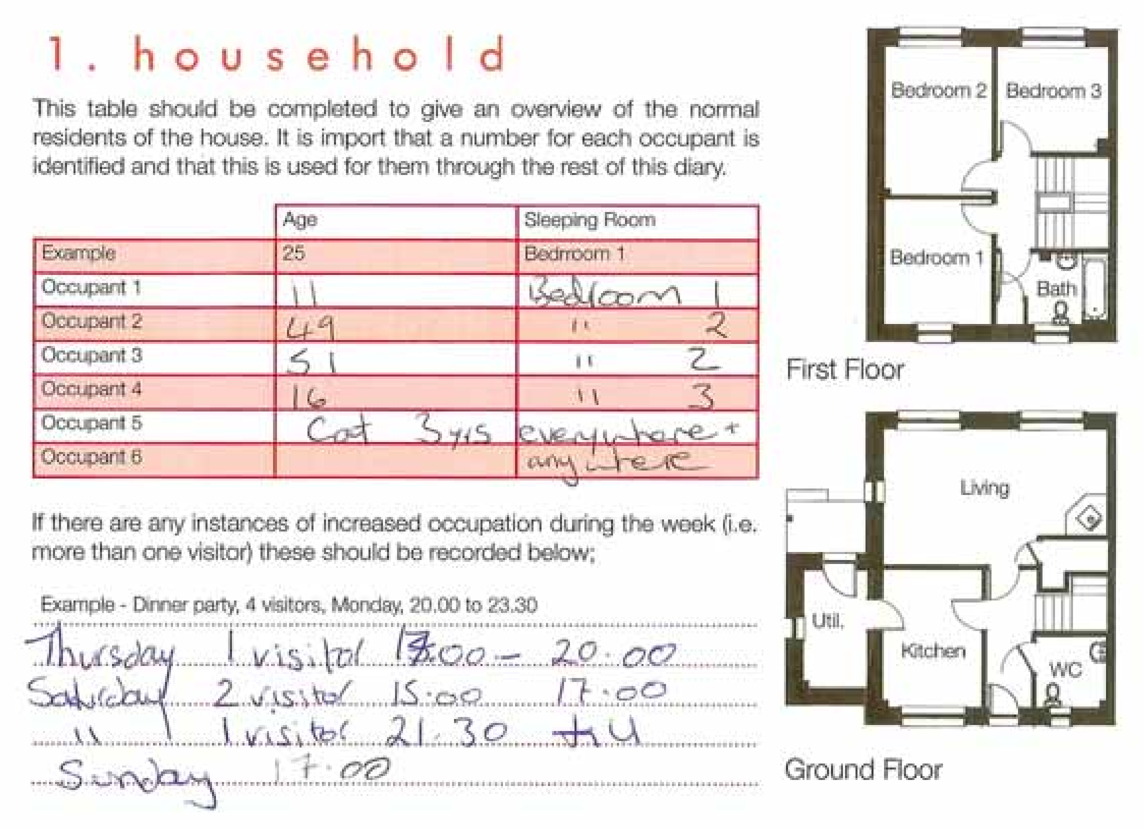
- *Household Occupant:* by number, age and bedroom.
- *House Occupancy:* a detailed 24 hour occupancy schedule.
- *Bedroom Occupancy:* when they got up and went to bed; whether the bedroom door was open or closed;
- *Bathing:* use of the bath or shower;
- *Cooking:* Cooking duration and meal description;

- *Laundry:* Detail of laundry washing and drying;
- A summary of comfort and air quality for each occupant.

The data procured from the occupant diaries was reported in conjunction with measurements of the environmental conditions recorded throughout the week. B**lank versions of the Pilot Diaries** are contained within **Appendix Folder 5.5**.

A Pilot study was undertaken at Dormont over the course of a single week in November 2013. There was a concern that it might represent an excessive expectation but all four diaries were completed fully and conscientiously and it does not appear to have been too much to ask. A completed first page is shown in figure 5.12 below.

The exercise allowed us to corroborate potential anomalies in the monitored data with 'real life' information. For example, both occupants of DA1 spent 2 nights away during the week (Sun/Mon and Thur/Fri) and these absences are clearly represented in the CO2 readings for each bedroom in figure 5.13.


1. household

This table should be completed to give an overview of the normal residents of the house. It is import that a number for each occupant is identified and that this is used for them through the rest of this diary.

	Age	Sleeping Room
Example	25	Bedrroom 1
Occupant 1	11	Bedroom 1
Occupant 2	49	" 2
Occupant 3	51	" 2
Occupant 4	16	" 3
Occupant 5	Cat 3 yrs	everywhere +
Occupant 6		anywhere

If there are any instances of increased occupation during the week (i.e. more than one visitor) these should be recorded below;

Example - Dinner party, 4 visitors, Monday, 20.00 to 23.30

Thursday 1 visitor 13:00 – 20:00
Saturday 2 visitor 15:00 17:00
" 1 visitor 21:30 +4
Sunday 17:00

Figure 5.12: Occupant Diaries: Pilot Exercise: occupants and visitors were all noted throughout the week.

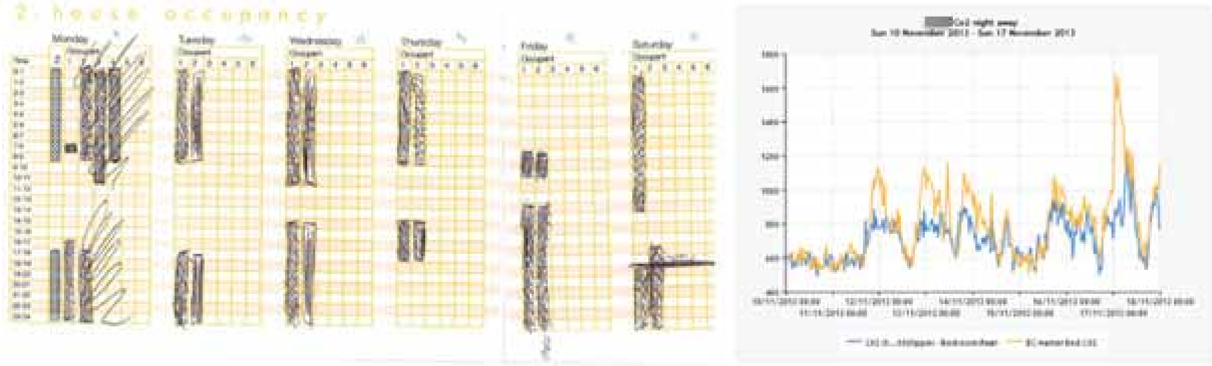


Figure 5.13: Occupant Diaries: Pilot Exercise: nights away can be clearly seen as night-time reductions in CO2 levels in bedrooms.

The comfort and air quality pages are of some interest. Almost universally, Occupants have recorded unwaveringly ‘good’ results with no variations between occupants or across the week. One minor exception is on the first two days in DB2 where results of ‘3’, ‘4’ and ‘3’ were noted on the Monday and ‘4’, ‘4’, and ‘2’ were noted on the Tuesday. Thereafter and for all other households, the results are uniform and positive. For DA1, the occupant has completed the IAQ table, figure 5.14, below.

On one hand this may represent a degree of lethargy on the part of the occupants, but on the other, it represents vindication on the part of the Passivhaus design strategies where clearly occupants are comfortable and perceive the air quality to be consistently good. Anecdotal feedback from the occupants during the visit indicated that filling in the diaries had been of interest and not too much trouble.

INTERNAL AIR QUALITY - based on the 7 point scale below the table should be completed in the evening of each day by answering the following question;

"how would you describe the air quality within the house today?"

Much too fresh	1	2	3	4	5	6	7	Much too stuffy

This should be completed for each occupant of the dwelling as far as is practical (realising that very young children will be unable to answer this).

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Example	3	2	2	4	4	4	3
Occupant 1	3						
Occupant 2							
Occupant 3							
Occupant 4							
Occupant 5							
Occupant 6							

Figure 5.14: Occupant Diaries: Pilot Exercise: IAQ deemed satisfactory throughout the week.

Following the pilot issue of diaries in November 2013 the first full issue of occupant diaries, to all Technology Strategy Board-funded projects was undertaken on the week commencing Monday 3rd February 2014.

5.6 Exit Surveys

Exit surveys were carried out in August 2014 to ascertain if there were any issues that occupants of the buildings surveyed felt had not been addressed or aspects of the process itself had been an issue.

Of the four houses, one (DA1) had new tenants so they did not complete a form having had no involvement in the process to date. Two surveys were collected, but the occupant of DB2 was not in and completed and returned the form later. The **report prepared for the Exit Surveys** is contained in **Appendix Folder 5.6.**

All three occupants surveyed were happy with the process and neither indicated any serious concerns. The occupant of DB2 noted however that occupants had been promised access to the monitoring information but that this had not happened.

All four occupants have indicated that they would be happy to allow the monitoring to continue for another year.

5.7 Conclusions and key findings for this section

- Overall the occupants like their homes and appreciate the measures taken to improve energy efficiency and comfort;
- Basic occupant surveys revealed unusual sleeping arrangements with adults in both 3-bed homes sleeping in the Living Room and Understair cupboard respectively;
- Occupant interviews revealed that handover had been handled well from their perspective and that despite teething problems, all appreciated the efforts made by the Estate to resolve any problems;
- Occupant interviews revealed that the main concerns were the overheating and issues arising from the complexity of services;
- The BUS exercise revealed a similar pattern with occupants overall very happy with the houses, but with concerns particularly with overheating and aspects of the services.
- The user engagement on this project was of a particularly high level and provides a good case study for the analysis of occupant feedback.

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

6.1 The Building Services

Following the Estate's conviction that a fabric first approach was the most cost effective way to save energy and provide affordable comfort, Passivhaus compliance with MVHR means the buildings need relatively little residual heat input. Without a mains gas infrastructure, the Estate was also keen to make best use of the resources at its disposal, so that beyond passive and active solar input, the principal energy source is wood from the Estate.

Heating and Hot Water

The heart of the heating and hot water system is a 300 litre thermal store, which receives hot water from the solar thermal panels and wood stove, while an electric immerser provides back-up. Hot water is delivered to the post heater of the MVHR as the main residual heating system. Hot water is also provided to the domestic hot water system as normal and to a towel rail which doubles as a heat dump. The system is shown diagrammatically below.

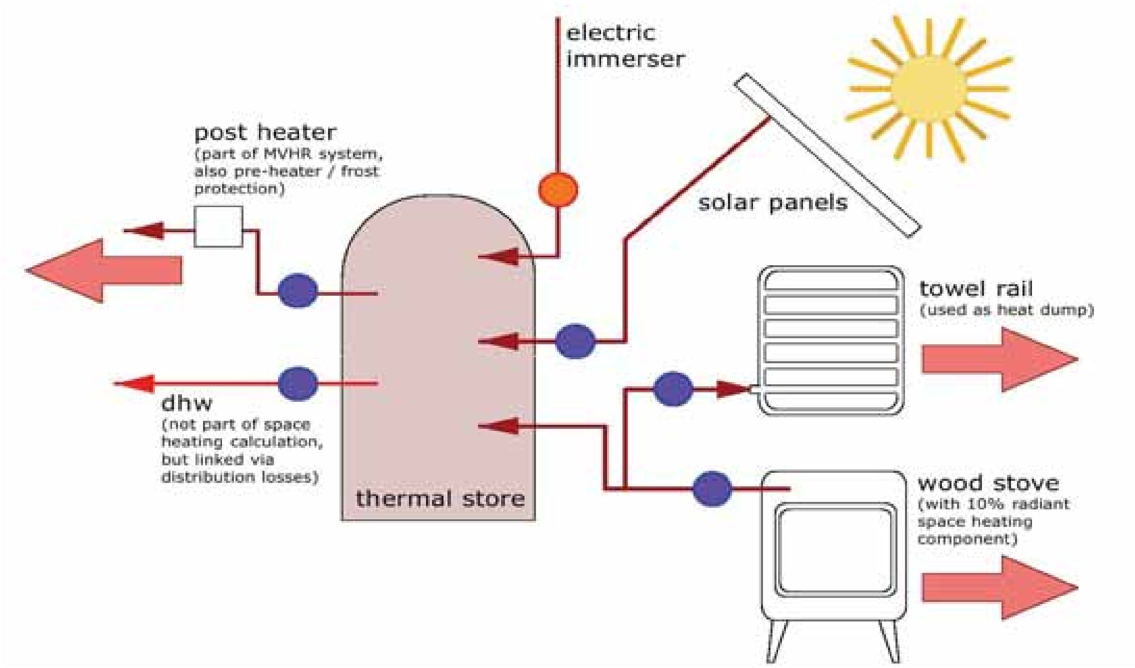


Figure 6.1: Simplified diagram of Dormont Heating Systems. Dots indicate monitoring locations.

The thermal stores are located in a cupboard off the upstairs landing in the 2-bed homes and in an attic, the larger part of which is located over the stairwell in the 3-bed houses. The tanks themselves are pre-insulated but in keeping with the rest of the house, all pipework was installed uninsulated. Thermographic images of this are shown in section 3.2. As a result of this project the Estate undertook insulation of all accessible pipework, mainly in the cupboards. The image below shows the pipework before insulation.

Figure 6.2: Thermal Store in Cottage DA2, showing uninsulated pipework, the expansion tanks and (surrounded by black polystyrene) the solar thermal panel controller, linked to an information display in the Kitchen.

The Woodfire F12 10.8 Kw wood stove is fitted with a direct external air supply and draws no air from the room which helps to maintain the air tightness of the houses (although the installation of the pipework for this itself is not airtight, refer Figure 3.7). It also provides 90% of its heat to the hot water system. This means that only 10% (nominally 1.1kW) is given off as direct space heating to the room, helping to avoid overheating when the stove is on.

Figure 6.3: Wood stove in House DA1 with warning lights to top left.

The stove is manually fed so there is no thermostatic control of fuel input and immediately after construction this had led to the systems overheating and 'kettling'. However, a simple arrangement was devised (post-completion) involving two warning lights visible above. The green light is on if the hot water tank requires heat input while the red light shines once sufficient heat is stored in the tank, alerting the occupant so that no more fuel is loaded and the stove can be shut down.

Wood logs are supplied by the Estate in tonne bags while the owner of DB1 tends to forage for timber and maintains an impressive wood stack and cutting operation in his back garden!

The solar panels are Worcester Bosch Greenskies Solar Thermal panels with associated controls. The panels themselves are 2.37m^2 each, and there are two on each house, visible on the external views 2.11 and 2.12 in Section 2. Internally, the interface with the occupants is located in the Kitchen showing the panel and tank temperature.

Figure 6.4: Three control panels in the Kitchen, being from left to right the thermostat for the MVHR post-heater, MVHR Unit Control panel and solar panel / tank temperatures.

There is a towel rail in both ground floor toilet and first floor bathroom. The downstairs rail acts as a heat dump if the thermal store is full of hot water.

The houses each have a nominal 90% efficient mechanical heat recovery ventilation system manufactured by Paul. The units extract warm and potentially moist air from the kitchen and bathrooms, and supply fresh air to the living room and bedrooms. Without contamination, both air streams are routed via a heat exchange in which the majority (>90%) of the heat from the outgoing air is picked up by the fresh incoming air. In this way, there is a constant flow of fresh air, but without the attendant cooling.

The 2-bedroom houses use the Focus unit (without summer bypass) and the 3 bedroom houses use the Novus unit (with summer bypass). The ventilation system in all houses has a post heater, which is fed with hot water from the hot water tank as well as the standard electric pre-heater which is a frost protection device. In the 2-bed houses, the units are located in the Utility Room for maintenance and replacement in filters, while in the 3-bed houses, they are located in a cupboard above, and accessed from the stairs. The maintenance is administered by the Estate so location is not really an issue for occupants. The control panel as noted above is located in the Kitchen.

Mains electricity is supplied to the site as normal. Except where replaced by occupants, all lighting in the development is of the CFL type.

Figure 6.5: The 'Focus' MVHR unit in (2-bed) Cottage DA1, showing its location in the Utility Room with Kitchen adjacent, to the right. The pre-heat box is the square black insulated box to the top left

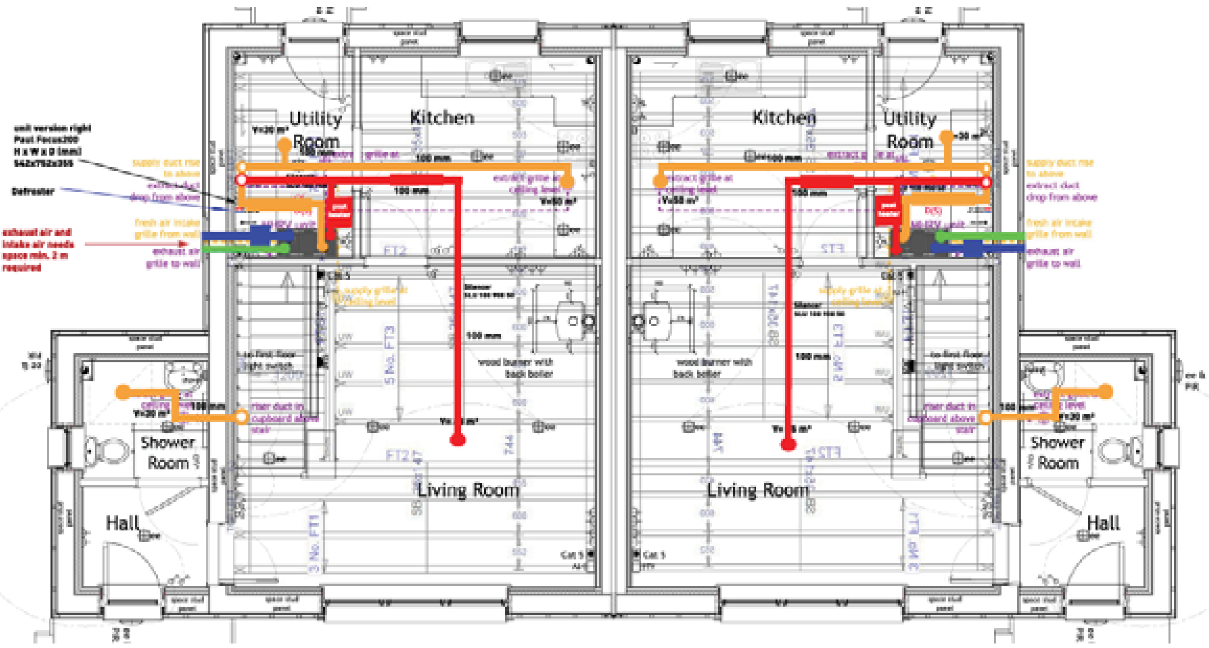


Figure 6.6: Layout of MVHR unit and ductwork for the ground floor of the 2-bed houses.

6.2 Issues Arising

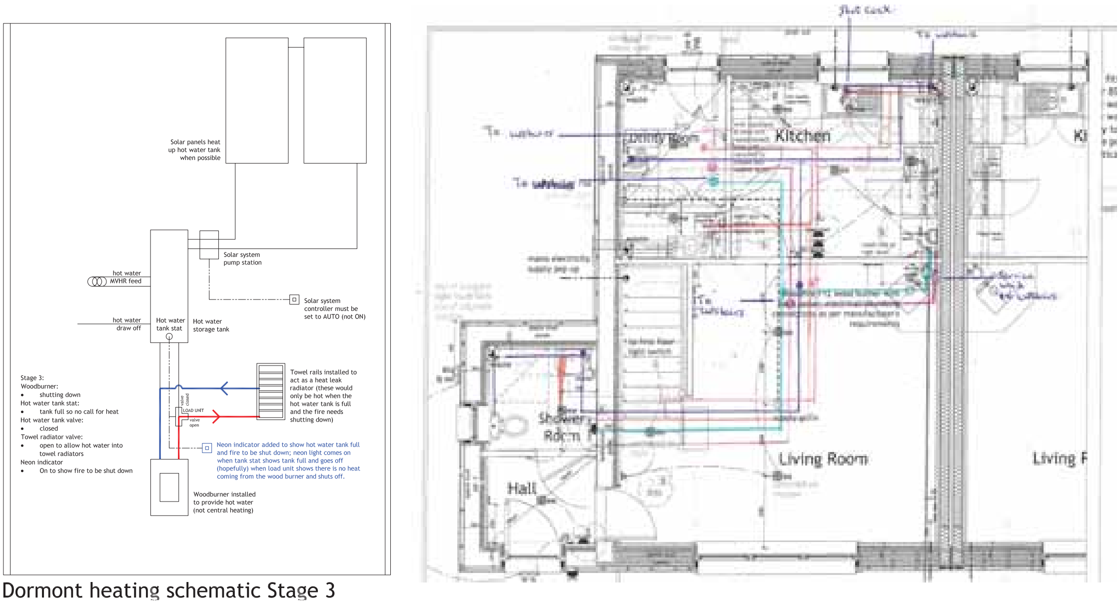
Procurement

As noted in section 2.5 the plumbing and electrics packages were procured as contractor-design elements and were not finalised until well into the build process. There was a basic specification and description to which the contractors were working but the detailed design and installation were the responsibility of sub-contractors with no experience of, nor particular interest in, either Passivhaus design or renewables. With no overview or client-side control, a number of issues developed which are described in the rest of this section.

Briefly, future projects would benefit from some or all of the following:

- providing much more detailed design and specification documentation and guidance to electrical and plumbing sub-contractors, and / or
- engaging (separately or as part of the main contractor) specialist sub-contractors with demonstrable interest and experience in Passivhaus, low energy and renewables-based installations
- ensuring that clear and accurate "as-built" drawings and related documents are provided as part of the contract
- placing even greater emphasis on the handover process, including clear verbal demonstrations and explanations of all active systems and controls, along with both 'quickstart' and more detailed information on the workings of all installed systems, their interactions and their controls

There are important lessons to be learnt from this in terms of either including the services as part of a detailed package of specification / details, or by ensuring that the Contractor has the relevant experience / expertise to design and install services to a Passivhaus standard. It is also important that the Installer is able to produce clear and accurate "as-built" drawings and is able to adequately explain the systems to the incoming occupants.



Dormont heating schematic Stage 3

Figure 6.7: Diagram of the Heating Plumbing Layout, left, and right, 'As-built' plumbing layouts.

Complexity

From the outset of the project it was clear that the complexity of the services was a problem. It has been an issue for the original installers themselves (who made mistakes), the Estate as Client, for all contractors brought in to maintain the system subsequently, for the occupants especially, and for those, such as MEARU staff investigating and monitoring the houses.

The complexity has been exacerbated, and in part caused by, the lack of accurate or clear drawings or documentation of the installations. For example, considerable time was spent on site at the time of the installation of the monitoring equipment trying to determine the correct pipe runs for location of the heat flow meters, which included lighting the Log Stove and adjusting thermostats to induce flows in the pipework.

A number of uncertainties lasted well into the project. The following is a brief description of the alterations and incremental improvements made to the various systems following completion, in no particular order, including alterations made through insights gained from this study.

- towel rail circuits intended as heat dumps were fitted with thermostats meaning there was nowhere else for boiling water to go if the stove was lit for too long, leading to “kettling” where boiling water and steam were ejected from the system via overflow pipes installed at low level into each private garden. As a result, the thermostats were removed and neon indicators were installed indicating the water temperatures enabling basic feedback to occupants to light, or shut down, the stoves;
- there has been considerable confusion about the respective roles of the post-heater and summer bypass of the ventilation systems (which exist on the 3-bed houses, but not the 2-bed houses), leading to an array of ad-hoc techniques developed to increase or reduce temperatures or perceived air quality including switching off the unit and opening windows. This confusion was not helped by inconsistent settings in the MVHR control panels;
- the control switches for the immersion heaters were initially installed in the attic of each houses, making any use of the immersers impractical on a day-to-day basis. Partly as a result of this, and partly because the Contractors advised the occupants to do so, immersers were left on constantly by some occupants, leading to very expensive electricity bills (which were reimbursed by the Estate initially);
- access panels to the post heaters in the 2-bed houses were inadequate and were replaced early in the process to enable the installation of the heat flow meters and for long-term access generally;
- the thermostat installed on the stove flue to control the pump providing hot water from the stove to the water tank did not work because the flue is double walled. The location of the thermostat was moved to a location just above the stove itself. In one case, this was discovered and resolved by the occupant herself;
- the solar control pump was initially set to pump glycol through the system continuously, thus cooling the system overnight. This was altered to ensure the pump was controlled thermostatically, stopping the pump when a set temperature is reached in the tank;
- after occupants complained that the “solar pumps” were running overnight leading to water that was hot in the evening being cold in the morning, it was discovered that the thermostatic controls to the MVHR post-heater was incorrectly wired so that it was always “on”. This was altered as late as November 2013.
- the complexities have additionally affected the monitoring, with mis-labelled circuits (by Contractors) leading to confusion (eg “Central Heating” and “Extract Fan”) while problems have been harder to identify and resolve for all concerned.

Clearly the sum of all of the above issues, coupled with the fact that the installed technologies are new or at least unfamiliar to most occupants has made it difficult for everyone involved to arrive quickly at a clear understanding of the systems and thus efficient control and use of the systems. Luckily the Estate have been extremely diligent in attempting to resolve each and every problem and this has no doubt helped in a situation where the occupants on the whole have been both tolerant and motivated to make the best of the houses. Had either the Estate as landlord not been so helpful, and the tenants less tolerant or engaged, it might have been a quite different story.

Pipework Insulation

A problem linked back to the issue of procurement has been that the original plumber persuaded those involved that heat 'lost' to the building by not insulating pipework was beneficial and so it was agreed on site that pipework need not be insulated.

Under the current (2014) version of the Technical Standards (Building Regulations in Scotland) it is mandatory to insulate all hot water pipework and storage vessels. It may not have been mandatory at the time of construction but it is still surprising that this was not mentioned by the Building Control Officer. Whilst it is not mandatory to insulate pipework in Passivhaus design, an important part of the compliance process is to state the length of hot water pipework and how much insulation is to be installed. Since it evidently saves energy to insulate said pipework, there is no doubt that an amount of insulation would have been stated in the PHPP document approved for certification.

Whilst there is little doubt that in colder months, such heat loss from pipework contributes to the overall warmth in the house, it is also the case that such *uncontrolled* heat loss is much less welcome in the warmer months, particularly in houses prone to overheating. This is discussed in greater detail in Section 7, while thermographic evidence of the uninsulated pipes is shown below.

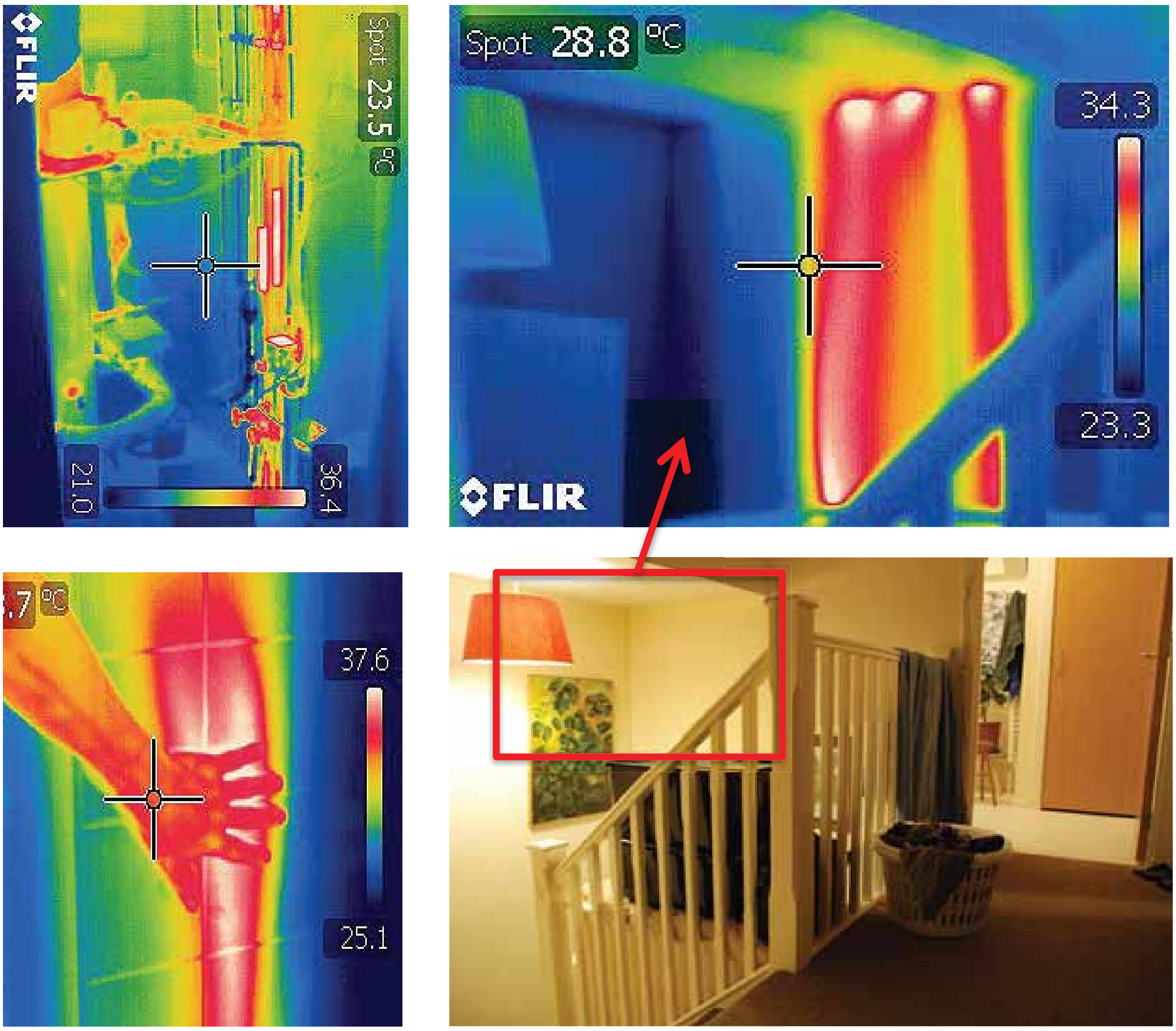


Figure 6.8: Top left: thermographic image of the uninsulated pipework in one of the landing cupboards. Top right: thermographic image of a section of wall to the stairwell with uninsulated hot water pipes running within and, bottom right: the same area of wall in context. Bottom left: thermographic image of the other side of the same area of wall, behind tiling to the bath with the Occupant's arm to indicate the high surface temperature created.

Wood Stove Use in DA1

In three of the four households studied, the main or corresponding occupant has been commendably engaged in not only the study itself, but the ongoing effort to make the most of their renewably heated Passivhaus. In cottage DA1 however, the occupant, a single young mother with a toddler, was noticeably less engaged in the drive for energy efficiency, at least, to begin with. For the study in many ways this has been helpful in allowing us to witness a divergence in occupant behaviour and energy use. It is also perhaps more representative of the wider population who are unlikely to be as committed, or have the time to commit to energy efficiency as the majority of those at Dormont Park.

The issue came to light in the first few weeks of monitoring. The graph below, a screen capture from the T-mac monitoring software in December 2012, showed immediately that one house – shown by the light orange line / fill – was consuming substantially more electricity than the other three dwellings.

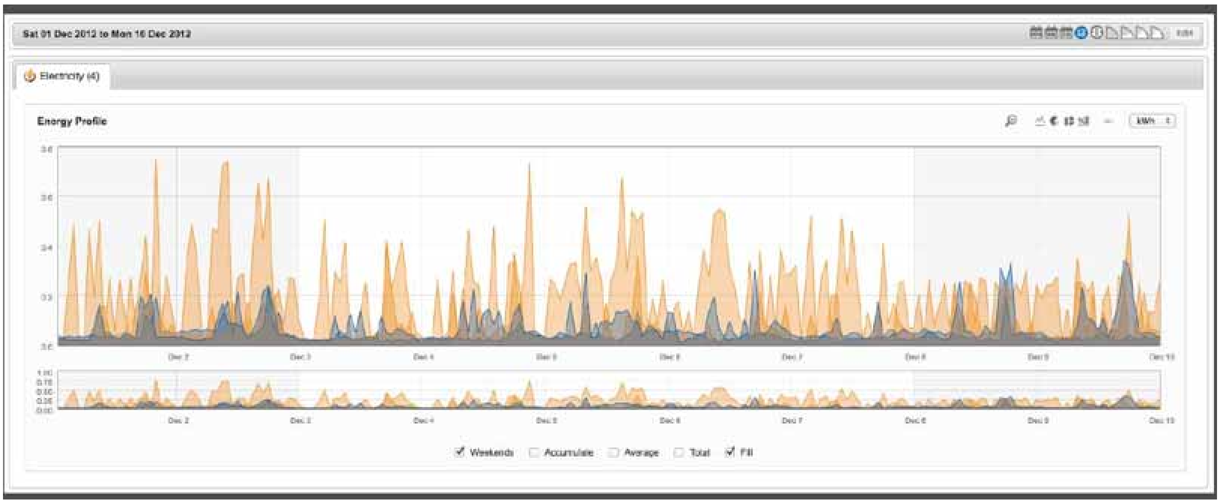


Figure 6.9: Total Electricity Consumption, all houses 2 – 9 Dec 2012

Looking in more detail at cottage DA1 in isolation, it became clear that the vast majority (80%) of this electrical consumption was due to the use of the immersion heater. The water heater is shown in pale green in both graphs shown below.

Figure 6.10: DA1 sub-metered electrical consumption for a typical week in December 2012 – water heating is shown light green

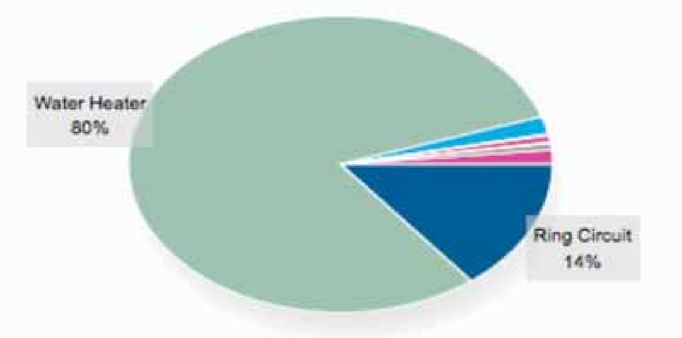


Figure 6.11: DA1 sub-metered electrical consumption for the same week as above, shown as a pie chart, with water heating accounting for 80% of all electrical consumption.

The situation was monitored throughout the rest of the project. The graph below is taken from the summer period in 2013 and compares the overall electrical consumption and immersion heater consumption for both cottages DA1 and DA2. The graph is shown with consumption stacked cumulatively for greater effect. The grey line / fill shows DA1 overall electricity use, while the green-grey line indicates the use of the immerser in DA1. The two pink lines show the overall electric consumption of cottage DA2 and – right along the bottom – the use of the immerser in DA2.

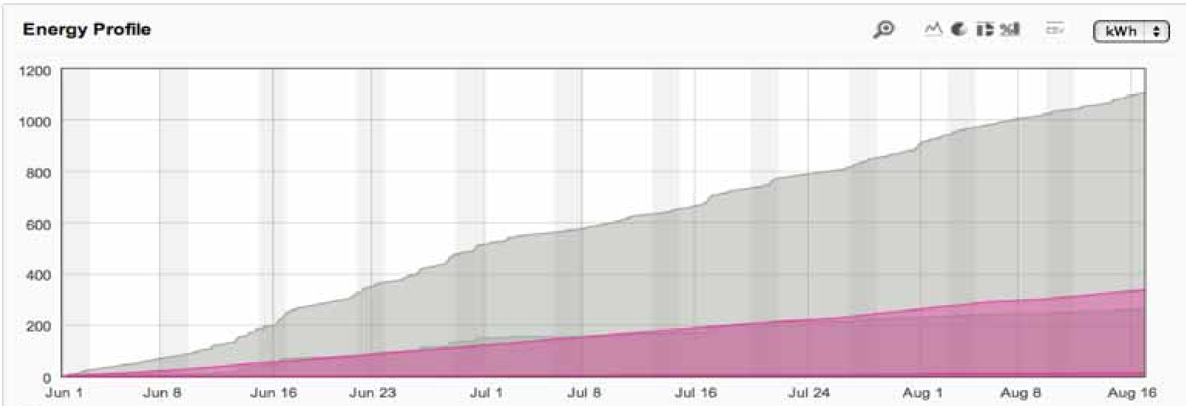


Figure 6.12: June 1st to August 16th 2013. Overall electricity and immerser consumption in cottages DA1 and DA2.

Two things are clear from the graph above. The first is that the use of the water heater in DA1 is almost exactly the same as the total use of electricity in DA2. The total electrical consumption of DA1 is over three times that of DA2 and the use of the electric immerser continues unabated through the summer months despite the supply of hot water from the solar panels. The second thing is that the immerser no longer appears to account for 80% of the electrical use in DA1.

There are a number of reasons why the occupant was not using the wood stove and was relying entirely on the immerser for hot water. These are:

- She had never had a wood stove in her house before, so was unfamiliar with the technology
- When she did use the wood stove, the issues noted before to do with lack of effective heat dump and feedback meant that 'kettling' took place which apparently makes a terrible noise and results in boiling water and steam emanating from a low level pipe in the garden. It does not bear thinking about what would have happened if this had taken place while the child was playing outside at the time.
- She worked full time and with a small child did not feel she had time to collect and store firewood, and light the stove whenever heat was required for either the house or hot water

- also, unbeknown to the occupant or the Estate at the time, the post-heater control was not wired correctly and so the post-heater was always 'on', draining the hot water store overnight and leading to constant re-heating of the water using the immerser.

Initial attempts by the Estate to encourage her to use the wood stove more failed. However, the results of this were becoming very expensive and the occupant expressed a desire to reduce costs and start using the wood stove. The Estate brought in in both the Electrician and Plumber who maintained the systems to explain how it all worked. By this time, a number of problems had also been resolved so the system worked as intended. The graph below, whilst rather undramatic, in fact shows the occupant starting to use the wood stove and as such represents a significant benefit of the efforts directly and indirectly related to this study.

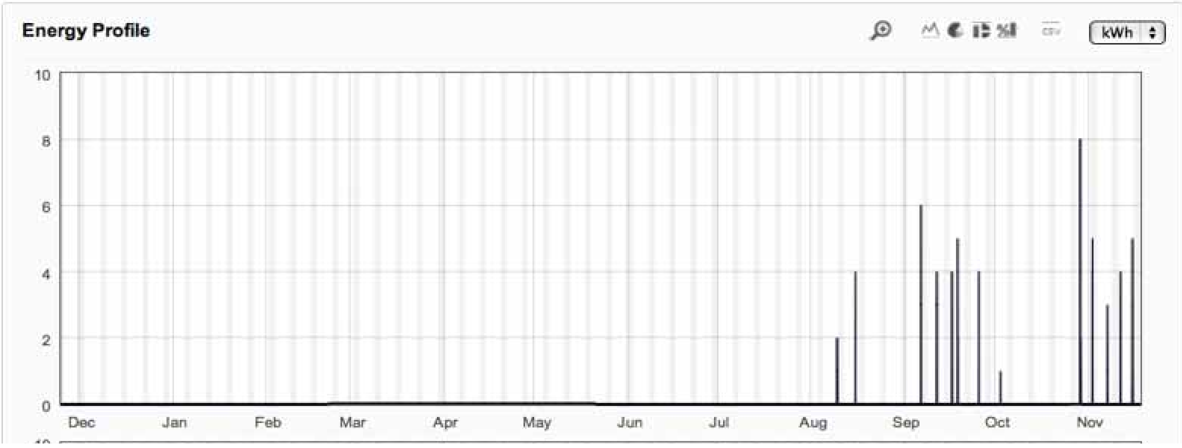


Figure 6.13: DA1. Dec '12 to Nov '13. Use of the wood stove since monitoring began. The peaks indicate hot water 'pulses' from the lit wood stove. Costs of electric bills and ongoing efforts by the Estate have combined to persuade the Tenant to begin to use the wood stove as the cold weather began.

The pie chart below also tells a story. It shows the breakdown of electrical consumption for the period January to May 2014. Although rather small, what can be seen is that in terms of consumption, the largest proportion (47%) is associated with the downstairs ring circuit (dark blue) while the second largest, at 37%, is associated with the immerser. Whilst still a high proportion relative to the other houses, it is nothing like the 80% noted at the beginning of the monitoring.

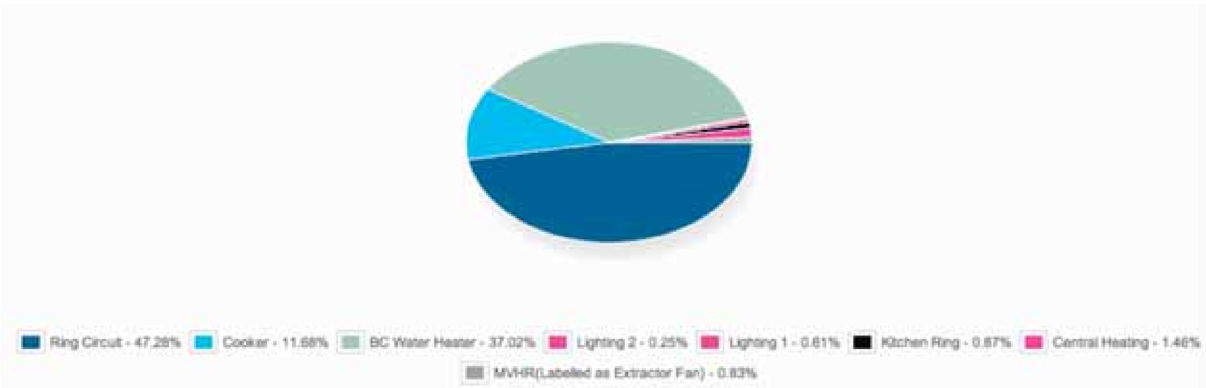


Figure 6.14: Electricity consumption by type at DA1 Cottage: almost half of the consumption (dark blue) is from the Downstairs ring circuit, likely to be due to the large television and associated gadgetry which tend to be on all the time, while the water heater (light green) still uses a significant chunk at 37%.

The final graph below, shows the overall electrical use and immerser consumption for the year May '13 to May '14. Whilst sub-metering data is missing for December to March '14, the trend is clear, showing both reduced electrical consumption overall, and reduced use of the immerser bring both wider environmental benefits and cost savings to the occupant.

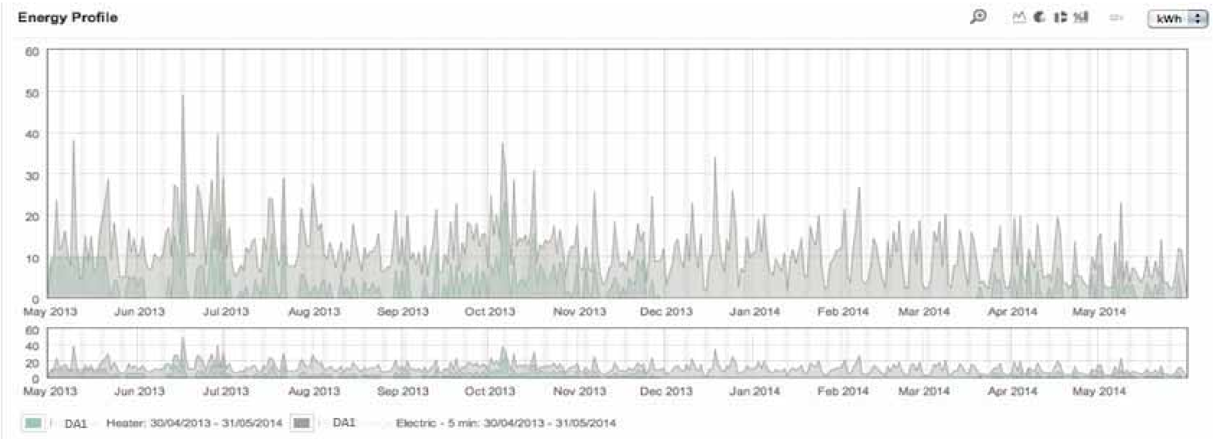
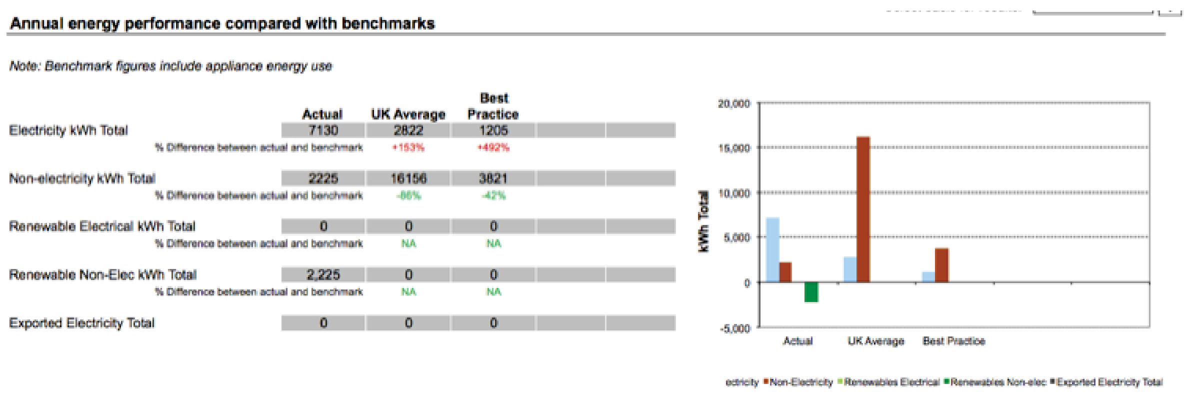


Figure 6.15: Overall Electrical consumption (grey) and water heater electrical use (green) for the period May 2013 to May 2014 inclusive in DA1. Sub-metered data is missing for December to mid-March but the trend is clear.

6.3 DomEARM

Survey work for the **DomEARM audit** was carried out by MEARU staff in November 2013 for all four units and copies of the resultant sheets are included in **Appendix Folder 6.3**. The process involves an audit of every item drawing electricity in the home, from regulated use such as immersers, lights and pumps to non-regulated use such as washing machines, kettles, TVs and mobile phone chargers. This information is fed into a spreadsheet which takes – in this case – accurately monitored energy consumption and derives graphical indications of the actual consumption of the dwelling compared to typical and best practice consumption in the UK.


Annual energy performance compared with benchmarks

Note: Benchmark figures include appliance energy use

	Actual	UK Average	Best Practice
Electricity kWh Total	7130	2822	1205
% Difference between actual and benchmark		+153%	+492%
Non-electricity kWh Total	2225	16156	3821
% Difference between actual and benchmark		-86%	-42%
Renewable Electrical kWh Total	0	0	0
% Difference between actual and benchmark		NA	NA
Renewable Non-Elec kWh Total	2,225	0	0
% Difference between actual and benchmark		NA	NA
Exported Electricity Total	0	0	0

Figure 6.16: DA1: DomEARM assessment: much higher electrical use than UK Average (light blue columns), balanced by far lower heat requirement even than best practice (red columns).

The sheets confirm that electrical use within the houses ranges from low (DA2) to high (DA1), relative to typical usage. There is no renewable generation of electricity. Anecdotally, the MEARU Staff who surveyed the houses at Dormont believe that the number of electrical and electronic gadgets generally in the homes is lower than elsewhere, even where teenage children were present.

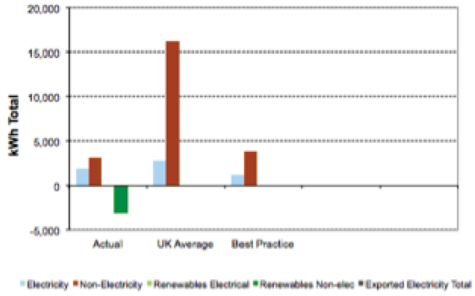
Heat energy consumption is extremely low in all cases and except in Cottage DA1 where the immerser was used to heat water, the demand for heat is being met by either thermal solar or biomass, which, being renewable, essentially cancel out the non-electric demands in each property according to the graphs below.

However, the software has not picked up the difference between space heating and water heating in the four spreadsheets submitted so the final graphic which breaks down all energy use by type is misleading as it does not recognise the water heating as part of the non-electric mix.

Annual energy performance compared with benchmarks

Note: Benchmark figures include appliance energy use

	Actual	UK Average	Best Practice
Electricity kWh Total	1880	2822	1205
% Difference between actual and benchmark		-33%	+56%
Non-electricity kWh Total	3142	16156	3821
% Difference between actual and benchmark		-81%	-18%
Renewable Electrical kWh Total	0	0	0
% Difference between actual and benchmark		NA	NA
Renewable Non-Elec kWh Total	3,142	0	0
% Difference between actual and benchmark		NA	NA
Exported Electricity Total	0	0	0



***Annual Emissions compared with benchmarks**

Note: Benchmark figures include appliance energy use

	Actual	UK Average	Best Practice
Electricity kgCO2 Total	972	1459	623
% Difference between actual and benchmark		-33%	+56%
Non-electricity kgCO2 Total	18	3199	757
% Difference between actual and benchmark		-99%	-98%
Renewable Electrical kgCO2 Total	0	0	0
% Difference between actual and benchmark		NA	NA
Renewable Non Elec kgCO2 Total	18	0	0
% Difference between actual and benchmark		NA	NA
Balance kgCO2 Total	972	4658	1380

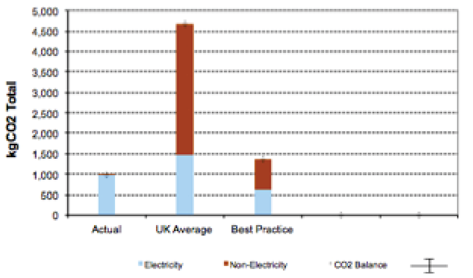


Figure 6.17: DA2: DomEARM assessment: lower electrical and non-electrical demand than UK Average, on a par with best practice, lower graph shows that renewable input for heating gives an overall emissions level better than best practice.

6.4 MVHR Testing

Assessment of the performance of each of the MVHR systems in the 4 study dwellings was undertaken at Dormont Park in May 2013. The visual inspection showed that the specification and installation of the system was of the relatively high standard that could be expected of a Passivhaus certified project. The exception to this was in DB2 where an inaccessible extract terminal means that the house could not feasibly have been balanced, nor therefore commissioned correctly. Whilst only one error amongst many dozens of terminals, it nonetheless raises concerns about the commissioning and subsequent certification process.

Figure 6.18: MVHR Unit in Cottage DB2 with Intake and Exhaust ductwork and extract grille behind, inaccessible for commissioning.

Furthermore, system imbalance (in bold type in the table below) was frequently found which might suggest further issues with original commissioning or, as 2 years has passed, make a case for recommissioning the systems. Whilst neither the poorly located terminal, nor the noted imbalances represent serious problems, the existence of both suggest a process that was not as rigorous as it should be for Passivhaus certification. Technically, the system at DB2 could not physically have been correctly commissioned which suggests that the certification was invalid. **The report of this inspection and test** (MVHR Test Report 1) is contained in **Appendix Folder 6.4** along with the individual test reports.

ADDRESS	TEST	CLEAN FILTER HIGH FLOW (L/S)	CLEAN FILTER LOW FLOW (L/S)	50% OCCLUSION HIGH FLOW (L/S)	50% OCCLUSION LOW FLOW (L/S)
DA1	Whole Hse Supply	56.97	39.89	49.01	**45.58**
	Whole Hse Extract	44.94	36.72	43.53	**38.63**
	Supply / Extract	**1.27**	**1.09**	**1.13**	**1.18**
DA2	Whole Hse Supply	33.46	28.30	35.56	**27.76**
	Whole Hse Extract	33.42	25.10	39.71	**30.65**
	Supply / Extract	**1.00**	**1.13**	**0.90**	**0.91**
DB1	Whole Hse Supply	50.60	42.17	51.28	**39.65**
	Whole Hse Extract	44.77	36.99	43.34	**35.33**
	Supply / Extract	**1.13**	**1.14**	**1.18**	**1.12**
DB2	Whole Hse Supply	47.17	41.11	47.85	**45.16**
	Whole Hse Extract	38.63	no value	39.11	**32.02**
	Supply / Extract	**1.22**	**no value**	**1.22**	**1.41**

Figure 6.19: Results of the Volume Air Flow of the MVHR Systems.

At the time of the above test and inspection, it was not sufficiently cold to undertake the thermal or electrical efficiency testing and these were put off until the winter. Thermal and Electrical Efficiency tests were undertaken on site in November and the report (**MVHR Test Report 2**) is included within **Appendix Folder 6.4**.

The electrical efficiency test consisted of maintaining two systems (Focus 200 at DA2 and Novus 300 at DB1) at known settings for a known period of time, and recording the electrical use via the T-Mac portal. However, the results gained from the portal were inconclusive and could not be used.

The thermal efficiency test consisted of inserting 4no thermocouple sensor probes into each of the 4no ducts immediately adjacent to the Paul Unit in DB1. A photograph of the set-up is shown below. The system was clearly operating well (refer MVHR Test Report 2) and whilst the initial result showed an exceptionally high efficiency, it was not possible to confirm these figures with certainty due to the electrical measurement issues note above, and explained below.

Figure 6.20: Thermal Efficiency Test Set-up in DB1.

A site visit with an Engineer was arranged in March 2014 to resolve the problems with the T-mac readings. The MVHR circuit was identified and tested using a range of amp meters, such as the example shown below. What became clear is that the installed clamps are not accurately picking up the differences in current between the various settings of the MVHR unit despite being an explicit requirement of MEARU and TSB. The clamps are rated at 100 Amps and the current changes between settings range between 0.1 and 0.3 Amps.

Furthermore none of the three amp meters brought by the Engineer could pick up the changes with any greater accuracy. Thus we were not in a position to test the MVHR with accuracy using either the installed clamps or the amp meters brought to site. Nonetheless we did undertake a test using the most accurate meter and obtained results consistent with our expectations, although these cannot be considered to be fully accurate. The results and conclusions are in **MVHR Test Report 3** contained in **Appendix Folder 6.4**

Figure 6.21: Measuring the current flow for the MVHR circuit in DA2 using a range of other amp meters.

This has a wider significance as it means that individual items rated at approximately 50-100 Watts or less are not being measured at sufficient resolution. It is likely that this will account for any discrepancies found between the fiscal meter readings and the sum of sub-metered data.

MVHR Energy Consumption

The results given in the above report are shown below and can be extrapolated to give an indication of the annual energy consumption of the MVHR units and compared to typical benchmarks.

MVHR SETTING	SAMPLE PERIOD	AMPS MEASURED	MULTIPLIED BY VOLTAGE	MEASURED WATTAGE
1	1 minute	0.1	230	**23 W**
2	1 minute	0.2	230	**46 W**
3	1 minute	0.3	230	**69 W**

Figure 6.22: Results of Insitu testing of MVHR Circuit current (Amps) at DA2, 20th March '14.

Taking the 'Normal' setting of '2': 46W x 1 hour / 1000 gives 0.046kWh x 24 = 1.104 kWh/day, or 403 kWh/year for DA2. Divided by the area of the house (87 m^2) gives us 4.63kWh/m^2/year. This is comparable to the indicative annual square metre consumption noted in DomEARM of 3.6 kWh/m^2.

The monitoring of the four properties for the period Dec'12 to Nov'13 inclusive shows, by comparison, annual consumption figures for the MVHR of 157, 86, 248 and 100kWh. The average for the properties is 147.8 kWh. This is less than half of the extrapolated figure noted above and when divided by the average floor area gives 1.56 kWh/m^2/yr.

The graph below shows the monitoring of the MVHR unit at DB2 during the period noted and shows (albeit subject to the 'blunt' accuracy of the clamps used) consumption ranging typically from a higher setting of around 70 Watts to a normal setting of around 35 Watts. This indicates that the 46W measurement taken above for DA2 is in the right order. However the graph also shows that the consumption is in peaks and that energy consumption is not constant, with many areas of notably lower draw.

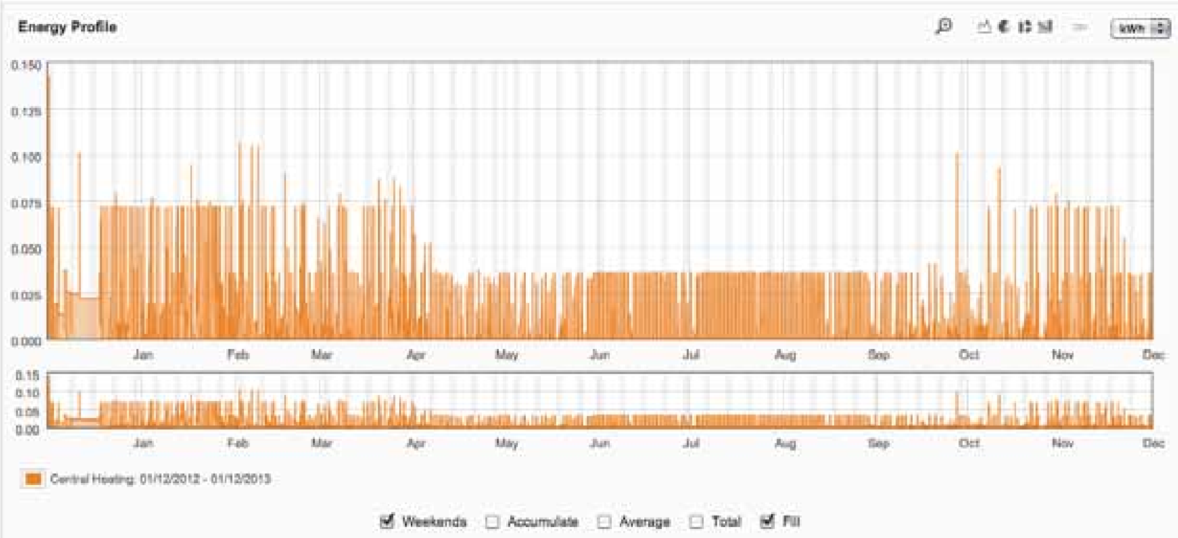


Figure 6.23: Results of Insitu testing of MVHR Circuit current (Amps) at Cottage DA2, 20th March '14.

Furthermore, the monitoring shows, for example, that in DA2, the unit is switched off for several months over the summer and is also clearly switched to very low levels of operation ("Standby" or "Unoccupied") for long periods in all of the properties which no doubt has lead to the lower figures recorded. We cannot say that this is typical across the UK, but it is certainly representative and consistent across the four properties at Dormont.

It is perhaps also worth noting that in general, the installation and maintenance at Dormont has been of a high standard, with filters regularly changed, relatively good balance on supply / extract and good commissioning generally. We know that MVHR installations generally across the UK are typically of a much lower standard, and perhaps this is another reason for the discrepancy in the annual figures noted.

6.5 Conclusions and key findings for this Section

- Passivhaus compliance meant that MVHR for ventilation was non-negotiable. Remaining service installation was based around the local lack of a mains gas grid, and the twin ideals of using renewables in general, and making the best use of local, rural resources. Hence beyond passive and active solar, locally sourced timber was used;
- While MVHR design and installation was by a Specialist company, plumbing and electrical works were contractor-designed. Future projects will engage a more specialised overview, design and specification, either through the Design Team, or via experienced Installers (or both);
- As complexity generally has been a problem for installers, Client, occupants, *simplicity* of services installation will be a key parameter of any future projects;

- greater importance should be placed on the provision of accurate 'As-built' drawings;
- greater importance will be attached in future developments to both the handover process, and, as part of this, the clarification and understanding of the controls for all systems;
- the diligence of the Estate (landlord) has been crucial in maintaining a good relationship with the tenants who for their part have been tolerant of the teething problems experienced in the development;
- hot water pipework should always be insulated, in all areas;
- a number of unforeseen circumstances led to one tenant using the immerser at all times in preference to the wood stove intended for most water heating. Resolution of system issues and encouragement by the Estate eventually led to significant changes in occupant behaviour with concomitant environmental benefits and cost savings
- the DomEARM audit confirms that non-electric consumption is exceptionally low in all houses and comparable to best practice, while electric consumption ranges from high (in DA1) to very low (DA2) when compared to typical UK consumption;
- The MVHR installation is generally of a high quality with sufficient airflow generally, but with one grille inaccessible and in three of the four houses a slight over-pressurisation;
- We were not able to accurately assess the electrical or thermal efficiency of the MVHR due to the clamps used by T-mac which are rated too high to capture the small grain of electrical flow in the smaller items in the house, including the MVHR unit. Insofar as we were able to (inaccurately) measure it, it was performing as expected and stated by the Manufacturer.

7 Monitoring methods and findings

7.1 Monitoring Set-up

A plan for monitoring and metering the energy consumption and environmental conditions of the 4 houses was developed by MEARU in discussion with T-Mac technologies, taking into account the location of the site and nature of occupants. The equipment suppliers selected for this project were ORSIS Ltd. for primary metering and T-Mac Ltd. for sub-metering and environmental monitoring, with whom MEARU have worked on previous projects including Bloom Court, Inverness and Barrhead. The items monitored by the whole system are as follows:

Metering and monitoring		**5 minute meter reading intervals**		
House Type	Utilities	Sub-metering – 8 circuits	Heat Flow	Environment
All Houses	Electricity	Cooker Immerser MVHR Kitchen Sockets Downstairs Sockets Upstairs Sockets Downstairs Lighting Upstairs Lighting	Wood Stove Dom'c Hot Water MVHR Post-heater Solar Panels Towel Rails	Living Room Kitchen Main Bedroom 2nd Bedroom all cases: temp, %RH and CO2 and window opening sensors Weather Station

Figure 7.1: Metering and monitoring in each house type.

A particular concern here was the remote rural location of the site. Two strategies were considered but on the basis that signal strength was determined to be sufficient, it was decided to use a remote data collection system which gathered data locally and transmits it over GRPS networks to a central server. A preference was made for a wireless data capture system as far as possible. In domestic situations this is preferable to wired systems as it makes sensor placement far less restrictive (it removes the need to be adjacent to power sockets) and robust (less risk of equipment being accidentally unplugged). Data is transmitted live to an off-site repository, to provide better security, reduce data loss and reduce the need for access to the houses. The repository was accessed through a password protected web portal, which allowed online viewing of data and creation of graphical displays, data was also downloadable from the repository.

T-Mac were able to supply a wireless solar powered temperature, relative humidity and Carbon Dioxide sensor, which were used to monitor the environmental conditions. This equipment has been used in conjunction with solar powered contact sensors to monitor window opening. This data is transmitted wirelessly to a central t-mac unit, which is hard-wired via a fused spur to the meter board in the utilities cupboard generally. At the meter board 8 electrical sub-circuits are monitored via CT clamps, which are connected back to the t-mac unit.

The images below show the installation of the main T-mac (left) and Orsis (right) metering arrangements, the clamps installed to monitor the sub-circuits, the layout of environmental monitoring sensors and the bottom diagram shows the heat flow meter points.

Figure 7.2: Left: Installation of the T-mac meter and associated wiring. Right: installation of the Orsis Fiscal Meter including the internal antenna which was subsequently moved outside.

Figure 7.3: Mains Distribution Board in Cottage DA2 showing the 10A clamps which measure the electrical flow through each sub-circuit.

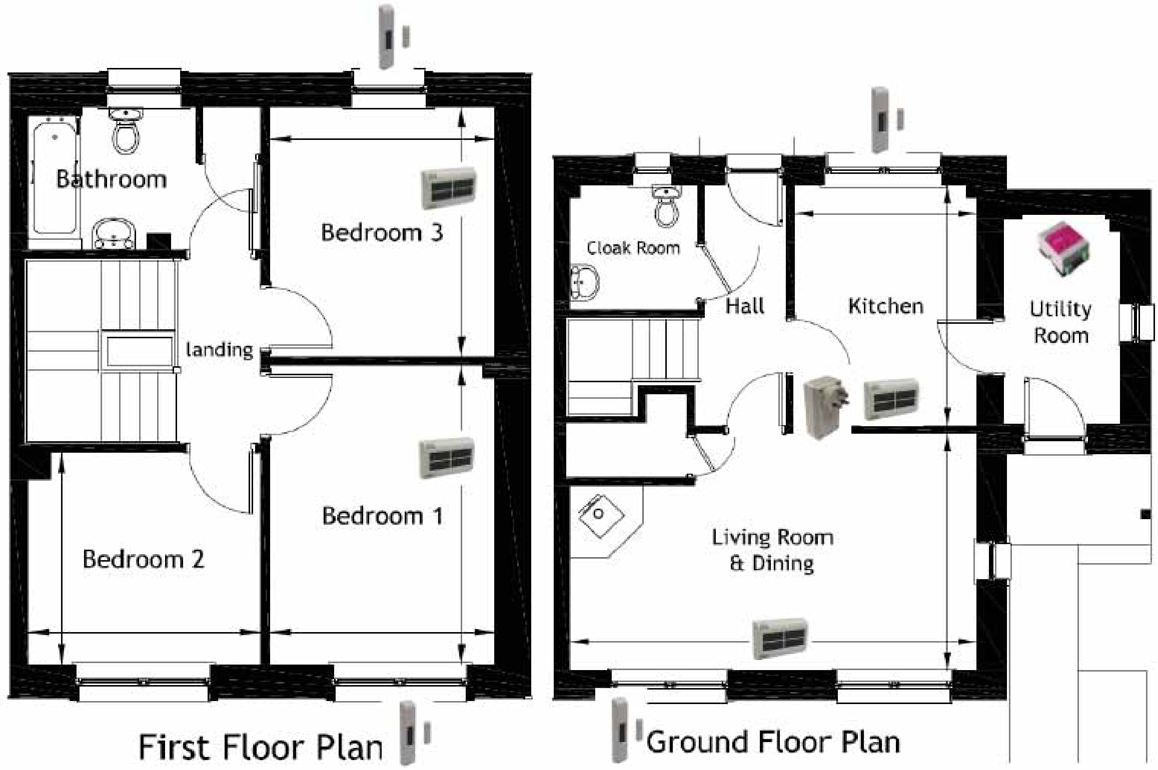


Figure 7.4: Layout of environmental sensors within one of the 3-bed homes

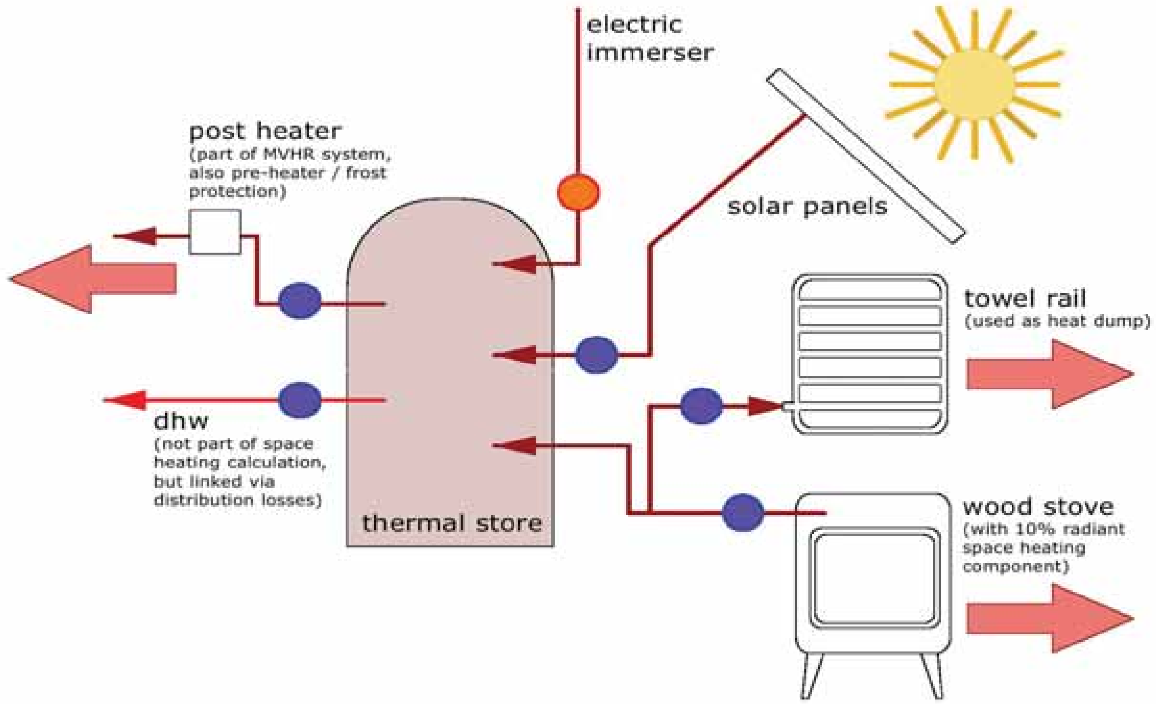


Figure 7.5: Simplified diagram of Dormont Heating Systems. Blue dots indicate heat/flow meters installed. The red dot indicates the electrical metering of the hot water immerser.

7.2 Equipment Issues

Several site visits were undertaken by MEARU in August and September 2012 and a site visit held between MEARU and T-Mac in August 2012. Following installation problems at another site a further detailed site survey was conducted on 2 October 2012. As a result of this investigation the metering strategy was revised to address issues of internal signal strength and GSM connection and the specification of the antennae, use of repeaters and the location of wireless sensors was revised to produce a robust solution. The **Monitoring Installation Reports prepared by T-mac and Orsis** on these discussions is included in **Appendix 7.1.**

The houses are not fitted with water meters (this is not a requirement of Scottish Building Standards) so retrofitting these would be both very expensive and also disruptive to the occupants, thus direct water metering was omitted. A number of problems were encountered in relation to the plumbing system, related controls and these are discussed briefly in Section 6 above.

The project benefitted from a learning curve established at the Highland Expo project, as a result of which the specification of equipment had been improved and T-mac had also revised their working methods. These steps included a more detailed site survey to accurately measure signal strength in the houses, identify locations for equipment, and identify space and location of the consumer units and space available for CT clamps and placement of heat flow meters. It has also been helpful where possible for this visit to be undertaken in conjunction with the electrician and plumber to that the position and nature of the equipment can be discussed. We have found that some cases a domestic electrician is unfamiliar with the equipment and wiring required, and this can lead to extended time on site during installation.

To assist this we also specified that the equipment should be pre-wired as far as possible, and MEARU also undertook some pre installation wiring of pulse counters to be used on the heat flow meters. These steps have reduced site time and complications considerably and have streamlined the installation process.

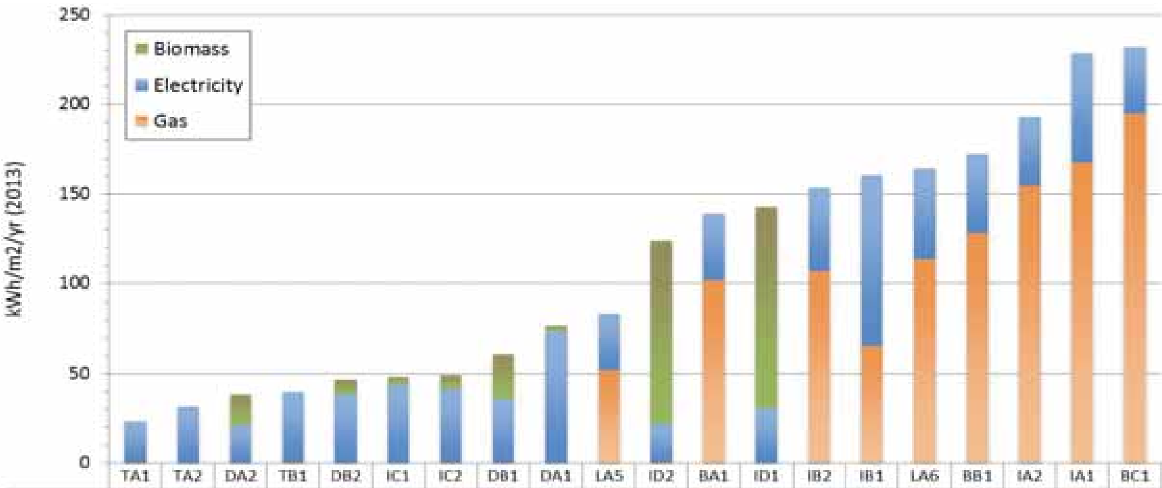
Notwithstanding the above, there have been a number of issues on site resulting in incomplete data in a number of places. Signal failures have taken place in all cottages, while a lengthy outage in DA1 turned out to be due to the T-mac meter being accidentally switched off by the Occupant. This was probably due to the fact that the cupboard had been filled with large children’s toys so it would have been easy to knock the switch without realising. A number of small signal failures were relatively quickly resolved. Early on in the process, the energy analysis portal required re-working after which it was found that imported data from the Orsis site was not displaying correctly on the T-Mac site. Additional heat flow meters were installed and have proved to be particularly prone to failure. For this reason, the overall heating energy calculations shown and discussed in Section 7 are not 100% accurate as noted.

Most importantly, it transpired that the 100amp CT clamps installed by T-mac are not sufficiently accurate to measure the relatively small electrical loads imposed by the various domestic-scaled items. This became clear after failing to record an accurate electrical load for the MVHR system. The report on this issue, primarily intended to report on the **MVHR thermal and electrical testing** is contained with **Appendix Folder 7.2.** While the total electricity demand is accurate as it is linked directly to the fiscal meter, the sub-metering is less than 100% accurate. The major loads are accurately recorded because the clamps are able to pick up the larger loads clearly, and because these major loads comprise the bulk of the energy demand, the totals for electricity demand are close. It is in the finer details and smaller loads that accuracy is lost – a problem which MEARU intend to remedy by installing more accurate clamps for additional and continued monitoring planned for 2015.

7.3 Energy Consumption

Overall Energy Efficiency

Energy use in the dwellings can be compared with 22 other low energy dwellings in Scotland being monitored as part of this TSB programme and this breakdown is shown below. Overall the buildings at Dormont – labelled DA1, DA2 DB1 & DB2 - are performing well against these buildings and most common benchmarks.



	TA1	TA2	DA2	TB1	DB2	IC1	IC2	DB1	DA1	LA5	ID2	BA1	ID1	IB2	IB1	LA6	BB1	IA2	IA1	BC1
Biomass	0.0	0.0	17.0	0.0	8.5	4.9	7.7	25.0	2.8	0.0	101.7	0.0	111.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Electricity	23.5	31.3	21.1	39.7	38.1	43.5	41.6	36.0	74.2	32.0	22.0	37.2	30.7	46.8	94.8	50.8	44.4	39.1	61.3	37.5
Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	51.7	0.0	101.7	0.0	106.6	65.4	113.4	127.9	154.1	167.2	194.7

Figure 7.6: Electricity, Gas and Biomass consumption for 2013 across 20 Scottish projects monitored by MEARU.

There are variations in overall consumption and reasons for this include different house types, occupancy patterns and behaviour, as well as location. The figure below shows the same projects, in the same order, with the total energy figures expressed as carbon emissions taking into account the relative emissions factors. With the exception of DA1, which used a lot of electricity, the Dormont projects fare well, dropping below the adjacent projects due to the use of woodfuel.

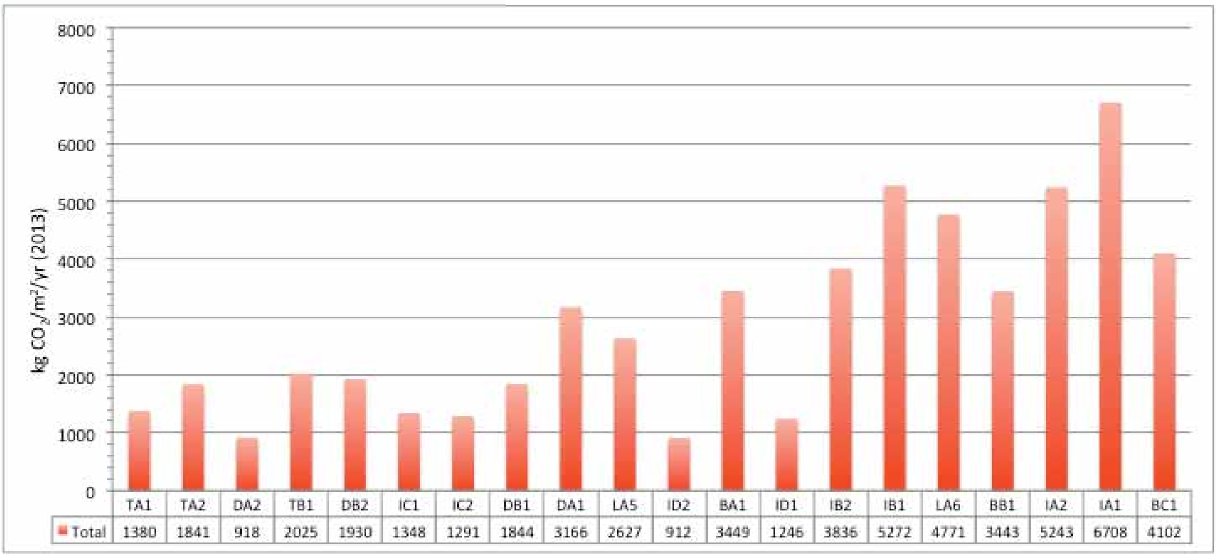
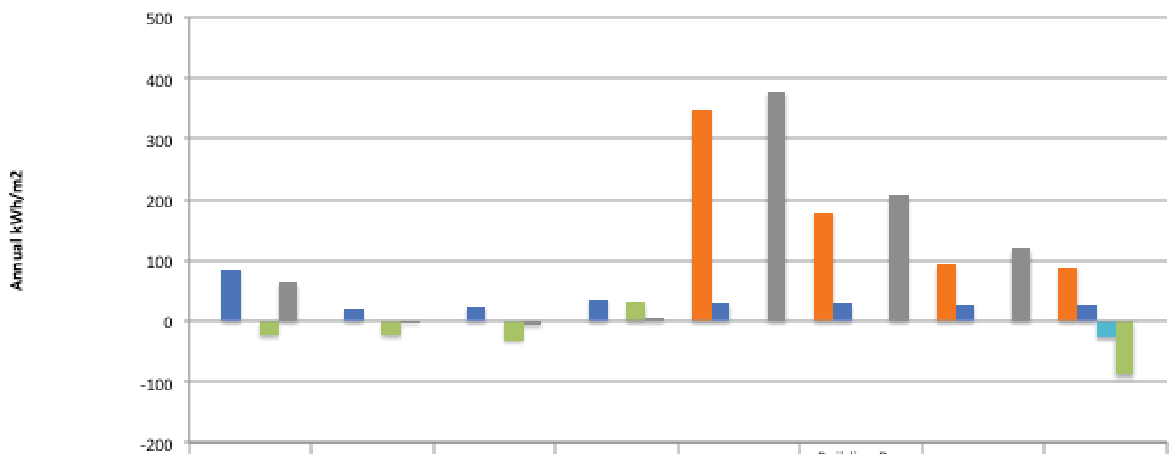


Figure 7.7: Associated CO2e emissions for 2013 across 20 Scottish projects monitored by MEARU.

The graph below shows the overall energy consumption of the four Dormont houses, indicated as per square metre results and divided into both electric and non-electric demands and generation, in comparison with a series of common UK benchmarks.

The graph shows immediately the low consumption of the Dormont houses in relation to all benchmarks. Further, it supports the Passivhaus assertion that demand reduction is a more effective tool than renewables generation. As can be seen by considering the "Net" energy consumption figures shown at the bottom of the legend, excluding DA1, the Dormont properties achieve net figures close to, and in two cases below zero. They have achieved this primarily by reducing demand levels to exceptionally low levels, which are then relatively easy to meet with non-renewable generation. In contrast, the CSH6 figures reach zero through a far greater generation of renewables to offset far higher consumption levels.



	DA1	DA2	DB1	DB2	UK Average	Building Reg Compliant	CSH4	CSH6
Gas	0	0	0	0	349	179	92	89
Electricity	86	21	24	36	29	28	27	27
Renewable Elec	0	0	0	0				-27
Renewable Non-Elec	-23	-23	-31	31				-89
Net	63	-2	-6	5	378	207	119	0

Figure 7.8: Annual per square metre energy consumption of Dormont properties in relation to common UK benchmarks.

No distinction is made between fuel type in the above graph nor between electric and non-electric consumption / generation when considering 'net' consumption, nor can it necessarily be assumed that renewable generation equates to a 'negative' figure so this figure could be somewhat misleading, however it follows a common way of presenting the overall energy consumption and generation balance. The issue of zero carbon is discussed in more detail in Chapter 8.

It is worth noting again the issue of energy cost discussed in Section 2.3. SAP predictions for energy consumption were, on average, relatively accurate. However, the predicted timber and electricity unit costs were unrealistically low which is the reason the overall energy costs of the houses have been around 4x higher than predicted by SAP at around £60 p/a for timber and £500 p/a for electricity.

Looking at the Houses in more Detail

The graph below shows the breakdown of energy consumption on a monthly basis for DA1. Note that there were monitoring issues in December and no results are displayed. What is immediately obvious is the significant percentage of energy consumed by the tank immerser (Dark Grey-Blue). This has been discussed in the previous chapter. However, an intriguing aspect shown here is that the principal demand for the immerser appears to be linked to space heating due to the reduction in demand due to the improved output from the solar thermal system. The corresponding increase toward the end of the year is missing, but this is likely to be due to the monitoring issues experienced.

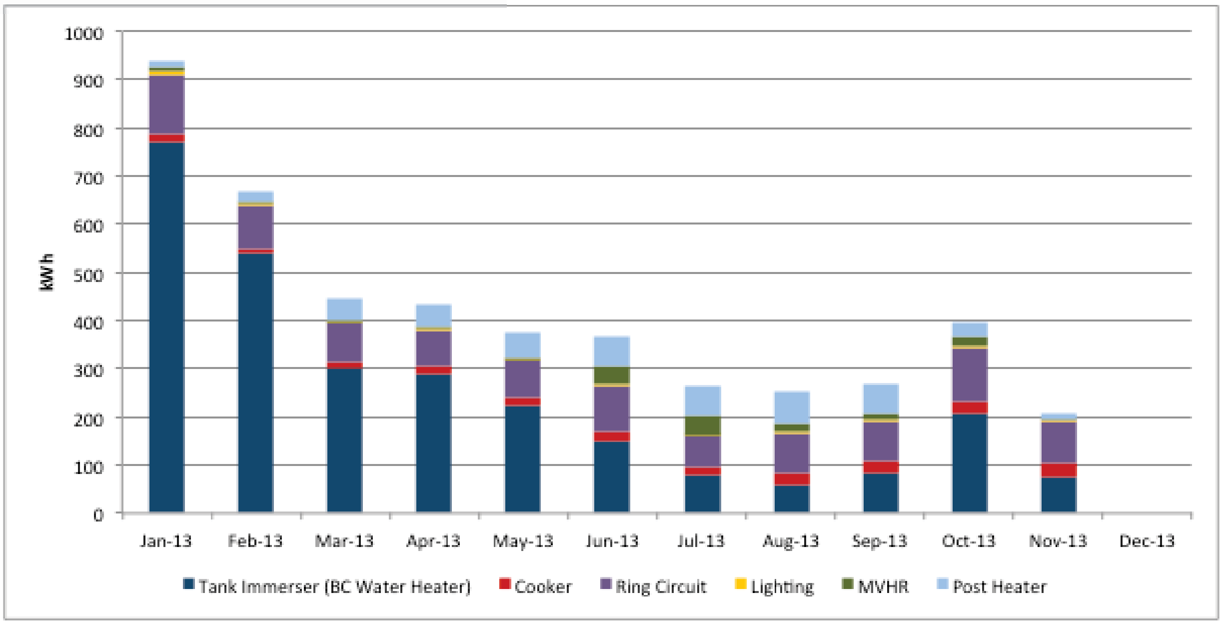


Figure 7.9: Monthly breakdown of energy consumption for 2013 in Cottage DA1

By contrast, the graph below shows the monthly breakdown of energy consumption in cottage DA2. The first thing to notice is the overall numbers on the Y-axis, where the highest total is just over 200 kWh, as opposed to nearly 1,000 in DA1. In this house, the largest percentage of consumption is from the cooker (red) and the sockets (purple) with almost no use of the tank immerser. Although it is harder to see due to the distorting effect of the tank immerser figures above, the consumption associated with cooking is actually around 3 times that of DA1 averaging around 60kWh per month compared to around 18kWh. Again comparing DA1 and DA2, the average monthly consumption via the sockets in DA1 is just over 80 kWh, while it is slightly lower at just below 70 kWh in DA2. Thus we can say that unregulated energy use, via TVs, phone chargers etc is very similar between the two properties, the occupant of DA2 uses three times as much energy cooking, while the main difference remains the use of the tank immerser in DA1.

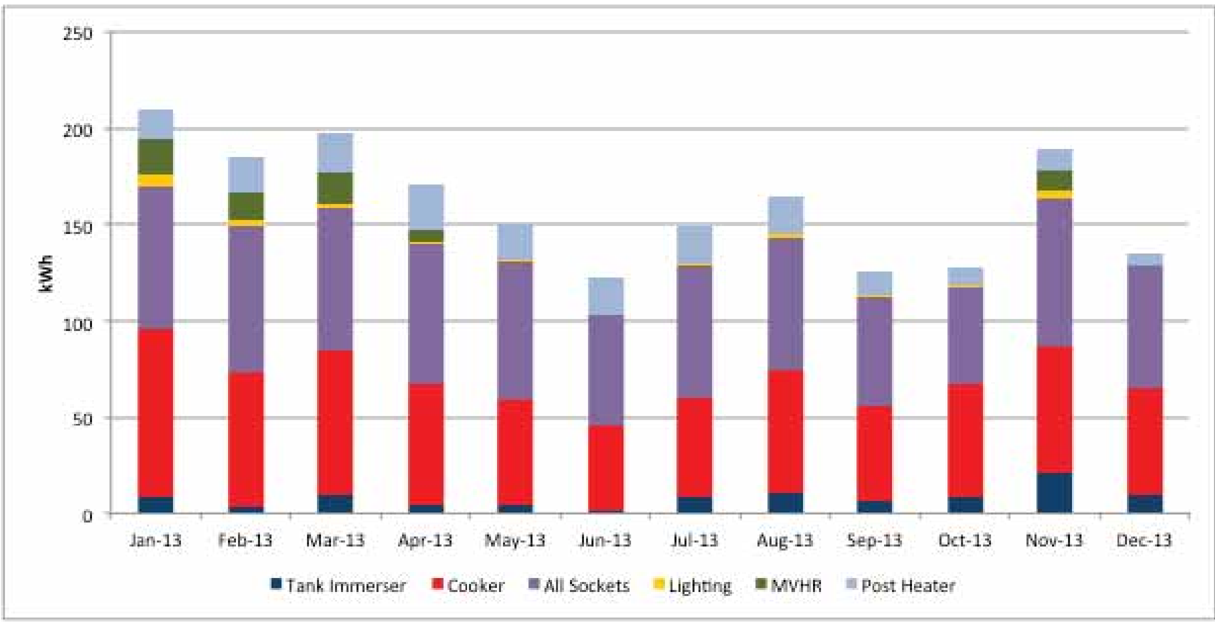


Figure 7.10: Monthly breakdown of energy consumption for 2013 in Cottage DA2

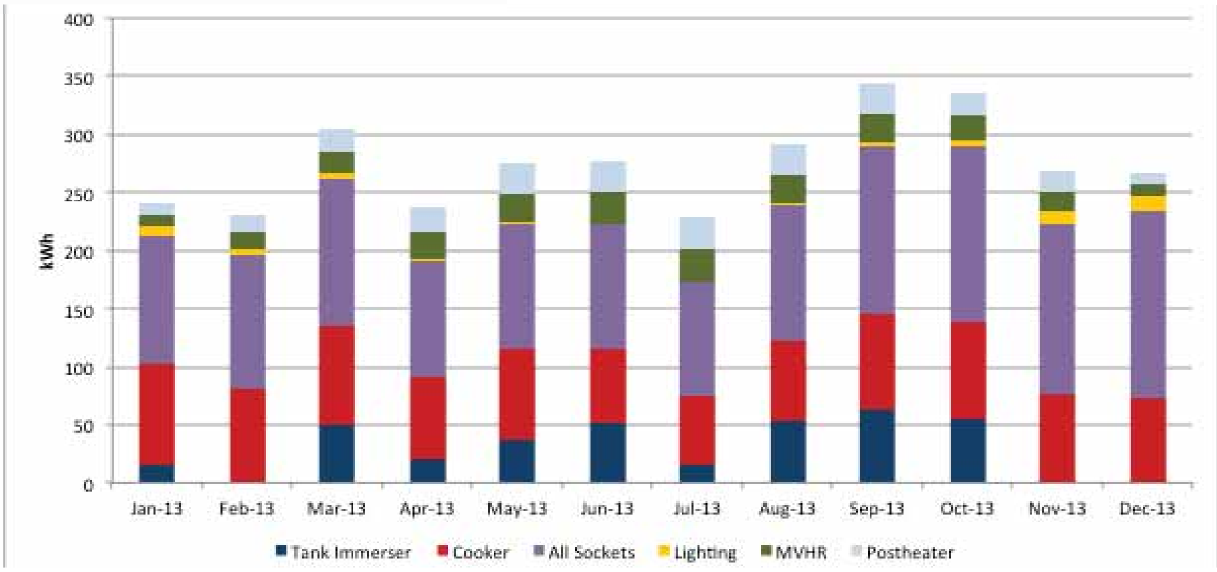


Figure 7.11: Monthly breakdown of energy consumption for 2013 in Cottage DB1

The graph above shows the monthly breakdown of energy consumption in DB1. Again it is worth noting the total consumption levels, which fluctuate between just below 250 kWh to almost 350 kWh. These figures are noticeably higher than DA2, but it is worth bearing in mind that there were generally four or five inhabitants of DB1, while for the majority of the time monitored, there was only one occupant in DA2, making these figures in some ways more impressive. As befits a family of five, there is a greater consumption of energy for cooking and also for the use of sockets, with three teenage children all using the usual array of computer games, TVs and mobile device chargers.

The graph below depicts the same circumstances in DB2, in which there is a family of four, but also including three teenage children. Overall levels of consumption are very similar, but slightly lower, reflecting perhaps one less person. Also, the ratio of unregulated consumption via sockets appears greater with a lower use generally of the cooker.

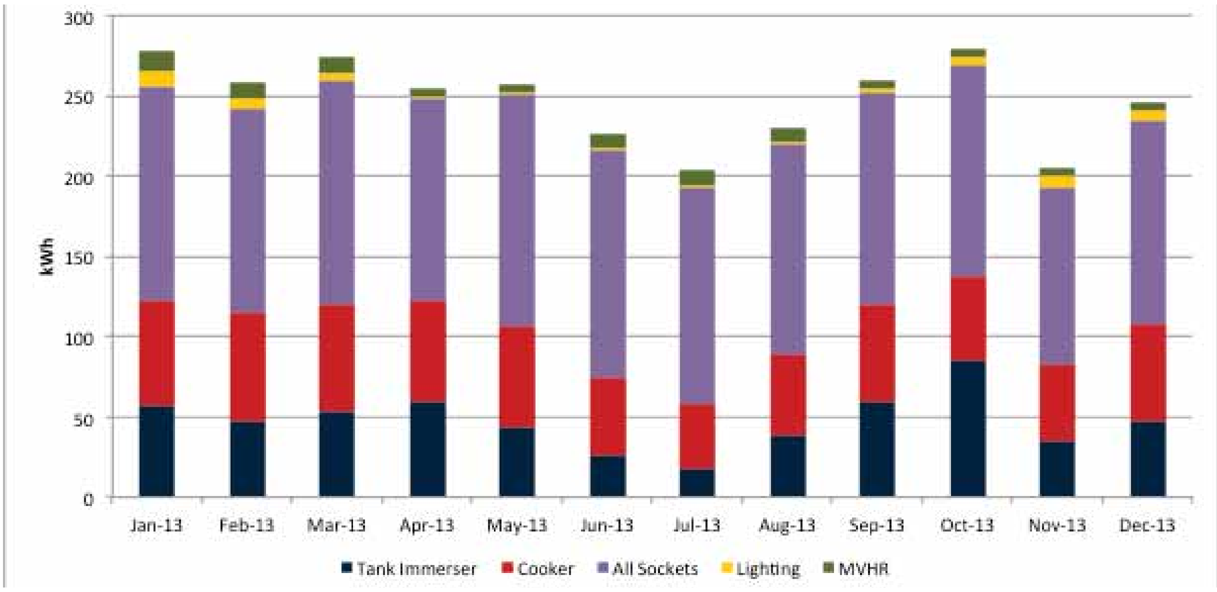


Figure 7.12: Monthly breakdown of energy consumption for 2013 in Cottage DB2

Regulated vs Unregulated Energy

As an overall approach therefore, the Dormont properties can be seen to successfully reduce energy consumption, but the monitoring raised the effects of incidental gains on space heating. Total electricity consumption was monitored at the fiscal meter, while a series of clamp meters also measured each sub-circuit within the house. This enabled a finer grain of understanding about energy consumption, and in particular, an assessment of the ratio between regulated and unregulated electricity use.

In the context of low overall electricity consumption, the graph below shows the breakdown between the regulated energy (associated with lights, immersion heater, pumps and MVHR) as opposed to the unregulated electricity consumption associated with cooking, TVs, computers and charging appliances etc.

It is immediately striking that the regulated electricity consumption is a small percentage of the total, ranging from 53.13% to 17.89%. Excluding DA1, the vast majority of electrical consumption at Dormont is unregulated. Frequently, this energy evades definitions of zero carbon performance because it is difficult to control. These findings however show the extent to which unregulated energy impacts on the total energy use and in particular the carbon output of buildings because mains electricity is relatively 'carbon dense.'

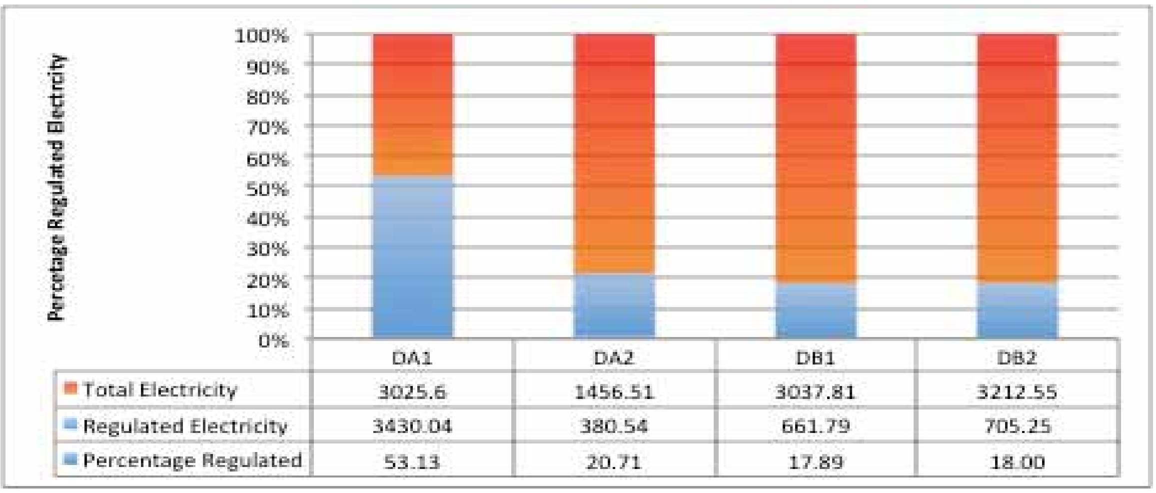


Figure 7.13: Regulated (blue) electricity as a percentage of overall electricity consumption in the Dormont Houses, 2013.

Although work is already being undertaken by manufacturers to reduce energy consumption of appliances, Figure 7.13 suggests that greater consideration should be given to how to manage this energy consumption. This may be a particular concern in affordable or social housing where occupants may be bringing older, relatively inefficient appliances, as replacement costs would be prohibitive This is reinforced when considering that a significant portion of space heating in highly insulated houses is likely to come from the use of unregulated devices such as televisions, computer and white goods etc. In some instances this will beneficial and some use will correspond with occupancy (as appliances are un use when the house is occupied), but heat delivery is always uncontrolled, and outwith heating the season, can contribute to overheating.

7.4 Environmental Monitoring

As part of the project, internal conditions were monitored to determine comfort conditions and to provide an indication of indoor air quality. Temperature, relative humidity, carbon dioxide concentrations (CO_2) and window opening patterns were monitored on a five-minute grain for a 21 month period overall in selected rooms in each dwelling.

This section of the report reviews the internal conditions for a complete year (2013), and compares space temperatures with the design guidance for dwellings as recommended in CIBSE (Chartered Institute of Building Services Engineers) design guide A (CIBSE, 2006). This data provides information with which to assess whether the subject rooms were considered comfortable during summer and winter periods. The following table depicts the ranges and corresponding factors for the environmental monitoring data graphs in Section 7.4. The temperature ranges differ between living rooms and bedrooms during different seasons, as defined in CISBE Design Guide A (CIBSE, 2006).

Variable	Factor	Winter		Spring		Summer		Autumn	
		1.1.1.1.1	Bed-rooms	Living Room/ Kitchen	Bed-rooms	Living Room/ Kitchen	Bed-rooms	Living Room/ Kitchen	Bed-rooms
Temp-erature °C	Cold	<16°C	<16°C	<16°C	<16°C	<16°C	<16°C	<16°C	<15°C
	1.1.1.1.2 Cool	1.1.1.1.3	1.1.1.1.4	1.1.1.1.5	1.1.1.1.6	1.1.1.1.7	1.1.1.1.8	1.1.1.1.9	1.1.1.1.10
	1.1.1.1.11 Comfortable	1.1.1.1.12	1.1.1.1.13	1.1.1.1.14	1.1.1.1.15	1.1.1.1.16	1.1.1.1.17	1.1.1.1.18	1.1.1.1.19
	1.1.1.1.20 Warm	1.1.1.1.21	1.1.1.1.22	23-25°C	1.1.1.1.23	1.1.1.1.24	1.1.1.1.25	1.1.1.1.26	1.1.1.1.27

	1.1.1.1.28 Hot	1.1.1.1.29	1.1.1.1.30	1.1.1.1.31	1.1.1.1.32	1.1.1.1.33	1.1.1.1.34	1.1.1.1.35	1.1.1.1.36
	1.1.1.1.37 Overheating	1.1.1.1.38	1.1.1.1.39	1.1.1.1.40	1.1.1.1.41	1.1.1.1.42	1.1.1.1.43	1.1.1.1.44	1.1.1.1.45
Air Quality: Carbon Dioxide ppm	Ambient	<500ppm							
	1.1.1.1.46 Ideal	1.1.1.1.47 500-1000ppm							
	Poor	1.1.1.1.48 1000-1500ppm							
	Very Poor	1.1.1.1.49 >1500ppm							
Humidity %	Dry	<40%							
	1.1.1.1.50 Comfortable	1.1.1.1.51 40-60%							
	1.1.1.1.52 Humid	1.1.1.1.53 >60%							

Figure 7.14: Key for ranges in Section 7.4, environmental monitoring data graphs.

The Living Room and Master Bedroom were monitored in each of the four dwellings; in addition there was a third room: Bedroom 2 (the Children's Bedroom) was monitored in DA1 and DB2; the Kitchen was monitored in DA2 and DB1. Refer to **Figure 7.4** for typical sensor locations.

At the beginning of the monitoring period there were problems with data collection and connectivity for all four dwellings but most problems were ironed out during 2012 and the data for 2013 is largely accurate.

7.4.1 Temperature

Overheating

The excessive temperatures in the houses are arguably the principal concern of the properties at Dormont in terms of building performance and occupant dissatisfaction.

An important criteria for Passivhaus certification is an assessment of, and limitation of potential overheating as predicted by the PHPP model. The certification criteria state that: "…The following are generally required: openable windows in all living areas, a low overheating frequency (≤ 10 % over 25°C) as well as user-adjustable ventilation volume flow rates and indoor temperatures." This 10% is generally considered to be too high since it allows, in effect a temperature of 25°C to be maintained for 10% of the whole year, or 36.5 days continuously. The PHPP assessment for Dormont established that there would be 0.2% overheating, i.e. ¾ of one day, or 18 hours in total across the whole year when the temperature in the house overall would rise above 25°C. However monitoring indicates that these temperatures are being exceeded for a far greater percentage of the time than this, so there is a significant mismatch between the PHPP assumptions and reality here.

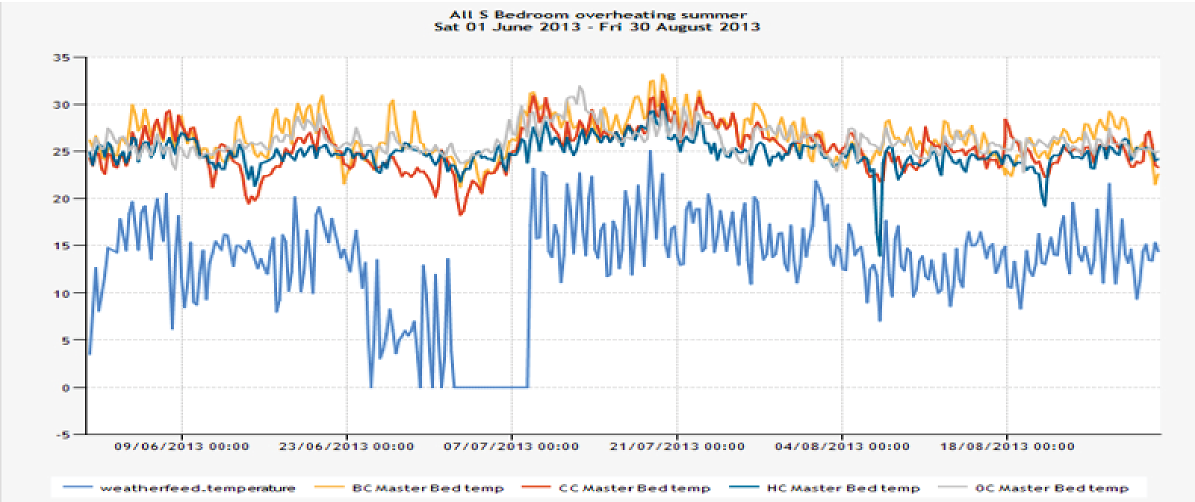


Figure 7.15: Showing the temperature (in °C) in all South facing bedrooms for the summer period (June 1st to 26th August 2013) along with the external temperature. (note fault in weather feed from 2nd July to 9th.)

The graph above shows the internal temperatures in the four South-facing bedrooms during an almost 3-month period over the summer in 2013. Whilst external temperatures fluctuate as one would expect, internal temperatures remain generally within the band between 25°C and 30°C. The graph below shows in more detail a 2-week period throughout which the temperatures in all four bedrooms remain above 25°C almost continuously and venture on occasion above 32°C.

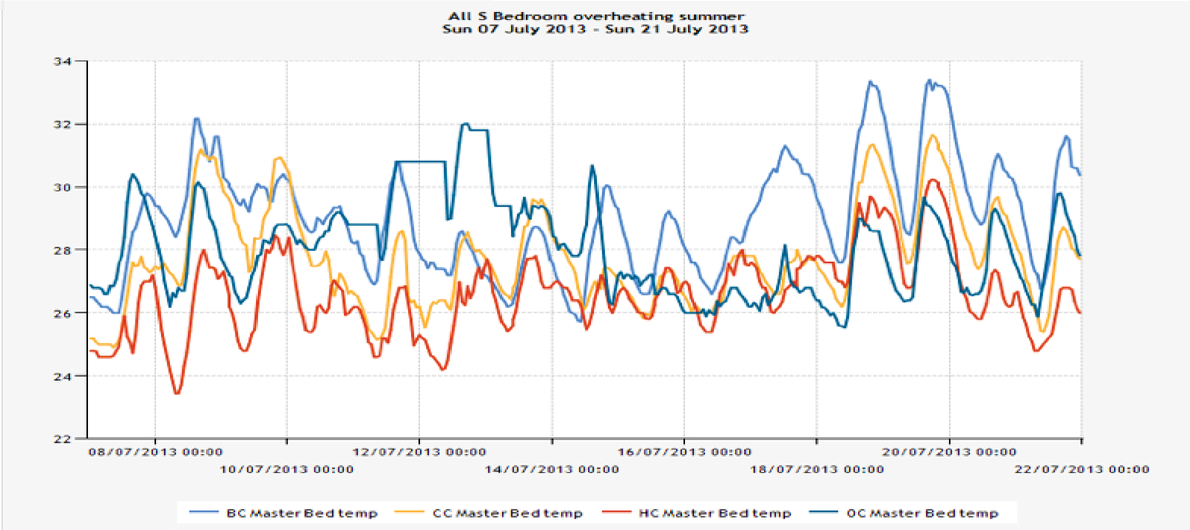


Figure 7.16: Showing the temperature (in ^{o}C) in all South facing bedrooms for the summer period (June 1st to 26th August 2013) along with the external temperature. (note fault in weather feed from 2nd July to 9th).

There are likely to be a number of reasons for the overheating. The houses are well insulated and the fabric is airtight and has little thermal mass, so the only effective way to remove heat is through ventilation. This will be the case in any season, but will be exacerbated in the summer months, especially to south facing apartments. The bedrooms are relatively small (especially in comparison to German space standards on which the Passivhaus standard is predicated) so heat cannot dissipate as readily, and upstairs rooms tend to gain heat through thermal stratification. In addition, there is no external shading, no high level rooflight to exhaust warm air and in the case of the 2-bed houses, no summer bypass on the MVHR – all standard devices to reduce overheating. All of these are significant aspects and even taken in isolation could lead to overheating.

Window opening appears to have a minimal effect on overheating. “Any overheating can be managed easily by opening windows” reports one occupant in the BUS survey, but the monitoring has not shown much support for this. Examining a 5-day period and comparing temperatures with window opening, we see that in three of the houses, the bedroom windows are kept largely open. In one house – shown in red on the graph below– the windows are closed for the latter three days. This has little effect on the overall internal temperatures in the bedroom, although in relation to the other three bedrooms, it goes from being consistently the lowest temperature, to being second or third, and the switch happens at exactly the time when the window is closed. This would suggest that opening the windows is helping to reduce the temperature, but the effect is marginal. Even with the windows open and a 12^{o}C difference between internal and external air temperatures at the time of opening, the internal temperatures remain high.

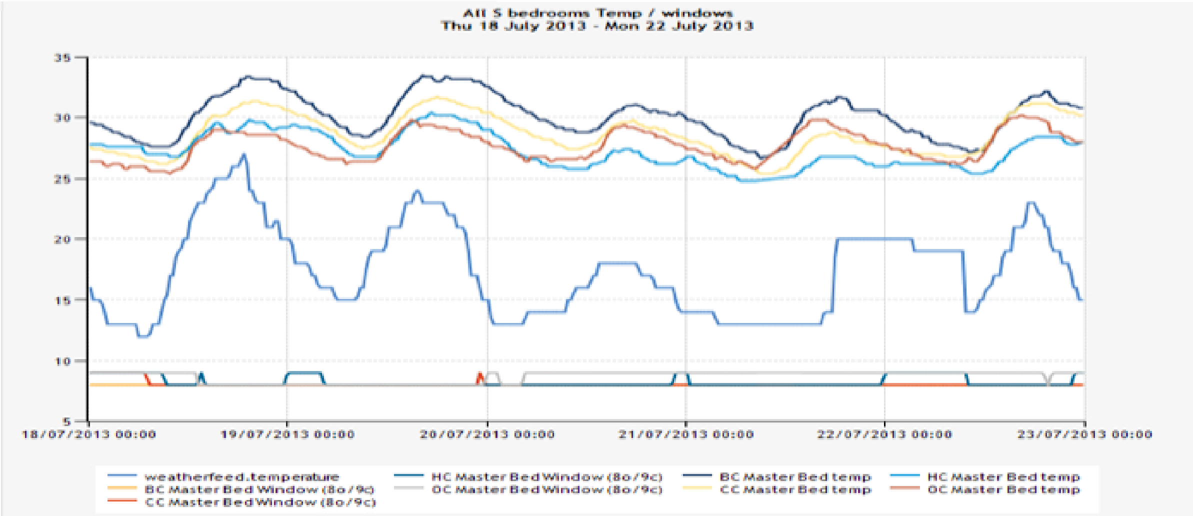


Figure 7.17: Showing the temperature (in °C) in all South facing bedrooms for the 5 day period July 18th to 22nd along with external temperature and window opening.

CIBSE (CIBSE, 2006) recommends an upper limit temperature of 24 °C and a lower limit of 18°C in interiors of occupied spaces. It also recognises that occupants in dwellings are able to adapt their clothing to suit internal temperature conditions during waking hours, however, temperatures exceeding 24°C in bedrooms may affect sleeping patterns of occupants. Dwellings in winter are mostly intermittently heated which allows the space temperature to fluctuate during the day and night. If the air temperature drops below 16°C and/or internal surface temperatures drop to below 12.6°C there is a risk condensation and mould growth could occur on surfaces. Both of these temperature extremes have been linked negatively with issues around fuel poverty (cold) and health and well-being (cold and hot), particularly in the young, elderly and infirm.

The following four charts provide an overview of temperature for all four houses, for each of the three rooms monitored, and for each season. Refer to the table of boundary conditions at the beginning of this section for explanations of the terms used below.

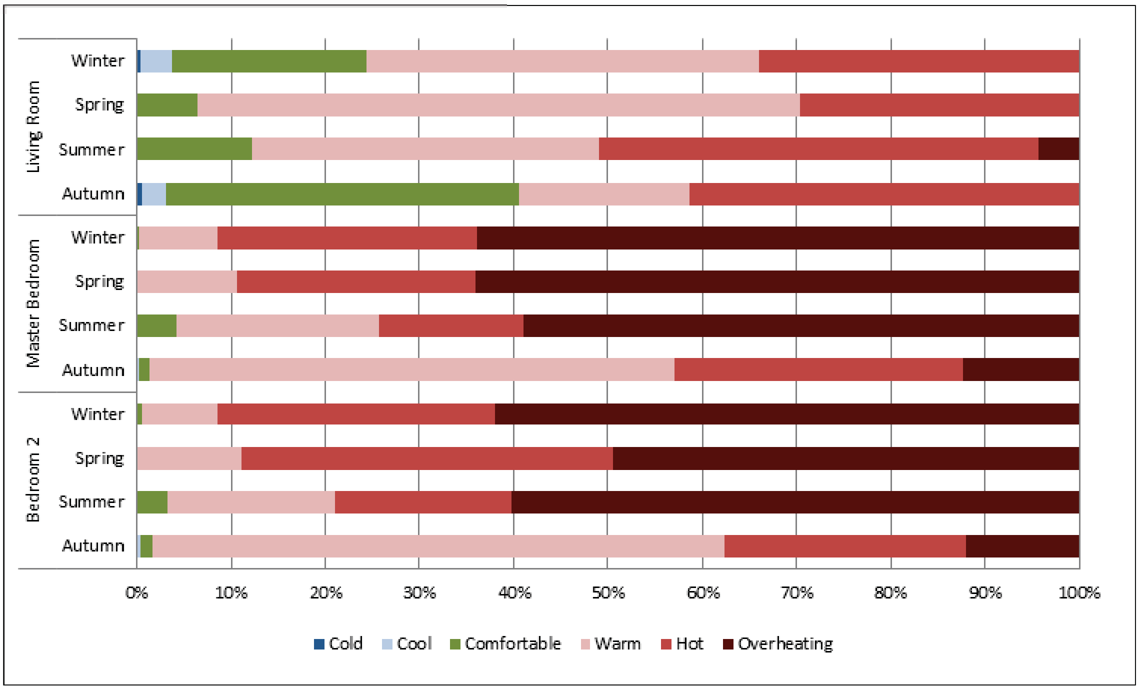


Figure 7.18: Dwelling DA1 – Thermal Comfort by Season during 2013

The most noticeable aspect in DA1 is that there is a worryingly high proportion of warm, hot and overheated periods. The second is that the downstairs Living Room is clearly better than the two upstairs rooms. In the bedrooms, temperatures were above 23°C for most of the year, with significant periods of overheating where temperatures exceeded 26°C in all seasons. The downstairs Living Room remained more regularly in the 'comfortable' range, however, there were incidences of no more than 4% of temperatures below 18°C, rating 'cool' to 'cold'.

One reason for the increased temperatures upstairs might be natural stack effect, although the house is provided with MVHR which tends to even out temperatures across both floor and all rooms – however any cooling effect in bedrooms would be through dilution of delivered air rather than extraction of warm air so is likely to be less effective. We can rule out the use of open windows downstairs as well, for as the graph 7.30 shows, in fact the Living Room windows were kept closed noticeably more than the bedroom windows. Also of interest is the fact that solar orientation does not appear to have any obvious effect, since the Living Room (and Main bedroom) face due South, while the Rear bedroom faces due North and receives little or no solar gain.

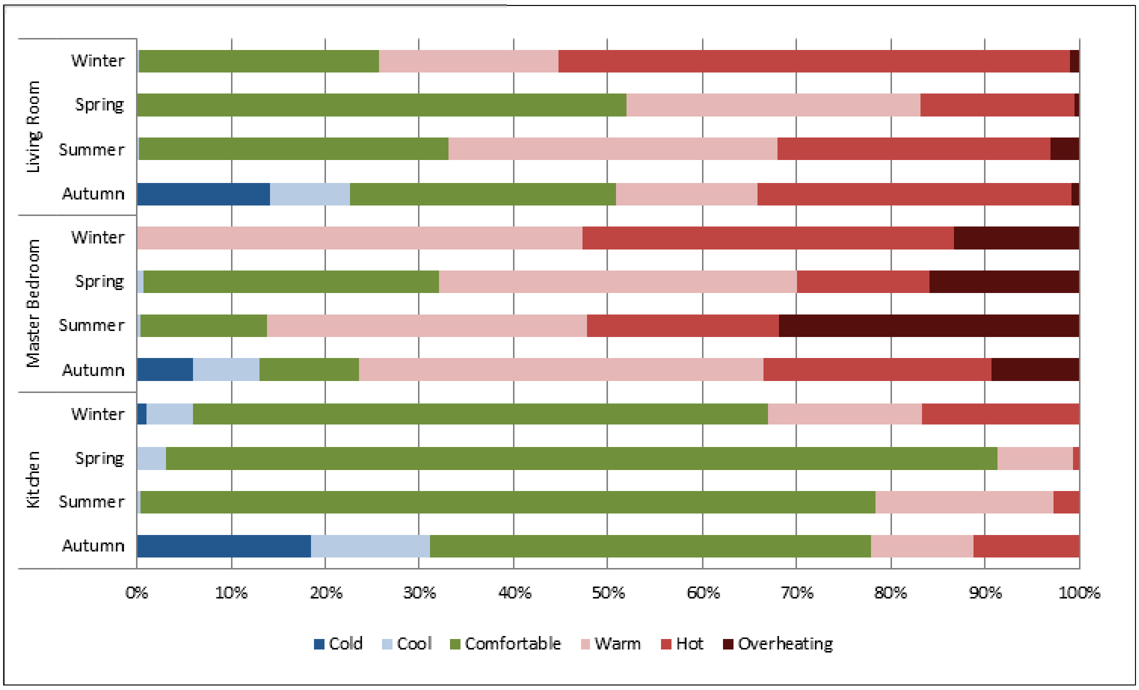


Figure 7.19: Dwelling DA2 – Thermal Comfort by Season during 2013

The temperatures in dwelling DA2 fluctuate significantly between rooms and seasons and this is particularly evident in the Autumn, when temperatures varied between <16°C to >28°C in the Living Room and Kitchen, and <15°C to >26°C in the Master Bedroom. In this case, solar orientation does appear to have some effect as the Kitchen – the only room facing North – is noticeably less prone to overheating.

At first glance, the spread of temperatures in DA2 resemble those from a conventional house which fluctuates more with the external temperatures, window opening and intermittent heating regime. A well-insulated Passivhaus with MVHR should temper internal temperatures more although this depends on small, but regular heat input to maintain temperatures. In this case, the spread in temperatures can be explained by the fact that the occupant switches off the MVHR during the summer (and early Autumn) and tends to leave her windows open for long periods. Thus, the summer and Autumn temperatures indeed reflect the external temperatures more as they would in a 'normal' house without MVHR.

In dwelling DB1, shown below, the temperatures fluctated between comfortable and hot throughout the year. This was particularly evident in the Master Bedroom where temperatures ranged from warm to overheating (>26°C) in all 4 seasons. The regulation of temperature and IAQ by opening the window (**Figure 7.32**) is of a mid-range occurance in the Master Bedroom, however the Kitchen window was open for 87% of the time in the Summer and 100% in the Autumn. The relative humidity (**Figure 7.28**) and CO_2 (**Figure 7.24**) during these months did not appear outside of the midrange in comparison with other rooms, to explain the need to open the Kitchen window for the entirity of Autumn.

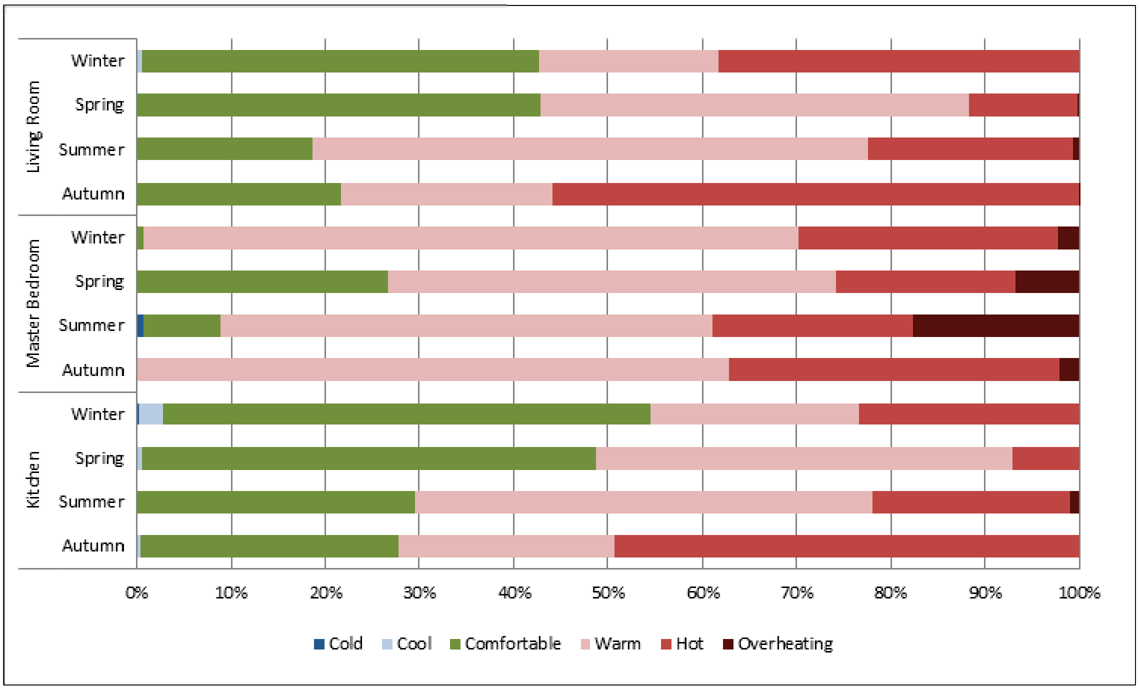


Figure 7.20: Dwelling DB1 – Thermal Comfort by Season during 2013

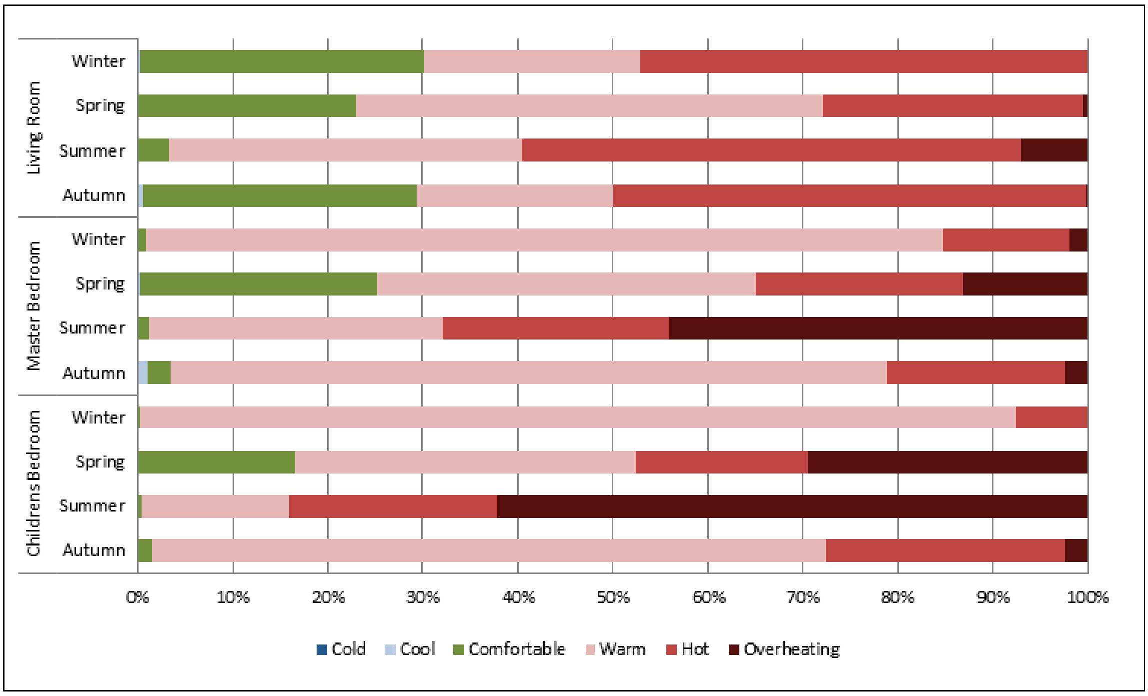


Figure 7.21: Dwelling DB2 – Thermal Comfort by Season during 2013

In dwelling DB2 above, temperatures were predominantly in the warm to hot ranges, with only the Living Room experiencing comfortable temperatures in every season, ranging from 3% in the Summer to 30% of the time in the Winter. However, this room also experienced periods of up to 50% hot temperatures, particularly in the summer when there was a 7% incidence of overheating.

The overheating in both the Master Bedroom (44%) and Children's Bedroom (62%) are of concern, particularly during the summer months. With temperatures at 22% hot for both rooms. The window in the Master Bedroom was only open for 16% of the summer months, whereas the Children's bedroom window was open for 64% (**Figure 7.33**).

Summary

Excluding DA2, temperatures in all three other dwellings were predominantly in the 'warm' and 'hot' temperature ranges, with significant periods of overheating in the bedrooms across all four seasons. Both bedrooms in dwelling DA1 were 'overheating' for more than 50% of the time between the Winter and Summer with peaks of between 60—64%, with the lowest rating of 12% in the Autumn. The bedrooms in the other three houses also experienced periods of 'overheating' in all four seasons, this is of particular concern in the Children's bedroom of DB2, where summer 'overheating' peaked at 62%.

The warm bedroom temperatures are generally of greater concern, as warm temperatures can affect health and sleep patterns. Children tend to spend more time in their rooms, may share and be less likely to regulate temperature than an adult.

The kitchens monitored in DA2 and DB1 exhibit the best levels of comfort achieved, however, in DA2 they also experienced the coldest temperatures of the dwellings.

There is no doubt that overheating is a serious issue in the Dormont properties, linked with excessive energy consumption at times, and occupant discomfort. Whilst it is a general problem, it is likely to be a particular concern in bedrooms. Potential reasons have been discussed, and both the issues of lack of pipework insulation and the inadequacy of window opening to relieve the situation noted. Clearly, a number of lessons can be learnt and a suite of measures taken in subsequent projects to address the issue.

7.4.2 Indoor Air Quality / CO_2

Monitoring CO_2 concentrations provides an indication of ventilation rates. People exhale CO_2 so the worse the ventilation rate, the greater the CO_2 concentration. CO_2 levels of outside air (notwithstanding climate change increases) tend to be around 500ppm. Measured rates between 500 and 1000ppm indicate that levels at, or close to outside air are being mantained and show as green while concentrations above this shown in pink and red indicate poor and very poor indoor air quality and corresponding low ventilation rates. While CO_2 at these levels is not known to be a threat to health it indicates poor ventilation regimes which allow contaminants such as VOCs, formaldehyde, mositure, dust mites etc. to potentially affect health.

The following four charts provide an overview of CO_2 ppm for all four houses, for each of the three rooms monitored, and for each season.

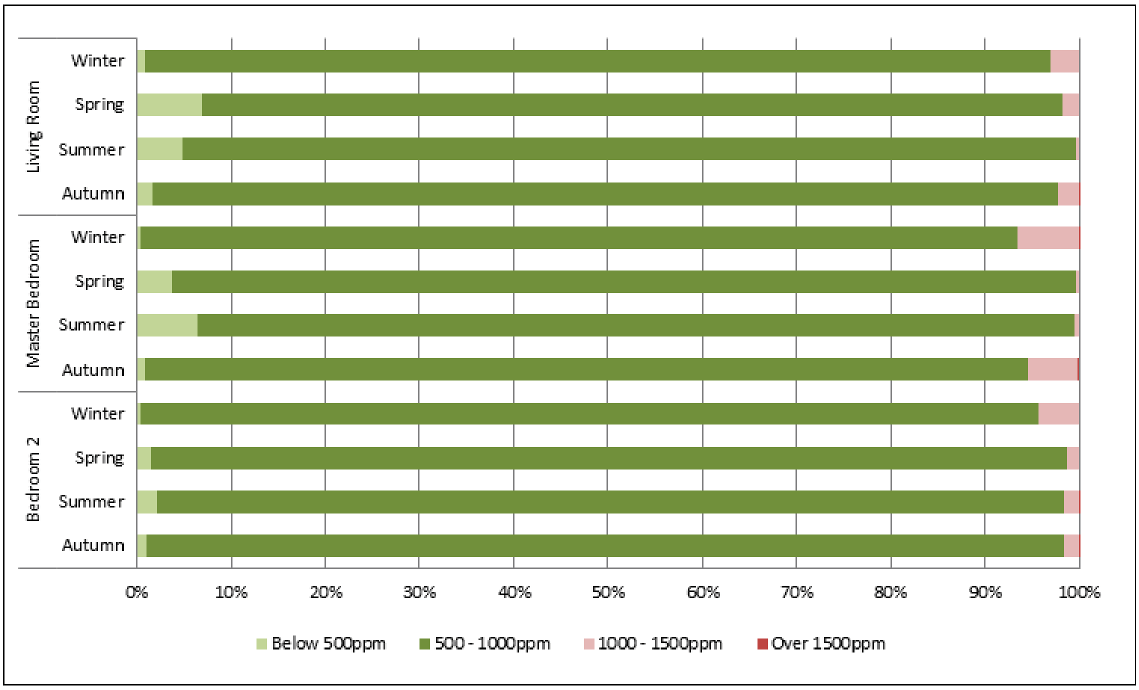


Figure 7.22: Dwelling DA1 –Carbon Dioxide concentrations by Season.

Dweling DA1 is consistently within the 'ideal' range of CO_2 concentrations, with minimal increases during the Autumn and Winter Months. Of the four dwellings, it has the least 'poor' air quality, suggesting good rates of ventilation. Windows are opened with seasonal variations, but the CO_2 results suggest good MVHR ventilation rates, however, this may well be helped by the lower number of occupants than other dwellings monitored.

Dwelling DA2, shown below, is similar to DA1, in that it is consistently within the 'ideal' range, with minimal increases during the Autumn and Winter Months when windows are opened less. There are instances of poor air quality in all room in all seasons, however, these are not significant. The CO_2 concentrations increases apparent in Autumn are likely to be associate with the arrival of the occupant's grandson who came to stay with her around this time and did not get a place in the local school for some time, doubling the exhalation rate in the property!

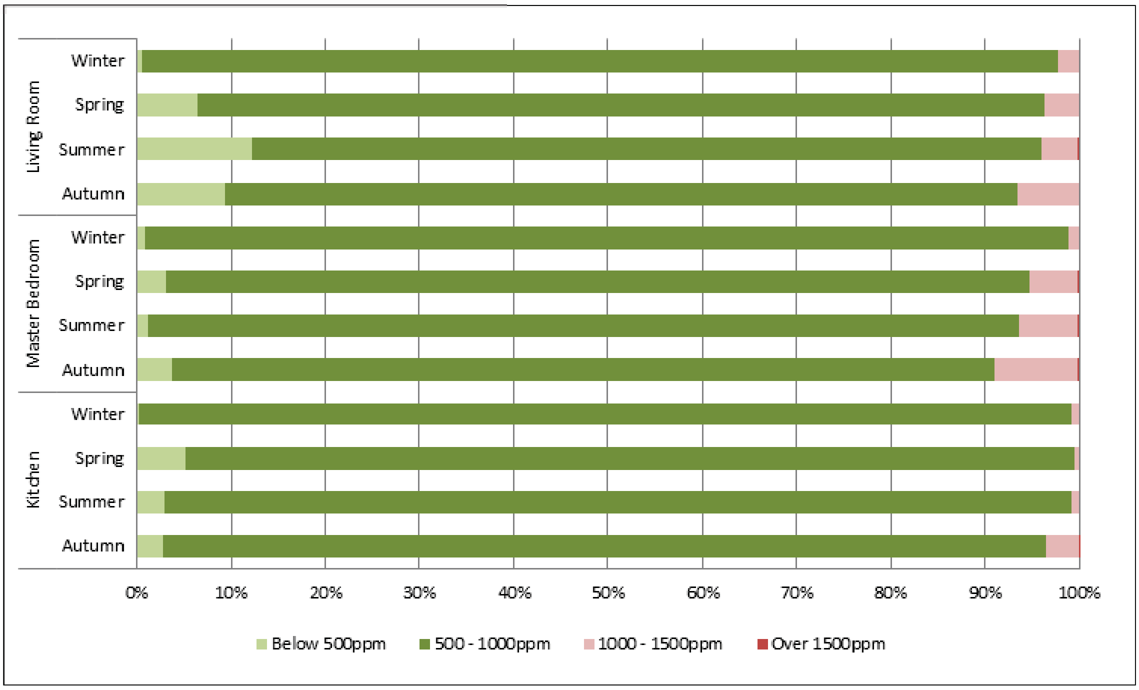


Figure 7.23: Dwelling DA2 –Carbon Dioxide concentrations by Season.

Figure 7.24: Dwelling DB1 –Carbon Dioxide concentrations by Season.

The CO_2 levels in both of the 3-bed houses indicate a greater prevalence of poorer air quality, although there are only rare and insignificant instances of concentration levels over 1500ppm. These raised levels are likely to be associated with the increased occupation of these houses with 5 and 4 occupants respectively compared to 2 (including 1 baby) and 1 (latterly with grandson) in the 2-bed houses. The windows are closed for the entirety of the winter period in the Living Room so the question needs to be asked of the MVHR system. The relationship between occupancy and MVHR is borne out by cross-referencing the MVHR flow rates noted in Section 6.4

(Figure 6.19) in which the whole house flow rates are broadly similar for the 5-person occupied DB1 as they are for the 2-person occupied DA1.

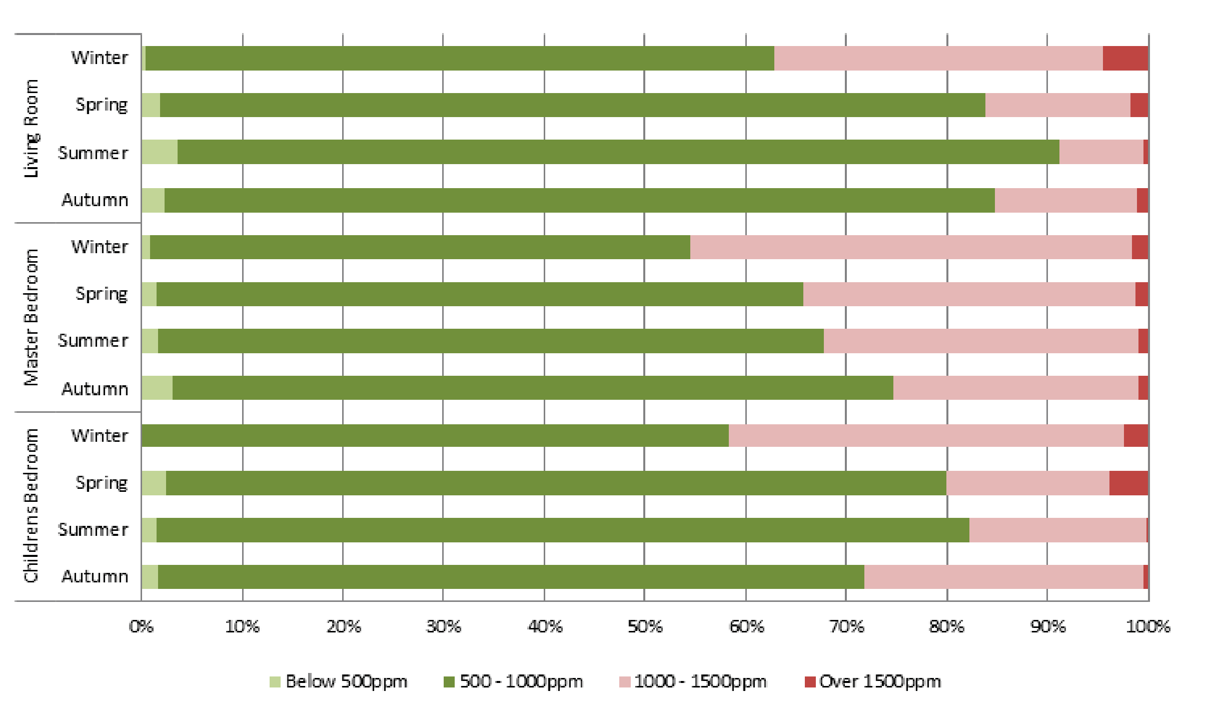


Figure 7.25: Dwelling DB2 –Carbon Dioxide concentrations by Season.

In Dwelling DB2, increased CO_2 concentration levels during the Winter heating months are common across all three rooms. Air is of a 'poor' quality for 44% and 39% of the time in the Master and Children's bedrooms respectively. The windows in all rooms were only opened a few times during the Winter months, registering at 1% or less of the total time. Again, this can be traced to the increased occupation not being matched by a sufficiently increased MVHR flow rate across the whole house.

Summary

Generally, air quality and CO_2 concentration levels are exemplary in the 2-bed houses, but these levels rise noticeably in the 3-bed houses due to a mixture of increased occupation and MVHR flow rates which have not been increased in concert with the occupation levels.

Note however, that with regard to RH levels, as discussed in the following section, reduced flow rates can also be a good thing, maintaining acceptable RH levels, so a balancing act needs to be struck between potentially conflicting requirements here.

7.4.3 Relative Humidity

Relative Humidity (RH) is a measurement not of absolute humidity, but of the humidity level in relation to the temperature. Thus air containing the same amount of moisture can register varying RH levels depending on its temperature. Based on the CIBSE guidance (2006), mould will grow when RH exceeds 60%and can then survive at lower levels once established. RH above 50% also encourages dust mite populations. Respiratory complaints, including asthma are associated with indoor mould growth and dust mites. On the other hand, low RH can be associated with skin or eye problems in some occupants and for this reason CIBSE (2006) recommends a comfort range of 40-60% RH.

RH can be an issue in energy efficient houses with MVHR because cold air is being constantly drawn in and heated, reducing its RH level. In the colder months, the air may contain less moisture and so heating it carries the risk that you are reducing the RH level of air that already has a low absolute moisture content. This is a well-known phenomenon in Passivhaus design and a number of strategies are generally engaged to minimise the risks, the principal one of which is to reduce air flow rates.

The following four charts provide an overview of percentage relative humidity for all four houses, for each of the three rooms monitored, and for each season.

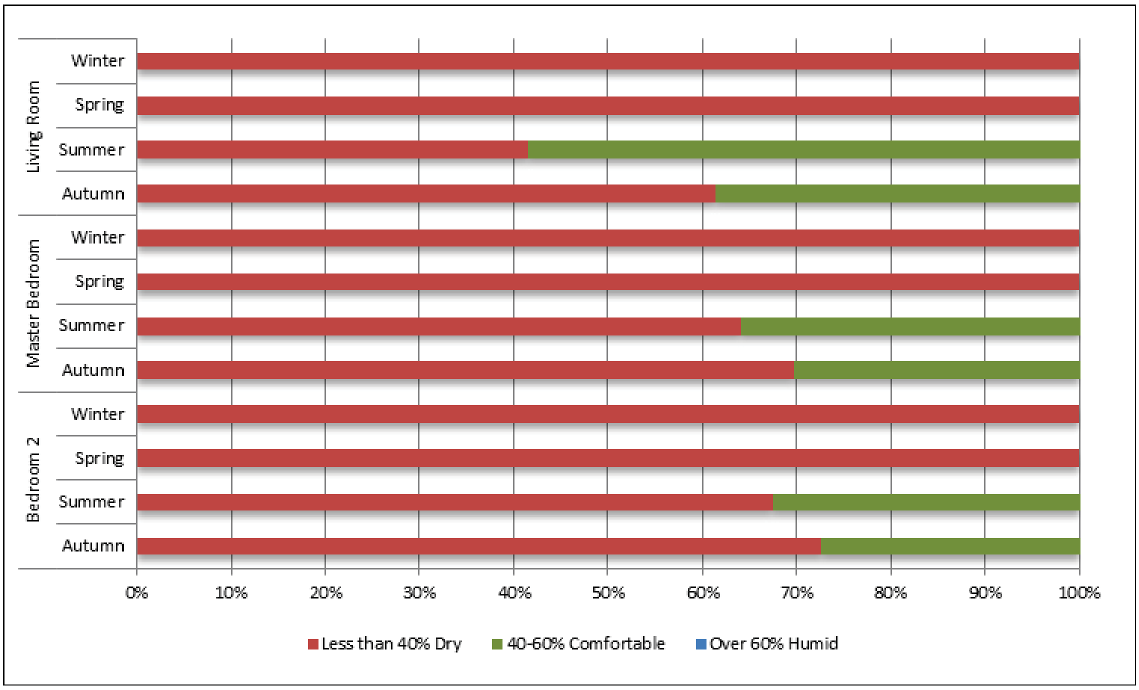


Figure 7.26: Dwelling DA1 – Relative Humidity (RH %) by Season.

Overall, humidity ranged from dry to comfortable, except in the Living Room and Bedroom 2 during the Winter and Spring months. The drier air, particularly in the heating months relates to the higher levels of heating in this dwelling, when there were significant 'hot' and 'overheating' periods. The long periods of time when humidity levels are low could have health implications on the occupants.

In Dwelling DA2 shown below, there was a wide range of RH levels. The trend in Winter and Spring was predominantly dry air in all rooms associated with a heating regime and MVHR use, whereas the trend in the Summer was towards a more comfortable level of humidity associated with reduced need for heating, less use of the MVHR system and greater window opening.

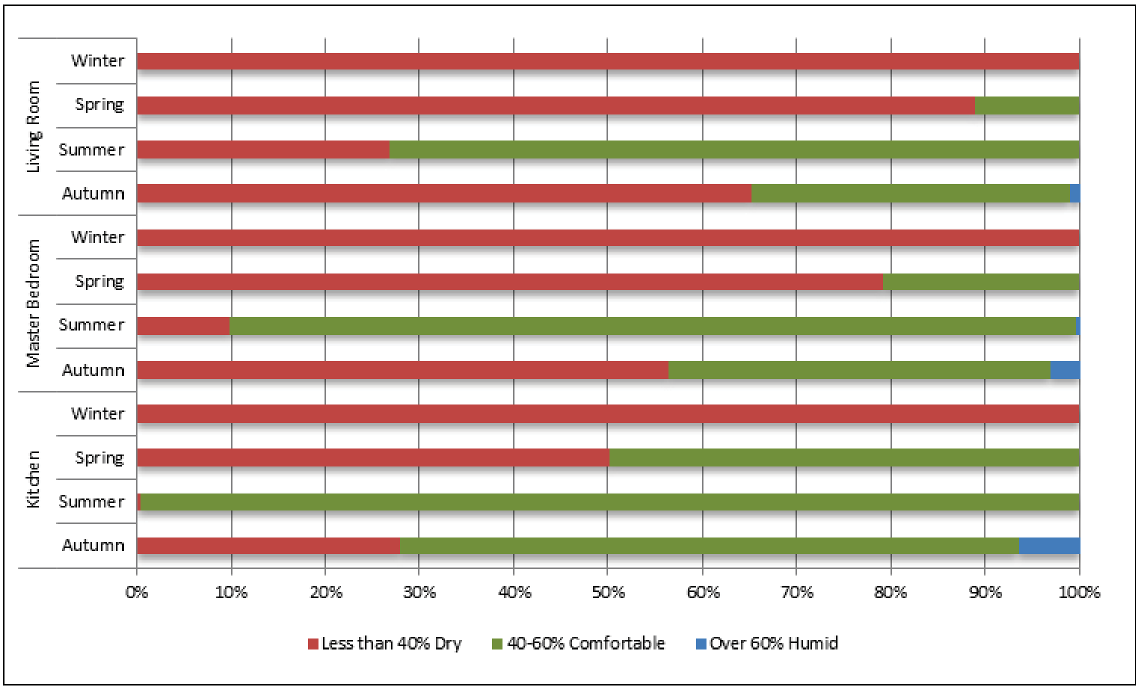


Figure 7.27: Dwelling DA2 – Relative Humidity (RH %) by Season.

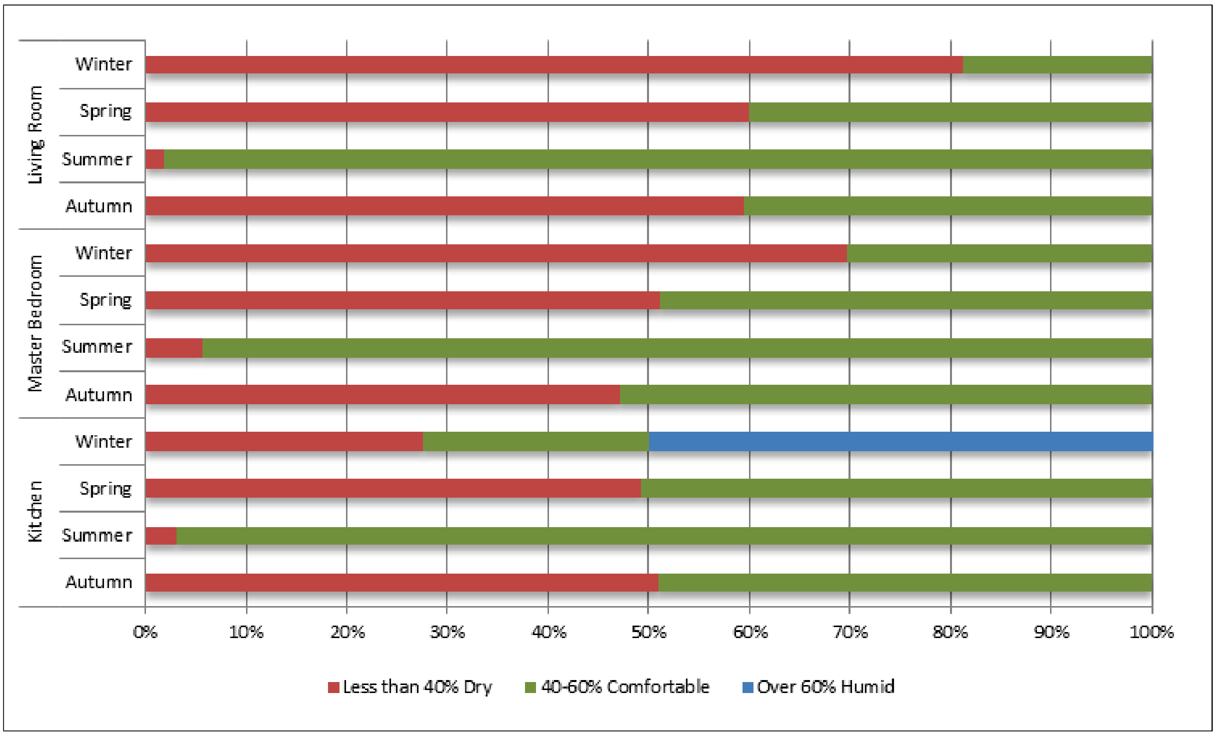


Figure 7.28: Dwelling DB1 – Relative Humidity (RH %) by Season.

In Dwelling DB1 the pattern noted above is repeated with noticeably drier air in the colder months associated both with heating and MVHR use, while summer levels are generally healthier. The 'humid' result for the Kitchen in winter is likely to be associated with insufficient extract rates to the Kitchen.

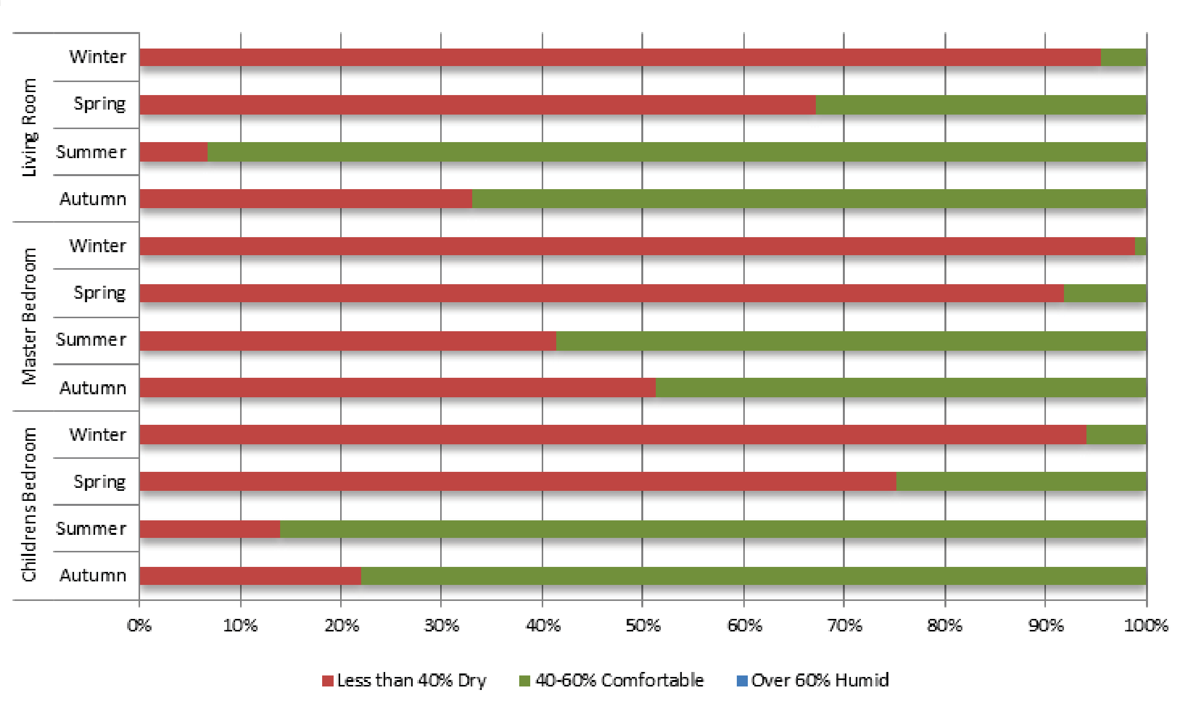


Figure 7.29: Dwelling DB2 – Relative Humidity (RH %) by Season.

In Dwelling DB2 the RH range fluctuates seasonally and by room, ranging between dry and comfortable, with no periods over 60% humidity. The Summer and Autumn months, as expected for non-heating season, have healthier levels of RH: in the 'comfort' range. All three rooms are drier during the winter months, this is related to the heating season, MVHR use and 'warm' to 'hot' internal temperatures achieved at this time.

Summary

All of the dwelling types reflect the typical pattern of drier air during the heating season when the MVHR is the sole source of incoming air, while Summer and Autumn figures reflect the reduced need for heating and MVHR mediation of incoming air.

For the benefit of occupants, it would be worth reviewing airflow rates generally to ensure both sufficient air flow to control CO_2 levels and manage RH.

7.4.4 Window Opening Patterns

Passivhaus homes are designed so that windows can remain closed while the building still receives adequate levels of fresh air, but users have the option to open windows as desired. The results of the monitoring indicate that windows were opened in all dwellings and with expected seasonal variations. The following four charts provide an overview of window opening patterns expressed as a percentage for all four houses, for each of the three rooms monitored, and for each season.

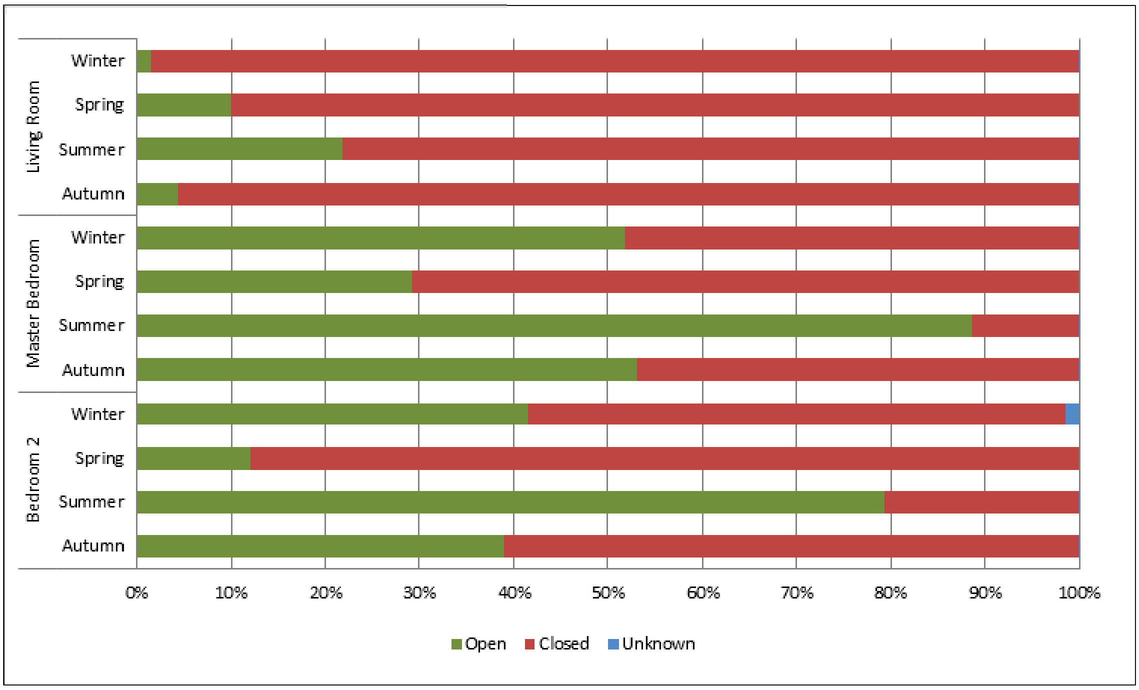


Figure 7.30: Dwelling DA1 – Window opening patterns (Ventilation) by Season.

In all rooms of dwelling DA1 the window opening patterns are fairly consistent with seasonal occupancy. However, **Figure 7.30** above shows that the Bedroom windows were opened more frequently than those of the Living Room, consistent with the occupant feedback about overheating. Window opening in the bedrooms is likely to be related to the more pressing overheating problems and the fact that these are being opened at all can be linked to the lack of a summer bypass in the MVHR.

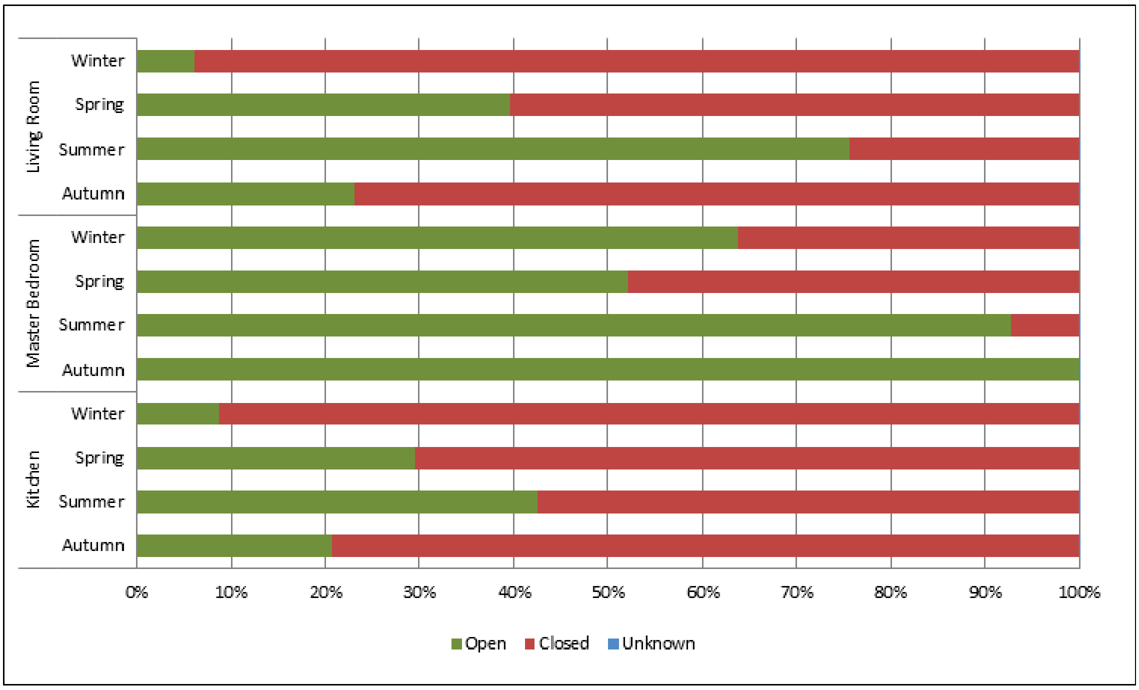


Figure 7.31: Dwelling DA2 – Window opening patterns (Ventilation) by Season.

As with DA1, the window opening patterns of dwelling DA2 indicate that, in all rooms the patterns are fairly consistent with seasonal occupancy. However, it also shows that the bedroom windows were opened more frequently than those of the Living Room, concurrent with issues identified with overheating, particularly in the Autumn.

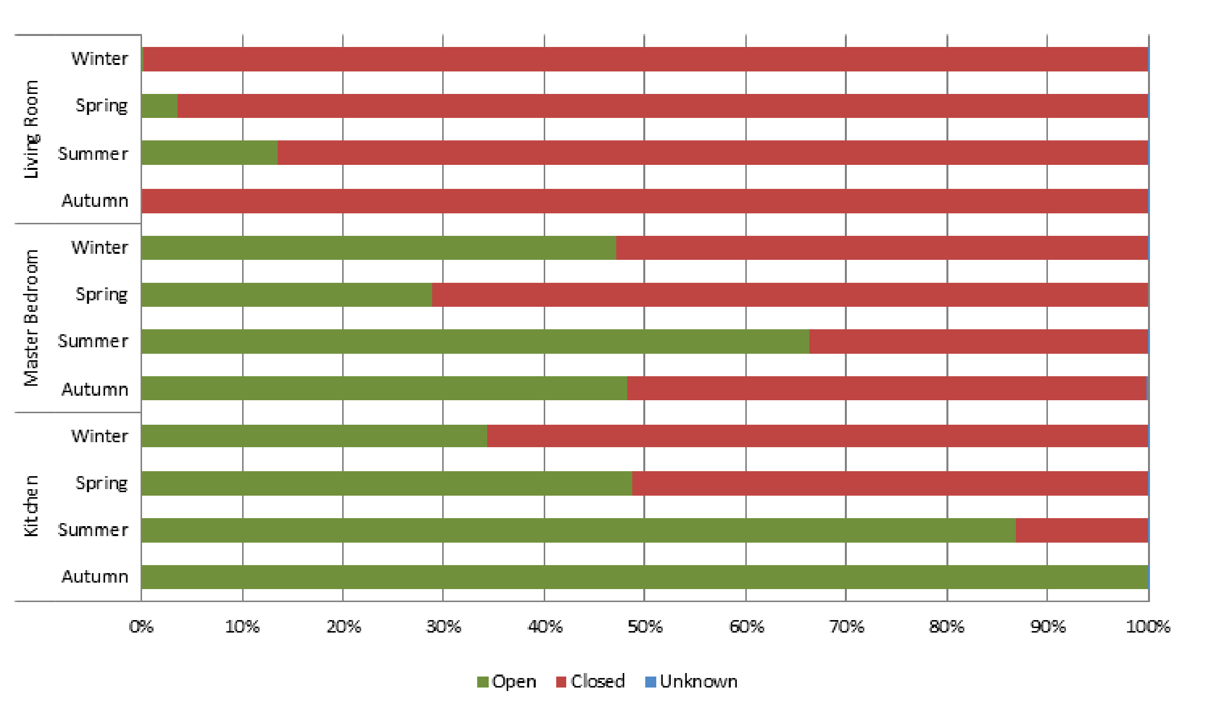


Figure 7.32: Dwelling DB1 – Window opening patterns (Ventilation) by Season.

The window opening patterns of DB1 are not consistent with seasonal patterns of opening. In the Living Room the windows were rarely open compared to the other two rooms. In the Winter and Autumn they were closed 100% of the time. Whereas in the summer they were only open for 14% of the time. The Master Bedroom opening patterns were more consistent with the seasons, however they were open less in the Spring than in the Autumn and Winter, the window was open for 66% of the summer months, this is not concurrent with the periords of 'hot' to 'overheating' in the temperatire analysis.

In the Kitchen the window was open for 87% of the time in the Summer months and 100% of the time in the Autumn. This would suggest a problem with temperatures and thermal comfort during this period.

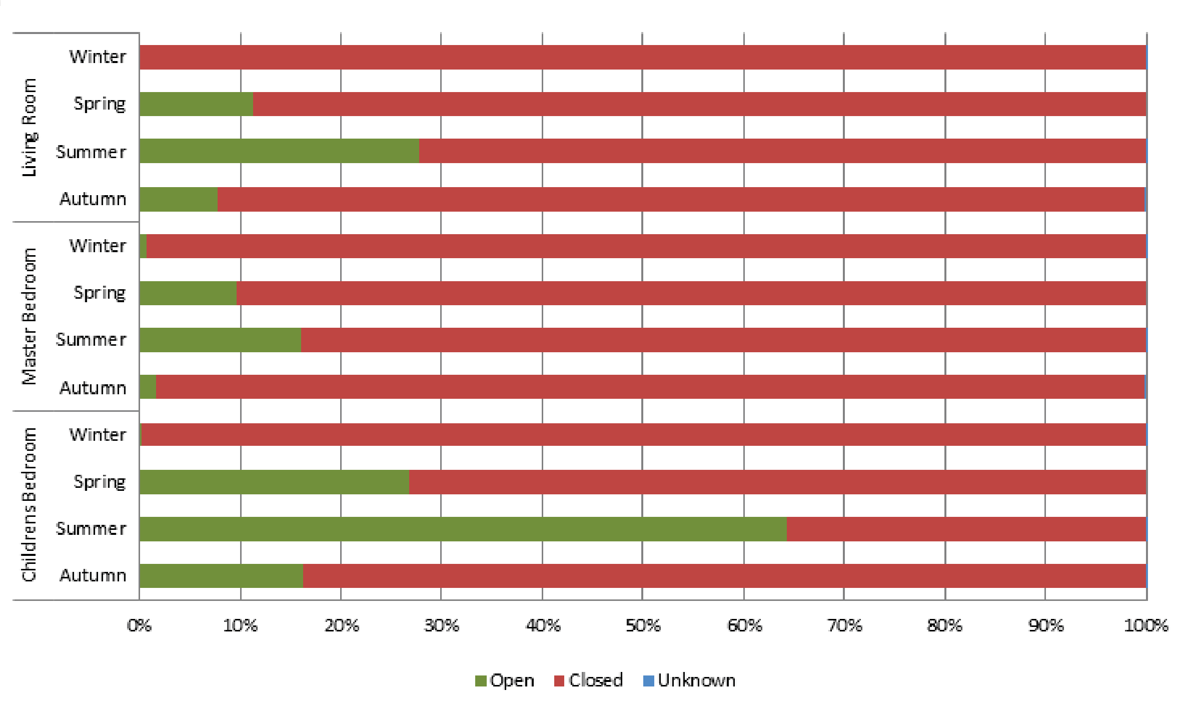


Figure 7.33: Dwelling DB2 – Window opening patterns (Ventilation) by Season.

The windows in DB2 are not opened much, the least of all of the dwellings. As expected with seasonal opening patterns, windows are opened in every room during the summer months, but closed throughout the winter.

Summary

Generally, the windows are opened more in the warmer months and less in the colder months as might be expected, though this is not consistent across the houses, nor within the houses. Anomalies include increased opening of bedroom windows due to more pressing overheating, although reference back to the temperature figures shows that opening windows does not appear to be as successful as might be hoped.

7.5 Conclusions and key findings for this section

- The Monitoring set-up was complicated by the remote site and relatively weak signal and this created some ongoing problems
- Data has been lost due to some occupant disruption (accidentally switching off the T-mac, for example) but the biggest problem has been the amp rating of the installed clamps which are too high to accurately pick up the low levels of electrical load imposed by many of the small-scale domestic devices. This is disappointing given that the site was both surveyed and commissioned by T-Mac.
- The energy efficiency of the houses has been shown to be excellent in comparison with other Passivhaus and Low Energy buildings monitored by MEARU.
- With the exception of DA1 – energy consumption in-use has been in keeping with the predictions made in PHPP and the Passivhaus certification.

- DA1 used considerable amounts of electricity for the tank immerser, while all four houses use comparable amounts of electricity for cooking and all other sockets, however electrical use in DA1 has been reduced through information and education.

- The unregulated electricity consumption comprises a far higher percentage of overall electricity use in three of the four buildings monitored.

- There is no doubt that overheating is a serious issue in the Dormont properties, with a relationship to excessive energy consumption at times, and occupant discomfort. Whilst it is a general problem, it is likely to be a particular concern in bedrooms. It would appear that the effects of incidental gains, particularly in smaller spaces, is more pronounced that using German space standards and some adhustment of PHPP may be needed to reflect this.

- Heat gains from the hot water system are likely to be a significant contributor. Whilst available exposed pipework has been retrofitted with insulation, there will be pipes hidden within the construction that will be releasing heat.

- The problem is exacerbated by lack of cooling provision – e.g high level openings, summer bypass or thermal mass. It should be noted however that additional ventilation to release excess heat would improve comfort but may increase energy consumption.

- Generally, air quality and CO_2 concentration levels are exemplary in the 2-bed houses, but these levels rise noticeably in the 3-bed houses due to a mixture of increased occupation and MVHR flow rates which have not been increased in concert with the occupation levels.

- All of the dwelling types reflect the typical pattern of drier air during the heating season when the MVHR is the sole source of incoming air, while Summer and Autumn figures reflect the reduced need for heating and MVHR mediation of incoming air.

- Generally, the windows are opened more in the warmer months and less in the colder months as might be expected, though this is not consistent across the houses, nor within the houses. Anomalies include increased opening of bedroom windows due to more pressing overheating.

8 Other technical issues

8.1 Passivhaus Compliance

Passivhaus certification is generally held to be a far more aspirational and rigorous set of standards than most other benchmarks, but it remains the case that certification is based largely on a model, prepared before construction. The exceptions to this are that the 'as-built' airtightness results must pass a certain threshold and the MVHR commissioning sheets must be submitted and comply generally. These two aspects offer us the opportunity to physically test the buildings and make tangible comment on whether the buildings are at the level required by Passivhaus certification. Beyond these two 'real world' aspects, we are left with the difficulties of comparing real life with a model.

Airtightness

The issues surrounding the airtightness of the buildings have been discussed in Section 3.3. Suffice here to say that whilst compliant certificates for airtightness were submitted at the time of certification, serious doubts have been raised about these through this study, and the two subsequent sets of tests, both of which have indicated consistent levels of airtightness in all houses at levels between 3 and 4 times higher (worse) than that required for Passivhaus compliance.

MVHR Commissioning

The other physical evidence required for Passivhaus certification is compliant MVHR commissioning documentation. In Section 6.4 it is noted that the inspection in May 2013 established that while the specification and installation of the system was of a relatively high standard as would be expected of a Passivhaus certified project, an inaccessible extract terminal in Cottage DB2 meant the commissioning could not have been undertaken completely, and the imbalance encountered in the systems raise some concern about the rigour of the commissioning and subsequent certification process.

Specific Annual Space Heating Demand

The best known feature of Passivhaus design is that the space heating requirement must not exceed 15 $kWh/m^2/a$.

It is readily acknowledged that the in-use consumption figures will be determined by occupant behaviour and will not present a 'straight line' of consistent consumption figures. However, as shown in the image below, which shows the in-use energy consumption measurements of three Passivhaus and one 'Low Energy' developments in Germany, it is the average of the spread of results which matters and it can be seen that in the three Passivhaus developments, whilst there is a spread of consumption among the different occupants, the average figures (horizontal blue lines) are almost identical to the predicted figures (red horizontal lines).

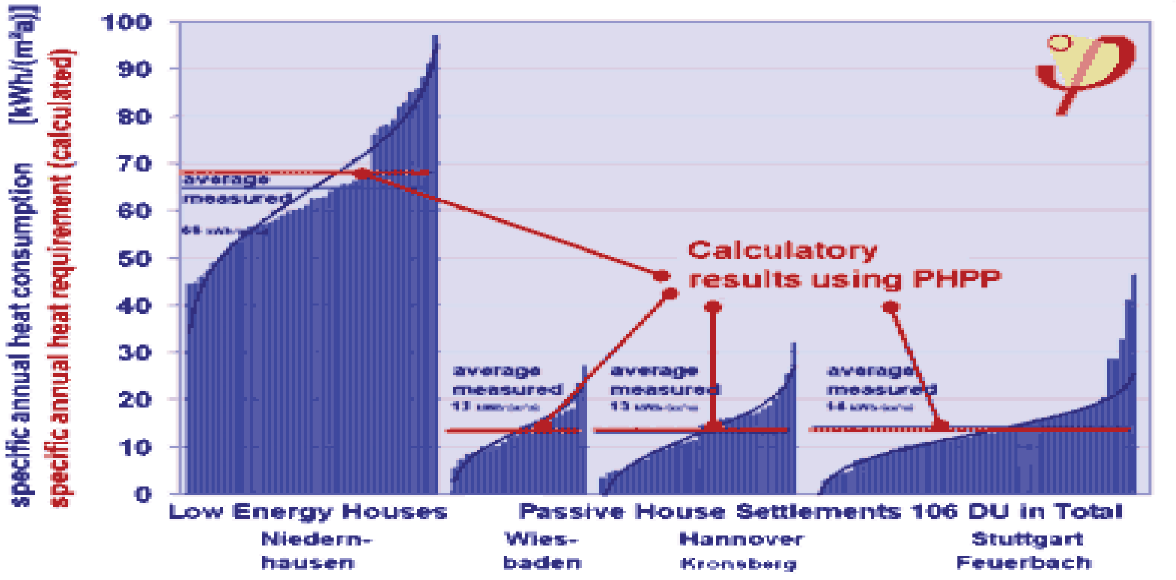


Figure 8.1: Publicly available graph from Passipedia (**http://passipedia.org/_detail/picopen/comparison_PHPP_ph_other.png?id=basics%3Awhat_is_a_passive_house**) showing range of in-use energy consumption figures against an average (blue line) and the predicted averages (red line)

So whilst it is clear that we cannot rely on individual figures, we can establish whether a house type has performed 'in a manner consistent with Passivhaus expectation' by examining a number of case studies and averaging their space heating consumption. However, at Dormont this is not simple to do.

Unfortunately, the overall complexity of the system, combined with lack of insulation to pipework, ambiguity about lengths of pipework and some uncertainties about the sub-metering, means that results gained cannot be relied upon. Furthermore there are three important reasons why such a seemingly simple calculation does not yield meaningful results.

The first is related to occupation. Once a building is occupied, it becomes impossible to separate building performance from occupant behaviour. The way to remove the variability associated with occupation and establish the 'base' building performance is to carry out a co-heating test, which was not carried out as part of this project due to the need to decant occupants for the duration of the test.

A related but distinct issue is that while insolation and internal gains are accounted for carefully in PHPP, it remains the case that these are based on typical figures rather than actual figures making any direct comparison unreliable. Finally, the 15 kWh/m^2/a limit is related to a constant (modelled) temperature of 20^{o}C whereas in reality the temperature in these houses fluctuates considerably and as shown has exceeded 20^{o}C for a considerable percentage of the time. It would be extremely difficult to accurately establish what percentage of heat input was 'excess'.

Nevertheless it was important to attempt an indication. The figures shown below are however only indicative and cannot be taken as accurate. They are derived from incorporating 10% of the total electrical consumption as an allowance of the contribution to space heating from such incidental gains, 10% of the biomass consumption (Manufacturer's stated percentage of direct room output compared to hot water provision) and the hot water flow results to the MVHR post-heater. However the two post-heater flow results for the cottages at DA1 and DA2 are suspect, rendering the final figures equally suspect.

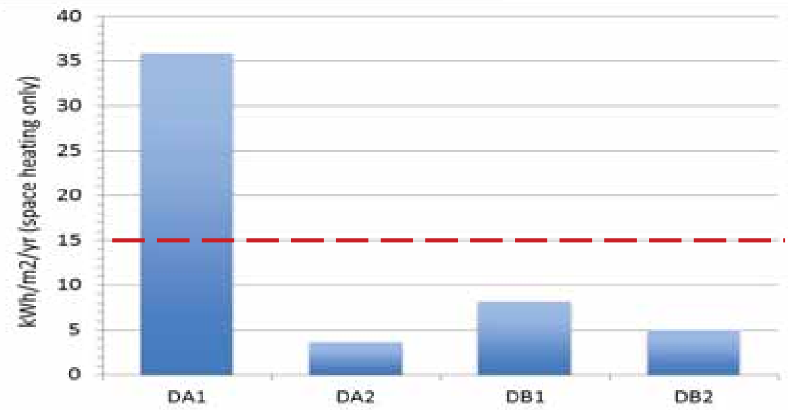


Figure 8.2: Actual annual space heating energy consumption per square metre for Dormont Park in 2013 in blue against Passivhaus threshold of 15 kWh/m2/yr.

It would appear that three of the houses are performing 'in a manner consistent with Passivhaus expectation', and all the more so given that a percentage of the energy expended has contributed to the overheating of the houses, such that energy expended to maintain the houses at 20°C exactly might have been less. The average space heating demand for the four monitored houses is 13.15 kWh/m^2/yr which on the basis noted above of averaging the 'real life' performance would reinforce the notion that the buildings are performing as expected.

Primary Energy Demand

Whilst the figures above give an indication of space heating performance, the issues noted mean that a more reliable indication of whether the buildings achieve the Passivhaus aspirations can be established by studying the Primary Energy consumption figures. A lesser known but equally important criteria for Passivhaus certification is that the (predicted, regulated and unregulated) Primary Energy shall not exceed 120 kWh/m2/yr. This is for all space and water heating, cooling, auxiliary (regulated) and household electricity.

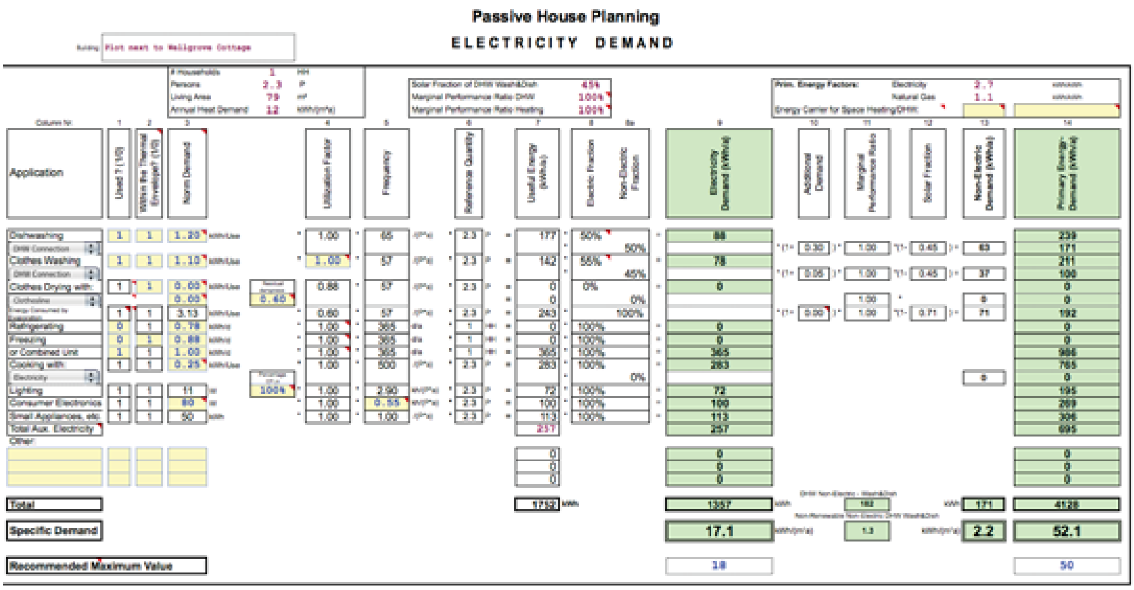


Figure 8.3: Snapshot from a typical PHPP 'Household Electricity' Worksheet showing the items (left column) requiring input on individual appliances, followed by a range of columns such as 'utilisation factor', 'useful electric fraction' and so on which provide standard ratios to

be applied to arrive at overall annual electricity consumption.

The image above shows a typical PHPP 'Household Electricity' Worksheet in which the applicant inputs all anticipated appliances and their kWh rating. The spreadsheet then applies standardised factors to be applied, such as utilisation factor, use frequency and a calculation to elicit electric fraction and non-electric fraction (for example where dishwashers or washing machines have hot water input) to arrive at an overall electricity consumption figure.

A separate worksheet – the "Auxiliary Electricity" worksheet – requires input and calculates the overall electrical consumption associated with fixed or regulated items such as fans, pumps and so on. Combined, they provide a robust attempt to anticipate overall electrical consumption which feeds into the primary energy calculation.

This project has enabled measurement of all inputs and outputs of the installed systems, with the exception of the timber input to the wood stoves. For this reason, MEARU undertook a relatively small additional project to quantify and extrapolate the timber consumption in order to give a complete picture of the total energy and carbon inputs into the houses. This helped establish how close the development has come to achieving the Scottish Government 2016 target of 'Zero Carbon' (ZC). This study is described in more detail in the next section of this chapter.

The total energy input to each house was found by combining the electric, solar and stove consumption, all taken from the period 01.12.12 to 30.11.13.

For the purposes of establishing the ZC figures in relation to Scottish Government requirements, it was necessary to separate out and use only the regulated electrical figures, but in PHPP and Passivhaus design, the total electrical consumption – including non-regulated consumption – is needed. This was not appreciated in the Zero Carbon work discussed in the next section, which has worked on the basis of regulated energy only.

The figure for electricity consumption is multiplied by 2.6 which is the stated PHPP conversion factor, and added to the timber total consumption. The timber contribution is established by using the monitored hot water output and adding the stated (10%) contribution to direct space heating which could not be monitored.

The solar contribution is not included in the calculation as it is 'free energy'. The electricity associated with the solar system is included in the regulated electricity figure. The key metrics are shown below.

	DA1	DA2	DB1	DB2
Floor Area (m^2)	87.00	87.00	102.77	102.77
Mains Electricity (kWh/a)	7136.28	1887.26	3295.97	3956.29
Mains Electricity x 2.6 (kWh/a)	18554.33	4906.88	8569.52	10286.35
Stove Total Consumption (kWh/a)	295.39	1879.40	3112.47	1056.91
Primary Energy (kWh/a)	18849.72	6786.28	11681.99	11343.32
Primary Energy ($kWh/a/m^2$)	**216.66**	**78.00**	**113.67**	**110.38**

Figure 8.4: Key Metrics relating to overall Primary Energy consumption for the period Dec '12 to Nov '13 inclusive.

We can see therefore that three of the houses comply with this requirement in reality, while DA1 – with its initially high level of immersion heater use in preference to use of the stove – falls outwith the 120 kWh/a/m2 threshold (shown in the blue dashed line).

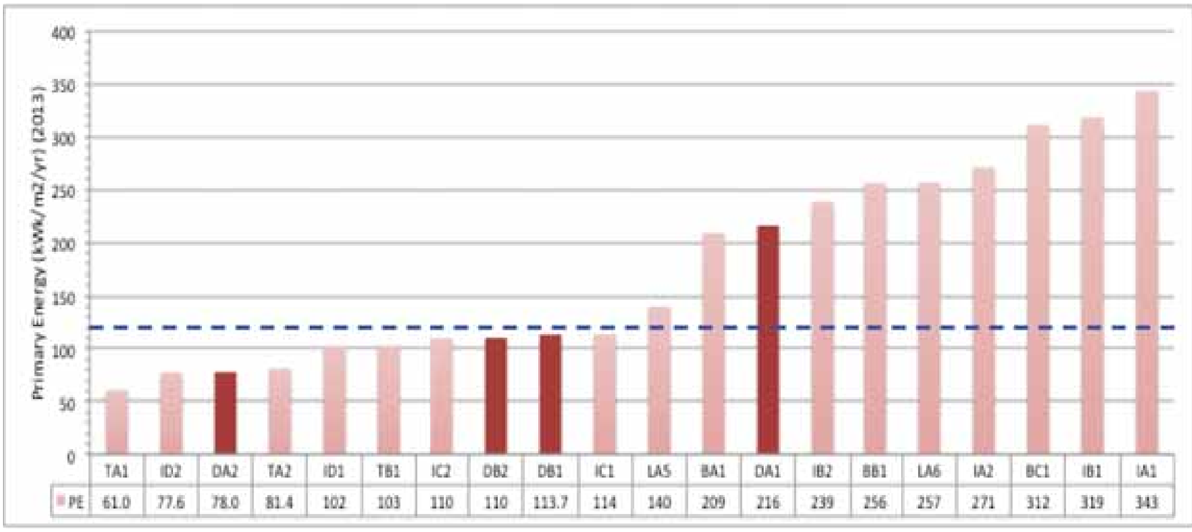


Figure 8.4: Overall Primary Energy Consumption per square metre in 20no monitored dwellings for the period Dec '12 to Nov '13 inclusive showing the Dormont houses in darker red and the Passivhaus PE threshold in blue dashed line (120 kWh/m2/yr).

This raises the question of design intentions, anticipated or typical use, against actual consumption by real occupants. For example, it could not have been anticipated that the Occupier of DA1 would eschew the use of the wood stove and use the immerser instead. There is no accounting for occupant behaviour and this is not necessarily a fair reflection on the design and construction of the building, but at the same time, it clearly illustrates the need for systems tobe understandable and usable.

Passivhaus proponents acknowledge that there are variations in occupant behaviour and as noted rely on the average figures for groups of buildings. In this case, the average primary energy consumption across the four houses is 129.68 kWh/m^2/yr placing the development above the threshold. It should be noted that excluding the unusually high consumption associated with DA1 brings the average well within the required threshold.

Conclusion

To answer the question as to whether the houses are indeed Passivhaus is ultimately to query the status of the certification itself, which is not the prime purpose of the project. On the basis that the PHPP sheets for the houses was assessed and approved at the time of construction, and that compliant airtightness results and MVHR commissioning sheets were submitted at the time, then it can said that the houses are indeed Passivhaus, regardless of what may be established subsequently.

However, on the basis that so soon after completion, it has been shown that the critical aspect of airtightness is not at the level required of a Passivhaus, nor that the MVHR commissioning could feasibly have been undertaken properly raises a serious question as to the validity of that certification.

This study has also established that U-values in reality are higher than the design intent, the primary energy average above the required level and overheating levels are far beyond that required for Passivhaus certification. In use therefore, there are undoubtedly causes for concern.

Finally to ask the question as to whether the houses are nonetheless operating ‘at a level consistent with Passivhaus certification’ then the answer is certainly “Yes” and the dwellings are well within the limits of affordability for their occupants. It is also clear that the occupants are very satisfied both with the overall comfort and affordability of these homes.

Dormont Estate decided to opt for Passivhaus certification rather than other energy or sustainability benchmarks because they believed that that was the route to more robust performance and there is little doubt that their conviction has been vindicated.

8.2 Zero Carbon Assessment

A separate project was undertaken by MEARU to establish the extent to which the development could claim to achieve the Scottish Government's 2016 target of being a "Zero Carbon" (ZC) housing development. The project was a partnership between Dormont Estate and MEARU and was supported and jointly funded by Interface, the Scottish Funding Council and the European Research Development Fund.

Initial assessments showed that a 'true' ZC energy balance was unlikely to be achieved as no on-site electrical energy generation was incorporated in the development. The intention was to identify what measures might be required to meet any residual energy demands with a view to informing future design proposals on the estate, and elsewhere. The **final report** is contained within **Appendix Folder 8.1.**

The total energy inputs, outputs and carbon impact of all aspects of the development have been monitored by the Technology Strategy Board funded research, with the exception of the timber consumption associated with the stoves. Here, a measured output was recorded, but the mass of timber used to create this remained an unknown.

To complete the picture of energy balance, it was necessary therefore to establish the energy and carbon content of representative timber fuel samples, and the mass of timber used by each dwelling. The calorific value of a number of samples of timber was measured in a laboratory. Five timber samples were used, using sources we knew were habitually used by the occupants. The exception to this was that the occupants of DB1 tend to use foraged timber, rather than timber provided by the estate so we were not able to derive accurate calorific values for this house.

In addition the mass of timber used was ascertained by asking each household to measure an accurate mass of timber used in a given week and extrapolating from that. Occupants were given luggage scales, timber storage bags and daily record sheets to allow them to log the mass of timber burnt on a daily basis.

These figures were then input to an overall energy and carbon balance comprising three main systems: the electricity consumption, the solar thermal energy production and the wood stove timber consumption and thermal output. Despite the complexity of the services, there are only these three systems overall. There were some accuracy issues with the figures which are described further in the report.

	DA1	DA2	DB1	DB2
Floor Area (m^2)	87.00	87.00	102.77	102.77
Mains Electricity (kWh/a)	7136.28	1887.26	3295.97	3956.29
Solar Contribution (kWh/a)	1754.00	1760.00	1760.00	1742.00
Stove Total Consumption (kWh/a)	295.39	1879.40	3112.47	1056.91
Total Energy Consumption (kWh/a)	9185.67	5526.66	8168.44	6755.20
Renewable Contribution (%)	**22.31**	**65.85**	**59.65**	**41.43**

Figure 8.5: Key Metrics relating to Overall Energy Consumption in the 4no monitored dwellings for the period Dec '12 to Nov '13 inclusive

noting the percentage contribution by renewables.

With the exception of DA1, the renewable contribution to each household energy balance is significant and admirable. With better understanding of the equipment and better education, it is likely that the occupant of DA1 could reduce the electrical consumption, replacing with wood and thus the overall picture could be much improved. It is also worth noting the high percentage of unregulated electrical use in houses DA2, DB1 and DB2 as discussed in Chapter 7 and the potential to reduce this and improve the balance even further.

Whilst the renewable contributions are generally impressive, it remains the case that without renewable generation of electricity, true 'ZC' will not be possible.

8.3 Conclusions and key findings for this section

- The level of airtightness of the four dwellings has been shown not to be at a level consistent with Passivhaus compliance, despite initial tests showing otherwise.
- The MVHR systems appear to be imbalanced and that of DB2 could not have been commissioned correctly so there are questions about the Passivhaus compliance.
- Other concerns regarding Passivhaus relate to the overheating, described elsewhere, which is far in excess of the 'allowable' level of overheating in certified Passivhaus properties.
- It is not possible to give accurate 'real-world' values to compare with the specific space heating demand threshold of 15kWh/m^2/yr, but insofar as it can be roughly indicated, the properties appear to be operating as anticipated with the exception of DA1.
- It is possible to give accurate comparisons to the Passivhaus requirement for Primary Energy Consumption of 120kWh/m^2/yr. Again, DA1 fails to achieve the standard, but the other three houses have done so.
- Whilst there are reservations about aspects of the certification process, it can be said that the buildings generally (excluding DA1) are operating at a level consistent with Passivhaus expectations. However, the experience of DA1 reveals how sensitive this process is to occupancy, and underlines the need for fail-safe, usable and robust active systems.
- With the exception of DA1, the renewable contribution to each household energy balance is significant (as much as 65% in the case of DA2), but it remains the case that without renewable generation of electricity, true 'Zero Carbon' performance will not be possible.

9 Key messages for the client, owner and occupier

9.1 Lessons learned by Client

The following points represent the lessons learned as volunteered by the Client following the design and construction process, as well as the monitoring process.

- Monitoring equipment should be installed as part of the build process. Retrofitting monitoring equipment was costly.
- Important information about the performance – leading to improvements – was revealed by the BPE process.
- Make sure all hot water pipework is insulated as the heat produced by uninsulated pipes especially in the summer months when the solar panels are working at their best does contribute considerably to overheating and also leads to loss of efficiency.
- Greater understanding of how the systems work and how the house performs / operates makes the handover to tenants a much simpler process.
- Design intentions for systems and usability should not be sub-contracted – a holistic view of the systems and how they are intended to be used (by both the landlord and occupants) is vital and better understanding of the systems leads to a better tenant handbook.
- Understanding how the house performs can better inform tenants how to get the best out of the systems and make real savings in energy consumption and bills.
- More understanding of integration of systems will make it easier and cheaper for any future development and also help prevent snagging issues.
- A good MVHR unit costs more initially but prevents future problems and costs less to run.
- We now have an understanding of how much electricity is consumed by the properties which will help us to size a photovoltaic array for installation in the future. This would then enable this development to become zero carbon in use.

9.2 Lessons learned by MEARU

The following points represent the conclusions of the MEARU team and are intended as recommendations for any future projects undertaken by the Estate. We agree with and have not duplicated the points raised above.

- Overall the initial intent, design, procurement and handover process can be seen as exemplary. All subsequent issues should be seen in this light, as the development and improvement on what was a very commendable approach and process.
- The most difficult aspect on site was achieving the required level of airtightness. Greater effort should be taken in future to ensure this issue is ‘designed out’ at an early stage in the design process.

- The plumbing and electrical works were Contractor-design packages and have proved the most problematic post completion. Future strategies might include either greater specialist input at design stage, or the engagement of experienced / specialist installers. The MVHR design and installation by a Specialist Design / Installation company has been trouble-free.

- Apart from issues associated with understanding of the active services, the main issue for occupants has been overheating and this should be addressed more rigorously in future projects.

- Insitu measured U-value results for the construction were higher (worse) than the design intent figures by a factor of 28.6% for the wall and 34.4% for the roof. Awareness of this should be fed back to subsequent Design and Construction Teams to avoid similar reductions in performance in use.

- Notwithstanding the above, thermographic inspection showed the basic fabric to be consistently thermally effective and in keeping with Passivhaus requirements.

- Areas of concern, which should lead to greater effort in future include the cooling effects of air leakage from doors and windows, uninsulated combustion air supply ducts and toilet cisterns, as well as heating effects of uninsulated hot water pipes. These elements also tend to be the weak points for air permeability.

- Air testing as part of this project has indicated much higher levels of air leakage than initially certified. Future projects should ensure that Air Testers are employed directly by the Client, not the Contractor.

- Differences in the methods of measuring air leakage have been shown to account for some differences in the results, but cannot account for the whole discrepancy.

- Overall the occupants like their homes and appreciate the measures taken to improve energy efficiency and comfort.

- Occupant interviews revealed that the main concerns were the overheating and issues arising from the complexity of services.

- As the overall complexity of the services has been a problem for everyone involved, the *simplicity* of services installation will be a key parameter of any future projects.

- Greater importance should be placed on the provision of accurate 'as-built' drawings, including services and active systems.

- The diligence of the Estate (landlord) has been crucial in maintaining a good relationship with the tenants who for their part have been tolerant of the teething problems experienced in the development.

- With the exception of DA1, energy consumption in-use has been in keeping with the predictions made in PHPP and the Passivhaus certification, despite concerns about the MVHR installation, airtightness and overheating.

- It is possible to give accurate comparisons to the Passivhaus requirement for Primary Energy Consumption of 120kWh/m^2/yr. Again, DA1 fails to achieve the standard, but the other three houses have done so.

- The unregulated electricity consumption (also contributing to heat gains) comprises a far higher percentage of overall electricity use in three of the four buildings monitored.
- With the exception of DA1, the renewable contribution to each household energy balance is significant (as much as 65% in the case of DA2), but it remains the case that without renewable generation of electricity, true 'Zero Carbon' performance will not be possible.

10 Wider Lessons

10.1 Wider Lessons for the Industry

The following points represent the lessons learned by all involved in the process and involve some duplication from the points made in the previous chapter.

- The Passivhaus approach has been shown to be an effective way to ensure excellent levels of energy efficiency, occupant satisfaction and ongoing energy costs.
- The Estate's commitment to renewable sources of energy, in particular the use of timber as a part of the rural economy and setting have been shown to be effective in reducing carbon emissions generally.
- The development cannot approach 'zero carbon' status unless renewable forms of electricity generation are installed. The monitoring has enabled the Estate to accurately size such installations however.
- The monitoring process has enabled the Client to fine-tune and improve performance and occupant experience.
- 'Embedded' or inbuilt monitoring equipment would be cheaper to install and should be considered on all projects.
- SAP predictions were fairly accurate for energy consumption, but not for energy costs, which were between 3x and 4x higher, due mainly to inaccurate unit costs within SAP
- Areas of weakness in design terms included: overheating control, airtightness and services design.
- Areas of concern in installation terms include: services procurement, insulation of water pipework and airtightness.
- Considerable effort needs to be paid to the design and specification of the services, along with production of accurate "as-built" drawings and handover information, so that everyone is clear how things work and inefficiencies / costs for occupants can be avoided from the outset.
- The diligence of the landlord in this case has been crucial in maintaining a good relationship with the tenants who for their part have been tolerant of the teething problems experienced in the development.
- The unregulated electricity consumption comprises a far higher percentage of overall electricity use in three of the four buildings monitored and this tendency is likely to be reflected in many projects, leading to questions of how to address the proliferation of unregulated electricity consumption.

11 Appendices

The following appendices are separately available:

2.1 Architect's Building Warrant Drawings

2.2 SAP Certificates

2.3 iQ System Details (sample)

2.4 Handover Materials

2.5 Photographic Surveys

3.1 Insitu U Value Testing

3.2 Thermographic Survey

3.3 Air Leakage Testing

4.1 Design Team interviews

6.3 DomEARM Audits

6.4 MVHR Testing

7.1 Monitoring Equipment Installation Reports

7.2 MVHR Testing and Clamps Reports

8.1 Zero Carbon Assessment