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Lessons from Post Occupancy Evaluation and Monitoring of the 1st Certified Passive House in Scotland

Paul Tuohy[1], Gavin Murphy[1], Gokay Deveci[2]
[1]Department of Mechanical and Aerospace Engineering, University of Strathclyde, Glasgow, Scotland. [2]The Scott Sutherland School of Architecture & Built Environment, Robert Gordon University, Aberdeen, Scotland

Abstract

This paper describes an investigation carried out to understand the performance in practice of the first certified Passive House in Scotland and associated low or zero carbon technologies LZCT. The aim was to provide some useful feedbacks on actual performance in order to inform and hopefully improve building industry processes and policy.

Monitoring was carried out on three dwellings on the west coast of Scotland. All dwellings are within 250m of each other with similar orientation and occupancy but were built to different standards representative of: 1950's Scottish building standards; 2010 Scottish building standards; and Passive House standards. The Passive House included mechanical ventilation with heat recovery (MVHR), air to air heat pump and solar thermal hot water heating LZCT systems which are in general being encouraged for new build and retrofit. The monitoring was carried out over 1 year and included indoor environment (RH, CO_2, T), outdoor conditions (Solar, T, RH), energy use (Watts, kWh), operation schedules, and hot water system temperatures (T).

In parallel with the monitoring, the Passive House and associated LZCT were investigated by inspection and observation and by comparison with both the Passive House Planning Package (PHPP) and the recommendations of the Certified Passive House Designer course.

There were many interesting findings from the investigation, these included: lower and more consistent CO_2 levels in the Passive House than in the houses without MVHR; poor layout and ducting of MVHR system giving poor energy performance and condensation problems; poor controls and specification of air to air heat pump giving poor space heating performance; poor control of solar thermal hot water system reducing performance; lack of occupant understanding of operation and maintenance for the LZCT systems.

The lessons learned are relevant to all future implementations of these LZCT systems in the building stock both new build and retrofit. Possible improvements in industry and Passive House processes are discussed.

Introduction

There is much policy focus on achieving reduction in the energy used in buildings and the carbon emissions associated with this. The Energy Performance of Buildings Directives [EU, 2002, 2010] are driving regulations across the EU and the Passive House standard has been proposed as a solution to help meet this policy intent. Much regulation is based on predictive calculation methods but there is growing evidence that there may be significant disconnects between predicted and actual performance [why buildings don't work], for this reason it is important to understand the actual performance achieved by advanced buildings and technologies and feed back lessons so that policy and industry initiatives can be made robust. The work described here aims to provide feedback on the performance of the 1st Scottish certified Passive House and associated LZCT and make suggestions for improvement in buildings industry processes. The findings are intended to be relevant to Passive Houses but also relevant to the deployment of LZCT systems in new build or retrofit of other buildings.

The study described here focused on three dwellings including: the first certified PassiveHouse in Scotland, a second non Passive House dwelling in the same award winning 'Tigh–Na–Cladagh' development, and an adjacent dwelling constructed in the 1950's. The Tigh–Na–Cladagh development was officially opened in October 2010 and described as: "15 terraced properties, located 1 mile south of Dunoon and overlooking the beautiful Firth of Clyde, boasts the First Passivhaus for Scotland, the First affordable Passivhaus for the UK, a Royal instutute of British Architects Awards (RIBA) 2011 and Scottish Saltire Housing Design Awards 2010 commendation which demonstrates that low energy homes can also be affordable". The Tigh-Na-Cladach development was constructed with timber frames.

Figure 1. Location in Scotland of the three monitored dwellings: 1 = Passive House, 2 = 2010 regulations house ('code 4'), 3 = 1950's house; Tigh-Na-Cladach development; the Passive house.

The Passive House was certified by the Passivhaus Institute [PHI, 2012] and occupied in October 2010. The developers Fyne Homes were keen for this to be an example project to inform future buildings and agreed to allow the independent POE and monitoring study to begin in the winter of 2010 and to last for 1 year.

The analysis methods

The post occupancy evaluation was in 2 inter - related parts: 1. inspection and observations, and 2. monitoring.

The Passive House and associated LZCT systems were investigated by inspection and observation and comparisons made with both the Passive House Planning Package (PHPP) and the recommendations of the Certified Passive House Designer course [Feist et al, 2007]. It should be noted that the Passive House was developed prior to the Certified Passive House Designer course being rolled out.

Monitoring was carried out of all three dwellings using wireless monitoring equipment. Monitoring was carried out with each reading point logged once per minute. While access to the dwellings was provided it was not possible to modify plumbing or electrical circuits to accommodate monitoring instruments so the monitoring points were limited to only those that were accessible. This restricted the electrical measurements to only the main circuit to each dwelling; different appliances power usage had to be identified by its characteristics from the main signal. Similarly it was not possible to re-plumb to install heat meters in the hot water pipes; hot water system characteristics were identified by monitoring the temperatures at different points on the tank and the attached pipe-work.

Findings from the analysis

There were many observations from the analysis; here just the most interesting are given:

1. Indoor environment

The CO_2, temperature and relative humidity were measured in the living rooms of each of the dwellings; in addition temperatures were recorded in the kitchens and in the 'coldest room' which was identified by the occupants. Figure 2 gives an example of a selection of the data collected for 1 week in March of 2011.

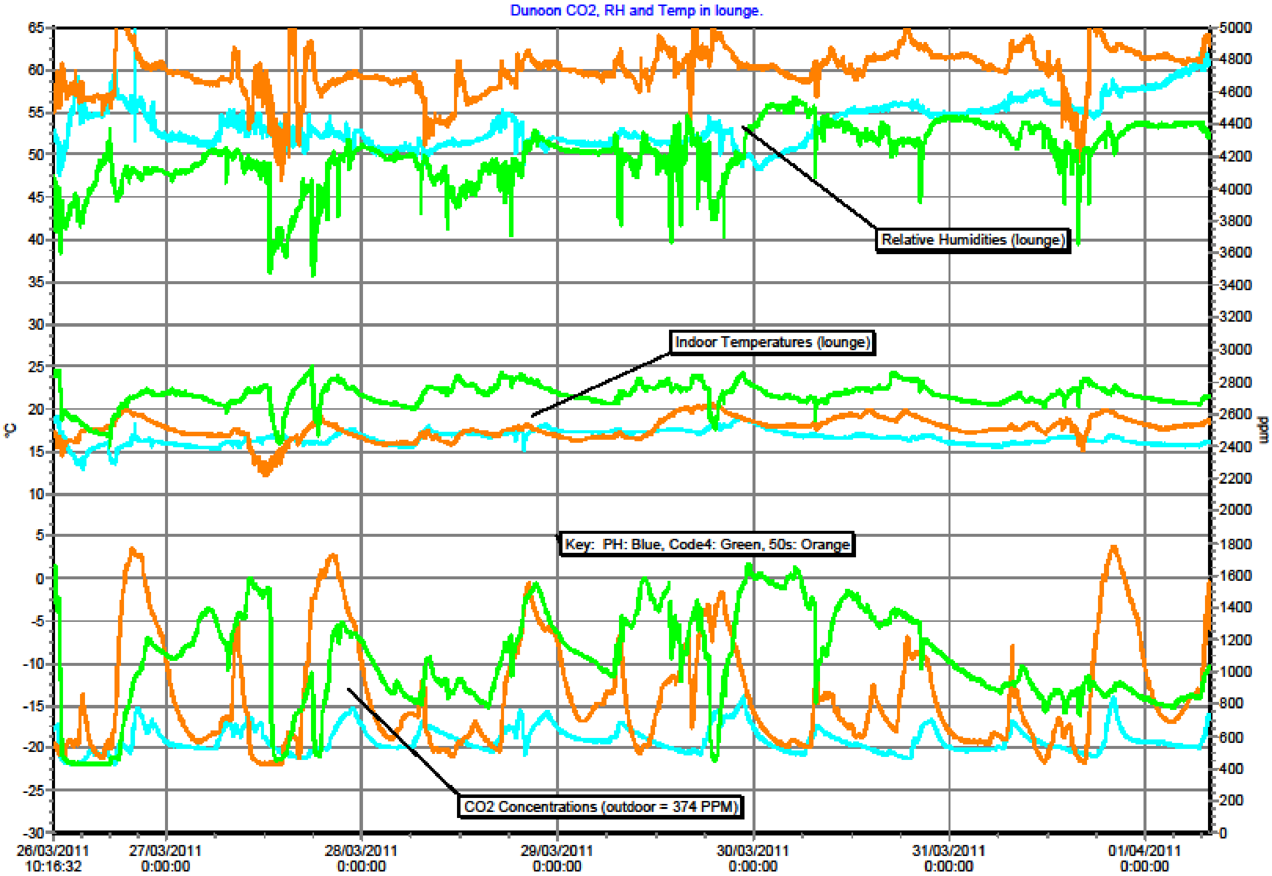

Figure 2. Monitored data for the Passive House (blue), 2010 regulations (code 4) house (green), 1950's house (orange). CO_2 (bottom 3 lines, right axis), Indoor temp and RH (both left axis).

The CO_2 levels appear to be lower and more consistent in the Passive House which has continuous whole house mechanical ventilation than the 2010 regulations (code 4) house which has intermittent extract ventilation and the 1950's house which relies on infiltration and window opening only. The CO_2 levels were analysed over a 3 month period and the results given in table 1, these show that in this period the Passive House the indoor air quality is generally class 1 according to EN 13779 and rarely exceeds class 2 while the 2010 regulations house generally has indoor air quality of class 2 or 3 and has some periods at class 4 CO_2 levels [CEN, 2007].

The temperatures in the lounge of the Passive House and the 1950's house were lower than in the 2010 regulations house, this was a surprising result for the highly insulated Passive House while not so surprising in the 1950's house with very poor insulation. The reason for the low temperatures in the Passive House are explained by the later sections on the MVHR and heat pump systems.

The RH in the three houses was generally observed to be in an acceptable range (30-70%) but the houses with intermittent ventilation by extract fans and window opening appear to have more short term fluctuations.

CO_2 parts per million	2010 regulations (code 4)	Passive House
Average	1060	594
Maximum	2231	1384
Minimum	422	401
% > 900ppm	66%	3.40%
% > 1000ppm	55%	1.70%

Table 1. Summary data for CO_2 for 3 month period between March and July 2011.

2. Mechanical Ventilation System with Heat Recovery (MVHR)

The Architect, as is normal in the UK, delegated the services to a sub-contractor, while the services sub-contractor had experience, this was the first time that the construction team had implemented an MVHR. On first inspection of the MVHR installation it became clear that there were significant issues. A first observation was that there was no provision of transfer openings to allow the flow of ventilation air from room to room (there should be 15mm gap under doors or over architraves etc), the occupant was in the habit of in general leaving doors open to allow the heat to move around the house but this should not have been necessary. The second observation was that the MVHR unit was at the centre of the house (ideally it should be adjacent to an outside wall or roof) requiring the long cold ducts to and from the outside air to be well insulated (> 100mm was planned in PHPP). The insulation of the ducts had however many problems: the applied insulation where visible was only 19mm and was open at the joint (hidden to the rear of the duct); close to the MVHR unit there was no insulation; where the cold ducts passed through a ceiling void the contractors had only applied mineral wool (of course for the whole length the cold ducts should be well insulated and have a moisture barrier), when the ceiling void was opened there was significant moisture accumulated due to condensation causing the mineral wool and the construction elements to be saturated. These long cold ducts resulted in: high heat losses for the house, reduced efficiency of heat recovery, and moisture damage.

Figure 3. Mechanical ventilation system problems.

3. Air to Air heat pump for space heating.

An air to air heat pump had been installed to provide space heating (the PHPP calculations indicated an annual heating requirement of 21kWh/m2 and a heating load of 10W/m2 for the 88m2 house). The seasonal COP of the system was given as 2.5 by the manufacturer and this was used in the planning. The unit was under manual control and did not have remote thermostat. The Passive House recommendation is that the space heating device is controlled automatically by a remote thermostat. The occupant observed that when the heating was required the unit operated but delivered very little heating. When this problem was identified the manufacturer was contacted and asked about performance at lower temperatures including defrost function (as detailed in EN14511 [CEN, 2012] and the EU Heat Pump Association quality standard), the manufacturer could not provide this data for the system and did not have any suggestions for the remote controls. Typically the space heating is required in a Passive House when outside temperatures are low, also the space heating system for a Passive House is sized to be continuously available and controlled by a remote thermostat and does not generally have capacity for quick recovery if the house becomes cold. On further discussion with the manufacturer they concluded that it was not suitable for the intended application in the Passive House. The situation was not helped by the lack of transfer openings for heat circulation and the higher than intended heat load due to the cold ducts. The issue of defrost is particularly a problem for Scotland due to the frequency of worst case conditions for frost formation i.e. 5^{o}C and high humidity rather than the EN14511 2^{o}C test point reported; it is very often 5^{o}C and raining in Scotland!

4. Solar thermal water heating with back-up electric heater.

The solar thermal hot water system was planned to cover 55% of the annual hot water demand and in June 97% is predicted to be covered by solar thermal in PHPP. The monitoring however showed a different picture with extensive use of electrical water heating on most summer days. The system had a 200litre vertical tank with a solar coil in the bottom half and an electric heater just above this at the midpoint. The guidance from the solar system installer had been that the electric backup heater should be left on a standard setting and that the electricity would not be used in summer as the solar system would do the job. This is a common instruction from solar system installers; another reason given is that this will ensure protection from legionella. In the Passive House development the standard setting was to have the electric heater available overnight and between noon and 2pm which reduced the potential benefit of afternoon sunshine. As a short term improvement the immersion heater was re-programmed to provide a 1hr boost at 5am and 5pm only but a more sophisticated control would be better. Studies of this type of system (electrical immersion twice a day with a solar thermal panel) have reported a best possible performance of around 40% [Ayompe et al, 2011]. Other issues seen were poor insulation of pipes connecting to the hot water system including un-insulated connection points and joints. A further issue with the system was that at some times it was observed that the water flowing to the solar panels was slightly warmer than that entering the tank from the collectors indicating a net heat loss to the tank on those occasions, this was surmised to occur when the tank stratification was such that the temperature difference of 6^{o}C between the bottom half of the tank and the panel used to trigger turn-on of the solar system pump was not sufficiently large. The question of legionella risk was raised as the immersion heater only sterilises the upper half of the water tank and the solar system was seen to rarely deliver water at high enough temperatures for complete tank sterilisation in the winter months, some UK solar system suppliers are adding a second electric heater to the bottom of the tank to address this but this approach could further compromise the solar performance unless suitable controls are put in place.

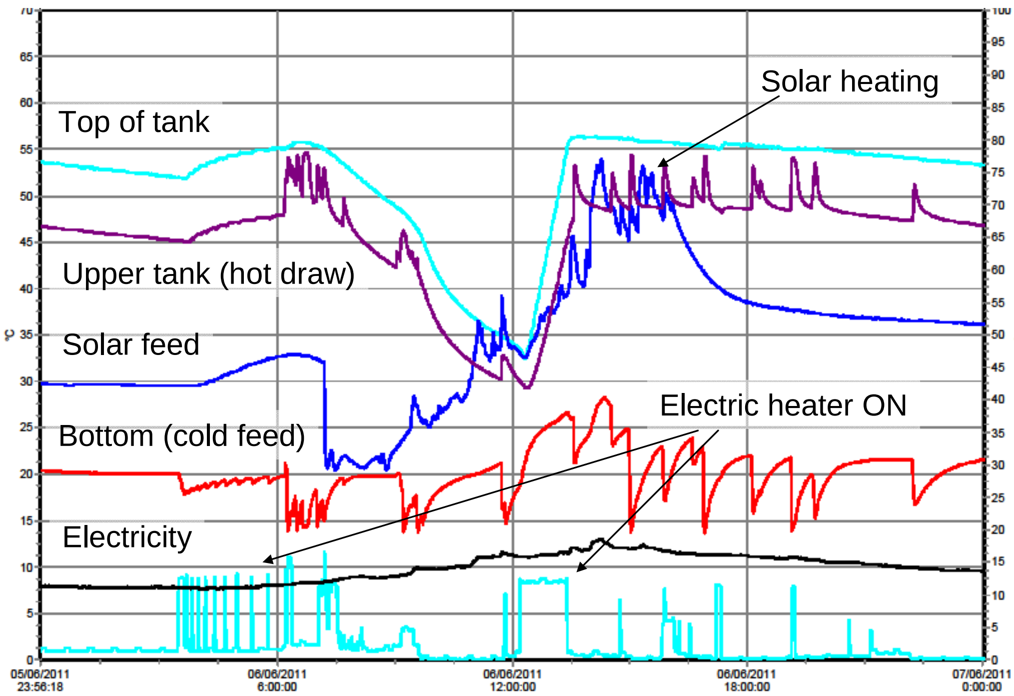

Figure 4. Monitored data for the hot water system in the Passive House.

5. Occupant experience

The occupant was very enthusiastic about the overall design of the Tigh-Na-Cladach homes. "The house has definitely met my expectations. Having the sea to the front of the property and the woodland to the rear makes it an encredible setting. The homes are very soundproof and ideal for families, the large windows mean I can watch my daughter if she is playing outside. Living here is very sociable as there are plenty of families living close by and the children can play safely away from the main road."

While the Passive House occupant overall was very pleased, there was frustration expressed about the problems with the systems and the disruption this caused. Other frustrations were expressed with the lack of easy to follow and comprehensive instructions for the use and maintenance of the unfamiliar LZCT systems.

Frequency of filter changes, how to clean or replace filters, when and how to switch the MVHR to summer bypass and when to switch it off were unanswered questions, the occupant found the 80 page manufacturers manual too confusing. Similarly the heat pump caused similar difficulties, when the system performance was questioned the occupant did not know who to contact to get the system checked etc. The solar thermal system maintenance was another challenge to be faced without simple guidance being provided.

The expected energy savings not being realised was also another problem.

6. Remediation of issues

Once the issues described above were identified it took considerable effort to define a remediation plan and to complete the required works. The issues were first identified in the early months of 2011 and the completed fixes were not in place until April 2012. It is difficult to establish accountability, finance, plans and execute to these plans after the construction phase has finished and the building is occupied.

The MVHR unit was replaced with another smaller one that could be sited outside the thermal envelope in the small porch. Placing the MVHR unit on the outside wall meant the long duct lengths inside the dwelling no longer needed to be insulated (as they were after the unit so ‘warm’), just the short ducts between unit and the outside through the porch and the ducts between the unit and the inside through the external wall required insulation with this configuration.

The heat pump was replaced by a unit that had guaranteed performance down to low outside temperatures including defrost capability.

The solar thermal system was explained to the occupant and they were advised to manually adjust the immersion heating to meet their needs without compromising the solar gains i.e. minimise use of the electric heating especially in the mornings.

An improved instruction manual for the house and the use and maintenance of the LZCT systems was provided.

Discussion of how to address the general issues

The POE and monitoring of the Passive House and its LZCT systems has highlighted deficiencies in the buildings industry process in the UK. It is imperative that these deficiencies are addressed quickly as these LZCT systems and many others are promoted by Government policy and going to become increasingly common across the whole building stock through new build and retrofit.

The awarding of Passive House certification in this case was through the submission of plans, PHPP calculations and a signed declaration from the construction supervisor that the construction had followed the plans. There were obviously gaps in this process highlighted by this case study. Some improvements to the Passive House process could be: to require photographs to be taken that match with each of the critical details; to require a more comprehensive set of inputs to correctly capture the performance of heat pump systems; to better represent actual performance of solar thermal systems including controls; to require some occupant feedback confirming they have received and understood how to operate and maintain their building; to require the submission of the first 2 years energy use data and occupant experience data.

The reliance of building performance standards such as Passive House and national regulation and rating systems on predicted rather than actual performance is an important issue. The accuracy of the predictions, and the capability of the industry to deliver the predicted performance where the predictions are indeed accurate, is in many cases largely unknown. Currently the Passive House method is reliant on the knowledge and diligence of the individual Designer, the Certifier, the certification requirements, and the provenance of the products used (certified products are available). As has been illustrated here this process is not always robust due to issues in the industry and supply chain. The Certified Passive House Designer qualification may help address this.

One recent initiative aimed at improving building industry process is Building Information Modelling (BIM) which is proposed as a vehicle for improving productivity in line with historical improvements seen in the retail, automotive, electronics and aerospace industries enabled through adoption of modern processes [BSI, 2012]. In figure 5 a simple model is used to represent the building industry flow based on these modern processes. The model is consistent with buildings industry 'Design-Construct-Use' process e.g. the RIBA plan of work [RIBA, 2011], but with explicit representation of validation, feedback and feed forward processes similar to the NASA Design Process for Complex Electronics [NASA, 2012]. Processes based on predictive methods address only the concept and detailed design stages, so far BIM has focussed only on these predictive methods.

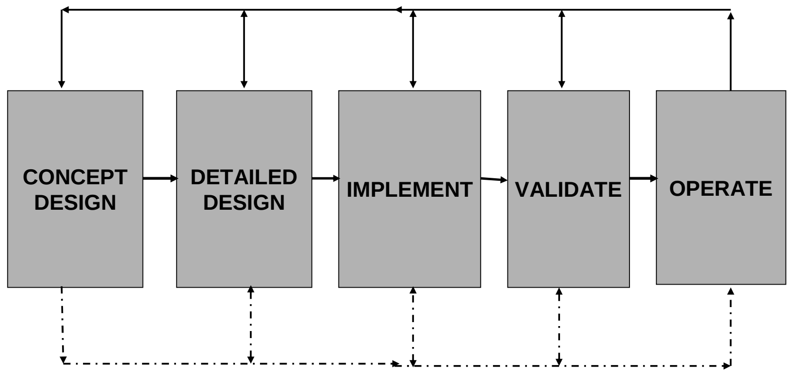

Figure 5. A simple model of the building industry process.

The UK Display Energy Certificate [DCLG, 2008] method of energy rating of public buildings in compliance with the EPBD is based on actual performance rather than predicted. The Australian NABERS scheme is of interest as it incorporates preliminary design based ratings as well as final ratings based on actual performance. The NABERS process has incorporated feedbacks from analysis of the gaps between intended and actual into its mandatory protocol to be followed when using predicted performance for marketing or design purposes, this protocol covers the methods to be employed in design stage including expert review and communication of assumptions and risks to the construction team. The protocol particularly focuses on systems and controls which is recognized to be an area of general weakness. The protocol requires there to be expert review prior to the awarding of the preliminary design rating, and submission of 1 year of operational data for the final rating to be awarded [NABERS, 2012].

In the UK a recent buildings industry initiative is the Soft Landings [BSRIA, 2011] process which requires expert review meetings at various stages and also includes the requirement for a 3 year handover and remediation period after the building is occupied. This would appear to be an admission that buildings cannot work as intended but require remediation. Remediation is negative for productivity and may not be possible.

Comparison with other industry has suggested that there is a great need for a quality system approach to be developed for buildings industry processes so that intended performance is delivered in practice and buildings work first time (i.e. 'out of the box' c.f. PCs and Cars) and have intuitive controls and clearly indicated energy performance [Tuohy, 2009]. A good first step would be to focus on actual performance, the reasons for performance gaps, and fixes that address these gaps.

The issues highlighted here may in future be addressed for new and retrofit through improved Passive House or building regulations standards, guidance documents, training, accreditation and certification of completed buildings but this must be done quickly to avoid repetition of problems.

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