MONITORING AND MODELLING THE FIRST PASSIVE HOUSE IN SCOTLAND

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ABSTRACT

The drive to reduce carbon emissions and energy utilisation directly associated with dwellings suggests that the energy efficiency of dwellings will have an increasingly prioritised role in the built environment. Created by the Passive House Institute, Passive House is a low-energy building standard that can reduce the energy use of a building. Passive Houses have been built in many parts of the world; with the first Passive House in Scotland completed recently. Monitoring and modelling advances in building design and technology can be useful to improve future constructions and technology applications. This paper describes the monitoring and modelling of a Passive House in Dunoon, Scotland. Monitoring results suggest that the Passive House approach is applicable in a Scottish climate and could be valuable to reduce carbon emissions and improve energy efficiency in dwellings. Modelling results suggest that simulation can be used to influence the design process; especially in low energy buildings as dynamic simulation can offer a quicker and cheaper alternative to experimental field trails.

INTRODUCTION

As Governments around the world look to increase the energy efficiency of dwellings for a multitude of reasons such as health factors, security of energy supply and mitigating climate change, the energy efficiency of dwellings becomes imperative.

"A simple collection of appropriate components is not sufficient to construct a building as a Passive House – the integration as a whole is greater than the sum of the individual parts." (Feist and PassivHaus Institut, 2007). The UK Government secretary of state for energy and climate change recently stated the Passive House standard was "a watershed moment in our relationship with the built environment (and that he) would like to see every new home in the UK reach the standard" (Cutting the Carbon, 2010). The CEPHEUS project (Schnieders and Hermelink, 2006, Schnieders, 2003) details the results from detailing POE of over 100 Passive Houses in Europe. It states the principle idea of a Passive House as the reduction of heat losses, through increased insulation, so that the use of internal gains, appliances / people / solar largely negate the need for a separate heating system.

The term Passive House, from the German PassivHaus, refers to a standard used to define highly insulated energy efficient buildings. Passive House standard can be achieved by both domestic and commercial buildings; this study will focus upon a Passive House in a domestic context. To be termed a Passive House, the building must meet a set of core fundamentals as descibed in Table 1, Passive House Criteria.

Table 1 – Passive House Criteria

CRITERIA AREA	MEASUREMENT
Heating Energy Demand	≤ 15 kWh/m^{2}a
Building Energy Load	Building Heating Load ≤ 10 W/m^2
Thermal Bridges	Thermal Bridge Free Design
Air Tightness	0.6 air changes / hour @ 50 Pa
Entire Specific Primary Energy Demand	Max 120 kWh/m2a
Mechanical Ventilation Heat Recovery	MVHR is critical in a Passive House, a system with a high efficiency (>75%) must be used
Domestic Hot Water Generation and Distribution Systems	Minimal Heat Losses
Structure	U Value ≤ 0.15 W/m^{2}K
Roof	U Value ≤ 0.15 W/m^{2}K
Floor	U Value ≤ 0.15 W/m^{2}K
Glazing	U Value ≤ 0.8 W/m2K Solar Energy Transmittance (G Factor) of at least 50% to achieve net heat gains in winter

An exciting development of low energy homes, including the first certified Passive House in Scotland, has been recently completed by Fyne Homes in Dunoon. The homes were officially opened the Scottish Government Minister for Housing and Communities with the properties detailed as follows: "The 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, and demonstrates that low energy homes can also be affordable." (Fyne Homes, 2010). Similar Passive House projects have also been constructed in other nations such as in Wales where there can often exist comparable maritime locations with difficult topographies (McLeod et al., 2011).

An initiative was taken forward by the University of Strathclyde and Fyne Homes to carry out detailed monitoring on a number of homes in the development and locality. The monitoring will be used to assess the applicability of Passive House design in a Scottish climate.

Objective

The objective of this paper is to detail the monitoring of the first Passive House in Scotland along with a highly insulated dwelling and a home built in the 1980's as comparators. All three dwellings are located within a 100 metre radius. The monitored information will be used to assess the impact of new design methods and materials to energy utilisation and occupant satisfaction. The focus of this paper is the monitoring and modelling of the first Passive House built in Scotland.

METHODOLOGY

Location of Monitoring Project

Location of the project was dictated to a large degree by the location of Scotland's first Passive House and the other test case dwellings. Situated on the Cowal Peninsula in Argyll Scotland, Dunoon enjoys a climate which rarely drops below 0°C and rarely exceeds 20°C (Weather 2 Ltd, 2011).

Figure 1 – Monitoring Project Location: Dunoon, Scotland

Non-invasive monitoring was a primary focus of the project to reduce the impact on the families living in each home. Telemetry monitoring was selected as the best method of conducting the monitoring. The telemetry monitoring placed a restriction upon the monitoring as each transmitter must be placed with 100meters of the main receiver. Repeaters could be used to boost the signal for more than 100meters but this would have added another layer of complexity to the monitoring process.

Description of Monitored Dwellings

A selection of three homes to monitor was made to represent the broad spectrum of housing types in Scotland, taking the controlling factor as being varying insulation constructions. As can be seen from Figure 1, all homes are within a close proximity to each other; therefore all of the homes will experience very similar external conditions. All homes are of a semi-detached design. Summary detail on each dwelling is provided in Table 2.

Table 2 – Summary of Monitored Dwellings

	TFA [1]	**U Values W / (m² K)**		**Heating**	
Name	m^2	Wall	Glazing	Space	Water
Passive House (#1)	88	0.09	0.8	ASHP	SDHW + Immersion
Highly Insulated Home (#2)	120	0.3	1.2	Storage Heaters	Immersion Boiler
1980's Home (#3)	72	1.6	3.1	Storage Heaters	Immersion Boiler

Passive House (Dwelling 1)

Figure 2 highlights the location of dwelling 1; located on the Firth of Clyde to ensure a favourable view (important in the design of a Passive House) and additional source of humidity. However, the location is shaded by local trees and does not have the benefit of southerly facing windows. Solar heat gain is therefore minimised in this location.

Figure 2 - Dunoon Passive House – Note Solar Thermal Panel Installation

The Passive House is heated primarily by use of an Air Source Heat Pump (ASHP, Eco Air Split Type Air Conditioner, model ECO0701S) supplying heat to the building to the lower hall by way of wall mounted heated air delivery. This ASHP has been recommended for the property based upon the calculations conducted during the certification process using the Passive House Planning Package (PHPP).

The Passive House also has the benefit of Solar Domestic Hot Water (SDHW) in the form of 4.6m^2 Velux M08 Collectors (6 collectors with a specified aperture of 0.9m^2 each). The solar collectors feed a 200litre tank which has a direct immersion top up which can be set by a timer. Intelligent controls are very important in systems such as SHDW to ensure that, for example, the immersion top up is made at the correct time of the day. Heating water will become especially important as demand for hot water

[1] Total Floor Area

will dominate in buildings which have low heat loss and meet advance building standards such as Passive House (Tuohy, 2009, Feist and PassivHaus Institut, 2007).

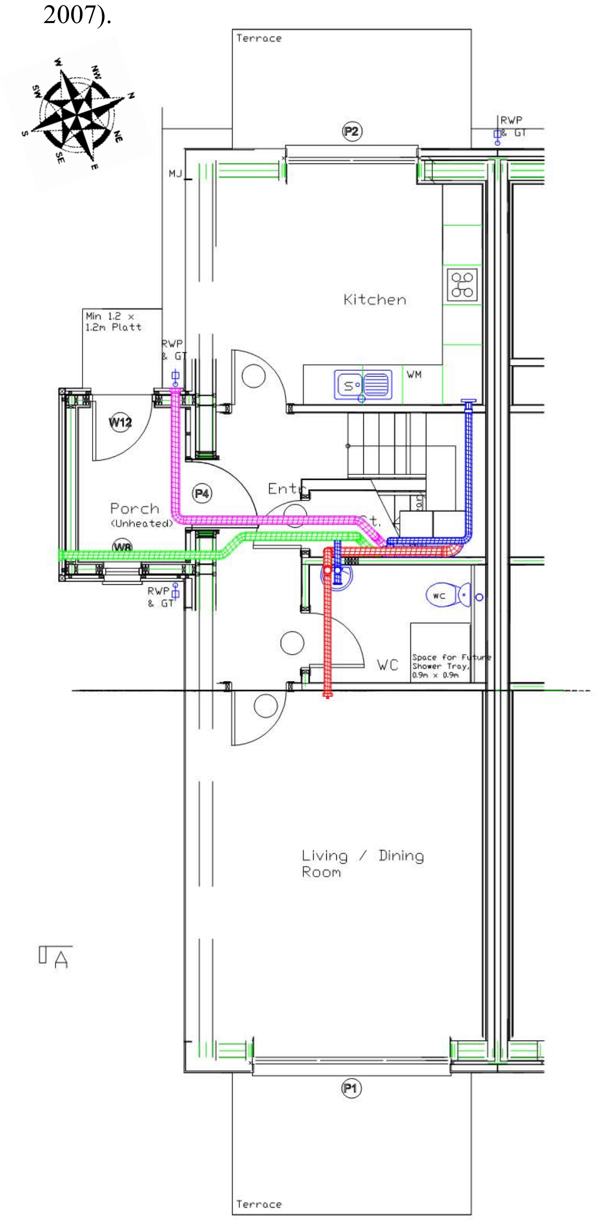

Figure 3 - Passive House Floor Plans ((Divici, 2011))

Figure 3 details the gound floor plans for dwelling 1. Noted on the diagram is the location of the supply air ductwork and supply air intake (western side of porch), the supply air inlets are placed appropriately in the living and sleeping areas of the home. Also highlighted is the extract air outlet (northern side of porch), the extract air outlets are placed in the kitchen and bathroom to recover the heat from these areas.

Location	**To Measure**	**ID**
Lounge	Relative Humidity + Temperature + CO_2	GD 47
Kitchen	Temperature	GC 05
Coldest Room	Temperature	GC 05
Bathroom	Temperature	GC 05
Electric Meter	Current	Eltek M2D
MVHR	Current	Eltek M2D / GS 42 Transmitter
Space Heat (Duct)	Current	Eltek M2D / GS 42
Heat Pump - Outside	Current	Eltek M2D / Eltek GS 42 Transmitter
SDHW	Tank Temperature / Cold Water Intake Temperature / Solar Heated Water Intake / Hot Water Extract	Eltek GS32 Transmitter
SDHW	Immersion Curent / Pump Current	Two * Clamp Meter + 1 * GS42

Energy Efficient House (Dwelling 2)

Energy efficient materials were utilised to ensure that the home is broadly in line with the Code for Sustainable Homes (Gaze, 2009) level 4.

Table 3 – Energy Efficient Home – Monitoring

Location	**To Measure**	**ID**
Lounge	Relative Humidity + Temperature + CO_2	GD47
Kitchen	Temperature	GC 05
Coldest Room	Temperature	GC 05
Bathroom	Temperature	GC 05
Electric Meter	Current	M2D / Eltek GS42 Transmitter
HW Immersion Heater	Current	M2D / Eltek GS 42 Transmitter
HW Tank	HW tank temp	1 Thermistor + 1 GS32
Hot Water - Cold Water Intake Feed	Cold Water Inlet Pipe	1 Thermistor (GS32 not required as one Gs32 / 2 Thermistor)
Hot Water - Hot Water Pipe Leaving Tank	Hot Water Outlet Pipe	1 Thermistor + 1 GS32

1980s House (Dwelling 3)

Constructed in the 1980's dwelling 3 (Figure 7) is an example of the type of dwelling which was commonplace throughout Scotland, but are known for their poor insulation and large energy use.

Figure 7 – 1980's Test Case Dwelling

Table 4 – 1980's House: installed Monitoring Equipment details

Location	**To Measure**	**Monitoring Equipment Reference**
Lounge	Relative Humidity + Temperature + CO_2	GD47
Kitchen	Temperature	GC 05
Coldest Room	Temperature	GC 05
Bathroom	Temperature	GC 05
Electric Meter	Current	M2D / GS42 (M2D Clamp Meter – Sense Heat Pump and House Electric Consumption)
HW Immersion Heater	Current	M2D / GS42
Hot Water Tank - Cold Water Intake Feed	Cold Water Inlet Pipe	1 Thermistor
Hot Water - Hot Water Pipe Leaving Tank	Hot Water Outlet Pipe	1 Thermistor + 1 GS32

Overarching Monitoring Installation

In addition to the monitoring equipment installed in each home, additional monitoring equipment was utilised: a pyranometer to record solar radiation, an external temperature sensor to measure the external temperature. The Pyranometer and external temperature sensor data was representative for all three dwellings.

Table 5 – Overarching monitoring equipment

Location	**To Measure**	**Monitoring Equipment Reference**
Passive House	Log all transmitters	Data Logger Receiver RX250AL (Squirrel)
Outdoors	Solar Intensity	Pyranometer Sensor SKS1110 (http://bit.ly/RFEzUg)
Outdoors	Outside Temperature	GC 05

SITE SURVEY OBSERVATIONS

Passive House

Figure 8 –Passive House MVHR Insulation

Figure 8 highlights that the insulation around the Paul Thermos 200DC MVHR unit has been incorrectly installed. This oversight will have the effect of reducing the temperatures in the Passive House and therefore requiring additional electricity to heat the home further.

Energy Efficient Home

Dwelling 2 suffered from poor insulation around the hot water storage tank and piping. The level of attention to detail regarding insulation could have been improved significantly.

1980's House

Dwelling 3 also suffered from poor insulation around the hot water storage tank and piping. It is clear that insulation of piping related to the hot water tank will reduce heat loss and reduce cost.

Site Survey Summary

Initial observations highlight the importance of insulation of services systems inside of each of the dwellings. The lack of attention to detail on the Passive House was unexpected as for a Passive House to function as intended, it is imperative that attention to detail is in place especially for areas such as insulation. On discussion with the owner of the Passive House it was clear that the MVHR system has not been adequately explained to her. Furthermore, the owners electricity bills for the Passive House were far higher than she had been led to expect. The owner also mentioned that the Passive House was very cold. Monitoring was required to determined how the Passive House was performing and if the expected 20°C throughout the home was being achieved.

MONITORING RESULTS

Figure 9 presents a summary of one week's data output from the monitoring process. The outdoor temperature can be seen to never rise above 10°C. The temperatures of the main living area of each dwelling is shown; this highlights that dwelling 2 (highly insulated home) is consistently higher than either dwelling 1 (Passive House) or dwelling 3 (1980's Home).

Initial Summary and Energy Saving Advice

Based upon the initial monitoring results, the following conclusions and recommendations were provided to each dwelling as follows:

Passive House

- Internal dry bulb temperature readings were below the comfort zone for nearly all the hours recorded
  - Temperatures of 15°C were commonplace in the Passive House
- Doors require undercutting between kitchen living room
  - As the doors were not undercut there was no way for the heated air to move around the Passive House as intended
- There are issues with the SDHW
  - Controls issues exist with the SDHW, a controller test bed could be used to assess the best controller strategy for the Passive House
- The ducting surrounding the MVHR unit was found to be missing insulation in certain areas
  - This is a major issue and must be rectified to help the Passive House perform as intended

Highly Insulated House

- Good air quality in the home
  - The house is performing well and has been built to a high specification
- Temperature of Lounge and Kitchen area could be reduced
  - Temperatures in the range of 24°C were commonplace (this is a personal preference)
  - Indicative figures highlight that turning down the thermostat by one degree could save £50 a year

1980's House

- Temperatures are in a sensible range
  - There is little overheating so energy is not being wasted on heating
- Additional Draft Proofing could be installed in the home
  - Indicative figures highlight that increasing draft proofing could save 10% on your heating bill due to the reduction of heat loss
  - The main issue is the insulation of the hot water tank and pipes

MODELLING

The modelling focus of this paper will be solely on - the Passive House for brevity.

For the Passive House to be constructed, a series of design and assessment stages were required:

Use of PHPP, a steady state calculation method that commonly used as a design tool, to certify that a building meets Passive House standard. The Standard Assessment Procedure (SAP) is used to suggest the energy rating of the Passive House. SAP is a steady state calculation method, which should not be used as a design tool. Created by BRE, SAP is the UK Government's recommended method of measuring the energy ratings of domestic dwellings. It is the recognisable tool used in the UK to generate EPCs and for building professionals to meet Buildings Compliance.

It can be seen from the Passive House monitoring results that the Passive House was not functioning as intended with too cold internal temperatures, too high

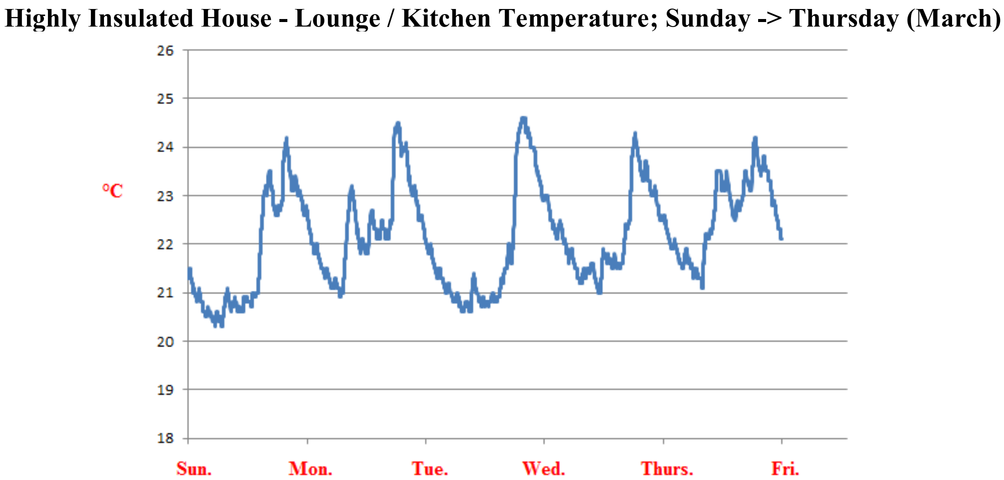

Figure 9 – Monitoring Detail, Highly Insulated House

electricity use and visible insulation defects, which were detrimental.
Additional modelling can be used to suggest where the Passive House can be improved.

IDEAS

An IDEAS based modelling environment was selected for this study. A SAP-compliant dynamic modelling and simulation tool named IDEAS (Inverse Dynamics based Energy Assessment and Simulation) has been developed to enable the performance assessment of novel control systems for domestic heating/cooling equipment and appliances. The tool is implemented in a MATLAB/Simulink environment and offers plug-in support for hypothesised control algorithms with outputs applied to the IDEAS systems models. In use, IDEAS ensures compliance with the UK Government's, empirically based, Standard Assessment Procedure (SAP) so that effective control regimes might be added to equipment to gain compliance approval.
IDEAS allows for an extension of SAP and PHPP in many areas, such as: the ability to make use of various dynamic weather files (Mylona, 2012) and the flexibility to amend the heating setpoint which is tracked (for example, comparisons can be made between tracking a constant setpoint vs. a varying setpoint).
IDEAS has been described in depth (Murphy et al., 2013, Murphy et al., 2011).
In IDEAS, heat gains such as external weather data and heat gains from appliances are described as disturbances to the model. These disturbances are taken into account by IDEAS and play an important part in the overall energy estimation analysis of a dwelling. For example, if there are more heat gains, then less heating could be required to be produced by the heating system for the standard temperature demand profile to be met.
The focus of this section of the paper is the use of IDEAS to suggest where simulation differs from the modelling results presented here and why.

IDEAS Method

An IDEAS model of the Passive House was created based upon appropriate inputs. Where possible, inputted parameters in IDEAS were identical to those which would have been used in PHPP – for example, parameters such as areas were identical. Full parameters used in the IDEAS model are reproduced here in Table 7.

Table 6 – IDEAS Passive House Parameters

Parameter	Nomenclature	Value (Units)
m_{si}	Mass of internal structure	20083 kg
m_{se}	Mass of external structure	20083 kg
m_{im}	Internal mass	15786 kg
m_a	mass of internal air	515.7998 kg
C_s	Thermal capacity of building structure	1075.6 J/(kg·K)
C_{im}	Thermal capacity of internal mass	1000 J/(kg·K)
C_a	Thermal capacity of air	1005 J/(kg·K)
U_w	U-value of windows	1.116 W/(m^2·K)
U_f	U-value of floor	0.1540 W/(m^2·K)
U_r	U-value of roof	0.870 W/(m^2·K)
U_{im}	U-value of internal mass	2.5 W/(m^2·K)
U_s	U-value of structure	0.3385 W/(m^2·K)
A_w	Surface area of windows	13.82 m^2
A_f	Surface area of floor	62.3 m^2
A_r	Surface area of roof	92.39 m^2
A_{im}	Surface area of internal mass	133.3 m^2
A_s	Surface area of structure	121.39 m^2
h_i	Internal air heat transfer coefficient	7.69 W/(m^2·K)
h_e	External air heat transfer coefficient	25 W/(m^2·K)
k_w	Equivalent thermal conductivity of the structure	0.1140 W/(m·K)
d_w	Thickness of the structure	0.3175 m

Climate plays an important role in modelling. In SAP, climate data for many aspects such as the predicted running costs of a dwelling are based in a Sheffield, England location. PHPP makes use of more localised climate data as the basis for solar gains and external temperature has a major bearing on the outcome of a PHPP model. The importance of climate date in Passive House modelling has been recognised (McLeod et al., 2012).
The Chartered Institute of Buildings Services Engineers (CIBSE) Test Reference Years (TRYs) data for Glasgow was used in the IDEAS model, as Glasgow is the closest TRY data available to the location of the Passive House. CIBSE TRYs and Design Summer Years (DSYs) are available for 14 locations across the UK. The importance of weather data has also been highlighted by CIBSE: "weather data has now become an essential component of virtually every new building design and major refurbishment"(CIBSE, 2012).
Any set-point can be tracked in the IDEAS method, the set-point tracked in this IDEAS model is based upon the standard SAP temperature demand profile 21°C demanded between 7am->9am / 4pm->11pm midweek & 7am->11pm weekend. By tracking the

standard SAP temperature demand profile setpoint, IDEAS will calculate the predicted energy consumption for that modelled dwelling over a year. This energy use will be affected by factors such as weather data and heat gains from appliances.

Appliance gains were taken from an International Energy Agency / Energy Conservation in Buildings and Community Systems Program (ECBCS) Annex 42 study based upon real UK test data for 69 monitored buildings (Beausoleil-Morrison, 2008).

IDEAS Results

Indicative results are presented here to suggest where a method such as IDEAS could assist in the performance improvement of advanced dwellings such as the Passive House. Figure 10 presents IDEAS calculated yearly heating energy consumption.

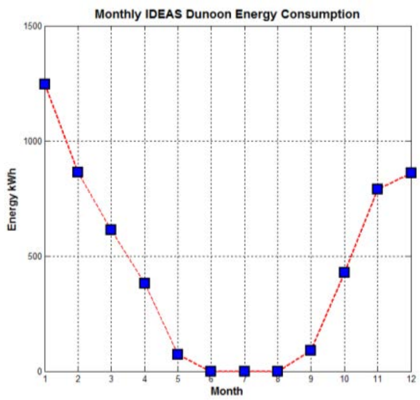

Figure 9 – Heating Consumption Summary

IDEAS energy consumption results could be calibrated with those assumed by PHPP but Post Occupancy Evaluation (POE) data would allow for results that are more representative of reality. Monitored POE data can help predict energy use: we can populate IDEAS with such data to help gain an improved modelling estimation of future energy use.

Also demonstrable is that by tracking the SAP demand profile, a minimum of 20°C will be generally achieved throughout the year assuming that the heater is sized appropriately for the dwelling is performing as designed. A benefit of IDEAS is that transitory behaviour can be analysed, in a SAP compliant framework as highlighted in Figure 11. Initial comparisons with monitoring data suggest that the Passive House is colder than the general minimum found of 20°C, and that this is due to in-use problems with the installed ASHP and so the setpoint will not in practice being tracked as well as that modelled in IDEAS and highlighted in Figure 11. IDEAS could be used to help size an appropriate heating system and to then assess the expected yearly energy and more granular transitory impact.

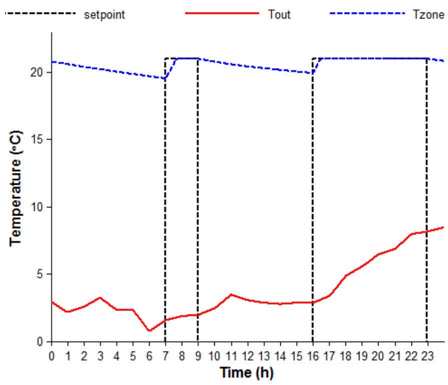

Figure 10- IDEAS Passive House transient response

CONCLUSION

This paper presented the process of monitoring 3 dwellings in Dunoon, Scotland. One of the monitored dwellings is the first certified Passive House in Scotland and the first affordable Passive House in the UK. Of the other two dwellings, one is a highly insulated home and one is an example of a dwelling constructed in the 1980s. Both of the modern buildings were found to have been built to a very good standard. It was found that there were recommendations that could be made for each of the dwellings. The Passive House was found to have significant issues with its servicing systems and these appeared to have a knock on effect with low internal temperatures and high energy bills being experienced. The results from the highly insulated home highlighted the overall hot temperatures in the dwellings and suggested that modelling occupant behaviour is very difficult. The 1980s dwelling highlighted the improvements that can be made to simply improve the energy efficiency of a home, such as insulating the piping around a domestic hot water tank. The important factors in the monitoring of the three dwellings is the impact which users can have upon their home and the need for greater attention to detail in homes in areas such as insulation.

Following on from the monitoring of these dwellings, focus was placed on the Passive House. It is interesting to note that the Passive House had been certified by the use of PHPP and the use of SAP, but that the Passive House was not performing to the occupant's satisfaction or expectation. Indicative modelling results were presented by the use of the IDEAS method: this method highlighted the importance of heat gains from appliances and climatic data in simulation.

DISCUSSION AND FUTURE WORK

The initial monitoring results highlight the dwelling requiring most attention appears to be the Passive House. The Passive House had been heralded as an exemplar dwelling and appears that the construction and design has met the high Passive House criteria standards. Unfortunately the same cannot be said about the servicing systems installed into the dwelling: issues were found the SDHW, MVHR and Heat Pump. Up-skilling of the industry and POE could help alleviate these issues.

The variation of monitored and modelled data is highlighted in this paper. The building industry is suffering from methods such as SAP and PHPP stating high expectations for dwellings which POE (as highlighted in this paper) often disproves. It is possible to achieve modelling results which are closer to what was actually measured. A detailed analysis is required comparing what was assumed for heat gains in the Passive House with what actually were the heat gains, this can then be contrasted with the POE data running in an IDEAS model.

IDEAS has been developed as a controller test bed: this is especially useful for assessing the potential impact of improving poor controls in dwellings. For example, controls issues were found in Passive House SDHW setup. IDEAS can be used to quickly assess the impact of improving the controls and the subsequent effect upon user satisfaction and dwelling performance.

SAP has also been compared to the Passive House Planning Package (PHPP) and it has been found that SAP may underestimate the heating required for a low energy house compared to PHPP (Reason and Clarke, 2008). Future work is suggested by comparing POE data for the Passive House in IDEAS, PHPP and SAP. Specifically future work will contrast in detail the yearly measured consumption with the aim of the Passive House standard. Yearly annual consumption for all monitored homes will also be compared and contrasted with modelling for each.

REFERENCES

BEAUSOLEIL-MORRISON, I. 2008. *Final Report of Annex 42 of the International Energy Agency's Energy Conservation in Buildings and Community Systems Programme*, CANMET Energy Technology Centre, Natural Resources Canada.

CIBSE. 2012. *CIBSE Weather Data Packages* [Online]. CIBSE Knowledge Portal: CIBSE. Available: https://www.cibseknowledgeportal.co.uk/weather-data [Accessed 27/11/12 2012].

CUTTING THE CARBON. 2010. *First UK Passivhaus Conference* [Online]. Available: http://www.cuttingthecarbon.co.uk/passivhaus [Accessed 2011/05/16.

DIVICI, G. 2011. Bethania Architectural Plans,.

FEIST, W. & PASSIVHAUS INSTITUT 2007. *Passive House Planning Package 2007: PHPP 2007: Requirements for Quality Approved Passive Houses*, Passivhaus Institut.

FYNE HOMES. 2010. *05.10.10; Tigh-Na-Cladach officially opened by Alex Neil, Housing and Communities Minister* [Online]. Available: http://www.fynehomes.org.uk/news.html [Accessed 2011/05/16.

GAZE, C. 2009. *Complying with the Code for Sustainable Homes - Lessons learnt on the BRE Innovation Park*.

MCLEOD, R. S., HOPFE, C. J. & REZGUI, Y. 2012. A proposed method for generating high resolution current and future climate data for Passivhaus design. *Energy and Buildings,* 55**,** 481-493.

MCLEOD, R. S., HOPFE, C. J., REZGUI, Y. & CARDIFF, W. U. K. 2011. APPLICATION AND LIMITATIONS OF REGIONAL AND FUTURE PREDICTIVE CLIMATE DATA IN PASSIVHAUS DESIGN. *12th Conference of International Building Performance Simulation Association.* Sydney, Australia.

MURPHY, G., COUNSELL, J., BASTER, E., ALLISON, J. & COUNSELL, S. 2013. Symbolic modelling and predictive assessment of air source heat pumps. *Building Services Engineering Research and Technology*.

MURPHY, G., KHALID, Y. & COUNSELL, J. 2011. A Simplified Dynamic Systems Approach for the Energy Rating of Dwellings. *Building Simulation 2011.* Sydney, Australia

MYLONA, A. 2012. The use of UKCP09 to produce weather files for building simulation. *Building Services Engineering Research and Technology,* 33**,** 51-62.

REASON, L. & CLARKE, A. 2008. PROJECTING ENERGY USE AND CO2 EMISSIONS FROM LOW ENERGY BUILDINGS; A COMPARISON OF THE PASSIVHAUS PLANNING PACKAGE (PHPP) AND SAP. AECB.

SCHNIEDERS, J. 2003. CEPHEUS–measurement results from more than 100 dwelling units in passive houses. *Time to Turn Down Energy Demand, eceee***,** 340-351.

SCHNIEDERS, J. & HERMELINK, A. 2006. CEPHEUS results: measurements and occupants' satisfaction provide evidence for Passive Houses being an option for sustainable building. *Energy Policy,* 34**,** 151-171.

TUOHY, P. 2009. ESRU: Benchmarking Scottish Energy Standards: Passive House and CarobonLite Standards: A comparison of energy demand using SAP, SBEM and PHPP Methodologies.

WEATHER 2 LTD. 2011. *Historical Weather Data,* [Online]. [Accessed 10/05 2011].