FS42 - Co-heating test for Alternative Refurbishment Strategy on Hard to treat House on Uist

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Introduction

Sustainable Uist (http://www.sustainableuist.org/) is a community organisation formed in 2009 to combat climate change on the Uists and the Western Isles. It has attracted funding from Climate Challenge Fund, BLF and CnES (Western isles Council) and Historic Scotland to support a number of environmental initiatives, only some of which are energy and refurbishment related.

One project involves research into 'Hard to Treat' housing, which accounts for about half of the Island's housing stock and as such is ineligible for the Government funded insulation schemes. The aim is to get a better understanding of the issues through extensive survey work across the Islands, to study potential domestic heating and micro-renewables options, but importantly, to construct and monitor three alternative refurbishment strategies to assess different energy efficiency models.

This feasibility study provides support for the 'real-world' testing of these strategies via a 'Co-heating' test which has been carried out by GCU in late January-February 2012 coupled with results of air-tightness testing on a typical single storey two bedroom stone walled croft house with a floor area of about 40m^2 (Figure 1) in Daliburgh, South Uist.

Figure 1. Typical single storey two bedroom stone walled croft house at Daliburgh, South Uist (Photograph from Uist HtT Housing Project 2011-12 Final Report Part 2).

The house was divided into two symmetrical halves and fitted with contrasting energy efficiency systems for the combined purposes of absolute and comparative testing of thermal performance and installation cost. There is a well insulated wall between the two rooms. Both rooms have small single glazed windows which have been secondary glazed with proprietary secondary glazing. The house also has a small entrance hall to act as a buffer zone when entering the building. The internal walls of the hall are insulated.

A conventional approach was applied to one half of the building using a Kingspan insulation system. This approach may be considered to be current best practice, but without any particular emphasis on improving air-tightness.

Locate Architects were asked to devised an alternative refurbishment strategy by Sustainable Uist with potential to provide much more cost effective energy efficiency but with minimum intervention and high air-tightness. The Locate solution may be particularly appropriate in the Hebrides because of the high average wind speeds.

The strategy devised by Locate Architects consists of fairly conventional ceiling and floor insulation; however the following aspects are unusual:

- No wall insulation, instead dry lining has been removed and the wall plastered using lime plaster, with well sealed junctions
- Great care given to air-tightness across the whole fabric including use of imported specialist tapes to seal all junctions
- Care given to reduce thermal bypass through additional membranes and specific detailing
- Treatment of the outer face of the walls to prevent rain penetration keeping the walls dry
- Exposing and connecting the thermal mass of the wall with the indoor air.

The objective of the co-heating and air-tightness testing was to evaluate the impact of the two strategies.

This report summarises the results of the tests and compares the two approaches.

Further information about the Sustainable Uist Hard to Treat (HtT) Housing Project can be found on their website www.sustainableuist.org/hard-to-treat-houses/ with links to the final report which is in two parts:

1. www.sustainableuist.org/file_store/files/Uist_HtT_Housing_Report_Part_1.pdf which includes the executive summary, a general introduction, and the results of the Uist HtT housing survey.
2. www.sustainableuist.org/file_store/files/Uist_HtT_Housing_Report_Part_2.pdf which includes a description and the results from the pilot projects, project conclusions and recommendations and appendices.

Co-heating Test - Method

A co-heating test is a method of measuring the heat loss (W/K) through the fabric and from background air infiltration in an unoccupied dwelling. It involves measuring the energy used to heat the inside of the dwelling to an elevated mean temperature (typically 25^{o}C) over typically between 1 and 3 weeks.

The term co-heating originated in the USA, where initially the building's own heating system was supplemented by electric heaters. Normal practice today (Wingfield et al, 2010) is to use electrical heating alone, as the electrical energy use is relatively easy to measure.

The electrical energy (heat input), internal and external temperatures are measured. Additional measurements of solar radiation and wind speed are useful to determine a solar gain factor and the influence of wind speed on the heat loss due to ventilation (particularly if the building is leaky). In order to obtain a sufficient value of the temperature difference ΔT (generally 10 K or more), the co-heating test should be carried out the heating season. In the case of the Daliburgh house, measurements were carried out during late January and February 2012. A room temperature set point of 21°C was used to achieve more realistic indoor conditions.

The schematic plan of the building (Figure 2) shows the measurement and equipment set-up used.

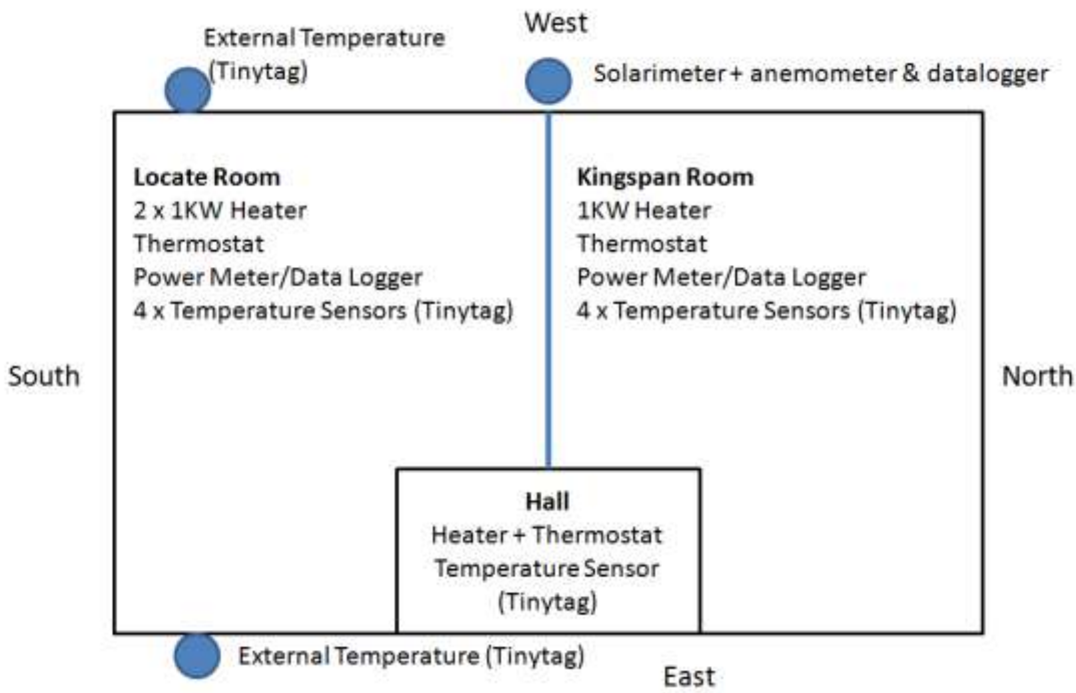

Figure 2. Daliburgh co-heating test set-up.

In the two main rooms:

- Electrical heaters (Figure 3) were thermostatically controlled using independent thermostats mounted on the walls.
- Electrical power was recorded as separate voltage and current readings using Electrocorder AL-2VA data loggers (Figure 3).
- Four Tinytag temperature and humidity sensors were used to measure the temperature in a vertical profile in the centre of the room.

In the hall an electrical heater was thermostatically controlled using an independent thermostat mounted on the wall with a Tinytag temperature and humidity sensor.

External temperatures were measured using shielded external Tinytag temperature sensors mounted on the East and West walls (Figure 4).

Figure 3. Electrical convector heaters and Electrocorder Voltage & Current data loggers in Locate room (Photograph from Uist HtT Housing Project 2011-12 Final Report Part 2).

Figure 4. External Tinytag air temperature sensor with shield (Photograph from Uist HtT Housing Project 2011-12 Final Report Part 2).

A horizontal solarimeter and an anemometer were mounted above the gutter on the West elevation (Figure 5). The instruments were connected to a Delta-T Devices DL2 data logger.

Figure 5. Horizontal solarimeter and anemometer (Photograph from Uist HtT Housing Project 2011-12 Final Report Part 2).

Initially a 2kW heater was used in the Locate room, however problems were experienced with power fluctuations, which resulted in the Electrocorder logger recording 'null' readings as the voltage or current exceeded the maximum values. The solution was to use two 1kW heaters with separate Electrocorder loggers.

Air-tightness test

A building pressurisation test was carried out for Sustainable Uist before the co-heating test in both rooms. The results at 50 Pa pressure difference are given in Table 1.

Table 1. Building pressurisation test results at 50 Pa for the Locate and Kingspan rooms. The results are given as the Volume Airflow rate and the number of Air Changes per hour (ACH_{50}).

	Locate Room	Kingspan Room
Volume Airflow m^3/h	421	1168
Air Changes per hour, ACH_{50} 1/h	7.6	24.0

The results show that the air-tightness measures undertaken in the Locate room were effective. ACH_{50} in the Locate room is about 1/3 of that in the Kingspan room.

After the co-heat test was completed the Kingspan room board joints were all sealed and a second pressurisation test carried out, which gave ACH_{50} of 6.6^{-h}.

Co-heating test results

Due to problems with electrical power logger in the Locate room only the last seven days (complete) of data were generally used for comparison, however all data from the Kingspan room were used for some of the analysis. Hourly average values are used in the analysis.

Figure 6 shows the temperatures in each room and the average external temperature from the two external sensors.

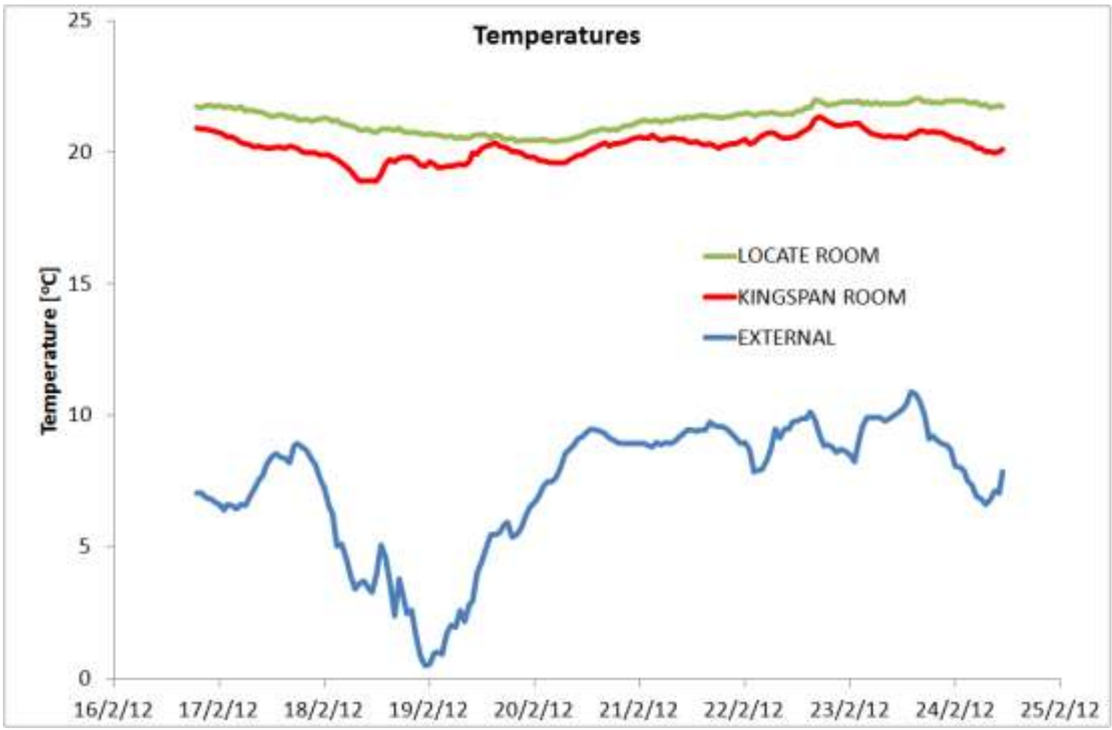

Figure 6. The room and external temperatures for the last seven days of complete data.

The room temperature in the Locate is about 1^{o}C higher than the Kingspan room. The average temperature differences between the rooms and the outside are 13.9^{o}C and 12.8^{o}C for the Locate and Kingspan rooms, respectively, indicating suitable temperature differences for analysis of the overall thermal losses from both rooms. It is assumed that the heat flows between the rooms are small and that the heat exchanges between each room and the hall are similar.

Figure 7 shows the electrical heating power in each room.

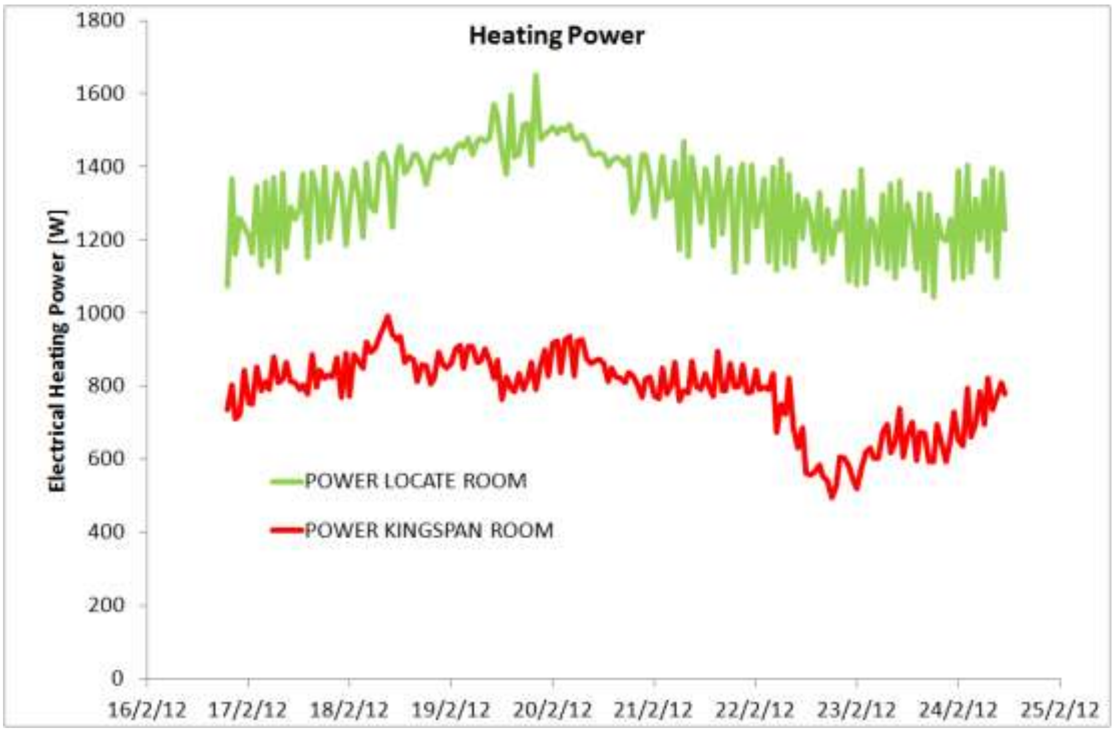

Figure 7. Electrical heating power

Clearly greater heat input is required in the Locate room to maintain the room temperature, however in order to give a better comparison between the two rooms the heating power is divided by the temperature difference:

$$\frac{Heating\_Power}{\Delta T} \text{ W/K} \qquad \text{Equation 1}$$

These values are shown in Figure 8.

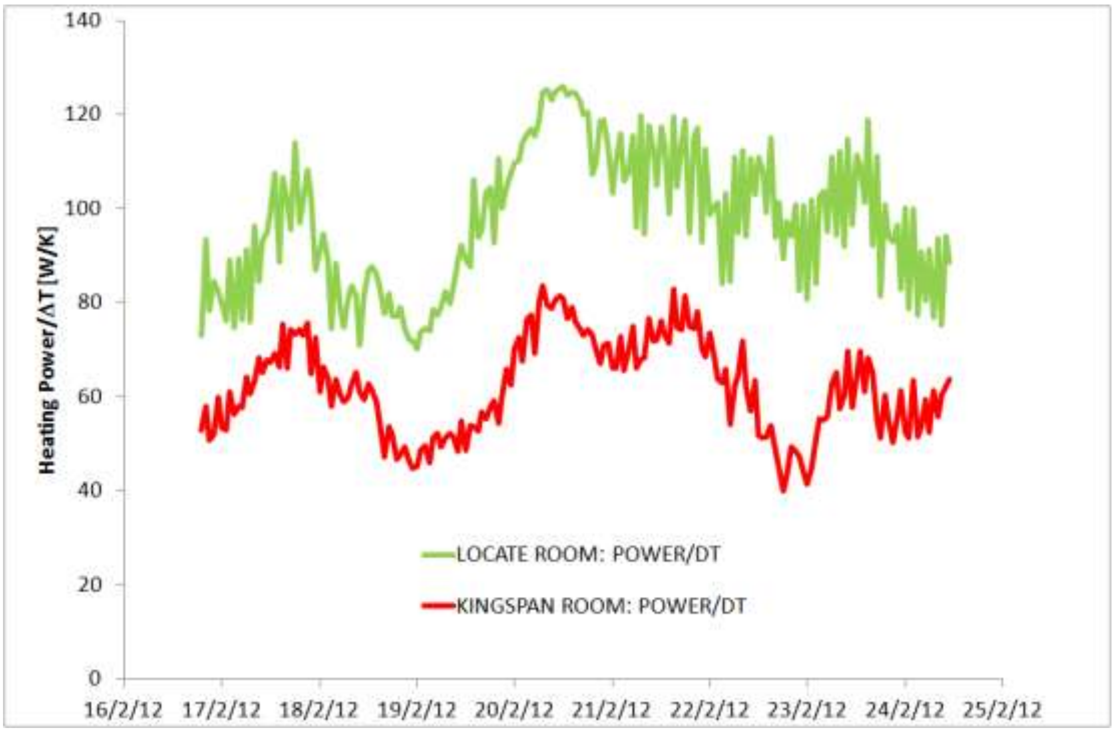

Figure 8. Heating Power/ΔT for the last seven complete days of testing.

Whole room heat transmittance values were calculated from measured average heating power and the average temperature difference between the room and exterior (ΔT) over the seven day period using Equation 1. These values also include the effect of infiltration. The whole room heat transmittance values are:

Kingspan	**62 W/K**
Locate	**98 W/K**

The ratio of these transmittance values Locate/Kingspan is 1.6, i.e. under the same conditions the Locate room uses 1.6x the heating power required in the Kingspan room.

The influence of external climate (wind speed and solar radiation)

If daily values of the transmittance values are plotted against wind speed the intercept can be considered as a 'zero wind speed' value (Figure 9). Whilst there is an observable trend for the transmittance value to increase with wind speed, the correlation coefficients are low. The 'zero wind speed' values are:

Kingspan	**52 W/K**
Locate	**92 W/K**

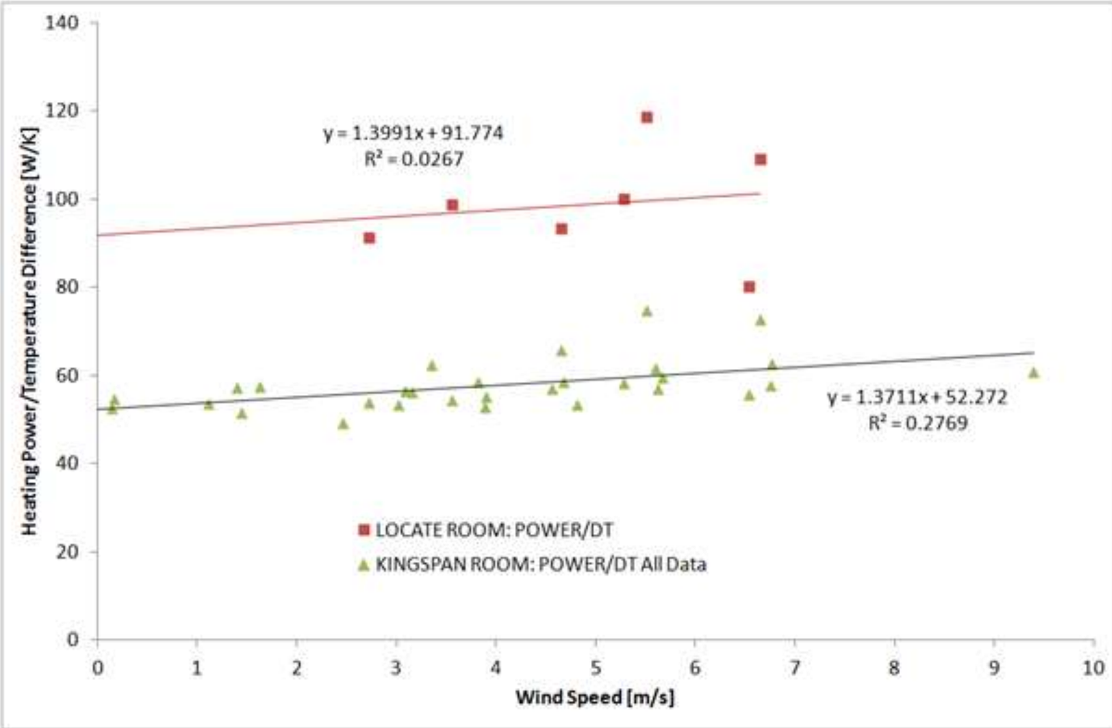

Figure 9. Daily values of the whole room thermal transmittance values plotted against wind speed. The intercepts on the Heating Power/Temperature Difference axis can be considered as 'zero' wind speed values.

If daily values of the ratio of transmittance values are plotted vs. the wind speed Figure 10 indicates that the ratio tend to decrease with increasing wind speed, implying that the wind may have a greater effect on the Kingspan room, however the correlation is low. More data would be required to be sure of this trend.

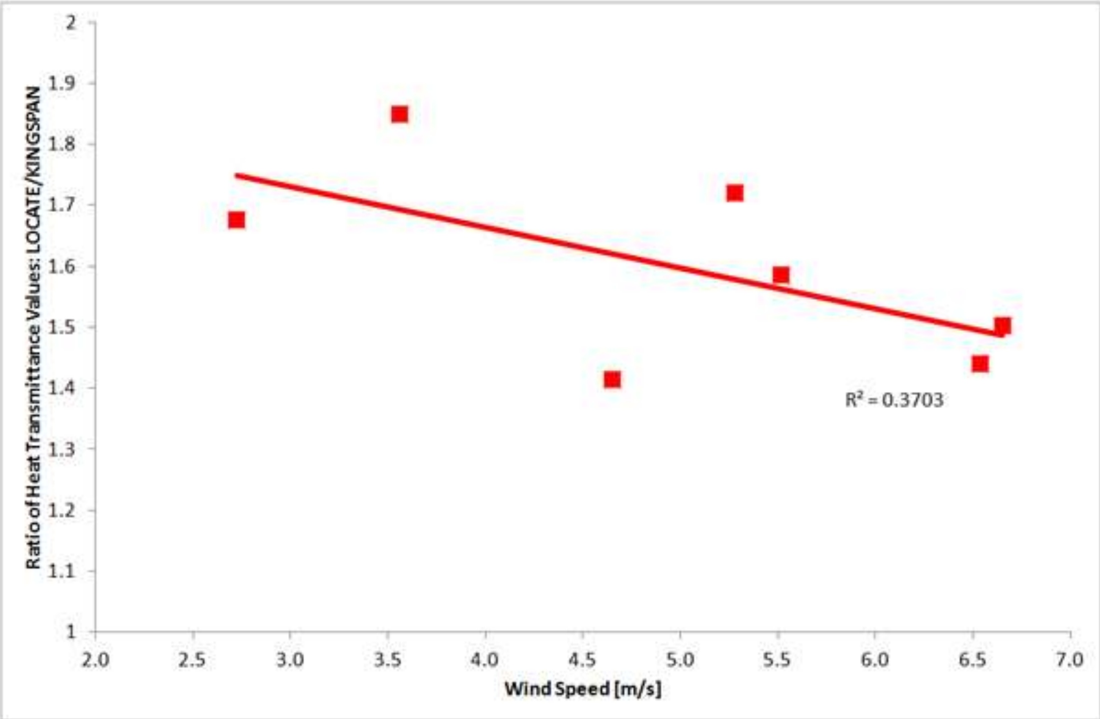

Figure 10. Daily values of the ratio of whole room thermal transmittance values plotted vs. the daily average wind speed.

A dynamic analysis software program LORD was also used (Gutschker 2004), which takes into account the thermal capacity of the room and includes the influence of wind speed and solar radiation. A network of 'nodes' is modelled, which is a simplified description of the room with external temperature and internal temperature connected by a series of thermal conductances and capacitances. The network considers that solar radiation is partly absorbed by the opaque parts of the envelope and is also transmitted through the windows and is absorbed within the room. The influence of wind speed can be modelled using a variable conductance with connections to inside and outside temperatures. The heat input is at the internal temperature node.

Initial guesses of the parameter values (e.g. thermal conductances, capacitances and admittances) are made. The *output* of the actual test (for instance, the heating power as a function of time) is compared with the *output* which the model produces for the same *input* conditions. By statistical analysis of the deviations between the calculated and the measured outputs, the parameter values are progressively adjusted in order to improve the agreement. With adjusted parameter values, the whole process of comparison of test and model output, followed by the statistical analysis, is repeated until optimum agreement is reached. The program produces thermal transmittance and solar gain factors.

For the analysis of the Kingspan room all available data were used. The results are shown in Figures 11 & 12 using hourly data to predict heating power. The model tends to smooth the hourly heating power estimate: however the total calculated & measured power values are within 1% indicating good overall agreement.

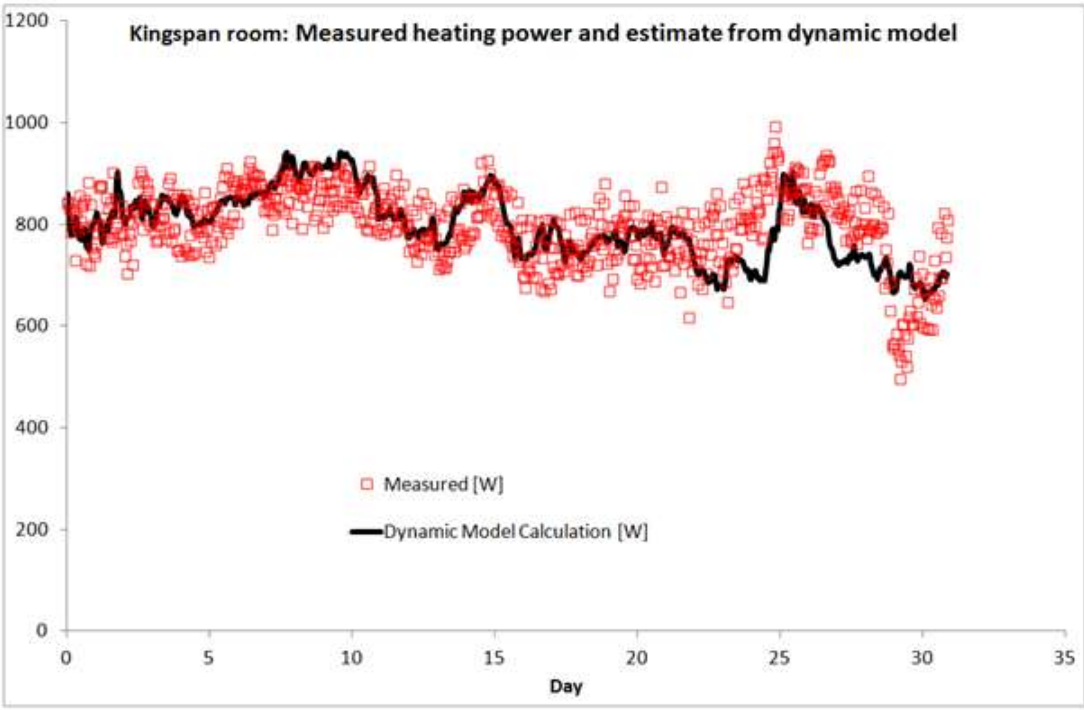

Figure 11. Results of LORD program for the Kingspan room.

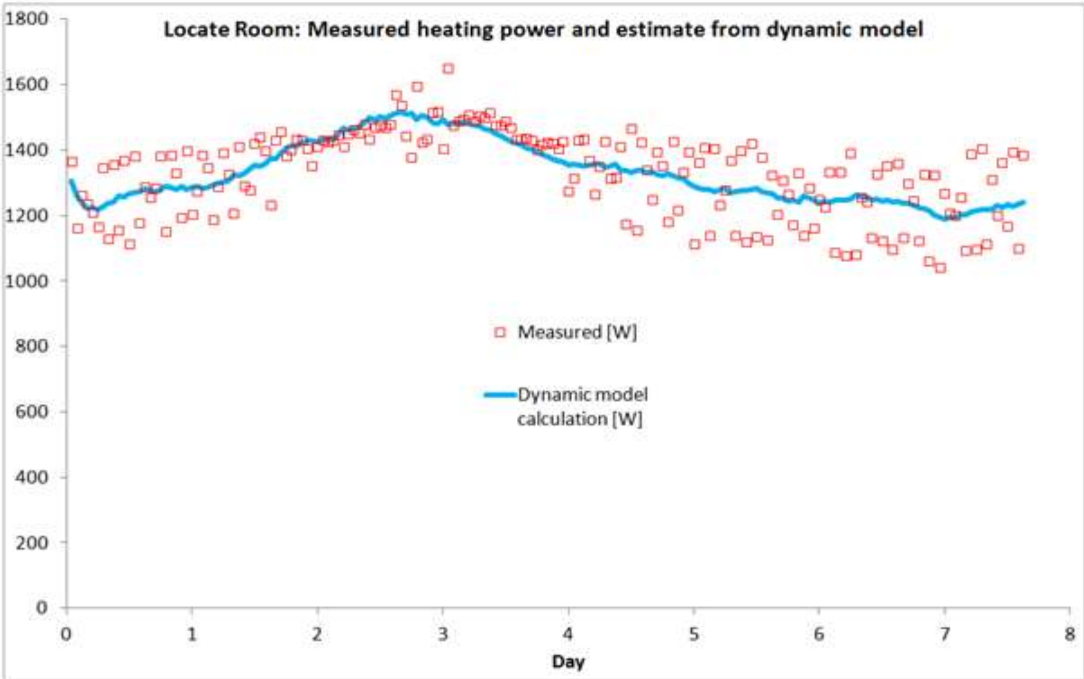

Figure 12. Results of LORD program for the Locate room.

The whole room thermal transmittance results estimated using LORD are as follows:

Kingspan **61 W/K**
Locate **87 W/K**

Discussion

Calculations of the whole house thermal transmittance values were made which are based on the measured in situ U-value, the room dimensions and pressurisation test results reported in the Sustainable Uist HtT Housing Report Part 2 (2012). An allowance is also made for thermal bridges as calculated using the SAP default, which is 0.15 x the area of the elements. In order to estimate the ventilation heat loss under 'normal' conditions, the ACH_{50} value is divided by a factor N=20. N is derived from correlations between building pressurisation tests and tracer gas tests used to measure infiltration rates, allowing an average infiltration/natural ventilation rate to be predicted from the ACH_{50} measurement. For domestic buildings, a value of 20 is commonly used (for example see: Meier, 1986) and is implemented in the SAP2009 calculations of infiltration. However, the Lawrence Berkeley Laboratories, for example, have derived factors for different US climate zones and levels of exposure (LBL 2001).

Table 2 summarises the results of the co-heating tests in the two rooms and the calculated values. The ratio of the Locate/Kingspan results is also included. The calculated values estimated from in situ U-values, room dimensions and ACH_{50}/20 are given in column 1.

Table 2. Summary of Co-heating test results and calculated values of whole room thermal transmittance values.

	Whole Room Thermal Transmittance Value, W/K			
	1. Calculated with ACH_{50}/20 value for infiltration	**2.** Determined from Measured Data	**3.** Using "Dynamic Analysis" Program on hourly data	**4.** Wind Speed=Zero from graph
Kingspan	57.1	62.2	60.9	52.3
Locate	109.0	98.3	86.6	91.8
Ratio Locate /Kingspan	1.9	1.6	1.4	1.8

The ratios of the Locate to Kingspan results are similar for the three treatments of the measured data with an average of 1.6, however, the 'zero wind speed' approach indicates that, when infiltration is effectively minimised, the requirement heating for the Kingspan room is reduced. The dynamic analysis approach accounts for both wind speed and solar gains, which will have some influence since the respective window areas of the Kingspan and Locate rooms are 2.5m^2 and 2.0m^2. Higher solar gains would perhaps be expected in the Kingspan room, which would account for the slightly lower ratio of 1.4, when these are considered by the dynamic analysis.

The calculated results including infiltration (1a) are similar to the measured values, with a slightly higher ratio of the Locate to Kingspan values of 1.9.

Table 3 gives the breakdown of the calculated values as a fabric heat loss (including thermal bridge allowance) and a ventilation heat loss derived from ACH_{50}/20. The effect of the improved air-tightness measures in the Kingspan room is also included.

Table 3. Calculated heat losses with proportions of heat losses due to fabric and ventilation.

	Calculated Total Heat Loss, W/K	Calculated fabric heat loss, W/K	Calculated ventilation heat loss, W/K
Kingspan without air-tightness measures	57.1	37.8	19.3
Kingspan with air-tightness measures	*43.1*	*37.8*	*5.3*
Locate	109.0	102.1	6.9

The effect of the infiltration is greatest for the Kingspan room before the air-tightness measures, with 34% of the heat loss due to ventilation. Using the ACH_{50} value of the Kingspan room after improved air-tightness measures to re-calculate the whole room thermal transmittance gives 43 W/K, which is a 25% improvement on the calculated value with poor air-tightness. The improvement measures reduce the proportion of heat loss to 12% of the total. For the Locate room, the proportion of heat loss due to ventilation is only 6%; however the calculated fabric heat loss is 2.7x greater than that of the Kingspan room. Comparing the calculated whole room thermal transmittance values for both rooms after air-tightness measures, the ratio of the Locate to Kingspan values is 2.5.

Generally, whilst the approach adopted in the Locate room reduces the ventilation heat loss, the fabric heat loss (particularly through the walls with a U-value of about 2.3 W/m^2K) is considerably higher than the Kingspan room. Air-tightness measures taken in the Kingspan room after the co-heating test reduce the infiltration significantly. The best approach is to insulate *and* improve air-tightness to maximise energy efficiency.

Conclusions

The co-heating and building pressurisation tests demonstrate that:

- Whilst the Locate approach to improving air-tightness is effective, the overall heat loss in the Locate room is 1.6x higher than that in the Kingspan room.
- Improving the air-tightness in the Kingspan room reduces the air infiltration to a value similar to the Locate room.
- Combining insulation and improved air-tightness is the best strategy for maximising energy efficiency (coupled with improved ventilation system).
- Best practice application of solid wall insulation system should include ensuring the air-tightness of the construction to avoid thermal bypasses and unwanted infiltration.

Acknowledgements

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