Ayrshirehousing

The Performance of Air Source Heat Pumps against alternative Energy Efficiency Measures – an Evaluation of an Affordable Housing Scheme at Maidens, Ayrshire

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Report

in respect of Monitoring Project at Harbour Road, Maidens

for

Ayrshire Housing

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PREAMBLE

1.0 Objectives

1.1 This report was commissioned by Ms Rose Estelles of Ayrshire Housing (the Clients) from the Scottish Energy Centre with the following objectives:

To undertake monitoring and report on the heating systems installed in 6 dwellings at Harbour and Turnberry Road, Maidens.

2.0 Restrictions

2.1 Copyright in this report and all associated notes etc. is retained by the Scottish Energy Centre.

2.2 This report and the associated items have been prepared for the exclusive use of the Client and are confidential between us. It has been prepared solely for the specific purpose to which it refers. It may be disclosed to other professional advisors assisting in respect of this purpose. It shall not be disclosed to any other party, be duplicated or be published in any way whatsoever, without our written consent. Any such party relies upon the report at their own risk.

2.3 The Scottish Energy Centre accepts no responsibility for any losses incurred as a result of any decisions made on the basis of the work reported herein.

3.0 Dwellings

Two blocks of 2-storey terraced dwellings (Plates 1&2) plus a single storey detached dwelling were constructed for Ayrshire Housing in Maidens.

Plate 1 North elevation 7a-c Harbour Road

The dwellings were designed as timber frame construction dwellings by ARP Lorimer & Associates and designed to achieve the following SAP and Environmental Impact ratings through the building envelope design/orientation and incorporation of low and zero carbon technologies (LZCT):

Dwelling	SAP Rating	Environmental Impact Rating ($kgCO_2/m^2$)
7a Harbour Rd	81	75
7b Harbour Rd	83	78
7c Harbour Rd	80	74
8 Turnberry Rd	75	79
10 Turnberry Rd	80	82
12 Turnberry Rd	74	79

Plate 2 South elevation of units 7b and 7c

The dwelling configuration of each terraced block was as shown in Plates 3 & 4 below.

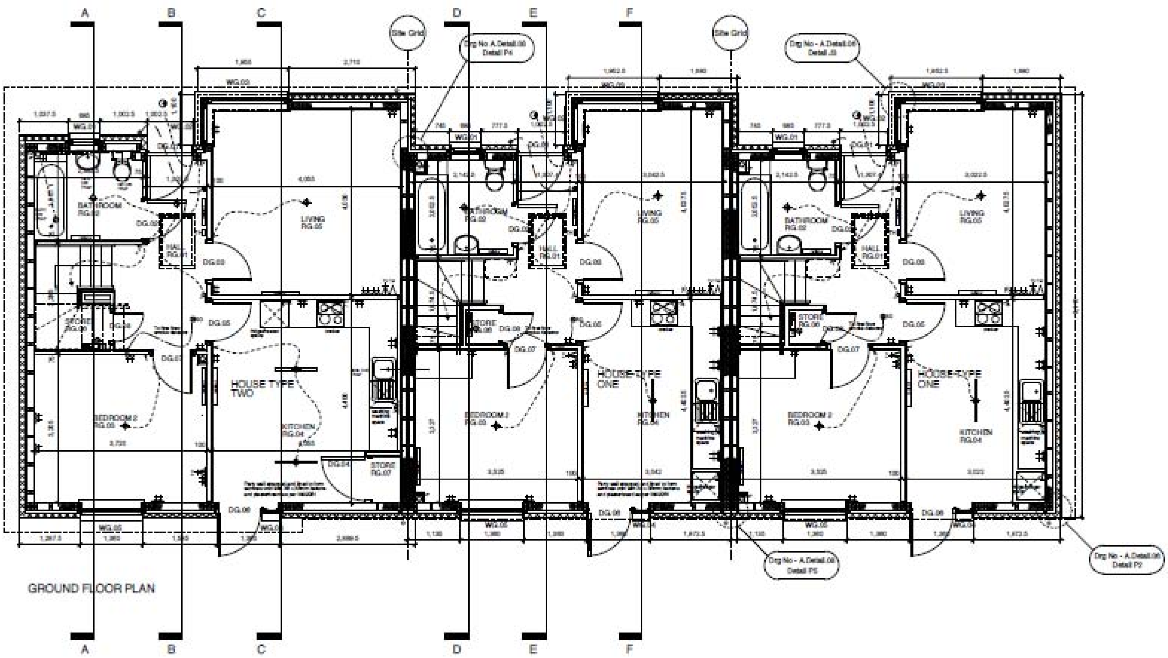

Plate 3 Ground floor plan

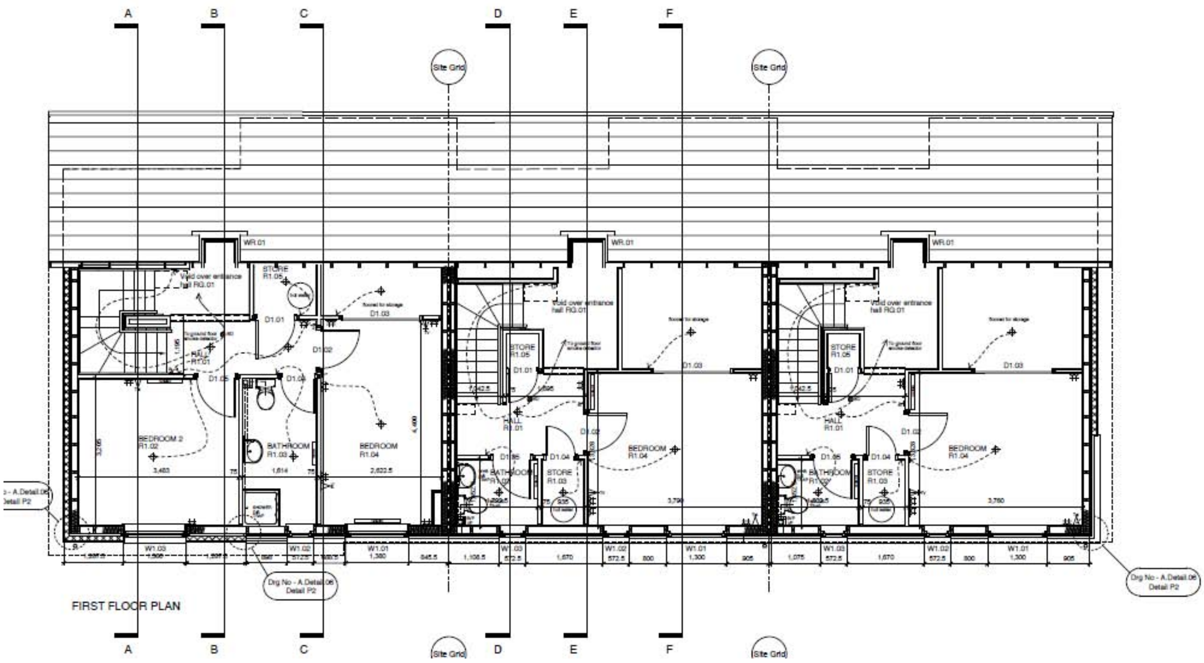

Plate 4 Upper floor plan

4.0 Monitoring

It was proposed that 6 No. dwellings would be monitored at the Maidens development as below:

Block 1: short terrace –1 x 3 bed and 2 x 2 bed storey and half buildings with Air Source Heat pumps (exhaust air recovery type – NIBE Fighter 360p) and underfloor heating on the ground floor and 1st floor.

Block 3: short terrace –1 x 3 bed and 2 x 2 bed storey and half buildings with Creda Supaslim combi storage/ panel and panel heaters throughout and a hot water cylinder (McDonald Engineer Powerflow unvented single coil solar insulated) and solar hot water collector on the roof. These units were also installed with Nuaire Drymaster 365 positive input ventilation units.

The statistically limited number of units in this study ruled out the operation of ‘control’ dwellings and hence placed an emphasis on ensuring good and comprehensive data analysis from the units evaluated

In respect of the heat pump installed dwellings additional sub-metering was fitted on the heat pump supply spur. The heat pumps had supplementary direct electric heating installed and this would enable some differentiation of the total heating and hot water energy requirements from the general domestic energy consumption.

An attempt was be made to evaluate the system benefits relative to occupant comfort by installing additional equipment to monitor temperature and relative humidity in the same occupied zone of all 6 monitored dwellings. A questionnaire survey was undertaken in support of this. Earlier studies revealed some quite interesting differences in system usage and occupant comfort requirements and this was supported by a post-occupancy evaluation which encompassed health benefits etc. and could be readily fed back to the occupants.

5.0 Data Collection

Data logging equipment was installed in the dwellings on 2nd September 2009 and initial meter readings taken. Subsequent visits were arranged at regular intervals with the tenants in order to download the data loggers and take meter readings and the equipment was finally removed on 7th September 2010; providing a full year of data.

Problems were experienced in a number of properties which resulted in incomplete data sets; this was mostly due to the tenants being unavailable during the arranged visit times resulting in some of the data loggers reaching capacity. Delays in billing by the utility provider resulted in debt accumulation by many of the tenants, which was addressed by the installation of pre-payment meters to replace the original equipment in 5 of the dwellings. The various timing of this created some doubt regarding the continuity of meter readings.

Questionnaire survey forms were presented to all 6 residences at both the beginning and end of the monitoring period. The responses received are given in Appendix 1 at the end of this report.

6.0 Data Analysis

6.1 Heat Pump Performance

The annual energy consumption for each dwelling is summarised in Table 1 below, together with the average temperature measured at the same point in each dwelling.

House	Off Peak (kWh)	Peak (kWh)	Total (kWh)	Avge Dwelling Temp (°C)
7a	6098	4249	10347	20.6
7b	11182	7416	18598	19.8
7c	6265	7672	13937	20.4
8	5004	9611	14615	19.9
10	2928	7517	10445	20.3
12	5170	9383	14553	20.6

Table 1 Meter readings and average temperature

It should be noted that the original meter configuration for all dwellings was based on a White Meter/ComfortPlus installation. Whilst this is suited to the electric storage heating systems installed in 7a-7c Harbour Road, it is not an ideal tariff structure for heat pump installations; where such systems are not specifically designed to operate with an off-peak demand control signal. This is reflected in Table 1 where the Off-peak consumption for the heat pump dwellings (8-12 Turnberry Rd) is much lower than the electric storage heated dwellings; indicating that a larger proportion of the heating consumption is on-demand during the daytime.

A supplementary meter was placed on the heat pump supply and used to establish their annual consumption. This can be used as a basis for comparing the heating and hot water demand for the equivalent electrically heated dwellings as shown in Table 2 below. It should be noted that these figures do not include supplementary peak heating demand (such as electric convection heaters) operated by the occupants for comfort control during periods outwith the off-peak demand periods.

House	Heating and DHW (kWh)
7a	6098
7b	11182
7c	6265
8	8078
10	8356
12	5443

Table 2 Annual dwelling heating and hot water consumption

The conventional electrically heated houses had been installed with solar water heating (SWH) systems and positive input ventilation (PIV) systems which are deemed to reduce the electric heating demand. It should also be noted that dwellings 7c Harbour Road and 12 Turnberry Road are larger 3 bedroom units; making a direct comparison with the other dwellings somewhat more difficult in energy terms. The fabric and ventilation heatlosses from each dwelling will also be different due to the number of exposed facades and volumetric profile.

An attempt was first undertaken to account for the additional benefits derived from the SWH and PIV units installed in 7a-7c Harbour Road. Given the orientation, roof pitch, and installed flat plate collector capacity it was estimated that the typical water heating potential for the solar thermal systems was 1650kWh per annum at this location. Previous work by the Building Research Establishment (BRE, 1999) and the author (Currie, 2006), established the benefits of the NuAire Drimaster PIV system as contributing a minimum of 550 kWh over a heating season.

Including these contributions into the energy required for heating and hot water in the test houses, the energy consumption comparison between conventional electric storage and air source heat pump changes to that shown in Table 3 below:

House	Heating and DHW (kWh)
7a	8298
7b	13382
7c	8465
8	8078
10	8356
12	5443

Table 3 Annual dwelling heating and hot water consumption (adjusted for SWH & PIV input)

A number of positions can be taken when trying to normalise the energy consumption for each dwelling in order to accommodate the differing volumetric footprints and heat losses, together with relative comfort temperatures operated by each dwelling occupant. Table 4 below summarises a range of normalisation parameters which can be applied to the dwellings in order to establish a basis for comparison.

Dwelling	Corrected Heating and DHW (kWh)	Floor Area (m^2)	Volume (m^3)	Avge Dwelling Temp (^oC)	Inside / Outside Temp Diff (^oK)	Fabric Heatloss Coefficient ($W/^oK$)	Fabric Heatloss (W)	Corrected Annual Heatloss (kWh)
7a Harbour Rd	8298	85	204	20.6	10.4	73.6	765.4	6705
7b Harbour Rd	13382	85	204	19.8	9.6	59.2	568.3	4978
7c Harbour Rd	8465	103	247	20.4	10.2	81.1	827.2	7246
8 Turnberry Rd	8078	85	204	19.9	9.7	73.6	713.9	6254
10 Turnberry Rd	8356	85	204	20.3	10.1	59.2	597.9	5238
12 Turnberry Rd	5443	103	247	20.6	10.4	81.1	843.4	7389

Table 4 Normalisation parameters

Typically, a floor area or dwelling volume could be utilised to establish a proportion for normalisation of energy consumption. However, given the small sample size and the divergence between average annual energy consumption (corrected) for the range of dwellings, it was proposed that a more rigorous benchmark would be required. The rate of fabric heatloss for each dwelling was thus calculated; as the rate of heatloss from mid-terraced dwellings was significantly less than those at either end, and that the 2-bed dwelling heatloss would be less than the 3-bed. A building heatloss coefficient was derived for each – based on a unit temperature differential across the building envelope. Utilising the annual inside/outside temperature differential obtained for each dwelling (i.e. the average inside temperature minus the average outside temperature measured over the year) an average fabric heatloss (in Watts) for each dwelling was thus obtained. Whilst this would not account for domestic hot water (DHW) consumption over the year (the change in electricity metering across the estate did not allow a summertime consumption profile to be obtained, which could be utilised to estimate the average DHW baseline) it could be utilised to differentiate between the different sized dwellings.

Utilising the normalisation parameters on the sample data gave the following results which are summarised in Table 5 below:

Dwelling	kWh/m^2	kWh/m^3	$kWh/^oK$	Normalised Energy (kWh/kWh)
7a Harbour Rd	98	41	798	1.24
7b Harbour Rd	158	66	1394	2.69
7c Harbour Rd	83	34	830	1.17
8 Turnberry Rd	95	40	833	1.29
10 Turnberry Rd	99	41	827	1.60
12 Turnberry Rd	53	22	523	0.74

Table 5 Normalised energy data for dwellings

Taking the comparable dwellings i.e. 7a Harbour Road is similar in construction, heatloss, and orientation to 8 Turnberry Road, 7b to 10 Turnberry Road and 7c to 12 Turnberry Road, then the following comparison can be made in Table 6 below:

	Corrected Heating and DHW (kWh)	kWh/m^3	Normalised Energy (kWh/kWh)
2 bed end-terrace - elec storage heating	8298	41	1.24
2 bed end terrace - ashp	8078	40	1.29
2 bed mid-terrace - elec storage heating	13382	66	2.69
2 bed mid-terrace - ashp	8356	41	1.6
3 bed end terrace - elec storage heating	8465	34	1.17
3 bed end-terrace - ashp	5443	22	0.74

Table 6 Dwelling type comparison

It can be seen from the information in table 6 that for all dwelling types the air source heat pump heated dwellings consumed less primary energy for heating and domestic hot water provision. This excludes any additional energy sourced by on-demand heating such as electric convection/fan heaters and point-of-use electric water heating such as electric shower units. When the data is normalised to account for comfort temperatures maintained within the dwelling as well as heatloss through exposed facades the same is generally reflected, with the exception of the 2 bed end-terraced dwelling at 8 Harbour Road. One significant anomaly to the data is the high off-peak corrected consumption for dwelling 7b Harbour Road at 13,383kWh.

6.2 Financial Analysis

Initial delays in billing by the utility provider resulted in debt accumulation by many of the tenants. Whilst meter readings were obtained at each site visit, all but one of the study group moved to the installation of pre-payment meters in order to reconcile the shortfall. The various timing of this caused some uncertainty regarding the continuity of meter readings and the ‘on-demand’ nature of the ASHP technology meant that a direct comparator could not be made on the basis of heating and hot water energy only.

The off-peak heating demand by the electric storage heated dwellings could be readily identified, although this did not include any supplementary top-up demand heating. Likewise the energy consumption for the ASHP systems was discretely monitored (excluding any supplementary demand heating) but, because this was operated across both the on and off-peak periods, the actual energy cost could not be apportioned.

Applying the published White Meter No.1 tariff prices from the utility provider of 21.85p/day service charge, 12.879p/kWh day rate, and 5.838p/kWh night rate (all including VAT) to Table 1 above gives an indication of comparative utility costs in each dwelling (Table 7 below) for the 372 day monitoring period:

House	Off Peak (kWh)	Peak (kWh)	Total (kWh)	Utility Cost (£)	Cost/day
7a	6098	4249	10347	984.51	£ 2.65
7b	11182	7416	18598	1,689.19	£ 4.54
7c	6265	7672	13937	1,435.11	£ 3.86
8	5004	9611	14615	1,611.22	£ 4.33
10	2928	7517	10445	1,220.33	£ 3.28
12	5170	9383	14553	1,591.54	£ 4.28

Table 7 Utility cost comparison

It is difficult to draw any significant conclusions from such cost comparison as the ASHP serviced dwellings consume heating energy during the peak demand periods at premium cost. With the ASHP serviced dwellings showing significant reductions in corrected primary heating energy (Table 6) than the electric storage heated dwellings one might expect to see a greater cost benefit to the tenants. The present tariff structures offered by the utility provider do not allow such LZCT technologies to benefit fully and, unless the ASHP operation can be re-profiled to operate for significant periods at lower unit rates, this will not be translated into lower cost.

6.3 Occupant Feedback

A questionnaire survey of all the occupants was conducted in order to obtain some user feedback regarding the operation of the systems installed, together with some indication of improvements in general comfort and wellbeing since moving in to the property - most of the occupants had moved from older, less well insulated and energy efficient, dwellings.

The questionnaire comprised a mix of quantitative and qualitative responses as is shown in Fig. 1 below. From a total of 12 structured interview questionnaires, 12 completed responses (100%) were obtained and are presented in Appendix 1 at the end of this report. The responses are summarised below:

Whilst the majority of households (67%) indicated that they understood how their heating system operated, an equivalent percentage indicated that they did not understand how the house ventilation system operated. This was a similar proportion in both the before and after survey despite the Housing Association having produced operating instructions and individually educated each user.

When asked how often the occupants used the heating controls, the pre study questionnaire showed that the majority (67%) used the heating controls (room thermostats) often. The post-study questionnaire revealed that the use of controls had diminished (33%) but that a greater mix of control interaction was being achieved (room stat/time clock/boost), perhaps due to the occupants being less afraid to obtain comfort control.

Semantic 5-point differential scaled questions were used to enquire about heating effectiveness and controllability. In the pre-study evaluation the occupants found the heating effective (3.5) and relatively easy to control (3.3). Whereas the post-study response showed that the overall heating effectiveness had reduced to a neutral value (3.0) and that the heating was more difficult to control (2.3) than they had originally surmised, albeit that most (4.0) reckoned heating was available when required. Comments received indicated that for two of the electric storage heated premises the hall heating could not be adequately controlled to achieve local comfort requirements; however the average temperature data does not reflect this.

A post study visit was conducted with a representative from EcoLiving, the air source heat pump installers who identified a control disparity between the heat pump and the separately controlled (Myson) underfloor heating system. This resulted in the two systems operating autonomously from each other with some residents attempting to control the heating provision through one or other system incorrectly. A wrong setting on the hall zone thermostat (i.e. too low) could inhibit the heat pump operation; as the heat pump internal control sensor would not reflect the dwelling heating requirements.

Maidens Survey Questionnaire

Present Electricity Meter Reading (meters located in under-stair cupboard)

Meter 1 Meter 2

Please circle as appropriate

1. Do you now understand how the house heating system operates? Yes / No

2. Do you now understand how the house ventilation system operates? Yes / No

3. How ofter have you used the system controls?

Heating	Ventilation
Often	Often
Sometimes	Sometimes
Never	Never

4. Which controls do you use? Room Thermostat / Time Control / Boost / Heat Pump

6. How effective do you feel the heating is? (circle 1-5 as appropriate)

Ineffective	1 2 3 4 5	Effective
Difficult to Control	1 2 3 4 5	Easy to Control
No heat when required	1 2 3 4 5	Heat when required

7. In comparison with previous houses; does this one feel (circle 1-5 as appropriate)

Colder	1 2 3 4 5	Warmer
Stuffy	1 2 3 4 5	Fresher
Uncomfortable	1 2 3 4 5	Comfortable

8. What is the availability of hot water? (circle 1-5 as appropriate)

Never when needed	1 2 3 4 5	Always available
Hotter in morning	1 2 3 4 5	Hotter in evening

9. Do you use the hot water/heating boost control?

Heating	Hot Water
Often	Often
Sometimes	Sometimes
Never	Never

10. Do you ever notice any condensation on bedroom windows? (e.g. in the mornings) Yes / No

11. In comparison with previous houses, is the house expensive to heat? Yes / No

12. Approximately how much are you spending on electricity? ____ £/week ____ £/month

What improvements can you suggest for the development?

Fig. 1 Questionnaire to occupants

A series of questions was presented in order to evaluate the comfort performance of the heated dwellings. In the pre-study evaluation the majority of occupants found the dwellings to be warmer (3.6), fresher (3.8), and more comfortable (4.0) than previous homes they had lived in. The post-survey evaluation showed that this perception had diminished to the houses being colder (2.2), and neutrally fresh (3.0) and comfortable (3.0). It was noted in the houses fitted with the NuAire Drimaster ventilation system that the controls were set to 'cold' and thus drawing ventilation air into the dwelling from the coldest source (usually outside air) rather than benefiting from the solar pre-heating potential. This could lead to a perception in these dwellings that the hall area where this air was discharged being cooler. In the air source heat pump dwellings the aforementioned control problems may have contributed to the general feelings of coldness.

The Drimaster ventilation system incorporates G4 grade air filters which can arrest particle sizes down to about 5 microns; this includes for instance asbestos fibres, cement dust, plant spores and pollens and some bacteria. As the electric storage heated dwellings had the added benefit of being supplied with filtered air the study enquired whether there were any perceived health benefits noticed by occupants; particularly those who might suffer from respiratory problems e.g. asthma. One of the residents indicated they had two asthma sufferers in the family noting an improvement in their condition since moving into the house.

Questions specifically relating to the domestic hot water provision fell into two response groupings. The air source heat pump dwellings had domestic hot water always available on demand, which reflects the onboard heat recovery system from the compressor charging the storage calorifier. The electric storage heated dwellings perception changed from a neutral provision (3.0) at the start of the study to a position of not always when needed (2.6) at the end of the study. This was in-part due to a faulty boost control in one dwelling, with another occupant not knowing that they had a boost control facility and operating for the first 3 months on solar water heating only! One occupant was not sure whether the overnight charging system for the hot water cylinder was operating.

Condensation forming on windows overnight can often be associated with inadequate levels of heating and/or ventilation in the dwelling (assuming average rates of moisture evolution). Most of the respondents to this question indicated that no condensation was present. Of the one occupant who did notice condensation, this was noted to appear on the hall velux window only.

The last two questions were included in order to gauge the occupant's perception of energy usage and the relative cost of that energy. Opinion was evenly divided on the relative expense of heating the dwelling and the figures provided for average monthly/quarterly electricity billing did not appear to correlate with the metered consumption. Many of the occupants had waited some considerable time before initial billing transactions were sent out by the utility company. Consequently the back-payments which had accumulated were higher than many of the residents had capacity to pay and the utility company installed pre-payment meters in order to recoup accumulated debt. All but one resident now have pre-payment meters installed which are operated at a higher unit rate.

All of the respondents took the opportunity to make additional comments on the questionnaire; in summary these indicated a lack of understanding/instruction in the operation of the heating system and that the controls were too complicated. In one case a resident complained of background noise transmission from the air source heat pump system

7.0 Conclusion

The heating systems installed at Maidens were aimed at establishing a comparative assessment of a notionally 'renewable' technology which claims to offer operating efficiencies matching on-grid hydrocarbon-fuelled cost benefits. The results are somewhat disappointing given that the exhaust air source heat pump technology demonstrated apparently significant reductions (>35%) for two of the comparable dwelling types. This is primarily due to the on-demand nature of the heat pump system resulting in premium rate electricity tariff operation.

At the present-time there is no suitable tariff pricing mechanism available from the utility providers to enable the heat pump system energy reduction to be exploited. Thus the off-peak storage heating systems installed with appropriate control metering can deliver heat in a similar cost environment.

Installation and control of the exhaust air source heat pumps must be undertaken by coordinated servicing specialists in order to allow the systems to attain maximum operating benefit. The installation at Maidens has an underfloor heating system operated by conventional programming controls. This was not linked in its operation to a heat pump which operates autonomously and, sometimes, at conflict. It is highly recommended that the control system for this is rationalised to obtain better operating efficiency.

Many of the occupants indicated a lack of understanding of how the heating and ventilation systems operated, despite the best efforts of Housing Association staff. The complexity of modern controls can not be overstated particularly when used in such demographic application. Attention should be paid when specifying such technology applications of the need to reduce complexity without compromising the systems ability to achieve efficient operation. In this study the occupant interaction with the technologies has probably resulted in as poorer result for this very reason; with the attendant problems this causes for maintenance and longer term operability. For future studies it is suggested that such statistically limited evaluation be undertaken over a longer monitoring timeframe; as year one provides useful information to inform the client and enable any adjustments to be made, while year 2 monitoring can provide important information to determine whether these adjustments have had the desired results.

8.0 References

Currie, J.I., (2006) Sunspace Augmented Positive Input Ventilation of Buildings, EuroSun 2006, Glasgow, ISBN 0 904963 73 1

BRE, (1999) Technical Report CR 106/99 and 379/99

Appendix 1

Pre-Monitoring Questionnaire