# Performance of exhaust air source heat pumps: Summary of detailed monitoring results

Department of Energy & Climate Change

## *Introduction*

This summary is to be read alongside the report *Temperature Monitoring in Social Housing units with Exhaust Air Heat Pumps.*

A Registered Social Landlord (RSL) and Kiwa GASTEC at CRE (Kiwa) have completed monitoring of the energy demand of under-floor heating and radiators in two social housing flats.

Each flat contains an exhaust air heat pump which provides domestic hot water (DHW) and space heating by way of an under-floor heating system. The development is a Code for Sustainable Homes Level 3 development and was completed in January 2010. Energy monitoring equipment was installed by Kiwa and the RSL in January 2010.

This project aims to determine the effect of radiators compared to underfloor heating on the performance of the EAHP.

One 3 bed property and one 1 bed property were subject to detailed monitoring over a period of 24 months. In addition a further 10 properties were subject to fiscal monitoring for the last 12 months of this period. The first 12 months of monitoring at 2 properties showed that residents used thermostats to call for heating in response to the specific conditions of that day as one would a traditional heating system. This contradicts the control strategy recommended by the manufacturer and the instructions issued to residents, however, it is understandable for social housing residents, to whom a 24 hour heating strategy appears an unaffordable luxury. This method of controlling the temperature is very un-responsive as the underfloor distribution requires the heating of the screed floor before the effects of turning up the thermostat can be felt. The householders found themselves trying to predict when they would require heat hours in advance of the event.

The exhaust air heat pump heats water to be used in the wet heating circuit (either underfloor or radiators) and for domestic hot water. The primary mechanism is the heat pump compressor and the secondary mechanism is an immersion. As either mechanism can be used for either heating or domestic hot water provision, references to immersion use in this document relate to both heating and hot water.

The resident at the 1 bedroomed property agreed to follow the recommended control strategy for the second 12 months, with periodic success in achieving high levels of efficiency, however, performance was compromised by a preference for high internal temperatures.

The resident at the 3 bedroomed property held the belief that they were not receiving heat from the underfloor heating. The project team suspected that, although internal temperatures were being maintained to an acceptable level, the lack of a visible radiating source of heat added to the resident's dissatisfaction. This belief was supported by anecdotal evidence from other sites with identical units installed which did not seem to generate the same levels of complaints.  As a result, it was suggested that radiators may be more suitable to the needs of social housing tenants.

To test this theory, radiators were installed in the 3 bedroomed property. The radiators were sized to operate with a low-temperature flow.  This had the unintended result of changing how the resident operated the system – choosing to turn off all radiators using the thermostatic radiator valves except for the hallway radiator which operates on an open circuit. The resident initially complained that the hallway radiator was on even when they did not want heat – however, this can be avoided by switching the unit to summer mode.

The resident at the 3 bedroomed property could not be convinced to adapt to the recommended strategy and this made it impossible to draw definite conclusions about the performance of the exhaust air heat pump.

### *3 bed property: detailed analysis of heat pump operation*

The resident at the 3 bed property was advised by the RSL staff members that she should be switching her exhaust air-source heat pump unit to the summer mode after it was discovered that the unit was still on winter mode despite clement weather conditions in the first 12 months.  The resident also reported that she had been switching the unit off and on according to need.  This is contrary to the advice given, but is considered relatively harmless whilst the unit is in summer mode.  The resident was advised that this control strategy would cause high consumption when the immersion was enabled in winter mode.

On 21/03/12, temperature sensors were attached to the floor surfaces (to measure the temperature of the underfloor). In the 3 bed property, the underfloor system was replaced with radiators to investigate the responsiveness of a smaller volume system. The surface temperature of the radiators was measured from 26/06/12.

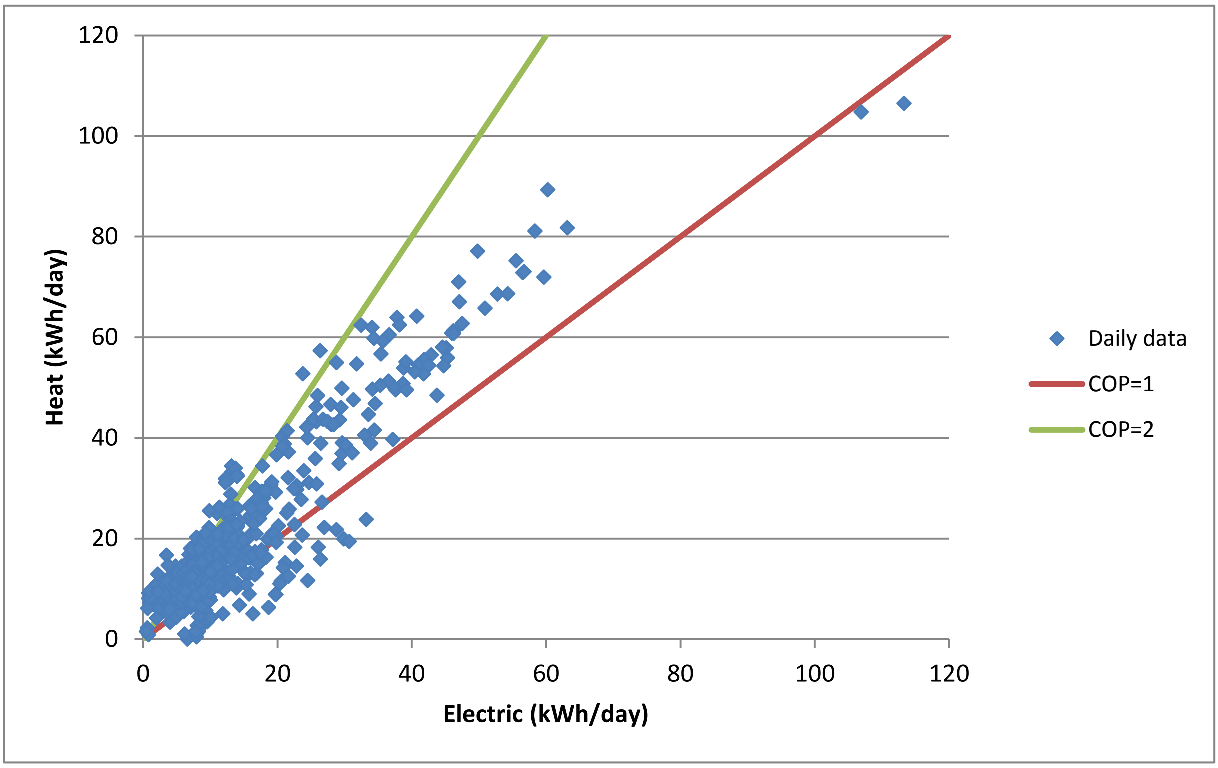



**Figure 1: Daily electric vs. heat usage for 3 bedroom property for both years**

The majority of points are between the COP of 1 and 2 line. This means that the heat pump was generally performing better than direct electric heaters, but was not performing as per the manufacturer's claims. According to manufacturer's data, the COP should be between 2.5 and 3 (depending on air flow rate) when heating water to 50°C, so the experimental COPs of between 1 and 2 were surprisingly low, suggesting there might have been a further fault with the heat pump.

The data points with exceptionally high electricity demand and heat output were identified as occurring during a period when the heat pump was broken (due to a power cut to the building). These outliers were noticed within the data and the information passed onto the RSL. The data was used to further help identify the source of the problem before the householder received a large bill. This example illustrates the value of monitoring heat pumps, or any new technology, remotely.

In summer 2011 the heat pump was configured to carry out a Legionella cycle fortnightly; however, regular Legionella cycles were not detected in data for summer 2012.

The following chart shows the monthly SPF of the heat pump (the total heat output to space heating and to taps) divided by the total electric input), and the COP (total heat output to space heating and taps – immersion) divided by (the total electric input – immersion)). The immersion heats the DHW and can also provide back up auxiliary heat to the space heating.

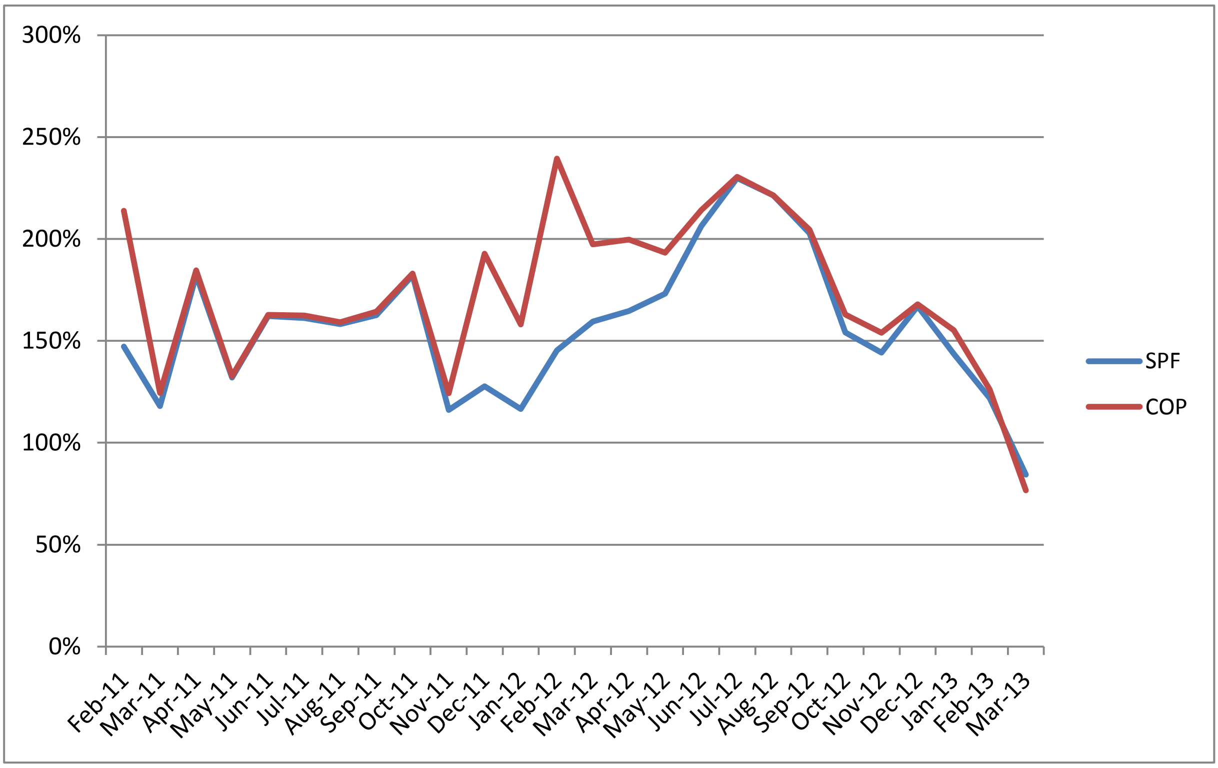



**Figure 2: SPF and COP at the 3bed property over both years**

Figure 2 shows that the SPF ranged between 1 and 2, even in the summer when it was mostly operating with the compressor providing all of the heat. The immersion commenced operation when the electric input was approximately 560W. Since the compressor was rated at 650W, it appears that the immersion was programmed to come on too early.

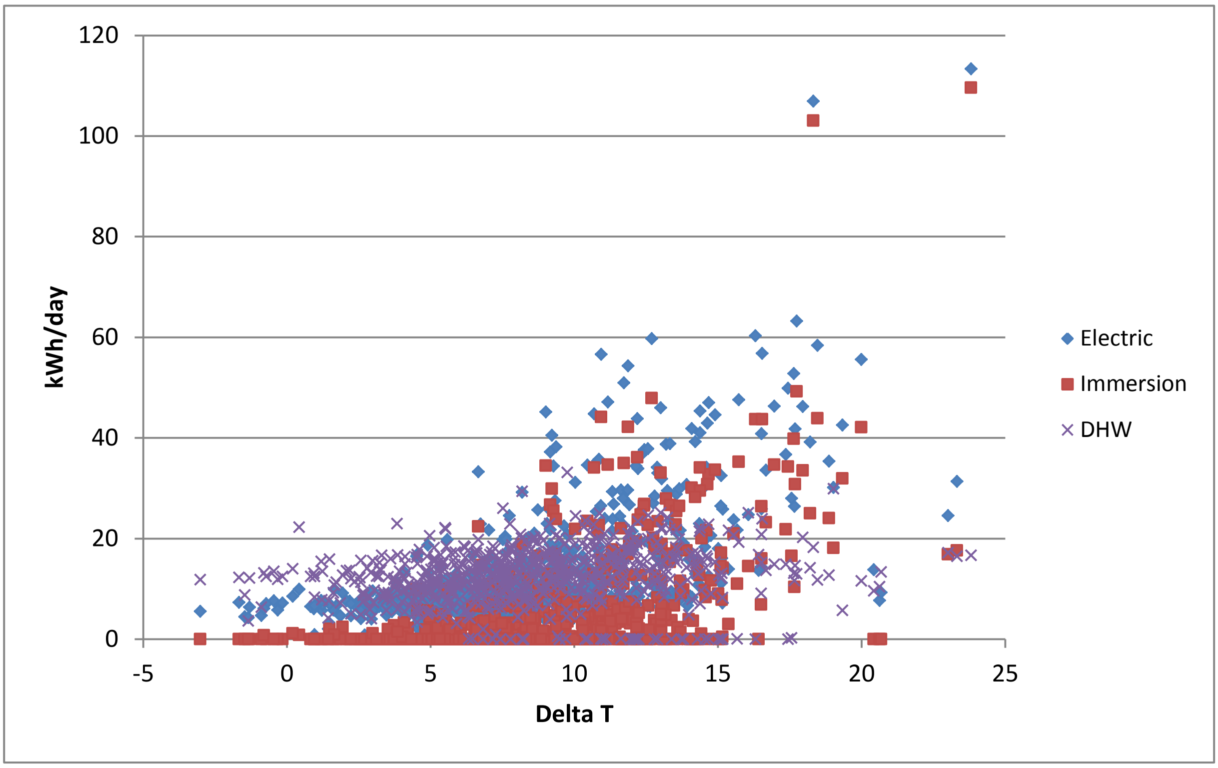



**Figure 3: Electric, DHW and immersion use against delta T for both years**

DHW use at this property was high, ranging from 10 to 25 kWh/day, with the average being 12kWh/day. This contributed to the poor SPF because the COP of a heat pump is lower when heating to 50°C (as required for DHW) rather than 30°C, the average flow temperature for the underfloor heating was around 45°C, and it stayed the same when the radiators were fitted. The heat output of the EAHP was stated to be 1200W (when operating with the compressor only) at a temperature of 50°C and an ventilation air flow rate of approximately $164m^3$/hr. This means that the maximum heat pump output (excluding the immersion) would be 28.8kWh/day, which, after taking tank and case losses into consideration, means that the total heat pump (only) output could be required to maintain the DHW supply. Therefore it was likely that the immersion would be required to provide any further heating i.e. the central heating. With the considerable DHW use observed, the immersion was required at much lower delta Ts to provide space heating.

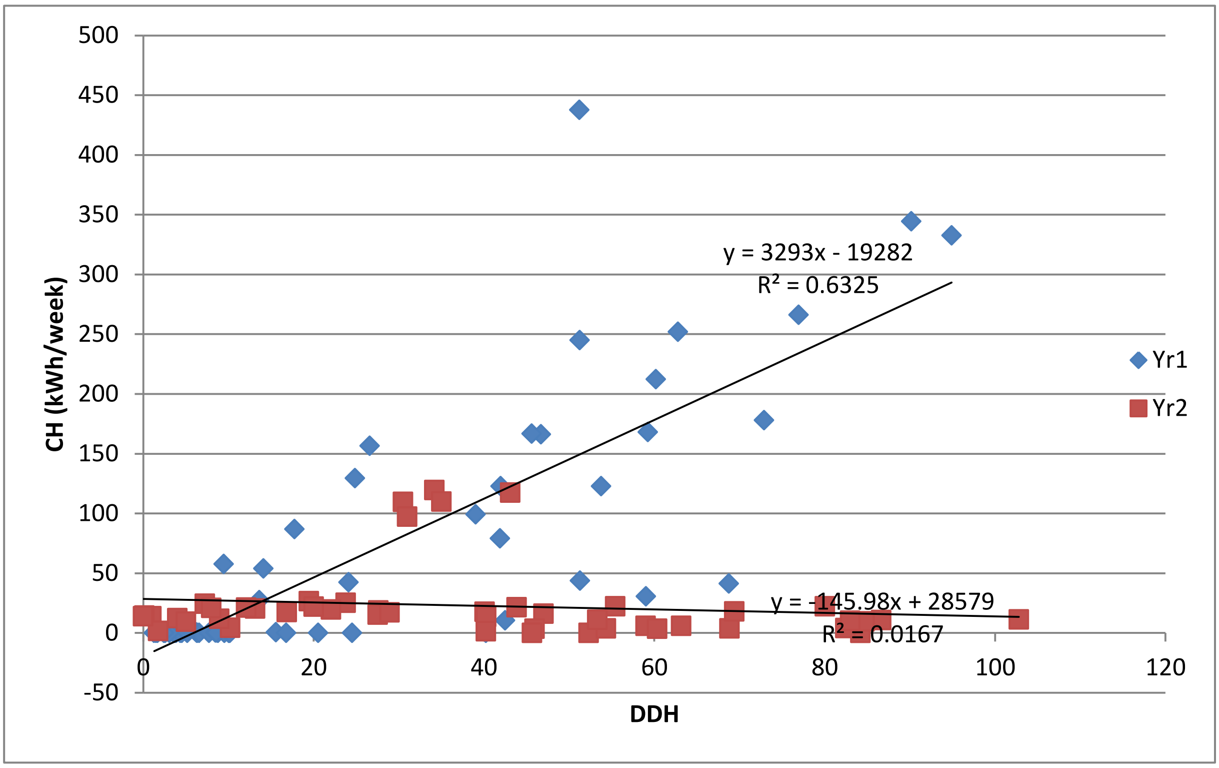



**Figure 4: $R^2$ graph showing relationship between degree day heating and CH for year 1 and year 2**

The $R^2$ was 0.6325 in the first year, which indicates that 63% of the heat was led by the degree day heating requirement. In the second year the heat pump was not used as intended and was basically only used to supply hot water and occasionally to heat the hall radiator, apart from at the tail end of the first winter period (Yr 2 is from March 2012-March 2013, the radiators were changed in April 2012). During most of the second year, all the radiators were turned off apart from the hall radiator. The householder then complained that the property was too cold, but there is no evidence in 2012 that the other radiators were utilised for long periods.

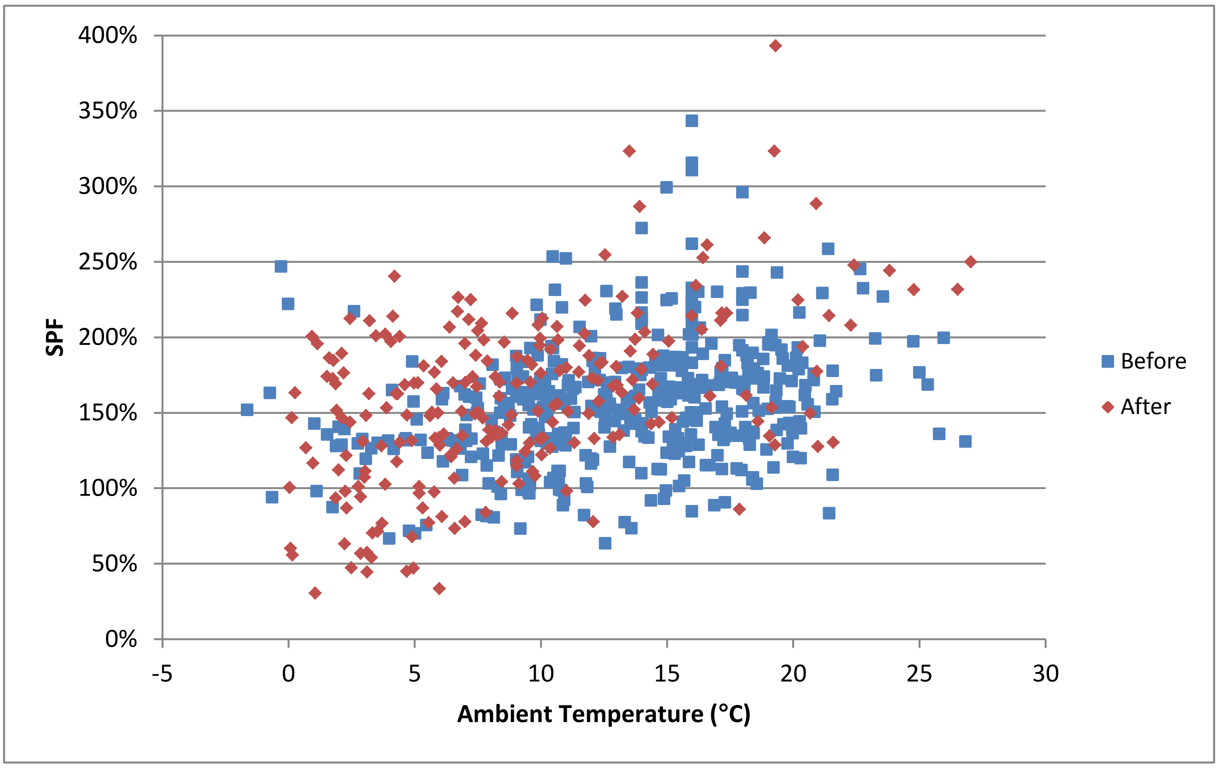



**Figure 5: SPF against ambient temperature for 3bed before and after the manufacturer's servicing visit**

It can be seen that the changes made by the EAHP manufacturer on the 24/07/12 had little effect on the SPF of the heat pump. This was mainly because the householder was not using the heat pump in the manner intended. DHW use was high and the radiators were not utilised fully, leading to lower overall COP.

Examining energy histograms during February 2013, it can be seen that the heat pump was not used as intended, with only 558kWh of energy used in the month. The immersion was turned off and the internal temperatures were low. The electric usage of the circulation pump is likely to be the peak in the under 250W category.

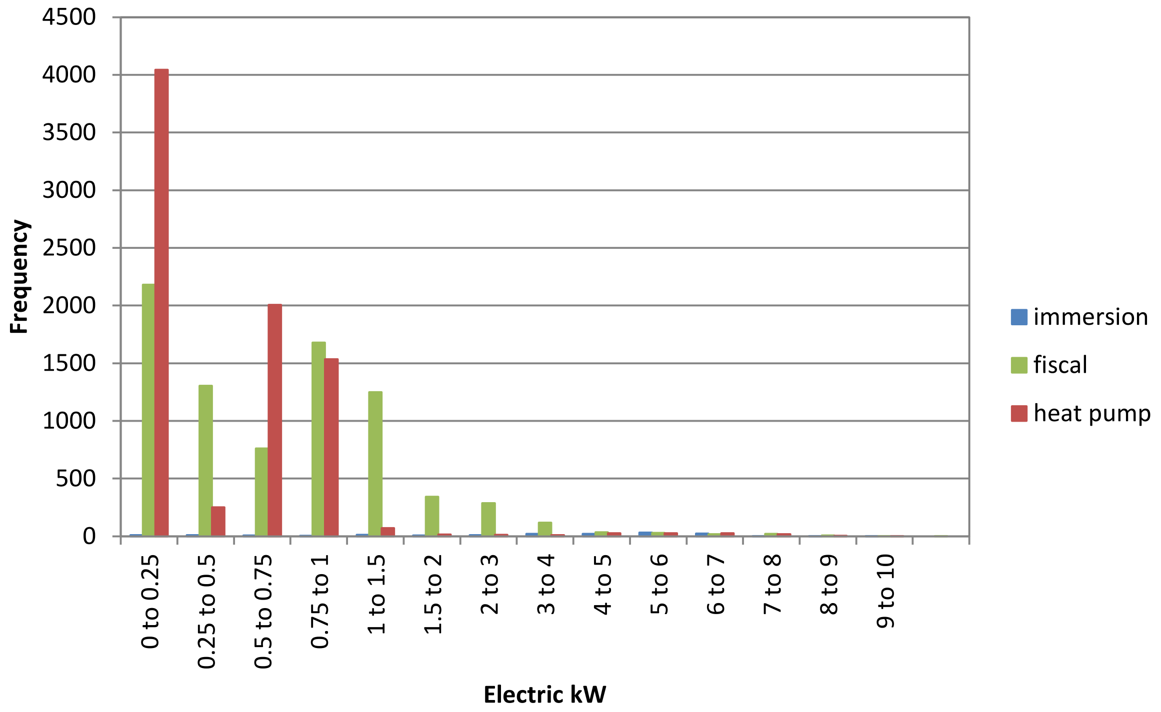



**Figure 6: February 2013, 3 bedroomed flat - heat pump not being used as intended**

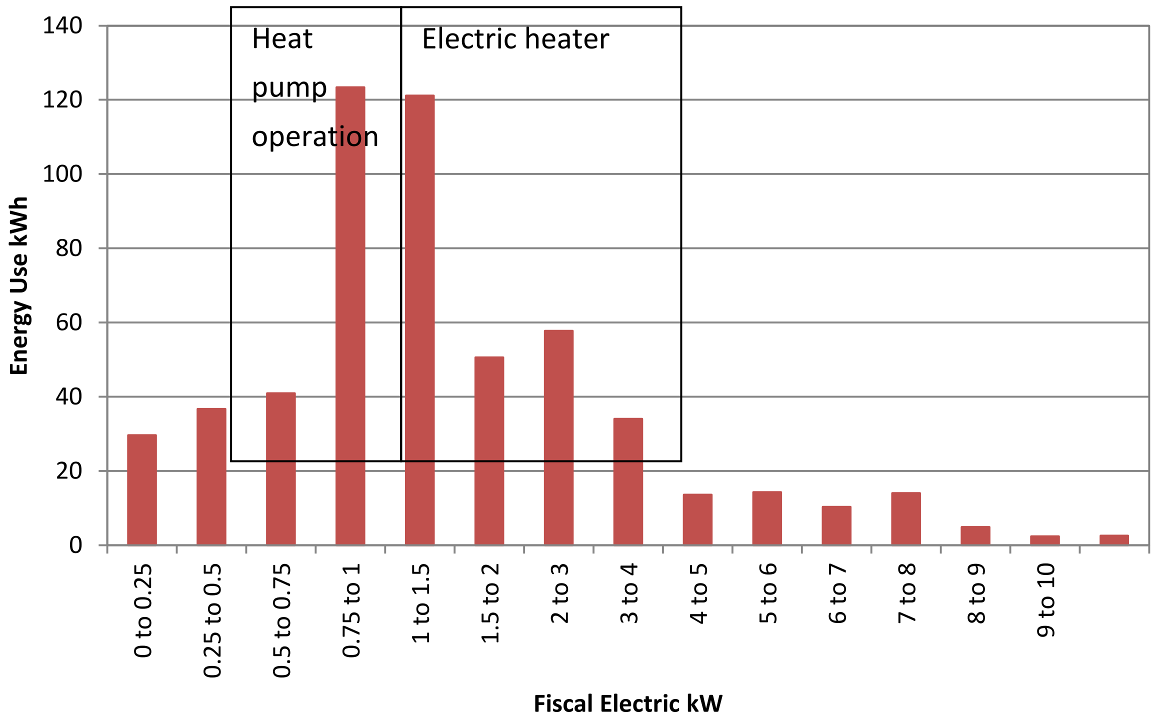



**Figure 7: 3 bed, histogram of the fiscal electric use showing the heat pump being used without immersion**

The usage above 1.5kW is likely to be a supplementary electric heater (or more than one heater) rated between 2 and 3kW. The immersion internal to the heat pump was not used (see Figure 10).

The analysis was undertaken for another month (February 2012) where the immersion use was 729kWh compared to a fiscal use of 1338kWh.

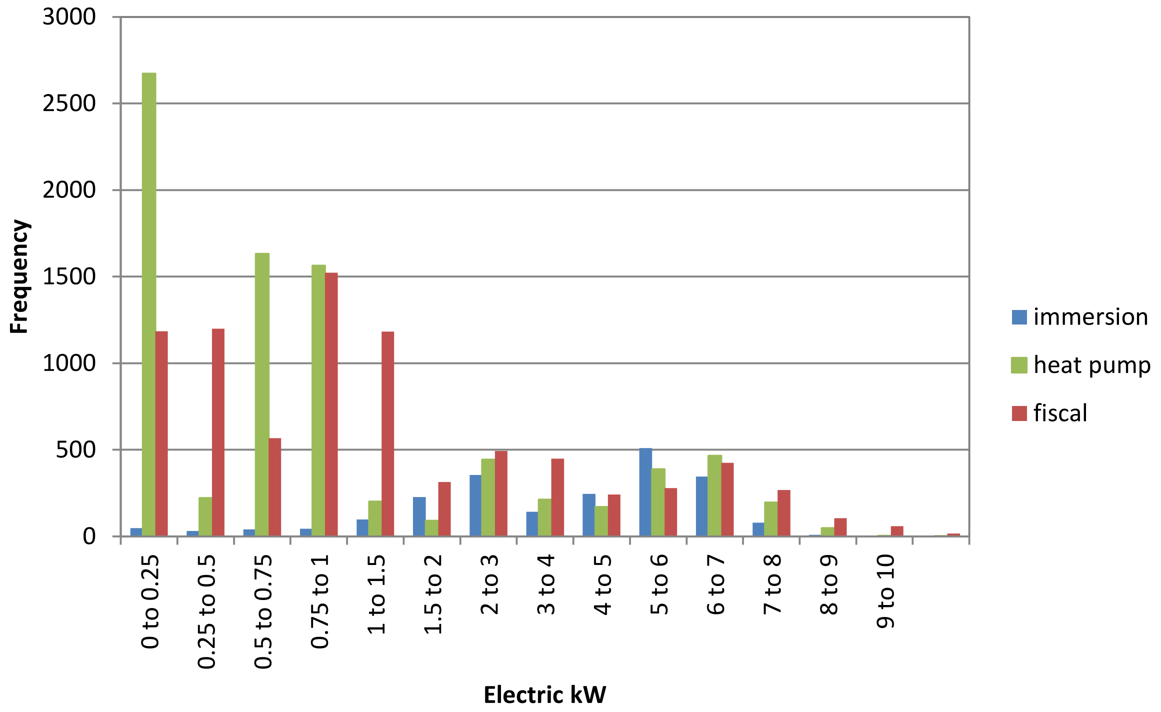



**Figure 8: February 2012, 3 bed property heat pump, showing the frequency of immersion, heat pump and fiscal electric use.**

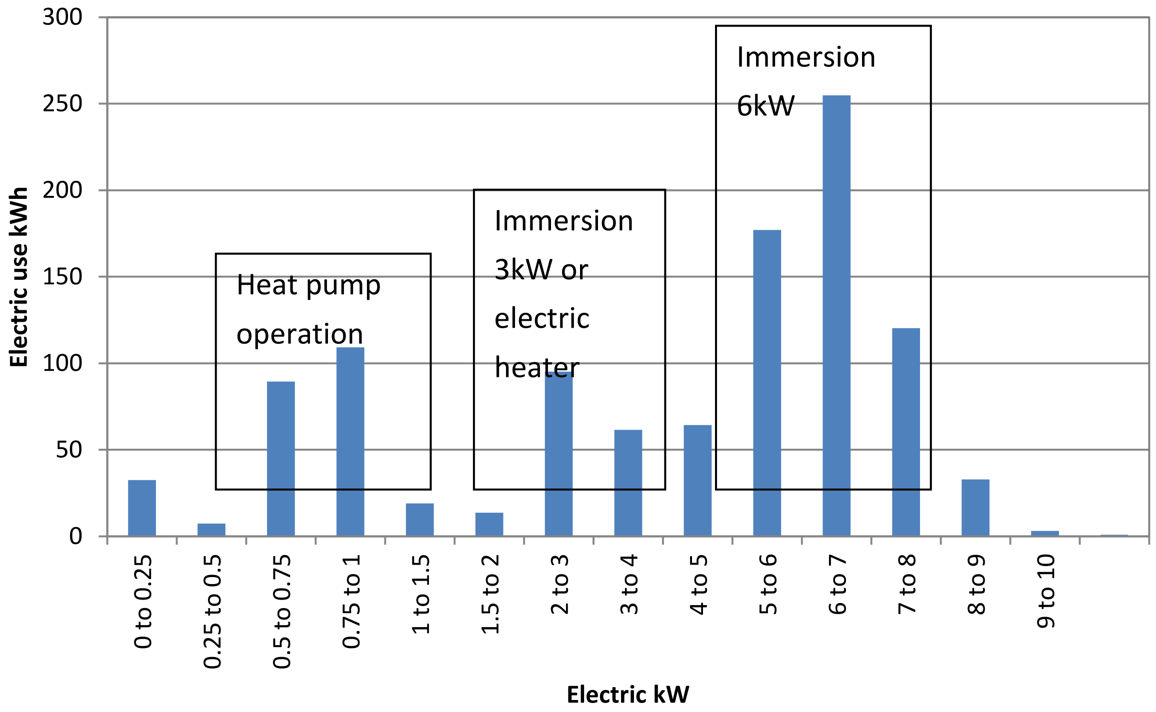
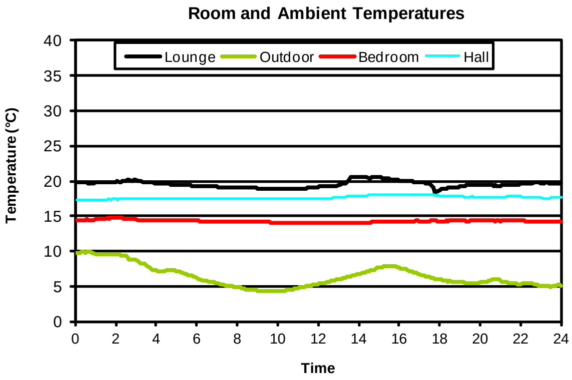
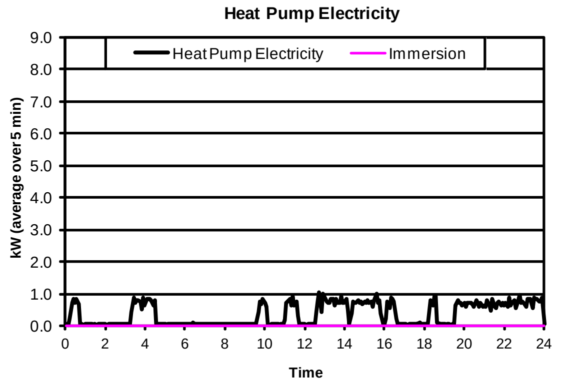


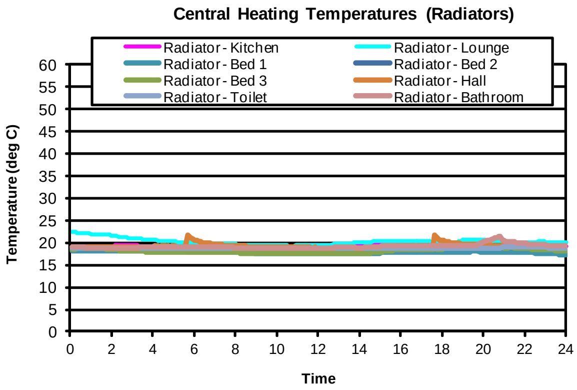

**Figure 9: February 2012, fiscal electricity use in a 3 bed property with internal heat pump immersion operational**

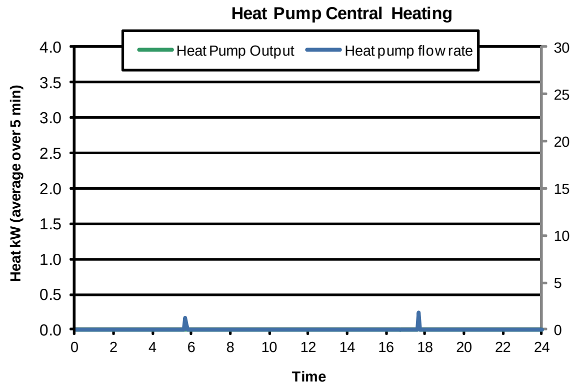
The switchable immersion in this heat pump can either be 3 or 6 kW, so the chart above shows the 2 stages and the heat pump only operation in black boxes. A bimodal pattern with peaks around 1 and 6 is typical for this model of heat pump, and is seen in 62% of the properties on this development with this particular model of heat pump.

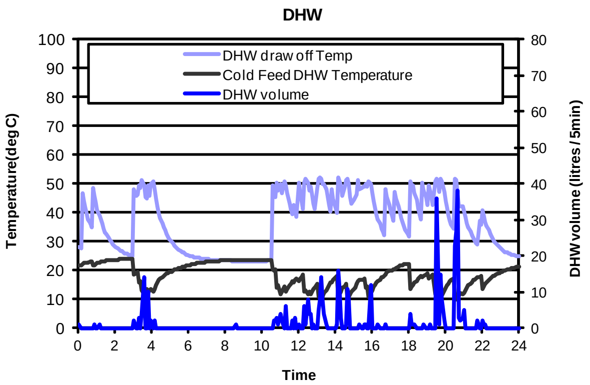
01/01/2013

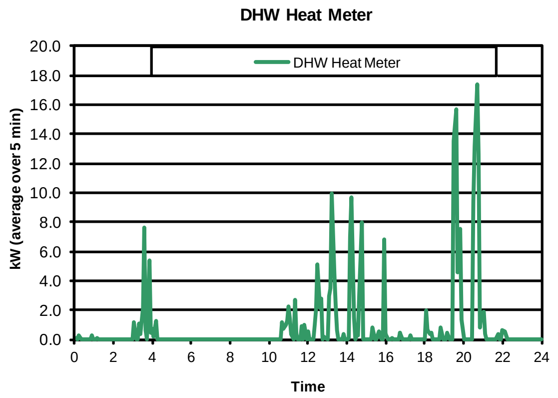



| | |
|---|---|
| Total electricity consumption (KWh) | 9.14 |
| Total central heating heat (kWh) | 0.00 |
| Total DHW heat used (kWh) | 18.88 |
| Total output energy from heat pump (kWh) | 18.88 |
| HP Daily SPF (based on total heat pump output) | 2.07 |
| Immersion consumption | 0.00 |
| % immersion | 0% |
| Average Ambient temperature | 6.38 |

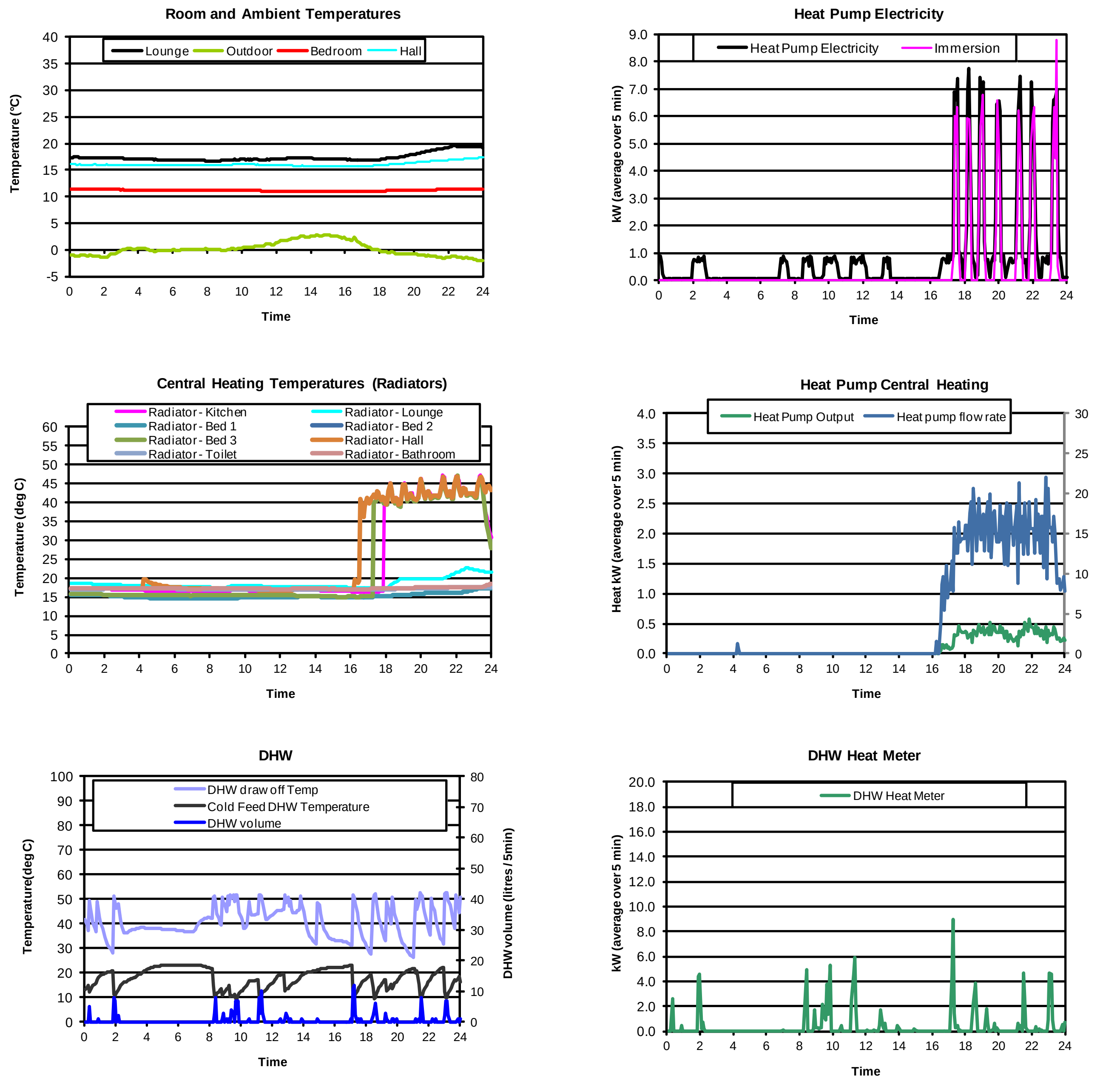
**Figure 10: January 1st 2013**

On this winter's day, the heat pump was not used to heat the property. However the heat pump was in operation for 50% of the day heating the DHW only. The immersion was not enabled, the DHW flow temperatures were 50°C and the SPF looks reasonable for these conditions. At 15˚C, the bedroom was colder than recommended in the CIBSE guidelines (17-19°C).

Since the heat pump was used to heat DHW for 50% of the time, then it would have been available for central heating for only 50% of the time. For an external temperature of 2˚C and internal temperature of 21˚C, the estimated heat demand for this property is ~19 kWh/day. In principle, an additional 8.31 kWh/day of electricity would have been sufficient to supply this heat demand without recourse to the electric immersion.

Unfortunately, when this method of intermittent heating is used, a large amount of extra heat is required to reheat the buffer tank, the radiator system and the thermal mass of the property, resulting in excessive use of the immersion

16/01/2013




| | |
|---|---|
| Total electricity consumption (KWh) | 20.56 |
| Total central heating heat (kWh) | 2.44 |
| Total DHW heat used (kWh) | 9.02 |
| Total output energy from heat pump (kWh) | 11.46 |
| HP Daily SPF (based on total heat pump output) | 0.56 |
| Immersion consumption | 11.61 |
| % immersion | 56% |
| Average Ambient temperature | 0.16 |

**Figure 11: 16/01/13 start-up of central heating**

The intraday chart above shows a day where the central heating was turned back on and the immersion was employed to try and reheat the property. This period coincided with DHW draw-offs which further exacerbate the issue. Only 3 radiators were opened and the maximum output of these 3 radiators at a radiator temperature of 45°C and room temperature of 15°C would be:

**Table 1: Output of different radiators**

| | H (mm) | W (mm) | Radiator type | Output at delta T = 50 (W) | Corrected output at delta T = 30 (W) |
|---|---|---|---|---|---|
| Bedroom 2 | 700 | 700 | K2 | 1408 | 725 |
| Kitchen | 700 | 400 | K2 | 804 | 414 |
| Hall | 700 | 500 | K2 | 1006 | 518 |
| **Total** | | | | **3218** | **1657** |

However, the graph above shows that the heat pump was not on for the full 5 minutes, which means that the output was not 1,657W. The on time was minimised, the immersion graph was spiky and it is likely that the heat pump was cycling. This may be due to the low water volume within the system which may cause the heat pump to turn on and off quickly. The heat pump appeared to be turning on and off, this was likely to be an error state based on either high temperature trip out or some other temperature fault.

This may have been avoided if the heating was left on continuously, with all the radiators open, however a period of this type of operation is yet to be found.

### *1bed property: detailed analysis of heat pump operation*

Heat pulses were not seen on the DHW heat meter in the 1 bed flat (from the 29/03/12 until the 26/06/12) although flow pulses were still seen. These were combined with the measured flow and return temperatures to calculate the DHW heat. The wiring had been disturbed and this was fixed on the 26/06/12. The data for June and July 2012 was incomplete due to the resident turning the monitoring equipment off. As a result, there were only 4 days of data collection in June and 8 days of data collection in July.

This heat pump was operated in two different ways which can be seen in the graph below. SPFs were generally either between 1 and 2, or above 2. There were a few days where the SPF was less than 1, these were generally days with low DHW use, where the draw-off was smaller, this also included days where the sterilisation cycle operated, and days where the immersion was operating all day.

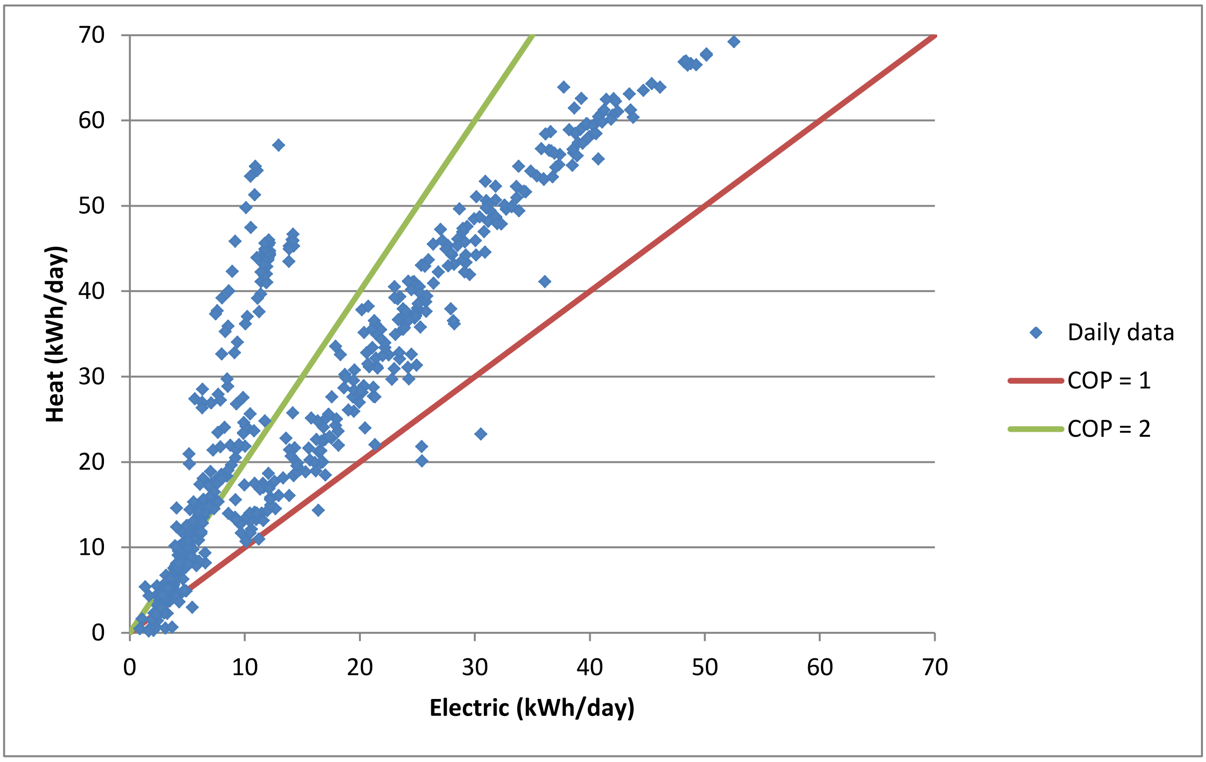



**Figure 12: Electric vs Heat for 1bed flat for both years**

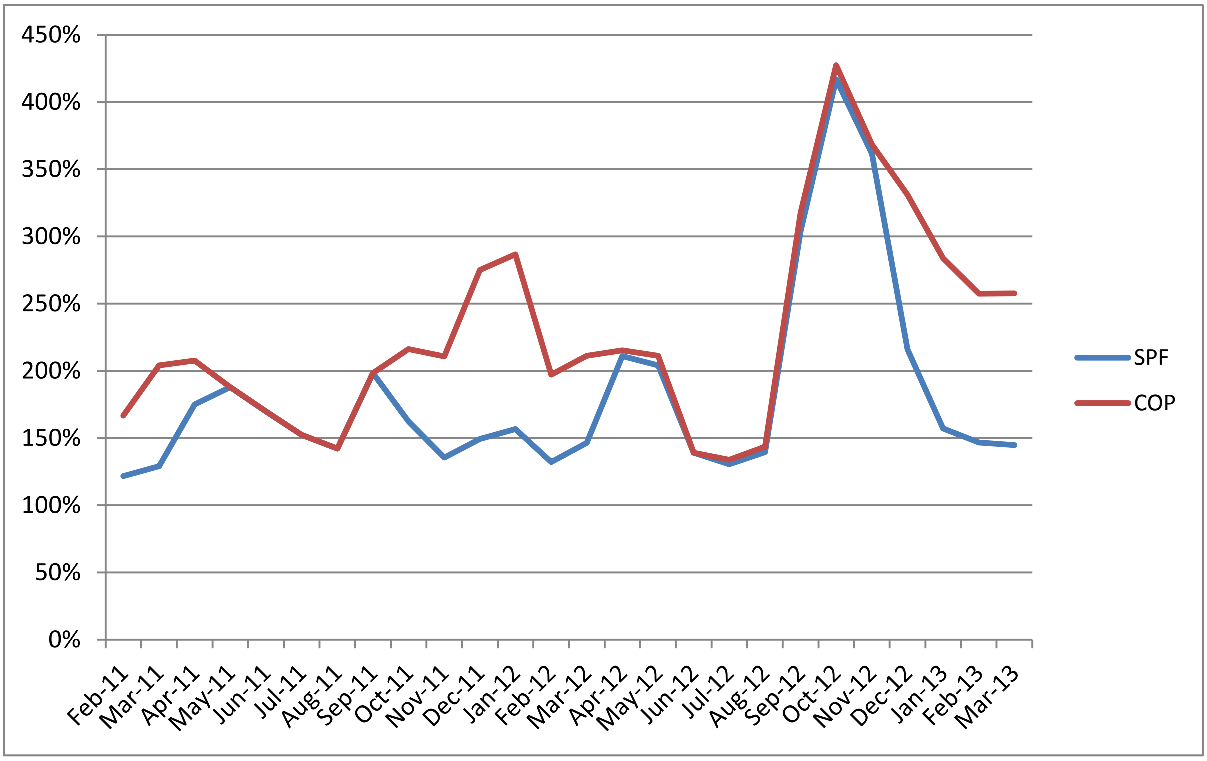



**Figure 13: SPF/ COP for 1bed flat over the 2 year period**

The SPF mirrored the COP where the immersion was not used (i.e. in the summer months). However where the immersion was used (i.e. from October to March 2012 and December to

January 2013), the SPF was lower than the COP because the immersion was direct electric and had a COP of 1.

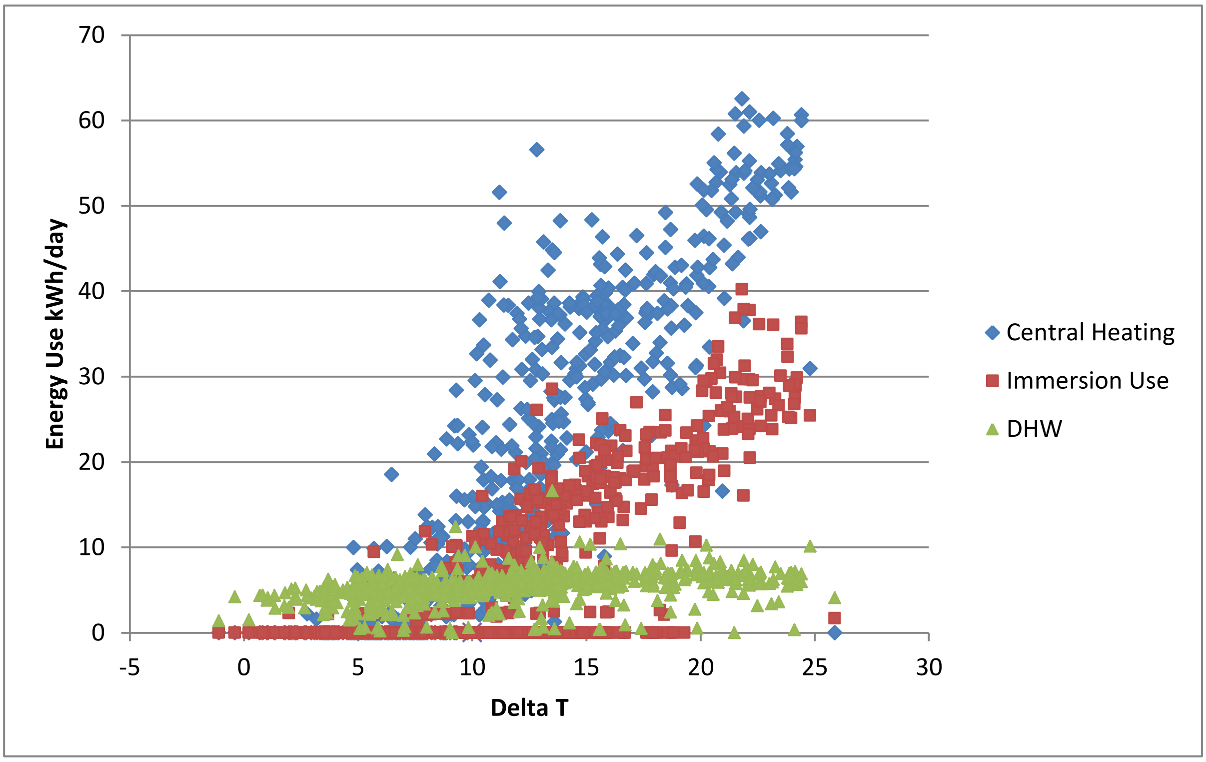



**Figure 14: Energy use at different delta Ts**

The DHW use was slightly lower when it was warmer outside compared to when it was colder, but it averaged 5.3kWh/day, which was higher than estimated within BREDEM.

The following plot shows the electric power for each 5 minute period during February 2013 that fell into each category.

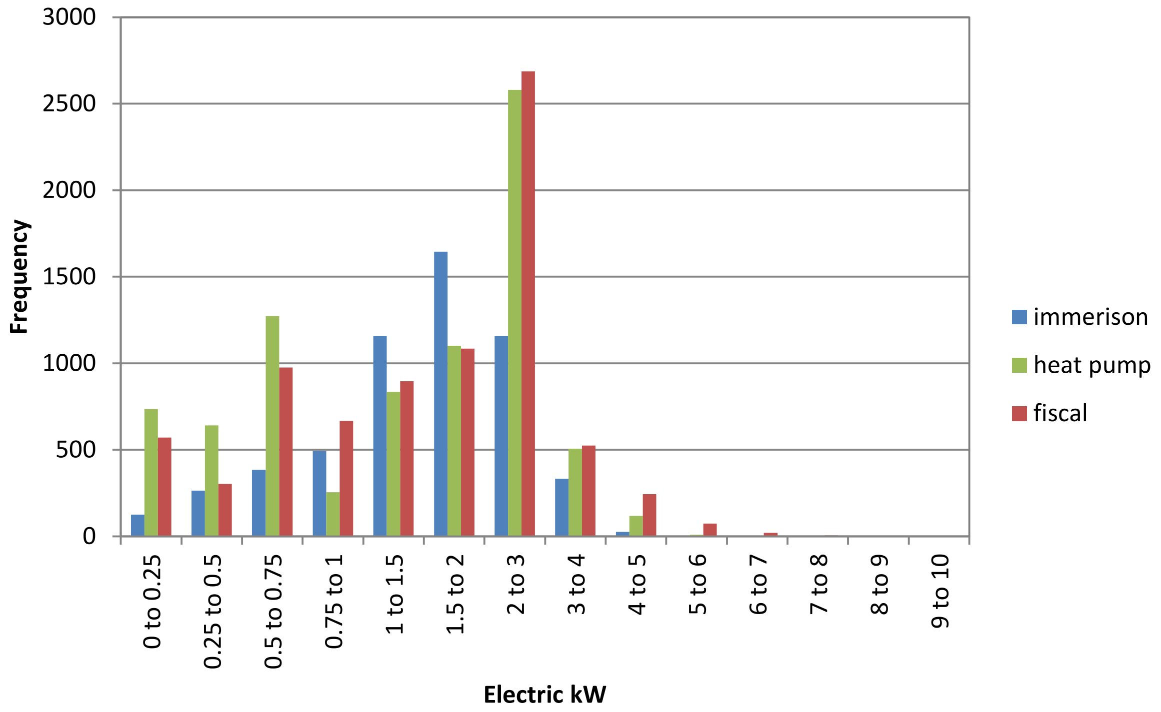



**Figure 15: Frequency profile of electric use 1 bed property split into immersion, heat pump and fiscal use**

This site had high immersion use (755kWh in February 2013) out of a total usage of 1,213kWh. The histogram in Figure 5 identifies this with a peak at 2 to 3kW for the fiscal data, and 1.5 to 2kW for the immersion data. The fiscal peak should be higher than the immersion peak because it includes heat pump and background load electric use as well. The immersion also appeared to cycle which can be seen in Figure 6, this means that the power input is lower than 3kWh in an hour period. The fiscal and heat pump data had similar profiles because the immersion was running every time the heat pump was in operation at this property.

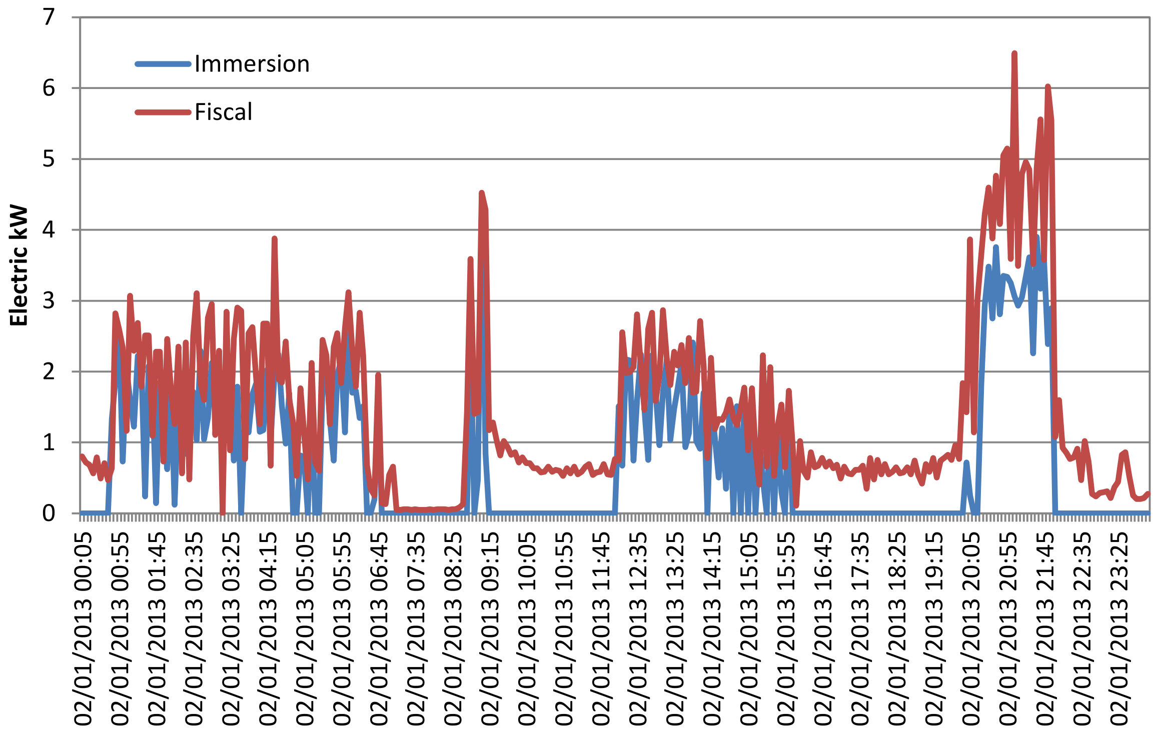



**Figure 16: 1 Bed property, evidence of immersion cycling**

Figure 17 shows an energy weighted histogram which shows that the majority of the electricity used in this property is going to the immersion; the energy weighted histogram was found to be more useful than the frequency graph because it shows where the highest usage is.

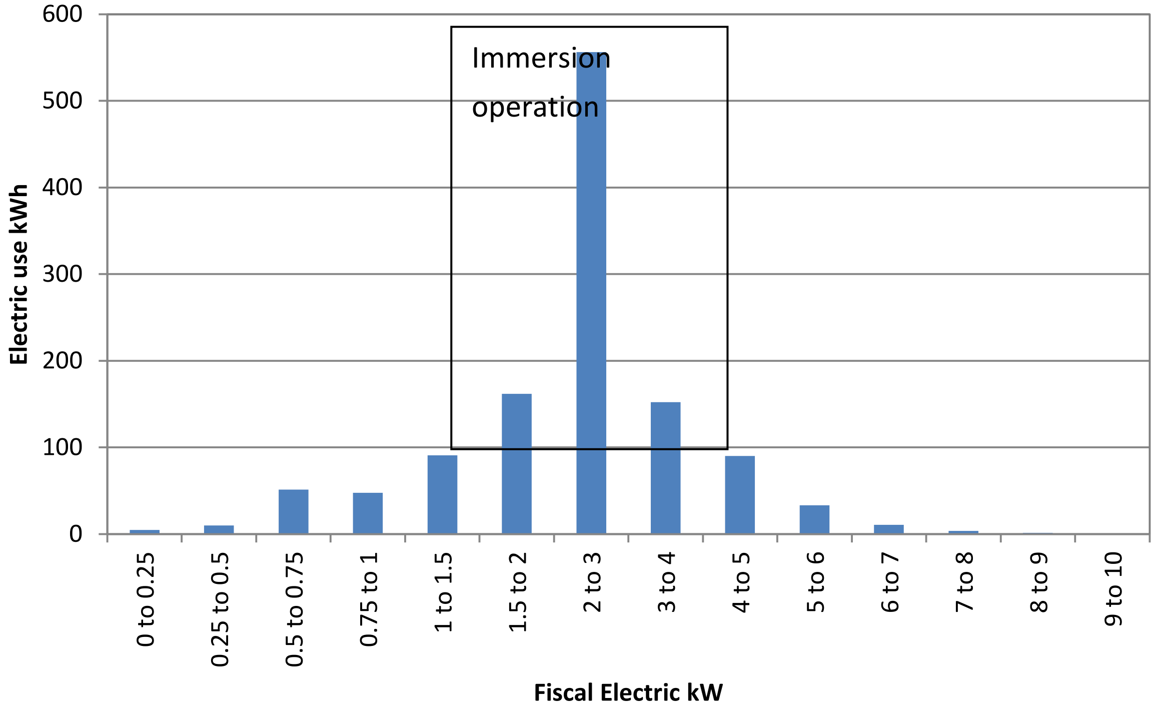
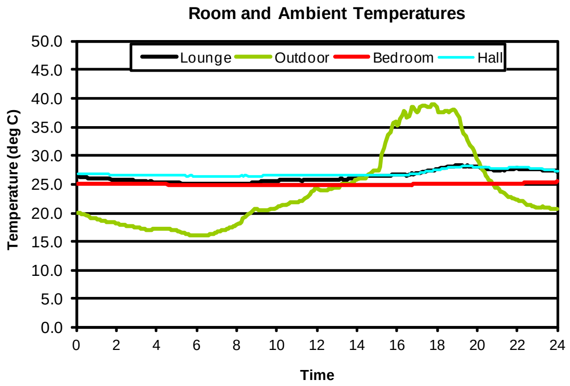
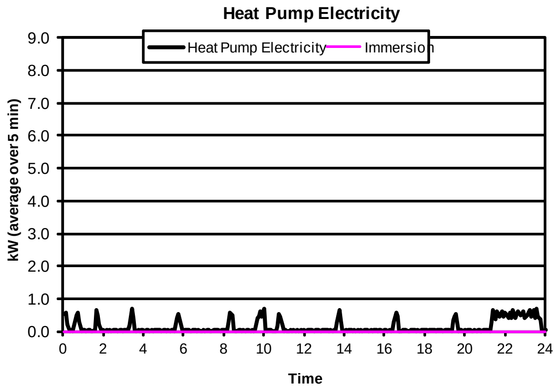
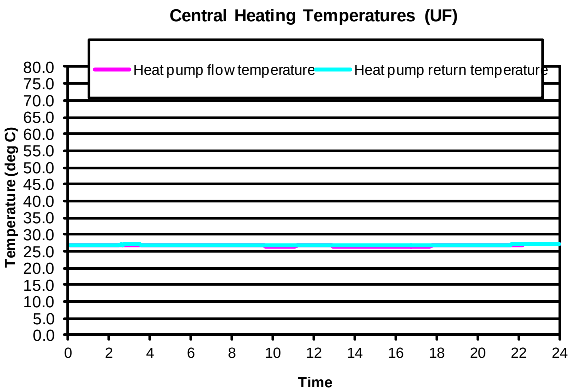


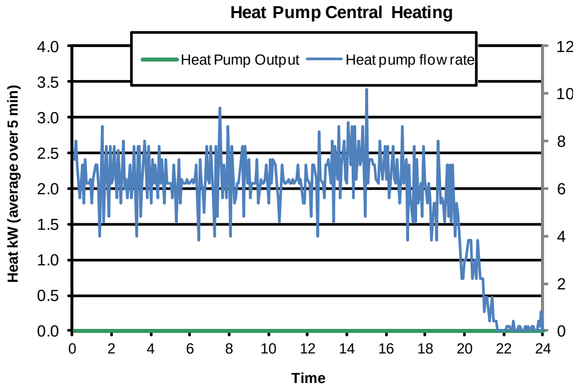

**Figure 17: February 2013 , histogram of whole house electricity use, 1 bedroomed flat**

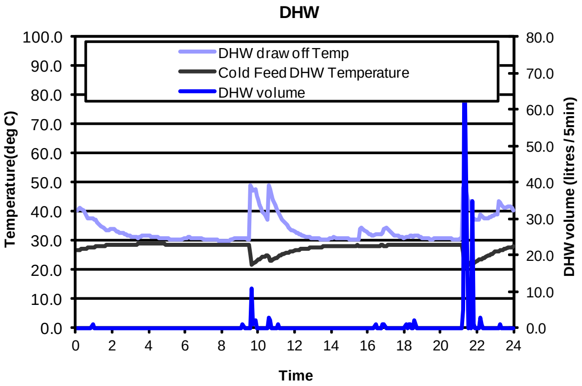
10/08/2012

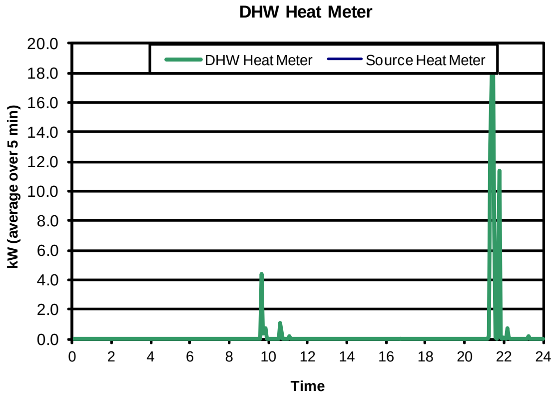


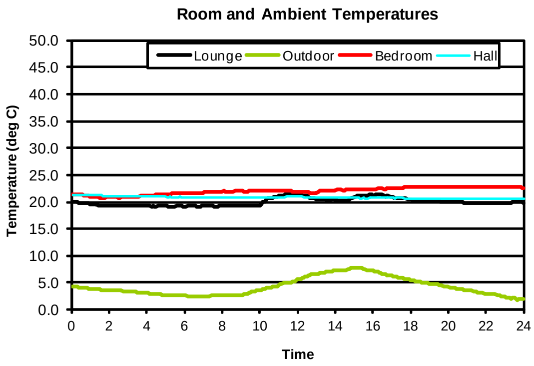



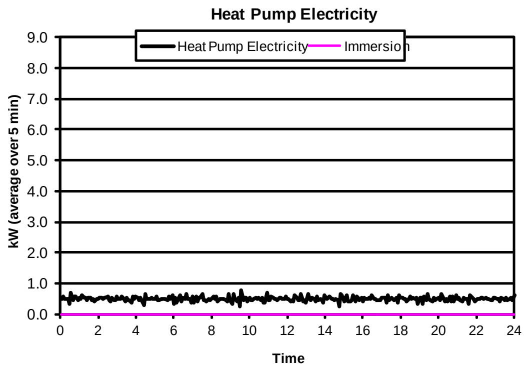

| | |
|---|---|
| Total electricity consumption (KWh) | 3.23 |
| Total central heating heat (kWh) | 0.00 |
| Total DHW heat used (kWh) | 5.21 |
| Total output energy from heat pump (kWh) | 5.21 |
| HP Daily SPF (based on total heat pump output) | 1.61 |
| Immersion consumption | 0.00 |
| % immersion | 0% |
| Average Ambient temperature | 23.82 |

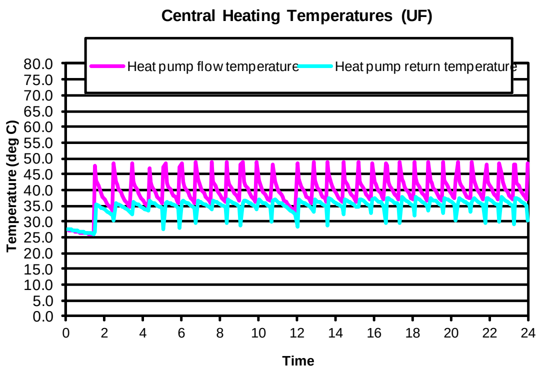
**Figure 18: Summer day 1 bedroomed flat**

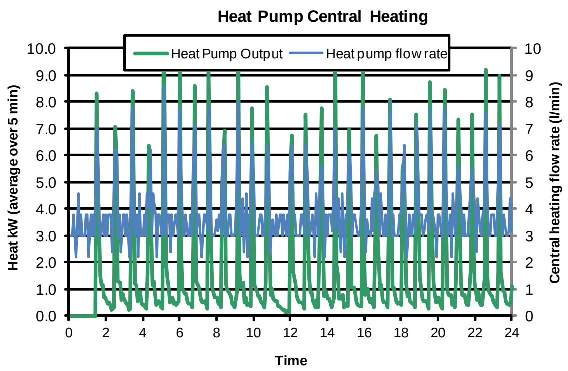
On this summer day, it can be seen that there was a flow around the heating system even though the internal flat temperature was above 25°C. This used unnecessary power. The heat pump was keeping the cylinder hot all day using 3.23kWh throughout the day and the draw-offs totalled 5.21kWh. The cylinder was storing energy at 50°C, which would have associated heat loss, so the daily SPF included some heat loss from the cylinder to the flat (possibly increasing the flat temperature further).

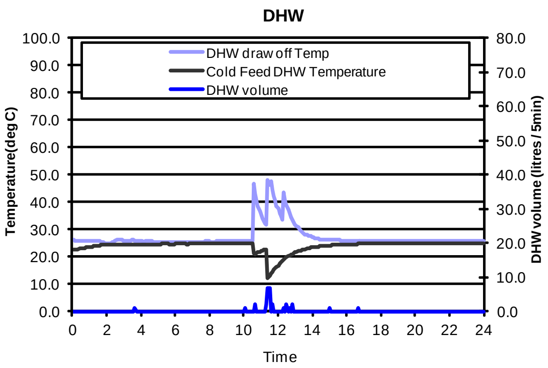
04/12/2012

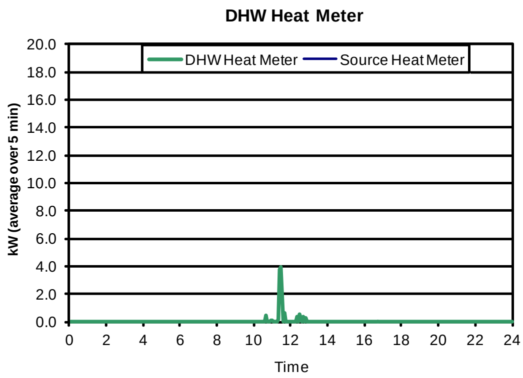


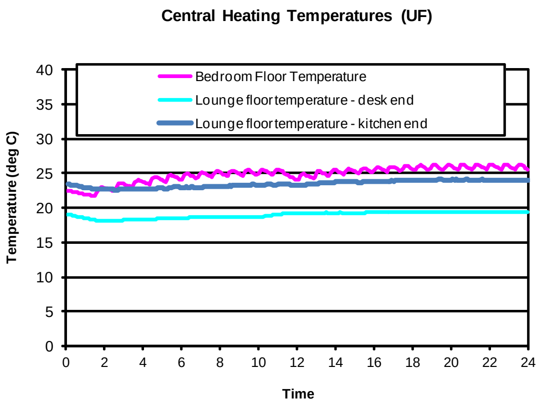



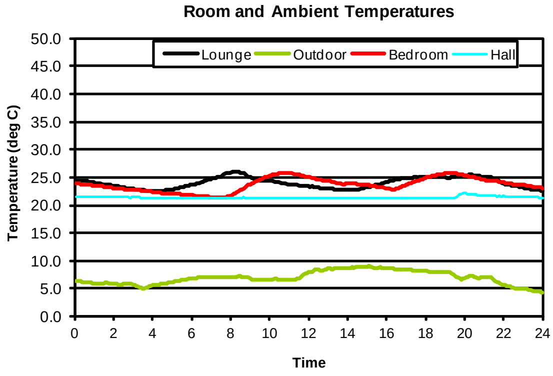



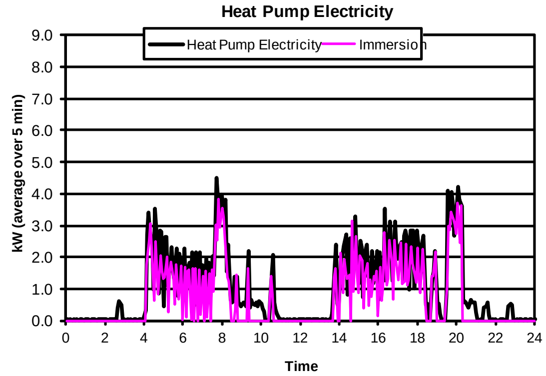

| | |
|---|---|
| Total electricity consumption (KWh) | 11.93 |
| Total central heating heat (kWh) | 40.15 |
| Total DHW heat used (kWh) | 0.91 |
| Total output energy from heat pump (kWh) | 41.06 |
| HP Daily SPF (based on total heat pump output) | 3.44 |
| Immersion consumption (kWh) | 0.00 |
| % immersion | 0% |
| Average Ambient temperature | 4.27 °C |
| Mean Internal Temperature | 20.98 °C |
| HLC | 100.1 W/K |

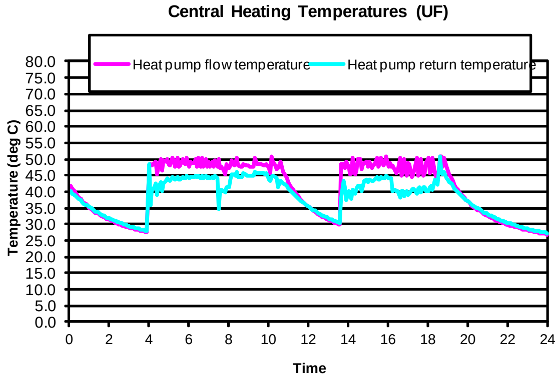
**Figure 19: Winters day without immersion, 1 bedroomed flat**

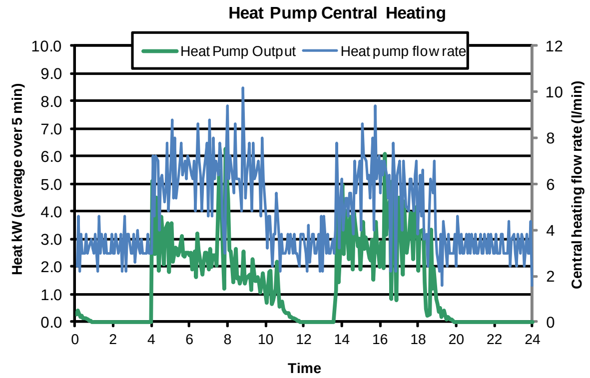
The flow temperature for the DHW and CH was 50°C, which was high for underfloor heating, however there is no weather compensation on this unit. The property temperature stayed consistent at 20°C, with a SPF of 3.44 because the immersion was disabled. The total heat to central heating over the day was 40kWh, when the delta T was 16.7°C, which means the heat loss coefficient for this day was approximately 100W/K, which ties in with the measured co-heating test data. The floor temperature in the bedroom appeared to be directly linked to the flow temperature of the heat pump while the other floor temperature sensors were slower to react.

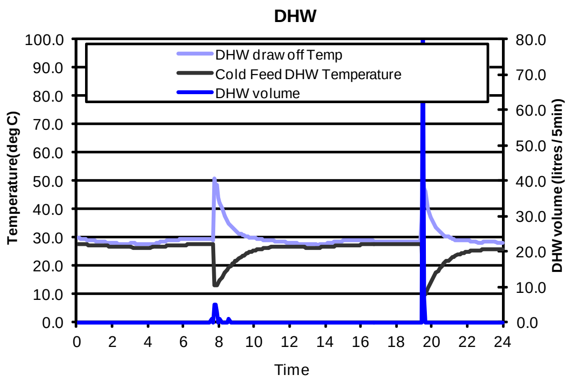
18/12/2012

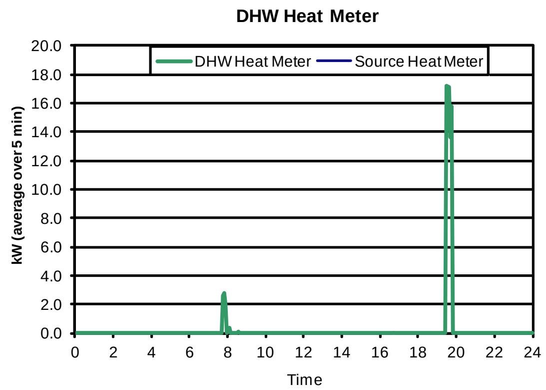


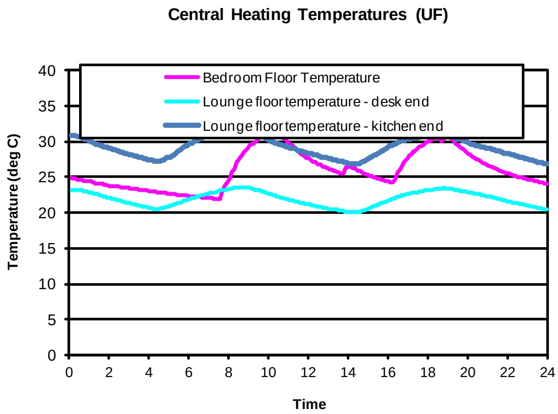




| | |
|---|---|
| Total electricity consumption (KWh) | 24.02 |
| Total central heating heat (kWh) | 31.65 |
| Total DHW heat used (kWh) | 5.97 |
| Total output energy from heat pump (kWh) | 37.61 |
| HP Daily SPF (based on total heat pump output) | 1.57 |
| Immersion consumption (kWh) | 16.59 |
| % immersion | 69% |
| Average Ambient temperature | 6.99 °C |
| Mean Internal Temperature | 23.05 °C |
| HLC | 82.1 W/K |

**Figure 20: Winters day with immersion, 1 bedroomed flat**

The bedroom temperature increased more slowly than the lounge, the floor temperatures followed the same trend, so it was likely that the circuit for the bedroom opened later, was this due to the householder adjusting the controls? This day had a lower heat load than the day without immersion (32kWh compared to 40kWh), however the SPF was only 1.57 compared to 3.44. The DHW use was higher, but it can be seen that the heat pump was rarely on compressor only without the immersion coming into operation. The heat loss coefficient on this date was 82.1W/K which is slightly lower than that anticipated by the co-heating test.

An engineer employed by the exhaust air heat pump manufacturer visited all the properties at this development on 24th and 25th of July 2012. The engineer adjusted the mixing valve, replaced the filter and adjusted the fan speed at the 1 bedroomed property. In addition the RSL issued instructions using monitoring data to demonstrate to the resident the benefits of maintaining heat with the immersion disabled (setting A). The results of these changes are seen in Figure 21. Subsequently the performance of the heating system was much improved during the colder days when central heating was required. This is likely to be because the heat pump was kept on setting A for longer. During the summer days the performance did not change, this was because DHW heating and storage generally lead to losses from the system.

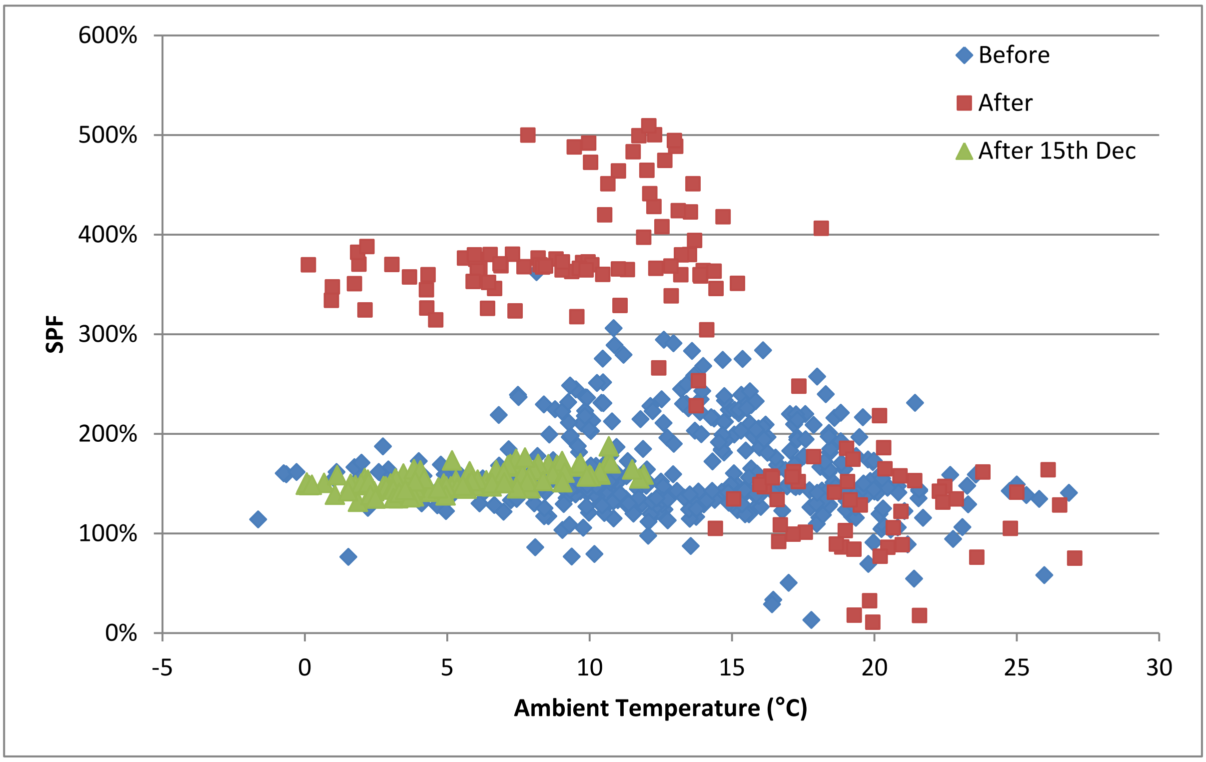



**Figure 21: SPF against the ambient temperature for a 1 bed property (showing from 15th December 2012 in green)**

The resident at the 1 bedroomed property did not use the immersion from 26th March to 15th December, this resulted in much higher COPs (i.e. the monthly SPF was 4.28 for October 2012), and this showed that the system can work well in the equinox periods if the immersion is disabled. It is thought to be higher than expected from theoretical data because the internal temperature is high (23.4°C). The immersion was used for the weekly sterilisation cycle for Legionella, which was enabled on this heat pump in summer 2012 (it was not enabled during summer 2011). The householder wished to continue heating without the immersion over the winter period, and hoped to do so by using the fan heater to top up if it got too cold. However on December 15th 2012 the EAHP immersion was enabled when the temperature in the flat cooled to 19°C. After this point, the immersion provided ~70% of the heat output and the flat temperatures rose to 24°C as this was the temperature preferred by the resident.

## *Conclusion*

This work has shown that if the heat pump is operated without the immersion it can perform well, however there is an imbalance between the responsiveness of the underfloor heating system and heat levels and the occupant heat demands. It is not possible to draw conclusions as to whether radiators are better than underfloor heating, as the householder did not use the system as intended in the second year.