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First year of monitoring of exhaust air heat pumps with underfloor heating

Prepared by: Kiwa GASTEC at CRE
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DECC

First year of monitoring of exhaust air heat pumps with underfloor heating

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Executive Summary

A housing provider and Kiwa GASTEC at CRE (Kiwa) are carrying out monitoring of the energy demand of under-floor heating and radiators in a two social housing flats.

Each flat contains an exhaust air heat pump (EAHP) 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 social housing provider in January 2010.

This project aims to determine the effect of radiators compared to underfloor heating on the performance of the EAHP. The underfloor heating was changed for radiators on the 26/04/12 in Flat 6. This report covers the data collected for the annual period April 2011 to March 2012, prior to the change.

On both flats the measured COP was low in comparison with the expected value. The measured COP is comparable to the typical annual system efficiency. The COP falls during the summer because the load is dominated by heating the DHW to higher temperatures, and improves in the winter as the load swings towards the lower temperature demands of the underfloor heating systems.

Lag on the underfloor heating was investigated and it was found that in Flat 14 the underfloor system appears to be unbalanced. One floor temperature in the flat responded very quickly to changes in heating, while the other floor temperatures did not appear to follow the same pattern. In the other flat, one air room temperature is a lot lower than in the other rooms, but the floor temperature follows the same pattern.

Glossary

EAHP	Exhaust Air Heat Pump
Immersion	This is the electric module within the heat pump which is used to heat the tank-within-tank arrangement inside the heat pump, this can be used for DHW and CH heating depending on the settings of the heat pump
CH	Central Heating
COP	Coefficient of Performance – the instantaneous heat delivered divided by the instantaneous electrical energy supplied
DDH	Degree day heating requirement
DHW	Domestic Hot Water
HLC	Heat loss coefficient
System efficiency	The CH and DHW heat output divided by the electrical energy supplied.

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1 Introduction

The site is a mixed use development of office/retail and residential. Two flats are being monitored in detail ; a second floor, 3 bedroom flat (flat 6) and a fourth floor, 1 bedroom flat (flat 14).

Each flat in the development contains an exhaust air heat pump (EAHP) 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 2010. This project aims to determine the effect of radiators compared to underfloor heating on the performance of the EAHP. The underfloor heating was changed for radiators on the 26/04/12 in Flat 6. This report covers the data collected for the annual period April 2011 to March 2012.

This report aims to look at the first year of operation of the heat pump with the existing underfloor heating. This report sets out to assess the performance of these sites by applying various analysis techniques to the data gathered during the first year. The sites are briefly introduced in Section 2. Section 3 then summarises the results from the first year of monitoring. Appendix A contains further analysis of the data for each site, while Appendix B contains the data analysis techniques used.

2 Site Details

Both sites have exhaust air heat pumps currently producing DHW and underfloor heating.

As part of the BPE, co-heating tests and CO_2 injection testing were undertaken.

Table 1: Site HLC

Site Reference	HLC W/K (as measured by co-heating test with closed vents)	SAP
1 bedroom	110	71
3 bedroom	113	79

CO_2 injection testing was undertaken in the 3 bedroom flat with the vents unsealed, with the vents unsealed and the exhaust air heat pump in operation. The ventilation rate increased by a factor of 3, from an air change rate of 0.29 (unsealed, EAHP off) to 0.86 when the heat pump was in operation. The increase in air changes when the heat pump was operational is significant because the heat pump fan increased the air change rate by approximately three times. This means that more energy would be required to compensate for the ventilation heat loss as can be seen in Table 2: The effect of air change rate on heat demand. This table assumes that the inside temperature of the flat is 25°C and the outside temperature is 10°C.

Table 2: The effect of air change rate on heat demand

	Air Change Rate	Ventilation heat requirement W
Unsealed, EAHP off	0.29	306
Heat pump operating	0.86	922

This is an increase of about 600W to the heat demand of the property when the external temperature is 10°C. The flow rate equates to 167m^3/hr through the flat. The EAHP recommendation is that for optimum heat pump performance the ventilation flow should not be less than 110m^3/hr.

3 Summary of results

Appendix A contains further analysis of the data for each site, while Appendix B contains the data analysis techniques used.

Table 3 shows the manufacturer's (predicted) COP and actual (i.e. measured) COP in a period of steady state when the immersion was not in use. Included in the table is the typical system effieniency for the winter months.

$$COP = \frac{HeatPumpOutput}{Electric_{HP}}$$

HeatPumpOutput is measured on the central heating circuit during the one hour tests shown below.
$Electric_{HP}$ includes the fans for the ventilation system and the immersion (although this was not in operation during the one hour tests shown below).
$Electric_{imm}$ is the electric used by the immersion that is integral to the heat pump.

$$AnnualSPF = \frac{CentralHeating + DHW}{Electric_{HP}}$$

$$AnnualCOP = \frac{CentralHeating + DHW - Electric_{imm}}{Electric_{HP} - Electric_{imm}}$$

Table 3: Steady State Measured and Modelled COP's

Site Reference	House Flow Temp °C	House Return Temp °C	Measured COP (A)	Manufacturer's (predicted) COP (B)	Ratio (A)/(B)	Annual system efficiency Measured	Annual COP Estimated
1bed	47.8	45.3	1.35	2.8	48%	1.51	2.14
3bed	31.3	30.3	1.29	4.5	29%	1.42	1.76

It is noted that the measured COP (A) was very low in comparison with the expected value (B) in both flats. The measured COP is comparable to the typical annual system efficiency. Again (for the avoidance of doubt), periods were chosen when the heat pump was in compressor operation and not using the internal immersion. The validity of calibration of the electric and heat meters have been checked by comparing electrical and heat energy into and out of the heat pump within Flat 6 during a period of immersion use only i.e. there was no heat pump use to complicate the situation. At these times, the energy in to the immersion heater (as measured by the electricity meter) should equal the energy out (as heat measured by the heat meter). Agreement was to within 4%.

A possible explanation for the poor measured COPs is that while the heat meter measures the heat provided to the central heating, the heat output in the steady state periods chosen was lower than expected because the appliance was simultaneously reheating DHW.

Supporting evidence for this is given in the column entitled Annual COP Estimated. These are 2.14 and 1.76 which are significantly better than the spot values. The monthly COPs (without immersion) shown in Tables 3 and 4 in the appendices are interesting because both flats show a pattern of summer COPs of 1.4 to 1.6 and winter COP's of 2.4 to 2.8. These are still lower than predicted values. It is suspected that the COP falls during the summer because the load is dominated by heating the DHW to higher temperatures, and improves in the winter as the load tilts towards the lower temperature demands of the underfloor heating systems.

Lag on the underfloor heating was investigated and it was found that in flat 14 the underfloor system appears to be unbalanced. One floor temperature in the flat responded very quickly to changes in heating, while the other floor temperatures did not appear to follow the same pattern. In the other flat, one air room temperature is a lot lower than in the other rooms, but the floor temperature follows the same pattern.

Qualitative information was collected by survey using the BUS occupancy questionnaire. The survey was carried out 21/03/12. The householder in flat 14 reported that they found the temperature in winter too cold and uncomfortable and that temperatures were variable throughout the day, whereas the householder at flat 6 gave answers that suggested that the temperatures were satisfactory. Again in summer the householder at flat 6 was more satisfied with the temperature than the householder flat 14. In response to the open text question regarding heating the resident at flat 6 said: It's confusing to understand how the system works. You have to think about it a lot and turn the thermostats up earlier than you want heat. Whilst the resident at flat 14 questioned whether the system worked at all. Neither respondent felt they had control over the heating. These answers suggest that the participants find the system complicated and that they do not have confidence in the unit's ability to provide enough heat.

Appendix A

A.1 Flat No 14 -1 Bedroom

Site Statistics:

- EAHP
- Supplies DHW and underfloor heating
- Heat pump sited in airing cupboard
- 1 occupant
- New build one bedroom flat, top floor
- Floor area – 49m^2
- SAP rating of 71, measured HLC (co-heating test) = 110W/K

Comments:

The flat under test was a one bedroom flat which was situated on the top floor at one end of the block. The flat was occupied by a single person, who is generally home during evenings and weekends. They operated the heating system using the thermostats and appear to like high internal temperatures. They often used an electric heater to deliver direct heat particularly in the morning and evening.

The heat pump in this flat had an annual system efficiency of 1.51, which peaked at 1.98 in September, when there was no immersion used. The householder changed the heat pump from setting 1 to setting 2[1] on 19/10/11, after this, it was observed that the immersion used a significant amount of electricity. Approximately 70% of the total electric load of the heat pump was used by the immersion; this had a large detrimental effect on the overall system efficiency.

Central heating use was observed in the summer months. The internal temperature in this property did not fall below 20°C and averaged 23.5°C during the winter months.

When the ambient temperature was high (>17°C), there was no immersion use, when the ambient temperature was low (<10°C), the immersion was used. There were a significant number of days when the ambient temperature was between 10 and 17°C when the

[1] Setting 1 is “Fan in operation. The compressor and the circulation pump are started up as required”. Setting 2 is “Fan in operation. The compressor, the electric heater element and the circulation pump are started up as required.”

immersion was used. There were no days in November 2011 or December 2011 when the immersion was not used, yet external temperatures ranged from 2-15°C. During the period 07/04/11 to 19/10/11 there was no observed immersion use. The immersion came on half way through October (19/10/11) and was always required every day from then on at about the same level.

During November the average temperature was 11°C and yet the unit used the immersion every single day. Even on the warmest day (which averaged 15°C), when very little heating was expected (even in view of the high internal temperatures in the flat) the immersion was on.

If the heat pump had a COP of 2 (as suggested by the measured data), the heat output from the heat pump would be 1100W. The heat loss coefficient of the property was 110W/K. This means that the heat pump could heat the property (without immersion use) if the delta T (between internal and external temperature) was 10°C or less. If the heat pump had a COP of 2.8 (as suggested by the manufacturer's data), the heat output from the heat pump would be 1540W. This means that the heat pump (without immersion) should be able to heat the property if the delta T was 14°C or less. However, Figure 3 shows that there was a large amount of immersion use when the external temperature was between 10 and 14°C. The heat produced by the heat pump increased as the delta T increased, but the immersion use appeared to be capped at 25kWh a day. The immersion appeared to be used too much at the lower delta T's, which did not give the heat pump a chance to operate solely on the compressor.

Figure 4 showed that the heat pump operates with a COP of between 2 and 2.6 when it is operating below an average compressor electric use of 400W a day. After this point the immersion is utilised at 70% of the total electric load, leading to a much lower COP, between 1 and 2. The compressor was rated at 550W, so immersion should not generally be required when the heat pump is operating up to this rating.

The immersion appeared to be set at 70% of the electric load, it is thought this should be decreased at lower electric loads to give the heat pump greater opportunity to deliver heat in sole operation.

The heating pattern suggested continual operation. DHW tank charging could be seen during the day in the latter parts of the month.

The control of the heat pump with respect to the ambient temperature was very good until February 2012. The R^2 was 0.965 excluding February 2012; however the householder became aware of how much energy the heat pump was using and decreased usage in February so the R^2 was 0.92 including February 2012.

On the 6/02/12 (external ambient temperature of 5°C), the flow temperature was about 50°C, and the heat pump tended to cycle using the compressor and the immersion. The DHW temperature is about 50°C. The required output was 45kWh/day; this was 1.875kW, which could not be supplied by the heat pump compressor alone, unless the COP was 3.4.

However, the immersion use was 69% of the electric use of the heat pump and therefore the COP was 1.59.

On the 13/06/11, the external temperature was 15°C between midnight and 6 a.m. yet the heat pump operated from 6 to 9 a.m. providing central heating, when the external temperature was rising and the internal temperature was above 20°C. The flow temperature reached 47°C. DHW was provided at 50°C. It is unexpected to see heating at this ambient temperature, and it is unknown whether the user is intentionally heating in the summer or not.

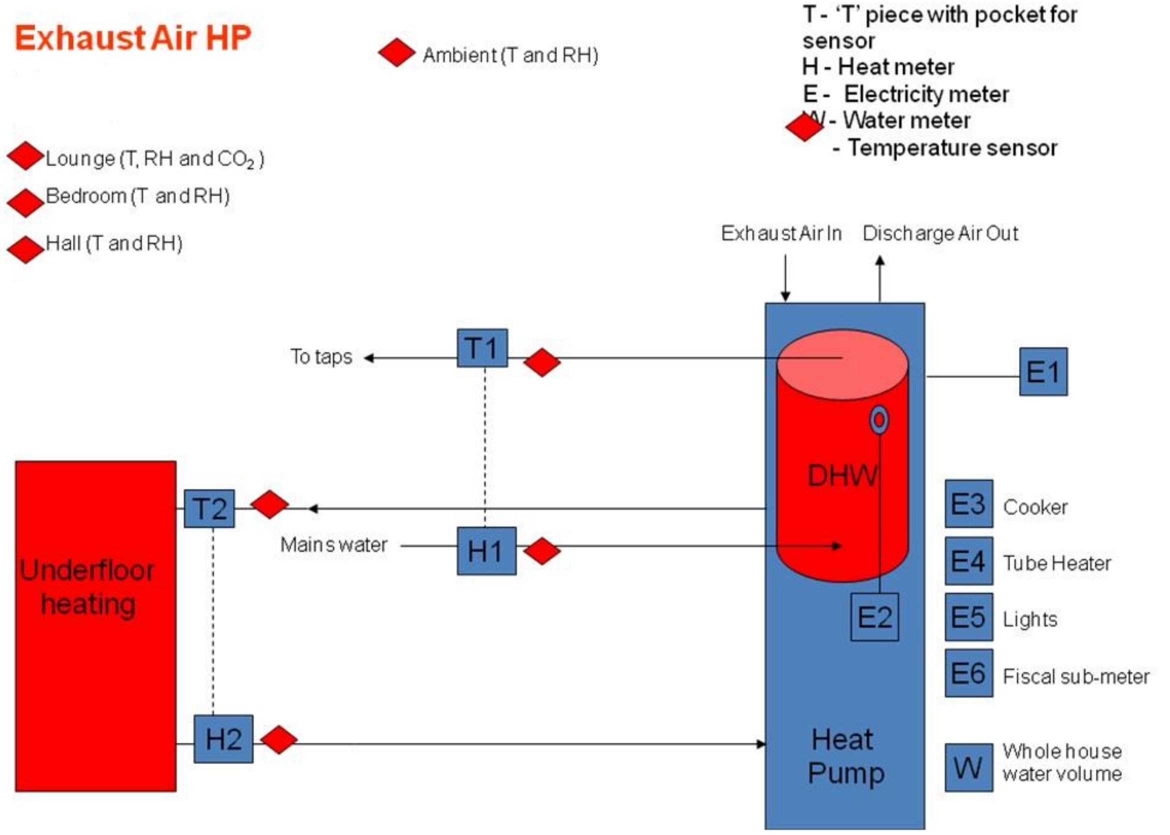
The HLC of the property as measured by the co-heating test was 110W/K, as occupied (with the heat pump) the HLC averaged 69W/K over the period November 2011 to February 2012. This is because the metabolic, solar and other electrical gains including an electric heater decrease the measured “as occupied” HLC. To express this in a different fashion assuming the heat pump delivers 1100W (COP=2) the delta T between internal and external temperature where sole heat pump operation would be expected could be increased to 16°C, i.e. the heat pump should operate alone at external temperatures of 9°C if the internal temperature is generally 25°C.

Against MCS design guidelines it could be argued that the heat pump was undersized for the property. However we are in no position to comment about this in light of the poor COPs seen.

The responsiveness of floor and air temperatures suggests that the underfloor heating within the flat is not balanced. The floor temperature in the bedroom responds very quickly to the heat pump operation, i.e. the floor temperature rises from 22°C, to 30°C within a 2 hour period, leading to a rise in room temperature from 21 to 25°C (see Figure 10). However there is an imperceptible rise in floor temperature within the other rooms over the same period (see Figure 9). Room air temperatures indicate that the bedroom in this flat is always hotter than the rest of the property.

In the resident survey conducted 21/03/12 the householder was generally dissatisfied with the temperatures achieved and reported that draughts from the vents were problematic in the winter. The householder also reported that there was little control over the heating.

System Schematic:



System efficiency by month:

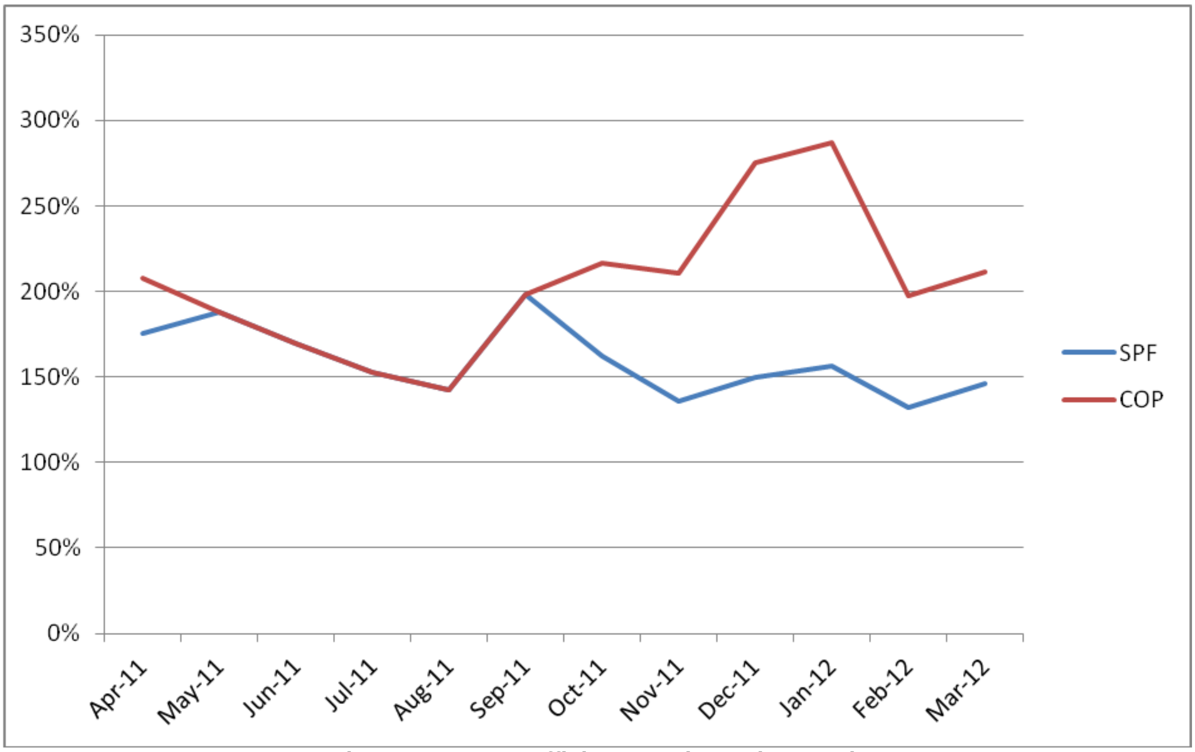


Figure 1: System efficiency and COP by Month

Immersion Use

Table 4: Immersion use at Flat 14

	Electric Power to the HP	Heat Pump immersion	% immersion use	CH direct heat out	DHW heat out	System Efficiency	COP
	(kWh)	(kWh)	(%)	(kWh)	(kWh)	(%)	
Apr-11	216	65	30%	229	150	175%	2.08
May-11	104	0	0%	92	102	188%	1.88
Jun-11	116	0	0%	59	139	170%	1.70
Jul-11	109	0	0%	10	156	152%	1.52
Aug-11	104	0	0%	0	148	142%	1.42
Sep-11	137	0	0%	129	143	198%	1.98
Oct-11	309	143	46%	354	148	163%	2.16
Nov-11	508	345	68%	529	159	136%	2.11
Dec-11	785	563	72%	975	197	149%	2.75
Jan-12	722	503	70%	930	201	157%	2.87
Feb-12	684	458	67%	707	198	132%	1.97
Mar-12	386	225	58%	364	201	146%	2.11

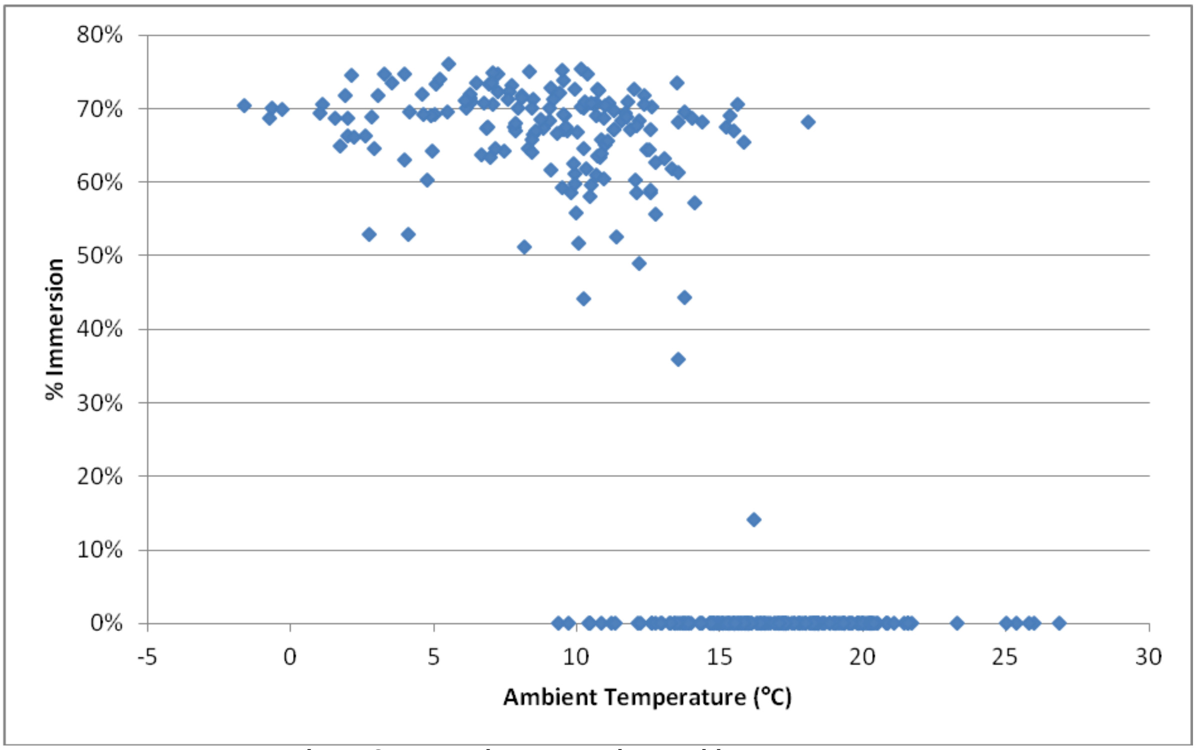


Figure 2: Immersion use against ambient temperature

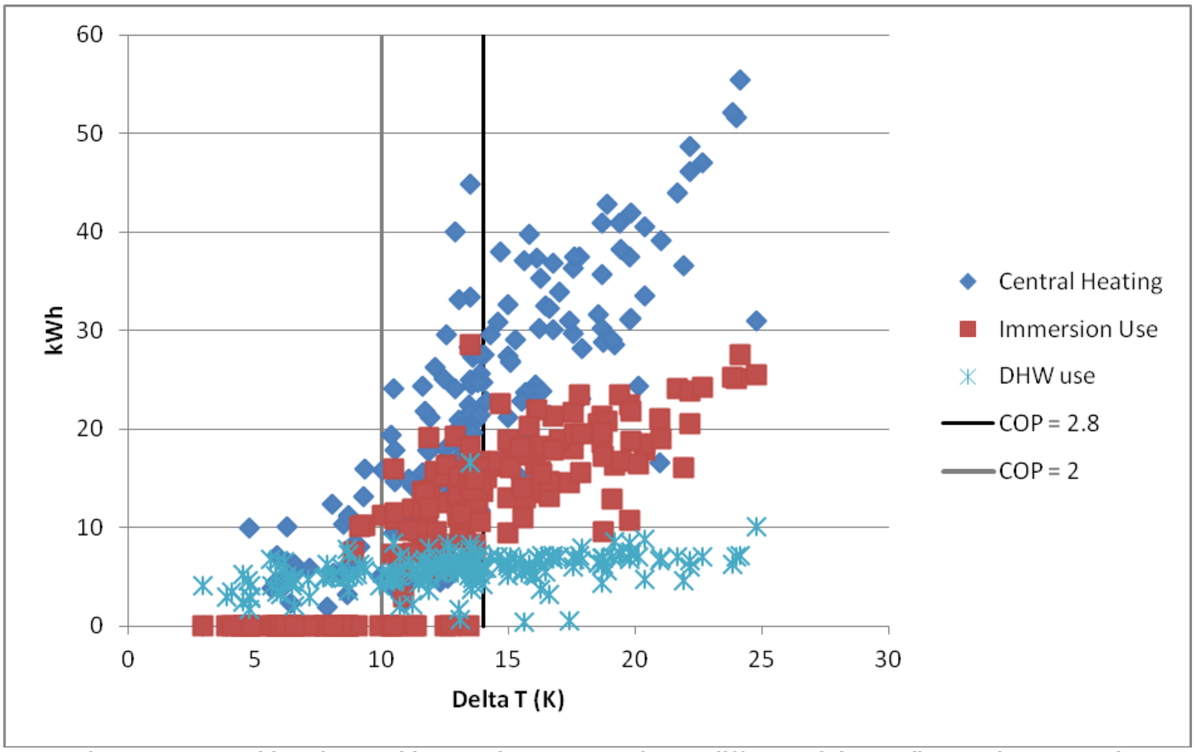


Figure 3: Central heating and immersion use per day at different delta Ts (internal – external temperature)

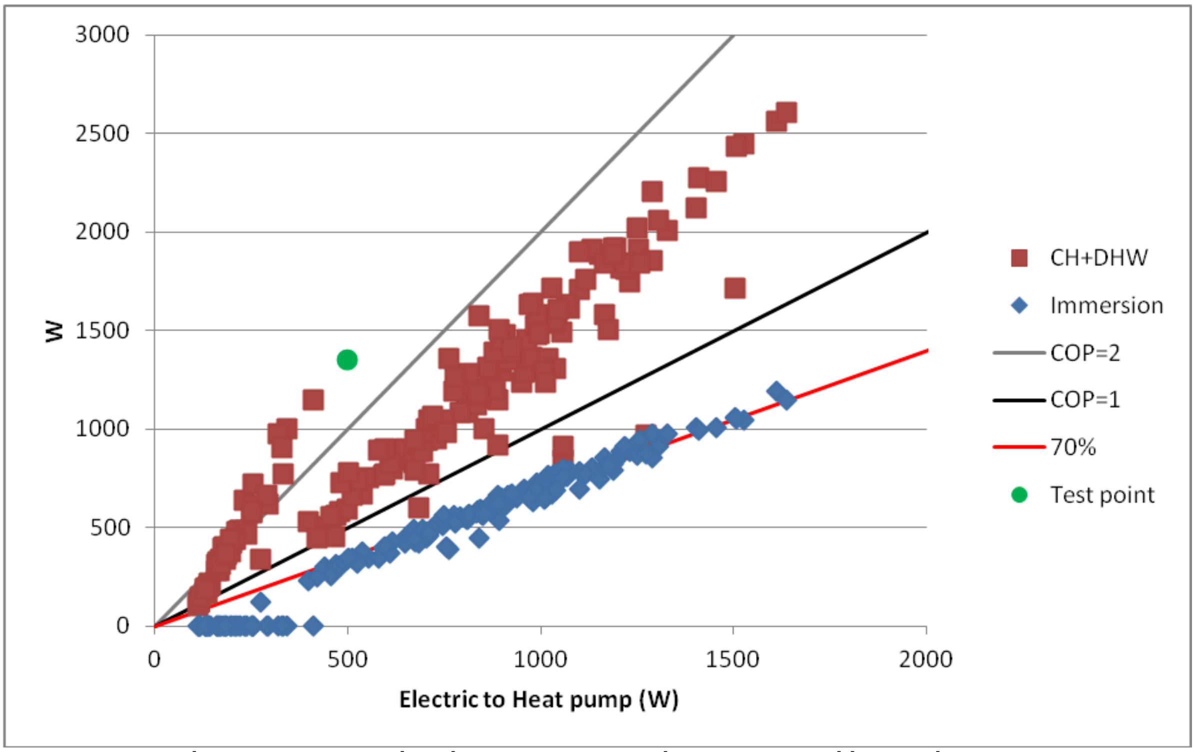


Figure 4: Average electric use vs. average heat output and immersion use

Heating Patterns

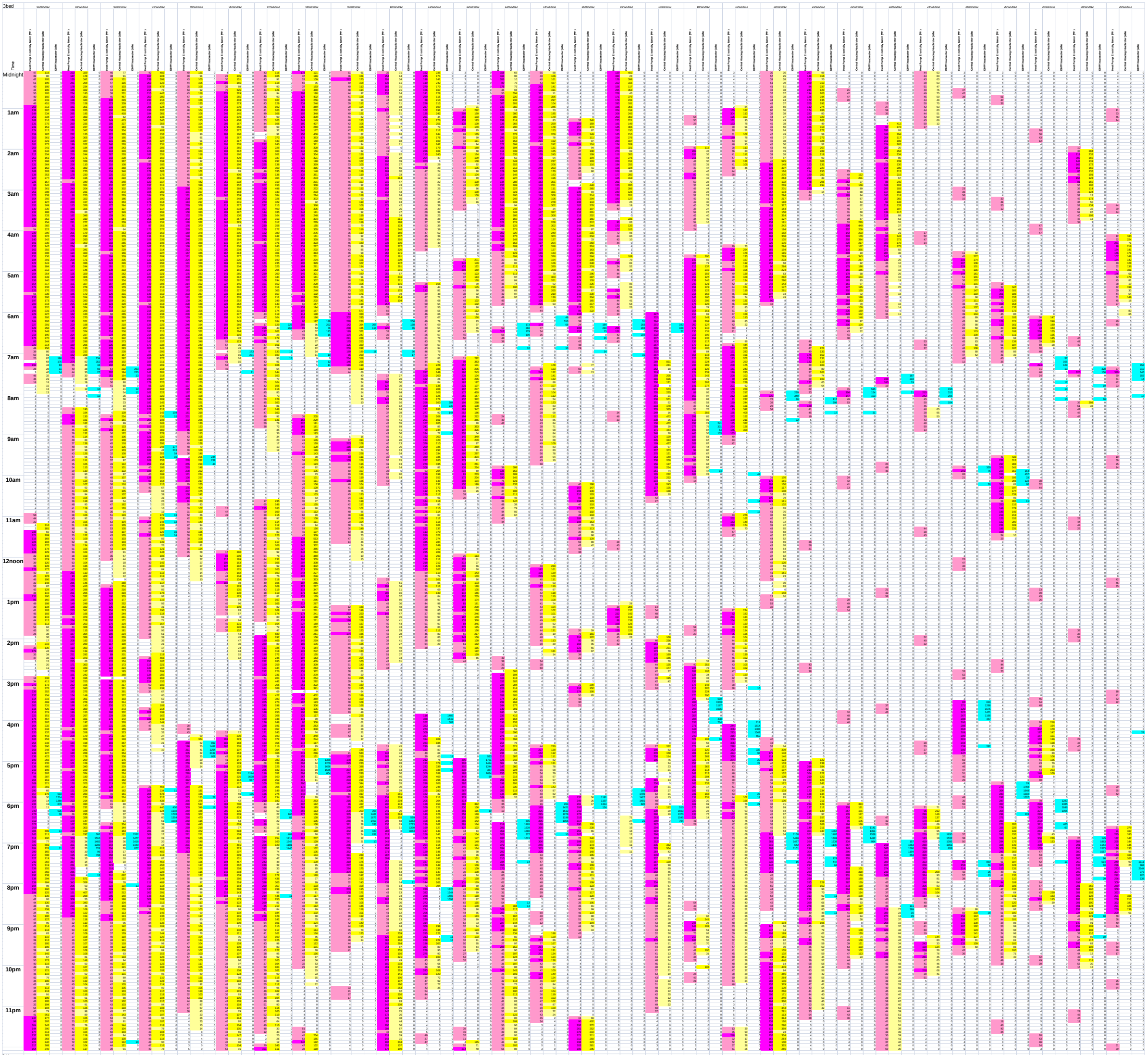


Figure 5: Heating pattern for February 2012

Control System Analysis

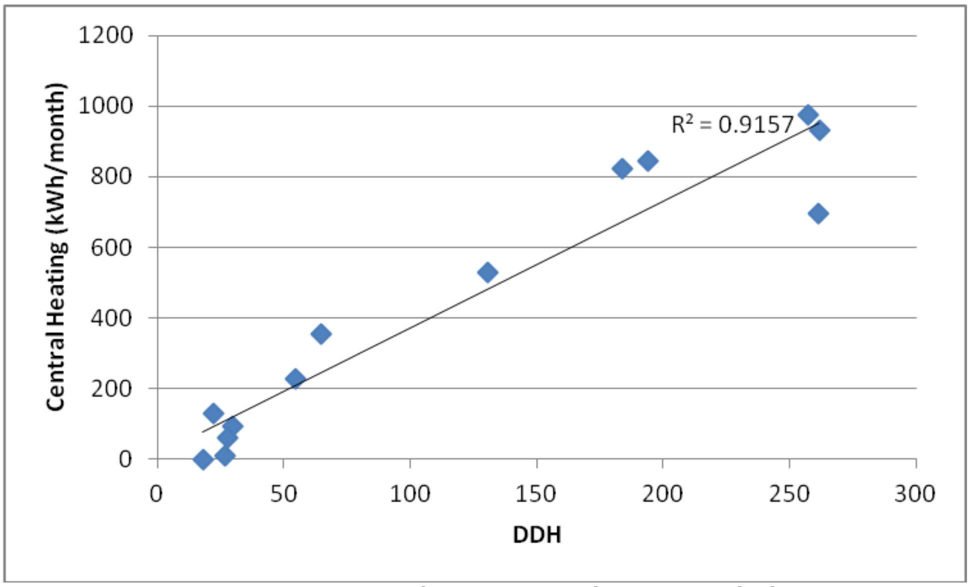
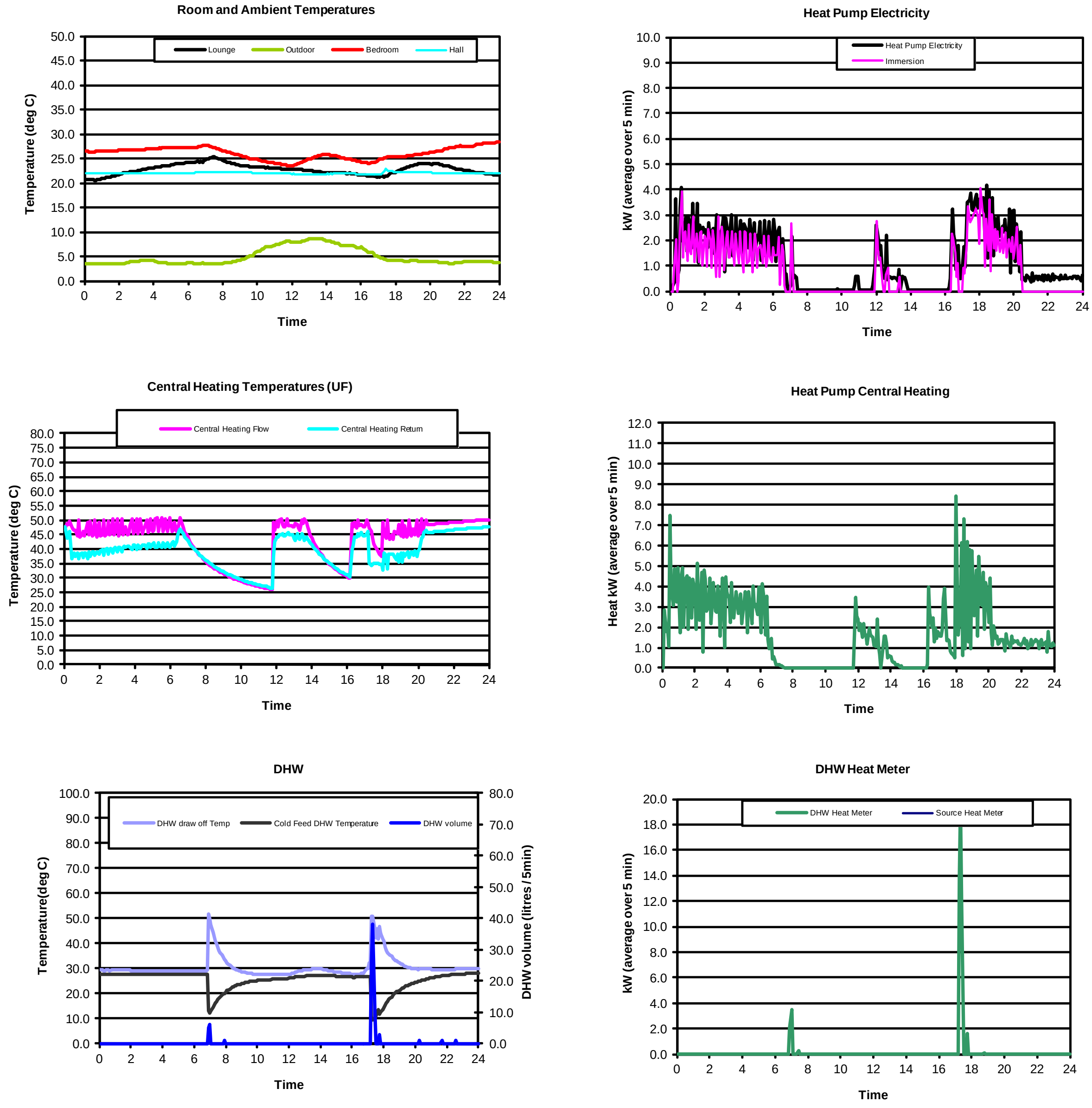


Figure 6: Control system analysis

Intraday graphs

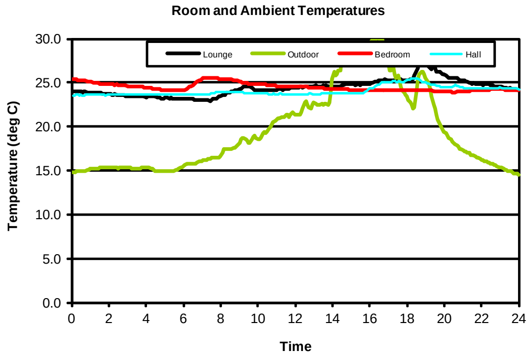
06/02/2012

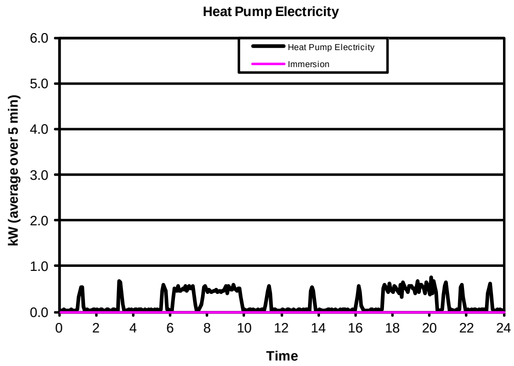


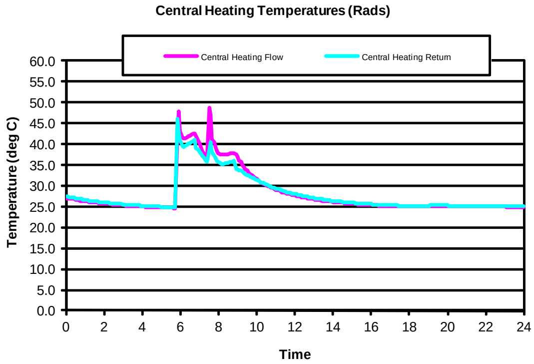
Total electricity consumption (KWh)	28.51
Total central heating heat (kWh)	40.95
Total DHW heat used (kWh)	4.39
Total output energy from heat pump(kWh)	45.34
HP Daily SPF (based on total heat pump output)	1.59
Immersion consumption	19.68
% immersion	69%
Average Ambient temperature	4.92

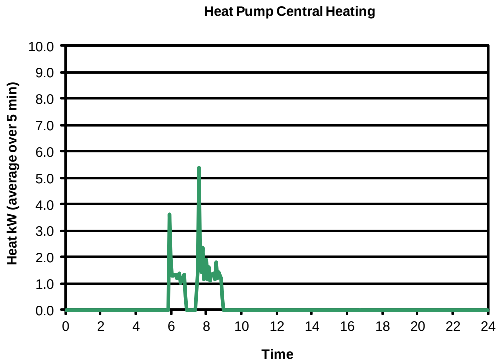
Figure 7: Intraday graph for 06/02/12

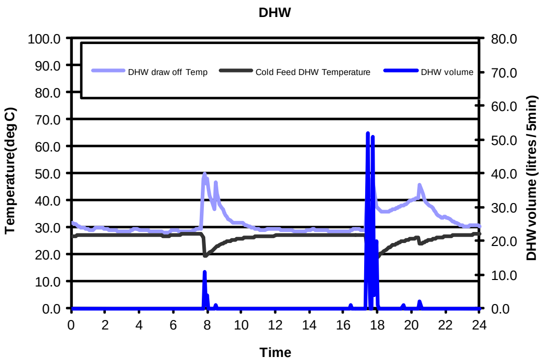
13/06/2011

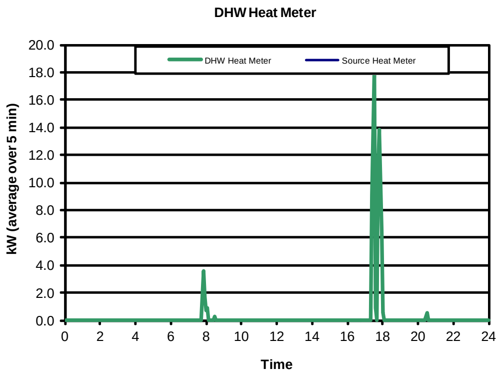












Total electricity consumption (KWh)	4.88
Total central heating heat (kWh)	3.93
Total DHW heat used (kWh)	5.65
Total output energy from heat pump(kWh)	9.57
HP Daily SPF (based on total heat pump output)	1.96
Immersion consumption	0.00
% immersion	0%

Figure 8: Intraday graph for 13/06/11

Responsiveness of Underfloor

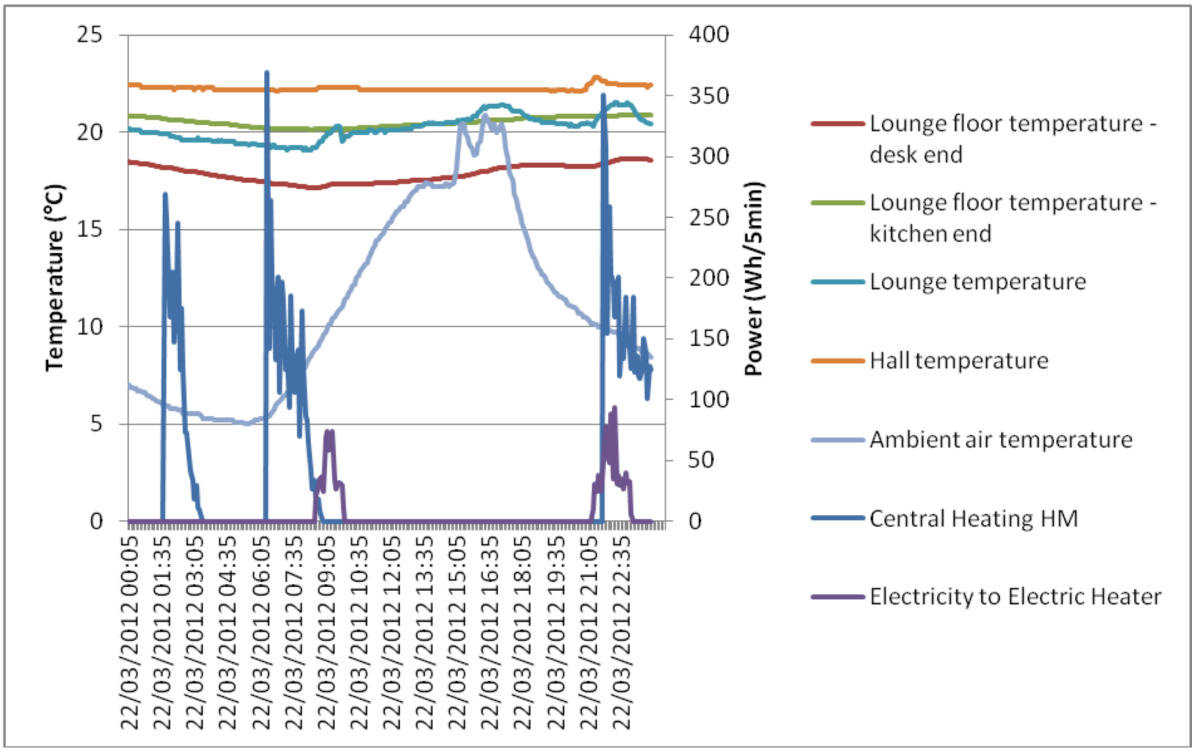


Figure 9: Lounge and Hall temperature responsiveness to heat pump

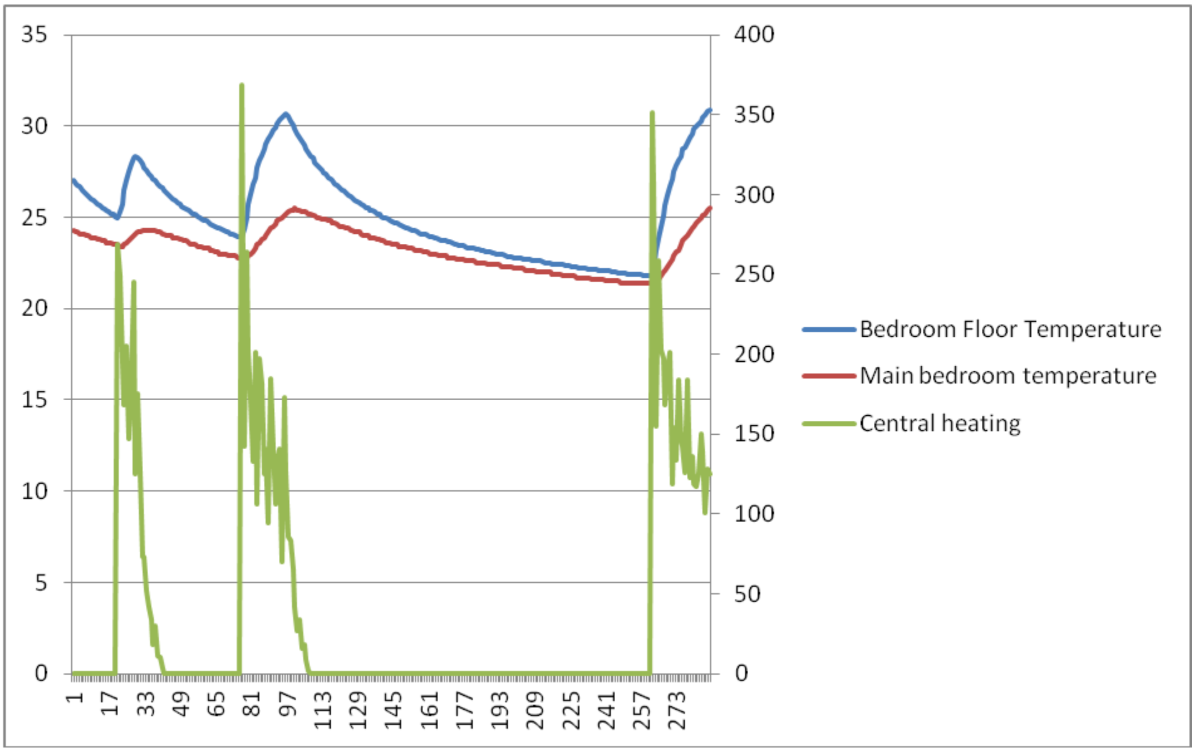


Figure 10: Bedroom floor and room temperature responsiveness to heat pump

A.2 Flat No 6 - 3 Bedroom

Site Statistics:

- EAHP
- Supplies DHW and underfloor heating
- Heat pump sited in airing cupboard
- New build three bedroom flat, 2nd floor
- 1 adult, 2 children
- Floor area – $83m^2$
- SAP rating of 79, measured HLC = 113W/K

Comments:

This flat was a three bedroom flat which was situated on the second floor in the middle of the block. The monitoring equipment and schematic was the same for both properties under test. The flat was occupied by a family, including one adult and two children. The occupants used the thermostats to control the heating and switched from 14°C during the day to ~30°C if they thought heat would be required in the evening. They struggled with the time lag and had to think about if they needed to heat much earlier in the day than when they had a gas/radiator system. They did not like to leave the heating on continuously because they felt this wasted money.

The heat pump in this flat had an annual system efficiency of 1.42, which peaked at 1.8 in April and October 2011.

There was immersion use seen fortnightly during the summer (April and October 2011), this was likely to be a sterilisation cycle. Generally there was little immersion use when the ambient temperature was greater than 13°C. There were some days in February 2012 with excessive immersion use which was when there were problems with the EAHP unit. The immersion use was most likely to be about 70% of the total electric load of the heat pump.

The DHW use of the property was high: ranging from 10 to 25 kWh/day. This will contribute to the poor system efficiency because the COP of a heat pump is lower when heating to 50°C rather than 30°C. The DHW temperature was typically 50°C. The heat output of the EAHP is stated to be 1200W 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 is required to maintain the DHW supply. Therefore it is likely that the immersion would be required to provide any further heating i.e. the central heating. With the considerable background DHW use observed, the immersion will be required at much lower delta Ts (see Figure 13), to provide space heating.

The R^2 is 0.8305, which indicates that 83% of the heat is led by the degree day heating requirement.

On the 17/02/12, there was a flow around the central heating system all the time. The flow temperatures were low ~35°C.

Figure 14 shows that the system efficiency ranged between 1 and 2, even in the summer when it was mostly running in heat pump operation. The COP should be between 2.5 and 3 (depending on air flow rate) when heating water to 50°C according to manufacturer data, so the COPs of between 1 and 2 were surprisingly low, suggesting there might have been a further fault with the heat pump. The immersion commenced operation when the electric input was approximately 560W. Since the compressor was rated at 650W, this appeared to be kicking in too early.

The floor and room temperatures drop as the heat pump turns down in the morning. The floor temperatures respond fairly quickly to the heat pump turning back on in the evening; however the main bedroom temperature does not reach the same temperature as the rest of the property, the cause of this is unclear.

In the resident survey, 21/03/12, the householder at flat 6 expressed that the temperatures achieved are neither comfortable nor uncomfortable, however has found the bills higher than expected. The main point of dissatisfaction is the lack of control over the temperature in the flat. The resident uses a bi-modal heating pattern and therefore would like to experience an instantaneous and noticeable increase in heat when the thermostats are turned up. This is not possible with this sort of heating system and the resident has to predict when heat will be wanted hours in advance. This is difficult and is likely to lead to dissatisfaction.

System efficiency by month:

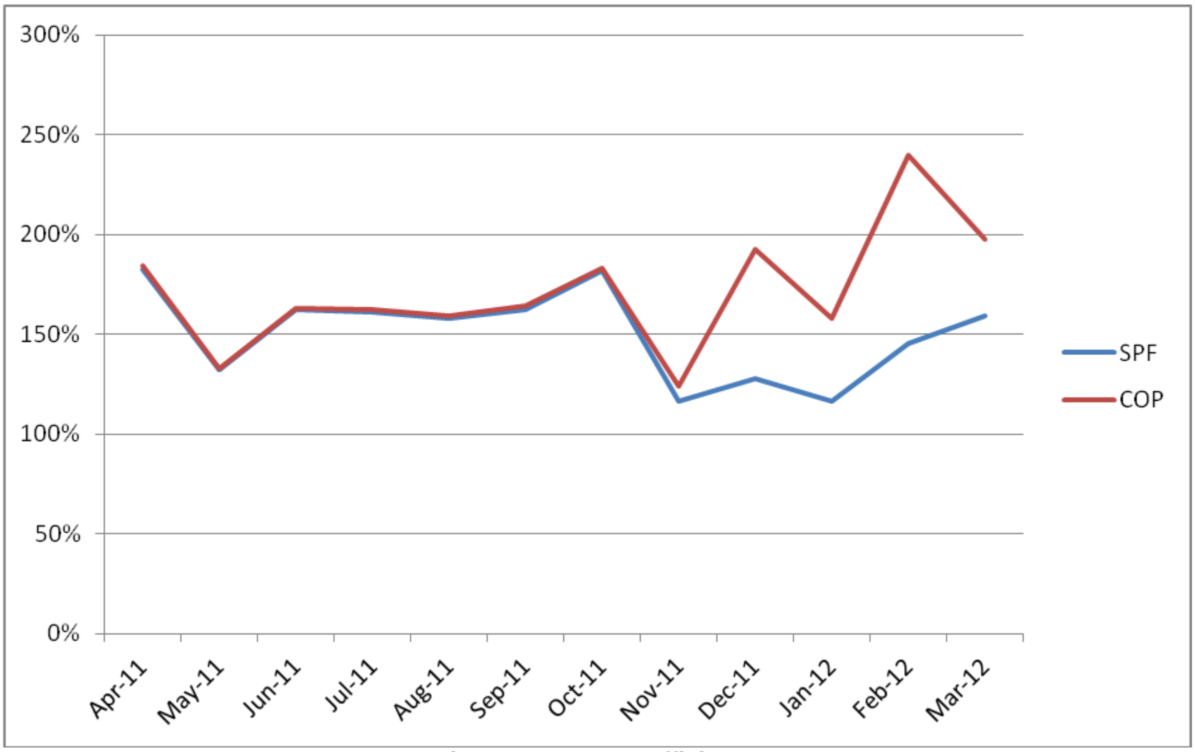


Figure 11: System efficiency

Immersion Use:

Table 5: Immersion Use Flat 6

	Electric Power to the HP	Heat Pump immersion	% immersion use	CH direct heat out	DHW heat out	Apparent Overall Efficiency	COP (without immersion)
	(kWh)	(kWh)	(%)	(kWh)	(kWh)	(%)	
Apr-11	230	6	1%	138	280	182%	1.85
May-11	191	5	2%	0	252	132%	1.33
Jun-11	203	2	1%	0	329	162%	1.63
Jul-11	200	4	2%	0	322	161%	1.62
Aug-11	192	3	1%	0	304	158%	1.59
Sep-11	214	6	2%	0	348	163%	1.64
Oct-11	288	4	1%	82	443	182%	1.83
Nov-11	411	138	23%	100	378	116%	1.24
Dec-11	1100	771	68%	900	505	128%	1.93
Jan-12	942	673	69%	583	516	117%	1.58
Feb-12	1081	730	57%	1109	461	145%	2.39
Mar-12	556	216	31%	336	550	159%	1.97

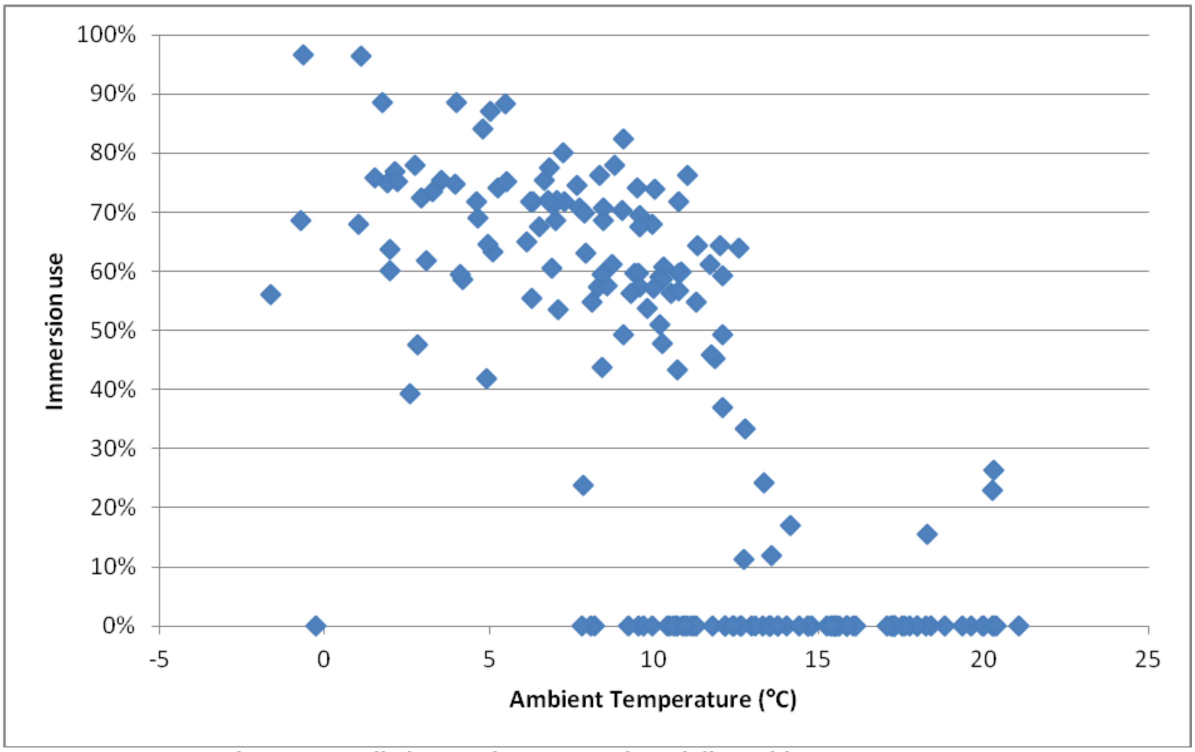


Figure 12: Daily immersion use against daily ambient temperature

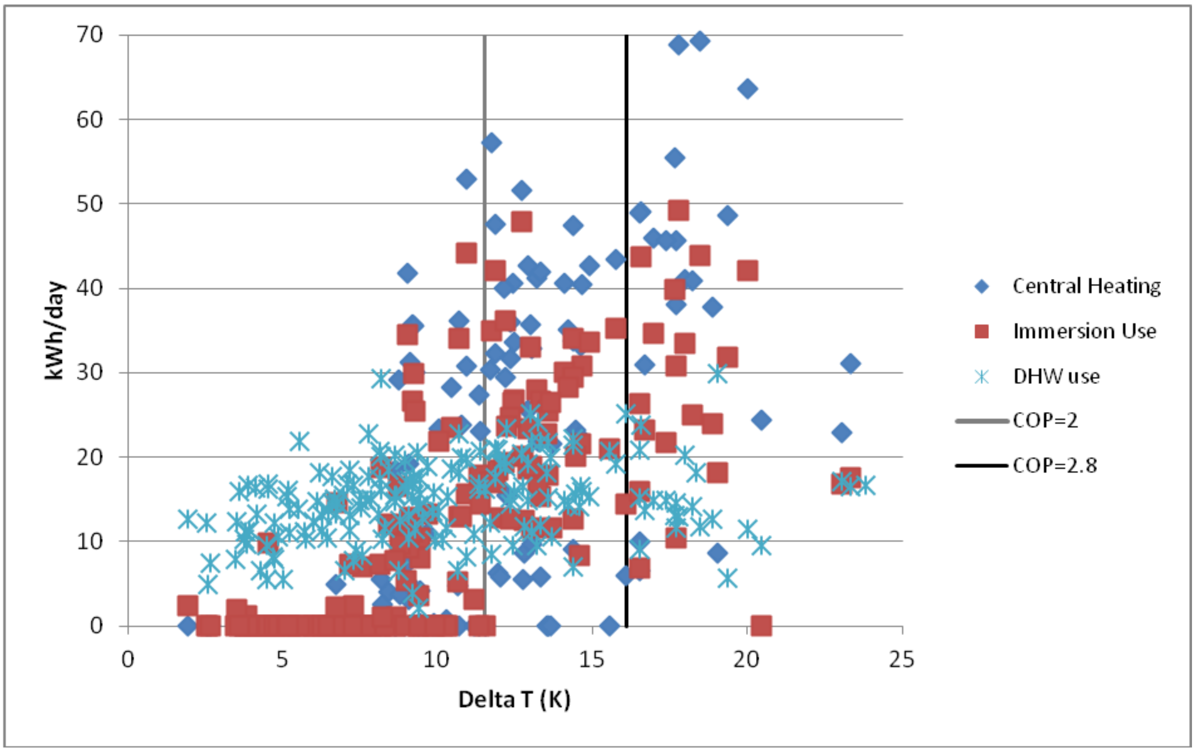


Figure 13: Central heating and immersion use per day at different delta Ts (internal – external temperature)

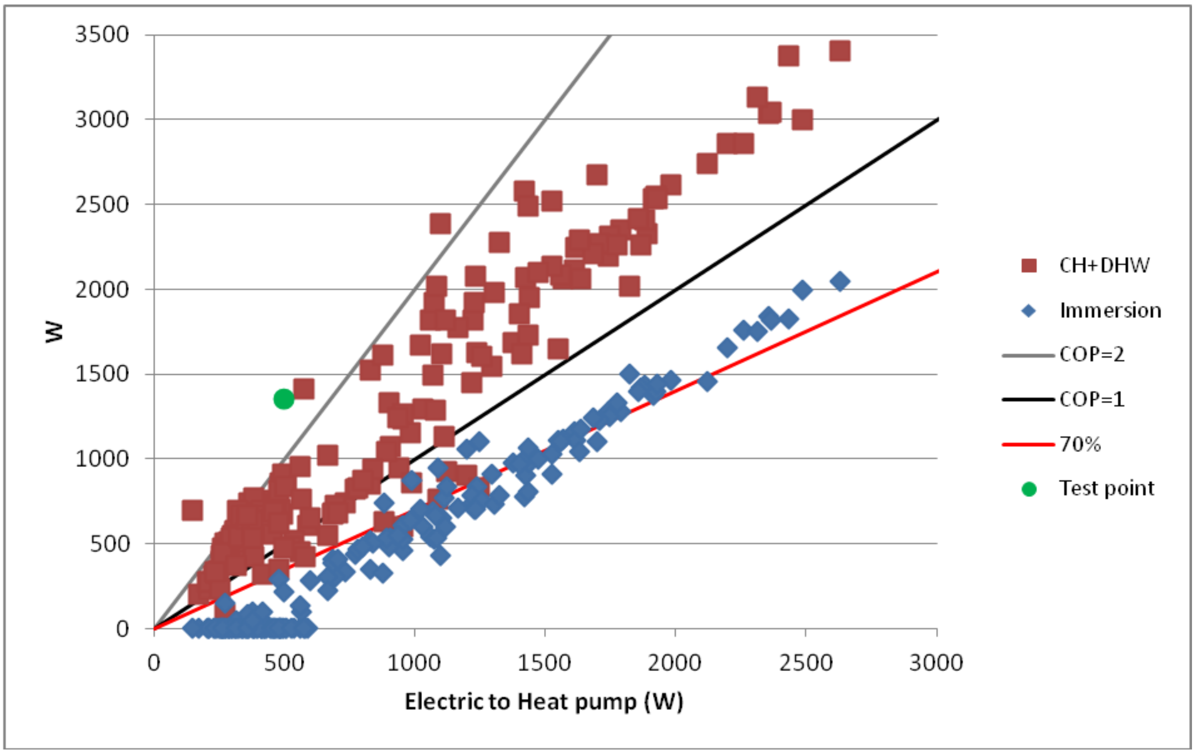


Figure 14: Average electric vs. average heat output and immersion use

Heating Patterns:

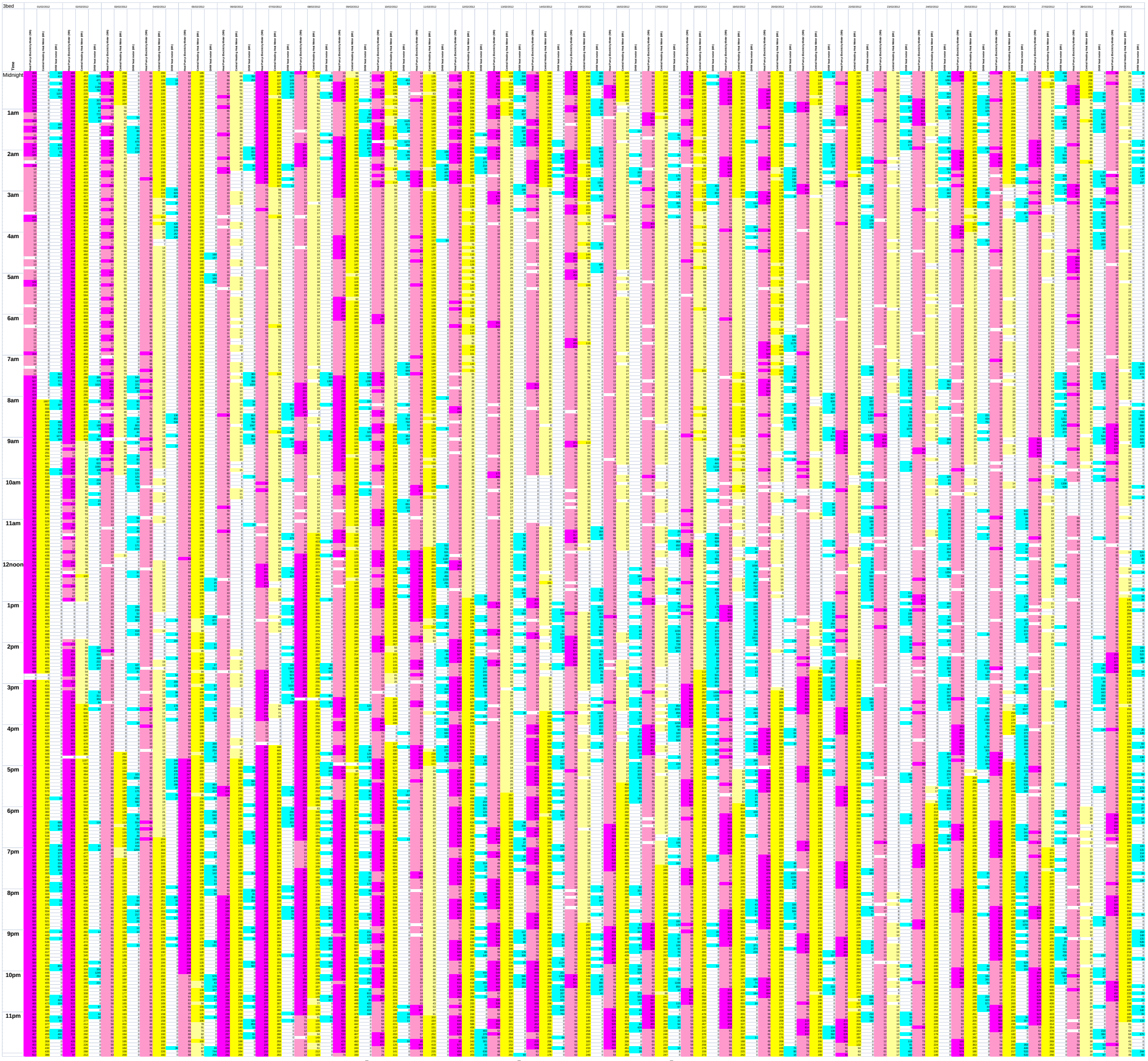


Figure 15: Heating pattern February 2012

Control System Analysis

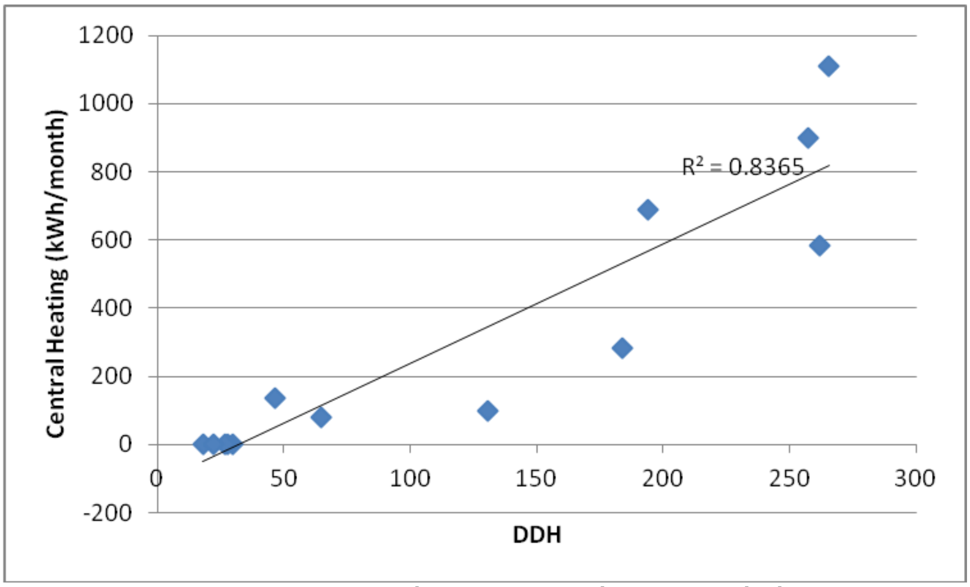
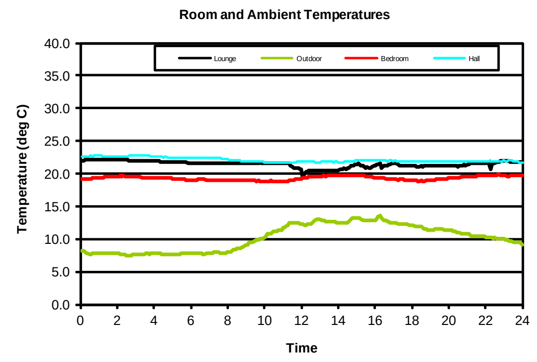
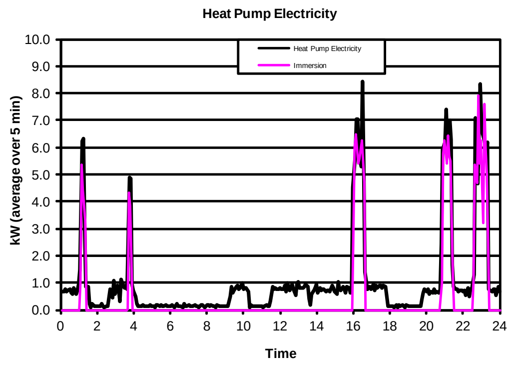


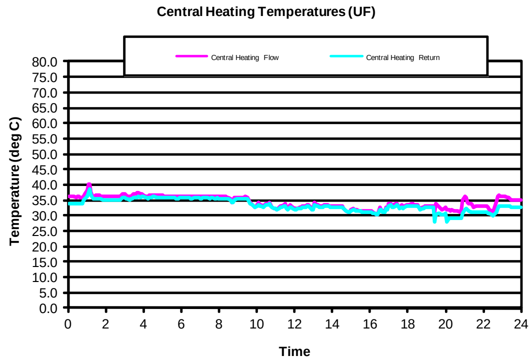
Figure 16: Control system analysis

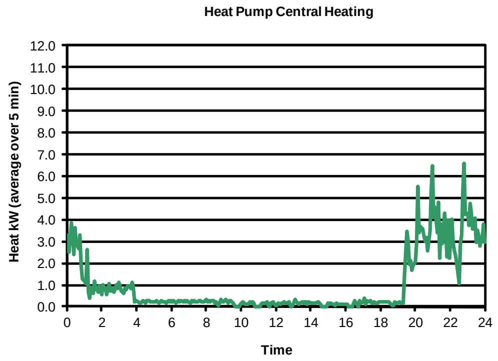
Intraday graphs

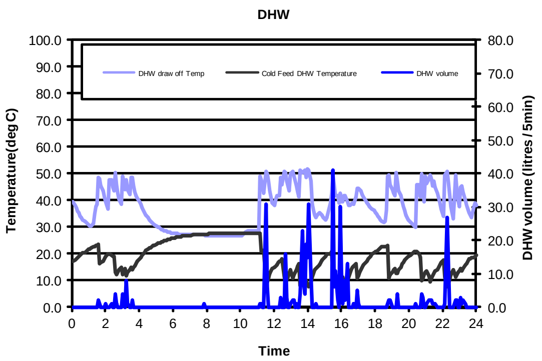
17/02/2012

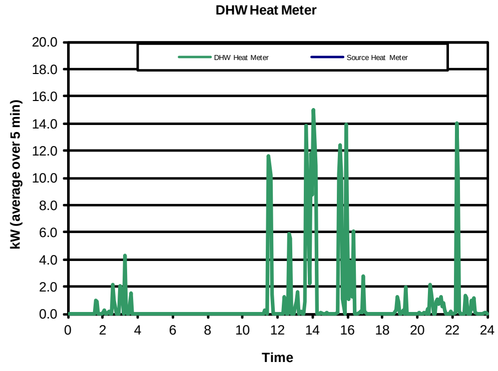








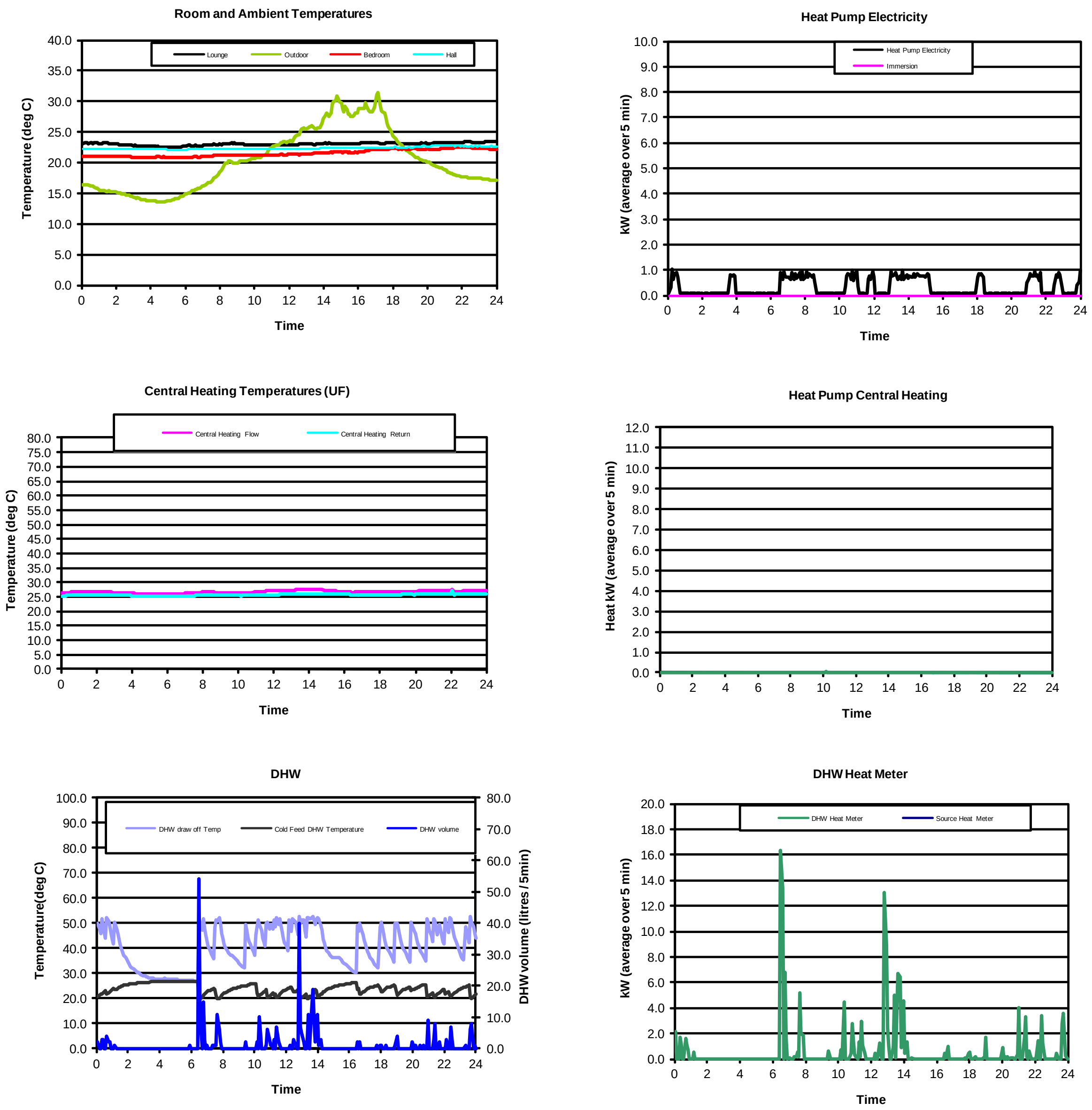




Total electricity consumption (KWh)	25.38
Total central heating heat (kWh)	23.76
Total DHW heat used (kWh)	19.90
Total output energy from heat pump (kWh)	43.66
HP Daily SPF (based on total heat pump output)	1.72
Immersion consumption	12.93
% immersion	51%
Average Ambient temperature	10.17

Figure 17: Intraday graph 17/02/12

15/07/2011



Total electricity consumption (KWh)	7.60
Total central heating heat (kWh)	0.01
Total DHW heat used (kWh)	13.57
Total output energy from heat pump (kWh)	13.58
HP Daily SPF (based on total heat pump output)	1.79
Immersion consumption	0.00
% immersion	0%
Average Ambient temperature	20.23

Figure 18: Intraday graph for 15/07/11

Responsiveness of Underfloor

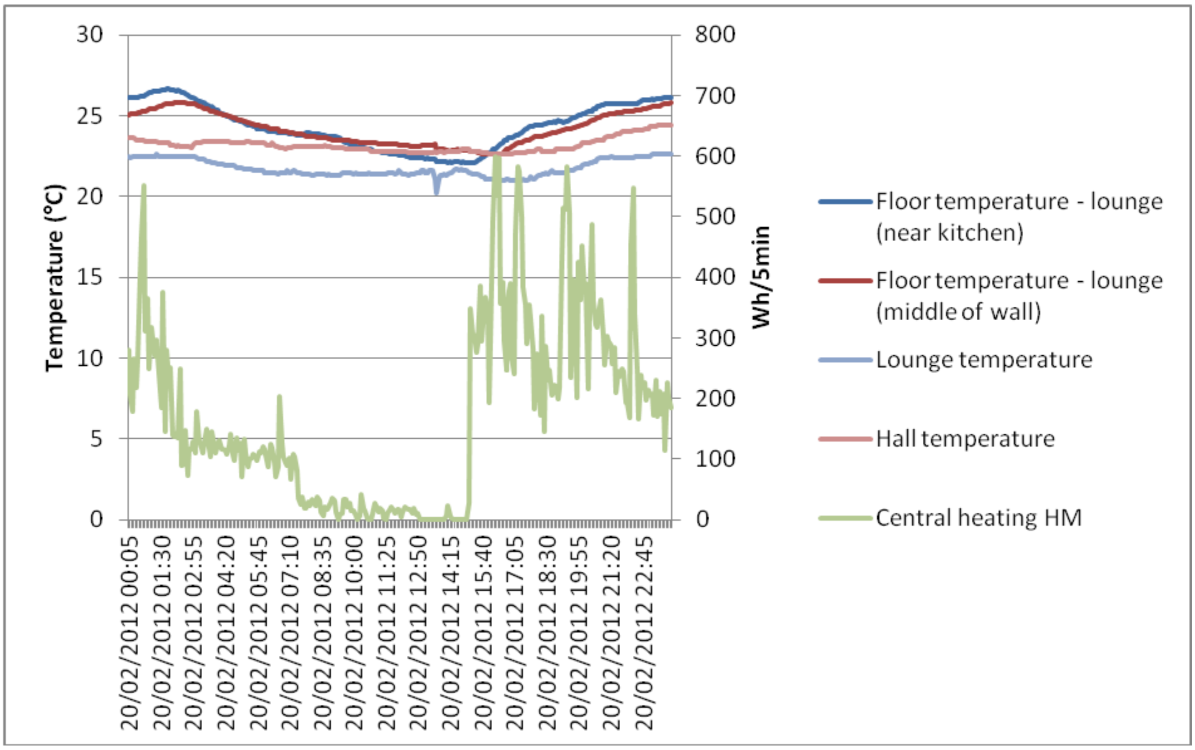


Figure 19: Lounge floor and room temperatures

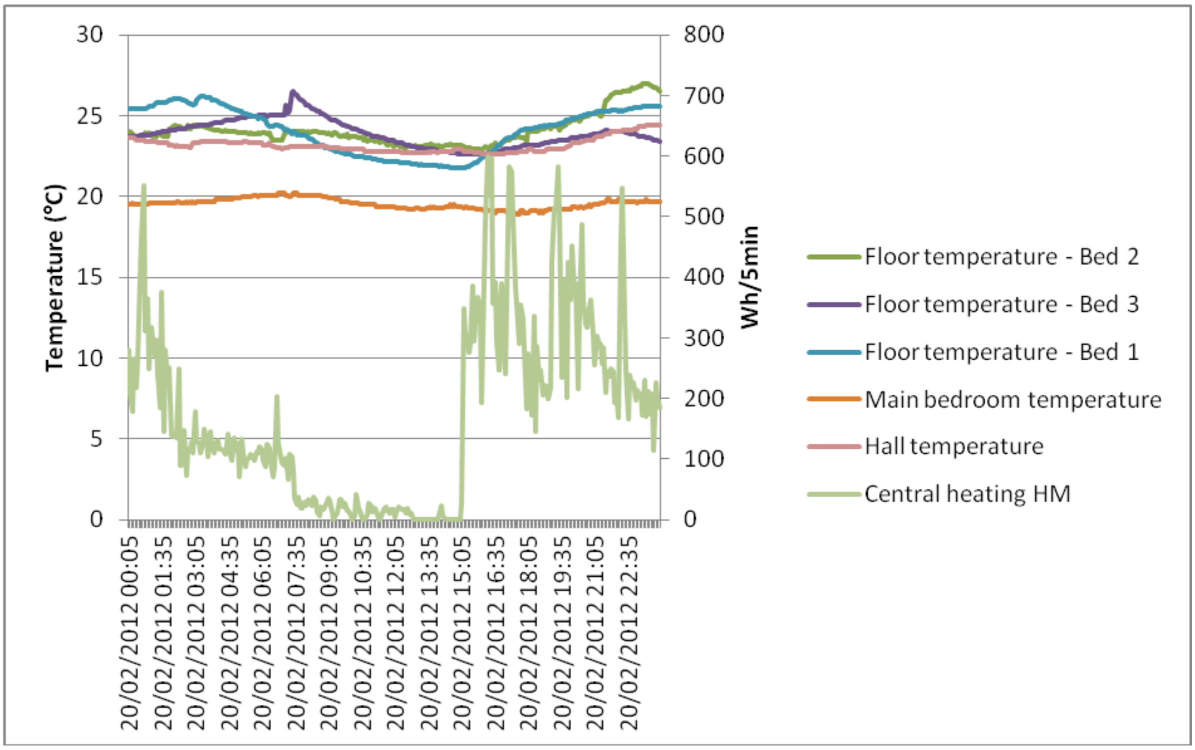


Figure 20: Bedrooms floor and room temperatures

Appendix B Analysis Techniques

B.1 COP analysis

The Coefficient of Performance (COP) of a heat pump (i.e. the heat delivered divided by the electrical energy supplied) varies with both source and sink temperature. The COPs reported by manufacturers (and, by inference, those that householders might expect) are only measured at very limited points (laboratory conditions) typically: source at 0°C or 7°C and sink at 35°C or 50°C, whilst in reality a much wider range of conditions is encountered.

A period of about one hour was chosen from the data when the heat pump compressor was operating in steady state and the fluid temperatures were relatively constant. This period was when the immersion was not operating. Data supplied by the manufacturer (COP B in Table 3) was used to determine the expected performance at the same conditions and this was compared to the actual performance. A low ratio of measured to predicted COP would indicate that the heat pump was performing less well than expected.

The COP analysis is presented in Section 3. Results from the other analysis techniques used (described below in Sections B.2 to B.6) are presented in the individual site Appendices.

B.2 Site descriptions and monitoring schematics

Each site is discussed in some detail in the Appendix. This includes a simple schematic showing the system layout and the locations of the monitoring equipment. The monitoring equipment is basically made up of:

- Heat meters, positioned at key points to measure the energy flows
- Temperature sensors, strapped to the copper pipework
- Ambient temperature sensors to measure room temperatures and the outside temperature
- Electricity meters to measure the electrical input into the key components.

B.3 Monthly System Efficiency

The system efficiency or seasonal performance factor (SPF) is a measurement of the ratio of all the heating output from the heat pump (central heating + domestic hot water) to all the energy the system consumes (electrical – compressor, immersions, pumps

Graphs have been produced for each site to indicate the system efficiency on a monthly basis.

The system efficiency is based on energy delivered to the CH and used by DHW draw-offs. This is not the same as the heat output of the heat pump and hence system efficiency may be lower than expected from a short spot calculation of COP. This is particularly noticeable in the summer months, when DHW use dominates, since the energy supplied to the DHW tank may be considerably in excess of that supplied to the taps, depending on usage patterns and system heat loss characteristics.

B.4 Immersion use

Table 3 and 4 shows immersion use, system efficiency and COP. The COP is calculated by taking the ratio of all the heat pump's heating output (central heating + domestic hot water) minus immersion use to all the energy the system consumes (electrical – compressor, pumps) excluding the immersion.

Graphs 3 and 11 show the immersion use of the EAHP unit against ambient air temperature, this was used to look for a cut off external temperature where the heat pump will not use the immersion.

Graphs 4 and 12 plot the daily central heating and immersion use at different delta Ts, (delta T is the difference between the external and average internal temperature of the property). The HLC of the property was used to find the delta T for different COPs and therefore different heat pump outputs. For instance, if the heat pump output was 1000W, and the HLC of the property was 100W/K, then the heat pump could heat the property by 10°C. The immersion use was plotted alongside this to see whether the immersion was being used when the heat pump could have fulfilled the heat demand.

The daily electric use was plotted against the daily central heating and DHW use (in red) and daily immersion use (in blue) in graphs 5 and 13. The lines for COP of 1 and 2 are also shown on the graph so it can be seen where the daily points fall. Also plotted was the average immersion use to see whether there was a divergence from this at any point.

B.5 Heating Pattern

For each site a "Tapestry" was produced to show the heating patterns for a particular month (February 2012). This heating pattern demonstrated, at a glance, how the heat pump was performing over a particular month.

The key for heat pump tapestries is shown in Figure 1, the electricity use of the heat pump was coloured bright pink if it was greater than 80Wh in the 5 minute period (indicating immersion use) and light pink if between 10Wh and 80Wh, the heat output to Central Heating was coloured yellow, while the DHW output to taps was coloured blue if greater than 10Wh in 5 minutes.

The tapestries were used to determine how the householders were heating their houses: whether they have set their programmer to come on for the same time periods all the day; or whether they were continuously heating their home. This tool can be used as part of the overall diagnostic approach to establish how householders control their houses.

Figure 21: Key for Monthly Tapestries for Heat Pump Use

Electricity Use	
	Less than 10 Wh per 5 minutes
	Over 10 Wh but less than 80 Wh per 5 minutes
	Over 80 Wh per 5 minutes
Central Heating	
	Less than 10 Wh per 5 minutes
	Over 10 Wh but less than 100 Wh per 5 minutes
	Over 100 Wh per 5 minutes
DHW Use	
	Less than 10 Wh per 5 minutes
	Over 10 Wh per 5 minutes

B.6 Control System Analysis

For low carbon heating, not only should the heat pump give a good COP but it should be readily and accurately controlled. By plotting heat output vs. degree day heating requirement on a monthly basis we can determine the controllability of heating systems.

If the control of the heating system is very good throughout the year, the plotted variables should form a straight line of points and thus have a coefficient of determination (R^2) value close to 1. This is because, when the system is well controlled, the heat output should be closely related to the degree day heating requirement. The poorer the control, the smaller the R^2 value. It is expected that the line should pass through or just above the origin, except where there is significant secondary heating.

If the line does not pass through the origin, it is probable that a significant part of the heat demand was being satisfied by a secondary heating system, alternatively it may indicate that there is a base load, such as a DHW. If the line crosses the y-axis, the intercept is an indication of the base load, if the line crosses the x-axis then there is likely to be supplementary heating to meet the heat demand.

B.7 Intra Day Graphs

Intra-day performance graphs are a good way of getting an in depth snapshot of the performance of a heat pump on a particular day. Graphs were produced mapping electricity consumption, heat production and temperatures over a ‘typical’ twenty four hour period. The graphs can visually give an indication of the way the heat pump is being operated, faults within the heat pump and how different modes of operation are affecting the performance of the heat pump