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Report to Harrogate Borough Council and NPower

Evaluation of Heat Pump Installations: Extracting Meaning from Existing Datasets

Final Report

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Executive Summary

1 The purpose of this study was to attempt a preliminary assessment of the Harrogate Heat Pump Installation Programme based on data already gathered by Harrogate Borough Council together with some additional data arising from a more in-depth study of a small number of typical dwellings

2 Data already held by H.B.C was based on manual readings taken from the heat pump control panels, and was necessarily sporadic and incomplete due to limited resources. The data collected was of two types. The first type consisted of a number of instantaneous system temperature readings. The "snapshot" nature of these readings severely limits their usefulness as a diagnostic or assessment tool. For these purposes it might be more appropriate to record instead a range of information on system settings (also obtainable from the heat pump control panel), as this would be more indicative of differences in the way the systems are operated which may lead to significant differences in electricity usage or efficiency.

3 The second data type was in the form of cumulative information about the number of heat pump operational hours, and the distribution between space heating, and water heating. From this information it is possible to calculate an estimate of the heat pump electricity usage, using nominal usage rates supplied by the manufacturer. It is important to understand that these figures are fairly crude estimates only, and they fail to take into account a number of factors which will affect the actual electricity usage. However, the calculations involved are quick and easy, so there may be value in continuing to collect this data for the purposes of screening individual installations for trends or unexpected changes over time. Nevertheless, the real performance and potential benefits of the systems cannot be properly understood unless the system CoP (Coefficient of Performance) and the SPF (Seasonal Performance Factor) are known, under real operating conditions, for a significant number of installations. At present, there is no way of establishing these parameters except by measuring energy input and heat output over a long period.

4 In the second part of the study, building fabric performance and occupant behaviour information was also gathered for 5 typical properties. This more detailed knowledge was then fed into an energy model based on SAP and the predicted electricity requirement compared with actual usage. In three of the five cases, the usage predicted by the model was within 10% of the actual usage over the period considered. However, the investigations revealed that even for fairly similar properties in terms of size, type and age, there can be a wide variation in building fabric performance and in occupant practices. This is likely to lead to significant variations in heat pump CoPs. Again, it is vital to acquire real measured CoP data for a number of dwellings in order to be able to estimate the range of this variation and to understand the most important contributing factors, some of which will relate to whole systems operation and component interactions as well as those relating to heat pump characteristics only.

5 In order to maximise the potential benefits of installing further systems it is recommended that both the building fabric performance and the heating system to be replaced should be considered. Dwellings which perform well in terms of air-tightness and insulation are more likely to result in good heat pump performance and tenant satisfaction. CO_2 savings will be considerably greater if the heating systems to be replaced are electric rather than gas. This discrepancy is likely to become even more marked as estimates of emissions factor for electricity are revised upwards in the National Calculation Methodology (SAP) for buildings regulation purposes. It is anticipated that the factor could be as high as 0.56 kg/kWh compared with the current value of 0.422 kg/kWh.

Summary of Conclusions and Recommendations

6 Conclusions:

a) The snapshot nature of data already collected is of very limited value as an assessment or diagnostic tool

b) It is not possible to assess the heat pump systems satisfactorily without a detailed knowledge of the CoP (Coefficient of Performance) and SPF (Seasonal Performance Factor) for at least some installations. Simple methods of estimating electricity usage from manufacturers' data and operational hours are subject to a number of errors.

c) The intensive part of the study shows that there is a wide variation in the performance of the building fabric, even in broadly similar properties of a similar age. This may have a significant effect on heat pump CoP.

7 Recommendations:

a) Some alterations to Harrogate's routine data collection protocol have been recommended. It is understood that routine data collection is undertaken with limited resources, and must therefore provide as much potentially useful information as possible within a very basic framework.

b) CoP and SPF measurements should be made over an appropriate time period (at least one year), for a representative sample of installations.

c) Dwellings should be assessed for potential fabric-related issues prior to heat pump installation.

d) Heat pumps should be installed preferentially in those dwellings which offer the highest potential carbon savings, i.e. off-gas grid properties where the fabric performs well or can be upgraded to a high standard.

Introduction and Background

8 In 2005 Harrogate Borough Council undertook a pilot project to install eight IVT Greenline C4 Ground Source Heat Pump systems in a small social housing development in the Borough. The systems were supplied by Ice Energy and installed by Help Link, and they replaced either coal fire with back boiler, or electric storage heater systems. The eight pilot installations were followed during the period May 2007 to February 2008 by the installation of a further 70 GSHP systems across the Borough. This second, larger group of installations were all IVT Greenline HT Plus C6 models, with a capacity almost 50% higher than the C4 model.

9 Harrogate Borough Council undertook some monitoring of the pilot group systems in the 21 months following their installation. This consisted of manually reading and recording various parameters from the heat pump control panels at intervals ranging from a few weeks to several months. However because this was a new venture, it was not clear at this stage what parameters or data collection regime would prove to be most useful in understanding the way the systems were operating. When the larger group of installations took place in 2007/2008 a similar method of monitoring was adopted by default, as additional staff resources were not available to undertake detailed analysis of the data collection regime. The rapidly expanding numbers of installations also meant that data collection could not be undertaken as regularly as for the pilot group, and the data which was collected could not be processed.

10 Nevertheless Harrogate Borough Council was fully aware of the importance of understanding as much as possible about the operation and potential benefits of the heat pumps under real conditions, including the effects of building fabric and other systems effects on the operation of the heat pumps. Therefore the Council, in association with Npower assigned to Leeds Metropolitan University the task of processing the data already collected, analysing the current data collection procedures, and developing a strategy for further enhancing understanding of the systems in context.

11 This report presents the results of that study. The available data is surveyed to extract useful information where possible, and recommendations are made for optimising future monitoring or installation procedures. A small group of properties (5) was investigated in some detail with respect to building fabric and occupant behaviour as well as heat pump operation, and the results of this intensive study are also presented[1]. The detailed objectives of the project were as follows:

a) To trawl existing data held by the council so as to build up a picture of the context in which the heat pumps are operating and the pattern of energy consumption across the cohort of installations that have been completed.

b) To evaluate, as far as possible from existing data, the extent to which the change from previous heating systems to the heat pump systems has been instrumental in any apparent change in energy consumption and associated carbon emissions.

c) To enhance the analysis undertaken in objectives a) and b) through a small number of detailed investigations of typical installations.

d) As far as existing data will allow, to comment on the process of design, installation and use and to identify any factors that could improve performance overall.

Installation and Operational Details

Property Types

12 The pilot group of properties consisted of eight semi-detached one and two-bedroom bungalows built by the Local Authority in the 1970s. The bungalows are of cavity wall construction with

[1] Note that this group of 5 properties (the intensive group) should be clearly distinguished from the group referred to as the pilot group of properties, which represents the first group of heat pumps installed (C4 models cf. C6 models for all subsequent installations).

pitched, tiled roofs and uPVC double-glazed windows (H.B.C. 2007). Prior to the installation of the heat pumps the properties already had both cavity wall and loft insulation, but additional loft insulation was installed concurrently with the heat pumps to bring them up to the prevailing (2005) building regulations standards for new dwellings, and to take advantage of available grants. The properties are in a rural location and have no mains gas. Previous heating systems were either solid-fuel or electric storage heaters.

13 The main group of 70 properties were distributed across the Borough, with the majority of installations located in Harrogate, Ripon and Masham. In this group there is a mix of types, with some houses and bungalows dating from the 1920s and '30s; flats, houses and bungalows from the '40s and '50s; and two houses built in 1990. The remainder are bungalows built in the '60s, '70s or later. By far the most common type (approximately half of all properties) is bungalows built during the period from 1960 to 1980. Occupancy data was available for almost all properties. The vast majority had either single or two-person occupancy. In around half a dozen cases (for larger semi-detached houses) the occupancy was 4 or more. Of this group of properties, at least 30, and probably 40 or more, require additional loft insulation to bring them up to current standards. Previous heating systems were solid-fuel, electric storage heaters or mains gas.

14 The group of 5 properties studied as described in paragraph 11c), (the intensive group) were all bungalows with single or two-person occupancy, built between 1960 and 1980. One of these was from the pilot group, and the rest were from the main group. All were in rural village locations.

Heat Pump Specifications

15 All the heat pump systems were designed to provide both space heating and domestic hot water, with hot water demand taking priority over space heating. The systems also include an integral resistance heating coil which boosts flow temperatures when additional heat input is required for either space or water heating as well as guaranteeing the ability of the system to perform a regular (weekly) pasteurisation cycle designed to guard against the accumulation of legionella bacteria in the hot water system. The total supplementary resistance heating available is 6kW for both C4 and C6 models (IVT Industrier AB, 2003, IVT Industrier AB, 2004). This is arranged in 2x3kW modules (i.e. only one 3kW module is called upon if this is sufficient to boost the heat pump output to meet demand). Under most conditions it is possible for the C6 models to achieve a sufficiently high water temperature for the weekly pasteurisation cycle without recourse to additional resistance input.

16 The heat pumps are normally operated such that the return temperature from the heating system is approximately 35°C This is a low temperature for conventional radiators and is more suited to an under floor distribution system. In Harrogate the existing radiators were replaced with new radiators oversized by 30% to partially compensate for the low distribution temperature.

17 The ground loops for the pilot group of properties were all initially panels, laid vertically in 6 cases and horizontally in the remaining 2 cases. In the larger group, the ground loops were all vertical boreholes as available ground space was an issue in some cases.

Installation Issues

18 For the pilot properties with panel ground loops, it was discovered that ground movement during the settling period tended to strain joints between panels, leading to heat collection fluid leakage. Persistent ground leaks have led to two of the vertical panels being replaced by boreholes, since it was found to be more cost-effective to excavate new boreholes than to locate and repair panel leaks. One of the pilot group properties has recently also been fitted with an additional air panel, intended to provide some pre-heating to fluid returning to the ground loop in appropriate circumstances.

19 The installation period for the main group was between May 2007 and February 2008. It was found that for some of the properties where installation took place during the winter, it was necessary to pre-heat the properties using resistance heating only, to avoid excessive further cooling of already cold ground. Also, due to the large number of installations taking place at that time it was sometimes necessary to install the heat pump before connecting to the ground loop, also necessitating use of the resistance heating only for a short period.

Heat Pump Temperature Control

20 The heat pumps automatically control the return temperature for space heating according to a pre-set "heat curve" which determines the return temperature set-point for any given outdoor temperature. The outdoor temperature is measured by a temperature sensor located on the outside wall of the property.

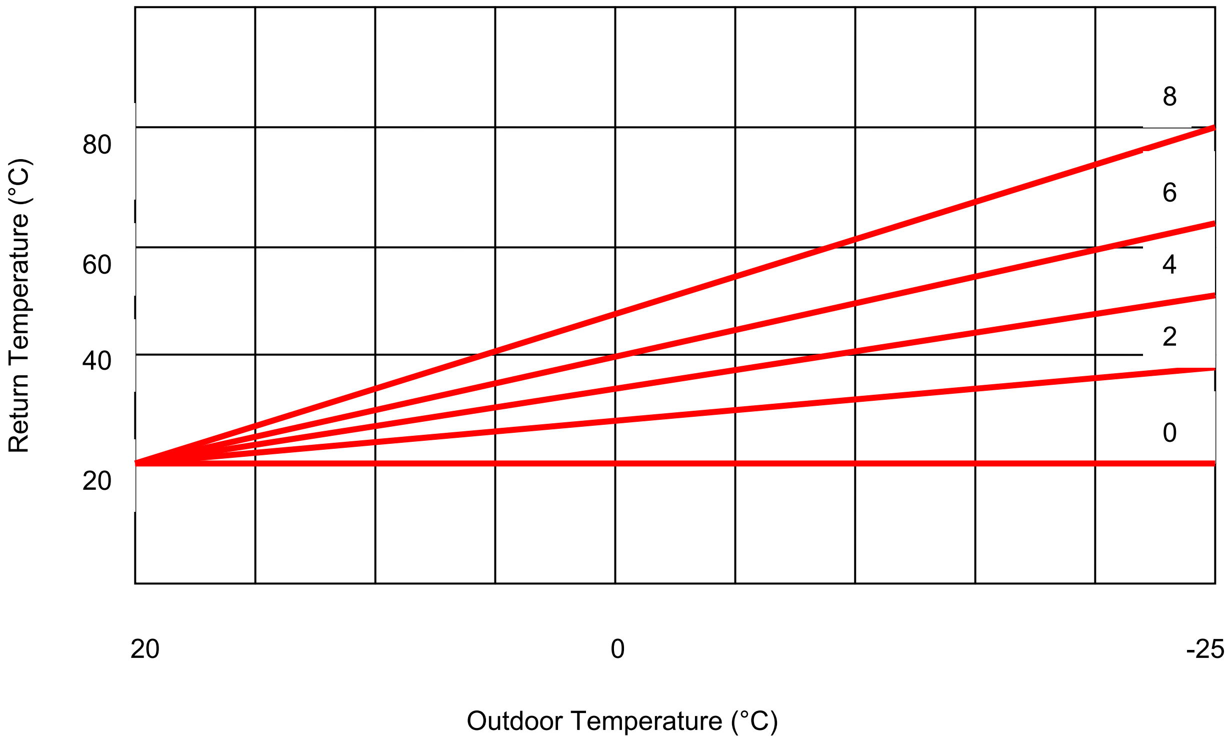

Figure 1: Effect of Different Heat Curve Settings

A number of heat curve settings are available and this enables each system to be set up to suit different requirements. The higher the slope of the preset heat curve, the higher the set-point temperature for a given outdoor temperature (below 20°C). The curve slope can be set by the user via the control panel (see paragraph 24 and Figure 4). The factory default setting is curve slope 4, which gives an output temperature of 35°C when the outdoor temperature is 0°C. Clearly a lower value of slope results in more efficient operation, but may not provide the required level of service. This means that the setting will always be a compromise between maximising efficiency (CoP) and the maintenance of comfort. Of course the settings required are also likely to be dependent upon the insulation and air-tightness of the building fabric.

21 The heat curve can also be 'fine-tuned'. If a higher fine-tuning number is chosen, then the heat curve slope remains the same but is offset from its normal position as shown below.

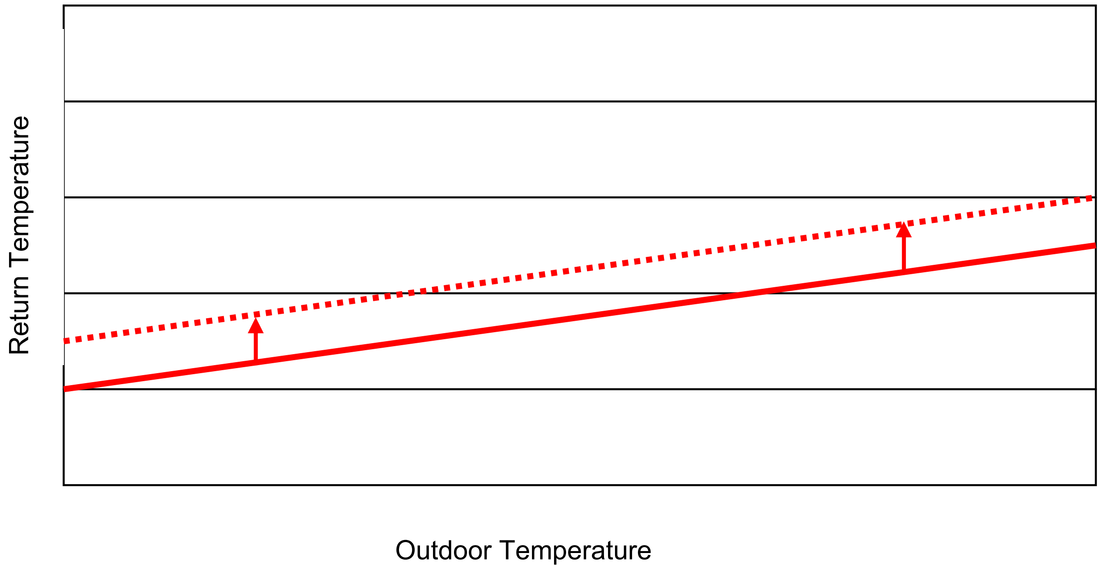

Figure 2: Fine Tuning

The fine-tune number can be increased or decreased from the factory default of zero, resulting in an increase or decrease in the return temperature set-points for all values of the outdoor temperature.

22 Although the temperature sensor located on the outside wall of the dwelling provides the main input which determines the space heating return temperature, the Harrogate systems are also fitted with indoor room temperature sensors. A set-point value for the room temperature can therefore also be input to the pump. However, this input is only capable of fine-tuning the heat curve to a greater or lesser degree (depending on the "degree of influence" setting chosen), and so it is important to ensure as first priority that the basic heat curve slope and fine-tune settings are optimised for the demand.

23 As well as these input temperature values, various fluid temperatures are continuously monitored at different points within the system in order to determine when set-points are reached and hence control the on/off cycle of the pump. A full list of temperature sensors is given below, together with a diagram to show their location in the system

a) T1 Radiator return flow temperature
b) T2 Outdoor air temperature
c) T3 Temperature of lower & outer section of electric water heater (around 5° lower than the temperature in the hot water tank
d) T4 Not applicable
e) T5 Room sensor temperature
f) T6 The working temperature of the compressor
g) T7 Not applicable
h) T8 Outgoing temperature from the heat pump (heat transfer fluid)
i) T9 Ingoing temperature to the heat pump (heat transfer fluid)
j) T10 Temperature of incoming fluid from the borehole or panel
k) T11 Temperature of outgoing fluid to borehole or panel.

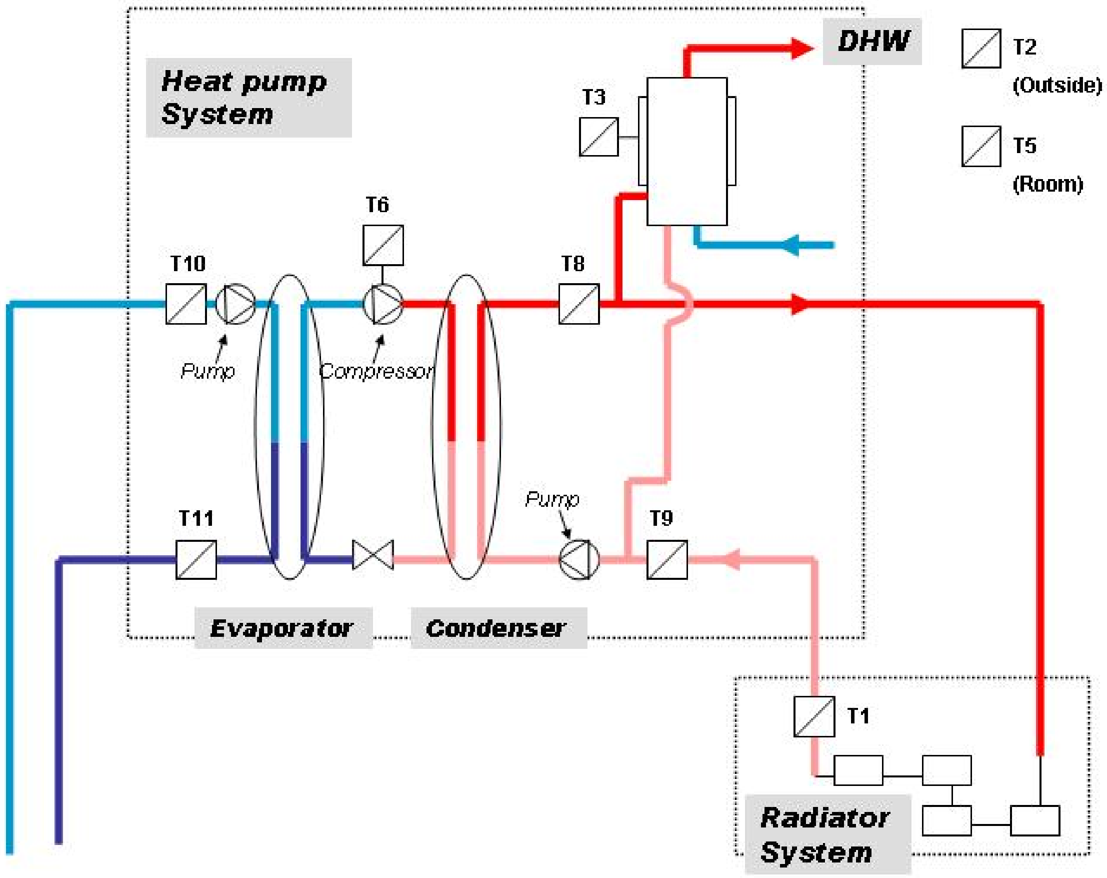

Figure 3: Heat Pump Control System (Temperature Sensors)

Heat Pump User Interface

24 The heat pump units are controlled via a control/display unit shown below

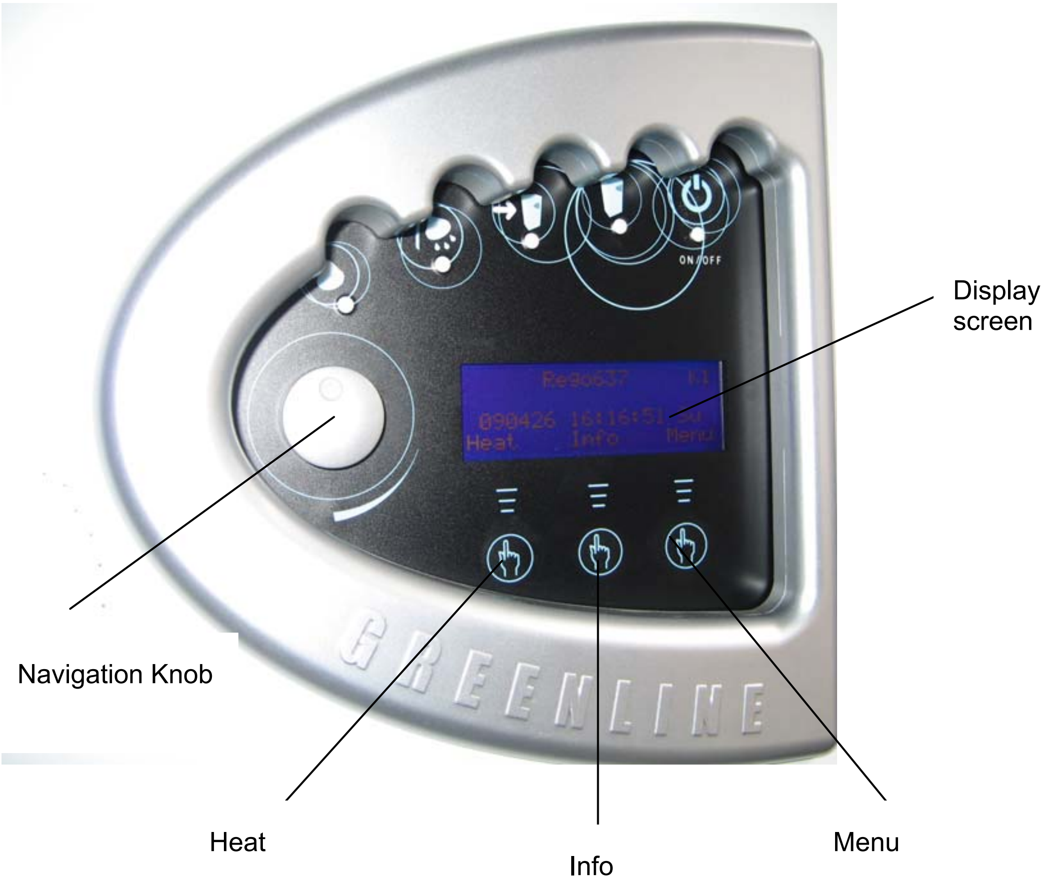

Figure 4: Heat Pump Control/Display unit

The three buttons designated Heat, Info and Menu, together with the navigation knob give access to a variety of menus and menu items, enabling the user to read off current parameters and settings, or to change settings as required. Parameters such as room temperature set-point and influence, heat curve slope, fine-tuning, hot water temperature set-point etc. may be set or altered. Instantaneous values of all the temperature sensors listed in paragraph 23 may be read off at any time.

25 It is also possible to read off from the heat pump display a group of parameters designated 7.1-7.4 on the control panel, which record the following cumulative data:

a) 7.1: The total number of hours that the heat pump has been in operation

b) 7.2: The distribution of these total hours between hot water and radiator heating.

c) 7.3: How many hours (total) that the additional resistance heating has been operating.

d) 7.4: The distribution of additional resistance heating between water and space heating.

Existing Data: Harrogate Borough Council Data Collection and Analysis Procedures

Data Collection

26 Data was collected by Harrogate Borough Council by visiting dwellings and noting readings from the heat pump control panel. The readings noted, in most cases were the instantaneous temperature sensor readings plus the cumulative hours data (7.1 – 7.4) detailed in paragraph 25 above. However in some cases the dataset for a particular dwelling is incomplete with either some temperature sensor or some cumulative hours data missing. In a very few cases the heat curve

slope and fine-tune number was also recorded. Also in a few cases electricity meter readings were taken at the same time as the heat pump readings.

27 It was originally intended to collect a full set of readings for each property shortly after installation and then at least annually thereafter. However due to absence of the resources required to visit a large number of properties regularly, some systems have not had readings taken since installation, and some others have no readings available at all. Of those properties with at least two sets of readings recorded (54 of 78), the interval between readings varied from just over 2 months to over 14 months.

Data Analysis

28 For the pilot group of properties, Harrogate Borough Council adopted a standardised procedure for estimating the electricity used by the heat pump, based on the cumulative data readings 7.1 – 7.3 (i.e. the number of heat pump operational hours, the distribution of these hours between space heating and water heating, and the number of additional resistance heating hours. These calculations depend upon the use of nominal values (provided by the manufacturer) for the rate of electricity consumption (power usage) in the three modes of operation i.e. HP space heating (assumed return temperature 35°C); HP water heating (assumed temperature 50°C); and resistance heating. In the calculation, these three modes are deemed to cover all possibilities.

Example Calculation:

For the C4 models, the rates of electricity consumption provided by the manufacturer were as follows:

HP (Space Heating @ 35°C): 1 kW

HP (Water Heating @ 50°C): 1.2 kW

Additional resistance heating: 3.2 kW

Therefore over a period where the hours recorded by the heat pump were 100, 50 and 10 respectively for the three modes, the total electricity consumption is:

$$(100 * 1) + (50 * 1.2) + (10 * 3.2) = 192 \text{ kWh}$$

In this type of calculation only the rate of electricity consumption (power) of the compressor is included in the nominal rate figures, and no account is taken of the power usage of the circulation pump, or of any effects due to cycling frequency. Therefore the calculation will almost certainly underestimate the actual total energy usage of the heat pump. The average assumed return temperature for space heating of 35°C is based on an outside temperature of 0°C and a heat curve setting of 4.

29 In the case of the larger group of properties this analysis was not performed by H.B.C., but in 46 cases there was sufficient data available for it to be performed subsequently as part of this study, using nominal consumption rate values appropriate to the C6 models.

Existing Data: Temperature Sensor Data

External Air Temperature

30 As previously stated, the external air temperature is measured by a sensor located on the outside wall of the property. Although air temperature data is collected continuously for the purpose of controlling the system, the only recorded information available was the value showing at the instant that heat pump readings were taken by H.B.C. This instantaneous value of air temperature was recorded on a different date and at a different time of day for each installation. However, it was possible to plot these instantaneous air temperature readings on the same graph as the daily temperature profile (mean, max and min) recorded by the Knaresborough/Scotton Weather Station. This weather station is a Davis Vantage Pro system, which automatically uploads data to a website (Briggs, S) every hour. The location is 2 miles from Harrogate, around 10 miles from Ripon and around 18 miles from Masham, and is therefore a reasonable estimate of the daily temperature profile (mean, max, min) across the various property locations. The figure below (Figure 5) shows

that there is a tendency for the externally measured air temperatures to exceed the maximum temperature for that day recorded by the weather station. This effect is found in a number of properties in all three main location areas, and is therefore not likely to be an effect of different conditions obtaining in areas further from the weather station.

31 Although efforts were made to install the external temperature sensors on a North-facing wall where possible, clearly in some cases this may not have been practicable, and the sensor may be in direct sunlight for part of the day, especially perhaps in the evening or early morning during summer. (Nevertheless it should be remembered that in all cases readings will have been taken during the working day, between 10am and 4 pm, and not in the early evening or morning).

32 Another possibility is that the external sensors may be inadequately shielded from the wall itself and may therefore be picking up additional thermal radiation from the house. This possibility is mentioned in the manufacturer's manual though no advice on prevention or minimisation of the effect is given.

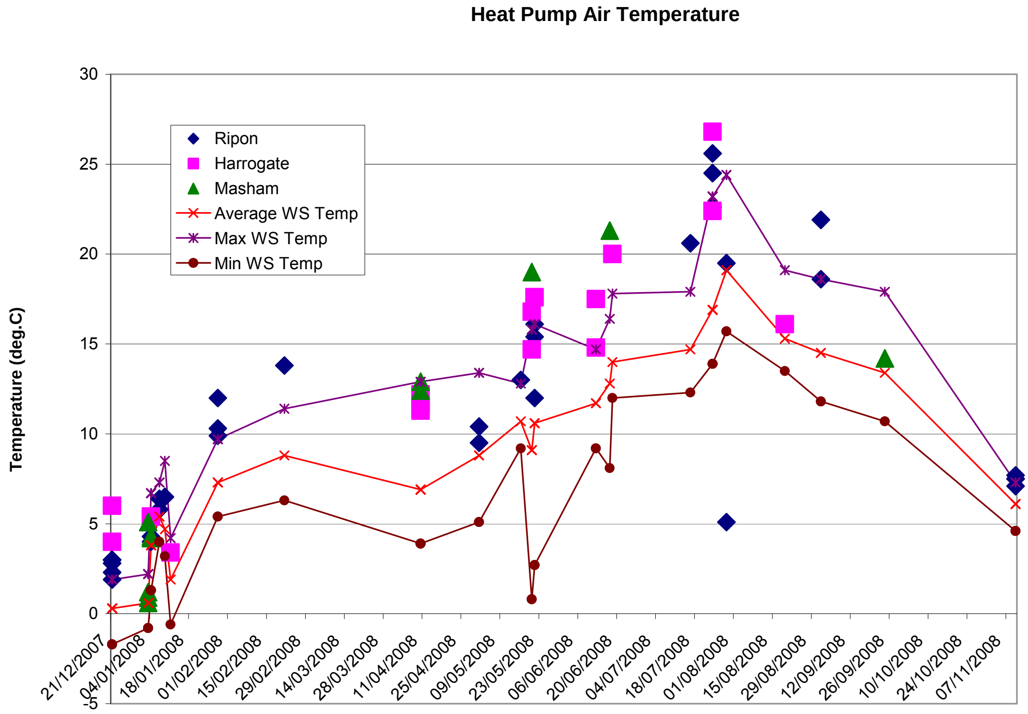

Figure 5: Instantaneous air temperature sensor (T2) data)

33 If the external temperature sensors are over-estimating the real outdoor temperature, this will result in a return temperature which is lower than it would otherwise have been.

Ground-loop Temperature

34 The temperature of the ground becomes more stable as the depth increases. At the surface air temperature and ground temperature are similar. At depths of a few metres the range of ground temperatures compared to air temperatures is reduced and at depths of 15m or more ground temperature is fairly constant at a value close to the average annual air temperature, around 10°C in the UK (Le Feuvre, 2007). There is some variation across the UK due to different climatic and geological conditions.

35 In the pilot group of properties, ground loop panels are buried to depths of around 1-2 metres, so ground temperature may be expected to vary, though the range will be less than the variation in air temperature (ground temperature range normally approximately 7°C - 13°C), and will tend to have a seasonal cycle which lags behind air temperature by up to a month. In the main group of

properties the boreholes are 50m-80m deep, and therefore over much of their length the ground temperature should be stable.

36 The temperature of the fluid returning from the ground loop may vary between about -5°C and +15°C. This is because the temperature of the fluid entering the ground loop may already be very low due to heat extraction by the pump, and also because the ground temperature itself may be reduced in winter by continual extraction of energy which is not sufficiently quickly replaced by solar input. Nevertheless, heat can still be extracted by the pump from fluid at these low temperatures.

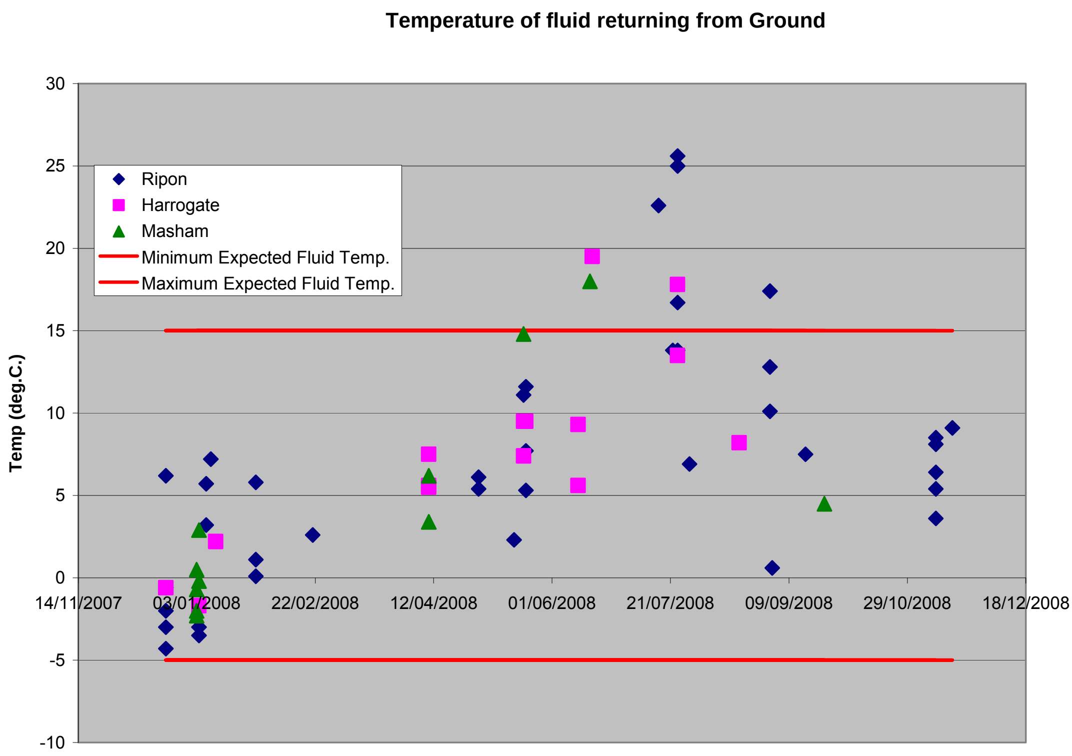

Figure 6: Recorded temperature of fluid returning from ground loop (T10)

37 As Figure 6 illustrates, some of the summer readings show very high values for the temperature of the fluid returning from the ground loop; up to 25°C or more. This is very unlikely to be a true reflection of the ground temperature. Inspection of Fig 3 shows that the temperature sensor T10 is located within the heat pump enclosure, close to the evaporator. This means that if the heat pump is not actively operating at the time of the reading, the value will actually more closely reflect the air temperature inside the heat pump enclosure, as the fluid may well have been static for long enough to reach thermal equilibrium with its immediate environment. This is almost certainly true of the readings around or above 15°C in Figure 6, but may apply to many of the other points also.

38 It is not possible to be certain, from the recorded readings alone, whether the heat pump was in the "on" or "off" part of its cycle when the reading was taken. However, in some cases it is possible to guess with some confidence, from the heat pump output and input temperatures (T8 and T9) combined with the set-point data. An inspection of these data would suggest that many readings (at least half) were taken with the pump in the "off" part of the cycle, especially during the summer months. There is little or no value in trying to interpret T10 or T11 readings if the heat pump is not operating at the time of the reading. This observation also applies to data on the heat pump output and input temperatures (T8 and T9).

Existing Data: Electricity Usage Estimation

39 The annual electricity usage of the heat pump for all the properties was estimated according to the procedure described in paragraph 28. The nominal power values recommended by the manufacturer for the two heat pump models are as follows:

	C6 Model (Main Group)	C4 Model (Pilot Group)
HP RAD (return temp. 35 deg.C.)	1.4	1.0
HP DHW (return temp. 50 deg.C.)	1.7	1.2
ADD HEAT (resistance heating)	3.5	3.2

Table 1: Nominal Power Multipliers for C4 and C6 models

These values are multiplied by the actual number of hours for each mode (taken from the heat pump display menu 7.1 – 7.3), to give a total estimated heat pump electricity usage over the period concerned. Sources of error are as follows:

a) Only the compressor usage is considered and not that of any circulation pumps.

b) No account is taken of the effects of pump cycling. Power surges may occur during pump start-up, leading to higher electricity usage when cycling is more frequent.

c) Return temperatures may vary from 35°C and 50°C due to variation in outdoor temperature, small variations in settings, and also the gradual nature of the heating/cooling cycle. The RAD return temperature is likely to be slightly less than 35°C over most of the year, as outdoor temperatures are more frequently above than below 0°C.

Whilst a) and b) will result in an underestimate of the actual pump usage, the effects described in c) may result in an overestimate, and may therefore be to some extent compensatory.

40 The following figure (Figure 7) shows the annual usage (Jul 2007/Jun 2008) of the heat pumps for each property, estimated as above. If the period between dataset collections was less than a full year, the estimated usage was normalised by simple scaling. This results in a slight overestimate (pink markers) or underestimate (green markers), depending upon the time of year not covered by the measured data.

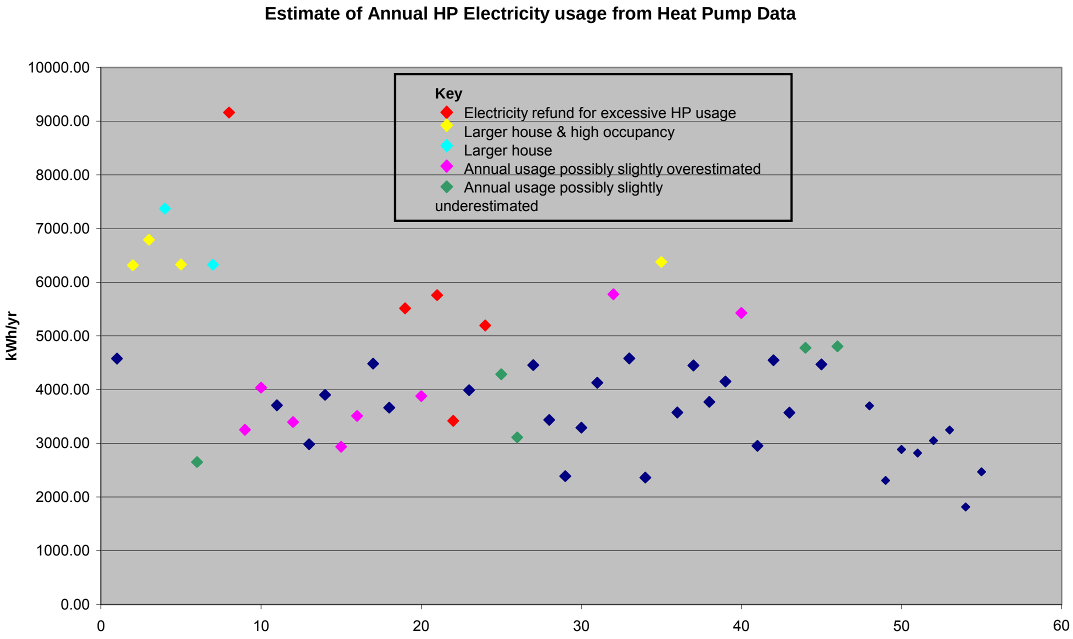

Figure 7: Estimated annual heat pump electricity usage

Red markers represent properties where some electricity costs were refunded due to unusually high usage associated with the initial installation (see paragraph 19). Yellow markers represent larger properties with high occupancy (four persons or more) and light blue markers represent larger properties with lower occupancy. The eight properties shown on the far right represent the pilot group of properties with C4 model heat pump installations.

41 Unless there is an identifiable reason for particularly high usage then, most of the properties have an estimated heat pump electricity usage falling between 2000 and 5000 kWh/yr. The properties falling within this band are all bungalows with one or two-person occupancy. This house type makes up the vast majority of Harrogate B.C. properties which have heat pumps installed at present.

Loft Insulation Issues

42 After the end of the period covered, a survey of loft insulation showed that some of the heat pump properties required further insulation to bring them up to 2006 Building Regulations standards. Figure 8 identifies those properties on a similar diagram to Figure 7, showing the amount of further insulation required.

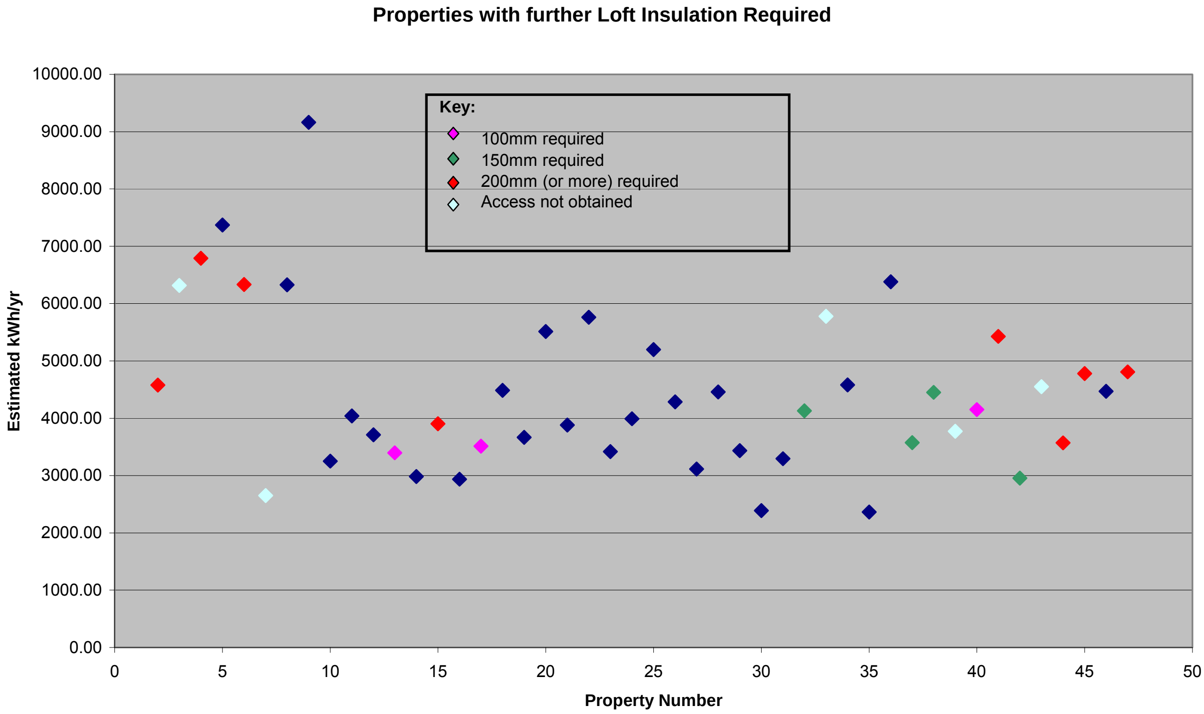

Figure 8: Properties requiring further loft insulation

It is possible that some of the properties shown above as requiring further loft insulation may have performed better (i.e. the estimated heat pump usage may have been lower due to fewer operating hours) if the loft insulation works had been undertaken before installation of the heat pump. However the importance of this effect is unknown at present, and can only be assessed by further monitoring after the works have been completed. Other fabric insulation issues may also be present in some properties.

Comparison with National Statistics

43 The Domestic Energy Fact File (J.I. Utley and L.D. Shorrock, 2006) gives the average expenditure on fuel light and power for Local Authority tenants in 2003 as £8.29 per week. The Fact File also states that the corresponding annual average total energy usage per household for local authority tenants (for 2004) was 60.8 GJ, and that space heating alone accounted for over 60% of this total (over 36 GJ). We may therefore conclude that the average usage for space and water heating combined would be well in excess of 10,000 kWh/yr (36 GJ/yr) in 2004. (Note also that the majority of contributions to this average figure will be from conventional space-heating systems which are not usually used continuously). EST also estimate that space-heating and hot water combined currently account for around 60% of the average household fuel bill over all heating types.

44 The estimated heat pump usage in 2007/2008 for most of the Harrogate properties was less than half of 10,000 kWh/yr. However, the following important points must be borne in mind:

a) The Harrogate properties are all small bungalows, with low occupancy, whereas the Domestic Energy Fact File figures apply to the national social housing stock as a whole, of which only 8% are bungalows (although a further 46% are flats which may also be expected to have a relatively low floor-area and energy demand).

b) The heat pump usage does not represent the full total space and water heating usage of the Harrogate properties. All have a supplementary electric fire in the living room, and some also have a separate electric shower.

c) The calculation method used for estimating heat pump usage is likely to underestimate the actual usage for the reasons given in paragraph 39.

d) Annual usage for space and water heating generally is likely to have decreased since 2004 as more properties have been modified to include energy saving measures such as additional insulation.

45 For the pilot group of properties, some information was available on the total energy usage via multiple electricity meter readings. Therefore it was possible to estimate the proportion of total electricity used by the heat pump.

Code	Estimated HP Usage (kWh)	Residual Usage (kWh)	Total usage (kWh)	% HP (S&W)
CH1	3670	4997	8667	**42%**
CH2	2405	4246	6651	**36%**
CH3	2862	3232	6094	**47%**
CH4	2797	4159	6956	**40%**
CH5	3028	4205	7233	**42%**
CH6	3224	5736	8960	**36%**
CH7	1802	3113	4915	**37%**
CH8	2452	4396	6848	**36%**

Table 2: Estimated heat pump energy and residual energy usage

The estimated percentage used by the heat pump was in these cases rather consistent at between 36% and 47%. This is considerably less than the 60% estimated by EST as the average percentage for space and water heating. However, these properties all have supplementary electric fires, and at least two are known to have separate electric showers.

46 Note also that whilst the Estimated Heat Pump Usage relates to a definite period (2007/2008), the figures for Total Usage are less reliable since they represent an annual average over two years. The precise periods of these two yearly figures has not been recorded, but may in some cases have included periods when the heat pump resistance heating contribution was unusually high as a result of ground leaks (prior to 2007).

47 The Department of Energy and Climate Change Regional and Local Authority Consumption Statistics (2008), give an average total electricity consumption figure for Harrogate of 4867 kWh per household (for 2007). This figure represents all dwellings of all sizes. The average dwelling size can be taken as approximately $80m^2$ (ODPM English House Condition Survey), with the CH1-CH8 dwellings being only around 60% of this size. By simple scaling therefore, we might expect the total electricity consumption of dwelling of this size in Harrogate to be around 60%* 4867 = 2920 kWh. These figures accord well with Carbon Independent's estimates of average consumption 4,800 kWh per household, with a "smaller than average" household average consumption of 3000 kWh. Since the majority of households will not use electricity for space heating, the 3000 kWh will, in the main represent residual electricity usage. Inspection of the table above shows that the residual electricity usage for CH3 and CH7 is only slightly higher than 3000 kWh, but in the other cases it is considerably higher. (almost double in the case of CH6 – but see paragraph 46). The discrepancy may be partially accounted for by the electric fires and showers mentioned in paragraph 45, which will here be included in the residual figure. However, since the residual electricity usage in the table above is taken simply as the difference between total usage and estimated heat pump usage, the high residual figures may also be partially an artefact of significant underestimations in the heat pump usage figure.

Recommendations arising from Data Trawling

48 Monitoring of heat pump performance by the method of periodic collection of pump display readings is of limited value due to the snapshot nature of the data obtained. However, some readings may provide valuable information provided the limits of applicability are well understood.

49 The set of readings designated 7.1 – 7.4 on the heat pump menu are cumulative (operational hours and RAD/DHW distributions) and therefore should continue to be collected as regularly as is practicable, since the scope for observing longitudinal trends for a particular installation will increase with time and with the number of observations. In those cases where the distribution of ADD HEAT (supplementary resistance heating) has not been recorded previously, consideration should be given to recording this datum in the future. If the availability of this datum is not provided as standard, the authority may wish to request its inclusion on future systems, as it can give valuable diagnostic information about possible usage patterns. As discussed previously, the 7.1 – 7.4 data can be used to estimate the electricity usage of the heat pump via nominal multipliers. It should be understood however that this estimate is at best crude, and at worst misleading since the estimate is subject to a number of potentially significant errors (paragraph 39), so its chief value may be relative rather than absolute – i.e. as a method of comparing periods or observing long-term trends.

50 Recording instantaneous temperature sensor data is probably not worthwhile (unless data are recorded automatically at very short time intervals). It would be useful however to record the set-points as listed below (unless these are likely to be changed frequently between reading periods)

a) Return flow switch-off temperature (T1, part 1)

b) Hot water switch-off temperature (T3, part 1)

c) Room-temperature sensor target temperature (T5, part 1)

d) Heat curve setting

e) Fine-tune adjustment setting

f) Return thermostat hysteresis setting (difference between heat pump start and stop temperatures)

Recording these set-point values will enable the authority to better understand the perceived needs and comfort practices of the tenants, as well as providing background data to support or explain estimated energy use, or estimated energy use changes. If compared with advice and operation information provided to occupants, the extent to which changes are made would indicate propensity to tailor what would appear to be a complex control system to individual user needs.

51 It is very important to acquire some data on the actual coefficient of performance (CoP) of the heat pumps in practice. In order to do this it will be necessary to measure the actual energy use of the pump, including both compressor and circulation pumps, together with the actual heat output, over a significant period of time. The interval should include at least part of a heating season and part of a non-heating season. Monitoring at this level of detail over a year or more for a number of properties would be very informative, and would also assist in understanding the relationship between estimated and actual electricity usage.

Intensive Study: Methodology

52 In order to cast further light on the factors which may affect heat pump performance in practice, five properties were chosen to be the subject of further investigations into building fabric performance and occupant behaviour practices. All 5 properties were bungalows of cavity wall construction built during the 1960s and 1970s. The table below gives further details.

Code Ref.	Built	Type	Floor Area (m^2)	Occupancy
WC9	1960	Semi-Detached	52.4	1
C11a	1976	Semi-Detached	64.8	2
CH4	1970s	Semi-Detached	48.5	2
CC37	1976	End Terrace	48.4	1
VR3	1967	Semi-Detached	48.8	1

Table 3: Intensive study property details

53 A pressurisation test was performed in each property to determine the air permeability. During the test, while the building was under depressurisation, thermal imaging was used to identify areas of cold air ingress, and other potential fabric problems. At the same time, readings were taken from the heat pump (the same parameters as previously recorded by H.B.C) together with an electricity meter reading. In all cases (except for CH4) this meter reading could be combined with a previous (H.B.C.) meter reading to determine the actual total electricity usage over a period of around 8 months (including most of the 2008/2009 heating season). In the case of CH4 the period covered in this way was only around 5 months.

54 Subsequently (approximately one week after the pressurisation test) each property was re-visited to discuss usage patterns and behaviours with the occupant(s). This took the form of a semi-structured interview, covering topics such as use of the supplementary electric fire, the range and rating of appliances, low-energy lighting, window-opening behaviour, general satisfaction with the Heat Pump system, and any other relevant topics arising from the discussion.

55 All of the data collected, including dimensional measurements, were input into a parametric energy calculator based on SAP (Lowe et. al, 2008). This is a semi-automatic spreadsheet version of SAP which can be used to calculate expected annual energy usage and dwelling CO_2 emission rate (DER). Any assumptions made regarding the heat pump or dwelling fabric are discussed in detail in paragraph 65. The calculated expected energy usage could then be compared with the actual usage from the meter readings (after modification of the calculation to account for differences in the periods covered). An attempt was then made to explain any discrepancies between expected and actual usages, on the basis of an understanding of additional behavioural factors drawn from the occupant interviews.

Intensive Study: Pressurisation Test Results

56 Pressurisation tests were carried out using an Energy Conservatory Minneapolis model 3 blower door system with DG-700 gauge, under both pressurisation and depressurisation. In all cases the r^2 coefficient of determination was above the value of 0.98 required to validate the tests.

Property Code	Permeability (depressurisation) ($m^3/m^2.h$)	Permeability (pressurisation) ($m^3/m^2.h$)	Mean permeability ($m^3/m^2.h$)	Air changes/hr
C11a	4.25	4.56	4.4	6.02
WC9	9.93	10.39	10.16	14.64
CC37	5.23	5.35	5.29	7.54
CH4	4.98	5.02	5.0	7.31
VR3	10.2	10.81	10.5	14.92

Table 4: Intensive study pressurisation test results

57 Inspection of the table above shows that the 5 properties fall into 2 distinct groups. The first group consists of C11a, CC37 and CH4, which are all properties with good air-tightness, even by 2006 Building Regulations standards. The second group (WC9 and VR3) have lower air-tightness, with a mean permeability around double that of the first group. It is interesting to note that the main structural difference between the two groups was the fact that the first group had solid floors, whereas the second group had suspended timber floors in some or all areas of the dwelling.

Intensive Study: Thermal Imaging Results

58 Thermal imaging of aspects of the properties under slight depressurisation using a FLIR ThermaCAM B4 thermal imaging camera revealed a variety of issues, which are discussed and illustrated in detail in a separate report (D. Miles-Shenton and A. Stafford, 2009). A few of the main issues for each property are reviewed in the paragraphs below.

C11a

59 Some air infiltration was observed around poorly sealed trickle-vents on windows, the loft-hatch and the electrical services channelling from the roof-space down into the kitchen. However, the most striking issue in this property was evidence of a strip of ceiling between 0.7m and 1.2m wide along the rear of the property which was at a temperature some 5°C less than that observed throughout the rest of the dwelling.

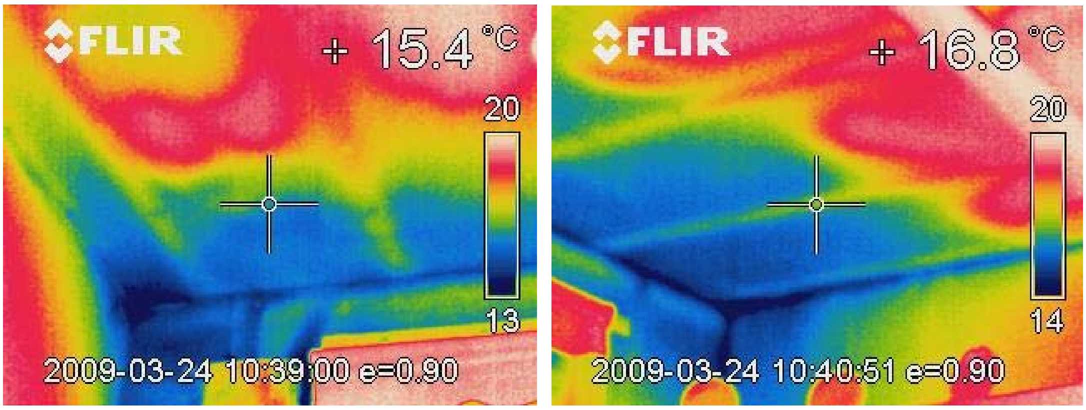

Figure 9: Missing areas of loft insulation (C11a)

This suggested a possible problem with the loft insulation in this region, and was of particular concern as the kitchen and bathroom, both situated at the rear of the property, were showing signs of mould growth around the ceiling-outer wall junctions, probably due to excess condensation at this cold strip. Inspection of the loft revealed that although an adequate layer of insulation was present in the main area of loft, it extended only as far as a timber purling running parallel to the rear eaves, resulting in an extensive area of un-insulated loft. This is an interesting example of a problem that, while not directly attributable to the heat pump installation, may have been previously concealed by the presence of other cold areas in the dwelling before the constant background heating of the heat pump was present. The fact that the problem of condensation in this region became apparent after installation is likely to affect the occupants' perception of the comfort levels provided by the system.

WC9

60 As previously stated, this dwelling had a suspended timber floor, and most of the air infiltration observed was associated with leakage through the floor between floorboards and at all room perimeters.

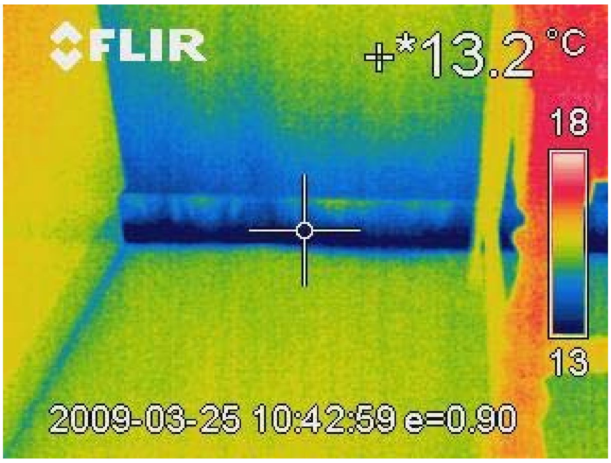

Figure 10: Air movement at floor level (WC9)

There was also some air movement around the fireplace surround, though it was unclear whether this was from the floor area, or from an unsealed chimney. Some evidence of loft insulation missing or inadequately installed in the eaves area was also observed in this property, though not as markedly as for C11a.

CC37

61 In this dwelling minor air movements were observed around the loft hatch and around service penetrations into the loft area. There was also some evidence of air movement between the living space and the ventilated roof space via a number of small cracks at the junction of the party wall and ceiling in the two rooms adjacent to the party wall.

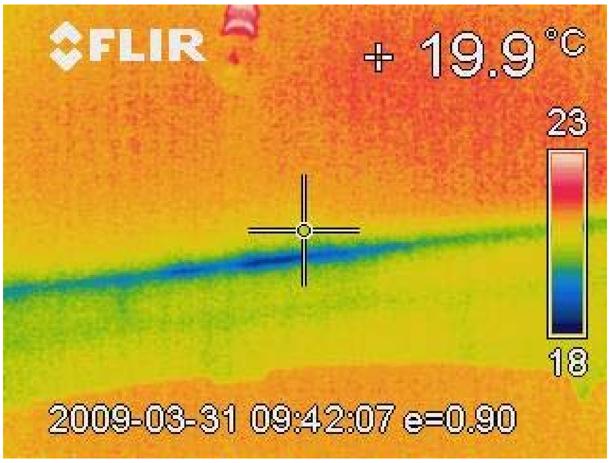

Figure 11: Party wall - ceiling junction (CC37)

In the above thermogram the party wall blockwork is also visible, possibly indicating thermal transfer directly into the cavity occurring differentially through the blockwork and cement. Windows performed adequately at the casements, but air infiltration was observed around the frames themselves, at the bottom of the back door and around service penetrations in the kitchen and bathroom.

CH4

62 Many of the relatively minor air infiltrations observed in the other properties were observed here also, e.g. loft hatch, trickle vents and around the back door and behind the electrical consumer unit. There was also some evidence of missing or poorly fitted insulation in some areas close to the eaves. In addition, although the windows performed reasonably well around the frames and casements, there was significant air movement through the glass-frame junction.

VR3

63 Like WC9, this property had a higher air permeability, attributed largely to a suspended timber floor in the main living areas of the dwelling. Considerable air infiltration was observed between floorboards and at wall-floor junctions.

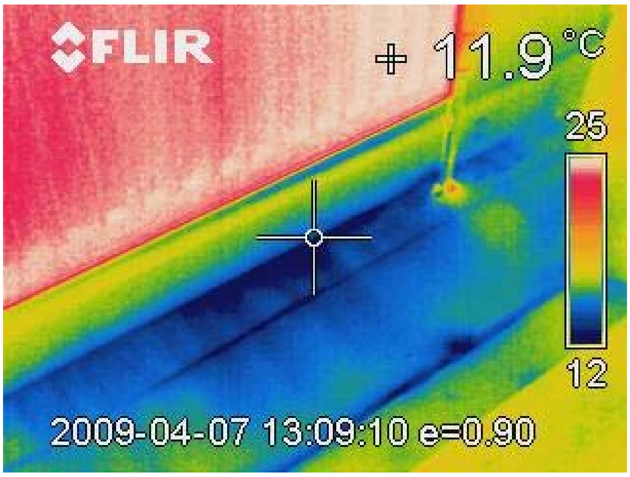

Figure 12: Air infiltration through floorboards (VR3)

Infiltration was also observed around window frames and casements, at the bottom of the back door, at the fire surround and around the loft hatch and service penetrations. Once again there was evidence of missing or poorly installed loft insulation close to the eaves of the property.

Intensive Study: Parametric Energy Calculations based on SAP

Calculation Methodology

64 The Parametric Energy Calculator is a spreadsheet based calculator based on SAP, using a "front-end" worksheet which allows a wide range of dwelling geometries to be defined in terms of a small number of parameters. Although it is based on a system of default values, it is possible to alter these values in favour of measured, or more accurately estimated parameters where appropriate. Expected annual energy requirements and associated CO_2 emissions are calculated via the usual algorithms and tables defined by SAP.

65 In the case of the five intensively studied Harrogate properties, inputs to the energy calculator were based as far as possible on a combination of real measurements and estimates resulting from data collected about the habits and practices of the occupants, together with heat pump operational data. These inputs are described in detail below:

a) Measured/observed dwelling dimensions, dwelling type, glazing ratios and orientations were used

b) Instead of an average occupancy for the dwelling type (default) the actual occupancy (1 or 2) was used

c) Since all the properties were built in the 1960s or 70s, the automatic thermal bridging calculation was based on "stock" i.e. on pre-1995 standards.

d) The following user-defined U-values were thought to be appropriate for these types of dwellings: roof = 0.25, walls = 0.5, ground floor = 1, doors and windows = 2.2.

e) Actual pressurisation test results were used in each case.

f) Standard SAP calculations assume a space-heating efficiency of 240% for ground-source heat pumps which drive conventional radiator systems with weather or load compensation (tables 4a and 4c). However the calculations also assume that 10% of space heating is supplied by a secondary source (direct electric heating). In the case of the Harrogate properties this percentage was modified according to knowledge gained about the actual usage of the heat pump supplementary resistance heating (for space heating) and also the actual usage of the supplementary electric fire which was present in all properties. (Details of the estimated percentage value used are given for each property in paragraphs 68-87).

g) Standard SAP calculations for a heat pump system which heats DHW partially by heat pump and partially by immersion heater assume that the contribution from the heat pump is 50%. An overall figure for water heating efficiency is then given by the expression $\eta = 100/\{(50/SPF) + 0.5\}$. In the case of the Harrogate properties, some information was available about the percentage contribution of the heat pump. However this was complicated by the fact that all properties had a separate electric shower. For the purposes of defining an overall water heating efficiency it was assumed that the separate electric shower provided 25% of the total hot water usage per occupant (i.e. 50% for 2 occupants). Significant supplementary resistance heating for DHW via the heat pump was added to this estimate, and the total used as a basis for calculating η using the equation above.

h) The ratio of low energy bulbs was estimated from observation and this figure used instead of the default 30%.

i) Standard SAP calculations use a figure for the annual number of degree-days based on a 20-year rolling average. In the case of the Harrogate properties an actual degree-days figure for the period 1st April 08 to 31st March 09 for the North East Region (Carbon Trust historical degree day data) was used in calculating the expected energy requirement.

66 The calculated expected annual energy usage produced by the parametric energy calculator from all the above inputs was modified to match the period for which actual energy usage data (from meter readings) was available for comparison. In the case of WC9, CC37 and C11a this period was from approximately the end of July 08 to the test date in late March 09 (around 8 months). In the case of VR3 this period was from May 08 to the test date (around 10.5 months) and in the case of CH4 it was from November 08 to the test date (approximately 5 months). The calculated annual figure was reduced by subtracting the actual proportion of the year not covered for water heating, lighting and appliances, and also subtracting a percentage of space heating determined by the proportion of the annual degree-days not covered by the period between meter readings. Thus it was possible to directly compare calculated and actual total electricity usages.

Results

Property Code	Period between meter readings	Calculated electricity requirement for period (kWh)	Actual electricity usage for period (kWh)	Discrepancy (Actual usage – calculated requirement) (kWh)	%age Discrepancy (A-C)*100/C
C11a	30/7/08 – 24/3/09	6392	4771	-1621	-25.6%
WC9	30/7/08 – 25/3/09	4717	4271	-446	-9.5%
CC37	24/7/08 – 31/3/09	4711	4677	-34	-0.7%
CH4	10/11/08 – 24/3/09	3544	3840	296	8.4%
VR3	21/5/08 – 7/4/09	5839	6726	887	15.2%

Table 5: Comparison of energy model with actual usage

Discussion of Results

67 The table shows that even allowing for data on fabric performance and some knowledge of behavioural differences, it is difficult to achieve a predicted total energy usage which is very close to the actual energy usage. There may be a number of reasons for this, some of which are listed below.

a) The fabric U-values have been chosen as appropriate for this type and age of dwelling. However the thermographic investigations suggested that there may be significant differences between the properties in terms of loft insulation, window/door performance and floor construction.

b) There may be significant differences in heat pump performance (either intrinsic or as a result of varying settings) which are not taken account of in the SAP type calculations.

c) An attempt was made to estimate the contribution of the electric shower to hot water requirement based on occupancy. However this was on a “reasonable guess” basis as no data was available, and may have been much wider off the mark in some cases than in others, depending upon individual showering frequencies, lengths and temperatures.

d) The range, type and usage of appliances varied considerably.

e) Reported window opening behaviour varied widely. This is likely to affect the cycling of the heat pump, and hence its overall efficiency.

The discrepancies relating to each individual dwelling are discussed further in the following paragraphs.

C11a

68 Of all the dwellings studied, this has the greatest discrepancy between the predicted and actual energy usage (actual usage much less than predicted). The discrepancy is also the most difficult to explain in terms of behaviours reported by the occupants, as the secondary electric fire is used occasionally as required and a wide range of appliances is in use, including 2 small freezers and a small tumble drier. The washing machine is A* rated (highly energy efficient). It seems likely that the discrepancy in this case is related to building fabric considerations. This property performed well with respect to air permeability, and it may be that the U-values and thermal bridging performance are also better than might be expected from the property age and type. A significant factor may be that the occupants have modified a small open porch area, enclosing it and adding a further outer door. Although the enclosed porch is unheated, it now forms a buffer between the outside and the heated areas of the house.

69 None of the heat pump resistance heating was used for space heating during the period covered, but a proportion of secondary electric space heating of 5% was included in the SAP calculation to account for the occasional use of the electric fire.

70 Very little of the heat pump resistance heating was used for DHW, but the effective water heating efficiency was based on 50% electrical contribution to take account of an electric shower used by 2 persons.

71 The occupants expressed a fairly high degree of satisfaction with the heat pump system.

WC9

72 For this property, the actual usage was again lower than the predicted usage, but in this case the discrepancy may be explained by occupant behaviour. The electric fire is not used, the occupant preferring to rely on additional clothing and warm slippers during the evenings if necessary. There is a washing machine which is not A or A* rated, but usage is low and no tumble-drier is used. Windows are sometimes opened if the heat pump is off at the time. Hot water set-point temperature has been reduced by 4 or 5° from the default heat pump setting.

73 Because the electric fire is not used, and the proportion of space heating provided by the resistance heater of the heat pump was also virtually zero, the proportion of secondary electric space heating in the calculation was set to zero.

74 The effective water heating efficiency was based upon a 25% electrical contribution to take account of the electric shower (one person) and a very small amount of resistance heater contribution (3%) from the heat pump system.

75 This occupant expressed moderate satisfaction with the heat pump system, although since it replaced a gas-fired system, costs were felt to be relatively high.

CC37

76 In this case the predicted usage matched the actual usage quite closely. There was nothing particularly noteworthy about the occupant's usage practices, though the washing machine was in use considerably more frequently than in the case of dwelling WC9. The electric fire was not used as it is not felt to be needed.

77 Although the electric fire was not used, the heat pump resistance heating contributed 2% to the total space heating. Therefore a proportion of secondary electric heating of 2% was used in the calculation.

78 The effective water heating efficiency was based upon an electric shower (used by 1 person) plus a heat pump resistance heater contribution of 6%. Therefore an overall figure of 30% for the electrical contribution to DHW was used in the calculation.

79 Again, the occupant expressed moderate satisfaction with the heat pump system in terms of warmth and convenience, but felt it was more expensive to run than tenants had been led to expect.

CH4

80 As part of the pilot group of properties, this heat pump system was of a different model from the other four systems studied. The discrepancy between predicted and actual usage was reasonably small; actual usage being only 8.4% higher than predicted. However, it should be noted that the period between readings was relatively short in this case (5 months) and so adjustments to the calculated annual usage to allow for direct comparison may introduce a relatively larger error. Again occupant usage practices and range of appliances was fairly standard, though the bedroom radiator was turned fully off contrary to advice from H.B.C. The washing machine was used with a frequency intermediate between WC9 and CC37, and a tumble drier was used occasionally. In general the occupants tried to avoid use of the electric fire, but owing to illness it had in fact been used on a regular basis for a period of a few weeks in December 08.

81 Although only 2.6% of the heat pump space heating was provided by the resistance heater, a proportion of secondary electric heating of 5% was used in the calculation, to take account of the period where the electric fire was also in use. This proportion was somewhat difficult to estimate under the circumstances, and errors here may account for much of the observed discrepancy.

82 Almost none of the DHW was provided by the resistance heater of the heat pump, but an overall figure of 50% electric contribution was used in the calculation to take account of the electric shower used by 2 persons.

83 The occupants expressed mild dissatisfaction with the system. The main problem was felt to be the slow response time of the heat pump to variations in outside temperatures.

VR3

84 Although this dwelling used over 15% more electricity over the period than predicted, it is difficult to account for the discrepancy in terms of general usage practices. No washing machine or tumble drier is used, and gas is used for cooking. Windows are not opened following advice from H.B.C. The electric fire is not used, though the occupant reports use of a portable halogen heater in the evenings. However, the heat curve on the heat pump was found to be set relatively high, and the number of heat pump operational hours over the period was higher than for the other properties.

85 The resistance heater of the heat pump made no contribution to space heating. However the default value of 10% for secondary electric heating was used in the calculation to cover fairly frequent use of the portable halogen heater.

86 The resistance heater of the heat pump made no contribution to water heating over the period. Effective efficiency for water heating was therefore based on a 25% electric contribution to cover use of an electric shower for one person.

87 The occupant expressed considerable dissatisfaction with the system on two grounds. Firstly it was felt to be unacceptably expensive. (Note that this system replaced a previous gas system as in the case of WC9). Secondly it was felt to provide inadequate levels of comfort. In fact the occupant mentioned that discomfort (leading to use of the halogen heater) tended to be centred around feet and legs whilst sitting, and therefore may well be associated with the presence of an unsealed suspended timber floor in the living room and bedrooms (see paragraph 63). If this is the case, then the floor U-value used in the calculation may have been underestimated.

Carbon-Reduction Considerations

88 The CO_2 savings associated with installing heat pump systems depends upon

a) The overall SPF (Seasonal Performance Factor) of the heat pump

b) The type of heating system which the heat pump is replacing.

c) In turn, the SPF is dependent upon both the building fabric performance and the way that the occupant uses the system.

89 Accurate values for the heat pump SPFs are not known in the case of the Harrogate properties, as this would require detailed continuous measurements to determine. However, in the three cases (WC9, CC37 and CH4) where the parametric energy calculator predicts an overall electricity usage which is reasonably close to the actual usage, we may compare the predicted CO_2 emissions from space and water heating for the heat pump system with the predicted CO2 emissions from the previous type of heating system (gas boiler or electric storage heaters)

90 The comparisons are made assuming that building fabric and occupant practices remain the same. For WC9 where the previous system was a gas boiler, it has been assumed that the boiler would have been replaced with a new condensing boiler (efficiency taken as 91%). CO_2 emissions are related to energy usage via an emissions factor (EF) for various energy types. For electricity the emissions factor has previously been taken to be 0.422 kg/kWh (i.e. 0.422kg of CO_2 released per kWh of electricity used). This EF figure is expected to be revised very shortly to a figure of 0.56 kg/kWh to take account of changes in electricity production. Both EF figures have been considered when calculating heat pump or electric storage heater emissions. The EF for mains gas is 0.19 kg/kWh. This is not expected to change, and therefore only one comparison figure is given for the gas boiler system[1]

[1] This is not strictly true as the gas boiler emissions total includes a small amount of electricity usage associated with the pump (taken as 130 kWh/yr). The emissions associated with this small element will increase if a higher electricity EF is used. However, the difference in this case is too small to be significant.

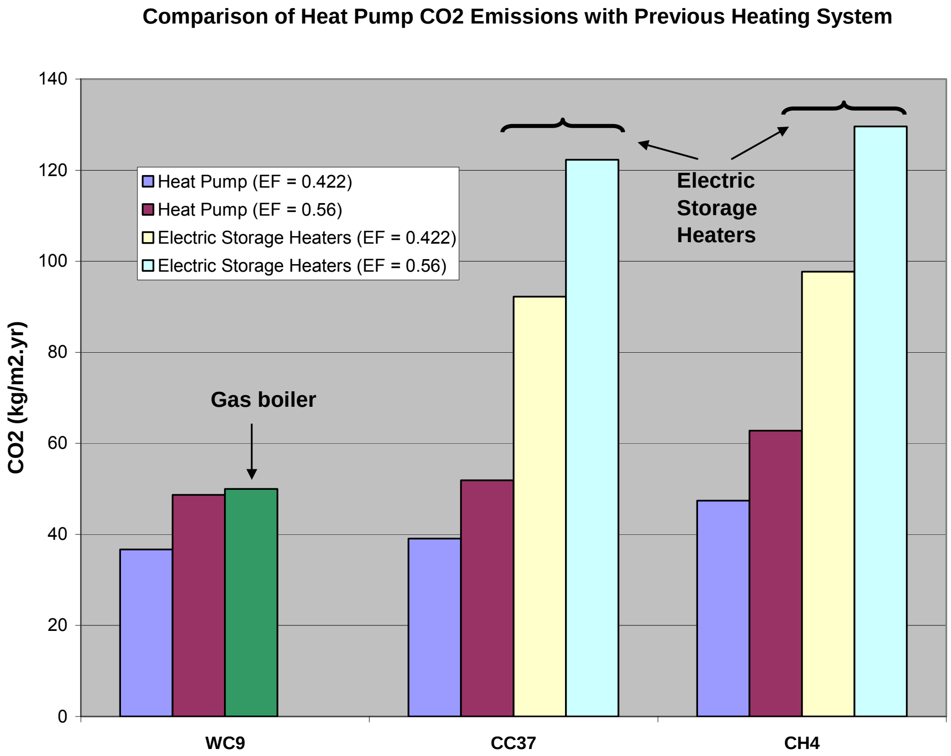

Figure 13: CO_2 emissions comparisons

Dwelling WC9 was previously on a mains gas heating system, whereas dwellings CC37 and CH4 were previously heated by electric storage heaters. It is clear from the plot that the potential CO_2 saving is much greater for the previously all-electric systems than for the gas system.

It should be noted however that a saving in CO_2 emissions does not necessarily translate into a cost saving, even for the previously all-electric dwellings, since cheaper night-time tariffs may no longer be advantageous.

Conclusions and Recommendations

Conclusions

91 It is unfortunate that installation of the heat pump systems in Harrogate has coincided with a period of rapid increase in electricity prices, as this fact may be affecting perceptions of the cost-effectiveness of the heat pumps themselves. Nevertheless, with the exception of C11a, all occupants felt that running costs were higher than expected. This was particularly marked in the two cases where the heat pump replaced a previous gas central heating system (WC9 and VR3).

92 The investigations into the building fabric of the five intensively studied properties showed that even for broadly similar properties of a similar age, there may be significant differences in performance (e.g. air permeability, loft insulation issues, window performance etc.). In several properties, although a good thickness of loft insulation was nominally present, the fact that it was not evenly installed right up to the eaves was leading to unnecessary heat loss, and potential condensation problems. The two properties with suspended timber floors (WC9 and VR3) would benefit from further insulation at floor level.

93 Without monitoring the CoP of the heat pumps over a long time period, it is impossible to accurately estimate either the pump electricity usage or the effect of different occupant practices. SAP type calculations rely on a number of assumptions about heat pump operation which may or may not be valid in individual cases. The assumptions at present do not rest on real system

performance data, though the forthcoming EST field trials may help to provide such data in the future. It should also be noted that it should in principle be possible for heat pump systems themselves to log real electricity usage and output information, and to make this information available to the user. This may be a matter for future discussion with manufacturers.

Recommendations

94 The recommendations previously detailed in paragraphs 48-51 are deemed to be included in these overall recommendations. In particular it is very important that real system measurements are made on a number of installations to determine the real CoP and SPF in operation. Unless this is done on a significant number of installations, it will not be possible to understand the extent of variation in performance due to different heat pump settings or occupant practices.

95 In more general terms, it is recommended that H.B.C/npower might explore with Heat Pump manufacturers the possibility of modifying standard heat pump systems so that data about real electricity usage (including pumps etc.) and heat output is recorded and is accessible to the user.

96 In addition, it is recommended that dwellings should be assessed for potential fabric-related issues before installation of heat pump technology. In particular loft insulation should be checked, not only for overall thickness but also for quality of installation, especially close to eaves, and consideration should be given to providing additional floor insulation in those properties with suspended timber floors.

97 The most benefit in terms of occupant satisfaction and overall CO_2 reduction is likely to be gained from installing heat pumps in properties where a) the building fabric performs relatively well (or can be modified to perform well), and b) the heat pumps are replacing electric, oil or solid fuel heating systems rather than mains gas. Consideration should therefore be given to installing preferentially in properties which meet these criteria.

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