Department
of Energy &
Climate Change

Preliminary data from the RHPP heat pump metering programme

January 2014

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Executive summary

This report is the first publication containing data from the Renewable Heat Premium Payment heat pump metering programme. More than 700 sets of high-frequency, high-resolution metering equipment have been installed in people's homes. By comparison with the EST's heat pump field trial, the results are encouraging.

Introduction

The Renewable Heat Premium Payment (RHPP) is a grant scheme that the Government first introduced in 2011 for ground-source heat pumps, air-source heat pumps, biomass boilers and solar thermal systems.

For the Government, the RHPP is a learning policy. Accordingly, participants were required to declare that they would allow meters to be fitted to their new heating system, should they be selected, so that DECC could monitor the results and feed them into future renewable heat policy and Microgeneration Certification Scheme (MCS) standards. In this way, the RHPP grants for heat pumps provided the population from which customers were selected for this metering programme.

The results are important because numerous publications in recent years have pointed towards the crucial role that heat pumps will play in meeting the UK's energy and climate change targets.

The results are also important given the previous field trial of domestic heat pumps in the UK by the Energy Saving Trust. It measured installations from 2008. The results of the EST's field trial were disappointing for the heat pump industry and the Government.

Since then, a lot of work has been undertaken by DECC and the UK heat pump industry to improve performance. The most significant part of this was the radical revision of the MCS Microgeneration Installation Standard for heat pumps, MIS 3005. The majority of the meters installed in this metering programme should have been installed on systems designed to the heavily-revised version of MIS 3005 rather than previous versions so this data should provide the first indication of how successful the revised standard has been.

Industry readers will also be aware that the domestic RHI is due to launch in spring 2014. This analysis comes, therefore, on the eve of what DECC and the heat pump industry hopes will be a significant increase in the take-up of domestic heat pumps.

The metering programme

The report provides details of the equipment used and how it was installed. A team of MCS installers were given training and issued sets of metering equipment to install on air-source and ground-source heat pumps in the private householder and Social Landlord parts of the RHPP scheme. Where the meters were fitted varied according to a set of schematics issued to the installers to take account of the variety of products and plumbing configurations used by the industry.

A significant fraction of the sets of metering equipment are suspected to have been erroneously installed so, where this has been identified, data from these systems is currently excluded from the analysis. The report focuses on the most recent data – from December 2013 – because this should be more robust. Generally it was the heat meter temperature probes that were fitted incorrectly. Either custom plumbing arrangements were fabricated on site or the temperature sensors were strapped to the outside of the pipework rather than installed in temperature probe pockets. Even with this high meter installation error rate, data from more than 400 heat pumps is presented in this report, many times more systems than have been metered in similar field trials.

The report explains that the approach taken is to take a relatively small number of high frequency, high-resolution energy measurements, along with key diagnostic temperature measurements and use them in conjunction with additional information recorded by the meter installers and innovative analysis techniques (making estimates where necessary) to determine a complete set of Seasonal Performance Factors (SPFs) at different system boundaries.

Seasonal Performance Factors

The report uses definitions of system boundaries first defined by a European project called SEPEMO. Analysis of the metered data from different metering arrangements into these consistent system boundaries enables different products and types of heat pump to be compared fairly. The SPFs in this report are labelled SPF_{H1}, SPF_{H2}, SPF_{H3} etc. The higher the number, the more electricity-consuming components are included in the SPF calculation and therefore the lower the SPF. Using analysis to produce different SPFs enables comparison with the EU's Seasonal Performance Factor threshold of 2.5 (SPF_{H2}), at or above which a heat pump is considered renewable, and allows estimates of heating bill and carbon savings by making comparisons with measured data from conventional heating systems (SPF_{H4}).

The data presented in the report is preliminary and further work is being conducted to improve its robustness. The results in the report also rely heavily on the assumption that the Seasonal Performance Factor of the metered RHPP systems in December 2013 is representative of their Seasonal Performance Factor for an entire year. However, if that assumption is valid, and arguments are presented to show that it should provide a good indication, then the preliminary data is encouraging.

Comparison with EST's heat pump field trial

Distributions of Seasonal Performance Factor for ASHPs and GSHPs are shown in Figure 1 in the top and bottom charts respectively. These are plotted using SPF_{H5} (which is defined in the report on page 14) to enable direct comparison with results from the first phase of the Energy Saving Trust's heat pump field trial. The 4-digit numbers in these charts are sites' logger numbers (or site IDs). Summary statistics for the charts are provided in Table 1. ASHPs from the EST field trial are the purple distribution; GSHPs are the pink distribution.

Dotted line shows the distribution of RHPP data based on different analysis assumptions

RHPP ASHP data

EST field trial phase 1 ASHP data

Individual heat pump

EST field trial phase 1 GSHP data

RHPP GSHP data

Figure 1: Distribution of SPF$_{H5}$ for ASHPs (top chart) and GSHPs (bottom chart) in December 2013, also showing the results from the EST field trial phase 1 (complete year).

	Number in plot	Mean	Standard deviation	25th percentile	Median	75th percentile	Inter-quartile range
ASHP	289	2.34	0.65	2.05	2.41	2.72	0.67
EST phase 1	22	1.84	0.29	1.63	1.83	2.07	0.44
GSHP	124	2.74	0.84	2.37	2.68	3.18	0.81
EST phase 1	49	2.39	0.45	2.10	2.31	2.66	0.56

Table 1: Summary statistics for the distributions of SPF$_{H5}$ in December 2013 from RHPP and for the whole year from EST field trial phase 1.

Figure 1 and Table 1 demonstrate the size of the sample of this metering programme compared with the size of the EST field trial. The spread of the RHPP data is much larger, probably reflecting this larger sample size and invalid data points in the preliminary data set, but the centres of the distributions are significantly better than those measured previously. The mean SPF for ASHPs has improved from 1.84 to 2.34 at this system boundary; the mean SPF for GSHPs has improved from 2.39 to 2.74. Both are good results.

The EU's renewable energy threshold

Data analysis has also been performed to allow comparison with the EU's renewable energy threshold. Only heat pumps with an SPF_{H2} of 2.5 and above are considered renewable under the EU Renewable Energy Directive. 69% of ASHPs (196 out of 286) and 84% of GSHPs (104 out of 124) are estimated to pass this criteria. Table 2 shows the summary statistics for the SPF_{H2} distributions shown in the report.

	Number in plot	Mean	Standard deviation	25th percentile	Median	75th percentile	Inter-quartile range	Number (%) ≥ 2.5
ASHP	286	2.71	0.75	2.36	2.76	3.13	0.77	196 (69%)
GSHP	124	3.01	0.94	2.67	2.91	3.37	0.70	104 (84%)

Table 2: Summary statistics, including the percentage of systems in December 2013 meeting the EU's renewable threshold of SPF_{H2} ≥ 2.5 for the purposes of being considered to generate renewable energy.

Heating bills and carbon savings

The preliminary data from RHPP for December can be extrapolated to estimate the percentage of heat pumps expected to reduce customers' heating bills and generate carbon savings. These results are summarised in Table 3 for ASHPs and Table 4 for GSHPs.

Darker yellow shading in Table 3 and Table 4 indicates a higher fraction of systems are likely to reduce heating bills. The percentages depend quite strongly on whether installation of a heat pump increases heating energy demand but are generally high for customers off the gas grid. Whether or not heat pumps increase heating energy demand is discussed in the Results section of the report. More than 82% of the metered ASHPs and more than 90% of the metered GSHPs would be expected to reduce customers' heating bills where their previous heating system is LPG, Economy 7 electricity or Oil. For ground-source heat pumps, we estimate that between 64% and 79% of on-gas-grid properties would also reduce heating energy bills by switching to a heat pump.

Further work

The report concludes that, provided the assumptions hold true, and in particular the extrapolation from December operation to an annual SPF, then the preliminary results from the RHPP metering programme indicate that the heat pump industry has – on average – moved a long way in the right direction compared with data from early installations.

Previous heating energy source	Efficiency of previous heating system	Number (%) of systems expected to provide fuel bill savings in Year 1 of operation		Number (%) of systems expected to provide carbon savings in Year 1 of operation	
		Heating energy demand is constant	Heat pump increases heating energy demand by 10%	Heating energy demand is constant	Heat pump increases heating energy demand by 10%
LPG	85%	266 (92%)	264 (91%)	241 (83%)	231 (80%)
Electricity (E7)	100%	264 (91%)	256 (89%)	276 (96%)	270 (93%)
Oil	84%	247 (85%)	236 (82%)	256 (89%)	250 (87%)
Solid (coal)	60%	224 (78%)	184 (64%)	276 (96%)	274 (95%)
Gas	85%	154 (53%)	89 (31%)	214 (74%)	167 (58%)

Table 3: Percentage of ASHP systems decreasing fuel bills compared with various other heat sources. The total number of sites in the sample is 289. >90% shaded dark yellow; >80% shaded light yellow

Previous heating energy source	Efficiency of previous heating system	Number (%) of systems expected to provide fuel bill savings in Year 1 of operation		Number (%) of systems expected to provide carbon savings in Year 1 of operation	
		Heating energy demand is constant	Heat pump increases heating energy demand by 10%	Heating energy demand is constant	Heat pump increases heating energy demand by 10%
LPG	85%	117 (94%)	117 (94%)	114 (92%)	110 (89%)
Electricity (E7)	100%	117 (94%)	116 (94%)	122 (98%)	121 (98%)
Oil	84%	115 (93%)	112 (90%)	116 (94%)	115 (93%)
Solid (coal)	60%	110 (89%)	107 (86%)	122 (98%)	121 (98%)
Gas	85%	98 (79%)	79 (64%)	109 (88%)	105 (85%)

Table 4: Percentage of GSHP systems decreasing fuel bills compared with various other heat sources. The total number of sites in the sample is 124. >90% shaded dark yellow; >80% shaded light yellow

Analysis of the metered data will continue. The highest priority is to finish cleaning up the data set. The amount of data presented in this report is limited because this work has not been completed.

Linking the analysis framework to the site information collected at the point of installation, the RHPP scheme management data, and potentially also to EPCs will refine the analysis, improve

the accuracy of the results and open up new avenues for exploration. It will also provide further opportunities to perform cross-checks and identify spurious results.

Following this exercise, it is our intention to start asking specific questions of the data to find out why some systems work well and others less well.

Much of this is work can be conducted while a full year's worth of data is being gathered from all sites – that process is scheduled to conclude at the end of October 2014 – so that a complete analysis can be presented by early 2015.

Acknowledgements

The following organisations have played a particularly significant role in the project. Numerous smaller installation companies – too many to mention here – installed equipment at fewer sites than the companies listed in the table.

Organisation	Role
Energy Saving Trust	Project managers
BRE	Main contractor
Energy Monitoring Company	Development of metering specification, equipment provider, data monitoring
Dalliam	Equipment installation
Husky heat pumps	Equipment installation
Mark Group	Equipment installation
New World Solar	Equipment installation
RES Devon	Equipment installation

Introduction

Metered data can provide the evidence needed to make and evaluate policies and take steps to improve the performance of technologies, should that be required. It tells us how well real-life systems are working and where improvements need to be found. It can also tell us what bill and carbon savings to expect and how much renewable energy installations typically generate.

The Renewable Heat Premium Payment (RHPP) is a grant scheme that the Government first introduced in 2011 for ground-source heat pumps, air-source heat pumps, biomass boilers and solar thermal systems[1]. It's administered by the Energy Saving Trust. For off-gas-grid householders in England, Scotland and Wales, it provided an upfront grant of approximately 6 - 8% of the value of an average installation when it was first introduced. All households both on and off the gas grid can apply for grants to install solar thermal systems as well. The RHPP householder scheme has been extended twice (in 2012 and 2013) and in May 2013 the value of the vouchers available was increased (approximately doubled for each technology).

The RHPP also provides grants to Social Landlords. This is conducted by running competitions where Social Landlords bid against each other for funding up to pre-defined maximums. Points are awarded to competitors for several factors, including the grant per installation applied for; what energy efficiency measures are being carried out at the same time; and what type of heating systems are being replaced. Lower cost bids; those making greater effort on energy efficiency; and/or those that stand to make greater carbon savings because they are replacing more carbon-intensive heating systems score favourably.

In addition to the householder and Social Landlord schemes, a communities' scheme was run in RHPP 2 where funding for households was channelled through and managed by Community groups.

For the Government, the RHPP is a learning policy. Accordingly, participants were required to declare that they would allow meters to be fitted to their new heating system, should they be selected, so that DECC could monitor the results and feed them into future renewable heat policy and MCS standards. In this way, the RHPP grants for heat pumps provided the population from which customers were selected for this metering programme. This report contains preliminary data from the heat pump installations in the RHPP Social Landlord and householder schemes where metering equipment has been fitted. Participants in the RHPP were also required to declare up front that they would complete questionnaires about the process of installing renewable heating and their first experiences of using the technologies. The evaluation of the data from these private householder questionnaires is published on DECC's website (AECOM, 2013).

The results are important because numerous publications in recent years have pointed towards the crucial role that heat pumps will play in meeting the UK's energy and climate change targets. DECC's heat strategy estimates that approximately 240 (77%) of the 310 TWh/year estimated to be needed for domestic space heating and hot water in 2050 will come from air-source and ground-source heat pumps (DECC, 2013). More recently, the Committee on Climate Change have estimated that 4 million heat pumps need to be installed in homes by 2030 in order to achieve the 4th carbon budget and be on a cost effective pathway to 2050 carbon targets (Committee on Climate Change, 2013). The 4 million heat pumps quoted in that report is a downward revision (from 7 million) compared with a previous report by the Committee on Climate Change but is still a significant number and will require installation rates many times greater than the 15,000 or so installations per year achieved at the moment.

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[1] For further information please see: www.energysavingtrust.org.uk/Generating=energy/Getting-money-back/Renewable-Heat-Premium-Payment-Phase-2

The results are also important given the previous field trial of domestic heat pumps in the UK by the Energy Saving Trust (Dunbabin & Wickins, 2012). The results of this field trial were disappointing for the heat pump industry and the Government.

Since then, a lot of work has been undertaken by DECC and the UK heat pump industry to improve performance. The most significant part of this was the radical revision of the Microgeneration Certification Scheme (MCS) Microgeneration Installation Standard for heat pumps, MIS 3005 (MCS, 2013), which was published in September 2011 and came into force in spring 2012. Several further versions have since been published. The majority of the meters installed in this metering programme should have been installed on systems designed to the heavily revised version of MIS 3005 rather than previous versions, so we may be able to infer from the results whether or not it has been successful at driving up performance.

Industry readers will also be aware that the domestic RHI is due to launch in spring 2014. This analysis comes, therefore, on the eve of what DECC and the heat pump industry hopes will be a significant increase in the take-up of domestic heat pumps.

There are lots of reasons, then, why the results of this metering programme are important. However, data is still being collected and therefore the information in this report is only preliminary. We have focussed heavily on the most recent data, since this is thought to be the most reliable. The final sets of meters started reporting valid data in October 2013. Therefore, a complete year of data will not be available from some systems until the end of October 2014, at which point a more robust analysis can be conducted.

This report provides details of the equipment used, how meters were installed, what data checking has been conducted to date, how the data is analysed and some preliminary results.

Heat pump system boundaries

Previous work reporting on the SEPEMO project (Zottl & Nordmann, 2011) and the second phase of EST's heat pump field trial (Dunbabin, Charlick, & Green, 2013) has explained at length the concept of different system boundaries when metering heat pumps. Results at different system boundaries have been effectively communicated in the past also, for instance by the Fraunhofer Institute on a field trial in Germany (Miara & et al., 2011). An explanation of different system boundaries isn't repeated in this report but the concept is important throughout.

In addition to the parameters defined in the SEPEMO project, SPF_{H1}, SPF_{H2}, SPF_{H3} and SPF_{H4}, we define one new parameter, SPF_{H5}, for this metering programme, which has the same meaning as the "system efficiency" parameter used by EST in their field trial. SPF_{H5} is reported using heat measured to the domestic hot water outlets rather than to the domestic hot water cylinder. The difference between SPF_{H4} and SPF_{H5} is any losses from domestic hot water cylinder and primary circuit pipework.

Equipment specification

Overall design paradigm

The primary aim of this metering programme is to meter a statistically-significant number of installations in a way that enables the most common sources of problems to be diagnosed. Data was to be provided from all parts of the UK in quasi-real time. Metering such a large number of installations requires a high degree of automation, so this was a requirement from the outset.

It was also the aim to be able to report data consistently at several different system boundaries to enable comparisons between systems (designed by different manufacturers, for example) and with results from other field trials. Ensuring data could be reported at all of the SEPEMO system boundaries would also allow comparison with the SPF_{H2} threshold of 2.5 set by the European Commission in the Renewable Energy Sources Directive (European Commission, 2013) for the purposes of electrically-driven heat pumps being considered to generate renewable energy.

Two other fundamental features of the metering programme relate to accuracy and "data completeness". Data completeness, is the term we have used in the project to describe the success with which the metering and data logging equipment captures data. The target was that 80% of the data that could be collected was collected. Data can be lost for a variety of reasons including broken or missing sensors and poor mobile phone signal (the mobile network is used to transmit data to a central secure server). Typically the monitoring equipment has achieved about 90% data completeness.

From the perspective of accuracy, the goal is to achieve +/-10% accuracy on all SPF parameters. This is relatively low compared with the accuracy of heat and electricity meters but is necessary to limit the cost of the programme by enabling reasonable simplifications and assumptions to be made. These are discussed later in this section.

Two of these requirements have a disproportionately large impact on the complexity of a cost-constrained metering programme like this one. Firstly, the requirement to be able to diagnose the most common sources of problems, one of which is fast cycling (Green & Knowles, 2012) (Curtis & Pine, 2012), points to the need for 'high-frequency' measurements that can resolve individual system cycles. High-frequency measurements require high-resolution meters that are capable of recording data accurately, even over short time periods. These are hard to come by. Secondly, the requirement to report data consistently at different system boundaries, despite the variety of systems installed, points to the need for flexible use of equipment and high dependence on analysis.

Resolution of meters

Data was collected over 5-minute time periods in the EST's heat pump trial (Dunbabin & Wickins, 2012). Commonly that data showed evidence of aliasing- the sampling phenomenon in which the sampled data was suspected of no longer accurately representing what was actually happening. A decision was therefore taken early in this project to increase the sampling frequency to time periods of two minutes. This increases the resolution of the meters required if individual data points are to remain accurate.

It's easiest to explain the impact of requiring 2-minute readings on the specification of heat meters by way of an example. Consider a fixed-speed, 15kW heat pump. To ensure the accuracy of the 2-minute reading isn't significantly increased by using a meter with insufficient resolution, we want to ensure that the error due to meter resolution is a similar order to the built-in meter error (which will be in the region of 3%). In two minutes, a 15kW heat pump can output 500Wh of heat. 3% of 500Wh is 15Wh. Accordingly, the smallest change that a heat meter needs to be able to resolve to accurately capture the behaviour of this heat pump is 15Wh. For a heat pump that can modulate to 1.x kW, as many do, the smallest change that the heat meter needs to be able to resolve is 1.x Wh.

In this project, the decision was taken to limit the number of heat meter models that would need to be supplied. One heat meter was therefore specified for use with all installations. This required limiting the capacity of heat pumps on which metering data could be installed to avoid potential problems with system pressure drops and pulse saturation in the heat meter (which occurs at ~18kW heat output in the heat meter selected).

Using high-resolution heat meters has been found to be important in previous work for another reason as well. When measuring hot water consumed (i.e. delivered from a domestic hot water cylinder to the domestic hot water outlets), high-resolution flow measurements are required to ensure the heat meter accurately captures short hot water draw offs. Our assessment is that the smallest change in flow that flow meters need to be able to resolve is of the order of 0.1 litres. Or, if the flow meter reports pulses, 10 pulses per litre. The flow meter used in this work exceeds this pulse rate.

A complete list of metering equipment is provided in Appendix A – Details of the metering equipment.

The variety of metering arrangements

It was well known from the EST field trial that a diverse range of plumbing arrangements are used by heat pump manufacturers and installers. In addition, space requirements for the heat metering equipment further constrain the options of the installer retrofitting it.

For these reasons, the approach taken in this metering programme was to fit the heat metering equipment wherever the system configuration allowed. A comprehensive set of flow charts was used to guide meter installers to the simplified schematic to use in each case. 24 different categories of metering arrangement were developed, each with their own variations (air-source vs ground-source, provides-domestic-hot-water vs doesn't-provide-domestic-hot-water, buffer-tank vs no-buffer-tank etc.). To generate the 24 categories, there are three types of heat metering arrangement:

- One heat meter measures the total heat output
- A second heat meter is used to measure heat to a domestic hot water cylinder
- A second heat meter is used to measure heat in domestic hot water delivered to the domestic hot water outlets

to which binary combinations of four categories of electricity metering arrangement are added:

- One electricity meter measures electricity consumption of the whole heat pump (always required)
- An additional electricity meter measures electricity consumption by a supplementary heater providing space heating and domestic hot water
- An additional electricity meter measures electricity consumption by a supplementary heater providing domestic hot water only (e.g. an immersion element)
- An additional electricity meter measures electricity consumption by a supplementary heater providing space heating only.

With the variations, the whole pack contained approximately 80 simplified schematics. Two common metering arrangements from the schematic pack are shown in Figure 2 and Figure 3. These demonstrate the challenge set to the person analysing the data.   Figure 2 has a metering arrangement with one heat meter (measuring the output of the compressor and any internal supplementary heater (if one is fitted)) and two electricity meters; Figure 3 has a metering arrangement with two heat meters (measuring the heat to space heating and the heat in the domestic hot water delivered to the outlets) and one electricity meter. The arrangement in Figure 3 is measuring SPF_{H5}. The arrangement in Figure 2 (after some analysis) is measuring SPF_{H4}.

Schematic 2.4
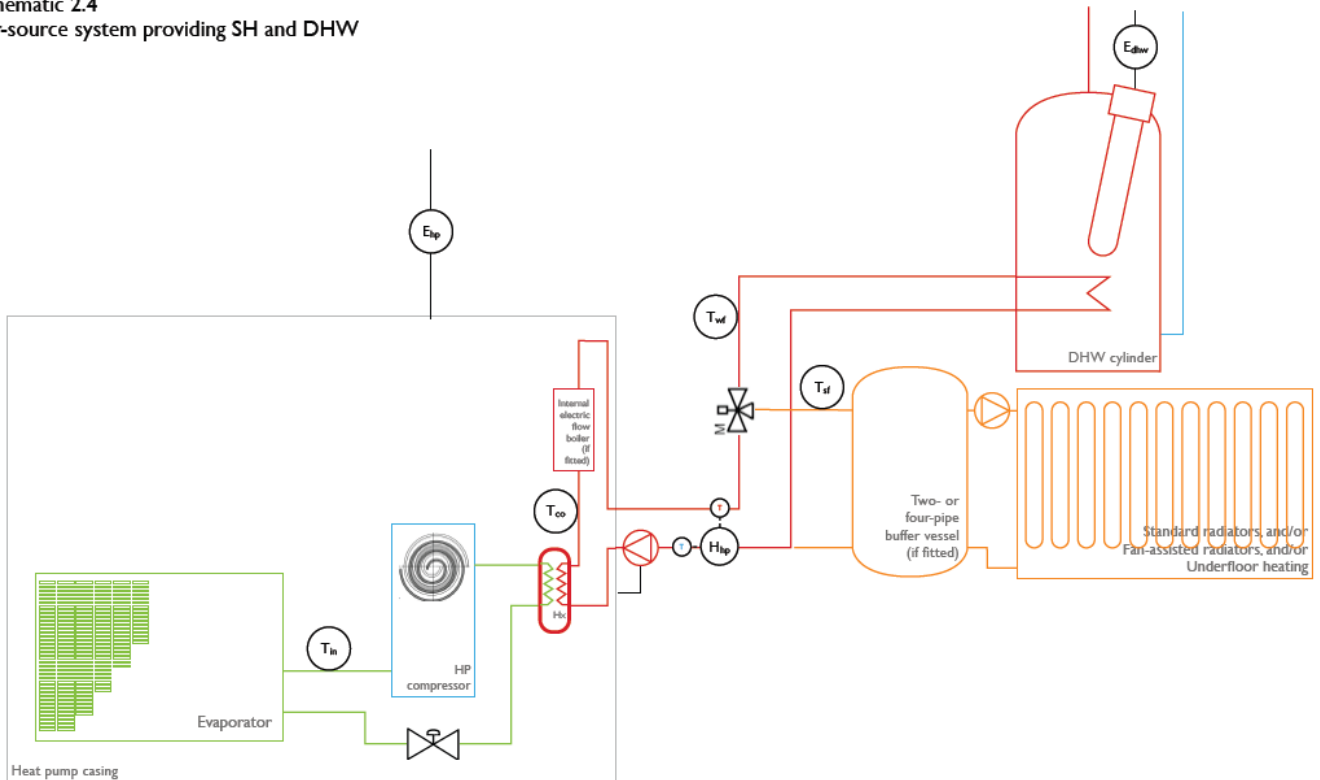**Air-source system providing SH and DHW**

Figure 2: An example simplified schematic of the metering arrangement for a monobloc ASHP that provides heat to space heating and a domestic hot water cylinder with an immersion element.

Schematic 16.12
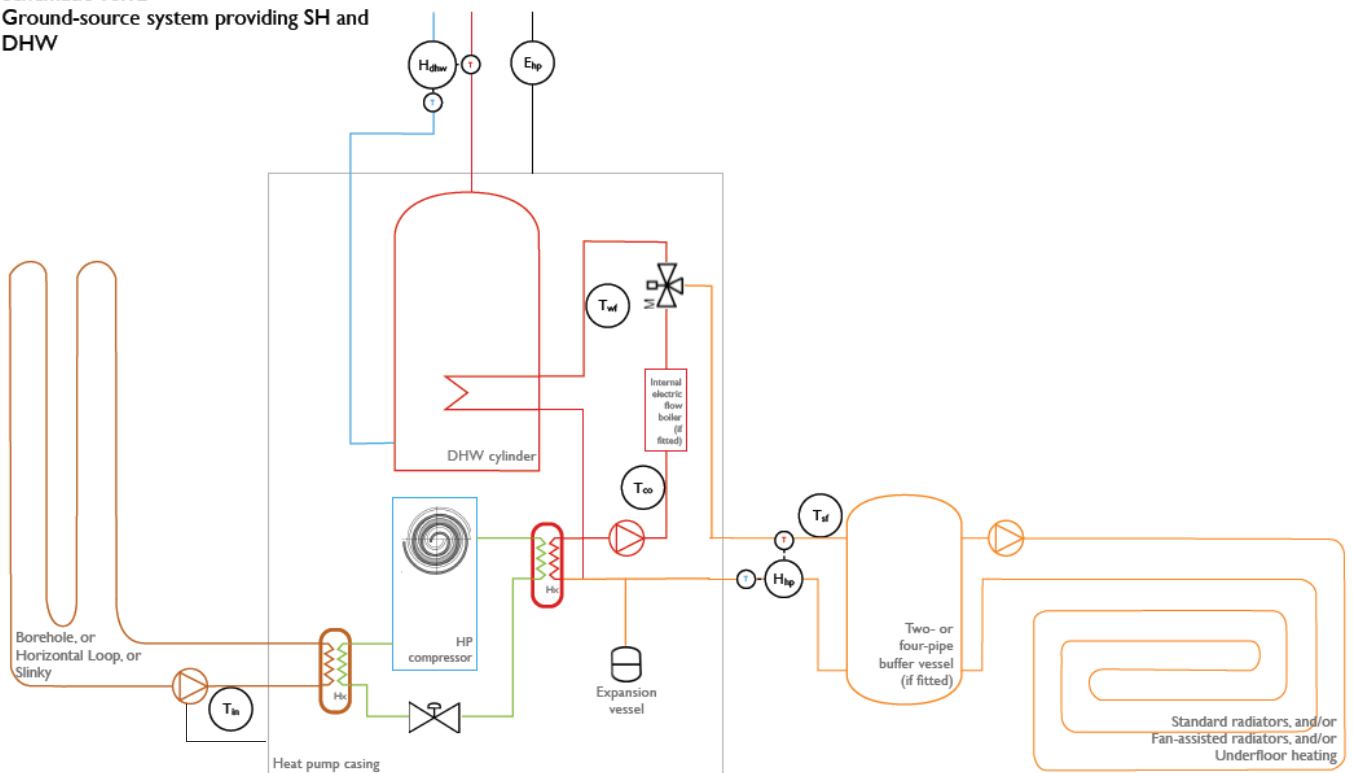**Ground-source system providing SH and DHW**

Figure 3: An example of a GSHP with an integrated domestic hot water cylinder

Accordingly, the raw data from these two sites is not directly comparable; the key difference being the inclusion of the domestic hot water cylinder losses in the heat measurement in Figure 3 (SPF$_{H5}$). Additional information is required for these two sets of measurements to be made comparable.

Estimated energy flows

The SEPEMO system boundaries are rigorous from the perspective of which components are included in each. This points to the need to measure each element of the different SPFs individually. However, the resources available to any monitoring project (including this one) are finite, and reducing the cost of each installation means that a larger sample can be monitored. Furthermore, some of the energy flows in a typical heat pump installation are relatively small and/or can be estimated with reasonable accuracy, especially in light of previous research. This reduces the number of sensors required, and hence the cost of each installation.

Source pump or fan energy

The power consumed by the source pump(s) or fan(s) will normally be included in the measurement of heat pump electricity consumption and heat output. For all parameters except SPF$_{H1}$ this is what is required, and no further action is needed. However, to determine SPF$_{H1}$ it is necessary first to estimate the energy used by the source pump or fan and to subtract it from the heat and electricity measurements. Since issue 3.0 of the MCS Microgeneration Installation Standard: MIS 3005 (MCS, 2013), the overall pumping power of the ground-loop circulation pump(s) should be "less than 3% of the heat pump heating capacity".

For this metering programme, the approach taken is to estimate the source pump or fan energy consumption rather than measure it directly by using the metering data and information collected during installation of the metering equipment (e.g. nominal pump power consumption).

Circulation pump energy

The term circulation pump is used to refer to any pumps which move heat from the heat pump into the building or hot water cylinder. This does not include pumps used to circulate fluid through a ground loop. The power consumption of most circulation pumps is relatively constant, although we note that variable-speed circulation pumps are increasingly entering the market. It is possible to determine when a circulation pump is running using the heat meter(s) to detect flow. This works in the situation where the pump is running with no temperature difference across the system for control purposes as well as when there is a heat output and is the approach used when analysing the data.

To estimate circulation pump power in this way, it is necessary for the data analysis team to know the powers of all circulation pumps, so these are recorded by the meter installers.

Defrost energy

Air-source heat pumps generally require some sort of defrost cycle to clear ice from the external heat exchanger. In some cases an electric heater is used for this; in others, the operation of the heat pump is temporarily reversed, and heat is extracted from the building or a buffer tank to melt the ice. Any electricity used will automatically be included in the heat pump electricity consumption, but heat extracted from the building will not be captured by the heat meters because the heat meters used to record these quantities are unidirectional. Any heat flowing in the opposite direction to that expected is simply ignored. However, the heat extracted is a small part (typically 2 to 5%) of the total heat delivered (Dunbabin, Charlick, & Green, 2013), and if an estimated value is used it will add an uncertainty of only a few percent to the estimated pump efficiency, keeping the uncertainty within the limits required by the overall design paradigm.

Building on the work conducted previously, heat extracted from properties for the purposes of defrosting ASHPs has not been explicitly metered in this metering programme and will be estimated instead.

Internal supplementary electric heater energy

In many cases it is not possible to measure the energy supplied to internal supplementary electric heaters, or to separate out the compressor energy to allow the supplementary heating to be obtained by subtraction. Systems represented by Figure 3 that have internal supplementary heaters are likely to be good examples of this. In these situations, it's necessary to estimate supplementary heater electricity consumption. In the EST field trial, electricity and heat data were used to explore supplementary heater use with partial success. Use of algorithms like this is still possible with this data but to try to do better, additional information has been captured in this metering programme using temperature sensors. The aim is to separate supplementary heater electricity consumption from compressor energy consumption when both are measured by the same electricity meter.

MCS has gone to great lengths to ensure heat pumps are sized to ensure energy consumption by supplementary electric heaters is minimal. Whether or not this has been successful is a key question to try and answer with the data collected in this programme.

Domestic hot water cylinder losses

For heat pumps with an integrated domestic hot water cylinder, it is usually not possible to measure the heat energy into the domestic hot water cylinder directly because there is limited space to install a heat meter. This presents a problem: it raises a major discrepancy with the data required for the evaluation of the SEPEMO system boundaries (SPF_{H1-4}), which do not consider the losses from the hot water tank to be part of the system load. In the opposite sense, comparison with EST's system efficiency parameter (SPF_{H5} in this report), requires the heat energy measured after a heat pump compressor (i.e. before the domestic hot water cylinder) to be apportioned between space heating and domestic hot water so that the amount of domestic hot water actually used can be estimated. Both calculations require an estimate of domestic hot water cylinder losses, which in turn depend on the temperature at which the water is stored, the temperature of the surroundings and the thermal loss rate of the domestic hot water cylinder.

In previous studies, domestic hot water cylinder losses *have* been closely studied (EST, 2011) (Kiwa GASTEC at CRE, 2013). Broadly speaking, this work found that domestic hot water cylinder losses varied between 30% and 70% of the energy entering the cylinder. In this metering programme a fixed estimate for domestic hot water cylinder losses is used. No further work to quantify these losses or refine the estimate has been conducted.

A universal set of temperature measurement points

It is clear from the last few sections that the estimation of the various quantities required to determine the full set of SEPEMO parameters can be greatly improved if some additional indicative measurements are available. We have therefore used four consistent temperature measurements on all sites, listed in Table 5.

T_{in} The source temperature of the system. For a ground-source system this sensor is placed on the return pipe from the ground loop into the heat pump. For an air-source system it is attached to the refrigerant pipe between the evaporator and compressor.

T_{co}	The temperature in the primary circuit at the outlet of the heat pump compressor. This sensor is mounted before any internal supplementary electric heaters.
T_{sf}	The space heating flow temperature before any buffer tank but after any supplementary electric heater supplying space heating.
T_{wf}	The hot water circuit flow temperature. This is the temperature of the liquid flow to a hot water cylinder.

Table 5: The set of four temperature measurements used on all systems to help separate energy flows

The locations of the four temperature sensors are shown on the schematics in Figure 2 and Figure 3.

Taken together, these temperatures can (in theory) provide a lot of valuable information about system operation. For example:

- For ground-source systems, when the compressor is running, T_{in} indicates whether the ground loop has been appropriately sized and installed;
- Examining T_{co} reveals when the heat pump compressor is running;
- Examining or comparing T_{sf} and T_{wf} reveals whether the system is supplying space heat or heating domestic hot water at any given time. Flow data from heat meters can also be used to help do this;
- Comparing T_{co} with both T_{sf} and T_{wf} may reveal whether any internal supplementary heating is in operation;
- T_{sf} indicates whether the heat distribution system has been designed to run at a suitably low temperature, in order to optimise heat pump performance; and
- The overall temperature difference across the system, T_{sf}-T_{in} when providing space heat or T_{wf}-T_{in} when heating domestic hot water, should be a key driver for explaining variations in SPF, both over time and across different systems.

Measurements that aren't taken

Two useful measurements that were intentionally omitted to reduce cost and installation effort are internal air temperature and external air temperature. Internal air temperature is a strong driver of space heating energy demand and high internal air temperature may be a root cause of inefficient heat pump performance but it will not be possible to investigate this using this data.

External air temperature can be used to investigate the presence and success (or otherwise) of weather compensation and use (or overuse) of defrost cycles. To do this using this metering data, the analysis will have to rely on data from local weather stations where it exists. Note, however, that it should still be possible to investigate the impact of low source temperatures using T_{in}.

Summary of equipment specification

It should be evident from this section that the approach taken in this metering programme is to take a small number of high frequency, high-resolution energy measurements, along with key diagnostic temperature measurements and use them in conjunction with additional information recorded at the time of installation to determine a complete set of SPFs at different system boundaries, making estimates where necessary.

This approach allows the metering equipment installers to be flexible from the perspective of where to put meters but requires much more significant analysis effort than would be required if all energy flows had been measured individually. It also reduces costs.

Installation of meters

By far the hardest part of the metering programme to date has been getting meters installed. Figure 4 shows the cumulative number of installations being metered over the course of the equipment installation phase of the programme. The rises and falls in installation rate correspond with changes to the scope of the project, its costs, project managers, sub-contractors, interim milestones and numerous other factors. Where the meters are installed is shown on the map in Figure 5.

The approach taken to getting sets of meters installed has changed throughout the project. More than a year was taken to identify the correct installer type to best meet the demands of the installations. It's apparent with hindsight that the relative complexity of the metering equipment and pricing of this work did not suit all installer business models.

It became clear, through the process of engaging with all installer types, that the work required by this project best suited SME businesses with multi-disciplined engineers and flat management structures where senior guidance and expertise were never far from the delivery environment.

There are numerous lessons to be learnt from this programme for anyone considering a large-scale and innovative project of this kind. In this section, we explore the process used to install the majority of meters and ensure data quality.
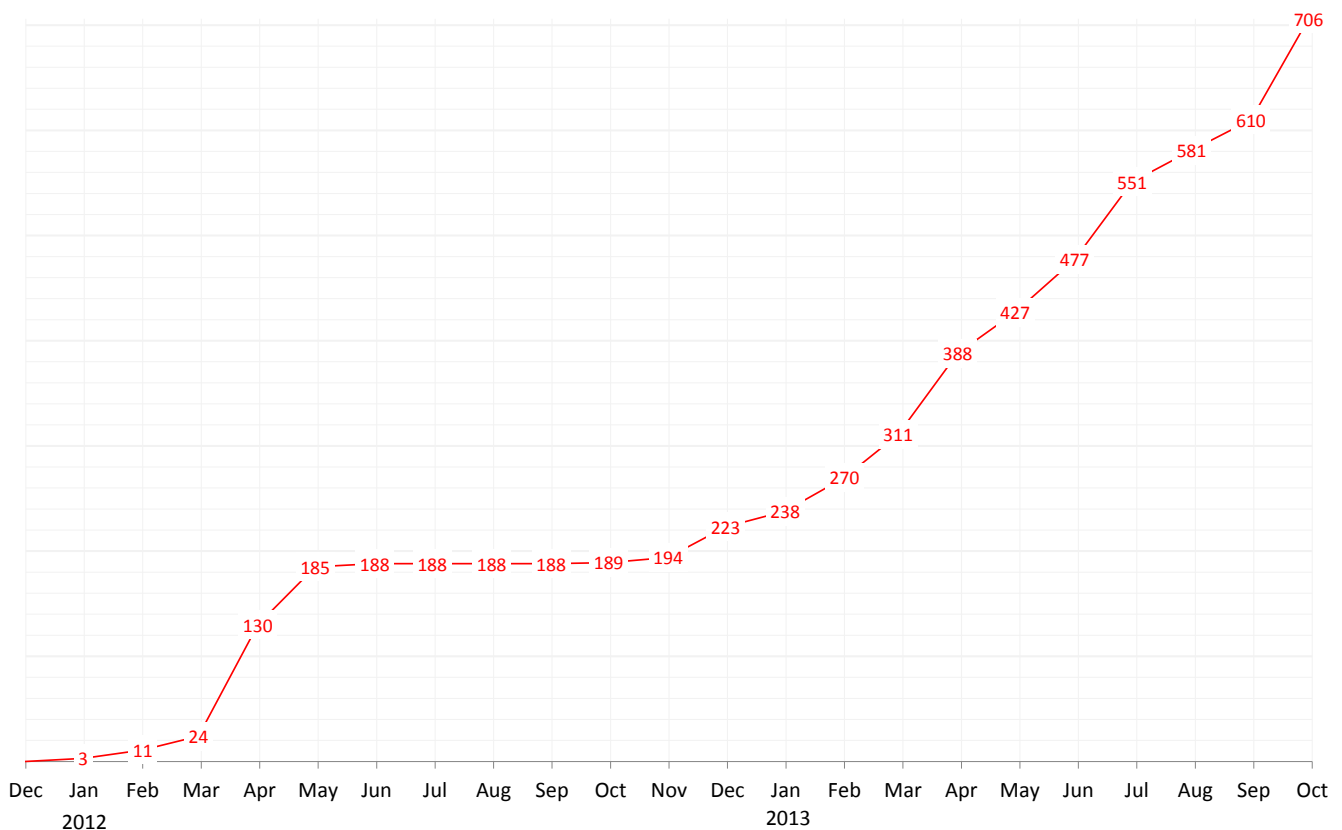

Figure 4: The history of metering equipment installation rates

Figure 5: Where sets of meters are installed. Purple: householder scheme ASHPs; green: Social Landlord scheme ASHPs; yellow: householder scheme GSHPs; red: Social Landlord scheme GSHPs

Installer training

Installation companies interested in taking part in the metering programme were first given training. In all, about 70 companies were trained. A specially-designed, fully-subsidised, all-day training course was developed to do this. It started with a presentation on the training equipment and used three practical workstations to cement knowledge of the equipment, where and how it needed to be fitted, and the commissioning process. Two of these workstations involved installing a set of meters on specially-designed test rigs. The training was considered complete only after a trained installer had fitted their first set of metering equipment on a real-life installation and it had been audited by a member of the project team.

It was observed through the training and subsequent supplier relationships that MCS installer capabilities vary significantly. This was most apparent when ensuring that the standards demonstrated during training continued into installations. This situation was exacerbated by the reliance on senior company members training their own staff outside of the formal training programme.

Distribution of equipment

Trained installers could draw down equipment from a logistics company free of charge. The list of equipment provided is given in Appendix A – Details of the metering equipment. Where sites required more than one heat meter, and/or one or more additional Radio Data Transmitter(s), devices that were used to send electricity and temperature sensor data to the data logger, this was included in the package supplied.   Installers were responsible for sourcing some of the more common items themselves, including the 'T's' to which the heat meter temperature pockets needed to be fitted. A spares pack containing multi-core cable, spare cable glands and blanking plugs and spare fuses for the web box was also provided.

The programme's logistical burden was high because of the number of installers involved and the variations in metering equipment required. The logistics were made harder by the use of non-standard components and some installers losing interest in the programme after having been shipped equipment, which then needed to be returned.

Site selection

Early experience on householder installations demonstrated the need to have a thorough site selection process to ensure adequate mobile signal for data transmission and sufficient space for heat meters.   This resulted in changes to the administration of the RHPP scheme from May 2012.

An "Installer Checklist" was introduced and linked to the RHPP grant (EST, 2012). For heat pump installations, all householders received 80% of their voucher value when a valid claim was submitted, together with a signed Installer Checklist confirming whether or not the installation could be fitted with a meter. Householders were told that they would receive the final 20% following a visit from the metering team to check that the installation really was 'meter ready' and install a set of equipment, or if their installer has been trained to install monitoring equipment and installed it on EST's behalf at the time of installation. If a householder indicated that they were not meter ready, they received the final 20% of the grant at the end of the scheme.

Householders were also required to rate the mobile signal strength at their property using a strong, medium, weak, no-signal scale to help filter out sites where data completeness could be low due to mobile signal strength. This proved to be more reliable than the online mobile signal strength websites that were used initially.

Using the information gathered through the RHPP application process, Installer Checklist and information about the product installed, a subset of sites to target for metering was created and sent to trained installers, who were free to choose where to try and fit metering equipment.

These explicitly excluded:

- Dual-fuel and hybrid systems
- Large heat pumps
- Systems with solar thermal providing some of the domestic hot water

which were ruled out of the programme to reduce the number of metering arrangements and variety of metering equipment required.

Selecting Social Landlord installations for metering proved to be much easier than householder installations. Project team members favoured the close proximity and consistency of these sites, which were therefore afforded special attention. Social Landlord projects could be visited ahead of equipment installation to ensure the systems were suitable and the first installations of many at a Social Landlord site could be closely supervised.

Site selection remained a challenge throughout the programme due to mobile network coverage and the lack of space to fit heat meters. Future projects will need to come up with more innovative ways of tackling these issues. In addition, it's thought that future projects would benefit from a strong incentive for the householder or tenant to participate so that the metering equipment is something they want or benefit from.

It's worth noting at this point that some of the metering equipment would have been installed on systems before the first full winter of operation. For ground-source heat pumps, especially those with boreholes, this means that the ground loop would have been unusually warm and that the performance data that comes from those sites could be higher than in subsequent years.

Aborted visits and surveys

Despite the selection process employed, over 130 early installations were aborted. The project eventually settled on a process whereby surveys were conducted before the metering equipment was installed, thus eliminating aborted installations. Installers differed in how they used this approach; some planned an installation and billed for a survey if the installation couldn't proceed; others planned surveys and conducted installations later if the survey indicated that installation of the metering equipment was possible.

Installation and commissioning

Installation times varied depending on the installer's ability, the complexity of the installation, the amount of prior preparation the installer had done and the proximity of sties. Some installers chose to pre-assemble metering equipment onto a board in factory conditions. The most successful installers were able to fit up to 4 sets of equipment into social housing in a day but 1 installation per day was considered successful. It was rare that installing the metering equipment would take more than a day, including travel time.

Commissioning the metering equipment proved to be an essential and invaluable process. Once the metering equipment was fitted, installers were instructed to telephone a member of the project team. The project team would record where a set of metering equipment had been fitted, then log into the equipment, if mobile signal allowed, and check valid readings were being received from all channels. The project team member would also record the information that would subsequently be needed for analysis. This process evolved through the project but an example of the "Monitoring Installation Form" used towards the end is in Appendix B – Example

installation form. A lot of the characteristics of the heating system required for analysis are captured on the final page.

Finally, the installers were required to photograph the work they had completed. Photos of the metering equipment have also proved invaluable from the perspective of quality assurance as will be discussed later in this section.

Initially the commissioning process was carried out on paper and unfortunately a number of these installation forms have been lost as a result.

Monitoring and auditing

Towards the end of the installation phase of the programme, it was becoming rarer that an installer would leave site before the metering equipment was fully functional. However, this wasn't always the case.

For this reason, and to monitor the performance of the metering equipment in service the project team used a website to view the metering data for all sites over the previous week. The website performs semi-automated checks on the data to identify sites where the metering equipment had not been installed correctly or where something had broken or otherwise stopped working. The website is also the way in which data completeness is tracked.

In general it has been the case that once a site is producing valid data, it continues to produce valid data. This is why the commissioning process is so important. However, for sites that have always had- or develop - problems with their metering equipment, a targeted auditing regime was conducted. To date approximately 190 sites have been re-visited in this way. This is the mechanism by which faulty or incorrectly installed metering equipment has been made good. Further audits to rectify problems will be conducted over the remainder of the data acquisition period. Random audits will also be conducted as a further quality control check.

Data checking

Data checking before payment

In addition to the checks conducted by the project team, DECC have strictly applied a set of quality criteria before releasing payment for installations.

Data from each site is loaded into MatLab and plotted to the screen to visually check:

- Readings are present from all sensors
- Readings from all sensors - and parameters calculated from the readings (e.g. the daily SPF) - are plausible
- Readings are correctly labelled
- There is correlation between electricity consumption, flow readings, heat output and the temperature sensors

Site documentation and photos are also reviewed to check:
- The documentation is complete
- All photos have been taken
- Heat meters have been fitted correctly

The site documentation also enables further cross-checking with the data to look for instances where:
- The metering arrangement indicated in the documentation isn't consistent with the number of meters that have been installed.
- The data collected isn't consistent with the metering arrangement indicated (this requires additional knowledge of heat pump products and how they are controlled).

Common problems

Approximately 15% of all installations have been rejected to date or are waiting for further information before checking. Instances of missing paperwork, photos and sensors, which are usually installed but not wired into the logger box correctly, have been relatively common but are relatively easy to fix.

The most concerning problem is heat meters that have not been installed according to the manufacturer's instructions. We have evidence that a significant number of sites have heat meters with temperature sensors that are cable tied or taped to the outside of pipes or fitted using custom plumbing arrangements, rather than fitted into 'T's' to ensure the temperature sensor pocket is surrounded by flow. This may be due to time pressure and the lack of space to fit heat meters as well as other factors. Some examples are shown in Figure 6. Some of these examples were rectified after installation as part of a site audit.

An example of a correctly installed flow meter and pair of temperature sensors is shown in Figure 7. Temperature sensor pockets and brass 'T's' have been used to ensure the temperature probe is in good thermal contact with the fluid inside the flow and return pipes and the flow meter has been installed on an angle to reduce the likelihood of air bubbles and dirt interfering with the measurement. The majority of heat meters *were* correctly installed.

The difficulty of measuring heat

Incorrectly installed heat meters are a particularly important issue for a metering programme designed to evaluate the performance of any heating technology since it's likely that they will negatively bias the results.

A lot of work has been conducted during this project to establish the impact of incorrectly installed temperature sensors. This work has included laboratory and field tests using sets of temperature probes and heat meters back-to-back. It is clear that the time constant of the temperature reading is highly dependent on the thermal contact of the temperature sensor and the fluid moving through the pipe. However, all temperature measurements (even those installed according to the heat meter manufacturer's instructions) have a time constant in response to a step change in fluid temperature. For highly dynamic, fast-cycling systems like some of the heat pumps metered in this field trail, this may result in heat being systematically underestimated by several percent, even when the heat meter is installed correctly.

Not using temperature probe pockets or 'T's' to ensure the temperature sensor is in good thermal contact with the fluid travelling through the pipe further exacerbates the problem. It was found that taping on *both* temperature sensors with aluminium foil and cable ties and insulating them well could limit errors for systems with longer cycle times. However, other methods of strapping on temperature probes and only strapping on one temperature probe (and installing the other correctly) were demonstrated to create large errors.

Further data checking

The project has had a particular focus on data quality in summer and autumn 2013 and consequently the number of sites considered to be reporting valid data has improved. However, there is further work to do in this area to ensure the final dataset is as robust and error-free as possible. That work will focus on reviewing historic data, audit reports and installation reports.
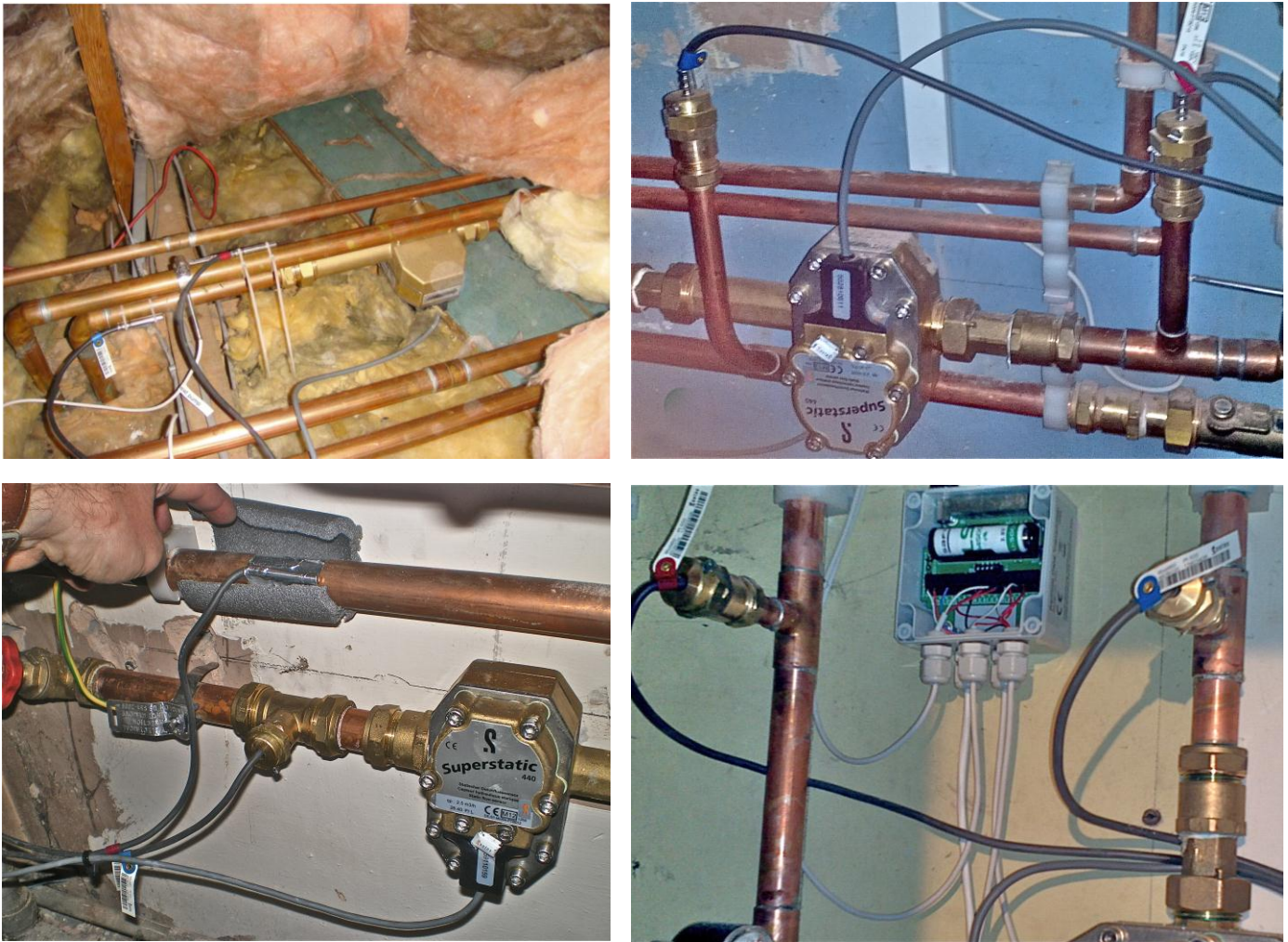
Figure 6: Examples of incorrectly installed heat meters. Clockwise from top left: a heat meter with both temperature sensors cable tied to the outside of the pipework (the flow meter is also not installed according to the manufacturer's instructions because the label is pointing directly down); custom 'temperature probe pipework extensions' at site 1633; custom copper 'T's' at site 1707; and a hot-side temperature sensor taped to the flow pipe using conductive foil tape and covered in insulation at site 1233 (the flow meter and cold-side temperature are installed correctly at this site).

Figure 7: A flow meter and pair of temperature sensors correctly installed at site 1089

Analysis

Analysis has been performed using MatLab, a matrix-based high-level computing language well-suited to analysis of 'big data'. In this section we provide details of the pre-processing conducted on the data and the analysis performed to show the results in the next section.

Before continuing, it is worth pointing out the scale of this data set. There are currently over 0.5 billion readings and consequently processing this data to create one distribution of SPF like the one in Figure 19 takes approximately 5 hours for a computer with 8GB RAM.

You will recall that one of the aims of this research is to be able to report data consistently at several different system boundaries. This is important because it enables comparisons between systems, with different field trials, and evaluation against the criteria set by the EU in order for a heat pump to be considered to generate renewable energy.

In the section on Equipment specification, it was explained that the approach taken was to record relatively few measurements, take observations during installation, and then rely on reasonable assumptions and analysis to determine energy flows at the SEPEMO system boundaries. However, before that can happen, the data must be pre-processed.

Pre-processing

The purpose of pre-processing is to exclude any metering data that is unrealistic and make it fit for future analysis. The job of pre-processing the data is largely complete by the time DECC downloads it from a remote server. Data may be excluded during the pre-processing stage because:

(a) Radio interference has caused delays in the web box receiving the data and therefore heat readings don't correspond to electricity meter and temperature sensor readings.
(b) Lines of data for each 2-minute interval are incomplete.
(c) Readings are unrealistically high or low.

Part of pre-processing the data is also to make it a continuous time series.

At this point it's possible to use the metering data to determine where the heat meters are installed using algorithms.

Determining where the heat meters are installed

By default, all systems are first assumed to have a single heat meter installed. A different categorisation is given to systems that regularly spend time consuming electricity without generating a heat output measured by the main system heat meter, labelled H_{hp}.

In these cases, energy is generally either simultaneously being measured entering the hot water cylinder by a second heat meter, our second categorisation, or it's not being measured at all, in which case it must be stored, our third heat meter arrangement.

Determining heat pump type

RHPP scheme management data is used to identify the heat pump type – ground-source or air-source – in the pre-processing stage as well.

Determining if the heat emitter circulation pump runs continuously

The final pre-processing step looks at whether or not the heat pump has a circulation pump that runs continuously. This is useful for later analysis.

Separating energy flows

This is the substantive part of the analysis. Our approach is to break the energy consumption and heat output that we have measured down into its constituent components so that they can later be built back up to produce any performance parameter we may require.

In a typical heat pump unit, the energy flows that we are interested in are:

1. Electrical energy used by the heat pump's control unit (also referred to as base load)
2. Electrical energy used by the heat pump's evaporator fan if it is an ASHP
3. Electrical energy used by the heat pump's ground loop circulation pump if it is a GSHP
4. Electrical energy used by the heat pump's compressor
5. Electrical energy used by the heat pump's supplementary heater(s)
6. Electrical energy used by the immersion heater in the domestic hot water cylinder
7. Electrical energy used by the heat pump's primary circuit circulation pump(s)
8. Electrical energy used by defrost cycles if it is an ASHP
9. Heat energy used for defrost cycles if it is an ASHP
10. Heat energy used for domestic hot water
11. Heat energy used for space heating

To separate these energy flows we have created customised algorithms. There are 7 currently in the analysis framework, and they look at:

1. Defrost cycles
2. Base load
3. Domestic hot water
4. Space heating
5. Periods of unknown operation
6. Circulation pumps
7. Supplementary heaters

Some of these are still being improved but one of the more developed is the algorithm used to identify domestic hot water cycles, which we'll use as an example. This is important because without identifying domestic hot water cycles it is impossible to jump between SPF_{H4} and SPF_{H5}. Being able to isolate periods of space heating and domestic hot water production is also attractive from an analysis perspective because it makes the data easier to understand.

Identifying periods of domestic hot water production

Figure 8 illustrates our starting assumption for how a hot water cycle might look as measured by the relevant temperature sensor, T_{wf}. When T_{wf} rises, energy is flowing into the domestic hot water cylinder.
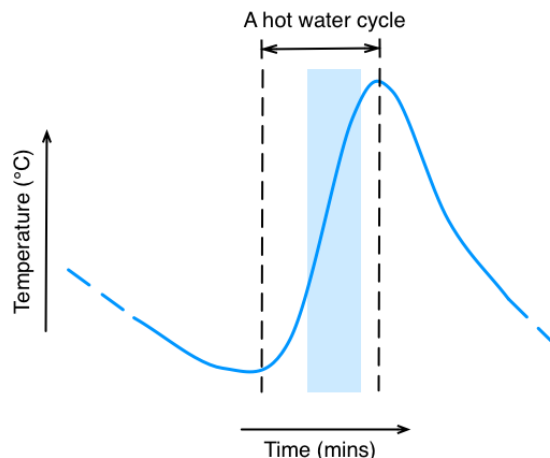

Figure 8: A cartoon of T_{wf} during a hot water cycle. T_{wf} is the temperature sensor measuring the temperature of the flow to the domestic hot water cylinder.

We assume that a hot water cycle would normally be between a minimum point and a maximum point on a trace of T_{wf}. To identify this period, we use a moving average to identify the blue shaded area. The high gradient of the line distinguishes it from other data points. Based on this conservative approximation, the start and end points of this cycle can be determined. The algorithm locally walks backwards to the closest minimum it can find, and forward to the closest maximum it can find. These become the underlying assumptions for identifying hot water cycles in the metering data.

During testing of this approach it was common to find extended domestic hot water cycles, like the one shown in Figure 9. Its end point has a tail compared with the one shown previously.

Figure 9: A cartoon of an extended domestic hot water cycle

To cater for this type of domestic hot water cycle, the algorithm extends its search for the end point by checking the gradient between the original end point and the data points that follow. The algorithm keeps extending the end point until the gradient is greater than (i.e. more negative than) a threshold.

In certain situations, the algorithm can be improved using flow data. Periods where domestic hot water is being created may have a distinctly higher or lower flow rate than periods where heat is being created for space heating owing to a difference in pressure drop through the different parts of a primary circuit. For systems with integrated domestic hot water cylinders and circulation pumps that are always on, periods of domestic hot water production show up clearly in the time series of the space heating flow measurement as the only periods where no flow is measured.

Software validation

The results of these algorithms can be shown graphically by shading the background of a plot according to the type of operation that has been identified.

Figure 10 shows, from the bottom, electricity consumption, primary circuit flow rate, heat output and the 4 temperature readings. The algorithm is very successful at spotting domestic hot water cycles, in blue, which are easily identifiable by eye because of their impact on T_{wf} in the top plot. Periods of space heating in pink and background operation in yellow are also shown. This is a ground-source heat pump metered with a single electricity meter and heat meter. It's easy to see that the primary circuit circulation pump is almost always on at this site and that is reflected by the purple bar across the top of each of the plots. Cycling like this is a common feature of most of the RHPP data.

The same charts for an ASHP on the same days are shown in Figure 11. Increases in T_{wf} are less obvious in this figure but again the domestic hot water cycles, space heating cycles and periods when the circulation pump is on are successfully identified. 5 suspected defrost cycles are also shown in this figure in orange; this is expected to be an underestimate. However, there is a grey area in Figure 11. This is a period of operation that the algorithms haven't been able to identify and it has therefore been marked as "unknown". In this case this looks to be a start-up period. Finally in Figure 12, another example of an ASHP shows that the main operating characteristics of the heat pump have been captured.

Figure 10: Use of the energy separation algorithms to identify energy flows on site 1261 on 28th and 29th December 2013.
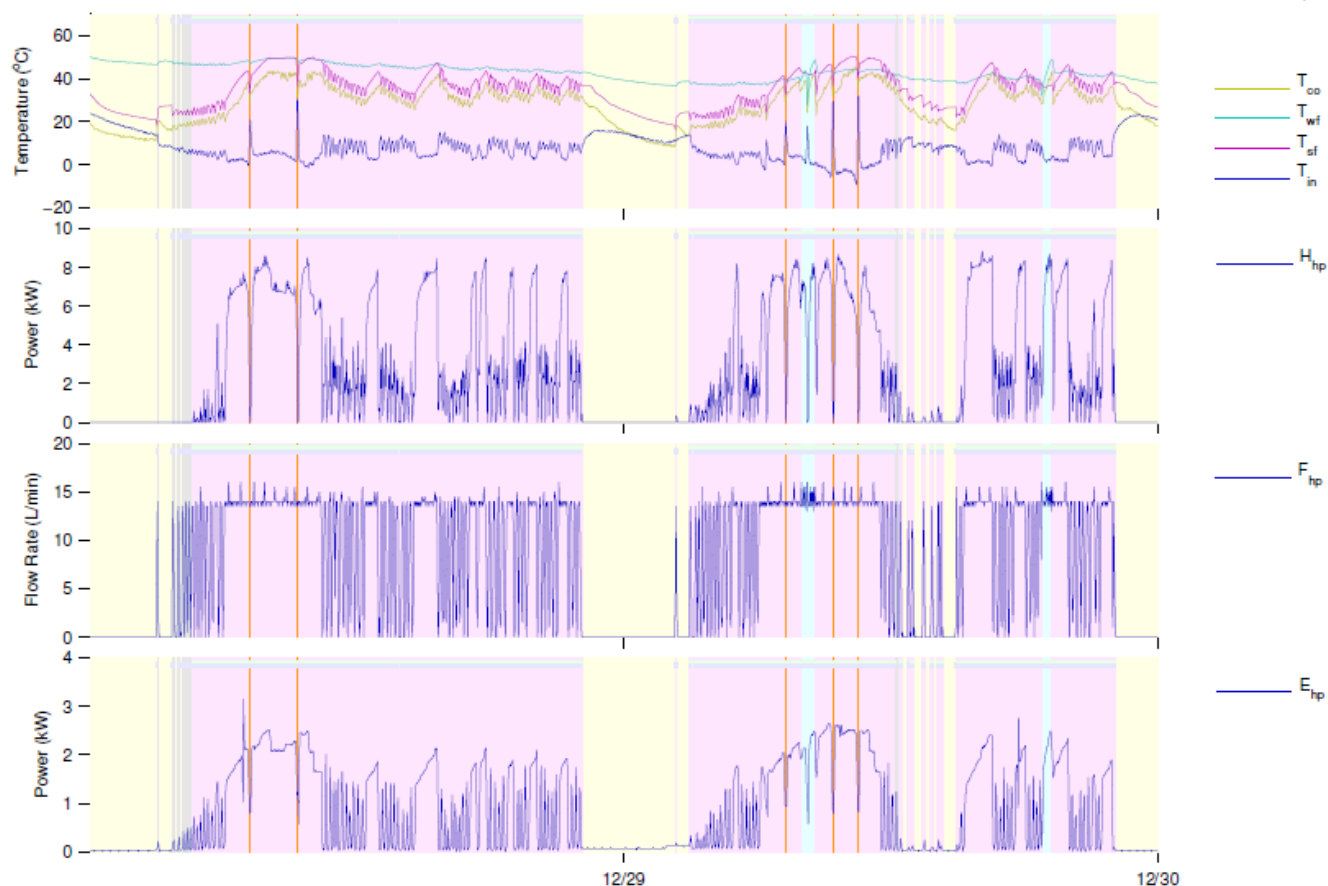
Figure 11: Energy flows on site 1311 on 28th and 29th December 2013.
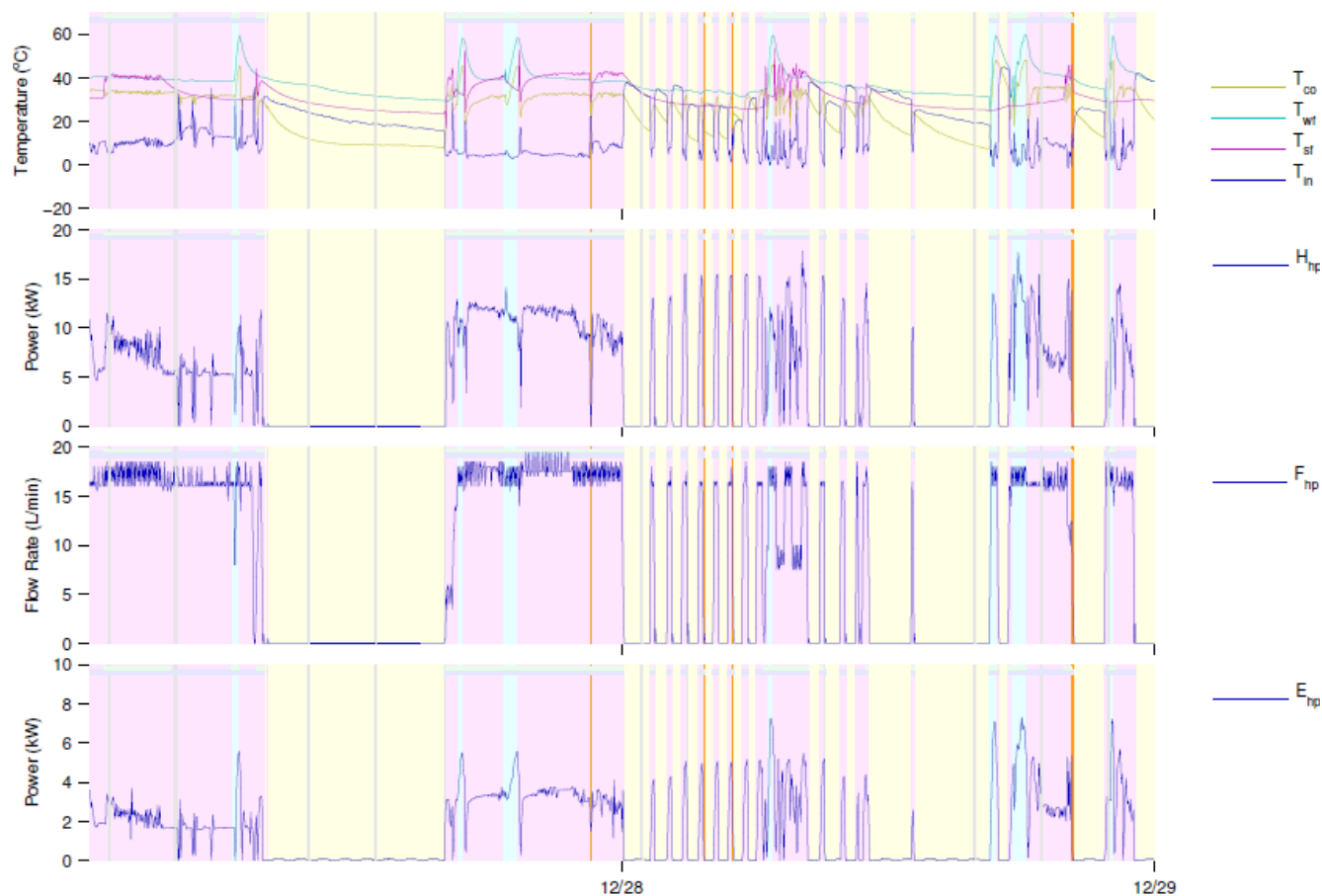

Figure 12: Energy flows on site 1252 on 28th and 29th December 2013.

Software validation has been conducted using graphical techniques like this with data from all seasons, all types of heat pump and all metering configurations with good success overall. Obviously, if the data is erroneous – for instance if temperature sensors have been incorrectly wired up – the algorithms fail, but with a few exceptions our software is successful at breaking down the energy consumption that has been measured into the key constituent parts.

The algorithm to determine the energy consumption by supplementary electric heaters has been more challenging to develop than expected and has not been thoroughly validated. This is required to move from SPF_{H3} to SPF_{H2} and on to SPF_{H1}. The results from these narrower system boundaries are therefore currently less reliable than SPF_{H4}, which is often measured directly.

Similarly, the algorithm to estimate defrost energy (which was previously only found to be 2 – 5% of heat output) is less developed than most of the others. It is likely that it currently under-reports defrost cycles.

Building SPFs

Re-assembling the energy flows into the SEPEMO system boundaries is relatively simple with the knowledge of what the heat pump is doing and when. However, it currently requires some important assumptions as listed in Table 6. The values used are based on discussions with members of industry and previous experience. Assumptions have been used because it has not yet been possible to integrate the information collected on site by the meter installers with the metering data.

Furthermore, it should eventually be possible to adjust the heat meter reading to take account of the fact that a lot of (ASHP) systems have antifreeze in their primary circuit but this exercise has not been completed. Using heat meters calibrated for water in primary circuits containing antifreeze is suspected to result in an over-estimate of heat output for those sites of up to approximately 5%.

Parameter	Assumption
Power consumption of control unit	30W
Power consumption of evaporator fan for ASHPs	60W
Power consumption of ground loop circulation pumps	75W
Maximum power consumption of primary circuit circulation pumps	180W
Domestic hot water cylinder losses	30%
Impact of glycol in heat meters calibrated for use with water	[None]

Table 6: Key assumptions used to create SPFs at different system boundaries.

Examples of SPF data at different system boundaries for 2 ASHPs and 2 GSHPs are shown in Figure 13, Figure 14, Figure 15 and Figure 16. The charts are plotted using all of the data collected before 10th January 2014. In some cases this is more than a year, in others it is less.

The number of days that have elapsed between the date the first data was received and the 10th January 2014 is indicated on each figure. This may be more than the number of days that we have metering data for.

The left-hand vertical axis in each figure should be compared with the electricity data (denoted "E") in each group of bar charts, not the heat bar (denoted "H"). The axis is created by assuming the price of electricity is 12p/kWh. The total cost of running the ASHP (system boundary H4 or H5) in Figure 13 for 401 days, for instance, is £480.

The vertical axis on the right of each figure displays energy consumption or production. The colours in each chart match the colours used previously to indicate what operation each heat pump is performing.

We can see in each figure the build-up of energy consumption and visually see how the parasitic loads, circulation pumps and fans and domestic hot water cylinder losses reduce the SPFs at wider and wider system boundaries. For the highest-capacity heat pump (Figure 15), the impact is smallest because these other uses of electricity are proportionally smaller. The different SPF values are written on the left-hand side of each figure. The charts also identify the system boundary that has been measured directly.

Each chart also estimates SPF_{H1} for space heating and domestic hot water heating alone. These results are written in the bottom left corner of each figure. By looking at these, it's possible to remove the impact of varying domestic hot water demands. We can see that despite having quite different overall SPFs, the ground-source heat pumps in Figure 15 and Figure 16 actually have very similar performance when providing space heating and domestic hot water. The difference in overall SPFs between the two may therefore be down to the proportionally higher domestic hot water demand in Figure 16 (indicated by the relative sizes of the blue and pink bars). It may be that once there is a year of data from both of these sites, their overall SPF is similar.
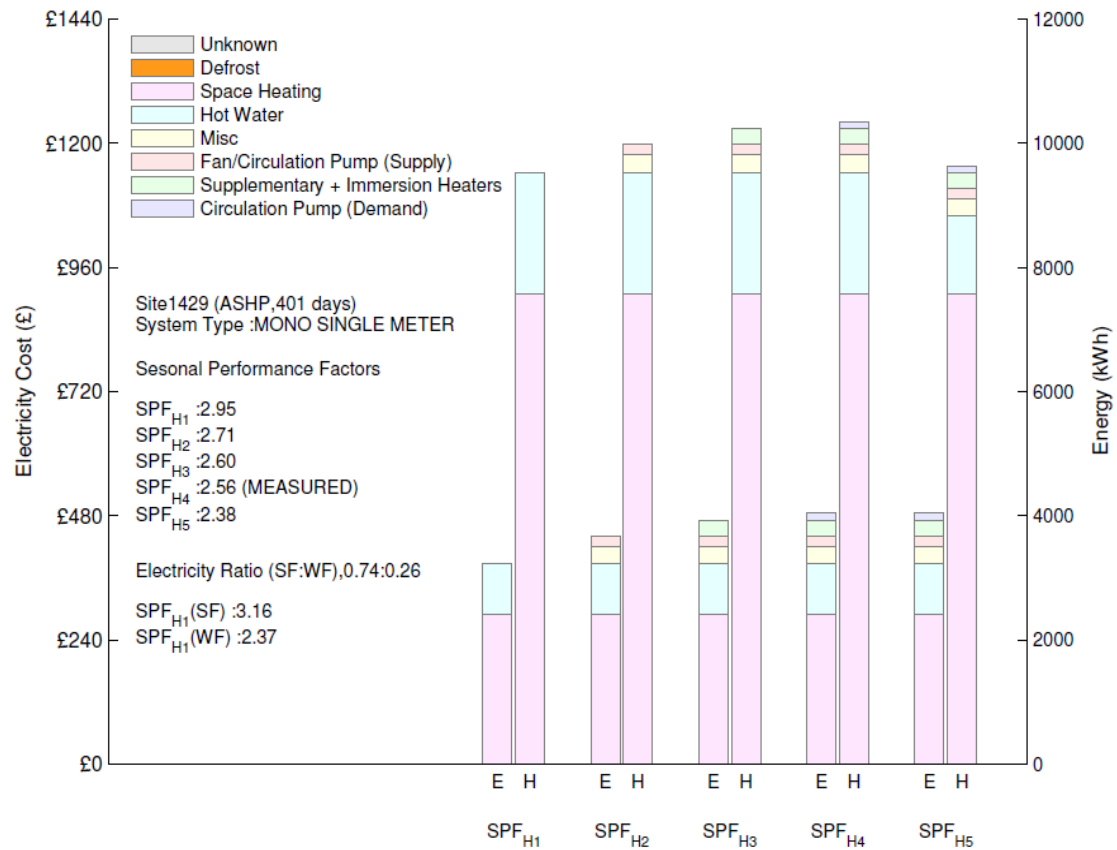
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Figure 13: Stacked bar charts showing the make-up of different SPFs at site 1429 (an ASHP). The figure uses all of the metering data collected.
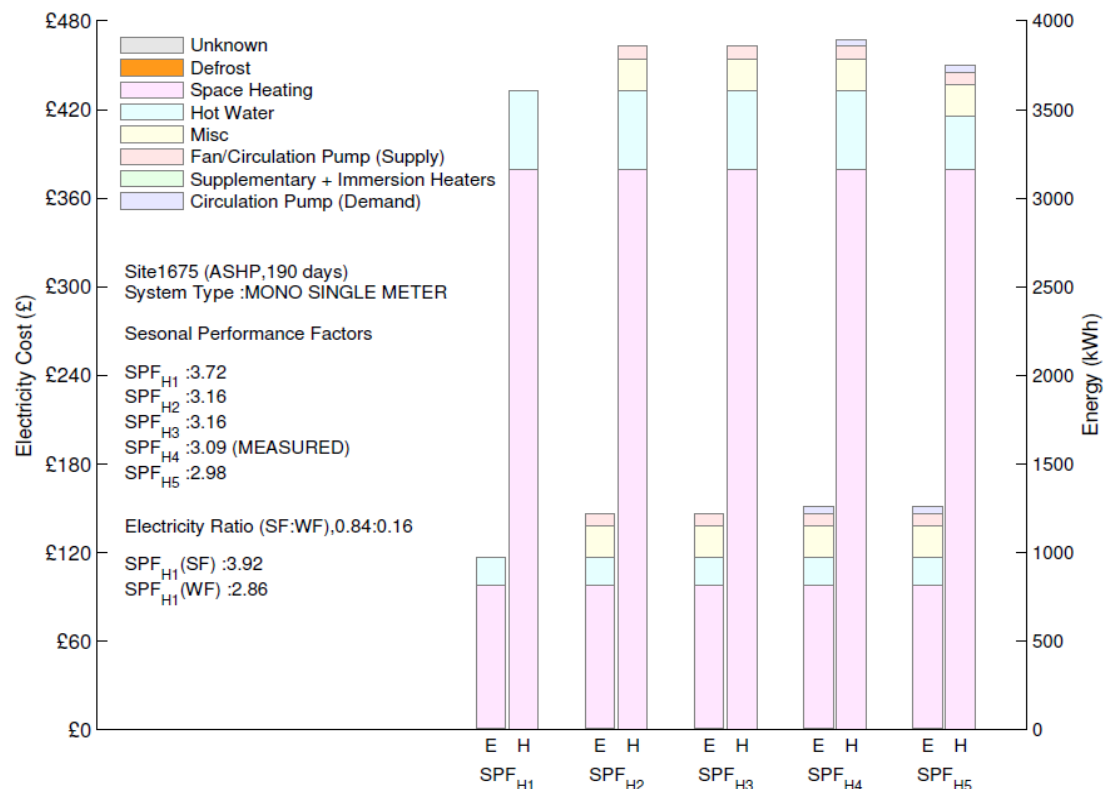

Figure 14: Stacked bar charts showing the make-up of different SPFs at site 1675 (an ASHP). The figure uses all of the metering data collected.
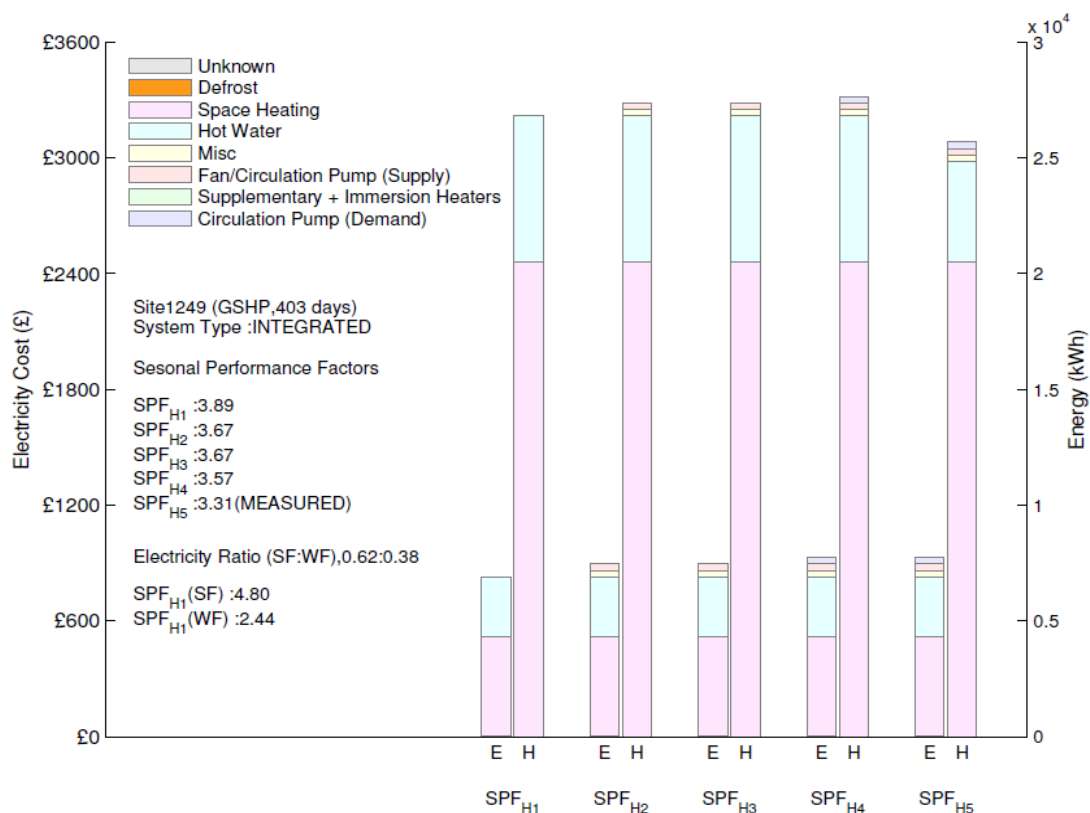
35

Figure 15: Stacked bar charts showing the make-up of different SPFs at site 1249 (a GSHP with integrated domestic hot water cylinder). The figure uses all of the metering data collected.
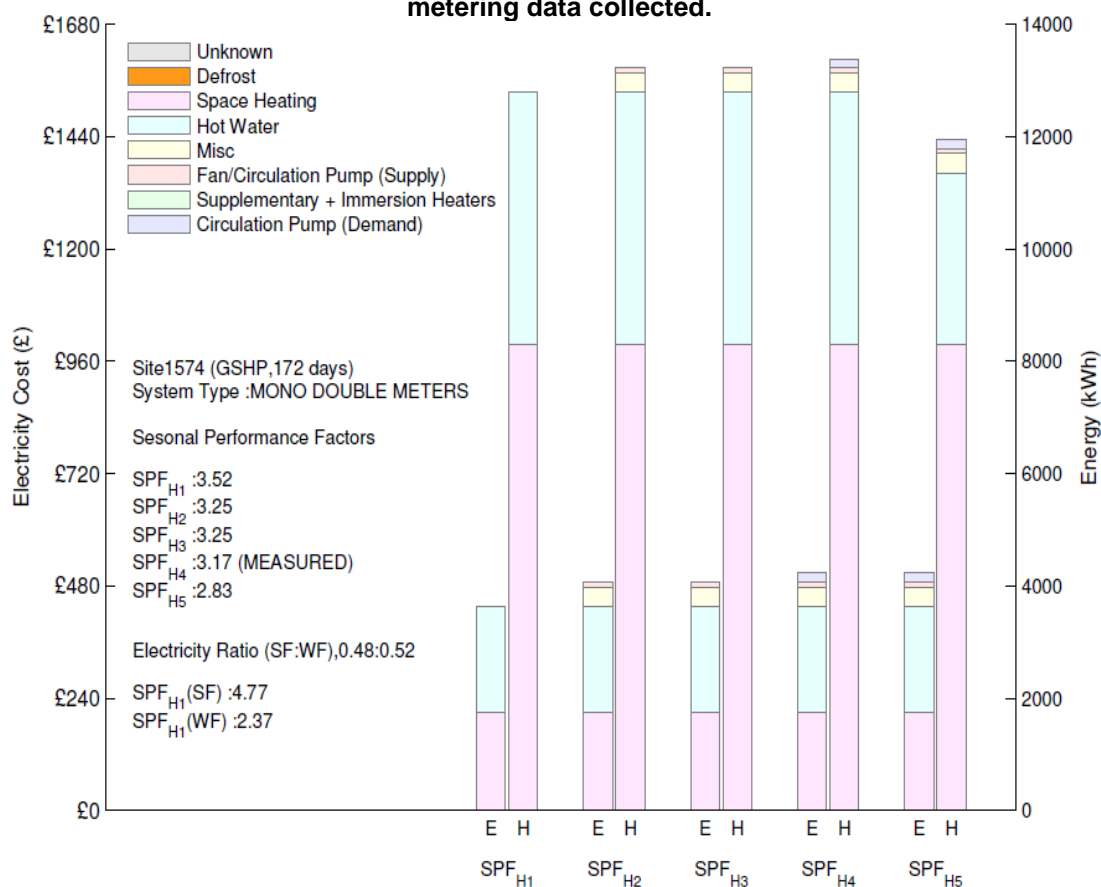

Figure 16: Stacked bar charts showing the make-up of different SPFs at site 1574 (a GSHP with separate meters for space heating and domestic hot water). The figure uses all of the metering data collected.

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Estimating bill and carbon savings

It is extremely challenging to match up metered sites with their previous heating fuel, make assumptions about the metered person's previous system's efficiency and produce an estimate of bill savings on a site-by-site basis. However, by making reasonable assumptions about average new boiler efficiencies and fuel prices, we have produced Table 7 showing the SPF required for heating bills to be constant when replacing different 'fuels' under two scenarios: (i) assuming installing a heat pump makes no difference to the heating energy demand; and (ii) assuming the heat pump puts up heating energy demand by 10%. The efficiencies for LPG and gas boilers are taken from the EST's condensing boiler field trial (for regular boilers); from table 4b in SAP 2009 (BRE, 2010) for oil boilers (winter efficiency figures); and from table 4a in SAP 2009 for solid fuel boilers.

Consideration that heating energy demand may increase after installation of a heat pump is in response to the EST heat pump field trial (Dunbabin & Wickins, 2012), which noticed that average internal temperatures were, on average, 1°C higher than in EST's condensing boiler field trial (Orr, Lelyveld, & Burton, 2009). Consideration of degree days shows that a 1°C increase in internal temperature puts up space heating energy demand by approximately 10%. In reality, whether or not heating energy demand increases is likely to be installation specific and depend on whether or not there has been a significant change in the number of hours per day space heating is being provided and whether or not users are intentionally heating their property for longer or to a higher temperature. A 10% increase in energy demand is not necessarily a bad thing if the heat user is more comfortable, but it will have an impact on fuel bill and carbon savings.

SPF's higher than the numbers in Table 7 will result in bill/carbon savings; SPF's lower than these numbers will result in bill/carbon increases.

Previous heating energy source	Efficiency of previous heating system	Required SPF for fuel bills to stay the same in Year 1[2]		Required SPF for carbon emissions to be the same in Year 1	
		Heating energy demand is constant	Heat pump increases heating energy demand by 10%	Heating energy demand is constant	Heat pump increases heating energy demand by 10%
LPG	85%	1.38	1.51	1.90	2.10
Electricity (E7)	100%	1.50	1.65	1.00	1.10
Oil	84%	1.82	2.00	1.65	1.82
Solid (coal)	60%	2.13	2.34	0.97	1.07
Gas	85%	2.49	2.73	2.21	2.43

Table 7: SPFs required to generate bill and carbon savings for different previous fuels

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[2] The fuel prices and carbon intensity factors used in these calculations can be found on the EST website: http://www.energysavingtrust.org.uk/Energy-Saving-Trust/Our-calculations: LPG, 8.59p/kWh, 214gCO2/kWh; Economy 7 electricity, 9.24p/kWh, 480gCO2/kWh; Oil, 6.43p/kWh, 244gCO2/kWh; Solid fuel, 3.92p/kWh, 296gCO2/kWh; Gas, 4.76p/kWh, 185gCO2/kWh; Flat rate electricity, 13.91p/kWh, 480gCO2/kWh.

The table above shows how dependent bill savings are on how the property was heated previously and whether or not heating energy demand remains constant when the heating system is changed.

In the next section of the report, we compare this data with the measured data from the RHPP installations.

Further analysis

Before detailed questions are asked of this data, further development of the analysis framework is required to make it useful.

The highest priority is to clean up the data set. Our intention is to create a log of "data incidents" to record situations where the data that has been collected isn't valid. The analysis framework can then be updated to exclude data incidents.

The amount of data presented in this report is limited because this work has not been completed. Our approach is therefore to only look at distributions of SPF from recent data, which, due to the effort to fix problems conducted before the start of the heating season, we can be more confident in. Data to explore the validity of doing this is presented in the next section.

Linking the analysis framework to the site information collected at the point of installation, the RHPP scheme management data, and potentially also to EPCs will further refine the analysis, improve the accuracy of the results and open up new avenues for exploration. It will also provide further opportunities to perform cross-checks and identify spurious results.

In addition, improving the analysis framework's ability to deal with defrost energy, supplementary heating, systems with antifreeze in their primary circuits and de-superheater systems will also improve the accuracy of the results.

This is work that can be conducted while a year's worth of data is being gathered from all sites so that the software is ready to be executed once the data acquisition period concludes at the end of October 2014.

During this period the intention is to also start asking specific questions of this data set:

- How does measured efficiency compare with the SPFs from the Heat Emitter Guide (MCS, 2013)?
- What are main causes of high performance?
- What are the main causes of poor performance?
- What is the impact of system cycle times on SPF?
- What is the impact of supplementary electric heater use on SPF?
- What is the impact of emitter temperature on SPF?
- What is the impact of ground loop return temperature on SPF?
- What is the impact of flow rate on SPF?

Results

It was explained in the last section that this report has focused on the most recent data because the data cleaning exercise that will identify periods of historic valid data has not been completed. Data for December 2013 only is being used in this section of the report. How representative is that of an entire year of operation?

One useful source of information to help answer that question is external temperature data. The Hadley Centre Central England Temperature (HadCET) dataset records daily and monthly temperatures that are representative of a roughly triangular area of the United Kingdom enclosed by Lancashire, London and Bristol[3]. Data for 2013 is shown in Figure 17. The black line is the daily average temperature records. The blue dots are 2013 monthly averages and the red line shows the long-term monthly average. The dataset clearly shows 2013's unusually cold March. The monthly averages for November and December are 6.17^{o}C and 6.34^{o}C so accordingly we shouldn't expect significant differences in the SPF data for the two months (at least for ASHPs). The average temperature in December is 1.69^{o}C higher than the long-term average, and approximately 2.5^{o}C higher than the long-term averages for January and February. Clearly then, the results in this report are not from the depths of winter.

However, previous work (Dunbabin & Wickins, 2012) has demonstrated for GSHPs that SPF's for December are indicative of a complete year of operation. The chart in Figure 18 shows the annual SPF (indicated by the green line), monthly SPFs (red dots) and distributions of SPFs based on 20-minute bursts of data (grey bars) in each month for one particular GSHP in the EST field trial phase 1. The monthly SPFs are higher than the annual average in October, November and April; lower during the summer months when the energy demand is dominated by domestic hot water production; and roughly equal to the annual SPF from December to March.

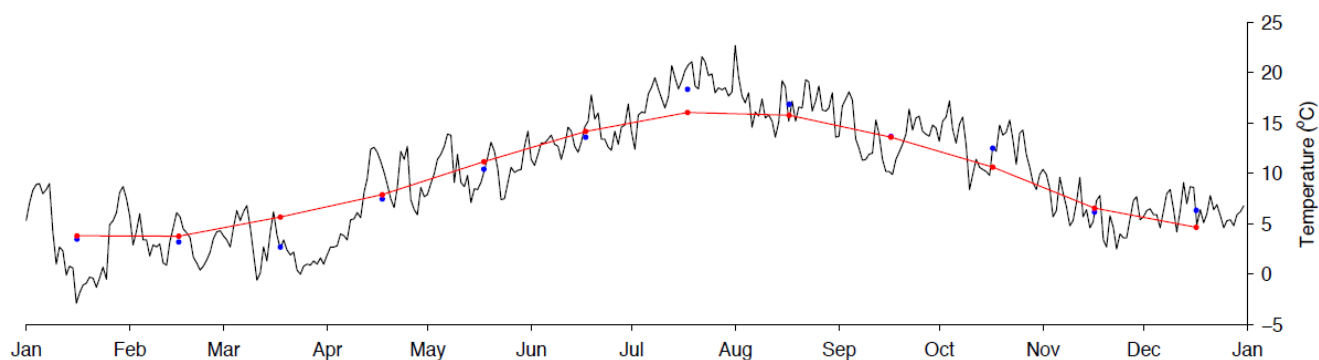Monthly SPFs created using 4 RHPP sites where data has already been collected for more than

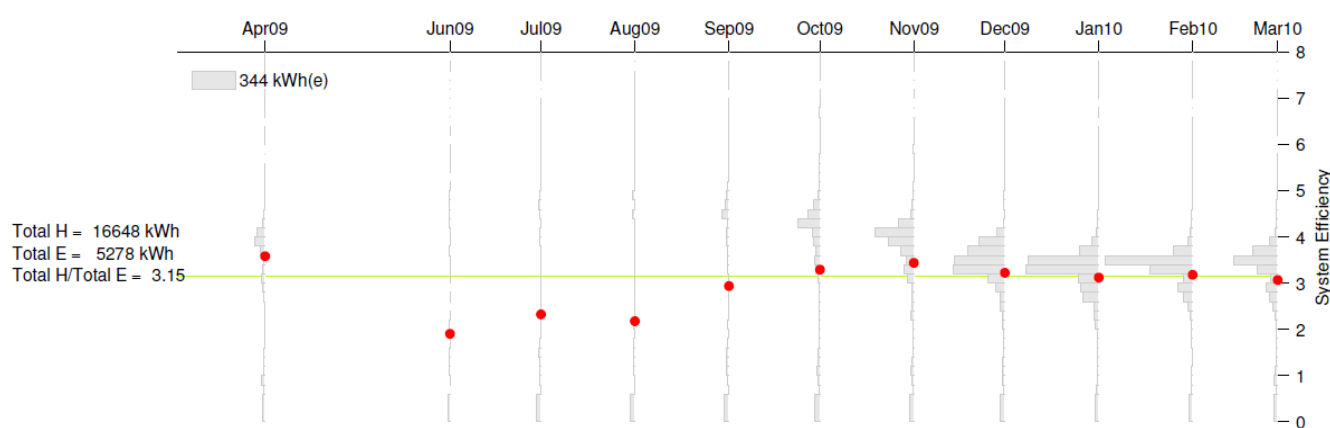**Figure 17: HadCET data for 2013**

Figure 18: Monthly distribution of seasonal performance factor from the one of the sites in the EST field trial

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[3] See http://www.metoffice.gov.uk/hadobs/hadcet/ for more details

1 year are shown in Appendix C – Example monthly and annual SPFs from RHPP data. The charts confirm that the SPF for December provides quite a good indication of the annual SPF in a typical year, particularly in light of 2013's unusually cold March, which would have dragged the annual SPF down in 2013.

Later in this section we will make comparisons with EST field trial data and infer fuel bill savings, carbon savings and renewable energy generation assuming that SPFs in December *are* representative of an entire year of operation. If anything, December is shown to produce an SPF slightly above the annual average in Appendix C – Example monthly and annual SPFs from RHPP data and that should be kept in mind. Once data collection is complete, we will be able to re-run our analysis and update these results if necessary.

SPF$_{H4}$ for December 2013

Most of the data in this programme is collected at SEPEMO system boundary H4 and therefore this parameter should be the most accurate of the SPFs presented because fewer assumptions need to be made to produce it.

The distributions for ASHPs and GSHPs are shown in Figure 19 in the top and bottom charts respectively. The 4-digit numbers in these charts are sites' logger numbers (or site IDs). Summary statistics for the charts are provided in Table 8.

These charts are created by running the software used to create the breakdowns of energy consumption shown in the last section on each site to build up a distribution. Sites with an SPF calculated to be less than 0.2 have been removed from the figures. Either these systems are off and only consuming a small amount of electricity, in which case the data is not relevant, or there is a problem with the metering arrangement.

In fact, any SPFs less than 1 at this system boundary may indicate a problem with the metering arrangement because there is an energy imbalance in the metered data. Caution should also be taken with very high SPFs.

Sites are excluded from this distribution if they have not passed DECC's checks for payment or if photos of the heat meters have shown that their temperature sensors have not been correctly installed. Later in this section, a distribution is shown with those sites identified.

It's immediately apparent that many more ASHPs have been metered than GSHPs. In large part this is because the RHPP (and in particular the RHPP Social Landlord competitions) has supported many more ASHPs than GSHPs. Approximately 2.4 times as many ASHPs as GSHPs have been paid grant funding in the householder voucher scheme to date (DECC, 2013). In the Social Landlord scheme the difference is greater.

The ASHP chart in Figure 19 shows a roughly normal distribution centred on an SPF of 2.5. However, the distribution has a tail on the left-hand side. These sites will need further investigation to confirm that the metering data is valid and identify the reason for this apparently poor performance.

The distribution of SPF$_{H4}$ for the GSHPs is less convincing because it is skewed to the right by about 20 sites with better measured performance than the median installation. Further investigation will be needed here to identify whether there are systematic differences between the systems with SPFs close to 4 and those that are lower. It's possible, for instance, that the distribution is distorted by a high number of installations that do not provide domestic hot water or from one Social Landlord. The age of the installations may also be a factor if the apparently high-performing systems are entering their first heating season and the ground is therefore warmer than it is at the other sites and will be in future years.
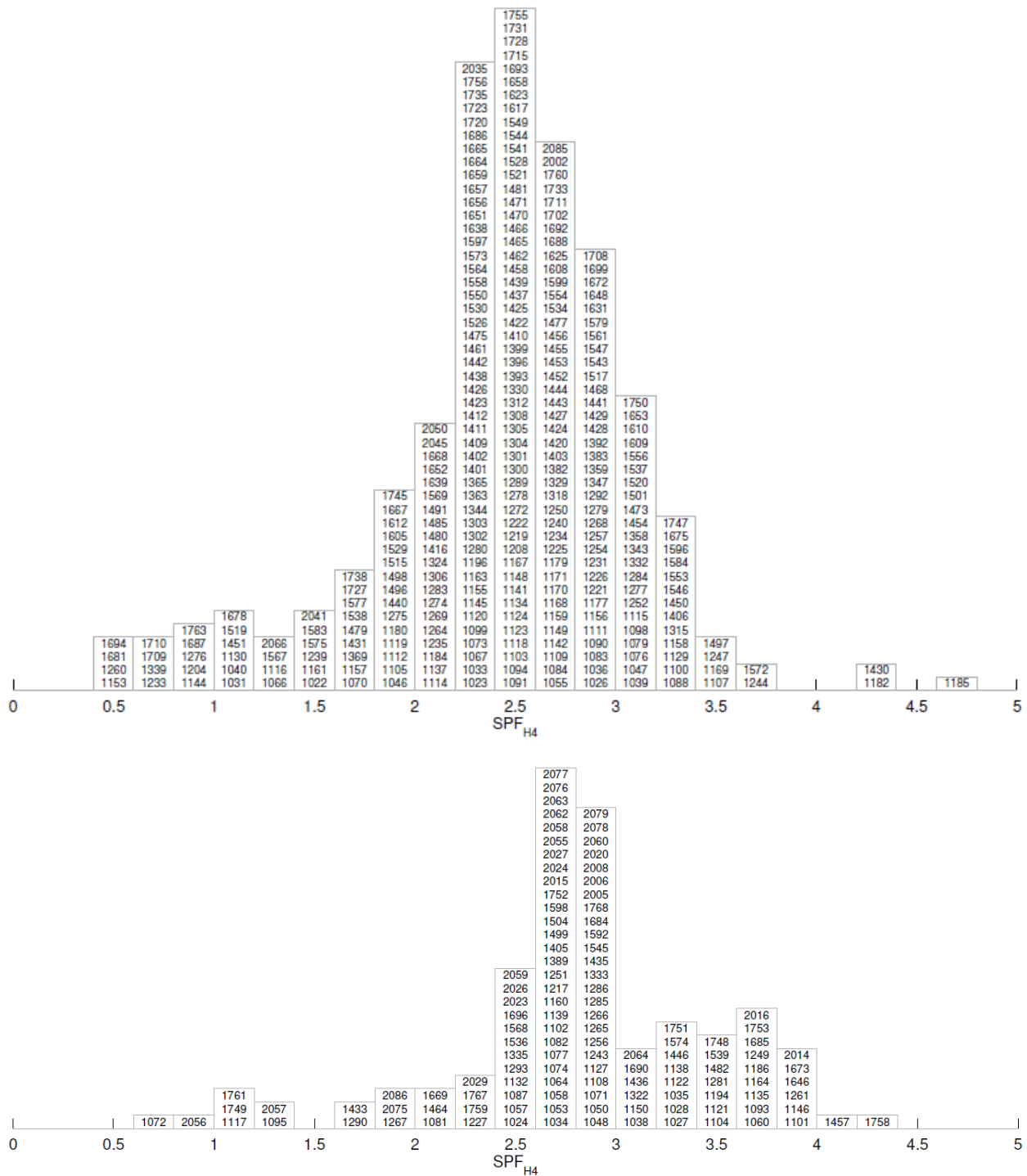
Figure 19: Distribution of SPF$_{H4}$ for ASHPs (top chart) and GSHPs (bottom chart) in December 2013

	Number in plot	Mean	Standard deviation	25th percentile	Median	75th percentile	Inter-quartile range
ASHP	289	2.43	0.65	2.18	2.51	2.83	0.65
GSHP	124	2.92	0.88	2.61	2.84	3.27	0.66

Table 8: Summary statistics for the distributions of SPF$_{H4}$ in December 2013

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Comparison with EST field trial phase 1 (SPF$_{H5}$)

A key result from the RHPP programme is whether or not there has been a significant improvement compared to phase 1 of the EST heat pump field trial. Phase 2 of that field trial isn't a fair comparison in this respect because it contains systems that had been targeted for improvement with the benefit of the metering data from phase 1. The RHPP data is a genuine snap shot of system performance in the same way phase 1 of the EST field trial was.

In Figure 20 and Table 9 the results from the two datasets are compared. Recall that the RHPP data is for December 2013 and installations from 2011 - 2013, whereas the EST data is for a whole year and installations from 2008. We also need to remember that a large assumption about domestic hot water cylinder losses is made to convert a lot of the metering data to SPF$_{H5}$. Domestic hot water cylinder losses are assumed to be 30%. This is thought to be representative of new or integrated domestic hot water cylinders but is better than previous measurements undertaken on solar thermal systems as discussed in the equipment specification section.

The improvements in SPF$_{H5}$ for both types of heat pump are easy to see and encouraging. The improvements remain encouraging if the domestic hot water cylinder losses are increased to 50%, which is more consistent with the measurements undertaken previously. This distribution is shown as a dotted line on the same figure.

In Figure 21 the RHPP results are shown next to the results from the second phase of the EST field trial. The results are more closely aligned, especially when the assumption of 50% domestic hot water cylinders losses is made (again shown as a dotted line). This is another good result since many of the systems in the second phase of the EST field trail were designed to the same installation standard as the RHPP installations.

Bill and carbon savings (SPF$_{H4}$)

SPF$_{H4}$ can be used to compare the performance of heat pumps with estimated efficiencies of fossil fuel heating systems as was explained in the analysis section (Table 7). The efficiencies for the conventional heating systems are what might be expected from a new replacement system.

The number and percentage of systems achieving the SPF$_{H4}$ needed to generate fuel bill and carbon savings in their first year of operation is shown in Table 10 for ASHPs and Table 11 for GSHPs. Higher percentages are shaded darker yellow.

Remembering that the data comes with the caveat that December operation is being compared with *annual* estimates of conventional heating system efficiency, high percentages of systems are shown to result in fuel bill and carbon savings for off-gas-grid applications, where heat pumps are often cited as most effective. More than 82% of the metered ASHPs and more than 90% of the metered GSHPs would be expected to reduce customers' heating bills where their previous heating system is LPG, Economy 7 electricity or Oil. For ground-source heat pumps, we estimate that between 64% and 79% of on-gas-grid properties would also reduce heating energy bills by switching to a heat pump.

These results indicate that the likelihood of a customer benefiting from switching from their conventional heating system to a heat pump is high, especially if they don't currently use mains gas.
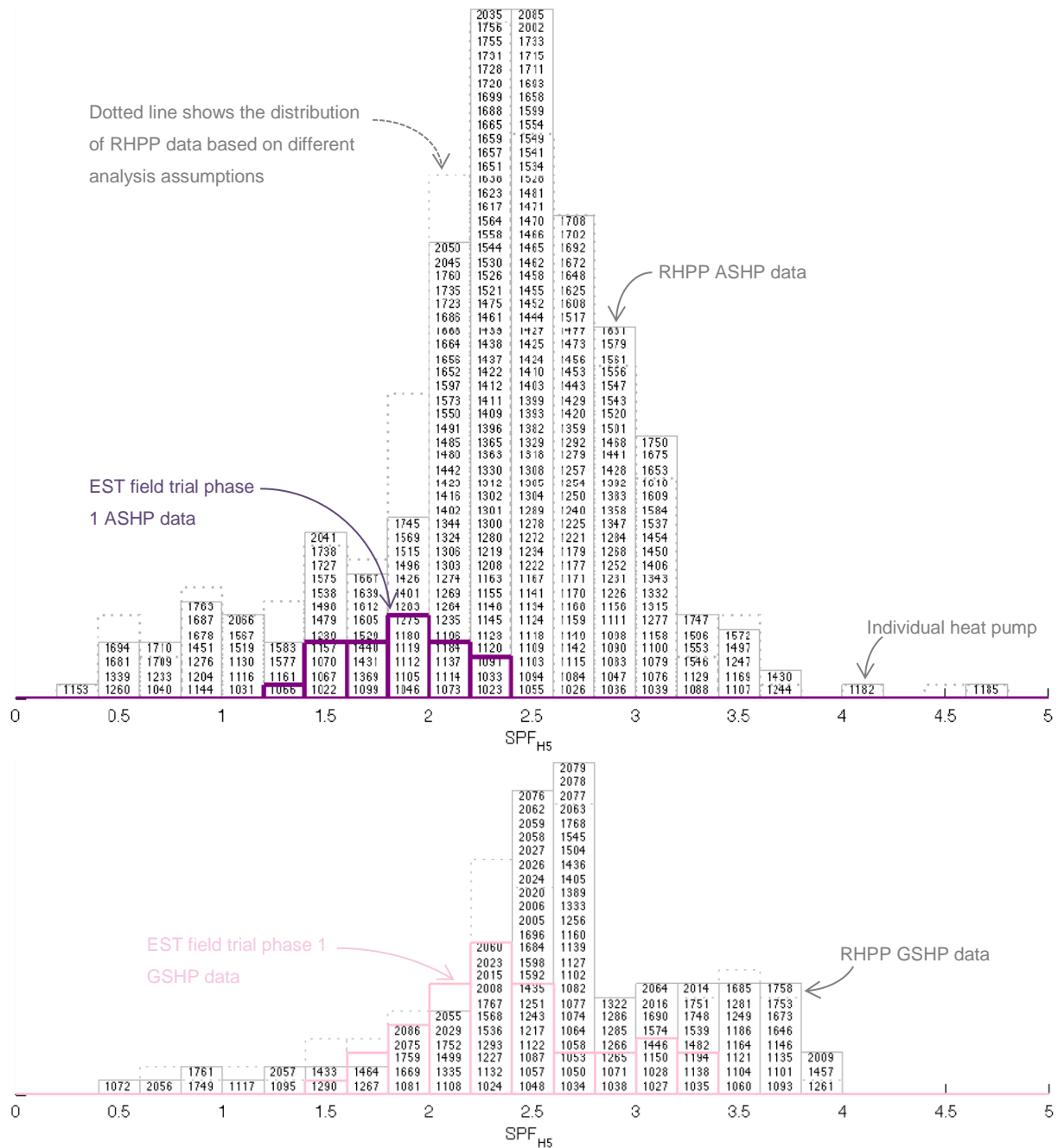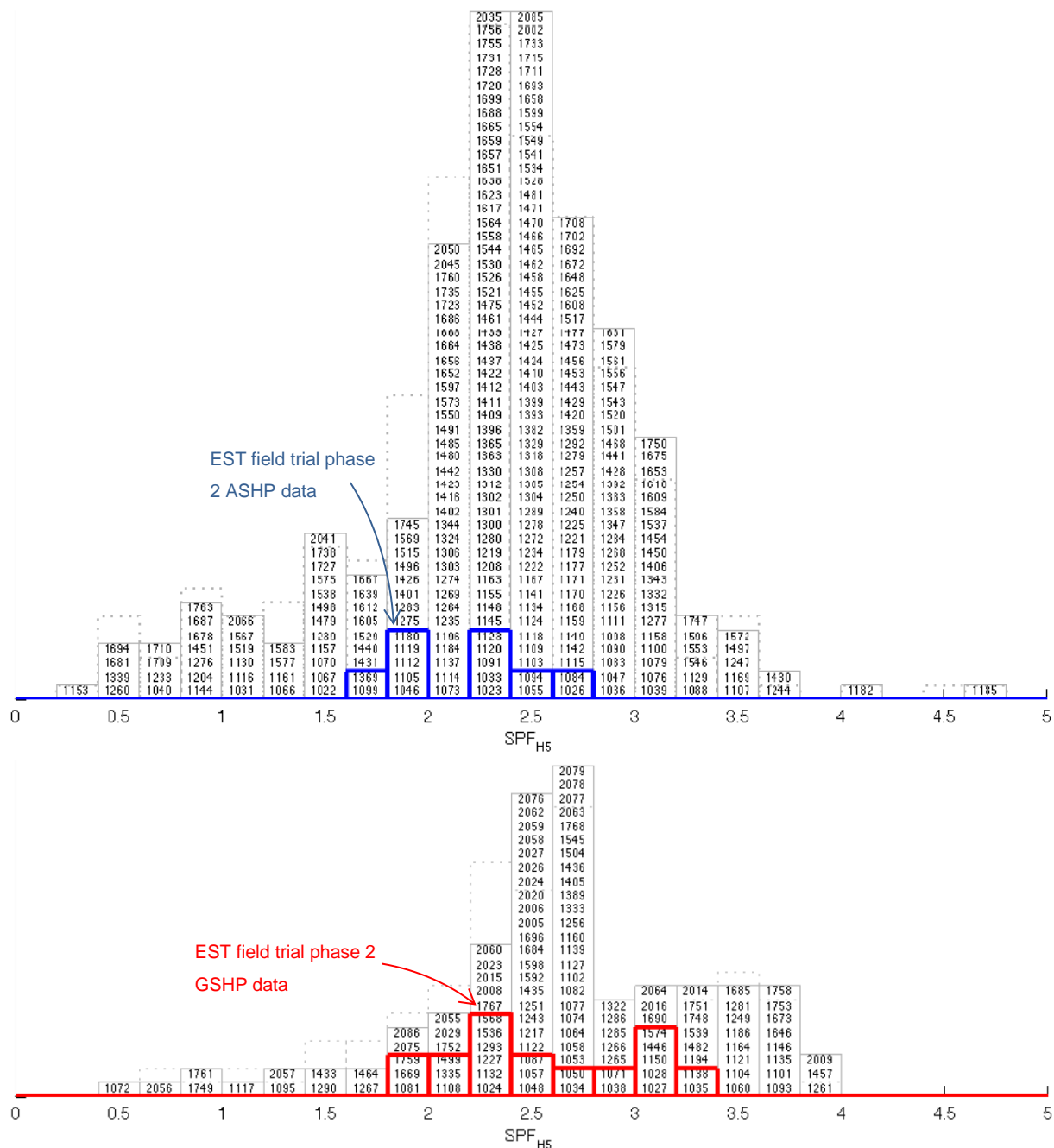
Figure 20: Distribution of SPF$_{H5}$ for ASHPs (top chart) and GSHPs (bottom chart) in December 2013, also showing the results from the EST field trial phase 1 (complete year).

	Number in plot	Mean	Standard deviation	25th percentile	Median	75th percentile	Inter-quartile range
ASHP	289	2.34	0.65	2.05	2.41	2.72	0.67
EST phase 1	22	1.84	0.29	1.63	1.83	2.07	0.44
GSHP	124	2.74	0.84	2.37	2.68	3.18	0.81
EST phase 1	49	2.39	0.45	2.10	2.31	2.66	0.56

Table 9: Summary statistics for the distributions of SPF$_{H5}$ in December 2013 from RHPP and for the whole year from EST field trial phase 1.

Figure 21: Distribution of SPF$_{H5}$ for ASHPs (top chart) and GSHPs (bottom chart) in December 2013, also showing the results from the EST field trial phase 2 (complete year).

Previous heating energy source	Efficiency of previous heating system	Number (%) of systems expected to provide fuel bill savings in Year 1 of operation		Number (%) of systems expected to provide carbon savings in Year 1 of operation	
		Heating energy demand is constant	Heat pump increases heating energy demand by 10%	Heating energy demand is constant	Heat pump increases heating energy demand by 10%
LPG	85%	266 (92%)	264 (91%)	241 (83%)	231 (80%)
Electricity (E7)	100%	264 (91%)	256 (89%)	276 (96%)	270 (93%)
Oil	84%	247 (85%)	236 (82%)	256 (89%)	250 (87%)
Solid (coal)	60%	224 (78%)	184 (64%)	276 (96%)	274 (95%)
Gas	85%	154 (53%)	89 (31%)	214 (74%)	167 (58%)

Table 10: Percentage of ASHP systems decreasing fuel bills compared with various other heat sources. The total number of sites in the sample is 289. >90% shaded dark yellow; >80% shaded light yellow

Previous heating energy source	Efficiency of previous heating system	Number (%) of systems expected to provide fuel bill savings in Year 1 of operation		Number (%) of systems expected to provide carbon savings in Year 1 of operation	
		Heating energy demand is constant	Heat pump increases heating energy demand by 10%	Heating energy demand is constant	Heat pump increases heating energy demand by 10%
LPG	85%	117 (94%)	117 (94%)	114 (92%)	110 (89%)
Electricity (E7)	100%	117 (94%)	116 (94%)	122 (98%)	121 (98%)
Oil	84%	115 (93%)	112 (90%)	116 (94%)	115 (93%)
Solid (coal)	60%	110 (89%)	107 (86%)	122 (98%)	121 (98%)
Gas	85%	98 (79%)	79 (64%)	109 (88%)	105 (85%)

Table 11: Percentage of GSHP systems decreasing fuel bills compared with various other heat sources. The total number of sites in the sample is 124. >90% shaded dark yellow; >80% shaded light yellow

Comparison with the EU SPF requirement (SPF$_{H2}$)

The SPF threshold for the EU to consider a heat pump to generate renewable energy is 2.5 (European Commission, 2013). This is defined at SEPEMO system boundary H2, which excludes the impact of supplementary heaters, including immersion heaters, and load-side circulation pumps.

Immersion heaters inside domestic hot water cylinders are generally measured separately in this metering programme and are therefore easy to exclude. However, the algorithms used to identify supplementary heating are less developed than other parts of the analysis software so the SPFs presented at this system boundary are likely to be underestimated when the electricity consumption by a supplementary heater is included inside the main heat pump electricity measurement. These results therefore need to be viewed with caution. This comparison, like the others in this section, also requires extrapolation from December operation to an annual SPF.

Figure 22 shows histograms of SPF$_{H2}$; summary statistics are shown in Table 12. The yellow cells in the table show the number and percentage of systems with SPF$_{H2} \geq 2.5$. Based on this analysis, these results are also encouraging. 69% of ASHPs and 84% of GSHPs measured meet the SPF criteria. These are relatively high percentages but they leave a significant minority. Further analysis should be able to identify the reasons for this apparently poor performance and enable the industry to learn from it.

Excluded data (SPF$_{H4}$)

In the results presented to this point, systems whose heat meter temperature probes are suspected (through examining photos from the installation) of being incorrectly installed and systems that haven't passed DECC's inspection criteria have been excluded from the data set. These checks were described in the sub-section titled "Data checking before payment" on page 25. The excluded sites have been added back in in Figure 23 and coloured red.

There are currently 109 of these in the ASAP chart and 11 in the GSHP chart.

Many of these appear to be biasing the data in the direction of poor performance. This should be a warning to people fitting heat meters; not following manufacturers' instructions when fitting temperature probes can reduce the amount of heat measured by an amount that may be hard to detect. Further investigative work needs to be done on these sites, including understanding why some appear to have a detrimental impact on measured performance but others do not. Several of these sites may have been rectified post-installation and may be now reporting valid data, which would explain why they appear in the centre of the distribution. Our approach for this report is to intentionally be conservative. Once further checking has been carried out, it's possible that we will be sufficiently confident in more of the data and if necessary, these results can be updated.
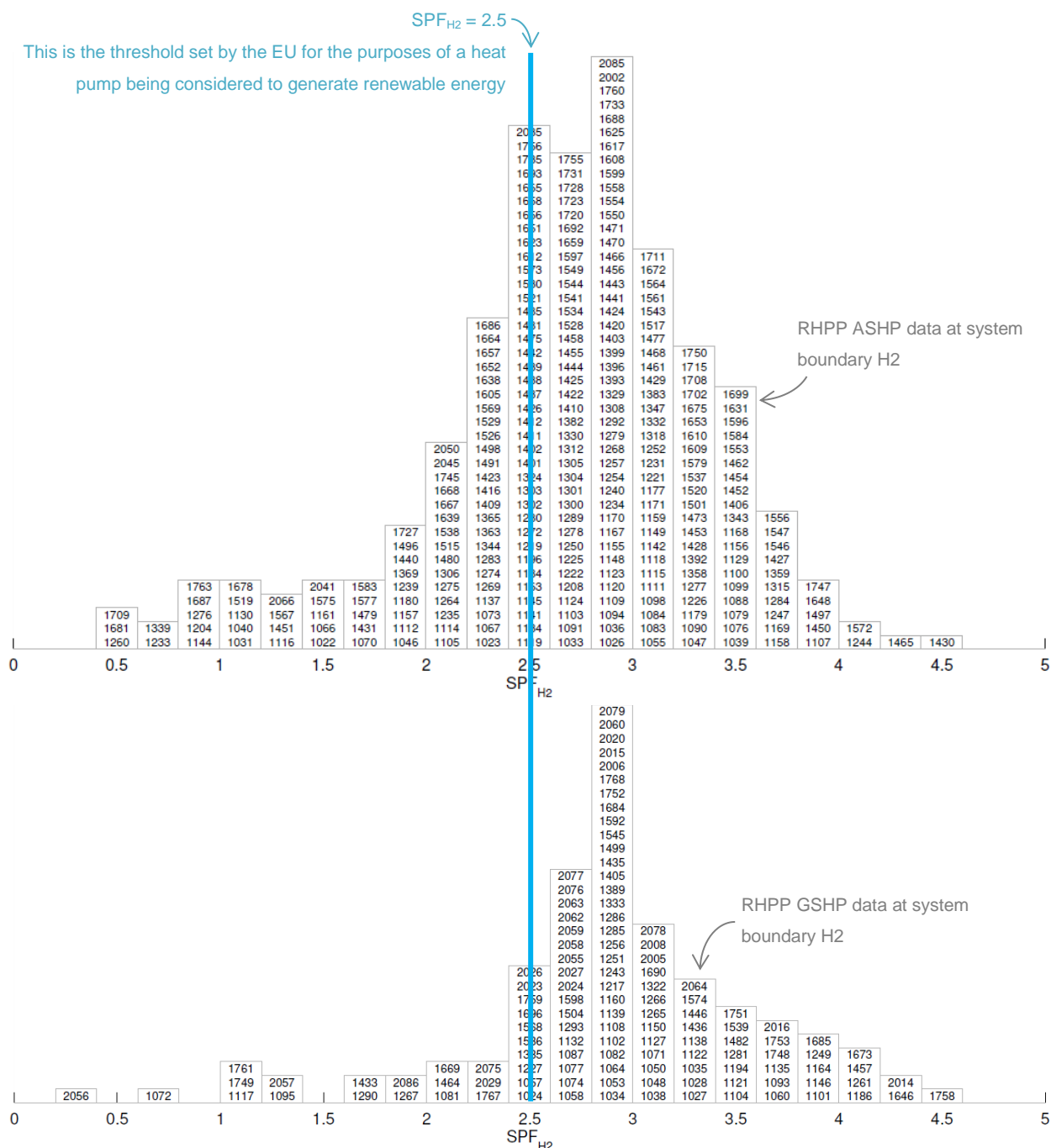
Figure 22: Distribution of SPF$_{H2}$ for ASHPs (top chart) and GSHPs (bottom chart) in December 2013, also showing the EU SPF threshold for a heat pump to be considered to generate renewable energy (SPF$_{H2}$ ≥ 2.5).

	Number in plot	Mean	Standard deviation	25th percentile	Median	75th percentile	Inter-quartile range	Number (%) ≥ 2.5
ASHP	286	2.71	0.75	2.36	2.76	3.13	0.77	196 (69%)
GSHP	124	3.01	0.94	2.67	2.91	3.37	0.70	104 (84%)

Table 12: Summary statistics, including the percentage of systems in December 2013 meeting the EU's renewable threshold of SPF$_{H2}$ ≥ 2.5 for the purposes of being considered to generate renewable energy.

Red sites have been excluded from the analysis in the rest of the report

Figure 23: Distributions of SPF$_{H4}$ showing data excluded for having heat meter temperature sensors that aren't included according to the manufacturer's instructions or for failing DECC's quality control checks.

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Conclusions and next steps

Metering RHPP heat pumps on this scale has been difficult at every stage of the process and consequently data from a high fraction of the metered systems has been excluded from the results that have been presented. This is due to suspected or known problems with the installation of the metering equipment. Even so, data from more than 400 heat pumps has been presented in this report, many times more systems than have been metered in similar field trials.

Relatively little metering equipment has successfully been combined with advanced analysis techniques and several assumptions to generate estimates of Seasonal Performance Factors at a comprehensive set of system boundaries.

This report has relied heavily on the assumption that the Seasonal Performance Factor of the metered RHPP systems in December 2013 is representative of their Seasonal Performance Factor for an entire year. If that assumption is valid, and arguments have been presented to say that it should provide a good indication, then the preliminary data from the RHPP metering programme is encouraging.

High percentages of the metered systems have been shown to generate fuel bill and carbon savings, particularly when replacing off-gas-grid heating systems. High percentages are also meeting the Seasonal Performance Factor threshold of 2.5 set by the EU for the purposes of a heat pump being considered to generate renewable energy. Furthermore, the average Seasonal Performance Factor for ASHPs and GSHPs using the EU's system boundary are significantly higher than that threshold.

Perhaps most encouraging of all is the demonstration of improvement compared to phase 1 of the EST's heat pump field trial in Figure 20, a comparison that has benefited from a much greater sample size than in the EST field trial.

There is a lot of further work to do to improve the robustness of these results and to extend the analysis to make maximum use of the data that has been collected.

Linking the analysis framework to the site information collected at the point of installation, the RHPP scheme management data, and potentially also to EPCs will refine the analysis, improve the accuracy of the results and open up new avenues for exploration. It will also provide further opportunities to perform cross-checks and identify spurious results.

Following this exercise, it is our intention to start asking specific questions of the data to find out why some systems work very well and others less well.

This work can be conducted while a full year's worth of data is being gathered from all sites. The data acquisition phase of the programme is scheduled to end at the end of October 2014. At that point a full analysis of the data can be run. It is our intention to publish a complete analysis from this programme early in 2015.

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Appendix A – Details of the metering equipment

The equipment

The schematic in Figure 24 shows the various components and their relationship. More information about the individual components is contained in Table 13.

Some of this equipment was supplied by the project team, whilst other equipment was sourced by MCS installers as set out below.
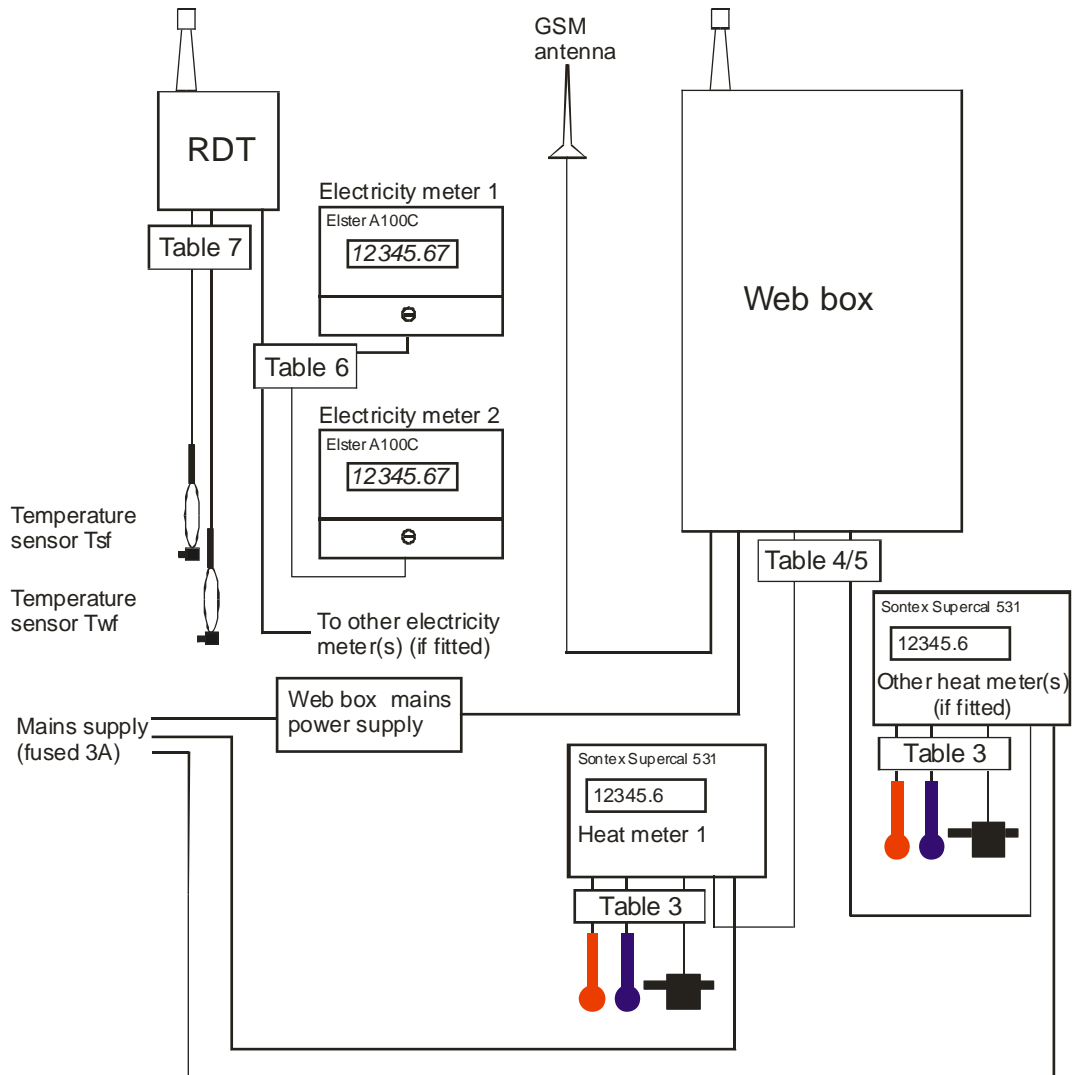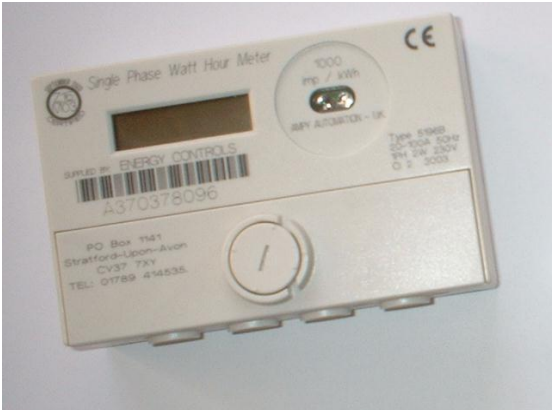

Figure 24: Metering and logging equipment

Equipment	Manufacturer/ Supplier	Product
Electricity meters (These produce 1 pulse per Wh by default)	Elster or Landis & Gyr	 MID 10/100A dircon 1phase pulse A100C IEC 62053-21 Class 1 or 2 IEC 62053-23 Class 2 or 3 MID 100A dircon 3ph pulse E110 single phase meter IEC 62053-21 Class 1 or 2 IEC 62053-23 Class 2 or 3
Heat meters	Sontex This flow meter has built-in flow straightening (visible on the right-hand side of this picture) so requires no additional space to be left upstream or downstream	 Superstatic 440 Qp2.5 ¾" Measuring Instruments Directive Class 2 heat meter

Equipment	Manufacturer/ Supplier	Product
Heat meter integrator (These were specially configured for the project to provide 1 pulse per Wh)	Sontex	 Screwed Supercal 531 Measuring Instruments Directive Class 2 heat meter
Web logger / web box	Energy Monitoring Company (EMC)	
Radio data transmitter/ receiver	Energy Monitoring Company (EMC)	RDT

Equipment	Manufacturer/ Supplier	Product
Pipe clamp temperature probes (separate to heat meter)	Tempcon Instrumentation Ltd.	
SIM cards	Orange O2 T-Mobile Vodaphone,	

Table 13: Details of metering components

Equipment supplied to installers

The following equipment was supplied by the project team. Installers were asked to make the team aware of their planned installations (pipeline) well in advance, ideally 3 to 4 weeks, to allow this to be sourced and distributed

- Web boxes

- RDTs

- Heat Meters (flow meter, integrator, F& R temperature probes and sensor pockets)

- Electricity meters

- Clamp on temperature sensors

- Spares kits (see contents below) – the RS parts numbers were provided to allow installers to order additional equipment:

COMPONENT	Spares kits issued with metering equipment		
	SPARESKIT10	SPARESKIT5	PART NUMBER
6 core signal cable	25 metre reel	12.5 metres	RS 660 4049
Conducting foam	10 foam strips	10 foam strips	RS 707 4597
Spare cable glands	10 off	5 off	-

Cable gland blanking plug	10 off	5 off	-
3.15 A web box fuse	5 off	2 off	-

Table 14: Components in the spares kit provided to installers

Equipment that installers were required to source

The following equipment was supplied by installers:

- All pipe fittings including 'T's for heat meter temperature probes (the fitting required depends on the exact nature of the pipework but pockets have a ½" female BSP thread, so generally require a pair of 22mm x 22mm x ½ inch tees or 28mm x 28mm x ½ inch tees).

- Local small power supplies (fused spurs, power cable, etc.)

Appendix B – Example installation form

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RHPP Monitoring Installation Form
Phase 2 v5

At the end of your installation please complete this Installation Checklist and take the monitoring equipment photos, as outlined at the end of the form. These are required as part of the quality assurance and invoicing process. The form should be completed and submitted to the RHPP Monitoring team with any supporting files via email.

If you have any questions about how to complete this form please call BRE on 0800 955 5081.

Administrative checklist

Task	Notes
Customer Name	
Customer postcode	

Heat meter checklist

Task	Notes	Done?
Using the left hand button on the front of the heat meter scroll through the various displays. In particular, check that the heat (kWh) and flow (m³) displays are counting when the heat pump is running. Also check that the flow and return temperatures are correctly displayed. The temperature on the left should be higher than the right.		✓
Check that the corresponding red LED on the web box is also illuminating (at higher pulse speeds it may appear to be permanently on).		✓
If a second heat meter has been installed, repeat the above checks for it.		✓

NOTE: All steps of the checklist must be carried out and confirmed as complete within the last column before the PDF can be saved and closed.

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Electricity meter checklist

Task	Notes	Done?
Check that the red LED on the front face of each electricity meter is pulsing when the associated load is powered up.		✓
If a second electricity meter has been installed repeat the check		✓
If a third electricity meter has been installed, repeat the check	N/A	✓
If a fourth electricity meter has been installed, repeat the check	N/A	✓

Temperature sensor checklist

Task	Notes	Done?
Install Tin sensor on the incoming pipe from the ground loop, or in the case of an air sourced unit on the pipe from the outdoor heat exchanger to the compressor		✓
Insulation around Tin sensor reinstated or installed.		✓
Install Tco sensor on the pipe between the output of the heat pump and any internal heater or flow boiler.		✓
Insulation around Tco sensor reinstated or installed.		✓
Install Tsf sensor on the space heating flow pipe, after all diverter valves and auxiliary heaters.		✓
Insulation around Tsf sensor reinstated or installed.		✓
Install Twf sensor on the water heating flow pipe, after all diverter valves and auxiliary heaters		✓
Insulation around Twf sensor reinstated or installed.		✓

NOTE: All steps of the checklist must be carried out and confirmed as complete within the last column before the PDF can be saved and closed.

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Monitoring equipment checklist

Task	Notes	Done?
Record the number of the schematic used	2.4	✓
Record web box serial number	1755	✓
Record RDT serial number	755	✓
Record the serial number(s) of any additional RDTs, together with details of the sensors connected to each	755 Tin	✓
Check all web box cable glands are tight		✓
Replace web box lid and tighten screws		✓
Insert RDT battery Note: LED should give two long flashes as the battery is inserted. If not remove the battery, wait ten seconds and try again.		✓
Check all RDT cable glands are tight		✓
Replace RDT lid and tighten screws		✓
Check that the web box RTX LED is illuminating every 30 seconds		✓

NOTE: All steps of the checklist must be carried out and confirmed as complete within the last column before the PDF can be saved and closed.

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Site information

Task	Notes	Done?
Record the type of heat pump	Air-source ⊙ Water/Ground-source ○	✓
If the heating loop has been refilled with an antifreeze mixture please note the type of fluid, and the concentration used or target freezing point	Fernox HP5C	✓
Is the electricity used by the ground loop circulation pump included in the metered consumption of the heat pump?	Yes ○ No ⊙	✓
If the rated power (in Watts) and speed setting of the ground loop circulation pump can be seen, please record it on the schematic, at the speed setting in use	N/A	✓
Record the type of heating system	Radiator ○ Fan-assisted radiator ○ Convector ○ Underfloor ⊙	✓
Are all heat meters mounted on the house side of the circulation pump(s)? If NO please record exact locations on schematics	Yes ⊙ No ○	✓
Is the electricity used by heating system circulation pump(s) included in the electricity metered at the heat pump?	Yes ⊙ No ○	✓
If the rated power (in Watts) and speed setting of the heating system circulation pump(s) can be seen please record it (them) on the schematic, at the speed setting in use.	Speed 3	✓

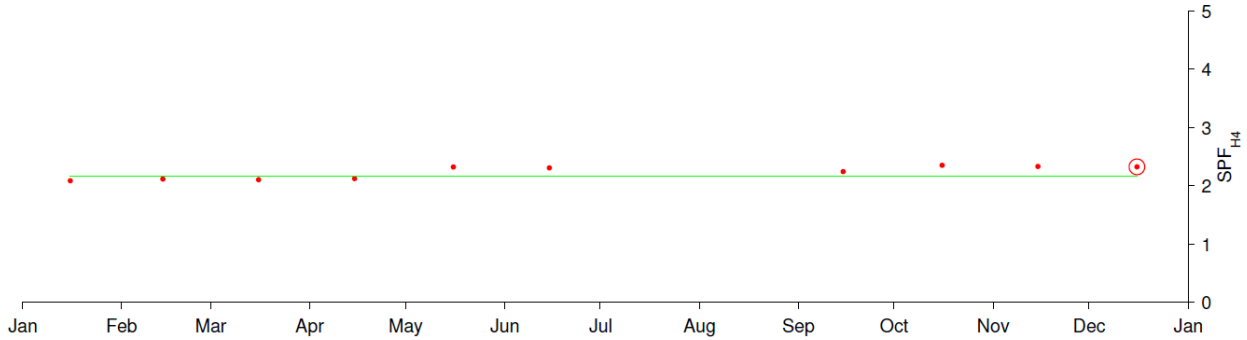## Evidence

Photograph	Done?	Photograph	Done?
Photograph the flow meter(s)	✓	Photograph locations of all temperature sensors	✓
Photograph the heat meter temperature probes	✓	Photograph the installed web box	✓
Photograph all electricity meters installed	✓	Photograph the RDT	✓

SUBMIT: To submit your form, please save this file and email along with all supporting image files to RHPPmonitoring@bre.co.uk
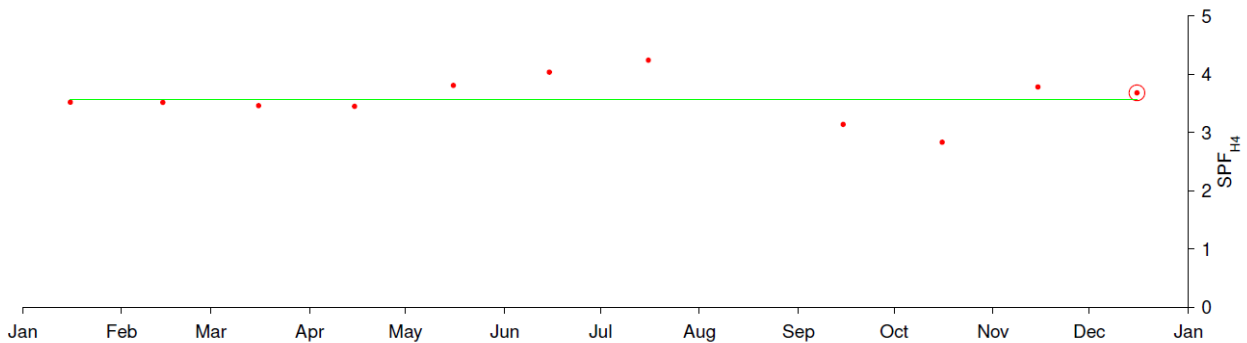
NOTE: All steps of the checklist must be carried out and confirmed as complete within the last column before the PDF can be saved and closed.

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Appendix C – Example monthly and annual SPFs from RHPP data
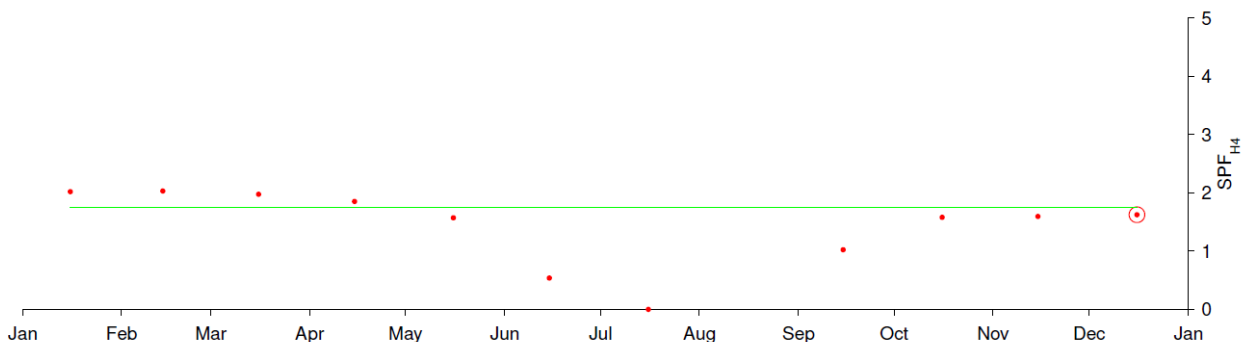
The series of charts in this Appendix show the monthly and annual SPFs (SPF$_{H4}$) for a randomly chosen selection of sites. Monthly SPFs are shown as red dots; the annual SPF is shown as a green line. The purpose of the charts is to enable a comparison of the SPF from December 2013 (the circled red dot) with the annual SPF and SPFs from the rest of the year.

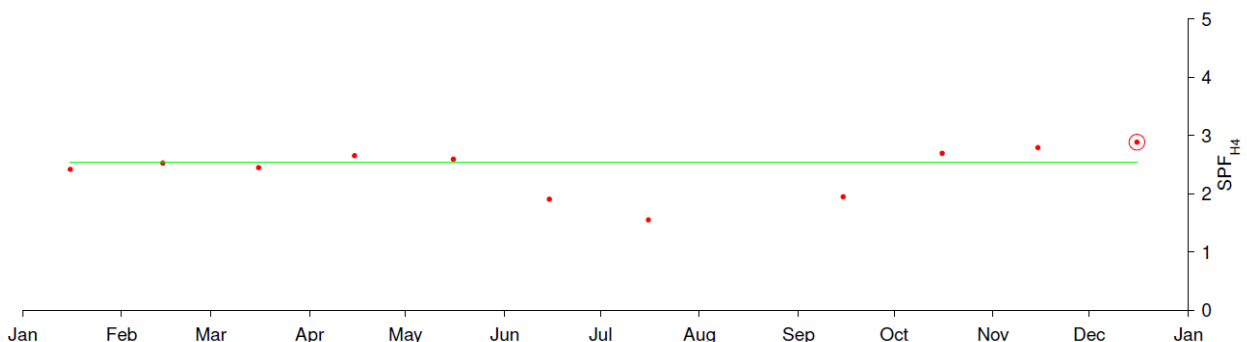**Monthly SPFs for site 1140**

Monthly SPFs for site 1249

Monthly SPFs for site 1372

Monthly SPFs for site 1429