Department for Energy Security & Net Zero

Electrification of Heat Demonstration Project

Interim Insights from Heat Pump Performance Data

Written by Energy Systems Catapult

This report has been funded by DESNZ and is issued on their behalf

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Glossary

ASHP	Air Source Heat Pump
BEIS	Department for Business, Energy and Industrial Strategy
CI	Confidence Interval (Usually 95%)
COP	Coefficient of Performance
DC	Delivery Contractor
DESNZ	Department for Energy Security and Net Zero
EoH	Electrification of Heat Demonstration Project
ESC	Energy Systems Catapult Ltd.
GSHP	Ground Source Heat Pump
HT	High Temperature
Hybrid	Gas-Electric Hybrid Heat Pump System
IQR	Interquartile Range
LT	Low Temperature
MC	Management Contractor
RHPP	Renewable Heat Premium Payment scheme
SPF	Seasonal Performance Factor

1. Executive Summary

The Electrification of Heat (EoH) demonstration project is funded by the Department for Energy Security and Net Zero (DESNZ – previously BEIS) and seeks to better understand the feasibility of a large-scale rollout of heat pumps across the UK. To do so, three Delivery Contractors (DCs) have overseen the installation of 742 heat pumps in existing homes across the Great Britain, the majority of which were previously heated by gas central heating. These heat pumps are now being monitored to assess their performance in-situ. Heat pumps were installed between September 2020 and November 2021.

This document provides interim insights from the monitoring data between November 2020 and August 2022. The monitoring period is ongoing until September 2023 and this document will be superseded by future insights following the cessation of the monitoring period and the analysis of the final dataset. At the time of writing, there is an insufficient data sample to draw any conclusions on the performance of Ground Source Heat Pumps (GSHP), as such, GSHPs are not included in the data analysis. Full details on how the analysis was undertaken, please see the Interim Heat Pump Performance Data Analysis Report. [1]

To collect the monitoring data, a monitoring system has been installed which meters each electrical component of the system as well as the heat pump heat output. A rigorous quality checking, cleansing and analysis process has been undertaken on the collected data to ensure robust data and analysis results.

This interim analysis investigated that seasonal performance factors of the heat pumps installed, which is a measure of the heat pumps efficiency expressed as a ratio of the total heat supplied to the home to the electricity used by the heat pump and other devices of the heating system. It also analysed heat pump performance on the coldest day (to inform peak demand), and how hybrid heat pump performance varies depending on the proportion of heating provided by the boiler.

1.1 Key Findings

1.1.1 Seasonal Performance Factor values

The median Seasonal Performance Factors (SPFs) observed in Air Source Heat Pumps (ASHPs) have increased significantly since RHPP (Renewable Heat Premium Payment scheme) [2] (not accounting for weather variations):

- Median ASHP SPF_{H4} = 2.80 (vs 2.44 in RHPP); IQR = [2.53, 3.09]; n=291
- Median ASHP SPF_{H2} = 2.94 (vs 2.65 in RHPP); IQR = [2.66, 3.20]; n=291

The median SPFs observed for heat pumps within hybrid systems (i.e. excluding boiler efficiency) is:

- Median Hybrid SPF_{H4} = 2.37; IQR = [2.01, 2.81]; n=58
- Median Hybrid SPF_{H2} = 2.54; IQR = [2.25, 2.93]; n=58

It should be noted that these SPF values do not account for the heat generated by the boiler. For estimated whole system efficiencies, refer to Section 9 of the Interim Heat Pump Performance Data Analysis Report. [1]

1.1.2 Seasonal Performance Factor variations

The variation in SPF between installations remains high with similar Interquartile Range (IQR) as observed in the RHPP project.

- EoH ASHP SPF_{H4} - [Q1, Q3]; IQR = [2.53, 3.09]; 0.56
- RHPP ASHP SPF_{H4} - [Q1, Q3]; IQR = [2.15, 2.67]; 0.52

The refrigerant used has an impact on the observed SPF. The median SPF_{H4} for each of the refrigerants used within ASHPs on this project is:

- Median R32 SPF_{H4} = 2.94; IQR = [2.57, 3.25]; n=82 (76 LT, 6 HT)
- Median R290 SPF_{H4} = 2.89; IQR = [2.68, 3.08]; n=98 (all HT)
- Median R410a SPF_{H4} = 2.66; IQR = [2.40, 2.84], n=111 (all LT)

It should be noted that the variation shown above is unlikely to be exclusively a result of the efficiency of the refrigerant. The R410a refrigerant is generally used in older units which may have less efficient mechanical components and control strategies.

The observed SPF is higher for installations that have a lower mean operating flow temperature.

ASHPs capable of operating at high temperatures (>65°C flow) are observed to operate at a similar SPF to low temperature ASHPs. This is likely due to a combination of higher performing refrigerants and weather compensation controls meaning that they operate at lower temperatures most of the time.

Heat pumps installed in detached houses have been observed to have a statistically significantly higher SPF compared to semi-detached houses The cause of this result may be because detached houses have the lowest proportion of heat pumps using the refrigerant R410a installed.

Home age and household income do not have a statistically significant impact on the observed SPF in this study.

1.1.3 Hybrid System Operation

A hybrid heat pump system is a system which utilises a gas boiler alongside a heat pump. In this project, the hybrid system control was cost-optimised and, as a result the system performance results are varied across the range of properties. The median heat pump energy output as a proportion of total space heating energy output observed in hybrid systems was 39%. As the heat pump energy output decreases as proportion of total space heating energy output, the observed SPF also decreases.

1.1.4 Coldest Day Performance

The observed heat pump efficiency ($COP_{(H4)}$) decreased as the external temperature decreased. The median COP on the coldest day (mean temperature -0.4°C) was:

- Median coldest day $COP_{(H4)}$ = 2.44; IQR = [2.20, 2.70]; n=484

2. Introduction

2.1 Project Introduction

The Electrification of Heat (EoH) demonstration project is funded by the Department for Energy Security and Net Zero (DESNZ) and seeks to better understand the feasibility of a large-scale rollout of heat pumps across the UK. It aims to demonstrate that heat pumps can be installed in a wide variety of homes and deliver high customer satisfaction across a range of customer groups.

The project team consists of a Management Contractor (MC) consortium led by ESC and three Delivery Contractors (DCs). The DCs were responsible for the participant recruitment, home survey, design, and installation of the heat pumps. They also maintain the heat pump monitoring systems to ensure continuous performance data is collected The MC is responsible for management of the project and collation of the data as well as associated analysis and dissemination of project findings.

The three DCs are: E.ON (operating in North-East England); OVO Energy (operating in South-East England, excluding London); and Warmworks (operating in South-East Scotland).

In total the EoH project has installed 742 heat pump systems.

2.2 Project Stages

Figure 2.1 below shows a flow chart of the key project stages. The mass recruitment began in June 2020 and final heat pump system was installed in November 2021. The monitoring stage began upon completion of the first installation (in September 2020) and, for many of the installations will run through until September 2023.

Figure 2.1: Flow chart of key project stages.

As the heat pump monitoring is ongoing, this document provides interim insights which will be revised following the cessation of monitoring for all installed heat pumps.

The data used to form the insights in this paper were collected from the date of the first installation (September 2020) up to and including August 24th 2022. For many of the heat pumps this is less than 12 months since installation, so more homes will have a Seasonal Performance Factor calculated when the final insights are released following project completion.

2.3 Document Purpose

This document provides an overview of the data quality checking, cleansing and analysis process used, and highlights the insights from the interim heat pump monitoring data analysis. The insights provided at this stage are prioritised based on DESNZ requirements.

For full details on the process and data analysis, please see the Data Analysis Report [1]. The full datasets are available on the UK Data Archive and USmart. [3] [4] [5]

3. Heat Pump Installations

3.1 Heat Pump Equipment

In total, the EoH project completed 742 domestic heat pump installations across Great Britain. These installations can be separated into four heat pump types: Low Temperature Air Source Heat Pump (LT ASHP), High Temperature Air Source Heat Pump (HT ASHP) (capable of producing flow temperatures >65°C), Ground Source Heat Pump (GSHP), Gas-Electric Hybrid Heat Pump System (Hybrid).

Table 3.1 provides the installation statistics based on heat pump type.

Table 3.1: Installation statistics by heat pump type.

Group	Installations (%)	Installations (No.)
LT ASHP	41.2%	306
HT ASHP	32.7%	243
GSHP	5.1%	38
Hybrid[1]	20.9%	155

The heat pumps were also installed in a range of home types and ages, this is discussed further in Section 5.4 and all installation statistics are presented in the Installation Statistics Report [6] and USmart datasets [7]. Note that, as mentioned in Section 2.1, all of the heat pumps were installed in three geographical areas around the UK, therefore there may be some geographical bias in the analysis results.

3.2 Monitoring Equipment

Whilst the configuration of the monitoring system for each heat pump type and model varies, Figure 3.1, Figure 3.2 and, Figure 3.3 show the typical monitoring system configuration for an ASHP, GSHP and hybrid installation respectively. The monitoring system consists of a maximum of five electricity meters, two heat meters and one internal temperature sensor. The five electricity meters / sensors record the following:

1. The whole heat pump system energy consumed.
2. Back-up heater energy consumed.
3. Circulation pump energy consumed.
4. Position of the control (diverter) valve (to inform hot water or heating mode).
5. Immersion heater energy consumed.

All installations have at least one heat meter which records the heat pump unit heat output. For hybrid systems, there is a second heat meter which records the boiler heat output. For GSHP installations, there are temperature sensors recording the brine temperatures going into and out

[1] Hybrid refers to both hybrid systems with a heat pump and boiler in separate units and integrated systems (which contain the heat pump and boiler in the same unit). The systems can be further broken down by those properties which installed heat pumps alongside existing boilers and those which had new boilers and heat pumps installed.

of the heat pump. All installations also have an internal temperature sensor to record room temperature. The external temperatures are collected from the local weather station.

The electricity and heat meters record cumulative data, so the readings should increase over time. All temperature sensors record an instantaneous reading at a given moment in time.

For more information on the monitoring equipment and configurations, please refer to the Interim Heat Pump Performance Data Analysis Report [1].

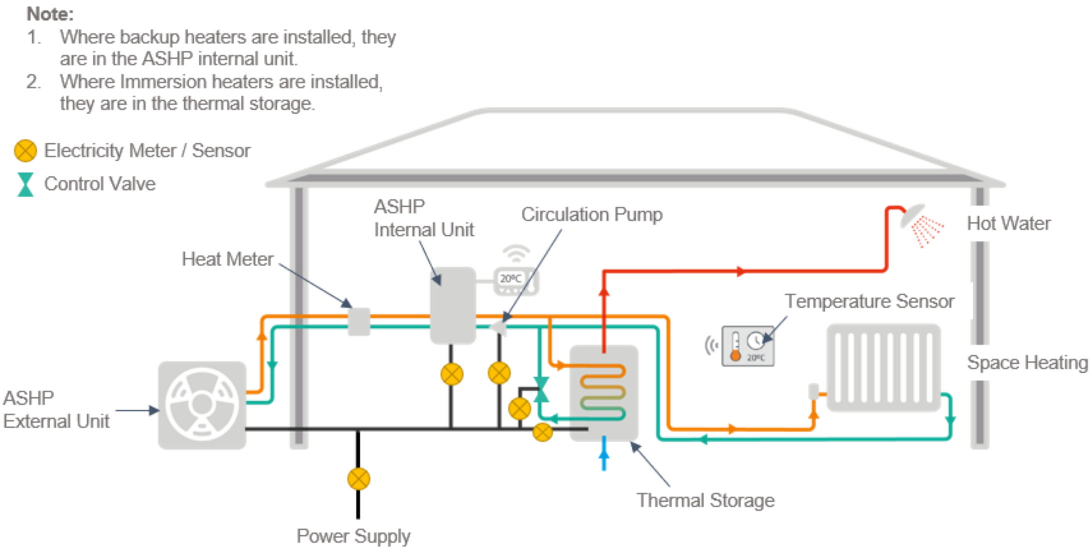

Figure 3.1: Typical arrangement of sensors in ASHP monitoring solution.

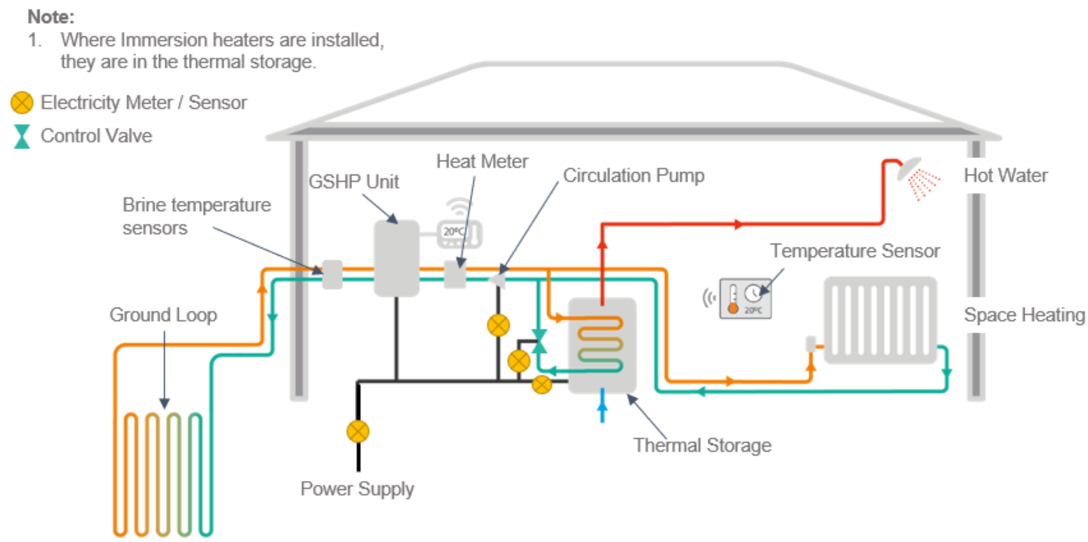

Figure 3.2: Typical arrangement of sensors in GSHP monitoring solution.

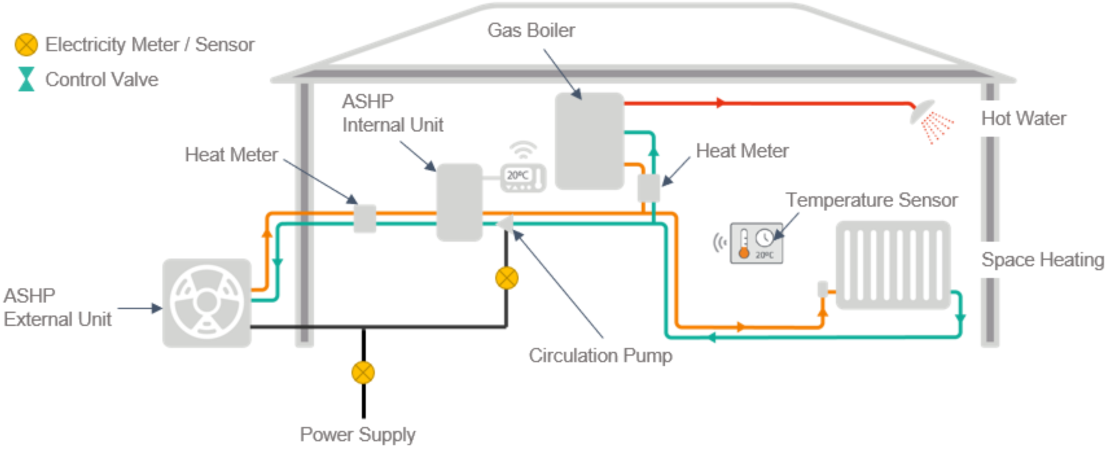

Figure 3.3: Typical arrangement of sensors in hybrid heat pump monitoring solution.

4. Data Cleansing, Quality Checks, and Analysis

The data collected consists of readings on average every two-minutes for the electrical inputs, heat outputs, and flow temperatures of the heat pump system, as well as internal and external air temperature for each property. For more details see the Interim Performance Data Analysis Report [1].

Prior to conducting any analysis, rigorous data quality checks and small amounts of data cleansing were performed. This section provides a brief overview of the quality checks, cleansing and analysis process. For a more thorough description of this procedure, please refer to the Interim Performance Data Analysis Report [1].

4.1 Process

To analyse the monitoring data, an iterative process of quality checking, cleansing, and analysing was followed. This process has been automated and it is repeatable for future analysis.

Initially a high-level quality check on the monitoring data was conducted to look for any gaps in the data and find any erroneous property ID numbers. If available, data was backfilled into the gaps, and ID errors were rectified to form the final "raw" dataset for this interim analysis.

Once finalised, the "raw" data was cleansed. This cleansing makes minor adjustments to the data to prepare it for analysis. All adjustments made to the data are listed in Section 4.2. In cases where the cleansing activity is performed to resolve quality issues, this is flagged by adjusting the data quality score described in Section 4.3.

Once the "cleansed" dataset was produced, a second set of quality checks were performed. These checks, described in Section 4.3, were more rigorous than the first and resulted in a data quality score for each property, based on various quality metrics. The best scoring data window for each property was then selected for the analysis. Each property was either included in or excluded from the analysis based on the quality of data within the selected window (i.e. any property where the best scoring window is still of insufficient quality was excluded).

Once the data quality was confirmed, the analysis was conducted as described in Section 4.4.

Insights based upon the analysis results are provided in Section 5 of this report.

4.2 Data Cleansing

As described above, data cleansing is the process of taking a "raw" dataset and making slight adjustments to ensure it is ready for analysis. Below is a list of the cleansing activity which was undertaken to prepare the data for analysis, additional detail and reasoning is provided in the Interim Performance Data Analysis Report [1].

- Timestamp realignment to exact 2-minute periods.
- Adjustments if meter was reversed (negative daily difference between readings).
- Anomalous single point removal from cumulative meter data.
- Removal of anomalous data from start of monitoring period (data indicating faulty monitoring equipment installation).

- Relevelling data following a meter reset.
- Removal of out-of-range temperatures.[2]
- Reassigning non-cumulative (temperature) data to the correct columns.
- Supplementary data cleansing – amending spelling or grammar variations.
- Supplementary data cleansing – aligning property age ranges.

4.3 Data Quality

Quality issues in the data arise where the monitoring equipment has not operated as intended. These can be categorised into transmission issues (where no data was received for a period) or equipment issues (where one sensor or meter sent anomalous readings or no readings).

Where gaps in any of the cumulative data arise, they are scored between 1 and 5 depending on the length of the gap and what happens before and after the gap period. Higher scoring gaps indicate worse data quality. In addition, each month of data is scored based on what happens in that month. If the monthly data is as expected, it is given a score of 0 and if it is not as expected it is scored between 3 and 4 and flagged for a manual check. A full breakdown of the data scoring and rationale is provided in the Interim Performance Data Analysis Report [1].

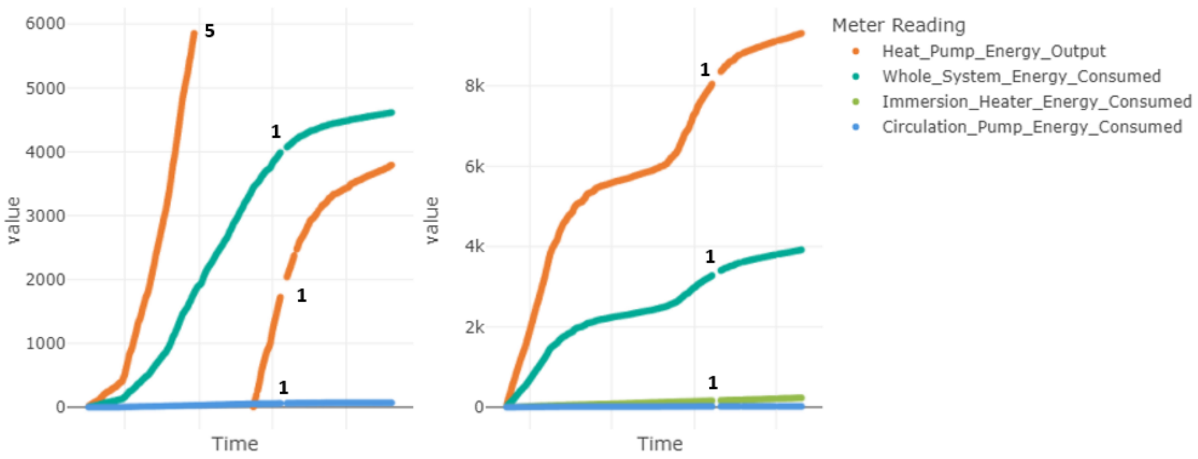

Figure 4.1: Two graphs showing unacceptable data (left) and acceptable data (right). The data shown on the left is rejected as it contains a max gap score of 5 due to meter reset following a large data gap.

Following data scoring, all possible 12-month windows were assessed and the window which was taken forward for analysis was selected based on the following prioritised criteria:

- Lowest maximum quality score.
- Lowest mean quality score.
- Highest percentage available data.
- Most recent window.

[2] Temperatures in the following ranges were accepted:
Internal air temp. = 0 – 40°C; External air temp. = -27.2 – 40.3°C;
HP flow and return temps = 5 – 80°C; Brine flow and return temps = -10 – 30°C.

SPF values were then calculated for the chosen window and the property was either included in the SPF analysis or was excluded for one of the following reasons:

- Window has quality score greater than or equal to 4.
- SPF is out of the acceptable range (1.5 to 4.5).[3]
- Less than 50% of the expected heat pump energy output or system energy consumed datapoints available.

For the cold snap analysis, the 12-month window quality scoring was not relevant so alternate quality measures were used. A 24 hour and 30-minute window were selected based on the lowest mean external temperature when the heat pump was operational. The Coefficient of Performance (COP) was calculated for each property over their 24 hour and 30-minute windows. Properties were excluded from the analysis for any of the following reasons:

- COP value out of acceptable range (0.75 to 7.5)
- Timestamps of the coldest day were not between Nov and Mar inclusive
- Total heat pump energy output excluded if outside of 2 interquartile ranges (IQR) of Q1 and Q3.

4.4 Data Analysis

Once the data were cleansed and quality assessed, it was possible to analyse the data. Data were only included in the analysis if they met the quality criteria laid out in Section 4.3. As a result, the property sample size was reduced. The graph shown in Figure 4.2 indicates the sample of properties which were included in the SPF analysis and reasons why other properties were excluded.

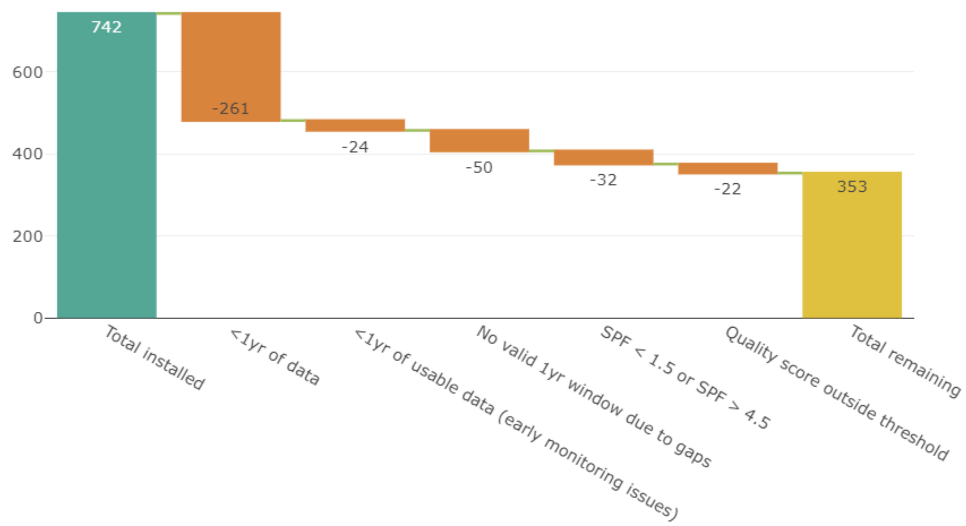

Figure 4.2: A graph showing the number of properties excluded from the SPF analysis for each reason as well as the number of properties remaining.

[3] Note that the SPF range is the same as that which was used to analyse the RHPP data. Further commentary on this is given in the Interim Heat Pump Performance Data Analysis Report. [1]

The checks undertaken for SPF analysis only consider the energy data, for the flow temperature related analysis, additional quality checks are performed on the temperature data and further properties are excluded. This only affects a small number of properties and is discussed further in the Interim Performance Data Analysis Report [1].

The SPF calculations and heat pump system boundaries are provided below, for more details on assumptions and calculation methodology, please refer to Section 7 of the Interim Performance Data Analysis Report [1].

Table 4.1: Data items and symbols associated with the SPF calculations.

Data Item	Symbol	Source
Heat Pump Energy Output	Q_{HP}	Meter reading
Whole System Energy Consumed	E_{HPS}	Meter reading
Back-Up Heater Energy Consumed	E_{BU}	Meter reading
Immersion Heater Energy Consumed	E_{IH}	Meter reading
Circulation Pump Energy Consumed	E_{CP}	Meter reading
Heat Pump Energy Consumed	E_{HPU}	$E_{HPU} = (E_{HPS} - E_{BU} - E_{IH} - E_{CP})$
Back-Up Heater Energy Output	Q_{BU}	$Q_{BU} = E_{BU}$
Immersion Heater Energy Output	Q_{IH}	$Q_{IH} = E_{IH}$

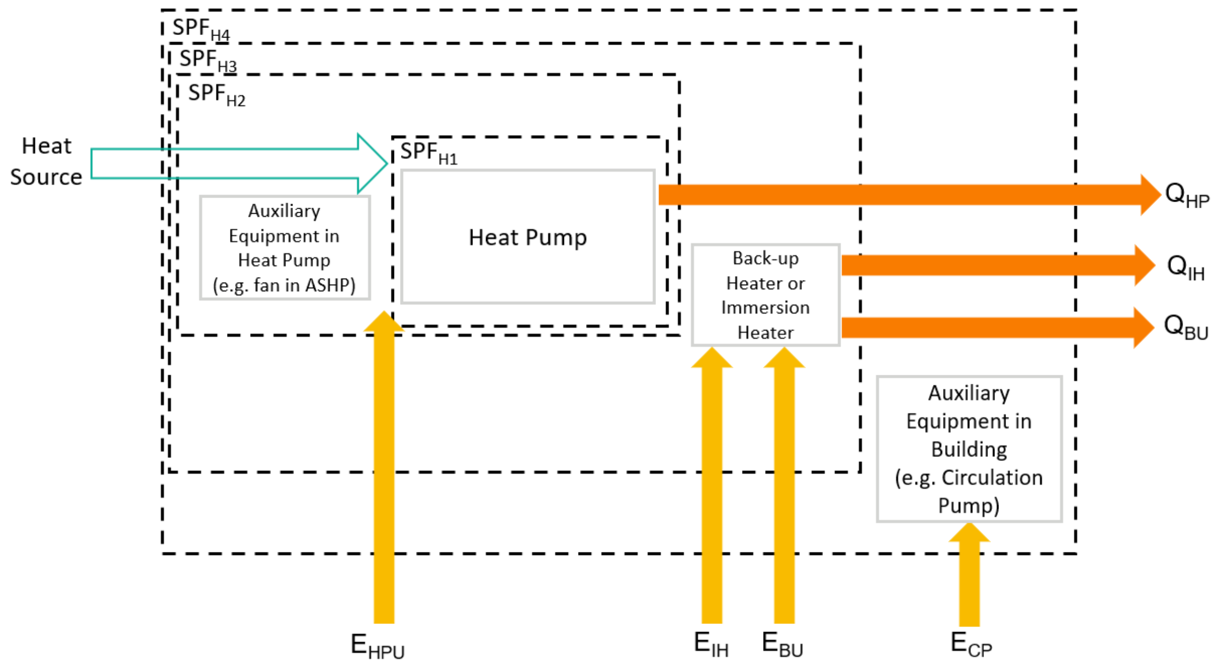

Figure 4.3: SPF system boundaries, as defined in the SEPEMO project [8]. Applied to the EoH monitoring system.

$$SPF_{H2} = \frac{(Q_{HP})}{(E_{HPU})}; \quad SPF_{H3} = \frac{(Q_{HP} + Q_{BU} + Q_{IH})}{(E_{HPU} + E_{BU} + E_{IH})}; \quad SPF_{H4} = \frac{(Q_{HP} + Q_{BU} + Q_{IH})}{(E_{HPU} + E_{BU} + E_{IH} + E_{CP})}$$

All SPF calculations were carried out on the 12-month data windows. The results of these calculations were then analysed to assess correlations and potential reasons for SPF variation. An overview of this analysis is provided in Section 5.

The COP results are denoted with a (H2) or (H4) based on which boundary they use. Generally, within the analysis the calculations use the same system boundaries as the SPF_{H4} calculation however they are performed over a period which is not equal to 12-months. For this project, COP calculations were used to assess heat pump performance during cold spells, this is discussed further in Section 5.6.

As well as efficiency, the hybrid heat pumps were analysed to assess the percentage of energy output by the heat pump compared with the boiler over the course of a 12-month window. Only data which met the 12-month window quality requirements was used in this analysis. The results and any insights from this analysis are provided in Section 5.5.

5. Data Insights

This section provides an overview of the results and some key insights from the interim data analysis. As mentioned in Section 2.2, it should be noted that these are interim insights based on the analysis of interim project data and on a prioritised set of analysis requirements. The analysis and related insights will be updated following the completion of heat pump monitoring.

For more information on the analysis process, full analysis results and further conclusions, please refer to the Interim Performance Data Analysis Report [1].

5.1 Seasonal Performance Factor

This section provides the median and mean SPF values broken down by heat pump type. Average GSHP results are not included in the analysis as, at the time of writing, there are only four with a 12-month sample of data which is sufficient for an SPF calculation. Thus, the reliability of an average would not be sufficient.

Table 5.1 below provides a breakdown of median and mean SPF values based for all ASHPs and heat pumps within hybrid systems separately. The median SPF has improved significantly since RHPP, when ASHP SPF_{H4} was 2.44.

Table 5.1: Median and mean SPF values for all ASHPs and all heat pumps in Hybrid systems. (Note Hybrid SPF_{H3} excluded as it is equal to SPF_{H2})

Heat Pump Type	SPF Type	Sample Size	Median [IQR]	Mean [95% CI]
ASHP	SPF_{H2}	291	2.94 [2.66, 3.20]	2.95 [2.90, 3.00]
	SPF_{H3}	291	2.89 [2.62, 3.17]	2.90 [2.85, 2.95]
	SPF_{H4}	291	2.80 [2.53, 3.09]	2.82 [2.77, 2.87]
(Heat Pumps within) **Hybrid systems**	SPF_{H2}	58	2.54 [2.25, 2.93]	2.60 [2.47, 2.73]
	SPF_{H4}	58	2.37 [2.01, 2.81]	2.42 [2.28, 2.55]

Figure 5.1 shows the median results in graphical format.

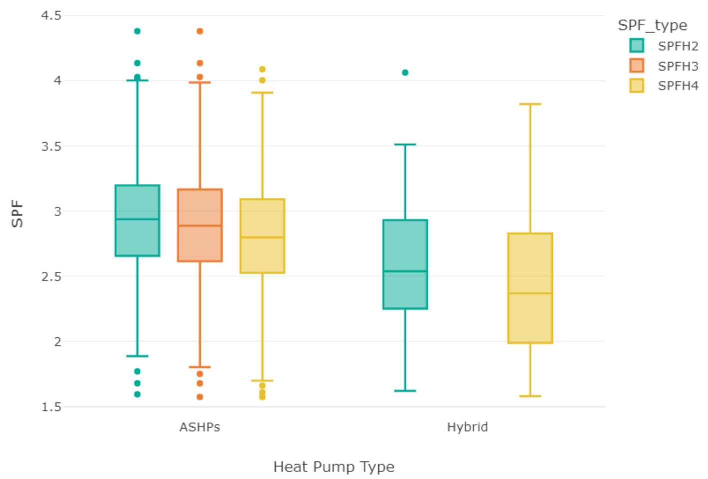

Figure 5.1: Q1, Q3 and median SPF values for ASHPs and heat pumps within hybrid systems.

Whilst median SPF has improved significantly since RHPP, variance in SPF across installations remains high (IQR between 0.52 and 0.62), some of the potential reasons for this variation are discussed in the following sections of this report however, much of this variation is difficult to explain.

It is also necessary to consider the difference between performance of the High Temperature and Low Temperature ASHPs based on the pre-project definitions. The pre-project definition of a HT ASHP is an ASHP which can achieve flow temperatures greater than 65°C. It should be noted that just because the heat pump can achieve these temperatures, it does not mean that temperatures greater than 65°C are required to keep the property warm.

As such, there may be HT ASHPs installed through the project which are operating in a similar manner and with similar flow temperatures to LT ASHPs. Despite this observation, the breakdown of SPF by LT ASHP and HT ASHP is provided below.

Table 5.2: Median and mean SPF values broken down for LT ASHPs and HT ASHPs based on pre-project definitions.

Heat Pump Type	SPF Type	Sample Size	Median [IQR]	Mean [95% CI]
LT ASHP	SPF_{H2}	187	2.94 [2.63, 3.26]	2.94 [2.88, 3.01]
	SPF_{H3}	187	2.86 [2.56, 3.19]	2.87 [2.81, 2.94]
	SPF_{H4}	187	2.74 [2.47, 3.09]	2.77 [2.71, 2.84]
HT ASHP	SPF_{H2}	104	2.94 [2.71, 3.15]	2.96 [2.88, 3.04]
	SPF_{H3}	104	2.94 [2.67, 3.15]	2.95 [2.87, 3.03]
	SPF_{H4}	104	2.89 [2.66, 3.07]	2.89 [2.82, 2.97]

Reviewing these results, the HT ASHP units are observed to be performing with a similar SPF_{H2} to the LT ASHP units. As the calculation boundary increases for the SPF_{H3} and SPF_{H4} calculations, the HT ASHP systems are observed to be operating more efficiently than the LT. This result indicates that factors such as actual heat pump operational temperatures, mechanical design and the refrigerant used may have a bigger impact on real world heat pump performance than the maximum temperature that a heat pump is capable of. Due to these factors, Sections 5.2 and 5.3 provide a breakdown of SPF by refrigerant and operating temperature.

5.2 SPF by Refrigerant

Heat pumps contain a fluid, known as a refrigerant, that facilitates the transfer of heat from the heat source to the heat sink as it circulates through the heat pump. In selecting a refrigerant, manufacturers need to make trade-offs between a range of factors, including performance at different temperatures, global warming potential and cost.

Figure 5.2 provides an indication of the median SPF_{H4} for all ASHPs broken down by refrigerant type as well as an indication of the IQR. Table 5.3 provides the median and mean SPF_{H4} values for each refrigerant type.

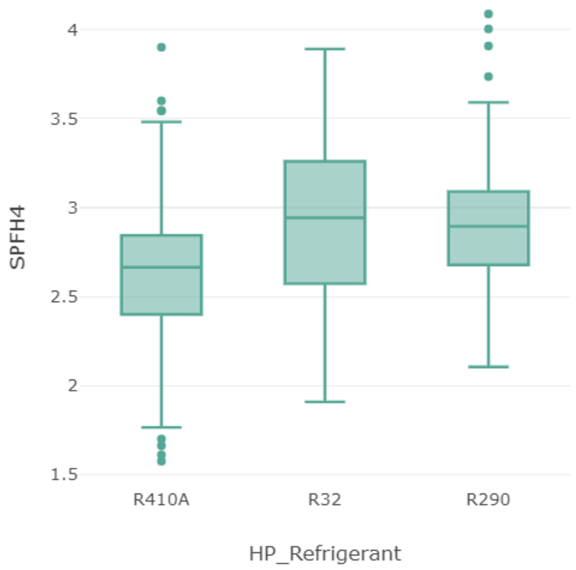

Figure 5.2: Q1, Q3 and median SPF_{H4} for all ASHPs broken down by refrigerant type.

Table 5.3: SPF_{H4} broken down by refrigerant type.

Refrigerant	Sample Size	Median [IQR] SPF_{H4}	Mean [95% CI] SPF_{H4}
R290	98	2.89 [2.68, 3.08]	2.92 [2.84, 2.99]
R32	82	2.94 [2.57, 3.25]	2.93 [2.83, 3.03]
R410a	111	2.66 [2.40, 2.84]	2.64 [2.56, 2.72]

Considering no other factors, these results suggest that differing refrigerants by heat pump type may contribute to the differences in heat pump efficiency. However, other factors such as the efficiency of mechanical equipment and control strategy may also impact the SPF observed.

Table 5.4: SPF_{H4} broken down by refrigerant type and heat pump type.

Heat Pump Type	Refrigerant	Sample Size	Median [IQR] SPF_{H4}	Mean [95% CI] SPF_{H4}
HT ASHP	R290	98	2.89 [2.68, 3.08]	2.92 [2.84, 2.99]
	R32	6	2.50 [2.25, 2.58]	2.53 [2.08, 2.98]
LT ASHP	R32	76	3.00 [2.66, 3.27]	2.96 [2.86, 3.06]
	R410a	111	2.66 [2.40, 2.84]	2.64 [2.56, 2.72]

Table 5.4 provides a further breakdown of these results based on the number of each ASHP type which utilises each refrigerant type. It is evident that the HT ASHPs installed through this project mainly utilise R290 whilst the LT ASHPs mainly utilise R410a and R32. The difference in performance seen between HT ASHPs and LT ASHPs may therefore be partially attributed to the choice of refrigerant. However, as refrigerant is highly correlated with manufacturer and model, it is worth noting that there may be other factors involved in this performance difference that were not reviewed as part of this analysis, such as the efficiency of mechanical equipment and the control strategy.

5.3 SPF by Operating Temperature

Heat pump operating flow temperature affects efficiency. Through this study, it has been observed that when considered in isolation, the heat pumps which operate with a higher mean flow temperature generally have a lower SPF. The mean flow temperature amongst ASHPs and Hybrids was 38.2°C. Figure 5.3 shows this relationship for all ASHPs.

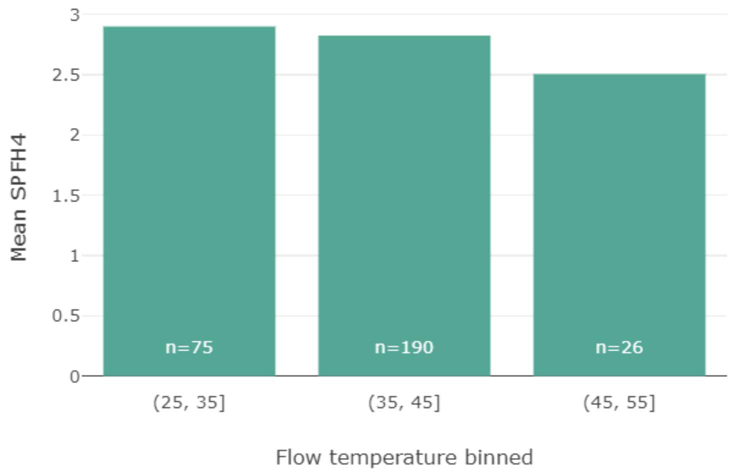

Figure 5.3: Histogram showing the mean SPF_{H4} by binned mean flow temperature (℃). Note that flow temperatures when the heat pump was not outputting heat have been excluded from the mean.

It can be seen in Figure 5.3 that the general trend is that as mean heat pump flow temperature decreases, SPF_{H4} increases.

It was noted in Section 5.1 that based on pre-project definitions, HT ASHPs have been observed to operate at a similar efficiency to LT ASHPs through this study, however this may be down to the actual operating temperature and control strategy. In practice, in many cases they may be operating at similar temperatures to LT ASHPs. As a result, more analysis has been undertaken to assess the heat pump efficiency against actual heat pump operation.

Figure 5.4 shows that whilst HT ASHPs are less likely to have a very low mean flow temperature, there is a significant overlap in typical operating temperatures for HT ASHPs and LT ASHPs.

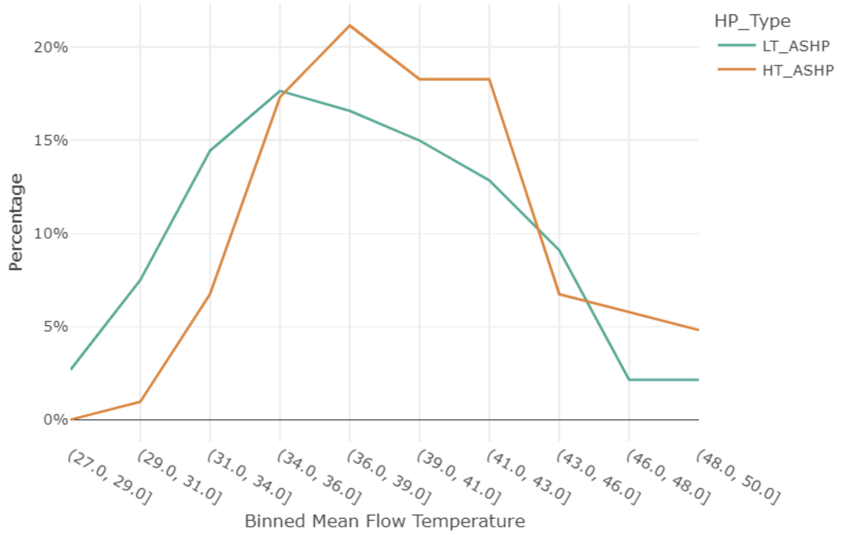

Figure 5.4: Frequency distribution of mean flow temperature by heat pump type.

In fact, defining HT operation as when a heat pump operates above 65°C at any point over the 12 months, Table 5.5 indicates that only 94 of the 104 HT heat pumps reached a flow temperature of 65°C. Figure 5.5 shows that operating above 65°C is not a common occurrence, with 81 of the 94 heat pumps operating above 65°C flow temperature less than 1% of the time.

Table 5.5: ASHP SPF values broken down by HT operation and LT operation.[4]

Heat Pump Type	SPF Type	Count	Median [IQR]	Mean [95% CI]
LT Operation (ASHP)	SPF_{H2}	197	2.94 [2.64, 3.25]	2.95 [2.88, 3.01]
	SPF_{H4}	197	2.74 [2.48, 3.07]	2.77 [2.71, 2.84]
HT Operation (ASHP)	SPF_{H2}	94	2.92 [2.69, 3.15]	2.96 [2.88, 3.05]
	SPF_{H4}	94	2.89 [2.66, 3.09]	2.90 [2.82, 2.98]

[4] Note that 14 ASHPs have been excluded from the flow temperature related analysis compared with the SPF only analysis as they had insufficient temperature data quality.

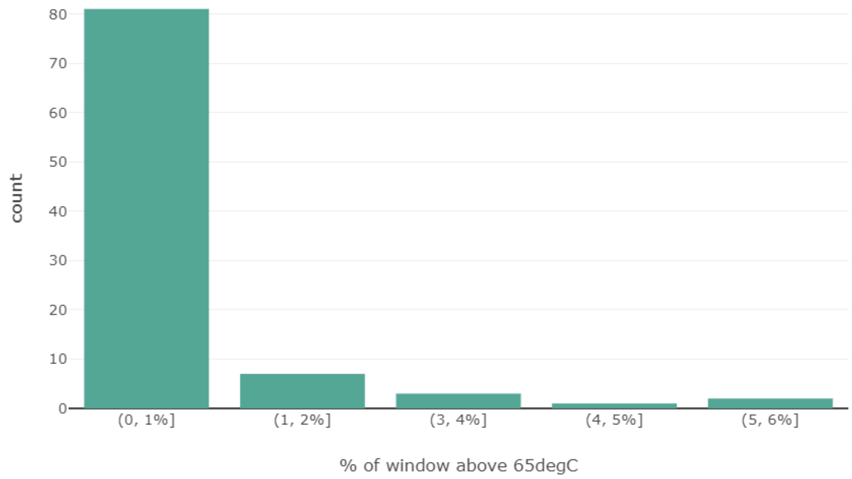

Figure 5.5: Percentage of heat pump operation above 65°C

It may therefore be concluded that, most of the time, the HT ASHPs are operating at similar flow temperatures to the LT ASHPs, which goes some way towards explaining the similar performance.

5.4 SPF by Home Type

It should be noted that all houses which received installations through the project were deemed suitable for a heat pump installation by trained designers and installers, so the following results may not be representative of the UK housing stock. Nonetheless, this analysis still provides valuable insight into the performance of heat pumps in homes which are recommended for an installation by trained designers and installers.

Figure 5.6 and Figure 5.7 show the SPF_{H4} by house type and house age respectively.

As indicated in Figure 5.6, detached homes have been observed to have a statistically significantly higher SPF compared to semi-detached homes however, there is no significant variation between the efficiency observed in semi-detached and terraced homes. Detached homes have a much lower proportion of heat pumps installed which utilise the R410a refrigerant. This may be one reason for the unexpected performance variation between house forms.

Figure 5.6: Mean SPF_{H4} by house type with 95% CI. Excludes Hybrids.

Figure 5.7 indicates that where a trained heat pump designer or installer has deemed a home to be suitable for a heat pump installation (as was the case in this project) the age of the houses which received heat pump installations does not have a significant impact on SPF.

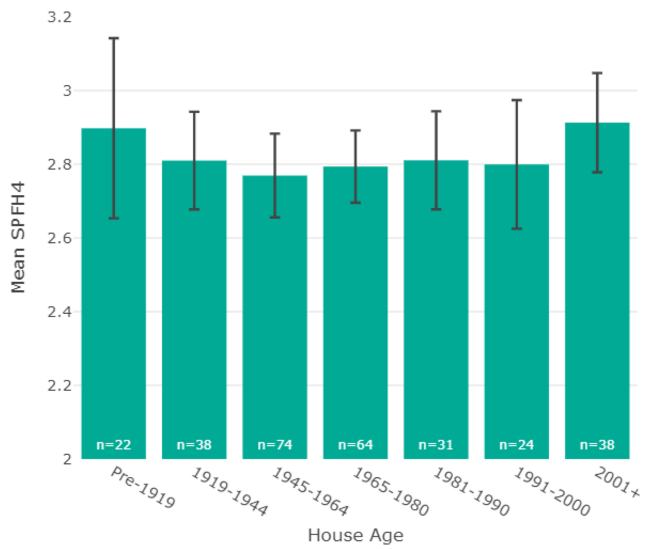

Figure 5.7: Mean SPF_{H4} by house age with 95% CI. Excludes Hybrids.

5.5 Hybrid Heat Pump Operation

When assessing hybrid heat pump operation using the data from this project, it is necessary to reiterate that the domestic hot water provision is not metered and that any proportions of heat pump to gas boiler operation are those for space heating only. In addition, the hybrid heat pumps have been controlled to operate cost-optimally.

Noting the above, the heat pump energy output as a percentage of total space heating output (from the heat pump and gas boiler combined) in Hybrid systems (over the course of the 12-month SPF calculation window) is presented in Table 5.6 and Figure 5.8.

Table 5.6: The median and mean heat pump energy output as a percentage total space heating output in hybrid systems.

Sample Size	Mean	Median (50%)	Q1 (25%)	Q3 (75%)
53	41.7%	38.6%	31.4%	49.6%

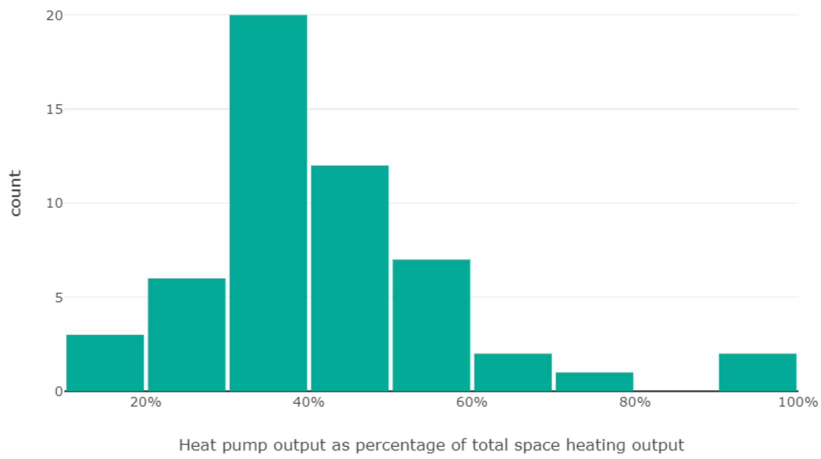

Figure 5.8: Frequency distribution of heat pump energy output as a percentage of total energy output in Hybrid systems.

When analysing these results, it should be noted that in spring 2022, a large proportion of the Hybrid systems installed through the EoH project had their controls optimised during a heat pump service visit. This optimisation may affect the energy output proportions and a reassessment of these proportions will be reported following the completion of the monitoring period.

The data indicates a statistically significant relationship between proportion of heat pump use in Hybrid systems and SPF, with systems that have a higher heat pump usage tending towards higher SPFs. This relationship is shown in Figure 5.9.

This result may be because intermittent heat pump operation is less efficient. It should be noted that whilst a linear relationship has been assumed in Figure 5.9, the actual relationship is likely non-linear, particularly for higher heat pump output proportions where the SPF_{H4} is likely to converge with that of a typical ASHP at 100% output proportion.

It should also be noted that when designing and commissioning the hybrid systems, the systems are generally cost-optimised so the gas boiler is only used for space heating when external temperatures are sufficiently low to warrant higher flow temperatures (which may result in less efficient heat pump operation). The SPF result therefore may be slightly skewed as the hybrid systems shown to use the heat pump less may be installed in less efficient homes with greater heat losses.

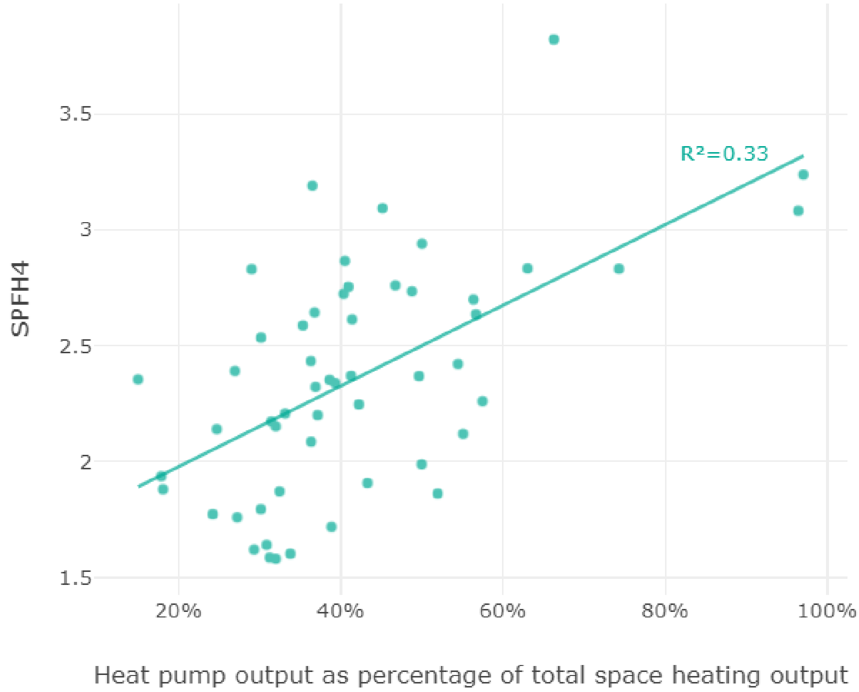

Figure 5.9: SPF_{H4} by heat pump output percentage in hybrid systems.

5.6 Coldest Day Analysis

To analyse heat pump performance during colder periods this analysis selected the coldest day where each heat pump was operational.

A COP was then calculated for each period to assess the heat pump performance over the coldest day. The median and mean COP is given in Table 5.7.

When reviewing these results, it should be noted that performance over shorter time frames is susceptible to large variations based on several factors such as the pre-conditioning of the home or extremely large heat gains or losses (i.e. if windows are doors are opened, or ovens are operational).

Table 5.7: Median and mean COPs for the coldest day and coldest 30 minutes (HH) across all ASHPs.

Efficiency Type	Sample Size	Median [IQR]	Mean [95% CI]
Coldest Day COP	484	2.44 [2.20, 2.70]	2.44 [2.40, 2.48]

Figure 5.10 indicates the COP variation against the mean difference between internal and external temperatures on the coldest day.

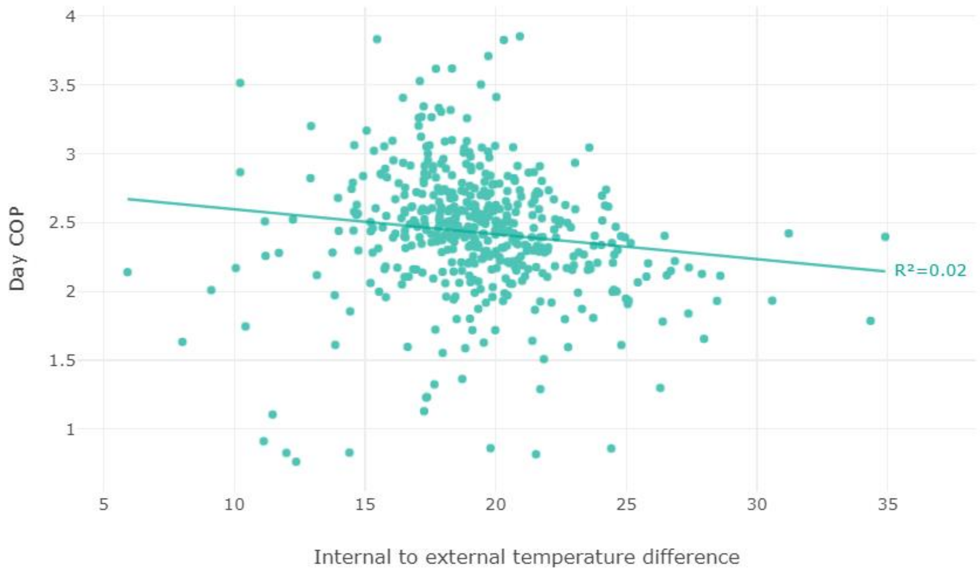

Figure 5.10: COP by difference between internal and external temperatures on the coldest day.

Reviewing this figure, there is significant variation in the COP values, especially where a mean temperature difference of 15 to 20°C. Despite these variations, it is evident that the trend in the results is such that as the difference in temperatures increases, the COP decreases.

6. Conclusions

The Electrification of Heat Demonstration Project has found that Air Source Heat Pump SPFs have improved by ~0.3 to 0.4 compared with installations completed under the Renewable Heat Premium Payment Scheme, with the median SPF_{H4} for ASHPs being 2.80 (median SPF_{H2} = 2.94).

The analysis indicates that some of this improvement is related to efficiency improvements in the heat pump units as, the heat pumps using the R290 and R32 refrigerants generally have performed better than those using the older R410a refrigerant (which is currently being phased out in the UK). This result may also suggest that the design (and installation) of heat pump systems has improved over the last seven years. This should be factored into modelling and policy decisions.

However, it has also found that variation in performance between heat pump installations remains high (and difficult to explain), which suggests that progress is still required on improving the quality and consistency of heat pump designs and installations to support a large-scale rollout of heat pumps in existing homes and deliver positive energy, carbon, and consumer outcomes.

High temperature ASHPs did not perform worse than low temperature ASHPs. This is likely in part due to the fact that they spend much of their time actually operating at similar temperatures, but may also be due to the use of a higher performing refrigerant in the models installed in this trial. Irrespective of the underlying cause, HT ASHPs should not be assumed to perform worse by default in modelling and purchasing decisions.

Median ASHP efficiency fell to 2.44 on the coldest day (-0.4°C) which quantifies the expected degradation in performance due to low temperature and could be used to inform modelling of peak winter demand.

Heat pumps in hybrid systems were typically used to meet 32-50% of the space heating demand (median 39%). They had lower efficiencies than ASHPs (median SPF_{H2} = 2.54) and were found to be less efficient the smaller the proportion of heating demand they met.

This analysis will be refreshed, and additional analysis (including of Ground Source Heat Pump performance) will be undertaken after the completion of the projects monitoring period in September 2023.

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This report has been funded by DESNZ
and is issued on their behalf

Electrification of Heat Demonstration Project

Department for Energy Security & Net Zero

Report produced in 2023

This report has been funded by DESNZ
and is issued on their behalf

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