Supplementary information on Heat Pump Performance Model

This supplementary information describes in more detail the number of heat pumps used in the model, and the applicability of the model at low outdoor air temperatures.

# Number of heat pumps in COP model

A criterion was applied of the minimum number of heat pumps present in the sample with valid data on a given day, for data from that day to be included in the heat pump performance model. Because the number of heat pumps available was different for the different performance models, depending on which heat pump type and performance level was of interest, the criterion of the minimum allowable number of heat pumps was also varied. The criteria applied, and the actual number of heat pumps in the sample are given for ASHP and GSHP models in Tables 1 and 2 respectively.

Table : Further detail on ASHP performance models

|  |  |  |  |
| --- | --- | --- | --- |
|  | **SPFH4>1.5 (Current performance)** | **SPFH4>2.5 (Good performance)** | **SPFH4>3 (Very good performance)** |
| Gradient m1 | 0.06 | 0.07 | 0.08 |
| Intercept c1 | 2.07 | 2.46 | 2.83 |
| Gradient m2 | -0.09 | -0.12 | -0.15 |
| Intercept c2 | 3.29 | 4.10 | 4.97 |
| r2 | 0.78 | 0.74 | 0.53 |
| Break-Point (°C) | 8.23 | 8.63 | 9.47 |
| Mean SPF | 2.28 | 2.77 | 3.28 |
| Number of heat pumps  | 446 | 124 (28% of sample) | 21 (5% of sample) |
| Minimum allowable daily sample size | 40 | 20 | 5 |
| Actual minimum daily sample size | 42 | 21 | 6 |
| Mean daily sample size | 198 | 62 | 12 |

Table : Further detail on GSHP performance models

|  |  |  |  |
| --- | --- | --- | --- |
|  | **SPFH4>1.5 (Current performance)** | **SPFH4>2.5 (Good performance)** | **SPFH4>3 (Very good performance)** |
| Gradient m1 | 0.00 | 0.00 | 0.00 |
| Intercept c1 | 2.50 | 3.01 | 3.49 |
| Gradient m2 | -0.05 | -0.06 | -0.09 |
| Intercept c2 | 2.77 | 3.32 | 4.58 |
| r2 | 0.71 | 0.54 | 0.11 |
| Break-Point (°C) | 5.00 | 5.22 | 12.63 |
| Mean SPF | 2.19 | 2.85 | 3.40 |
| Number of heat pumps  | 110 | 30 (28% of sample) | 6 (5% of sample) |
| Minimum allowable daily sample size | 20 | 10 | 3 |
| Actual minimum daily sample size | 21 | 11 | 3 |
| Mean daily sample size | 41 | 16 | 4 |

# Applicability of ASHP performance model during colder weather

The performance of the national stock of heat pumps is of particular interest during the coldest weather, since this will determine the peak heat pump electricity demand. This is especially important for ASHPs, as their performance is known to decline during colder weather. The Carnot COP, which is the maximum theoretical COP, can be determined from the source and sink temperatures of the heat pump. It might be supposed that the real heat pump COP would be a constant fraction of this, and thus the ASHP performance at low temperatures could be obtained theoretically. However, in a real heat pump installation, there are a range of other factors that can affect heat pump performance at low outdoor temperatures, such as the use of booster heaters, changes in heating patterns, weather compensation curve, defrosting and others. Therefore, it is helpful to examine the real ASHP performance at low outdoor temperatures.

Because the aim is to predict GB national heat pump electricity demand, the outdoor temperature[[1]](#footnote-1) of interest is the mean of the temperatures experienced at each heat pump. Therefore, when constructing the model of heat pump performance, the mean is taken of the daily outdoor temperatures from each of the heat pumps having valid data for that day. As noted in the main paper (Watson et al. 2023), there were only two days where this temperature was below -2°C. There was one day at -4.1°C and one at -3.4°C. When the model is used to give predictions of national heat pump performance, the input temperature is the mean temperature experienced by the GB housing stock. The lowest temperature input to the model is -3.6°C, which occurred in the 2010 weather data.

Since there are few data points for particularly cold weather experienced by the sample of heat pumps as a whole, it is of interest to examine the performance of individual heat pumps during particularly cold weather. It is generally preferrable for the model to err on the side of caution i.e. underestimate heat pump performance during cold weather. It is therefore useful to examine whether there is a deviation from a straight-line relationship between COP and outdoor temperature at low outdoor temperatures, especially whether the actual COP is lower than would be predicted by a straight-line relationship based on observations at higher temperatures.

Heat pumps having at least eight days of outdoor temperature below -2°C were selected, and daily COP was plotted against outdoor air temperature, for days with outdoor air temperature below 5°C. A least-squares straight line was fitted. Some examples of this are shown in Figures 1-4. There was no tendency for COP at low temperatures to be lower than predicted by a straight line, indicating that the model is not over-predicting COP at low temperatures.

Scatter graphs of individual daily COP vs daily outdoor air temperature, where all ASHPs are shown on one scatter graph, are given by Watson (2020).



Figure : Daily Coefficient Of Performance vs daily outdoor air temperature, for one ASHP, showing only days with outdoor temperature below 5°C.



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# Applicability of GSHP performance model during cold weather

In the case of GSHPs, there is not a direct link between outdoor air temperature and performance, since the heat is extracted from the ground, which is only influenced by the air temperature over much longer timescales than daily. However, GSHP performance does decline with higher outdoor air temperature, due to a combination of a greater proportion of heat output being required for DHW, cycling, and relatively greater parasitic loads. GSHP performance was therefore constrained to be constant at outdoor air temperatures below 5°C, but no further constraint was placed on the broken-stick regression algorithm. The reasonableness of constraining GSHP performance to be constant at outdoor temperatures below 5°C was investigated by looking at scatter plots of individual GSHP performance against outdoor air temperature. GSHPs were selected which had at least eight days of data when the outdoor temperature was below -2°C. For these heat pumps, the daily Coefficient Of Performance was plotted against daily outdoor air temperature, for all days with outdoor air temperature below 5°C. A horizontal line was added, indicating the mean COP of all these days. Examples are given in Figures 5-8. In one case the GSHP performance at low temperatures was lower than the mean COP at outdoor temperatures below 5°C (Figure 5), whereas in another case the COP at low temperatures was higher than the mean COP at outdoor temperatures below 5°C (Figure 6). In general, mean COP on days with outdoor temperature below 5°C gave a reasonable estimate of COP at low temperatures (Figures 7 and 8). Therefore, it can be seen that constraining COP to be constant at outdoor temperatures below 5°C in the GSHP performance model was a reasonable approach.

Scatter graphs of individual daily COP vs daily outdoor air temperature, where all GSHPs are shown on one scatter graph, are given by Watson (2020).



Figure : Daily Coefficient Of Performance vs daily outdoor air temperature, for one GSHP, showing only days with outdoor temperature below 5°C. Note that in this case the COP on particularly cold days appears to be lower than the mean COP of all days below 5°C.



Figure : Daily Coefficient Of Performance vs daily outdoor air temperature, for one GSHP, showing only days with outdoor temperature below 5°C. Note that in this case the COP on particularly cold days appears to be higher than the mean COP of all days below 5°C.



Figure : Daily Coefficient Of Performance vs daily outdoor air temperature, for one GSHP, showing only days with outdoor temperature below 5°C. Note that in this case the COP on particularly cold days appears to be similar to the mean COP of all days below 5°C.



Figure : Daily Coefficient Of Performance vs daily outdoor air temperature, for one GSHP, showing only days with outdoor temperature below 5°C. Note that in this case the COP on particularly cold days appears to be similar to the mean COP of all days below 5°C.

# References

1. This is the exponentially-weighted moving average, as described inWatson et al (2018). [↑](#footnote-ref-1)