Department for
Energy Security
& Net Zero

Lab testing of heat pumps providing Domestic Hot Water

Validation of the Home Energy Model methodology for heat pumps

December 2023

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Introduction

A heat pump model was developed in the Home Energy Model (HEM) to determine the performance of heat pumps. For more information on the heat pump model please see HEM-TP-12 Heat pump methodology.

This report uses data from lab tests and HEM modelling to explore the effectiveness of the HEM's heat pump model and heat pump test data in predicting heat pump performance.

Most heat pumps currently stored in the product characteristic database (PCDB) offer both space and water heating. HEM's heat pump model uses EN 14825 test data for space heating to predict both space and water heating performance. Heat pumps that only offer hot water heating, are required to provide data based on a hot water test standard (EN 16147).

The first part of this study investigated the ability of EN 14825 test data (at 55°C) to predict water heating performance across a range of scenarios. The scenarios included: outside air temperature, Domestic Hot Water (DHW) tapping profile, cylinder volume, thermostat location in the cylinder and heat pump maximum thermostat temperature settings.

The second part of this study investigated the ability of the EN 14825 test standard itself. The EN 14825 assumes a Plant Size Ratio (PSR) of 1 which means the heat pump has been perfectly sized to the building's load. As buildings become more energy efficient, the maximum heating load decreases, while the demand for DHW remains constant. Heat pumps may be sized for continuous DHW supply rather than peak heating loads, potentially increasing PSR and affecting performance. This study undertook EN 14825 tests at different PSR across various outdoor temperatures to explore its effect on heat pump performance.

Hot water testing

Method and materials

The tests were conducted using a 5 kW Monoblock heat pump with inverter-controlled compressor and variable speed water pump that is currently available on the UK market.

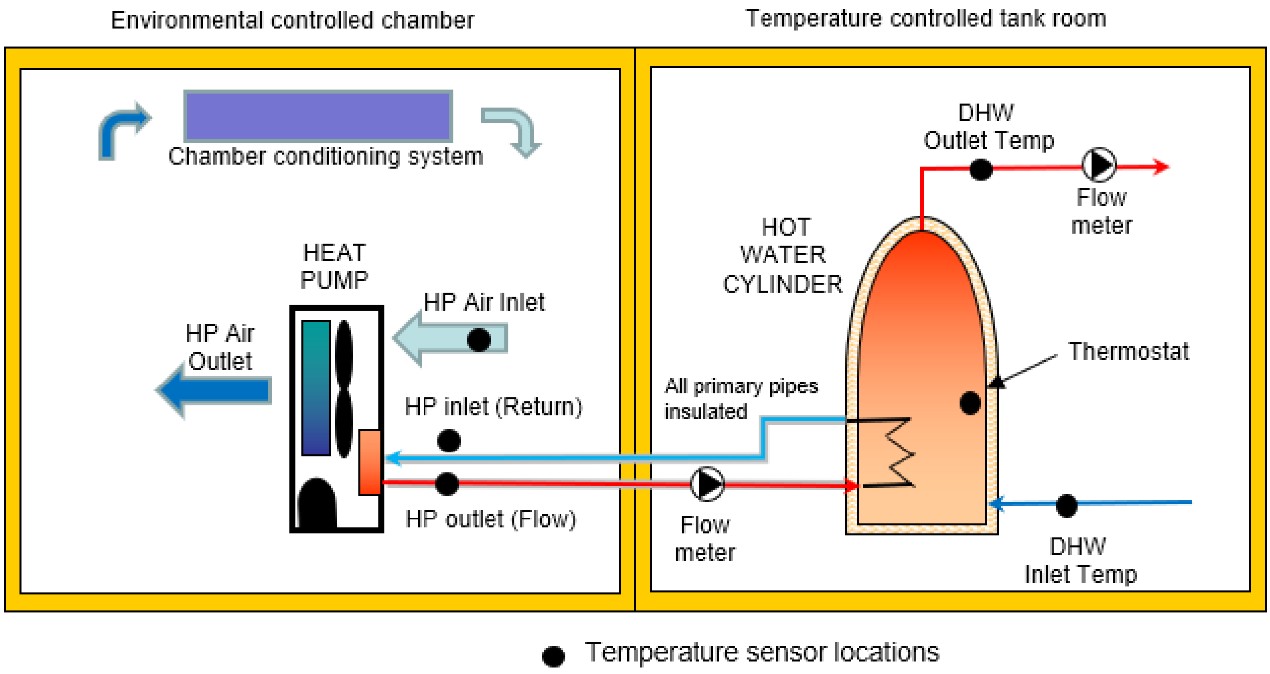


Figure 1 - EN16147 Hot water test rig

The testing involved an analysis of five key independent variables, which were selected based on their potential impact on the performance of installed heat pump systems. The variables were: outside air temperature, DHW tapping profile, cylinder volume, thermostat location in the cylinder and heat pump maximum thermostat temperature settings. A detailed overview of these variables can be found in Table 1.

Table 1 - Variations of testing conducted

Variable	Values assessed	Logic for choice of variable range
Outside air temperature (°C)	2°C, 7°C & 14°C	Typical UK outside air temperatures.
Draw off load (kWh per day)	2.9 kWh (Small), 6.0 kWh (Medium), 8.9 kWh (Large) & 12.7 kWh (XLarge)	Represent occupancy patterns from a single/double occupancy dwelling up to a five/six-person occupancy dwelling.
Tank volumes (L)	150L & 210L	Typical manufacturer recommended cylinders for the size of heat pump tested.
Thermostat settings – Heat pump on / off temperatures (°C)	Eco mode. On – 43°C Off – 52°C Comfort mode. On – 50°C	The two heat pump settings typically used on installation. No specific temperatures were set in the hot water tank. The on and off temperatures were noted from the laboratory test data after the testing was completed.

	Off – 57°C	Anti legionella settings were switched off as this would have required much more testing to ensure repeatability.
Thermostat locations in cylinder (from top)	¼ & ¾ height – 210 L ½ height – 150 L	210L cylinder had two pockets for the thermostat, allowing a choice of volume of hot water stored. 150L has one pocket for the thermostat.

The test rig was set up so that the hot water tests could be conducted to EN 16147 standard as shown in Figure 1.

To provide a more detailed understanding of the impact of increasing the hot water usage between medium to large tapping patters, an additional tapping pattern was developed and the existing patterns modified to reflect more typical use of showers. The tapping patterns can be seen in Figure 2. These were modified from the standard EN 16147 tapping profiles, the detailed tapping profile data can be found in Appendix A. Please note that these are separate to the DHW tapping profiles developed for the FHS assessment wrapper.

The lab testing results were expressed as Coefficient of performance (COP) DHW. The COP has a SEPEMO system boundary of SPF4. The COP is the useful heat delivered during the tapping pattern divided by the total electrical energy consumed by the heat pump over the 24-hour period. The heat delivered by the heat pump exceeds that required by the tapping pattern as it includes the standing loss of the cylinder, the losses in the distribution pipes and the cycling losses of the heat pump.

Multiple tests were conducted at each operating point to allow the repeatability of the testing to be assessed and minimise overall uncertainty in the results. This also ensured that the starting condition of the cylinder did not impact the measured COP.

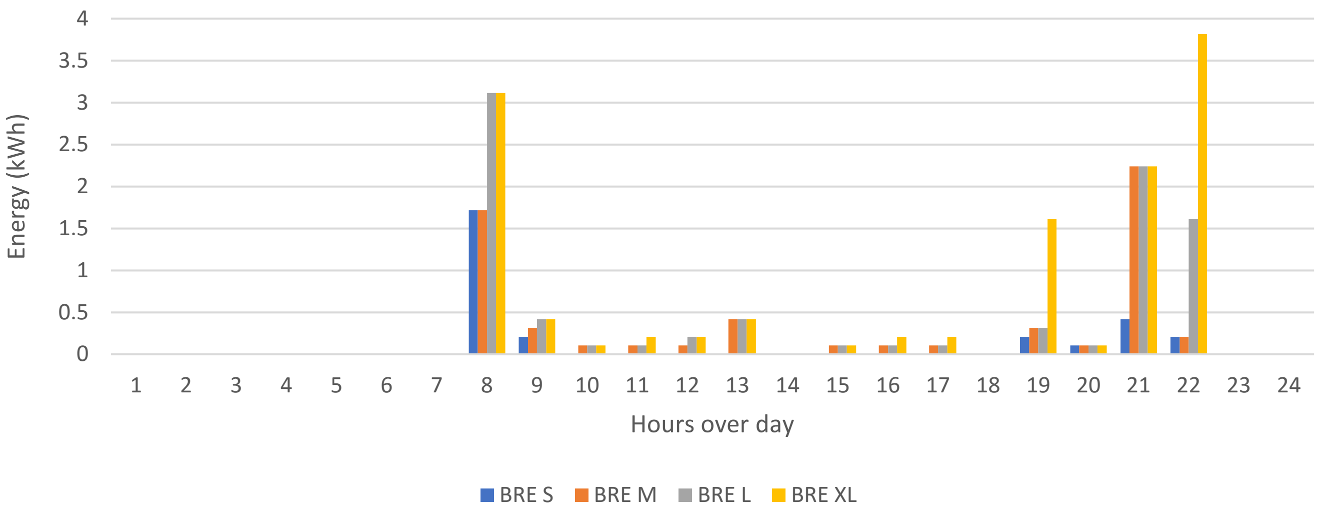


Figure 2 - Tapping profiles used in SAP 11 heat pump testing

Results and discussion

To accurately replicate the lab conditions as far as possible, the same inputs were used as described in Table 1. The tapping patterns set out in Annex A used in the lab testing were included in the model, as well as a fixed outside air temperature to match that used in the test chamber. In addition to these changes, the cold-water inlet to the cylinder temperature was fixed at 10°C, to replicate that set in EN16147 test standard. The HEM modelling was run over a repeating seven-day period and the COP determined as the average over the whole period.

To gain insight into the behaviour of the tank, water temperatures were extracted at the four different layers within the HEM tank model. The temperature variations within the tank, as well as the amount of electricity consumed by the heat pump over the course of a week, are illustrated in Figure 3.

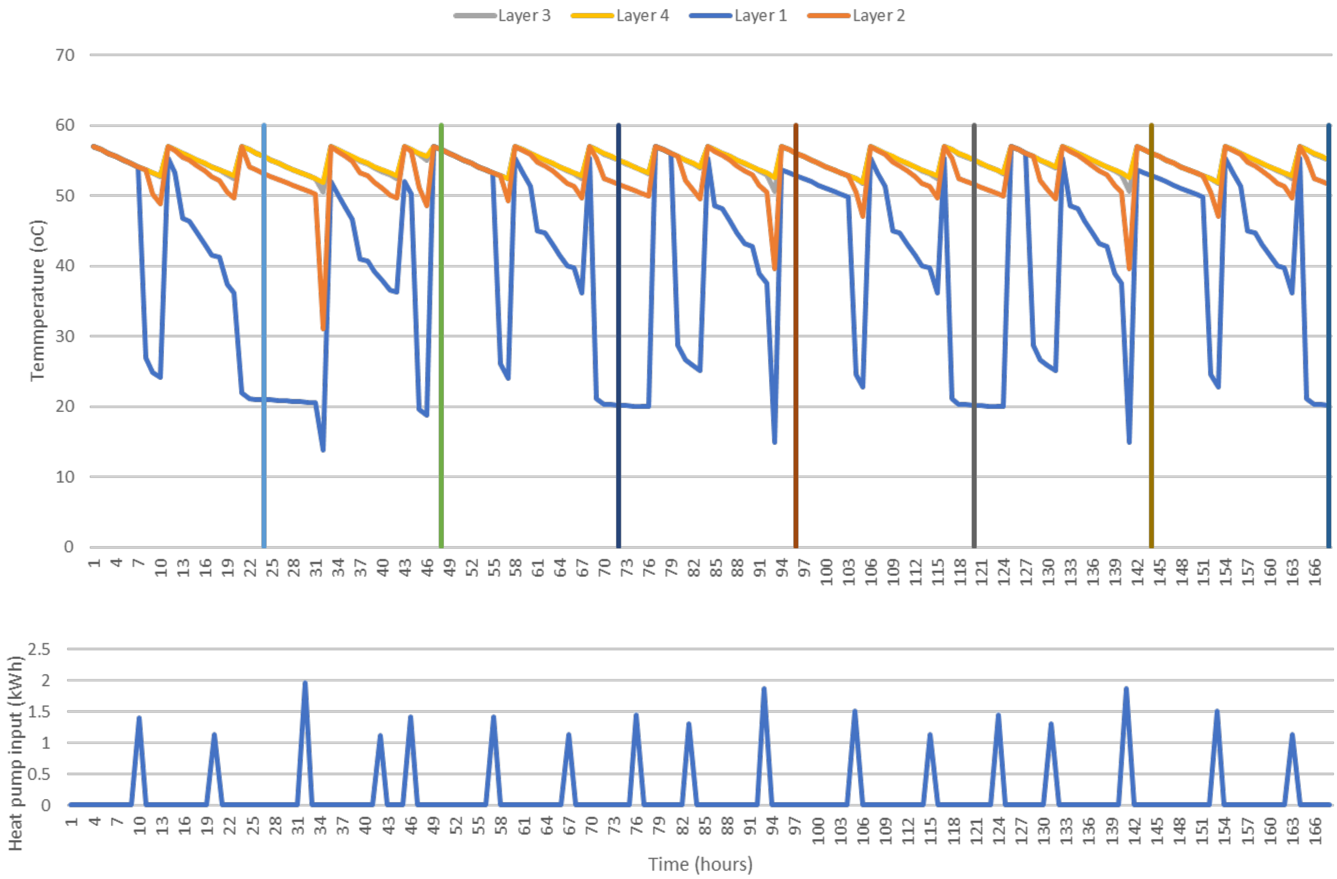


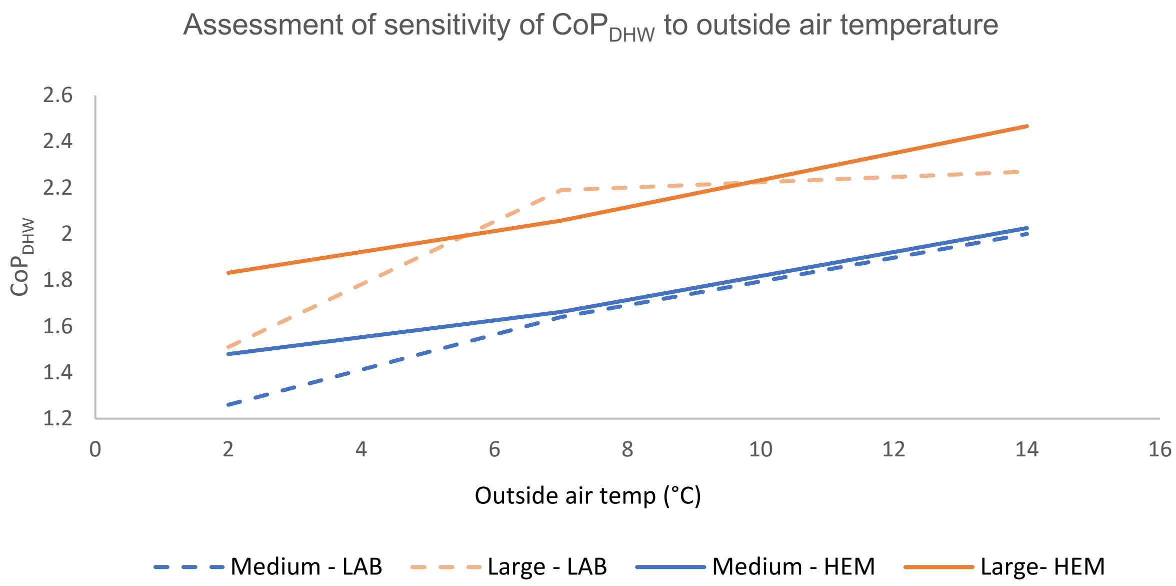
Figure 3 - An example of temperatures throughout the tank when BRE medium tapping profile is run over a week in the HEM model

The vertical lines represent the days in the week. The tank was divided into four layers for analysis, where Layer 4 is the top quarter, Layer 3 is at the quarter to half height from the top, Layer 2 is at the quarter to half height from the bottom, and Layer 1 the bottom quarter.

In this specific scenario, the thermostat is in Layer 2 of the tank. The thermostat was set in Comfort Mode, i.e., whenever the temperature in Layer 2 fell below 50°C, the heat pump was triggered and starts heating the tank until the temperature in Layer 2 reached the desired set point of 57°C.

Line graphs comparing the results of the lab testing and the HEM were created and can be seen in the next five plots below.

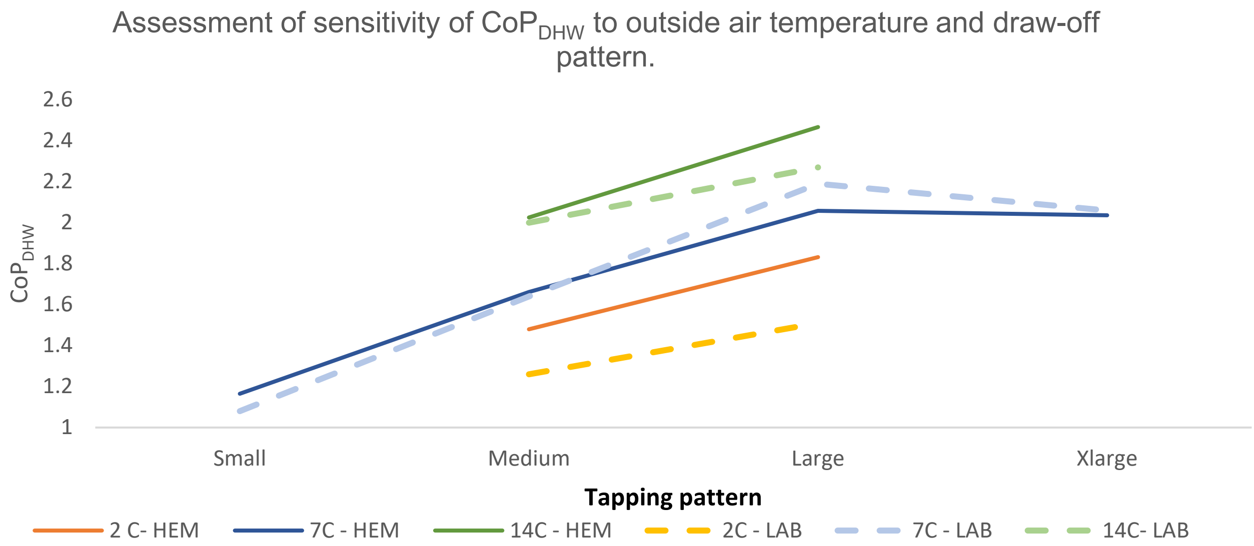
Plot 1



Varied	Fixed
• Outside air temperature: 2, 7 and 14°C • Tapping pattern: medium and large	• Thermostat location – top pocket • Heating mode – Comfort • Cylinder size – 210 L

The lab and modelling values of COP follow similar trends with changes in outside air temperature. This is reassuring as it confirmed that the assumptions regarding changes in refrigeration performance across the typical UK outside air temperatures range are broadly correct.

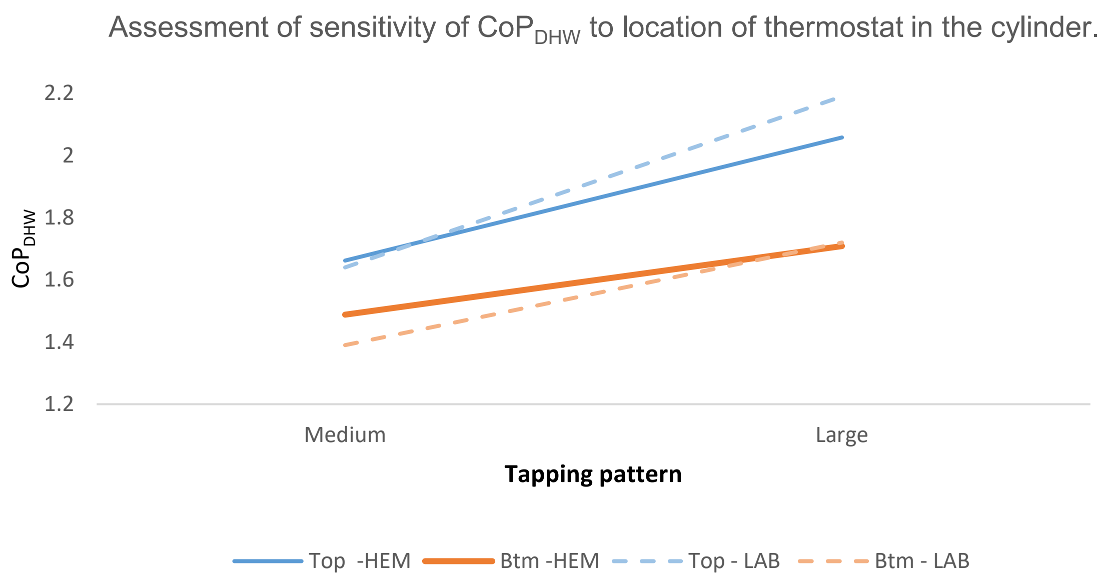
Plot 2



Varied	Fixed
• Outside air temperature: 2, 7 and 14°C • Tapping pattern: small, medium, large and Xlarge	• Thermostat location – top pocket • Heating mode – Comfort • Cylinder size – 210 L

The overall trends with changes in tapping pattern were very similar suggesting that the model was capturing the impact of the change in DHW load effectively. However, at 2C, HEM can be seen to be overestimating the heat pump performance compared to lab data.

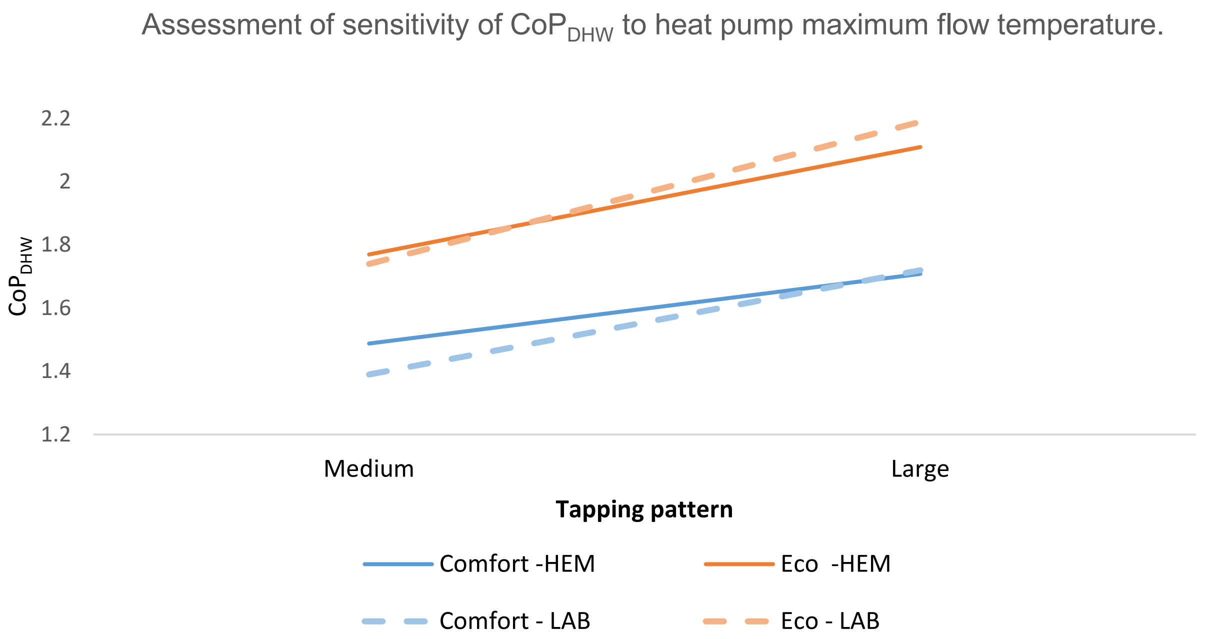
Plot 3



Varied	Fixed
• Thermostat location: top and bottom pocket • Tapping pattern: medium and large	• Outside air temperature – 7°C • Heating mode – Comfort • Cylinder size – 210 L

The results show HEM did correctly predict an increase in COP when the thermostat was moved. This shows in the lower thermostat position the heat pump started cycling more, therefore increasing the cycling losses and reducing the overall COP.

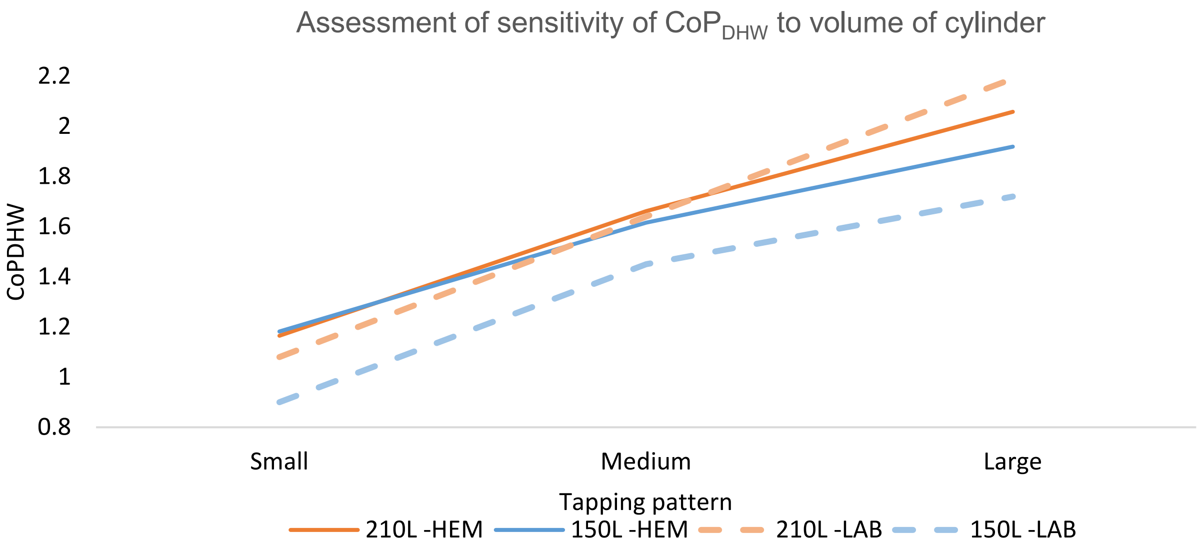
Plot 4



Varied	Fixed
• Heating mode: Comfort and Eco • Tapping pattern: medium and large	• Outside air temperature – 7°C • Thermostat location – top pocket • Cylinder size – 210 L

The data shows HEM predicted a similar overall trend in performance to that found in the lab testing. However, it is worth noting that the tank set point and minimum temperature inputs into the HEM modelling was based on temperatures seen in the tank after the testing was undertaken.

Plot 5



Varied	Fixed
• Cylinder size: 150 and 210 L • Tapping pattern: small, medium and large	• Outside air temperature – 7°C • Thermostat location – top pocket • Heating mode – Comfort

It is evident that the HEM model was able to capture the difference in overall performance of a change in cylinder size. The variation due to changes in tapping pattern was predicted well. However, at the lower tank size there is a consistent difference in COP between HEM and labs. The difference between the COP values may have been due to different levels of cylinder heat losses and differences in the location of the thermostat within the cylinder. The model may not have captured the additional level of cycling that occurred in the lab tests when the smaller cylinder was tested.

Space heating testing

Method and materials

The testing involved evaluating the performance under various conditions. The table below shows the approximate percentages of full space heating load for different plant size ratios (PSR), compared to the test data obtained from EN14825 testing. The cells highlighted in orange indicates values of load below 25%, which could lead to the heat pump transitioning from inverter controlled continuous operation to on-off control, potentially impacting efficiency. Air source heat pumps perform better at higher outdoor temperatures; however, the impact of part load cycling may be greater causing overall efficiency to decrease.

Test temperature (°C)	Approximate percentage of full load (%)			
	EN14825 PSR = 1	SAP PSR = 1	SAP PSR = 2	SAP PSR = 3
-7 (SAP Tdesign~-5°C)	88	100	50	33
2	54	65	33	22
7	35	45	23	15
12	15	15	7	5

The tests were conducted using a 10 kW Monoblock model equipped with an inverter-controlled compressor and fixed speed water pump. The flow temperature during testing was set at the design condition of 45°C. The COP data was measured at four different air temperatures and across three PSR. Clause 11.6.2 of EN 14825 standard allows manufacturers to fix the compressor speed. However, the inverter compressor speed was set to vary freely as this is how the heat pumps will be installed.

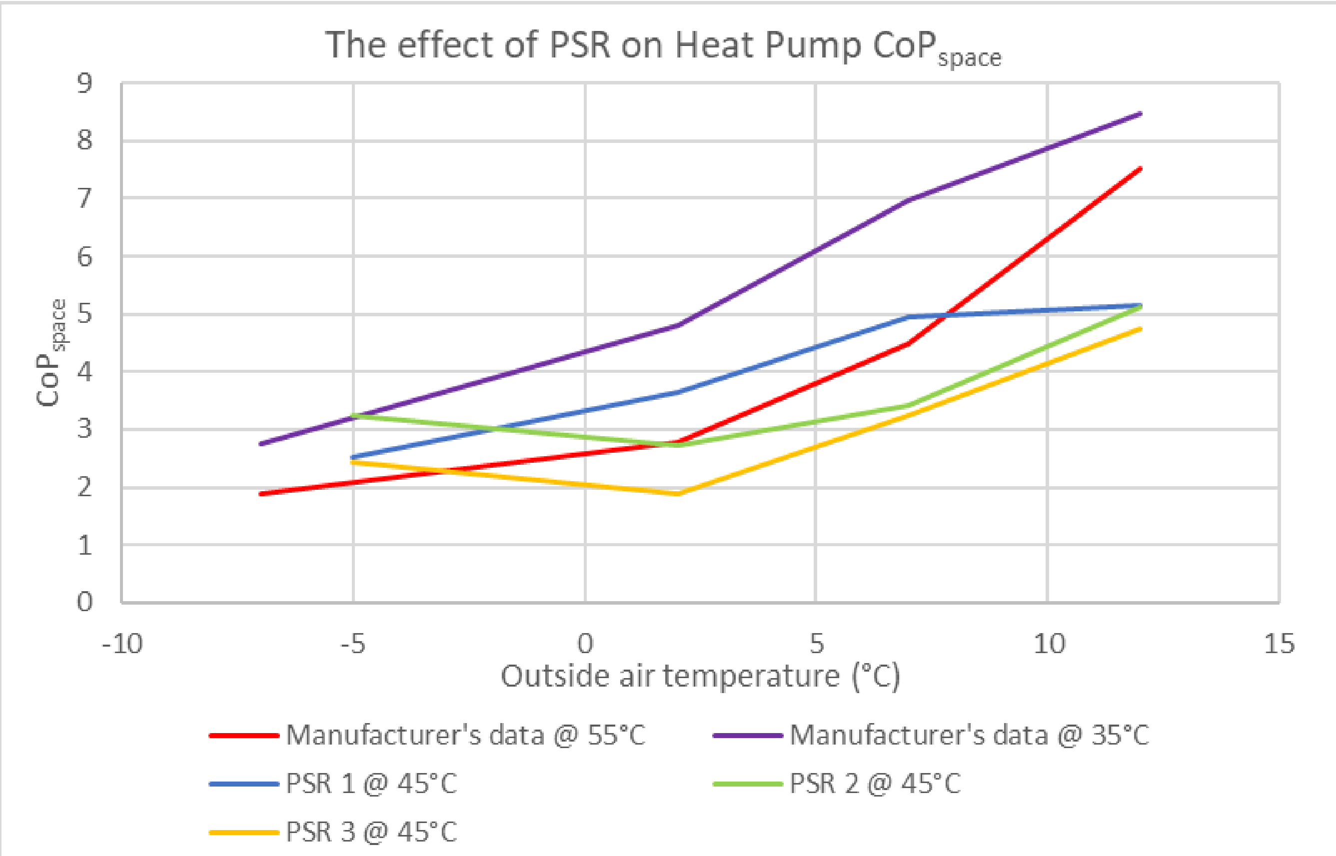
Results and discussion

The table below shows that the unit operated continuously at PSR=1 only at temperatures below 12°C, and at a PSR=2 at -7°C. At a PSR=3 and outside air temperature of -5°C, the compressor cycled once across the test period. At all other test conditions, the compressor was in on/off mode.

Test temperature	PSR = 1	PSR = 2	PSR = 3
-5°C	2.52	3.24	2.44
2°C	3.64	2.71	1.88
7°C	4.95	3.41	3.24
12°C	5.15	5.12	4.73

The cells highlighted in orange indicates the test were undertaken where compressor was in on/off mode.

The measured data was plotted against the manufacturer's data as shown in the figure below. It is worth noting, the manufacturer data was at flow temperatures of 35°C and 55°C values at a PSR =1, while the lab test data was carried out at a flow temperature of 45°C . Therefore, it is expected that the manufacturer test data performance at 45°C lies between 35°C and 55°C.



The figure above shows when the compressor is running continuously up to 7°C at a PSR =1, the COP data is not dissimilar to the manufacturer's data. However, at all other test points the COP is significantly lower, and below the manufacturer's COP for a flow temperature of 35°C.

A likely reason for the difference is the manufacturer testing was undertaken at the lowest continuous compressor run speed, with the compressor set at a fixed speed. While the lab data was conducted with the heat pump free to vary its compressor speed.

This shows that the EN14825 test data overpredicts heat pump performance as it does not capture the on/off part load performance which is likely to be how the heat pump will operate. This becomes critical as the PSR increases and more of the heating season falls in this mode of operation. As a result, it may be necessary to request increased test data input from manufacturers or adopt more conservative assumptions when duty falls below an agreed-upon capacity ratio.

The HEM heat pump methodology applies adjustments to capture cycling behaviour for variable capacity control heat pumps. Further modelling will be needed to see if the cycling adjustment that HEM's heat pump method is similar to the difference found in the lab testing.

Conclusion

For water heating, the results indicate that the HEM heat pump model predicted similar trends with the EN16147 test data across a range of variables. However, the test data was taken from one monoblock heat pump and a range of cylinders that were specified as suitable by the heat pump manufacturer. Currently EN16147 test data is not requested when heat pumps are listed on the PCDB for space and hot water heating. It is noted that most manufacturers are already undertaking EN16147 tests for their products, as this is required for MCS if the heat pump is to be listed as a combination heater that can provide both space heating and DHW. It is suggested that, where available EN16147 test data for all heat pumps, is requested as optional additional data points. The additional data can be used to cross-check EN14825 test data to ensure that any very significant variations from 'normal' are identified, minimising the risk that poor or overoptimistic data is being submitted.

For space heating, the results show that the standard EN 14825 testing may be overpredicting heat pump performance. However, due to the limited amount of test data used for this comparison, it is not possible to make any suggestions that global correction factors should be introduced to correct the overpredictions found.

Further testing

Further lab testing may be needed to validate the HEM. Below are specific testing areas to consider.

For water heating:

- Run the EN 16147 hot water tests on further 2 heat pumps to ensure similar results are seen. It is suggested further improvements are made to the testing equipment for comparison purposes. This may include, installing additional sensors on the surface of the cylinder to partially capture the stratification and assess that against the SAP model. Assess the rate of heat losses from a range of cylinders and use the SAP model to compare the rate of cooling.
- Run the tests with different levels of insulation and length of the flow and return pipes from the heat pump to the cylinder to assess the standing losses and how well these are captured in the model.

For space heating:

- As there was limited amount of test data, it is proposed that the testing is carried out on a further 2 heat pumps to see if similar results are seen.
- The overall HEM heat pump space heating efficiency wasn't explored as the test rig could not be set up to carry out dynamic testing. This may be explored in a further round of testing to validate the space heating efficiency.
- It is noted that there are heat pumps are on the market that are switched in capacity using software rather than hardware. This may result in heat pumps more likely to go into cycling more often and would not be captured in the standard testing. Further testing could explore such systems and the impact on performance.

Annex A – Tapping profiles

	EN 16147 patterns			**BRE patterns**			
Time	**Small**	**Medium**	**Large**	**Small**	**Medium**	**Large**	**Xlarge**
07:00	0.105	0.105	0.105	0.105	0.105	0.105	0.105
07:05		1.400	1.400	1.400	1.400	1.400	1.400
07:15		0.000					
07:30		0.000		0.105	0.105	1.400	1.400
07:30	0.105	0.105	0.105				
07:45			0.105	0.105	0.105	0.105	0.105
08:01		0.105					
08:05			3.605			0.105	0.105
08:15		0.105		0.105	0.105	0.105	0.105
08:25			0.105				
08:30	0.105	0.105	0.105	0.105	0.105	0.105	0.105
08:45		0.105	0.105		0.105	0.105	0.105
09:00		0.105	0.105		0.105	0.105	0.105
09:30	0.105	0.105	0.105				
10:00					0.105	0.105	0.105
10:30		0.105	0.105				0.105
11:00							
11:30	0.105	0.105	0.105		0.105	0.105	0.105
11:45	0.105	0.105	0.105			0.105	0.105
12:00							
12:30					0.105	0.105	0.105
12:45	0.315	0.315	0.315		0.315	0.315	0.315
14:30		0.105	0.105			0.105	0.105
15:00							0.105
15:30		0.105	0.105		0.105	0.105	0.105
16:00							0.105
16:30		0.105	0.105		0.105	0.105	0.105
17:00							
18:00	0.105	0.105	0.105	0.105	0.105	0.105	1.400
18:15	0.105	0.105	0.105		0.105	0.105	0.105
18:30		0.105	0.105	0.105	0.105	0.105	0.105

19:00		0.105	0.105	0.105	0.105	0.105	0.105
19:30							
20:00							
20:15	0.420	0.735	0.735	0.315	0.735	0.735	0.735
20:30					1.400	1.400	1.400
20:45				0.105	0.105	0.105	0.105
21:00			3.605		0.105	1.400	3.605
21:15		0.105		0.105	0.105	0.105	0.105
21:30	0.525	1.400	0.105	0.105	0.105	0.105	0.105
21:35							
21:45							
Qref	**2.100**	**5.845**	**11.655**	**2.870**	**5.950**	**8.855**	**12.670**

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