Yukon

Air Source Heat Pump Pilot Project Technical Report

Winter 2020-21

Air-Source Heat Pump Pilot Project

The Government of Yukon's Energy Branch, with Natural Resources Canada, is coordinating a pilot project on air-source heat pumps and their performance in the Yukon's cold climate.

1.0 Introduction

In winter of 2020-21, five cold-climate air-source heat pumps were installed in five single detached homes in Whitehorse, Yukon during the first year of this pilot project.

In April 2021, three months of heating season data from each heat pump was downloaded and analysed to determine how well each heat pump was performing in the field. Throughout the three month duration, commentary from each home owner was collected as part of the analysis.

The goal of this technical report is to provide Coefficient of Performance (COP) results for each of the heat pump installations, compare against manufacturers' specifications, and, using further data metrics, make conclusions on their current performance.

Results show three out of four installations are generally oversized, with overall performance reduced. This can be seen from the COP results, and when heat capacity is compared to the expected output of the heat pump.

These results demonstrate that the heat pump is performing significantly lower than expected. However, there is a possibility that results might increase with more data points once the units are monitored for a full heating season.

Analysis is required from a full heating season to provide further insight into each heat pumps true performance.

2.0 Cold climate heat pumps

There were five cold climate air-source heat pump systems installed. Northeast Energy Efficiency Partnerships (NEEP) defines a cold climate air-source heat pump as being "best suited to heat efficiently in cold climates (IECC climate zone 4 and higher)"[1] and meets the following performance requirements:

- for non-ducted systems: HSPF >10;
- for ducted systems: HSPF >9;
- COP @5°F >1.75 (at maximum capacity operation); and
- SEER > 15.

All five systems:

- are Mitsubishi Zuba models with two rated at 36,000 BTU/hr and three rated at 42,000 BTU/hr;
- are installed with built-in electric auxiliary heating systems;
- are centrally ducted systems; and
- are installed in single detached homes.

Four of the indoor units were installed vertically with single side return while the fifth indoor unit was installed horizontally.

2.1 Standard heat pump operation

When operating, a heat pump cycles through various system **modes** to meet the demand of the home, and keep the indoor and outdoor units fully operational. This includes **steady state** mode when the heat pump is producing heat, **standby** mode when the temperature in the home is at the desired temperature, or when the outdoor unit needs to **defrost**, and **off** mode when there are longer periods where no heat is required. The unit may also **start up** and **power down** between each mode.

Ideally, a properly sized heat pump will spend a higher proportion of time in an active steady state mode. In this steady state, the heat pump will modulate the fan speed to control the heat produced, to meet the heat demand in a home. Only at warmer

[1] Cold Climate Air-Source Heat Pump Specification (Version 3.0), Jan 2019, accessed 29/6/21

temperatures where the heat pump is not required may the heat pump sit in standby or off modes. Below a temperature of around -29°C the back up heat will become the primary heating system.

2.1.1 Oversized operation

An oversized system will cycle on and off, known as short cycling. A short cycling system will struggle to provide the comfort and energy savings expected by a properly sized heat pump.

Furthermore, an oversized heat pump may encounter issues with engaging defrost mode if short cycling occurs frequently. It may not be efficient for the heat pump to go into defrost mode if the heat pump only runs for a couple of minutes at a time and then shuts off again due to being oversized. Ice buildup on the outdoor unit's coil can potentially lead to permanent damage if not addressed.

2.1.2 Undersized operation

Conversely, when a heat pump is undersized, the system runs constantly at full capacity to achieve the set heating temperature. In the winter, the constant running of the heat pump at maximum capacity, attempting to reach a set temperature, triggers the defrost mode more than needed.

In both scenarios, when a heat pump is too big or too small for its operating space, the heat pump uses more electricity to reach a desired indoor temperature. The heat pump never gets a chance to do what the system does best, maintain a set temperature without having to run at its peak. This is where energy and cost savings are introduced.

3.0 Pilot project events and timeline

3.1 Heat pump sizing

Each participant was asked to select their heat pump model from an approved list provided by Natural Resource Canada (NRCan). NRCan also provided a heat pump sizing tool that recommended a size of heat pump based on a number of factors, including, home heat load and duct sizes. Table 1 summarizes the heat pump sizing data:

Table 1: Heat pump sizing selection

ASHP	House heat load (NRCan sizing tool)	Selected unit
1	34,087 BTU/Hr	Mitsubishi PUZ-HA42NKA1 – 42,000 BTU/Hr
2	42,617 BTU/Hr	Mitsubishi PUZ-HA42NKA1 – 42,000 BTU/Hr
3	37,874 BTU/Hr	Mitsubishi PUZ-HA36NKA – 36,000 BTU/Hr
4	39,171 BTU/Hr	Mitsubishi PUZ-HA42NKA1 – 42,000 BTU/Hr
5	27,297 BTU/Hr	Mitsubishi PUZ-HA36NKA – 36,000 BTU/Hr

3.2 Installation, commissioning and data collection period

Table 2 is a timeline of events to install and commission the monitoring equipment. To commission the system a series of short term tests were conducted.

Table 2: Key installation dates

ASHP	Heat pump install date	Monitoring commissioning date	Monitoring period
1	November 10 to 16, 2020	January 25 to 29, 2021	February 2 to April 30, 2021
2	December 1 to 7, 2020	January 29, 2021	February 2 to April 30, 2021
3	December 8 to 15, 2020	January 8, 2021	January 12 to April 30, 2021
4	December 14 to 18, 2020	February 22, 2021	February 23 to April 30, 2021
5	December 14 to 18, 2020	October 27, 2021	Not available*

*The installation of heat pump 5's monitoring equipment was delayed as the home was a new build. The heat pump was initially installed onto temporary electrical service, and it was decided to install the monitoring equipment once the electrical service was transferred over to the main service later in 2021.

3.3 Summary of major events

- *Heat pump sizing* – Prior to each system's installation, an energy audit was completed for reach home. The Energy Branch entered data from the audit report into NRCan's sizing tool to appropriately size each unit to the participants' homes. The heating loads and the duct sizes found in the energy assessments were used in conjunction with manufacturer performance data from NEEP as inputs in the NRCan sizing tool to determine the appropriate CCHP size for the homes. In some cases, the size of unit selected was higher than the recommended size reported in NRCan's sizing tool.
- *Freeze up and humidity* – Due to long winter period of cold temperature and high humidity, the unit experienced freeze up with a build up of frost on the outdoor unit. A wind baffle was installed on each of the heat pumps to negate this issue.
- *Factory defect* – Following occasions where the auxiliary heat was not being engaged when required, a factory defect was identified by the manufacturer and the installer. The unit was incorrectly detecting the outdoor air temperature. This was mitigated by replacing the computer board, under warranty. This issue may have contributed to the freeze up, and caused complications to the defrost cycle. This event will be further analysed after a second heating season.

4.0 Monitoring equipment and methodology

Monitoring equipment was installed on each heat pump and electrical service to record heat pump data, also known as the **raw data points**. The data, recorded in **one-minute intervals** was collected through a data logger and equipment connected through an environmental monitoring board. This data could be accessed from an online portal.

Table 3: Monitoring equipment raw data points

Ref.	Raw data points	Equipment	Purpose	Make / model	Precision
(a) (b) (c) (d) (e) (f) (g) (h) (i) (j) (k) (l) (m) (n) (o) (p) (q) (r)	ASHP Indoor Current A ASHP Indoor Voltage A (120V) ASHP Indoor Voltage B (120V) ASHP Indoor Voltage A-B (240V) ASHP Indoor Active Power A (ASHP) ASHP Indoor Active Power B (Backup) ASHP Indoor Reactive Power ASHP Outdoor Reactive Power ASHP Total Active Power ASHP Total Apparent Power ASHP Total Reactive Power ASHP System Power Factor ASHP Indoor Power Factor House Active Power Total House Apparent Power Total House Voltage A House Voltage B House Net Total Energy Resetable	Voltage and current transformers	Measure the electricity consumption of the heat pump	Elkor WattsOn power transducers	ANSI Class 0.2
(s) (t) (u) (v)	Building Indoor Air Density ASHP Return Velocity ASHP Return Volumetric Flow ASHP Return Mass Flow	Airflow sensor for ducts	Measure delivered heat through air flow	Monnit Alta differential air pressure sensor	3% of reading +/- 0.1 Pa
(w) (x)	ASHP Supply Temp – Right, Left and Centre ASHP Return Temp – Right, Left and Centre	3 thermistors	Determine delivered heat energy	Cygnus Tech	
(y)	ASHP Vapour Line Temp	Thermistor	Monitor defrost status	Cygnus Tech	
(z) (aa)	Outdoor Temp Outdoor Humidity	3 combined thermometer 27and relative humidity sensor	Monitor local outside temperature and relative humidity	Monnit Alta Wireless Humidity Sensors and Temperature Sensors	Accurate to +/- 0.3°C +/- 3% accuracy for RH
(ab) (ac) (ad) (ae)	Thermostat Indoor Temp Thermostat Indoor Humidity ASHP Supply Center Humidity ASHP Return Center Humidity	3 combined thermometer and relative humidity sensor	Monitor indoor temperature and relative humidity	Monnit Alta Wireless Humidity Sensors and Temperature Sensors	Accurate to +/- 0.3°C +/- 3% accuracy for RH
(af) (ag)	ASHP Backup Heat Current ASHP Backup Heat Power Factor	Back-up heat source sensor equipment	Determine percentage of heat supplied by the backup system	Variable.	

The data was logged using a Modbus logging software deployed on a Raspberry Pi computer (see Figure 1). Each data logger was directly plugged into an internet modem to avoid Wi-Fi connection issues. An internal clock was added to the data loggers to avoid potential complications due to power outage.

The data collection interval was sampling every second and then averaged values logged every minute. An hourly data submission to a remote server allowed for real-time viewing of the data.

Figure 1: Inside of the indoor CCHP unit and the backup auxiliary heat with the power monitoring.

4.1 Power measurements

A majority of the electrical monitoring equipment was installed near the electrical panel. Power monitoring was conducted using Elkor Technologies3 Inc. measuring equipment. The WattsOn-Mark II power transducer was used with MSTC1 and MCTA current transformers for whole-house and CCHP energy monitoring, and the i-Snail-VC series of current transducer was used for current monitoring of fans and electrical backup heat source consumption.

4.2 Airflow measurements

In situ airflow measurements were taken by installing a Dwyer Instrument PAFS-1000 series averaging flow sensor in the return duct, which provides a differential pressure related to the velocity of the air.

The instruments were calibrated and compared against the following instruments:

- TPI DC580 hot-wire anemometer.
- TSI 8345-E-GB hot-wire anemometer.
- TSI 9565 with TSI 960 hot-wire anemometer.
- TSI 9565 with TSI 634634002 pitot tube.

4.3 Environmental monitoring

Temperature and humidity sensing were performed using Honeywell 192502LET-A01 thermistors and HIH-5031 humidity sensors. The return air and supply air temperature and humidity were measured. Indoor and outdoor temperature and humidity were also measured.

4.4 Monitoring equipment verification

A series of short term tests were completed following each installation to verify that the monitoring equipment was operating and logging data correctly. These included:

- volumetric flow rates comparison with manufacturers' data sheets;
- 24hr data sets of all data points, and;
- efficiency calculations.

4.4 Monitoring equipment calculations

In addition to the raw data points listed in the Table 3, a number of pre-set **calculated data points** (*see Table 4*), were built-in to the data logger, to be collected at the same minute-long intervals.

Table 4: Monitoring equipment calculated data points

Ref.	Calculation	Raw data points used	Formula
(ba)	ASHP indoor unit apparent power	ASHP Indoor Voltage A-B (240V) – (a) ASHP Indoor Current A – (b)	$(ba) = (a) * (b)$
(bb)	ASHP indoor unit active power	ASHP Indoor Power Factor – (c)	$(bb) = (ba) * (c)$
(bc)	ASHP outdoor unit active power	ASHP Total Active Power – (d) ASHP Indoor Active Power A (ASHP) – (e)	$(bc) = (d) - (e)$
(bd)	ASHP outdoor unit apparent power	ASHP Outdoor Unit Active Power – (bc) ASHP Total Reactive Power – (f) ASHP Indoor Reactive Power – (g)	$(bd) = (bc) + [(f) - (g)]$* *(f)-(g) = outdoor reactive power
(be)	Outdoor temperature bin	Outdoor Temp – (h)	*See section 4.2 – Temperature Bins*
(bf)	ASHP supply average temperature	ASHP Supply Temp – Right – (i) ASHP Supply Temp – Left – (j) ASHP Supply Temp – Centre – (k)	$(bf) = [(i) + (j) + (k)]/3$
(bg)	ASHP return average temperature	ASHP Return Temp – Right – (l) ASHP Return Temp – Left – (m) ASHP Return Temp – Centre – (n)	$(bg) = [(l) + (m) + (n)]/3$
(bh)	ASHP backup heat power	ASHP Indoor Voltage A-B (240V) – (a) ASHP Backup Heat Current – (o)	$(bh) = [(a) * (o)] / 1000$

4.2 Temperature Bins

To provide deeper analysis into heat pump performance, certain performance metrics in this report have been grouped into 17 temperature bins, and the results averaged. This approach can be found in the CSA standard EXP07-19[2].

Table 5: Temperature bins

Temperature bin	Temperature range (°C)
1	Less than -28.9
2	-28.9 to <-26.1
3	-26.1 to <-23.3
4	-23.3 to <-20.6
5	-20.6 to <-17.8
6	-17.8 to <-15.6
7	-15.6 to <-12.5
8	-12.5 to <-10.0
9	-10.0 to <-7.2
10	-7.2 to <-4.4
11	-4.4 to <-1.7
12	-1.7 to <1.1
13	1.1 to <3.9
14	3.9 to < 6.7
15	6.7 to < 9.4
16	9.4 to < 12.2
17	12.2 and greater

[2] CSA EXP07-19 - Load-based and climate-specific testing and rating procedures for heat pumps and air conditioners.

5.0 Data analysis

5.1 Temperature and humidity profile

Using minute interval data for outdoor temperature and humidity, a daily average across all four heat pumps is shown in Figure 2.

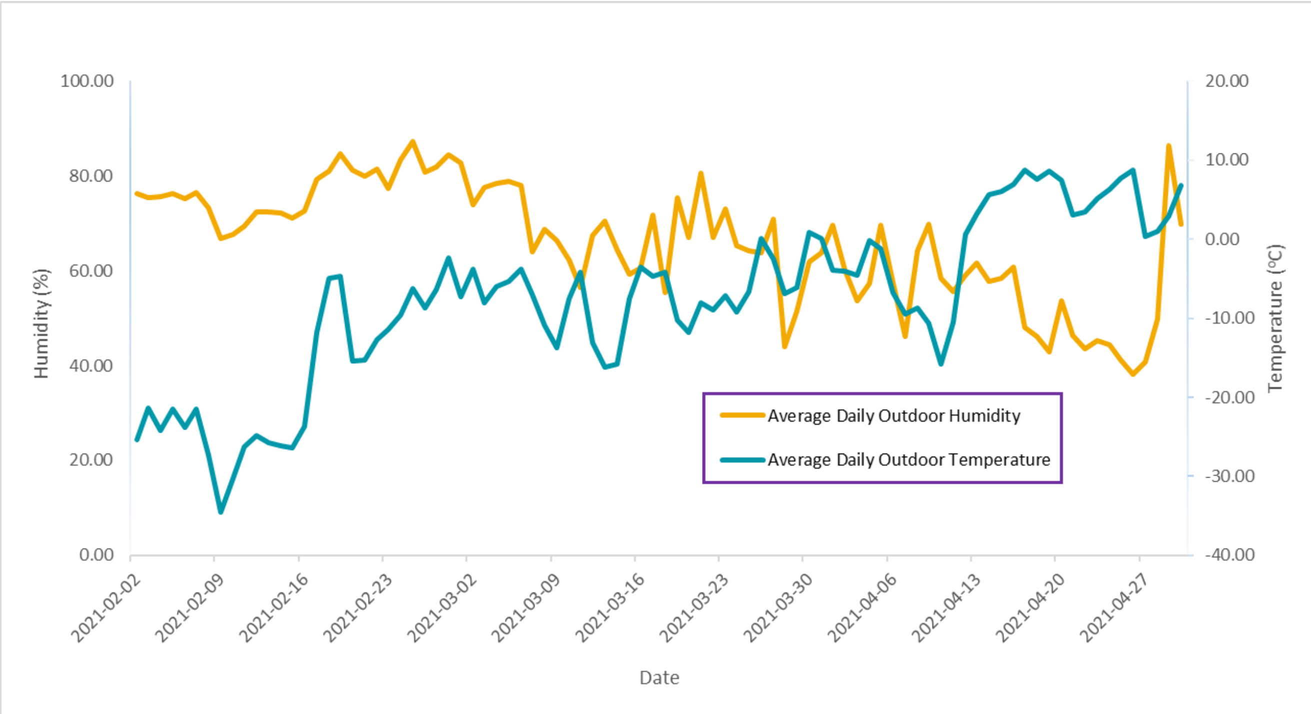

Figure 2. Averaged daily outdoor temperature and humidity profile across four heat pumps.

It is worth noting that the lowest average temperature recorded was roughly -35°C, and the lowest recorded temperature was below -42°C. Humidity during the coldest temperature averages around 80%, and generally drops as temperature increases. Air-source heat pumps are designed to switch to the backup heat source around -29°C.

It was noted by the participants that some outdoor units experienced a large amount of ice build up in December and January. This was discussed with NRCan and local installers. The cause was determined to be the combination of extreme cold temperatures with unusually high humidity that affected multiple heat pumps across Whitehorse.

5.2 COP, ICOP and SCOP – Comparison to manufacturer specifications

Coefficient of Performance (COP) is an indicator of the efficiency of a heat pump. It is a measure of the amount of energy that a heat pump delivers compared with what it draws from a power supply. For example, if a heat pump delivers 10kW of power, and draws 2kW from the power supply, the heat pump has a COP of 5, which is calculated as follows: 10/2 = 5. This compares to an electric furnace, boiler or baseboard that has a COP of 1. The higher the COP is, the more efficient the system is. COP can be calculated as an instantaneous measurement, or as an average over a specified time period. The latter is more useful.

When operating, a heat pump cycles through various system modes to meet the demand of the home, and keep the indoor and outdoor units fully operational. This includes **steady state** when the heat pump is producing heat, **standby** mode when the temperature in the home is at the desired temperature, or when the outdoor unit needs to **defrost**, and **off** mode when there are longer periods where no heat is required. The unit may also **start up** and **power down** between each mode. Different COP calculations incorporate different combinations of these modes, and provide further insight how a heat pump is operating.

COP is typically what the manufacturer quotes for the efficiency of a heat pump system, and is determined by calculating the COP at different temperatures when the heat pump is in a steady state only, and then averaging the COP over a set time period, normally a year. If we analyse a sample COP graph (at -12°C) over an hour, we might see the following (in Figure 3), where the steady state period of a heat pump is shown:

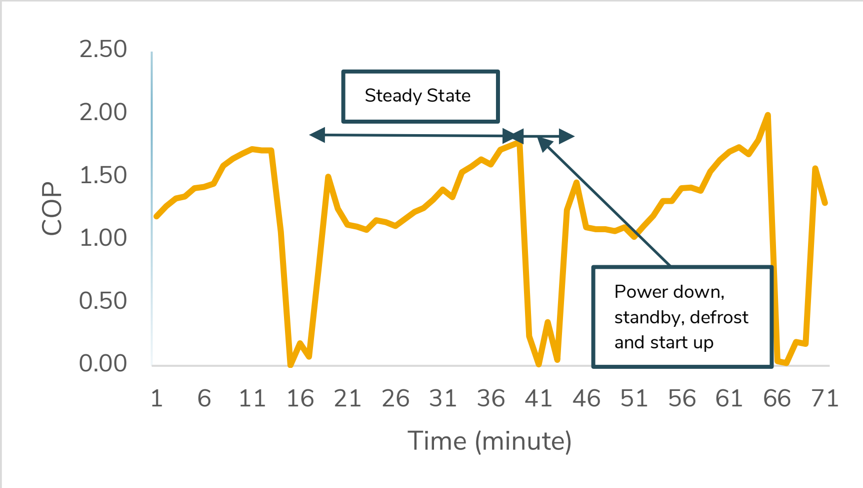

Figure 3. COP of a heat pump over time at -12°C.

Integrated COP (ICOP) is a measure of the efficiency of heat pumps that includes all system modes, and is averaged for different temperatures, similarly to COP. This provides an additional layer of analysis, and can provide much needed insight into how a heat pump is operating at different temperatures. For example, while COP could remain high, a low ICOP might suggest a heat pump is in standby mode often, still drawing power, and therefore, less efficient.

Seasonal COP (SCOP) a single value that measures the efficiency of heat pump. SCOP includes all system modes, at all temperatures, and is averaged over a period of a year that includes an entire heating season. Like ICOP, it gives a realistic idea about how energy efficient a heat pump system is in practice, and overall.

5.2.1 Method

To calculate COP, ICOP and SCOP the following formula was used:

Table 6: COP calculation methodology

Calculation		Data points used	Formula
COP	$Q_{HP_{Active-on}}$	(s) - Building Indoor Air Density (v) - ASHP Return Mass Flow (bf) - ASHP Supply Average Temp (bg) - ASHP Return Average Temp Other data: Air density – 1.006	FOR EACH TEMPERATURE BIN: $Q_{HP_{Active-on}} = \sum (s) * 1.006 * (v) * [(bf) - (bg)]$
	$P_{HP_{interior\,Active-on}}$	(bb) - ASHP Indoor Unit Active Power	FOR EACH TEMPERATURE BIN:

			$P_{HP_{interior_{Active-on}}} = (bb)$
	$P_{HP_{outdoor_{Active-on}}}$	(bc) - ASHP Outdoor Unit Active Power	For each temperature Bin: $P_{HP_{outdoor_{Active-on}}} = (bc)$
	COP	$Q_{HP_{Active-on}}$ $P_{HP_{interior_{Active-on}}}$ $P_{HP_{outdoor_{Active-on}}}$	For each temperature Bin: $COP = \frac{Q_{HP_{Active-on}}}{P_{HP_{interior_{Active-on}}} + P_{HP_{outdoor_{Active-on}}}}$
	Description	To calculate COP QHP is summed for all data points where the heat pump is in active mode, and broken down into temperature bins. Both power calculation for the indoor and outdoor unit are calculated by the monitoring equipment. Dividing the total heat output of the heat pump by the power attributable to the indoor and outdoor units will give the COP.	
ICOP	$Q_{HP_{Total}}$	$Q_{HP_{Active-on}}$ $Q_{HP_{Standby}}$ $Q_{HP_{BackUpHeat-On}}$ $Q_{HP_{Defrost}}$	$Q_{HP} = \sum(s) * 1.006 * (v) * [(bf) - (bg)]$ For each temperature Bin: $Q_{HP_{Total}} = Q_{HP_{Active-On}} + Q_{HP_{Standby}} + Q_{HP_{BackUpHeat-On}} + Q_{HP_{Defrost}}$
	$Q_{Aux_{Total}}$	$P_{Aux_{Total}}$	For each temperature Bin: $Q_{Aux_{Total}} = P_{Aux_{Total}}$ (assumes 100% efficiency)
	$P_{HP_{interior_{Total}}}$	(bb) - ASHP Indoor Unit Active Power $P_{HP_{interior_{Active-on}}}$ $P_{HP_{interior_{Standby}}}$ $P_{HP_{interior_{BackUpHeat-On}}}$ $P_{HP_{interior_{Defrost}}}$	For each temperature Bin: $P_{HP_{interior_{Total}}} = P_{HP_{interior_{Active-On}}} + P_{HP_{interior_{Standby}}} + P_{HP_{interior_{BackUpHeat-On}}} + P_{HP_{interior_{Defrost}}}$
	$P_{HP_{outdoor_{Total}}}$	(bc) - ASHP Outdoor Unit Active Power $P_{HP_{outdoor_{Active-on}}}$ $P_{HP_{outdoor_{Standby}}}$ $P_{HP_{outdoor_{BackUpHeat-On}}}$ $P_{HP_{outdoor_{Defrost}}}$	For each temperature Bin: $P_{HP_{outdoor_{Total}}} = P_{HP_{outdoor_{Active-On}}} + P_{HP_{outdoor_{Standby}}} + P_{HP_{outdoor_{BackUpHeat-On}}} + P_{HP_{outdoor_{Defrost}}}$
	$P_{Aux_{Total}}$	(bh) - ASHP Backup Heat Power	For each temperature Bin: $P_{Aux_{Total}} = \sum(bh)$
	ICOP	$Q_{HP_{Total}}$ $Q_{Aux_{Total}}$ $P_{HP_{interior_{Total}}}$ $P_{HP_{outdoor_{Total}}}$ $P_{Aux_{Total}}$	For each temperature Bin: $ICOP = \frac{Q_{HP_{Total}} + Q_{Aux_{Total}}}{P_{HP_{interior_{Total}}} + P_{HP_{outdoor_{Total}}} + P_{Aux_{Total}}}$
	Description	To calculate ICOP Q_{HP} is summed for all data points where the heat pump is in all modes; active, standby, defrost and back up heat on. Similarly to COP, ICOP is broken down into temperature bins. Power calculations for the indoor and outdoor unit, and the back up heat are calculated by the monitoring equipment. Dividing the total heat output of the heat pump and the auxiliary heat by the power attributable to the indoor and outdoor units, and the auxiliary heat will give the ICOP.	
SCOP	System mode	(u) - ASHP Return Volumetric Flow (y) - ASHP Vapour Line Temp	For each minute of Data: If $P_{Aux_{Total}} > 0, system\ mode = BackUpHeat - On$ If $COP > 0.1, sytem\ mode = Active - On$ If $(u) < 0.05\ AND\ (y) < 10, system\ mode = Defrost$ All other data points, $sytem\ mode = Standby$
	Temperature bin ratio	Timestamp data System mode	For each temperature Bin:

			$$Ratio = \frac{Active\,mode_{mins} + Standby_{mins} + Defrost_{mins} + BackUpHeat_{mins}}{Total\,number\,of\,data\,minutes}$$
	SCOP	ICOP Temperature Bin Ratio	$$SCOP = \sum ICOP * Temperature\,Bin\,Ratio$$
	DESCRIPTION	SCOP is a single value that indicates the efficiency of a heat pump system over an entire heating season. SCOP is calculated by taking the ICOP for each temperature bin and multiplying it by the temperature bin ratio. A sum of all ratio ICOP values will give the SCOP. As with ICOP, SCOP includes data when the heat pump is in all modes; active, standby, defrost and back up heat on.	

5.2.2 Results

Figure 4 compares the COP data from three 42,000 BTU/hr heat pumps, and how it compares to the manufacturer specifications (heat pump 3 is compared in Figure 4 as it is a smaller sized unit). A gap between the heat pump and manufacturer COP data shows that, generally, the heat pumps are performing at a lower than expected efficiency (approximately 33% less). It is worth noting that less than three months of data is being reviewed and with an entire heating season of data, the COP lines may improve, demonstrating better performance.

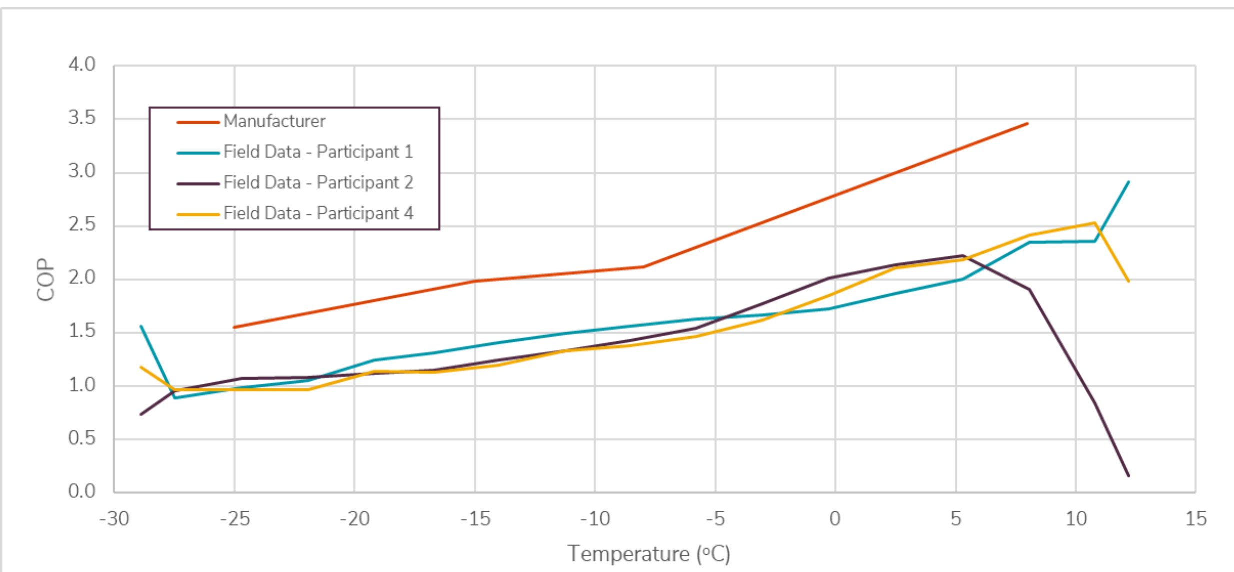

Figure 4. Comparison to Manufacturer Specifications (42,000BTU/hr heat pump) – heat pumps 1, 2 and 4.

Figure 5 conveys a similar trend to the results in Figure 4, with a gap between heat pump 3's COP data, and the manufacturer data for the 36,000 BTU/hr unit.

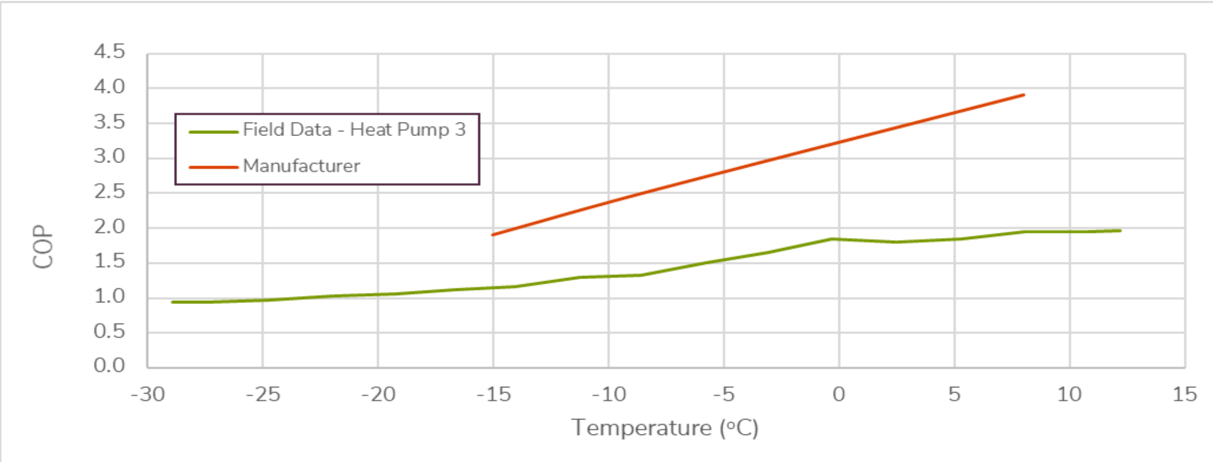

Figure 5. Comparison to manufacturer specifications (36,000BTU/hr unit) – heat pump 3.

Figure 6 compares ICOP for across all four installations showing a similar trend in the -15°C to -5°C range, but at the coldest and warmest temperatures the graphs vary. Interestingly at the coldest temperatures the ICOP for heat pump 1 and 3 is below 1.00. This could be explained by low air flow, and the use of secondary heat. At higher temperatures there is a drop off in ICOP for all heat pumps. This could be explained by the reduced number of data points at these temperatures, or short-cycling with low heating demand for the home.

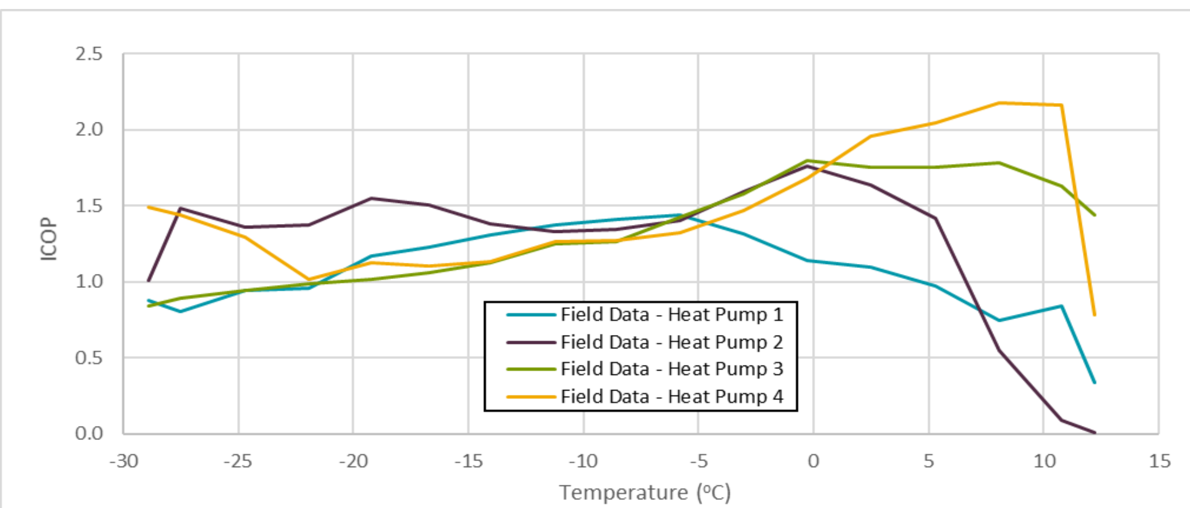

Figure 6. Comparison of ICOP data from all heat pumps at various temperatures.

Figure 6 suggests that heat pump 1 has generally a lower ICOP at most temperature bins suggesting a less efficient system than the other installations. A review of the SCOP results in Table 7 confirms this:

Table 7: Heat Pump SCOP

Heat Pump	SCOP
1	1.16
2	1.36
3	1.34
4	1.47

These results are further supported in the subsequent results sections 5.3 and 5.4.

5.3 Unit and duct airflow

A review of initial commissioning data confirmed air flow measurements in each of the 4 installed units. The 5th unit was also included as it has been fully commissioned.

With retrofitted systems, restriction to air flow may come from the type of installation, and the existing ducting. Participants noted increased noise levels which may be impacted by ducts sizing and airflow. It was noted by the installer that a typical installation includes a single side air return, although the manufacturers guideline suggest double sided return air would be acceptable. Each installation included a small air gap underneath the unit allowing for increased return air.

5.3.1 Method

A review of commissioning test data was completed with a focus on the following data points:

Table 8: Commissioning test data methodology

Review	Data points reviewed	Formula
Commissioning Test Data	ASHP Return Volumetric Flow – (u) Manufacturer Flow Rate Specifications	FOR EACH 24HR TEST PERIOD IDENTIFY: Maximum volumetric flow rates
	DESCRIPTION	The test data supplied during installation will give an indication how much flow is being detected in the system. If the flow rate is less than the manufacturer specifications, this could cause the system to be less efficient.

5.3.2 Results

Results using the method described in Table 8 are as follows:

Table 9: Commissioning test results

Heat Pump	Duct size	Selected unit size	Unit location	Installation orientation	Return sides	Manufacturer flow rates: high, medium, low fan speeds	Test data (maximum flow rate detected in 24 hour period)
1	11" by 24"	42,000 BTU/Hr	Basement	Vertical	Single, gap underneath	1450 cfm, 1200 cfm, and 1000 cfm	640cfm
2	10" by 20"	42,000 BTU/Hr	Basement	Vertical	Single, gap underneath	1450 cfm, 1200 cfm, and 1000 cfm	878cfm
3	18.25" by 20.25"	36,000 BTU/Hr	Basement (in utility room)	Vertical	Single, gap underneath	1450 cfm, 1200 cfm, and 1000 cfm	672cfm
4	17" by 8" 16" by 8" 14" by 8"	42,000 BTU/Hr	Basement	Vertical	Single, small 2" gap underneath	1450 cfm, 1200 cfm, and 1000 cfm	730cfm
5	18" by 8"	36,000 BTU/hr	Crawlspace	Horizontal	Single, open underneath	1450 cfm, 1200 cfm, and 1000 cfm	698cfm

While it was not determined which fan speed each unit was operating at the time of the commissioning test, all 5 test results fall below the manufacturers flow rate for the lowest fan speed. Each flow rate measurement was verified using multiple pieces of equipment (see *Section 4.2*). Reduced fan speed will result in reduced efficiency of the heat pump system.

5.4 Oversized heat pump units

It was noted in Section 3.3, in some cases, the size of unit selected was higher than the recommended size recommended in NRCan's sizing tool. To assess the implications, the percentage of time the heat pump spent in each system mode (active, standby, off) was calculated. A heat pump that spends a large percentage of the time in standby mode may be short cycling as the heat pump is oversized. In standby mode, the unit is still consuming electricity but not producing heat, reducing the efficiency. A review of heat produced versus the heat pumps capacity will also provide further insight into performance, and potential unit oversizing.

5.4.1 Method

To calculate the percentage each heat pump spent in each system mode, the following formula was used:

Table 10: System mode methodology

Calculation		**Data points used**	**Formula**
System Mode %	% Heat Pump in Active Mode	COP Temperature Bin	FOR EACH MINUTE OF DATA: IF $COP > 0.1, sytem\,mode = Active - On$ FOR EACH TEMPERATURE BIN: $\%\,Active\,mode = \frac{Data\,points\,in\,Active\,mode}{Total\,Data\,Points\,for\,all\,modes} * 100$
	% Heat Pump in Back Up Heat Mode	$P_{Aux_{Total}}$	FOR EACH MINUTE OF DATA: IF $P_{Aux_{Total}} > 0, system\,mode = BackUpHeat - On$ FOR EACH TEMPERATURE BIN: $\%\,Back\,Up\,Heat\,mode = \frac{Data\,points\,in\,Back\,Up\,Heat\,mode}{Total\,Data\,Points\,for\,all\,modes} * 100$
	% Heat Pump in Defrost Mode	(u) - ASHP Return Volumetric Flow (y) - ASHP Vapour Line Temp	FOR EACH MINUTE OF DATA: IF $(u) < 0.05\,AND\,(y) < 10, system\,mode = Defrost$ FOR EACH TEMPERATURE BIN: $\%\,Defrost\,mode = \frac{Data\,points\,in\,Defrost\,mode}{Total\,Data\,Points\,for\,all\,modes} * 100$
	% Heat Pump in Standby Mode		FOR EACH MINUTE OF DATA: ALL OTHER DATA POINTS, $sytem\,mode = Standby$ FOR EACH TEMPERATURE BIN: $\%\,Standby\,mode = \frac{Data\,points\,in\,Standby\,mode}{Total\,Data\,Points\,for\,all\,modes} * 100$
	DESCRIPTION	As formulated in section 5.1 for the SCOP calculation, defrost is identifying when the fan speed of the heat pump was below 0.05m3/s and the heat pump vapour line temperature was below 10oC. By summing the total power of the heat pump, and summing the power when the heat pump is in defrost mode, the consumption and % of total heat pump consumption can be found.	

To calculate heat pump capacity, the following data points were used, and compared with the maximum capacity of the heat pump taken from the manufacturer specifications:

Table 11: Heat capacity data methodology

Graph	Data points used	Formula
Heating Capacity vs Temperature	$Q_{HP_{Total}}$ $Q_{Aux_{Total}}$ Outdoor Temp - (z)	FOR EACH MINUTE OF DATA GRAPH: Scatterplot
	Manufacturer Specifications Sheet (42,000BTU/hr unit)	PLOT ON SCATTERPLOT: At -25°C Max Heat Cap is 11.25kW At -15°C Max Heat Cap is 14.07kW At -8°C Max Heat Cap is 14.07kW At 8°C Max Heat Cap is 15.82kW
	Manufacturer Specifications Sheet (36,000BTU/hr unit)	PLOT ON SCATTERPLOT: At -25°C Max Heat Cap is 10.55kW At -15°C Max Heat Cap is 11.14kW At -8°C Max Heat Cap is 11.14kW At 8°C Max Heat Cap is 11.72kW
	DESCRIPTION	Graphing the heat output of the heat pump against temperature, and comparing against the manufacturer specifications will identify how the heat pump is operating at different temperatures, and highlight the range of capacity the unit uses to meet the demand of the building.

5.4.2 Results

Figures 7 and 8 show the percentage each heat pump spends in standby and active modes respectively, at each temperature range. In Figure 7, heat pump 1 is in standby mode more than the other heat pumps at all temperature ranges. In Figure 8, the same heat pump has spent the least percentage of time in active mode, across all temperature ranges. This suggests the unit is oversized. The same might be said for heat pumps 2 and 4 since at warmer temperature ranges, the percentage of time spent in standby mode increases considerably.

As evident in the SCOP result, heat pumps 2, 3 and 4 spend less time in standby mode, and the majority of time in active mode. Based on the time spent in active and standby mode, heat pump 3 appears to be sized correctly. Heat pumps 4, based on COP results, appears correctly sized, but with one less month of data - the coldest month for data collection, analysis of heat pump capacity may provide further insight.

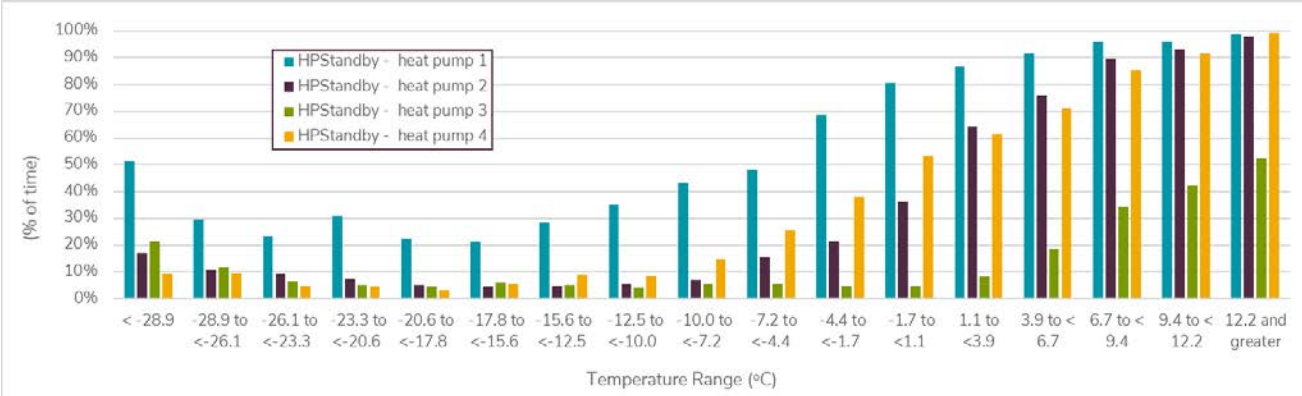

Figure 7. Percentage of time each heat pump spends in standby mode.

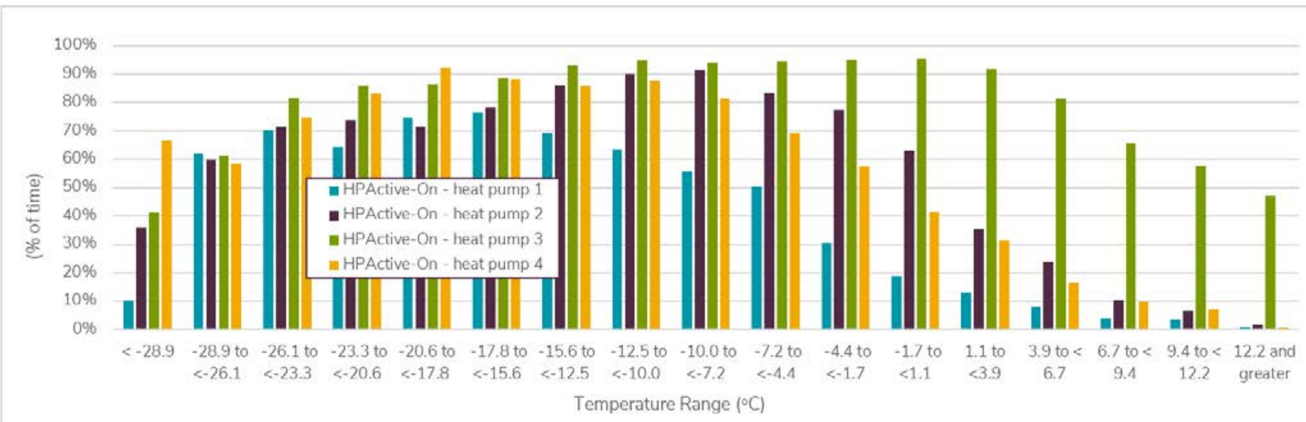

Figure 8. Percentage of time each heat pump spends in active mode.

Table 12 lists the house heat load, selected heat pump size, and percentage overall that each heat pump spent in each system mode. The largest gap between house heat load and selected unit size can be seen for heat pump 1. As seen in the results in this section, the table shows that heat pump 1 appears oversized for the home. The table indicates that heat pumps 3 and 4 are appropriately sized, and heat pump 2 may be slightly oversized.

All units show low percentages for time spent in back-up heat and defrost mode.

Table 12: Heat pump system mode results

Heat Pump	House heat load (NRCan sizing tool)	Selected unit size	Unit size minus heat load	Active mode (%)	Standby mode (%)	Back-up heat mode (%)	Defrost mode (%)
1	34,087 BTU/Hr	42,000 BTU/Hr	7,913 BTU/hr	40.4	56.4	2.0	1.2
2	42,617 BTU/Hr	42,000 BTU/Hr	-617 BTU/hr	67.3	24.6	5.9	2.2
3	37,874 BTU/Hr	36,000 BTU/Hr	-1,875 BTU/hr	85.4	10.6	3.0	1.1
4	39,171 BTU/Hr	42,000 BTU/Hr	2,829 BTU/hr	83.0	11.7	0.4	4.9

Figures 9 to 12 illustrate the heat output of the heat pump against temperature, compared against the manufacturer maximum capacity specifications. An appropriately sized heat pump will have a range of heating capacity readings at the same temperature. Visually, this will look as a thick green cloud covering the area below the manufacturer's blue line. A heat pump that is not utilizing its full range, or heating capacity, will not vary heat output, and will have a thin green cloud.

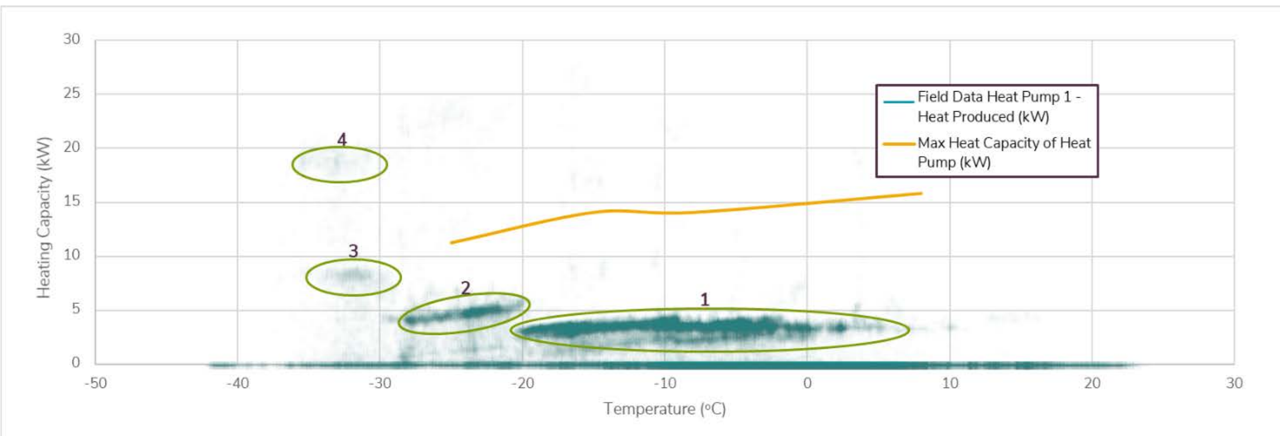

Figure 9. Heating capacity for all data points across all temperature ranges for heat pump 1. Maximum capacity of heat pump unit included.

In Figure 9 for heat pump 1, four specific areas are highlighted with some explanation as follows:

- Area 1 – the majority of data points exist in this area, and suggests the unit is using low capacity (1st stage heating) and cycling on and off to meet the demands of the house above -20°C.
    - As discussed in Section 2.1, a standard operating heat pump modulates its capacity to meet the demands of a home, and cycling on and off is not desirable.

- Area 2 – Below -20°C, it appears that the heat pump unit engages a second stage of heating to meet the demand of the home.
- Area 3 and 4 - Below -29°C, the back-up heat becomes the primary heating source. Area 3 represents the start up and shutdown of the back-up heat, and Area 4 represents the back-up heat in a steady state of heating.

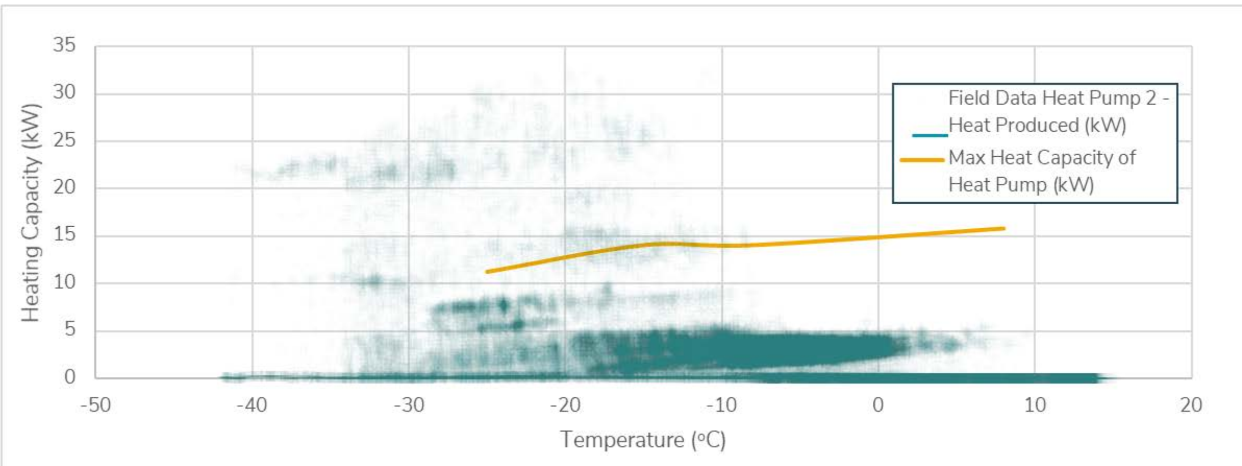

Figure 10. Heating capacity for all data points across all temperature ranges for heat pump 2. Maximum capacity of heat pump unit included.

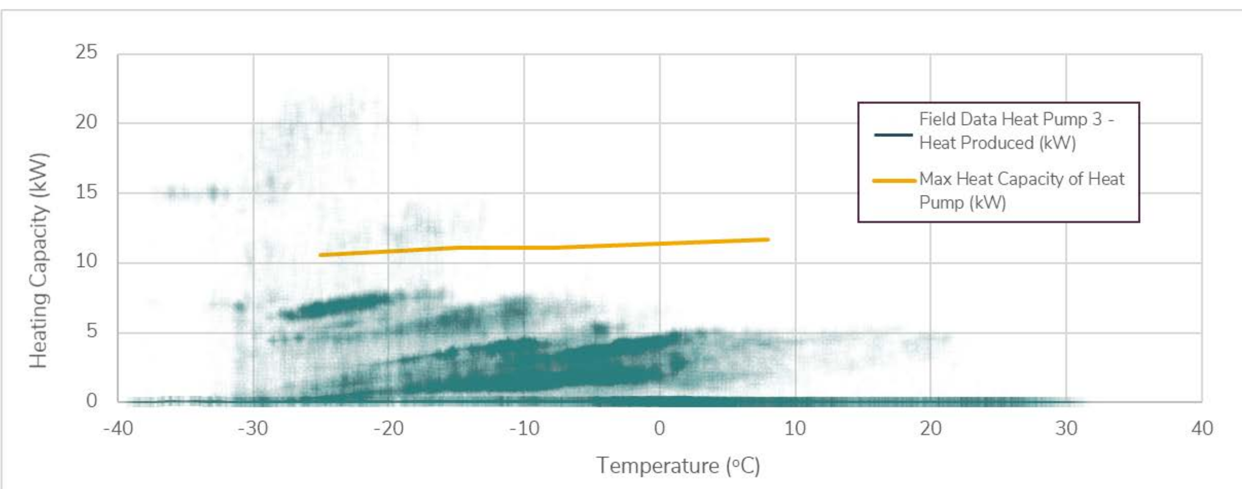

Figure 11. Heating capacity for all data points across all temperature ranges for heat pump 3. Maximum capacity of heat pump unit included.

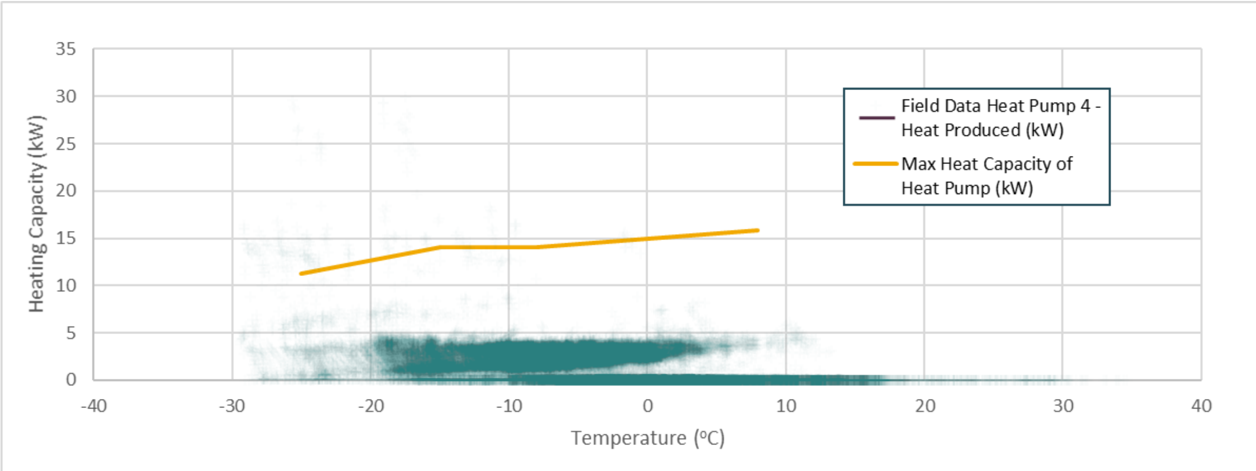

Figure 12. Heating capacity for all data points across all temperature ranges for heat pump 4. Maximum capacity of heat pump unit included.

In the case of heat pumps 1, 2, and 4, the units appear oversized. Heat pump 3 appears to be modulating the heat produced at the majority of temperature ranges suggesting it has been appropriately sized.

5.5 Defrost consumption / freeze up and high humidity

It was noted by participants that outdoor units produced high levels of defrost water. This required additional maintenance to control ice build up and water run off during the winter months. A review of defrost consumption was completed to determine if there were any unusual results that would require investigating.

5.5.1 Method

Table 13 details the methodology to calculate defrost consumption and percentage of total heat pump consumption.

Table 13: Defrost consumption methodology

Calculation		Data points used	Formula
Defrost	Total Heat Pump Consumption	$P_{HP_{interior_{Total}}}$ $P_{HP_{outdoor_{total}}}$	$p_{HP_{Total}} = \frac{(P_{HP_{interior_{total}}}+P_{HP_{outdoor_{total}}})}{60}$(kWh)
	Total Defrost Consumption	$P_{HP_{outdoor_{defrost}}}$	$P_{HP_{outdoor_{defrost}}} = \sum \frac{P_{HP_{outdoor_{defrost}}}{}^{*}}{60}$(kWh)
	DEFROST %	$p_{HP_{Total}}$ $P_{HP_{outdoor_{defrost}}}$	$Defrost\,\% = \frac{P_{HP_{outdoor_{defrost}}}}{P_{HP_{outdoor_{defrost}}}} * 100$
	DESCRIPTION	As formulated in section 5.1 for the SCOP calculation, defrost is identifying when the fan speed of the heat pump was below 0.05m3/s and the heat pump vapour line temperature was below 10oC. By summing the total power of the heat pump, and summing the power when the heat pump is in defrost mode, the consumption and % of total heat pump consumption can be found.	

5.5.2 Results

Using the formula in Table 13, the results are shown in Table 14.

Table 14: Defrost consumption results

Heat Pump	Heat pump consumption (kWh)	Defrost consumption	
		(kWh)	(%)
1	2418	44	1.8
2	3696	57	1.5
3	4558	27	0.6
4	1756	48	2.7

The results show consistency across all four units, with defrost consumption below 3%. This was lower than expected, which may be a result of the length of the monitoring period.

While participants noted high levels of defrost water, the results do not show this to be abnormal.

6.0 Conclusion

In summary, the results from Section 5.0 conclude that all 42,000BTU/hr heat pumps are oversized. COP and SCOP results, system mode results, and the heating capacity graphs make this conclusion.

Heat pump 3 appears to be sized correctly, most evident in the heating capacity graph (see Figure 11).

Comparing COP results against the manufacturers' specifications indicates that all heat pumps are generally under performing to expected efficiency levels. As data was collected for half of the heating season, results are expected to improve. While we might expect to see efficiency gains for each heat pump, overall conclusions of oversizing are not expected to change.

7.0 Next Steps

The next steps are as follows:

- Update report following second heating season with a full year of data.
- Incorporate analysis and results for heat pump 5.
- Further update report based on new monitoring other system set-ups, including mini-splits, multi-splits and other back-up heating integration.
- Energy cost analysis and energy savings post heat pump.