Yukon Cold Climate Heat Pump Study

2024/2025 Heating Season

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Version	Date	Description
0.1	October 31, 2025	Draft Report for 2024/2025 Heating Season
1.0	November 30, 2025	Final Report for 2024/2025 Heating Season

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1. Introduction

1.1. Project Background

Heat pump systems have been known to deliver 1.5 to 3 times more heat energy than the electrical energy they consume, with efficiency largely impacted by ambient outdoor air temperatures. There is limited research on how this equipment functions in service in the cold climates in North America; therefore, it is difficult to predict the true efficiency of air-source heat pumps.

RDH was commissioned by the Government of Yukon to conduct a research study on cold climate air-source heat pumps installed in existing residential homes in southern Yukon. This project followed a previous study by the Government of Yukon and a separate subconsultant conducting similar research on five (5) central ducted air-source heat pumps for heating homes in the Yukon from April 2021 to April 2023. This current study included various air-source heat pump system types: ductless (multi- or mini-split) air-to-air systems, central ducted air-to-air systems, and central air-to-water systems.

During the summer of 2023, RDH installed monitoring equipment to measure the performance of nineteen (19) air-source heat pump systems in eighteen (18) homes. Monitoring for this project was for two heating seasons, and spanned approximately 19 months from September 1, 2023 to March 23, 2025. This project included the development of a near-real time dashboard and analysis of the data to evaluate in-service performance of the heat pumps.

This report summarizes the findings from the monitoring of the heat pump systems from April 1, 2024 until equipment removal at the end of March 2025 (approx. 12 months), and captures the performance during the second heating season. A report for the first heating season (2023/2024) was also submitted.

1.2. Project Objectives

This research assesses in-service efficiency, energy savings potential, and general feasibility of various air-source heat pump retrofit configurations (ductless air-to-air, central ducted air-to-air, and central air-to-water systems) in existing homes in southern Yukon. More specifically, the main objectives of this study are as follows:

1. Assess cold climate heat pump performance in terms of heating energy delivered and heating coefficient of performance (COP) against outdoor temperatures;
2. Compare the measured seasonal COP (SCOP) of these systems to published data;
3. Assess potential energy and cost savings from heat pump retrofits in Northern communities;
4. Identify lessons learned on system operation, design, and maintenance of cold climate heat pumps in the Yukon; and
5. Develop general recommendations related to overall feasibility and widespread adoption of air-source heat pumps in the Yukon.

2. Methodology

2.1. Sites & Equipment Types

During the summer of 2023, RDH installed monitoring equipment to measure the performance of nineteen (19) air-source heat pump systems in eighteen (18) homes throughout the southern Yukon.

The equipment was installed in three (3) separate groupings:

- Group 1 from June 29 to July 2, 2023,
- Group 2a from August 9 to 11, 2023, and
- Group 2b from August 30 to 31, 2023.

Figure 2.1 is a map with the locations of the homes in which the monitoring equipment was installed.

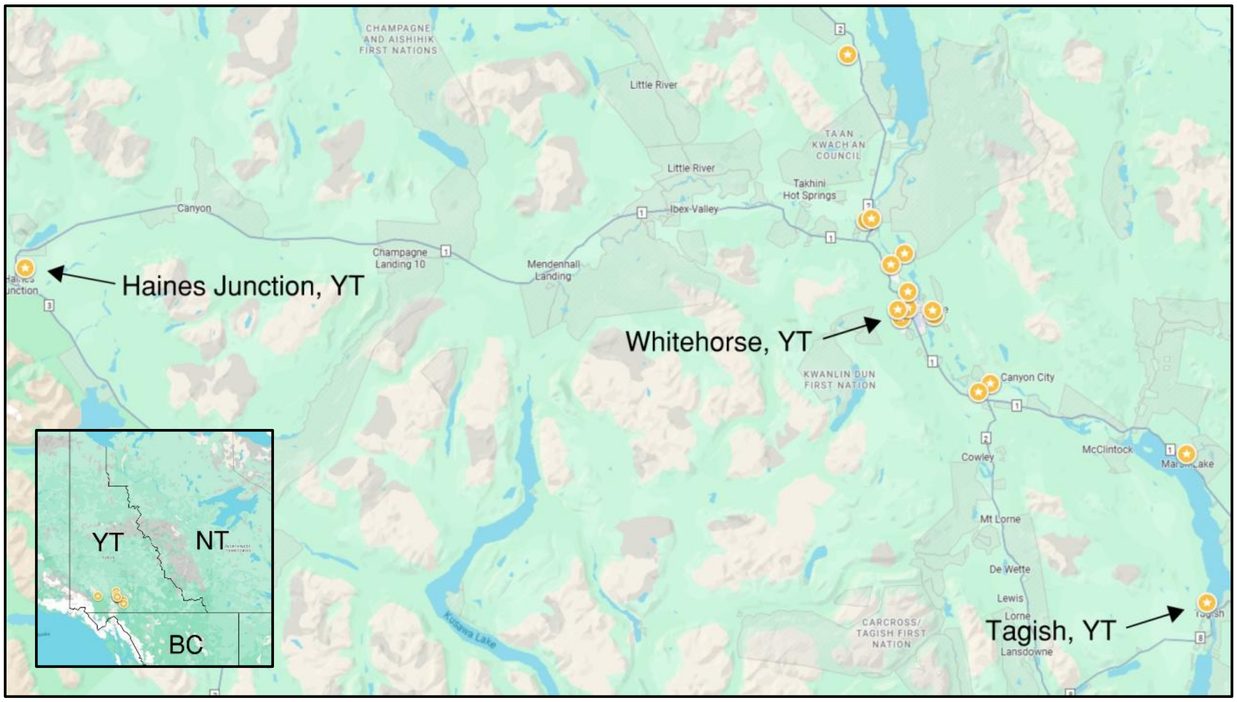


Figure 2.1 – Location of monitored heat pumps are indicated by yellow stars (source: Google Maps, 2025).

Three (3) types of air-source heat pump systems were monitored:

1. Ductless heat pump (multi- or mini-split, 13 homes),
2. Central ducted heat pump (3 homes), and
3. Central air-to-water heat pump (2 homes).

A summary of the equipment locations and system types is provided in Table 2.1 below, and additional site and system information is presented in **Appendix A**.

TABLE 2.1 SUMMARY OF SITE SYSTEMS

Site ID	Heat Pump System Type	Location	# of Outdoor / Indoor Units	HSPF2 Region 4 (rated)	Supplemental Heating Type
WH-01	Ductless	Whitehorse	1 / 1	9.8	Electric baseboards and wood stove
WH-02	Ductless	Whitehorse	1 / 3	9.7	Electric thermal storage and electric baseboards
WH-03	Ductless	Whitehorse	1 / 3	10	Electric baseboard and electric unit heaters
WH-04	Central ducted	Whitehorse	1 / 1	9.3	Electric coil
WH-05	Ductless	Whitehorse	1 / 1	10.3	Electric baseboards and wood stove
WH-06	Ductless	Whitehorse	1 / 2	10.1	Electric baseboards and in-floor heating
WH-07	Ductless	Whitehorse	2 / 3	9.1	Electric baseboard, electric unit heaters, and wood stove
WH-08	Ductless	Whitehorse	1 / 2	10.1	Propane furnace
WH-09	Ductless	Whitehorse	1 / 3	9	Electric baseboards and propane fireplace (only for power outages)
WH-10	Ductless	Whitehorse	1 / 2	10.1	Oil boiler
WH-11	Ductless	Whitehorse	1 / 3	9.5	Electric thermal storage and wood stove
WH-12	Ductless	Tagish	1 / 3	9.5	Oil heater and wood stove
WH-13	Ductless	Whitehorse	1 / 3	Not available	Electric baseboards and wood stove
WH-14	Central ducted	Haines Junction	1 / 1	9.3	Wood stove
WH-15	Central ducted	Whitehorse	1 / 1	9.3	Wood furnace
WH-16	Ductless	Whitehorse	1 / 4	9.5	Electric thermal storage, propane fireplace, and wood stove
WH-17	Central air-to-water	Whitehorse	1 / n/a	Not available	Electric boiler and wood stove
WH-18	Central air-to-water	Whitehorse	1 / n/a	Not available	Wood stove

2.2. Summary of Monitoring System Installation

This section describes the variables that were measured in the field to estimate the in-service performance of the selected heat pumps.

All electrical monitoring equipment was installed by Tlingit Electric with the guidance of RDH. The data were collected between September 1, 2023 and March 23, 2025.

2.2.1. System and Fan Electricity Consumption

For each home, monitoring equipment was installed in the participant's electrical panel to measure the total electrical consumption of the heat pump and to sub-meter electrical consumption of electrical supplemental heating (e.g., baseboards) at homes with central ducted or air-to-water systems.

Indoor fan consumption at central ducted systems was sub-metered at the blower. For ductless mini-split and multi-split heat pump systems, indoor fan consumption was sub-metered at each indoor head. Figure 2.2 shows two photos of the equipment installation process.

Figure 2.2 – Installation of monitoring equipment at a mini-split indoor head (left) and at the electrical panel (right).

2.2.2. Air Temperature and Relative Humidity Measurements

The temperature and relative humidity of the return and supply airstreams (i.e. on either side of the fan-coil unit), as well as the surface temperature of the vapour (refrigerant) line, were measured (see Figure 2.3 and Figure 2.4).

For each fan coil unit, the following sensors were installed:

- Supply air temperature,
- Return air temperature,
- Supply air relative humidity,
- Return air relative humidity, and
- Vapour line surface temperature.

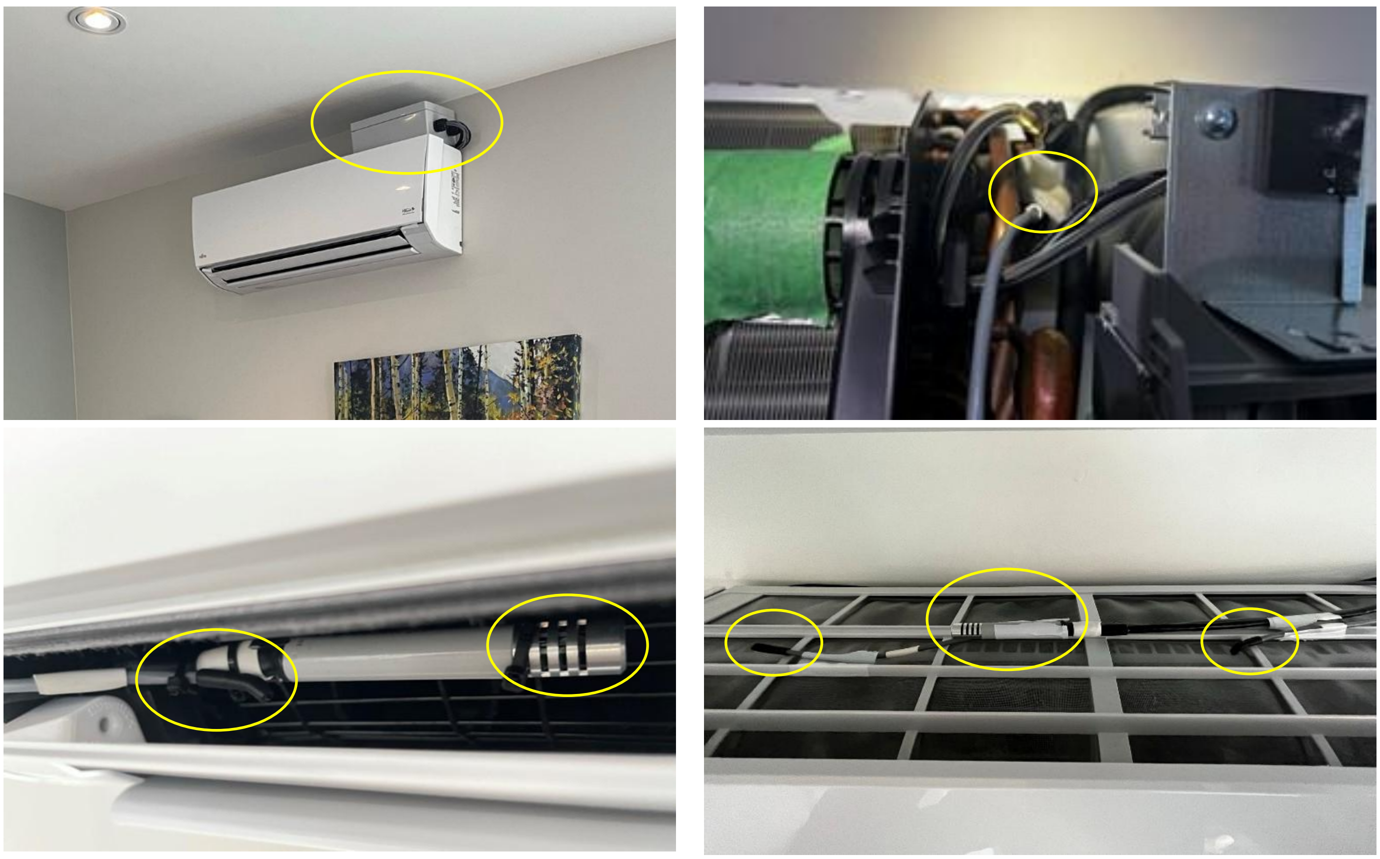


Figure 2.3 – Mini-split indoor head with monitoring equipment box (top left), surface temperature sensor at the vapour line (top right), and temperature and relative humidity sensors at the supply louver (bottom left) and at the return louver (bottom right).

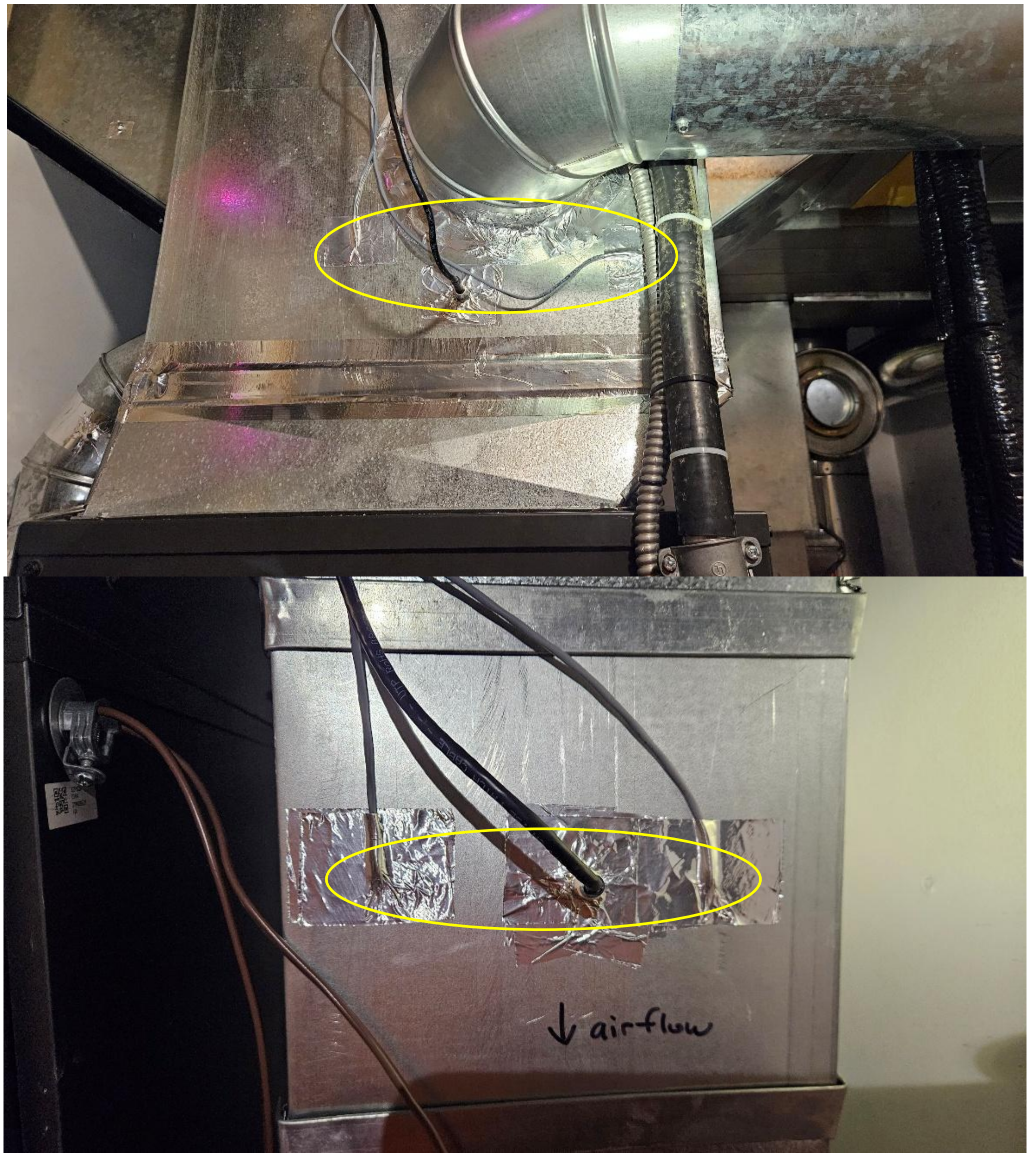


Figure 2.4 – Temperature and relative humidity sensors installed in supply (top) and return (bottom) ducting near the central ducted heat pump fan-coil unit.

2.2.3. Airflow Measurements

The airflow rate of each unit was measured at each fan setting during the initial site visit. The sub-metered fan consumption, which was continuously measured throughout the monitoring period, was used as a proxy for airflow rate. Typically, higher fan speeds consume more energy, and the energy consumption patterns can be used to correlate to the fan speed setting at a given time. To classify fan speed settings based on sub-metered fan consumption, sub-metered fan consumption data points were filtered to include only those that satisfied the difference in supply and return temperatures and system energy consumption thresholds for heating or cooling operation (as defined in Table 2.2). From this filtered dataset, the distribution of fan power consumption was analyzed and discretized into a number of ranges corresponding to the known discrete fan speed settings. Based on the assessed fan setting, the fan airflow rate measured during the initial site visit was used to determine the energy delivery of the unit at a given time. Figure 2.5 is an image of the apparatus used during the initial site visit to measure the airflow rate at each fan setting. Over the course of the study, some of the units were observed to have clogged filters. This would increase static pressure and reduce airflow. For variable speed fans, this could mean slightly higher electrical current draw because of the increased torque to meet the airflow requirements, or if the fan is already operating at full capacity, this would mean reduced airflow and potentially unmet setpoint temperatures. While site observations confirmed clogged filters, a pattern of increasing fan consumption as filters filled over time could not be discerned from the data.

Figure 2.5 – Apparatus used for measuring the in-field flow rate (CFM) of indoor heads using a rigid airtight plenum, flow-adjustable fan, and manometer.

2.2.4. Water Flow Measurements

Two air-to-water heat pumps were monitored in this study. To measure the flow of the glycol solution being supplied to the heating/cooling loops in the homes, in-line flow meters were installed by a plumber (see Figure 2.6). Surface temperature sensors were installed at the supply and return pipes.

Figure 2.6 – In-line flow meter installed to measure the volumetric flow rate of the glycol solution being delivered to the heating/cooling loops in the home by an air-to-water heat pump.

2.2.5. Additional Measurements

Additional data were also collected from each site. Supplemental electrical heating equipment, if present, was sub-metered at the electrical panel.

Microclimate data including ambient outdoor air temperature and relative humidity were also measured at each site, rather than relying on hourly weather station data that may not accurately reflect the conditions to which the heat pumps were exposed. Where possible, these measurements were taken close to the heat pump outdoor unit.

Ambient indoor air temperature and relative humidity were measured in either one or two heating/cooling zones (e.g., in the living room), depending on the layout of the home. Where possible, these were located near the thermostat.

Examples of the above are shown in Figure 2.7.

Figure 2.7 – Sub-metering equipment in electrical panel for measuring supplemental electric heating (left), sensor for measuring ambient indoor air temperature and relative humidity (middle), and sensor for measuring ambient outdoor air temperature and relative humidity (right).

2.3. Summary of Field Data Collection

All the data collected from this study were transmitted to SMT Research Ltd. (SMT)'s secure cloud-based server via data gateways and cellular modem installed in each home. While additional (supplemental) data discussed in Section 2.2.5 were stored in the equipment providers' respective cloud-based server, an application programming interface (API) was developed by SMT to collect these data and store them centrally on SMT's server.

The "Monitoring Equipment Installation Report" dated March 20, 2024 includes sample plots of the raw data.

Figure 2.8 is an image of some of the equipment used for remote cellular data transmission.

Figure 2.8 – Equipment for remote cellular data transmission. From top right, clockwise: gateway for SensorPush devices, WiFi router/cellular modem, SMT data logger, and gateway for SMT dataloggers.

2.4. Heat Pump Data Analysis

Data collected in the field were used to assess key heat pump performance metrics. This section describes the methodology and assumptions used to conduct the analysis.

2.4.1. Energy Output – Ductless and Central Ducted Heat Pump Systems (Air-to-Air)

The energy output was calculated using the following measurements:

→ Psychrometric properties of the supply and return air, derived from the measured dry-bulb temperatures and relative humidities;

→ Movement (mass flow rate) of conditioned air.

As discussed in Section 2.2, supply and return air temperatures and relative humidities were measured using thermistors and relative humidity sensors, respectively. The mass flow rate of the conditioned air was estimated using indoor fan energy consumption as a proxy, correlated to previously measured flow rates at various fan speed settings, rather than direct live measurements.

Because air-to-air heat pump systems rely on convective heat transfer of forced air, the mass typically enters the unit (through the return air louver) as a mixture of air and water vapour and matches the mass of the exiting mixture (through the supply air louver). In a cooling process, however, water vapour can condense out of the supplied air when its dry-bulb temperature reaches its dew-point temperature. This cooling and dehumidification process is shown below in Figure 2.9.

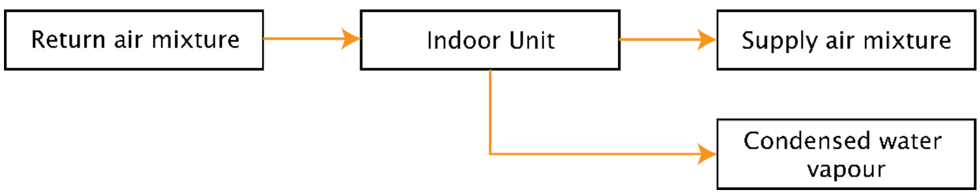


Figure 2.9 – Mass flow through indoor unit under cooling and dehumidification.

Latent energy generated by the phase change process of the return air from gas to liquid should, in theory, increase the effectiveness of the cooling process since a greater amount of energy is being removed via a condensate drain before it is exhausted as supply air. Latent energy was included in heat pump performance when the difference in measured conditions between return and supply air suggest that condensation has occurred.[1]

For example, when the return air is cooled by the coil to a temperature below the air's dew point, relatively less water vapour should be present in supply air. This process of cooling and dehumidification must satisfy a conservation of air mass and an energy balance between return and supply states. The mass and energy balance equation for this case is described below:

$$\Delta E = \dot{V}_2\rho_2[(h_2 - h_1) - (W_2 - W_1)h_{w2}]$$

Where subscript 1 refers to the return air, subscript 2 refers to the supply air, $\dot{V}$ is the volumetric flow rate (m³/s), ρ is the density of the moist air mixture (kg/m³), h is the specific enthalpy of moist air (kJ/kg), W is the humidity ratio (kg/kg), and h_w is the specific enthalpy of condensed water (kJ/kg).

When measured conditions between return and supply air suggest that no condensation has occurred, the mass of the air entering the indoor unit (the return air) matches with the mass of the air exiting the indoor unit (the supply air), representing a sensible heating or cooling process. Note that a negative value will result when heat energy is removed, indicating a cooling process. The energy balance equation for this case is described below:

$$\Delta E = \dot{V}_2\rho_2(h_2 - h_1)$$

Where subscript 1 refers to the return air, subscript 2 refers to the supply air, $\dot{V}$ is the volumetric flow rate (m³/s), ρ is the density of the moist air mixture (kg/m³), and h is the specific enthalpy of moist air (kJ/kg).

[1] ASHRAE (2017). Fundamentals (SI Edition)

To calculate the performance metrics in scenarios with multiple indoor units (i.e. ductless multi-split systems), the useful heat provided or removed by all indoor units was summed to determine the total energy output of the system.

Psychometrics and Equipment Accuracy

As described above, a mass and energy balance must be conserved through the conditioning process of the indoor unit. Therefore, in theory, it is possible to calculate an expected relative humidity of the exhaust air, based on the measured relative humidity of the intake air. However, during an initial comparison between the measured and expected relative humidity, results suggested in some cases that the mass and energy balance were not conserved (i.e. expected did not match measured). This phenomenon is attributed to the accuracy of the instruments and affects the calculated performance of the studied heat pumps.

For the purposes of this study, it is important that the humidity ratio remains constant between supply and exhaust air, particularly in heating mode. For example, an error in relative humidity measurement that would falsely suggest that moisture has been removed during the heating process could result in a significantly lower COP, as this would imply that some moisture-related energy was removed.

To identify the inherent error of the measurements made in this study, the following steps were undertaken to evaluate the mass and energy balance:

- → Calculate the measured partial vapour pressure of the return and supply states of air using the measured dry-bulb temperature and relative humidity
- → Calculate the expected partial vapour pressure of the supply state of air by equating it to the measured specific vapour pressure of the return state.
- → Calculate the expected relative humidity of the supply state of air knowing the expected partial vapour pressure.
- → Check the agreement between the expected and measured relative humidity of the supply state of air.

The methodology used to evaluate agreement between the expected and measured values of relative humidity was to compare the range of uncertainty via the combination of errors in quadrature, also known as the square root of the sum of squares.[2] Listed accuracy for the instruments allowed the computation of uncertainty ranges for each measurement and their calculated derivatives. The agreement between the expected and measured values was evaluated based on the propagated error of both calculated values and is related to the accuracy of the instruments used. This process is illustrated in Figure 2.10. This technique reduced the variability of the calculated heat pump performance from the overall sample of collected data.

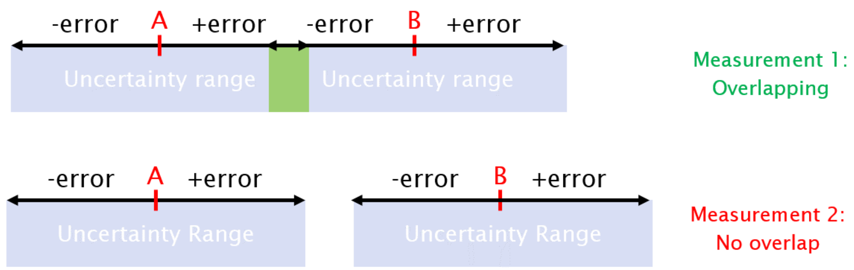


Figure 2.10 – examples of propagated error between two calculated values. In this example, Measurement 1 would be accepted as its error band (B) overlaps with expected result's error band (A). Measurement 2 error band (B) does not overlap with expected error band (A) and therefore would be rejected.

[2] Wolfram (2019) Experimental Data Analyst Documentation. Available online: https://reference.wolfram.com/applications/eda/ExperimentalErrorsAndErrorAnalysis.html

2.4.2. Energy Output – Air-To-Water Heat Pump Systems

In air-to-water heat pump systems, energy output from the heat pump is distributed though hydronic loops. The temperature difference between supply and return outlets from the buffer tank towards the indoor establishes the amount of heat being supplied or removed. The flow rate of glycol solution passing through the hydronic loops was measured; a 50% propylene glycol solution was assumed.[3] The added or removed energy calculation is described below:

$$\Delta E = \dot{V} \cdot \rho \cdot C_p \cdot (T_2 - T_1)$$

Where $\dot{V}$ is the volumetric flow rate (m³/s), ρ is the density of the glycol solution (kg/m³), C_p is the specific heat capacity of the glycol solution (kJ/kg), T_1 refers to the return inlet temperature, and T_2 refers to the supply outlet temperature.

2.4.3. COP Calculations and Assumptions

Heating and Cooling COPs

The coefficient of performance (COP) for each five-minute period during active heating or cooling was averaged to determine the average COP at corresponding outdoor temperatures. For the second heating season, data were collected at 5-minute intervals. Heating COP is calculated using the ratio of total useful heat delivered and total energy consumption by the heat pump system, during active heating and defrost periods (Equation 1). Cooling COP is similarly calculated using the ratio of total useful heat removed and total energy consumption by the heat pump system during active cooling (Equation 2).

$$COP_{heating} = \frac{heat\ delivered\ to\ the\ indoor\ environment\ [W{\cdot}h]}{energy\ consumed\ by\ the\ heat\ pump\ [W{\cdot}h]} \qquad (Equation\ 1)$$

$$COP_{cooling} = \frac{heat\ removed\ from\ the\ indoor\ environment\ [W{\cdot}h]}{energy\ consumed\ by\ the\ heat\ pump\ [W{\cdot}h]} \qquad (Equation\ 2)$$

The criteria to determine whether the heat pump is actively heating or cooling are outlined in Table 2.2 below.

TABLE 2.2 HEATING AND COOLING CRITERIA (5-MINUTE DATA)

Parameters	Ductless System	Central Ducted System	Air-to-Water System
Difference in supply and return temperatures ($\lvert T_{supply} - T_{return} \rvert$); and	≥ 1°C; except WH-05: ≥ 3.8°C	≥ 5°C	> 0°C
Indoor fan operation (5A CT) or flow (flow meter); and	> 0 kWh		> 0 L/s
System consumption (50A CT)	≥ 0.01 kWh		≥ 0 kWh

The system consumption thresholds were selected to be above typical fan electricity consumption for the air-to-air systems (over a five-minute period). For ductless systems, the supply and return temperatures of the heat pump system were measured in close proximity; thus the temperature difference threshold to determine heat pump operation is lower. In the case of WH-05, a higher temperature difference (ΔT) threshold was applied because the indoor unit is a floor-mounted type. For wall-mounted mini-split heads installed near the ceiling, warm supply air, though directed downward, quickly rises and elevates the return temperature measured near the ceiling. This results in a smaller ΔT, requiring a lower threshold to detect heating operation. Unlike typical wall-mounted units, the floor unit has its supply grille at the top and return near the bottom, making it less affected by thermal stratification. This configuration reduces the likelihood of buoyant warm supply air artificially increasing the return temperature and decreasing the apparent temperature difference. As a result, a tighter filter was applied to remove low-output outliers, which were more likely to represent noise or measurement artifacts rather than active heating. A minimum ΔT threshold of 3.8°C was selected to correspond to a heating output of at least 0.5 kW at the unit's lowest fan speed setting.

[3] From Page 9 of Arctic Heat Pumps' "Installation & Instruction Manual - EVI DC Inverter - Air to Water Heat Pump" V4.7, Aug. 2024.

For central systems, supply and return temperatures were measured in the ducting (before branching), where return temperature was impacted by supplemental heating operation in the space and thermal stratification due to the difference in heights of the supply and return grilles at the indoors. As such, the temperature difference threshold to determine heat pump operation was higher. Similarly, based on the schematics of air-to-water systems from the equipment manual, supplemental heating is delivered upstream of the supply outlet where supply temperature is measured; supplemental heating output needs to be subtracted from the total output to isolate for the heat pump-only output. Isolation of supplemental heating impact on heat pump COP is outlined in “Supplemental Heating” section below.

Additionally, for all system typologies, a filter with maximum COP of 10 when outdoor temperature is ≥ -10°C, and maximum COP of 4 when outdoor temperature is <-10°C was applied to remove outliers. These COPs (and higher) are typically unrealistic, even under lab testing (ideal) conditions.

Defrost Cycles

When the outdoor ambient temperature is around freezing, condensation can occur on refrigerant lines of the outdoor heat pump unit and turn to ice. Defrost cycles occur periodically, or on a demand-detected basis, to prevent ice build-up by temporarily reversing the refrigerant cycle to deliver heat to the outdoor coil. At the same time, the heat pump system typically reduces or stops the airflow to the indoors, to limit the amount of air being cooled in the indoor space. Central ducted systems are typically equipped with a built-in supplemental heating source that turns on during defrost.

Defrost cycles were estimated by isolating periods of sporadic drops in vapour line temperature during the heating season. The criteria to identify the start and the end of a defrost cycle is outlined in Table 2.3. Local peak system consumption (more than the five-minute periods before and after) is used to identify the end of the defrost cycle because consumption was observed to spike at the end of the defrost cycle, when the compressor operates continuously to raise the supply temperature back to the typical heating range. Otherwise, defrost cycles were assumed to continue for a maximum length, based on available manufacturer’s literature or typical defrost cycles lengths observed.

Heating/cooling and defrost were determined independently. While simultaneous heating and defrost is not theoretically possible due to the directions of the refrigeration cycles being opposite, the indoor fan is not always off during defrost, and supply temperature of the heat pump sometimes remain higher than the return temperature from residual heat by at least the threshold in Table 2.2. As a result, the heat pump system is supplying heat to the indoor environment based on the heating criteria above.

<table>
<tr><th colspan="4">TABLE 2.3 DEFROST CRITERIA (5-MINUTE DATA)</th></tr>
<tr><th colspan="2">Parameters</th><th>Ductless System</th><th>Central Ducted System</th></tr>
<tr><td rowspan="4">Start of Defrost</td><td>Change in vapour line temperature (ΔT_{vapour}); and</td><td>≤ -10°C; except
WH-06: ≤ -12°C
WH-07: ≤ -8°C
WH-11: ≤ -5°C</td><td>≤ -15°C</td></tr>
<tr><td>Vapour line temperature (T_{vapour}); and</td><td colspan="2">≤ T_{supply}</td></tr>
<tr><td>System consumption (50A CT); and</td><td>≥ 0.04 kWh; except
WH-03: 0.075 kWh
WH-05: 0.050 kWh
WH-11 & 12: 0.070 kWh</td><td>≥ 0.04 kWh</td></tr>
<tr><td>Outdoor temperature</td><td colspan="2">≤ 10°C</td></tr>
<tr><td rowspan="3">End of Defrost</td><td>Vapour line temperature (T_{vapour}); and</td><td colspan="2">≥ T_{vapour} at start of defrost cycle</td></tr>
<tr><td>System consumption (50A CT)</td><td colspan="2">Local maximum</td></tr>
<tr><td>Or, Defrost cycle length</td><td>≥ 20 minutes; except
WH-03, 06, 08, & 16: ≥ 30 minutes</td><td>WH-04: ≥ 30 minutes
WH-14 & 15: ≥ 20 minutes</td></tr>
<tr><td colspan="4"><u>Note:</u> Defrost was not evaluated for air-to-water systems; defrost cycle of the heat pump was assumed to have limited impact to the supply and return hydronic temperatures due to them being measured after the buffer tank.</td></tr>
</table>

Supplemental Heating

In central ducted and air-to-water systems, supplemental heating was assumed to affect supply and return temperatures differently. When estimating heat pump heating output based on the temperature difference (and additional psychrometric properties for central systems) between supply and return states, the influence of supplemental heating must be considered when determining heat pump COPs.

For central ducted systems, supplemental heating output was estimated by multiplying the sub-metered supplemental heating consumption by the assumed efficiency of 1 (for electric resistance heat).

For air-to-water systems, supplemental heating is delivered upstream of the buffer tank, where mixing with the return solution happens, and heating is circulated to the interior space downstream. As a result, supplemental heating output is not reflected instantaneously by the difference between measured supply and return temperatures. To account for the dispersed supplemental heating delivery, supplemental heating output was estimated from sub-metered consumption using a six-hour backward-looking rolling window (assumed efficiency of 1), consistent with the observed maximum interval in sub-metered consumption.

Finally, the estimated supplemental heating output was then subtracted from the calculated energy output (see Sections 2.4.1 and 2.4.2). All heating energy supplied by the supplemental system was assumed to be delivered to the indoor environment to produce a conservative heat pump output.

Seasonal Performance

The following metrics were used to understand seasonal performance of the heat pumps:

- The **Seasonal Coefficient of Performance (SCOP)** is a measurement used to the assess the energy efficiency of the heat pump. Two metrics can be calculated, one for the heating season and one for the cooling season. Heating SCOP accounts for electric energy consumption during heating and during defrost. The following equation outlines the equation for calculating heating SCOP:

$$SCOP = \frac{total\ seasonal\ heating\ output\ [W \cdot h]}{total\ electric\ energy\ consumed\ by\ the\ heat\ pump\ for\ heating\ [W \cdot h]} \quad (Equation\ 3)$$

- The **Heating Seasonal Performance Factor (HSPF)** is a measurement of the heat pump's efficiency over a heating season. It is calculated as the ratio of the total heat output over the season and the electricity consumed during that time. Using monitoring data, the equivalent HSPF is determined by dividing the seasonal heating COP by 0.293 (i.e. performing a unit conversion).

$$HSPF = \frac{total\ seasonal\ heating\ output\ [BTU]}{total\ electric\ energy\ consumed\ by\ the\ heat\ pump\ for\ heating\ [Wh]} \quad (Equation\ 4)$$

- The **Seasonal Energy Efficiency Ratio (SEER)** is a performance metric used to evaluate the heat pumps space cooling performance over a cooling season. The SEER values for heat pumps are typically higher than their HSPF values, since defrosting is not needed during the cooling season. SEER is calculated as the ratio of the total cooling output over the season and electricity consumed during that time. For heat pumps, the equation is:

$$SEER = \frac{total\ seasonal\ cooling\ output\ [BTU]}{total\ electric\ energy\ consumed\ by\ the\ heat\ pump\ for\ cooling\ [Wh]} \quad (Equation\ 5)$$

2.5. Financial, Emissions & Energy Savings Assumptions

Since utility data were not available, a simplified approach was used to estimate the theoretical energy savings over a typical meteorological year. Analysis steps are described below:

- **STEP 1:** Based on the monitoring data, linear regressions between the heat pump's total energy *output* (in kW) and outdoor temperature (in 1°C bins) were conducted to arrive at the dark blue lines in Figure 2.11. Similarly, linear regressions were conducted between the heat pump's total energy *consumption* and outdoor temperature to arrive at the light blue lines.

  For the moderate temperature regressions (where the slope is negative), the calculation was limited to an upper bound outdoor temperature of 15°C to reflect the typical operating range for heat pump heating among all sites. The lower bound for the moderate temperature regressions generally corresponds to the heat pump's peak total energy output, representing conditions where heating output increases to fulfill increasing heating demand as outdoor temperature decreases.

  Where sufficient data is available at outdoor temperatures below the heat pump's peak total energy output, a second linear regression (where the slope is positive) was conducted. This second cold temperature regression represents conditions where the heat pump's energy output decreases as outdoor temperature further decreases, despite further increasing heating demand, as the heat pump can no longer or controls are not set up for it to meet the heating demand.

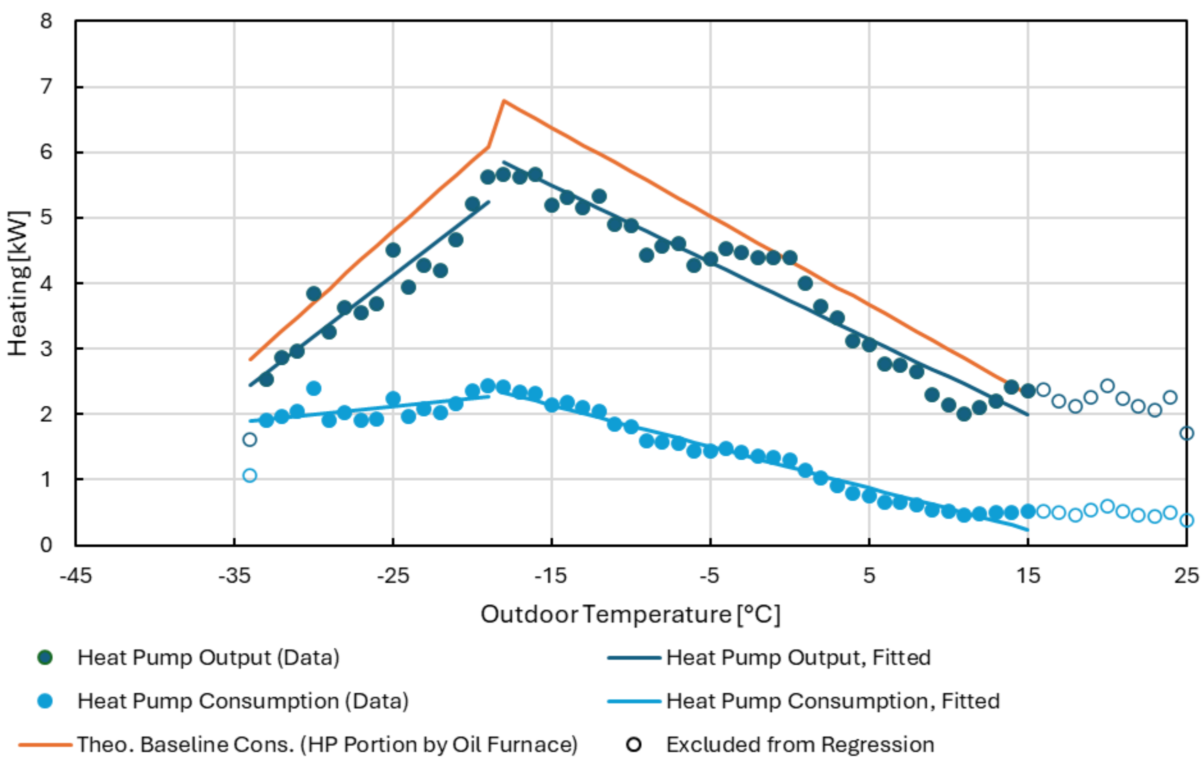


Figure 2.11 – Example of Step 1 for WH-07, which demonstrates how the regressions of the heat pump consumption (light blue lines) and output (dark blue lines) were performed. Theoretical baseline consumption assuming oil stove is represented by the orange line.

- **STEP 2:** To determine the theoretical total baseline consumption, CSA F280 design heating loads (or EnerGuide heating loads, if F280 is unavailable) provided by the Government of Yukon were used. Figure 2.12 plots the demand between the design load calculated at -41°C and the indoor heating design temperature of 21°C (where it is assumed that heating demand is zero) as the grey dashed line. The theoretical supplemental energy output (dark green line) was estimated by subtracting the heat pump output (dark blue line determined in Step 1) from the total heating demand (gray dashed line). Heat pump usage above the CSA F280 demand was omitted at this step (i.e. where dark blue line is above the gray dashed line at higher outdoor temperatures).

  The theoretical supplemental consumption (light green line) was estimated by dividing the total estimated supplemental energy output by the baseline system efficiency. Note that this analysis assumes typical baseline (pre-retrofit) system efficiencies. For non-electric furnaces, electricity consumption by the blower motor was omitted to provide a conservative savings estimation (i.e. a lower baseline consumption).

  In the example figure below, between outdoor temperatures of -34°C and 15°C, both the supplemental heating and heat pump are operating; below -34°C (where no heat pump heating data is available), the system was assumed to rely 100% on the supplemental, and thus the supplemental output is assumed to equal the CSA F280 Design Heat Load.

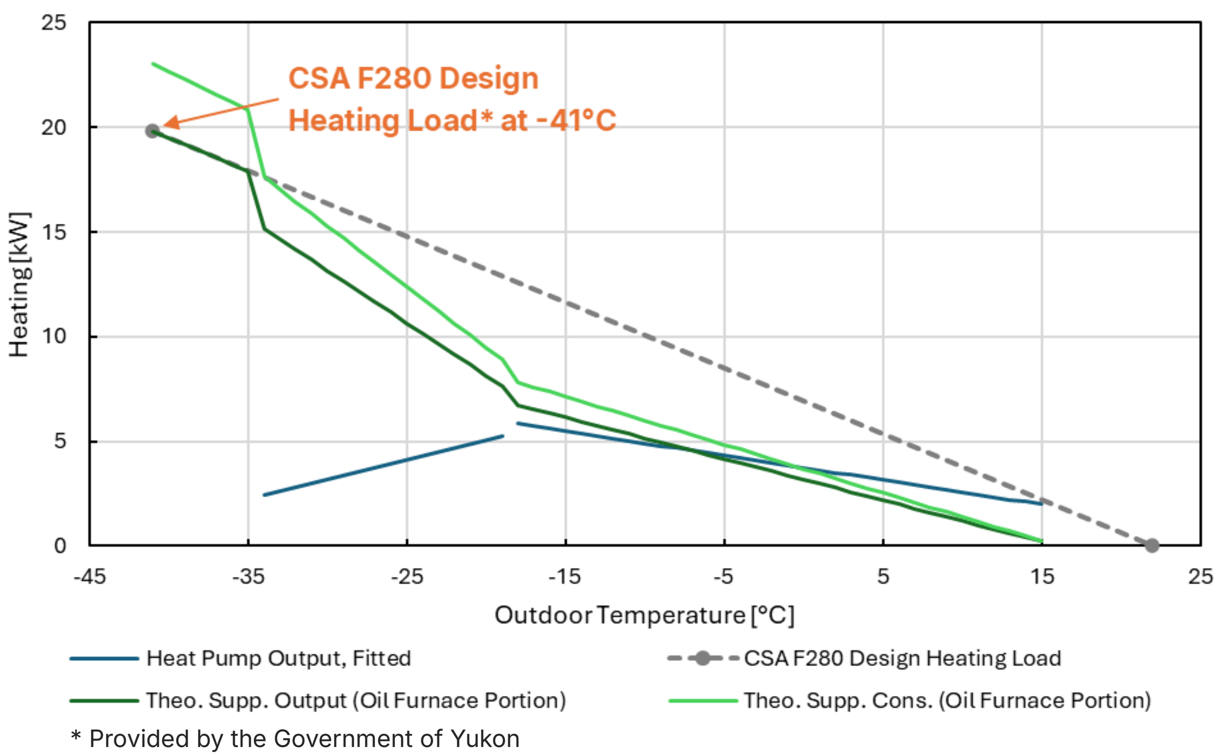


Figure 2.12 Example of Step 2 for WH-07, which demonstrates how the theoretical supplemental consumption was estimated (light green line).

- **STEP 3:** Total energy consumption (purple line in Figure 2.13) was determined by summing the heat pump consumption (light blue lines from Step 1) and the theoretical supplemental consumption (light green line from Step 2). The theoretical baseline heating consumption (red line) was calculated by summing the theoretical baseline consumption (orange line from Step 1) and the total theoretical supplemental consumption (light green line from Step 2).

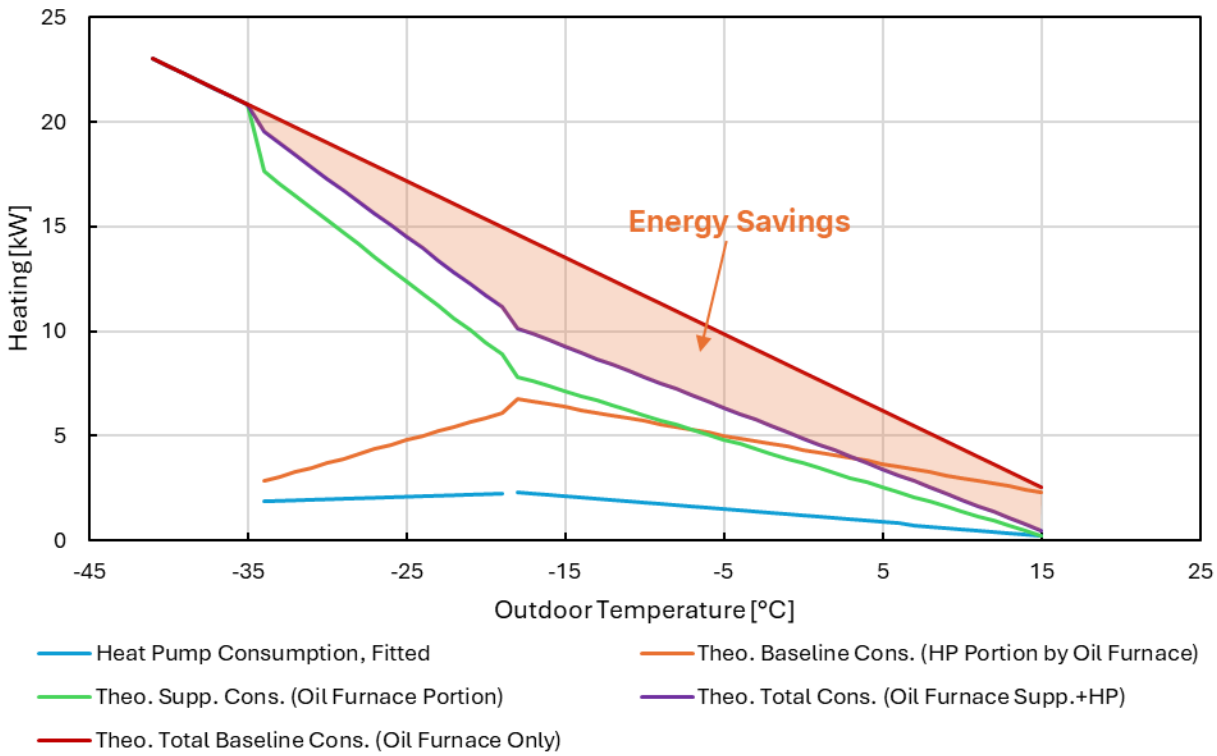


Figure 2.13 – Example of Step 3 for WH-07 which demonstrates how the energy savings were calculated; this is represented by the orange highlighted area.

- **STEP 4:** Annual energy consumption for each electricity/fuel type was determined by calculating the sum-product of the heating consumption (in kW, at varying outdoor temperatures) and the outdoor temperature distribution (in hours) of the Canadian Weather Year for Energy Calculation (CWEC) 2020 Version 2.0 weather file to represent a typical year. The Whitehorse CWEC file was geographically the nearest and used for all sites except for WH-14, which used the Haines Junction CWEC file. Annual savings were calculated between two bounds: 1) upper bound of 15°C, and 2) lower bound of lowest CWEC outdoor temperature (-44°C for all sites except -41°C for WH-14).
- **STEP 5:** Annual energy savings were calculated as the difference between the baseline and post-retrofit energy consumptions. Utility costs and savings were calculated using the corresponding monetary rates.
- **STEP 6:** Finally, greenhouse gas (GHG) emission reductions were determined by multiplying the normalized energy consumptions by the corresponding residential emissions factor, and the GHG emissions savings were calculated to be the difference between the baseline and post-retrofit cases.

Table 2.4 provides residential electricity, heating oil, and propane rates; and thermal efficiencies used for the conducting the financial and energy savings analysis. Rate assumptions were provided to us by the Government of Yukon based on data from the Yukon Bureau of Statistics.

TABLE 2.4 SAVINGS ANALYSIS ASSUMPTIONS					
Energy Source	**Energy Content[4] [kWh/L]**	**Emission Factor[5,6] [g CO_2e/kWh]**	**Rate [7] [$/Unit]**	**Equipment**	**Efficiency[8]**
Electricity	Not applicable	70	$0.2419/kWh	Baseboard	100%
				Boiler	100%
Heating oil	10.2	270.1	$1.60/L	Furnace	86%
				Boiler	90%
				Stove	78%
Propane	7.1	217.8	$0.97/L	Furnace	82%

2.6. Missing Data

Missing data during the monitoring period from April 1, 2024 to March 23, 2025 (covering the second heating season) is summarized as follows:

- WH-01: System consumption data (50A CT) were corrupt after November 27, 2024; only a very limited number of heating data points during a limited range of outdoor temperatures were available.
- WH-02: Missing data at indoor head B between June 27 and August 29, 2024 (battery failure).
- WH-03: Missing data at indoor head A between June 17 and Aug. 22, 2024 (battery failure). Missing data at indoor head C between June 6 and July 13, 2024 (battery failure). Data for indoor head B after November 23, 2024 were omitted due to faulty sensor readings; only a limited number of heating data points during a limited range of outdoor temperatures were available.
- WH-06: Homeowner unplugged 50A CT logger on Jan. 18, 2024, plugged it back on May 6, 2024 and then unplugged it again on November 20, 2024. Missing data at indoor head A between July 23 and Aug. 30, 2024 (battery failure).
- WH-08: Missing data at indoor head A between June 9 and Aug. 29, 2024 (battery failure).
- WH-09: System consumption data (50A CT) were corrupt, preventing reliable COP calculation for this site.
- WH-10: The participant withdrew from the study in October 2023.
- WH-11: Missing data at indoor head A between March 28 and Aug. 12, 2024 (battery failure). Missing data at indoor head B between March 26 and August 16, 2024 (battery failure). Missing data at indoor head C between April 18 and August 19, 2024 (battery failure). 50A CT outdoor unit data logger unplugged June 8, 2024 and plugged back in on August 8, 2024.
- WH-12: Data for indoor heads A and C were missing after April 2 and November 4, 2024, respectively (battery failure). Data for indoor head B was missing between January 13 and 15, 2024 (battery failure).
- WH-13: Data for indoor heads A, B, and C were missing after August 10, 2024 August 11, 2024 and November 26, 2024, respectively. Data for indoor head A was also missing between March 28 and April 11, 2024. Homeowner unplugged 50A CT outdoor unit data logger on June 19, 2024, plugged it back in on Aug. 21, 2024, and unplugged again on Feb. 14, 2025.
- WH-15: Indoor head fan consumption data (5A CT, proxy for airflow rate) were corrupt; however, there was only one fan setting and corresponding airflow rate for this system.
- WH-16: Data acquisition system was unplugged by homeowner on April 26, 2024. Homeowner was also turning off the monitoring equipment overnight, resulting in loss of approximately 25% of the data on daily basis when data

[4] Canada Energy Regulator (2016). Energy conversion tables (accessed July 2025). https://apps.cer-rec.gc.ca/Conversion/conversion-tables.aspx
[5] Environment and Climate Change Canada (2024). Emission factors and reference values (accessed July 2025). https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work/output-based-pricing-system/federal-greenhouse-gas-offset-system/emission-factors-reference-values.html *Note: Based on 2025 values.*
[6] Department of Justice (2025). Greenhouse Gas Pollution Pricing Act (accessed July 2025). https://laws-lois.justice.gc.ca/eng/acts/g-11.55/FullText.html *Note: Schedule 3 Global Warming Potential.*
[7] Rates for this study were provided by the Yukon Government (2025).
[8] Natural Resources Canada (2012). Heating with Oil. https://natural-resources.canada.ca/sites/nrcan/files/energy/pdf/energystar/Heating-with-Oil_EN.pdf

acquisition system was still on. Data acquisition system was plugged back in on 11/17 but batteries for battery-powered equipment had already died trying to reconnect to data acquisition system.

- WH-18: System 200A CT (supplemental) is always reported as zero, which means that output cannot be subtracted from HP output to calculate COP. HP system consumption (50A CT) and flow gauge were unplugged on Dec. 22, 2024.

WH-01, WH-09, WH-10 and WH-18 were excluded from COP vs. outdoor temperature, SCOP, time spent in various modes, and savings summaries due to the issues noted above and resulting limited data.

WH-12 did not have sufficient data over the heating season to present a SCOP value or time spent in various modes even though sufficient data were available to present outdoor temperature-based results.

3. Results & Discussion

3.1. Heat Pump Performance

Typical Energy Consumption and Output Profiles of Different Heat Pump Types

Figure 3.1, Figure 3.2, and Figure 3.3 display the measured ambient outdoor temperature collected at each site; the temperatures at indoor unit supply/return, and the equivalent energy provided or removed by the heat pump compared to total energy consumption for a sample of sites; a ductless system (WH-05), a central ducted system (WH-15) and an air-to-water system (WH-17) for the monitoring period from April 1, 2024 to March 23, 2025. Plots for the other sites are included in **Appendix B**.

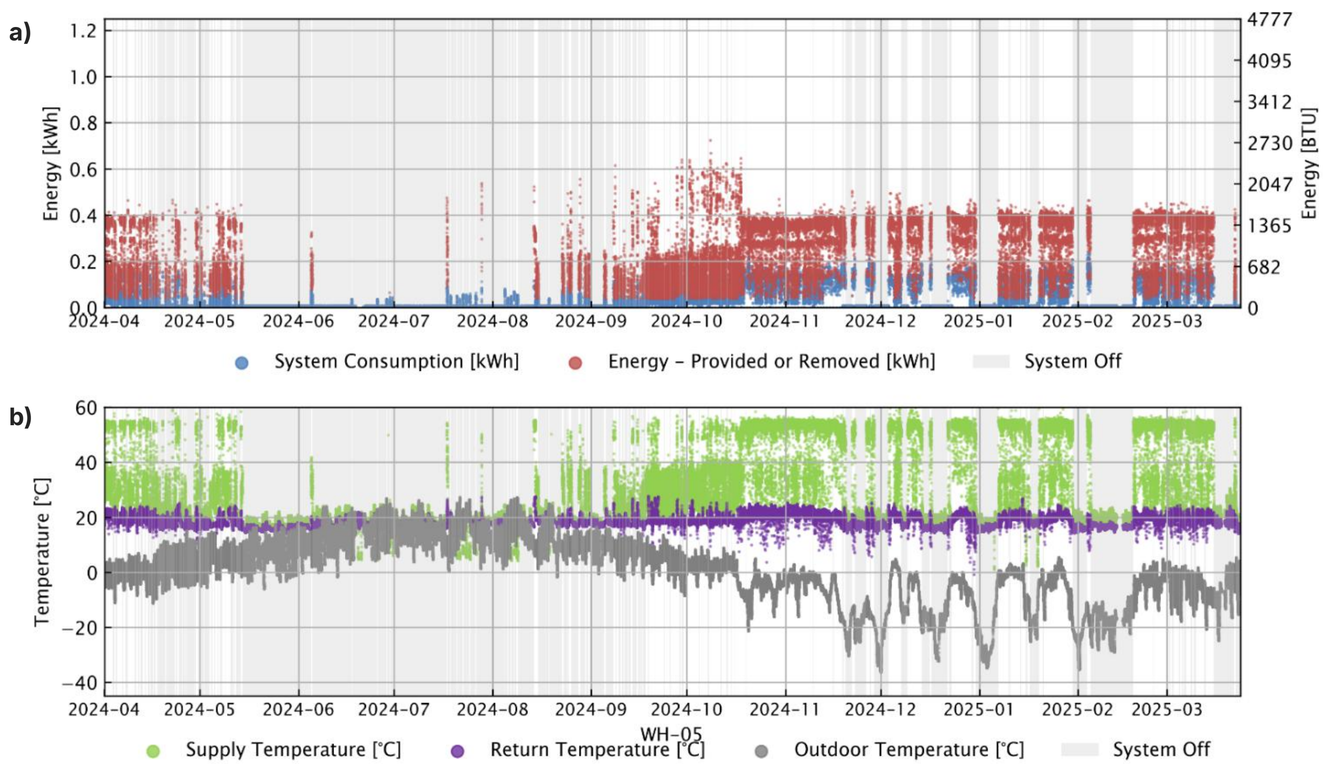


Figure 3.1 Sample plot for ductless heat pump system, WH-05. a) Measured equivalent energy provided/removed by heat pump compared to energy consumption. b) measured ambient outdoor temperature, and temperatures at the supply/return of the indoor unit (head).

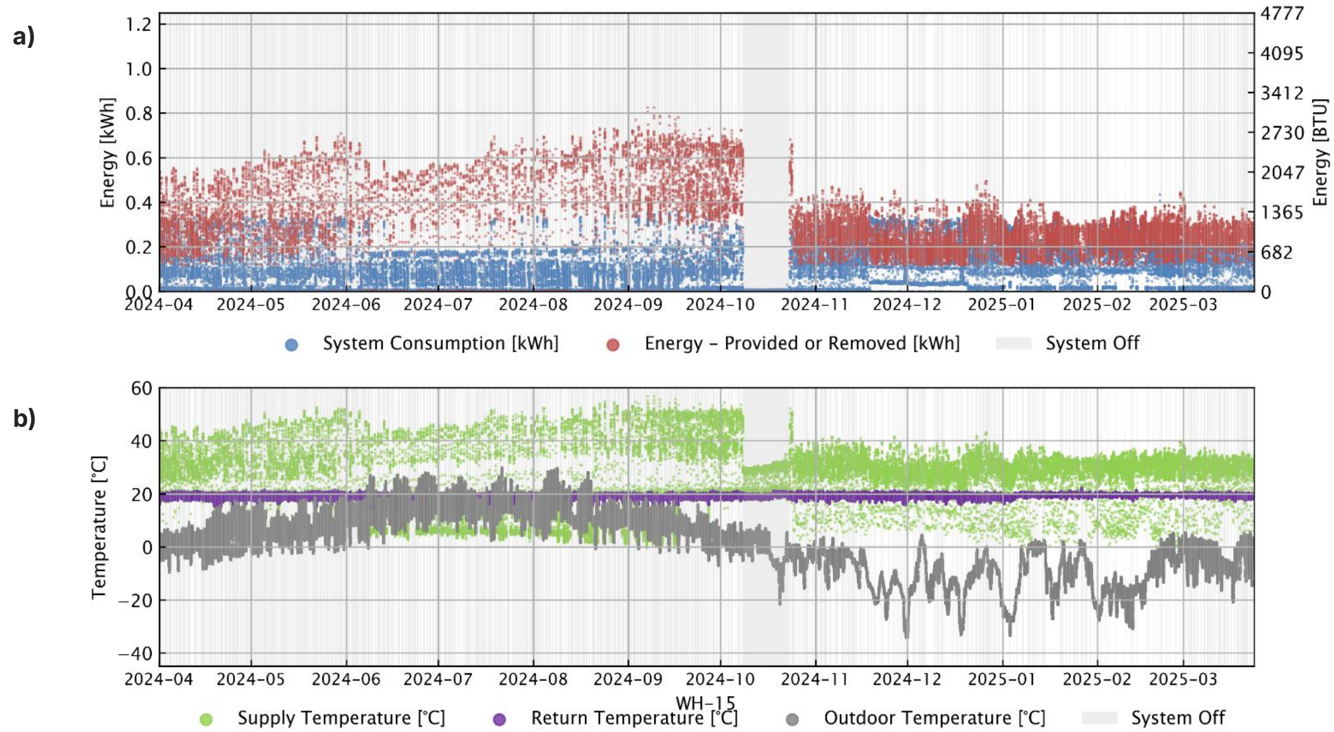


Figure 3.2 Sample plot for central ducted heat pump system, WH-15. a) Measured equivalent energy provided/removed by heat pump compared to energy consumption. b) measured ambient outdoor temperature, and temperatures at supply/return ducting.

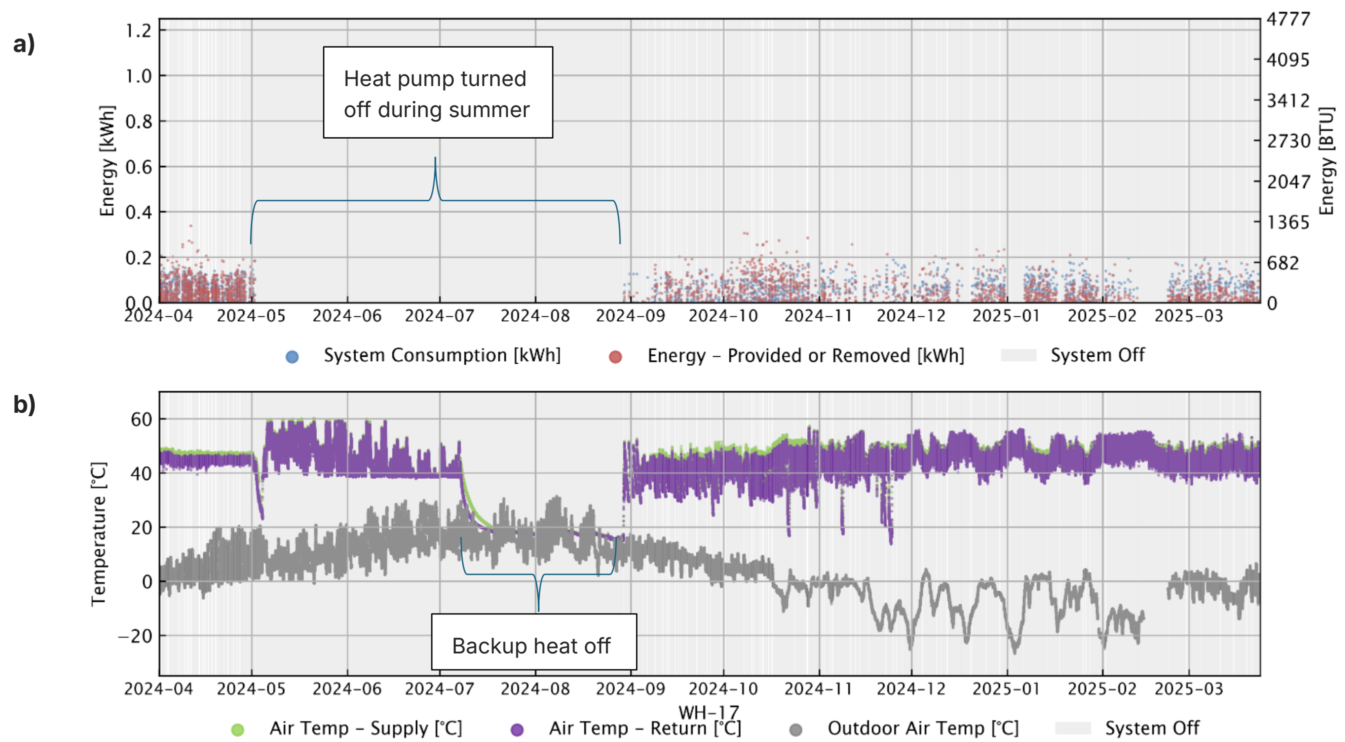


Figure 3.3 Sample plot for central air-to-water heat pump system, WH-17. a) Measured equivalent energy provided/removed by heat pump compared to energy consumption. b) measured ambient outdoor temperature, and temperatures at supply/return pipes.

Figure 3.4 and Figure 3.5 show plots of heat pump operation for Sites WH-03 and WH-15 on a sample day. It can be noted that the vapour line temperature (blue) regularly dips below the supply (green) and return (purple) temperatures during periods of low outdoor temperatures. This indicates defrost cycles, when the heat pump temporarily reverses to send heat to the outdoor coil instead of the indoor coil. It can also be noted that supply temperatures do not consistently remain above or below the return temperature during defrost, even at the same indoor unit, demonstrating when simultaneous defrost and heating can occur.

Figure 3.4 Heat pump cycles for site WH-03 (ductless system with 3 indoor units), during a sample day on November 4, 2024. Each indoor unit has its own subplot. The blue, purple and green lines show the vapour line, return airflow, and supply airflow temperatures of the heat pump, respectively. The grey line shows the measured ambient outdoor temperature. Data points that are considered part of the defrost cycle are shown in red.

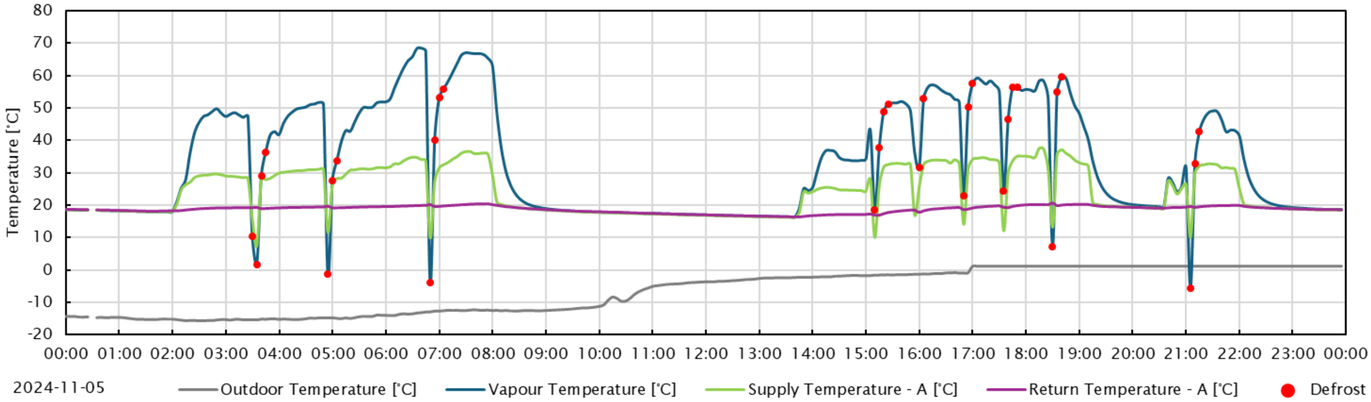


Figure 3.5 Heat pump cycles for site WH-15 (central ducted system), during a sample day on November 4, 2024. The dark blue, light blue, purple, and green lines show the vapour line temperature at supply, vapour line temperature at return, return airflow temperature, and supply airflow temperature of the heat pump, respectively. The grey line shows the measured ambient outdoor temperature. Data points that are considered part of the defrost cycle are shown in red.

Average Coefficient of Performance (COP)

Coefficient of performance (COP) is a common metric for measuring the efficiency of heat pumps. It is a dimensionless number and is defined as the energy delivered or removed from a space divided by the energy required by the system to perform the work. If the energy provided or removed is greater than the energy consumed by the heat pump, the COP will be greater than 1. For comparison, electric baseboards have a constant COP of 1 (at the device and not accounting for grid transmission losses); meaning that for every one unit of energy provided to the equipment, one unit of heat is output to the space.

Figure 3.6 presents the relationship between the average heating COPs and outdoor air temperature for the ductless heat pump (i.e. mini- and multi-split) systems. For each site, COP values are only plotted at temperatures where there were a sufficient number of data points. The number of datapoints collected for each site is summarized in **Appendix C**.

Key observations include:

- As expected, the heating COP generally increases with rising outdoor air temperature, consistent with typical heat pump performance.
- At approximately -20°C, most or all of the systems are still capable of COPs greater than 1.
- At higher temperatures (above 0°C), the majority of systems are capable of achieving COPs between 3 and 5.
- Three sites did not have sufficient data to be included in the average heating COP vs. outdoor temperature plot:
    - WH-01: Data were corrupt after September 2023, so no results were included for this heating season.
    - WH-09: System consumption data (50A CT) were corrupt, preventing reliable COP calculations for this site.
    - WH-10: The participant withdrew from the study in October 2023.
- The following systems had poor performance for various reasons:
    - WH-08: A refrigerant leak was reported in the outdoor unit. Although the issue was reportedly repaired before the end of the study, the participant noted that the repair process took longer than expected. Low refrigerant levels reduce heat transfer efficiency, which likely contributed to poorer COP values. It is anticipated that refrigerant leakage was occurring for at least part of both heating seasons.
    - WH-11: A refrigerant leak occurred in one of the indoor units, located in the living room. The problem was discovered during space cooling operation, though it is unclear how long the leak had been present. Again,

COPs for this site are lower than anticipated, although the performance appears better than what was observed in the 2023/2024 heating season. This aligns with our understanding (from discussion with the homeowner) that the system was repaired before the summer.

- WH-13: Homeowner reported that system issues were evident immediately after installation and commissioning of the heat pump system. They determined that a faulty outdoor temperature sensor was likely shutting down the heat pump when outdoor temperatures were around -16°C or lower (not anticipated performance). Operational issues may have persisted through the second heating season, but were unconfirmed due to limited data collected at this site.

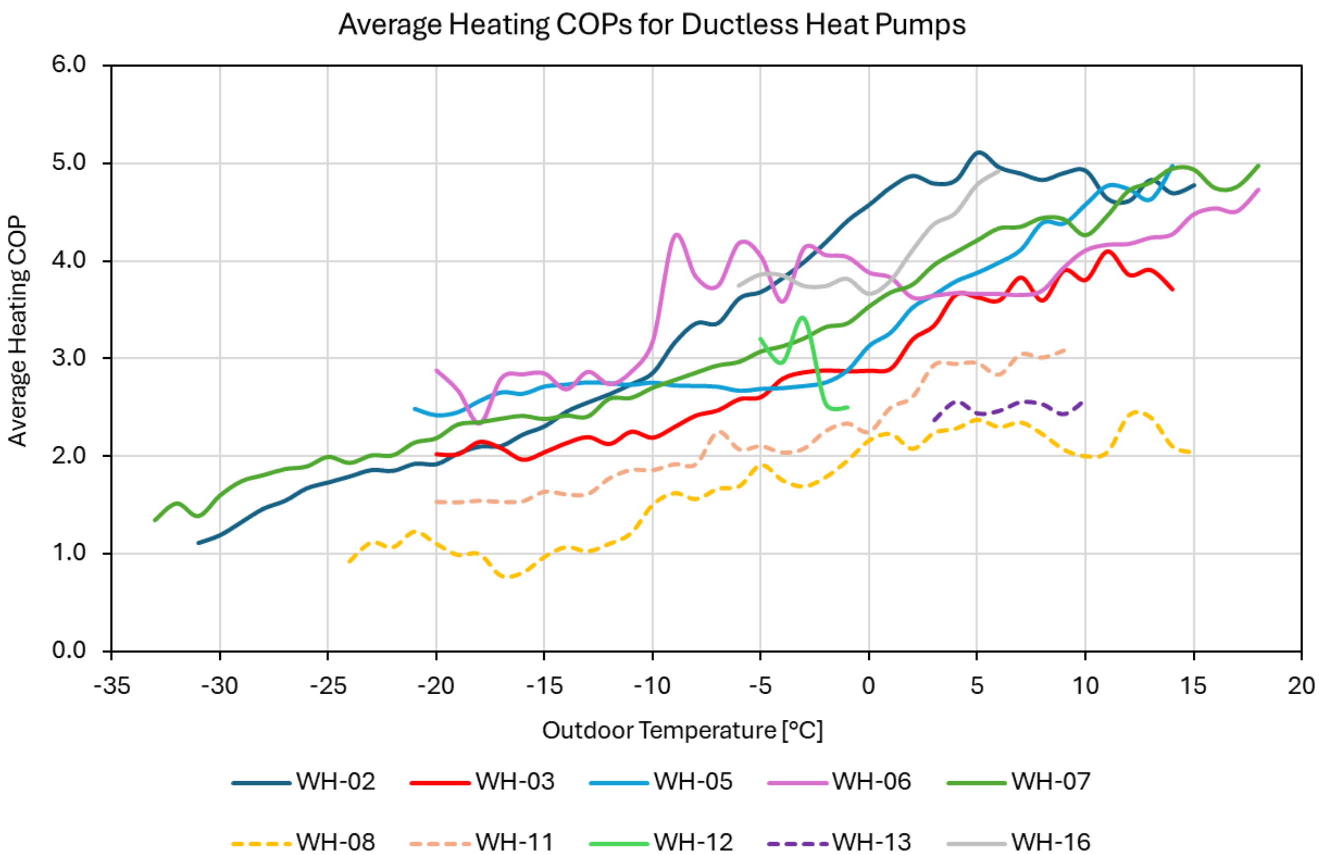


Figure 3.6 Average heating COP versus outdoor air temperature for sites with ductless heat pumps. COP values for each site were included at extreme temperatures (very low or high) only if more than 40, 5-minute data points were available at those temperatures (note: WH-12 was the exception; data was included if more than 30, 5-minute data points were available). This report only includes heating results from April 1, 2024 to March 23, 2025. Sites indicated with dashed lines are those the heat pumps were not operating as intended for various reasons (e.g. refrigerant leaks).

Figure 3.7 presents the relationship between the average heating COP and outdoor air temperature for the central ducted heat pump systems. There were three systems of this type in the study.

Key observations include:

- Two of the sites (WH-04 and WH-15) had similar performance. They were able to achieve COPs of 1 at very low outdoor temperatures (down to -30°C for WH-04 and down to -20°C for WH-15). Above 0°C, they were able to achieve COPs between 2.2 and 5.3.

- WH-14 demonstrated relatively poor performance. The average COP only exceeds 1.5 once it reaches an outdoor temperature of 7°C. The exact reason for poor performance at this site is unclear; however, the heat pump did not spend much time in heating mode and instead spent most of the time in fan-only mode, which may suggest issues with the commissioning/controls, and that the heat pump was not operating as intended. This is the same trend that was observed in 2023/2024 heating season report.

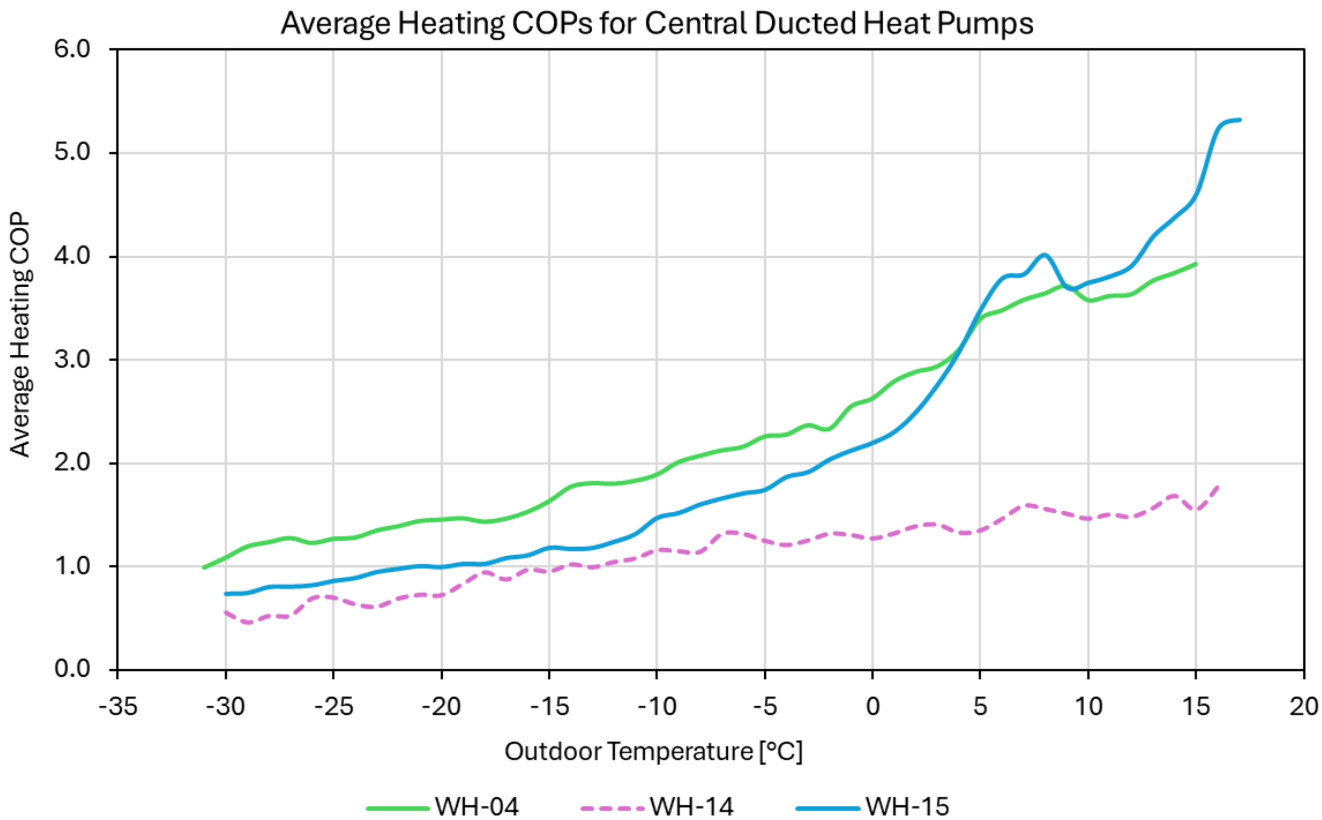


Figure 3.7 Average heating COP versus outdoor air temperature for sites with central ducted heat pumps. COP values for each site were included at extreme temperatures (very low or high) only if more than 40, 5-minute data points were available at those temperatures. This report only includes heating results from April 1, 2024 to March 23, 2025. WH-14 is represented as a dashed line as it was not operating as intended; the heat pump spent most of its time in fan-only mode, which may indicate issues with controls although this is unconfirmed.

Figure 3.8 presents the relationship between the average heating COP and outdoor air temperature for the air-to-water heat pump systems. Only one system, WH-17, had complete data and is plotted.

WH-18's supplemental heating consumption (200A CT) was always zero; however, heating was being provided when heat pump consumption (50A CT) was zero; therefore, heating was likely provided by the supplemental system. This suggests that supplemental heating monitoring may not have been properly configured.

For the plot below, the average COP at a given outdoor temperature was plotted if more than 20, 5-minute data points were available at those temperatures. This number of data point threshold was reduced for this plot because of the limited data collected for this site; the result is that while the plot shows average COP for a range between -12°C and 13°C, this plot is less smooth.

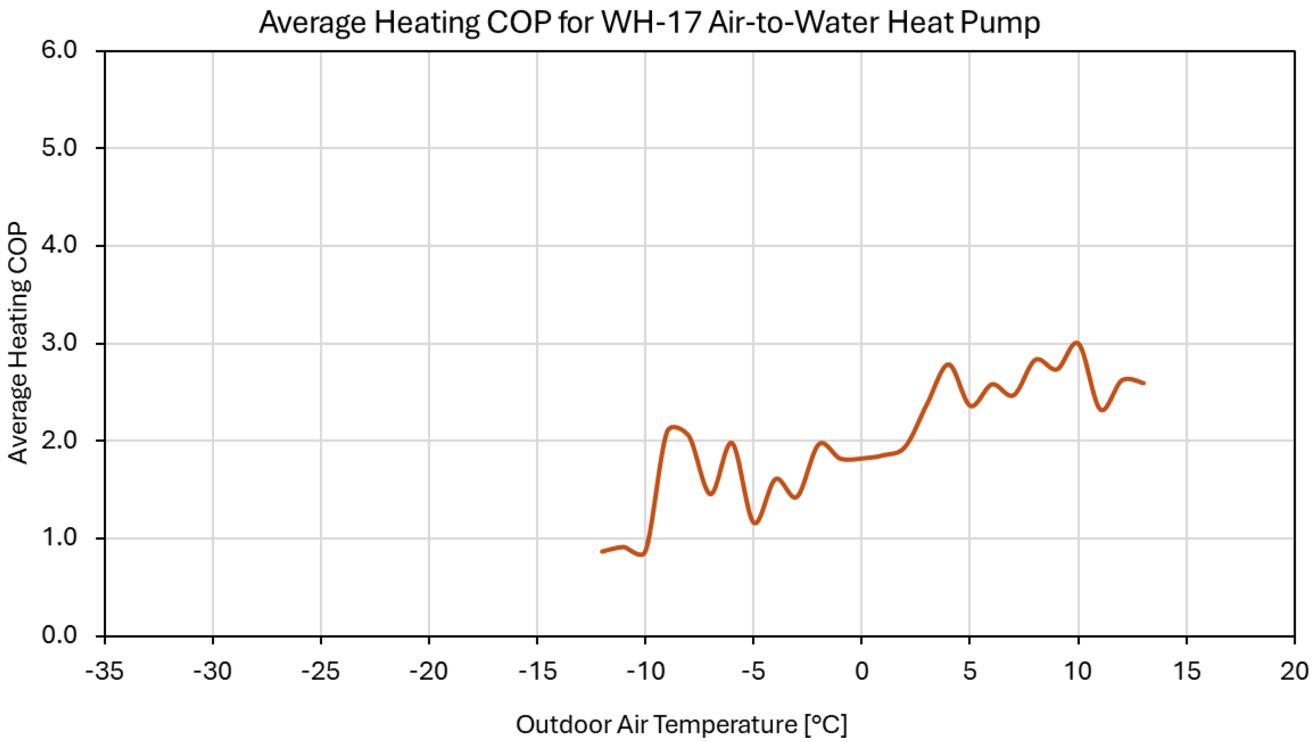


Figure 3.8 Average heating COP versus outdoor air temperature for site with a central air-to-water heat pump. COP value for WH-17 was included at extreme temperatures (very low or high) only if more than 20, 5-minute data points were available at those temperatures. Note that there were only two air-to-water heat pumps in this study, and one (WH-18) had missing/corrupt data, so only the COP of WH-17 is plotted. This report only includes heating results from April 1, 2024 to March 23, 2025.

Seasonal Performance of Heat Pumps (SCOP, SEER, HSPF)

Seasonal efficiencies provide an understanding of a heat pump's performance over a heating or cooling season. These values account for how the system behaves over a season when outdoor temperature fluctuates. Figure 3.9 shows the hourly outdoor temperature distribution during the monitoring period from a nearby weather station.

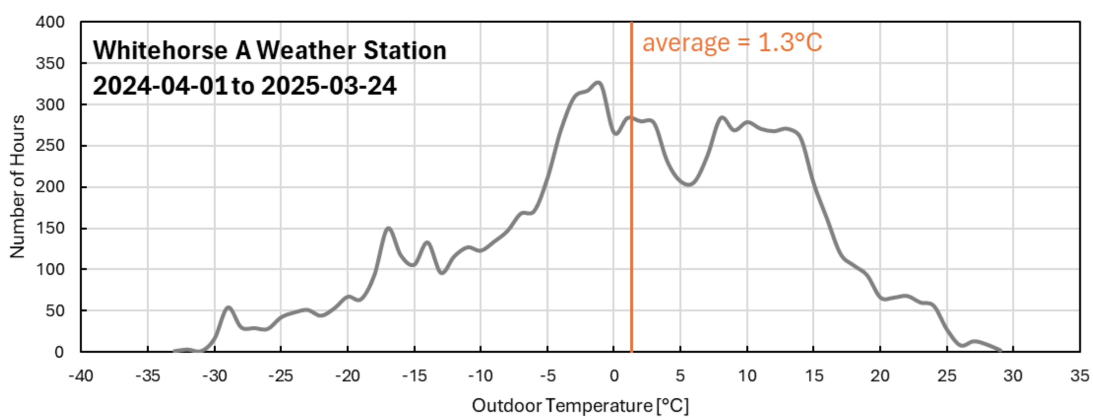


Figure 3.9 Outdoor temperature distribution during the monitoring period (April 1, 2024 to March 24, 2025); hourly temperatures at "Whitehorse A" weather station (ID#2101303) were obtained from Environment and Climate Change Canada.

Figure 3.10 presents the *measured* heating SCOPs across the thirteen (13) different heat pump systems for which sufficient data is available for the period between April 1, 2024 and March 23, 2025, alongside manufacturer *rated* heating SCOP values where available. A whisker plot of the outdoor air temperature (measured locally at site) corresponding to data points included in the measured SCOP calculation is also provided for context. This was included to capture variability of heat pump operation from one site to another due to differences in owner preferences, operational issues, heat pump supplemental integration/controls and data availability.

Key observations are as follows:

- In general, the measured SCOPs (green bars) were lower than the manufacturer-rated SCOP equivalents (pink bars) for both distributed and central ducted systems (9 of the 13 sites). This is not surprising if the rated temperature (which is a standardized laboratory test condition) for a given system is higher than the average outdoor temperature that the heat pump was operating at. Exceptions to this (e.g. WH-06 and WH-16) were sites where significant periods of data were missing over the winter months, so the performance was reportedly better (refer to the outdoor temperature).
- Note that rated SCOP values are not available for the air-to-water systems (WH-17 and WH-18). WH-18 was omitted from this figure because of the lack of data.
- For four of the nine ductless systems plotted, the measured SCOP values were broadly in line with rated values. Two of these which operated at an average outdoor temperature below 0°C (WH-02 and WH-07) had measured SCOP values that were slightly higher than the manufacturer rated values and approximately a SCOP of 3.
- For the central ducted systems (WH-04, WH-14, and WH-15), measured SCOP values were consistently lower than both their rated values and the performance of the ductless systems. However, these systems on average operated in colder outdoor temperatures, which likely contributed to the reduced measured SCOP. WH-14 had the worst performance of the three, which is consistent with what is seen in Figure 3.7 and also seen in the report for the 2023/2024 heating season. On average, the central ducted systems had lower measured SCOPs than the ductless systems although the systems had similar rated SCOPs. This is expected as central systems heat at the source and then must move air to/from the rooms.
- All systems were able to achieve SCOPs greater than 1, even those that had the lowest performance.

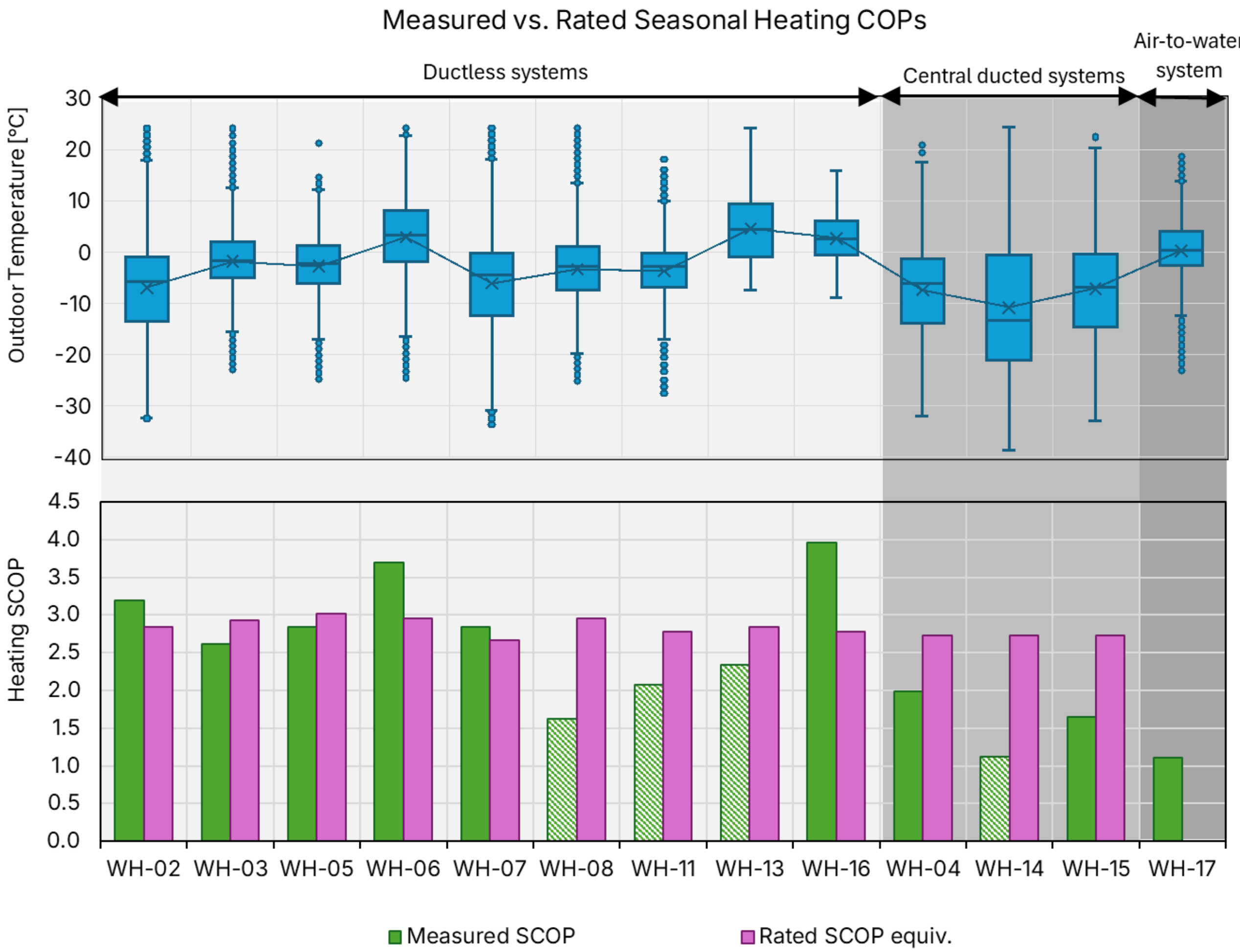


Figure 3.10 Seasonal heating COPs (SCOPs) for all sites; measured (green bars) and rated (pink bars). This report only includes heating results from April 1, 2024 to March 23, 2025. Note that WH-01, WH-09, WH-10, WH-12 and WH-18 are omitted from this plot because there was not sufficient data to calculate measured SCOPs for these sites. WH-08, WH-11, WH-13 and WH-14 are hatched because these systems were not performing as intended. For WH-08 and WH-11, refrigerant leaks were reported. WH-14 had low SCOP possibly due to control issues, but this was unconfirmed.

Table 3.1 presents the average measured SCOP by system type for all sites, and an average measured SCOP for sites that were operating as intended.

TABLE 3.1 AVERAGE HEATING SCOP BY SYSTEM TYPE AND OPERATION

Type	All	Operated as Intended
Ductless	2.9	3.2
Central Ducted	1.6	1.8
Air-to-Water	1.1 (one site*)	1.1 (one site*)

* Only one of the two sites with an air-to-water heat pump had sufficient data to report on this.

Note: “All” groupings excluded WH-01, -09, -10, -12, and -18 which did not have sufficient data; “Operated as Intended” groupings excluded WH-01, -08 through -13, -14, and -18 which did not have sufficient data, and/or did not operate as intended.

Heat Pump System Uptime and Time Spent in Different System Modes

The criteria for determining heating, cooling and defrost periods is described in Section 2.4.3.

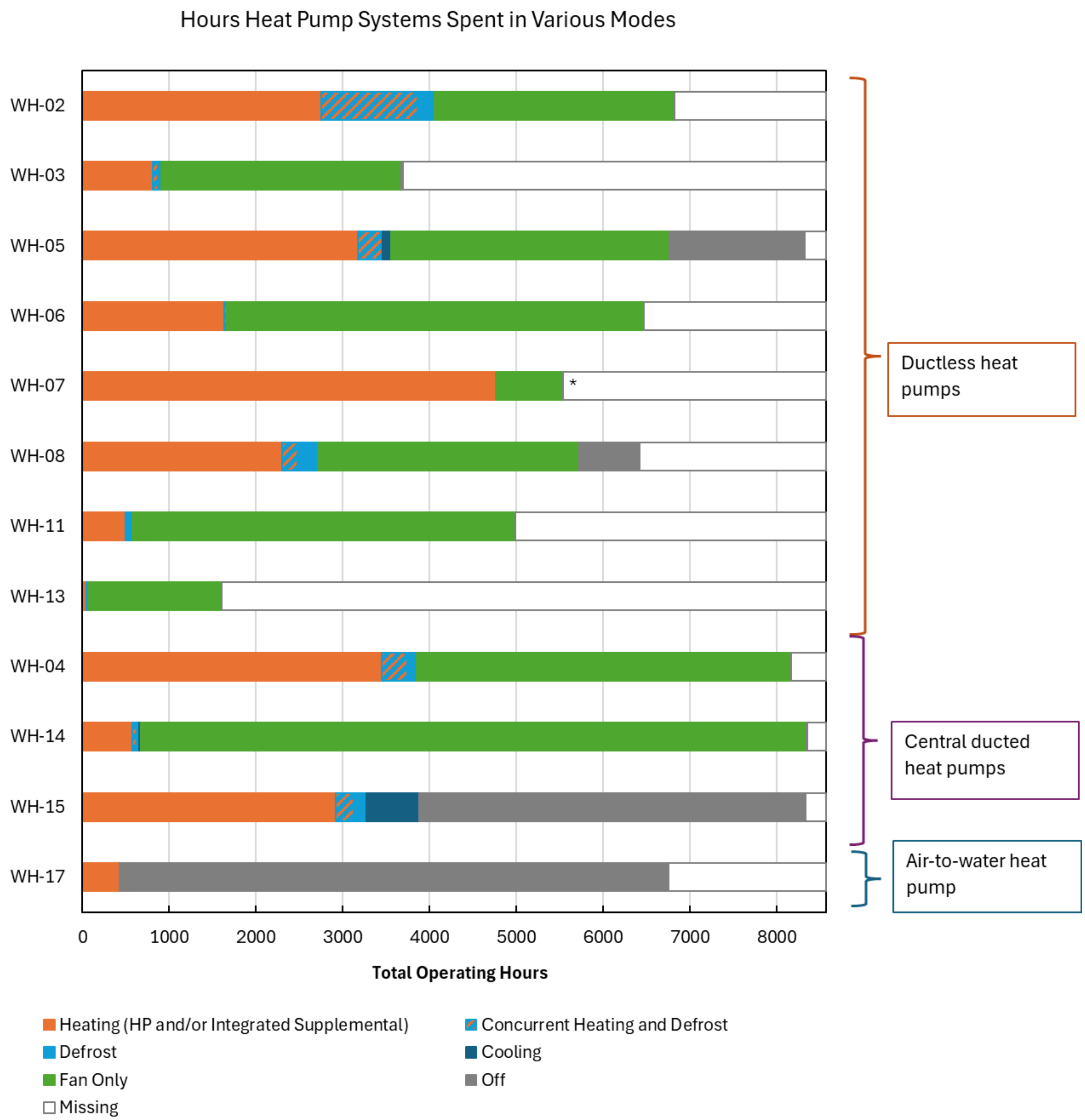
Figure 3.11 shows the total operating hours across different modes for each of the heat pump system installations. Modes were divided into heating (HP and/or integrated supplemental), concurrent heating and defrost, defrost only, cooling, fan only, and off. Hours when data were missing or incomplete are also indicated.

Observations are as follows:

- Heat pump systems were operating (i.e. in heating, cooling, defrost only, or fan only mode), i.e. system was not 'off', between 80% and 100% of the time.[9] There were two exceptions: the first was the air-to-water system, WH-17, which was only operational 6% of the time (likely because of the buffer tank); the second was WH-15 which operated 47% of the time. We are unclear as to why there was this change in usage for WH-15 from what was observed in the first report (may have been occupant-initiated).
- For most of the systems, the dominant modes of operation were heating (orange) and fan-only (green) when the system is on. There was more fan-only usage observed in this report than in the 2023/2024 heating season report; this is expected given that the monitoring period covered in this report includes data from Summer 2024 when heat pump usage for heating decreases. With the exception of WH-07, both the ductless and non-ducted heat pumps spent more time in fan-only mode than they did in heating mode.
- Defrost-related operation (solid blue and hatched blue) was present to varying degrees. The ductless and central ducted systems were seldom in defrost mode (solid blue; less than 2% on average). This is generally in line with expectations and consistent with what was observed in the previous report.
- Even with the summer 2024 period monitored, there was limited cooling at the sites. Only three sites (WH-05, WH-14 and WH-15) had cooling (89 hours, 12 hours, and 605 hours, respectively). This indicates that few participants wanted or needed to cool their homes, and also that it is unlikely that any of the systems are increasing space temperatures too quickly during heat pump operation, triggering subsequent periods of space cooling (i.e. they are likely appropriately sized).
- WH-07's heat pump spent most of its time in heating mode (of the data available where the heat pump was operational), which suggests that this heat pump system was relied on primarily for heating at this site and supplemental heat likely played a much smaller role.

Figure 3.12 further shows the breakdown of heat pumps systems that have integrated supplemental heating. This includes the three central ducted systems (WH-04, WH-14, WH-15) and one of the air-to-water systems (WH-17) where there was sufficient data. From this figure, it can be noted that the integrated supplemental heating is rarely used. It appeared that WH-15 did not use its integrated supplemental heating (the 200A CT read zero) for the duration of the monitoring period. For WH-17, the heat pump did not spend much time in heating mode during the 2024/2025 heating season, and of the time spent heating, approximately half was spent using supplemental either concurrently or independently. It is our understanding that this home had a period of vacancy during the winter, and it is possible that the electric boiler and/or wood stove were relied on more heavily.

[9] For these percent time estimates for each site, note that this is calculated as: (hours of interest)/(total hours of data collected); i.e. we are not considering time where data were missing in the denominator. This applies to all percent time estimates in this section.



* Defrost could not be reported for WH-07 as vapour line sensor data was missing; however, fraction is anticipated to be small (based on what is observed for other systems).

Figure 3.11 Hours spent in various modes for heat pumps. Systems WH-01, WH-09, WH-10, WH-12, WH-16 and WH-18 have been omitted due to lack of reliable or insufficient data. Heating (HP and/or Integrated Supplemental) means that either the heat pump and/or the integrated supplemental are providing heating to the home.

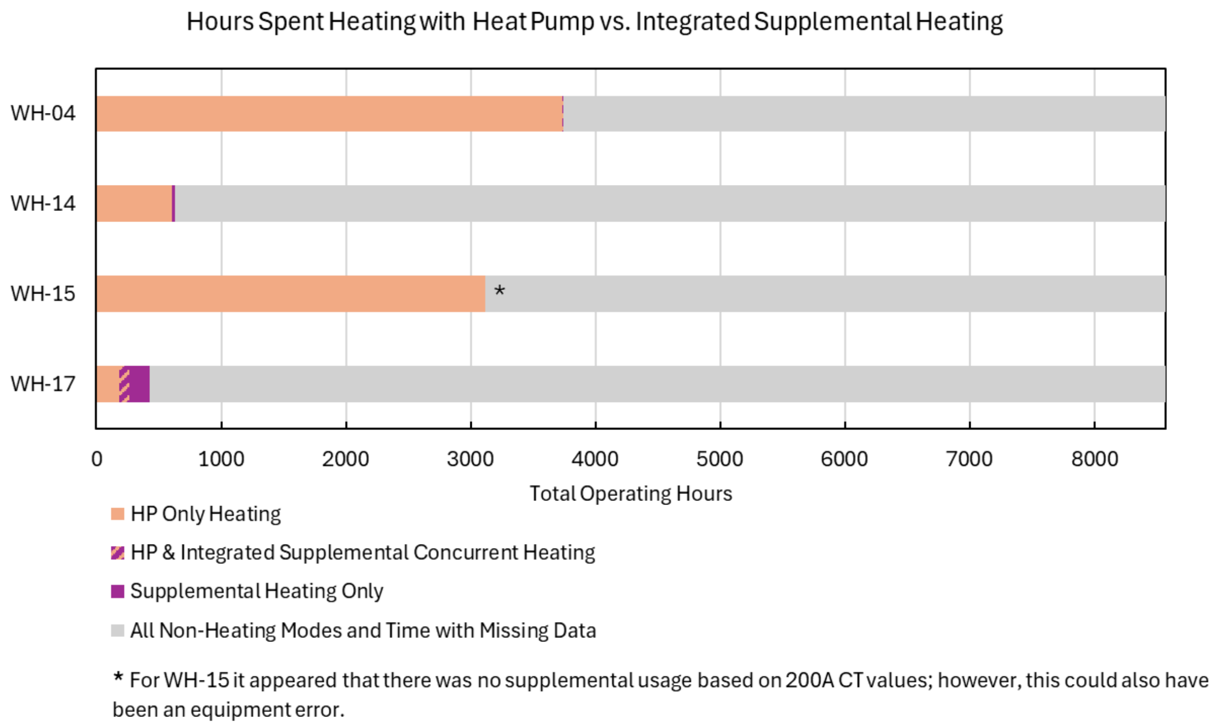


Figure 3.12 Hours spent in various heating modes for heat pump systems with integrated supplemental heating. Note that WH-18 also had integrated supplemental heating, but was omitted from this figure because of the lack of reliable data.

Sizing Commentary

Properly sizing heat pumps for their intended operating range is critical for ensuring optimal performance. If a heat pump's capacity is too low, the system will likely rely excessively on supplementary heating systems during colder weather, increasing overall operating costs (where supplementary heating is electric, propane or oil based). The additional running costs associated with an undersized air-source heat pump (ASHP) typically outweigh the higher upfront cost of installing a larger unit. Conversely, oversized systems can also present issues, such as excessive cycling and reduced performance (i.e. lower COPs) at milder temperatures. To get an understanding of heat pump sizing at each site, plots of the measured average and maximum heat outputs for each heat pump system and the heating demands of the sites are in **Appendix D.**

Based on discussions with contractors operating in the Yukon, it appears that common practice is to size equipment based on square footage of the home (for both ductless, and centrally ducted air-to-air heat pumps), unless results from energy audits are provided to them by the homeowner. This approach can lead to incorrect sizing; conducting a proper energy assessment to determine the design heating load for the home and then sizing the heat pump accordingly is the preferred approach.

For central systems, contractors will also account for duct sizing. If a home is well-insulated this is factored into heat pump sizing based on experience, but does not have a formalized approach. Residential heat pump installers in the Yukon do not typically conduct CSA F280 calculations; if they are working on a larger project that involves mechanical engineers, then the mechanical engineer will conduct the analysis and provide them with the values. Anecdotally, many heat pump installation companies in the Yukon do not have ticketed refrigerant technicians (as refrigeration is not a certified trade in Yukon unlike many other provinces in Canada).

Based on these findings, there is an opportunity for government and partners to provide education and potentially new requirements (e.g. tied to incentive programs) to improve the rigour of the sizing and installation process for cold climate heat pumps in the region.

3.2. Energy, Emissions and Financial Savings

This section presents the estimated theoretical energy savings over a typical meteorological year per Section 2.5. The distribution of outdoor temperatures in a typical meteorological year per CWEC 2020v2 files for Whitehorse, YT and Haines Junction, YT are summarized in Figure 3.13.

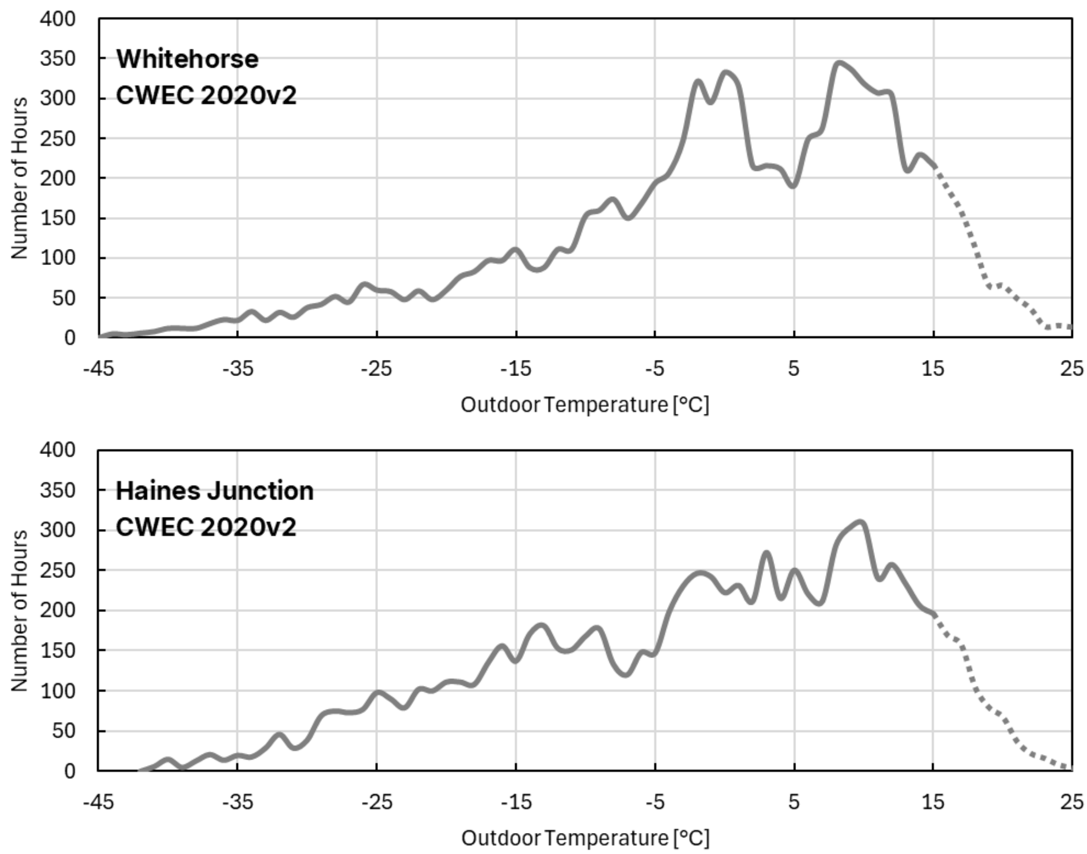


Figure 3.13 Outdoor temperature distribution in a typical meteorological year per CWEC 2020v2 in Whitehorse, YT (all sites except WH-14) and Haines Junction, YT (WH-14).

An example of the model used to estimate the energy savings is shown in Figure 3.14; it includes the estimated heating load at the heating design outdoor temperature.[10] The more detailed step-by-step methodology for the energy savings calculation is presented in Section 2.5, and summary plots for the remaining systems are included in **Appendix E.** Figure 3.14 presents an example (WH-07) where the heat pump system is operated as intended and the modeled energy savings are appreciable over the range of outdoor temperatures seen in Whitehorse.

[10] Per CSA F280-12. Values provided by the Government of Yukon.

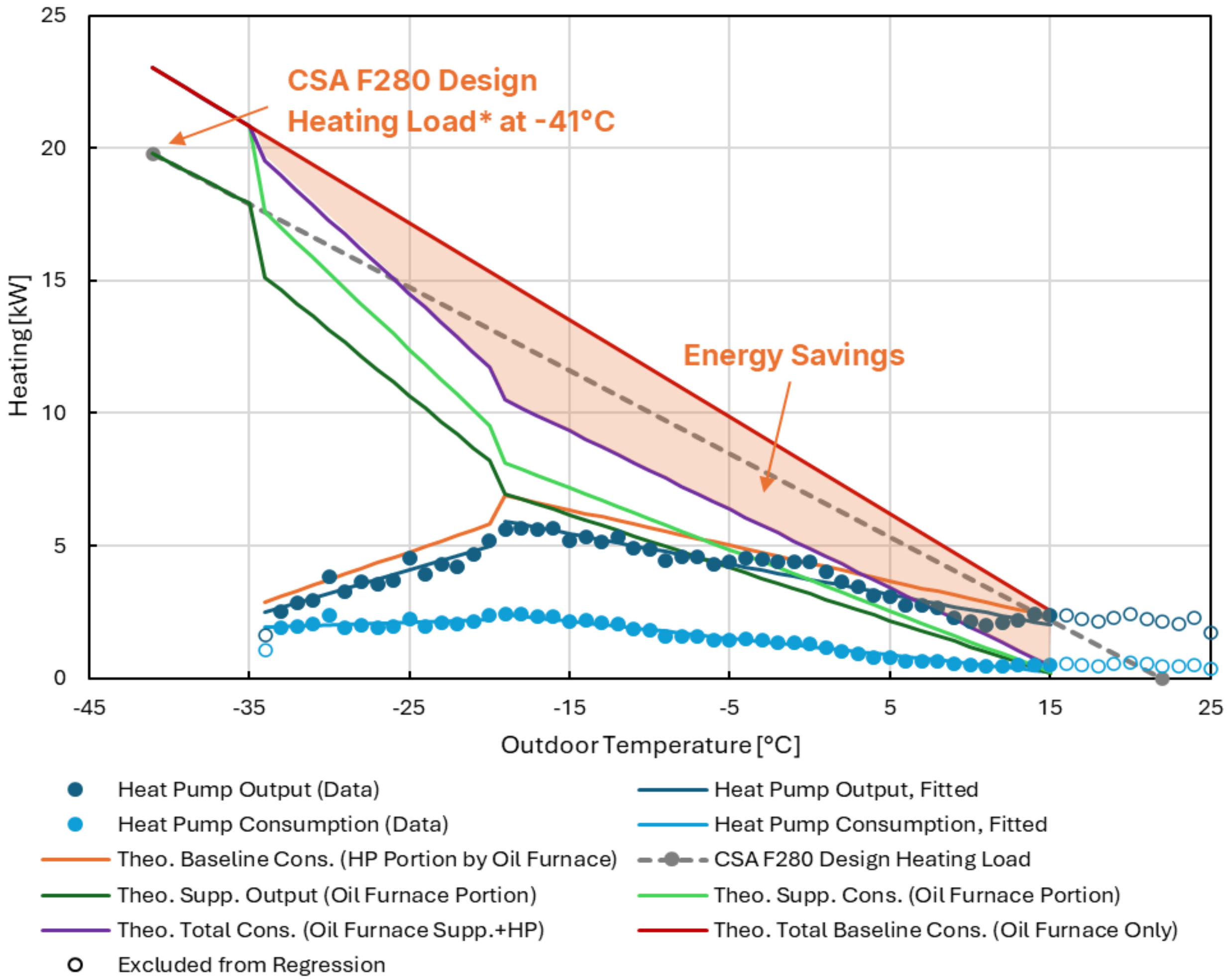


Figure 3.14 Sample plot for energy savings analysis at ductless heat pump system, WH-07, where energy savings across the full range of expected operating outdoor temperatures is shown in the savings model.

The net energy savings calculated for each site were then used to calculate the theoretical GHG emission savings and utility cost savings for a typical meteorological year. The resulting weather-normalized annual energy and emissions savings are summarized in Table 3.2. A breakdown of baseline (pre-retrofit) and post-retrofit annual energy consumptions, greenhouse gas emissions, and utility costs/savings is included in **Appendix E.** Some of the sites below did not have calculated savings; these were for the sites for which insufficient data was available to evaluate HP performance and thus calculate savings.

TABLE 3.2 NET ANNUAL ENERGY, EMISSIONS, AND FINANCIAL SAVINGS PER SITE						
Site ID	**Heat Pump System Type**	**Baseline Heating System (i.e. Previous Heating System)**	**Supplemental Heating System (Non-integrated)**	**Energy Savings [ekWh] (%)**	**GHG Emissions Savings [kgCO₂e] (%)**	**Utility Cost Savings [$] (%)**
WH-01	Ductless	Oil furnace	Oil furnace	Insufficient data; no CSA F280 heating load		
WH-02	Ductless	Oil stove	Oil stove	21,940 (56%)	7,145 (68%)	2,924 (48%)
WH-03	Ductless	Electric baseboard	Electric baseboard	No CSA F280 heating load		
WH-04	Central Ducted	Propane furnace	Electric baseboard	39,508 (60%)	12,440 (87%)	2,675 (30%)
WH-05	Ductless	Electric baseboard (assumed)	Electric baseboard (assumed)	No CSA F280 heating load		
WH-06	Ductless	Electric baseboard	Electric baseboard	8,936 (49%)	625 (49%)	2,162 (49%)
WH-07	Ductless	Oil furnace	Oil furnace	23,709 (35%)	8,294 (45%)	2,916 (27%)
WH-08	Ductless	Propane furnace	Propance furnace	4,636 (17%)	1,676 (28%)	160 (4%)
WH-09	Ductless	Electric baseboard	Electric baseboard	Insufficient data		
WH-10	Ductless	Oil boiler (unconfirmed)	Oil boiler (unconfirmed)	Insufficient data		
WH-11	Ductless	Oil stove	Oil stove	No CSA F280 heating load		
WH-12	Ductless	Oil furnace (unconfirmed)	Oil furnace (unconfirmed)	No CSA F280 heating load		
WH-13	Ductless	Oil heater	Oil heater	13,351 (35%)	5,212 (50%)	1,412 (23%)
WH-14	Central Ducted	Oil furnace	Oil furnace	9,067 (20%)	6,407 (51%)	-259 (-4%)
WH-15	Central Ducted	Electric baseboard (assumed)	Electric baseboard (assumed)	16,969 (45%)	1,188 (45%)	4,105 (45%)
WH-16	Ductless	Electric baseboard	Electric baseboard	14,388 (34%)	1,007 (34%)	3,481 (34%)
WH-17	Central Air-to-Water	Electric boiler (unconfirmed)	Electric boiler (unconfirmed)	544 (1%)	38 (1%)	132 (1%)
WH-18	Central Air-to-Water	Oil boiler	Oil boiler	Insufficient data		

Note: if baseline heating system was unknown, it was assumed for the purpose of the energy savings calculation that the baseline system was electric; these were noted with '(assumed)'. For sites where we were reasonably confident of the previous system type based on discussion with the homeowner or current system, but it was not fully confirmed, these have been annotated as '(unconfirmed).' Savings for WH-09, -10, and -18 were not calculated as the measured heating consumption and/or output (see Sections 2.5 for calculation methodology and 2.6 for missing data). For the remaining sites, savings were only calculable if we had CSA F280 heat load value. The one exception was WH-17, which although it did not have an F280 heat load value, it had one from EnerGuide.

Table 3.3 below summarizes the average savings by system type and compares all systems against those operating as intended. Generally, sites that were operating as intended resulted in significant utility, emissions and energy savings.

TABLE 3.3 AVERAGE ANNUAL ENERGY, EMISSIONS, AND FINANCIAL SAVINGS BY SYSTEM TYPE AND OPERATION

Type	Average Energy Savings [ekWh] (%)		Average GHG Emissions Savings [$kgCO_2e$] (%)		Average Utility Cost Savings [$] (%)	
	All	Operated as Intended	All	Operated as Intended	All	Operated as Intended
Ductless	14,493 (38%)	17,243 (44%)	3,993 (46%)	4,268 (49%)	2,176 (31%)	2,871 (40%)
Central Ducted	21,848 (42%)	28,238 (45%)	6,678 (61%)	6,814 (66%)	1,087 (24%)	4,105 (38%)
Air-to-Water*	544 (1%) (one site*)		38 (1%) (one site*)		132 (1%) (one site*)	

* Only one of the two sites with an air-to-water heat pump had sufficient data to report on this.

Note: "All" groupings exclude WH-01, -03, -05, -09 through -12, and -18 which did not have sufficient data or CSA F280 values; "Operated as Intended" groupings exclude WH-01, -03, -05, -08 through -14, and -18 which did not have sufficient data, CSA F280 heating load values, or did not operate as intended.

Sites with electric baseline systems had consistent percentage savings across energy consumption, greenhouse gas emissions, and utility costs, while sites that switched from oil- or propane-fuelled baseline systems to electric heat pumps achieved higher percentage emission savings due to the relatively clean electricity grid in Yukon. However, these systems had lower percentage savings in, and in some cases, higher utility costs due to electricity being more expensive (on a $/ekWh consumption basis) than heating oil and propane.

WH-14 was not operating as intended and thus used more energy to operate the heat pump systems compared to the baseline systems (in ekWh) at outdoor temperatures below -22°C, which resulted in net increases in utility costs at these sites. This is consistent with the performance of the system shown in Figure 3.7, where average COP falls below 1 in outdoor temperatures below around -13°C. Systems that operated as intended generally achieved higher savings.

Overall, the heating systems spend more time operating at more moderate temperatures (above -10°C per Figure 3.13) in the southern Yukon climate, and thus all sites that could be assessed for savings achieved net energy and emissions savings, and most achieved utility cost savings through a heat pump retrofit.

4. Summary of Findings

This report includes results from data collected between April 1, 2024 until equipment removal at the end of March 23, 2025 (approximately 12 months).

Comments on Overall Efficiency of Heat Pumps in the Southern Yukon

When considering the three major system types included in this study (ductless, central ducted, and air-to-water):

- On average, the ductless heat pump systems (i.e. mini-splits and multi-splits) that were operating as intended were able to achieve COPs of approximately 2.4 at an outdoor ambient temperature of -20°C, and COPs of approximately 3.6 at outdoor ambient temperature of 0°C. These systems also tended to have measured SCOPs within the ballpark of the manufacturer rated SCOPs; an average measured SCOP of 3.2 for ductless systems operating as intended was observed.
- On average, the central ducted heat pump systems that were operating as intended were able to achieve COP of approximately 1.1 at -25°C and approximately 2.4 at 0°C. An average measured SCOP of 1.8 was observed for ducted systems that operated as intended. These did not perform quite as closely to rated SCOP values as the ductless systems; however, they also were operating at lower average outdoor air temperature over the monitoring period than the ductless systems.
- The COP of the air-to-water heat pump system (WH-17) was approximately 0.9 at -10°C and approximately 1.8 at 0°C. The measured SCOP for this system was reported as 1.1.

When considering the suitability of different system types, as there were fewer central ducted and air-to-water systems included in the study compared to ductless, the results for those are not as statistically robust as for the ductless heat pump systems.

Comments on the Variables Associated with Equipment Functioning Below their Rated Efficiency

The following are reasons why certain systems did not appear to be performing as well as others:

1) **Refrigerant leaks or low refrigerant levels** – Based on discussions with participants, we suspect that installers did not consistently verify that systems were fully charged at commissioning. Low refrigerant levels were reported at a minimum of two sites. In addition, refrigerant leaks were confirmed at least at two other locations. While these leaks were repaired, the fixes occurred only after homeowners reported performance issues. A lack of sufficient refrigerant reduces the system's ability to transfer heat, leading to diminished heating (or cooling) capacity and overall lower system efficiency.
2) **Clogged filters** – Clogged filters were observed at several sites. Restricted airflow through the system increases static pressure, reduces heat exchange efficiency and overall performance. Although this was observed during equipment removal by RDH in March 2025 (outside the official reporting period), it is likely that clogged filters were already affecting system performance during both heating seasons. Several participants indicated they were unaware that regular filter cleaning was necessary, suggesting a knowledge gap in routine maintenance requirements.
3) **Faulty equipment or improper commissioning** (e.g. faulty temperature sensors) – For example, in at least one instance, a temperature sensor malfunction led to the heat pump consistently shutting down at –16°C, despite being rated for colder conditions. Equipment-related issues can significantly compromise performance, particularly during peak demand periods.
4) **Proximity of indoor systems** – For example, at one site (WH-10), it was reported that the indoor heads were installed too close to one another, resulting in overlapping coverage zones. This may have caused the units to compete, reducing system efficiency and comfort.

Energy, Emissions and Financial Savings of Homes with Heat Pumps

The savings calculations (energy, emissions, and financial) demonstrated appreciable savings when a heat pump system was operating as intended Table 4.1.

TABLE 4.1 AVERAGE ANNUAL ENERGY, EMISSIONS, AND FINANCIAL SAVINGS FOR SITES WHERE SYSTEMS OPERATED AS INTENDED

Type	Average Energy Savings [ekWh] (%)	Average GHG Emissions Savings [$kgCO_2e$] (%)	Average Utility Cost Savings [$] (%)
Ductless	17,243 (44%)	4,268 (49%)	2,871 (40%)
Central Ducted	28,238 (45%)	6,814 (66%)	4,105 (38%)
Air-to-Water	544 (1%) (one site*)	38 (1%) (one site*)	132 (1%) (one site*)

* Only one of the two sites with an air-to-water heat pump had sufficient data to report on this.

Note: "Operated as Intended" groupings exclude WH-01, -03, -05, -08 through -14, and -18 which did not have sufficient data or did not operate as intended.

Participant Satisfaction

- When systems were properly commissioned, participants were generally very satisfied with their heat pump performance. On average, users reported positive experiences, particularly regarding comfort, energy savings and reduced reliance on supplemental heating (e.g. wood stove).
- A knowledge gap exists among homeowners regarding the operation and maintenance of their systems. Several participants were unaware of the need to clean filters regularly and expressed uncertainty about how to operate or adjust system settings. Despite this, many homeowners demonstrated a strong willingness to learn.
  This presents an opportunity for industry stakeholders or government bodies to provide targeted homeowner education, such as workshops, webinars, or user-friendly guides, to improve confidence and system performance through better-informed usage.
- Multiple participants reported challenges in finding qualified service providers. In one case, a homeowner contacted several companies before finding one willing to inspect their system. There is a clear opportunity to support homeowners post-installation by offering access to a directory of qualified service providers (and by providing contractor training to provide this service), and/or by encouraging contractors to offer follow-up service visits. Including this kind of support as part of rebate or incentive programs could improve long-term satisfaction and system upkeep.

5. Closure

In all, the results suggest that cold climate air-source heat pumps have the potential to serve as the primary heating technology for heating in the Yukon and other subarctic regions, provided the equipment is properly commissioned and some form of supplemental heating can be provided during periods below the heat pump's rated outdoor operating conditions.

We trust this report adequately summarizes the results of the cold climate heat pump study in Yukon. Please contact the undersigned should you require further information.

Yours Truly,

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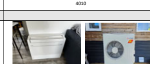
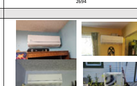
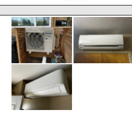
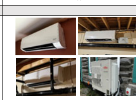
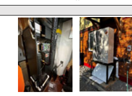
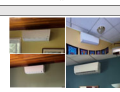
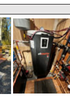
Appendices

Appendix A - Site Information

Appendix A summarizes key site information for WH-01 through WH-18.

Site ID	WH-01	WH-02	WH-03	WH-04	WH-05	WH-06	WH-07
Site Form Created By	CM	CM	CM	CM	CM	CM	CM
Occupations	full-time	full-time	Maternity Leave - WFH 2 Day/week	full-time		full-time	
Daytime Occupants	0	0	1	0	4 days/week in town	1.5	1
Type of home	Single family home	Single family home	Townhouse	Single family home	Single family home	Single family home	Single family home
Appx. Home Floor Area (ft^2)	1500	2500	1800	2500	820	2200	2000
Number of Floors	2.5	2		2	1	2	
Approx. Year of Construction	1978	2005	2017	1996		2018	1965
Wall Framing Type			2x6		2x6		2x4
Window Panes	double	triple	triple	double & triple	triple	triple	double & triple
Air Tightness	poor		good	good	good	good	poor
Air tightness Value (ACH)	6.5		1.5				
Ventilation Strategy		HRV	HRV		HRV	HRV	
High Performance Features	roof upgrade	ETS					
Thermostat		3 living zone thermostats		1 thermostat on second floor (in the main living area)	1 zone	5 zone thermostats (3 bedrooms, kitchen/living/dining, basement living room) some thermostats in bathrooms but they can be excluded	
HEAT PUMP SYSTEM DESCRIPTION							
Heat Pump System Type	ductless minisplit	ductless multi-split	ductless multi-split	central ducted	ductless minisplit	ductless multi-split	ductless multi-split
Number of Outdoor Units	1	1	1	1	1	1	2
Number of Indoor Units	1	3	3	N/A	1	2	3
Outdoor Unit 1 Make		Daikin	Fujitsu	Mitsubishi	Mitsubishi	Panasonic	Senville
Outdoor Unit 1 Model	SENA/24H/IF	3MXL24RMJUA, 24000 Btu 3 Head	AOU 24 (RLXFZ or RLXFZH)	Zuba 42 with built-in resistive backup	MUFZ-KJ18NAHZ-U1	CU-3E19RBU-5	SENA/18HF/MOZ
Outdoor Unit 2 Make							Senville
Outdoor Unit 2 Model							SENA/12HF/OZ
Indoor Unit 1 Make	Senville Aura 24,000 BTU, 1 zone hp	Daikin	Fujitsu	Mitsubishi	Mitsubishi	Panasonic	Senville
Indoor Unit 1 Model	SENA/24H/IF	FTXR09TVJUW - Daikin 9000 Head - emura	ASU7RLF1	PVA-A42AA7	MFZ-KJ18NA-U1	CS-XE12WKUAW	SENA/09HF/IZ
Indoor Unit 2 Make			Fujitsu			Panasonic	Senville
Indoor Unit 2 Model		CTXS07LVJU - Daikin 7000 Head	ASU12RLF1			CS-XE9WKUAW	SENA/09HF/IZ
Indoor Unit 3 Make		Daikin	Fujitsu				Senville
Indoor Unit 3 Model		FVXS09NVJU - Daikin 9000 Head Floor Mounted	ASU7RLF1				SENA/12HF/IZ
Indoor Unit 4 Make							
Indoor Unit 4 Model							
Outdoor Unit 2 Make							
Outdoor Unit 2 Model							
Electric Distribution	1 panel	1 panel	1 panel	2 panels	1 main, 1 sub	1 panel	1 main 3 sub
BACKUP SYSTEM DESCRIPTION							
Backup Heating System	Electric baseboards and wood stove	Electric thermal storage and electric baseboards	Electric baseboard, 2 resistive electric unit heaters with fans	Electric coil	Electric baseborads and wood stove	Electric baseboards, in-floor heating	Electric baseboard, wood stove, electric unit heaters
~ Cords of Wood per Year	1-1.5				2.5		1.5 (from 3 pre-heat pump)
~Oil (L) per Year							
Backup Cooling System	HP - barely used	N/A				N/A	
Notes on previous heating and cooling equipment	Oil furnace (HP replaced this system)	Oil stove (HP replaced this system)	Baseboards	Propane furnace		Baseboards	Oil furnace (removed)
CONTROL SETUP DESCRIPTION							
Heat Pump Control Specifications	Always Auto	ETS set below HP control temp.			Auto	Auto fan, app on phone	Auto
Control Setup	Set to Auto Hot - higher than baseboards HP (primary), BB (secondary)	Auto - only temp up and down	Auto setpoint values	Thermostat set at 20.5°C always	Heat, cool sometimes, fan was set to low during site visit		
COMMENTS FROM HOMEOWNERS							
Heat Pump Sizing Calculations	No, Selected unit to replace Oil furnace. Sized based on "biggest unit they could get"	- Contractor suggested size - Energy audit	Energy assessment	- Don't know how heat pump was sized - Energy audit - Installed larger unit because they thought it would run less often	Don't know how the heat pump was sized, but provided contractor with floor plans	- Sizing calculated based on plans	- Energy Audiit - NRCAN spreadsheet
Comments on Performance (from site visit in 2023)	Working great. Happy with performance.	Good performance.	Awesome	- Heating performance is good - Constant temperature is comfortable	Ok.	Great	Great
General Comments (from site visit in 2023)	- Use 1-1.5 Chords of Wood (upstairs) - HP opperates down to -30°C, shuts off below - Lots of defrost below -30°C - Little to no ice build up below -30C - Electricity bill has not gone up much	- Like the heat quality - not dry. - Quieter than oil, - No smell vs oil, - Outdoor unit looks nicer, - No oil truck	- Working Below -30C - Lower bills - Fujitsu has coldest performance vs Mitsubishi - Upstairs unit is a bit loud but adjusting refrigerant made it a bit better (more than specified for the lines). "like water in lines"	- Windows (triple glazed) installed the year before HP - Outdoor unit bit loud in cold (next to bedroom + 1 floor below) - Originally forgot to set/program backup, now it's set to turn on at -28°C - Lower heating bill (vs. propane bill) - Big issue with ice build up under outdoor unit	- Louder than they wanted (indoor and outdoor) - Temperature management isn't as expected - Set at 16°C, unit still working ~23°C (above setpoint temp) - Little loud (especially outdoor unit when it's cold)	Response time is a bit slow	- Air-Source HP sizing and selection tool +(NEEP) - Wood Stove (from 3 to 1.5 chords due to HP) - Need calculations (NRCan tool) for incentives - Runs to minimum outdoor temp. of -38°C and ~ -34°C (not much heat output by HP), ~ at -35°C producing heat, but need to supplement with baseboard or wood stove
General Comments (from site visit in 2025 at time of monitoring equipment removal)	- Heat pump is working well - Electric baseboard is used for supplement - Because HP is located in entryway, sometime the entryway get's very warm	- Filters were clean - Red light" on living room unit - Looking for someone to service - Winter heat pump vs ETS usage is 80:20 - Had oil before - Gap in home owner appliance knowledge - Homeowner would like quick reference guide for heat pump operation & maintenance	- Filter in basement & upstairs bedroom clean - Filter for "B" in living room a little dirty. Owner said this filter is also regularly cleaned every 1000hr of operation. Extra dirt is likely due to higher level pollutant, kitchen, etc. - Winter 2023/24 mostly on - Winter 2024/25 did not turn off - Around -26 deg celsius heat pump performance is okay - Between -26deg and -38deg, 2/3 no heat pump, more electric baseboards - Heat pump used for cooling in summer - Negative feedback on installer - Initially outdoor unit installed against external wall on L-bracket - very noisy, owner built a stand out of lumber, a few inches away from the wall Heat pump was still noisy, owner researched potential source of sound; flashing, uninsulated line. Insulating helped a little. Flashing would contribute to loss of efficiency. - If owner was to do again: floor unit for basement, living/main ducted (for better mixing)	- Owned home for 17-20 years, mainly used propane until heat pump - Wished installer would have mentioned how loud the outdoor unit is - Defrost cycle would result in ice build-up below outdoor unit - West facing large window but heat pump not used for AC (open window) - Dirty filter	- Indoor unit louder than expected - Installed by HVAC North (Dillan) - Middle of night: noise, vibration, rattling sound from indoor unit (cyclic) - Filter was okay, some dust - Uses HP for cooling in summer: helps keep house cool - Never shown how to properly use the control - Auto setting: inefficient heat - Intentionally turn heat pump off when temperature is expected <-22deg celsius	- Heat pumps are operating well, although sometimes the thermostat thinks that the temperature upstairs is 30 deg C (and it's actually below 20 degC) - Participants use their heat pumps for cooling throughout the summer.	- Heat pumps running all the time, otherwise baseboards kic in. Wood stove supplement. - Manufacturer warranty is lacking (e.g. contractor may be subsidized $60/hr for repair, but the going rate for the specialized labor is > $100/hr), so then contractor (or owner) ends up paying out of pocket for labor.
Missing data in 2024/2025 Report period	System consumption data (50A CT) were corrupt after November 27, 2024; only a very limited number of heating data points during a limited range of outdoor temperatures were available.	Missing data at indoor head B between June 27 and August 29, 2024 (battery failure).	Missing data at indoor head A between June 17 and Aug. 22, 2024 (battery failure). Missing data at indoor head C between June 6 and July 13, 2024 (battery failure). Data for indoor head B after November 23, 2024 were omitted due to faulty sensor readings; only a limited number of heating data points during a limited range of outdoor temperatures were available.	n/a	n/a	Homeowner unplugged 50A CT logger on Jan. 18, 2024, plugged it back on May 6, 2024 and then unplugged it again on November 20, 2024. Missing data at indoor head A between July 23 and Aug. 30, 2024 (battery failure).	n/a
SUMMARY OF PERFORMANCE							
Heating SCOP	n/a	3.2	2.6	2.0	2.8	3.7	2.8
HSPF	n/a	10.9	8.9	6.8	9.7	12.6	9.7
COP at -15°C	n/a	2.3	2.0	1.6	2.7	2.8	2.4
Rated SCOP	**2.9**	2.8	2.9	2.7	3.0	3.0	2.7
Rated HSPF2 (Region 4)	**9.8**	9.7	10.0	9.3	10.3	10.1	9.1
Average Outdoor Temperature [°C]	n/a	-6.9	-1.7	-7.4	-2.7	3.0	-6.1
Heating Hours	0	2749	805	3452	3175	1631	4767
Concurrent Heating and Defrost Hours	0	1115	59	289	274	31	0
Defrost Hours	299	197	40	113	14	4	0
Cooling Hours	0	0	0	0	89	0	0
Off Hours	2	0	17	0	1556	6	4
Fan Only Hours	6876	2763	2774	4315	3216	4801	771
Valid Data Hours	7177	6823	3694	8169	8324	6472	5542
Missing Hours	1391	1745	4874	399	244	2096	3026
HP Heating Hours	0	2749	805	3448	3175	1631	4767
Concurrent HP and Int. Supp. Heating Hours	n/a	n/a	n/a	3	n/a	n/a	n/a
Integrated Supplemental Heating Hours	n/a	n/a	n/a	0	n/a	n/a	n/a
Insitu Balance Point Temperature [°C] - *estimated as intersect of max. measured heat output and heating demand (Appendix D)*	n/a	-18	n/a	-20	n/a	-23	-10
Design Outdoor Temperature for Heating [°C]	-41	-41	-41	-41	-41	-41	-41
F280 Design Heating Load (KW) - provided by Yukon Gov.	No known assessment done	9.6	No known assessment done	13.5	No known assessment done	6.0	19.8
Design Heating Load at Design Outdoor Temperature per EnerGuide Evaluation [kW]	n/a	9.12	n/a	14.85	n/a	5.47	21.00
Baseline Heating System	Oil Furnace	Oil Stove	Elec. Baseboard	Propane Furnace	Elec. Baseboard, assumed	Elec. Baseboard, assumed	Oil Furnace
Baseline Heating Energy Consumption [ekWh/year]	Not calculated	33281	Not calculated	50142	24353	13534	30827
Post-Retrofit Heating Energy Consumption [ekWh/year]	Not calculated	7490	Not calculated	14828	7775	4313	8853
Heating Energy Savings [ekWh/year]	Not calculated	25791	Not calculated	35314	16577	9313	21974
Baseline Heating GHG Emissions [kgCO2e/year]	Not calculated	8990	Not calculated	10920	1705	947	8327
Post-Retrofit Heating GHG Emissions	Not calculated	524	Not calculated	1131	544	302	620
Heating GHG Emission Savings	Not calculated	8466	Not calculated	9789	1160	645	7708
Baseline Heating Utility Cost	Not calculated	5221	Not calculated	6858	5891	3274	4836
Post-Retrofit Heating Utility Cost	Not calculated	1812	Not calculated	3907	1881	1043	2142
Heating Utility Cost Savings	Not calculated	3409	Not calculated	2951	4010	2231	2694
HEAT PUMP SYSTEM PHOTOS							
							

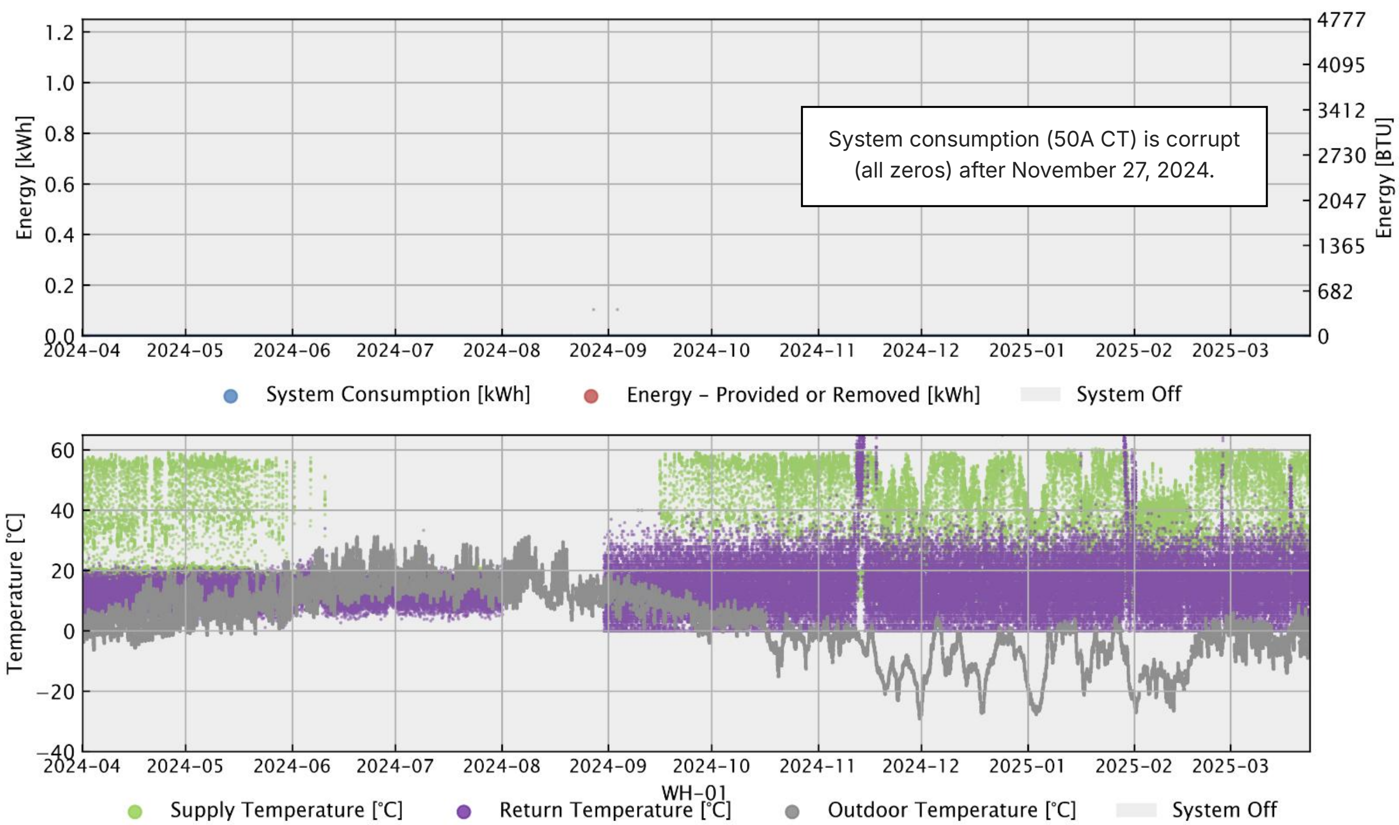
Site ID	WH-08	WH-09	WH-10	WH-11	WH-12	WH-13	WH-14
Site Form Created By	CM	CM	CM	CM	CM	CM	CM
Occupations	full-time		part-time	full-time	retired		
Daytime Occupants	0	1 summer/ 0 winter	0.5	1.5	2	1	2
Type of home	Duplex	Single family home	Duplex	Single family	Single family	Single family	Single family
Appx. Home Floor Area (ft^2)	1750	1400 (although heated floor space is 2800 because crawlspace is heated)	850	1800		2000	3000
Number of Floors			1.5	1	3	1	3 (including loft)
Approx. Year of Construction	2004		1965	2004	1920	1987	1998
Wall Framing Type	2x6		2x4		log		
Window Panes	quad	triple	triple	double	triple + storm (3 years)	quad	triple
Air Tightness			average				good
Air tightness Value (ACH)			0.54 GJ/m^2/yr, 5.57 ACH50				
Ventilation Strategy		HRV	HRV			HRV	HRV
High Performance Features	- Quad panes installed Sept 2021 - Solar Panels			ETS	Solar Array		
Thermostat	2 living zone thermostats	3 bedroom thermostats The kitchen, dining and living room is one big open space, with 3 electrical thermostats and the heat pump is located in the middle (dining room) – We can choose one to monitor (likely the living room sensor)	1 thermostat in the open kitchen/dining/living room (none in the bedrooms or bathrooms)				
HEAT PUMP SYSTEM DESCRIPTION							
Heat Pump System Type	ductless multi-split	ductless multi-split	ductless multi-split	ductless multi-split	ductless multi-split	ductless multi-split	central ducted
Number of Outdoor Units	1	1	1	1	1	1	1
Number of Indoor Units	2	3	2	3	3	3	N/A
Outdoor Unit 1 Make	Panasonic RAC Multi E	Daikin	Panasonic	Fujitsu	Fujitsu	Daikin	Mitsubishi
Outdoor Unit 1 Model	CU-3E19RBU-5	4MXL36TVJU	CU-3E19RBU-5	AOU36RLXFZH	Unconfirmed - Note: Multiple compatible outdoor units for indoor heads	3MXL24RMVJUA	PUZ-HA42NKA1
Outdoor Unit 2 Make							
Outdoor Unit 2 Model							
Indoor Unit 1 Make	Panasonic	Daikin	Panasonic	Fujitsu	Fujitsu	Daikin	Mitsubishi
Indoor Unit 1 Model	CS-E12RB4UW	FTXR18LVJUW	CS-XE12WKUAW	ASU18RLF	ASU12RLF1	FTXR12TVJUS	PVA-A42AA7-1
Indoor Unit 2 Make	Panasonic	Daikin	Panasonic	Fujitsu	Fujitsu	Daikin	
Indoor Unit 2 Model	CS-XE9WKUAW	FTXS18TVJUW	CS-ME7RKUA	ASU9RLF1	ASU12RLF1	FTXR18TVJUS	
Indoor Unit 3 Make		Daikin		Fujitsu	Fujitsu	Daikin	
Indoor Unit 3 Model		CTXS07LVJU		ASU9RLF1	ASU12RLF1	CTXS07LVJU	
Indoor Unit 4 Make							
Indoor Unit 4 Model							
Outdoor Unit 2 Make							
Outdoor Unit 2 Model							
Electric Distribution	1 panel	1 panel	2 panels				
BACKUP SYSTEM DESCRIPTION							
Backup Heating System	Propane furnace	Propane fireplace (only for power outages), electric baseboards	Oil boiler	3 electric thermal storage (ETS), 1 wood stove	2 oil heaters, 1 wood stove	Wood stove and 3 electrical baseboards	Wood stove
~ Cords of Wood per Year				3-4	4	5	3-4
~Oil (L) per Year					1200-1400		
Backup Cooling System	Auto -> furnace @ lower set point		Oil water boiler				
Notes on previous heating and cooling equipment	Propane furnace	Propane fireplace + baseboards		Oil Stove (removed)		Oil Monitor (removed)	Oil Furnace (removed)
CONTROL SETUP DESCRIPTION							
Heat Pump Control Specifications		Scheduling	Separate thermostats (oil lower)	Fan only on for cooling during summer	Mostly Auto	Auto mainly ~ 20°C at night	Haven't Used
Control Setup				Auto			
COMMENTS FROM HOMEOWNERS							
Heat Pump Sizing Calculations	Participant doesn't recall if any sizing was done			Energy audit	Yes		Yes
Comments on Performance (from site visit in 2023)	Like it	Fantastic, air comfy/warm	Ok (see notes)	Great, love the cooling	Exceptionally pleased	Great. Approx. $100 extra per month, but less wood	Haven't really used yet (just installed), have only used cooling
General Comments (from site visit in 2023)	- Propane in 2017 cost approximately $2000-2500 - Heating costs lower after HP install - Wanted to keep furnace - Panel upgrade would be ~10k - ~$12k all in from install - Rebates from Greener Homes Rebate and Yukon Government - Outdoor unit loud (quad pane windows helps) - Lots of condensation + ice on outdoor unit	- Scheduling set to: 18°C, 23°C, 18°C, 24°C (on,on,on,on) - Crawlspace has a HP to heat floors, Don't have to use main HP as much - Garage has HP	- Issue, 2 units compete (close in proximity) - HP best for shoulder season - Use water boiler only below -20°C to avoid water freezing - Not a lot of guidance from installer - Shocked about where unit was installed and height of install (wish unit was installed somewhere else) - Don't find unit loud	1 issue with water pooling on indoor head in cooling (but fixed)	- Reduction of oil was ~90% (very happy with this) - Little to no water build up - Heat down to -30°C /-35°C		
General Comments (from site visit in 2025 at time of monitoring equipment removal)	- External unit was leaking refrigerant. - Relied on propane furnace the winter of 24/25. -The warranter had limited support. - Downstairs stays colder and upstairs says warmer.	- Heat pumps working well (1 in crawlspace, 1 in garage, and 1 in living room). - He cleaned his filters (noticed that the one in his living room was much dirtier)	- Owner bought the house ~1.5 years ago - Tenant moved in August 2024 - Tenant had electric baseboard before, and had never used heat pump - Tenant was not shown or explained how to use heat pump - Tenant used oil for heating 2024/2025 winter	- There was a leak in the line for living room unit, issue was noticed when space cooling was turned on & addressed before the summer - When outdoor temp was expected to be <-25deg celsius, homeowner proactively turned heat pump off	- Heat pump installed Oct 2022 - Before heat pump: Toyo oil heater - Heat pump much better than oil - After heat pump install, used about ~179L of oil between May 2024-March 2025. - Before heat pump, oil delivery every month in winter - Upstairs/dining filter dirty - Downstairs filters clean - Used for cooling summer - Did not understand the remote/control -20deg celsius was heat pump's lower limit & too cold. In 2024/2025 was finally able to increase temperature. - Solvest installed solar panels July 2023 July 21/22 vs 22/23: 40% kWh decrease Heat pump increase 22% kWh	- Issue with heat pump from day 1 - Daikin distributor/supplier issue ie. wrong parts for repair/fix sent - Issue: outdoor temp sensor is likely faulty & turning heat pump off at around -16deg celsius outdoor temp - Below -16deg celsius, wood stove is being used - Before heat pump: wood stove mid Oct to end of April - After heat pump: end of Nov to end of March - 30% reduction firewood usage - cooling used in summer	- Replaces filter proactively (July 4, Oct 14, March 2025) - Uses cooling sometimes - Often turn heat pump off during the day - Backup is off unless cold spell is expected - Uses HRV: upgraded ducting for efficiency - Paul Savage helped with HRV/heat pump setup, provided quick reference guide for homeowner operation - Wish that heat pump setting would go below 17deg celsius (would like 15deg) - Lots of solar heat gain
Missing data in 2024/2025 Report period	Missing data at indoor head A between June 9 and Aug. 29, 2024 (battery failure).	System consumption data (50A CT) were corrupt, preventing reliable COP calculation for this site.	The participant withdrew from the study in October 2023.	Missing data at indoor head A between March 28 and Aug. 12, 2024 (battery failure). Missing data at indoor head B between March 26 and August 16, 2024 (battery failure). Missing data at indoor head C between April 18 and August 19, 2024 (battery failure). 50A CT outdoor unit data logger unplugged June 8, 2024 and plugged back in on August 8, 2024.	Data for indoor heads A and C were missing after April 2 and November 4, 2024, respectively (battery failure). Data for indoor head B was missing between January 13 and 15, 2024 (battery failure).	Data for indoor heads A, B, and C were missing after August 10, 2024 August 11, 2024 and November 26, 2024, respectively. Data for indoor head A was also missing between March 28 and April 11, 2024. Homeowner unplugged 50A CT outdoor unit data logger on June 19, 2024, plugged it back in on Aug. 21, 2024, and unplugged again on Feb. 14, 2025.	n/a
SUMMARY OF PERFORMANCE	te						
Heating SCOP	1.6	n/a	n/a	2.1	n/a	2.3	1.1
HSPF	5.5	n/a	n/a	7.1	n/a	8.0	3.8
COP at -15°C	1.0	n/a	n/a	1.6	n/a	n/a	1.0
Rated SCOP	3.0			2.8	2.8	2.8	2.7
Rated HSPF2 (Region 4)	10.1			9.5	9.5	9.7	9.3
Average Outdoor Temperature [°C]	-3.3	n/a	n/a	-3.7	n/a	4.7	-10.7
Heating Hours	2304	0	0	494	36	49	578
Concurrent Heating and Defrost Hours	178	0	0	20	0	1	48
Defrost Hours	228	327	0	63	0	12	30
Cooling Hours	0	0	0	0	0	0	12
Off Hours	700	3	0	0	0	0	6
Fan Only Hours	3011	7401	0	4408	10	1540	7679
Valid Data Hours	6421	7731	0	4985	46	1602	8354
Missing Hours	2147	837	8568	3583	8522	6966	214
HP Heating Hours	2482	0	0	494	36	49	560
Concurrent HP and Int. Supp. Heating Hours	n/a	n/a	n/a	n/a	n/a	n/a	1
Integrated Supplemental Heating Hours	n/a	n/a	n/a	n/a	n/a	n/a	17
Insitu Balance Point Temperature [°C] - *intersect of max. measured heat output and heating demand (Appendix D)*	-9	n/a	n/a	n/a	n/a	< -7 (not observed)	-12
Design Outdoor Temperature for Heating [°C]	-41	-41	-41	-41	-41	-41	-45
F280 Design Heating Load (KW) - provided by Yukon Gov.	7.7	7.3	13.7	No known assessment	No known assessment	10.1	11.6
Design Heating Load at Design Outdoor Temperature per EnerGuide Evaluation [kW]	7.29	6.78	15.37	n/a	n/a	9.48	2.25
Baseline Heating System	Propane Furnace	Elec. Baseboard, assumed	Oil Boiler, assumed	Oil Stove	Oil Furnace, assumed	Oil Furnace, assumed	Oil Furnace
Baseline Heating Energy Consumption [ekWh/year]	27841	Not calculated	Not calculated	17951	27048	40051	46426
Post-Retrofit Heating Energy Consumption [ekWh/year]	23205	Not calculated	Not calculated	7668	6871	12518	37359
Heating Energy Savings [ekWh/year]	4636	Not calculated	Not calculated	10283	20177	27533	9067
Baseline Heating GHG Emissions [kgCO2e/year]	6063	Not calculated	Not calculated	4849	7306	10819	12541
Post-Retrofit Heating GHG Emissions	4386	Not calculated	Not calculated	537	481	876	6134
Heating GHG Emission Savings	1676	Not calculated	Not calculated	4312	6825	9943	6407
Baseline Heating Utility Cost	3808	Not calculated	Not calculated	2816	4243	6283	7283
Post-Retrofit Heating Utility Cost	3648	Not calculated	Not calculated	1855	1662	3028	7542
Heating Utility Cost Savings	160	Not calculated	Not calculated	961	2581	3255	-259
HEAT PUMP SYSTEM PHOTOS							
							

Site ID	WH-15	WH-16	WH-17	WH-18
Site Form Created By	CM	CM	CM	CM
Occupations	Homeowner not home at time of visit		Homeowner not home at time of visit	
Daytime Occupants		1.5		0
Type of home	Single family			
Appx. Home Floor Area (ft^2)		2000		2700
Number of Floors				2
Approx. Year of Construction		1990		
Wall Framing Type				
Window Panes		triple		double
Air Tightness				
Air tightness Value (ACH)				
Ventilation Strategy		HRV		HRV
High Performance Features		ETS		
Thermostat				
HEAT PUMP SYSTEM DESCRIPTION				
Heat Pump System Type	central ducted	ductless multi-split	air-to-water	air-to-water
Number of Outdoor Units	1	1	1	1
Number of Indoor Units	N/A	4	N/A	N/A
Outdoor Unit 1 Make	Mitsubishi	Fujitsu	Arctic	Maritime Geothermal
Outdoor Unit 1 Model	PUZ-HA42NKA1	AOU36RLXFZH	MACRW060ZA/(BE)	ACE-65/75-P-1/6-KDE-08
Outdoor Unit 2 Make				
Outdoor Unit 2 Model				
Indoor Unit 1 Make	Mitsubishi	Fujitsu	Arctic	Thermo2000
Indoor Unit 1 Model	PVA-A**24**AA7-1	ASU12RLF1	ARC80	ALTSOURCE 70-15 CA-E
Indoor Unit 2 Make		Fujitsu		
Indoor Unit 2 Model		ASU9RLF1		
Indoor Unit 3 Make		Fujitsu		
Indoor Unit 3 Model		ASU9RLF1		
Indoor Unit 4 Make		Fujitsu		
Indoor Unit 4 Model		ASU9RLF1		
Outdoor Unit 2 Make				
Outdoor Unit 2 Model				
Electric Distribution				
BACKUP SYSTEM DESCRIPTION				
Backup Heating System	Wood furnace	ETS, propane fireplace, wood stove	Electric boiler and wood stove	Wood stove
~ Cords of Wood per Year		0	0.5-1	3 to 4
~Oil (L) per Year				
Backup Cooling System				
Notes on previous heating and cooling equipment		Baseboards + Propane Fire Place		Oil Boiler/Wood Stove
CONTROL SETUP DESCRIPTION				
Heat Pump Control Specifications				
Control Setup				
COMMENTS FROM HOMEOWNERS				
Heat Pump Sizing Calculations	Homeowner not present		Homeowner not present	
Comments on Performance (from site visit in 2023)	None. Homeowner not present	None.	None. Homeowner not present	Not sufficient last year
General Comments (from site visit in 2023)	Homeowner not present	- Unit mounted to exterior wall, very noisy, forced to turn off at night - Installer will build standalone support for outdoor unit	Homeowner not present	Last year did not heat well enough, had to increase boiler temperature for this year
General Comments (from site visit in 2025 at time of monitoring equipment removal)	- Filter okay, much better than how dirty it was during sensor install - Heat pump is a lot better than propane Installed wood furnace to have backup energy source for heating - Midnight Sun installed but Paul Savage noticed control was not set up properly during wood furnace commissioning - Once heat pump was running properly, homeowner spoke highly of heat pump & Paul	- Not happy w/ installation/service - Would not recommend original installer. - Generally happy with heat pump, some noise issue - Filters were clean - Typically, intentionally turn heat pump off when temperature is expected < -25deg celsius - Tried operating at ~-30deg, interested in data to see how efficient at that temp Generally, did not notice short-cycling	No feedback available.	- Not the homeowner when sensor was installed (moved in July 2024) - New to heat pump but seeemd heat pump didn't work well - Previous owner didn't really notice the difference installing heat pump to existing hydronic heating system - First issue: low pressure & constant defrost cycle. Line had 2lbs and needed 6lbs (not confirmed) - Neighbour had Paul working on their HVAC, so homeowner asked Paul to come over and Paul commented on low refridgerant level and control not being wired correctly. - Also temperature sensor for glycol (hydronic) was reading wrong. - When heat pump/heating system was working as it should, they saw 20% decrease in energy bill. - Homeowner usually turns backup heat for heat pump off at the breaker - They are generally happy with heat pump but some learning curve (never had heat pump before) - They are looking to add (wood) fire, just to have another source of heat
Missing data in 2024/2025 Report period	Indoor head fan consumption data (5A CT, proxy for airflow rate) were corrupt; however, there was only one fan setting and corresponding airflow rate for this system.	Data acquisition system was unplugged by homeowner on April 26, 2024. Homeowner was also turning off the monitoring equipment overnight, resulting in loss of approximately 25% of the data on daily basis when data acquisition system was still on. Data acquisition system was plugged back in on 11/17 but batteries for battery-powered equipment had already failed.	n/a	System 200A CT (supplemental) is always reported as zero, which means that output cannot be subtracted from HP output to calculate COP. HP system consumption (50A CT) and flow gauge were unplugged on Dec. 22, 2024.
SUMMARY OF PERFORMANCE				
Heating SCOP	1.7	4.0	1.1	n/a
HSPF	5.6	13.5	3.8	n/a
COP at -15°C	1.2	n/a	n/a	n/a
Rated SCOP	2.7	2.8	2.7	2.7
Rated HSPF2 (Region 4)	9.3	9.5	n/a	n/a
Average Outdoor Temperature [°C]	-7.1	2.7	0.3	n/a
Heating Hours	2923	183	425	245
Concurrent Heating and Defrost Hours	198	6	0	0
Defrost Hours	150	1	0	0
Cooling Hours	605	0	0	0
Off Hours	4453	0	6329	3443
Fan Only Hours	0	69	0	0
Valid Data Hours	8329	259	6753	3688
Missing Hours	239	8309	1815	4880
HP Heating Hours	2923	183	182	244
Concurrent HP and Int. Supp. Heating Hours	0	n/a	84	0
Integrated Supplemental Heating Hours	0	n/a	159	1
Insitu Balance Point Temperature [°C] - *intersect of max. measured heat output and heating demand (Appendix D)*	-11	n/a	9	n/a
Design Outdoor Temperature for Heating [°C]	-41	-41	-41	-41
F280 Design Heating Load (KW) - provided by Yukon Gov.	8.8	14.1	report but no MEX, searching for the file	13.6
Design Heating Load at Design Outdoor Temperature per EnerGuide Evaluation [kW]	9.69	14.94	17.27	14.55
Baseline Heating System	Elec. Baseboard, assumed	Elec. Baseboard, assumed	Elec. Boiler, assumed	Oil Boiler
Baseline Heating Energy Consumption [ekWh/year]	28824	25957	7810	Not calculated
Post-Retrofit Heating Energy Consumption [ekWh/year]	13030	8055	6785	Not calculated
Heating Energy Savings [ekWh/year]	15794	17903	1025	Not calculated
Baseline Heating GHG Emissions [kgCO2e/year]	2018	1817	547	Not calculated
Post-Retrofit Heating GHG Emissions	926	564	479	Not calculated
Heating GHG Emission Savings	1091	1253	68	Not calculated
Baseline Heating Utility Cost	6973	6279	1889	Not calculated
Post-Retrofit Heating Utility Cost	3201	1948	1655	Not calculated
Heating Utility Cost Savings	3772	4331	235	Not calculated
HEAT PUMP SYSTEM PHOTOS				
			 	 

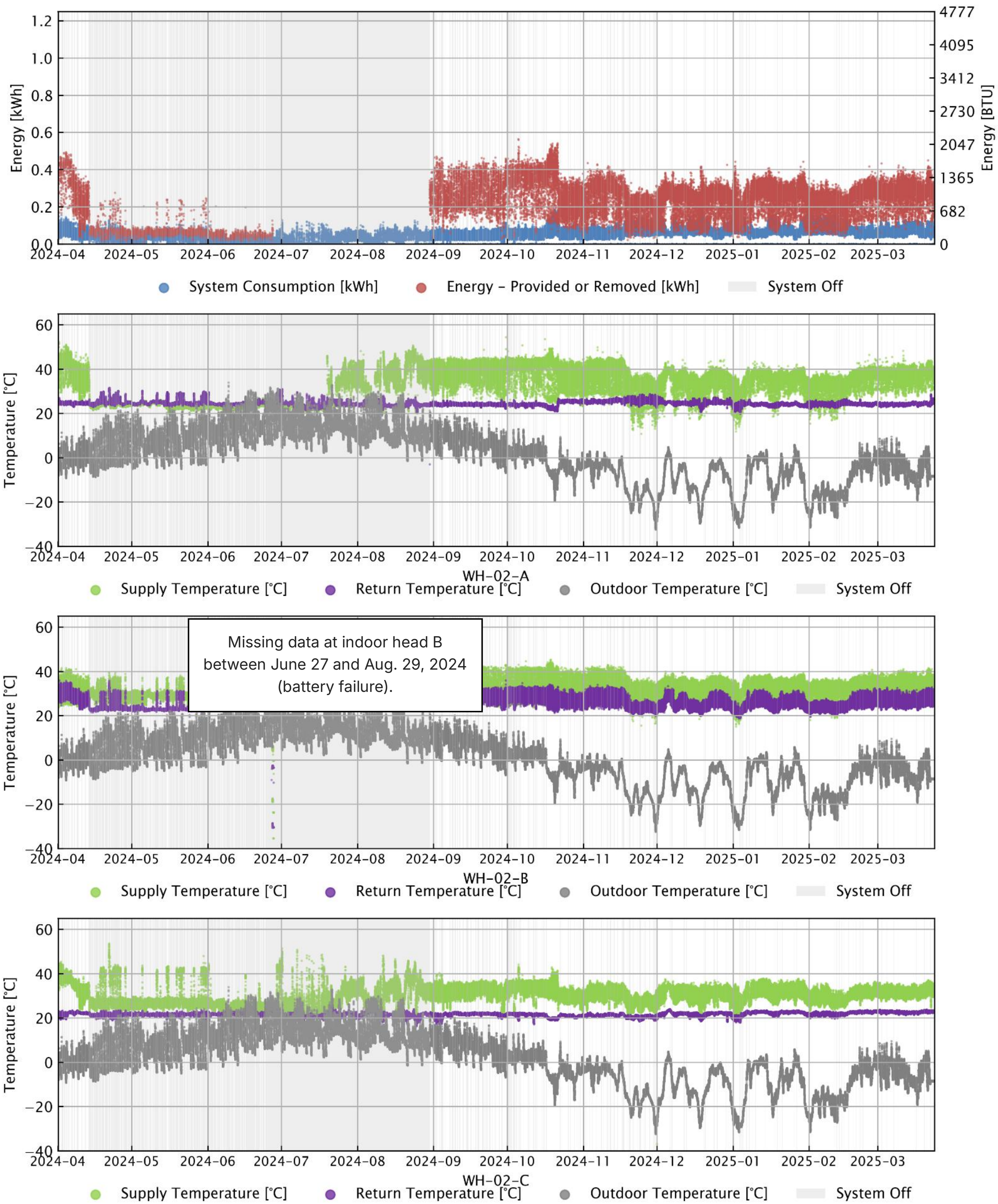
Appendix B - Energy Consumption & Output Profiles

Appendix B displays the measured ambient outdoor temperature; the temperatures at indoor unit supply/return, and the equivalent energy provided or removed by heat pump compared to total energy consumption for site WH-01 through WH-18.

WH-01

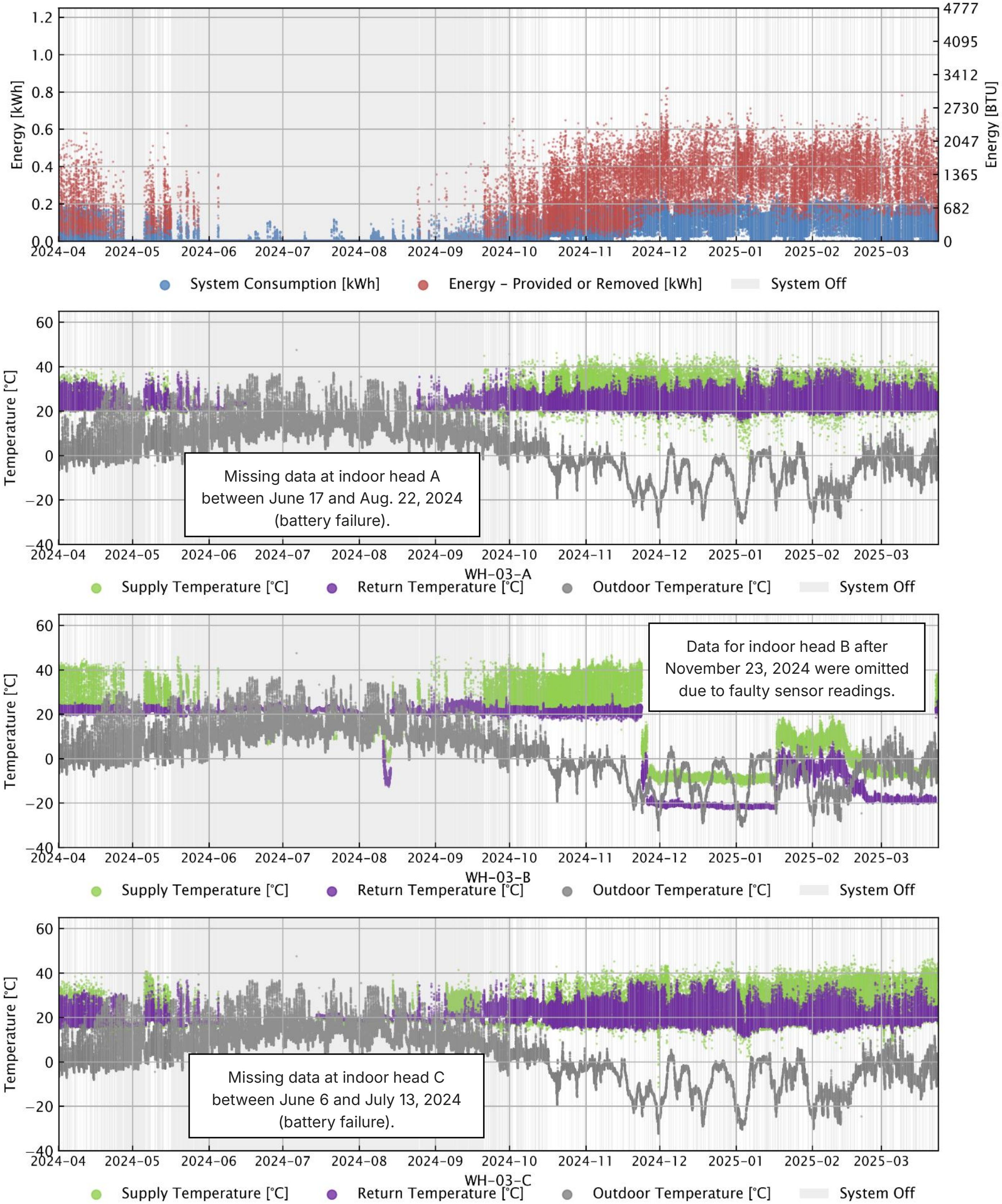


WH-02



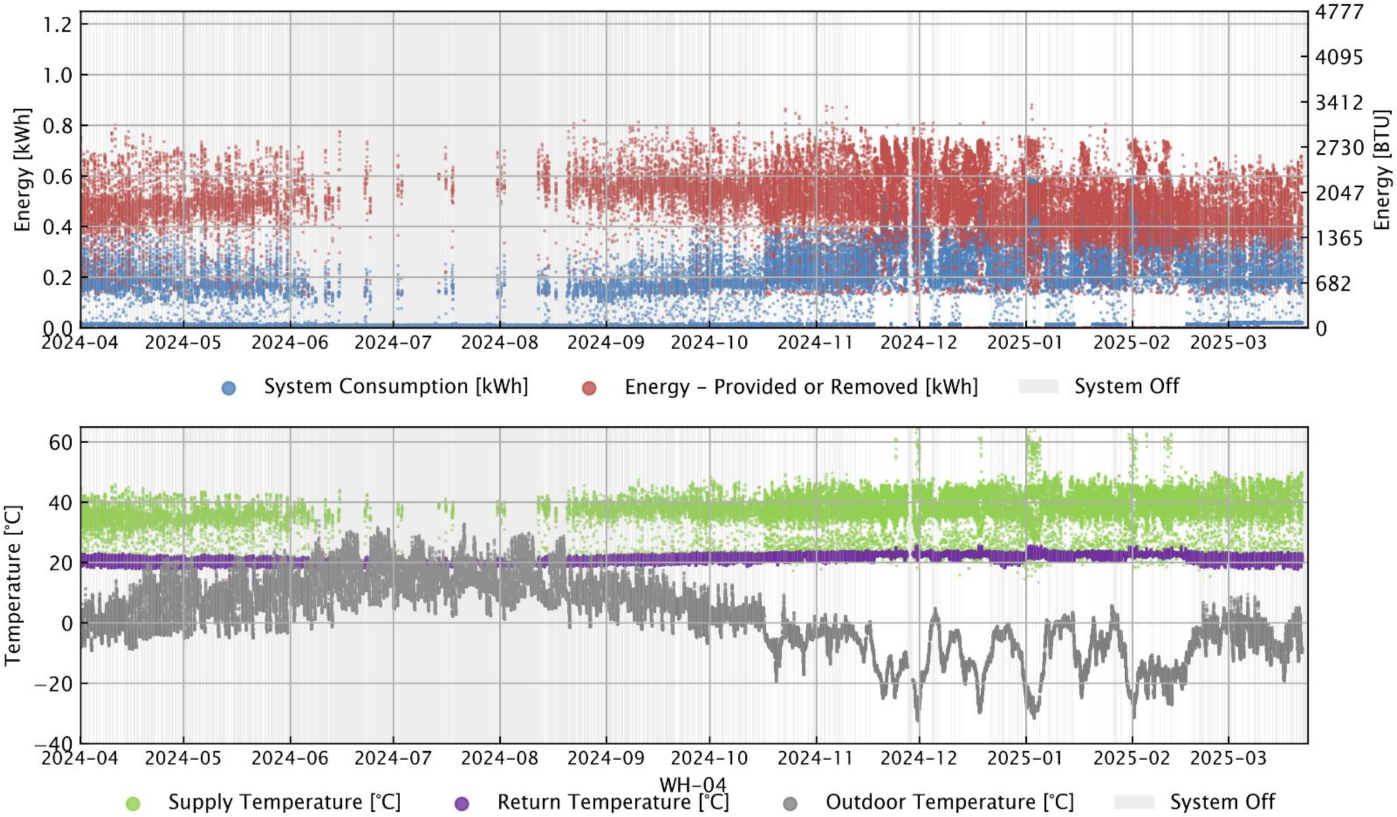
Energy [kWh]
Energy [BTU]
System Consumption [kWh]
Energy – Provided or Removed [kWh]
System Off
Temperature [°C]
WH-02-A
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off
Missing data at indoor head B between June 27 and Aug. 29, 2024 (battery failure).
WH-02-B
WH-02-C

WH-03



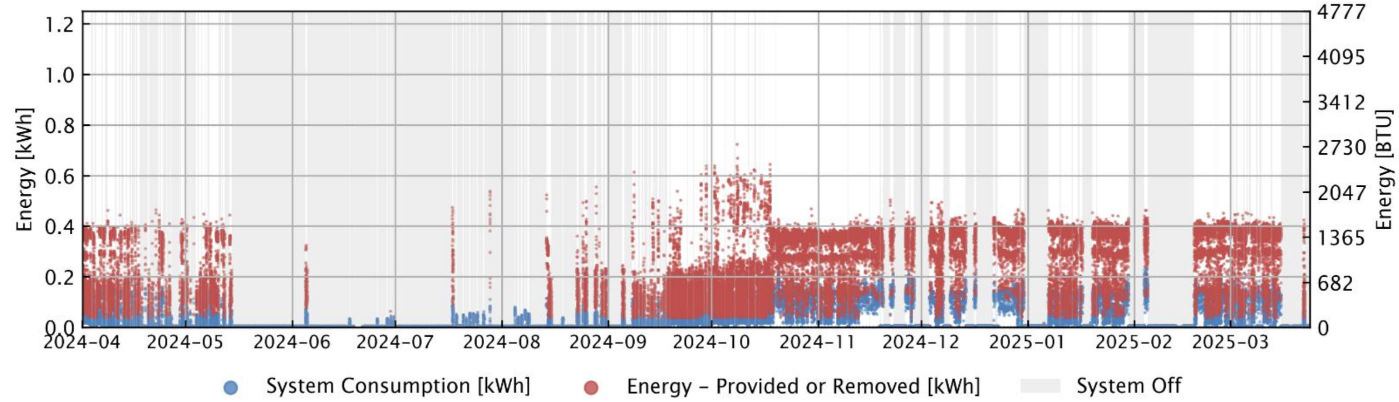
At indoor heads A and C, occasional periods with return temperatures above supply temperatures occur when the indoor fan is off and the coil stays warm. This appears to be creating local stratification near the return sensor (which is installed right above the coil).

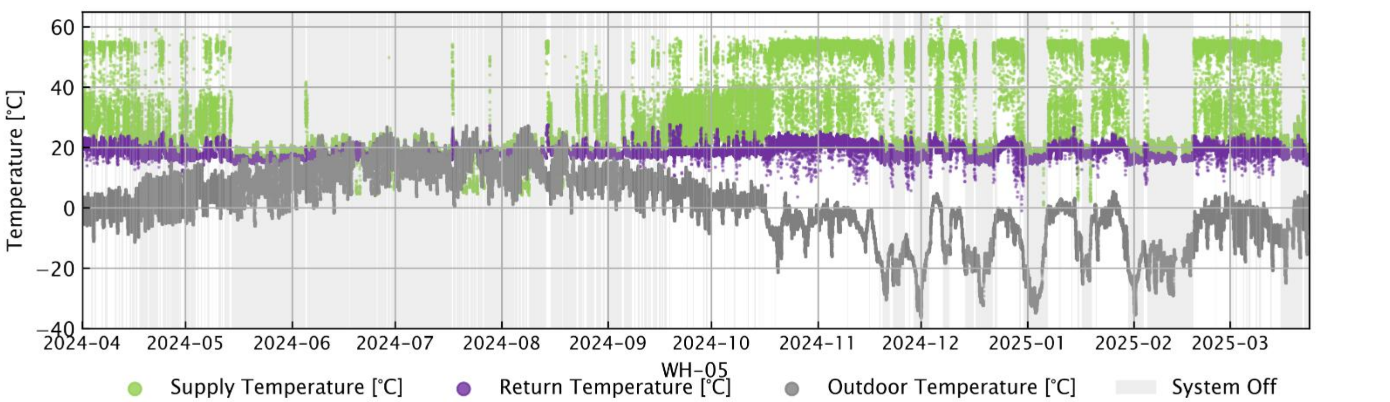
WH-04



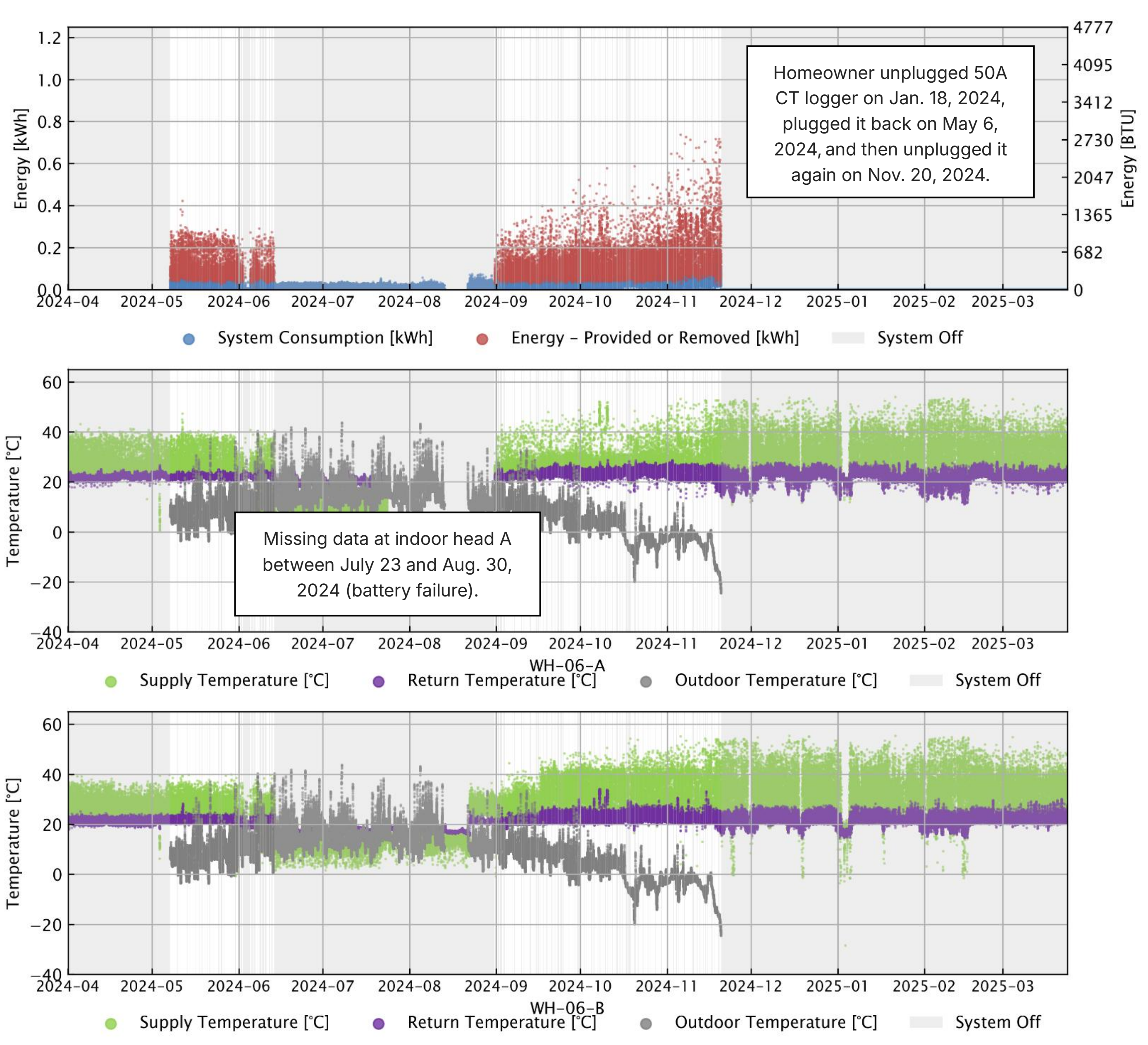
Energy [kWh]
Energy [BTU]
System Consumption [kWh]
Energy – Provided or Removed [kWh]
System Off
Temperature [°C]
WH-04
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

WH-05


Energy [kWh]
Energy [BTU]
1.2
1.0
0.8
0.6
0.4
0.2
0.0
4777
4095
3412
2730
2047
1365
682
0
2024-04
2024-05
2024-06
2024-07
2024-08
2024-09
2024-10
2024-11
2024-12
2025-01
2025-02
2025-03
System Consumption [kWh]
Energy - Provided or Removed [kWh]
System Off

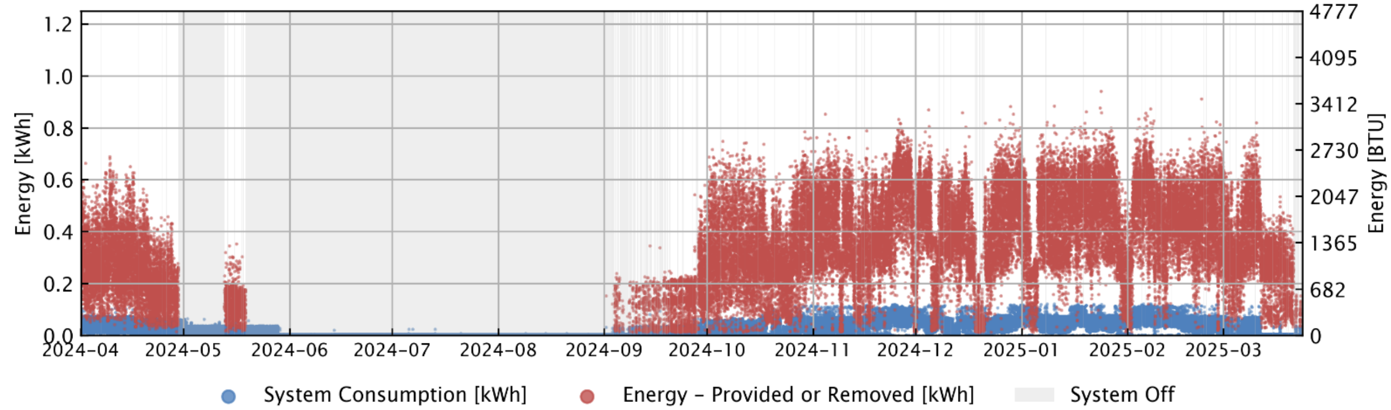

Temperature [°C]
60
40
20
0
−20
−40
2024-04
2024-05
2024-06
2024-07
2024-08
2024-09
2024-10
2024-11
2024-12
2025-01
2025-02
2025-03
WH-05
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

WH-06

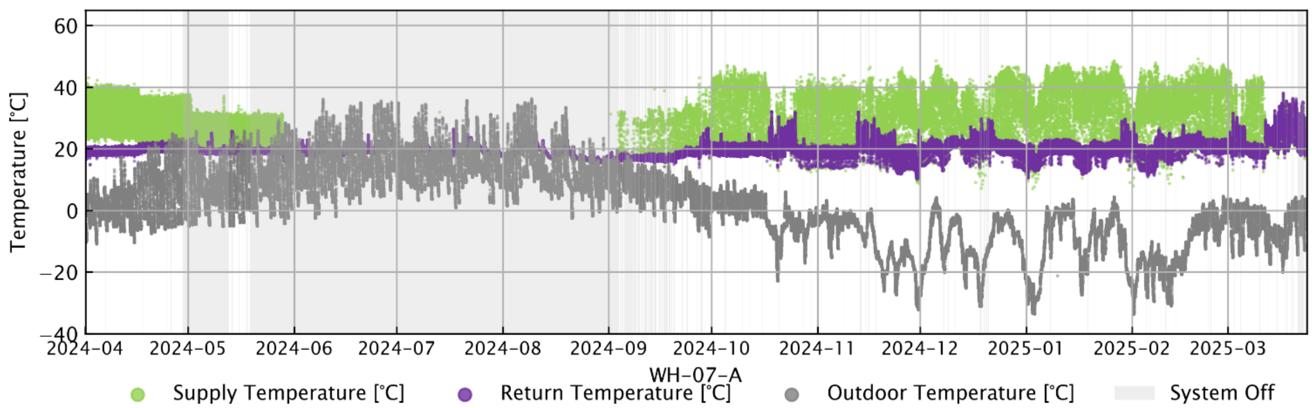


Energy [kWh]
Energy [BTU]
Homeowner unplugged 50A CT logger on Jan. 18, 2024, plugged it back on May 6, 2024, and then unplugged it again on Nov. 20, 2024.
System Consumption [kWh]
Energy – Provided or Removed [kWh]
System Off
Temperature [°C]
Missing data at indoor head A between July 23 and Aug. 30, 2024 (battery failure).
WH-06-A
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off
Temperature [°C]
WH-06-B
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

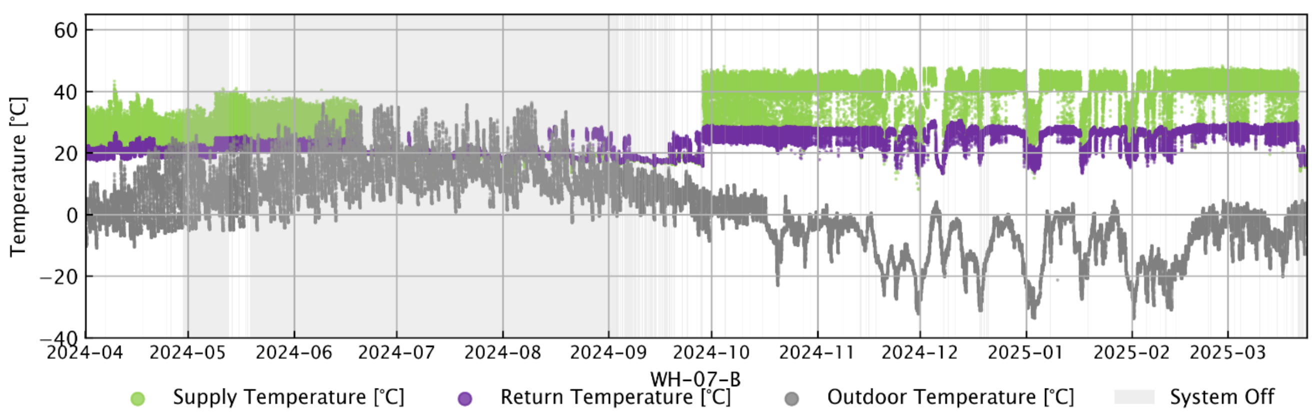
WH-07



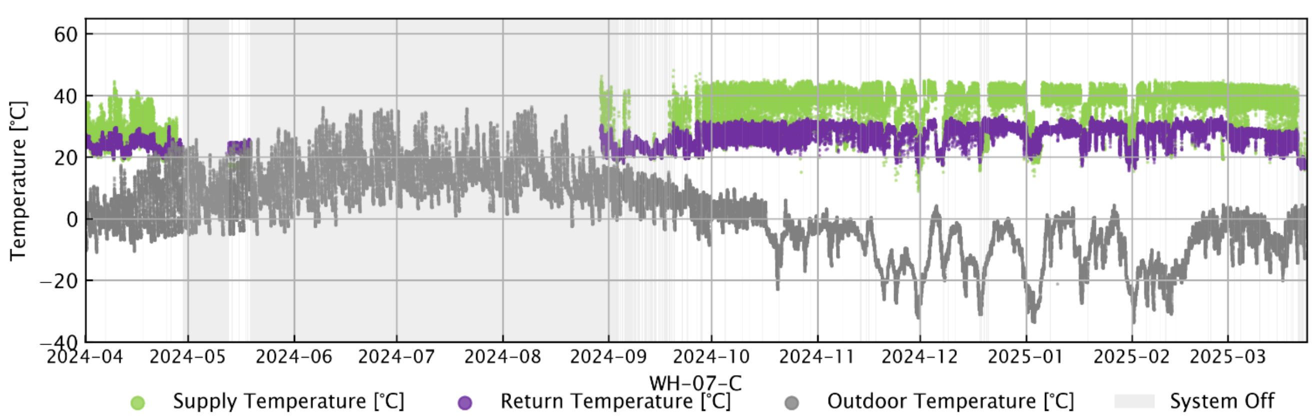
Energy [kWh]
Energy [BTU]
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
682
1365
2047
2730
3412
4095
4777
2024-04
2024-05
2024-06
2024-07
2024-08
2024-09
2024-10
2024-11
2024-12
2025-01
2025-02
2025-03
System Consumption [kWh]
Energy – Provided or Removed [kWh]
System Off



Temperature [°C]
−40
−20
0
20
40
60
2024-04
2024-05
2024-06
2024-07
2024-08
2024-09
2024-10
2024-11
2024-12
2025-01
2025-02
2025-03
WH-07-A
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

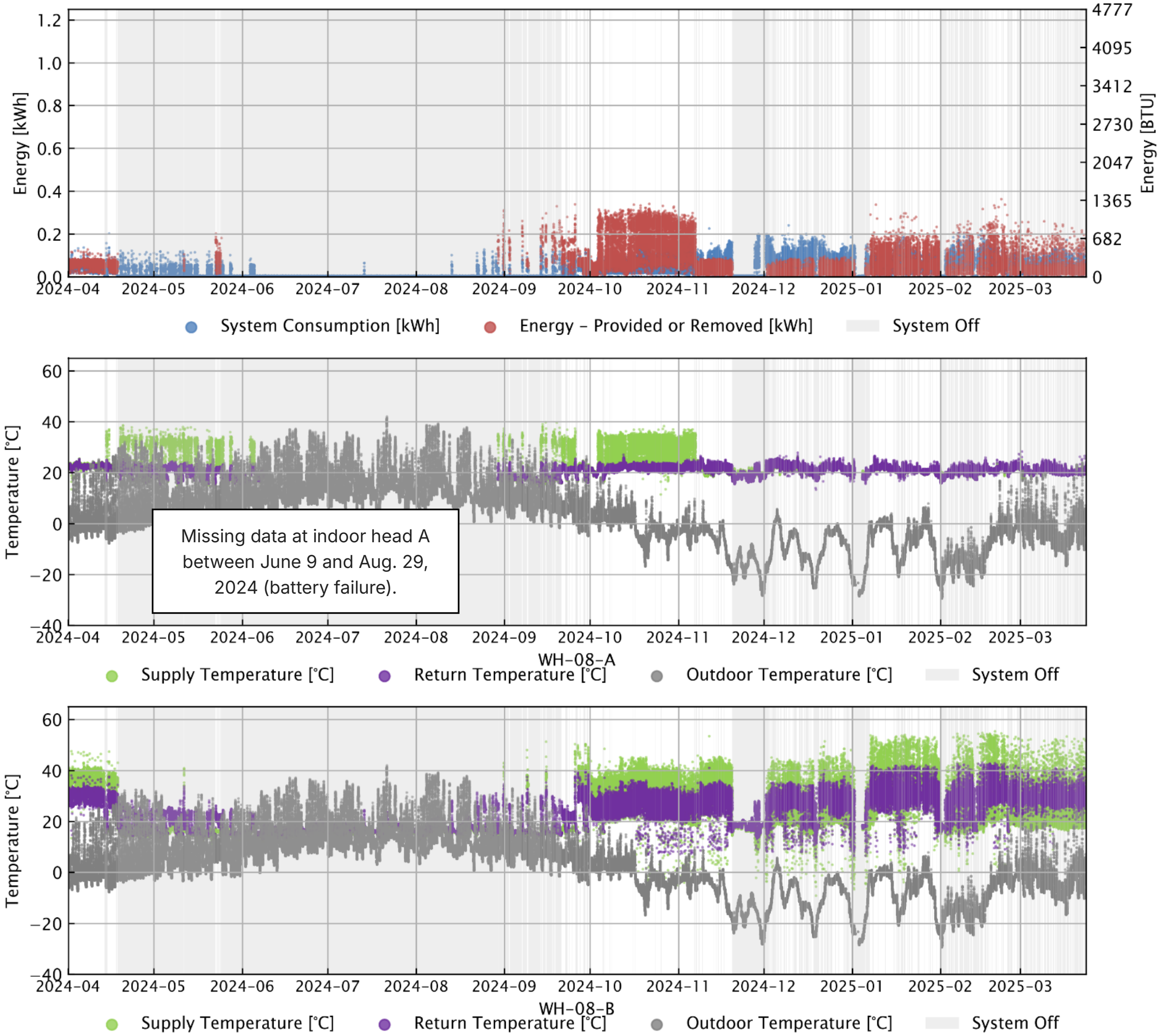


Temperature [°C]
−40
−20
0
20
40
60
2024-04
2024-05
2024-06
2024-07
2024-08
2024-09
2024-10
2024-11
2024-12
2025-01
2025-02
2025-03
WH-07-B
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off



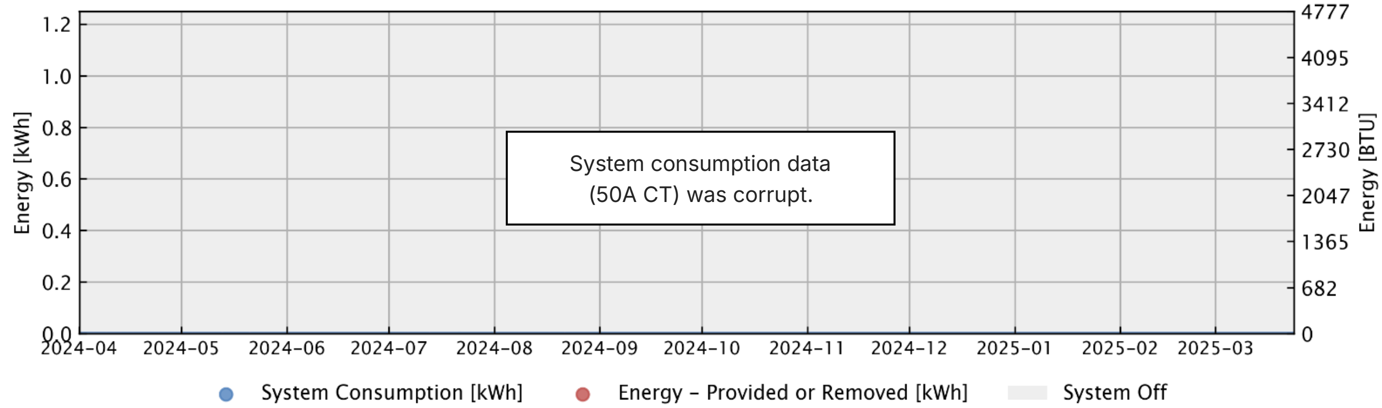
Temperature [°C]
−40
−20
0
20
40
60
2024-04
2024-05
2024-06
2024-07
2024-08
2024-09
2024-10
2024-11
2024-12
2025-01
2025-02
2025-03
WH-07-C
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

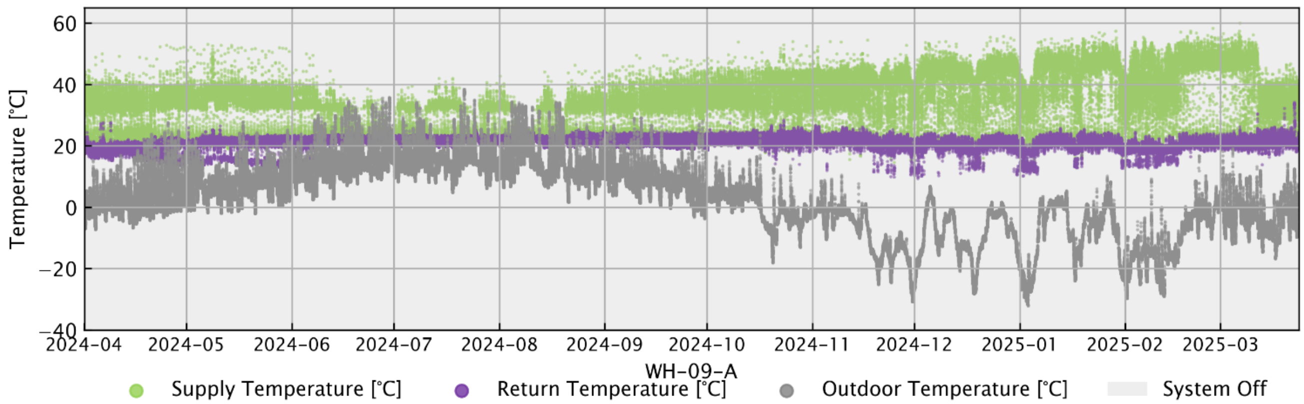
WH-08

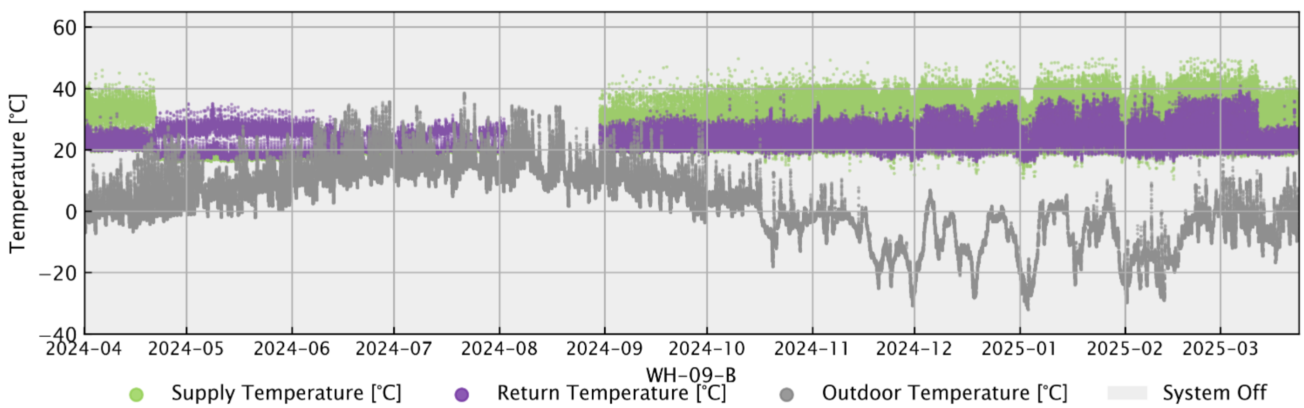


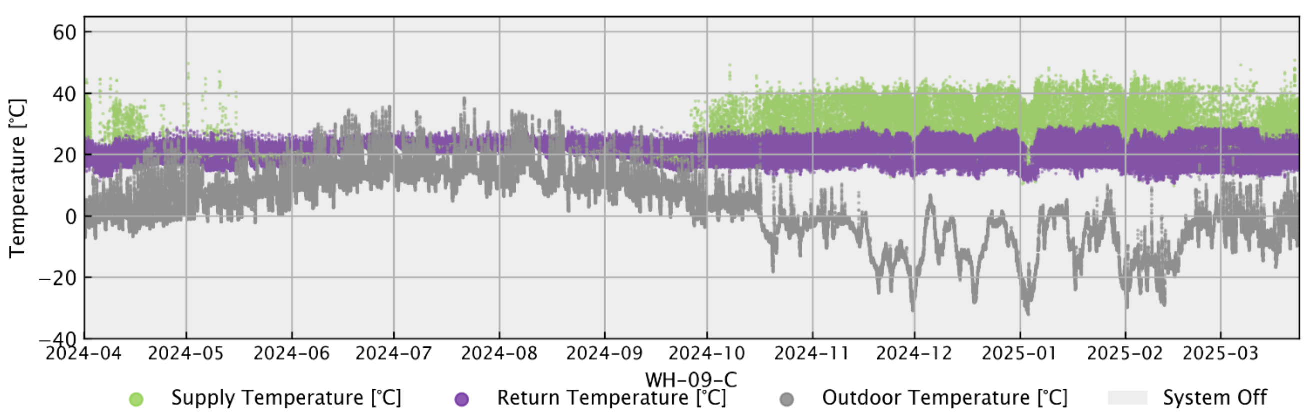
Energy [kWh]
Energy [BTU]
System Consumption [kWh]
Energy – Provided or Removed [kWh]
System Off
Temperature [°C]
Missing data at indoor head A between June 9 and Aug. 29, 2024 (battery failure).
WH-08-A
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off
Temperature [°C]
WH-08-B
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

WH-09

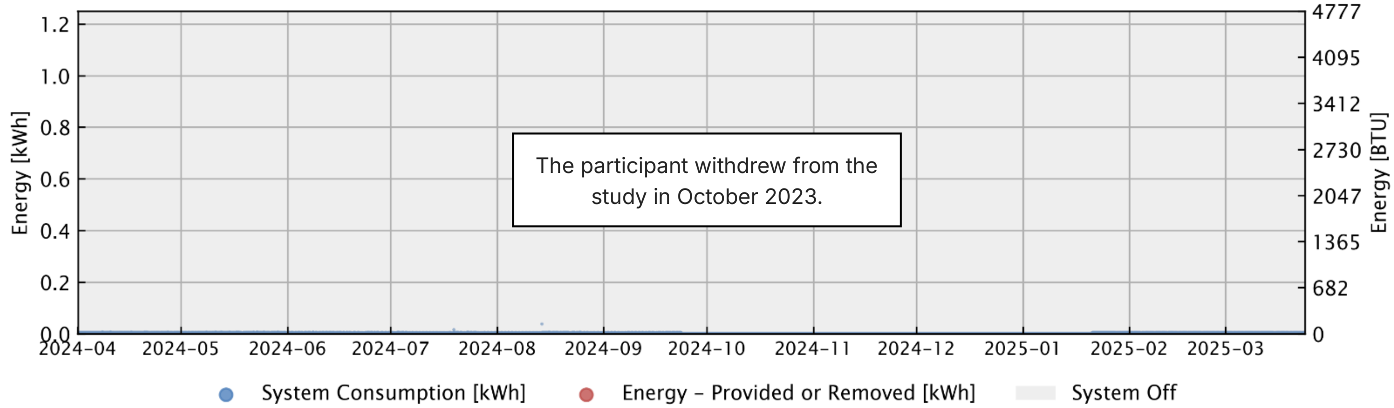

System consumption data
(50A CT) was corrupt.
Energy [kWh]
Energy [BTU]
System Consumption [kWh]
Energy – Provided or Removed [kWh]
System Off


Temperature [°C]
WH-09-A
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

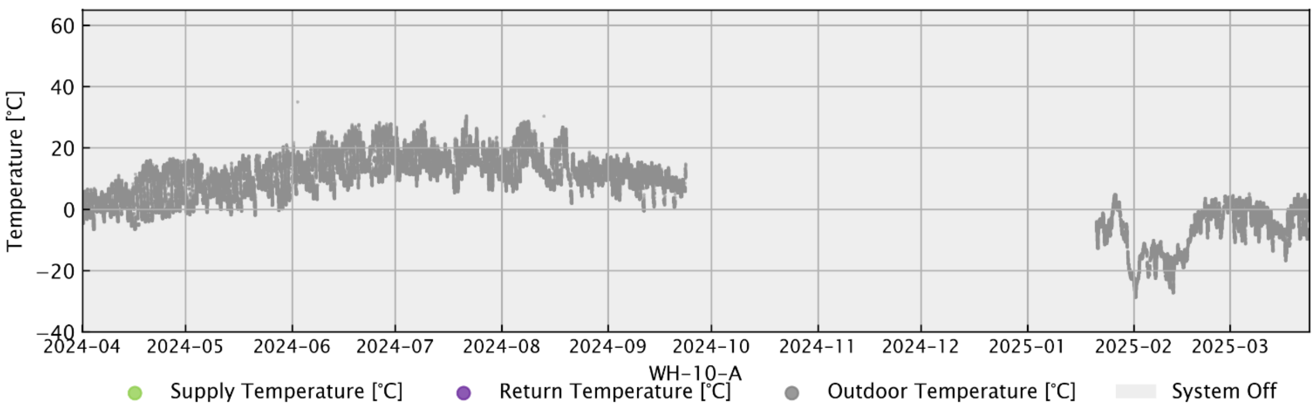

Temperature [°C]
WH-09-B
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off


Temperature [°C]
WH-09-C
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

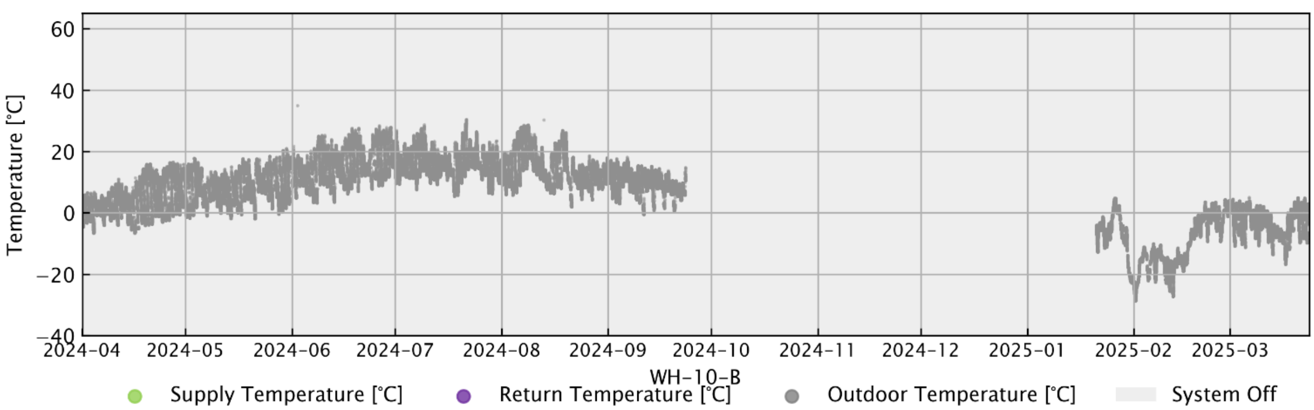
WH-10



Energy [kWh]
Energy [BTU]
The participant withdrew from the study in October 2023.
System Consumption [kWh]
Energy – Provided or Removed [kWh]
System Off

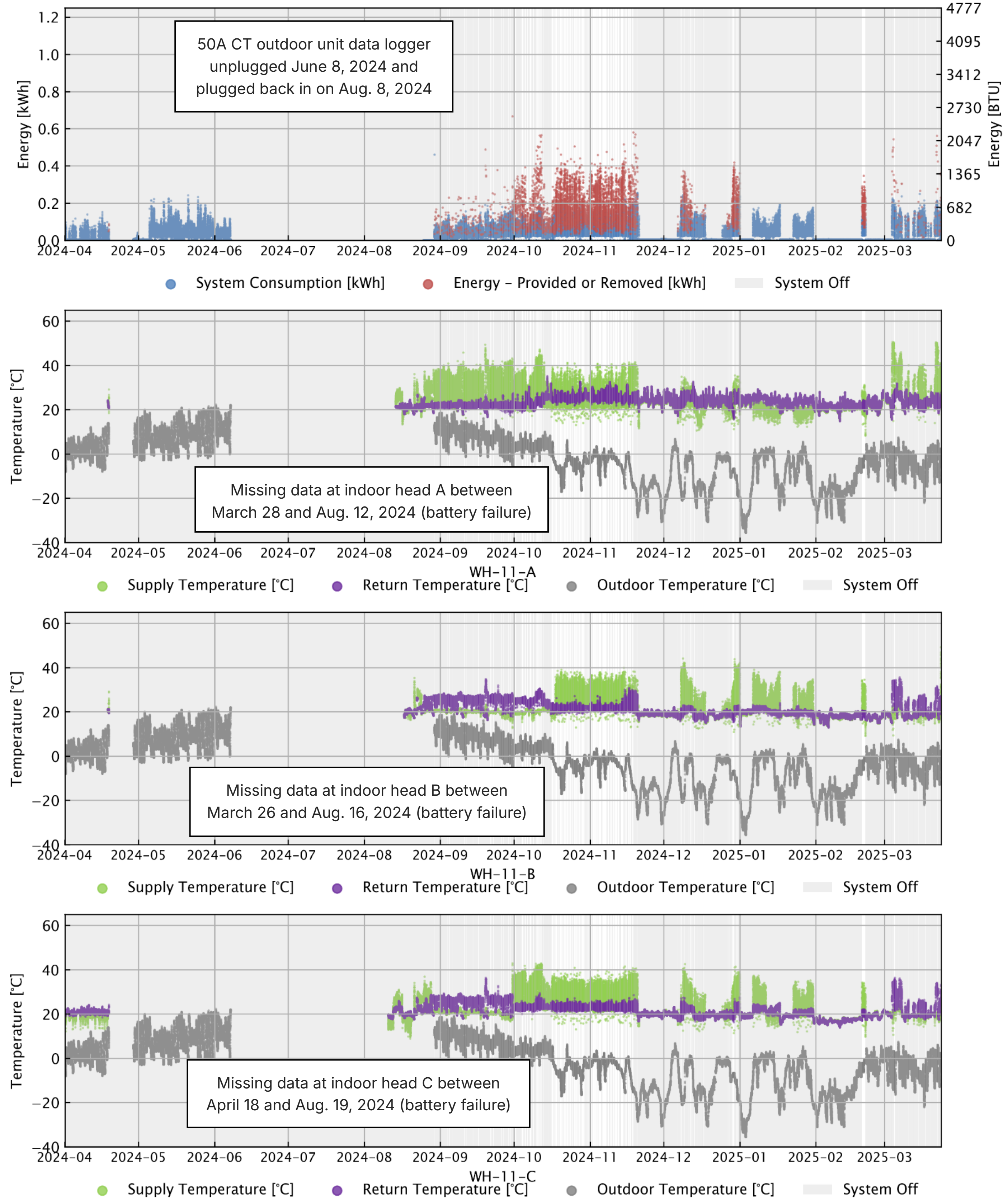


Temperature [°C]
WH-10-A
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

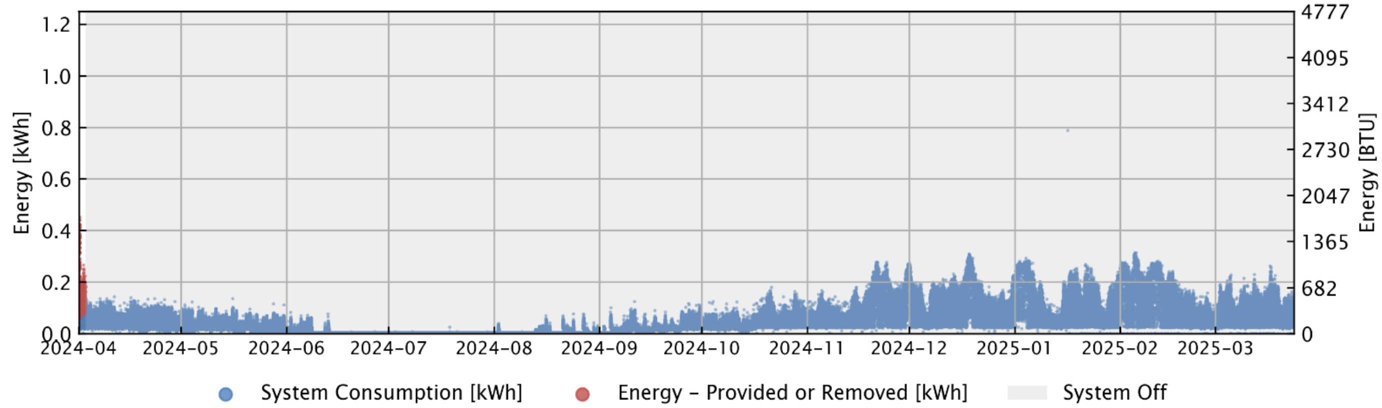


Temperature [°C]
WH-10-B
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

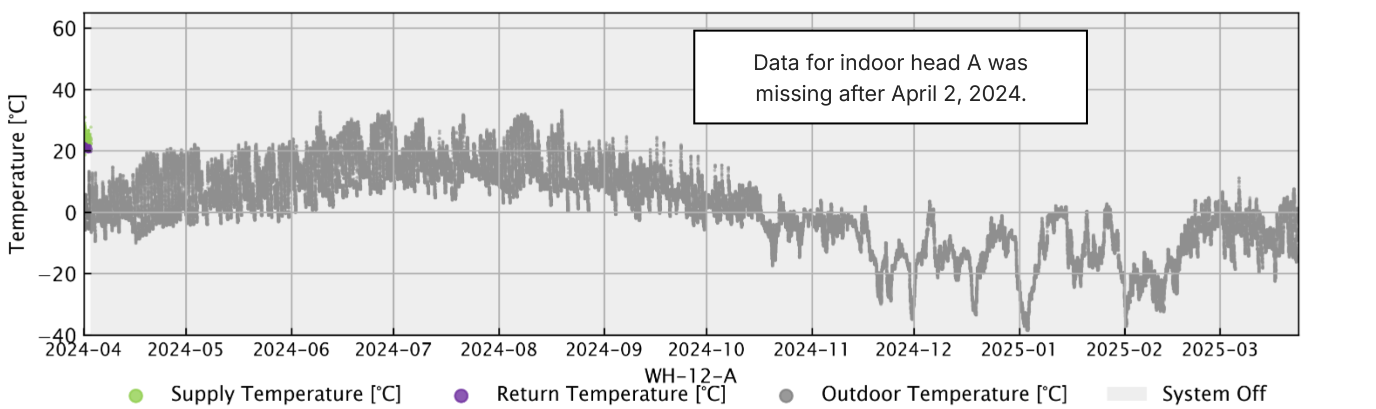
WH-11


Energy [kWh]
Energy [BTU]
50A CT outdoor unit data logger unplugged June 8, 2024 and plugged back in on Aug. 8, 2024
System Consumption [kWh]
Energy – Provided or Removed [kWh]
System Off
Temperature [°C]
Missing data at indoor head A between March 28 and Aug. 12, 2024 (battery failure)
WH-11-A
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off
Missing data at indoor head B between March 26 and Aug. 16, 2024 (battery failure)
WH-11-B
Missing data at indoor head C between April 18 and Aug. 19, 2024 (battery failure)
WH-11-C
2024-04
2024-05
2024-06
2024-07
2024-08
2024-09
2024-10
2024-11
2024-12
2025-01
2025-02
2025-03

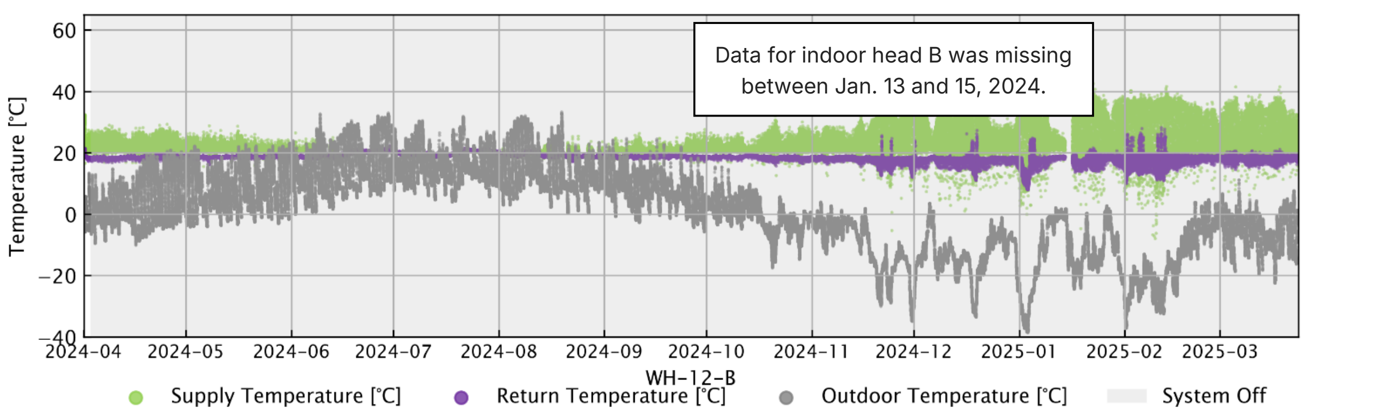
WH-12



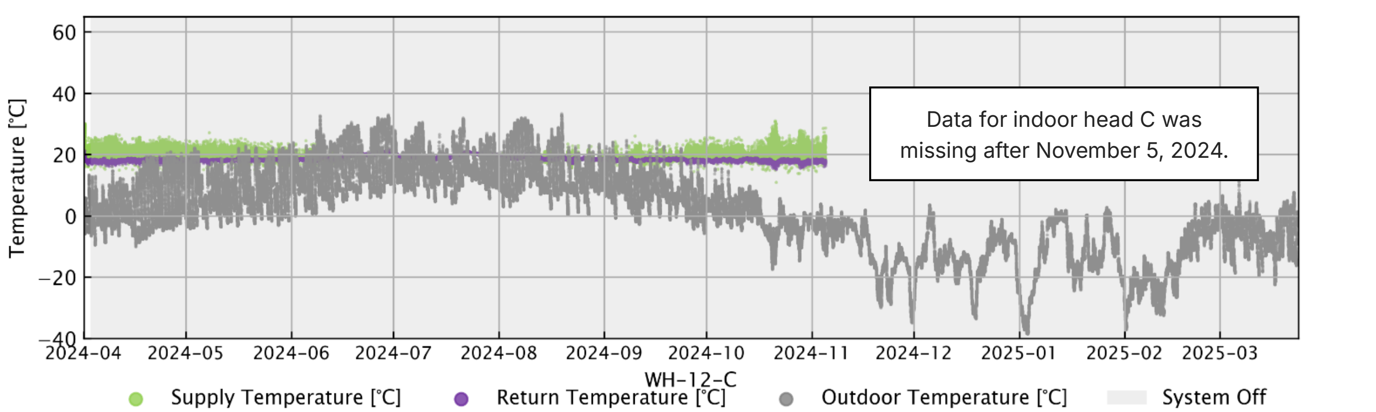
Energy [kWh]
Energy [BTU]
1.2
1.0
0.8
0.6
0.4
0.2
0.0
4777
4095
3412
2730
2047
1365
682
0
2024-04
2024-05
2024-06
2024-07
2024-08
2024-09
2024-10
2024-11
2024-12
2025-01
2025-02
2025-03
System Consumption [kWh]
Energy – Provided or Removed [kWh]
System Off



Temperature [°C]
60
40
20
0
−20
−40
Data for indoor head A was missing after April 2, 2024.
2024-04
2024-05
2024-06
2024-07
2024-08
2024-09
2024-10
2024-11
2024-12
2025-01
2025-02
2025-03
WH-12-A
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

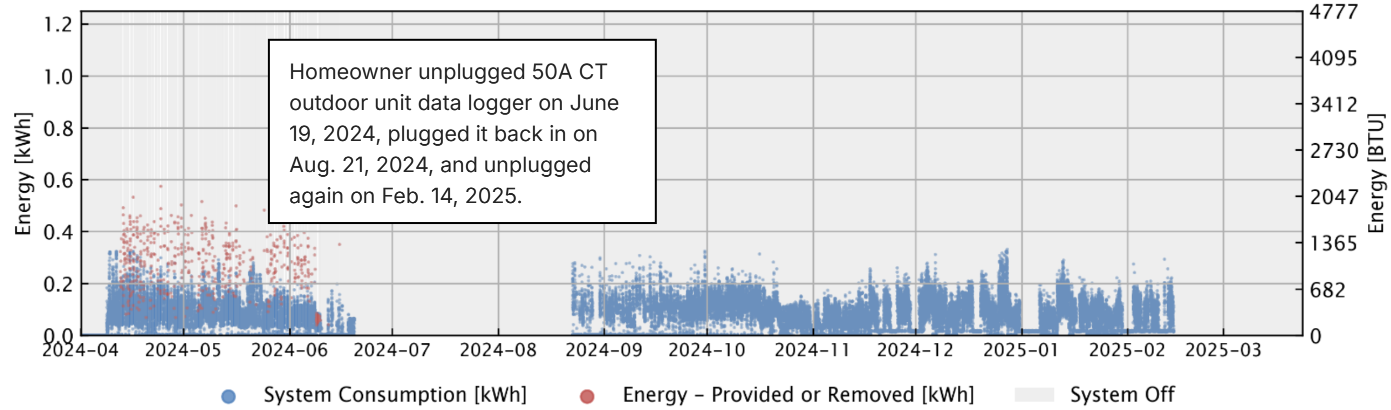


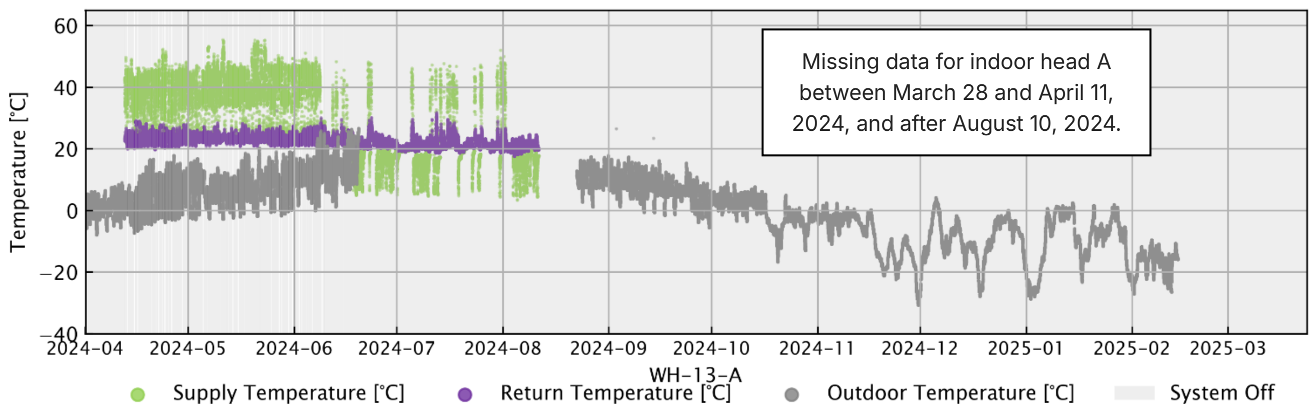
Temperature [°C]
60
40
20
0
−20
−40
Data for indoor head B was missing between Jan. 13 and 15, 2024.
2024-04
2024-05
2024-06
2024-07
2024-08
2024-09
2024-10
2024-11
2024-12
2025-01
2025-02
2025-03
WH-12-B
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

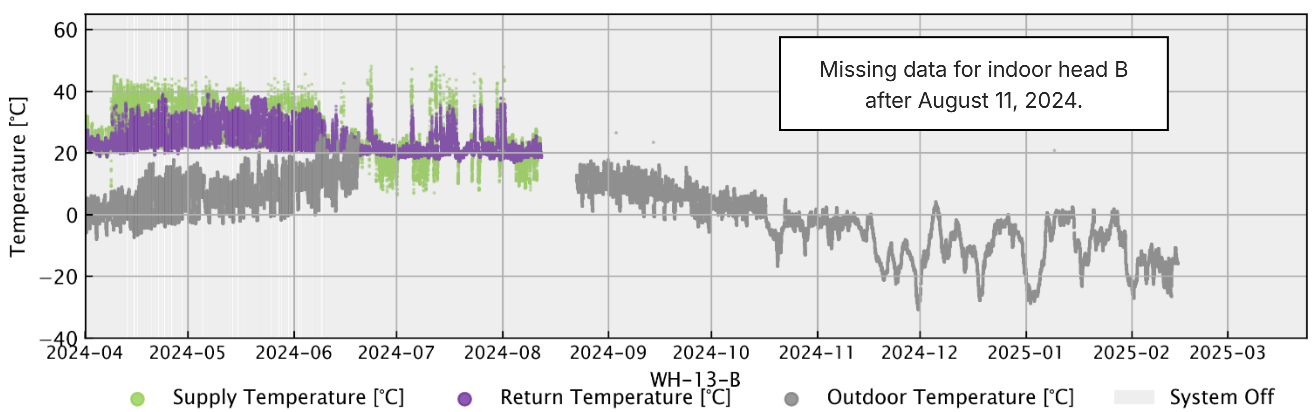


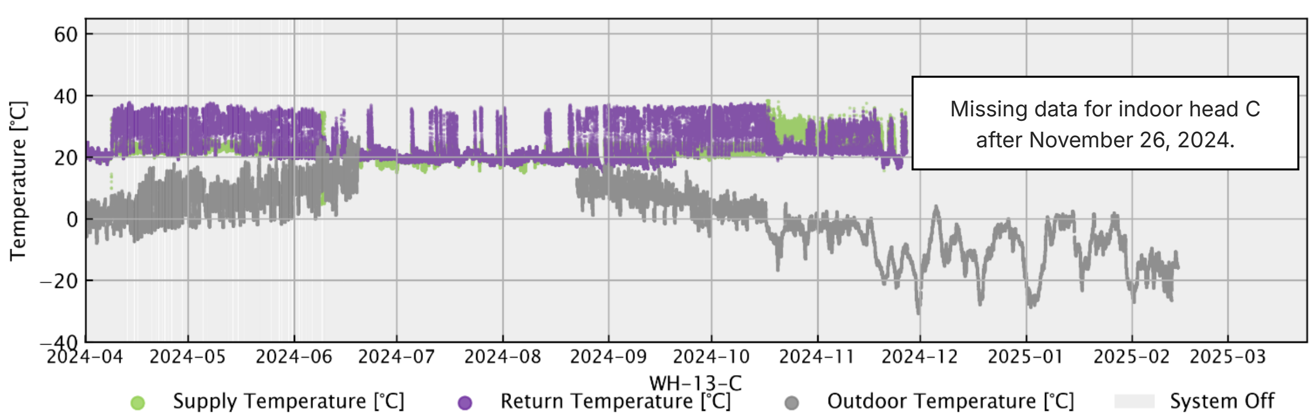
Temperature [°C]
60
40
20
0
−20
−40
Data for indoor head C was missing after November 5, 2024.
2024-04
2024-05
2024-06
2024-07
2024-08
2024-09
2024-10
2024-11
2024-12
2025-01
2025-02
2025-03
WH-12-C
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

WH-13

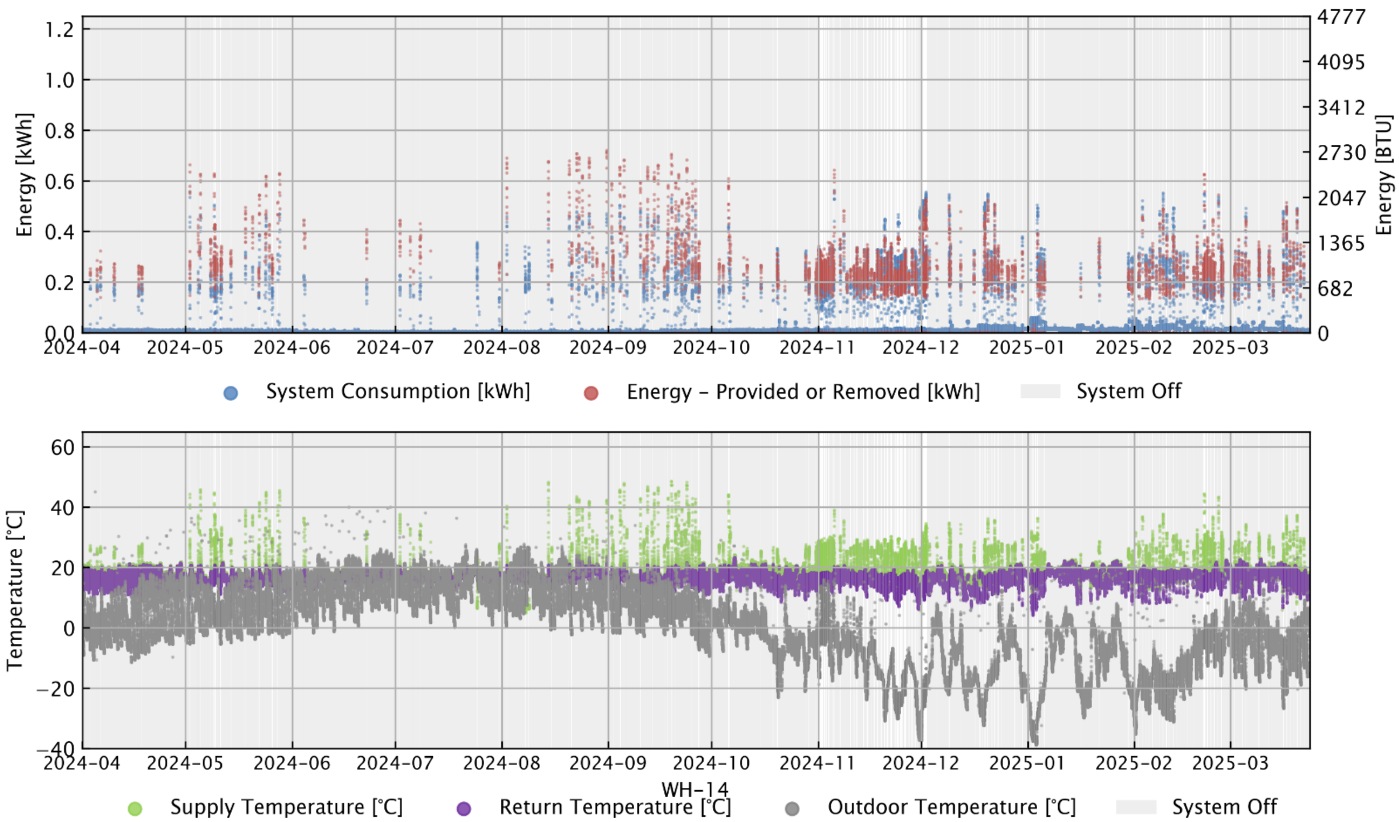

Homeowner unplugged 50A CT outdoor unit data logger on June 19, 2024, plugged it back in on Aug. 21, 2024, and unplugged again on Feb. 14, 2025.
Energy [kWh]
Energy [BTU]
System Consumption [kWh]
Energy – Provided or Removed [kWh]
System Off


Missing data for indoor head A between March 28 and April 11, 2024, and after August 10, 2024.
Temperature [°C]
WH-13-A
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off


Missing data for indoor head B after August 11, 2024.
Temperature [°C]
WH-13-B
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

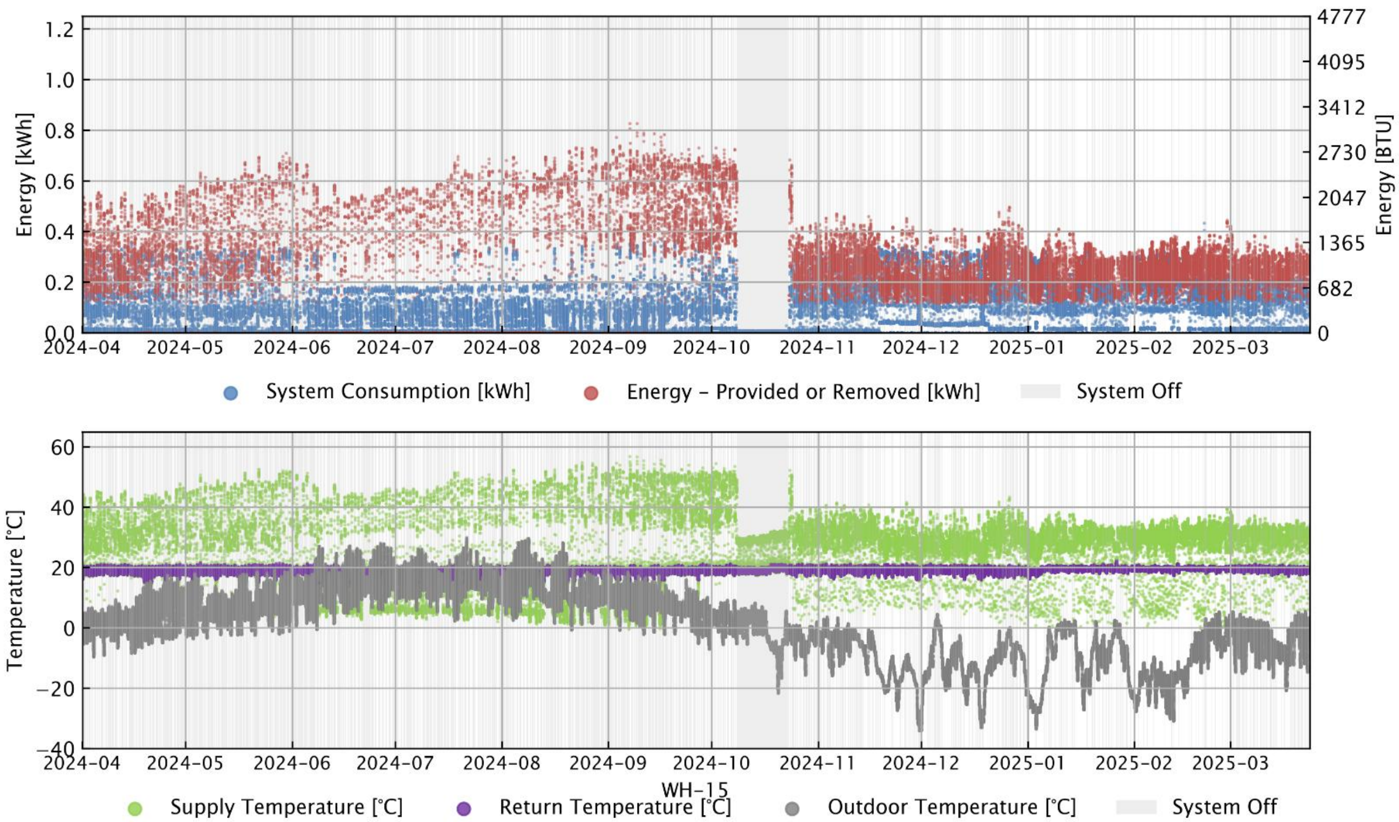

Missing data for indoor head C after November 26, 2024.
Temperature [°C]
WH-13-C
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

WH-14



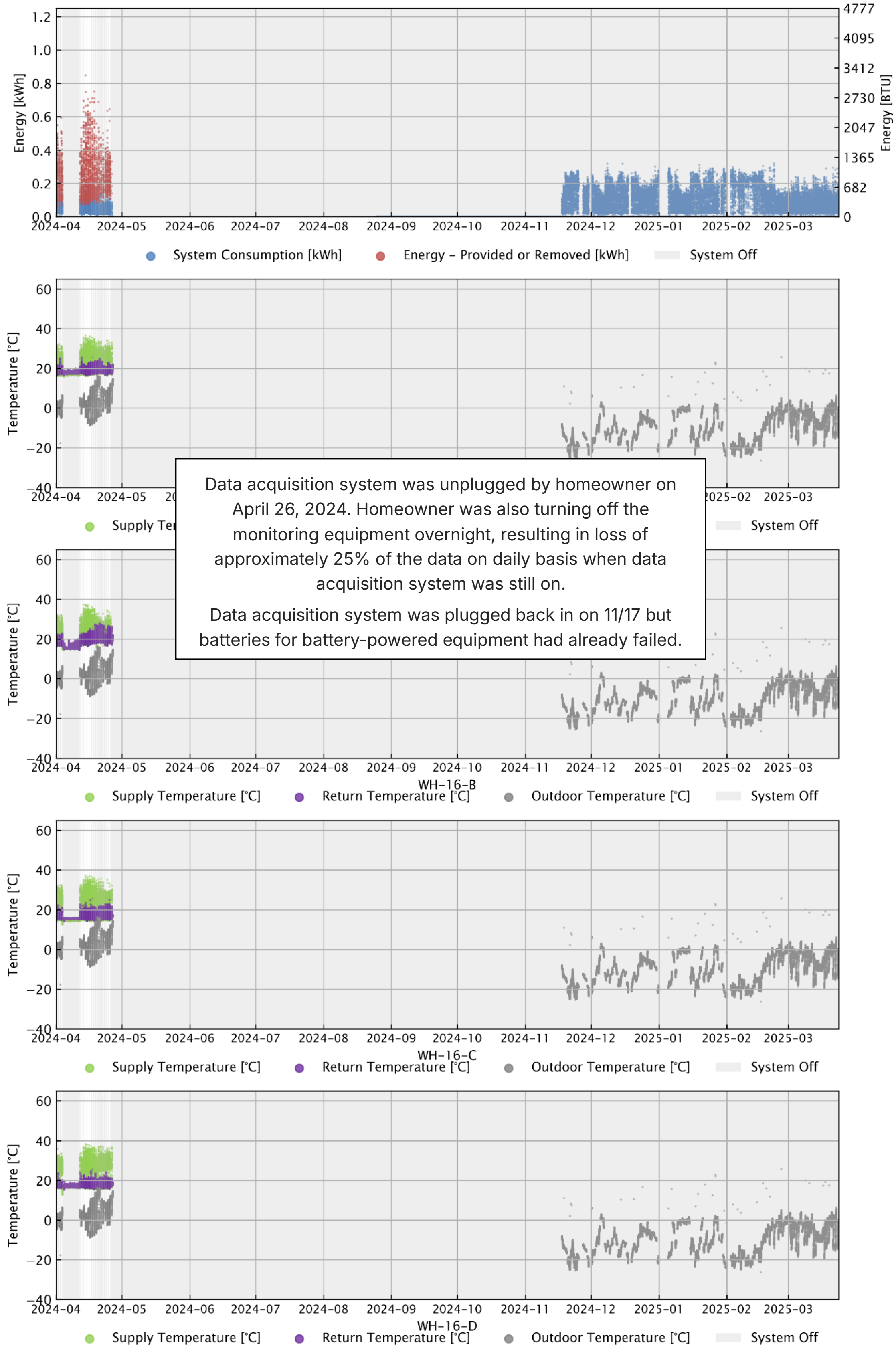
Energy [kWh]
Energy [BTU]
1.2
1.0
0.8
0.6
0.4
0.2
0.0
4777
4095
3412
2730
2047
1365
682
0
2024-04
2024-05
2024-06
2024-07
2024-08
2024-09
2024-10
2024-11
2024-12
2025-01
2025-02
2025-03
System Consumption [kWh]
Energy – Provided or Removed [kWh]
System Off
Temperature [°C]
60
40
20
0
−20
−40
WH-14
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

WH-15



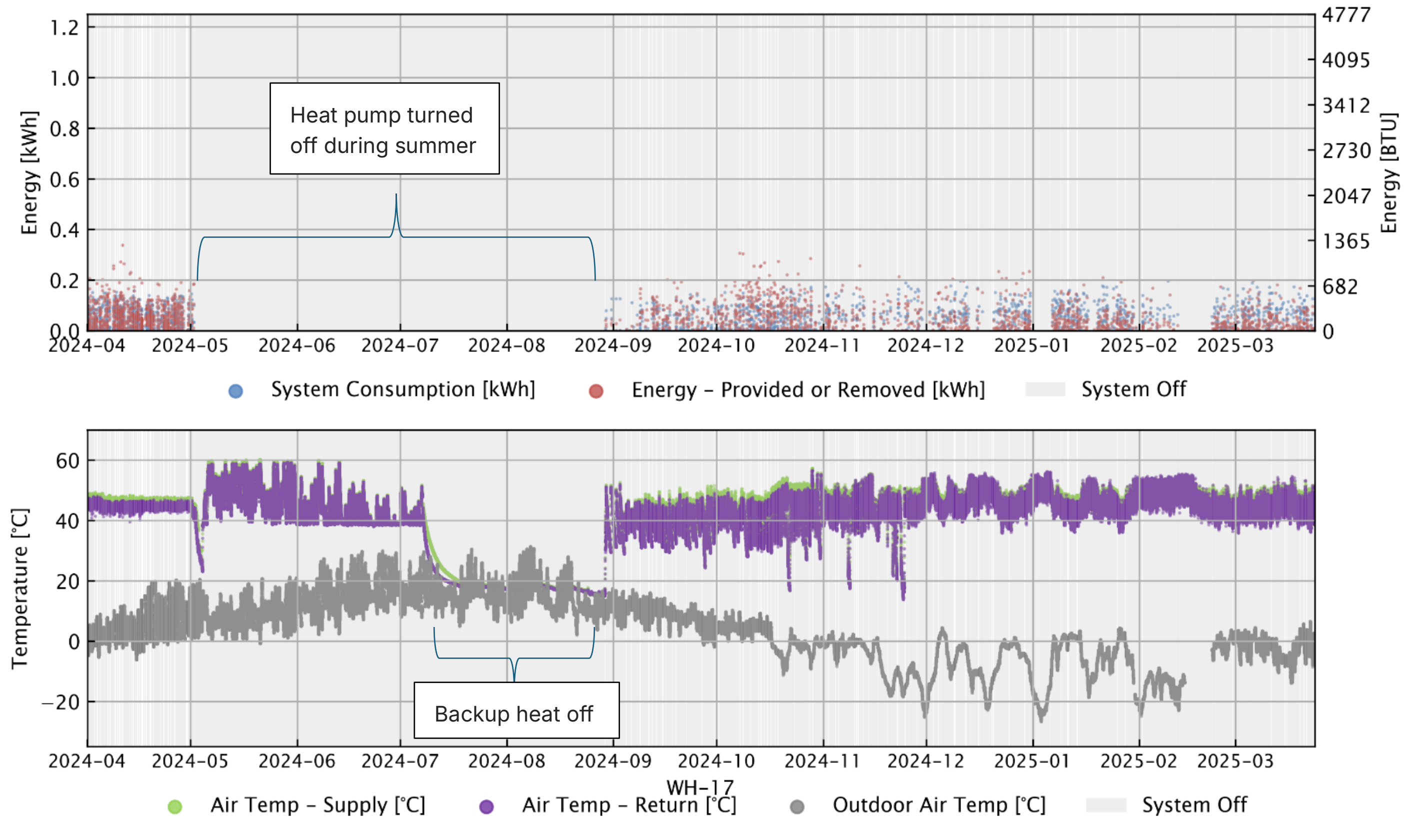
Energy [kWh]
Energy [BTU]
1.2
1.0
0.8
0.6
0.4
0.2
0.0
4777
4095
3412
2730
2047
1365
682
0
2024-04
2024-05
2024-06
2024-07
2024-08
2024-09
2024-10
2024-11
2024-12
2025-01
2025-02
2025-03
System Consumption [kWh]
Energy - Provided or Removed [kWh]
System Off
Temperature [°C]
60
40
20
0
−20
−40
WH-15
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

WH-16

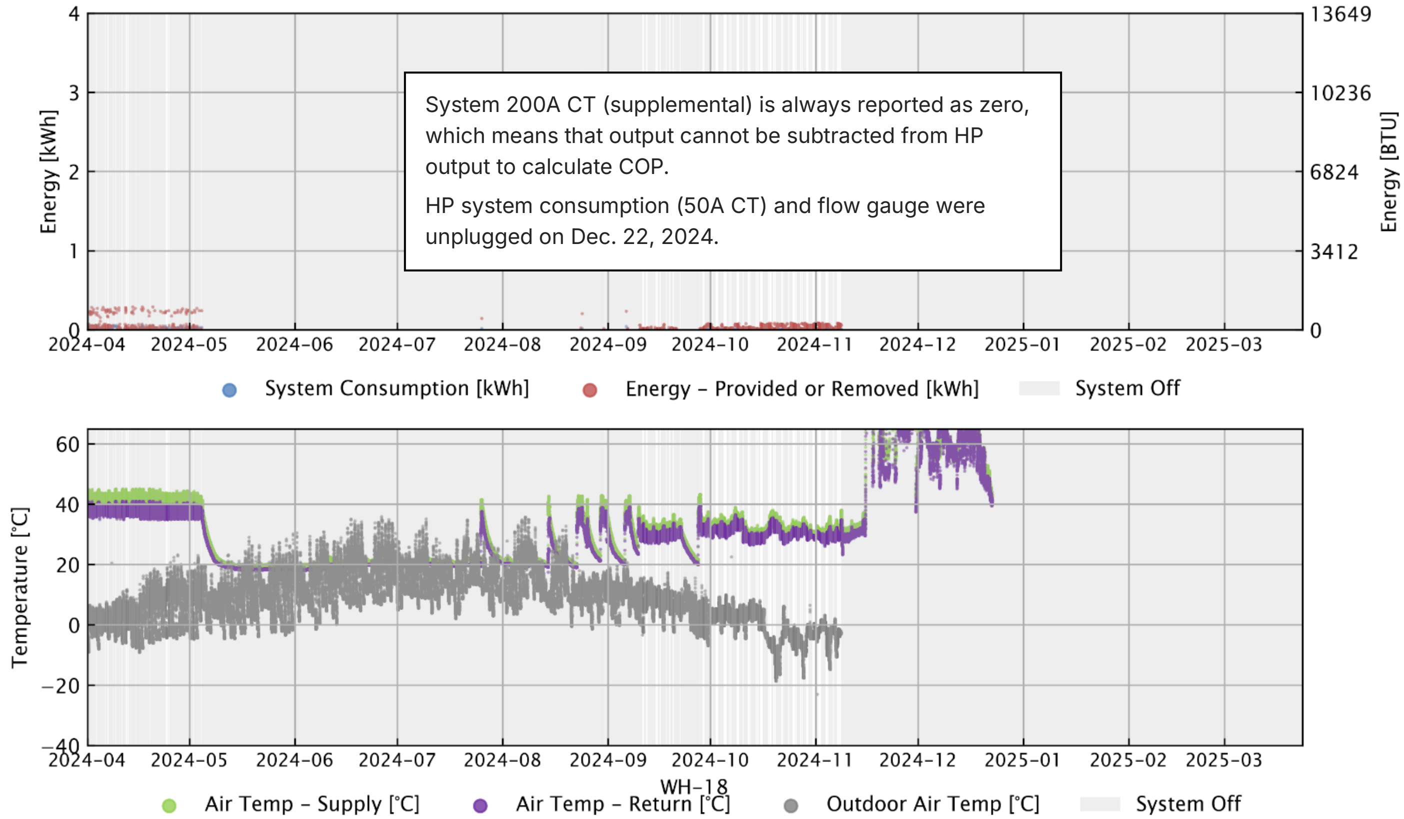


Energy [kWh]
Energy [BTU]
System Consumption [kWh]
Energy – Provided or Removed [kWh]
System Off
Temperature [°C]
Data acquisition system was unplugged by homeowner on April 26, 2024. Homeowner was also turning off the monitoring equipment overnight, resulting in loss of approximately 25% of the data on daily basis when data acquisition system was still on.
Data acquisition system was plugged back in on 11/17 but batteries for battery-powered equipment had already failed.
WH-16-B
WH-16-C
WH-16-D
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]

WH-17


Heat pump turned off during summer
Energy [kWh]
Energy [BTU]
1.2
1.0
0.8
0.6
0.4
0.2
0.0
4777
4095
3412
2730
2047
1365
682
0
2024-04
2024-05
2024-06
2024-07
2024-08
2024-09
2024-10
2024-11
2024-12
2025-01
2025-02
2025-03
System Consumption [kWh]
Energy – Provided or Removed [kWh]
System Off
Temperature [°C]
60
40
20
0
−20
Backup heat off
WH-17
Air Temp – Supply [°C]
Air Temp – Return [°C]
Outdoor Air Temp [°C]
System Off

WH-18

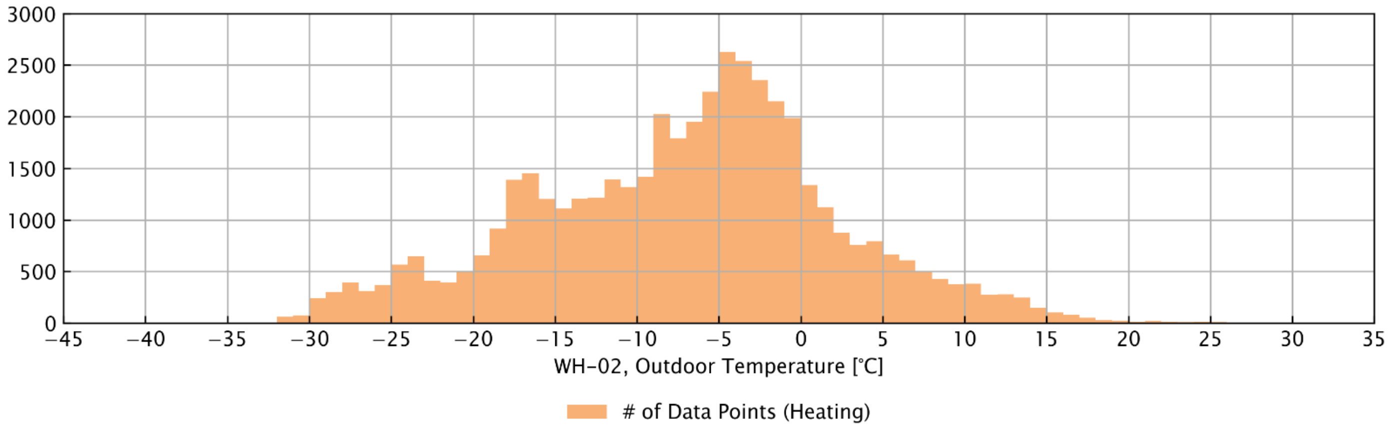


Energy [kWh]
Energy [BTU]
System 200A CT (supplemental) is always reported as zero, which means that output cannot be subtracted from HP output to calculate COP.
HP system consumption (50A CT) and flow gauge were unplugged on Dec. 22, 2024.
System Consumption [kWh]
Energy – Provided or Removed [kWh]
System Off
Temperature [°C]
WH–18
Air Temp – Supply [°C]
Air Temp – Return [°C]
Outdoor Air Temp [°C]
System Off

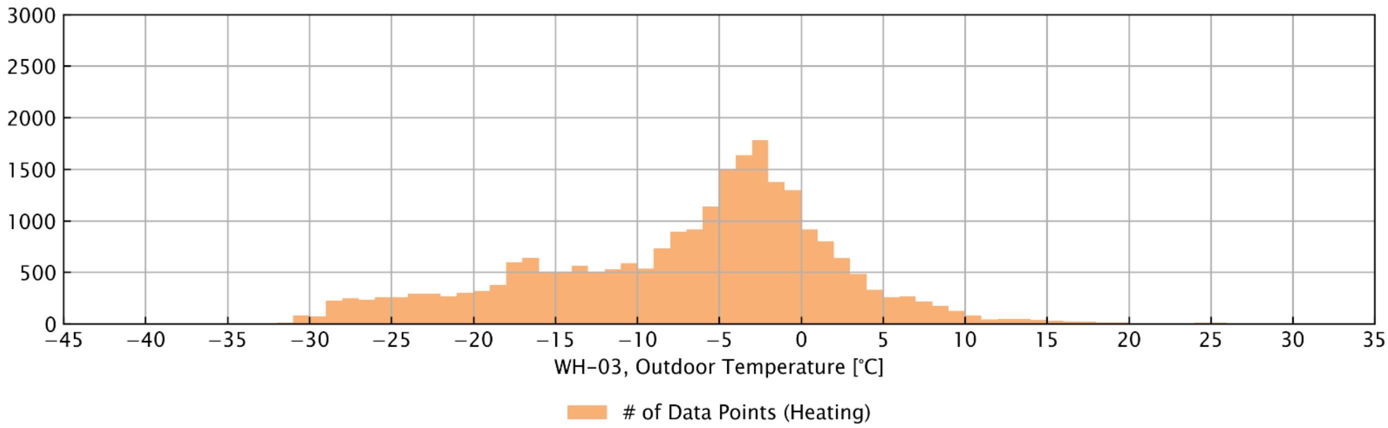
Appendix C - Number of Data Points

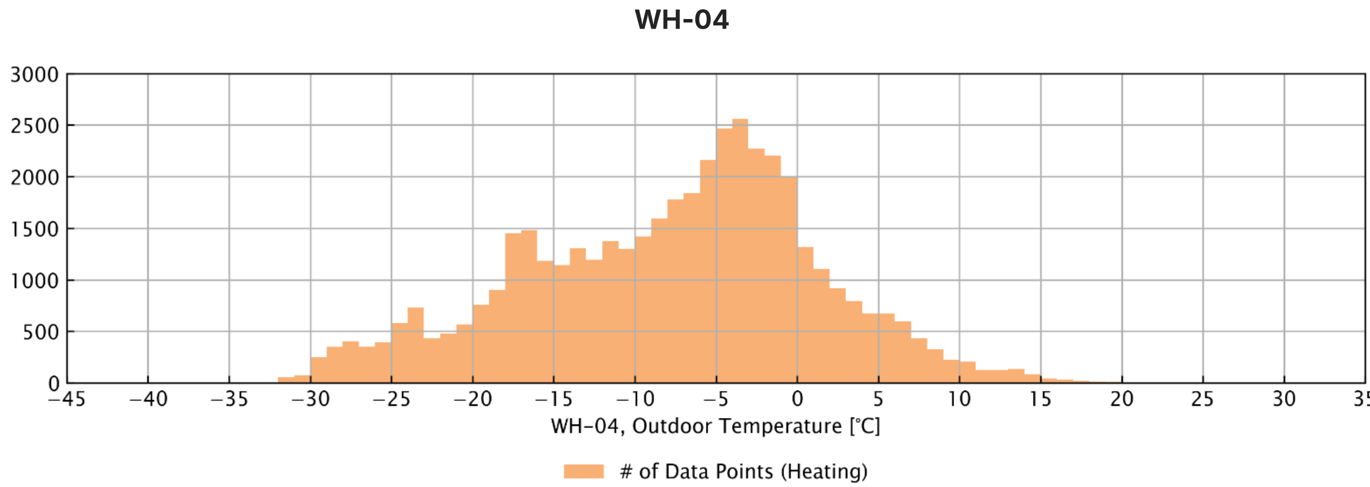
Appendix C plots the number of data points collected in each temperature bin for sites WH-01 through WH-18 (with the exception of WH-01, WH-09, WH-10).

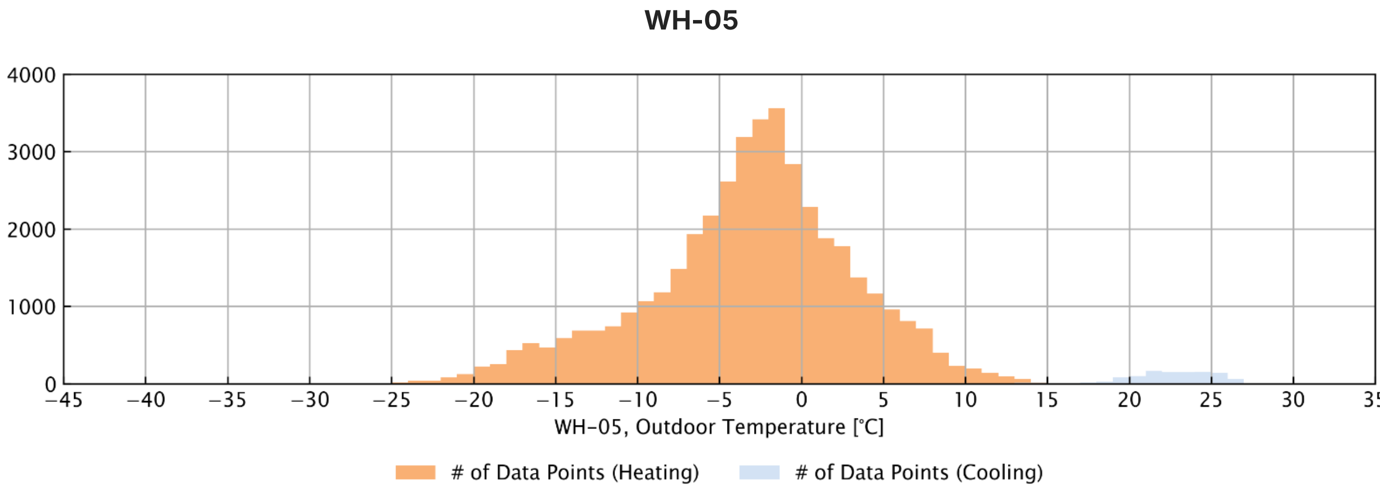
WH-02

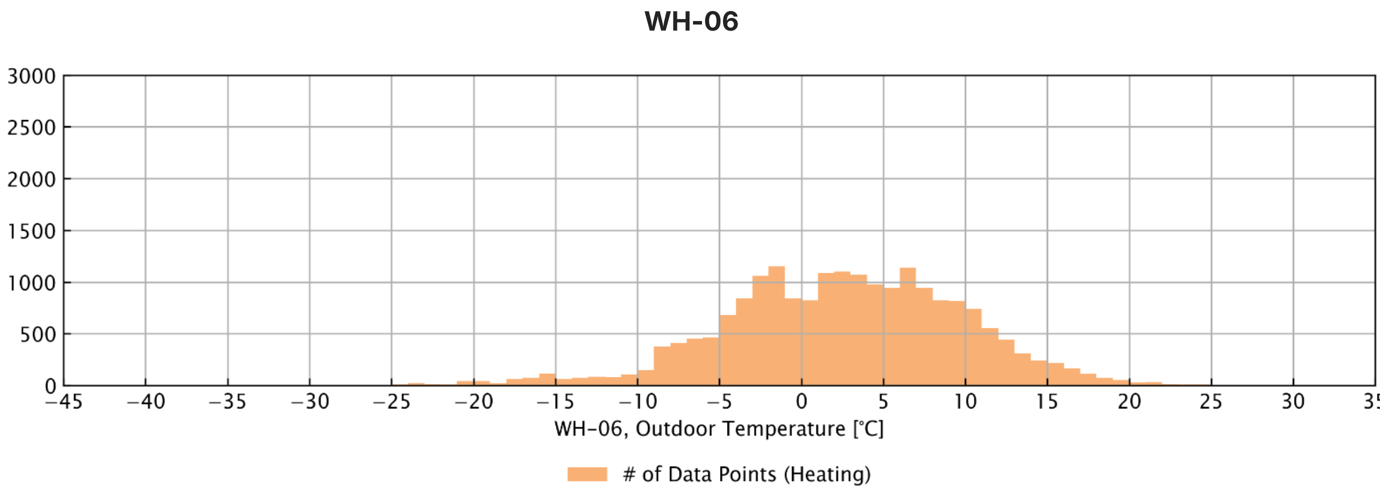


WH-03

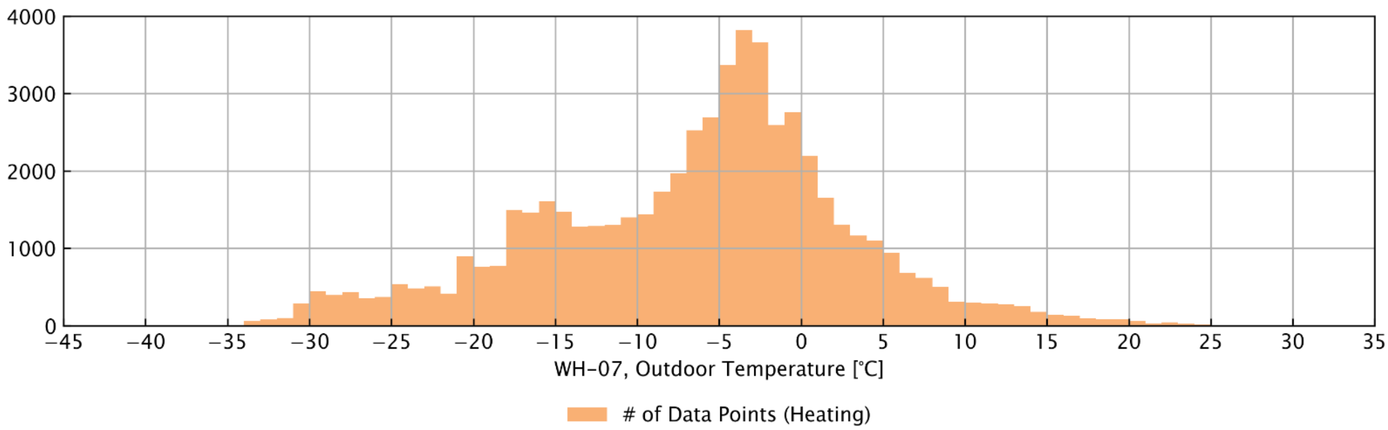



WH-04
3000
2500
2000
1500
1000
500
0
−45 −40 −35 −30 −25 −20 −15 −10 −5 0 5 10 15 20 25 30 35
WH-04, Outdoor Temperature [°C]
# of Data Points (Heating)

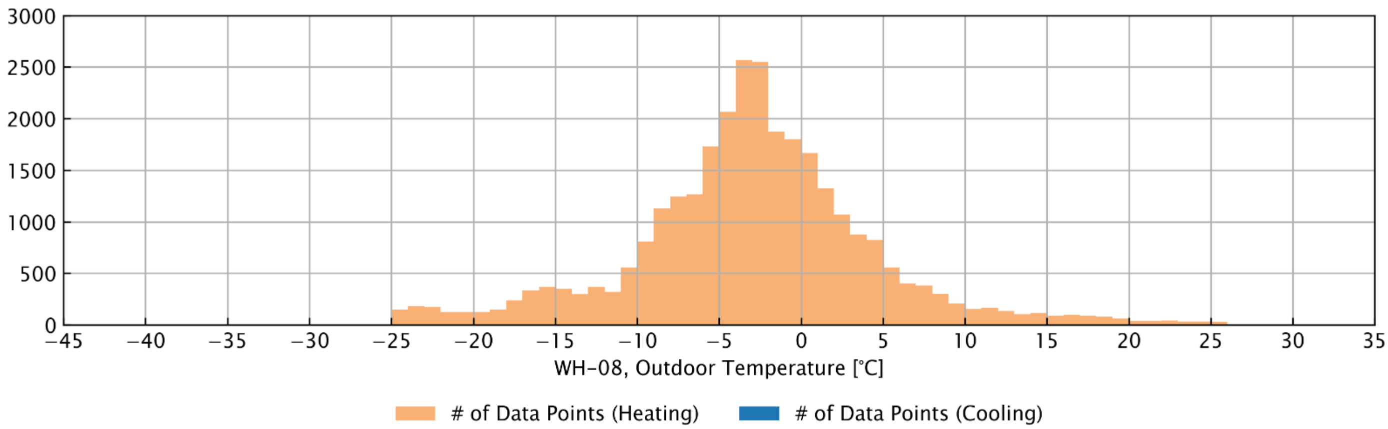

WH-05
4000
3000
2000
1000
0
−45 −40 −35 −30 −25 −20 −15 −10 −5 0 5 10 15 20 25 30 35
WH-05, Outdoor Temperature [°C]
# of Data Points (Heating)
# of Data Points (Cooling)


WH-06
3000
2500
2000
1500
1000
500
0
−45 −40 −35 −30 −25 −20 −15 −10 −5 0 5 10 15 20 25 30 35
WH-06, Outdoor Temperature [°C]
# of Data Points (Heating)

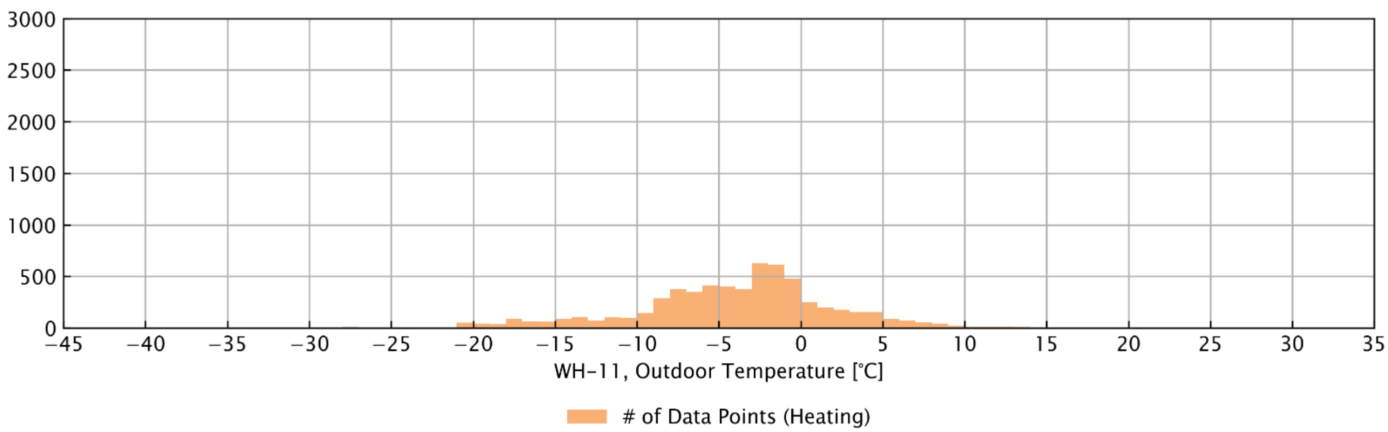
WH-07



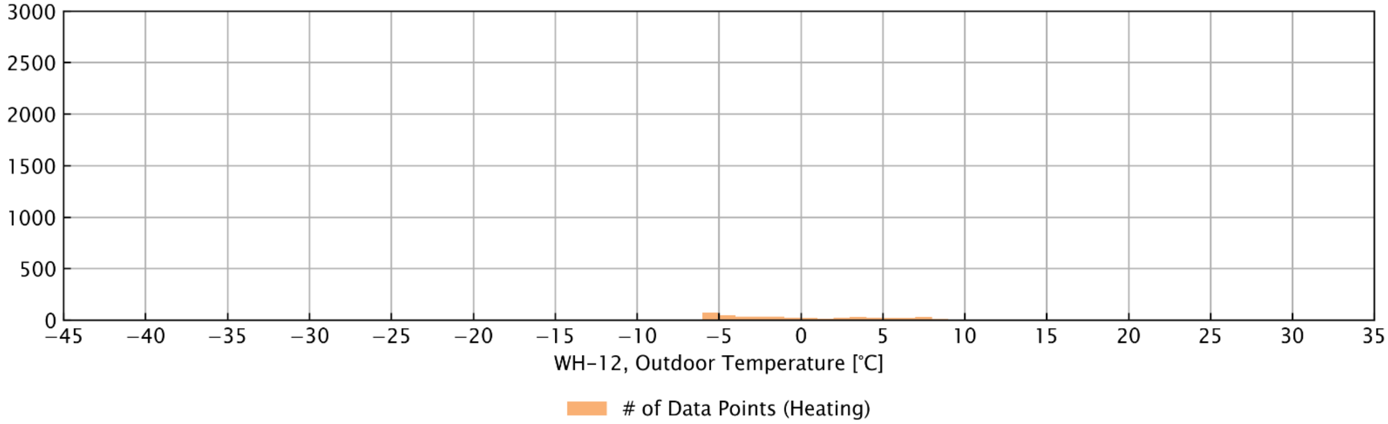
WH-08



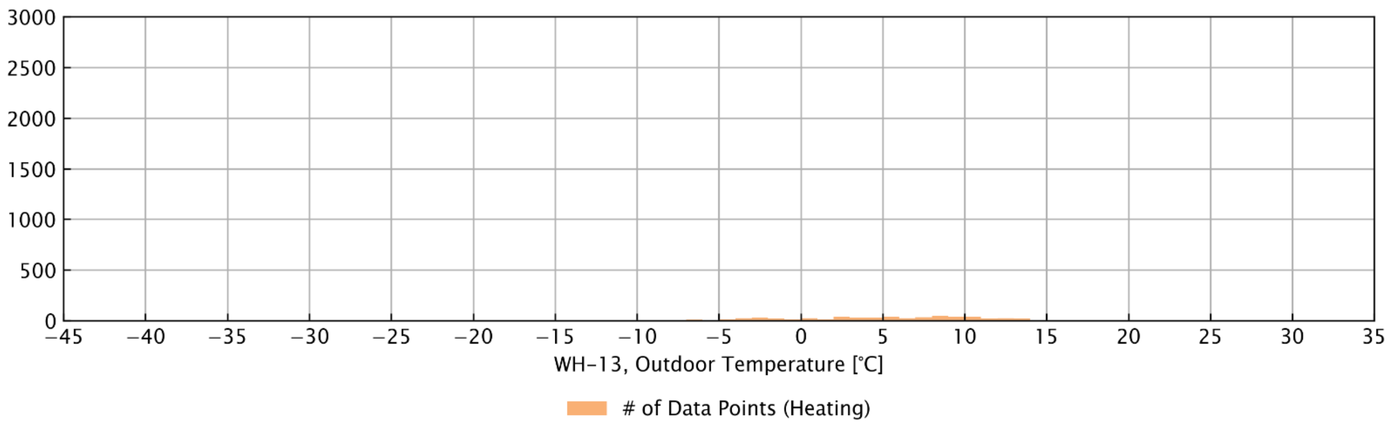
WH-11



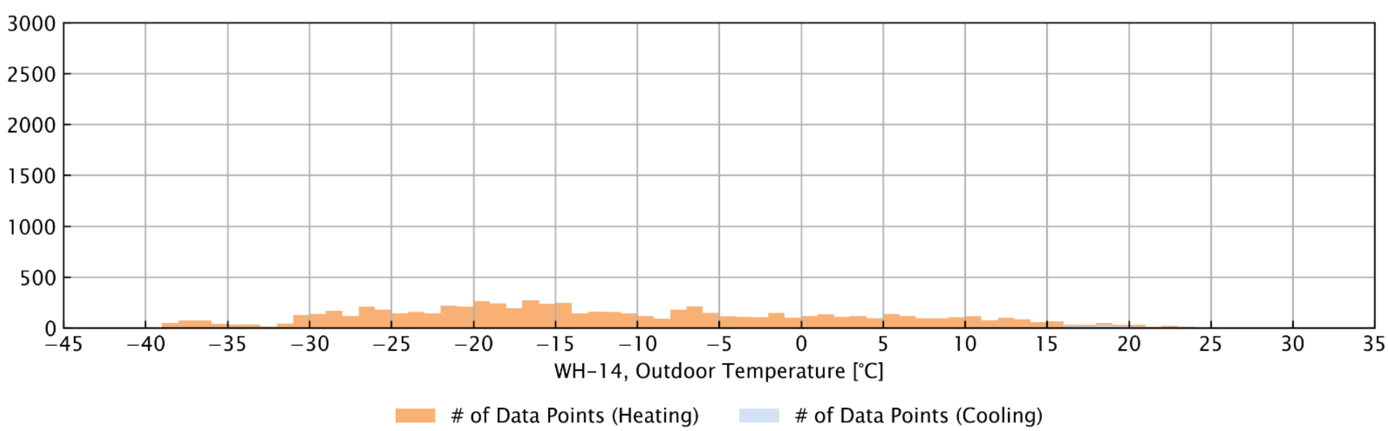
WH-12



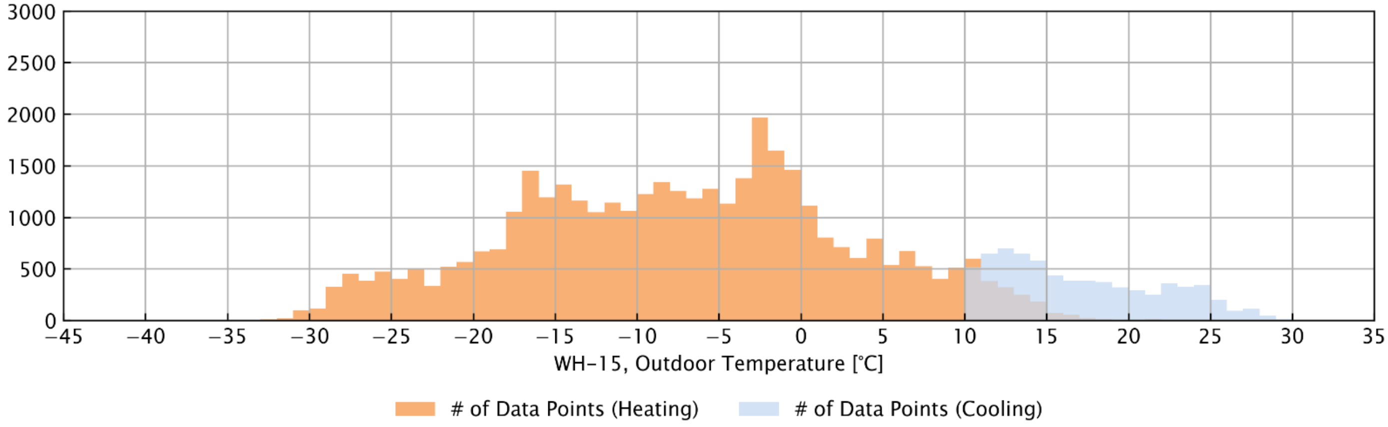
WH-13



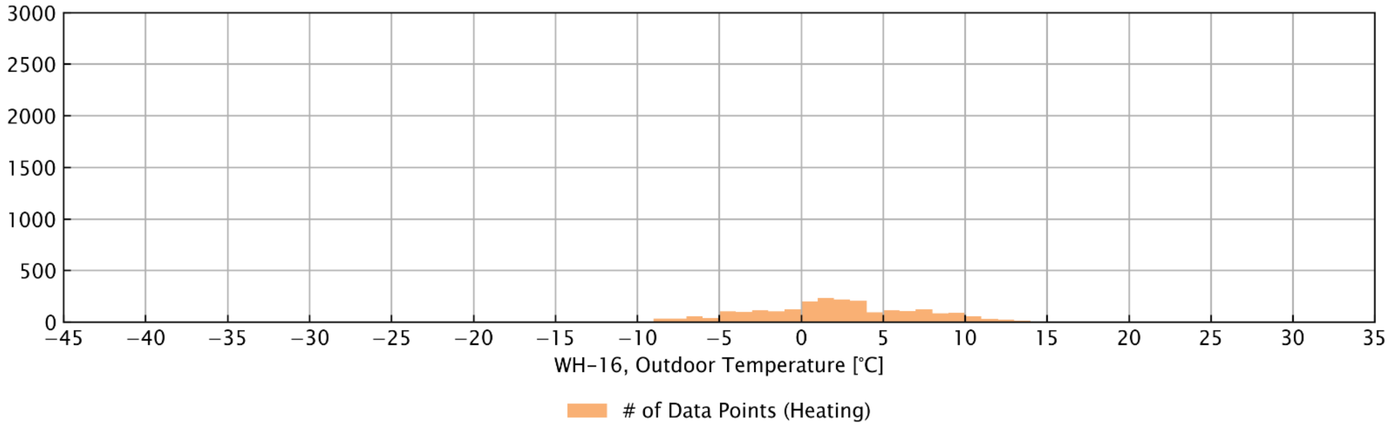
WH-14



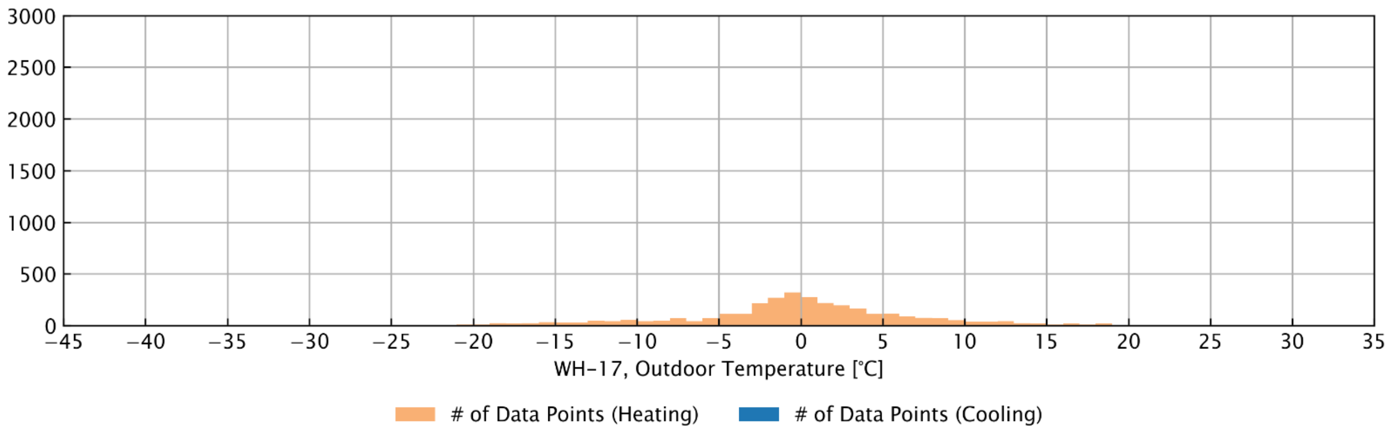
WH-15



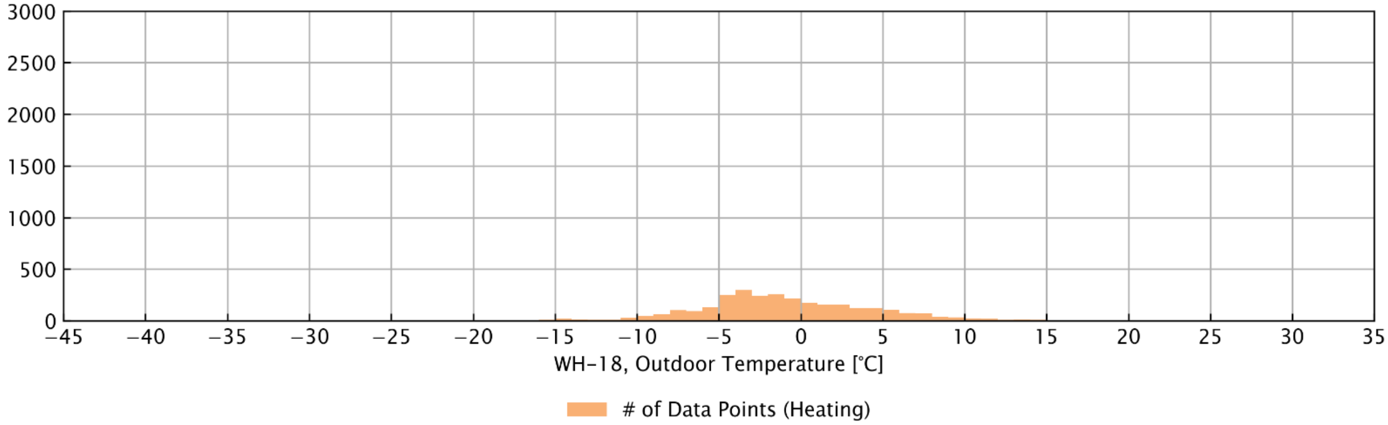
WH-16



WH-17



WH-18


3000
2500
2000
1500
1000
500
0
−45
−40
−35
−30
−25
−20
−15
−10
−5
0
5
10
15
20
25
30
35
WH-18, Outdoor Temperature [°C]
# of Data Points (Heating)

Appendix D - Theoretical and In-Situ Balance Points

The balance point temperature is the outdoor temperature below which the heat pump no longer has the capacity to provide all the heating for the home. It can be estimated by evaluating when the heat pump's heating capacity curve and heating demand (i.e. heat loss of the home) curve intersect. The balance point temperature varies for the different sites and different models of heat pumps.

Figures D1, D2 and D3 show the maximum capacity of the heat pump units based on the manufacturer's specifications (shown with grey dots). These values were obtained from AHRI Directory of Certified Product Performance online database (which includes 'AHRI certified ratings' and 'other ratings'). Where available, the modeled heating demand from Government of Yukon-provided CSA F280 calculations was used to plot the linear relationship in orange; the exception being WH-17 where the CSA F280 value was unavailable, but an EnerGuide value was. Note that not all homes had CSA F280 calculation or results of EnerGuide audit available; therefore, only a handful of sites could be plotted in this way.

The blue dots represent the average measured heating capacity (i.e. measured output from monitoring data) of the heat pumps. The solid blue line represents the maximum measured heating capacity determined from the monitoring data.

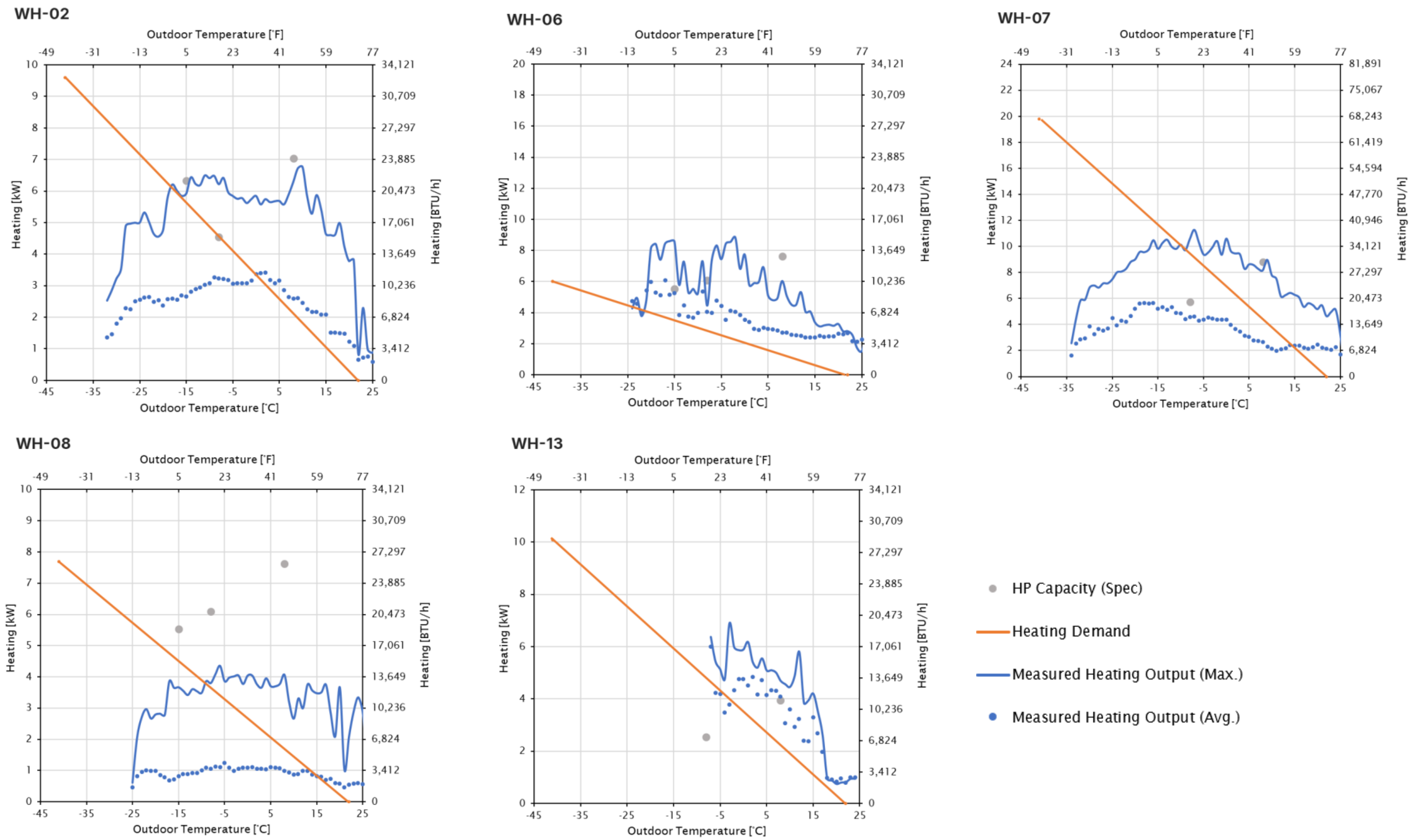


Figure D.1. Measured heating outputs (average and maximum) for the ductless heat pump systems and heating demands. CSA F280 calculated heating demands supplied by the Government of Yukon were used. Specified capacity values (grey dots) are from the AHRI Directory of Certified Product Performance.

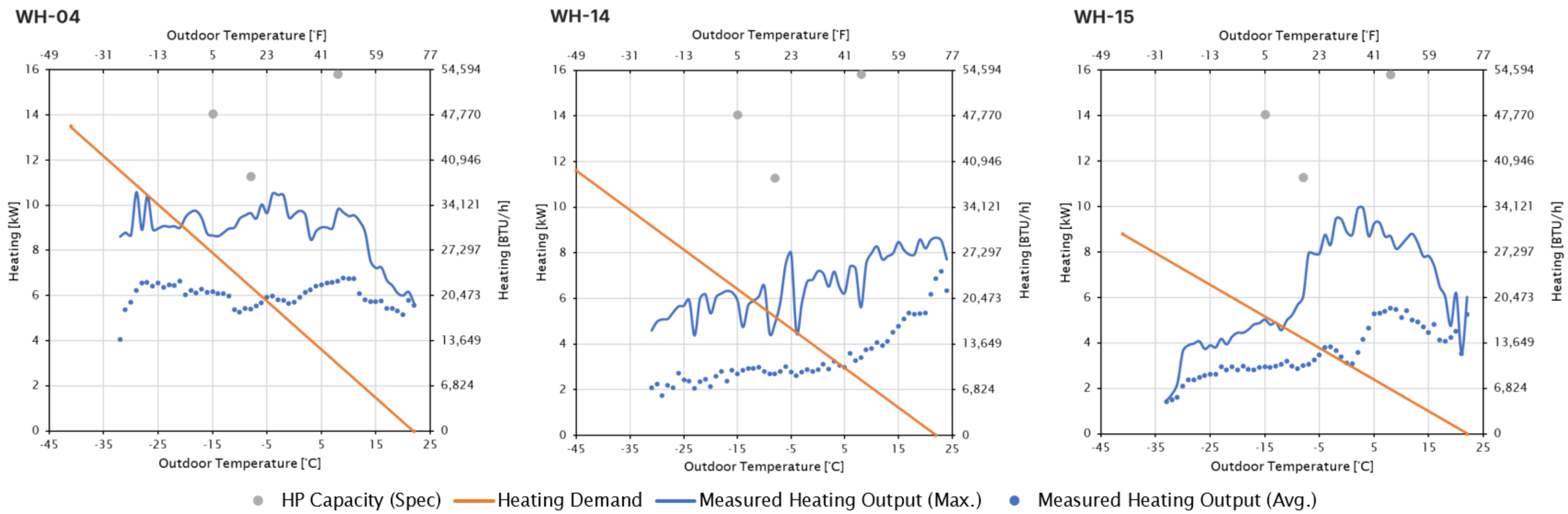


Figure D.2. Measured heating outputs (average and maximum) for the central ducted systems and heating demands. CSA F280 calculated heating demands supplied by the Government of Yukon were used. Specified capacity values (grey dots) are from the AHRI Directory of Certified Product Performance.

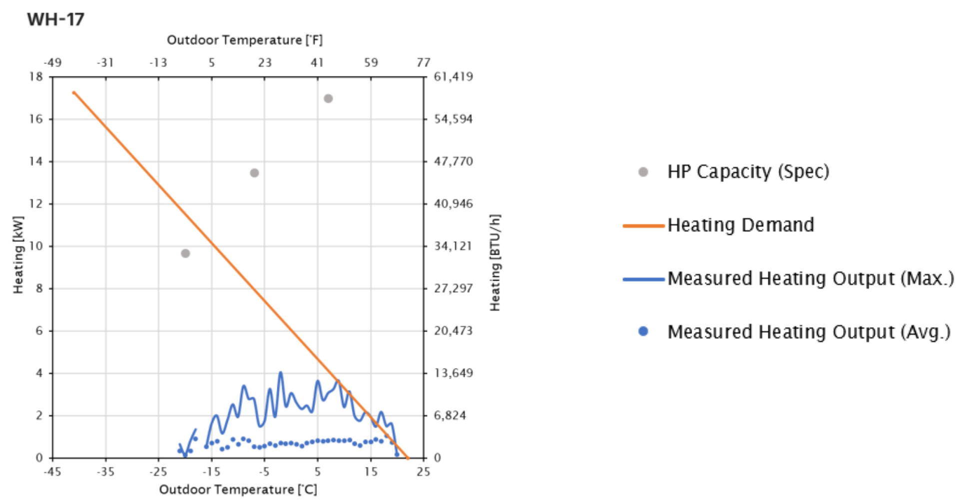
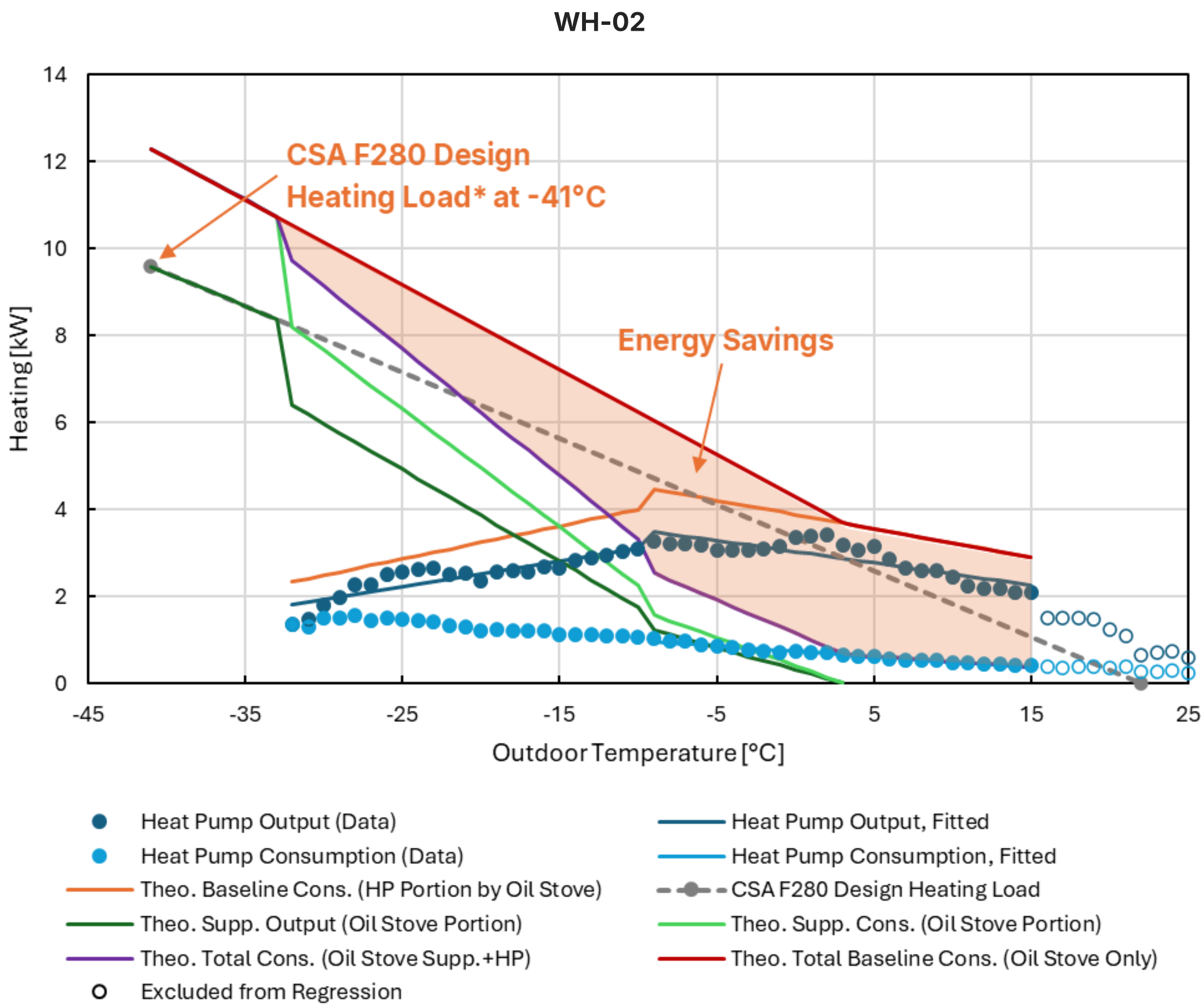


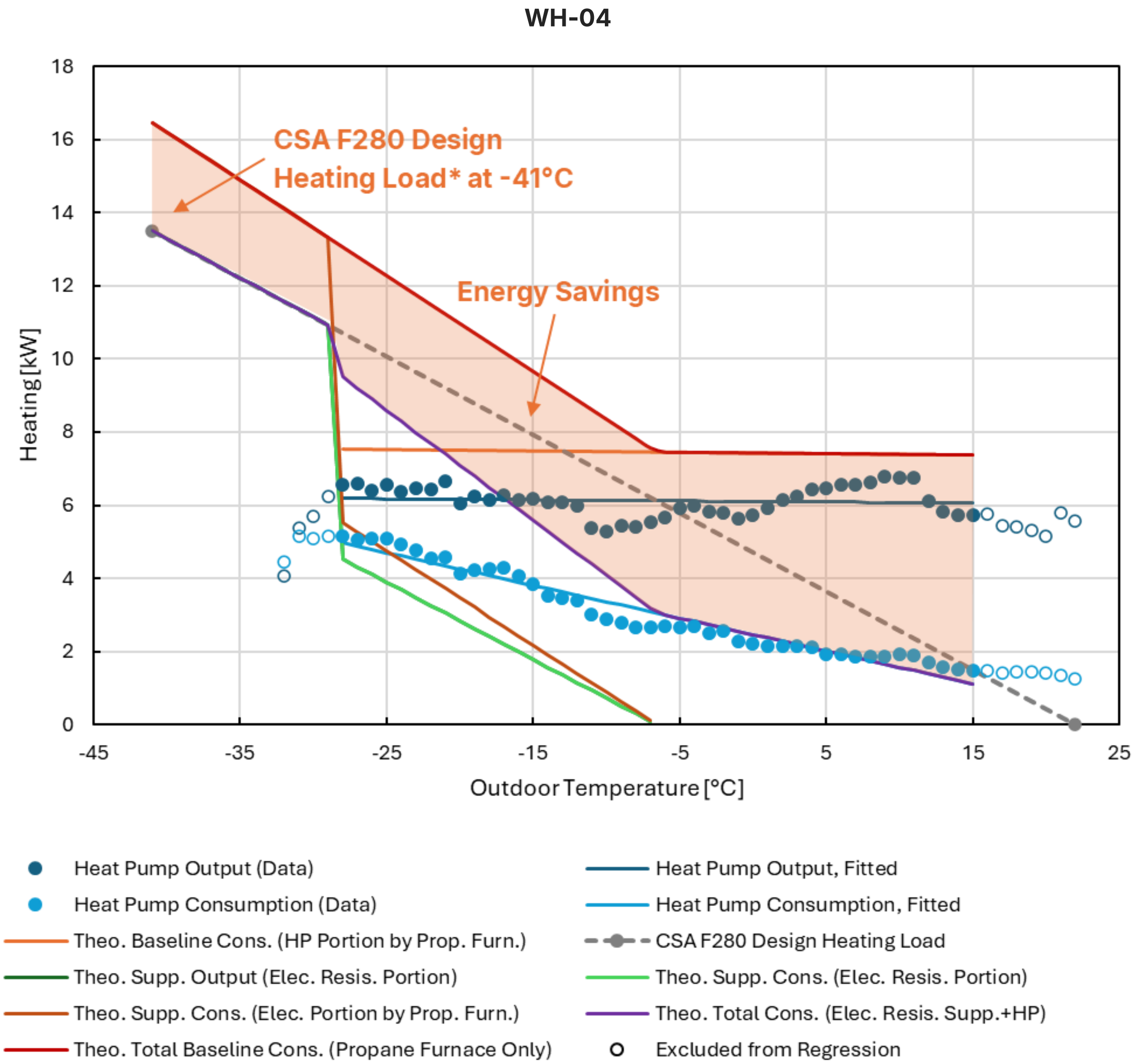
Figure D.3. Measured heating outputs (average and maximum) for an air-to-water heat pump system (WH-17) and heating demand. CSA F280 calculated value was not available for this site, but the EnerGuide value is and was thus used instead. Specified capacity values (grey dots) are from the AHRI Directory of Certified Product Performance.

Appendix E - Energy Savings

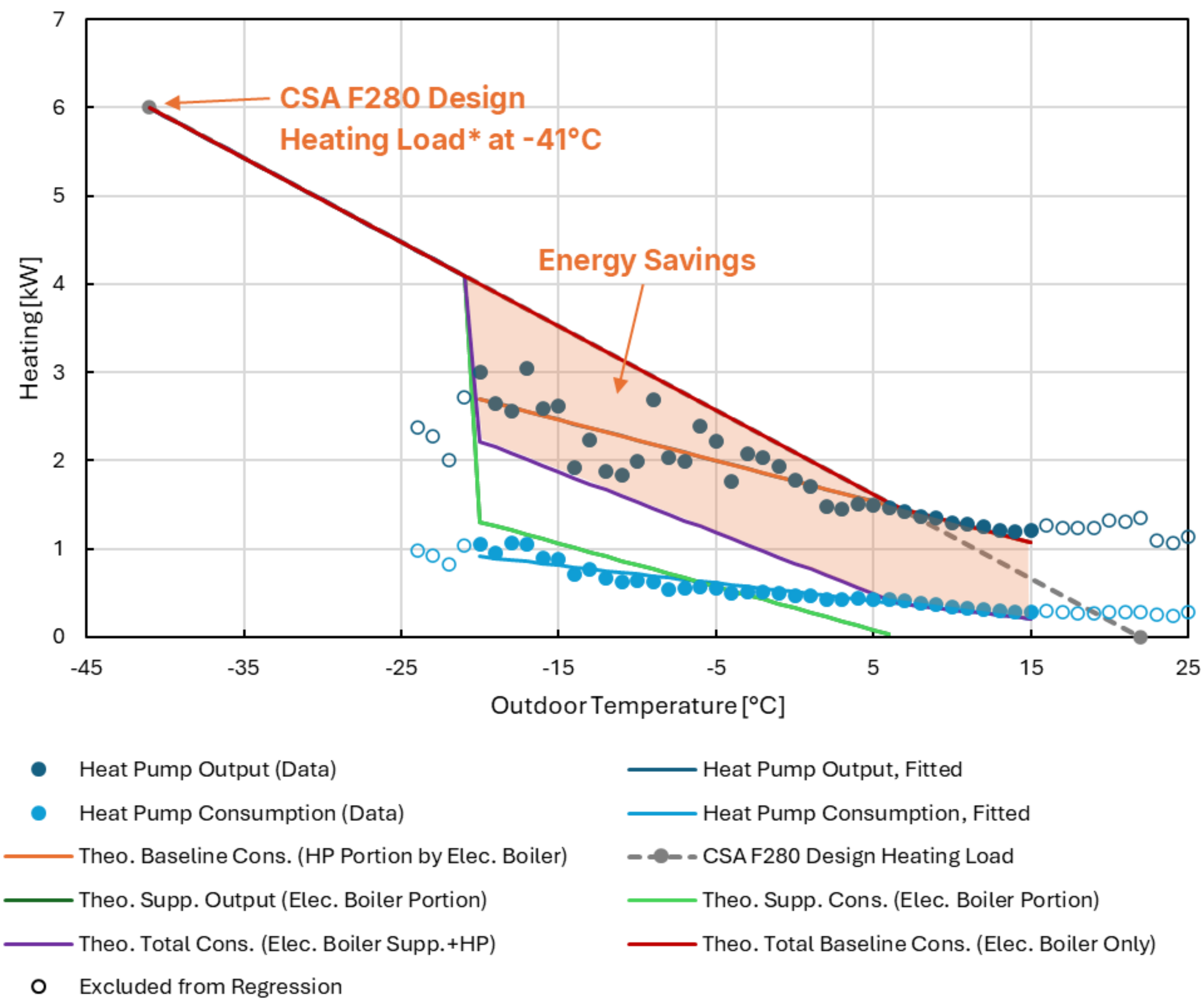
Appendix E details the energy savings estimation for sites WH-01 through WH-18. Note the values in this table assumed supplemental heating to be the CSA F280 heating demand unmet by the heat pump (i.e. difference between heating demand and heat pump output).

Site ID	Heat Pump System Type	Baseline heating system (i.e. previous heating system)	Energy Consumption [ekWh/year]			Greenhouse Gas Emissions [kgCO2e/year]			Utility Cost [$/year]		
			Pre-Retrofit	Post-Retrofit		Pre-Retrofit	Post-Retrofit		Pre-Retrofit	Post-Retrofit	
			Baseline	Heat Pump and/or Supplemental	Savings (%)	Baseline	Heat Pump and/or Supplemental	Savings (%)	Baseline	Heat Pump and/or Supplemental	Savings (%)
WH-01	Ductless	Oil Furnace	Insufficient data; no CSA F280 heating load								
WH-02	Ductless	Oil Stove	39,075	17,135	21,940 (56%)	10,555	3,410	7,145 (68%)	6,129	3,205	2,924 (0%)
WH-03	Ductless	Elec. Baseboard	No CSA F280 heating load								
WH-05	Ductless	Elec. Baseboard, assumed	No CSA F280 heating load								
WH-06	Ductless	Elec. Boiler, assumed	18,282	9,347	8,936 (49%)	1,280	654	625 (49%)	4,422	2,261	2,162 (49%)
WH-07	Ductless	Oil Furnace	68,237	44,528	23,709 (35%)	18,433	10,139	8,294 (45%)	10,704	7,788	2,916 (27%)
WH-08	Ductless	Propane Furnace	27,841	23,205	4,636 (17%)	6,063	4,386	1,676 (28%)	3,808	3,648	160 (4%)
WH-09	Ductless	Elec. Baseboard, assumed	Insufficient data								
WH-10	Ductless	Oil Boiler, assumed	Insufficient data								
WH-11	Ductless	Oil Stove	No CSA F280 heating load								
WH-12	Ductless	Oil Furnace, assumed	No CSA F280 heating load								
WH-13	Ductless	Oil Furnace, assumed	38,415	25,064	13,351 (35%)	10,377	5,165	5,212 (50%)	6,026	4,614	1,412 (23%)
WH-16	Ductless	Elec. Baseboard, assumed	41,942	27,554	14,388 (34%)	2,936	1,929	1,007 (34%)	10,146	6,665	3,481 (34%)
Ductless Average			**38,965**	**24,472**	**14,493 (38%)**	**8,274**	**4,281**	**3,993 (46%)**	**6,873**	**4,697**	**2,176 (31%)**
WH-04	Central Ducted	Propane Furnace	65,471	25,963	39,508 (60%)	14,258	1,817	12,440 (87%)	8,955	6,280	2,675 (30%)
WH-14	Central Ducted	Oil Furnace	46,426	37,359	9,067 (20%)	12,541	6,134	6,407 (51%)	7,283	7,542	-259 (-4%)
WH-15	Central Ducted	Elec. Baseboard, assumed	37,474	20,505	16,969 (45%)	2,623	1,435	1,188 (45%)	9,065	4,960	4,105 (45%)
Central Ducted Average			**49,790**	**27,942**	**21,848 (42%)**	**9,807**	**3,129**	**6,678 (61%)**	**8,434**	**6,261**	**1,087 (24%)**
WH-17	Central Air-to-Water	Elec. Boiler, assumed	51,185	50,641	544 (1%)	3,583	3,545	38 (1%)	12,382	12,250	132 (1%)
WH-18	Central Air-to-Water	Oil Boiler	Insufficient data								


WH-02
CSA F280 Design
Heating Load* at -41°C
Energy Savings
Heating [kW]
Outdoor Temperature [°C]
14
12
10
8
6
4
2
0
-45
-35
-25
-15
-5
5
15
25
Heat Pump Output (Data)
Heat Pump Consumption (Data)
Theo. Baseline Cons. (HP Portion by Oil Stove)
Theo. Supp. Output (Oil Stove Portion)
Theo. Total Cons. (Oil Stove Supp.+HP)
Excluded from Regression
Heat Pump Output, Fitted
Heat Pump Consumption, Fitted
CSA F280 Design Heating Load
Theo. Supp. Cons. (Oil Stove Portion)
Theo. Total Baseline Cons. (Oil Stove Only)

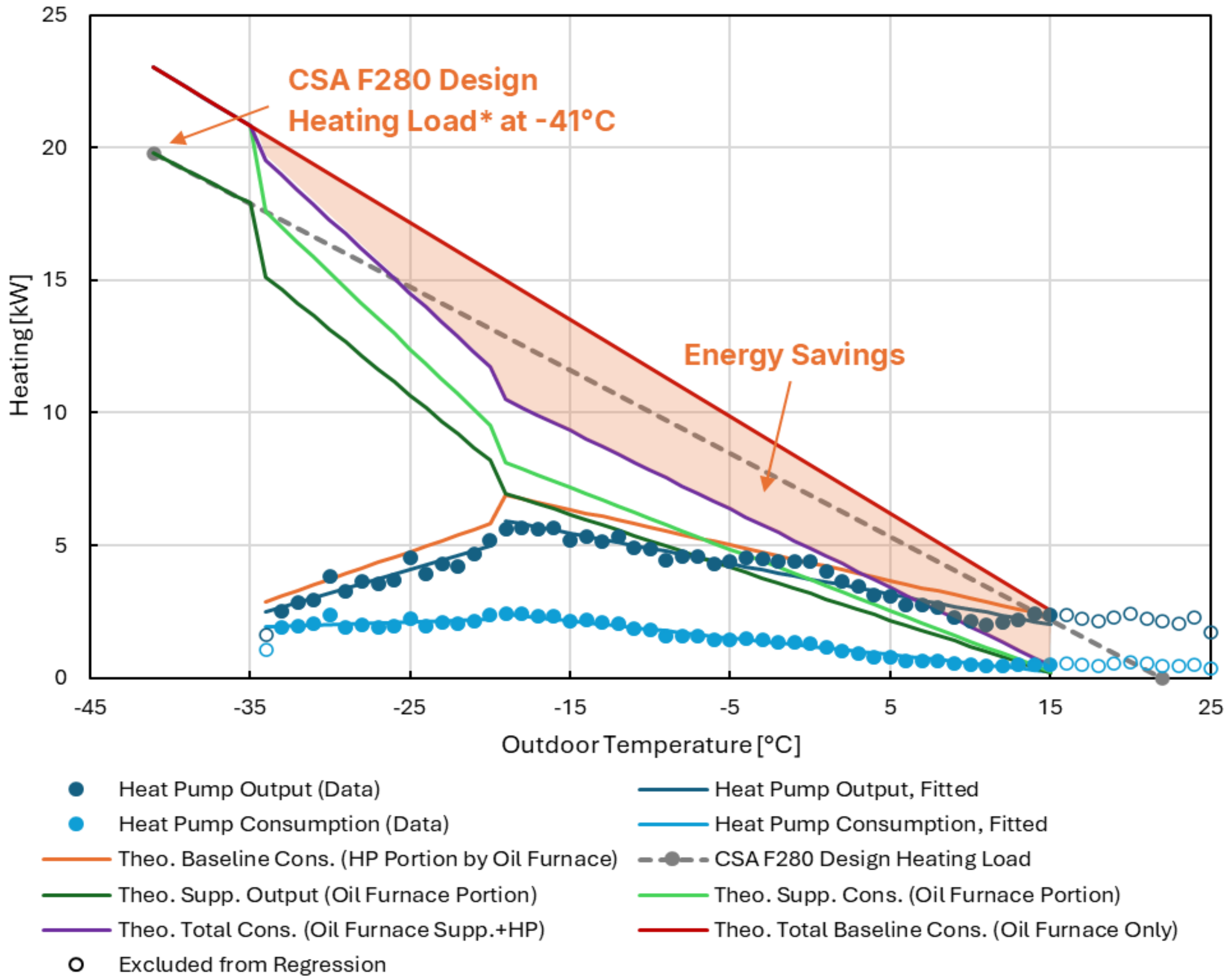

WH-04
CSA F280 Design
Heating Load* at -41°C
Energy Savings
Heating [kW]
Outdoor Temperature [°C]
18
16
14
12
10
8
6
4
2
0
-45
-35
-25
-15
-5
5
15
25
Heat Pump Output (Data)
Heat Pump Consumption (Data)
Theo. Baseline Cons. (HP Portion by Prop. Furn.)
Theo. Supp. Output (Elec. Resis. Portion)
Theo. Supp. Cons. (Elec. Portion by Prop. Furn.)
Theo. Total Baseline Cons. (Propane Furnace Only)
Heat Pump Output, Fitted
Heat Pump Consumption, Fitted
CSA F280 Design Heating Load
Theo. Supp. Cons. (Elec. Resis. Portion)
Theo. Total Cons. (Elec. Resis. Supp.+HP)
Excluded from Regression

WH-06



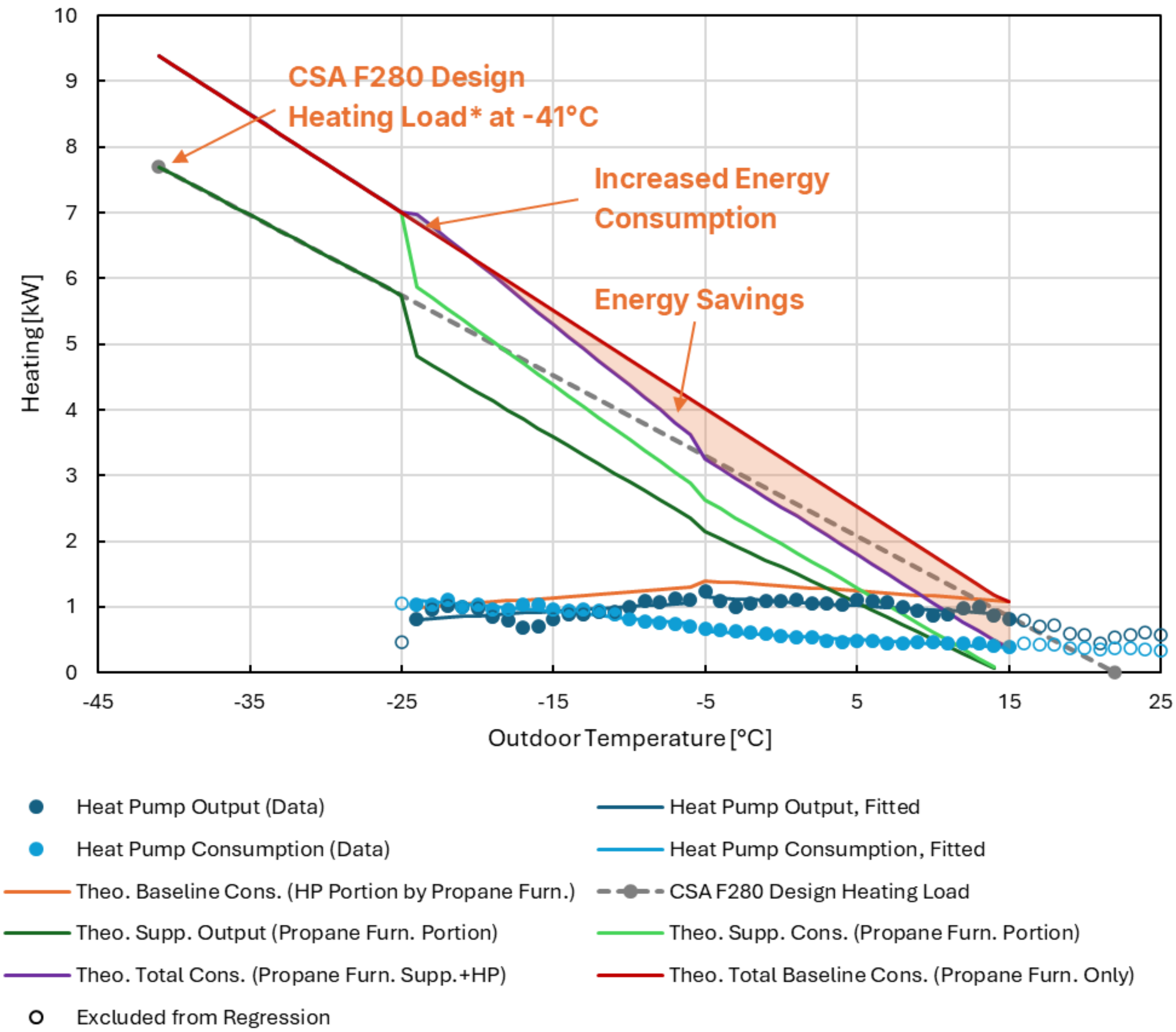
CSA F280 Design
Heating Load* at -41°C
Energy Savings
Heating [kW]
Outdoor Temperature [°C]
7
6
5
4
3
2
1
0
-45
-35
-25
-15
-5
5
15
25
Heat Pump Output (Data)
Heat Pump Consumption (Data)
Theo. Baseline Cons. (HP Portion by Elec. Boiler)
Theo. Supp. Output (Elec. Boiler Portion)
Theo. Total Cons. (Elec. Boiler Supp.+HP)
Excluded from Regression
Heat Pump Output, Fitted
Heat Pump Consumption, Fitted
CSA F280 Design Heating Load
Theo. Supp. Cons. (Elec. Boiler Portion)
Theo. Total Baseline Cons. (Elec. Boiler Only)

WH-07

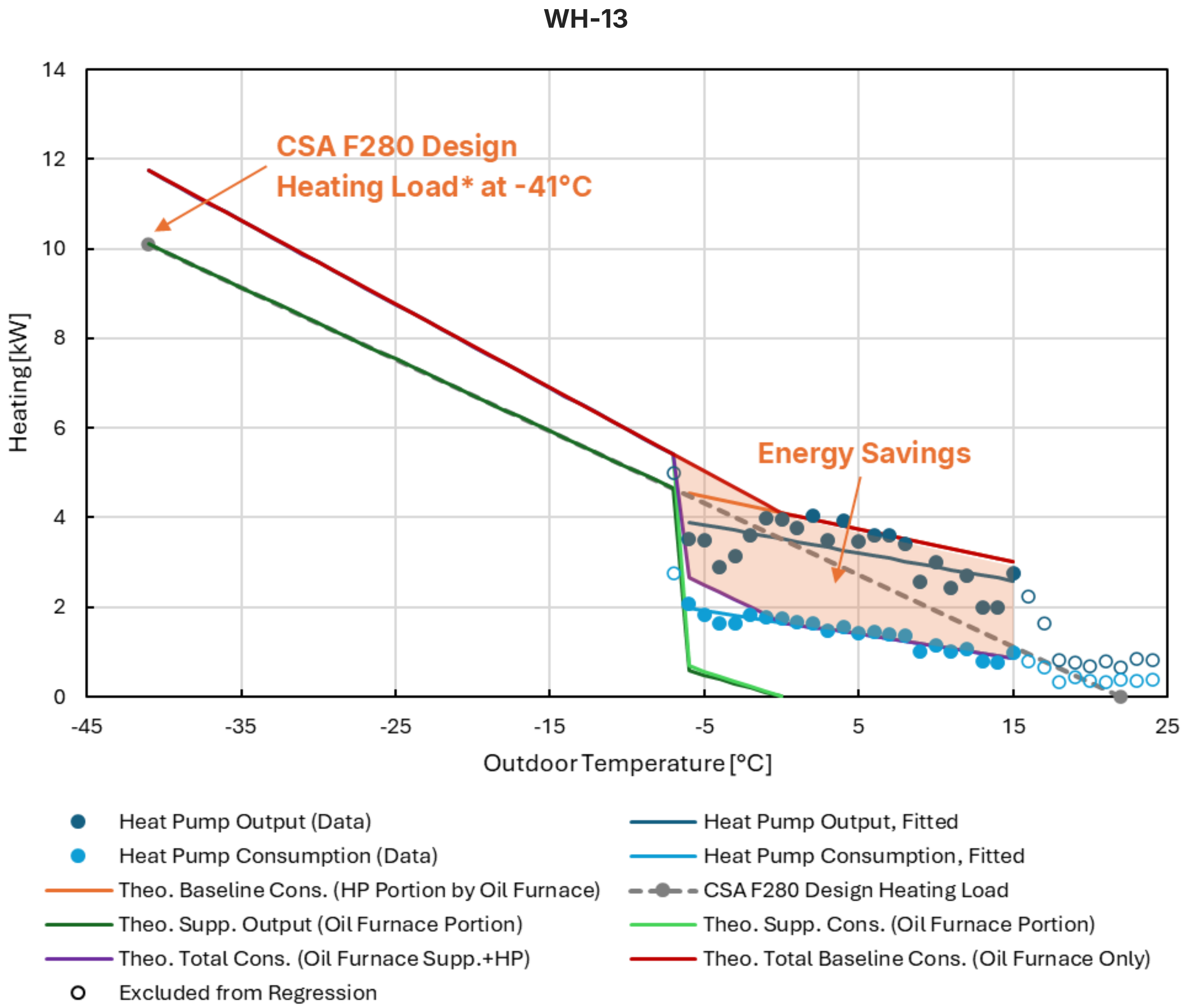


CSA F280 Design
Heating Load* at -41°C
Energy Savings
Heating [kW]
Outdoor Temperature [°C]
25
20
15
10
5
0
-45
-35
-25
-15
-5
5
15
25
Heat Pump Output (Data)
Heat Pump Consumption (Data)
Theo. Baseline Cons. (HP Portion by Oil Furnace)
Theo. Supp. Output (Oil Furnace Portion)
Theo. Total Cons. (Oil Furnace Supp.+HP)
Excluded from Regression
Heat Pump Output, Fitted
Heat Pump Consumption, Fitted
CSA F280 Design Heating Load
Theo. Supp. Cons. (Oil Furnace Portion)
Theo. Total Baseline Cons. (Oil Furnace Only)

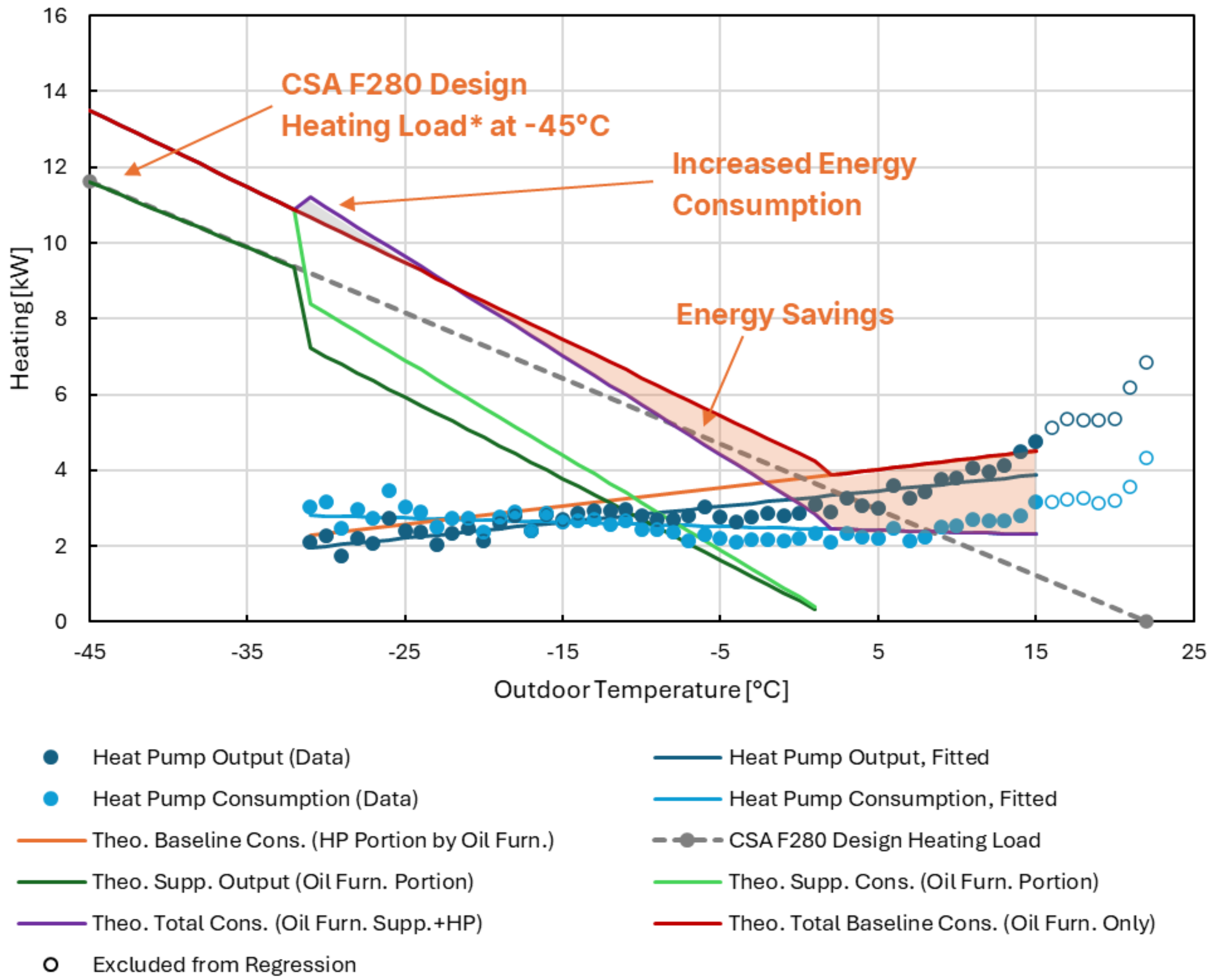
WH-08



10
9
8
7
6
5
4
3
2
1
0
Heating [kW]
-45
-35
-25
-15
-5
5
15
25
Outdoor Temperature [°C]
CSA F280 Design
Heating Load* at -41°C
Increased Energy
Consumption
Energy Savings
Heat Pump Output (Data)
Heat Pump Consumption (Data)
Theo. Baseline Cons. (HP Portion by Propane Furn.)
Theo. Supp. Output (Propane Furn. Portion)
Theo. Total Cons. (Propane Furn. Supp.+HP)
Excluded from Regression
Heat Pump Output, Fitted
Heat Pump Consumption, Fitted
CSA F280 Design Heating Load
Theo. Supp. Cons. (Propane Furn. Portion)
Theo. Total Baseline Cons. (Propane Furn. Only)

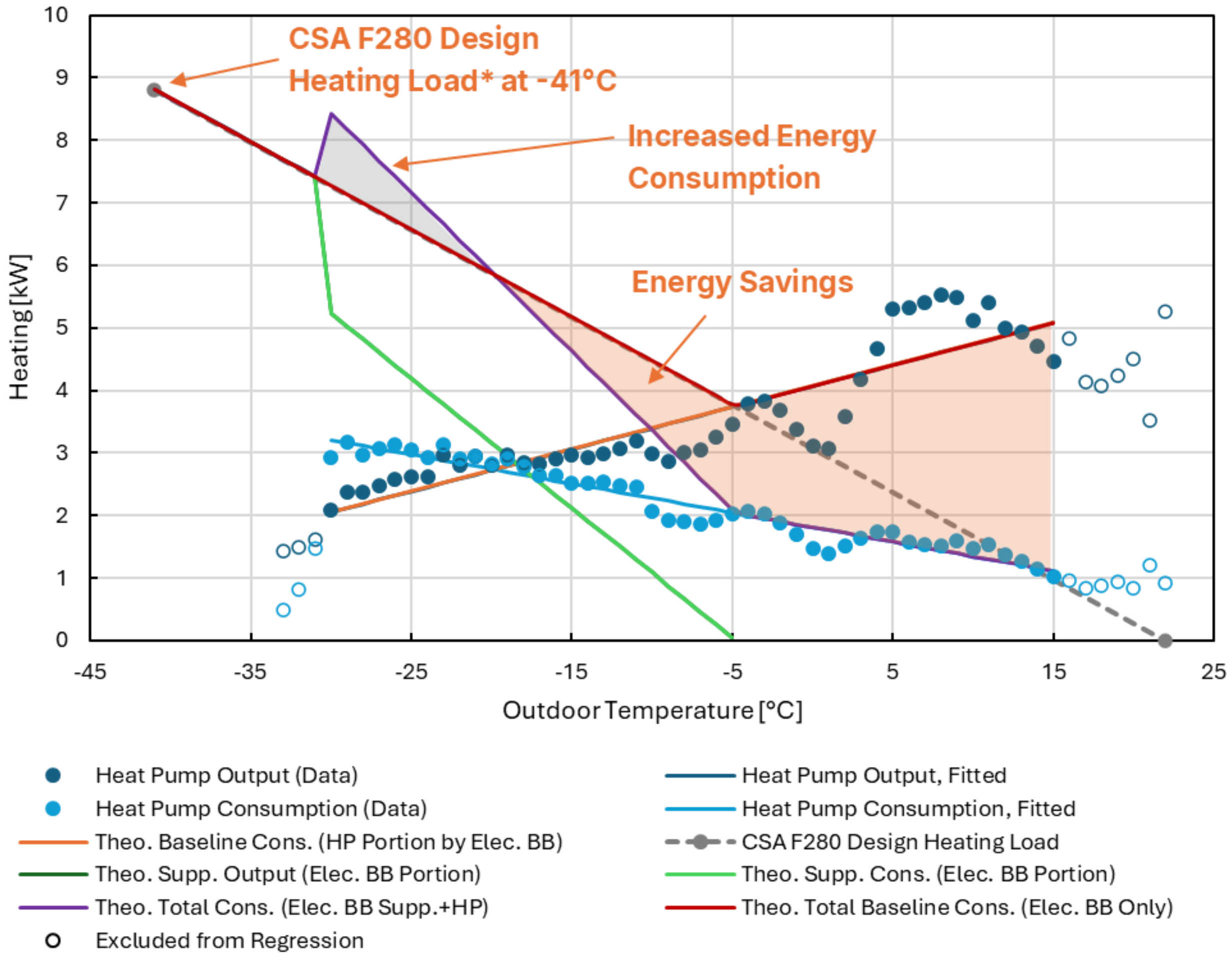

WH-13
CSA F280 Design
Heating Load* at -41°C
Energy Savings
Heating [kW]
14
12
10
8
6
4
2
0
-45
-35
-25
-15
-5
5
15
25
Outdoor Temperature [°C]
Heat Pump Output (Data)
Heat Pump Output, Fitted
Heat Pump Consumption (Data)
Heat Pump Consumption, Fitted
Theo. Baseline Cons. (HP Portion by Oil Furnace)
CSA F280 Design Heating Load
Theo. Supp. Output (Oil Furnace Portion)
Theo. Supp. Cons. (Oil Furnace Portion)
Theo. Total Cons. (Oil Furnace Supp.+HP)
Theo. Total Baseline Cons. (Oil Furnace Only)
Excluded from Regression

WH-14



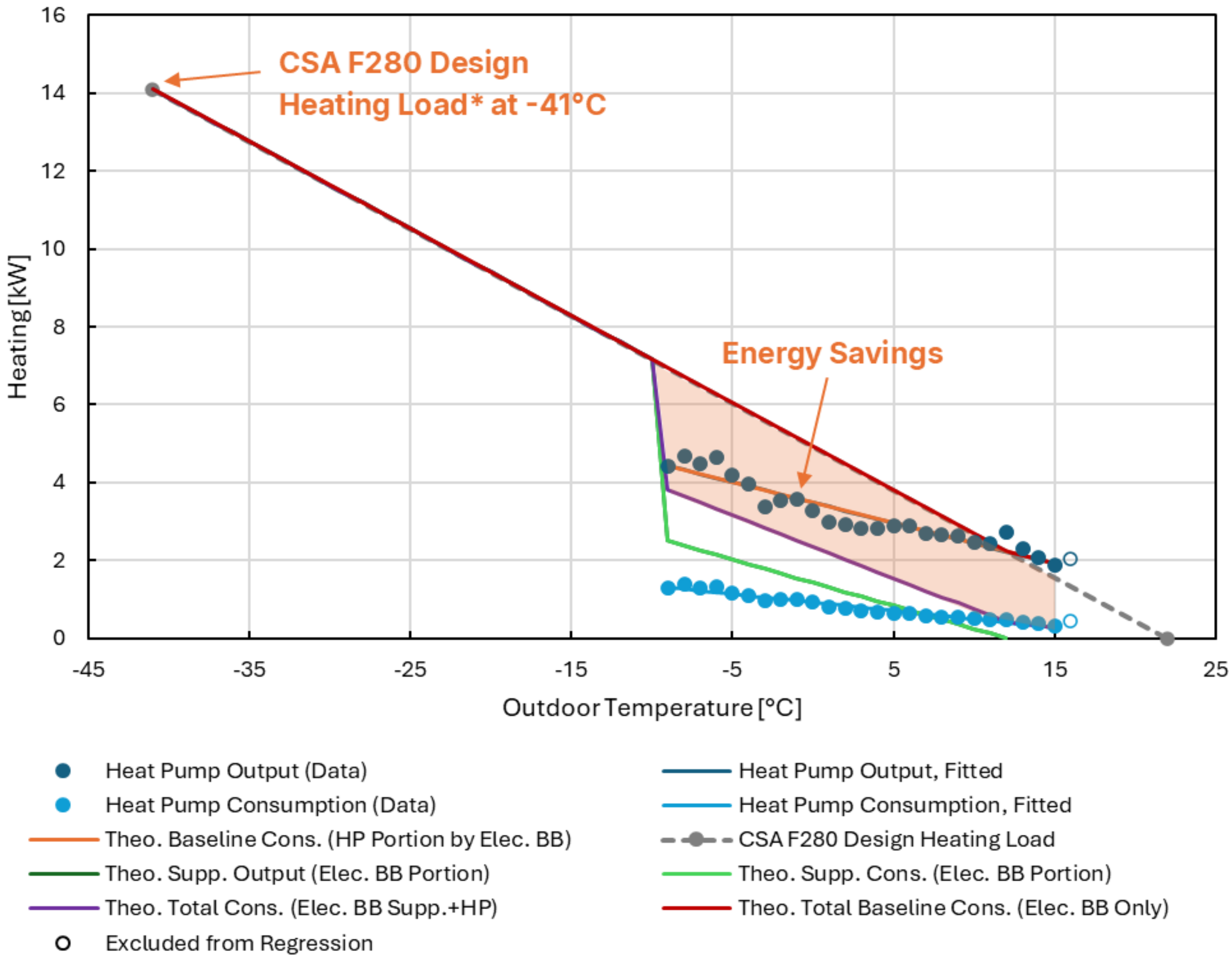
16
14
12
10
8
6
4
2
0
Heating [kW]
-45
-35
-25
-15
-5
5
15
25
Outdoor Temperature [°C]
CSA F280 Design Heating Load* at -45°C
Increased Energy Consumption
Energy Savings
Heat Pump Output (Data)
Heat Pump Consumption (Data)
Theo. Baseline Cons. (HP Portion by Oil Furn.)
Theo. Supp. Output (Oil Furn. Portion)
Theo. Total Cons. (Oil Furn. Supp.+HP)
Excluded from Regression
Heat Pump Output, Fitted
Heat Pump Consumption, Fitted
CSA F280 Design Heating Load
Theo. Supp. Cons. (Oil Furn. Portion)
Theo. Total Baseline Cons. (Oil Furn. Only)

WH-15

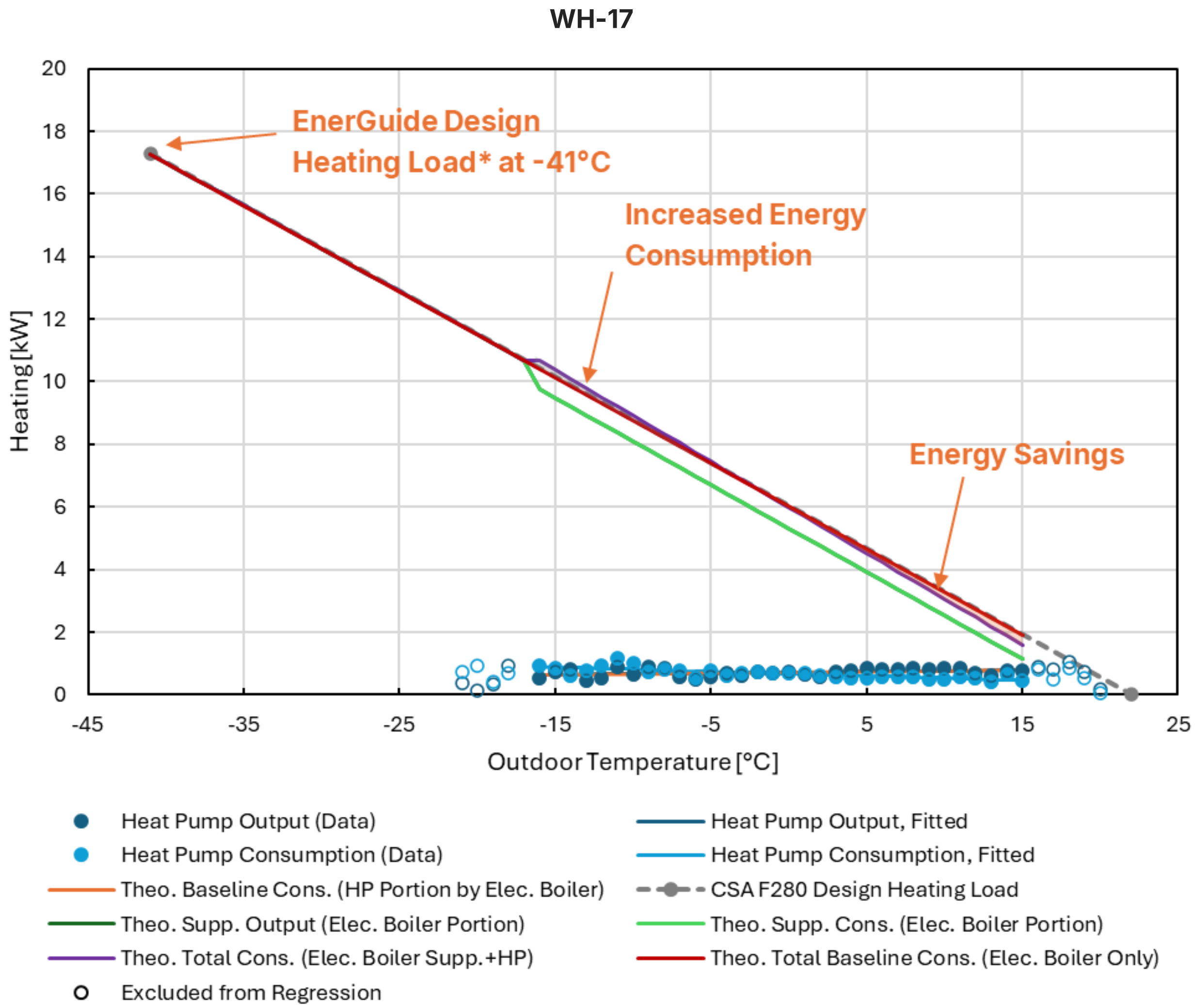


CSA F280 Design Heating Load* at -41°C
Increased Energy Consumption
Energy Savings
Heating [kW]
Outdoor Temperature [°C]
10
9
8
7
6
5
4
3
2
1
0
-45
-35
-25
-15
-5
5
15
25
Heat Pump Output (Data)
Heat Pump Consumption (Data)
Theo. Baseline Cons. (HP Portion by Elec. BB)
Theo. Supp. Output (Elec. BB Portion)
Theo. Total Cons. (Elec. BB Supp.+HP)
Excluded from Regression
Heat Pump Output, Fitted
Heat Pump Consumption, Fitted
CSA F280 Design Heating Load
Theo. Supp. Cons. (Elec. BB Portion)
Theo. Total Baseline Cons. (Elec. BB Only)

WH-16



CSA F280 Design Heating Load* at -41°C
Energy Savings
Heating [kW]
Outdoor Temperature [°C]
16
14
12
10
8
6
4
2
0
-45
-35
-25
-15
-5
5
15
25
Heat Pump Output (Data)
Heat Pump Consumption (Data)
Theo. Baseline Cons. (HP Portion by Elec. BB)
Theo. Supp. Output (Elec. BB Portion)
Theo. Total Cons. (Elec. BB Supp.+HP)
Excluded from Regression
Heat Pump Output, Fitted
Heat Pump Consumption, Fitted
CSA F280 Design Heating Load
Theo. Supp. Cons. (Elec. BB Portion)
Theo. Total Baseline Cons. (Elec. BB Only)


WH-17
EnerGuide Design Heating Load* at -41°C
Increased Energy Consumption
Energy Savings
Heating [kW]
Outdoor Temperature [°C]
20
18
16
14
12
10
8
6
4
2
0
-45
-35
-25
-15
-5
5
15
25
Heat Pump Output (Data)
Heat Pump Consumption (Data)
Theo. Baseline Cons. (HP Portion by Elec. Boiler)
Theo. Supp. Output (Elec. Boiler Portion)
Theo. Total Cons. (Elec. Boiler Supp.+HP)
Excluded from Regression
Heat Pump Output, Fitted
Heat Pump Consumption, Fitted
CSA F280 Design Heating Load
Theo. Supp. Cons. (Elec. Boiler Portion)
Theo. Total Baseline Cons. (Elec. Boiler Only)