Yukon Cold Climate Heat Pump Study

2023/2024 Heating Season

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Version History

Version	Date	Description
0.1	August 1, 2025	Draft Report for 2023/2024 Heating Season
0.2	October 2, 2025	Draft 2 Report for 2023/2024 Heating Season
1.0	November 30, 2025	Final Report for 2023/2024 Heating Season

Table of Contents

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 the first heating season, from September 1, 2023 to March 31, 2024 (7 months). A second report covers the period from April 2024 until equipment removal at the end of March 2025 (approx. 12 months).

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.

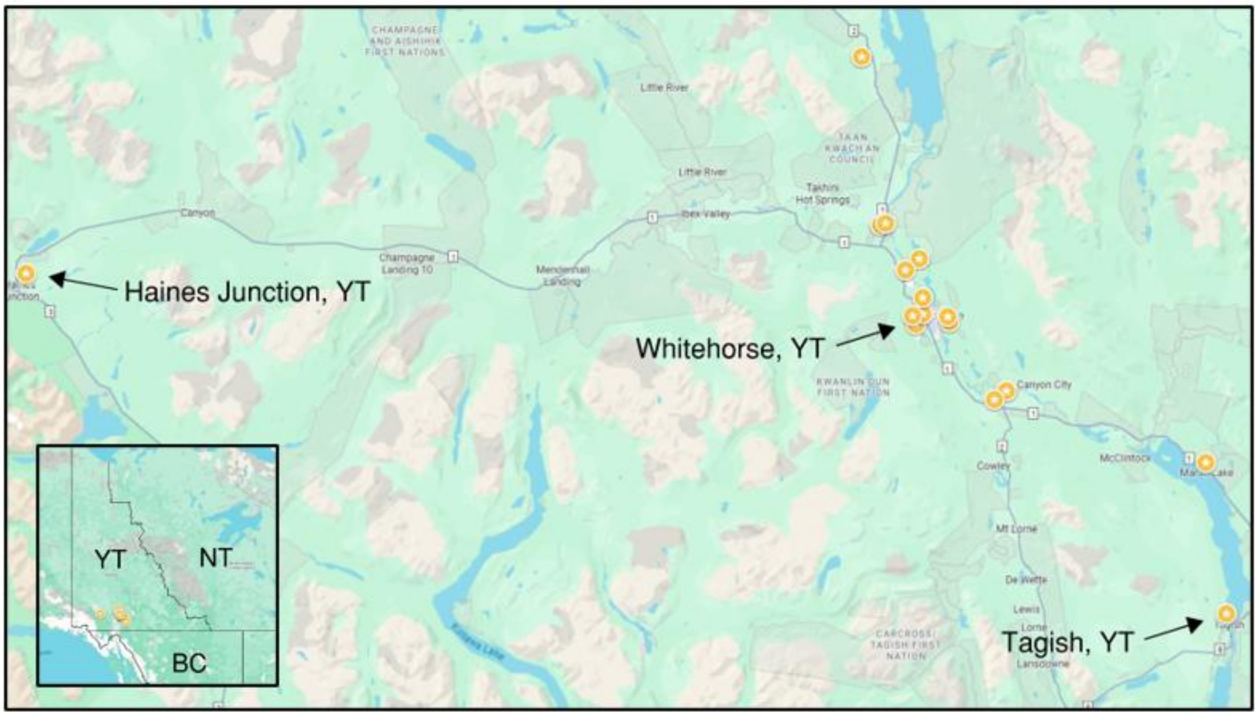


Figure 2.1 – Location of monitored heat pumps are indicated by yellow stars (source: Google Maps, 2025).

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 31, 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- and multi-split heat pump systems, indoor fan consumptions were 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.

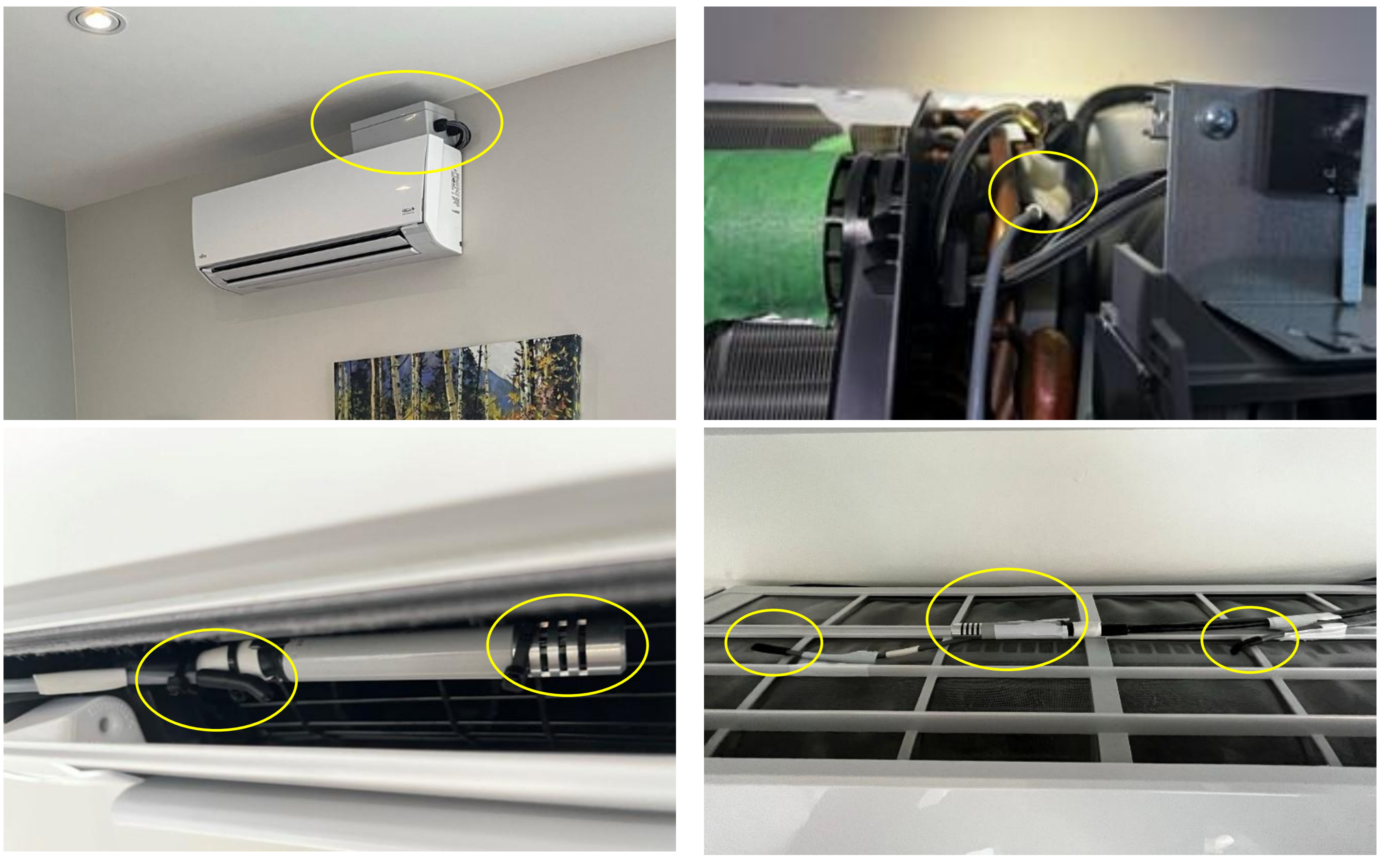


Figure 2.3 – Mini-split indoor head with monitoring equipment box (top left), surface temperature sensor at the vapour line (top right), and temperature and relative humidity sensors at the supply louver (bottom left) and at the return louver (bottom right).

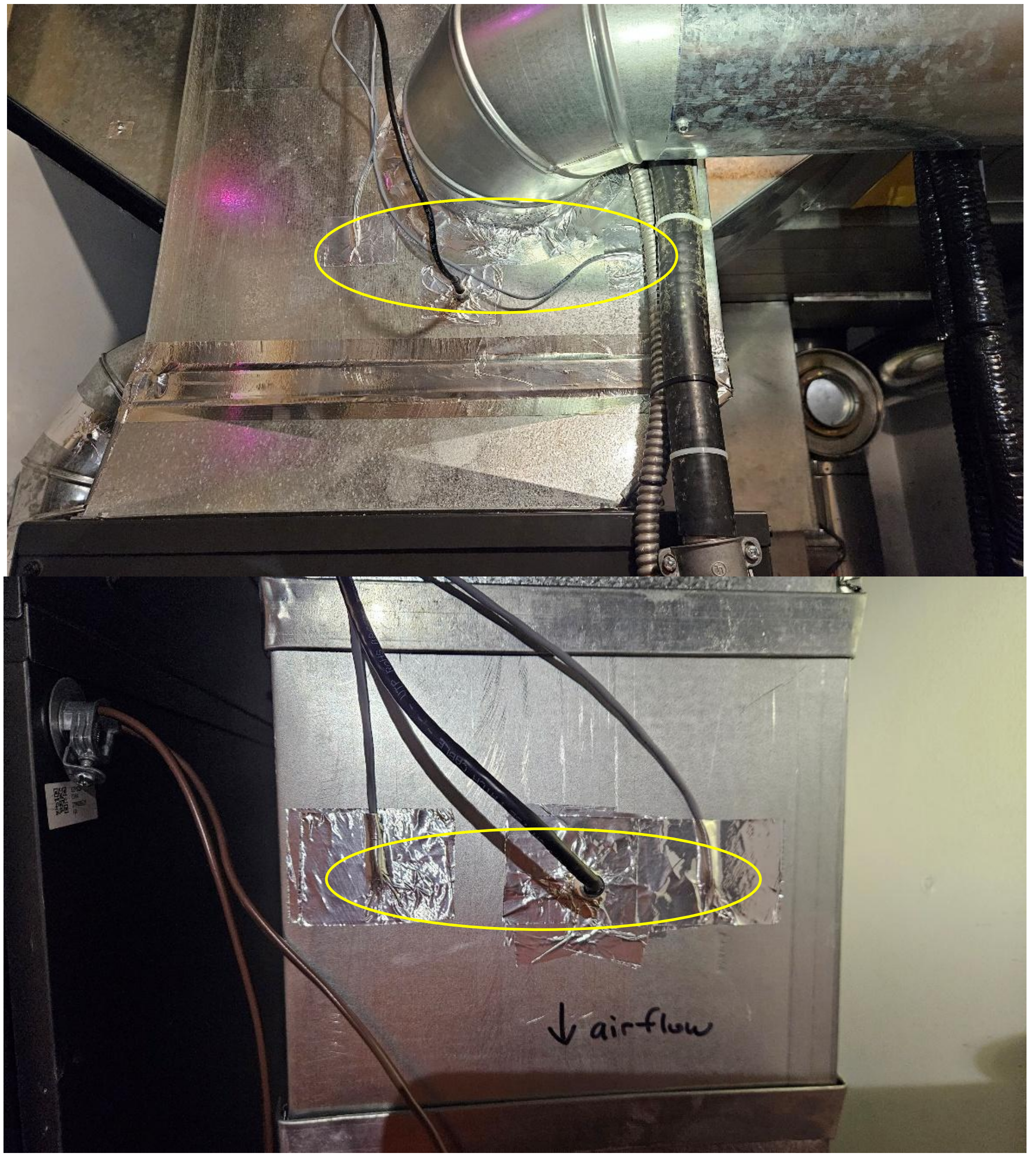


Figure 2.4 – Temperature and relative humidity sensors installed in supply (top) and return (bottom) ducting near the central ducted heat pump fan-coil unit.

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 any, were 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 was 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.

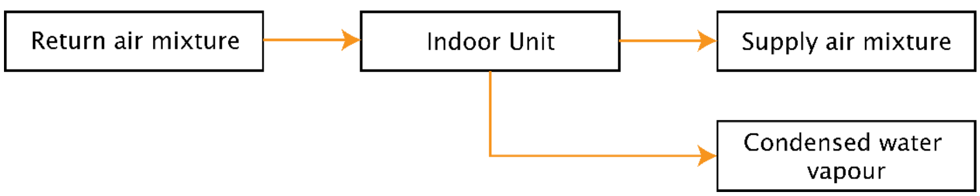


Figure 2.9 – Mass flow through indoor unit under cooling and dehumidification.

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.

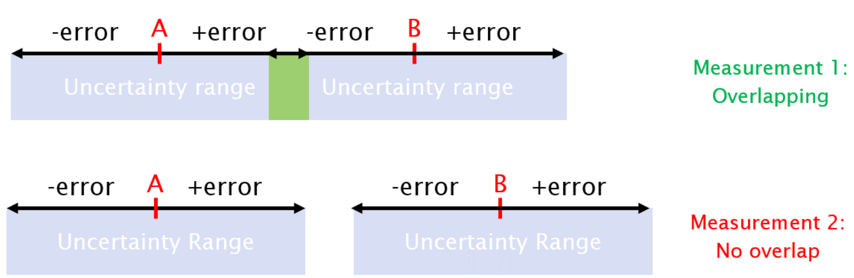


Figure 2.10 – examples of propagated error between two calculated values. In this example, Measurement 1 would be accepted as its error band (B) overlaps with expected result's error band (A). Measurement 2 error band (B) does not overlap with expected error band (A) and therefore would be rejected.

[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. Note that data was measured at 1-minute intervals with monitoring equipment and resampled to 5-minute data. 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 and 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 consumptions 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 2.3 DEFROST CRITERIA (5-MINUTE DATA)

Parameters		Ductless System	Central Ducted System
Start of Defrost	Change in vapour line temperature (ΔT_{vapour}); and	≤ -10°C; except WH-06: ≤ -12°C WH-07: ≤ -8°C WH-11: ≤ -5°C	≤ -15°C
	Vapour line temperature (T_{vapour}); and	≤ T_{supply}	
	System consumption (50A CT); and	≥ 0.04 kWh; except WH-03: 0.075 kWh WH-05: 0.050 kWh WH-11 & 12: 0.070 kWh	≥ 0.04 kWh
	Outdoor temperature	≤ 10°C	
End of Defrost	Vapour line temperature (T_{vapour}); and	≥ T_{vapour} at start of defrost cycle	
	System consumption (50A CT)	Local maximum	
	Or, Defrost cycle length	≥ 20 minutes; except WH-03, 06, 08, & 16: ≥ 30 minutes	WH-04: ≥ 30 minutes WH-14 & 15: ≥ 20 minutes

Note: 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.

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. For the heating SCOP, the calculation accounts for electric energy consumption during heating and during defrost. The following equation outlines the equation for calculating heating SCOP:

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

- 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).

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

- 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:

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

2.5. Financial, Emissions & Energy Savings Assumptions

Since utility data was 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.

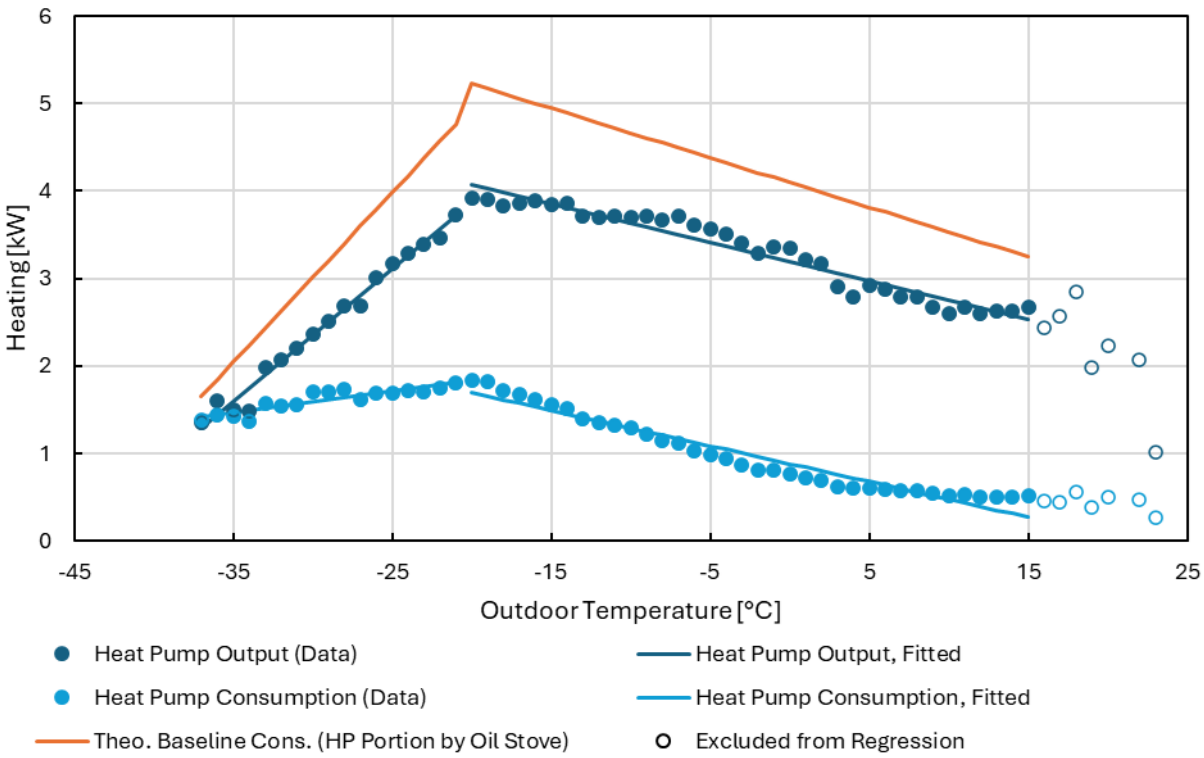


Figure 2.11 – Example of Step 1 for WH-02, which demonstrates how the regressions of the heat pump consumption (light blue lines) and output (dark blue lines) were performed. Theoretical baseline consumption assuming oil stove is represented by the orange line.

- **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 -37°C and 1°C, both the supplemental heating and heat pump are operating; below -37°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.

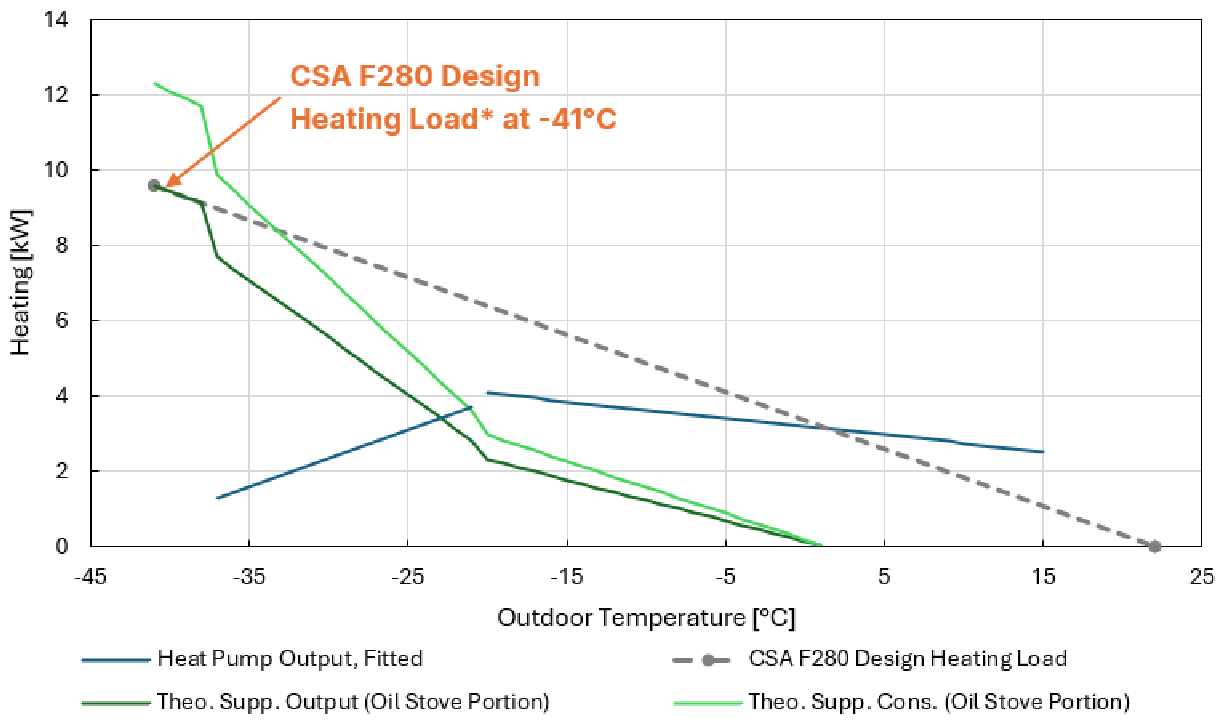


Figure 2.12 Example of Step 2 for WH-02, which demonstrates how the theoretical supplemental consumption (light green) was estimated.

- **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).

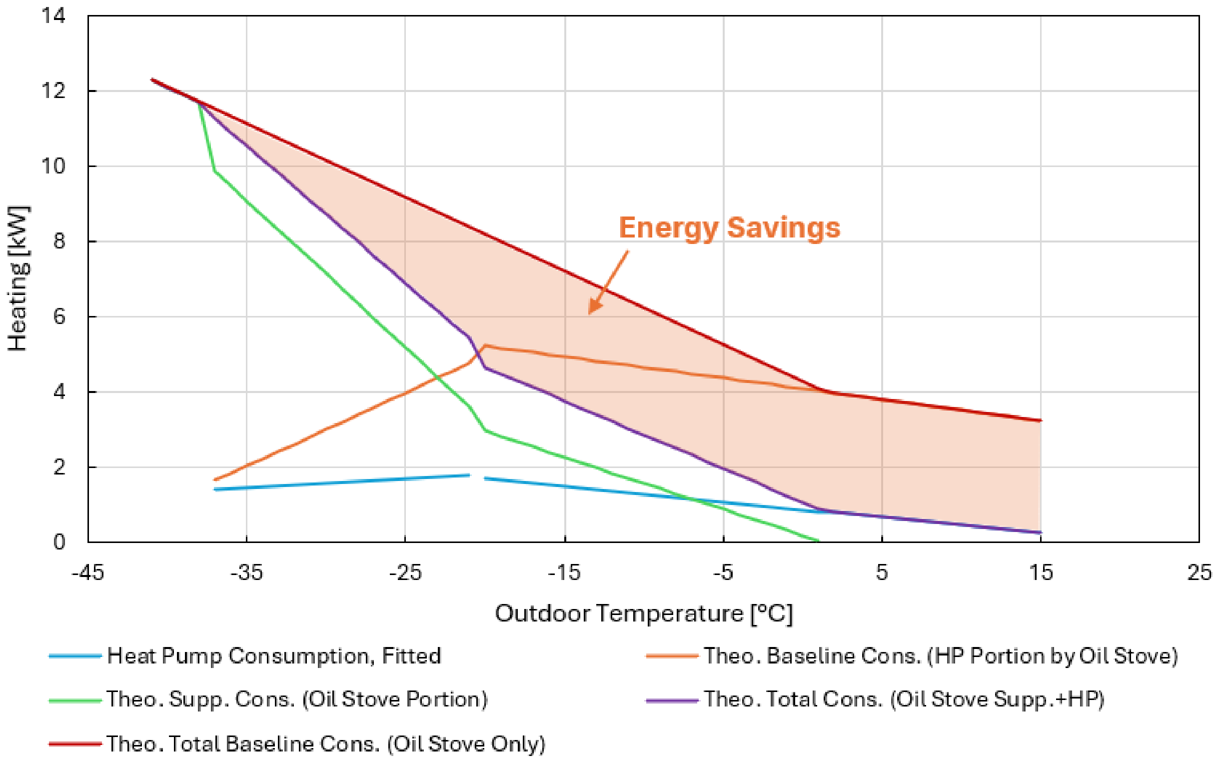


Figure 2.13 – Example of Step 3 for WH-02 which demonstrates how the energy savings were calculated; this is represented by the orange highlighted area.

- **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 September 1, 2023 to March 31, 2024 is summarized as follows:

- WH-01: System consumption data (50A CT) was corrupt after September 2023; therefore, only a very limited number of data points during a limited range of outdoor temperatures were available.
- WH-03: Data for indoor head B between November 28, 2023 and March 2, 2024 was omitted due to faulty sensor readings. Data for indoor head A missing between September 8, 2023 and October 28, 2023.
- WH-04: Data from the indoor coil and fan are missing between October 25 and December 6, 2023.
- WH-06: Data from the indoor head A missing between September 27 and November 27, 2023 (battery failure). Data from indoor head B missing between October 28 and November 27, 2023 (battery failure). Data logger appears to have been unplugged by homeowner on Jan. 18, 2024.
- WH-07: Data from the indoor head B missing between September 9 and October 24, 2023 (battery failure).
- WH-08: Supply and return temperatures were corrupt for indoor heads A and B between October 21, 2023 and February 16, 2024.
- WH-09: System consumption data (50A CT) was corrupt for entire period, preventing reliable COP calculation for this site.
- WH-10: The participant withdrew from the study in October 2023. Before that, no supply temperature was available for indoor head A.
- WH-11: Data were missing from indoor head A between October 9 and November 28, 2023, and at indoor head B between October 14 and November 28, 2023 (battery failures).
- WH-12: Data missing at indoor head A between October 9 and November 29, 2023 (battery failure). Data missing at indoor head B between November 3 and 29, 2023 (battery failure).
- WH-13: Data missing at indoor head A between October 10 and Nov. 27, 2023, and between March 28, 2024 and April 11, 2024 (battery failure). Data missing at indoor head B between Feb. 13 and Feb. 28, 2024 (battery failure). Data missing at indoor unit head C between Nov. 15 and Nov. 27, 2023 (battery failure).
- WH-15: Indoor head fan consumption (5A CT, proxy for airflow rate) was corrupt, however, there was only one fan setting and corresponding airflow rate for this system.

[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

- WH-16: Data for indoor head A before December 1, 2023 were omitted due to faulty sensor readings. Homeowner also reported turning off the monitoring equipment overnight, resulting in loss of approximately 25% of data on daily basis.
- WH-18: Integrated supplemental heating consumption data (200A CT) is always reported as zero. Integrated supplemental heating was used based on measured supply temperatures up- and down-stream of the buffer tank, and thus heating output by the heat pump alone could not be isolated.

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 lack of sufficient data.

WH-01 and WH-03 did not have sufficient data over the heating season to present a SCOP value even though sufficient data was 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 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 September 1, 2023 to March 31, 2024. Plots for the other sites are included in **Appendix B**.

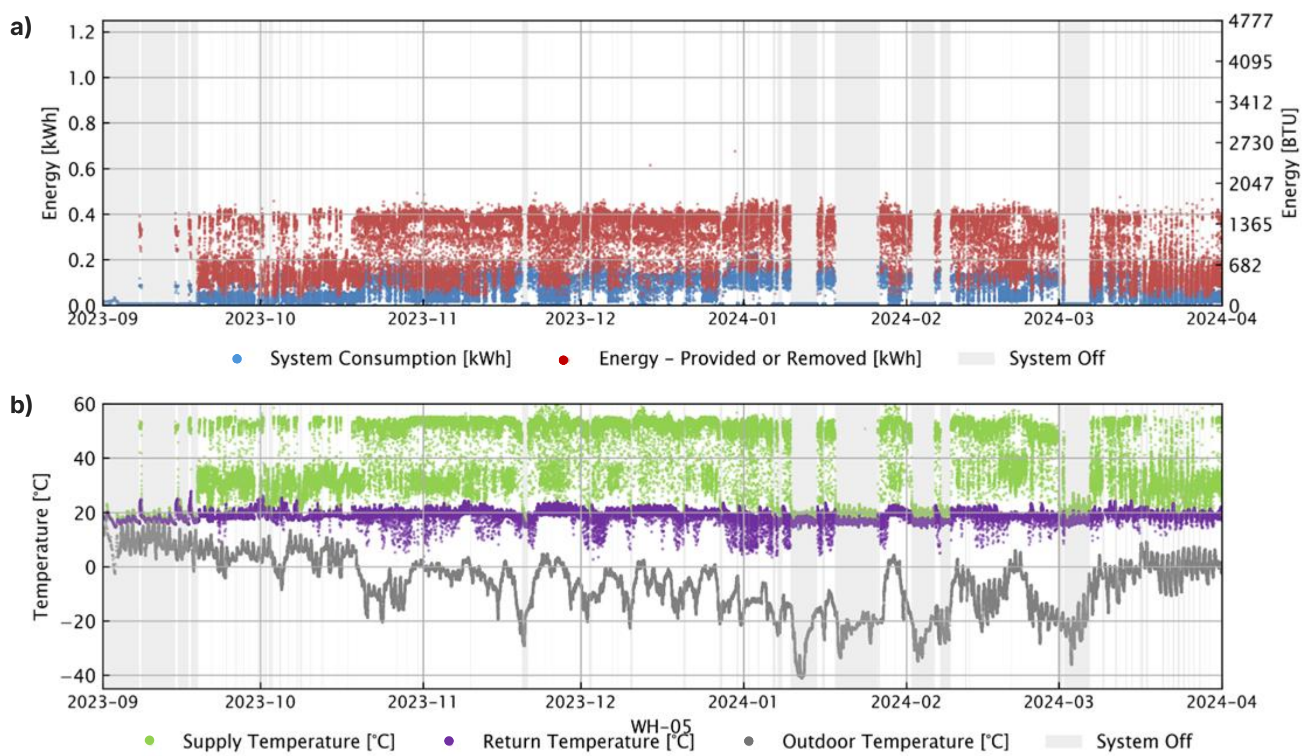


Figure 3.1 Sample plot for ductless heat pump system, WH-05. a) Measured equivalent energy provided/removed by heat pump compared to energy consumption. b) measured ambient outdoor temperature, and temperatures at the supply/return of the indoor unit (head).

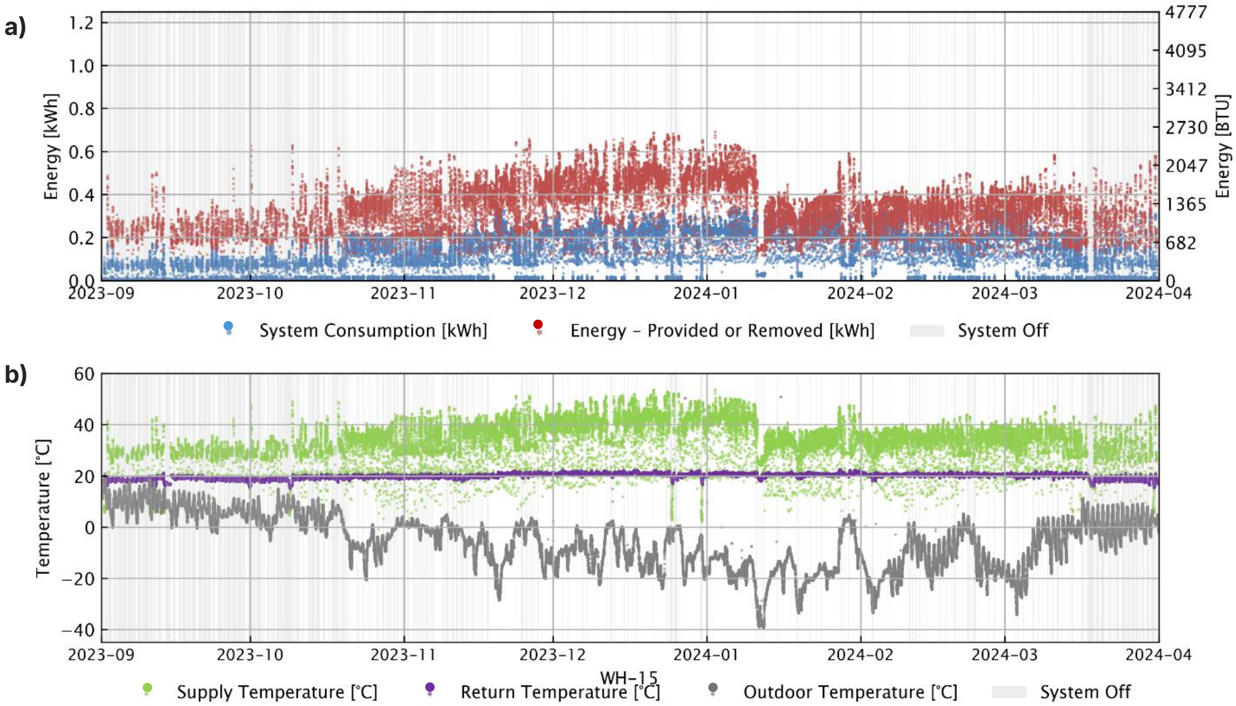


Figure 3.2 Sample plot for central ducted heat pump system, WH-15. a) Measured equivalent energy provided/removed by heat pump compared to energy consumption. b) measured ambient outdoor temperature, and temperatures at supply/return ducting.

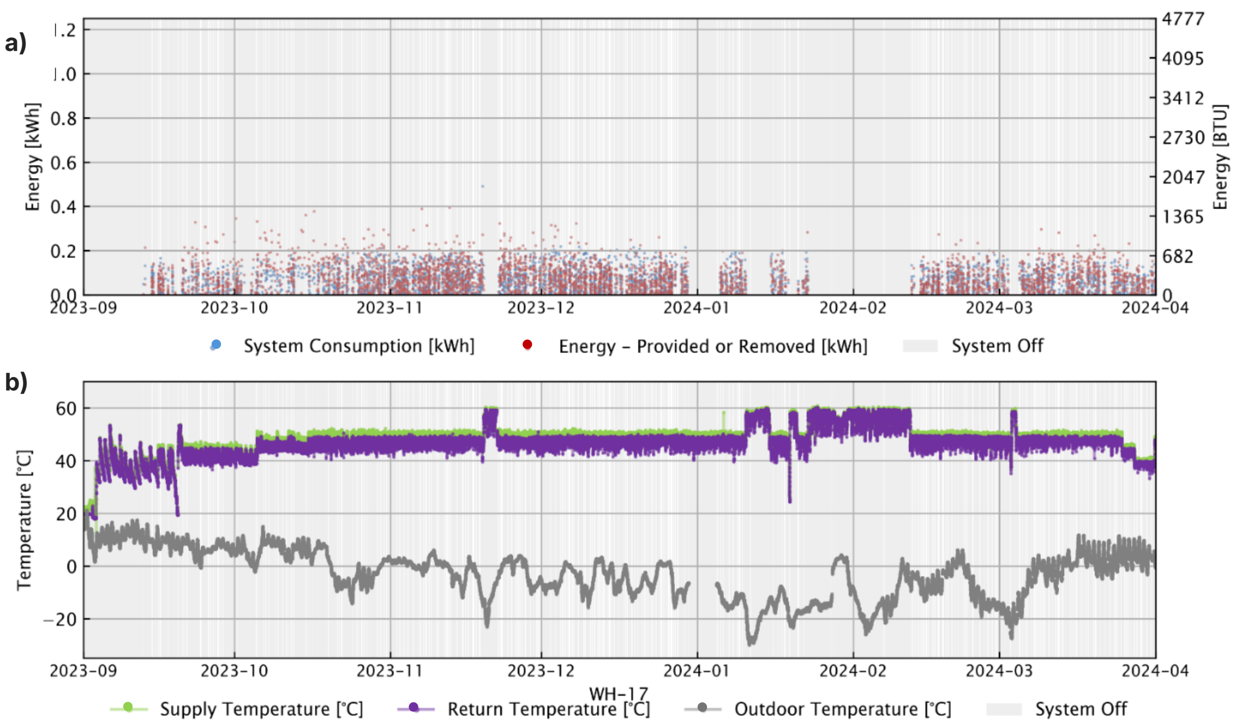


Figure 3.3 Sample plot for central air-to-water heat pump system, WH-17. a) Measured equivalent energy provided/removed by heat pump compared to energy consumption. b) measured ambient outdoor temperature, and temperatures at supply/return pipes.

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 December 5, 2023. 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.

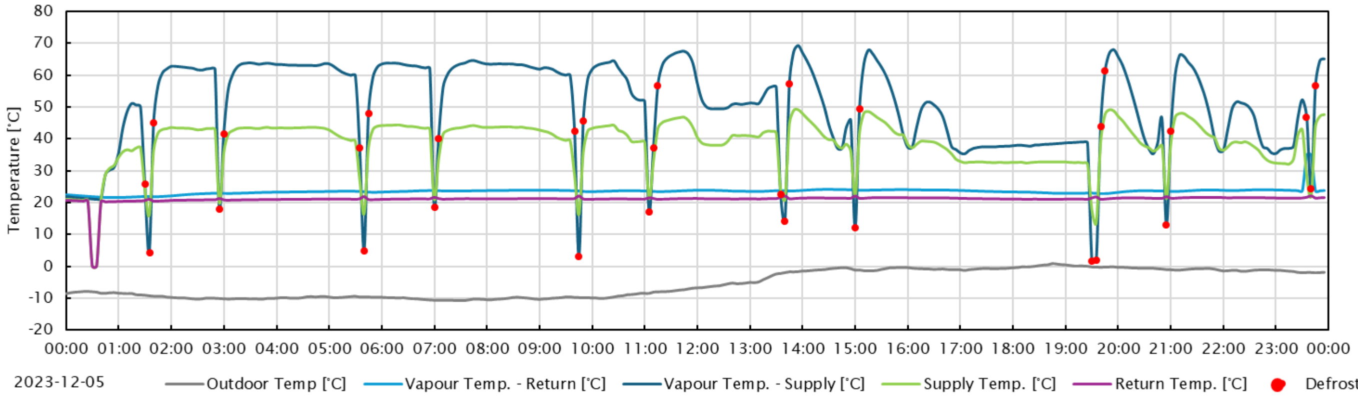


Figure 3.5 Heat pump cycles for site WH-15 (central ducted system), during a sample day on December 5, 2023. The dark blue, light blue, purple, and green lines show the vapour line temperature at supply, vapour line temperature at return, return airflow temperature, and supply airflow temperature of 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 very low temperatures (below -25°C), most of 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 4.5.
- Two sites did not have sufficient data to be included in the average heating COP vs. outdoor temperature summary:
  - 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.
- For site WH-01, data was corrupt after September 2023; therefore, only a very limited number of data points during a limited range of outdoor temperatures were available. It was included in the plot for completeness, but the results are not considered statistically robust.
- The following systems had poor performance for various reasons:
  - WH-03: System appears to be underperforming; however, only about two months of reliable data were available for analysis, as a portion of the data was excluded due to faulty sensor readings, which may have

contributed to results below. Initial observations suggest that the system at this site exhibits shorter heating cycles compared to higher-performing systems, which may be a contributing factor to the reduced efficiency.

- WH-08: A refrigerant leak was reported in the outdoor unit. Although the issue was reportedly repaired, the participant noted that the repair process took longer than expected. Low refrigerant levels reduce heat transfer efficiency, which would have contributed to poorer COP values. It is anticipated that refrigerant leakage was occurring 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.
- 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).

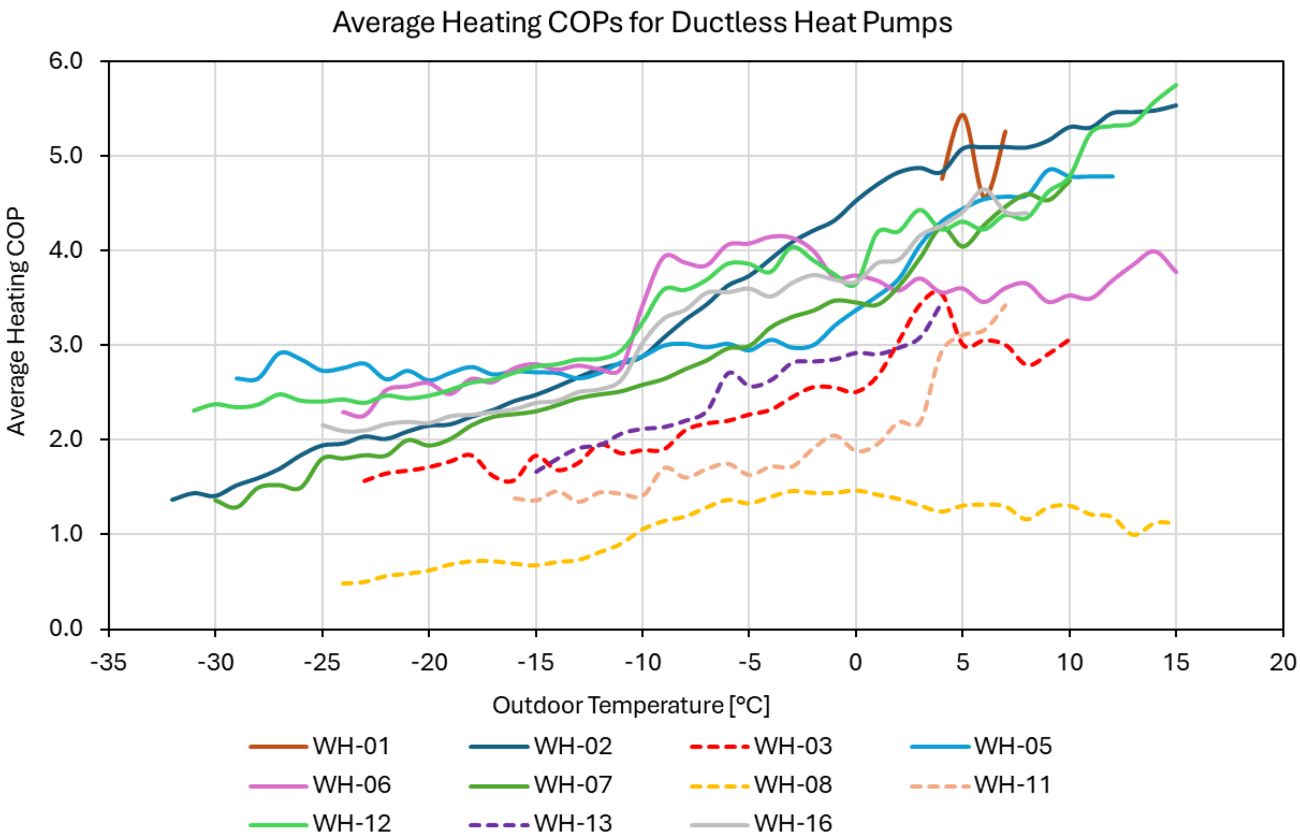


Figure 3.6 Average heating COP versus outdoor air temperature for sites with ductless heat pumps. COP values for each site were included at extreme temperatures (very low or high) only if more than 40, 5-minute data points were available at those temperatures. This report only includes heating season from September 1, 2023 to March 31, 2024. Sites indicated with dashed lines are those where 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 (below -25°C), and above 0°C, they were able to achieve COPs between 2.5 and 4.
- WH-14 demonstrated relatively poor performance. The average COP only exceeds 1.5 even at temperatures above 2°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.

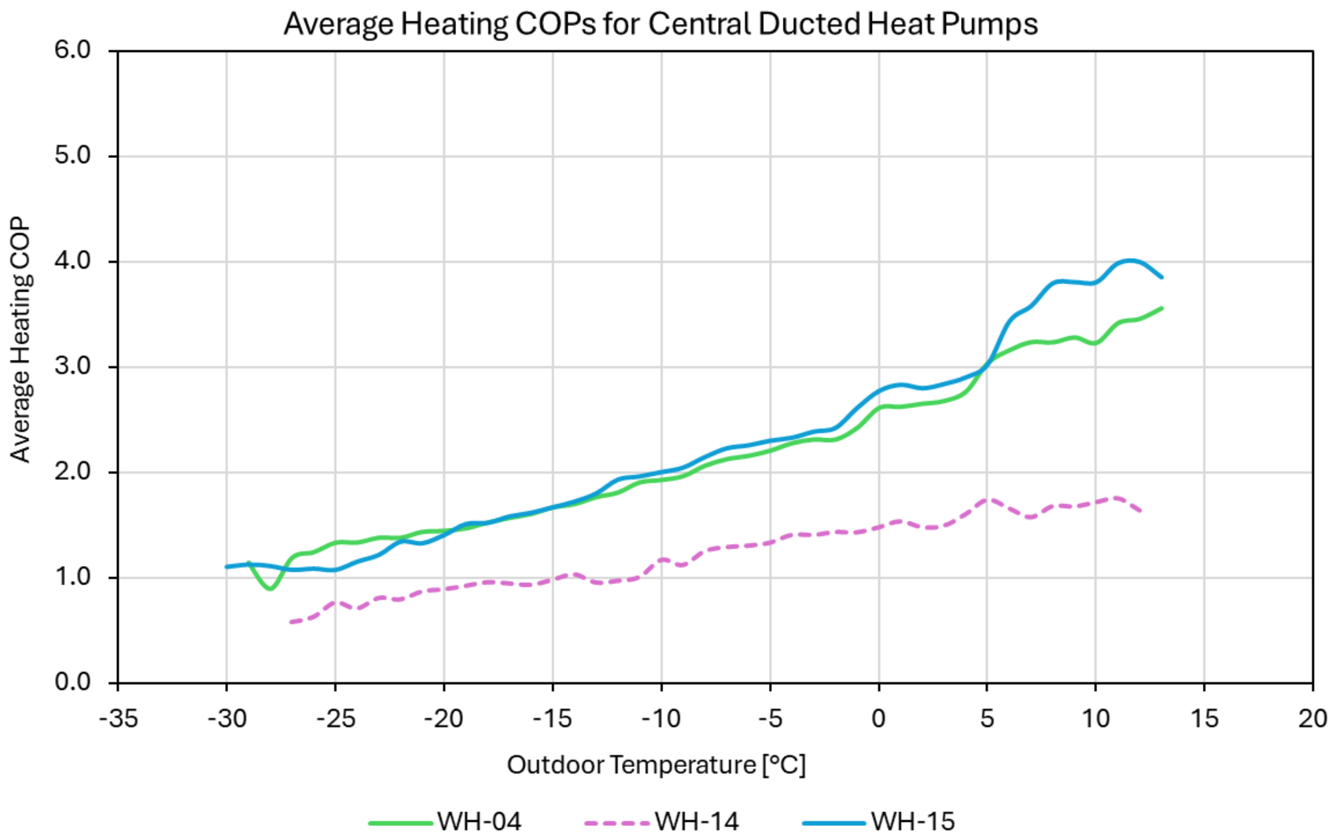


Figure 3.7 Average heating COP versus outdoor air temperature for sites with central ducted heat pumps. COP values for each site were included at extreme temperatures (very low or high) only if more than 40, 5-minute data points were available at those temperatures. This report only includes heating season from September 1, 2023 to March 31, 2024. 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

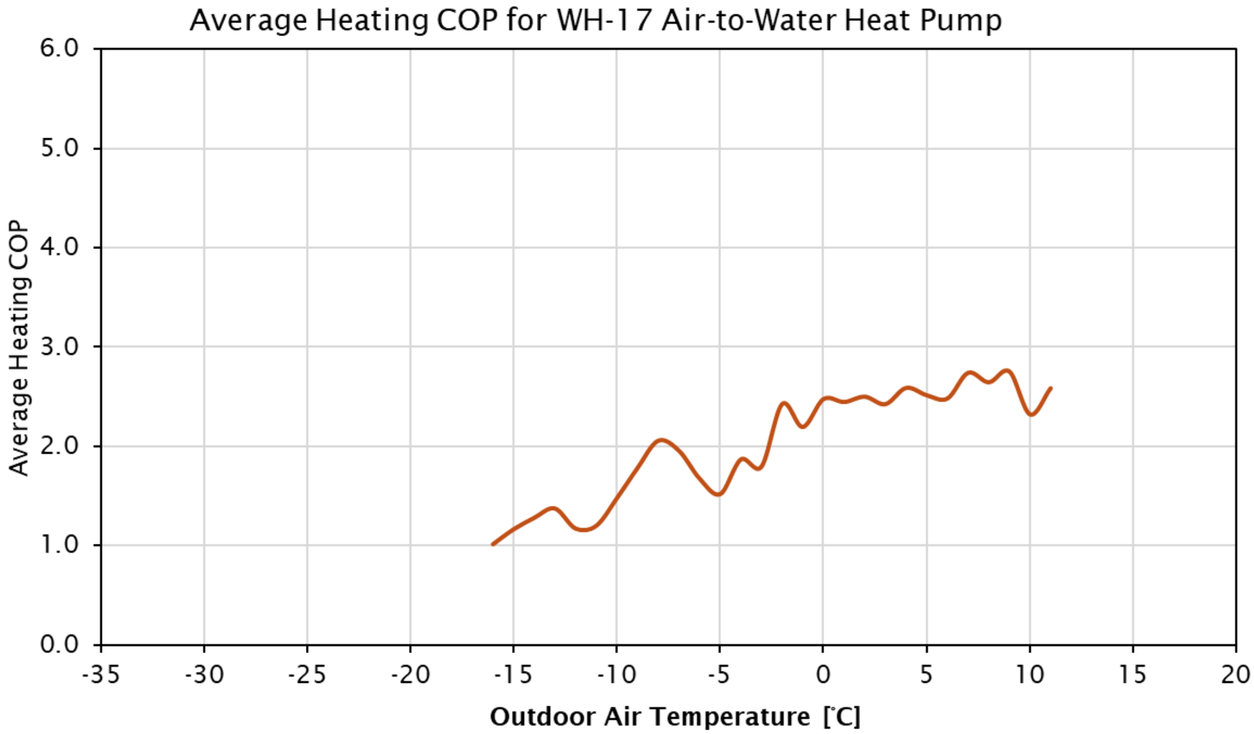


Figure 3.8 Average heating COP versus outdoor air temperature for site with a central air-to-water heat pump. COP value for WH-17 was included at extreme temperatures (very low or high) only if more than 20, 5-minute data points were available at those temperatures. Note that there were only two air-to-water 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 season from September 1, 2023 to March 31, 2024.

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.

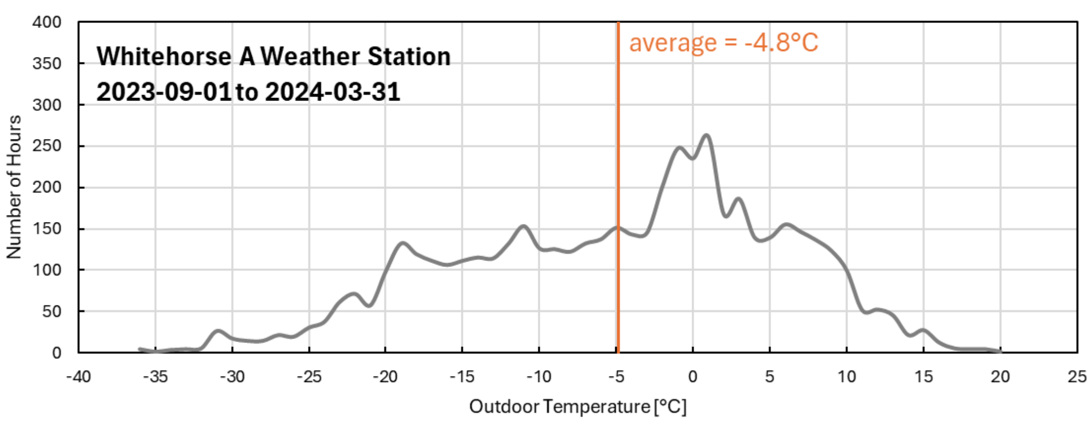


Figure 3.9 Outdoor temperature distribution during the monitoring period (September 1, 2023 to March 31, 2024); hourly temperatures at "Whitehorse A" weather station (ID#2101303) was obtained from Environment and Climate Change Canada.

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 September 1, 2023 and March 31, 2024, 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 (10 of the 14 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.
- 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 six of the ten ductless systems plotted, the measured SCOP values were broadly in line with rated values though slightly lower on average. Three of these (WH-02, -06, and -12) had measured SCOP values that were slightly higher than the manufacturer rated values and exceeding a SCOP of 3.0. WH-9 and WH-10 were omitted from this figure because of the lack of data.
- 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 would result in a lower measured SCOP. WH-14 had the lowest measured SCOP of the three, which is consistent with what is seen in Figure 3.7. 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.

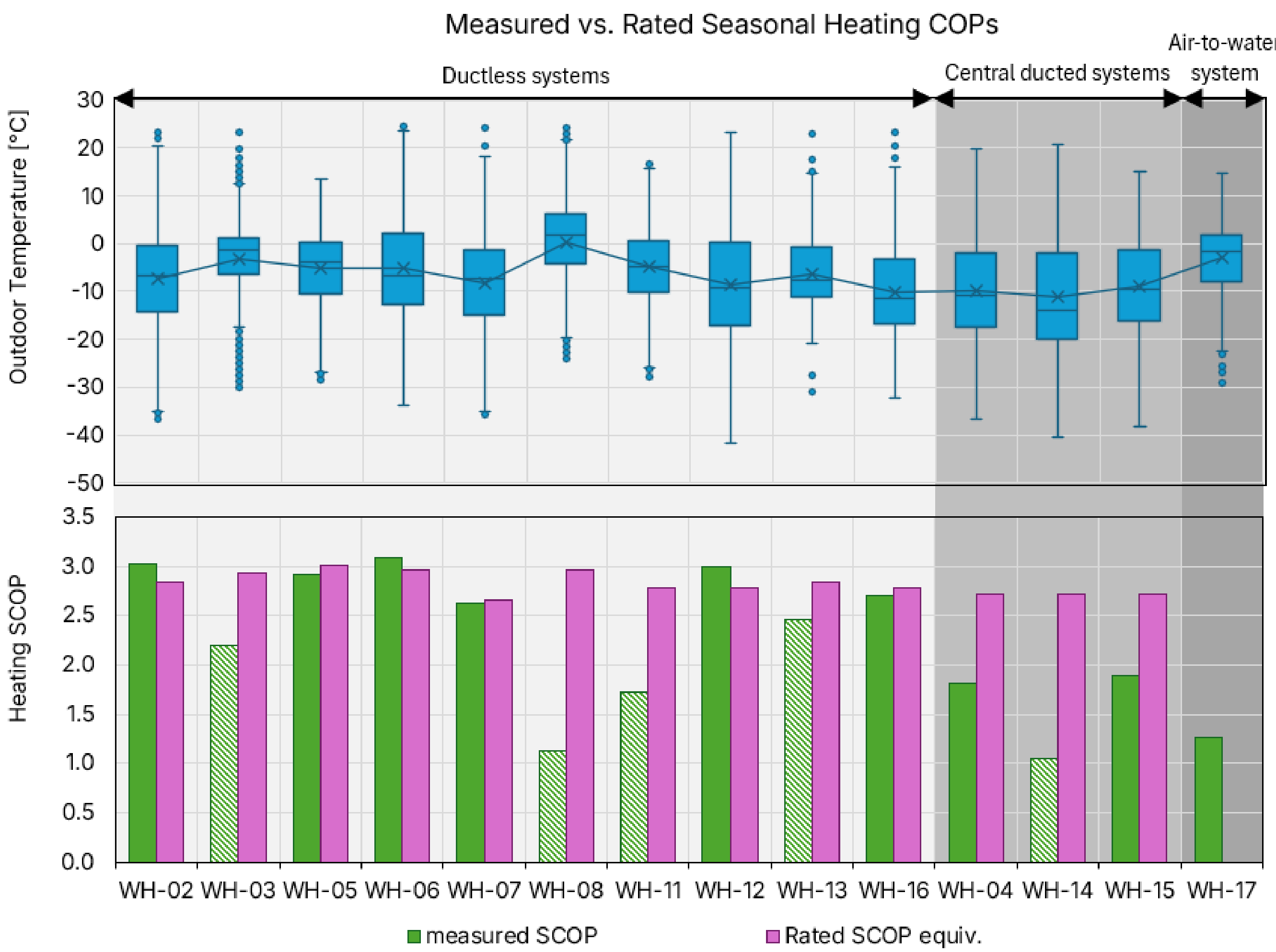


Figure 3.10 Seasonal heating COPs (SCOPs) for all sites; measured (green bars) and rated (pink bars). This report only includes heating season from September 1, 2023 to March 31, 2024. Note that WH-01, WH-09, WH-10 and WH-18 are omitted from this plot because there was not sufficient data to calculate measured SCOPs for these sites. WH-03, 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. WH-03 results may have been impacted by short cycling of the unit and less data availability.

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 SCOP BY SYSTEM TYPE AND OPERATION		
Type	All	Operated as Intended
Ductless	2.5	2.9
Central Ducted	1.6	1.9
Air-to-Water	1.3 (one site*)	1.3 (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, and -18 which did not have sufficient data; "Operated as Intended" groupings excluded WH-01, -03, -08 through -11, -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.

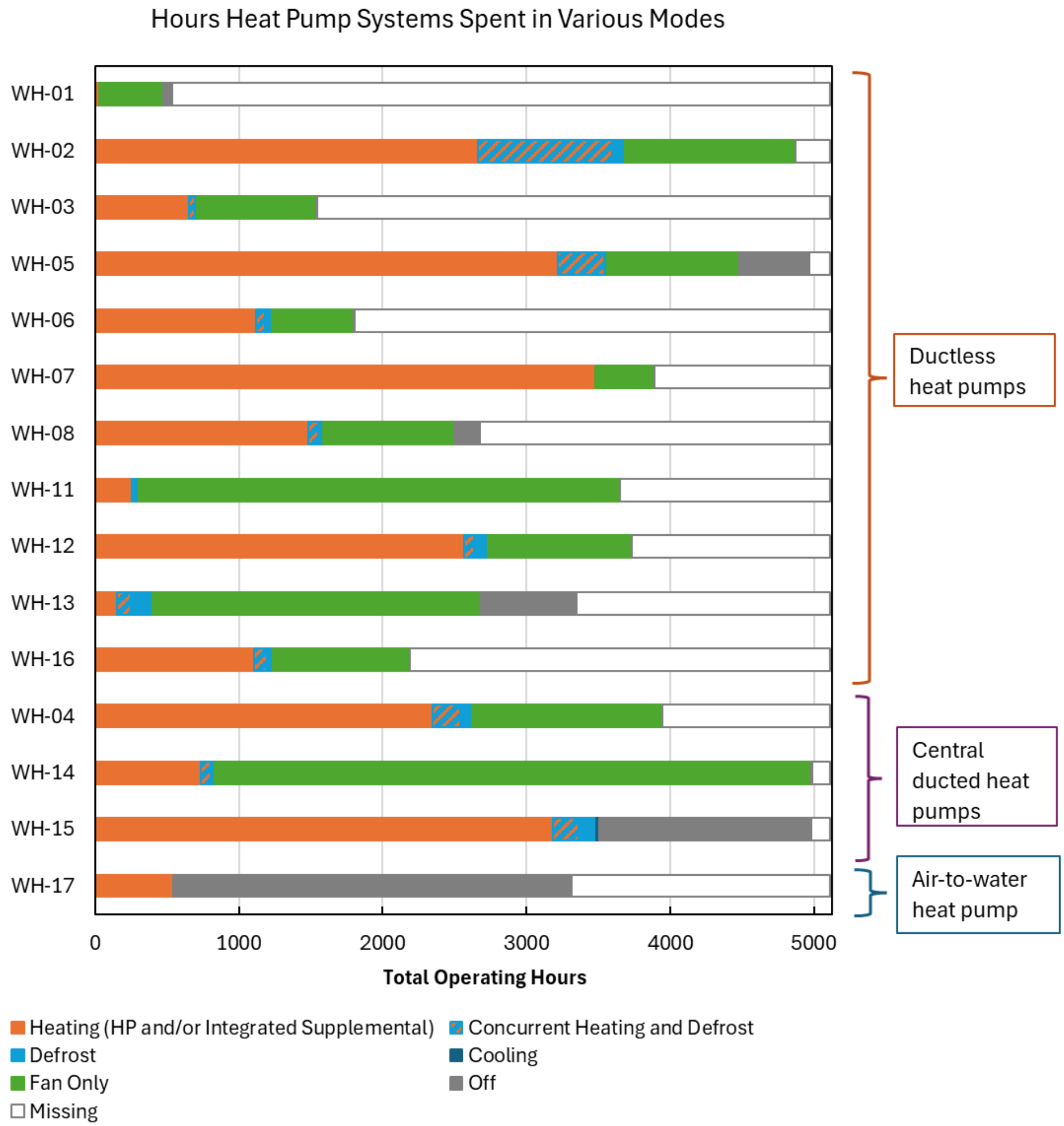
Figure 3.11 shows the total operating hours across different modes for each of the heat pump system installations. Modes were divided into heating (HP and/or integrated supplemental), concurrent heating and defrost, defrost only, cooling, fan only, and off. Hours when data was missing or incomplete are 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 70% to 100% of the time.[9] One notable exception was the air-to-water system WH-17, which was only operational 16% of the time (likely because of the buffer tank).
- For most of the systems, the dominant mode of operation was heating (orange) when the system is on.
- 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.
- For WH-11, WH-13 and WH-14, it appeared that the heat pumps spent more time in fan only mode (estimated at 92%, 68% and 83% of time, respectively). The heat pumps systems at these sites also spent very little time in heating mode. It is important to note that these three systems (two ductless, and one central ducted) all had lower than average performance compared to their counterparts (as seen in Figure 3.1 and 3.2). This seems to indicate that their configuration was not optimized and/or homes were primarily reliant on non-integrated supplemental heating, or in the case of WH-14, high solar heat gains (this home had significant amounts of glazing at the southwest aspect). All three of these homes have wood stoves. WH-11 and WH-13 also have electric supplemental heating (unit heaters or baseboards).
- Unsurprisingly, there was almost no cooling at any of the sites over the monitoring period in the winter season. Only two sites (WH-14 and WH-15) had small amounts of cooling (0.3 hours and 19.2 hours, respectively). This indicates that none 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).

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. For WH-04, WH-14, and WH-17, this accounts for 0.6%, 0.7% and 6.8% of the time, respectively. It appeared that WH-15 did not use its integrated supplemental heating (the 200A CT read zero) for the duration of the monitoring period.

[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 was 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-09, WH-10 and WH-18 have been omitted due to lack of reliable data. Heating (HP and/or Integrated Supplemental) means that either the heat pump and/or the integrated supplemental are providing heating to the home.

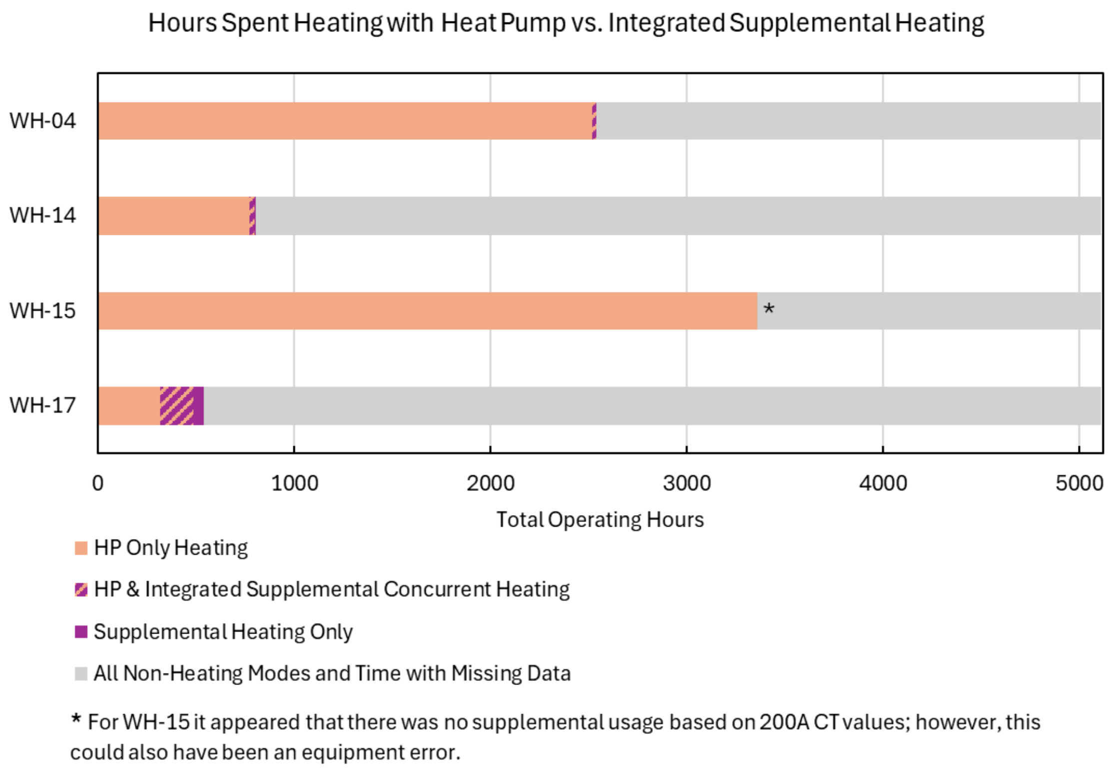


Figure 3.12 Hours spent in various heating modes for heat pump systems with integrated supplemental heating. Note that WH-18 also had integrated supplemental heating, but was omitted from this figure because of the lack of reliable data.

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.

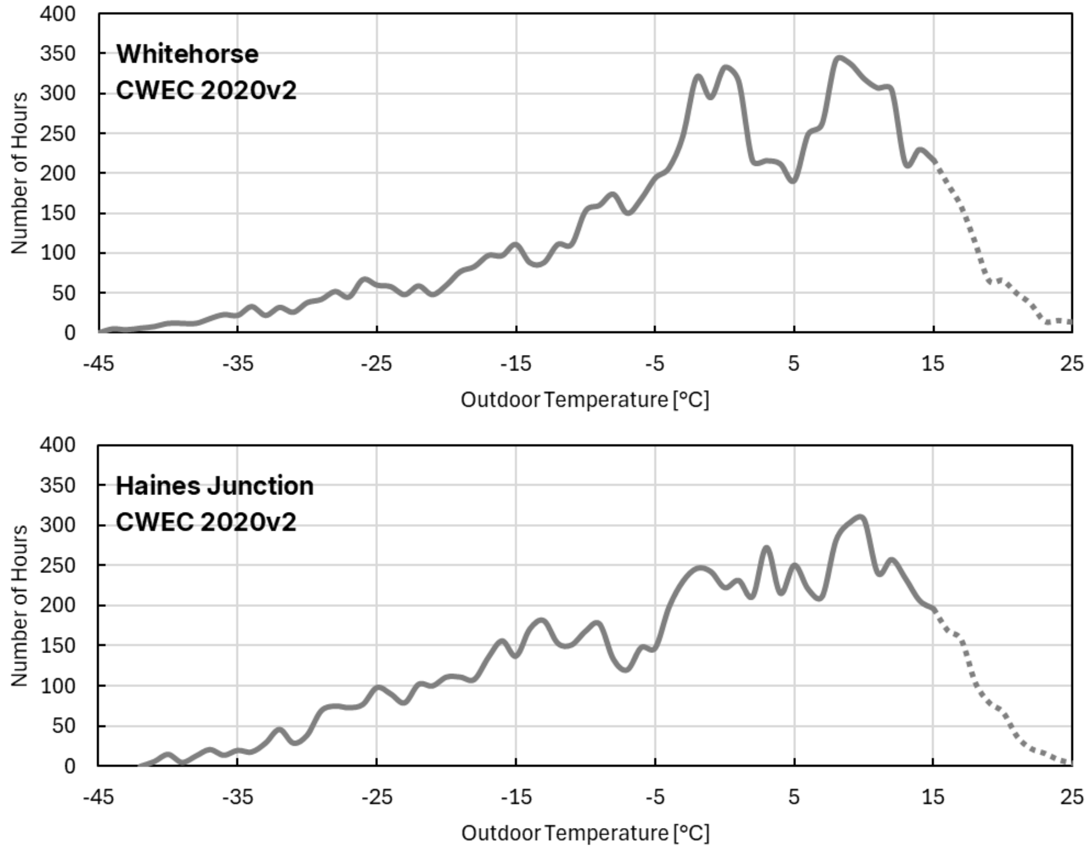


Figure 3.13 Outdoor temperature distribution in a typical meteorological year per CWEC 2020v2 in Whitehorse, YT (all sites except WH-14) and Haines Junction, YT (WH-14).

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-02) 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.

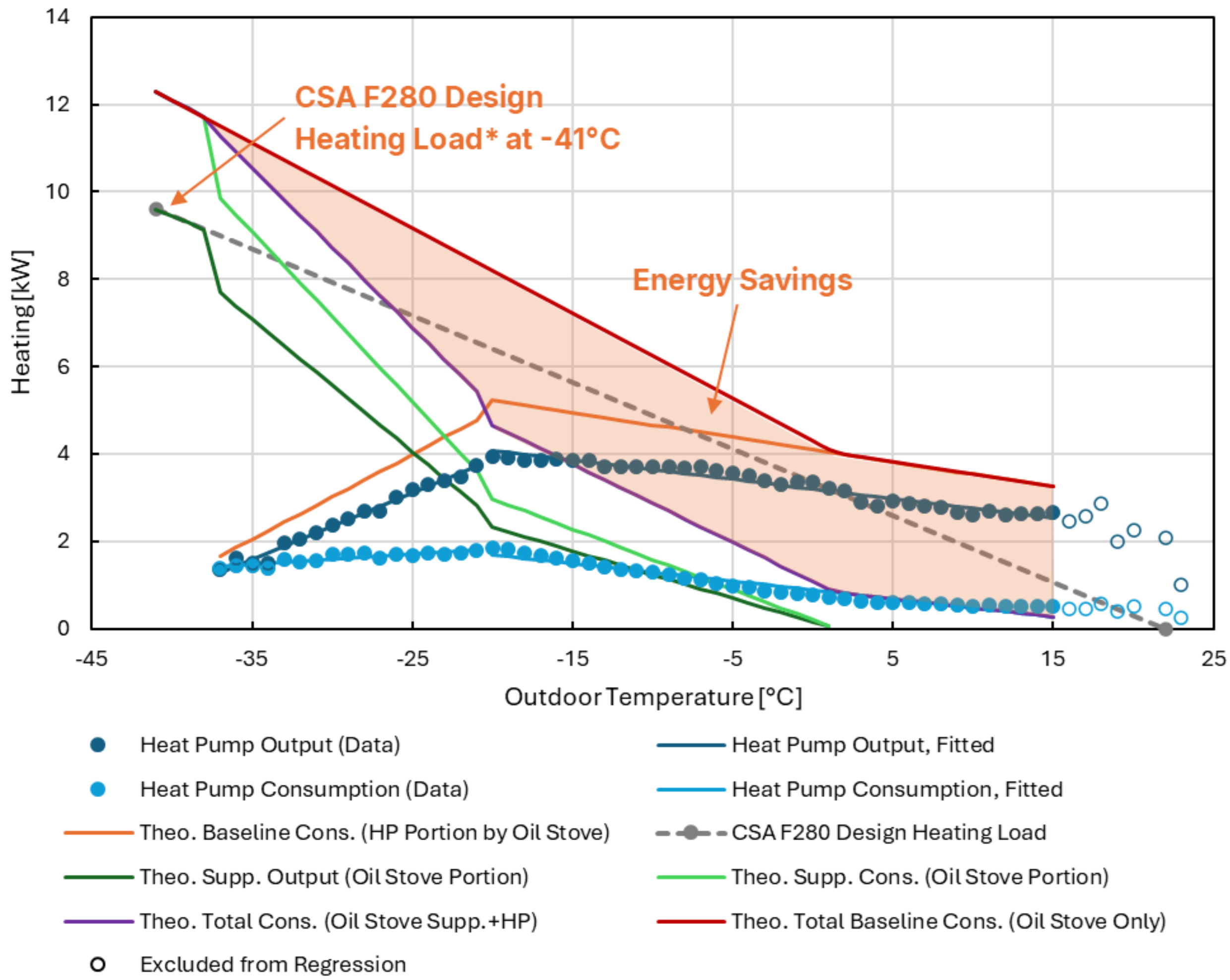


Figure 3.14 Sample plot for energy savings analysis at ductless heat pump system, WH-02, where energy savings across the full range of expected operating outdoor temperatures is shown in the savings model.

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 consumption, 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 [kgCO_2e] (%)**	**Utility Cost Savings [$] (%)**
WH-01	Ductless	Oil furnace	Oil furnace	Insufficient data; no CSA F280 heating load		
WH-02	Ductless	Oil stove	Oil stove	24,503 (61%)	8,064 (74%)	3,230 (51%)
WH-03	Ductless	Electric baseboard	Electric baseboard	No CSA F280 heating load		
WH-04	Central Ducted	Propane furnace	Electric baseboard	35,657 (58%)	11,572 (87%)	2,169 (26%)
WH-05	Ductless	Electric baseboard (assumed)	Electric baseboard (assumed)	No CSA F280 heating load		
WH-06	Ductless	Electric baseboard	Electric baseboard	8,113 (45%)	568 (45%)	1,963 (45%)
WH-07	Ductless	Oil furnace	Oil furnace	20,977 (31%)	7,438 (40%)	2,538 (24%)
WH-08	Ductless	Propane furnace	Propance furnace	1,848 (7%)	1,202 (20%)	-316 (-8%)
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	24,272 (54%)	8,486 (70%)	2,988 (42%)
WH-14	Central Ducted	Oil furnace	Oil furnace	10,882 (22%)	7,299 (55%)	-146 (-2%)
WH-15	Central Ducted	Electric baseboard (assumed)	Electric baseboard (assumed)	16,347 (51%)	1,144 (51%)	3,954 (51%)
WH-16	Ductless	Electric baseboard	Electric baseboard	20,156 (47%)	1,411 (47%)	4,876 (47%)
WH-17	Central Air-to-Water	Electric boiler (unconfirmed)	Electric boiler (unconfirmed)	4,131 (8%)	289 (8%)	999 (8%)
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 were missing for these sites (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	16,645 (41%)	18,438 (46%)	4,528 (49%)	4,370 (52%)	2,546 (33%)	3,152 (42%)
Central Ducted	20,962 (44%)	26,002 (51%)	6,672 (64%)	6,358 (69%)	996 (25%)	3,954 (38%)
Air-to-Water*	4,131 (8%) (one site*)		289 (8%) (one site*)		999 (8%) (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 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.

The heat pump system at WH-08 was reported to have refrigerant leaks during the monitoring period, which likely reduced its overall performance. Despite this, WH-08 achieved energy and emissions savings when the heating output exceeded the heat pump's electricity consumption at outdoor temperatures above -10°C (i.e. when COP exceeds 1 in Figure 3.7). Additional savings also occurred between the outdoor temperature range of -17°C to -10°C, when the measured average heat pump consumption remained below the theoretical baseline consumption for a propane furnace (i.e. heat pump efficiency remained better than the assumed baseline efficiency of 0.82). However, because the heat pump system operated at relatively low efficiency compared with its rated performance, and because electricity is more expensive than the baseline propane, WH-08 likely did not achieve utility cost savings. It should be noted that the differences between the baseline and post-retrofit cases are small and fall within the expected uncertainty range of this savings analysis.

Similarly, 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 -19°C, which resulted in net increases in utility costs at the site; however, the differences between the baseline and post-retrofit cases are limited and fall within the expected error range of this savings analysis. This is consistent with the performance of this system shown in Figure 3.7, where average COP falls below 1 in outdoor temperatures below around -14°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 September 1, 2023, and March 31, 2024.

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 2.2 at an outdoor ambient temperature of -25°C, and COPs of approximately 3.7 at outdoor ambient temperature of 0°C. These systems also tended to have SCOPs within the ballpark of the manufacturer rated SCOPs; an average measured SCOP of 2.9 for ductless systems that operated as intended was observed.
- On average, the central ducted heat pump systems that were operating as intended were able to achieve COP of approximately 1.2 at -25°C and approximately 2.7 at 0°C. An average measured SCOP of 1.9 was observed for ducted systems operating 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.
- COP of the air-to-water heat pump system (WH-17) was 1.1 at -15°C and approximately 2.5 at 0°C. The measured SCOP for this system was determined to be 1.3.

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 the first heating season. 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	18,438 (46%)	4,370 (52%)	3,152 (42%)
Central Ducted	26,002 (51%)	6,358 (69%)	3,954 (38%)
Air-to-Water	4,131 (8%) (one site*)	289 (8%) (one site*)	999 (8%) (one site*)

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

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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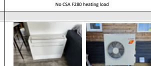
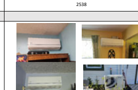
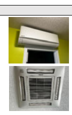
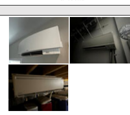
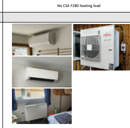
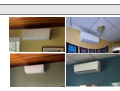
Appendices

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℃ 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.
SUMMARY OF PERFORMANCE							
Measured Heating SCOP	n/a	3.0	2.2	1.8	2.9	3.1	2.6
HSPF	n/a	10.3	7.5	6.2	10.0	10.5	8.9
COP at -15°C	n/a	2.5	1.8	1.7	2.7	2.8	2.3
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	-7.4	-3.3	-9.9	-5.1	-5.1	-8.3
Heating Hours	28	2661	1912	2350	3221	1121	3478
Concurrent Heating and Defrost Hours	1	937	168	192	324	62	0
Defrost Hours	0	90	93	77	18	48	0
Cooling Hours	0	0	0	0	0	0	0
Off Hours	64	0	4	0	484	0	0
Fan Only Hours	443	1187	1624	1324	922	571	411
Valid Data Hours	536	4875	3800	3944	4969	1802	3889
Missing Hours	4576	237	1312	1168	143	3310	1223
HP Heating Hours	28	2661	649	2518	3221	1121	3478
Concurrent HP and Int. Supp. Heating Hours	not applicable	not applicable	not applicable	23	not applicable	not applicable	not applicable
Integrated Supplemental Heating Hours	not applicable	not applicable	not applicable	1	not applicable	not applicable	not applicable
Missing Data in 2023/2024 Report period	System consumption data (SOA CT) was corrupt after September 2023	n/a	Data for indoor head B between November 28, 2023 and March 2, 2024 was omitted due to faulty sensor readings. Data for indoor head A missing between September 8, 2023 and October 28, 2023.	Data from the indoor coil and fan are missing between October 25 and December 6, 2023.	n/a	Data from the indoor head A missing between September 27 and November 27, 2023 (battery failure). Data from indoor head B missing between October 28 and November 27, 2023 (battery failure). Data logger appears to have been unplugged by homeowner on Jan. 18, 2024.	Data from the indoor head B missing between September 9 and October 24, 2023 (battery failure).
Insitu Balance Point Temperature [°C] - *estimated asintersect of max. measured heat output and heating demand (Appendix D)*	n/a	-20.0	n/a	-20	n/a	-22	-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	n/a	n/a	5.47	n/a
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]	Insufficient data; no CSA F280 heating load	40097	No CSA F280 heating load	61422	No CSA F280 heating load	18188	68237
Post-Retrofit Heating Energy Consumption [ekWh/year]	Insufficient data; no CSA F280 heating load	15593	No CSA F280 heating load	25765	No CSA F280 heating load	10075	47259
Heating Energy Savings [ekWh/year]	Insufficient data; no CSA F280 heating load	24503	No CSA F280 heating load	35657	No CSA F280 heating load	8113	20977
Baseline Heating GHG Emissions [kgCO2e/year]	Insufficient data; no CSA F280 heating load	10831	No CSA F280 heating load	13376	No CSA F280 heating load	1273	18433
Post-Retrofit Heating GHG Emissions	Insufficient data; no CSA F280 heating load	2767	No CSA F280 heating load	1804	No CSA F280 heating load	705	10995
Heating GHG Emission Savings	Insufficient data; no CSA F280 heating load	8064	No CSA F280 heating load	11572	No CSA F280 heating load	568	7438
Baseline Heating Utility Cost	Insufficient data; no CSA F280 heating load	6290	No CSA F280 heating load	8401	No CSA F280 heating load	4400	10704
Post-Retrofit Heating Utility Cost	Insufficient data; no CSA F280 heating load	3060	No CSA F280 heating load	6233	No CSA F280 heating load	2437	8166
Heating Utility Cost Savings	Insufficient data; no CSA F280 heating load	3230	No CSA F280 heating load	2169	No CSA F280 heating load	1963	2538
HEAT PUMP SYSTEM PHOTOS							
							

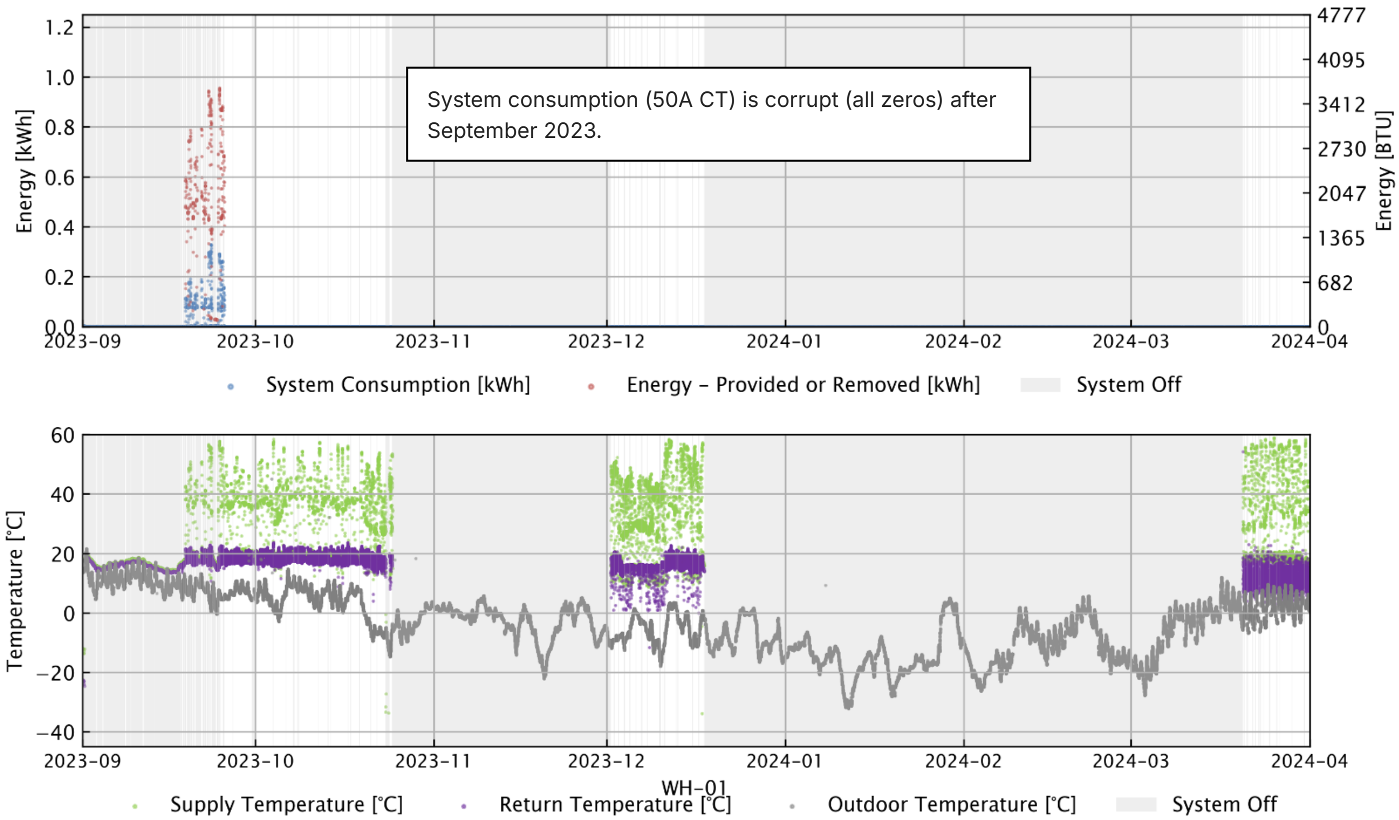
Site ID	WH-08	WH-09	WH-10	WH-11	WH-12	WH-13	WH-14
Site Form Created By	CM	CM	CM	CM	CM	CM	CM
Occupations	full-time		part-time	full-time	retired		
Daytime Occupants	0	1 summer/ 0 winter	0.5	1.5	2	1	2
Type of home	Duplex	Single family home	Duplex	Single family	Single family	Single family	Single family
Appx. 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 gas 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
SUMMARY OF PERFORMANCE							
Measured Heating SCOP	1.1	n/a	n/a	1.7	3.0	2.5	1.1
HSPF	3.9	n/a	n/a	5.9	10.2	8.4	3.6
COP at -15°C	0.7	n/a	n/a	1.4	2.8	1.7	1.0
Rated SCOP	3.0	n/a	n/a	2.8	2.8	n/a	2.7
Rated HSPF2 (Region 4)	10.1	n/a	n/a	9.5	9.5	n/a	9.3
Average Outdoor Temperature [°C]	0.2	n/a	n/a	-4.8	-8.5	-6.3	-11.2
Heating Hours	1484	n/a	n/a	256	2564	154	735
Concurrent Heating and Defrost Hours	68	n/a	n/a	9	71	90	71
Defrost Hours	30	n/a	n/a	37	93	156	26
Cooling Hours	0	n/a	n/a	0	0	0	0
Off Hours	180	n/a	n/a	1	1	664	1
Fan Only Hours	917	n/a	n/a	3350	1006	2285	4153
Valid Data Hours	2679	n/a	n/a	3653	3736	3350	4987
Missing Hours	2433	n/a	n/a	1459	1376	1762	125
HP Heating Hours	1484	n/a	n/a	256	2564	154	772
Concurrent HP and Int. Supp. Heating Hours	not applicable	not applicable	not applicable	not applicable	not applicable	not applicable	27
Integrated Supplemental Heating Hours	not applicable	not applicable	not applicable	not applicable	not applicable	not applicable	8
Missing Data from Sept. 1 2023 to March 31, 2024	Supply and return temperatures were corrupt for indoor head A between October 21, 2023 to February 16, 2024.	System consumption data (50A CT) was corrupt for entire period	The participant withdrew from the study in October 2023. Before that, no supply temperature was available for indoor head A.	Data were missing from indoor head A between October 9 and November 28, 2023, and at indoor head B between October 14 and November 28, 2023 (battery failures).	Data missing at indoor head A between October 9 and November 29, 2023 (battery failure). Data missing at indoor head B between November 3 and 29, 2023 (battery failure).	Data missing at indoor head A between October 10 and Nov. 27, 2023, and between March 28, 2024 and April 11, 2024 (battery failure). Data missing at indoor head B between Feb. 13 and Feb. 28, 2024 (battery failure). Data missing at indoor unit head C between Nov. 15 and Nov. 27, 2023 (battery failure).	n/a
Estimated Balance Point Temperature [°C]; estimated using max. heat output (intersection of plotted values)	-5	n/a	n/a	n/a	n/a	< -15 (not observed in monitoring data)	-16
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	n/a	n/a	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]	27931	Insufficient data	Insufficient data	No CSA F280 heating load	No CSA F280 heating load	45038	49295
Post-Retrofit Heating Energy Consumption [ekWh/year]	21982	Insufficient data	Insufficient data	No CSA F280 heating load	No CSA F280 heating load	20766	38413
Heating Energy Savings [ekWh/year]	5949	Insufficient data	Insufficient data	No CSA F280 heating load	No CSA F280 heating load	24272	10882
Baseline Heating GHG Emissions [kgCO2e/year]	6010	Insufficient data	Insufficient data	No CSA F280 heating load	No CSA F280 heating load	12166	13316
Post-Retrofit Heating GHG Emissions	4808	Insufficient data	Insufficient data	No CSA F280 heating load	No CSA F280 heating load	3681	6016
Heating GHG Emission Savings	1202	Insufficient data	Insufficient data	No CSA F280 heating load	No CSA F280 heating load	8486	7299
Baseline Heating Utility Cost	3807	Insufficient data	Insufficient data	No CSA F280 heating load	No CSA F280 heating load	7065	7733
Post-Retrofit Heating Utility Cost	4123	Insufficient data	Insufficient data	No CSA F280 heating load	No CSA F280 heating load	4077	7878
Heating Utility Cost Savings	-316	Insufficient data	Insufficient data	No CSA F280 heating load	No CSA F280 heating load	2988	-146
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
SUMMARY OF PERFORMANCE				
Measured Heating SCOP	1.9	2.7	1.3	n/a
HSPF	6.5	9.2	4.3	n/a
COP at -15°C	1.7	2.4	1.2	n/a
Rated SCOP	2.7	2.8	n/a	n/a
Rated HSPF2 (Region 4)	9.3	9.5	n/a	n/a
Average Outdoor Temperature [°C]	-9.0	-10.2	-2.9	n/a
Heating Hours	3183	1484	1794	n/a
Concurrent Heating and Defrost Hours	179	125	0	n/a
Defrost Hours	127	73	0	n/a
Cooling Hours	19	0	0	n/a
Off Hours	1476	5	2926	n/a
Fan Only Hours	0	2645	0	n/a
Valid Data Hours	4984	4332	4720	n/a
Missing Hours	128	780	392	n/a
HP Heating Hours	3362	1105	317	n/a
Concurrent HP and Int. Supp. Heating Hours	0	not applicable	173	n/a
Integrated Supplemental Heating Hours	0	not applicable	51	n/a
Missing Data from Sept. 1 2023 to March 31, 2024	Indoor head fan consumption (5A CT, proxy for airflow rate) was corrupt, however, there was only one fan setting and corresponding airflow rate for this system.	Data for indoor head A before December 1, 2023 was omitted due to faulty sensor readings. Homeowner also reported turning off the monitoring equipment overnight, resulting in loss of approximately 25% of data daily.	n/a	Integrated supplemental heating consumption data (200A CT) was corrupt. Integrated supplemental heating was used based on measured supply temperatures up- and down-stream of the buffer tank, and thus heating output by the heat pump alone could not be isolated.
Estimated Balance Point Temperature [°C]; estimated using max. heat output (intersection of plotted values)	-23.0	n/a	10	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	n/a	17.27	n/a
Baseline Heating System	Elec. Baseboard, assumed	Elec. Baseboard, assumed	Elec. Boiler, assumed	Oil Boiler
Baseline Heating Energy Consumption [ekWh/year]	32243	43264	52230	Insufficient data
Post-Retrofit Heating Energy Consumption [ekWh/year]	15895	23107	48099	Insufficient data
Heating Energy Savings [ekWh/year]	16347	20156	4131	Insufficient data
Baseline Heating GHG Emissions [kgCO2e/year]	2257	3028	3656	Insufficient data
Post-Retrofit Heating GHG Emissions	1113	1618	3367	Insufficient data
Heating GHG Emission Savings	1144	1411	289	Insufficient data
Baseline Heating Utility Cost	7799	10465	12635	Insufficient data
Post-Retrofit Heating Utility Cost	3845	5590	11635	Insufficient data
Heating Utility Cost Savings	3954	4876	999	Insufficient data
HEAT PUMP SYSTEM PHOTOS				
			 	 

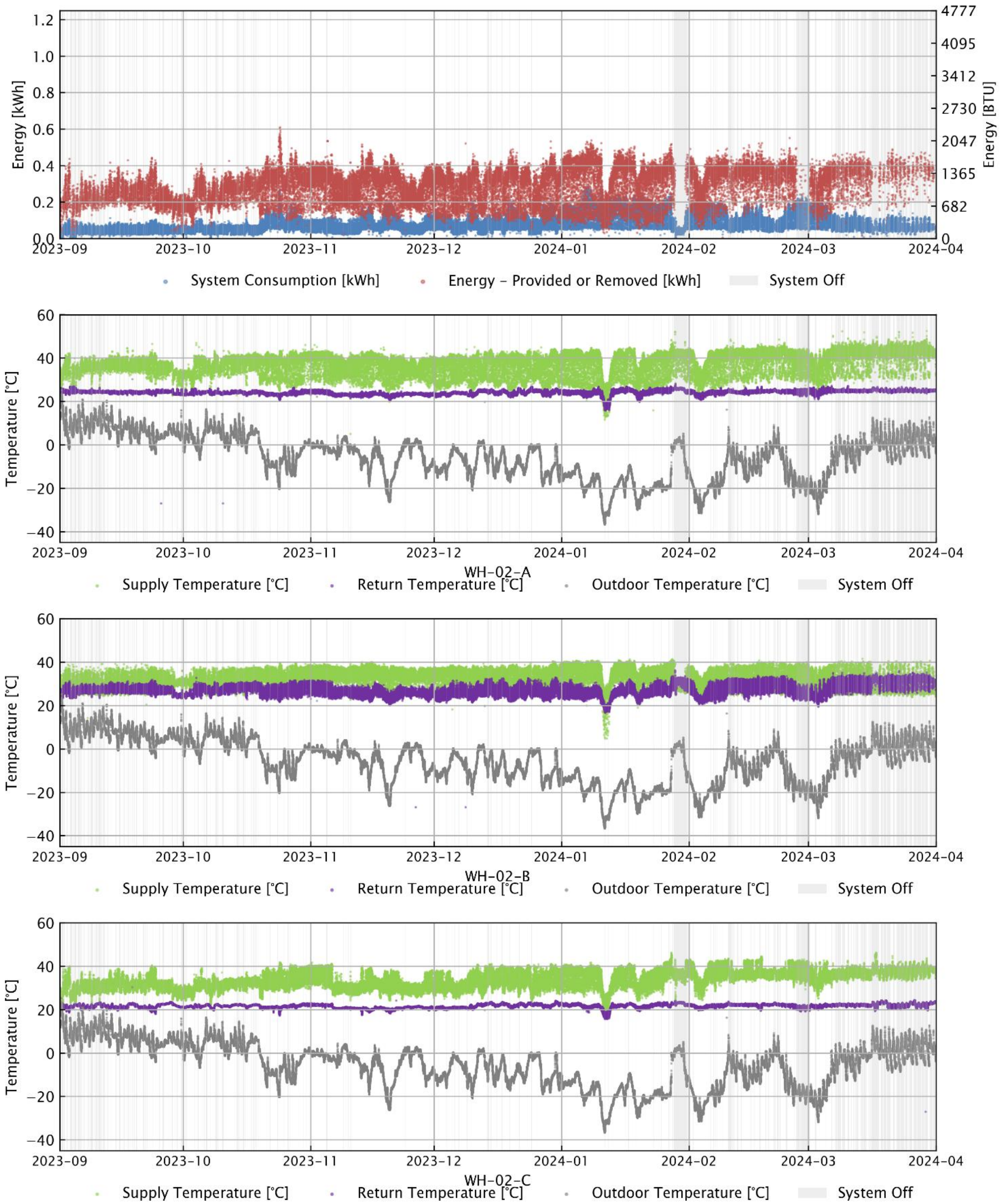
Appendix B - Energy Consumption & Output Profiles

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.

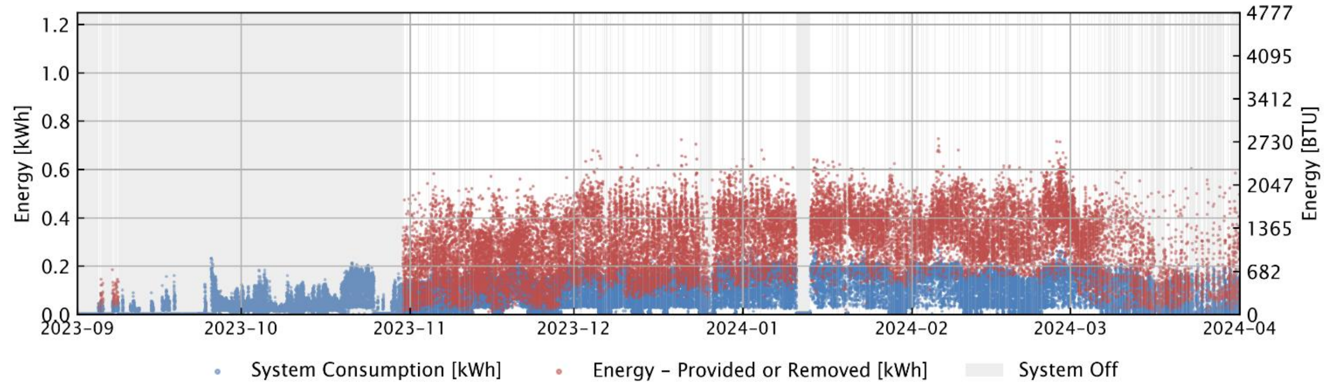
WH-01

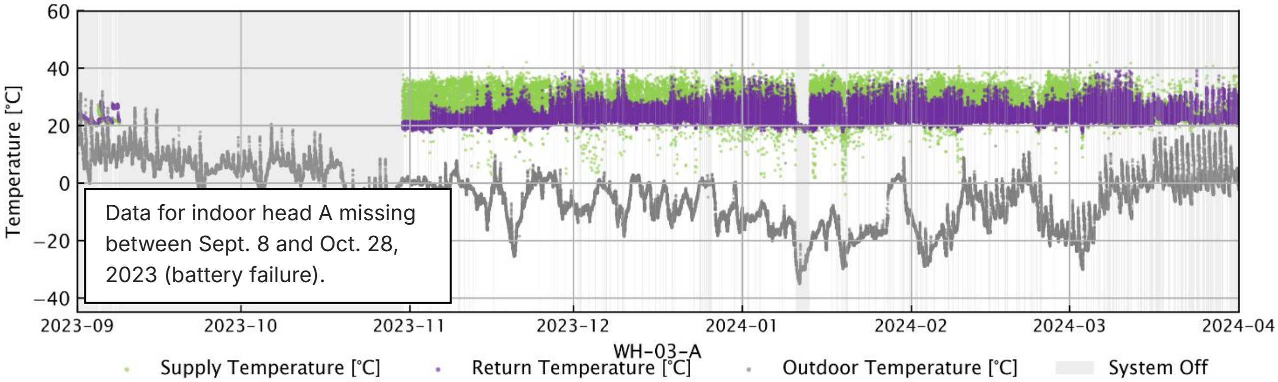


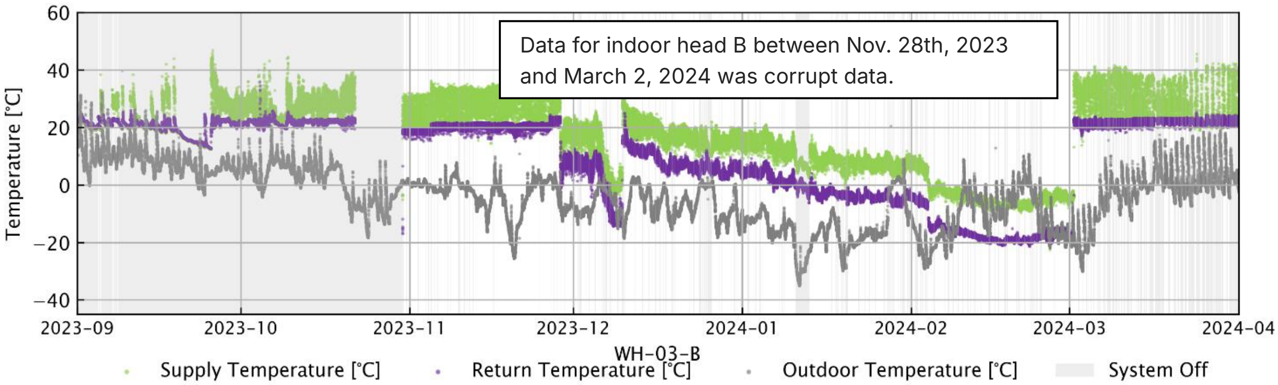
WH-02

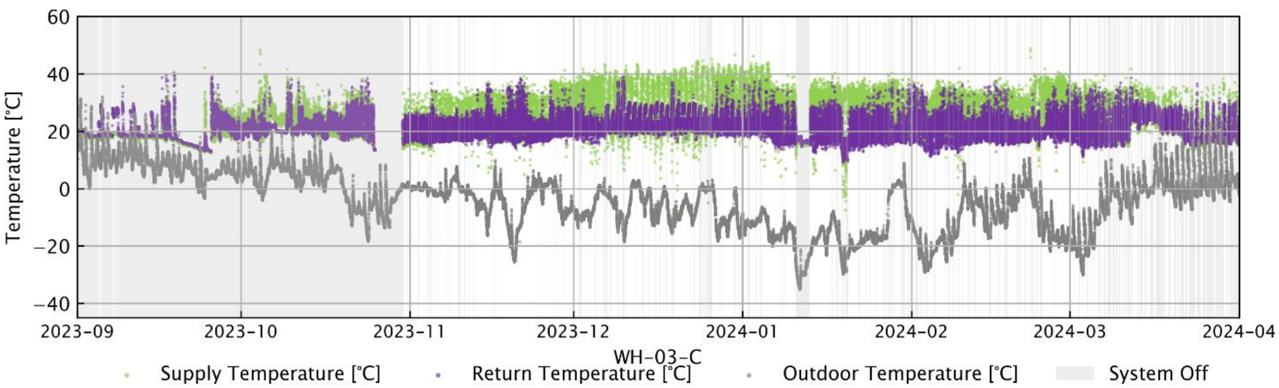

Energy [kWh]
Energy [BTU]
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
682
1365
2047
2730
3412
4095
4777
2023-09
2023-10
2023-11
2023-12
2024-01
2024-02
2024-03
2024-04
System Consumption [kWh]
Energy – Provided or Removed [kWh]
System Off
Temperature [°C]
−40
−20
0
20
40
60
WH-02-A
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off
WH-02-B
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off
WH-02-C
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

WH-03



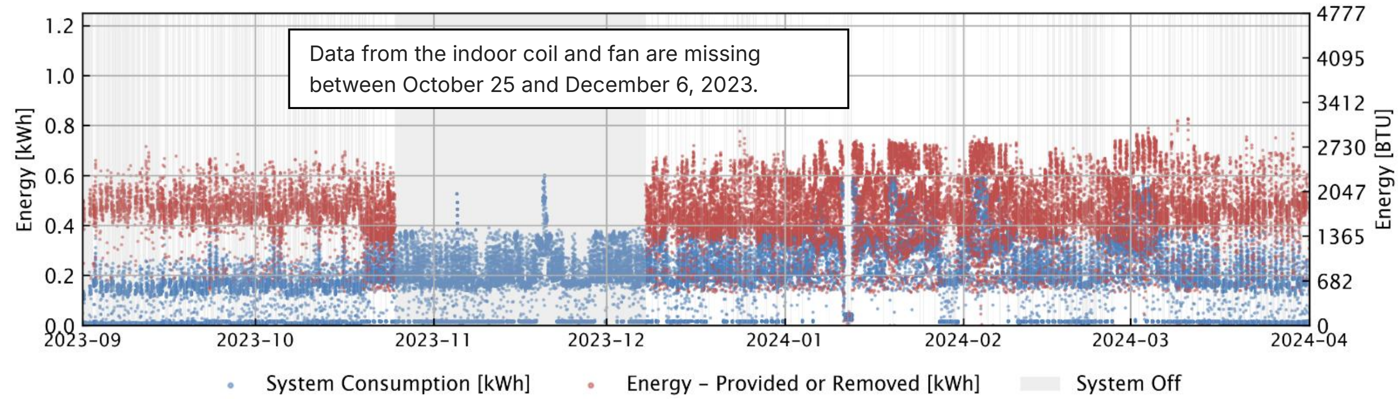




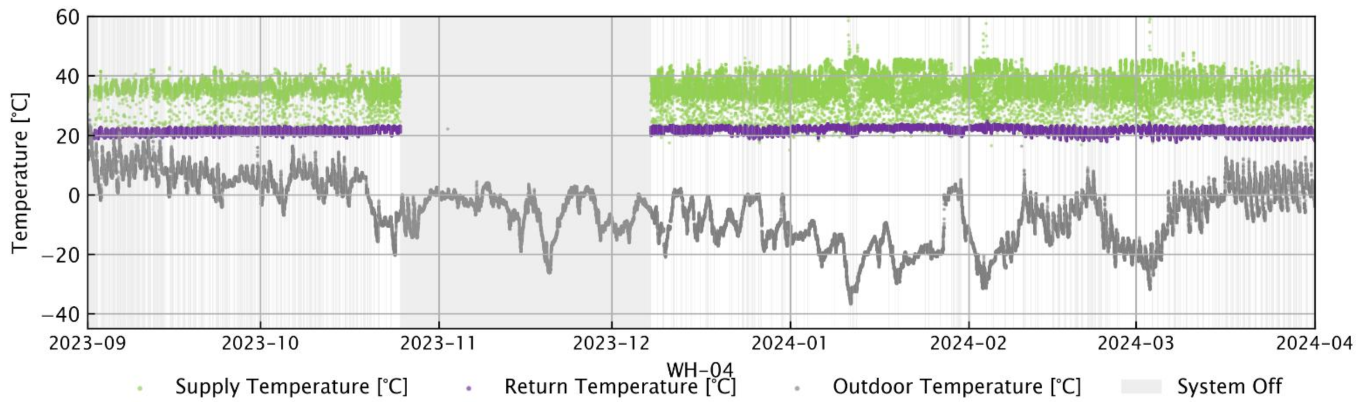


At indoor heads A and C, occasional periods with return temperatures above supply temperatures occur when the indoor fan is off and the coil stays warm. This appears to be creating local stratification near the return sensor (which is installed right above the coil).

WH-04

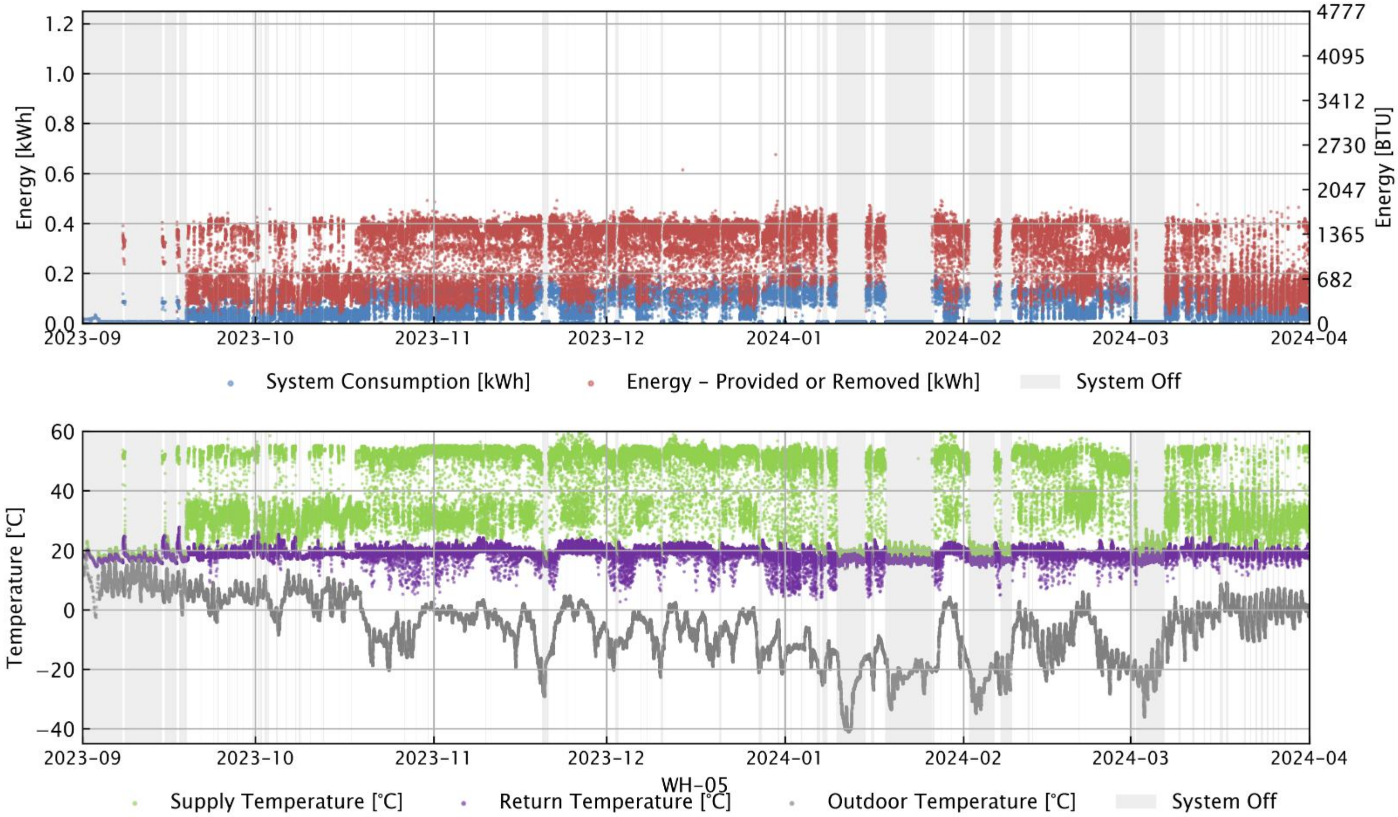


Data from the indoor coil and fan are missing between October 25 and December 6, 2023.
Energy [kWh]
Energy [BTU]
1.2
1.0
0.8
0.6
0.4
0.2
0.0
4777
4095
3412
2730
2047
1365
682
0
2023-09
2023-10
2023-11
2023-12
2024-01
2024-02
2024-03
2024-04
System Consumption [kWh]
Energy - Provided or Removed [kWh]
System Off



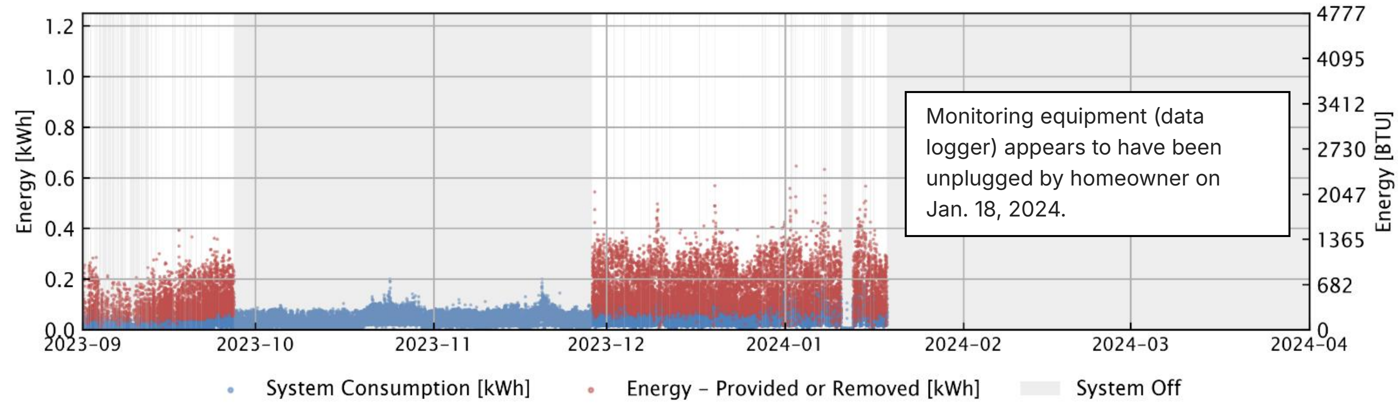
Temperature [°C]
60
40
20
0
−20
−40
2023-09
2023-10
2023-11
2023-12
2024-01
2024-02
2024-03
2024-04
WH-04
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

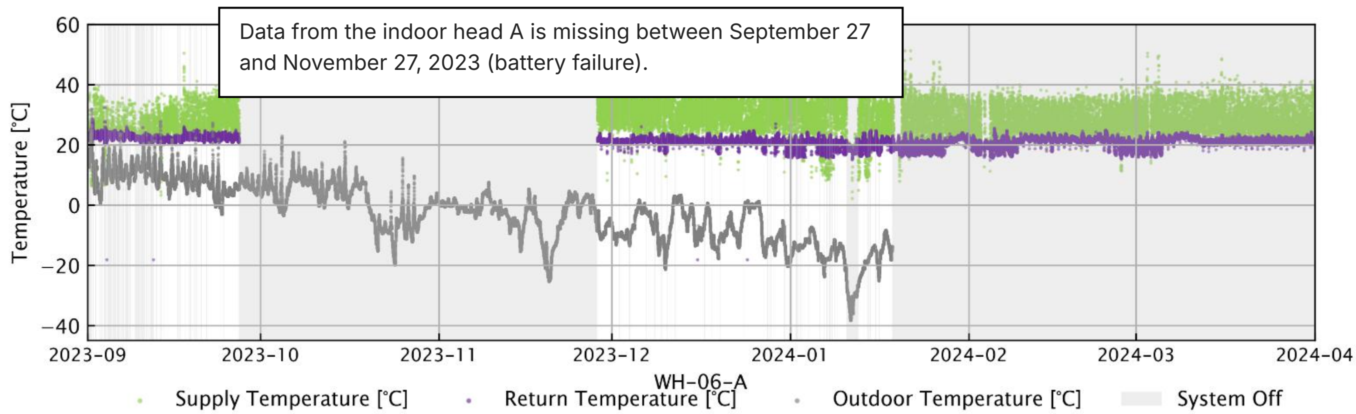
WH-05

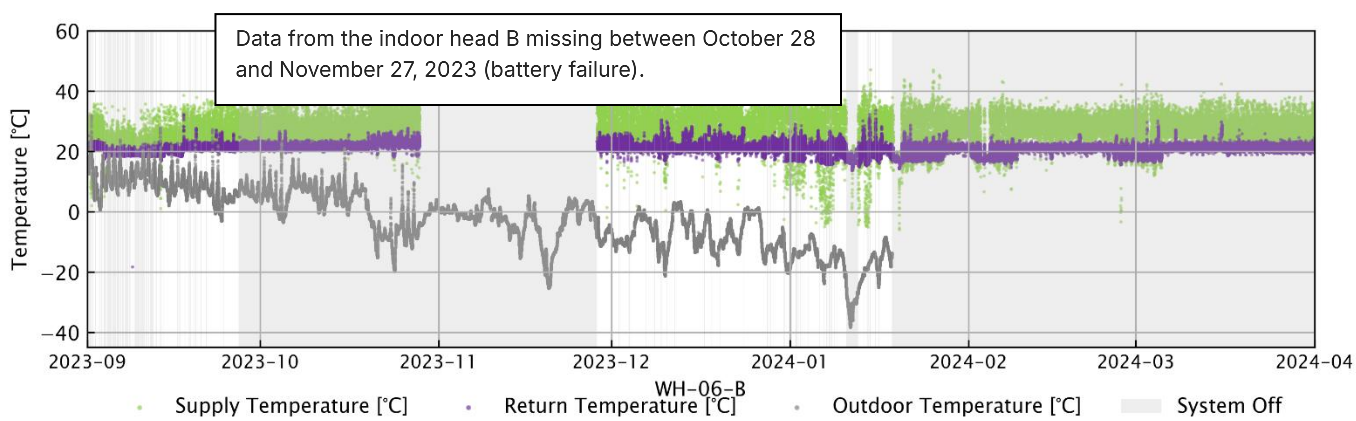


Energy [kWh]
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Energy [BTU]
4777
4095
3412
2730
2047
1365
682
0
2023-09
2023-10
2023-11
2023-12
2024-01
2024-02
2024-03
2024-04
System Consumption [kWh]
Energy – Provided or Removed [kWh]
System Off
Temperature [°C]
60
40
20
0
−20
−40
WH-05
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

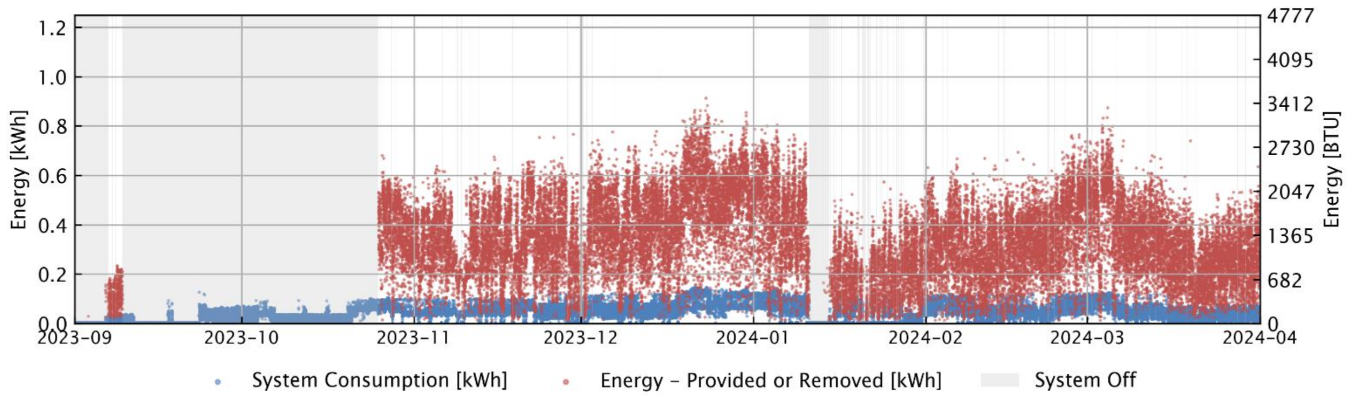
WH-06

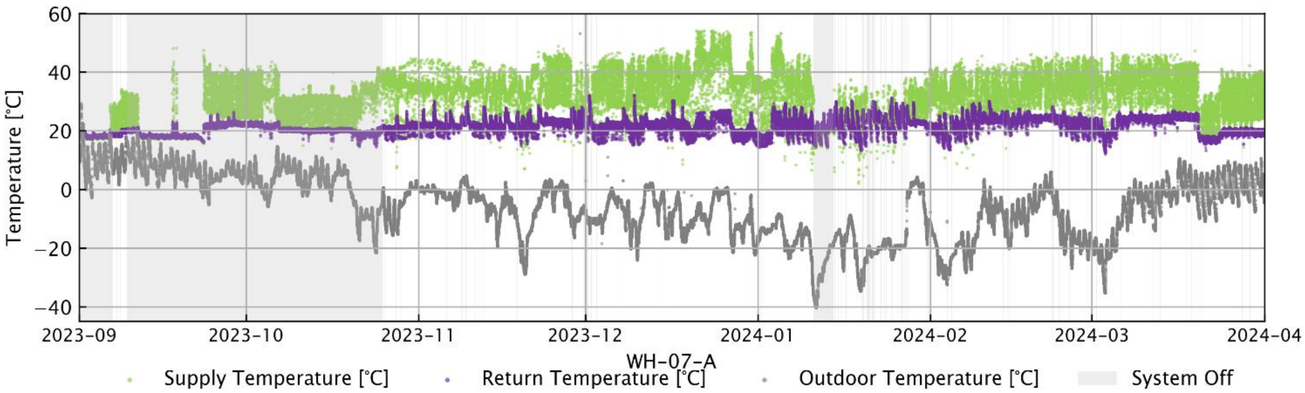

Energy [kWh]
Energy [BTU]
1.2
1.0
0.8
0.6
0.4
0.2
0.0
4777
4095
3412
2730
2047
1365
682
0
2023-09
2023-10
2023-11
2023-12
2024-01
2024-02
2024-03
2024-04
Monitoring equipment (data logger) appears to have been unplugged by homeowner on Jan. 18, 2024.
System Consumption [kWh]
Energy – Provided or Removed [kWh]
System Off

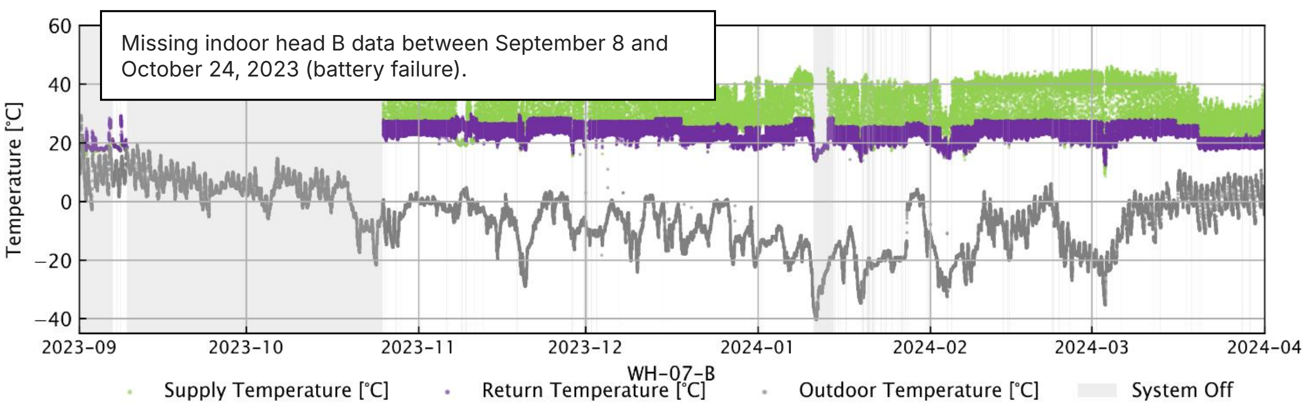

Temperature [°C]
60
40
20
0
−20
−40
Data from the indoor head A is missing between September 27 and November 27, 2023 (battery failure).
2023-09
2023-10
2023-11
2023-12
2024-01
2024-02
2024-03
2024-04
WH-06-A
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

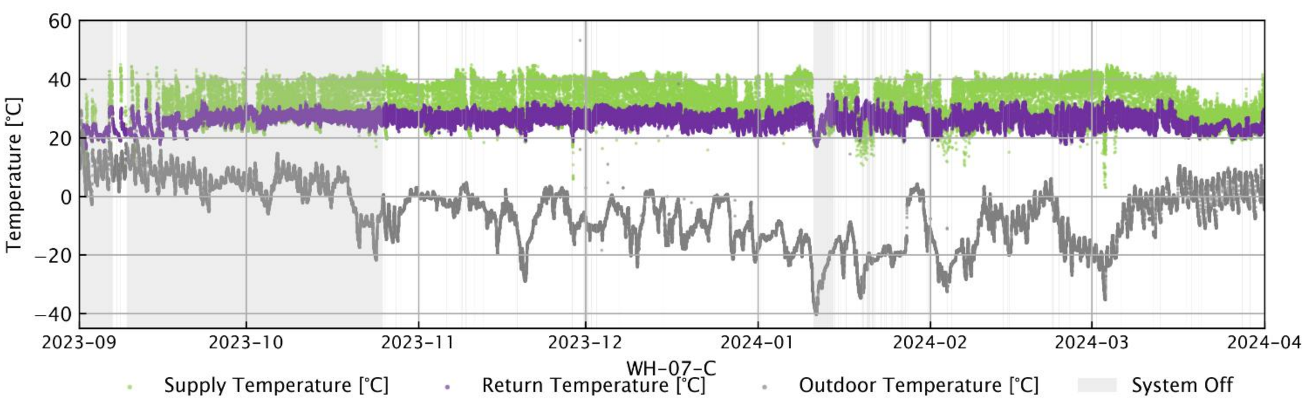

Temperature [°C]
60
40
20
0
−20
−40
Data from the indoor head B missing between October 28 and November 27, 2023 (battery failure).
2023-09
2023-10
2023-11
2023-12
2024-01
2024-02
2024-03
2024-04
WH-06-B
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

WH-07

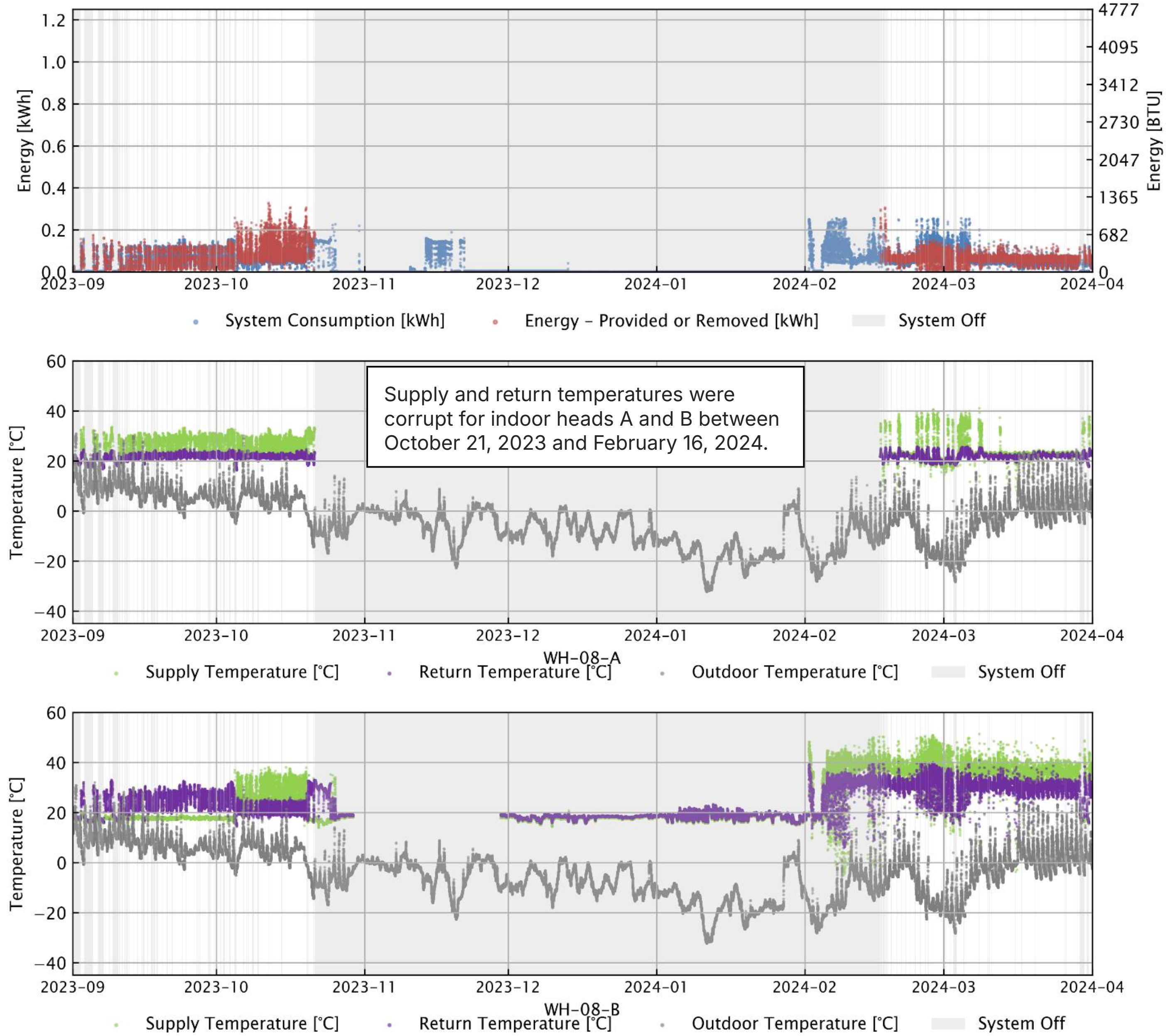

Energy [kWh]
Energy [BTU]
System Consumption [kWh]
Energy – Provided or Removed [kWh]
System Off


Temperature [°C]
WH-07-A
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

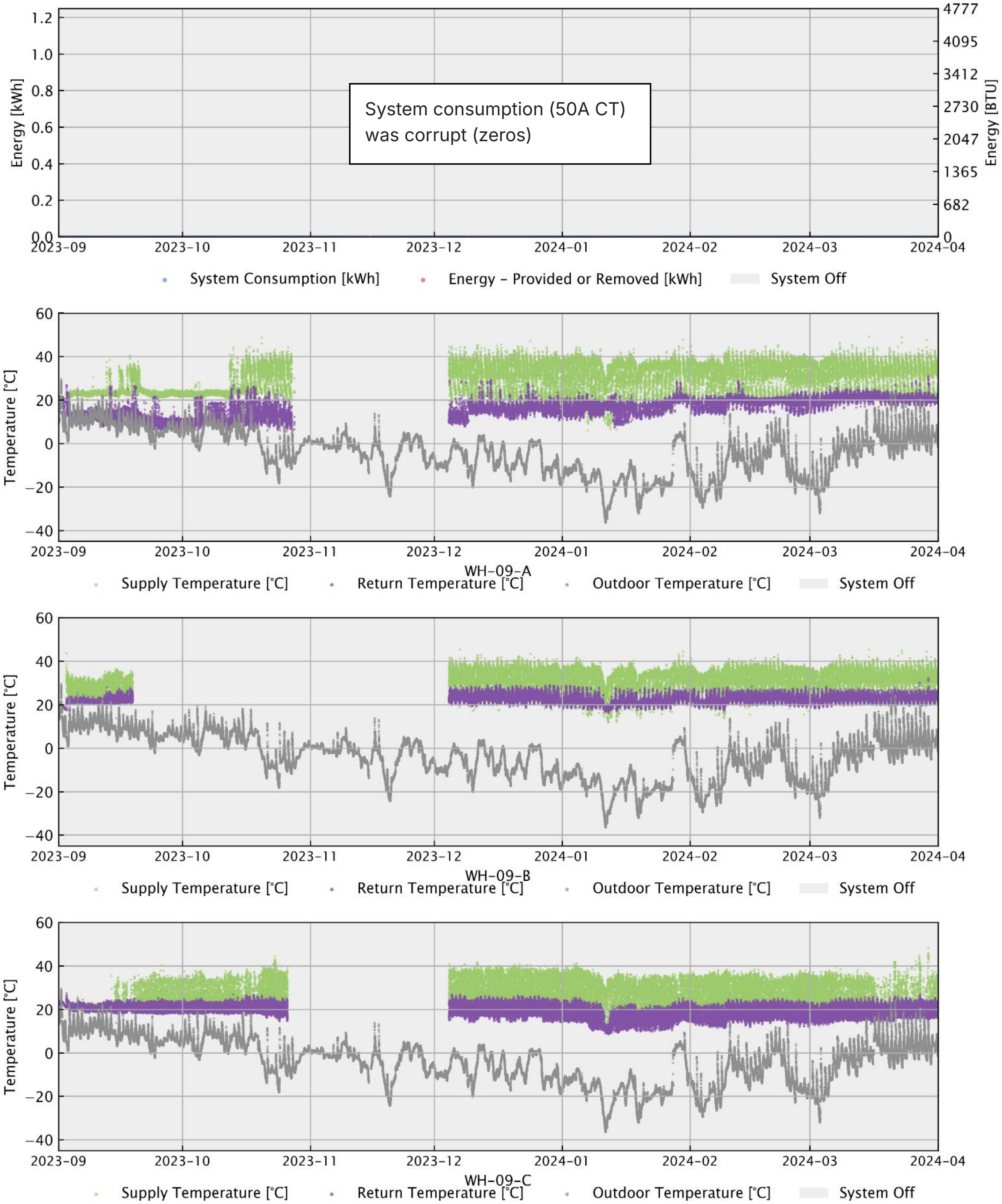

Missing indoor head B data between September 8 and October 24, 2023 (battery failure).
Temperature [°C]
WH-07-B
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off


Temperature [°C]
WH-07-C
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

WH-08

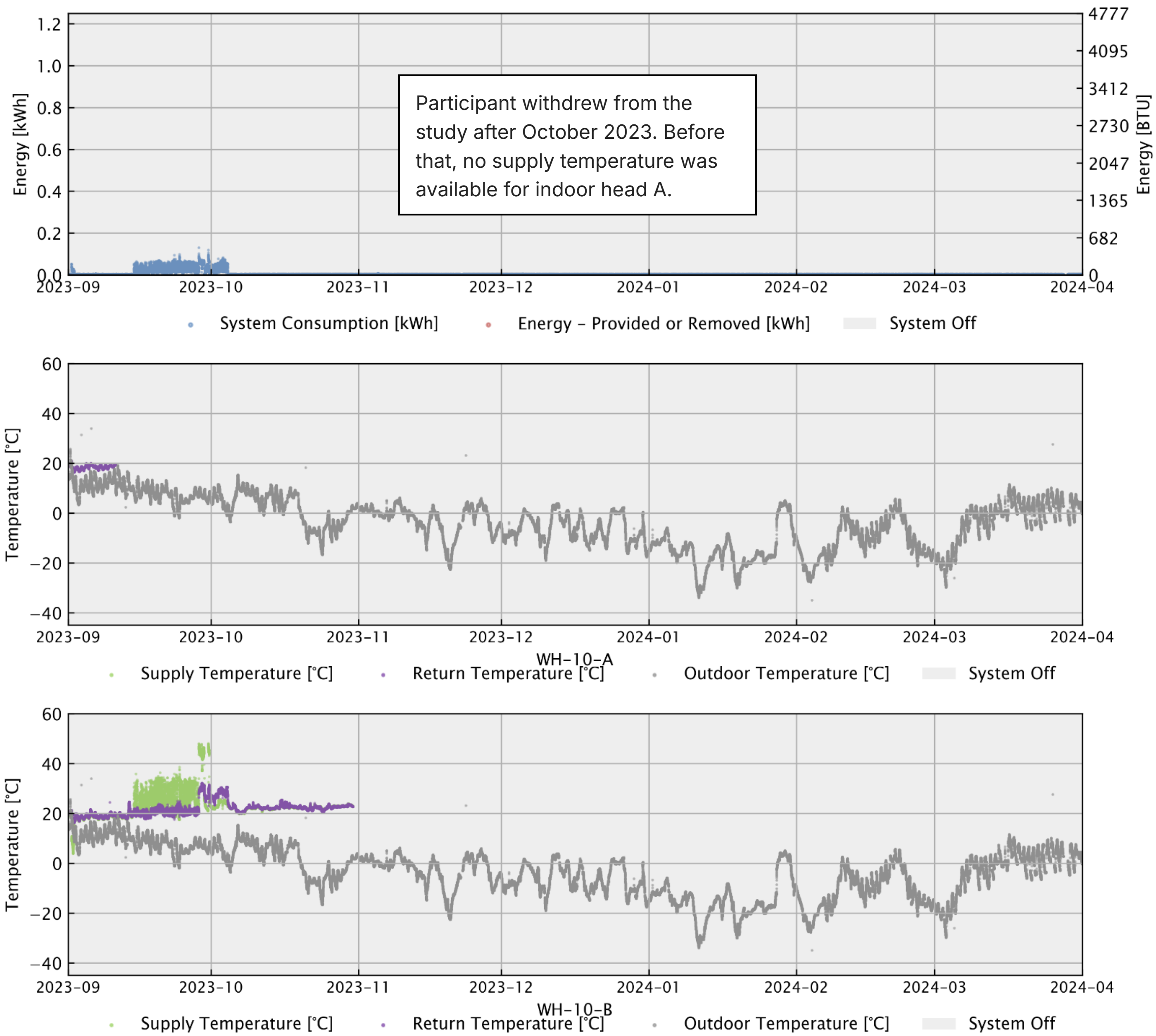

Energy [kWh]
Energy [BTU]
1.2
1.0
0.8
0.6
0.4
0.2
0.0
4777
4095
3412
2730
2047
1365
682
0
2023-09
2023-10
2023-11
2023-12
2024-01
2024-02
2024-03
2024-04
System Consumption [kWh]
Energy - Provided or Removed [kWh]
System Off
Supply and return temperatures were corrupt for indoor heads A and B between October 21, 2023 and February 16, 2024.
Temperature [°C]
60
40
20
0
−20
−40
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



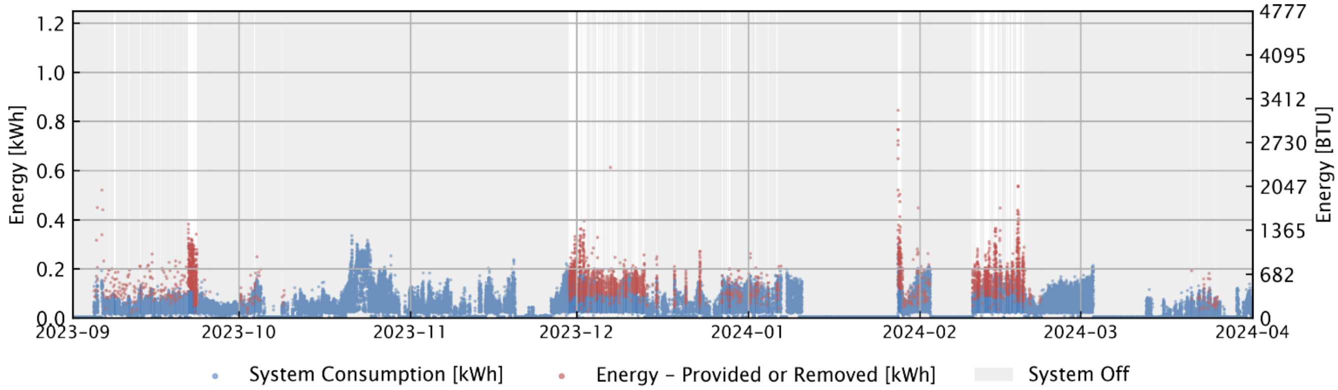
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Energy [kWh]
4777
4095
3412
2730
2047
1365
682
0
Energy [BTU]
System consumption (50A CT) was corrupt (zeros)
2023-09
2023-10
2023-11
2023-12
2024-01
2024-02
2024-03
2024-04
System Consumption [kWh]
Energy - Provided or Removed [kWh]
System Off
60
40
20
0
−20
−40
Temperature [°C]
WH-09-A
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off
WH-09-B
WH-09-C

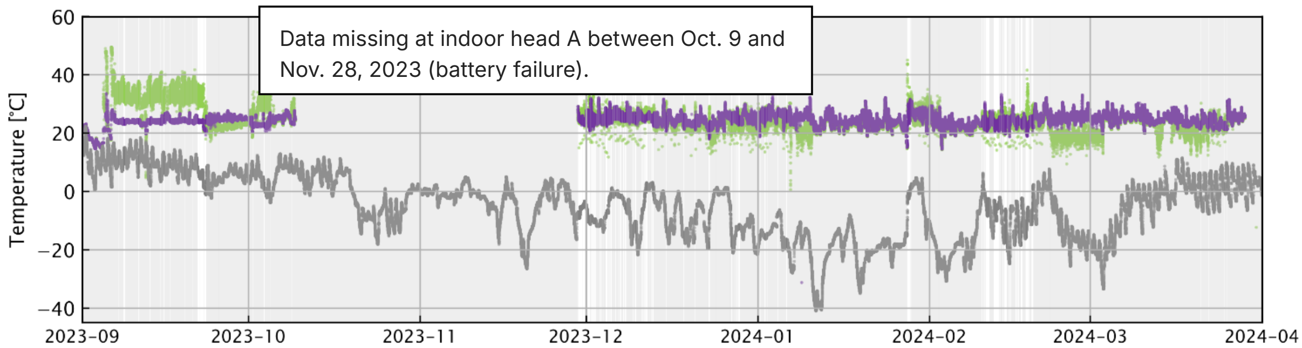
WH-10



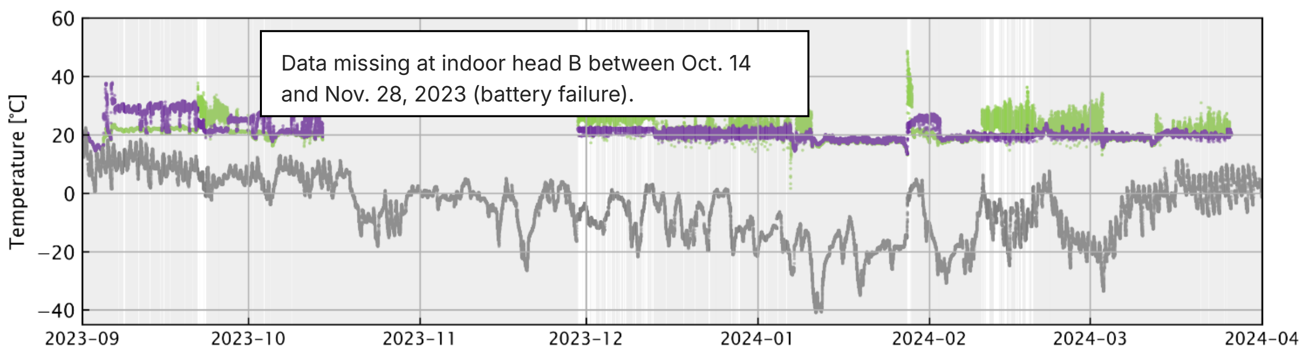
Participant withdrew from the study after October 2023. Before that, no supply temperature was available for indoor head A.
Energy [kWh]
Energy [BTU]
System Consumption [kWh]
Energy – Provided or Removed [kWh]
System Off
Temperature [°C]
WH-10-A
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
WH-10-B

WH-11

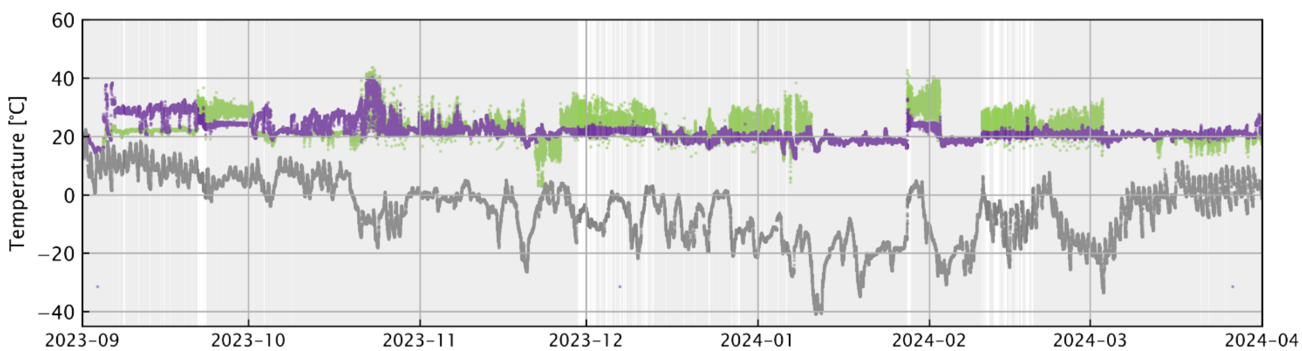




WH-11-A

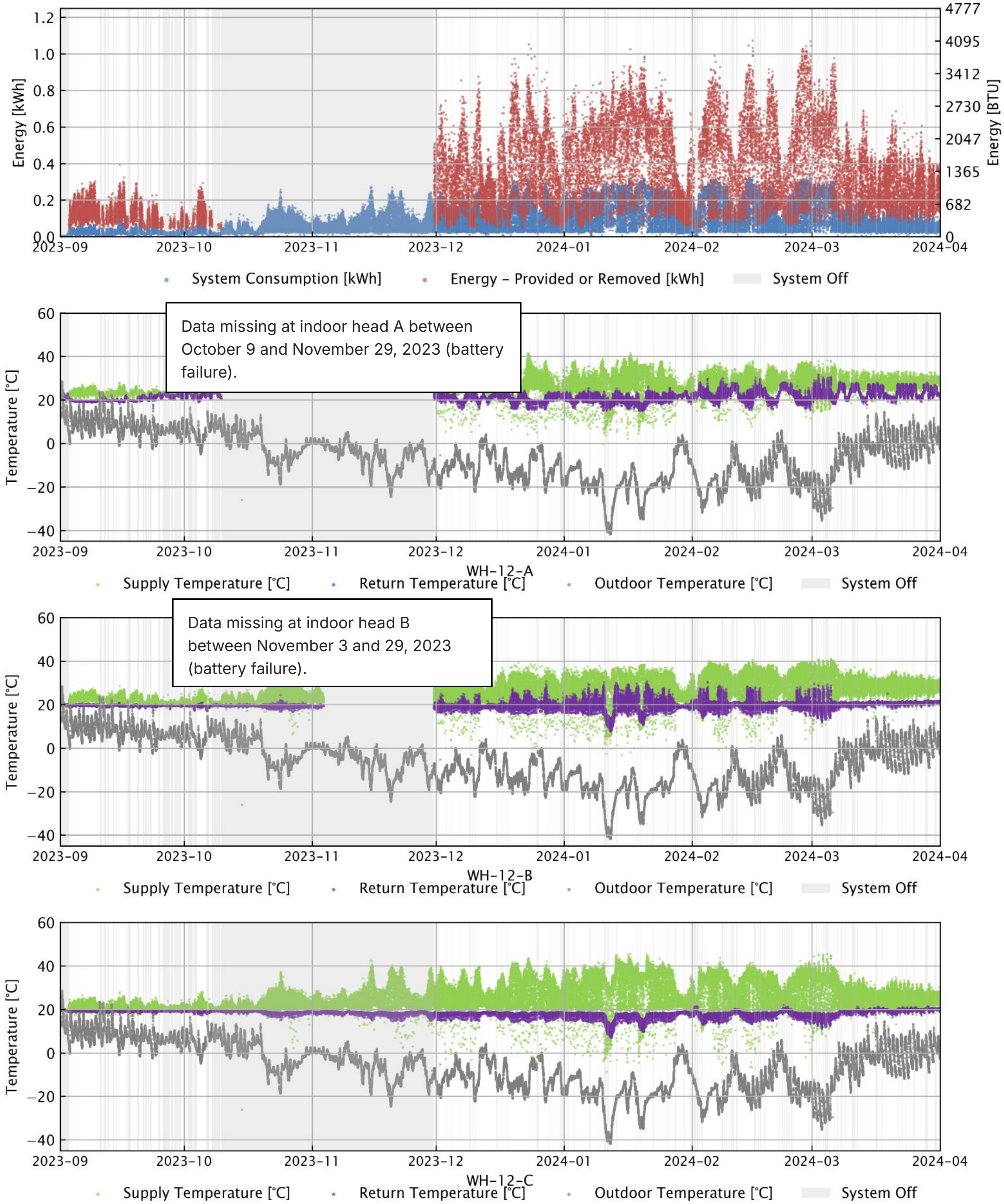


WH-11-B

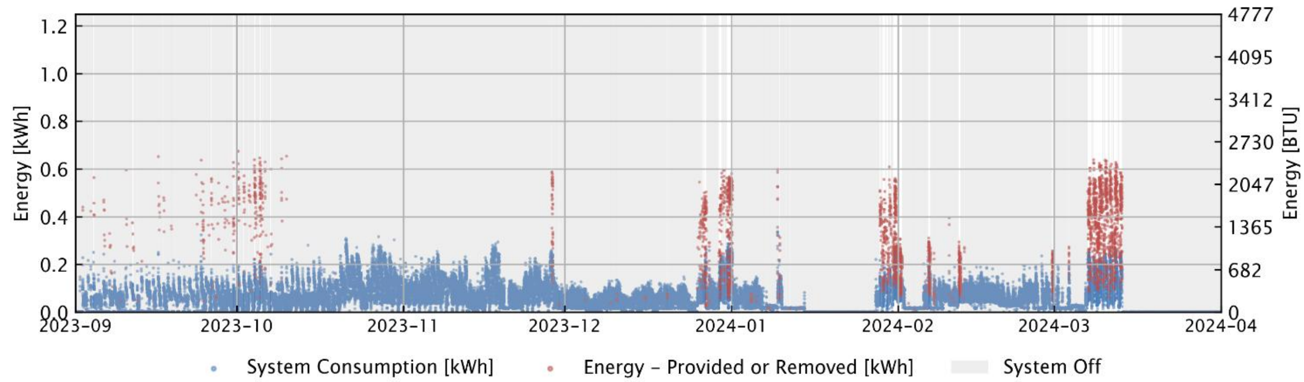


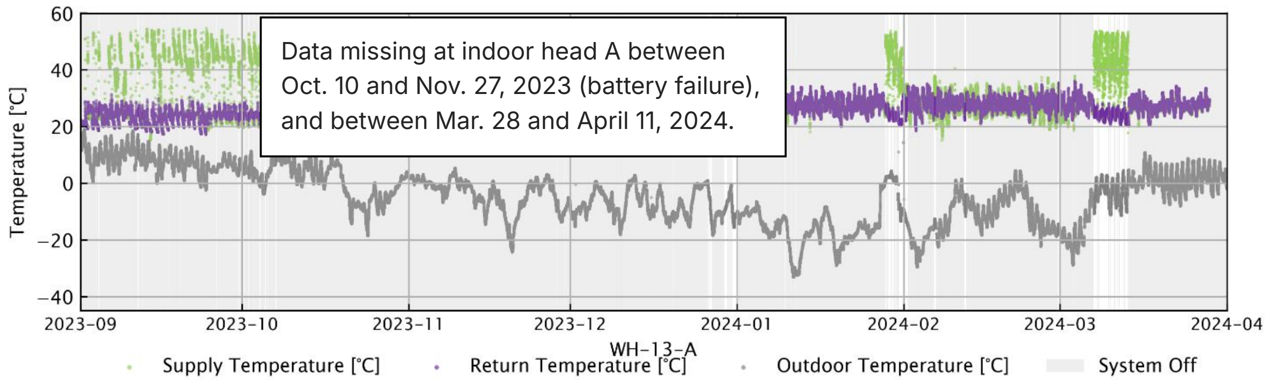
WH-11-C

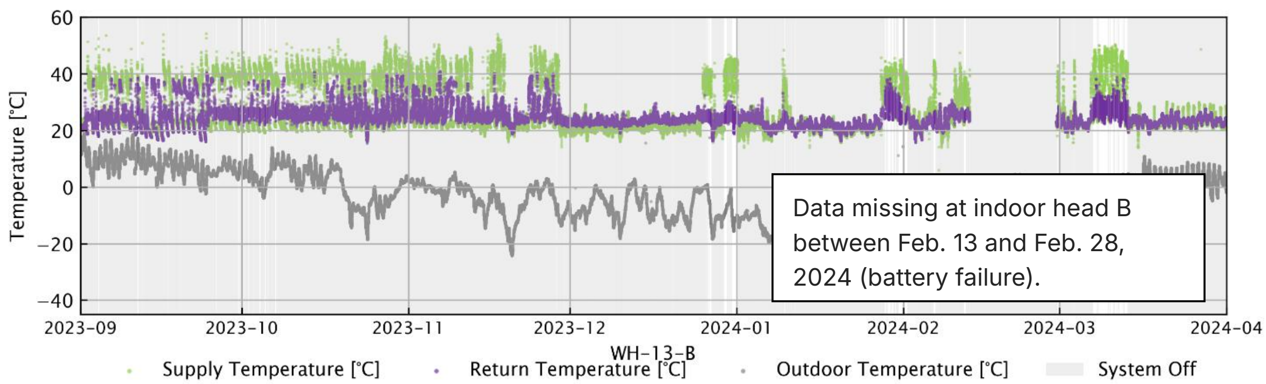
WH-12

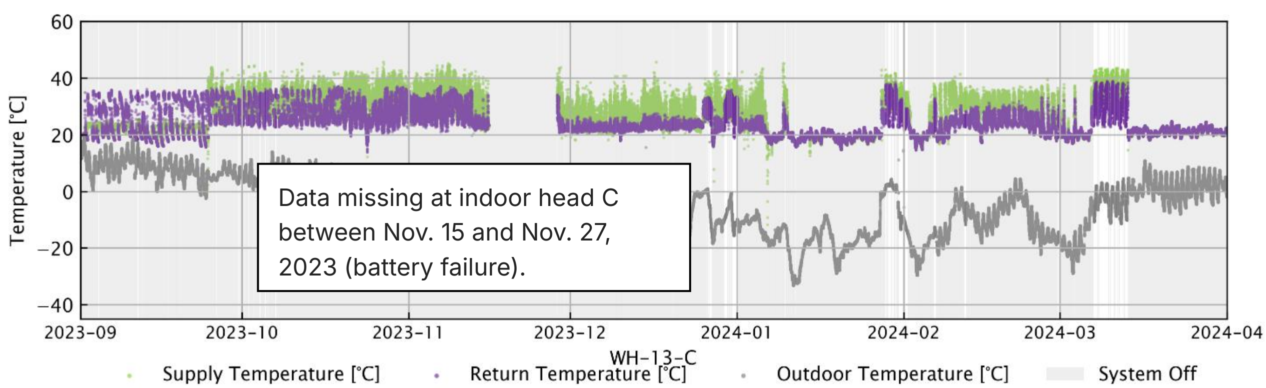

Energy [kWh]
Energy [BTU]
1.2
1.0
0.8
0.6
0.4
0.2
0.0
4777
4095
3412
2730
2047
1365
682
0
2023-09
2023-10
2023-11
2023-12
2024-01
2024-02
2024-03
2024-04
System Consumption [kWh]
Energy – Provided or Removed [kWh]
System Off
Data missing at indoor head A between October 9 and November 29, 2023 (battery failure).
Temperature [°C]
60
40
20
0
−20
−40
WH-12-A
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off
Data missing at indoor head B between November 3 and 29, 2023 (battery failure).
WH-12-B
WH-12-C

WH-13

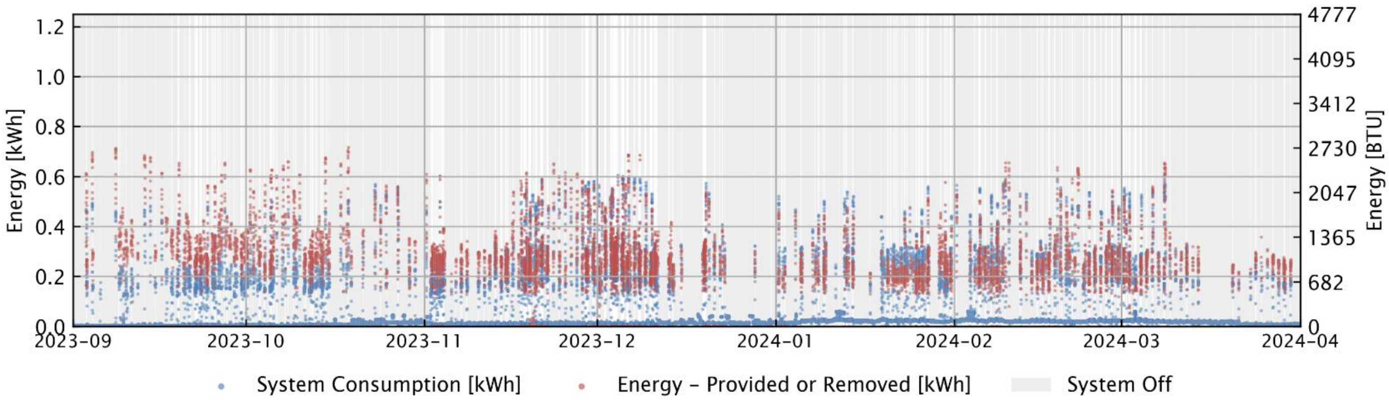

Energy [kWh]
Energy [BTU]
1.2
1.0
0.8
0.6
0.4
0.2
0.0
4777
4095
3412
2730
2047
1365
682
0
2023-09
2023-10
2023-11
2023-12
2024-01
2024-02
2024-03
2024-04
System Consumption [kWh]
Energy – Provided or Removed [kWh]
System Off


Data missing at indoor head A between Oct. 10 and Nov. 27, 2023 (battery failure), and between Mar. 28 and April 11, 2024.
Temperature [°C]
60
40
20
0
−20
−40
2023-09
2023-10
2023-11
2023-12
2024-01
2024-02
2024-03
2024-04
WH-13-A
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

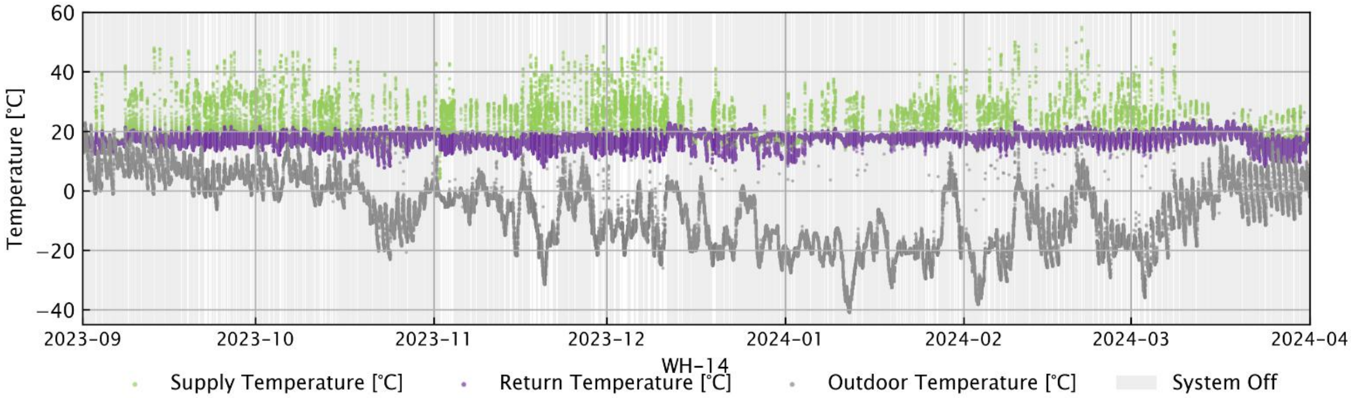

Data missing at indoor head B between Feb. 13 and Feb. 28, 2024 (battery failure).
Temperature [°C]
60
40
20
0
−20
−40
2023-09
2023-10
2023-11
2023-12
2024-01
2024-02
2024-03
2024-04
WH-13-B
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off


Data missing at indoor head C between Nov. 15 and Nov. 27, 2023 (battery failure).
Temperature [°C]
60
40
20
0
−20
−40
2023-09
2023-10
2023-11
2023-12
2024-01
2024-02
2024-03
2024-04
WH-13-C
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

WH-14

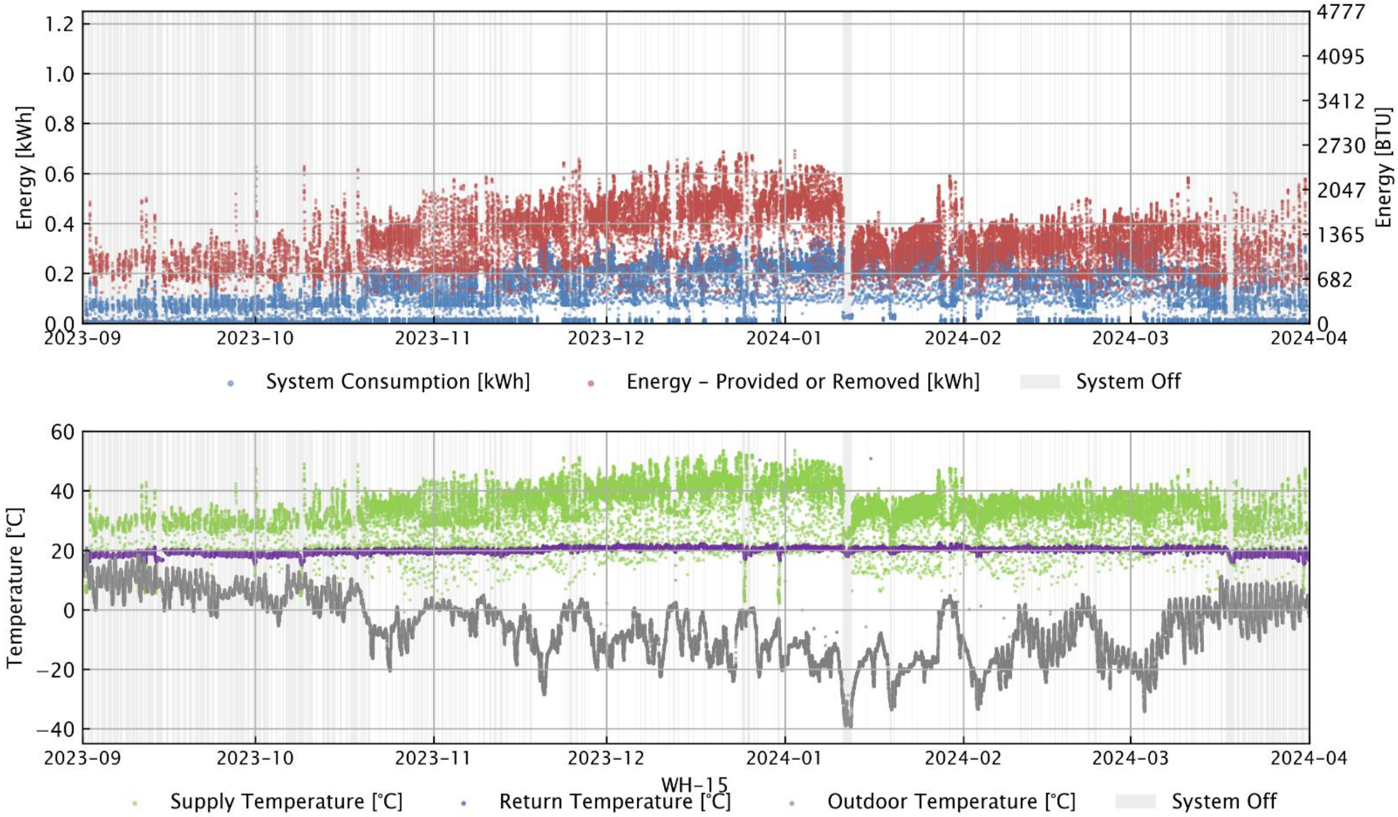


Energy [kWh]
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Energy [BTU]
4777
4095
3412
2730
2047
1365
682
0
2023-09
2023-10
2023-11
2023-12
2024-01
2024-02
2024-03
2024-04
System Consumption [kWh]
Energy - Provided or Removed [kWh]
System Off



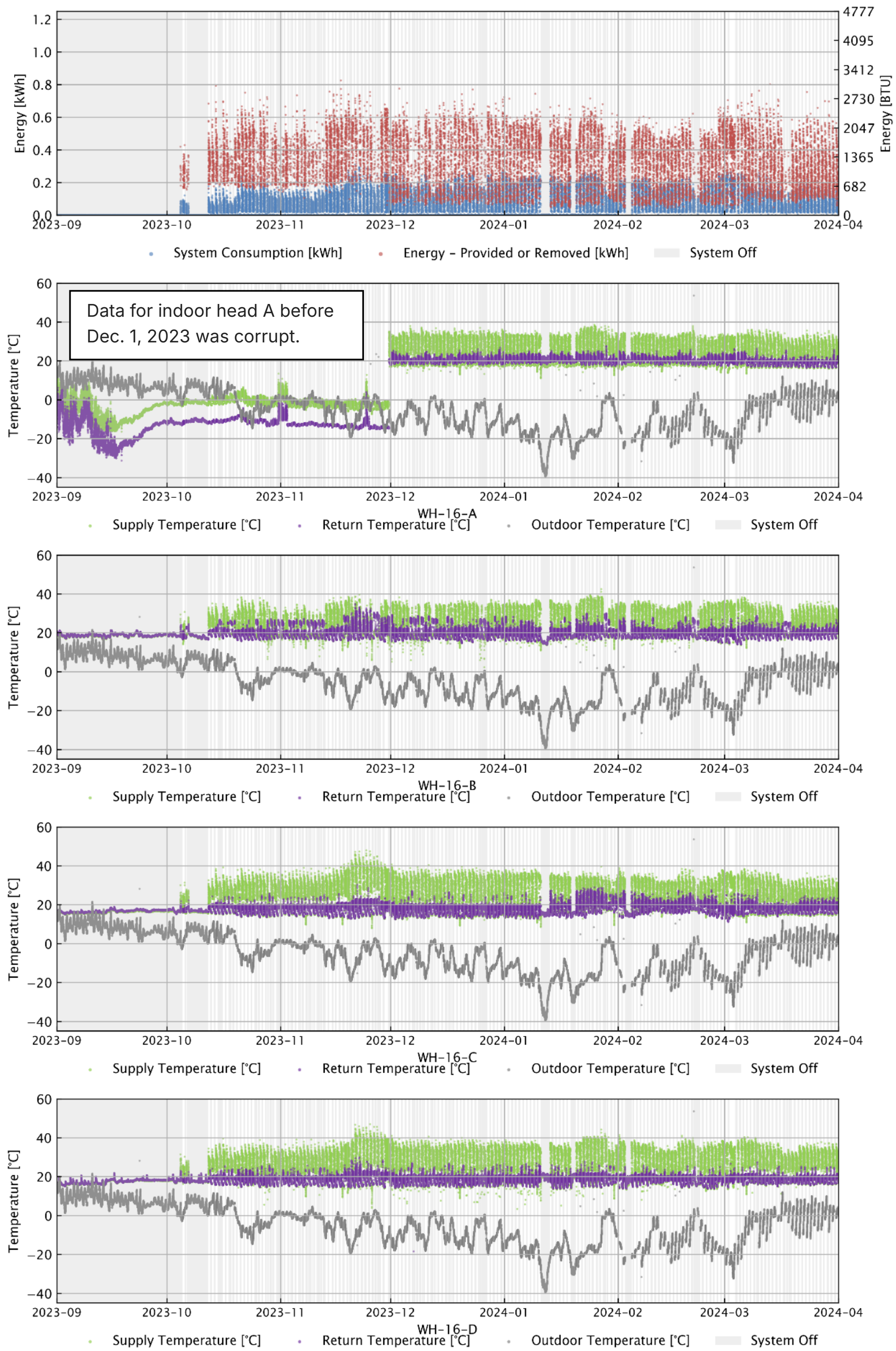
Temperature [°C]
60
40
20
0
−20
−40
2023-09
2023-10
2023-11
2023-12
2024-01
2024-02
2024-03
2024-04
WH-14
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

WH-15



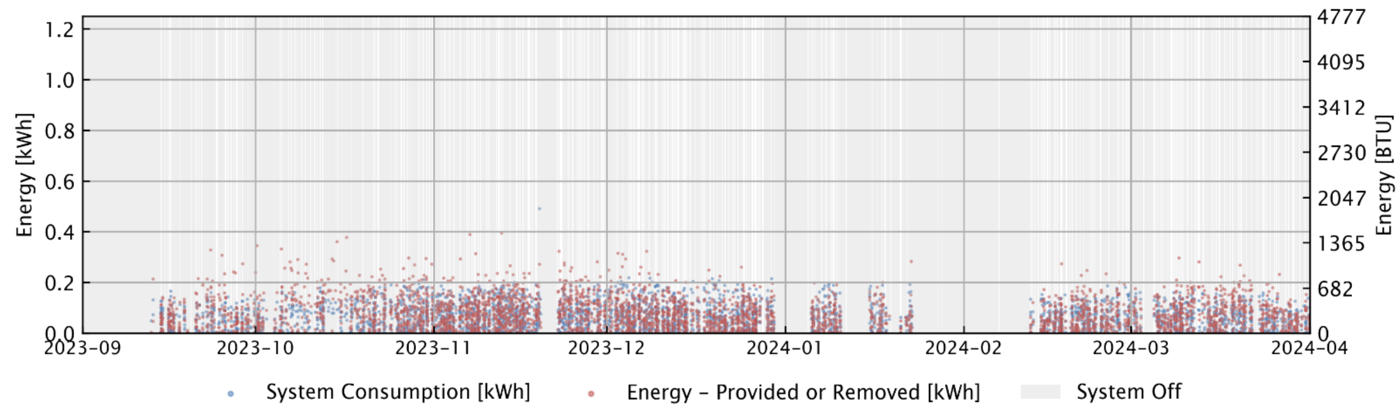
Energy [kWh]
Energy [BTU]
1.2
1.0
0.8
0.6
0.4
0.2
0.0
4777
4095
3412
2730
2047
1365
682
0
2023-09
2023-10
2023-11
2023-12
2024-01
2024-02
2024-03
2024-04
System Consumption [kWh]
Energy - Provided or Removed [kWh]
System Off
Temperature [°C]
60
40
20
0
−20
−40
WH-15
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

WH-16

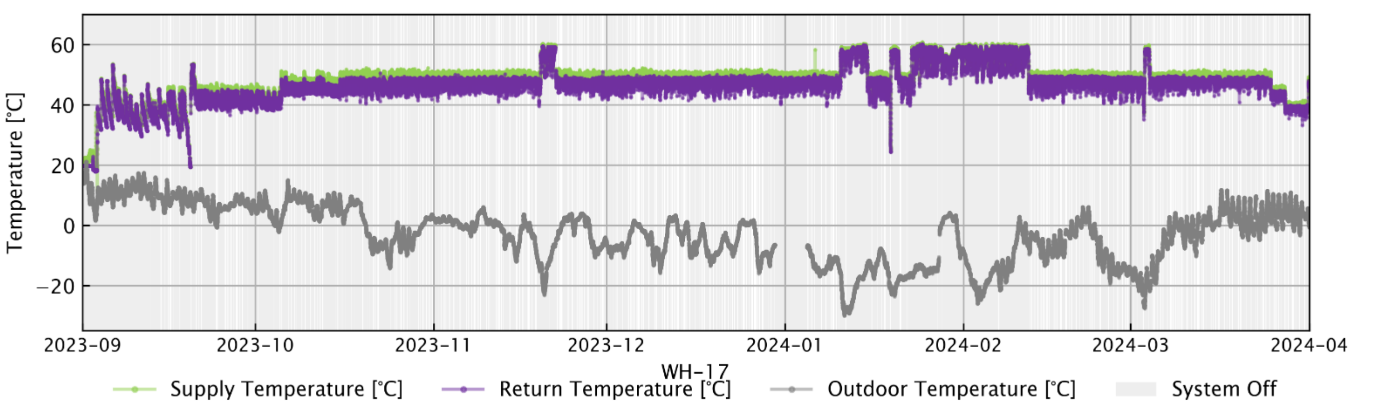


Energy [kWh]
Energy [BTU]
System Consumption [kWh]
Energy - Provided or Removed [kWh]
System Off
Data for indoor head A before Dec. 1, 2023 was corrupt.
Temperature [°C]
WH-16-A
WH-16-B
WH-16-C
WH-16-D
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

WH-17

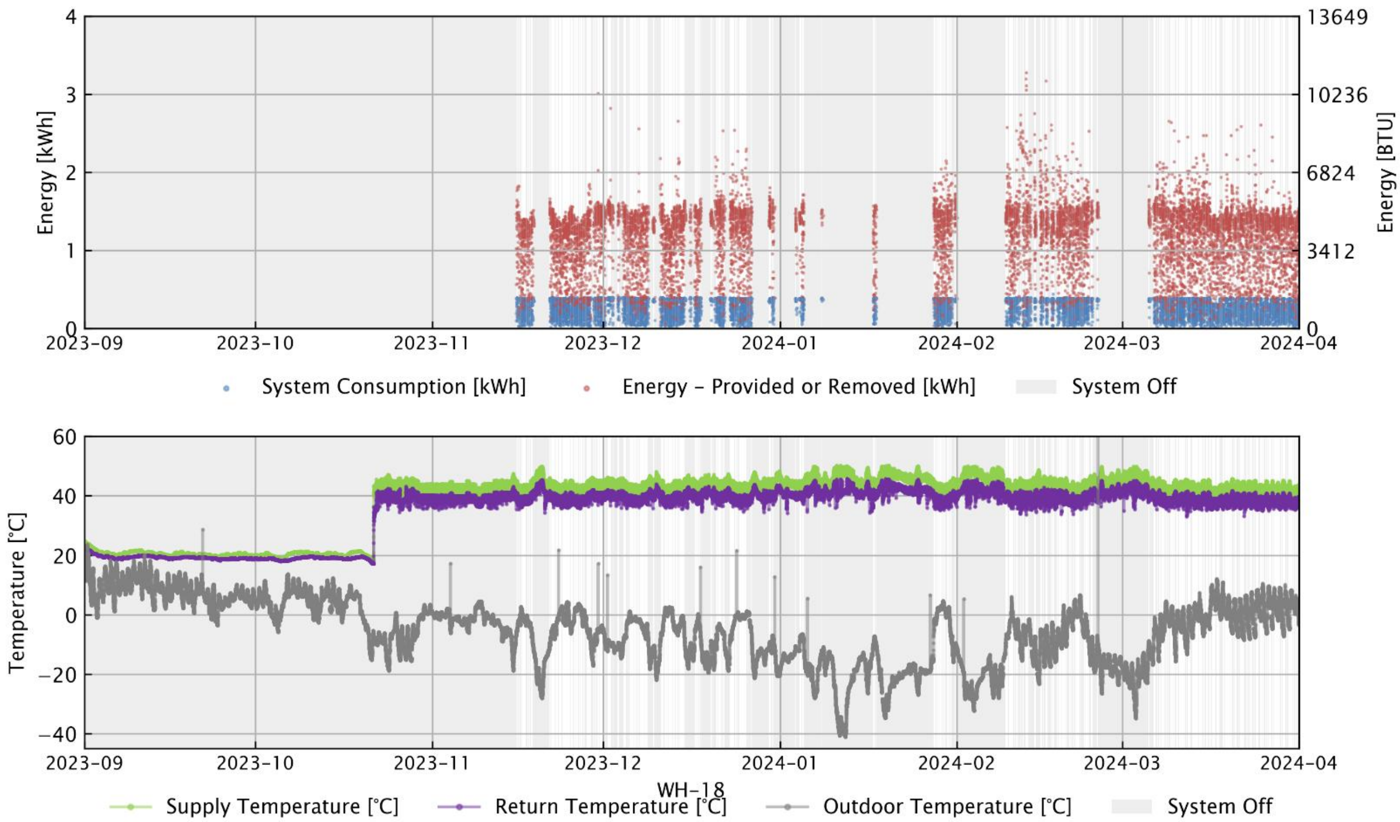


Energy [kWh]
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Energy [BTU]
4777
4095
3412
2730
2047
1365
682
0
2023-09
2023-10
2023-11
2023-12
2024-01
2024-02
2024-03
2024-04
System Consumption [kWh]
Energy - Provided or Removed [kWh]
System Off



Temperature [°C]
60
40
20
0
−20
2023-09
2023-10
2023-11
2023-12
2024-01
2024-02
2024-03
2024-04
WH-17
Supply Temperature [°C]
Return Temperature [°C]
Outdoor Temperature [°C]
System Off

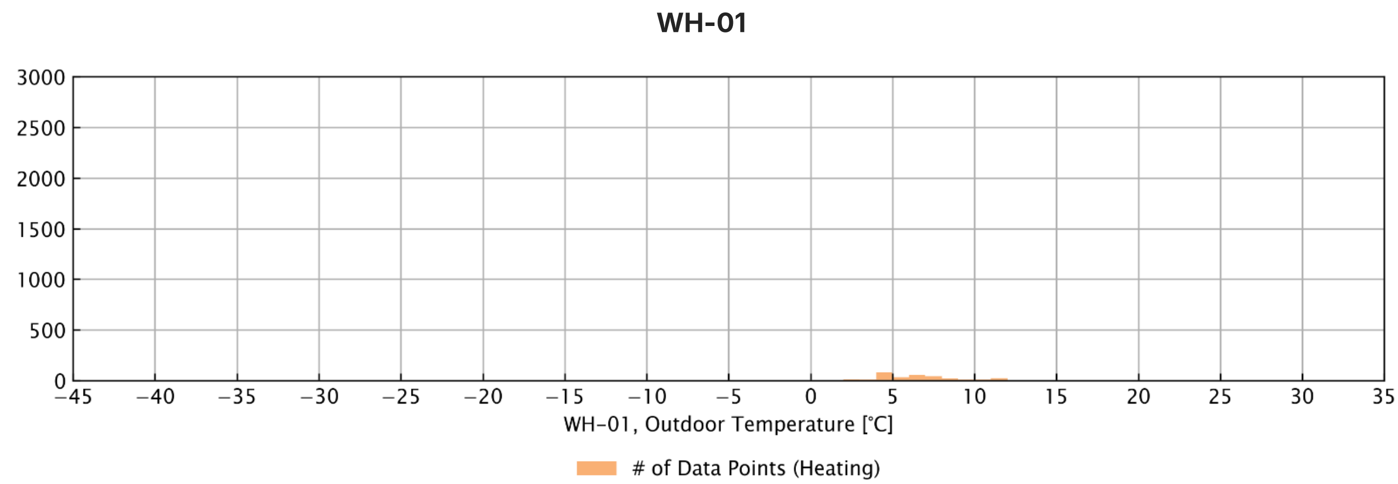
WH-18

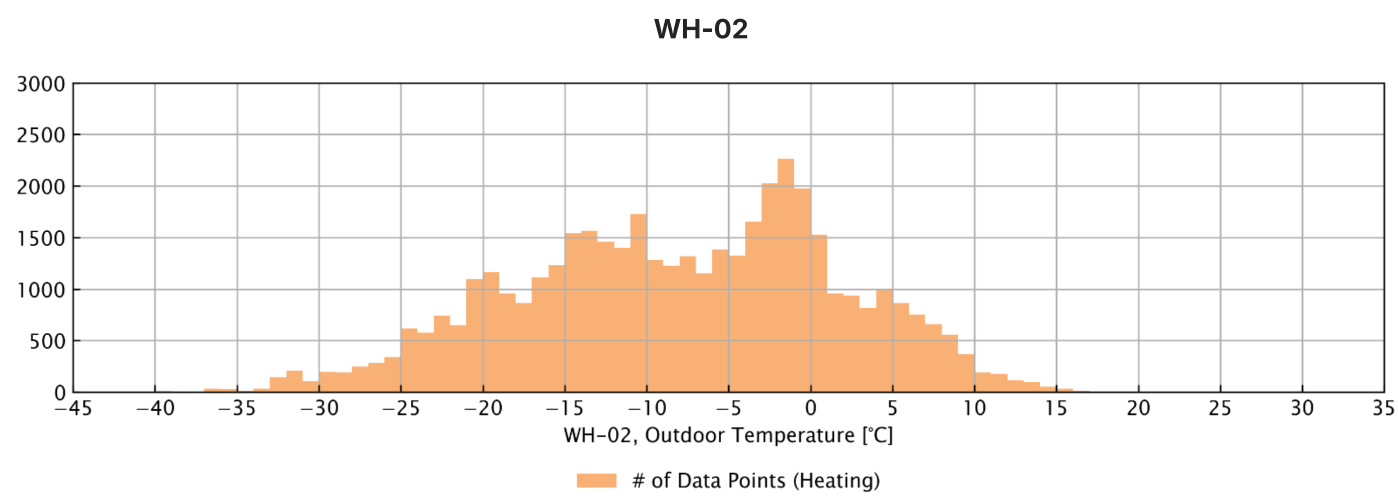


Note: System 200A CT (supplemental) is always reported as zero, which means that output cannot be subtracted from HP output to calculate COP.

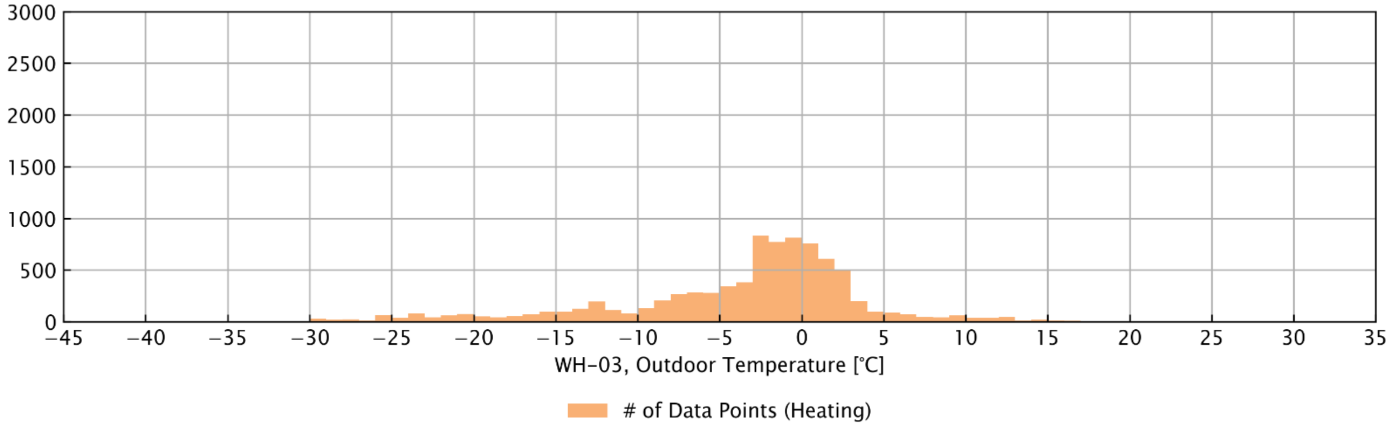
Appendix C - Number of Data Points

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-09 and WH-10).

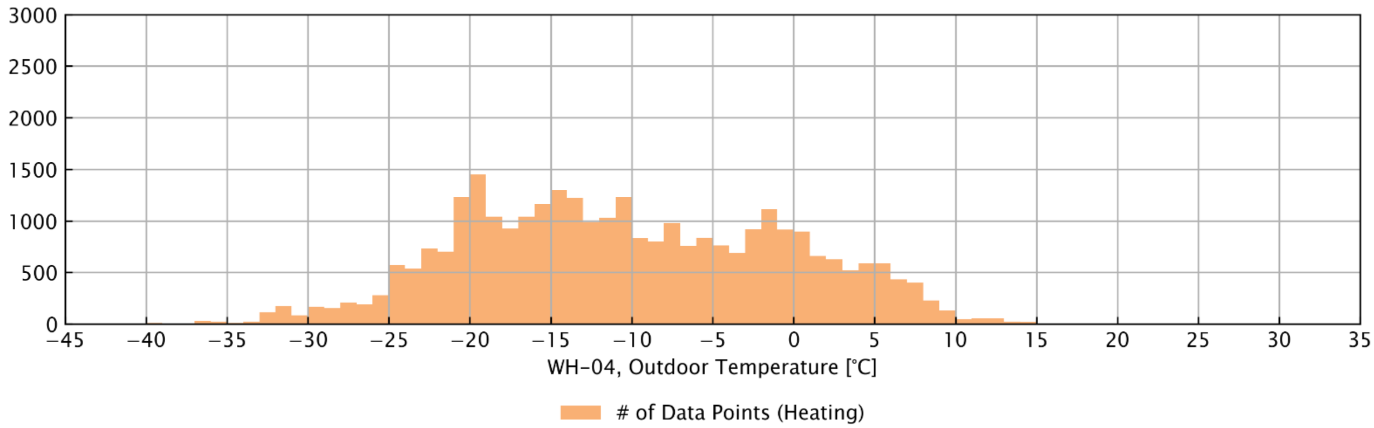




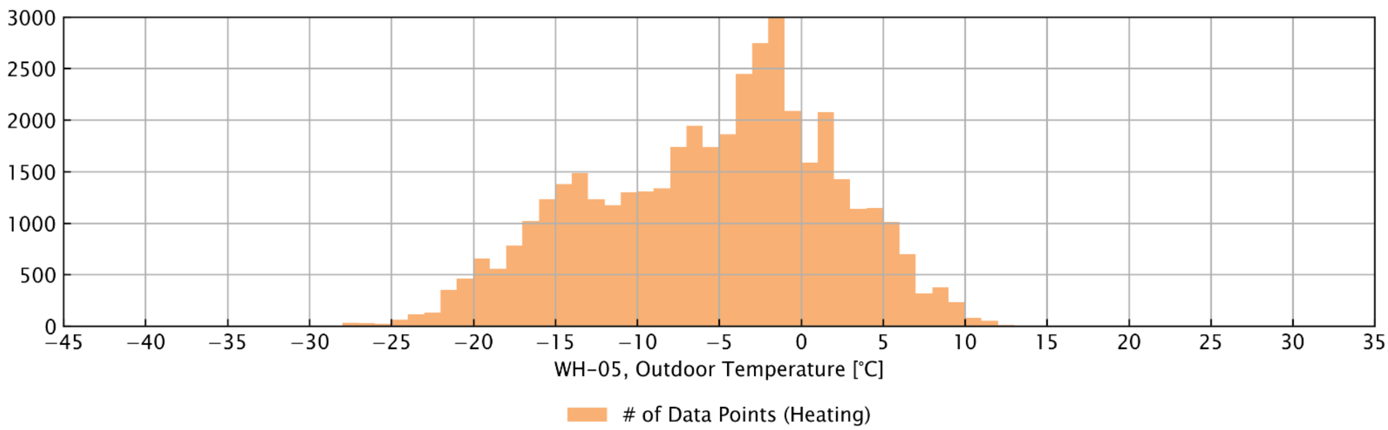
WH-03



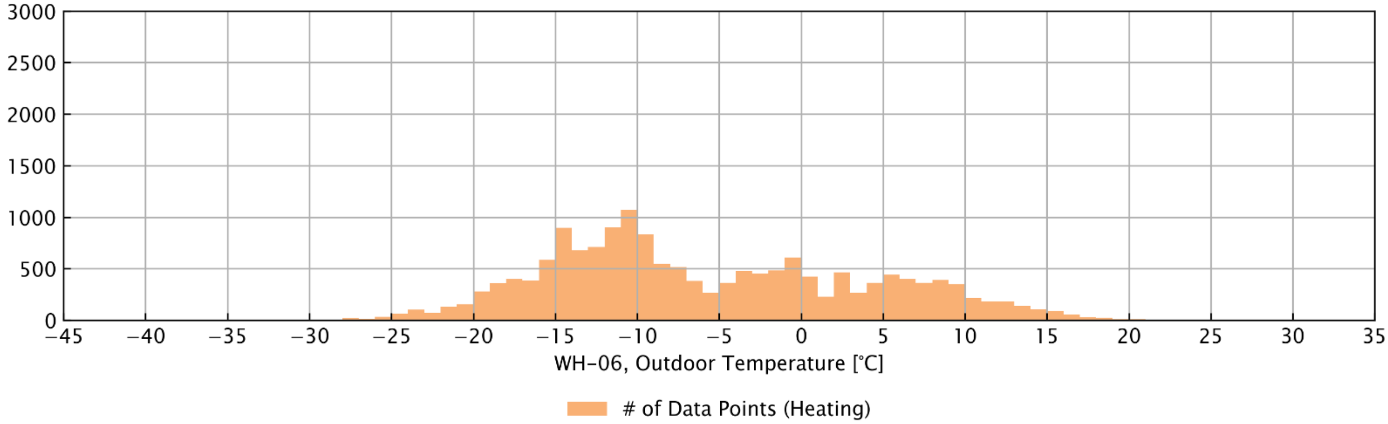
WH-04



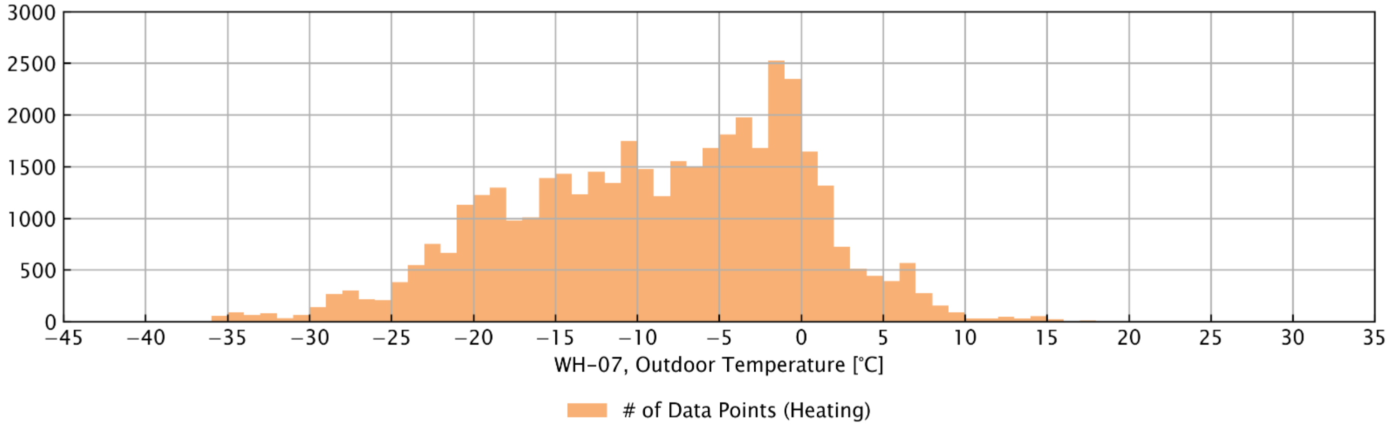
WH-05



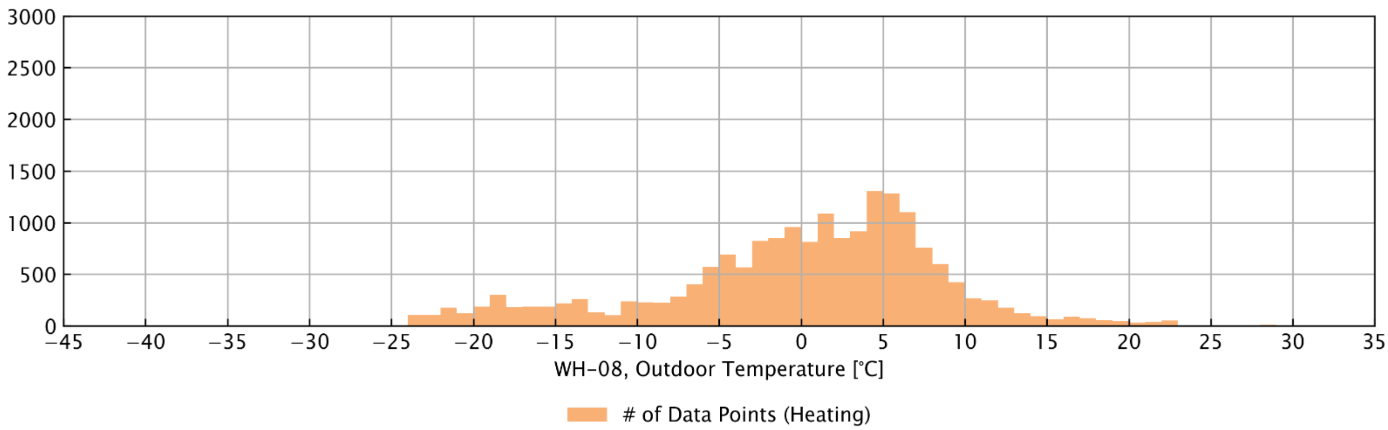
WH-06



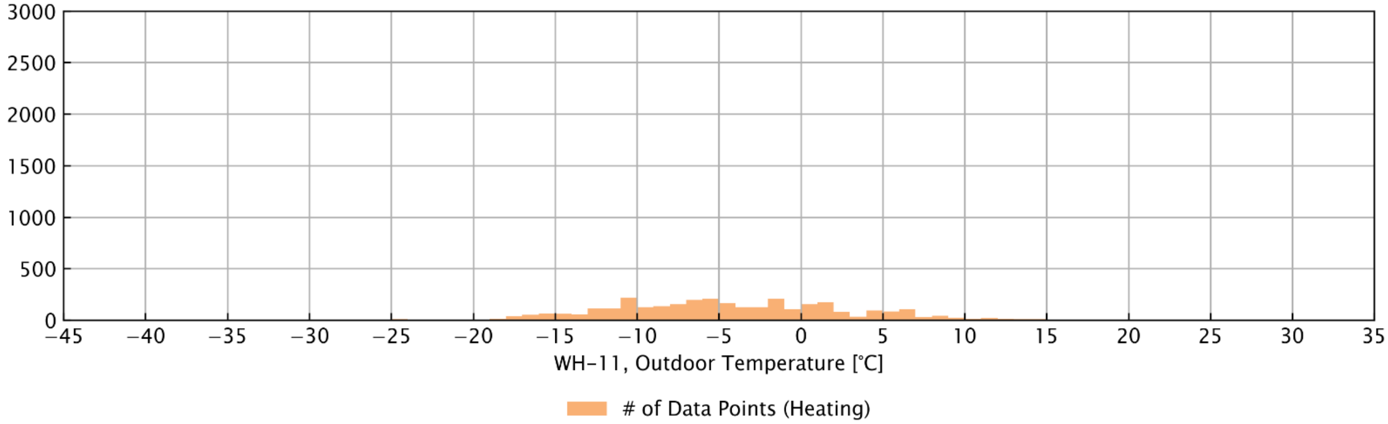
WH-07



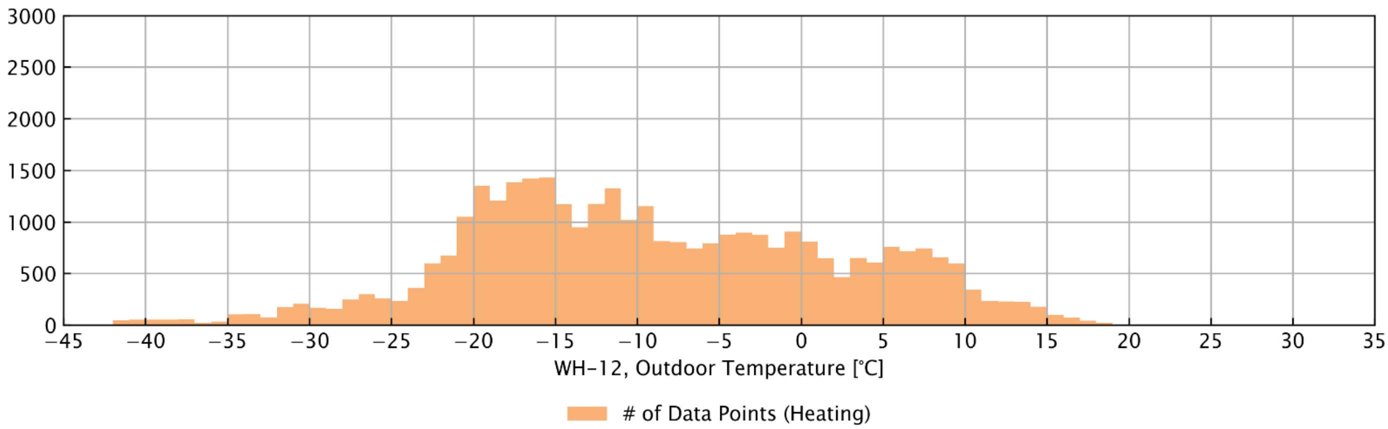
WH-08



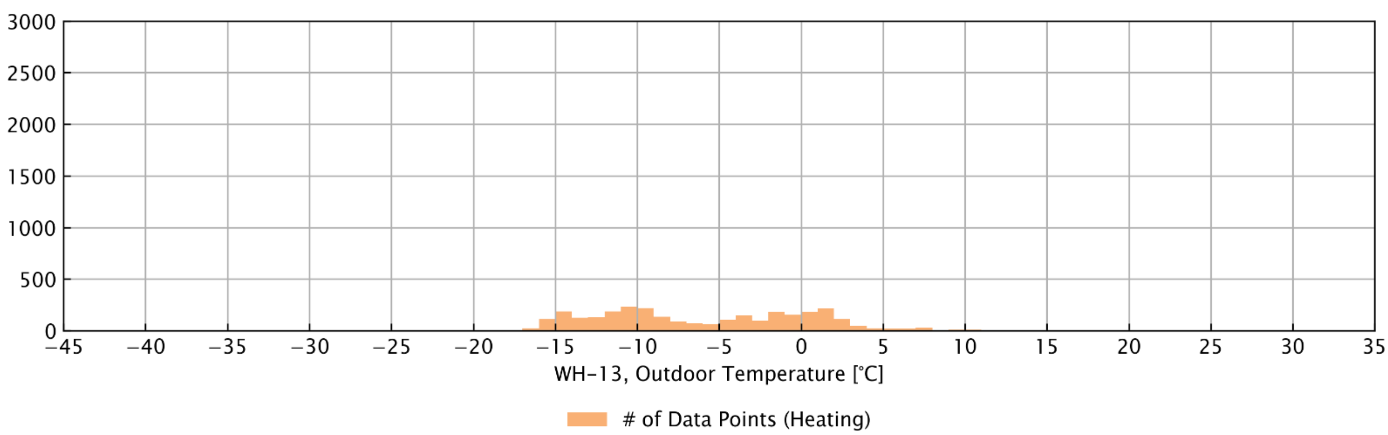
WH-11



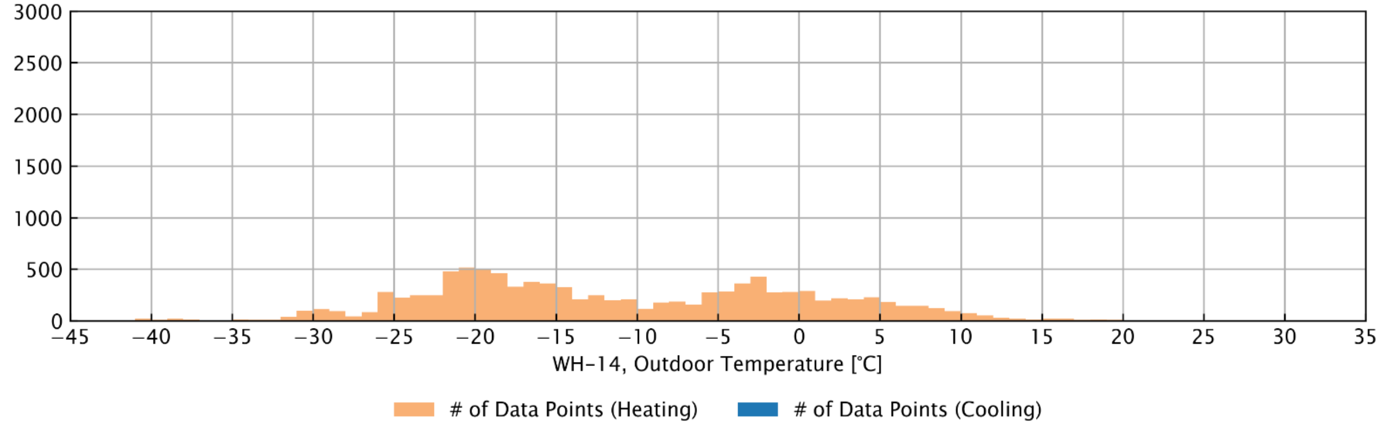
WH-12



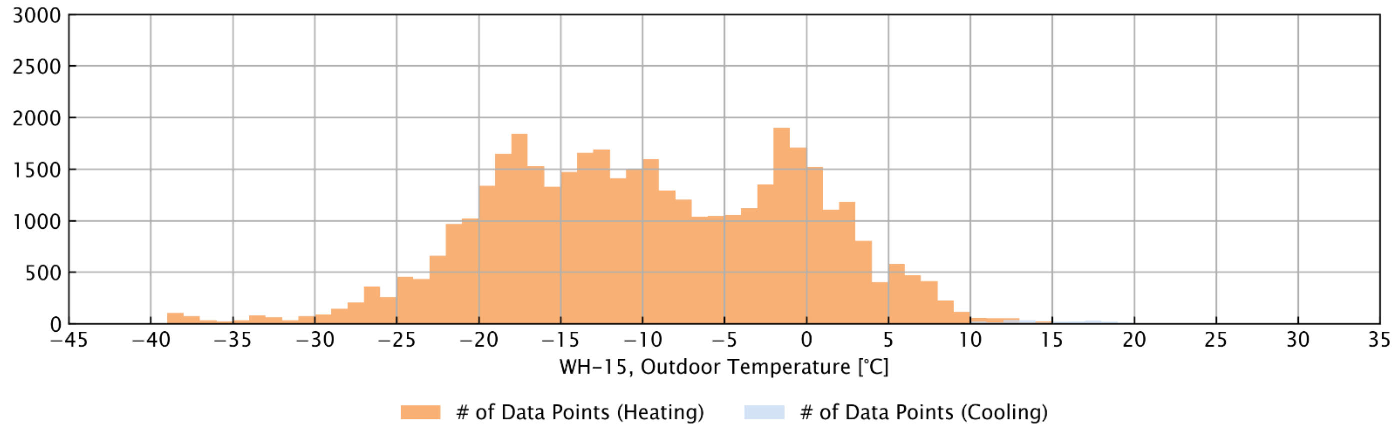
WH-13



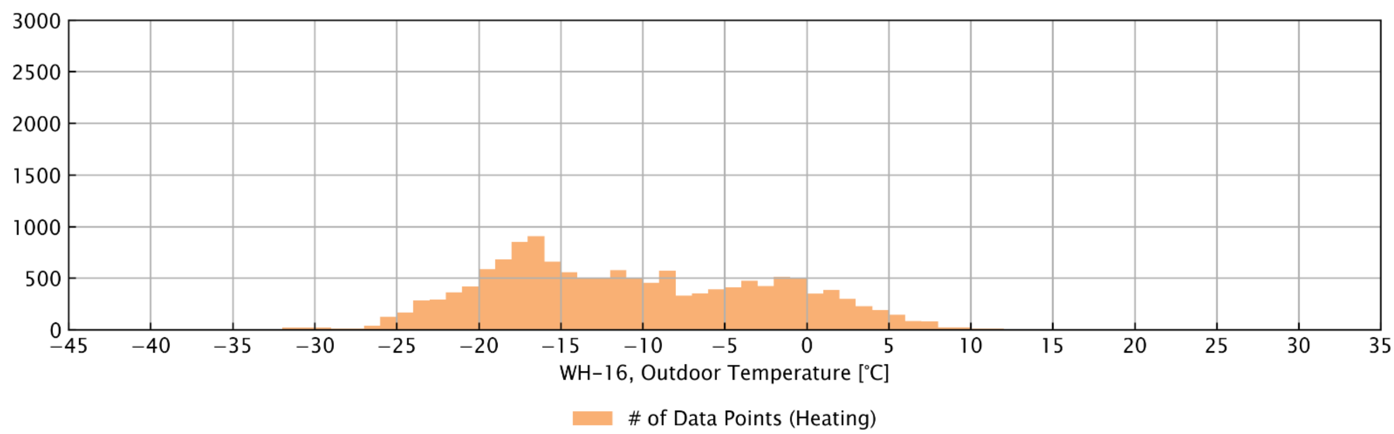
WH-14



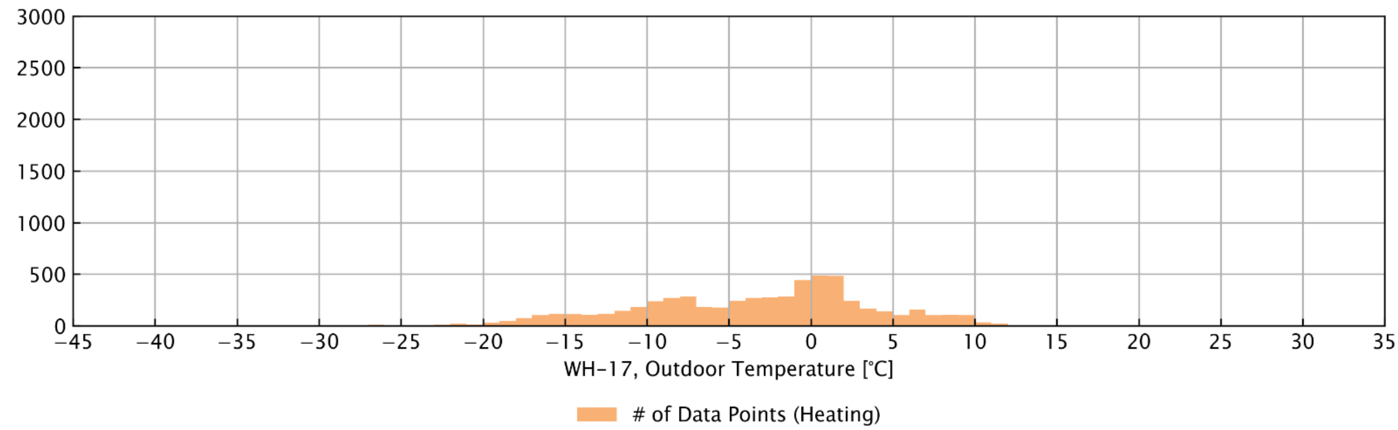
WH-15



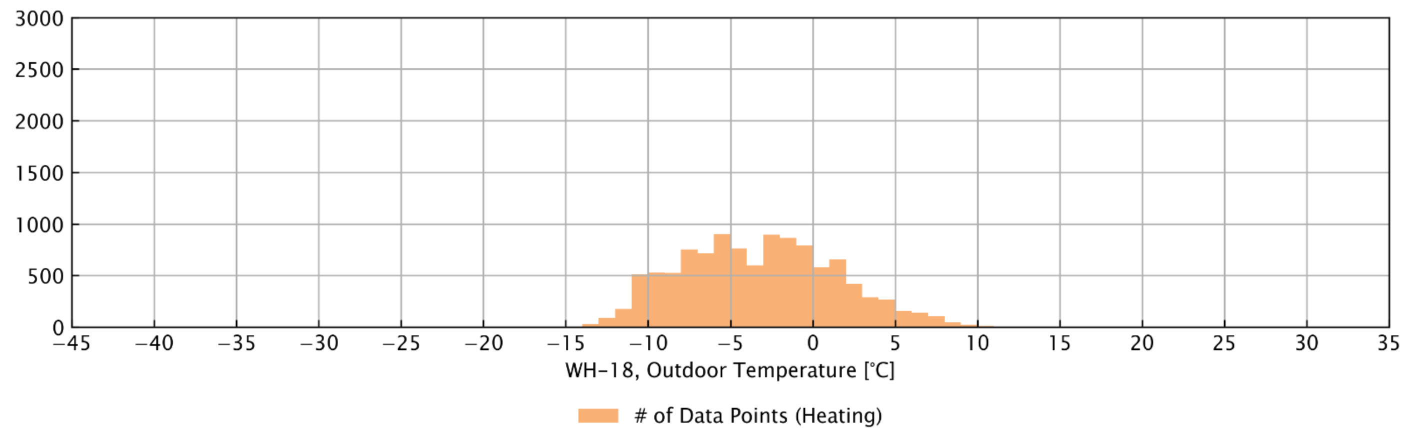
WH-16



WH-17


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−17, Outdoor Temperature [°C]
# of Data Points (Heating)

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.

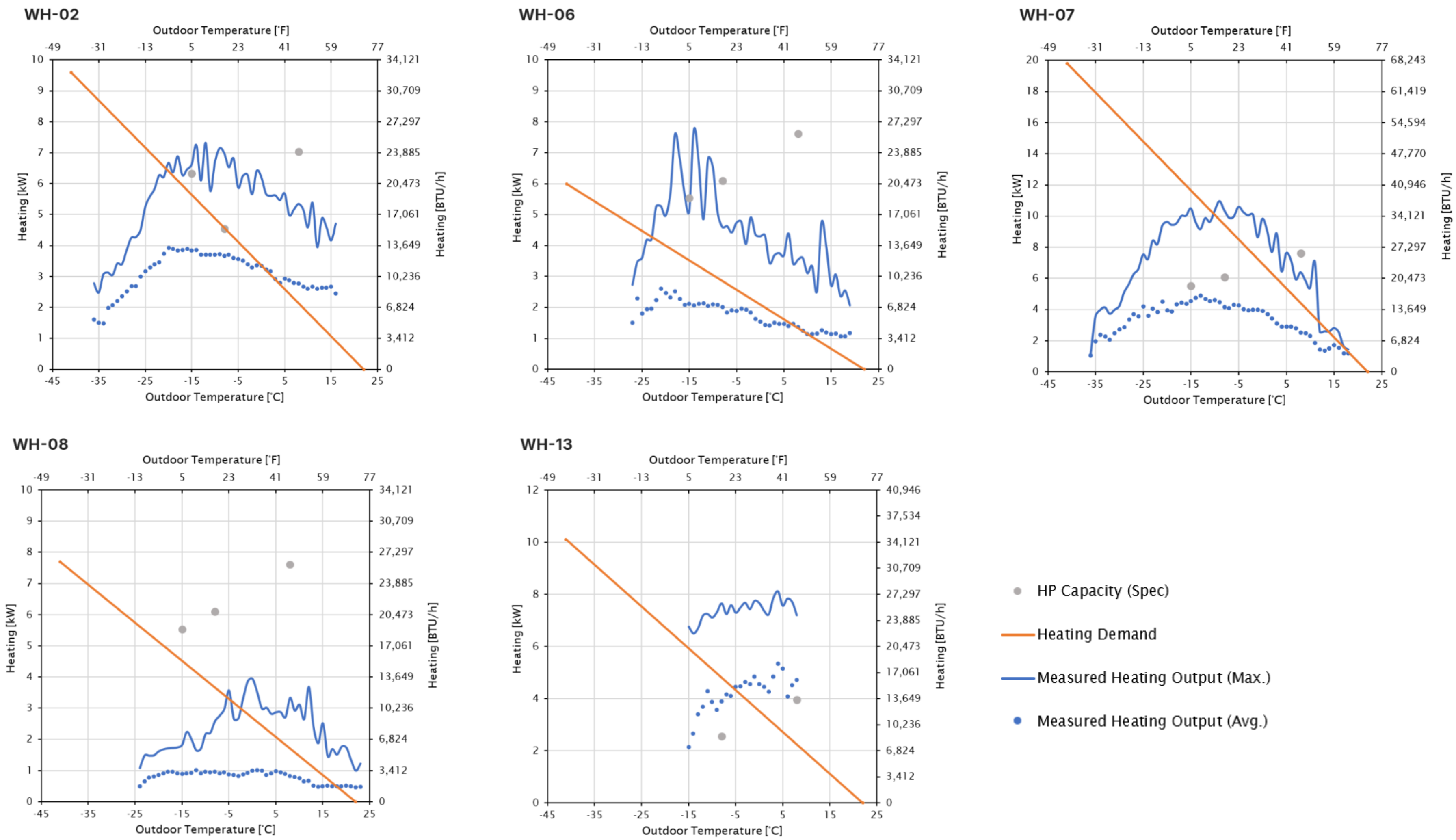


Figure D1. Measured heating outputs (average and maximum) for the ductless heat pump systems and heating demands. CSA F280 calculated heating demands supplied by the Government of Yukon were used. Specified capacity values (grey dots) are from the AHRI Directory of Certified Product Performance.

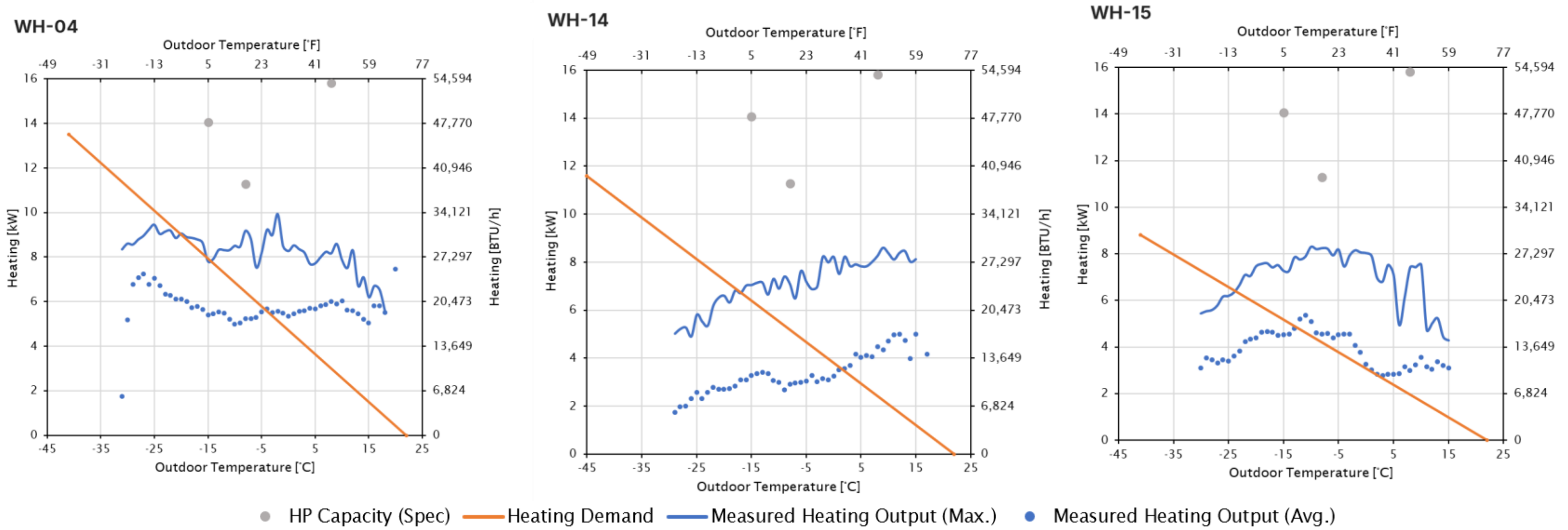


Figure D2. Measured heating outputs (average and maximum) for the central ducted systems and heating demands. CSA F280 calculated heating demands supplied by the Government of Yukon were used. Specified capacity values (grey dots) are from the AHRI Directory of Certified Product Performance.

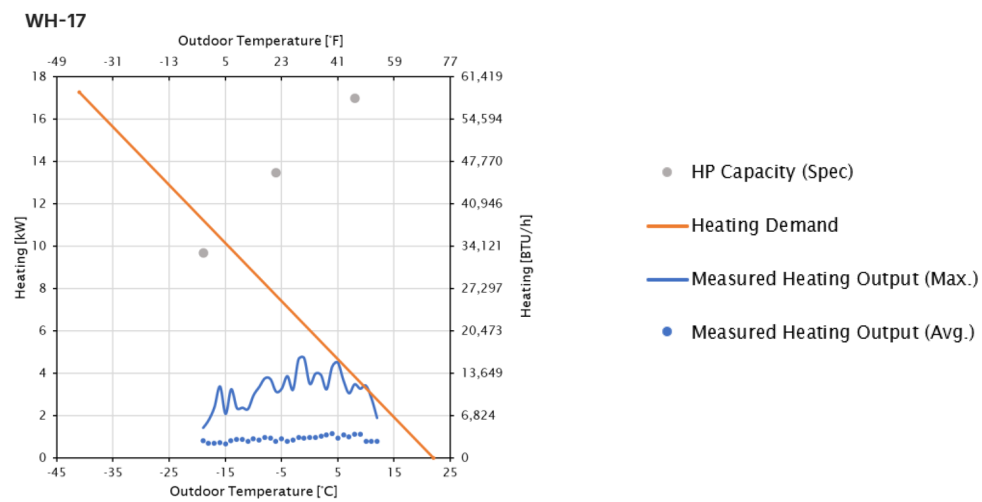
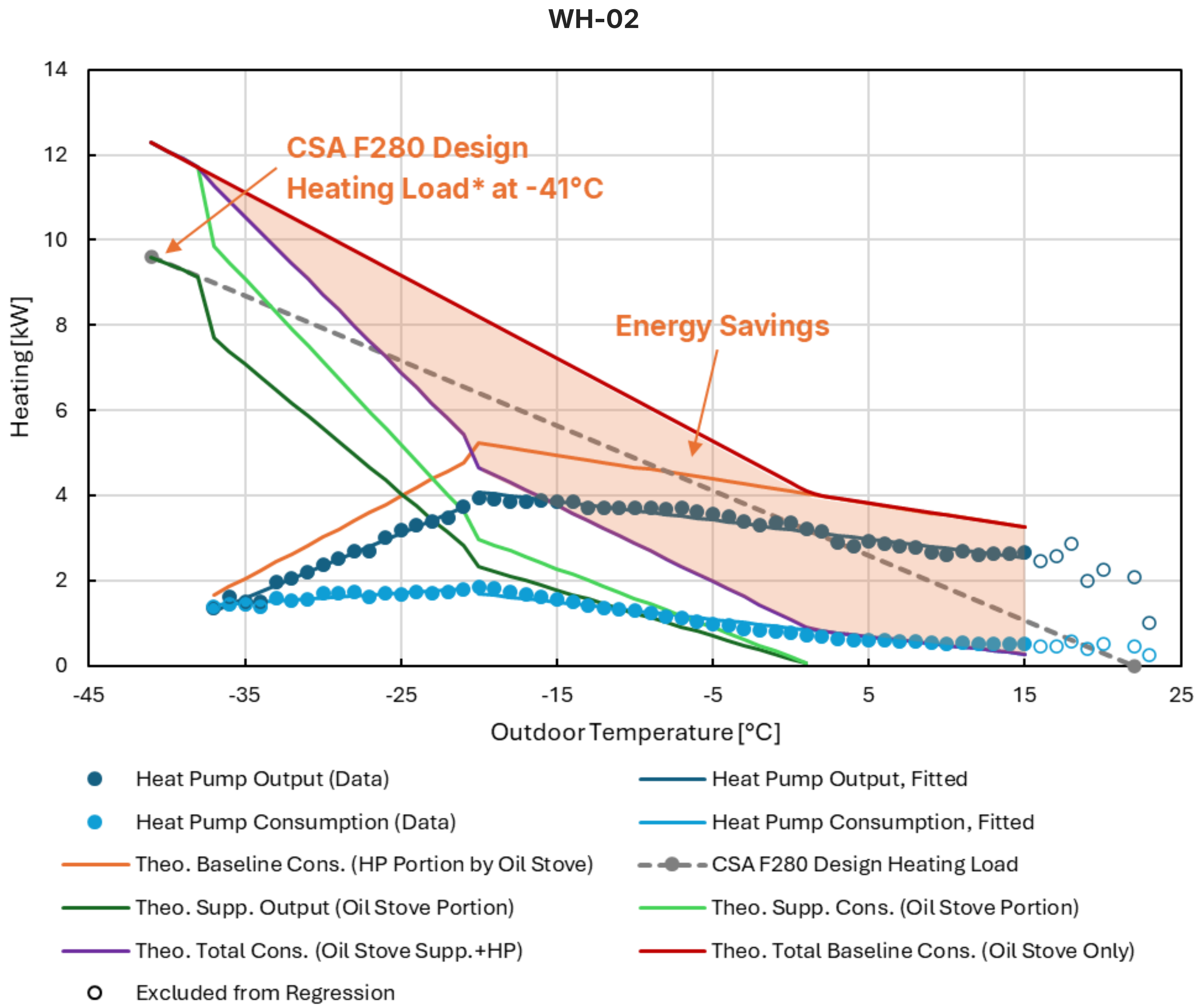


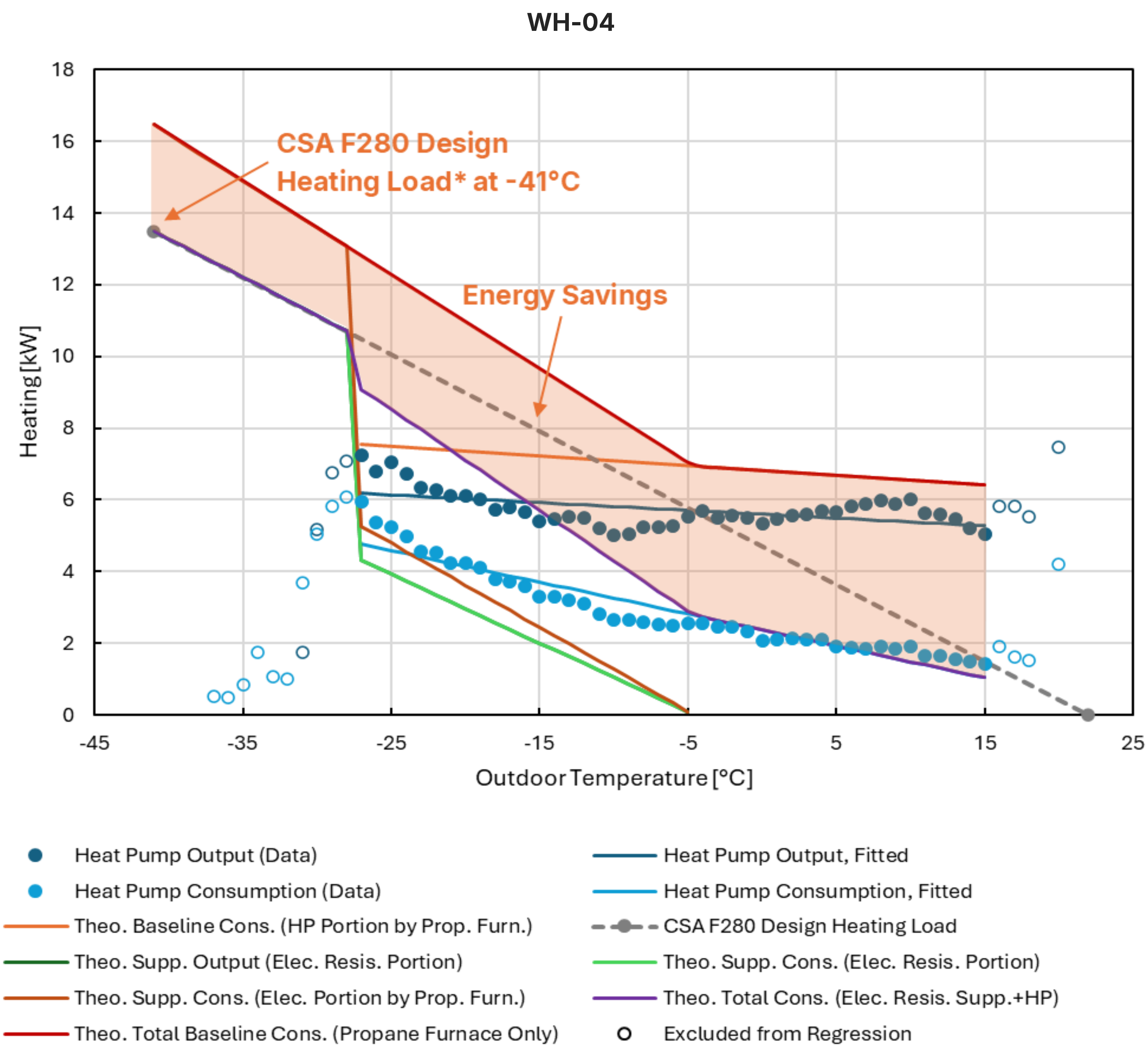
Figure D3. Measured heating outputs (average and maximum) for an air-to-water heat pump system (WH-17) and heating demand. CSA F280 calculated value was not available for this site, but the EnerGuide value is and was thus used instead. Specified capacity values (grey dots) are from the AHRI Directory of Certified Product Performance.

Appendix E - Energy Savings

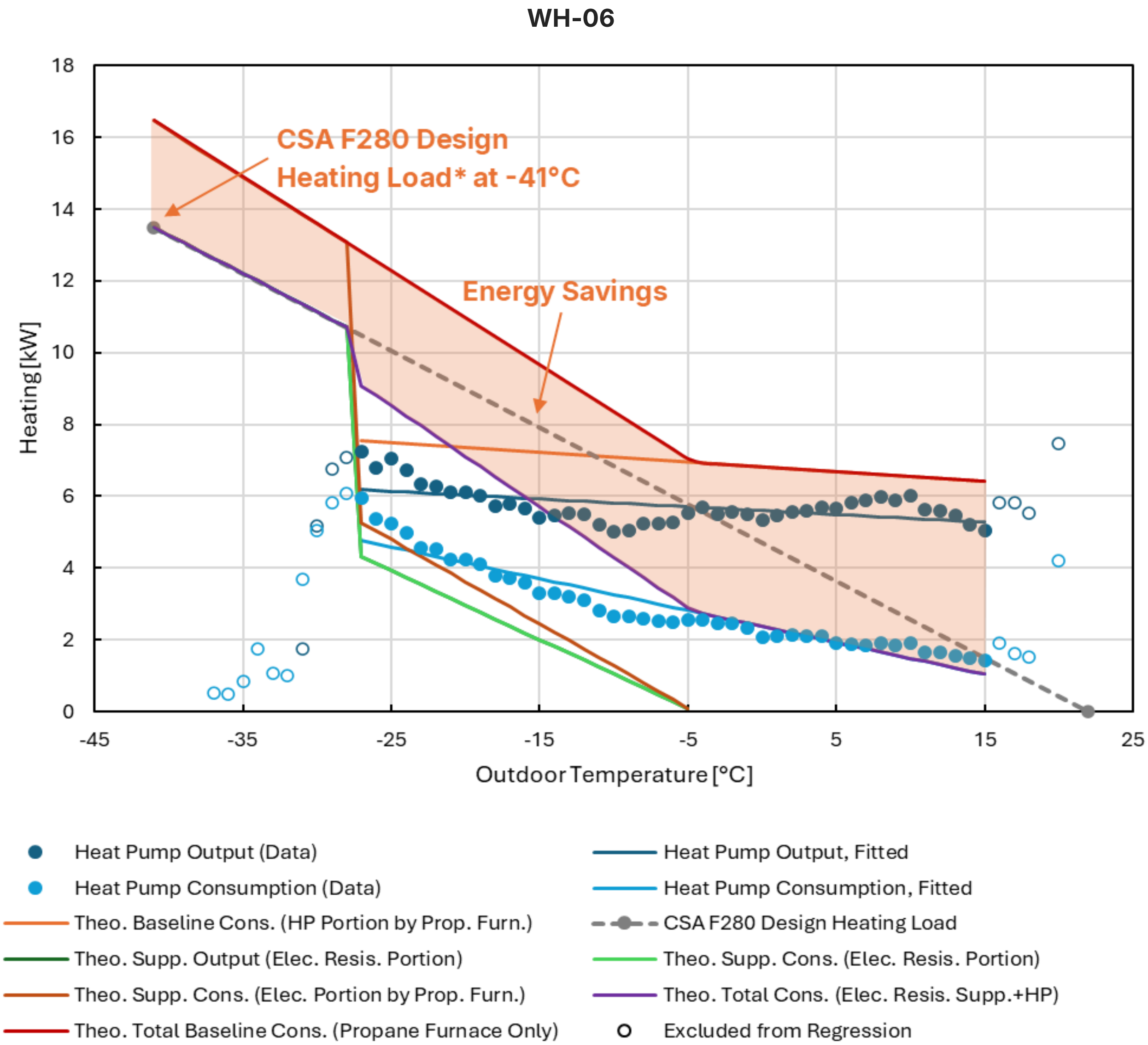
Appendix E details the energy savings estimation for sites WH-01 through WH-18. Note the values in this table assumed supplemental heating to be the CSA F280 heating demand unmet by the heat pump (i.e. difference between heating demand and heat pump output).

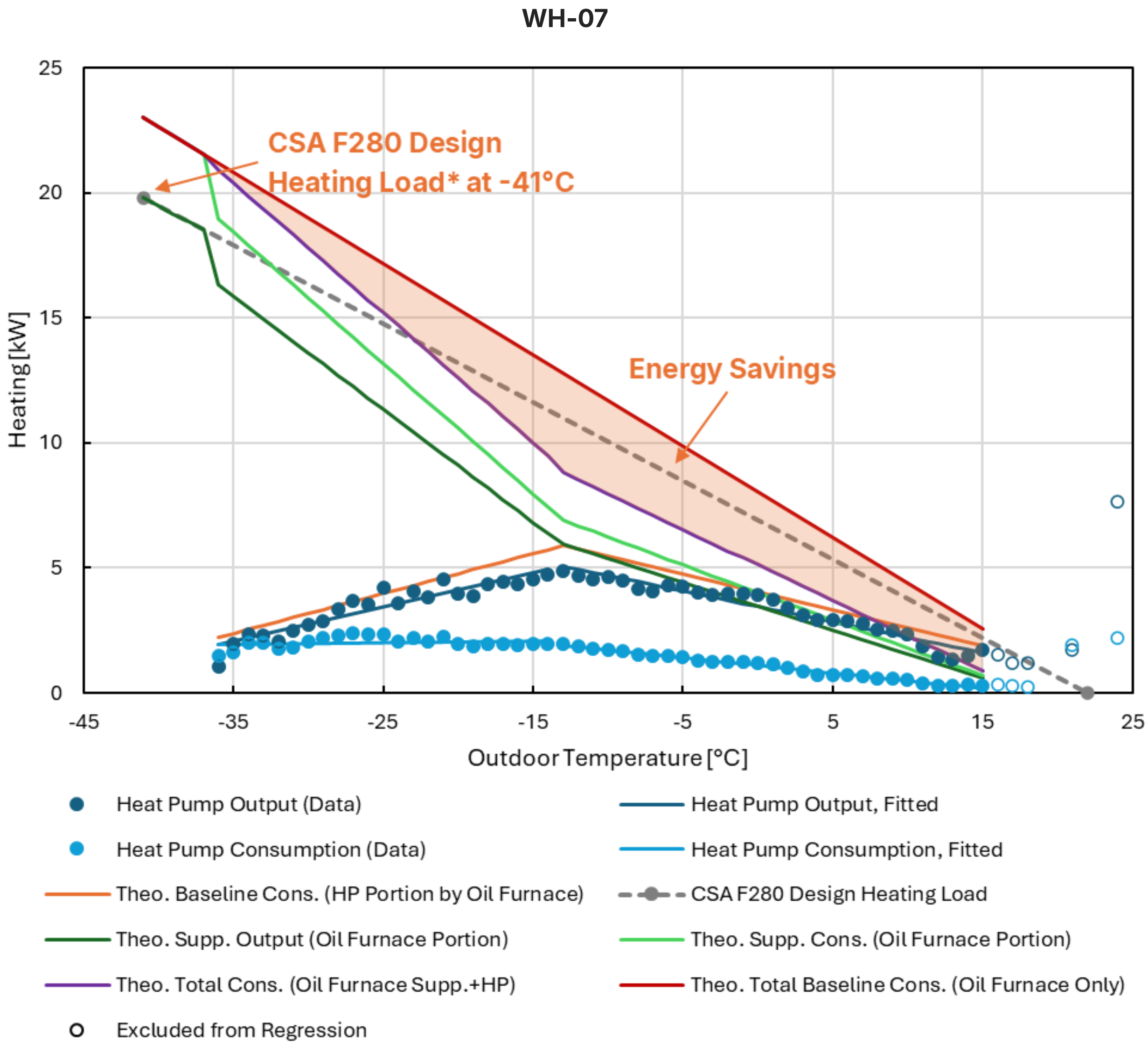
Site ID	Heat Pump System Type	Baseline heating system (i.e. previous heating system)	Energy Consumption [ekWh/year]			Greenhouse Gas Emissions [kgCO2e/year]			Utility Cost [$/year]		
			Pre-Retrofit	Post-Retrofit	Savings (%)	Pre-Retrofit	Post-Retrofit	Savings (%)	Pre-Retrofit	Post-Retrofit	Savings (%)
			Baseline	Heat Pump and/or Supplemental		Baseline	Heat Pump and/or Supplemental		Baseline	Heat Pump and/or Supplemental	
WH-01	Ductless	Oil Furnace	Insufficient data; no CSA F280 heating load								
WH-02	Ductless	Oil Stove	40,097	15,593	24,503 (61%)	10,831	2,767	8,064 (74%)	6,290	3,060	3,230 (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	18,188	10,075	8,113 (45%)	1,273	705	568 (45%)	4,400	2,437	1,963 (45%)
WH-07	Ductless	Oil Furnace	68,237	47,259	20,977 (31%)	18,433	10,995	7,438 (40%)	10,704	8,166	2,538 (24%)
WH-08	Ductless	Propane Furnace	27,831	25,982	1,848 (7%)	6,061	4,858	1,202 (20%)	3,807	4,123	-316 (-8%)
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	45,038	20,766	24,272 (54%)	12,166	3,681	8,486 (70%)	7,065	4,077	2,988 (42%)
WH-16	Ductless	Elec. Baseboard, assumed	43,264	23,107	20,156 (47%)	3,028	1,618	1,411 (47%)	10,465	5,590	4,876 (47%)
Ductless Average			**40,442**	**23,797**	**16,645 (41%)**	**8,632**	**4,104**	**4,528 (49%)**	**7,122**	**4,575**	**2,546 (33%)**
WH-04	Central Ducted	Propane Furnace	61,422	25,765	35,657 (58%)	13,376	1,804	11,572 (87%)	8,401	6,233	2,169 (26%)
WH-14	Central Ducted	Oil Furnace	48,885	38,003	10,882 (22%)	13,205	5,906	7,299 (55%)	7,668	7,814	-146 (-2%)
WH-15	Central Ducted	Elec. Baseboard, assumed	32,243	15,895	16,347 (51%)	2,257	1,113	1,144 (51%)	7,799	3,845	3,954 (51%)
Central Ducted Average			**47,516**	**26,554**	**20,962 (44%)**	**9,613**	**2,941**	**6,672 (64%)**	**7,956**	**5,964**	**996 (25%)**
WH-17	Central Air-to-Water	Elec. Boiler, assumed	52,230	48,099	4,131 (8%)	3,656	3,367	289 (8%)	12,635	11,635	999 (8%)
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 Output, Fitted
Heat Pump Consumption (Data)
Heat Pump Consumption, Fitted
Theo. Baseline Cons. (HP Portion by Oil Stove)
CSA F280 Design Heating Load
Theo. Supp. Output (Oil Stove Portion)
Theo. Supp. Cons. (Oil Stove Portion)
Theo. Total Cons. (Oil Stove Supp.+HP)
Theo. Total Baseline Cons. (Oil Stove Only)
Excluded from Regression



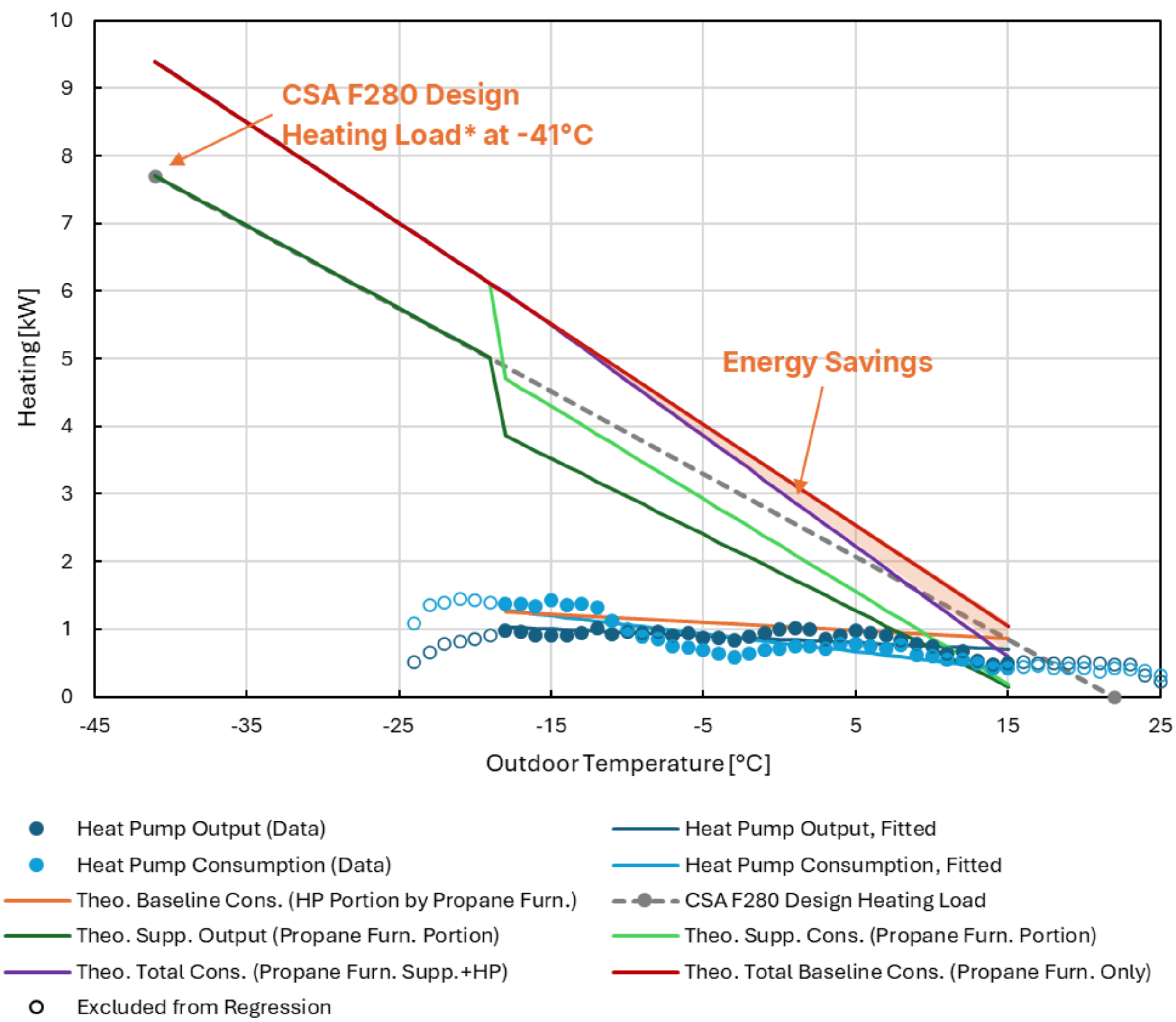
WH-04
CSA F280 Design Heating Load* at -41°C
Energy Savings
Heating [kW]
Outdoor Temperature [°C]
18
16
14
12
10
8
6
4
2
0
-45
-35
-25
-15
-5
5
15
25
Heat Pump Output (Data)
Heat Pump Consumption (Data)
Theo. Baseline Cons. (HP Portion by Prop. Furn.)
Theo. Supp. Output (Elec. Resis. Portion)
Theo. Supp.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

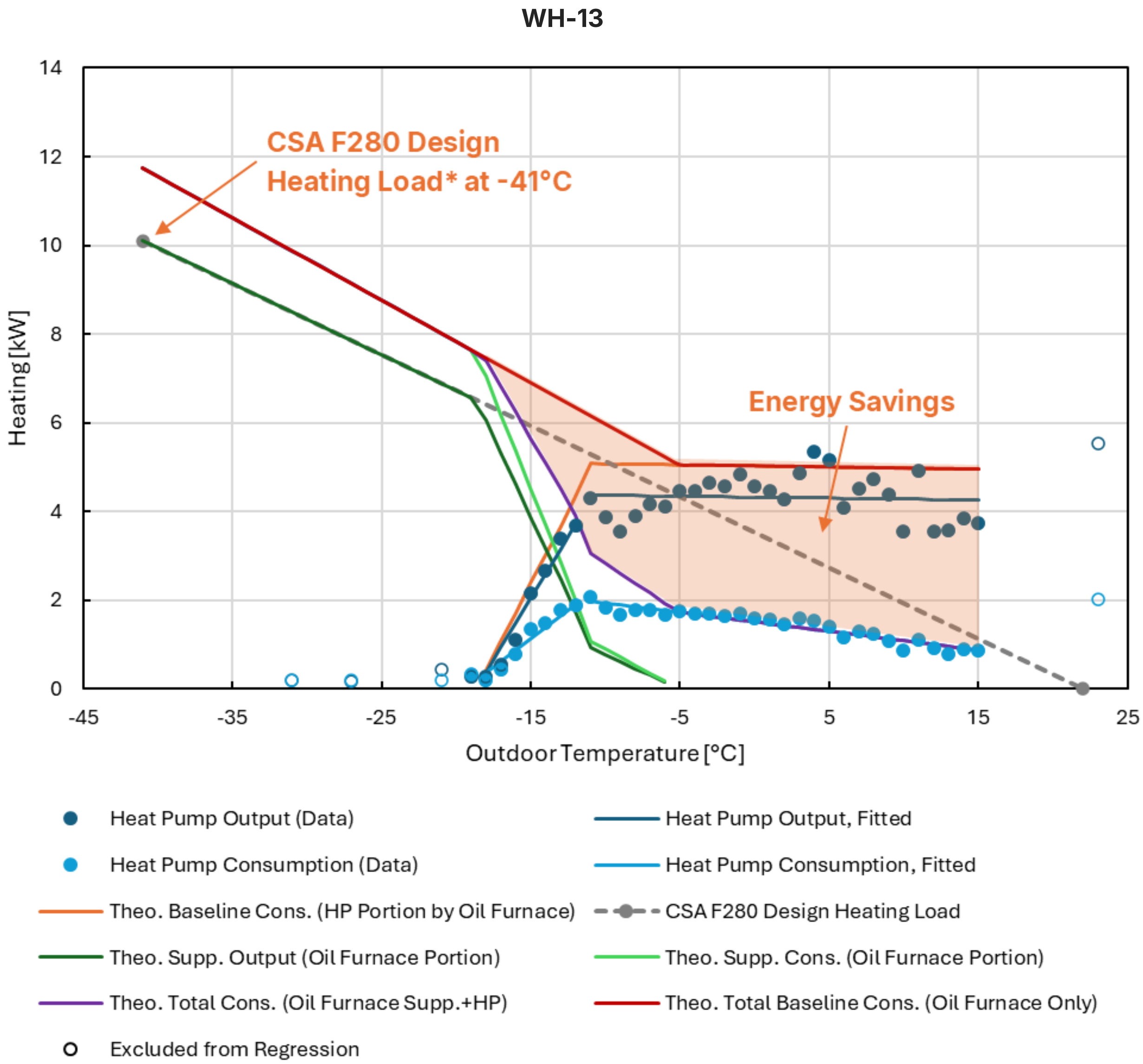


WH-07
CSA F280 Design
Heating Load* at -41°C
Energy Savings
Heating [kW]
Outdoor Temperature [°C]
25
20
15
10
5
0
-45
-35
-25
-15
-5
5
15
25
Heat Pump Output (Data)
Heat Pump Output, Fitted
Heat Pump Consumption (Data)
Heat Pump Consumption, Fitted
Theo. Baseline Cons. (HP Portion by Oil Furnace)
CSA 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-08

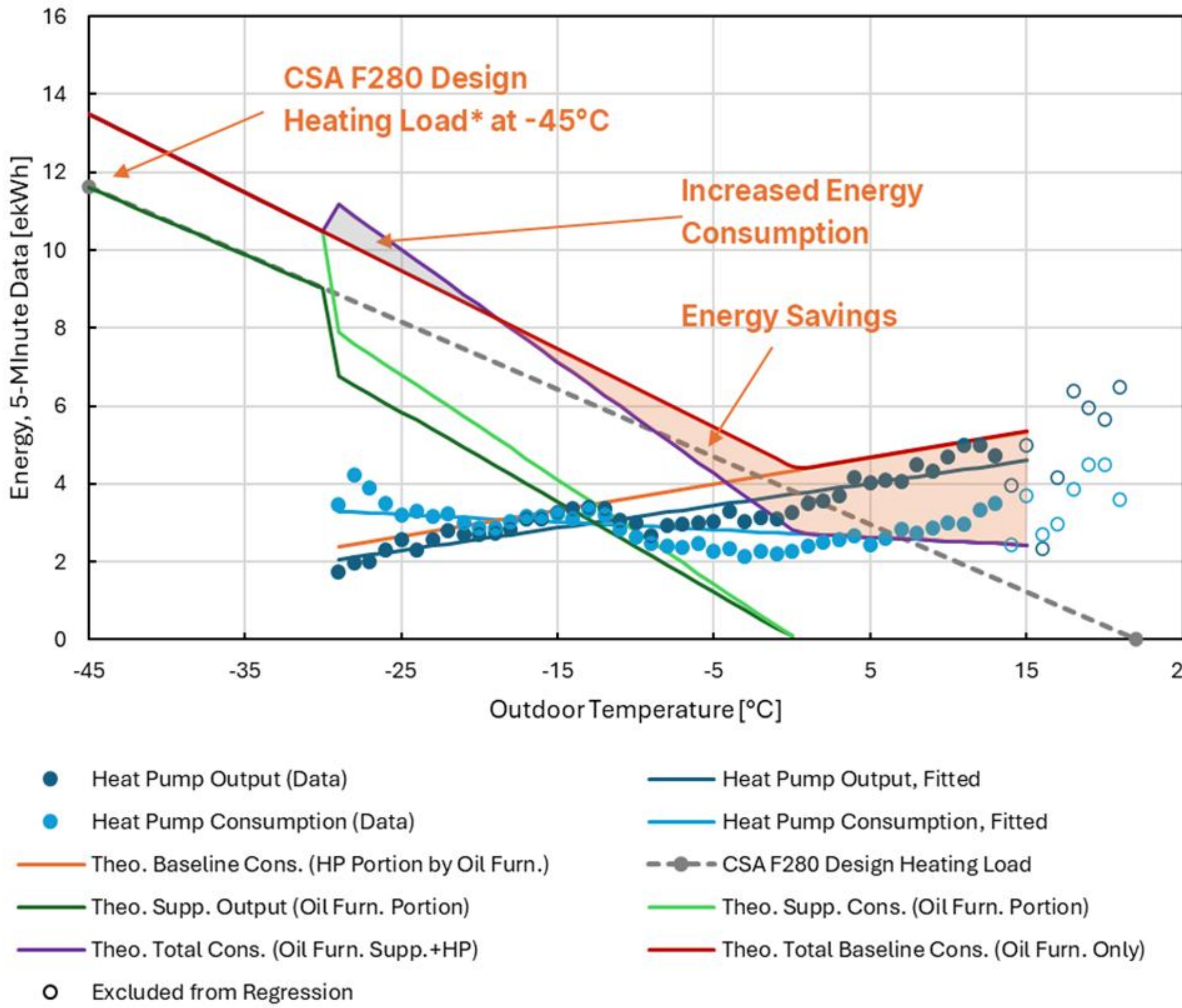


10
9
8
7
6
5
4
3
2
1
0
Heating [kW]
-45
-35
-25
-15
-5
5
15
25
Outdoor Temperature [°C]
CSA F280 Design Heating Load* at -41°C
Energy Savings
Heat Pump Output (Data)
Heat Pump Consumption (Data)
Theo. Baseline Cons. (HP Portion by Propane Furn.)
Theo. Supp. Output (Propane Furn. Portion)
Theo. Total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



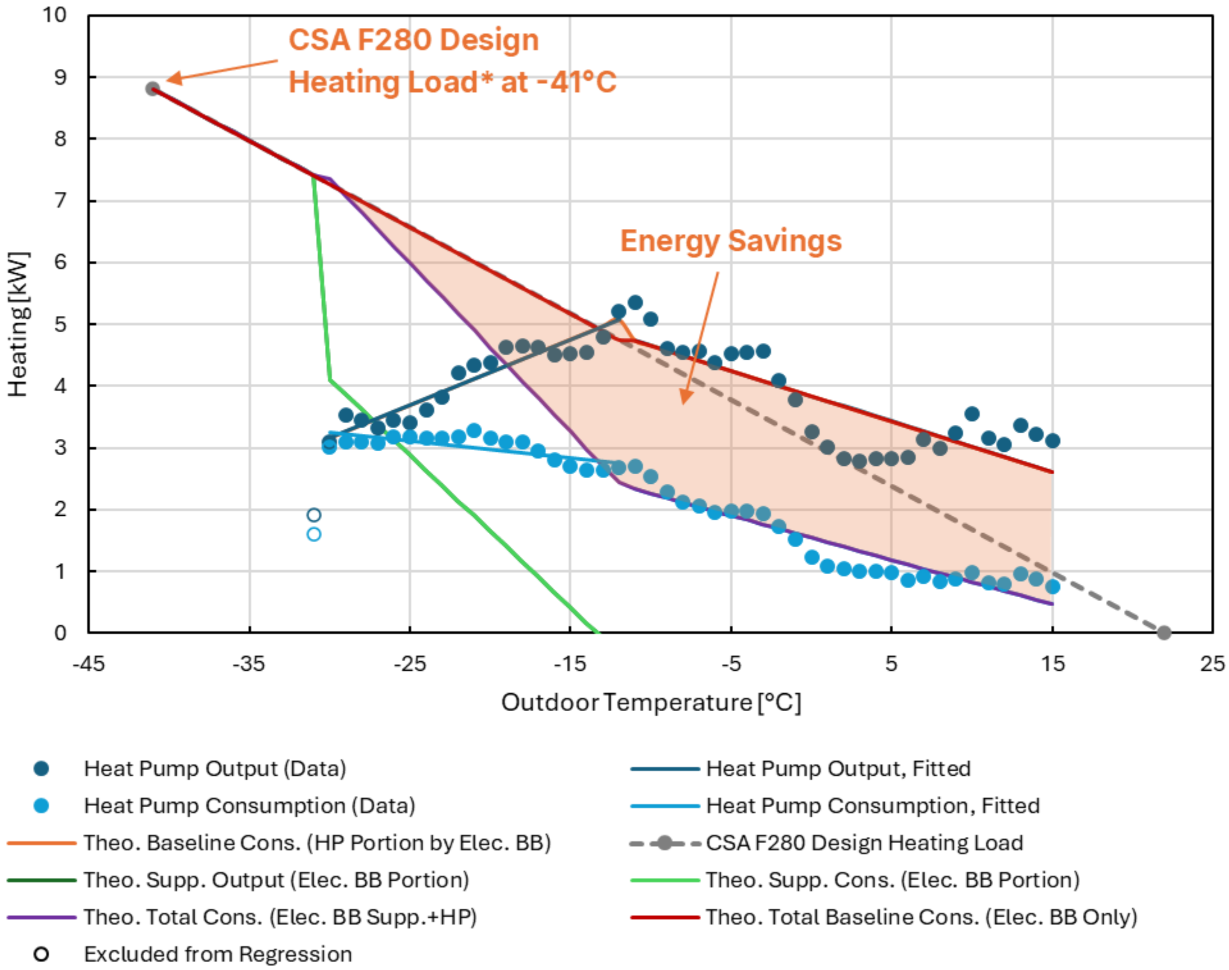
WH-13
CSA F280 Design Heating Load* at -41°C
Energy Savings
Heating [kW]
Outdoor Temperature [°C]
14
12
10
8
6
4
2
0
-45
-35
-25
-15
-5
5
15
25
Heat Pump Output (Data)
Heat Pump Output, Fitted
Heat Pump Consumption (Data)
Heat Pump Consumption, Fitted
Theo. Baseline Cons. (HP Portion by Oil Furnace)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

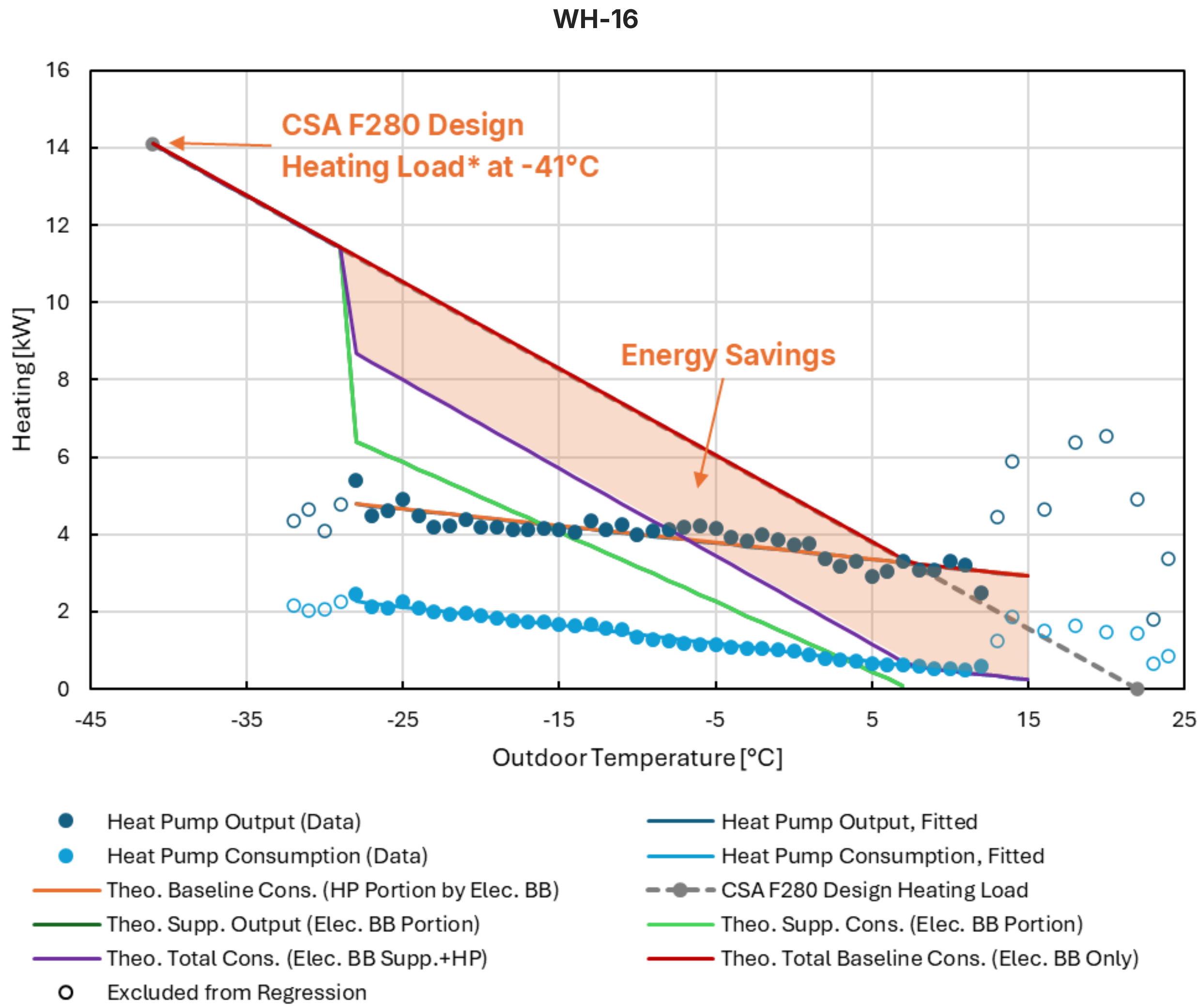


CSA F280 Design Heating Load* at -45°C
Increased Energy Consumption
Energy Savings
Energy, 5-MInute Data [ekWh]
Outdoor Temperature [°C]
16
14
12
10
8
6
4
2
0
-45
-35
-25
-15
-5
5
15
25
Heat Pump Output (Data)
Heat Pump Output, Fitted
Heat Pump Consumption (Data)
Heat Pump Consumption, Fitted
Theo. Baseline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

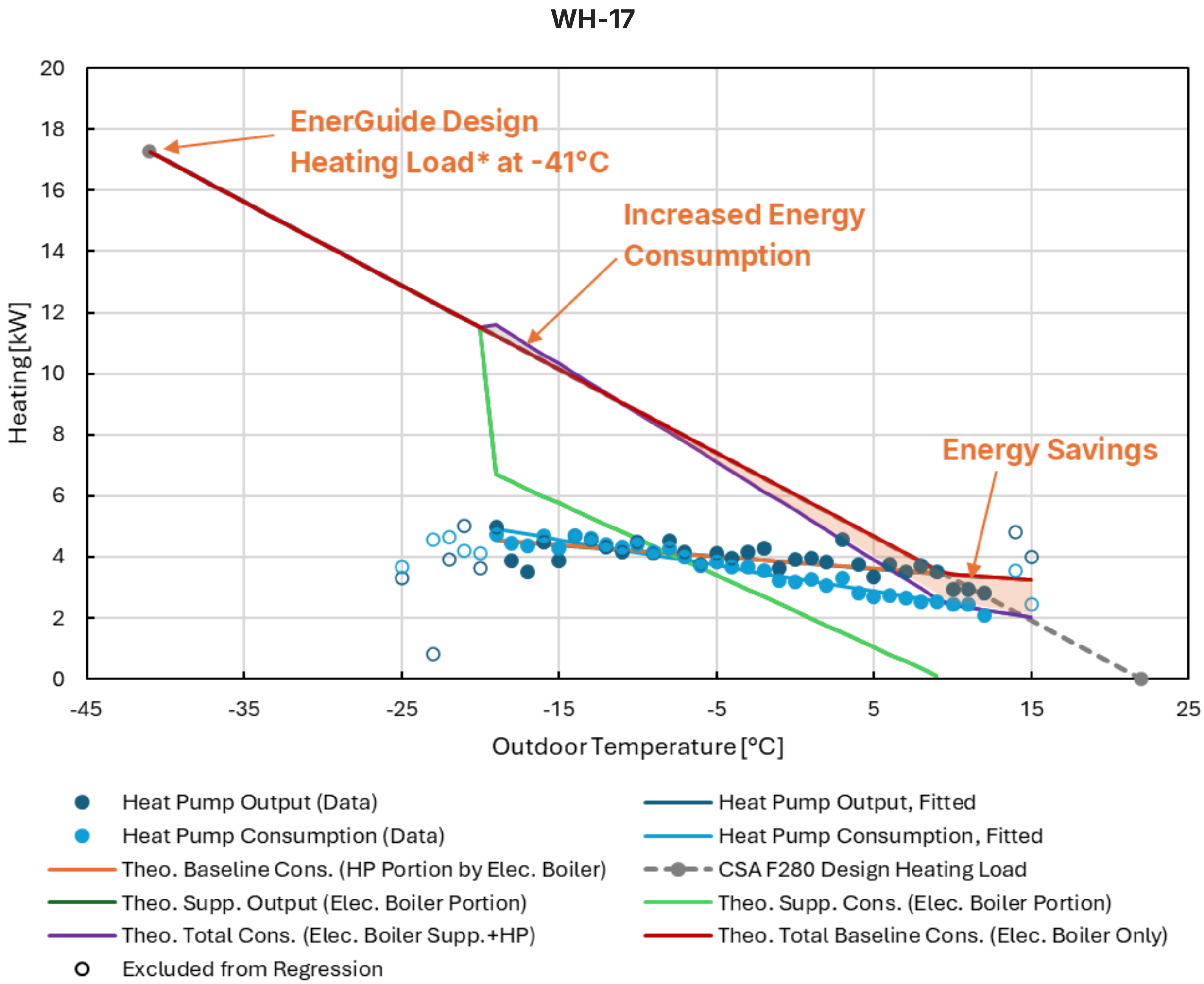
WH-15



CSA F280 Design Heating Load* at -41°C
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]
16
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 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)