



High-Performance High-Capacity Heat Pump Field Study Report

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High-Performance High-Capacity Heat Pump Field Study Report

Prepared for

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The following report was funded by the Bonneville Power Administration (BPA) to assess emerging technology topics that have the potential to increase energy conservation. BPA is committed to identify, assess, and develop emerging technologies with significant potential for contributing to efficient use of electric power resources in the Northwest.

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List of Acronyms

ACCA	Air Conditioning Contractors of America
AHRI	Air-conditioning, Heating, and Refrigeration Institute
BPA	Bonneville Power Administration
BTU/h	British Thermal Unit per Hour
ccASHP	Cold Climate Air Source Heat Pump
ccDHP	Cold Climate Ductless Heat Pump
CEC	Central Electric Coop
CFM	Cubic Feet per Minute
COL	Colville Tribal Housing
COP	Coefficient of Performance
DOE	Department of Energy
EER	Energy Efficiency Ratio
ER	Electric Resistance
GEC	Glacier Electric Cooperative
HDD	Heating Degree Day
HEMS	Home Energy Use Metering Study
HP	Heat Pump
HPHC	High-Performance, High-Capacity
HPHCHP	High-Performance, High-Capacity Heat Pump
HSPF	Heating Seasonal Performance Factor
HVAC	Heating, Ventilation, and Air Conditioning
HVACST	HVAC Sizing Tool
HZ1	Heating Zone 1
HZ2	Heating Zone 2
HZ3	Heating Zone 3
INL	Inland Power and Light
kWh/yr	Kilowatt Hours per Year
NEEP	Northeast Energy Efficiency Partnership
NEEA	Northwest Energy Efficiency Alliance
NPCC	Northwest Power and Conservation Council
ODB	Outdoor Dry Bulb
OLS	Ordinary Least Squares
PLU	City of Plummer
PV	Photovoltaic
QPL	Qualified Product List
RTD	Resistance Temperature Detector
RTF	Regional Technical Forum
SEER	Seasonal Energy Efficiency Ratio
SNO	Snohomish PUD
TAC	Tacoma Power
TMY	Typical Meteorological Year
VSHP	Variable Speed Heat Pump
WSU	Washington State University
YAK	Yakama Power



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1.0 Executive Summary

The High-Performance High-Capacity Heat Pump Field Study tested new, high efficiency heat pumps to determine both energy and peak demand reduction benefits. Recent heat pump (HP) advances (including both increased heating capacity at low outdoor temperatures and variable speed/variable capacity controls) can greatly reduce, if not eliminate, auxiliary electric resistance (ER) heating. These advances will unleash a new era of energy abundance by strengthening grid reliability and addressing the cost-of-living crisis by reducing consumer utility bills.

Four research objectives guided the study:

- **Energy savings:** Quantify the annual energy savings of High-Performance high-capacity heat pumps (HPHC HPs) compared to standard air-source HPs.
- **Peak demand reduction:** Assess the ability of HPHC HPs to reduce utility peak demand during winter and summer critical hours.
- **Measurement and Verification:** Validate that manufacturer-reported performance parameters—e.g., from the Northeast Energy Efficiency Partnership (NEEP) database—correlate with observed in-field results.
- **Performance Correlation:** Determine the set of operational metrics (such as thermostat settings, system sizing, and auxiliary heating) that influence performance and potential savings.

HPHC HPs include products that operate efficiently and with sufficient capacity in (1) high heating load and low outdoor temperatures; (2) low heating load and mild

outdoor temperature; and (3) high cooling load and high outdoor temperature.

The study evaluated both centrally ducted and multizone systems installed either prior to or as part of this study. Homes selected for participation had high ER baseline heat loads and often no existing cooling equipment. Bonneville Power Administration (BPA) engineers, with support from hired consultants, metered the energy use from Spring 2022 through Spring 2025 and calculated the heating load for each site. In Heating Zone 1 (HZ1), BPA set a balance point target of 20°F or lower to test whether ER heat could be eliminated. This same target was maintained in Heating Zones 2 (HZ2) and 3 (HZ3) because, although design temperatures drop below 20°F, sizing to the design load could result in impractically large and uneconomical heat pumps. In total, this study monitored equipment in 57 homes, covering 34 unique systems from 7 manufacturers, comprising 22 product lines. The equipment ranged in nominal size from 2-5 tons.

The HPHC HP field study investigated some of the most promising equipment on the market. Energy savings were strongly proportional to baseline heating energy use. Sites that used more heat before the HPHC HP installation showed greater energy savings. On average, the HPHC HPs saved 30-50% energy over the ER baseline, operating with seasonal COPs (coefficient of performance) of 2 or greater. Combined with adequate sizing, the HPHC HPs allow ER heat to be eliminated in HZ1 and greatly reduced in HZ2. In HZ1, the HPHC HPs sized to a 20°F balance point completely met the building design heating loads. In HZ2, analysis showed that at outdoor temperatures of 5-10°F the HPHC HPs – sized to the 20°F balance point or lower – can offset substantial ER heat.



The HPHC HPs delivered the claimed cold-weather heating performance. The data showed the systems provided the expected heating output in cold conditions (capacity at 17°F) generally at, or near, the expected system efficiencies. Irrespective of whether the HPHC HP was a Study-Install or Prior-Install, under sizing of the units was not a problem. The equipment's capacity performance curve, or capacity, was a good indicator of performance.

The study found that Heating Seasonal Performance Factor 2 (HSPF2) was not a reliable indicator of either energy savings or efficiency. Instead, the listed COP at maximum capacity at 17°F outdoor temperature and, surprisingly, Energy Efficiency Ratio 2 (EER2) were found to be the most predictive of heating use. On centrally ducted systems, nighttime thermostat setbacks reduced system performance and increased peak demand. HPHC HPs successfully reduced both morning and evening grid peaks. Performance of these new HPs offers a path to eliminating costly and inefficient ERI. Overall, energy and demand savings unleash a new era of energy abundance by strengthening the grid and reducing the consumer utility bills.

2.0 Introduction

Bonneville Power Administration (BPA) ensures regional resource adequacy by balancing electricity supply and demand across the Northwest.

2.1 Problem Statement

Shifting generation resources and rising seasonal demand are straining the electrical grid, particularly during winter mornings (6-8 a.m.) and summer evenings (6 – 8 p.m.). HVAC loads represent the largest opportunity, exceeding the savings potential of lighting and water heating combined.

Conventional air-source HPs save energy, but rely heavily on auxiliary ER heating in cold weather – reducing their effectiveness during grid-critical times. Recent advances in HPHC HP technology offer the potential to reduce or eliminate ER heating. These advances include extended heating capacity at low outdoor temperatures and variable-speed/variable-capacity controls. This technology provides opportunities to both strengthen grid reliability and reduce consumer energy costs.

2.2 Purpose and Objectives

This study evaluates the performance of commercially available HPHC HPs in residential installations across the Northwest. The primary objectives align across four key research pillars:

- **Energy Savings:** Quantify annual energy savings.
- **Peak Demand Reduction:** Assess peak demand reduction.
- **Measurement and Verification:** validation of database metrics against in-field data.
- **Performance Correlation:** identification of the key operational metrics that drive energy conservation.



2.3 Scope of Work

The study was conducted from 2020 to 2025 through a collaborative partnership led by BPA, with Washington State University (WSU) Energy Program and five subcontractors: OTS Energy, Larson Energy Research, Keel Energy, and Ecotope. The study monitored 57 residential sites across all three BPA heating zones, with metered data collected at one-minute intervals to measure energy input and – for centrally ducted systems – thermal output. Both new study installations (Study-Install) and recently installed utility rebate program systems (Prior-Install) were included. Equipment from seven manufacturers, spanning 34 unique systems and 22 product lines, was evaluated.

The study also examined differences between ducted and multizone systems, the role of equipment sizing in reducing ER reliance, and the impacts of thermostat setback strategies on load shape and peak demand. Utility and tribal partners supported recruitment, site selection, and equipment installation.

2.4 Organization of the Report

This report is organized as follows:

Section 1- Executive Summary

Section 2 - Introduction

Section 3 – Background: Provides context on residential HVAC measures, historic performance, and the rationale for pursuing HPHC HPs.

Section 4 – Methodology: Describes site selection, equipment qualification, monitoring methods, and analytical approaches.

Section 5 – Metered Data Collection and Processing: Describes the types of data collected and analyses performed by the research team.

Section 6 & 7 – Findings: Explores findings from data analyses from both an energy consumption and equipment performance perspective.

Section 8 - Peak Load Demand Reduction: Describes the factors that determine peak load reduction, including equipment efficiency and savings.

Section 9 – Site Specific Observations: Describes specific results for particular study sites and provides recommendations for improving performance.

Section 10- Conclusions: Explores findings in the context of grid benefits, efficiency gains, equipment performance, and sizing, with additional conclusions around thermostat setbacks.

3.0 Background

This section provides an overview of the context for this work: recent history of heat pump programs in the region, discussion of the research team’s hypothesis regarding HPHC HPs, and the research questions and objectives addressed in this report.

3.1 Historic Energy Savings

Over the past 15+ years, the Regional Technical Forum (RTF) of the Northwest Power and Conservation Council (NPCC) has maintained a suite of air source HP equipment efficiency measures including both conversions from electric furnaces and upgrades from existing HPs or current



practice. The savings estimates have been based on a combination of evaluation studies and modeling. Both the equipment specifications and associated savings have changed over that 15-year period. At the outset of this project, in 2020, the measures were as follows:

The air-source HP conversion from an electric furnace required an HSPF ≥ 8.5 product and was deemed Proven in heating zone one (HZ1) and Planning in HZ2 & HZ3. The savings for the conversion measure were determined by calibrated modeling with the simulations calibrated to evaluation results. The program evaluation studies showed surprisingly lower (and variable) savings in HZ2 & HZ3 than in HZ1. Since heating needs are larger in the colder climates, higher and more reliable savings would be expected there. However, some unaccounted-for variable was leading to lower savings, such as supplemental fuel switching, comfort take-back, etc. From 2020, the measure savings determined by the RTF were $\sim 4,400$ kWh/yr in HZ1 and $\sim 2,700$ kWh/yr in HZ2 & HZ3.

The air-source HP upgrade measures (existing HP to new HP) assumed a baseline HSPF 8.5 and had two measure identifiers: HSPF 9 or variable speed heat pump (VSHP) with an HSPF ≥ 10 . Savings were determined based on modeling alone since the incremental savings of each upgrade was generally thought to be too small to observe in a billing analysis or field study. The savings, regardless of heating zone were: HSPF 8.5 to 9.0, ~ 50 kWh/yr and HSPF 8.5 to VSHP, ~ 300 kWh/yr.

3.2 HPHC HP Opportunities

At the outset of this study, the team hypothesized that HPHC HPs could deliver greater savings than traditional air-source HP measures if equipment performance and

installation practices were improved. Four primary opportunity areas were identified:

- **Reducing or Eliminating Electric Resistance Heating** Conventional equipment and installation practices often rely heavily on auxiliary ER output at cold outdoor temperatures. HPHC HP systems, with extended heating capacity, provide an opportunity to dramatically reduce or eliminate ER use, offering both energy conservation and peak demand benefits.
- **Thermostat Control Improvements** Thermostats with shallow setbacks or advanced control logic can help avoid unnecessary ER use during morning warm-up. The variable capacity of HPHC HP systems may further enable this opportunity by providing rapid response without triggering ER heating.
- **Optimized Sizing Practices** Accurate heating load calculations are essential, and HPHC HP systems' extended output capacity provides opportunities to size with aggressive goals. In moderate climates (HZ1), systems can meet the entire home load, reducing concerns about undersized units. In colder climates (HZ2 and HZ3), extended capacity may not eliminate ER use entirely but can substantially reduce reliance on it.
- **Improved Efficiency Across Conditions** HPHC HP systems are expected to achieve higher efficiencies through both increased output capacity at low temperatures and improved COP at mild conditions, driven by better turndown ratios and low-load COPs.



These proposed benefits provided the foundation for the study's research objectives and guided the team's field evaluation strategy. The results of this work are framed around trying to evaluate these hypotheses.

3.3 Research Questions

To achieve the study goals, the team conceptualized additional, specific research questions to guide the methods and analysis. Those included:

OBJECTIVE 1 – QUANTIFY ENERGY SAVINGS

Primary Question:

- Do HPHC HPs deliver greater annual energy savings than standard air-source HPs?

Supporting Questions:

- To what extent can HPHC HP systems reduce or eliminate auxiliary ER heating?
- How do HPHC HP savings compare to those of an ER furnace baseline?
- What levels of power consumption are observed during peak heating and cooling events?
- Are HPHC HP systems capable of meeting full dwelling loads at their calculated balance point, and how does equipment size influence energy use?

OBJECTIVE 2 – ASSESS PEAK DEMAND REDUCTION

Primary Question:

- Can HPHC HPs provide measurable peak demand reduction for BPA customer utilities during winter and summer peak hours?

Supporting Questions:

- What are the in-field efficiency curves of HPHC HPs across low and moderate outdoor temperatures?
- Do these systems provide greater output capacity at low temperatures?
- Do they achieve improved COPs under mild conditions?
- What is the effective system COP when accounting for both HP and auxiliary resistance heating?

OBJECTIVE 3 – EVALUATE PREDICTIVE METRICS

Primary Question:

- Are there standard parameters (e.g., SEER, HSPF, EER) or non-standard metrics (e.g., detailed performance data in the NEEP database) that reliably predict field performance?

Supporting Questions:

- Beyond traditional program specifications (e.g., HSPF, EER), can additional parameters provide stronger predictions of in-field performance?



- Do reported manufacturer metrics align with observed field performance, and which parameters best correlate with actual outcomes?

OBJECTIVE 4 – CHARACTERIZE LOAD SHAPES

Primary Question:

- What are the heating and cooling load shapes of HPHC HPs in residential applications?

OBJECTIVE 5 – EXAMINE THERMOSTAT IMPACTS

Primary Question:

- How do thermostat setback and recovery strategies influence system load shape and demand profiles?

4.0 Methodology

This section provides an overview of the study approach. The overall study design, site selection, site surveys, equipment selection, and approach to system sizing are each detailed here.

4.1 Study Design

The research was designed as a field-based monitoring study of HPHC HPs in residential settings across BPA service territory. The approach included years-long, in situ monitoring of energy input at one-minute intervals. For the centrally ducted systems, supply and return air temperature and airflow measurements were used to calculate delivered heating capacity and to directly quantify efficiency and energy use. Analyzing the data to identify energy use determinants

will enable future grid peak power reduction benefits and operating cost savings.

Initially, the study focused on centrally ducted equipment, where both input power and output capacity could be measured at the outdoor unit and the single air handler. As recruitment progressed, the scope was expanded to include multizone ductless HPs and represent homes without existing ducts or with inadequate ducts. Given the complexity of measuring output capacity at multiple heads, the team opted not to do so for these sites.

As utility recruitment continued, the research scope expanded in three key areas:

- Include considerations of both heating and cooling energy and peak reductions consistent with the BPA Resource Plan.
- Broaden equipment types to analyze both centrally ducted and multizone products.
- At utility partners' suggestion analyze both Study-Install sites (new installations under project oversight) and Prior-Install sites (qualifying systems installed within the last three years).

To complement the valuable metered data, the team collected pre-installation utility billing records for participating homes. This data enabled the team to extract a site heat signature and a baseline for comparing pre- and post-installation performance.

By study completion, the team monitored 57 residential sites (including centrally ducted and multizone ductless systems) representing seven manufacturers, and captured performance across all three BPA heating zones for both heating and cooling seasons.



4.2 Site Selection

4.2.1 Utility Engagement

Regional utilities and tribes were instrumental in the research. They identified, screened, and recruited the study participants. Furthermore, they also recruited reliable HVAC contractors to complete equipment installations. In all, eight utilities and four tribes participated. Tribal Housing Authorities served by a utility are shown in parenthesis:

- Central Electric Cooperative
- Glacier Electric Cooperative (Blackfoot Housing)
- Inland Power
- Snohomish Public Utility District
- Tacoma Power
- Yakama Power (Yakama Housing)
- Okanogan Public Utility District (Colville Housing)
- City of Plummer (Coeur d' Alene Housing)

4.2.2 Site Qualification

Participating sites were screened for:

- A minimum of two years of continuous residency.
- Existing central, ER furnace, or zonal ER heating.
- Energy billing data that supported an annual heating energy use of at least 4,000 kWh.

The team researched two different sets of installations: *Study-Install*, with installation conducted specifically during this project, and *Prior-Install*, where qualifying HPs were installed within the last three years.

INSTALLATION TYPES

Four types of installations were included:

- Study-Install: HPs installed for this study with guidance provided to contractors.
- Prior-Install: Qualifying HPs installed within the last three years, as part of a participating utility rebate program.
- Centrally Ducted: Single-zone, centrally ducted systems serving as the site's primary heat source.
- Multizone: Whole-home multi-head ductless systems, with a single outdoor unit connected to multiple indoor units, that served as the site's primary heat source.

All systems in this study were Cold Climate Air-Source Heat Pumps (ccASHP), satisfying the NEEP ccASHP specification¹. Many also met the research definition of High-Performance, High-Capacity (HPHC) criteria, including efficiency and capacity requirements in 1) high-load heating and low outdoor temperature heating, 2) low-capacity mild outdoor temperature heating, and 3) high-capacity high outdoor temperature cooling.

¹ <https://neep.org/heating-electrification/ccashp-specification-product-list>



RECRUITMENT

Site recruitment required a detailed process that ensured participant eligibility, properly sized equipment, and quality installations. The recruitment process included:

- **Utility Bill Pre-Screening:** The utility screened sites for minimum 4,000 kWh of annual heating energy use.
- **Site Approval:** The research team approved candidate sites to receive a heating loss and HVAC equipment survey.
- **Energy Surveys:** Field surveys tested building infiltration, measured duct leakage, and tested air handlers.
- **Contractor Sizing Proposal:** HVAC contractors completed an on-site load calculation per the Air Conditioning Contractors of America (ACCA) Manual J and submitted proposed sizing.
- **Sizing Verification:** The research team validated that the contractor sizing proposal conformed with the research sizing requirements and provided necessary feedback.
- **Site Approval:** The research team approved the candidate site for research participation.
- **Homeowner Agreement:** The HVAC contractor presented proposal to homeowner for acceptance.
- **Equipment Install:** The HVAC contractor installed equipment.
- **Metering Install:** The research team installed research-grade metering equipment to enable high-resolution performance monitoring.

For Prior-Install sites, BPA engaged utilities to recruit sites with centrally ducted and multizone systems installed in the last three years. The utilities provided equipment information, which the research team reviewed for eligibility. Selected sites received an energy survey before the metering installation.

Table 1. Final Site Selection

(numbers in parentheses indicate homes with wood heat.)	HZ1	HZ2	HZ3	Total
Study-Install Ducted	11	10 (3)	0	21
Prior-Install Ducted	3	5 (1)	0	8
Study-Install Multizone	2	13 (2)	2	17
Prior-Install Multizone	8	3 (2)	0	11
Total	24	31 (8)	2	57
Site Location Alias	SNO, YAC, YAK	CEC, COL, INL, PLU	GEC	

4.2.3 Site Types and Location

The final site disposition is shown in *Table 1*. The numbers in parentheses indicate sites where regular wood burning was a primary or significant heat source prior to HP installation. The site location alias is also given by heating zone. Locations and definitions of heating zones are shown in *Figure 1* on the map of Regional States Climate Zone Assignments by Utility on the following page.



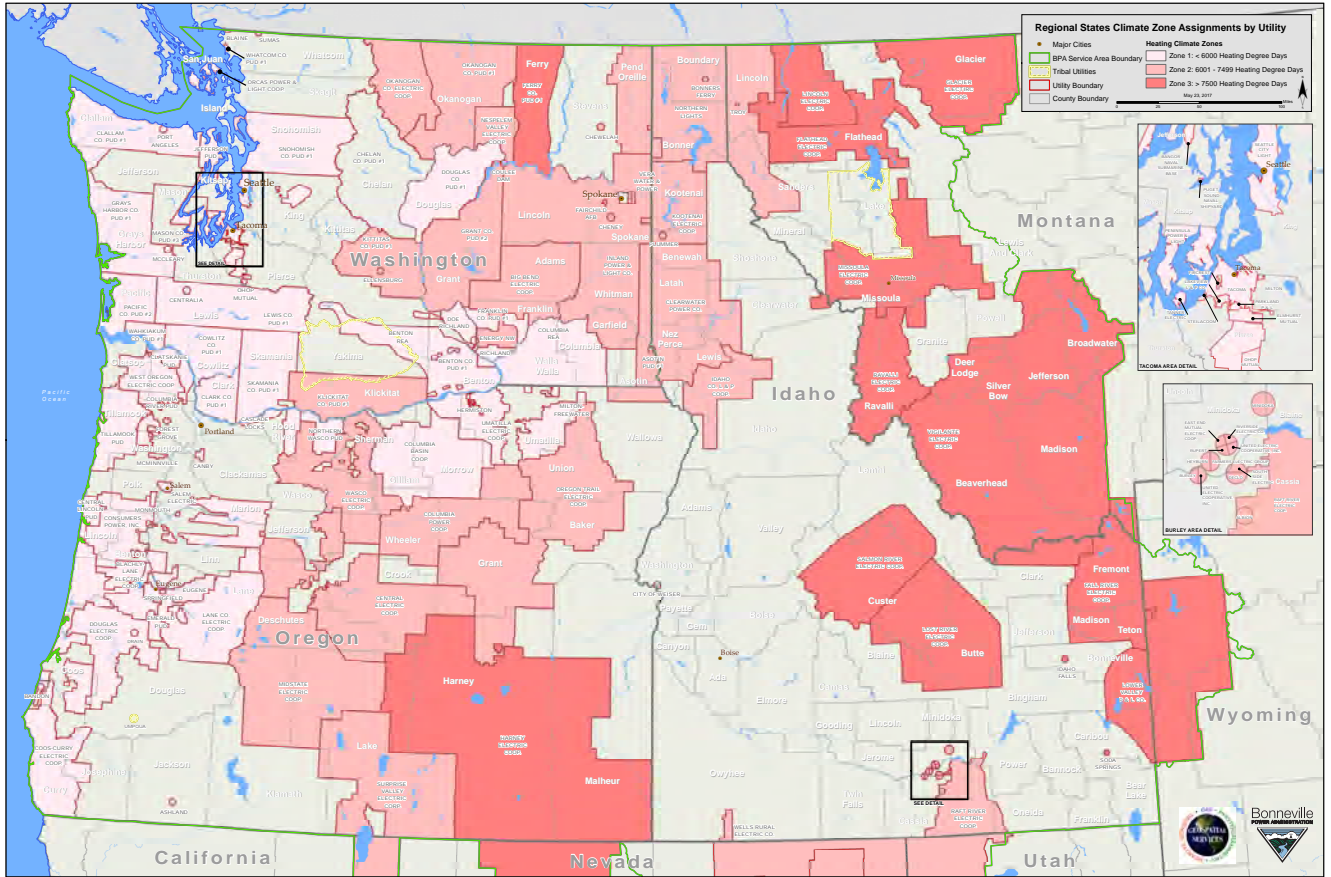


Figure 1. Regional States Climate Zone Map by Utility.

4.3 Site Survey Material

Each of the proposed research sites underwent an initial comprehensive energy survey:

- Occupant Questionnaire: Collected occupancy history, thermostat schedules, comfort with existing HVAC system, and use of supplemental non-electric heating.
- Building Characteristics: Documented insulation values, pressure diagnostic measurements, duct leakage and system airflow, and determined the heat loss.
- Load Calculation: Performed detailed heating load calculations based on ACCA Manual J and Manual D procedures.



Figure 2. Duct Blaster test in progress.

- Duct System Evaluation: Identified whether the existing duct system could support the proposed new system airflow.
- Establish Energy Use Baseline: Established baseline consumption patterns for post-install comparisons.
- Sizing Recommendations: Reviewed contractor sizing proposals and, only if necessary, provided equipment sizing

guidance to ensure project criteria requirements were met.

To enhance research accuracy, the survey methodology was intentionally more rigorous than standard contractor practices. BPA chose to use a single firm for all the site surveys to provide consistent, reliable findings across all the sites. Site surveys included observations of conductive heat loss, and direct measurement of infiltration,



Figure 3. Blower Door test in Progress.



Figure 5. Total Air Handler floor test.

HVAC
SIZING TOOL

Figure 4. HVAC Sizing Tool Example load calculation.

TAC_8	
Site ID: 10971	Heating: 35,200 BTU/hr
Area: 2,063 ft ²	Cooling: 29,100 BTU/hr
Climate: Tacoma-McChord AFB	Latent: 500 BTU/hr



duct leakage, and system airflow. Duct airflow data were especially critical, as they were later paired with leave-behind power measurement to calculate delivered capacity. The researchers validated the field data with spot checks and load calculations. The result was a rigorous and consistent estimate of heat load for each site, accounting for both infiltration and distribution efficiency. At the conclusion of the monitoring period, an exit survey gathered more occupant thermostat settings, schedule, occupant comfort levels, and any supplemental non-electric heat usage patterns. Both the initial and exit survey forms are included in *Appendix C*.

4.4 Equipment Selection

The researchers sought to identify and test the most promising HPs for inclusion in the study. Starting with NEEP ccASHP list and Northwest Energy Efficiency Alliance's (NEEA) cold climate ductless heat pump (ccDHP) specifications, the researchers screened products based on energy analysis and available manufacturer data. The result was a HPHC HP qualified product list (QPL).

While the initial filtering criteria were useful in narrowing down the equipment pool for the study, many of the criteria did not yield meaningful or consistent results for predicting in-field performance. Nevertheless, the criteria, methods and outcomes are provided here to give context for which criteria proved most effective for predicting in-field performance.

4.4.1 Heating Load and Heat Pump Size Determinations

HEATING LOAD

The heating load is the rate of energy required (BTU/h or watts) to maintain the indoor temperature at a specified setpoint under given outdoor temperatures. It is comprised of the home heat loss, including any distribution (duct) losses. Ensuring research consistency, the heating load was calculated using the HVAC Sizing Tool (HVACST), with inputs from the initial survey, for each site by the home performance contractor.

HEAT PUMP BALANCE POINT

The HP balance point temperature is the lowest outdoor temperature at which the HP's output capacity can meet the home's heat load (temperature setpoint). Below this temperature, auxiliary or backup ER heating is needed to maintain indoor temperature.

HEAT PUMP SIZE

It is convenient to specify HP sizes in tonnage, however characterizing HPs by balance point temperature provides a metric that normalizes capacity across varying loads. For example, Home A may have a 2.5 ton unit and Home B may use a 3.0 ton unit, but both units can meet the heating load down to a balance point of 20°F. Characterizing units by tonnage may overlook the important point that both units, irrespective of tonnage, can provide all of the heating needed at a given temperature.



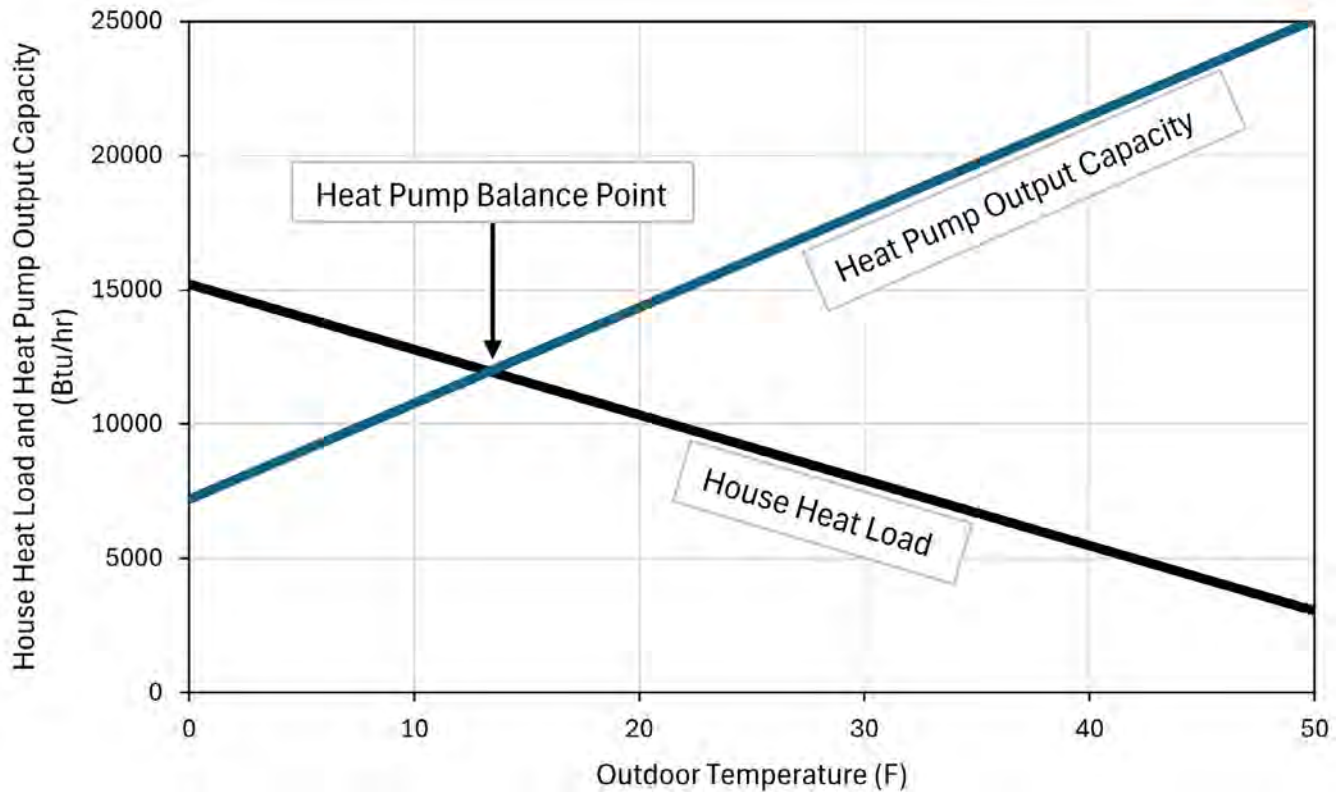


Figure 6. Heat Pump Balance Point Example.

Figure 6 shows the graphical representation of the balance point for a hypothetical home. For this small home, the heating load is 3,000 BTU/hr at 50°F and increases to 12,000 BTU/hr at 13°F. The HP has a nominal output capacity of 2 tons (24,000 BTU/hr) at 47°F. It decreases as the outdoor temperature drops. The two lines cross at the HP balance point where the building heating load equals the HP output.

4.4.2 Specification and HPHC HP QPL Development

BPA sought to identify the best commercially available HPHC HP options for utility programs. Products considered for this study needed to meet several objectives:

- **High Capacity and Efficiency in Heating:** Candidate systems needed to maintain high efficiency heating across three

heating zones from mild marine climates (HZ1) to very cold climates in Montana and Idaho (HZ2 and HZ3). Because most energy consumption occurs in milder to moderate weather conditions, rather than in temperature extremes, the systems must be efficient at low-load, mild outdoor temperature conditions as well as at high-load, colder conditions.

- **Minimizing Resistance Heat:** While the researchers did not expect to fully eliminate ER heat, candidate systems should be able to minimize its use by maintaining high HP heating capacity in colder outdoor temperatures.
- **Cooling Performance:** Given the growing importance of summer peaks, the systems must be efficient and reliable in cooling mode, particularly high load and high outdoor temperature conditions.

NEEP LIST

To ensure consistency with industry efforts, in 2021 the researchers reviewed the existing definitions of “cold climate” performance in the following four primary specification sets: 1) NEEP ccASHP, 2) NEEA ccDHP (which is a subset of NEEP’s), 3) ENERGY STAR’s draft Version 6.0 specification, and 4) Energy Trust

of Oregon’s (ETO) draft requirements for their “Extended Capacity” heat pump pilot. Each specification had a range of qualification criteria that can be found in the references; the primary technical criteria are compared in *Table 2*.

As of 2025, the similar relevant industry specifications include those listed in *Table 3*.

Table 2. Cold Climate Air Source Heat Pump Specifications, 2021

List	SEER	HSPF	EER	Maintenance Capacity
NEEP	15+	9+ ducted 10+ ductless		None (Least Restrictive)
NEEA	15+	10+		Max capacity at 5°F at least 80% of rated at 47°F (more restrictive)
Energy Star	17+	10+	11.5	Max capacity at 5°F at least 70% of rated at 47°F (less restrictive)
ETO	15+	10+		Max capacity at 17°F at least 85% of Max at 47°F (more restrictive)

Table 3. Cold Climate Air Source Heat Pump Specifications, 2025

List	SEER2	HSPF2	EER2	COP @ 5°F	Other Capacity Specification
NEEP	14.3+ ducted 15+ Ductless	7.7+ ducted 8.5+ ductless	-	1.75+ at Maximum Capacity Operation	-
NEEA (same as 2021)	15+ (SEER)	10+ (HSPF)	-	1.75+	Max capacity at 5°F at least 80% of rated at 47°F
Energy Star	15.2+	8.1+ ducted 8.2+ ductless	-	1.75+	-
8.2+ ductless	-	1.75+	-		
ETO	Meets Energy Star Standard				Maximum capacity at 17°F of 85% or more of their rated or nominal capacity at 47°F
DOE Cold Climate Challenge (same as 2021)	-	8.5	-	Minimum COP of 2.1-2.4	Capacity ratio of 100% for 5°F capacity to 47°F capacity
CEE	16+	8.5+ (Path A) 8+ (Path B)	9.8+ (Path A) 11+ (Path B)	1.75+	>60% 5F/47F (Path A) >45% 5F/47F (Path B)
CEE Advanced Tier	Meets DOE CC Heat Pump Challenge Spec				



RELIANCE ON NEEP CCASHP SPECIFICATION

Early on, the researchers determined that industry stakeholders regarded NEEP's ccASHP specification as the de facto definition of cold climate HPs. The NEEP database provides comprehensive, manufacturer-maintained listings of qualified equipment pairings (indoor and outdoor units) along with associated performance data. For each system pairing, the NEEP QPL includes:

- AHRI Directory Reference Number
- System Details: nominal capacity, outdoor and indoor unit model numbers, system configuration, and (if applicable) duct configuration
- Standard Test Results: nominal ratings such as SEER2, HSPF2, and EER2; and power, capacity, and COP at rated conditions (measured during standard ratings tests, with system controls overridden)
- Manufacturer-Reported Performance: power, capacity and COP based on laboratory or engineering calculations intended to reflect normal operations with built-in system controls
- Additional Features: such as refrigerant, description of how the drain pan heater is controlled, qualification for Energy Star or other criteria, etc.
- Calculated Metrics: such as maintenance capacity (the ability of the system to sustain heating output at decreasing outdoor temperature)

NEEP specifies that the performance data should be reported under both laboratory and "real-world" conditions:

"Provide laboratory testing data or engineering data for the conditions shown below. 'Minimum' and 'Maximum' refer to the steady-state heating (and cooling) capacities and input power at each condition that the rated outdoor equipment model can deliver continuously (without cycling), during normal operation using the equipment's built-in controls (e.g. not using fixed-speed test modes). Capacities in the 'Rated' column should correspond to those listed on the AHRI certificate at 47°F and 17°F ODB for heating and 95°F ODB for cooling. (In some cases, these may be equal to the 'Maximum' capacity values but shall still be reported.) BTU/h is total heat or cooling capacity, and kW is power input. Do not include the power required for defrost cycling or drain pan heater operation in the table."

A research question addressed herein is whether manufacturer-submitted "real world" data is a more accurate proxy for real system performance versus SEER and HSPF, which are approximate indicators of efficiency and widely believed to be unreliable for differentiating between variable speed systems. The researchers used the NEEP "real world" minimum and maximum capacity and power data for performance calculations and filters.

DISCUSSION OF FILTERS

The research team developed equipment filters based on the following HP goals:

- Size to a low balance point (20°F or lower), emphasizing HP heating, without impractical oversizing.



- Minimize power demand during peak winter conditions by having a high COP during low temperatures and maintaining HP capacity at decreasing outdoor temperature.
- Maintain high efficiency during the most common operating hours, which are relatively mild temperatures and low load. This requires very high COPs at low load and mild temperature conditions, and/or the ability to reduce cycling losses through “turn down” capability combined with good COP.
- Minimize summer peak demand by maintaining high efficiency at hot weather cooling operations.

These goals translated to four filter main filter criteria for generating a HPHC HP QPL:

WINTER PEAK PERFORMANCE:

To evaluate performance under peak heating conditions (high load at low outdoor temperatures), the researchers developed a “Peak Score” metric.

$$Peak\ Score = \frac{(0.05 \times Maintenance\ Capacity + COP_{Max17})}{105}$$

The metric accounts for:

- Efficiency (COP) at a maximum capacity at 17°F outdoor temperature
- Maintenance capacity defined as the system’s ability to retain output between 17°F and 5°F

Systems with higher COPs at 17°F will deliver required capacity with less power. Systems with higher maintenance capacity will require less ER backup than systems with lower maintenance capacity. **Figure 7**

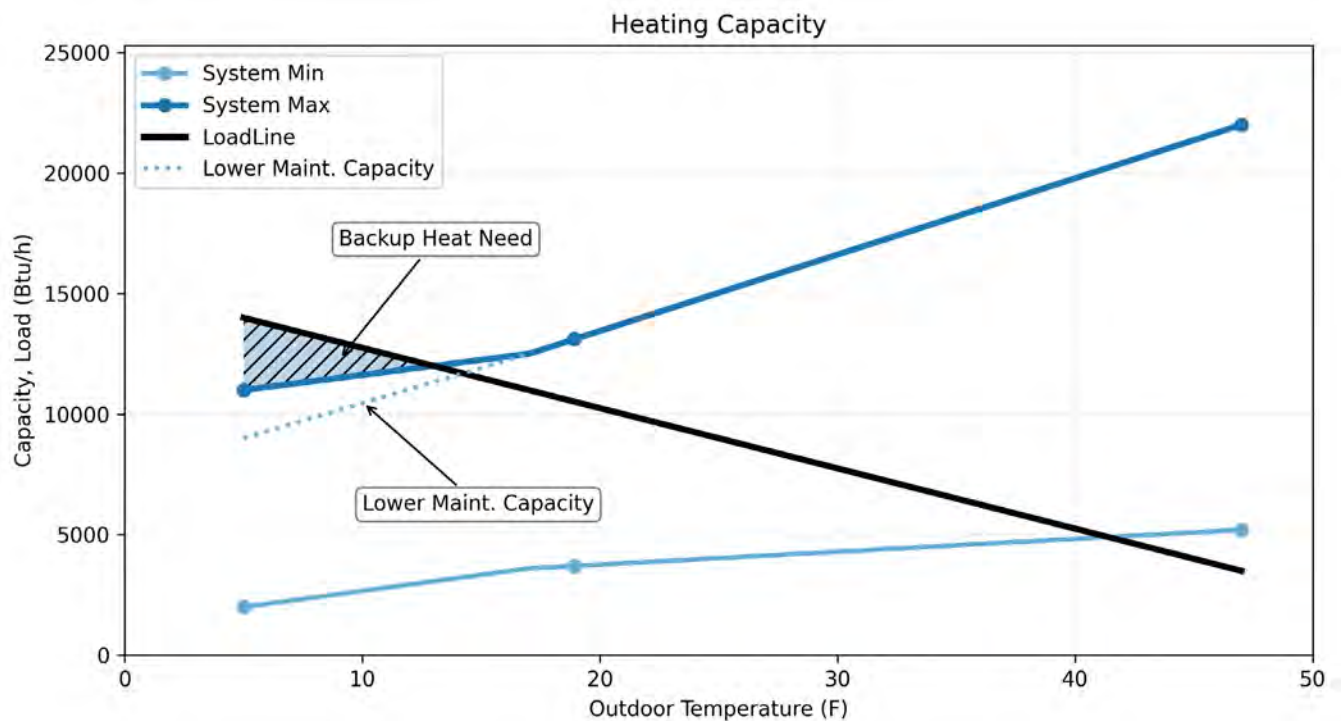


Figure 7. Impact of heating maintenance capacity on need for backup heat.



below illustrates the potential backup heat needed (in the blue and black hatched area) when outdoor temperature is lower than the balance point. The lower maintenance capacity illustrated by the dotted line would require still more backup heat to satisfy the load. Total power is minimized when the HP does most of the heating, and with high COP.

OVERALL EFFICIENCY AND ENERGY CONSUMPTION

The researchers sought to reduce generalized energy consumption using a weighted-average COP. This approach was intended to reflect the most common operating stage of the HP. Considering again the load line and capacity lines in the above figure: if the HP had been sized for a 20°F balance point for example, and if outdoor temperatures were mild (close to 47°F), the system would likely be operating at low capacity or cycling, and therefore the COP at minimum capacity at 47°F would be the most relevant of the available data points. As the outdoor temperature approached the balance point, the system would likely be operating close to maximum capacity, and the 17°F maximum-capacity COP would be the most relevant data point.

Researchers used a weighted average COP, combining the minimum-capacity COP at 47°F and the maximum-capacity COP at 17°F. The weighting was calculated as the ratio of the calculated energy consumption in temperature bins closer to 47°F (outdoor temperature above 32°F) and temperature bins closer to 17°F (outdoor temperature below 32°F). These weightings were then used to calculate an average COP:

$$COP_{avg} = \frac{(\% \text{ Energy, } ODT > 32^\circ F) \times COP_{min, 47^\circ F} + (\% \text{ Energy, } ODT < 32^\circ F) \times COP_{max, 17^\circ F}}{100}$$

The fraction of energy consumed during hours closer to 17°F was low in the mildest HZ1 cities (e.g. in the greater Seattle area). Since the 17°F portion was only about 1.5% of the heating season energy consumption in those mild conditions, researchers simplified the filter, and COP at 47°F minimum capacity was used. In HZ2, the weighted average COP described above was used. For shorthand, these are referred to as “mild climate” and “cold climate” COPs.

TURN-DOWN RATIO

HPs lose efficiency when cycling off and on. Variable capacity HPs must cycle off and on when the load is less than the minimum capacity the heat pump can deliver when running continuously at minimum speed. The magnitude of this cycling penalty is not definitively known for all systems. In extreme cases, efficiency penalties of 40% or more could be possible. Generally, the cycling penalty is greater with lower duty cycle (meaning more “off” time over a given time period). Since systems are being sized for relatively low balance points, there is potential for more cycling and lower duty cycles at mild conditions.

To minimize this potential, a turn-down ratio is used to filter for heat pumps with lower expected cycling penalties. Turn down ratio is defined as the ratio of the maximum capacity at 17°F and minimum capacity at 47°F:

$$Turn\ Down\ Ratio = \frac{Capacity_{max, 17^\circ F}}{Capacity_{min, 47^\circ F}}$$

For a given capacity at 17°F, a system with a higher turn-down ratio can operate at lower capacity at 47°F. For many systems, this also corresponds to lower capacity in cooling mode at mild temperatures, meaning that the potential benefit of low-capacity, continuous operation can be realized in both heating and cooling modes.



SUMMER PEAK PERFORMANCE

EER is used to rate cooling efficiency under summer peak. Although systems that are oversized for cooling may not operate at full capacity at 95°F, peak cooling conditions can exceed this temperature. Under those hotter conditions, systems are more likely to approach maximum capacity, making EER the most appropriate available metric for evaluating efficiency at peak cooling operation.

Although wary of using ratings conditions (in part because of potential differences in ducted and ductless system performance at rating conditions), the researchers used EER values because they closely align with centrally ducted equipment COP at maximum capacity 95°F. Since EER is readily available for all equipment, it was chosen to simplify communication.

COMBINING TURN-DOWN RATIO AND COP

There are two paths for qualifying equipment: in the first path, COP, EER and Peak Score are considered. In the second path, EER and Peak Score remain the same, but a reduced COP is permitted if the system has a high turn-down ratio. The rationale for two paths is that some systems may achieve the same equivalent efficiency in different ways. Consider the following example:

- System A has a COP of 5.0 at minimum capacity at 47°F and has a low turn-down ratio. It cycles at 50% duty cycle at 47°F, resulting in a 15% efficiency penalty. This leads to an equivalent COP of 4.25.
- System B has a COP of 4.25 at minimum capacity at 47°F, but has a turn-down ratio greater than 2.2, and would not be

expected to require cycling at 47°F. Since there is no cycling penalty, the equivalent COP is 4.25.

Since the two systems could be expected to have equivalent efficiency at these outlined conditions, the researchers decided to allow more options with no expected drawback by permitting 1) systems with excellent COP regardless of turn-down ratio, and 2) systems with good COPs combined with good turn-down ratios.

TURNING FILTERS INTO A QPL

The researchers selected the filters above and created a HPHC HP QPL. There two paths to qualify, with slightly different criteria for HZ1 and HZ2. The filters are:

- HZ1, Path 1: Mild-Climate COP \geq 5.0; Peak Score \geq 6.2; EER \geq 11.0.
- HZ1, Path 2: Mild-Climate COP \geq 4.25; Turn-Down Ratio \geq 2.2; Peak Score \geq 6.2; EER \geq 11.0.
- HZ2, Path 1: Cold-Climate COP \geq 4.4; Peak Score \geq 6.2; EER \geq 11.0.
- HZ2, Path 2: Cold-Climate COP \geq 3.9; Turn-Down Ratio \geq 2.2; Peak Score \geq 6.2; EER \geq 11.0.

For cold-climate COPs in HZ2, Redmond, OR was selected as a representative city. The ratio of COPs at 47°F minimum capacity and 17°F maximum capacity is 70:30.

The filter thresholds that were applied are inherently somewhat arbitrary and the researchers sought to avoid making arbitrary cuts that would complicate the list. To reduce this concern, after the initial list was developed, they also considered near miss



products “just outside” the filter criteria. This was defined loosely as having one parameter of the filter that was outside the cut-off, but within 10%. This exception allowed the inclusion of, for example, the full product line for a product family where only the 2-ton and 4-ton outdoor units strictly qualified (but the 3-ton unit was just off). To simplify the list, the results were reported for only the qualifying outdoor unit. If the resulting list was restricted to the fully integrated air handlers for the outdoor units (and not mix-and-match pairings of coils and blowers), each outdoor unit listed qualified for most or all pairings.

A copy of the February 2023 QPL is included for reference in **Appendix B**. As the study progressed, so did the NEEP database, which made updates challenging. New systems were tracked separately, and contractors were encouraged to raise questions to the researchers.

4.4.3 Equipment Sizing Principles

The HP sizing goal was to eliminate, or greatly reduce, any backup, auxiliary, resistance heat. In the maritime Northwest (HZ1), systems were sized to a 20°F or lower balance point. Since 99.6% design temperatures in HZ1 are above the 20°F balance point, the HP should serve the entire heating load, essentially eliminating ER backup. In HZ2 and HZ3, the study team again selected a 20°F or lower target for balance point. The rationale was that in these colder design temperatures, it was not practical to require a HP large enough to meet the full heating load (though this is still technically possible in some homes in HZ2). The sizing approach overall enabled a significant reduction in ER backup.

For Study-Installs, researchers reviewed contractor sizing proposals to ensure they conformed with the above sizing principles

and provided feedback as necessary. In the case of Prior-Installs, the team conducted a site survey to estimate sizing needs but no feedback was provided to the installing contractor.

4.5 Thermostat Setback Study

Early in the data analysis stage, the researchers observed higher-than-expected morning peaks at mild temperatures. They hypothesized that the thermostat setback was causing ER backup to operate and cause these peaks. In January and February of 2025, they controlled and tested the impact of setbacks on the hourly power profile. A total of 14 sites participated in the thermostat setback study. Participating utilities communicated the following test procedure to willing participants.

ESTABLISH BASELINE OPERATION ENERGY AND CAPACITY MEASUREMENT

- Before January 1, 2025, operate as usual, no change modifying thermostat behavior.

BEGIN THERMOSTAT SETBACK TEST PERIOD

- Starting January 1, 2025, select a daytime set temperature, a setback amount of 3-5°F, and 8-hour setback schedule (e.g. 9 p.m. – 5 a.m., 10 p.m. – 6 a.m., or 11 p.m. – 7 a.m.). Ensure the setback schedule and temperature setback operate 7 days a week.
- Starting February 1, 2025, select a temperature in the range of setback temperatures, set the thermostat to the new temperature with no setback for the entire 24 hours.



END THERMOSTAT SETBACK PERIOD

- Starting March 1, 2025, return thermostat to any preferred operation.

The team accommodated two homeowners who requested different start/end times to their setback schedules due to their personal needs, including one with a setback to end at 3 a.m. and another with a setback to end at 8 a.m.

The results of this study are found in *Section 7.6 – Thermostat Setbacks*.



Figure 8. Central Thermostat and Temperature Logger

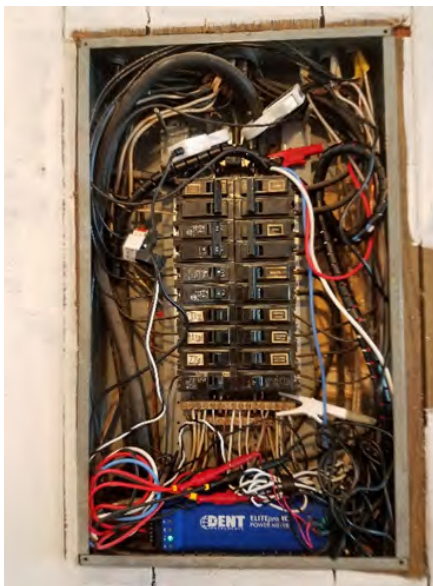


Figure 9. Elite Logger (Blue) at the Main Panel

5.0 Metered Data Collection and Processing

Each home in the study received a metering package designed specifically for the study. Data was also collected from the utilities and from homeowner surveys for each site. The data collection and processing is detailed in this section.

5.1 Site Equipment and Setup

To ensure accurate, consistent, and comparable measurements across all of the sites, the researchers deployed a standardized metering equipment package.



Figure 10. Onset Hobo Temperature Logger



Figure 11. MX Gateway Temp Logger Collector.

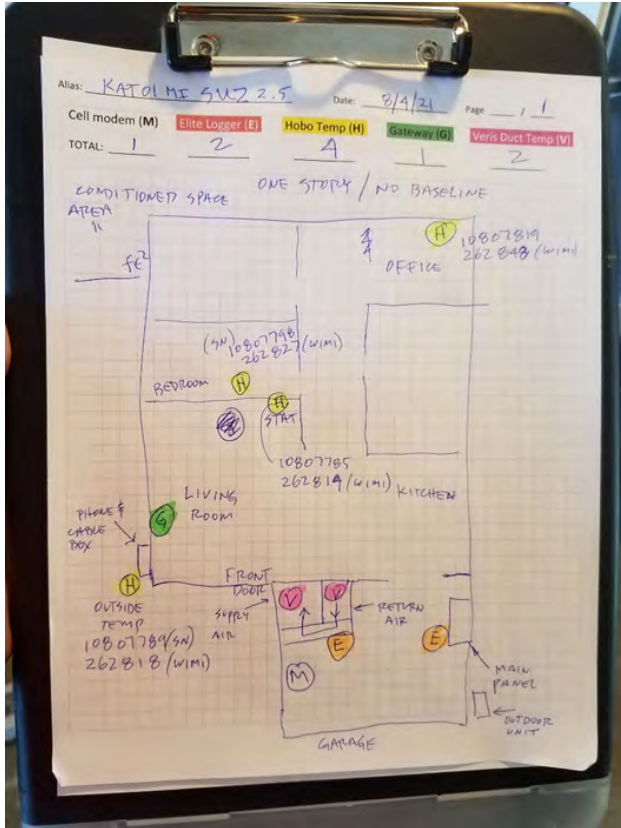


Figure 12. Hand Drawn Locations of installed monitoring equipment.



Figure 14. Elite Logger (inside gray box) next to indoor fan.



Figure 13. Internet Cell Modem (AT&T) and temperature probes in supply ducts



Figure 15. MX Gateway installed



Figure 16. Temperature Logger outside

CENTRALLY DUCTED

At the initial site installation visits for centrally ducted sites, a TEC True Flow Plate device was used to measure airflow. The researchers installed Dent Instruments Elite 4-channel loggers at the main electrical panel and recorded the both the whole-home and HVAC equipment-level power use. An Onset MX Gateway and several HOBO MX loggers recorded indoor air temperature in different rooms. However, the HOBO MX loggers proved to be unreliable as their battery life was much shorter than predicted and they lacked robust Bluetooth communication, so their installation was discontinued. Where possible, a hardwired resistance temperature detector (RTD) sensor was added for conditioned space air temperature. An Elite logger with hardwired RTD sensors was installed next to the indoor blower to capture supply air, return air, and outdoor temperatures. A second Elite Logger recorded 1-minute interval current to the indoor fan. The fan current was used as a proxy for air flow estimates, by correlating minute-by-minute fan current to several air flow regimes.

MULTIZONE

Each multizone site was equipped with two Dent Instruments Elite 4-channel loggers installed at the main electrical panel. The logger captured both whole-home and HVAC equipment-level power use. Another logger measured baseline baseboard or wall cadet type ER heaters, which remained available to heat at the discretion of the occupants. Since measuring air flow output from each indoor ductless head was not feasible, the researchers did not calculate COP for the multizone sites. Indoor temperatures were logged initially with HOBO MX sensors and, after discovering the reliability issues, with RTD sensors.

REMOTE DATA DOWNLOAD

The researchers installed a cellular modem at each site. The modem used Wi-Fi capability to connect to the Elite loggers and MX gateway. A site-specific metering inventory and map documented the research equipment and location, providing both researchers and participants clarity and transparency. On a seven-day cycle, the metering package remotely communicated research data, which eliminated the need for site visits and resulted in fewer impacts to occupants. These data were stored in a central repository. Researchers and other interested parties have direct access to the central repository for analysis.

DATA PROCESSING AND ANALYSIS

The analysis plan balanced rigor with flexibility, ensuring the capture of consistent baseline metrics while allowing new insights to emerge as the study progressed. For all systems, the researchers examined:

- HP and ER power use relative to outdoor temperature
- Seasonal and annual load shapes
- The impact of HP sizing on performance
- Frequency and magnitude of ER use
- Effects of thermostat setbacks on energy and peak demand
- Seasonal and annual energy consumption and savings (via billing analysis)
- System power at peak heating and cooling conditions



- Comparisons of measured performance to ranges reported in the NEEP database

For centrally ducted systems, additional analyses focused on capacity and efficiency relative to outdoor temperature, seasonal COP in heating mode, and verification of measured performance against database reference values.

METHODOLOGICAL APPROACHES

Airflow calibration was accomplished through a one-time measurement with a TEC True Flow Plate and indoor unit power meter. By stepping the air handler through multiple speeds, the researchers established a current-to-cubic foot per meter (CFM) relationship that could be applied to ongoing measurements. The researchers calculated delivered capacity using these airflow estimates combined with supply/return air temperature differentials.

Quality control checks were built into the process. For example, resistance heating events provided a known COP of 1.0 against which the researchers validated temperature sensor readings. In cases where poor air mixing skewed some sensors, the researchers used the highest differential sensor to bring results in line with expectations. Site-specific anomalies – such as reversed current transducers or incomplete load capture – were corrected in the data cleaning process.

As the project unfolded, equipment challenges required adjustments. As mentioned previously, early reliance on HOBO MX loggers revealed problems with battery life and intermittent communication. Later installations replaced these with wired RTD sensors that provided more reliable indoor temperature measurements. In addition, the power loggers themselves, without

warning, switched off data logging mode approximately every 90 days, resulting in occasional data gaps. To correct this, the researchers remotely connected to each logger to re-set the clock.

STRENGTHS, CHALLENGES, AND LESSONS LEARNED

The field monitoring strategy proved successful in many respects. Remote data capture reduced participant burden and gave researchers near real-time access to performance data. The use of standardized instrumentation and calibration methods improved comparability across sites, while cross-checks against known baselines (e.g., resistance heat COP = 1.0) provided confidence in the data.

At the same time, the researchers faced common field challenges. Logger reliability issues and one-time airflow calibration limited long-term accuracy and introduced uncertainty in capacity estimates (approximately 7–8%). Site-specific problems such as occupancy changes, metering mis-installations, or equipment malfunctions also reduced the usable dataset in some cases.

Despite these challenges, the lessons learned are clear:

- Remote capture with cellular modems and centralized repositories is scalable and effective for large field studies.
- Sensor redundancy and validation strategies are essential to ensure reliability.
- Careful documentation and correction protocols can mitigate the inevitable data gaps in long-term field monitoring.



Throughout the project, data was collected, processed, and analyzed in real time. The analysis deliberately allowed flexibility, leaving open the inclusion of new findings and insights from ongoing collaboration and review. The researchers planned data analysis in advance, including the following key considerations.

For all systems:

- HP and ER heat power vs. outdoor temperature
- Load shapes
- Effect of HP sizing
- Quantifying use of ER heat
- Thermostat setbacks and their impact on energy and power
- Seasonal energy consumption
- Seasonal and annual energy savings via billing analysis
- System power at expected peak heating and cooling conditions
- Comparison of measured power against expected power range based on NEEP database

For centrally ducted systems:

- Capacity and efficiency vs. outdoor temperature in heating mode
- Seasonal heating COP
- Comparison of measured heating capacity and COP against expected range based on NEEP database

During the study, supply temperatures were reviewed for each of the ducted sites. Since most sites had three supply temperature sensors, the default strategy was to average these. However, the researchers observed that while most sites had strong agreement among the supply temperature sensors, a few did not. Using periods with ER heating with a measured power input and known COP = 1, the researchers identified that a few of the temperature sensors appeared to be reading artificially low, likely due to incomplete air mixing. An adjusted approach – using the sensor registering the highest temperature differential – brought results into alignment. This left the results substantially unchanged for most sites, and brought a small number of the systems closer to agreement with expected performance data. It did not appear to inflate measured capacity above expected values.

Additional data cleansing occurred to resolve site-specific issues as they arose. For example, at one site, an electrician briefly removed the power meter in the course of work at the home and re-installed the current transducer backwards, which the researchers adjusted for after discovery. At a small number of sites, the field-installed, whole-home power meter did not capture the full load. For these sites, the researchers discarded the whole-home measurement. Also, for these sites the HP-specific power metering was double-checked against expected performance and peer sites to ensure that measured power levels aligned with expected thresholds.

5.1.2 Overcoming Data Gaps

With more than a year of metering across dozens of sites, data gaps were inevitable. Instead of discarding incomplete records, the researchers adopted a regression-based approach to reconstruct missing intervals



for presentation in aggregated data. For each site, the measured energy use was regressed against outdoor temperature to generate temperature-energy relationships for both the HP and ER heating. This method is not applied to any minute-by-minute data analysis in this report.

When data gaps occurred, the researchers estimated the energy use for the missing periods under equivalent weather conditions. This method had two advantages:

- It enabled the reporting of complete seasonal totals, even when short data segments were missing.

- It allowed comparisons on a standardized weather basis by applying the regressions to a consistent weather dataset typical meteorological year (TMY) 2009–2023.

This approach ensured that the dataset remained robust and comparable across the study, and preserved the ability to normalize energy use for weather variations.

5.2 Data Availability and Expansion

The site-by-site start and stop dates are illustrated in *Figure 17*. The goal was to obtain at least one full year of data for every site.

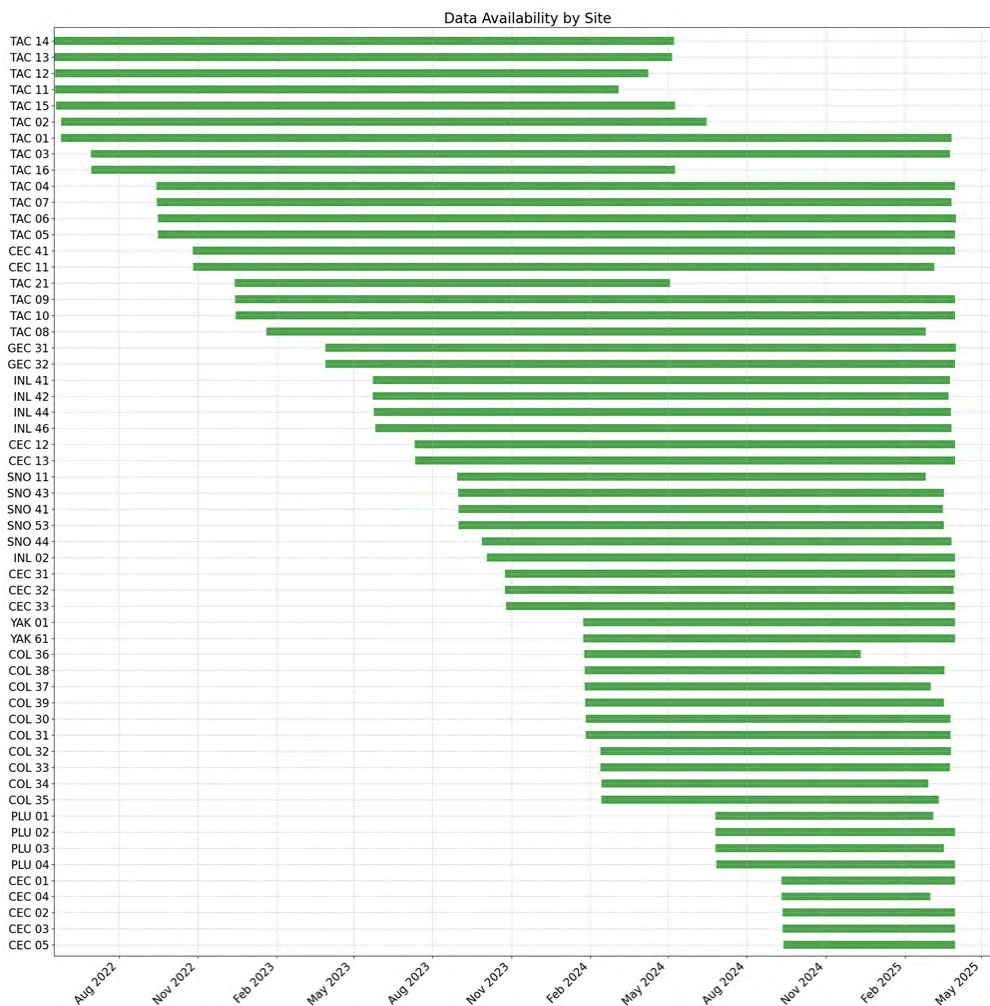


Figure 17. Data Availability by Site



For most sites this was achieved, but a few sites that were added late in the research had limited data: a full heating season but not a full cooling season. The late inclusion was nevertheless valuable. The additions included sites PLU 01– PLU 04 and CEC 01 – CEC 05.

Site start and end dates are also listed in *Appendix A*.

5.2.1 Measurement Uncertainty

Although power measurements were highly accurate – better than 1% Dent ElitePro (<0.2% typical) for kW –the largest uncertainty arose in the field-estimated capacity values. These calculations depended on airflow estimates derived from a one-time True Flow calibration, which carries a $\pm 7\%$ uncertainty, compounded by temperature sensor tolerances. When combined, under typical conditions, the overall uncertainty in calculated capacity was approximately 7.6%.

Additional unknown uncertainty occurred over time as part of system operations. For example, the researchers monitored for measurement drifts caused by dust accumulation in air filters. They checked the relationship between calculated CFM and outdoor unit power changes over time, and found no evidence of problems. However, this measurement should be treated with caution and considered in the context of other measurements.

5.3 Billing Analysis

While the high-resolution metered data revealed detailed performance trends, the utility billing data provided the only way to establish pre-installation energy use. One-month billing data had a much lower time resolution than the onsite loggers, but it

allowed for useful comparisons in energy consumption. The billing analysis was done with industry-standard methods in alignment with the International Performance Measurement and Verification Protocol Option C: Whole Facility².

For each site, the researchers performed temperature-energy regression using variable-base degree day methods to extract the heating (and cooling) energy use from the bill data. Specifically, the RTERM package for the software tool R was used^{3,4}. After the bills were cleaned and organized, the energy consumption data was paired with temperature data from a local weather station for each site⁵. Next, energy use was iteratively regressed against degree days with varying bases. Each iteration is a site-specific, physically based heat loss model. The model searches for the best fit of both heating degree day base and heating load slope. The heating degree day base determines the temperatures below which heating is

2 <https://evo-world.org/en/products-services-mainmenu-en/protocols/ipmvp>

3 RTERM is a collection of tools that facilitates temperature-energy regressions. It also has functions that easily access weather data. The variable-base degree day fitting method is a more generalized version of the “PRISM” technique described by Fels (1986). Fels, M. 1986. PRISM: An Introduction. Energy and Buildings, Volume 9 (1986), pp. 5-18. The package and the source code for RTERM are available here: <https://github.com/ECotopeResearch/rterm>.

4 For an in-depth assessment of regression-based bill analysis techniques, see also Hannas, Benjamin and Michael Logsdon, Comparison of Bayesian Billing Analysis to Pooled Fixed Effects and Variable-Base Degree-Day. 2015 2015 International Energy Program Evaluation Conference, Long Beach. <https://www.iepec.org/wp-content/uploads/2015/papers/017.pdf>

5 Weather data come from the National Oceanic and Atmospheric Administration’s (NOAA) National Climatic Data Center (NCDC). <https://www.ncdc.noaa.gov/cdo-web/webservices/v2>



needed and, conversely, the base energy load that does not depend on temperature. The heating load slope determines the amount of energy used per degree day to meet the respective load. Combined, these values establish the base load and heating energy use in the pre- and post-install periods. The researchers then normalized the data and compared the pre- and post-energy, adjusting both to a common weather pattern, and then used the energy use / degree day dependence to calculate annual energy use. For the normal weather, the researchers used Typical Meteorological Year data, vintage 2009-2023 (TMYx), from Climate.OneBuilding.org⁶.

One limitation was that cooling savings could not be quantified from bills, as monthly billing cycles lack sufficient time resolution to reliably capture cooling loads. In regions like the Northwest, where cooling demand is modest, only daily billing data could have offered meaningful insight. Some sites increased energy use in the summer, but this often reflected only one or two months.

⁶ The Regional Technical Forum (RTF) also uses TMYx data files from Climate.OneBuilding.Org. See how the RTF uses them here: <https://rtf.nw-council.org/work-products/supporting-documents/climate-files/>

5.3.1 Building Characteristics

All participating sites primarily used ER heat – either central furnaces or zonal heaters. Many participants also reported additional heat sources, including wood stoves, pellet stoves, gas fireplaces, and electric space heaters. Initial and exit surveys documented these auxiliary systems.

Survey responses revealed two distinct categories of auxiliary, non-electric heat use. The first category included sites that reported infrequent auxiliary non-electric equipment use, or use to heat only a small portion of the home. In these cases, auxiliary heating rarely had a measurable effect on overall energy outcomes, and system performance was similar to homes without auxiliary equipment. The second category included sites where auxiliary systems – most often wood stoves – were used and contributed significantly to total space heating.

Across the cohort, 26 sites reported some form of additional heating in the initial survey. Of those 26 sites, only 16 sites still reported auxiliary heat use in the exit survey. This reduction suggests that, in some cases, the new HPHC HPs eliminated or nearly eliminated occupants’ reliance on auxiliary heating sources.

Table 4. Auxiliary Heat Usage Based On Site Survey At Project Beginning

Homes reporting infrequently used or partial auxiliary heat sources	Homes reporting regular auxiliary heat use
CEC 01, CEC 03, COL 36, COL 37, COL 39, INL 02, INL 42, INL 46, PLU 01, PLU 02, SNO 53, YAK 01	
	CEC 05, CEC 12, CEC 13, CEC 33, CEC 41, COL 38, PLU 03, PLU 04, INL 44*
*INL 44 has natural gas second-stage heat in the new system	



Table 5 includes only those sites for which both initial and exit survey data were available.

Table 5. Auxiliary Heat Usage Based On Site Surveys Including Project Beginning And End

	Additional Heat Sources Used (Inclusive of Auxiliary Electric Heaters)	
	Pre-Study	During Study
Number of Sites	26	16
Total Sites	31	

Not all sites were included in the billing analysis due to data quality issues. Some exclusions resulted from confounding factors such as solar photovoltaic (PV) installations

(which masked heating signatures in billing data) or occupancy changes. Other sites were excluded because of limitations in capturing second-stage or auxiliary fuels, such as natural gas backup systems. The researchers retained as much usable data as possible, and when exclusions were necessary, they documented these in the analysis tables. The data in **Table 6** was collected from the initial and exit surveys and the utility provided billing data. The researchers did not discard any sites outright, although a few sites had to be excluded from much of the consequential group analysis.

Although most sites represented detached, single-family homes, a subset of townhouses were also included (specifically, sites COL 30–35). The variation in housing type did not dominate the results and was noted where

Table 6. Sites Excluded From Pre/Post Analysis And Reason For Exclusion

Site	Excluded from...	Reason
TAC 21	Pre/post billing analysis	In "pre" condition, house was mostly unconditioned
TAC12	Pre/post billing analysis	Solar photovoltaic install confounds billing data (it offsets the reported kWh) so no pre-period heating signature can be generated
INL 41	Pre/post billing analysis	Mid-project occupancy change
INL 42	Pre/post billing analysis	Prior heat pump installation data not documented
INL 44	Pre/post billing analysis; regression analysis; seasonal efficiency; COP-based savings	House has natural gas second-stage heat, which is not fully metered. House also has solar photovoltaic net meter install issue
INL 46	Pre/post billing analysis	Heat pump serves an unknown portion of the house
COL 39	Whole-home, site-metered analysis	Whole-house power meter issue [can still include in billing]
SNO 41	Pre/post billing analysis	Electric service interruption and occupancy change
SNO44	Pre/post billing analysis	Occupancy change two months before HP install
GEC 31	Pre/post billing analysis	Significant occupancy changes during the period of the study including some unoccupied times
COL 35	Regression analysis; seasonal efficiency	Data shows that in Winter 24-25, the heat pump in December switched to some kind of error or off state (steady 0.05 kW, with backup heat)
PLU 04	Regression analysis; seasonal efficiency; COP-based savings	Data suggests significant woodburning which offsets nearly all heat pump usage
TAC 01, dates from Jan 12, 2024 – Feb 7, 2024	Site-metered analysis	Homeowner switched into "emergency heat mode" and forgot to exit the mode until alerted



relevant. The mean area in HZ1 was slightly larger, 1856 ft² compared with 1601 ft² in HZ2. The two homes in HZ3 had the same layout, 960 square feet. Heating loads at 20°F outdoor temperature were calculated for each site. There was a higher average calculated load in HZ1 (34,297 BTU/h) than HZ2 (23,882 BTU/h) or HZ3 (10,138 BTU/h).

The data in **Table 7** on the following pages shows the rated capacity at 47°F and maximum capacity at 17°F for the installed HPs (which are discussed in more detail in **Section 5.3.2 – Heat Pump Characteristics**). This shows that systems installed in HZ2

and HZ3 often had higher capacity relative to the heating load, compared to those installed in HZ1 (**Figure 18**). This could reflect more aggressive equipment sizing and selection from contractors in colder outdoor conditions.

The site selection process was not designed to produce a representative sample of diversity in regional housing. Instead, it intentionally targeted homes with ER heating and site conditions suitable for study installation. This focus allowed the researchers to isolate HP performance under specific, high-relevance conditions.

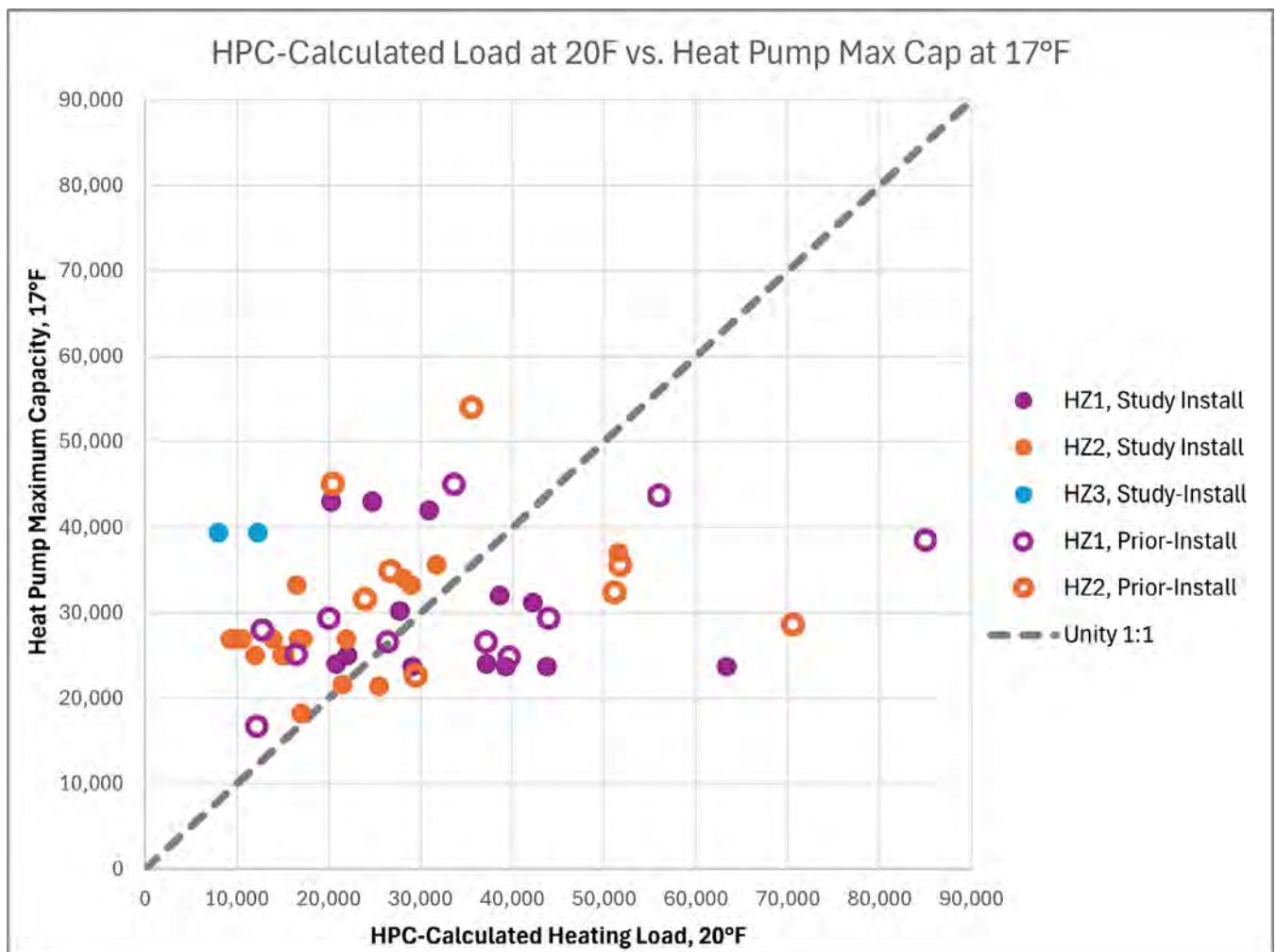


Figure 18. Calculated House Heating Load at 20°F vs. Heat Pump Maximum Capacity at 17°F.

Table 7. Site Square Footage and System Capacity

HZ	Heat Pump Type	ID	Floor Area (ft ²)	(CALC) 20°F Heating Load (BTU/hr)	47°F Rated Capacity (BTU/hr)	17°F Max Capacity (BTU/hr)
HZ 1	Study-Install Ducted	TAC 01	1784	39,293	34,600	23,700
		TAC 02	1396	63,328	34,600	23,700
		TAC 03	2450	37,200	35,000	24,000
		TAC 04	1740	29,085	34,600	23,700
		TAC 05	1936	43,793	34,600	23,700
		TAC 06	1716	42,256	42,500	31,200
		TAC 08	2063	38,634	34,000	32,000
		TAC 09	1034	20,854	35,000	24,000
		TAC 10	1426	27,768	35,738	30,200
		YAK 01	1440	24,750	40,000	43,000
		YAK 61	1416	20,250	40,000	43,000
	Study-Install Multizone	TAC 07	2016	30,951	42,000	42,000
		TAC 21	972	22,061	25,000	25,000
	Prior-Install Ducted	SNO 43	1132	12,150	21,000	16,700
		SNO 44	5631	84,938	54,500	38,500
		SNO 41	1082	12,770	34,200	28,000
	Prior-Install Multizone	TAC 11	1822	55,976	47,500	43,760
		TAC 12	3192	37,098	36,000	26,600
		TAC 13	1025	16,463	23,000	25,150
		TAC 14	1824	39,622	24,800	24,800
		TAC 15	2612	43,902	29,000	29,400
TAC 16		1194	19,976	29,000	29,400	
SNO 11		1024	26,392	36,000	26,600	
SNO 53		2623	33,638	45,000	45,000	



HZ 2	Study-Install Ducted	INL 02	2688	21,491	28,800	21,600	
		PLU 01	1127	12,000	28,000	25,000	
		PLU 02	1127	14,932	28,000	25,000	
		PLU 03	1127	15,205	28,000	25,000	
		PLU 04	1127	15,273	28,000	25,000	
		CEC 01	2203	28,107	36,000	34,000	
		CEC 02	1780	31,721	40,000	35,600	
		CEC 03	1248	[Not calculated]	23,200	18,200	
		CEC 04	785	17,041	23,200	18,200	
		CEC 05	1316	25,473	28,800	21,400	
	Study-Install Multizone	CEC 31	1008	16,554	36,600	33,200	
		CEC 32	1128	28,992	36,600	33,200	
		CEC 33	2096	51,566	48,500	37,000	
		COL 30	1000	10,045	25,000	26,928	
		COL 31	1000	9,321	25,000	26,928	
		COL 32	1000	9,482	25,000	26,928	
		COL 33	1000	9,321	25,000	26,928	
		COL 34	1000	10,607	25,000	26,928	
		COL 35	1000	9,884	25,000	26,928	
		COL 36	1188	16,714	25,000	26,928	
		COL 37	960	17,196	25,000	26,928	
		COL 38	856	21,938	25,000	26,928	
		COL 39	1152	13,982	25,000	26,928	
	Prior-Install Ducted	INL 41	1584	29,483	32,800	22,600	
		INL 42	2700	23,974	46,000	31,600	
		INL 44	3300	51,750	53,500	35,600	
		INL 46	4578	51,129	34,000	32,400	
		CEC 41	1890	26,705	40,000	34,900	
	Prior-Install Multizone	CEC 11	1537	20,434	45,000	45,000	
		CEC 12	2304	70,598	28,600	28,600	
		CEC 13	2826	35,557	54,000	54,000	
	HZ 3	Study-Install Multizone	GEC 31	960	8,000	36,400	39,341
			GEC 32	960	12,278	36,400	39,341



Table 8. House Area, Load, and HP Tonnage by Heating Zone

HZ	Heat Pump Type	Avg. Square Footage	Avg. 20F Heating Load	Count	Count, < 2.5 HP Tons	Count, ≥2.5 HP Tons < 3.5	Count, ≥3.5 HP Tons < 4.5	Count, ≥ 4.5 HP Tons
HZ1	Study-Install Ducted	1673	35201	11	1	9	1	
	Study-Install Multizone	1494	26506	2	1	1		
	Prior-Install Ducted	2615	36619	3	1	1		1
	Prior-Install Multizone	1915	34133	8	2	5	1	
HZ2	Study-Install Ducted	1453	20138	10	8	2		
	Study-Install Multizone	1107	17354	13	10	2	1	
	Prior-Install Ducted	2810	36608	5		3	1	1
	Prior-Install Multizone	2222	42196	3	1	1	1	
HZ3	Study-Install Multizone	960	10139	2		2		

Before installation of the Study-Install systems, the researchers carried out a site visit, survey, and measurements. For ducted homes, they performed duct and blower door measurements. Contractors were instructed not to modify the existing ducts beyond what was necessary for installation, to isolate the impact of the HP for pre-/post analysis. The data summarized in **Appendix A** reveals that most existing ducts were leaky or semi-leaky, insulation levels were moderate, and degree of leakage varied. Duct system impacts included in the analysis in **Section 8 – Determinants of Peak Load Demand Reduction Benefit, Efficiency, and Energy Savings**. The researchers assumed that the status of the existing ducts remained constant and did not re-measure the ducts after HP installation or at the end of the study.

Occupant comfort is an important consideration in the context of the HP energy used for delivering heating or cooling. This was evaluated in both the initial and exit surveys. Participants were asked to assess whether comfort increased, decreased, or remained the same. Of the 31 complete responses to both rounds of surveys, 19 reported increases in comfort, 12 reported similar comfort, and zero reported decreases in comfort. In reviewing the individual responses, it appears that the sites with comfort issues often referred to issues with air distribution. Those participants often reported that a particular room was too hot or too cold both prior to and after the study. The researchers assumed the existing duct configuration created airflow distribution issues, which would not have been resolved by simply upgrading to a HP without also fixing ducting issues.

Table 9. Changes In Comfort

	Improved Comfort	Decreased Comfort	No Change
# of Sites	19	0	12



The initial survey responses also indicated that 23 sites had cooling prior to the study; the remaining 32 sites would have had new cooling capacity added during the study. From the remaining two sites, no survey responses on this topic were received.

Table 10. Pre-Study Cooling

	Cooling Present Before Study
# of Sites	23
Total Responses	55

5.3.2 Heat Pump Characteristics

The heating capacity of installed systems is illustrated in *Figures 19 and 20*, which shows data for each HP from the NEEP database. The systems in HZ1 have an orange background, HZ2 systems have a blue background, and HZ3 systems have a purple background. The blue lines represent the maximum capacity datapoints listed in the NEEP database, while the orange lines represent the minimum capacity. The same systems are described in *Table 11*.



Installed Systems Heating Capacity – Ducted

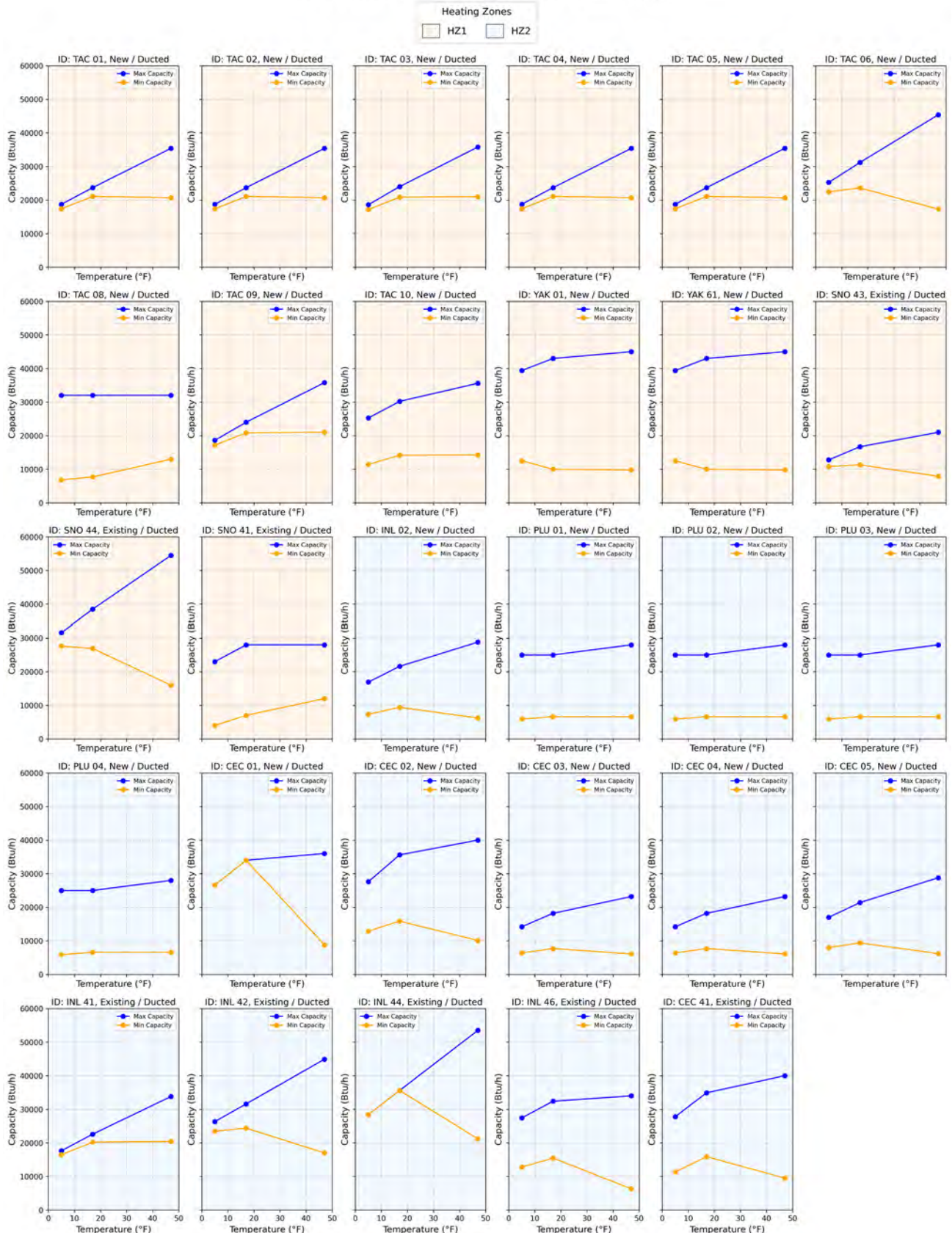


Figure 19 - Heating Capacities of Installed Ducted Systems.



Installed Systems Heating Capacity — Multi-zone

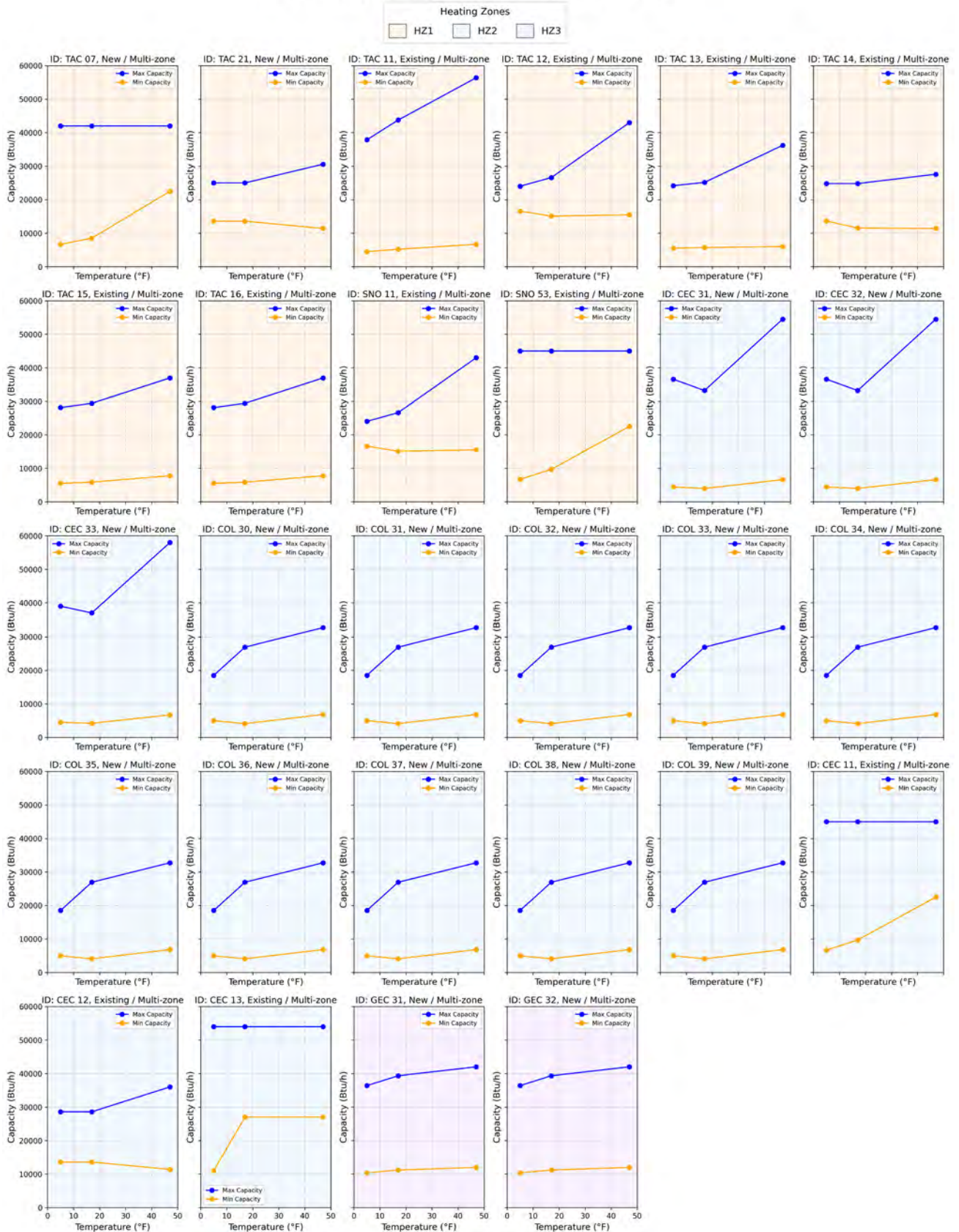


Figure 20. Heating Capacities of Installed Multi-Zone Systems.



Table 11. Installed Heat Pumps

HZ		ID	Brand	ODU	IDU	Nominal Capacity	SEER2 (converted if needed)	HSPF2 (converted if needed)	EER2 (converted if needed)
HZ 1	Study-Install Ducted	TAC 01	American Standard	4A6L9036A1000A	AMSTAM9A0B30V31DA	3	17	9	11.5
		TAC 02	American Standard	4A6L9036A1000A	AMSTAM9A0B30V31DA	3	17	9	11.5
		TAC 03	Trane	4TWL9036A1000A	1TEM8A0B30V31DB	3	17	9	10
		TAC 04	Trane	4TWL9036A1000A	TAM9A0C36V31DB	3	17	9	11.5
		TAC 05	Trane	4TWL9036A1	TAM9A0C36V31	3	17	9	11.5
		TAC 06	Trane	4TWL9048A1000AC	TAM9A0C42V41DAB	4	19	8.7	12
		TAC 08	Mitsubishi	SUZ-KA30NAHZ	SVZ-KP30NA	2.5	15.2	8.5	12.8
		TAC 09	Trane	4TWL9036A1	TEM8A030V3+0BA	3	17	9	10
		TAC 10	Carrier	25VNA036A00SID	FE4ANF003	3	18.1	10	11.1
		YAK 01	Lennox	MLB036S4S-2P	MMA036S4-*P	3	14.9	8.9	8.9
		YAK 61	Lennox	MLB036S4S-2P	MMA036S41P	3	14.9	8.9	8.9
	Study-Install Multizone	TAC 07	Mitsubishi	MXZ-SM36NAMHZ-U1	MSZ-FS12NA; SVZ-KP24NA	3	20.8	11.5	13.5
		TAC 21	Mitsubishi	MXZ-3C24NAH4Z		2	19	9	13.5
Prior-Install Ducted		SNO 43	American Standard	4A6V8024A1000BD	TAM9A0B30V31	2	17.1	9.5	11.1
		SNO 44	American Standard	4A6L9060A1	TEM8A0C60V51+TDR	5	18.1	9.5	8.9
		SNO 41	Bosch	BOVA-36HDN1-M20G	BVA-36WN1-M20	3	19	9.5	12
Prior-Install Multizone		TAC 11	Daikin	5MXS48TVJU		4	16.9	9.4	8.1
		TAC 12	Mitsubishi	MXZ-4C36NA2		3	18.2	10.5	8
		TAC 13	Carrier	38MGRQ24C--3		2	21.9	9.5	10.6
		TAC 14	Mitsubishi	MXZ-3C24NAHZ2		2	16.4	9	10
		TAC 15	Carrier	38MGRQ30D--3		2.5	21.3	9.5	9.6
		TAC 16	Carrier	38MGRQ30D--3		2.5	21.3	9.5	9.6
		SNO 11	Mitsubishi	MXZ-4C36NA2		3	18.2	10.5	8
		SNO 53	Mitsubishi	MXZ-4C36NAHZ2		3	19	10.7	11.9



HZ 2	Study-Install Ducted	INL 02	Daikin	DZ6VSA3010A*	DZ36FECC14A	2.5	17.1	8.2	9.9	
		PLU 01	Mitsubishi	SUZ-KA24NAHZ	SVZ-KP24NA*	2	16	8.4	9.9	
		PLU 02	Mitsubishi	SUZ-KA24NAHZ	SVZ-KP24NA*	2	16	8.4	9.9	
		PLU 03	Mitsubishi	SUZ-KA24NAHZ	SVZ-KP24NA*	2	16	8.4	9.9	
		PLU 04	Mitsubishi	SUZ-KA24NAHZ	SVZ-KP24NA*	2	16	8.4	9.9	
		CEC 01	Lennox	SL25XPV-036-230A**	CBA38MV-036-230*+TDR	3	22	9.1	13.4	
		CEC 02	Goodman	GSZS604210A*	AHVE42CP1400A*	3.5	16.7	8.1	8.5	
		CEC 03	Goodman	GZV6SA2410A*	AHVE24BP1300A*	2	18	8.5	10.2	
		CEC 04	Goodman	GZV6SA2410A*	AHVE24BP1300A*	2	18	8.5	10.2	
		CEC 05	Goodman	GZV6SA3010A*	AHVE36CP1300A*	2.5	17.5	8.5	10	
	Study-Install Multizone	CEC 31	Daikin	4MXL36WVJU*		3	20	9	11.7	
		CEC 32	Daikin	4MXL36WVJU*		3	20	9	11.7	
		CEC 33	Daikin	5MXS48WVJU*		4	20.6	9.3	10.5	
		COL 30	Carrier	38MGHBQ24CA3		2	24.6	10	13.4	
		COL 31	Carrier	38MGHBQ24CA3		2	24.6	10	13.4	
		COL 32	Carrier	38MGHBQ24CA3		2	24.6	10	13.4	
		COL 33	Carrier	38MGHBQ24CA3		2	24.6	10	13.4	
		COL 34	Carrier	38MGHBQ24CA3		2	24.6	10	13.4	
		COL 35	Carrier	38MGHBQ24CA3		2	24.6	10	13.4	
		COL 36	Carrier	38MGHBQ24CA3		2	24.6	10	13.4	
		COL 37	Carrier	38MGHBQ24CA3		2	24.6	10	13.4	
		COL 38	Carrier	38MGHBQ24CA3		2	24.6	10	13.4	
		COL 39	Carrier	38MGHBQ24CA3		2	24.6	10	13.4	
	Prior-Install Ducted	INL 41	Trane	4TWL9036A1	TAM9A0C42V41	3	17.5	8.7	11.7	
		INL 42	Trane	4TWL9048A1	TAM9A0C48V41	4	19	9	11.7	
		INL 44	Lennox	XP25-060-230-03	SLP00DFD0-XV60C-02	5	17.6	9.2	9.8	
		INL 46	Carrier	25VNA436A00310	FE4ANB006L+UI	3	20.9	10.9	11.5	
		CEC 41	Daikin	DZ17VSA42	DV42FECC14A	3.5	16.7	8.1	8.5	
	Prior-Install Multizone	CEC 11	Mitsubishi	MXZ-4C36NAHZ2		3	19	10.7	11.9	
		CEC 12	Mitsubishi	MXZ-3C30NAHZ3***		2.5	18	9.7	12.5	
		CEC 13	Mitsubishi	MXZ-SM48NAMHZ		4	19.5	10.5	11.8	
	HZ 3	Study-Install Multizone	GEC 31	Fujitsu	AOU36RLXFZH		3	20.5	9.5	13
			GEC 32	Fujitsu	AOU36RLXFZH		3	20.5	9.5	13.0



Table 12. Count of systems by COP at Minimum Capacity At 47° F.

COP, 47°F Min Cap	<3.5	3.5-3.75	3.75-4	4-4.25	4.25-4.5	4.5-4.75	4.75-5	5-5.25	5.25-5.5	>5.5	Total
Study-Install Ducted	0	0	1	2	2	11	5	v	0	0	21
Study-Install Multizone	0	0	1	10	0	0	0	2	0	4	17
Prior-Install Ducted	0	0	1	2	1	3	0	1	0	0	8
Prior-Install Multizone	4	0	2	2	0	0	0	0	0	3	11
Total	4	0	5	16	3	14	5	3	0	7	57

Table 12 shows the distribution of COP for the minimum capacity data point at 47°F outdoor temperature (as listed in the NEEP database).

Table 13. Count of Systems by COP at Maximum Capacity At 17° F.

COP, 17°F Max Cap	1.75-2	2-2.25	2.25-2.5	2.5-2.75	2.75-3	3-3.25	3.25-3.5	3.5-3.75	3.75-4	Total
Study-Install Ducted	0	6	4	1	2	4	0	4	0	21
Study-Install Multizone	0	4	2	1	0	0	0	0	10	17
Prior-Install Ducted	0	0	2	5	1	0	0	0	0	8
Prior-Install Multizone	1	2	7	1	0	0	0	0	0	11
Total	1	12	15	8	3	4	0	4	10	57

Table 13 shows the distribution of the COP at the maximum capacity datapoint at 17°F outdoor temperature.



The distribution of SEER2, HSPF2 and EER2 are shown in *Table 14, Table 15, and Table 16*.

Table 14. Distribution of SEER2 Ratings.

SEER2	<16	16-16.5	16.5-17	17-17.5	17.5-18	18-18.5	18.5-19	19-19.5	19.5-20	20-20.5	20.5-21	21-21.5	21.5-22	>22	Tot.
Study-Install Ducted	3	4	1	7	1	3	0	1	0	0	0	0	0	1	21
Study-Install Multizone	0	0	0	0	0	0	0	1	0	2	4	0	0	10	17
Prior-Install Ducted	0	0	1	1	2	1	0	2	0	1	0	0	0	0	8
Prior-Install Multizone	0	1	1	0	0	3	0	2	1	0	0	2	1	0	11
Total	3	5	3	8	3	7	0	6	1	3	4	2	1	11	57

Table 15. Distribution of HSPF2 Ratings.

HSPF2	8-8.5	8.5-9	9-9.5	9.5-10	10-10.5	10.5-11	11-11.5	11.5-	Total
Study-Install Ducted	6	7	7	1	0	0	0	0	21
Study-Install Multizone	0	0	4	2	10	0	0	1	17
Prior-Install Ducted	1	1	2	3	0	1	0	0	8
Prior-Install Multizone	0	0	2	4	2	3	0	0	11
Total	7	8	15	10	12	4	0	1	57

Table 16. Distribution of EER2 Ratings.

EER2	8 - 8.5	8.5 - 9	9 - 9.5	9.5 - 10	10 - 10.5	10.5 - 11	11 - 11.5	11.5 - 12	12 - 12.5	12.5 - 13	13 - 13.5	13.5 - 14	Total
Study-Install Ducted	0	3	0	5	5	0	1	4	1	1	1	0	21
Study-Install Multizone	0	0	0	0	0	1	0	2	0	0	12	2	17
Prior-Install Ducted	0	2	0	1	0	0	2	2	1	0	0	0	8
Prior-Install Multizone	3	0	0	3	0	1	0	3	0	1	0	0	11
Total	3	5	0	9	5	2	3	11	2	2	13	2	57



6.0 Findings – Energy Use

This section details the research findings regarding site energy usage, including daily energy consumption and energy consumption as it varies with temperature. It is primarily focused on determining energy savings. Heat pump performance will be examined in more detail in *Section 7 Findings – Performance*.

6.1 Site-by-Site Performance

This section details the power and energy consumption at each site. Two approaches were used to calculate site annual energy consumption: field-installed metering data and utility-provided meter data. The field data provide finer resolution but was not fully usable at all sites. The utility interval data are presumed to be highly accurate but generally available only in monthly intervals. Both performance measurement approaches are useful and combining the two provides a fuller picture.

6.1.1 Daily Average Energy Consumption

The metered energy data per year are shown in *Table 17* for all the centrally ducted systems and *Table 18* for all the multizone systems. Since the data begin and end mid-year for each site and may contain some gaps, these data are presented as energy per day with the count of days.

Some of the ducted sites that stand out for comparatively high energy HVAC consumption are TAC 08, SNO 44, PLU 01, INL 44, CEC 02, and CEC 04. Among the multizone sites, TAC 11 and CEC 13 stand out.





Table 17. Ducted Systems Metered Energy.

	2022						2023						2024						2025					
	Whole House (kWh/day)	Heat Pump (kWh/day)	ER (kWh/day)	HP-ER (kWh/day)	Count of days		Whole House (kWh/day)	Heat Pump (kWh/day)	ER (kWh/day)	HP-ER (kWh/day)	Count of days		Whole House (kWh/day)	Heat Pump (kWh/day)	ER (kWh/day)	HP-ER (kWh/day)	Count of days		Whole House (kWh/day)	Heat Pump (kWh/day)	ER (kWh/day)	HP-ER (kWh/day)	Count of days	
CEC 01	-	-	-	-	0	-	-	-	-	-	0	-	30.9	14.2	7.4	21.6	104	-	43.5	22	12.2	34.3	86.1	
CEC 02	-	-	-	-	0	-	-	-	-	0	-	46.9	14.8	9.7	24.5	104.9	-	82.5	22.5	16.1	38.5	87		
CEC 03	-	-	-	-	0	-	-	-	-	0	-	28.8	8.7	4.5	13.2	106.5	-	36.2	14.8	6.4	21.2	89		
CEC 04	-	-	-	-	0	-	-	-	-	0	-	48.5	12.5	11.3	23.9	111.7	-	76.8	21.9	29.1	51	55.1		
CEC 05	-	-	-	-	0	-	-	-	-	0	-	26	8.2	5.9	14.1	107.4	-	39.6	13.4	13.4	26.8	83.1		
CEC 41	62.3	22.4	12.5	36	67.4	40.7	10.2	5.9	15.5	349.5	40.4	9.2	5.5	14.7	270.9	-	52.6	17.4	9.3	26.7	82.8			
INL 02	-	-	-	-	0	39	10.8	8.2	19	86.4	19.6	7.9	5.5	12.9	354.2	-	37.6	16	15.5	31.5	88.4			
INL 41	-	-	-	-	0	32.1	6.9	3.2	10.1	202.7	42.5	7.9	2.4	10.4	348	-	54.3	13.7	6.7	20.4	71.8			
INL 42	-	-	-	-	0	37.7	10.2	4.9	15.1	203.5	34.9	9.8	6	15.7	359.4	-	57	15.2	16.3	31.5	79.3			
INL 44	-	-	-	-	0	63	11.6	9.9	21.5	164.8	69.2	13.5	8.5	22	259.3	-	69.2	22.7	14.3	36.9	68.2			
INL 46	-	-	-	-	0	47	15.4	1.9	17.4	206.5	63.2	12.2	12.2	12.2	321.8	-	63.2	39.8	17.1	39.8	81.7			
PLU 01	-	-	-	-	0	-	-	-	-	0	-	66.4	21.6	2	23.6	177.6	-	80.1	42.9	5.1	46.4	64.6		
PLU 02	-	-	-	-	0	-	-	-	-	0	-	29.9	10.6	10.5	11.2	183.6	-	47.8	30.7	5.9	31.4	88.4		
PLU 03	-	-	-	-	0	-	-	-	-	0	-	69.1	14.4	1.3	15.7	177.3	-	83.2	39.7	1.9	41	77.5		
PLU 04	-	-	-	-	0	-	-	-	-	0	-	31.9	6.7	7.7	7.2	182.8	-	41.7	8.9	6.7	27	85.4		
SNO 41	-	-	-	-	0	16.9	4.7	0.5	6.7	114	15.1	4.6	7.4	5.2	345.4	-	26.7	9.6	7.4	11	73.9			
SNO 43	-	-	-	-	0	17.1	6.4	1.6	7.9	111	15.9	6.6	1.2	7.8	349.2	-	17.4	13.5	1.7	15.1	76.3			
SNO 44	-	-	-	-	0	50.9	11.5	6	17.5	93.3	28.6	13.3	7.3	20.6	316.1	-	34.8	20.9	16.4	37.3	81.6			
TAC 01	36.6	5.9	1.8	7.7	154.1	39.5	8.2	2.4	10.5	329.5	40.7	6.7	5.5	12.1	341.8	-	47.7	12	5	17	81.3			
TAC 02	36.6	6.9	1.8	6.5	211.6	34.3	7.1	1.9	8.4	335.2	35.7	7.8	1.3	9	161.7	-	-	-	-	-	-	0		
TAC 03	36.2	10.3	5.2	15.4	170.5	40.3	10.2	4.9	15.1	323.9	39.4	9.9	3.8	13.7	325.5	-	60.8	16.4	11.5	29.9	82.6			
TAC 04	26.9	2.2	3.2	7.7	65	27.9	6.6	3.1	9.7	319	27.1	6.5	2.8	9.3	344.2	-	37	10.3	6.3	16.7	87.6			



	2022	2023	2024	2025	2026	2027	2028	2029	2030											
TAC 05	28.2	7.2	3.4	10.6	96.1	30.3	8.9	1.5	7.4	351.6	28.2	5.2	0.9	4.5	332.5	27.2	10.7	3.4	14.1	85.1
TAC 06	35.5	7.6	3	10.6	95.8	32	8.5	2.3	8.2	341.3	32.4	5.5	2	7.2	341.5	45	11.2	3.5	14.6	88.1
TAC 08	-	-	-	-	0	53	19	2.8	21.8	329.6	49.8	17.2	2.8	20	341.5	66.3	34.8	5.7	40.5	52.3
TAC 09	23.5	11.6	2.7	14.4	17.6	69	6.9	1.7	8.6	332.3	19.9	6.6	1.9	8.5	336	24.8	10.9	2.6	13.5	84.5
TAC 10	57.6	25.9	4.1	30	17.4	42	12.5	2	14.5	318.2	34.7	11.8	1.8	13.6	336.1	49.8	22.3	3.9	26.2	87.6
YAK 01	-	-	-	-	0	-	-	-	-	0	58.9	19.4	3	19.5	253.4	70.5	33.1	3.7	33.1	83.8
YAK 61	-	-	-	-	0	-	-	-	-	0	54.2	18.9	3.8	19.8	299	71.2	21.6	3.4	23.4	84.4

Table 18. Multizone Systems Metered Energy.

	2022	2023	2024	2025	2026	2027	2028	2029	2030										
CEC 11	22.7	32.5	9.3	41.9	60.3	15.4	5.4	23.8	334.5	23.7	17.3	4.5	21.8	341.3	53.5	32.3	9.2	41.6	64.3
CEC 12	-	-	-	-	0	22.9	14.9	1.4	16.3	153.5	28.1	23	4.8	27.8	45.2	38.9	12.8	51.7	88
CEC 13	-	-	-	-	0	77	35.2	3.1	34.3	134.8	70.9	37.2	6	37.2	89.2	63.7	13.1	60.7	88.6
CEC 31	-	-	-	-	0	69.7	18.9	1.1	18.9	64.8	56	13.8	6	13.8	81	24.8	11.1	24.8	85.8
CEC 32	-	-	-	-	0	37.4	15.6	1.1	15.6	64.9	27.7	7.2	6	7.2	26.3	8.3	3.9	8.3	85.7
CEC 33	-	-	-	-	0	55.2	30.5	1.1	30.5	67.5	41.5	18.6	6	18.6	55.6	29.7	15.7	29.7	87
COL 30	-	-	-	-	0	-	-	-	-	0	32.2	9.8	9.5	15.1	51.6	19	15.7	25.7	84.6
COL 31	-	-	-	-	0	-	-	-	-	0	33.7	7.9	16.1	24.1	38.8	10.1	20.6	36.7	83.2
COL 32	-	-	-	-	0	-	-	-	-	0	28.3	3.1	8.3	12	53.6	17.1	37	37	76.1
COL 33	-	-	-	-	0	-	-	-	-	0	19.1	4.5	0.9	8.9	38	10.1	9.9	20	84.6
COL 34	-	-	-	-	0	-	-	-	-	0	19.7	9.3	2.4	11.7	59.8	10.7	31.7	42.4	59.6
COL 35	-	-	-	-	0	-	-	-	-	0	24	3.5	3.5	8.5	73.9	8.7	10.7	11.4	71.4
COL 36	-	-	-	-	0	-	-	-	-	0	32.2	7.9	6.6	8.5	-	-	-	-	0
COL 37	-	-	-	-	0	-	-	-	-	0	30.8	10.4	1.9	12.3	42.3	11.3	5.9	17.3	61.4

6.1.2 Heating Energy

Since HP heating performance was of particular interest, the weather-normalized energy consumption is tabulated in **Table 19** for centrally ducted and **Table 20** for multizone systems. The weather normalization was done by extracting the temperature-energy regression data for each home from RTERM, and re-calculating a full heating season using TMYx 2009-2023 temperatures for the nearest weather station. This approach allowed a site-level adjustment to a common weather basis and filled gaps from missing data to ensure each site was compared on an equivalent basis.

Data are presented for both the HP and known ER heat, as well as the whole home as measured by the installed metering equipment. Since the sites differ in size and weather, they are presented normalized per square foot and per square foot per heating degree day (HDD). HDD are determined for each site from a separate variable-base degree analysis performed on the metered data. While square footage and weather normalizations are two of the major drivers for measuring performance, they are incomplete and do not account for home heat loss or setpoint and occupant behavior differences.

One example that illustrates the benefit of this normalization is SNO 44. SNO 44 has much higher total use than the other SNO sites, but the home was significantly larger. On a per-square-foot basis, the energy consumption is on the lower end of the range of sites. Conversely, TAC 08 stands out for high HP energy consumption compared to the other the ducted TAC sites. Once adjusted for square footage, energy consumption remains high. Another example, in the multizone group, is TAC 21: the total HP and resistance heat energy consumption is toward the lower

end of the range; however once adjusted for the site's low square footage and mild Tacoma weather, the site is among the higher end of the range of energy per square foot, per heating degree day. A few sites – TAC 14 and TAC 16, for example – also stand out for having high whole-home energy usage, which is not accompanied by particularly high HP usage. Closer inspection of billing data reveals that these two sites had high non-HVAC base loads. Further exploration of those other end uses is outside the scope of this study. In all, normalizing the site data per square foot and per square foot heating degree day permitted more nuanced observations.



Table 19. Weather Normalized Consumption For Ducted Systems

ID	HP + ER kWh/yr	HP+ER kWh/yr/Sqft	HP+ER Watt-hour/Sqft/HDD	Whole House kWh/yr	Whole House kWh/yr/sqft	Whole House Watt-hour/sqft/HDD
TAC 01	2,880	1.61	0.52	9,146	5.13	1.64
TAC 02	2,414	1.73	0.55	8,057	5.77	1.85
TAC 03	4,011	1.64	0.52	9,776	3.99	1.28
TAC 04	2,679	1.54	0.49	6,808	3.91	1.25
TAC 05	1,930	1.00	0.32	6,725	3.47	1.11
TAC 06	2,213	1.29	0.41	8,108	4.72	1.51
TAC 08	5,295	2.57	0.82	11,730	5.69	1.82
TAC 09	2,169	2.10	0.67	4,564	4.41	1.42
TAC 10	4,073	2.86	0.92	9,268	6.50	2.08
YAK 01	5,443	3.78	0.89	13,745	9.55	2.24
YAK 61	4,642	3.28	0.77	15,892	11.22	2.64
PLU 01	7,044	6.25	1.40	15,775	14.00	3.15
PLU 02	5,416	4.81	1.08	8,731	7.75	1.74
PLU 03	6,227	5.52	1.24	15,931	14.14	3.18
PLU 04	1,557	1.38	0.31	7,703	6.83	1.54
CEC 01	6,148	2.79	0.65	8,180	3.71	0.86
CEC 02	6,890	3.87	0.90	11,813	6.64	1.54
CEC 03	3,745	3.00	0.69	6,718	5.38	1.25
CEC 04	6,338	8.07	1.97	11,640	14.83	3.62
CEC 05	3,949	3.00	0.73	6,600	5.01	1.23
INL 02	4,716	1.75	0.39	5,369	2.00	0.45
SNO 43	2,410	2.13	0.65	3,639	3.22	0.98
SNO 41	1,850	1.71	0.52	4,413	4.08	1.25
SNO 44	5,757	1.02	0.31	7,799	1.39	0.42
INL 41	3,303	2.08	0.47	10,017	6.32	1.42
INL 42	4,655	1.72	0.39	10,135	3.75	0.84
INL 44	7,642	2.32	0.52	13,205	4.00	0.90
INL 46	5,728	1.25	0.28	20,210	4.41	0.99
CEC 41	4,998	2.64	0.61	10,676	5.65	1.31



Table 20. Weather Normalized Consumption For Multizone Systems

ID	HP + ER kWh	HP+ER kWh/Sqft	HP+ER Watt-hour/Sqft/HDD	Whole House kWh	WholeHouse kWh/sqft	WholeHouse Watt-hour/sqft/HDD
TAC 07	4,967	2.46	0.79	10,193	5.06	1.62
TAC 21	4,283	4.41	1.41	6,899	7.10	2.28
CEC 31	3,945	3.91	0.96	14,208	14.10	3.44
CEC 32	2,103	1.86	0.43	6,630	5.88	1.36
CEC 33	5,165	2.46	0.60	10,598	5.06	1.24
COL 30	5,029	5.03	1.03	9,580	9.58	1.96
COL 31	7,231	7.23	1.48	9,114	9.11	1.86
COL 32	5,819	5.82	1.19	9,483	9.48	1.94
COL 33	2,566	2.57	0.52	5,855	5.86	1.20
COL 34	5,097	5.10	1.04	7,152	7.15	1.46
COL 35	1,421	1.42	0.29	10,010	10.01	2.05
COL 36	3,025	2.55	0.52	8,883	7.48	1.53
COL 37	3,586	3.74	0.76	8,221	8.56	1.75
COL 38	2,933	3.43	0.70	6,410	7.49	1.53
COL 39	3,786	3.29	0.67			
GEC 31	6,974	7.26	1.24	12,131	12.64	2.16
GEC 32	5,891	6.14	1.05	9,606	10.01	1.71
TAC 11	8,959	4.92	1.58	13,489	7.40	2.37
TAC 12	5,352	1.68	0.54	11,473	3.59	1.15
TAC 13	2,646	2.58	0.83	4,381	4.27	1.37
TAC 14	4,021	2.20	0.71	16,428	9.01	2.89
TAC 15	5,015	1.92	0.62	7,786	2.98	0.96
TAC 16	3,138	2.63	0.84	17,624	14.76	4.73
SNO 11	4,949	4.83	1.48	10,368	10.13	3.09
SNO 53	4,850	1.85	0.56	13,335	5.08	1.55
CEC 11	6,940	4.51	1.04	5,521	3.59	0.83
CEC 12	8,038	3.49	0.85	6,293	2.73	0.67
CEC 13	10,763	3.81	0.93	18,450	6.53	1.59



6.1.3 Cooling Energy

Cooling Season energy consumption is similarly weather-normalized and presented in **Table 21** and **Table 22**. Sites CEC 01-CEC 05 did not have sufficient cooling data for analysis. The data are presented as annual cooling total kWh, as well as normalized per square foot, and per square foot per cooling degree day (base 65°F). The cooling data

show a wide range of total and normalized usage. TAC 05, TAC 06, and CEC 32 are examples of sites where, in the exit survey, the occupant reported controlling the system manually based on individual preference. Unlike heating in the Northwest, cooling use is still relatively minor and it appears that many occupants discretionarily, manually controlled cooling output instead of relying on consistent automatic thermostat control.

Table 21. Weatherized Multizone System Cooling Energy

ID	Heat Pump kWh	HP+ER kWh/Sqft	HP+ER Watt-hour/Sqft/CDD	Whole House kWh	WholeHouse kWh/sqft	WholeHouse Watt-hour/sqft/CDD
TAC 07	828	0.41	1.31	3830	1.9	6.07
TAC 21	651	0.67	2.14	1954	2.01	6.42
CEC 31	737	0.73	0.91	5196	5.15	6.40
CEC 32	145	0.13	0.18	2424	2.15	2.95
CEC 33	880	0.42	0.52	2648	1.26	1.57
COL 30	930	0.93	1.02	2485	2.48	2.71
COL 31	1,476	1.48	1.62	2,529	2.53	2.77
COL 32	638	0.64	0.70	2444	2.44	2.67
COL 33	475	0.48	0.52	2131	2.13	2.33
COL 34	838	0.84	0.92	1871	1.87	2.05
COL 35				2013	2.01	2.20
COL 36	809	0.68	0.74	3575	3.01	3.29
COL 37	637	0.66	0.72	2527	2.63	2.88
COL 38	1,336	1.56	1.71	2,803	3.27	3.58
COL 39	153	0.13	0.14	966	0.84	0.92
GEC 31	169	0.18	0.75	1771	1.84	7.67
GEC 32	230	0.24	1.00	1750	1.82	7.59
TAC 11	815	0.45	1.44	2541	1.39	4.44
TAC 12	660	0.21	0.67	3250	1.02	3.26
TAC 13	332	0.32	1.02	1325	1.29	4.12

6.1.4 Heating Power vs. Outdoor



Table 22. Weather Normalized Ducted System Cooling Energy

ID	Heat Pump kWh	kWh/sqft	Watt-hours/sqft/ CDD	Whole House kWh	kWh/sqft	Watt-hours/sqft/ CDD
TAC 01	730	0.41	1.31	4157	2.33	7.44
TAC 02	371	0.27	0.86	3528	2.53	8.08
TAC 03	810	0.33	1.05	3572	1.46	4.66
TAC 04	626	0.36	1.15	2563	1.47	4.70
TAC 05	432	0.22	0.70	2594	1.34	4.28
TAC 06	459	0.27	0.86	2904	1.69	5.40
TAC 08	1,782	0.86	2.75	5,466	2.65	8.47
TAC 09	689	0.67	2.14	2004	1.94	6.20
TAC 10	930	0.65	2.08	3788	2.66	8.50
YAK 01	1,987	1.38	1.30	6,708	4.66	4.38
YAK 61	2,321	1.64	1.54	8,673	6.13	5.77
PLU 01	2,462	2.18	2.51	7,335	6.51	7.49
PLU 02	327	0.29	0.33	2070	1.84	2.12
PLU 03	1,151	1.02	1.17	6,178	5.48	6.30
PLU 04	913	0.81	0.93	3819	3.39	3.90
CEC 01						
CEC 02						
CEC 03						
CEC 04						
CEC 05						
INL 02	383	0.14	0.16	2268	0.84	0.97
SNO 43	485	0.43	1.83	1800	1.59	6.76
SNO 41	93	0.09	0.38	1159	1.07	4.55



Temperature

The researchers looked at the distribution of average power consumption, by temperature bin, for each HP in heating mode and the backup heat and residual power. **Figure 21** and **Figure 22** on the following pages show the average power of each HP plotted vs. outdoor temperature, in 5°F temperature bins. The data include both when the HP is on and when it is off. The power of the HP outdoor unit is blue; the power of indoor units and known ER heat is orange. Any temperature-dependent residual power is also included in gray. The temperature-dependent residual typically represents other electric heat sources not directly metered (such as plug in heaters), and is explained via an illustrative example in **Section 9 – Site-Specific Observations** and Illustrations. The data show a wide range of behavior in terms of the balance of HP outdoor unit operation and backup or other ER heating. The data also identifies for a given temperature if the HP meets the entire load or if additional backup ER or residual heat is needed. Some general trends are visible:

- Many sites – including TAC 03 through TAC 13, TAC 21, SNO 41, SNO 43, CEC 11, and CEC 13 – exhibit traits of HP heating with little or no substantial backup or auxiliary heating as outdoor temperature decreases. In these cases, the HP usage steadily ramps up as the weather gets colder, with proportional increases in blower fan and ER heat.
- Several sites, such as TAC 15, INL 02, SNO 44, and CEC 01, show HP usage that steadily ramps up in colder weather, but with substantial increases in blower fan and ER power below a certain temperature (e.g., the 20°F temperature bin for TAC 15).

This indicates regular second-stage ER heating.

- Data at several sites – including CEC 02, CEC 05, CEC 41, CEC 12, and INL 42 – show that in very cold temperatures the HP either cannot meet the load alone, or the unit controls limit the HP operation. In these cases, ER backup is used to meet the entire heating load. This may be caused by compressor lockout.
- A few sites present evidence of heating load met by unmetered auxiliary heat from non-electric sources used in the coldest of temperatures. In this case, the metered heating sources plateau, or decline, in colder weather. INL 44, INL 46, and CEC 31 are examples.
- Two sites, GEC 31 and GEC 32, had no directly metered ER heat, but the data show residual heating from plug-in 120V heaters associated with an extreme cold snap (discussed more in Section 9 – Site-Specific Observations and Illustrations.)
- A few sites, particularly several later additions, appear to experience a control or commissioning issue. For example, COL 31, COL 32, COL 35, and PLU 04 have limited or sporadic HP usage combined. In the case of the COL sites, there was high ER backup heat. PLU 04 confirmed in its exit survey to have continued extensive use of wood heating.

The researchers observed manufacturer-specific differences in how ER heat was used during defrost in centrally ducted HPs. Most systems only used ER for the defrost cycle, a duration often in the range of 1-3 minutes. By contrast, the data recorded on another unit showed the system regularly deployed



ER heat for up to 10 minutes per defrost call, which was substantially longer than the defrost cycle itself. Therefore, some systems show relatively high ER heat usage beginning around 35- 40°F. Further data analysis

supports that the usage is not caused by HP capacity, but rather is driven by the defrost cycle programmed operations.

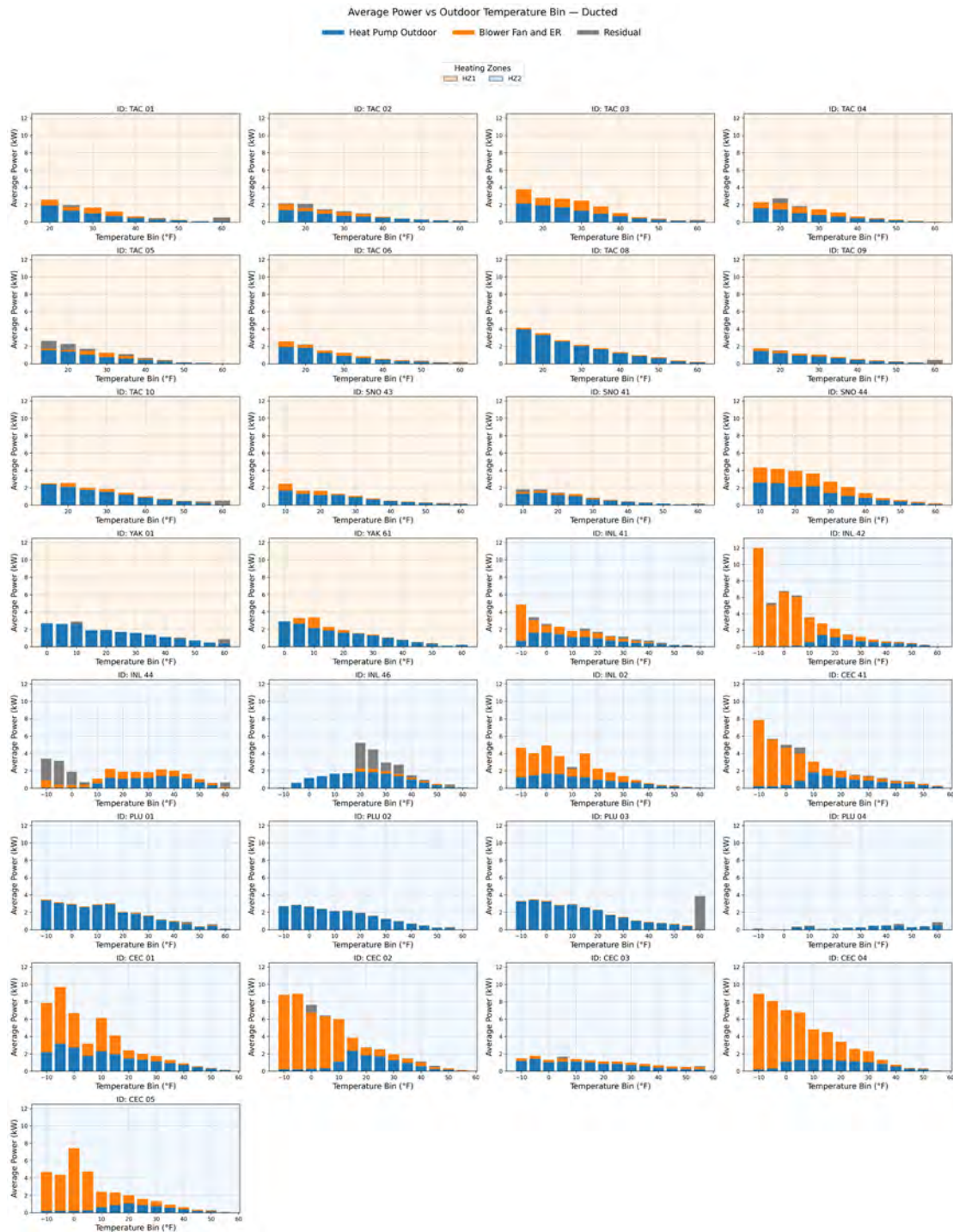


Figure 21. Average Outdoor Unit, Indoor Blower+ER, and Residual Power in Temperature Bins for Ducted Heat Pumps.



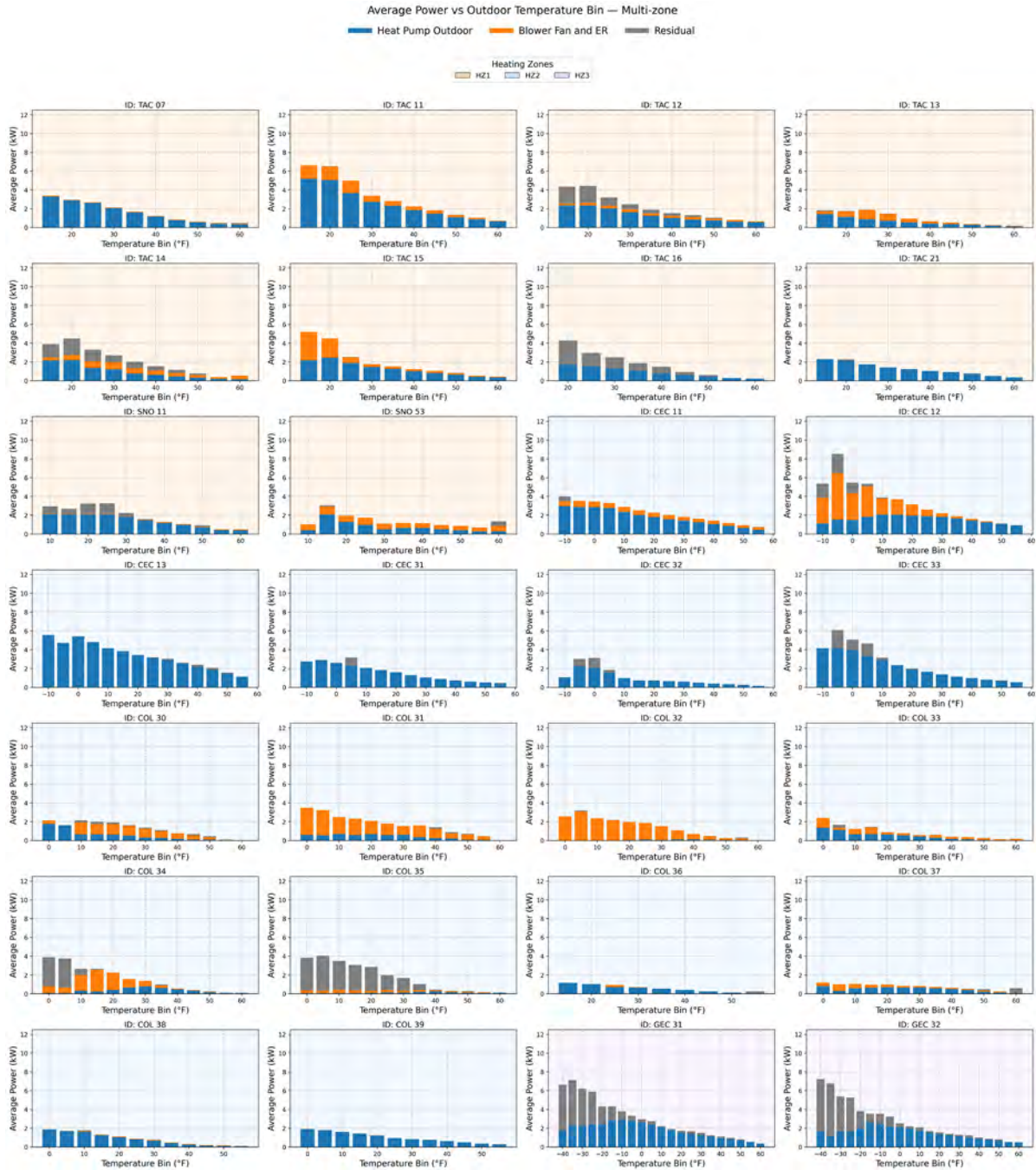


Figure 22. Average Outdoor Unit, Indoor Unit + ER, and Residual Power in Temperature Bins for Multi-Zone Heat Pumps.



6.1.5 Cooling Power vs. Outdoor Temperature

In cooling mode, the average power of the HPs is shown in *Figure 23* and *Figure 24*. Here, a few sites stand out: SNO 44 and INL 42 each reach an average power of 4 kW, SNO 44 reaching that level in the 85°F temperature range. INL 42 was noteworthy

for being a 4-ton system with a high measured indoor fan power (500 Watts while running was typical). INL 42 also had a thermostat schedule that pulled return temperatures down to 62°F each afternoon, and had a lower-than-typical measured supply temperature of approximately 40°F. Similarly, SNO 44 (a 5-ton system) had indoor fan power measured around 600 Watts. While

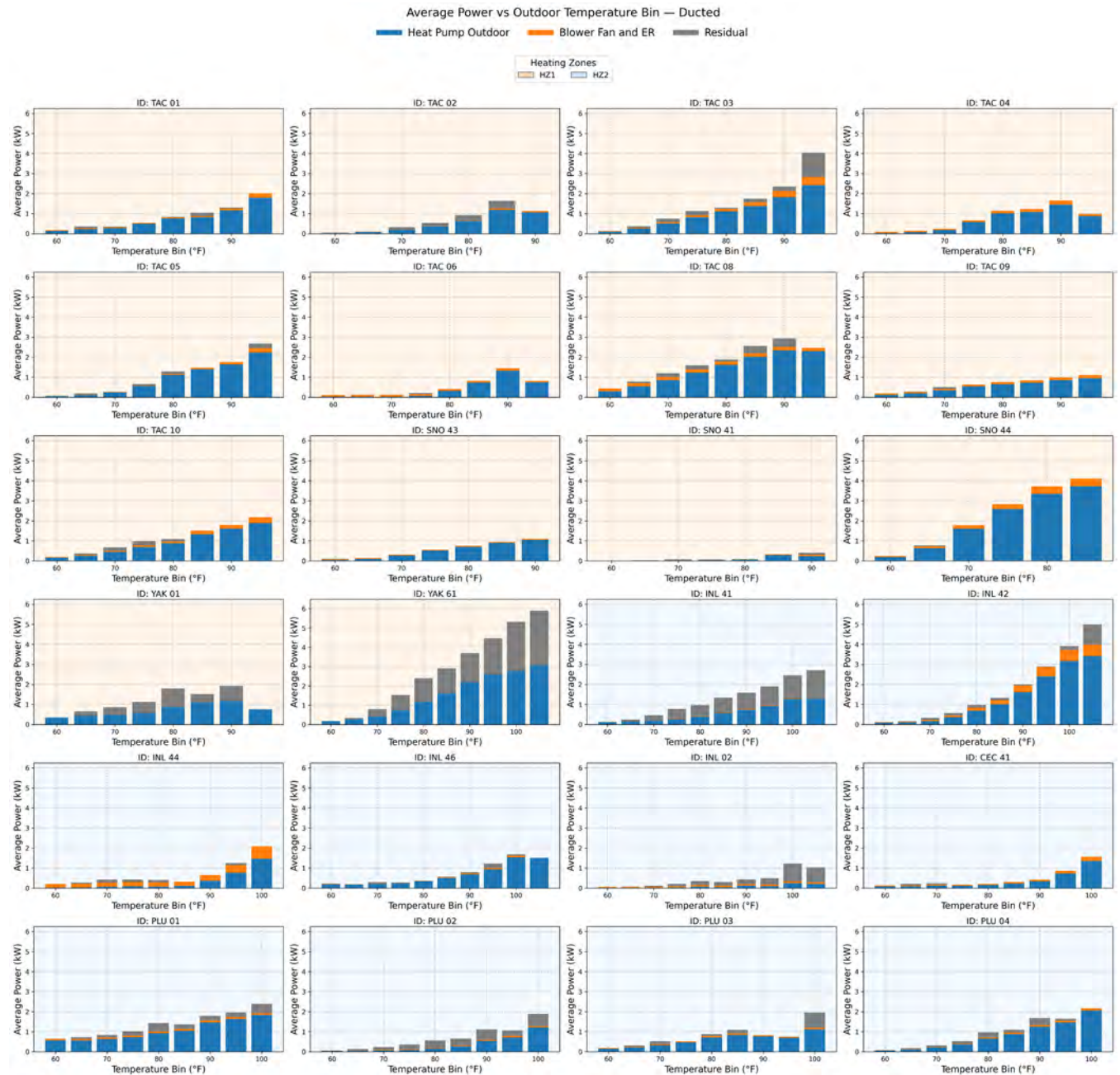


Figure 23. Cooling Mode Average Outdoor Unit, Indoor Blower+ER, and Residual Power in Temperature Bins for Ducted Heat Pumps.



this home did not appear to have a setup or very low indoor set temperature, it also had a lower-than-typical supply temperature in the range of 40–45°F. By contrast, other sites often had supply temperatures in the range

of approximately 50°F in similar conditions. INL 42 and SNO 44, both of the same product line, may have been set to prioritize comfort or low humidity. This conclusion could not be confirmed in exit survey data. YAK 01 and

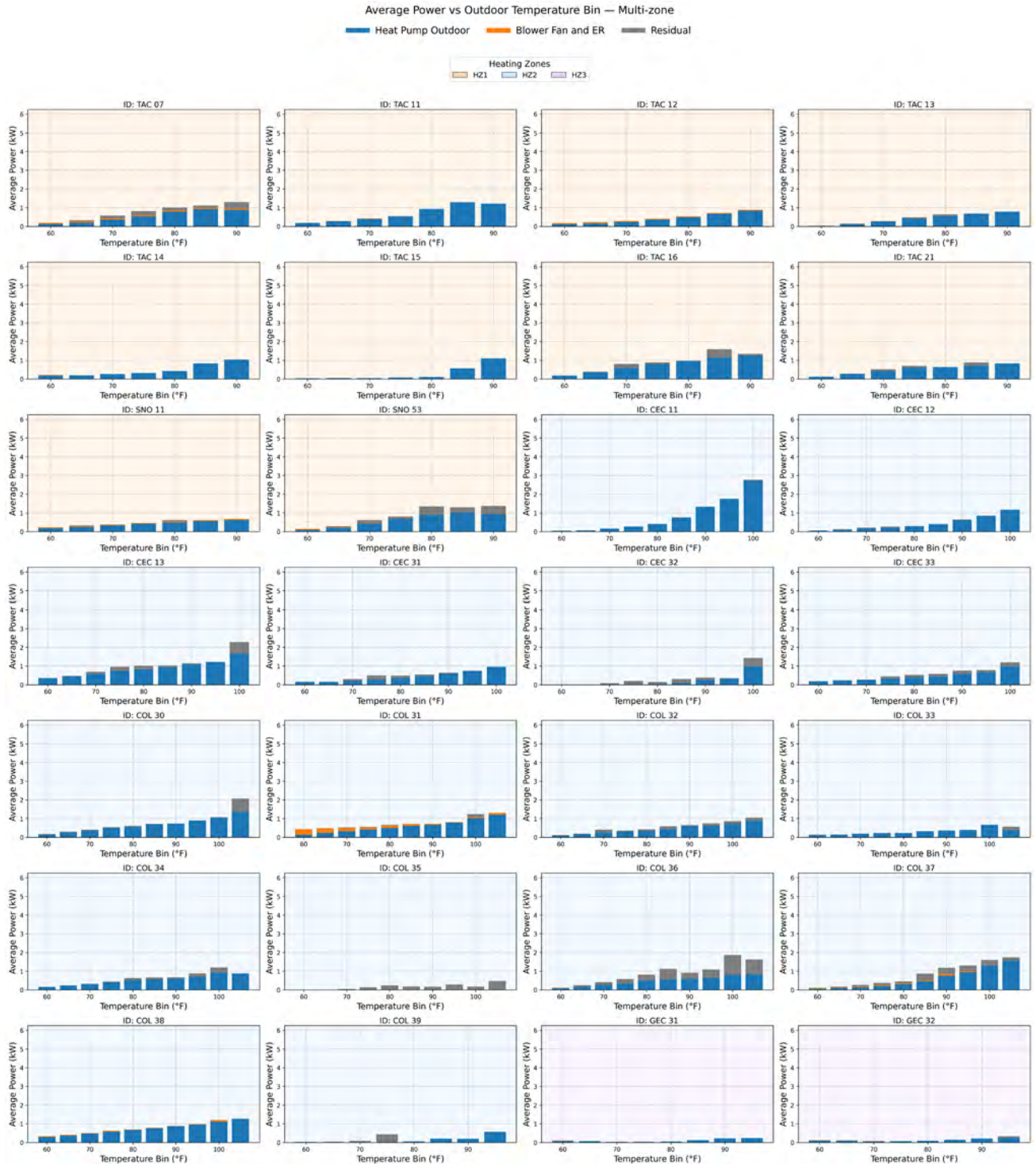


Figure 24. Cooling Mode Average Outdoor Unit, Indoor Unit + ER, and Residual Power in Temperature Bins for Multi-Zone Heat Pumps.



YAK 61 have residual power consumption that increases proportionately to warmer weather, likely indicating window units or similar. CEC 01, CEC 02, CEC 03, CEC 04, and CEC 05 were excluded from Figure 23 because they were installed late and did not record sufficient summer operations.

For the above graphs, the data are available in tabular form in *Appendix A*.

6.1.6 Interior Temperature

The average indoor temperature for each site was evaluated using available data for room temperatures or return air temperatures.

Figure 25 summarizes those findings. The graph also shows sites with clear setbacks. The daytime temperatures are shown with a filled dot while the nighttime temperatures are shown with a hollow dot. The exact set

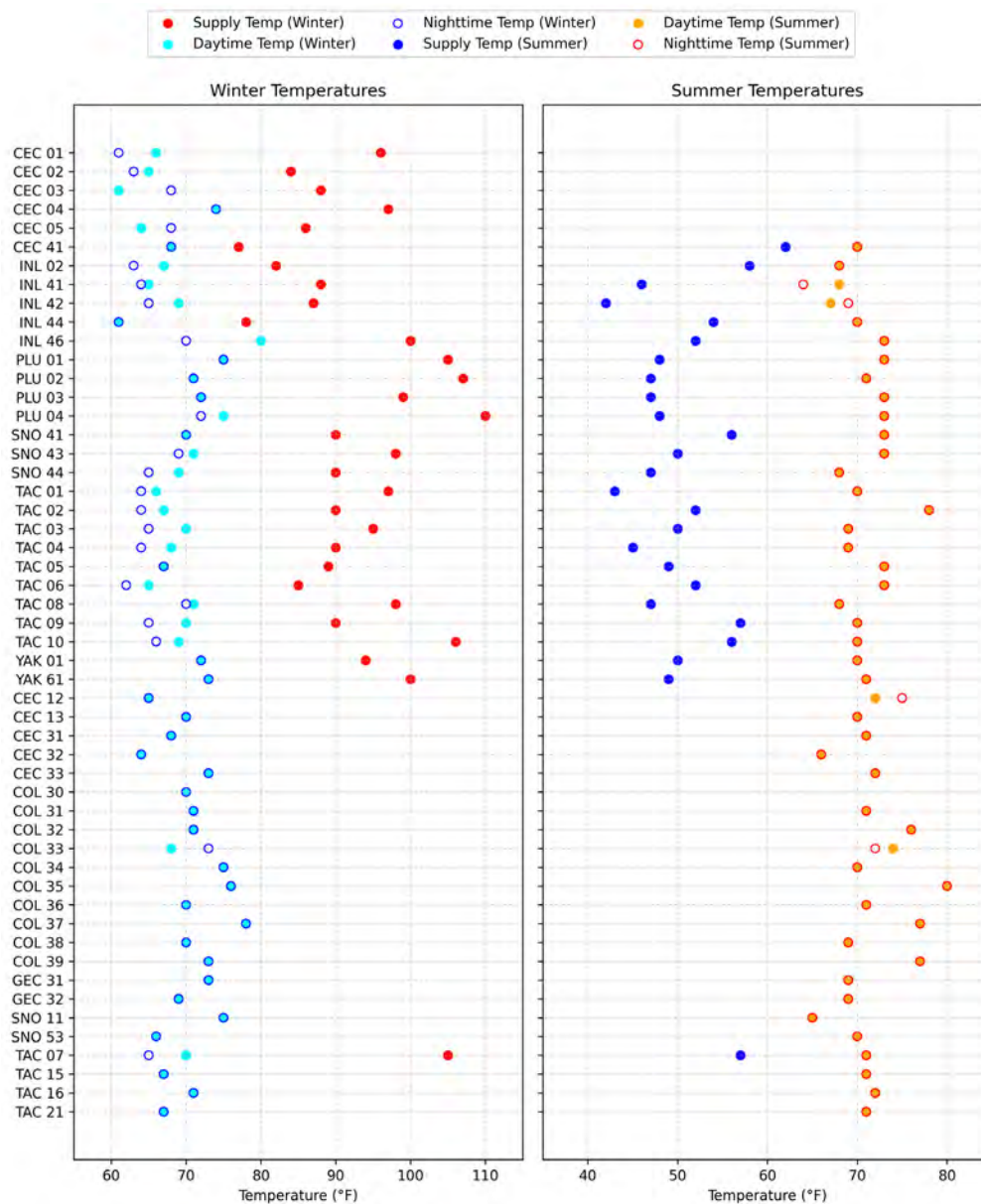


Figure 25. Indoor and Supply Air Temperatures (where available) for All Sites; Supply Temperatures Based on 25-35°F ODT bin for Winter and 85-95°F ODT bin for Summer.



temperature was not always apparent from the field data. For example, some winter daytime periods have a clear temperature plateau, slightly increasing in temperature over the day. During overnight periods, the temperatures appear to trend down without the system running until morning when temperatures increase, indicating that an actual setpoint for heating might not be reached. Site-by-site judgment was used to select representative temperatures and values.

The supply temperature is represented in Figure 25. At a given set of conditions, a system that provides hotter supply air in heating mode, or colder supply air in cooling mode, would presumably operate with a lower COP than the same system delivering more temperate air. To identify supply air temperatures on a common set of conditions, the researchers filtered data to include periods when the HP outdoor unit was on, but the sum of fan power and any ER heat was less than 1 kW (effectively filtering out backup heat). The researchers also filtered for outdoor temperatures in the range of 25-35°F in winter and 85-95°F in summer. This ensured a plentitude of data and that the systems were well within normal operating conditions. The results in Figure 24 show a wide range of supply temperatures. In heating mode, for example, five systems have supply air temperatures of 100°F or higher, while five have supply air temperatures of 85°F or lower.

6.1.7 COP-Based Savings Estimates

For the centrally ducted sites, the study directly measured the HP system output capacity (inclusive of both refrigerant system heating and ER). Therefore, total heating delivered to the home was known. Dividing by the measured input energy, it was then possible to calculate the efficiency, or COP.

This value provided a direct efficiency measurement of the system as operated. The researchers then calculated actual, seasonal average COP for each site by summing all the delivered heat and dividing by all the input energy. **Table 23** includes the seasonal average COP by site.

Table 23. Per-Site COP-Based Heating Energy Savings.

Site	Seasonal COP	Weather-Normalized kWh	COP = 1 kWh	Savings
INL 46	3.39	5728	19420	13691
TAC 08	3.02	5295	15987	10692
SNO 44	2.74	5757	15759	10002
TAC 02	4.17	2414	10057	7643
INL 42	2.61	4655	12148	7493
CEC 01	2.16	6148	13289	7140
TAC 03	2.76	4011	11072	7061
PLU 01	2	7044	14091	7047
CEC 02	2.02	6890	13925	7035
TAC 04	3.55	2679	9519	6841
YAK 61	2.35	4642	10918	6276
CEC 03	2.67	3745	9984	6239
TAC 06	3.69	2213	8175	5962
CEC 04	1.91	6338	12127	5789
PLU 03	1.9	6227	11817	5590
TAC 10	2.23	4073	9078	5005
TAC 09	3.3	2169	7155	4986
SNO 43	2.94	2410	7089	4679



One measurement of energy savings directly follows from COP calculation and is referred to as the COP-based savings method. It compares the measured performance of the metered equipment with a theoretical baseline delivering the exact same heat output. The researchers compared the measured heating output of the HP in the post-install period to a theoretical ER furnace (operated in an identical way) in the post-install period. Because both the ER COP and HP COP are known, researchers could calculate theoretical savings assuming equal heating. For instance, if the measured thermal output of the HP was observed to be 30 kWh over a day, and the metered COP for that day was 3, then the savings for that day would be 20 kWh. It is important to note a few key considerations with this approach:

- If a site that was not previously well-conditioned (and experienced cold spaces during winter) becomes more comfortable, this method may over-estimate savings because it assumes equal heating is delivered.

- This method does not consider the actual previous condition of the site, existing equipment, temperature set-points, or similar factors.
- If the HP and backup heat provided less-than-adequate heating in some conditions, this method assumes the baseline COP 1.0 system providing the same heating output.

For those reasons, the COP-based method should not be expected to equal the bill-based method, nor would it match a detailed pre-post monitoring set-up.

Table 23 shows the measured seasonal COP at each site, the weather-adjusted energy consumption (first presented in Section 6.1.2 – Heating Energy), the calculated kWh had all that heat been delivered by a COP of 1.0, and the energy savings associated with that difference.

Table 24 shows the same data, aggregated by heating zone. The average system COP,

Table 24. COP-Based Heating Energy Savings by Heating Zone

		HZ1	HZ2	Total
Heating Annual COP	Mean	2.89	2.17	2.52
	Std Dev	0.65	0.56	0.70
Heat Input (kWh/yr)	Mean	3,412	5,224	4,349
	Std Dev	1,412	1,624	1,759
Heat Delivered (kWh/yr)	Mean	9,395	11,618	10,545
	Std Dev	3,281	5,493	4,622
Heat Savings (kWh/yr)	Mean	5,983	6,394	6,196
	Std Dev	2,309	4,291	3,424
Count		14	15	29



weather normalized to TMYx 2009-2023 and inclusive of ER operation, is 2.5 with a standard deviation of 0.7 across 29 sites. The heat savings averages 6,200 kWh/y, with slightly more savings in HZ2 than HZ1.

6.2 Bill-Based Savings Estimates

The temperature-energy regression analysis of the site utility bills provides another estimate of energy savings (bill-based) by comparing pre-HP install heating estimates to post-HP install heating estimates. These estimates encompass the totality of occupant behavior, equipment efficiency, and operational settings. For example, changes in behavior across the pre- and post- periods can change the energy savings estimates. Specifically, the occupants may have kept the house warmer (or cooler) after the HP install. This would effectively lower the energy savings, but it would provide occupants with increased comfort. Because numerous independent variables can alter energy savings, a billing analysis is most suitable on large population samples. The research sites here are neither a random sample of the population, nor are they a large sample. Therefore, the results are informative but not necessarily representative. Further, temperature-energy regression is a more precise tool when used to assess utility bills in shorter data intervals. In some cases, electricity bills were available only on a bi-monthly basis. Such a low time resolution increased the analysis uncertainty by obscuring when seasonal heating ends and cooling begins.

Several sites were excluded from the billing analysis for the following reasons. GEC31, INL41, INL42, SNO41, SNO44, TAC21 had occupancy changes shortly before or after the HP install. At INL 44 and TAC12, solar PV panels were operating and only net-metered

bills were provided. The HP at INL46 served an unknown portion of a 4,500 ft² home.

6.2.1 Pre-Heating Energy

Understanding the nature of pre-heat energy use is a determinative factor in calculating site savings. The researchers were cautious in relying heavily on utility billing for attributing causation. Intuition suggests that a larger home would experience higher energy losses, all other things being equal. However, **Figures 26 and 27** demonstrate that conditioned floor area and heat loss rate are not correlated with the pre-heat annual consumption. The billing data suggests that a 1,200-square foot home could use 3,000 kWh or 13,000 kWh; size of the home was not predictive of heating energy in the pre-retrofit condition.

Table 25 shows that, considering all sites, pre-heating energy is nearly the same between the climate zones (note HZ3 is excluded because the two sites there do not constitute a large enough sample for comparison). This finding was perplexing (since HZ2 is colder than HZ1 and sites there should use more energy), until the research team considered alternate heat impacts. Using the participant surveys, the researchers categorized each site as burning none, some, or a significant amount (“lots”) of wood. Table 25 shows that those sites in HZ2 with lots of alternate heat use had significantly lower pre-heating electric use. Further, for sites with no significant alternate heating, the characteristics differ: the heating load is substantially lower in HZ2. Combined, these two findings demonstrate why the all-site, average pre-heat electricity is nearly the same. Last, even when the sites with lots of wood heat were excluded from a regression analysis, there was still no correlation between home size or heat loss and pre-heat electricity. Essentially, while the averages



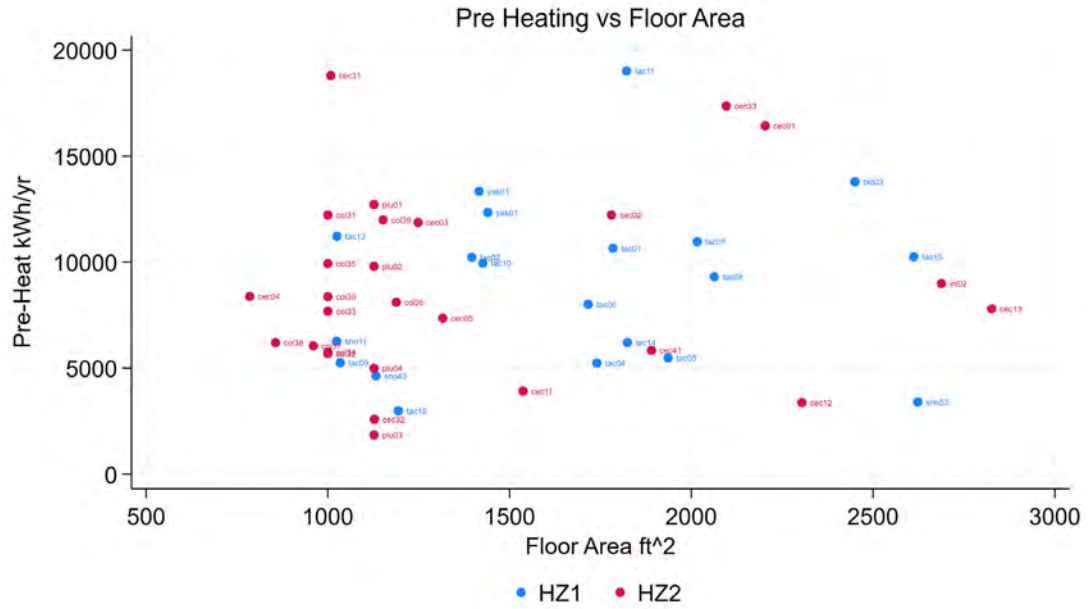


Figure 26. Pre-Study Heating Energy per year vs. House Square Footage

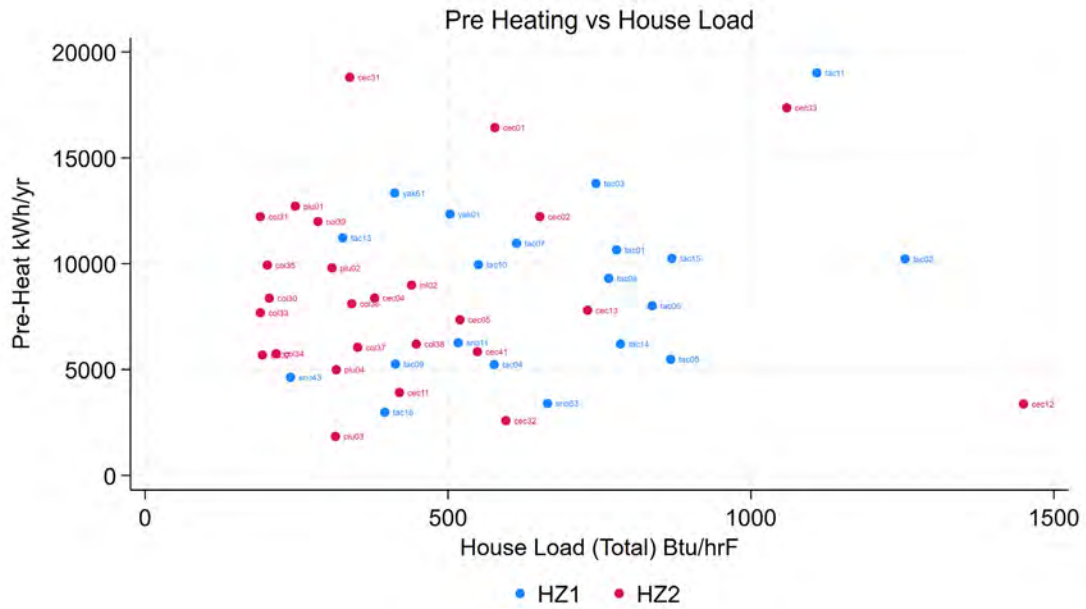


Figure 27. Pre-Study Heating Energy per Year vs. Calculated Heating Load.

Table 25. Pre-Condition Heating Energy from Billing

	Sites with no Alternate Heat		Sites with lots of Alternate Heat		All Sites	
	HZ1	HZ2	HZ1	HZ2	HZ1	HZ2
Floor Area (ft ²)	1634	1260	2623	1693	1684	1388
Heating Load (BTU/hr-degF)	661	341	664	673	661	443
Pre-Heat (kWh/yr)	9217	9552	3402	6846	8926	8751
n	19	19	1	8	20	27

tell a coherent story, there is still too much variation, driven likely by occupant operating choices, to consistently predict pre-heat electricity.

The figure supports the clearest finding from the utility bill analysis: the larger the pre-heat energy, the larger the heat savings. The data also hints at other findings, confirmed later, that the centrally ducted Study-Install saved the most energy over all the other categories. There are too few Prior-Install centrally ducted sites to draw any conclusions for that category.

6.2.2 Bill-Based Energy Savings

Figure 28 plots the weather normalized heat savings against the pre-heat annual energy use. Different colors indicate the HP type.

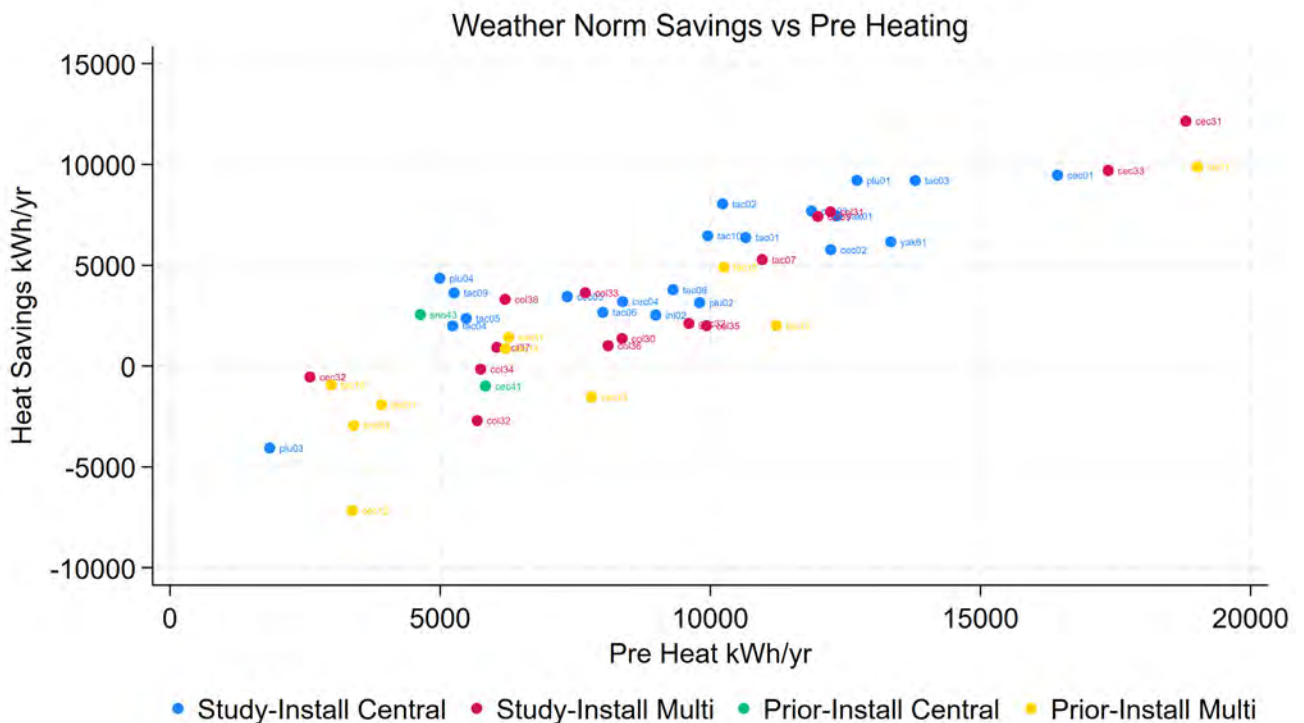


Figure 28. Weather Normalized Heat Savings vs. Pre-Study Heating Energy per Year.



Figure 29 shows a similar graph as Figure 28 except the color categories are now for alternative heat (i.e. wood stove). Those sites that burned a significant amount of wood experienced lower and sometimes negative

savings. Survey data indicate that, in some cases, participants reduced the amount of wood they burned, shifting a large portion of heating load from unmetered wood burning to metered, electric HP heating.

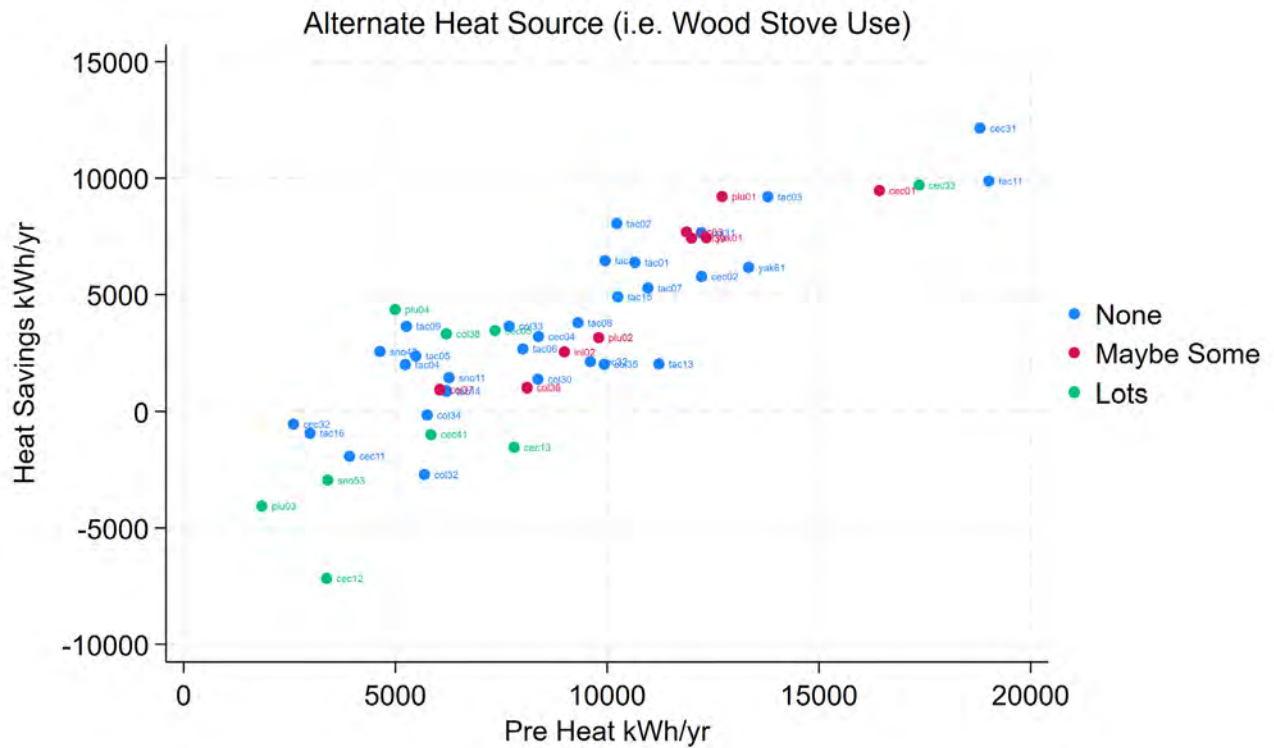


Figure 29. Heating Energy Savings and Alternate Heat Sources

Table 26. Pre-Condition Heating Energy and Heating Savings by System Type

	Pre-Heating kWh/yr			Heat Savings kWh/yr		
	Heat Pump Type			Heat Pump Type		
	Prior Install	Study-Install	Total	Prior Install	Study-Install	Total
Central Ducted						
Mean	4634	10222	9928	2555	5510	5354
Std. Dev		3083	3259		2620	2635
n	1	18	19	1	18	19
Multi-Zone Ductless						
Mean	8550	9057	8879	2322	3091	2822
Std. Dev	5518	4028	4464	3986	4064	3948
n	7	13	20	7	13	20



The sites that comprised the majority of the negative savings were associated with “lots” of wood burning. Restated, changes in wood use minimize electric savings. The sites that indicated occasional wood use (mostly for ambiance or sporadic) are indistinguishable from those sites that indicated no wood burning.

Table 26 shows the pre-heating and heat savings, excluding sites with significant wood burning, by install and HP type (Study-Install/Prior-Install, ducted/ductless). The data are weather normalized and span all heating zones. The researchers excluded sites with significant wood burning from this energy analysis to focus on the HP equipment behavior alone, without mixing in occupant fuel choice effects. The Table 26 results show what the equipment can do. Note that any region-wide program savings estimates would need to account for fuel choice.

Table 27 presents the heating savings for HZ1 and HZ2. Again, heavy wood burning sites are excluded. With the data sliced by HP install type and climate zone, there are relatively few sites in each cell making it more difficult to draw robust conclusions. Still, several trends emerge. First, the savings for Study-Install centrally ducted systems are greater than Study-Install multizone ductless installs. Second, the savings for Study-Install sites are greater than Prior-Install sites. The researchers suspect the screening of the Study-Install sites, focused on the presence of a high heat load, skewed that population toward sites with greater savings opportunity while the Prior-Install sites may have included a wider pre-heating range. The HPHC HP characteristics (and even sizing) were similar between Study-Install and Prior-Install sites. Third, savings in HZ2 is generally the same or lower than HZ1 because the HZ2 sites have a lower heat loss rate and used more wood heat in the pre-period.

Table 27. Heating Savings by Heating Zone and System Type.

	Heat Savings HZ1 kWh/yr			Heat Savings HZ2 kWh/yr		
	Heat Pump Type			Heat Pump Type		
	Prior Install	Study-Install	Total	Prior Install	Study-Install	Total
Central Ducted						
Mean	2555	5285	5058		5862	5862
Std. Dev		2494	2505		2975	2975
n	1	11	12	0	7	7
Multi-Zone Ductless						
Mean	3028	5283	3350	-1915	2981	2573
Std. Dev	3857		3623		4385	4413
n	6	1	7	1	11	12



In summary, for the bill-based comparison, the Study-Install centrally ducted sites in HZ1 with floor area of ~1,700 ft² and a heating load of 660 BTU/hrF saved approximately 5,000 kWh/yr. In HZ2, the size was ~1,400 ft², the heating load 440 BTU/hrF, and the savings 5,900 kWh/yr. Of further interest, the results show all the centrally ducted sites saved 50% of the pre-heating energy while the multizone ductless sites saved 30% (Table 26).

6.3 Savings Discussion

This report presents two approaches for estimating energy savings at the centrally ducted sites: bill-based and COP-based. Given the lack of correlation in the billing data energy use with heating load or conditioned floor area, the researchers urge caution when using those results. Since this was an engineering-based research study into

the measured operation of HPHC HPs, the COP-based savings estimates provide the measured and most useful insight of system efficiency.

Figure 30 plots utility bill savings and COP calculated savings estimates against one another. The figure suggests little correlation between the methods. This is unsurprising given that participant operating factors drive energy consumption. COP-based savings are always positive because all the sites have efficiencies well above one. The two sites with negative bill savings had increased electricity usage for the same reason: the surveys show both CEC 41 and PLU 03 switched from burning lots of wood to less wood. While the annual COPs at those sites were relatively low at 1.6 and 1.9 respectively, some energy savings would still be expected if the previous heating was only delivered with ER.

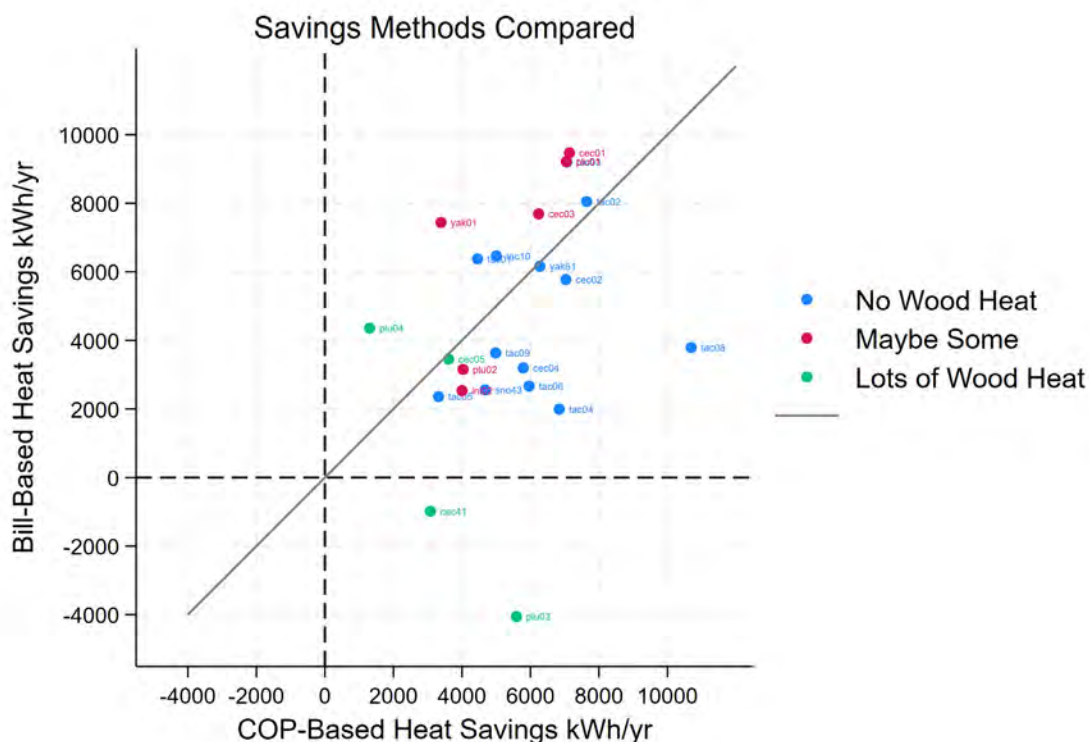


Figure 30. Energy Savings calculated with Bill Savings and COP Savings.



Table 28 presents the averages of the two savings approaches by heating zone. On average, across all the centrally ducted sites, the COP-based savings are 20% higher. The researchers inferred that occupant activities “take-back” 20% of the potential savings offered by HPHC HP equipment. This likely includes changes in fuel preference and operating choices.

Table 28. Bill-Based and COP-Based Savings Compared

		HZ1	HZ2	Total
Exclude Wood Burning	Bill-Based Heat Savings (kWh/yr)	5,058	5,862	5,354
	COP Based Heat Savings (kWh/yr)	5,859	5,898	5,873
	Count	12	7	19
Include Wood Burning	Bill-Based Heat Savings (kWh/yr)	5,058	3,981	4,543
	COP-Based Heat Savings (kWh/yr)	5,859	4,988	5,442
	Count	12	11	23

7.0 Findings – Performance

Heat pump performance is defined by its heating output (capacity), input power, and efficiency. All three metrics are important. Capacity, which varies with outdoor air temperature, determines the equipment’s ability to keep the building comfortable. Input power, at any given

condition, determines how much electricity the equipment draws from the grid. Efficiency refers to the ratio of useful heating output to the total electrical energy input required to produce that heat.

The following sections summarize performance-related findings over a range of outdoor temperatures, seasonal averages (including site-level seasonal COP and a weather-adjusted, field-observed efficiency represented as HSPF2), and comparisons to expected values from the NEEP database. Outputs from this analysis are used in subsequent regressions to determine the parameters that influence efficiency, energy savings, and improve grid capacity (see *Section 9 – Site-Specific Observations and Illustrations*).

7.1 Measured Input Power, Heat Output, and Efficiency versus Outdoor Temperature

This section documents how systems performed in different outdoor temperatures. For centrally ducted systems, the researchers

Importance of Finding High Performing Equipment

In this study, we seek to find efficient heat pumps and understand what makes some heat pumps more efficient than others. Examining efficiency in this context is critical because a given site may have yielded low energy savings but the equipment efficiency could remain high. Low site-specific heat pump savings is not indicative of poor equipment, Savings may be low because of changes in wood use habits, occupant behavior, low pre-heating energy, or other variables. Our goal is to identify high-efficiency equipment, its characteristics and prioritize those models for inclusion in efficiency programs.



measured input power, heat output capacity, and calculated efficiency as COP. For multizone systems, they only measured input power and other metered ER heat sources.

GRAPH OVERVIEW:

Data is shown in box-and-whisker plots:

- **Gray Box** = middle 50% of values
- **Black Line** = median
- **Whiskers** = 5th to 95th percentile
- **Dots** = 1-minute samples
- **Green** = HP only
- **Purple** = HP + ER
- **Orange** = ER only

Four sample operating behaviors demonstrate different system performance and operations. The examples support the interpretation of the graphs throughout. All the available performance data is shown in *Section 7.1.5 – All Sites*.

FOUR SAMPLE OPERATING BEHAVIORS:

- TAC 09: A high efficiency system that closely matched its rated performance and did not use ER heat.
- TAC03: A system that was consistent with NEEP ratings in mild weather, but in colder conditions its performance dropped slightly. ER was used during defrost and thermostat setback recovery.
- CEC 04: A system that aligned with NEEP ratings in HP only mode, but needed ER heat supplement in colder weather. The capacity, power, and COP suggest a lack of sufficient capacity in the approximate range of 10-20°F.
- INL 02: A system that frequently used ER in operations and in response to thermostat setback recovery, and had a particularly large ER element.

7.1.1 TAC 09: Heat Pump Heating with No ER Heat in HZ1

Figure 31 illustrates the delivered capacity (left), power (middle), and calculated COP when on (right) at TAC 09 in 5°F temperature

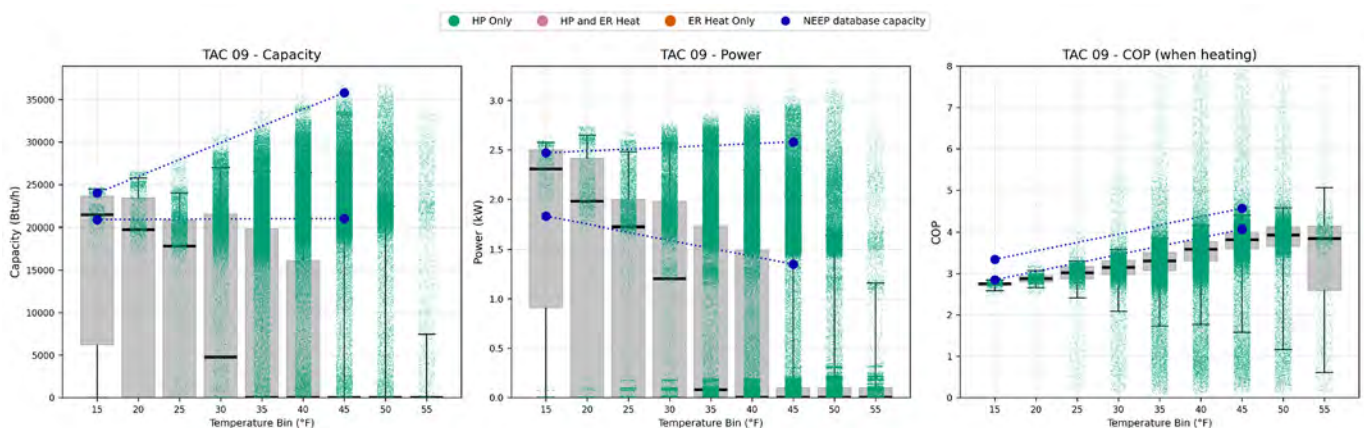


Figure 31. Capacity, Power and COP (when heating) at TAC 09.



bins. The power and capacity data include all data: when the system is on, defrosting, or off. The COP data, however, only includes when the system is delivering heat (since a COP cannot be computed for a system that is off). The data are represented by a box-and-whisker plot, for which the box represents the middle 50% of the data: the median is shown as a bold black line; the box below the median represents the second quartile; and the box above the median represents the third quartile. The whiskers extend from the 5th percentile to the 95th percentile (meaning, for example, that 5% of the dots are above the upper whisker). The large blue dots and associated dotted lines show the system capacity, power, or COP as found in the NEEP database for maximum and minimum capacity. Each small green, purple, or orange dot on the plot represents one minute of measured data. At TAC 09, there was no metered backup ER heat, so just green HP-only values are plotted. The capacity graph illustrates that the system was usually off (at least 75% of the time, as indicated by the entire box being at zero) for outdoor temperatures 45°F and higher. When it did run, the capacity was in the range of the NEEP data, with a higher concentration toward the low end of that range. System capacity increased with decreasing outdoor temperature. However, even in the 20-25°F

temperature bin, the system was still off about 25% of the time, and when on was delivering heating capacity in the relatively narrow range of 20-25,000 BTU/h (in close agreement with the range expected from NEEP data). In the power graph, similar observations can be seen. The COP is very close to, but slightly below, the expected range based on what is presented in the NEEP database. Overall, this shows a system operating at high efficiencies and very close to the manufacturer’s claimed performance, using no ER heat.

7.1.2 TAC 03: Heat Pump Heating with Modest Use of Larger ER Elements in HZ1

The graphs in *Figure 32* again show capacity, power, and COP in the same format for TAC 03. In this case, the system used some ER heat. From detailed observation, resistance heat was used in two scenarios: during and surrounding a defrost (to avoid delivering cold air to the space) and, in some cases, in response to a thermostat setback recovery. For this product line, the researchers observed across several sites that the defrost control strategy included running the ER heater for several minutes longer than the duration of the actual reverse-cycle defrost.

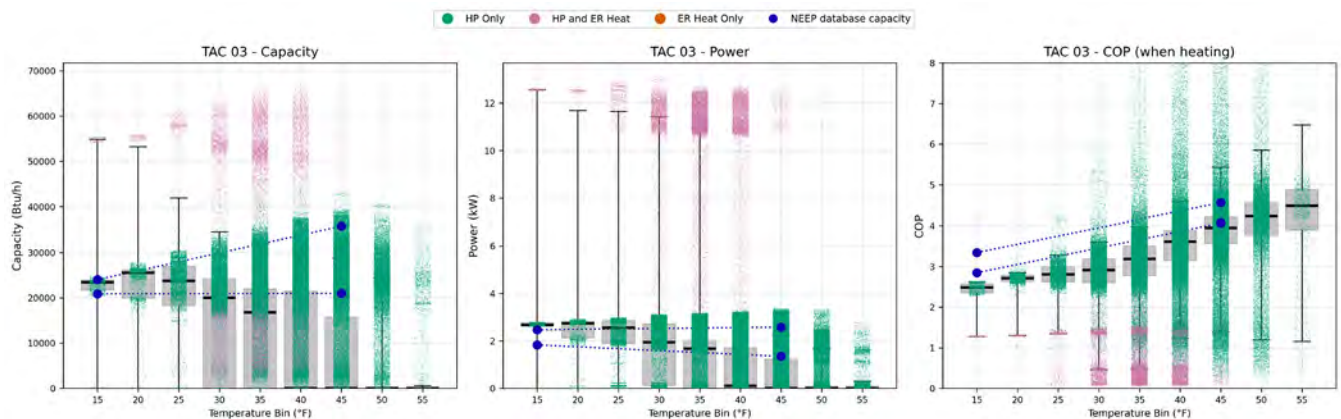


Figure 32. Capacity, Power and COP (when heating) at TAC 03.



The capacity, power, or COP when both the HP and ER heat are running are shown with purple dots. In Figure 31, the purple dots can be seen both above and below the main cluster of delivered capacity, starting first in the 40-45°F temperature bin. This often reflects defrost, where the measured capacity varies quickly in response to the compressor reversing cycle (capacity is briefly low) and through the continuation of ER heating after the defrost has ended (capacity is higher than HP only). There is also a small amount of ER heating in the 15-20°F and 20-25°F temperature bins, although in both bins the majority of the measurements are HP-only heating, and there is still a meaningful amount of off time. For TAC 03, the system COPs again reflect fair agreement with the NEEP data, particularly in milder weather, and are slightly below the claimed performance at colder temperatures.

7.1.3 CEC 04: Possible Low Temperature Heat Pump Lockout

The same format is used for site CEC 04 in *Figure 33*. This site also includes periods of time where the HP did not run, but ER heat was on; these are shown with orange dots in addition to the green (HP only) and purple (HP with ER heat). In this case, the data show a modest amount of HP with ER, and a small amount of ER only, in the 20-40°F temperature range, with a substantial increase in the 10-20°F range, and nearly no HP-only operation beginning in the 0-5°F bin and below. This might indicate a compressor lockout.

The capacity, power and COP data for this site show, when operating in HP only mode, the system was able to deliver the expected capacity and COP. However, the increasing reliance on backup heat (>25% of the time starting in the 15-20°F bin) suggests that the system did not have the full capacity needed to meet the load below those temperatures.

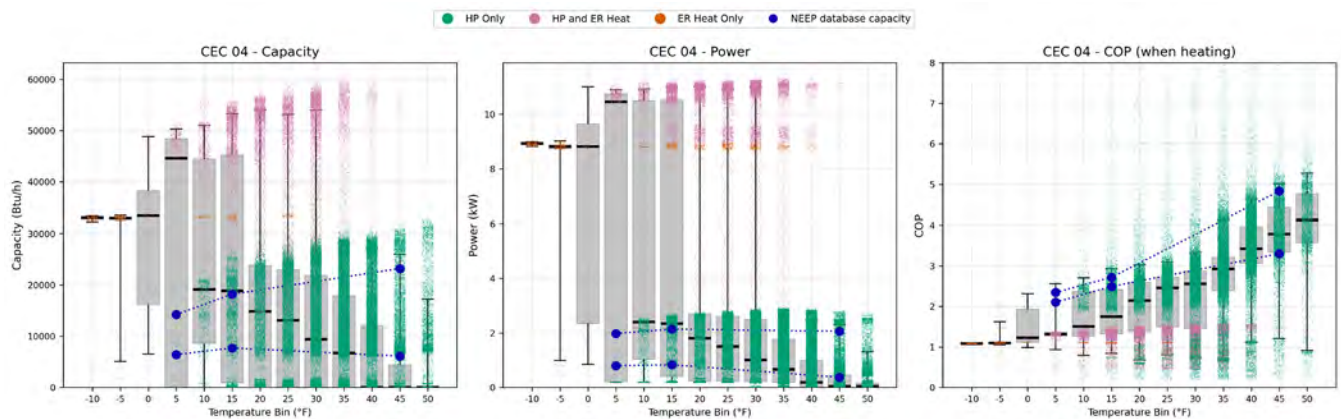


Figure 33. - Capacity, Power and COP (when heating) at CEC 04.



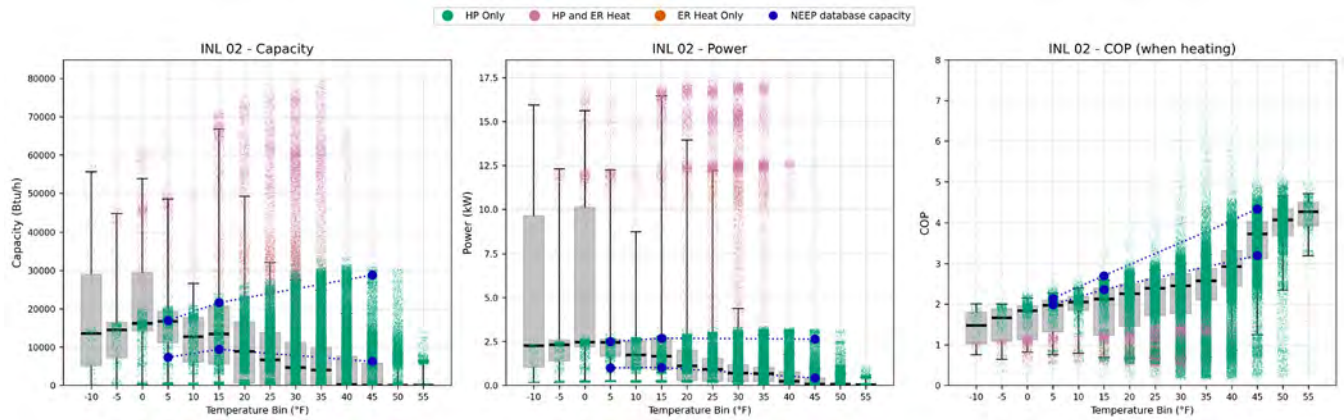


Figure 34. Capacity, Power, and COP (when heating) at INL 02

7.1.4 INL 02: High HP Capacity, Higher Power ER Heat, Cold Weather

Data of INL 02 are shown in *Figure 34*; this site interestingly uses a large ER element that operates fairly frequently. In HP-only mode, the capacity matches the NEEP data. However, ER heat at this site is significantly higher-power and higher-capacity than the HP alone can provide. Figure 34, displaying the delivered capacity at this site, shows the median delivered heat gradually increasing with decreasing outdoor temperatures until approximately the 5-10°F bin. In the 0-5°F bin and lower, the delivered capacity slightly

decreases, possibly suggesting wood. This site shows a substantial gap between the majority of the delivered heating capacity and the less-frequent but very high-power backup heat usage. For instance, in the 5°F bin, the combined system is still delivering less than 20,000 BTU/h of capacity and using less than 2.5 kW of input power combined more than 75% of the time. However, the backup element is using an additional 10 kW with some regularity. In a case like this the performance may have significantly improved by using a smaller or staged backup heater – or by not using a thermostat setback.

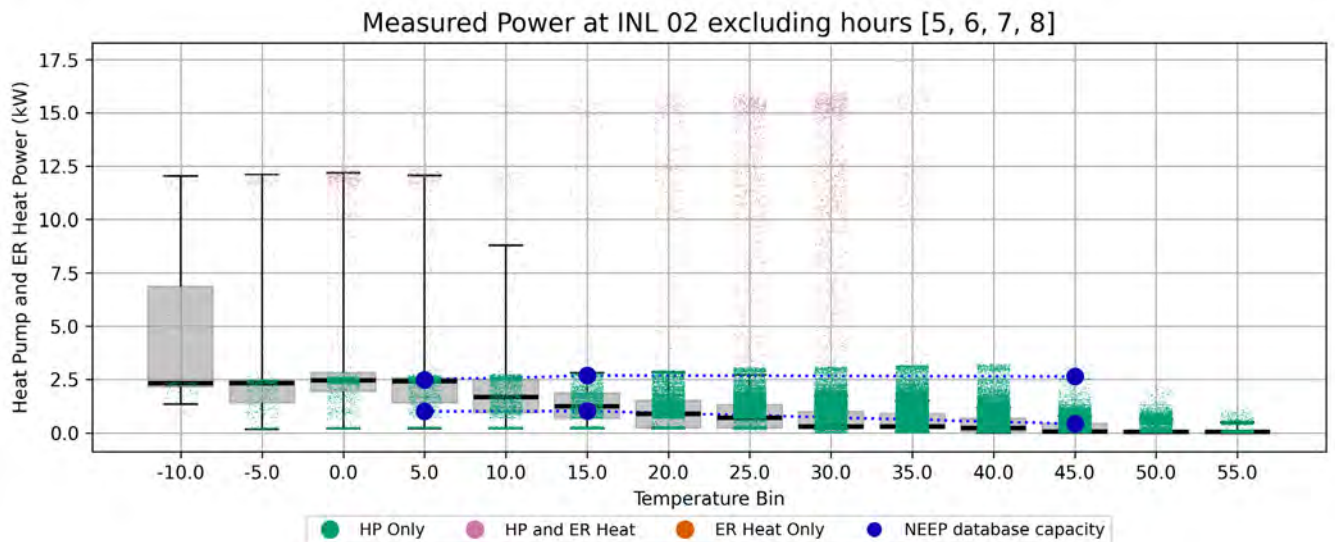


Figure 35. Power at INL 02 excluding the hours of 5:00 AM to 8:59 AM.

At INL 02, the high ER heating issue described above is almost entirely explained by thermostat setback recovery. **Figure 35** shows the power for that system, with a filter applied to remove data from 5:00 - 8:59 a.m., which reflects the window of time for thermostat setback recovery. This filtered graph shows a substantial reduction in ER heat usage, with the majority of the ER heat in milder temperature bins no longer present.

7.1.5 All Sites

The following several graphs (**Figures 36-39**) show the same graphical format for all sites. The sites are sorted into centrally ducted sites (which have capacity and COP as well as power) and multizone sites (power only).

Some trends that may be observed in those graphs include:

- Several sites appear to have compressor lockouts, set at the thermostat, which manifest in the data as a tight cluster at a fixed power level and COP of 1. CEC 02, CEC 04, CEC 05, CEC 41, and INL 42 appear to exhibit this behavior.
- Site INL 44 had second stage gas heat, which was not directly metered in the project instrumentation; this creates the appearance of exceptionally high capacity and COP during cold conditions, and can be seen in the near-zero power consumption in the 10°F and lower temperature bins.
- A number of sites have little or no resistance heat usage. CEC 03, PLU 01, PLU 02, PLU 03, PLU 04, TAC 08, TAC 09, and YAK 01 show little or no ER heat.

- Many sites have HP-only power which is regularly higher than the levels estimated from the NEEP database.
- Among the multizone systems, several stand out for having a significant amount of regular metered ER heat usage across the range of outdoor temperatures. CEC 11, CEC 12, SNO 53, TAC 11, TAC 12, TAC 14, and TAC 15 stand out in this respect. It is suspected that this usage reflects distributed, locally controlled zonal heaters which have not been adjusted and may compete with the HP to run.

Several of the sites that were installed later in the project, including COL 31, COL 32, and particularly COL 35, appear to have had some issues related to system commissioning or control settings, and ran with significant use of their pre-existing ER heat for long durations because the heat pumps were not operating properly. COL 35, for example, was observed to operate only the ER during the winter of 2024-25, meaning most of the winter data collected at that site were for ER-only operation.



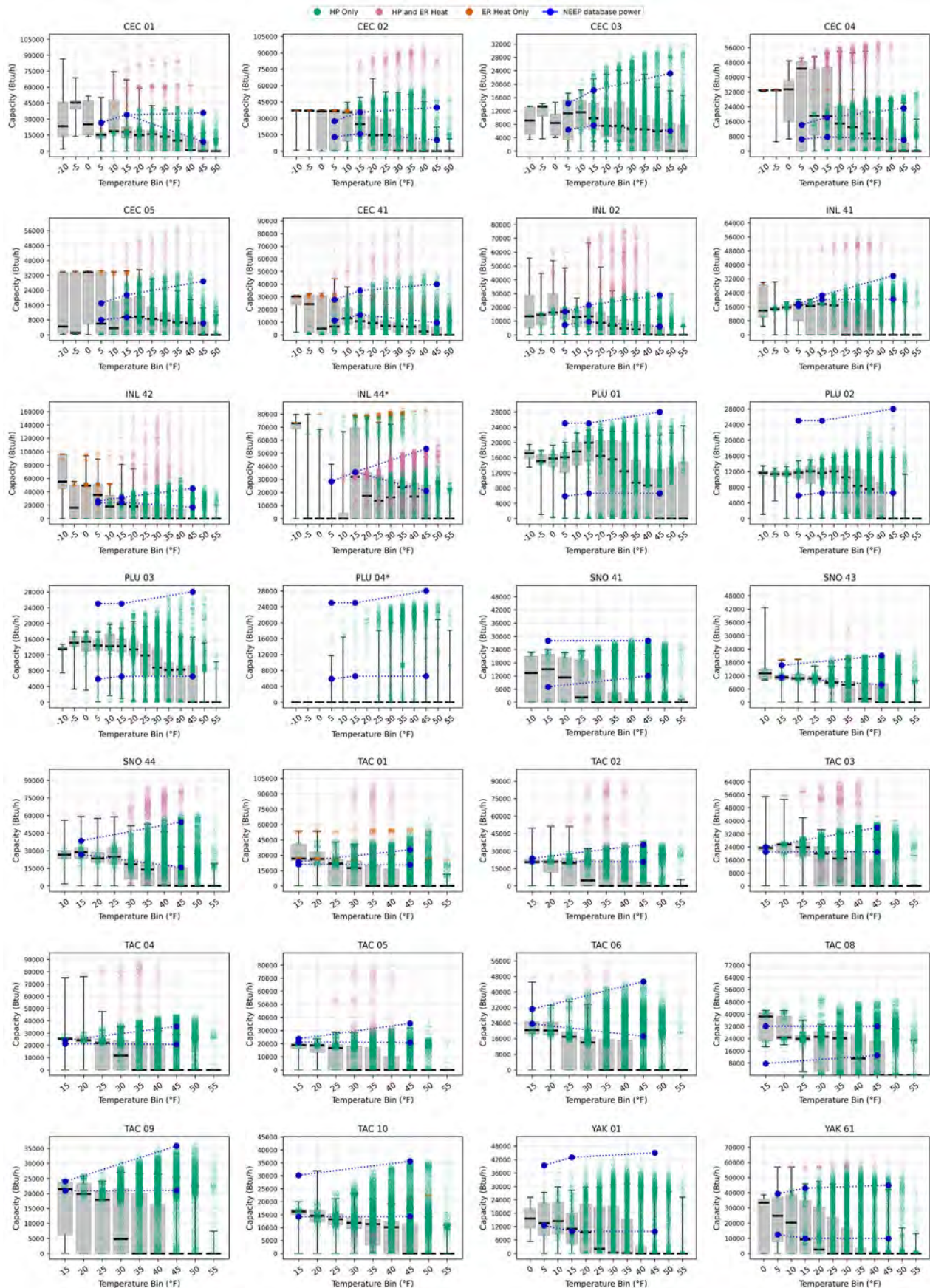


Figure 36. Ducted Heating Capacity Box-and-Whisker Plot, 1-Minute Interval



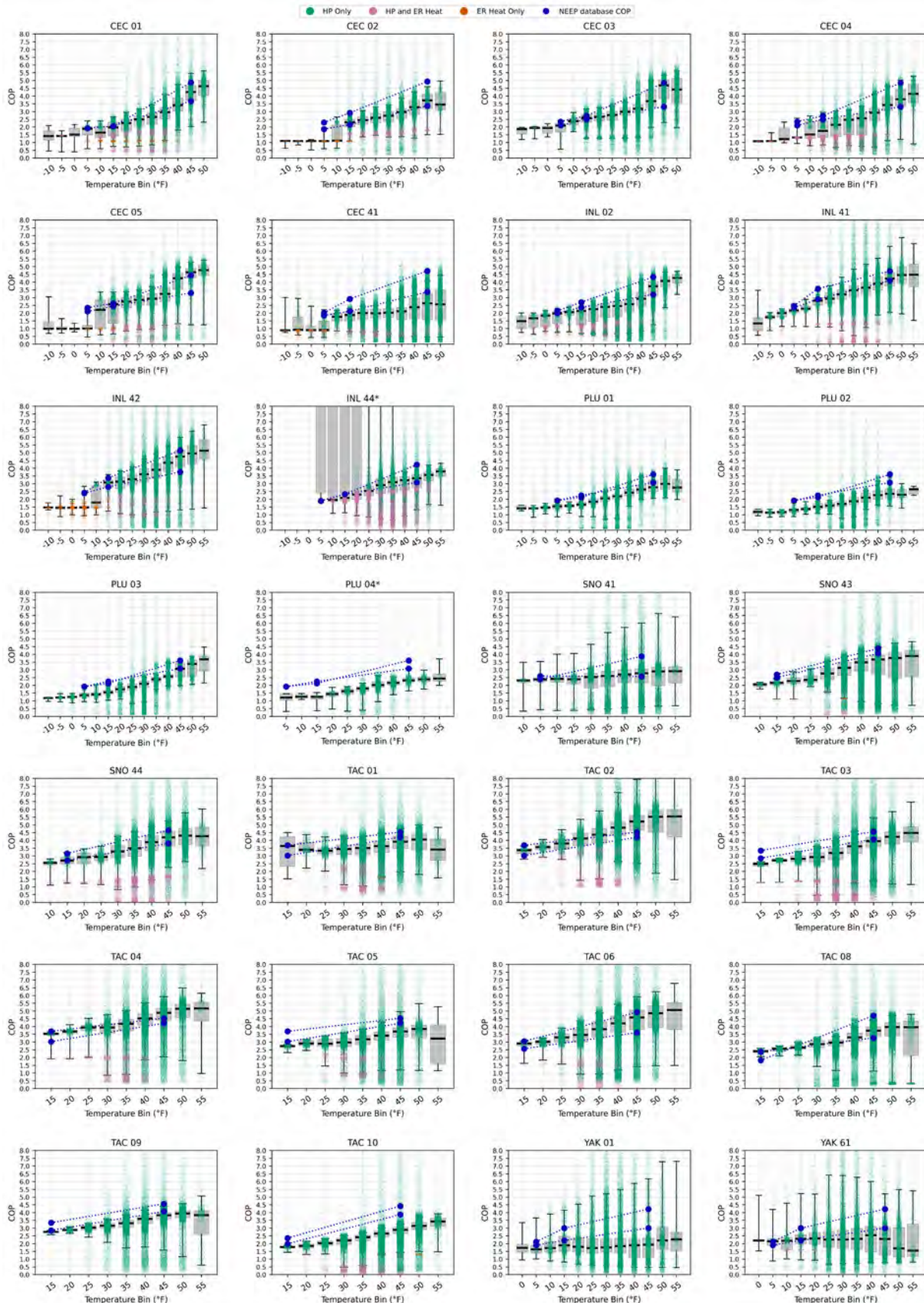


Figure 37. Ducted Heating COP Box-and-Whisker plot, 1-minute Interval.



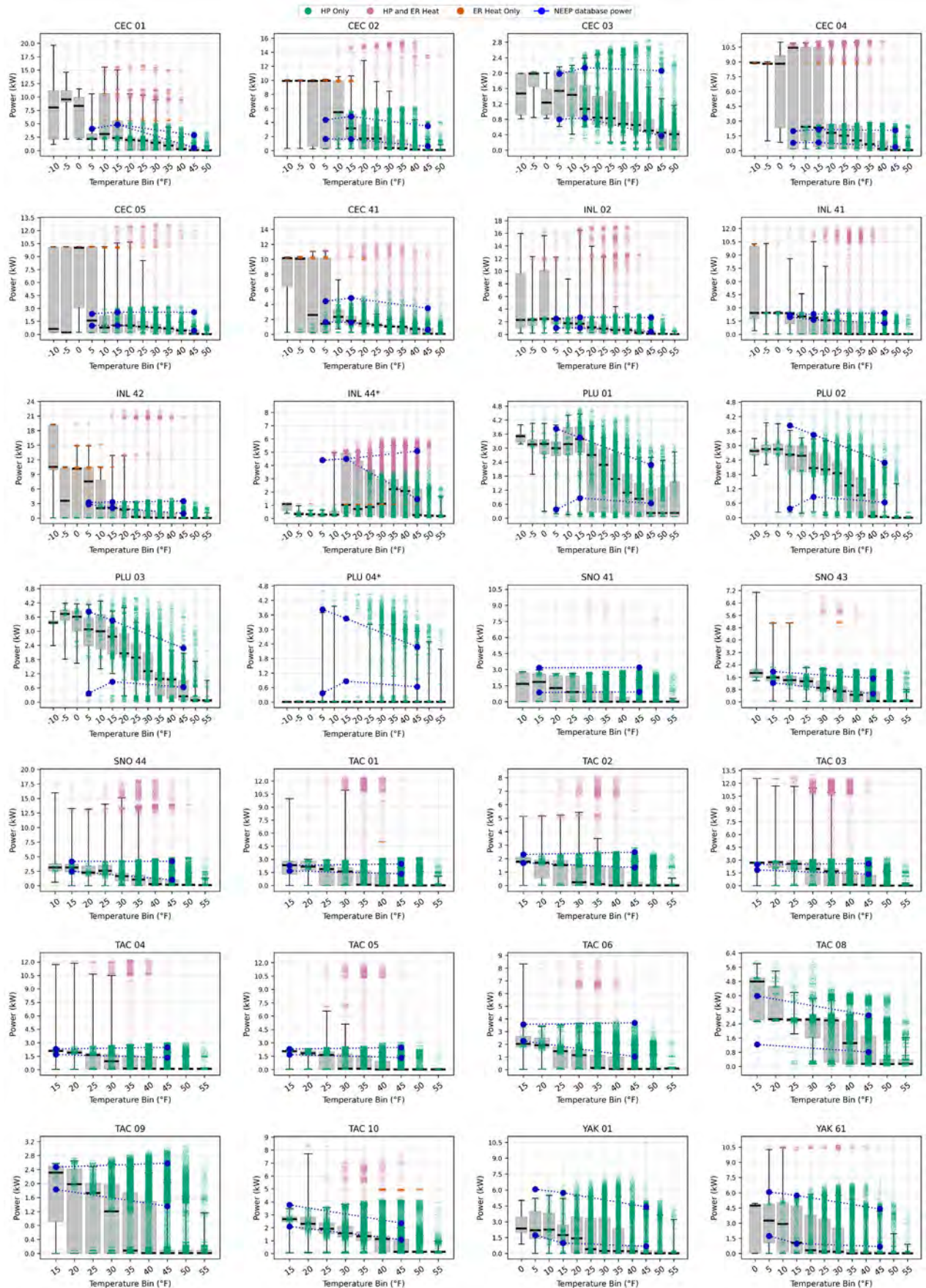


Figure 38. Ducted Heating Power Box-and-Whisker, 1-minute Interval.



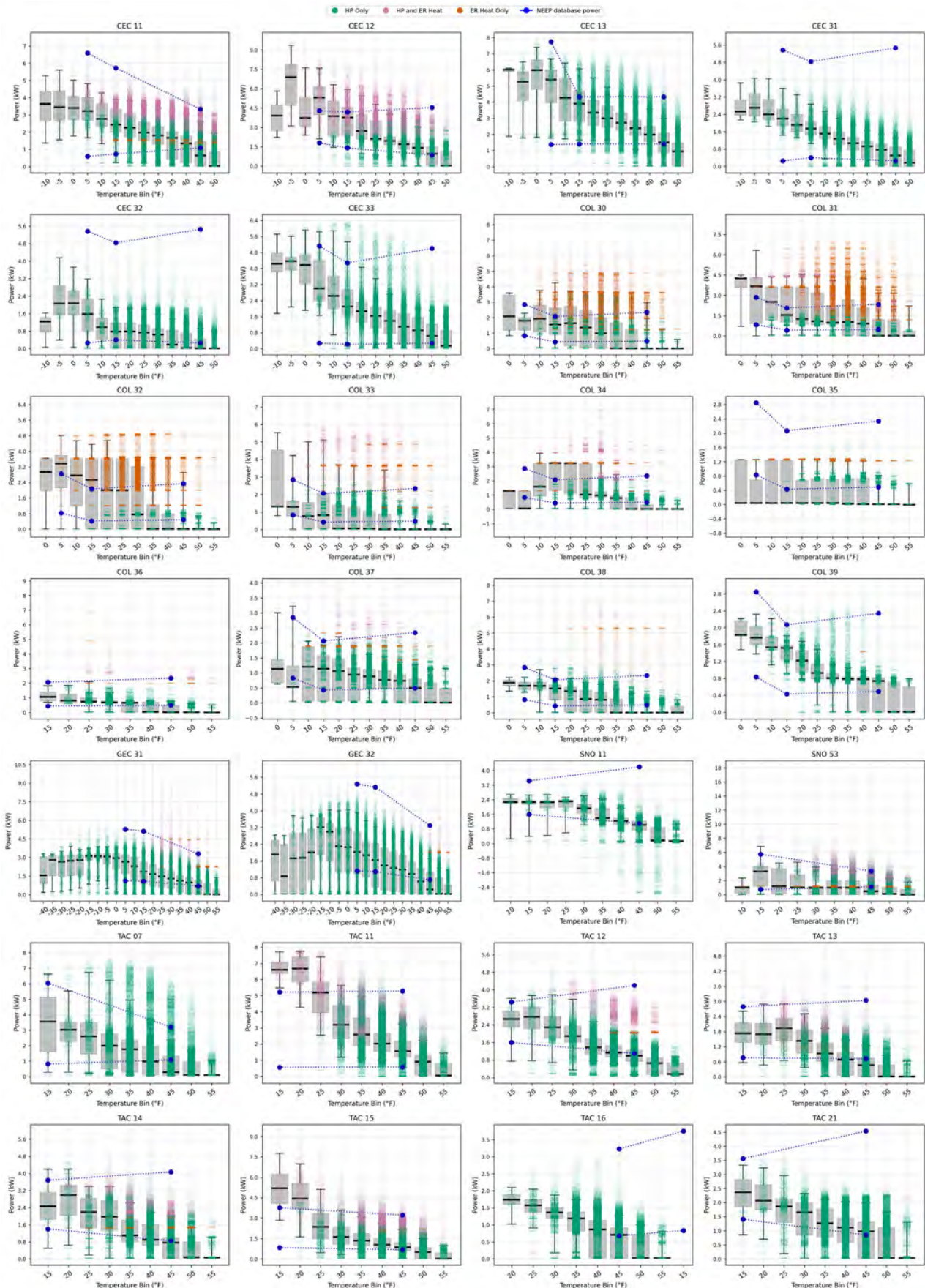


Figure 39. Heating Power Box-and-Whisker plot, 1-minute intervals, Multizone Systems



7.2 Comparison to NEEP Data

An important focus of the research study was to understand the value of readily available performance data that goes beyond standard rated capacity and efficiency metrics. The NEEP ccASHP database is an extensive source of manufacturer-reported performance values but, because the numbers are self-reported by manufacturers and not part of a standard protocol, there is an inherent risk of inaccuracy. If shown to be widely accurate across a range of brands and product lines, this type of data could enable more sophisticated system selection and program design.

7.2.1 Note on Brand-Specific Differences

In this section, detailed graphs show the operation and performance of each system for the available data, at conditions near each of the outdoor temperature conditions in the NEEP database. Since the distribution of sites was not uniform by manufacturer or product line, some product lines only had one or two systems in the study. Thus, to avoid giving readers a false impression about any particular brand or product line, this report does not contain detailed results organized by manufacturer. However, it is important to understand whether brand-by-brand differences are present. The findings show that they are. In each of the below cases, with five or more sites across a range of locations, the researchers observed consistent traits at multiple sites. The following summarizes a few observations.

- One product showed consistent agreement between field-measured power, capacity, and COP across a wide range of outdoor temperatures in heating mode, in multiple different locations. This product line had

very good agreement with the NEEP data, except for low-load, mild-weather cooling conditions.

- Another product had good agreement between measured performance and NEEP data in cold weather conditions, but about half of the systems showed significantly higher power in mild weather, low-load conditions, leading to worse-than-expected mild-weather COPs. This product had partial agreement with the NEEP data.
- A third product had power and capacity data across a range of conditions that were frequently outside the range described in the NEEP data, generally trending higher. Some of the systems had COPs in the expected range while a few had lower-than-expected COPs. While these systems did not necessarily perform particularly poorly, the NEEP data and measured data were in disagreement.

In general, across all the tested systems, the researchers did not observe cases where capacity at cold conditions was less than advertised. Across the sites, they did not see evidence of systems running at full power but failing to deliver full capacity. This may be because the “maximum capacity, 17°F outdoor” condition is similar to the mandatory, standardized, rated capacity at 17°F which manufacturers must test and report, and therefore less subject to judgment or estimation than other conditions which are not similar to a specific mandatory ratings test.

The above suggests that, for the product with good agreement with NEEP data, the data are likely to be reliable. It also suggests that for the other two products, there is a systematic disagreement with the NEEP data (and not random measurement error).



The most important conclusion from the above discussion is that accuracy of the NEEP ccASHP database should be assumed to vary from product to product, particularly at low-load conditions. The study's findings do not suggest that the NEEP data overstate systems' heating capacity, but some systems demonstrated lower-than-expected COP under mild weather or low-load conditions.

The database remains useful to support system sizing. But analysis intended to calculate annual energy savings, for example, is likely to be inaccurate. The findings suggest that caution must be used when relying on this data to predict energy performance or to design efficiency measures.

7.2.2 Heating Mode, 47°F Outdoor Temperature

Figure 40 shows the capacity, COP, and power, respectively, in the range of 47°F, +/- 5°F. The data points are filtered to include when the system is on, to present the most direct comparison against the claimed values of the NEEP database. This can illustrate whether systems run in the claimed range, and whether they tend to run more frequently at one end or the other of the performance range. For a large number of sites, including TAC 01, the boxes representing the middle 50% of the data – for both delivered heating capacity and power consumption – are situated near the minimum of the NEEP database range. This indicates that when that system was on and the outdoor temperature was close to 47°F, it was often operating

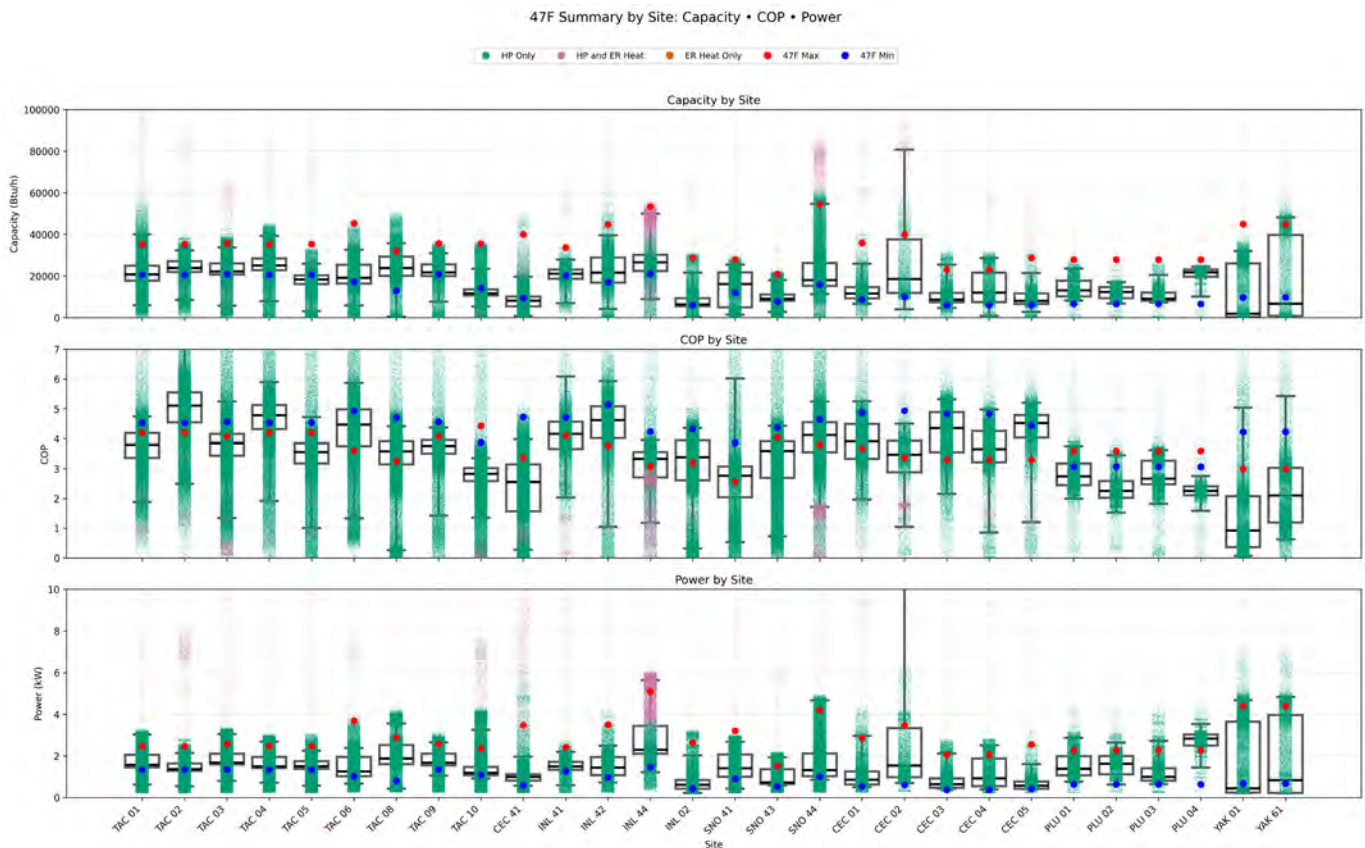


Figure 40. Box-and-Whisker plots and Minute Data, 47°F Outdoor Temperature, Ducted Sites.



at or near minimum power and delivering the claimed capacity. TAC 08 can serve as a counter example, where the boxes indicating the middle 50% of power and delivered capacity are both significantly above the minimum level, and in fact the whisker representing the top 5% of the data extends significantly above the claimed maximum power and capacity from the NEEP database. This indicates disagreement between the data claimed in the NEEP database and the actual performance of this system.

In the 47°F temperature range, systems would be expected to run at or near minimum capacity much of the time that they were on. One way to examine this is to identify which systems have a 25th–75th percentile range (middle 50%) that closely

matches the NEEP minimum values for power, capacity, or COP. If a system is frequently at or near that level, it can be assumed that the NEEP data are fairly accurate and that the system’s behavior permits it to run regularly at or near the minimum state. Analysis has shown that this varies brand to brand (see Section 7.2.1 – Note on Brand-Specific Differences).

Figure 41 shows power only for all sites, including multizone systems, along with the NEEP database data. It is worth noting here that many of the multizone systems have additional heat sources which are not under control of the HP thermostat; this manifests itself in high power consumption, for example sites TAC 12 and TAC 15 show considerable power consumption of “HP and ER Heat” (shown in orange).

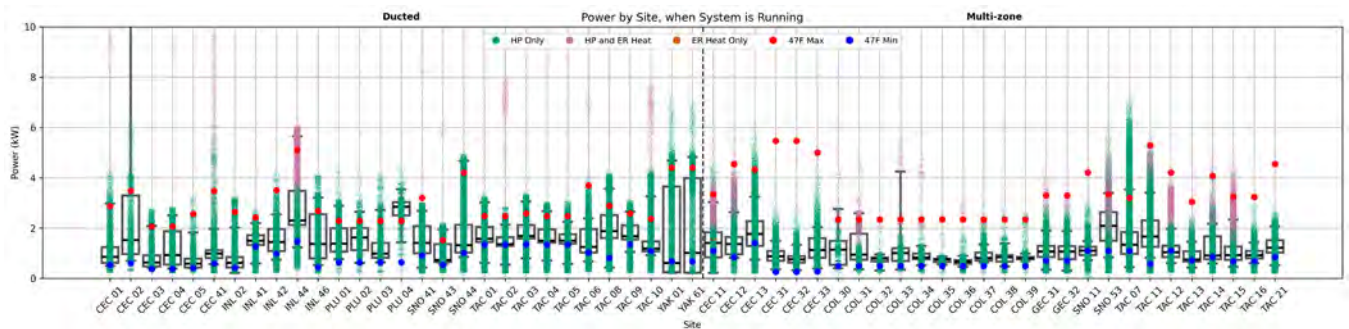


Figure 41. All Sites, Box-and-Whisker and Minute Data, Power at 47°F Outdoor Temperature.

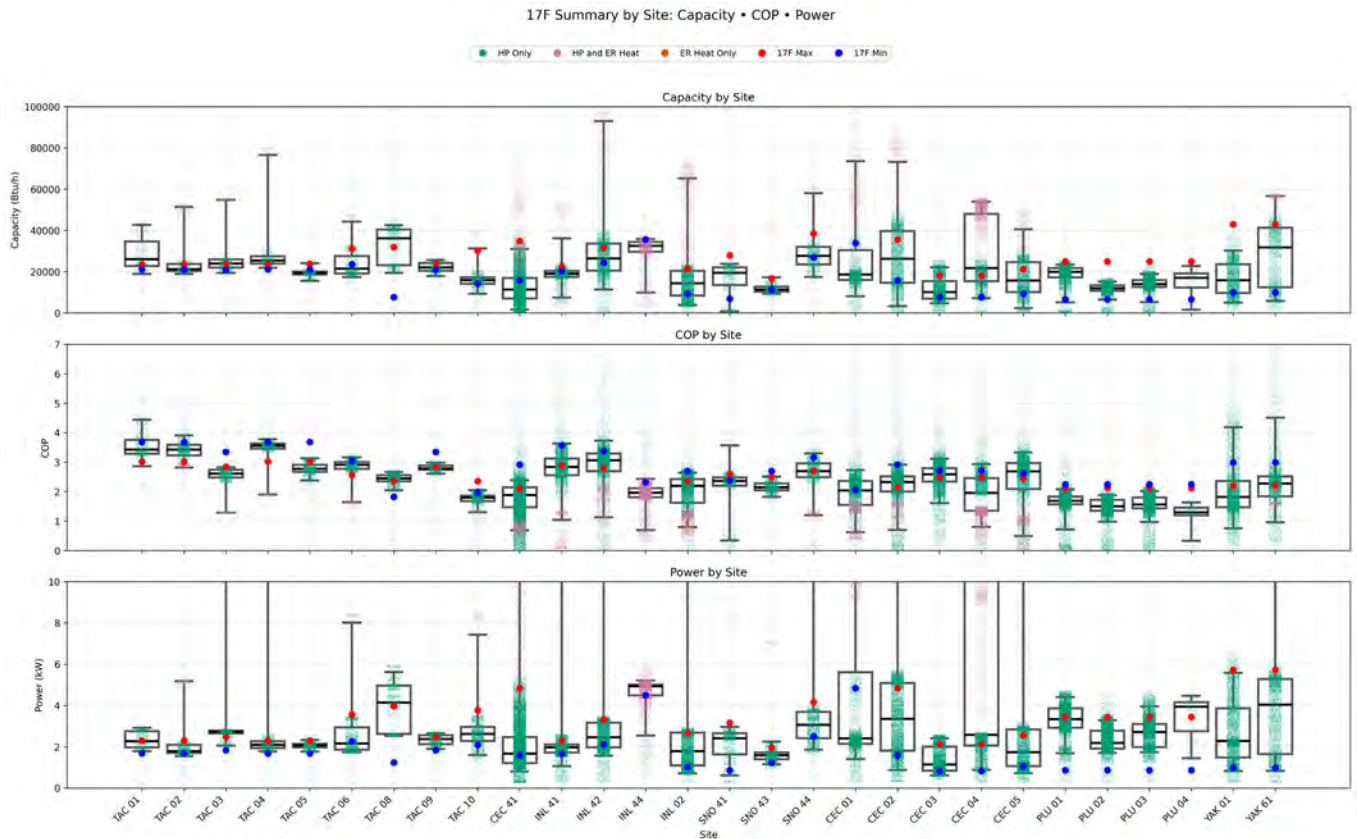


Figure 42. Summary by Site, Box-and-Whisker and Minute data, 17°F Outdoor Temperature.

7.2.3 Heating Mode, 17°F Outdoor Temperature

Figure 42 shows this same data for 17°F, +/- 5°F, and the accompanying maximum and minimum capacity data from the NEEP database. These data are revealing with regards to sizing and backup heat. For many of the systems, most of the delivered heat is provided by HP only, and there is a modest amount of HP with ER heat. CEC 04 on the other hand has a considerable amount of backup heat, with the 75th percentile of data

including HP with ER heat and over 10 kW of power consumption. Other sites that seem to use a greater amount of backup heat in this temperature range include INL 42, INL 02, and CEC 01. Most of the systems have significant overlap between delivered capacity and the capacity claimed in the NEEP database. A few sites, such as PLU 02 and PLU 03, show power levels near the middle or higher end of the expected range but delivered capacity on the lower end of the range (and, corresponding lower-than-expected COP).

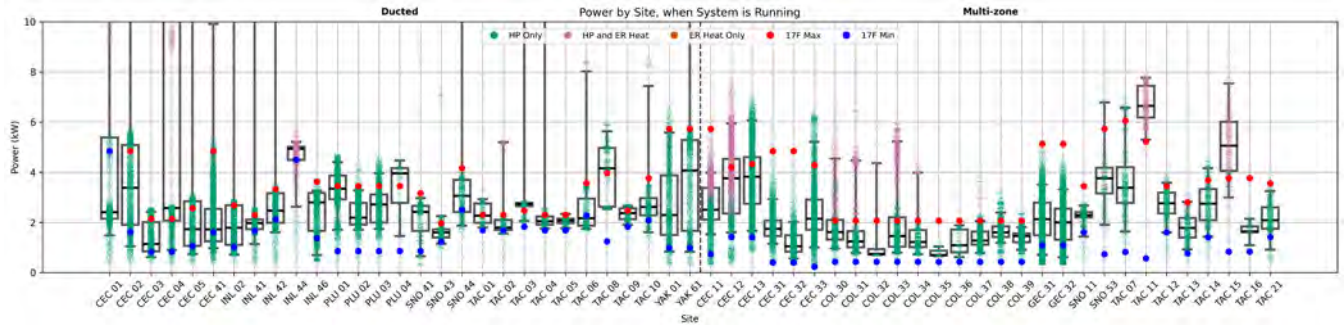


Figure 43. All Sites Box-and-Whisker and Minute Data, Power at 17°F Outdoor Temperature.

The power data for all sites (including multizone) in the range of 17°F outdoor temperature is shown in **Figure 43**. This graph shows considerably more HP with ER heat operation in several of the multizone systems, including CEC 11, CEC 12, COL 30, COL 33, TAC 11, and TAC 15. These systems all have auxiliary heat, which is separate from the control of the HP thermostat; this can lead to ER heat operating even if the HP has more than enough capacity to meet the loads. As an example, CEC 12 data show significant overlap between the maximum system power

from the NEEP database, and backup heat operation; this suggests the backup heat may be operating while the HP is running at lower-than-maximum capacity, reducing efficiency.

7.2.4 Heating Mode, 5°F Outdoor Temperature

For ducted sites that operated in weather in the 5°F +/- 5°F outdoor temperature range, the capacity, power, and COP are shown in **Figure 44**.

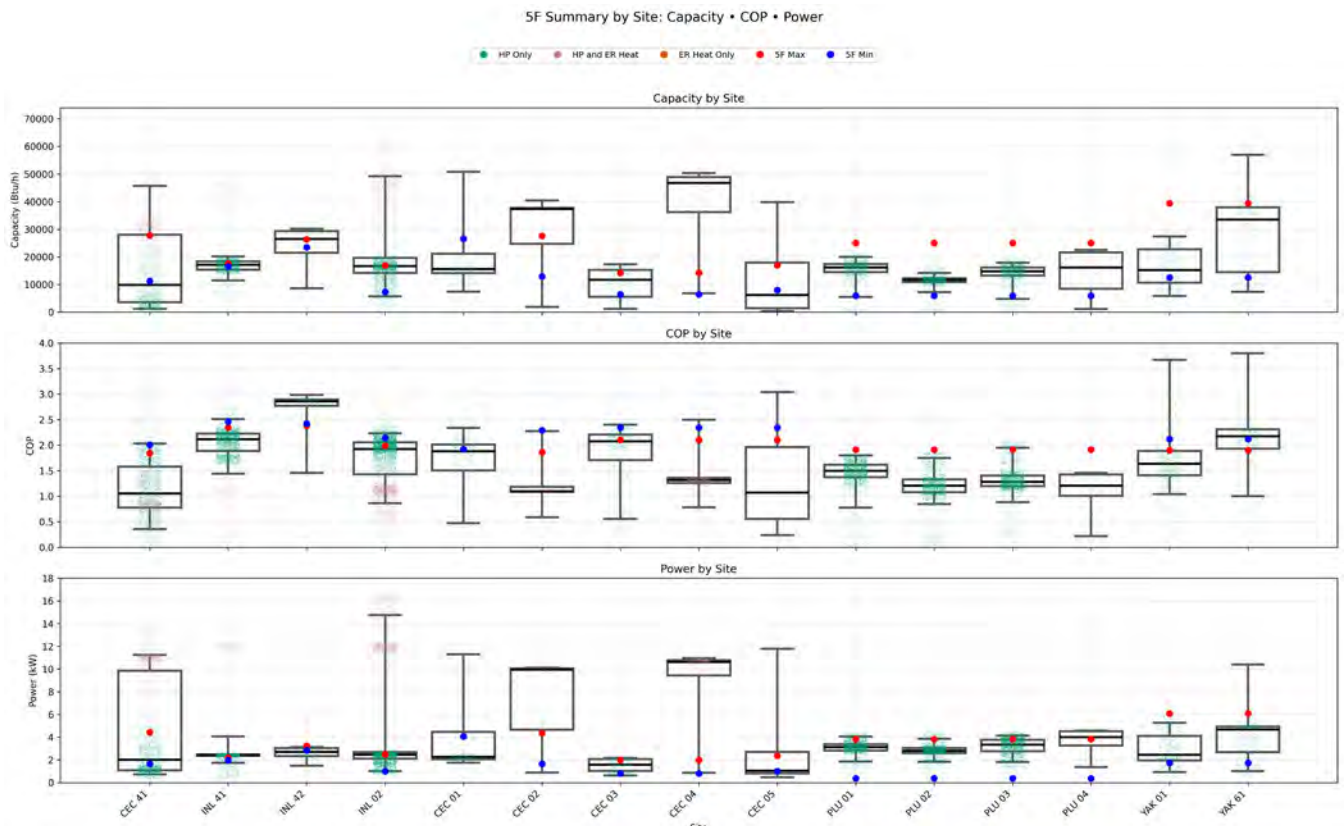


Figure 44. Summary by site, Box-and-Whisker and Minute Data, 5°F Outdoor Temperature



The results for these systems show that many systems deliver the claimed heating capacity in HP mode, sometimes with no second stage ER heat. However, 21 sites are known to have burned at least some wood (at least 9 of them regularly) in the baseline period prior to this study, and some of them used wood heating systems again during the coldest hours of this study. Nevertheless, the data show frequent efficient heating at several of these sites. For INL 41, INL 42, INL 02, CEC 01, CEC 03, and YAK 61, 50% or more of the data are at a COP of 1.75 or greater.

A brand-by-brand comparison with NEEP data is not feasible here due to significantly less data, the presence of ER heat, and possible auxiliary heat at several sites. However, visual examination of the graphs shows that when operating in HP-only mode (green dots), the systems with frequent operation tend

to operate within the expected range of power and with mixed agreement on capacity and COP. The four PLU systems had lower than expected capacity when running at the expected power level; however, many of the other systems demonstrated the ability to match the claimed capacity, power, and COP levels. These results should be taken with caution due to the limited amount of data and the possible impact of auxiliary heat and high backup heat usage on the results.

For all of the ducted and ductless systems that operated in the 5°F +/- 5°F range, the power consumption is shown in **Figure 45**. Many of the systems appear to run with relatively low power level, but 16 of the 31 sites shown here indicated at least some wood burning on the initial surveys, and therefore may have had wood burning during these very cold hours.

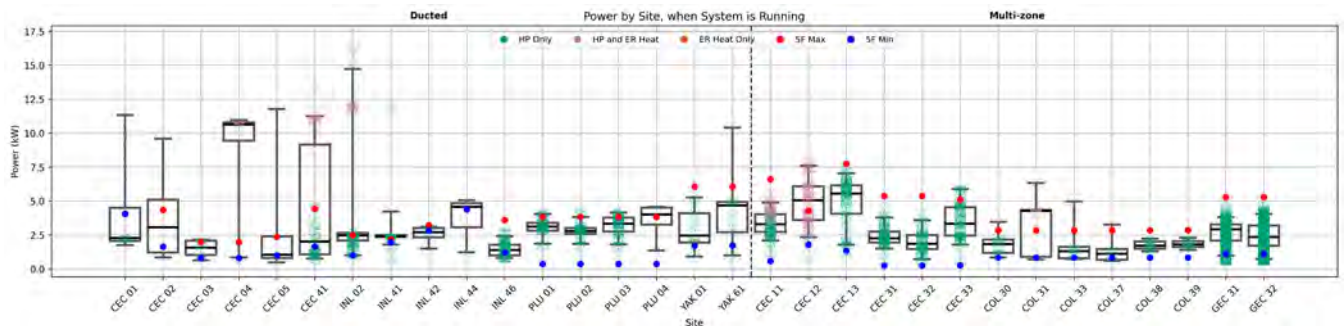


Figure 45. Box-and-Whisker and Minute Data, Power, 5°F Outdoor Temperature.



7.2.5 Cooling Mode, 82°F Outdoor Temperature

The field measurements do not include cooling mode capacity, but the input power for each system at 82°F and 95°F is revealing nevertheless. The 95°F bin corresponds to the nominal rating point for HPs, while the 82°F bin corresponds to a low-load condition (similar to the 47°F bin in heating mode).

Figure 46 shows the power distribution within +/- 5°F of 82°F, with the corresponding NEEP maximum and minimum power levels. These

data exclude time when the HPs are off. In this data set, very few of the systems ever exceed the claimed maximum power level meaningfully; only YAK 01 and YAK 61 have significant data points above the claimed levels. One trend that emerges in this figure is that several of the systems (including, for example TAC 01-TAC 06) appear to have inaccurate entries in the NEEP database for the low-load, 82°F condition, as none of those systems run at power levels close to the database's very low claimed power level.

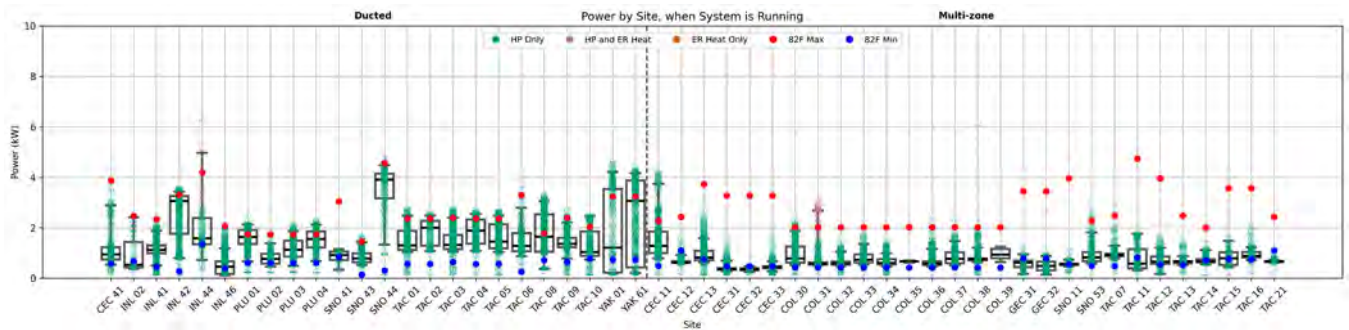


Figure 46. Box-and-Whisker and Minute data, Power at 82°F Outdoor Temperature.

7.2.6 Cooling Mode, 95°F Outdoor Temperature

In the 95°F +/- 5°F bin there are fewer data points, but the median power levels for most systems are a bit higher, as would be expected. Still, most of the systems operate considerably

lower than maximum power level, indicating that the heating mode-focused sizing leaves these HPs with more than enough capacity for the high-load periods of cooling mode. This is shown in **Figure 47**.

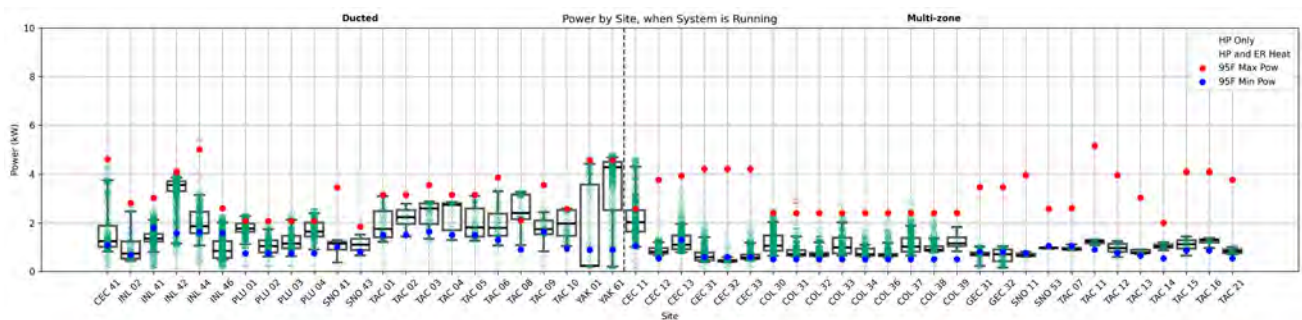


Figure 47. Box-and-Whisker and Minute data, Power at 95° Outdoor Temperature.

7.3 Heat Pump Seasonal Efficiency and Performance Metrics

For the ducted systems, which have measured heating capacity, it is possible to calculate a seasonal efficiency that can be used to compare systems and identify the factors driving energy savings. To evaluate seasonal efficiency, the researchers computed the cumulative COP in representative temperature bins for each ducted HP in the study. In this case the COPs are calculated by dividing the sum of the delivered heating energy by the sum of the consumed electric energy. This means that the COP calculated in this section is inclusive of energy consumed in standby and cycling losses. The COP includes HP power and ER heat power in all ducted systems but excludes any ER heat that is not part of the ducted system (such as separate zonal space heaters), to isolate the efficiency of the central system itself.

One way to assess this seasonal efficiency is by using the bin data to calculate a field-measured HSPF2 and compare that value with the nominal HSPF2. To do this and compare all systems across equivalent conditions, the researchers used the temperature bin weights (Region IV) from AHRI 210/240 for HSPF2 and applied the actual field COPs for each bin. The result is essentially a temperature-weighted COP (converted by a factor of 3.412 to match the units of HSPF2). In the study’s milder locations, not all of the coldest bins in Region IV were encountered. For example, Tacoma had no data in the bins from -8°F to 12°F outdoor temperature. In the following results, the researchers re-normalized the values by dividing by the total number of hours for which data were present. This reflects only 6% of the hours, so the re-normalization is minimal. The data in Table 29 show the seasonal efficiency of the product, with site-

measured performance data re-mapped on to a standardized temperature distribution (Region IV). Site-measured efficiency is adjusted to a different range of weather to match Region IV.

Table 29 shows the calculated values for each site. The values are also graphed in *Figure 48*, which shows the rated HSPF2 versus the

Table 29. Field-Measured HSPF-2

Site	HSPF2 from NEEP database, converted from HSPF if needed	Field-Measured HSPF2 (IV)
TAC 01	9.0	9.7
TAC 02	9.0	13.8
TAC 03	9.0	9.0
TAC 04	9.0	11.6
TAC 05	9.0	9.2
TAC 06	8.7	12.6
TAC 08	8.5	10.2
TAC 09	9.0	11.3
TAC 10	10.0	7.7
INL 02	8.2	6.7
INL 41	8.7	8.7
INL 42	9.0	10.0
INL 46	10.9	11.5
SNO 41	9.5	10.0
SNO 43	9.5	10.2
SNO 44	9.5	9.1
CEC 41	8.1	6.3
YAK 01	8.9	5.8
YAK 61	8.9	7.9
PLU 01	8.4	7.1
PLU 02	8.4	6.2
PLU 03	8.4	6.8
CEC 01	9.1	7.3
CEC 02	8.1	7.1
CEC 03	8.5	9.2
CEC 04	8.5	7.0
CEC 05	8.5	6.8



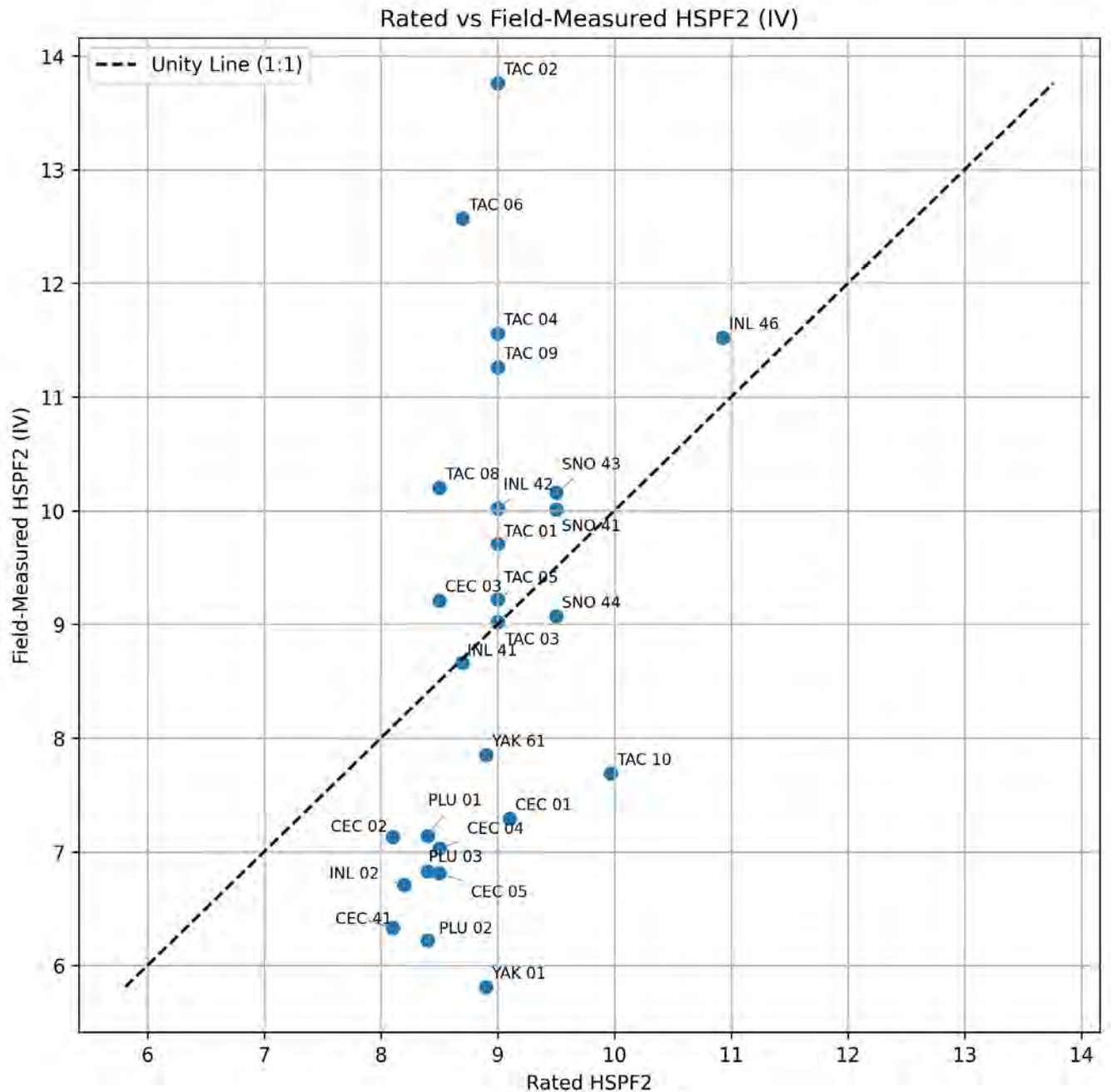


Figure 48. Field-Measured HSPF2 (IV) vs. Rated HSPF2 (IV).

field-measured value. This figure shows that approximately 13 of the 29 (45%) systems evaluated had field-measured HSPF2 values below the rated value by at least 10%; 7 of the 29 (24%) systems had field values 10% or more greater than rated; and the remaining 9 systems (31%) were within 10% of the rated value. The graph also shows that the

variation in field efficiency is much wider than the variation in rated HSPF2. For example, systems with rated HSPF2 of approximately 9 ranged in the field from almost 6.0 to almost 14.0 for field-measured HSPF2 (IV). This wide variability in the field reflects many factors, including user control decisions (indoor temperature set-points, setbacks),



manufacturer control decisions (how ER heat is deployed), site-specific factors (such as restrictive ducts leading to higher indoor fan power), and others not considered here. Interestingly, the simple mean of the rated HSPF2 values was 8.9, and the simple mean of the field-measured HSPF2 values was 8.8. In other words, the fleet of HPs performed on average as would be predicted by HSPF, even though the variation from site to site was quite wide. This is mostly coincidence, as the pool of sites and equipment included was not representative of anything except itself; more or less sites from a given product line would have resulted in a different average of field-measured HSPF2 values.

The averaged COPs in each temperature bin are also presented in tabular form (see *Appendix A*).

To evaluate the significant driver of overall energy and efficiency, it is necessary to evaluate what proportion of energy consumption is the HP, and what is ER heat. *Figure 49* above approximates this, and for each site presents the percentage of

energy consumed by the HP indoor unit and the measured ER heaters. This percentage includes fan power for centrally ducted systems (since this was measured on the same circuit). Sites with very low ER heat, such as TAC 09 and TAC 08, show that fan energy alone can represent approximately 10-20% of the energy used by a HP.

7.4 Findings – Limiting Electric Resistance and Heat Pump Size

One of the key objectives of this study was to examine the extent to which high-performance, high-capacity HPs can reduce or eliminate the need for ER heat. Doing so can significantly reduce a home’s contribution to winter peak demand. In HZ1, where heating design temperatures are typically in the range of 17°F or warmer, HPHC HPs can achieve COPs in the range of 3. If a HP is sized to meet all of the heating load at this temperature, every 10 kW of required heating to keep the home comfortable requires only 3.3 kW of electric power, compared with 10 kW of power if using ER only.

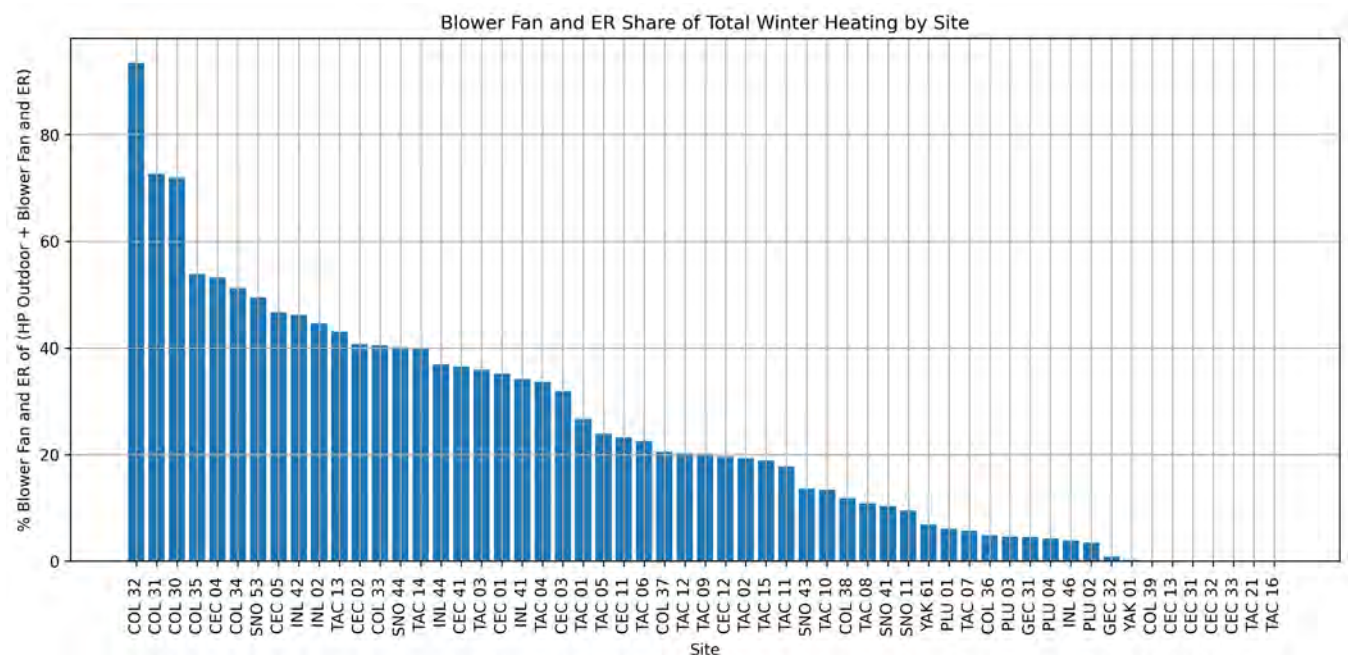


Figure 49. Blower Fan and Electric Resistance Heat Share of Total Winter Heating Energy.



Since systems are often installed with more ER heat capacity than is needed, and thermostat setbacks often trigger ER heat in the morning (often coincident with utility peak), minimizing or eliminating active ER heat is of particular interest. This can include using smaller resistance elements, locking out elements except for emergency use, or not installing elements at all.

HPs with greater heating capacity at the design heating temperature will require less backup heating than HPs with less capacity; it is important that contractors look at the specific capacity curves for the HP, as not all variable-speed HPs have the same capacity vs. outdoor temperature curve. As discussed in *Section 7.2 – Comparison to NEEP Data*, for sites at which delivered capacity could be measured, the capacity data listed the NEEP database was found to be reliable.

7.4.1 Heat Pump Balance Points by Site

Early in the study, a key challenge was identified: distinguishing between ER heating that was genuinely necessary due to insufficient HP capacity for the load, and ER heating that was not strictly necessary but was caused by other control functions, in particular by thermostat setback recovery and defrost with centrally ducted systems. This issue is also covered in *Section 7.5 – Load Shapes* on power profiles, which showed that many of the ducted HPs used ER heat during recovery from thermostat setbacks even in mild weather. Also, some of the multizone systems had ER usage even during the mildest weather conditions, because the auxiliary heaters are independently controlled and their controls may not have been adjusted to avoid running unless needed.

The ability of a HP to offset ER heating can be examined by identifying the HP's capacity

balance point, the temperature at which the home heating load is perfectly balanced with the HP's maximum capacity. Below the balance point temperature, either the indoor temperature will decrease or backup heat will be used. The balance point temperature is not an exact number for a given home, because the actual load on the home varies not just with outdoor temperature but also with indoor temperature, wind, sunlight, and occupant behavior. For each home, an attempt was made to estimate the capacity balance point of the HP, rounded to the nearest 2.5°F. For some of the homes, a threshold was crossed and the balance point could be identified with a high degree of confidence. Others either did not reach the balance point or had other factors that made estimating more difficult.

The research team did not identify a single precise method to calculate the balance point for all sites. Complicating variables included auxiliary heat sources (such as wood burning) at some homes, incomplete indoor temperature data at some homes, and overlapping operation of separate ER heat in some homes. Therefore, manual review of data and judgment were used to approximate the temperature for each site. The approach to estimating balance point was based on the following considerations:

- Is there a clear increase in measured ER heat usage or residual electric power consumption (whole home power minus all known heat sources) at a certain outdoor temperature?
 - » This is evidence of crossing the balance point temperature.
- Does the HP run at a high duty cycle and at or near the maximum of its power/capacity range?



- » At the balance point temperature, one would expect nearly 100% run time and power at or near the maximum of the system's range.
- If the balance point is not clearly reached, is there a steady increase in duty cycle, power, and/or delivered capacity approaching the system's maximum?
- Is there evidence of other auxiliary heat usage at or below a certain temperature, such as a clear decrease in how much the HP is used at colder outdoor temperatures?
 - » This does not directly indicate the balance point; it could, for example, reflect a period of time where an occupant started using a wood stove. However, it does indicate the need to extrapolate trends from milder temperatures when auxiliary heat sources are not used.
- If backup heat sources are not detected, does average indoor temperature drop below a certain outdoor temperature, after controlling for possible thermostat setbacks?
 - » For sites where the balance point appears to be significantly colder than the temperatures reached on-site, -10°F was selected as a minimum.

While real values lower than this could be plausible, the data at GEC 31 and GEC 32 (where temperatures reached almost -30°F) showed a practical limit around -10°F for those systems. Some manufacturers claim operating capacity to temperatures of -13°F or -15°F .

Several examples to illustrate judgments on balance point temperatures at each site are shown in *Section 7.4.2 – Example Balance Point Estimates* for illustration.

The estimated balance points by site are shown in *Figure 50*, which also shows the annual weather percentiles based on the local weather stations for the two full calendar years (2023 and 2024) contained within the project data. A few sites had no estimated balance point, because of insufficient data or too much disruption to the data. For example,

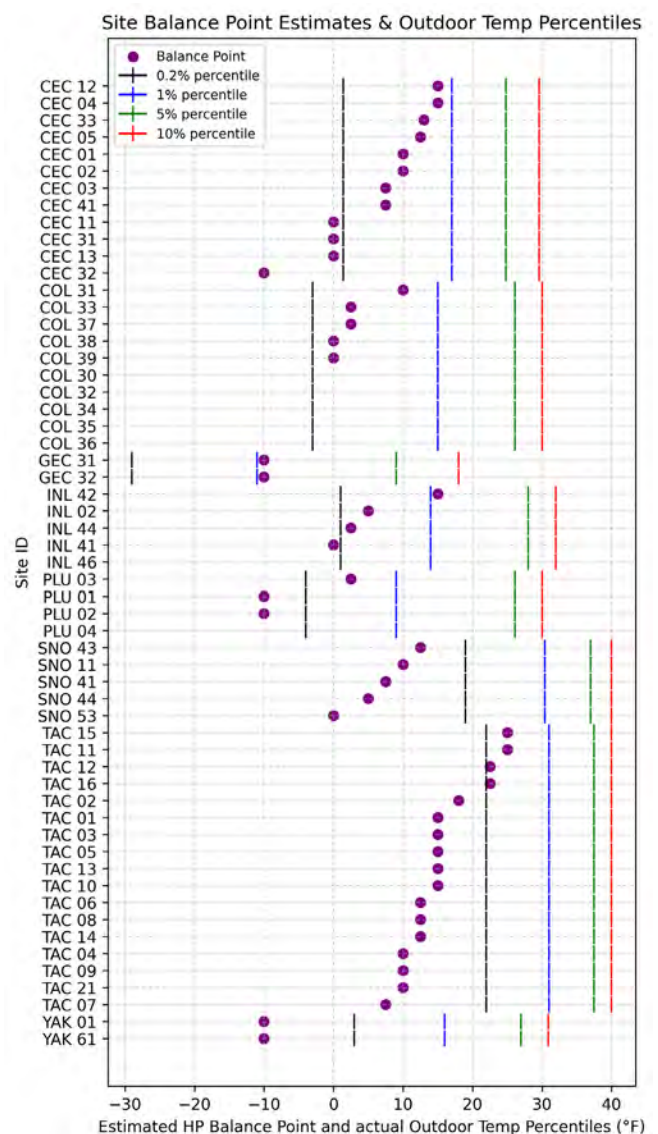


Figure 50. Estimated Heat Pump Capacity Balance Point and ODT Percentiles.

much of the measured data at several of the COL sites included what appeared to be thermostat setting/control issues causing extensive ER heat operation which, combined with limited data, made estimating the balance point too uncertain.

These data show that for nearly all sites the estimated actual balance point was below the first percentile for weather recorded from 2023-2024. For 22 of the sites (including 13 of 17 TAC sites) estimated balance points were below the 0.2% level, equivalent to 18 hours per year at or below that temperature. Only 3 of the sites – including the two at Glacier, which experienced extreme cold – had balance points above the 1st percentile of measured temperatures (corresponding to 88 hours per year).

7.4.2 Example Balance Point Estimates for Illustration

This section shows data for four sites, illustrating different approaches to estimating the balance point. These sites show that it is

not always possible to state the balance point with precision, but that reasonable estimates can usually be made.

TAC 09: BALANCE POINT NOT REACHED, CLEAN TREND IS APPARENT

Figures 51 and 52 show data for site TAC 09, which was a centrally ducted site observed to have very little ER heat usage. Figure 51 shows a box-and-whisker plot of measured power of the HP, blower, and ER heater, and Figure 52 shows the percentage of time the HP was operating. In both figures, 2.5°F temperature bins are used. At this site, it appears the system did not reach the balance point: in the coldest bin with data, the system ran less than 80% of the time, and the box-and-whisker plot shows that there was still a moderate amount of time the HP was running at lower-than-maximum power, or off. For this site, the researchers extrapolate and estimate that the system would reach 100% duty cycle around the 10-12.5°F outdoor temperature range.

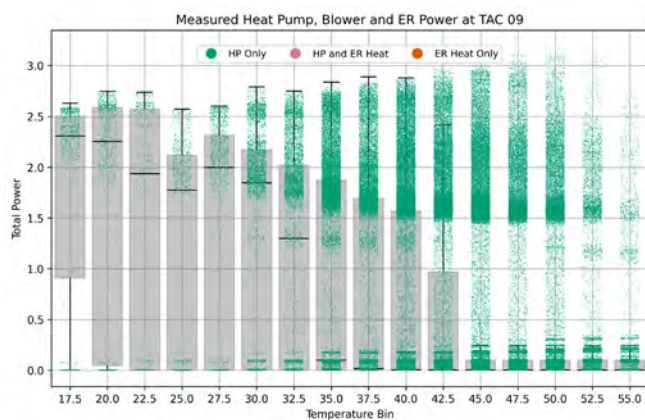


Figure 51. Box-and-Whisker and One Minute Power at TAC 09.

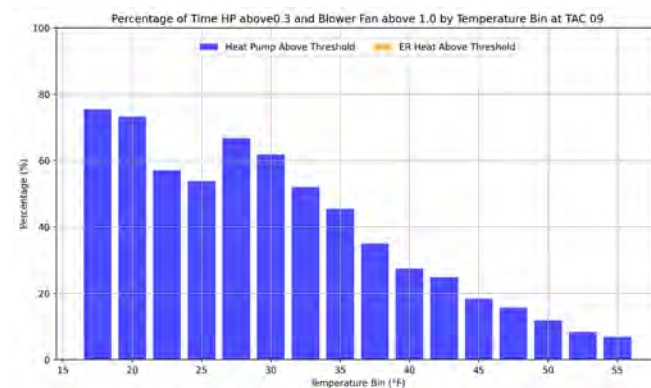


Figure 52. Percentage of time Heat Pump and ER Heat are running at TAC 09.



TAC 15: STEP-CHANGE IN POWER POINTS TO KNOWN BALANCE POINT

Figure 53 shows a box-and-whisker plot of measured power of the HP and known auxiliary heat at TAC 15, and *Figure 54* shows the percentage of time that the HP and the known ER heat sources were on. At this site, one observes a low usage of ER heaters in temperature bins down to the 30°F range, and the HP-only power level varying widely in the

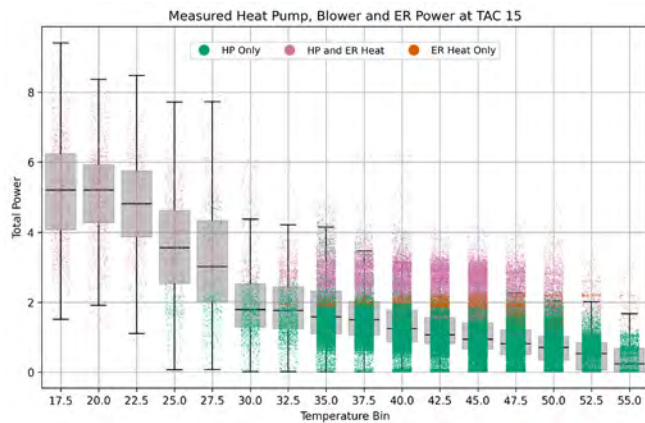


Figure 53. Box-and-Whisker plot and One Minute Power at TAC 15.

box-and-whisker plot, indicating modulating operation not at full capacity. Below 30°F, a change in behavior is observed, as both the HP power and the other electric heat sources ramp up significantly. In particular, there is a step change in the median power of the measured heating equipment in the 22.5-25°F temperature bin; the HP is running near 100% of the time, and resistance heat is also frequently on. Therefore, the likely balance point for this site is in the 22.5-25°F range.

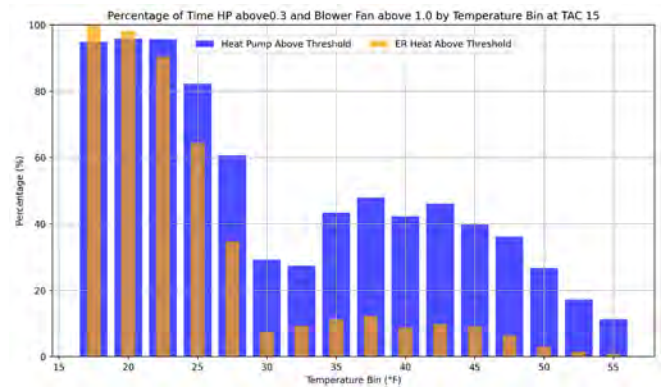


Figure 54. Percentage of time Heat Pump and Electric Resistance are running at TAC 15.

CEC 11: REGULAR UN-CONTROLLED ER HEAT COMPLICATES BALANCE POINT ESTIMATE

Figure 55 again shows a box-and-whisker plot of power, and the percentage of time the HP and ER heat are running for site CEC 11. This site is presented to illustrate a case

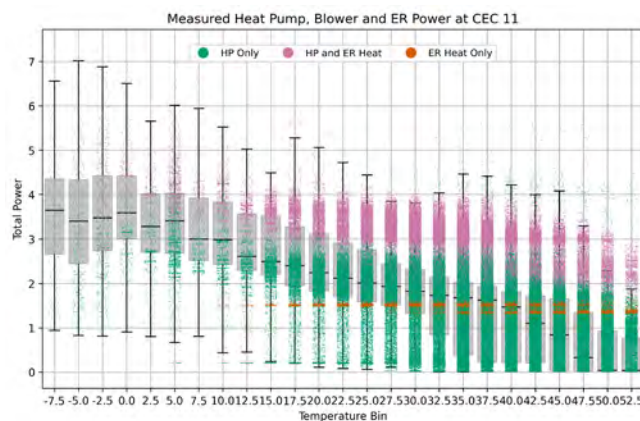


Figure 55. Box-and-Whisker and One Minute Power at CEC 11.

where determining the balance point is quite difficult. The site always has some metered ER heat operating, and it tends to run more frequently at lower outdoor temperatures. The HP itself also increases run-time at lower outdoor temperatures; however, the HP is not running at its maximum outdoor unit power level (listed in the NEEP database as 6.6 kW)

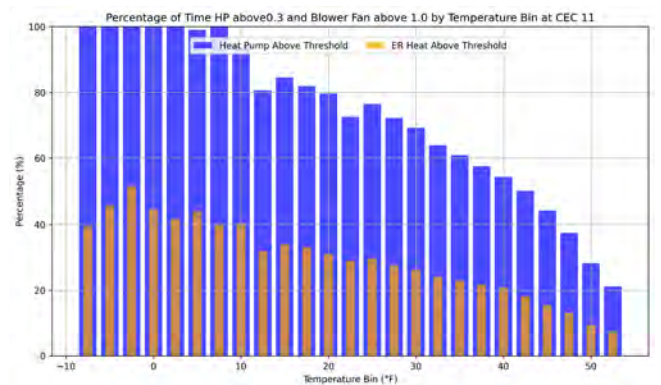


Figure 56. Percentage of time Heat Pump and ER Heat are running at CEC 11.



except very infrequently. For this site, the 0-2.5°F bin was selected as the balance point, as the HP is running 100% of the time (even if not always at maximum speed) and ER heat is also frequently on.

CEC 02: BEHAVIOR AND CONTROLS COMPLICATE ESTIMATE

Figure 57 shows the measured power of the HP and backup heat, and the percentage of time the equipment is running at CEC 02. This site is helpful in illustrating a case where behavior and controls again obscure exactly where the HP capacity and home load would have intersected. In this case, the data show that a compressor heat lock-out appears to be present, since in the 0°F bin there is no HP operation and only ER heat operation. Close inspection of the minute-by-minute data at this site indicates a lock-out below 10°F. (Differences between the hourly temperature from the nearby weather station, and site temperature at the outdoor unit, likely explain why there is some limited HP run data in some bins below 10°F.) Examining milder weather, the system appeared to have more than adequate capacity in the range of 15°F and higher. For example, the NEEP database lists a maximum system power at 17°F of 4.8 kW, and the data show the system was operating approximately 55% of the time in this outdoor temperature range, and the box-and-whisker plot indicates that the system was below maximum power approximately 75% of the time. Extrapolating the duty cycle and median power levels, it is estimated that this system would have reached full duty cycle at full power in the approximate range of 10-12.5°F outdoor temperature without the lock-out.

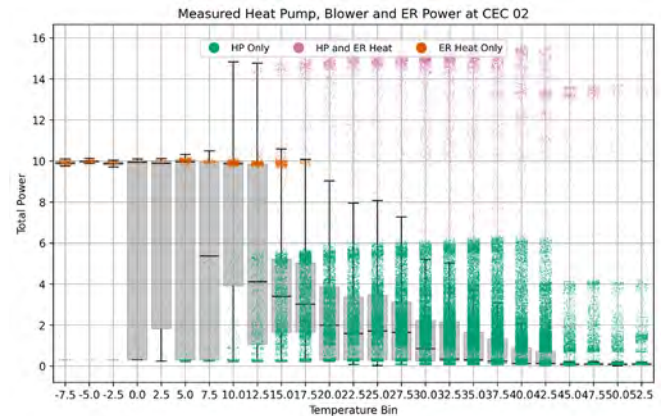


Figure 57. Box-and-Whisker plot and One Minute Data at CEC 02.

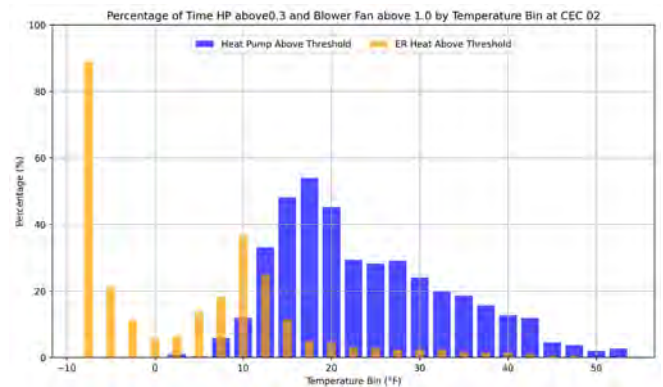


Figure 58. Percentage of Time Heat Pump and ER Heat are Running at CEC 02.

7.5 Load Shapes

This section examines the load shapes of the HPs in this study, which are important for addressing the peak demand contribution (i.e. grid capacity reduction potential) of HPHC HPs.

7.5.1 Heating Season

Figure 59 shows the average power profile of all the HPs and their measured backup heat, filtered for the years 2023 and 2024, and for the months of November, December, January, February and March. This power profile includes the HP outdoor unit as well as any known and metered ER heat; any un-metered

heaters, such as plug-in space heaters that may have been caught in the residual loads calculation in **Section 6.1.4 – Heating Power vs. Outdoor Temperature**, are not captured here. The thicker blue line is the average of all sites, and each green line represents a single site. It is clear from this figure that there is a wide range of operation: while many systems

have a low and fairly flat average usage profile, a few sites have either high baseline heating power, or a very high morning peak power. The resulting average is a power profile with a pronounced morning power peak from 5 - 8 a.m., which is clearly driven by a small number of sites with high peaks during those hours.

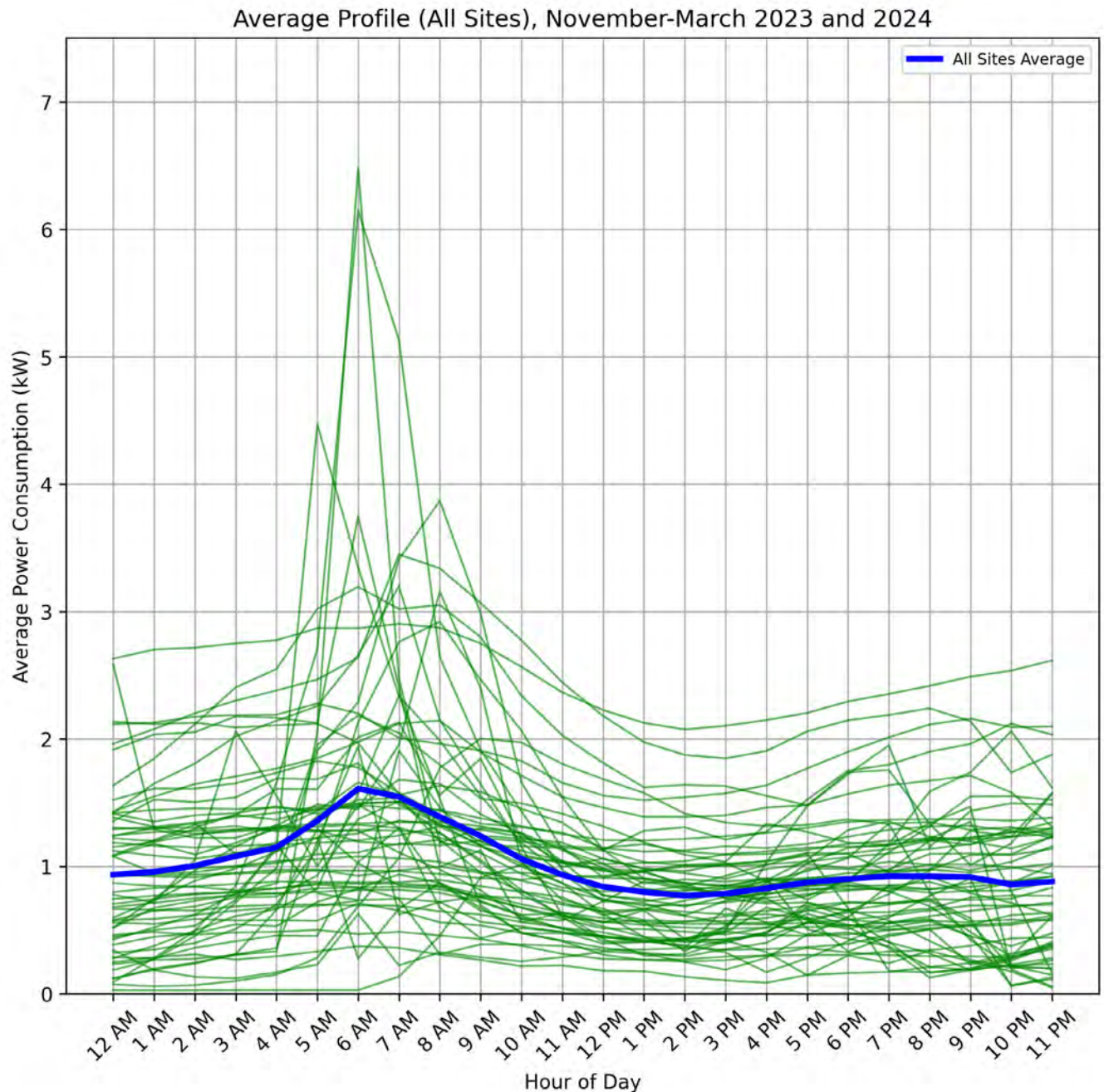


Figure 59. Average Heat Pump and ER Heat Power Profile for All Sites, November-March during Study Period



To disaggregate and more closely examine these results, the following series of graphs show the power profiles of each category of system. The graphs are filtered to only include days with daily low temperatures in 15-degree temperature bins, starting with the 45-60°F bin. In each case, the figure shows the HP and all known/measured ER heat. The number of sites (n) is listed, as well as the number of sites known to have alternative heat sources (w/ alt. heat).

HEATING SEASON, DAILY LOW TEMPERATURE 45-60°F

Figure 60 shows the power profile for days with daily low temperatures between 45°F and 60°F. These are very mild winter weather conditions, and the power profiles on average reflect this with very low average power. In each category of system, a small number of sites demonstrate relatively high peaks, but many systems also average near zero power.

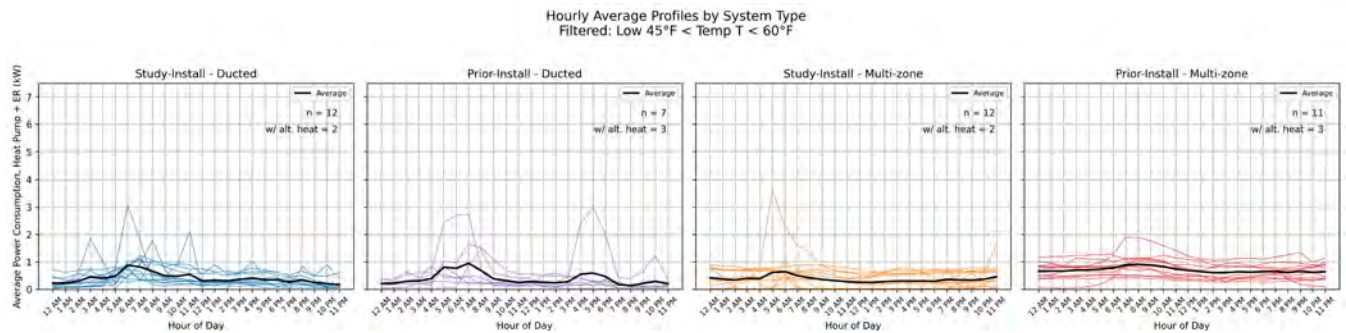


Figure 60. Hourly Avg Power Profile by System Type, 45-60°F.

HEATING SEASON, DAILY LOW TEMPERATURE 30-45°F

Figure 61 shows the power profile for days with daily low temperatures between 30°F and 45°F. These are moderate winter days, and the average power profiles show some

steady load with increased morning peaks for each system type. In this case, the ducted system types show a higher morning peak power as compared with the multizone systems. There is again a wide range of performance, with a few homes dominating the morning peak average.

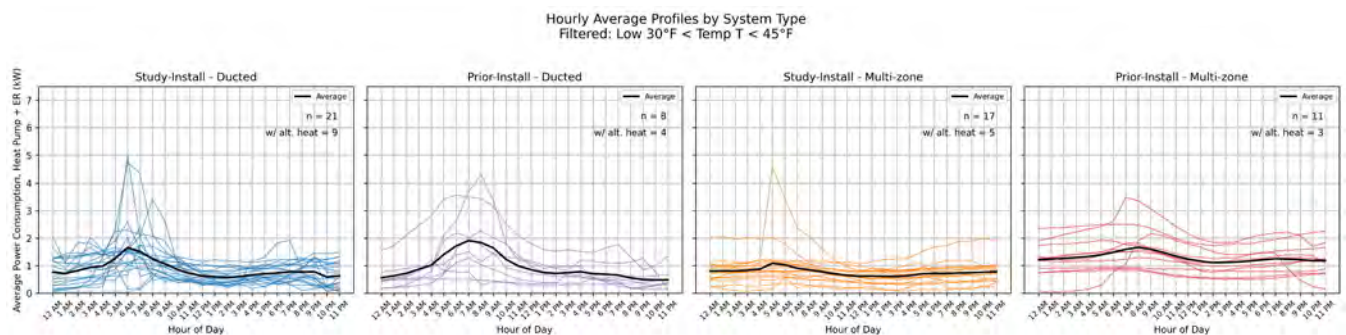


Figure 61. Hourly Avg Power Profile by System Type, 30-45°F.



HEATING SEASON, DAILY LOW TEMPERATURE 15-30°F

Figure 62 shows the power profile for days with daily low temperatures between 15°F and 30°F. This is the coldest range for HZ1 sites and includes the winter design conditions. Here, more prominent morning peaks emerge in a few of the centrally ducted sites, which drive high average peak power profiles. These include Study-Install systems CEC 01, INL 02, and TAC 04 which each exceed 5 kW at maximum, and Prior-Install system SNO 44, which exceeds 10 kW. In the

multizone systems, only the Study-Install system at TAC 07 and the Prior-Install system at TAC 11 (which had high usage across all hours) exceeded 5 kW at peak. The averaged power profile is peakier in the ducted cases than the multizone cases, and there remains a fairly wide variation in behavior from home to home. It is important to note that while some individual sites have average peak power reaching or exceeding 10 kW, the average of the sites combined is much lower, under 3.5 kW for all the HPs and metered ER heat in the Prior-Install ducted category, which had the highest average.

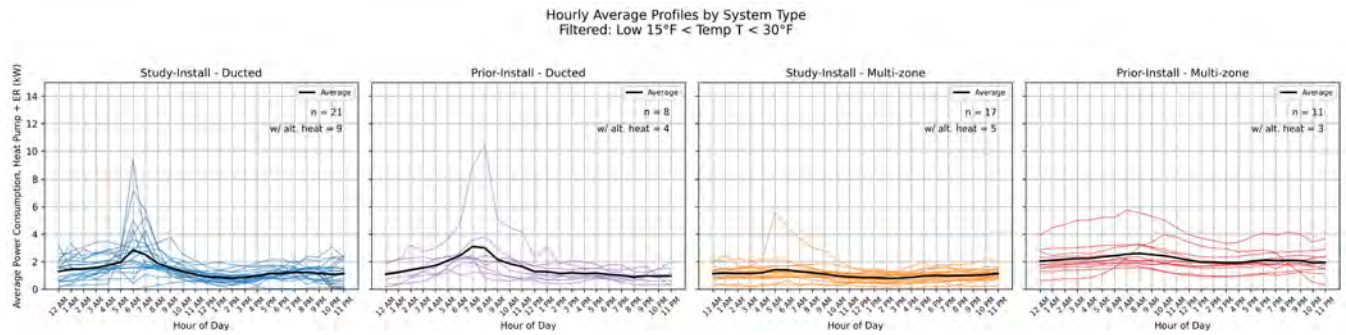


Figure 62. Hourly Average Power Profile by System Type, 15-30°F.

HEATING SEASON, DAILY LOW TEMPERATURE 0-15°F

Figure 63 shows the power profile for days with daily low temperatures from 0-15°F. These are very cold days for all climate zones. It is important to note the following. The number of sites drops in each category, because HZ1 does not get this cold, and sites with some known alternative heat source

(whether or not it was used) represent half or more of the sites in three of the four categories. For centrally ducted systems, the trend continues with fairly peaky load with high morning peaks on average, driven by a few systems with particularly high usage. The multizone systems have much flatter power profiles and lower average power; however, the small sample size likely contributes here. For example, the Study-Install multizone

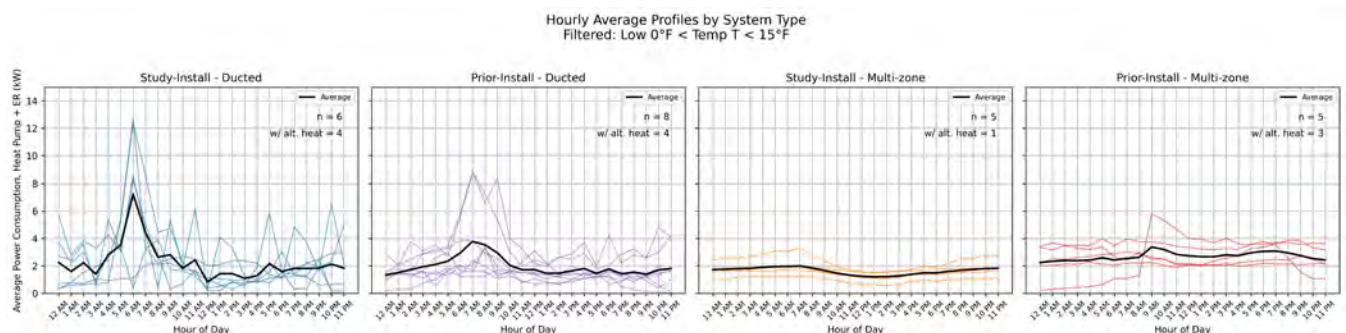


Figure 63. Hourly Average Power Profile by System Type, 0-15°F.

category includes the two sites at GEC, which were under 1,000 square feet, got new HPs with high heating capacity relative to the home heating load, and no installed backup heat. Also, several of the sites in the Prior-Install multizone bin were known to still use auxiliary heat sources on at least some cold winter days.

HEATING SEASON, DAILY LOW TEMPERATURE -15-0°F

Finally, **Figure 64** shows the power profiles where data are available in the days with low

temperatures from -15-0°F. The sample size here, again, is smaller and, again, alternative fuel burning is a significant factor, with many of the homes having at least the potential to offset some heating load with auxiliary fuels. High, steady power among the multizone systems indicates that they are running all day. There is still evidence of thermostat setback recovery for the ducted systems. Among the Prior-Install ducted systems, two sites have very low usage owing to the alternative fuel usage offsetting nearly the entire heating load.

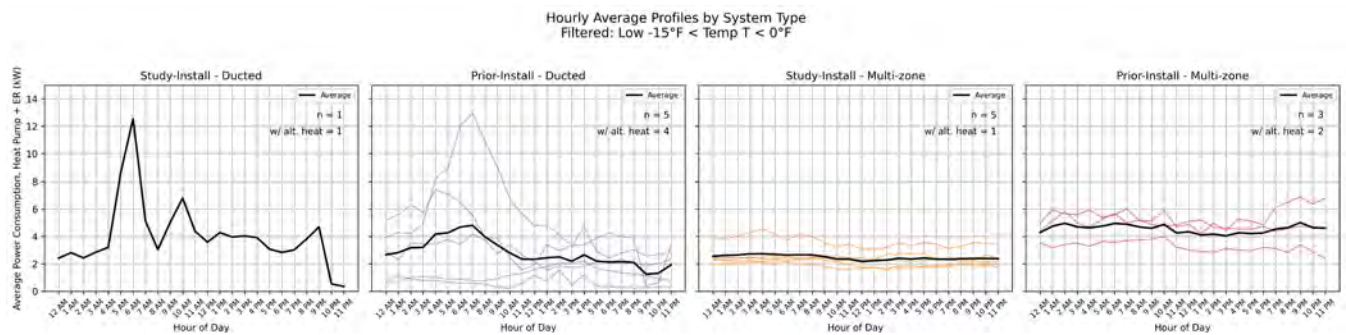


Figure 64. Hourly Average Power Profile by System Type, -15-0°F.

POWER PROFILE DIFFERENCES BETWEEN CENTRAL DUCTED AND MULTIZONE SYSTEMS

A key takeaway related to heating season power profiles is a distinction between centrally ducted systems and multizone

systems. The ducted systems, both Study-Install and Prior-Install, tended to have peakier power profiles, especially in colder weather, compared with the multizone systems. **Table 30** shows the load factor of the average power profile of each system type, reported for each 15-degree temperature bin.

Table 30. Load Factor Of Average Power Profile in Heating Season.

Temperature Range	Study-Install - Ducted	Prior-Install - Ducted	Study-Install - Multi-zone	Prior-Install - Multi-zone
60°-45°	2.18	2.46	1.73	1.31
45°-30°	1.94	2.04	1.42	1.28
30°-15°	2.07	2.05	1.34	1.2
15°-0°	3.19	2.28	1.23	1.43
0°- -15°	3.09	1.71	1.11	1.1



Load factor is defined as the maximum hourly value divided by the average value for the full day; a load factor of 1.0 means the power profile is perfectly flat, while 0.5 means that the average is half of the peak hour. If energy consumption is equal, a higher load profile would be preferable for having a smaller peak power. Across all temperature ranges, both Study-Install and Prior-Install ducted systems had significantly lower load factors than either Study-Install or Prior-Install multizone systems.

While this difference may partly reflect differences in homes (the ducted systems on average went into larger homes, for example), site-by-site analysis shows that square footage or calculated heating load are not the primary drivers of high peak power at some homes. Instead, system control is the key driver of power profile.

A likely explanation is that with centrally ducted systems, control of the HP and the ER heat are centralized to one thermostat that manages heating to the entire home. During a setback recovery, the system may call for both HP and resistance heat operation. Since the system serves the whole home, the entire home is brought up to a new setpoint. This drives high, sustained power usage. In contrast, multizone systems usually have separate controls for different zones, each of which may have an independent setback schedule or no setback. Also, any ER heat in the home is generally independently controlled and not tied to a central thermostat. This decentralized control reduces the likelihood that all of the home's heating equipment will operate at once, and leads to flatter power profiles.

POSSIBLE POWER PROFILE - ENERGY TRADE-OFF

When combining the observations in this section with the energy savings differences discussed in *Section 6.2 – Bill-Based Savings Estimates*, a possible trade-off emerges: the centrally ducted systems had higher energy savings, but the multizone systems had considerably higher load factors and less contribution to morning power peaks. These findings are based on a small sample size, and future studies could clarify differences in energy savings potential between the two system types. However, the difference in load factor is clear and supported by a plausible technical explanation of disaggregated zoning and control of auxiliary ER heat for multizone systems. Improvements to the control to minimize the use of ER heat in centrally ducted systems would reduce this difference. Differences associated with zoning may be harder to eliminate.



7.5.2 Cooling Season

The average power profile of all HPs is shown in **Figure 65** for the months of June, July, August, and September in 2023 and 2024. This power profile includes the HP outdoor unit as well as indoor units for ducted systems, and any metered ER heat (though

it should not be on). The thick blue line is the average of all sites, while each green line represents a single site. It was observed that cooling is particularly dominated by occupant behavior: some sites have their HP off for much of the summer, only turning it on during hot days; others had more regular operation. Some had setbacks and others

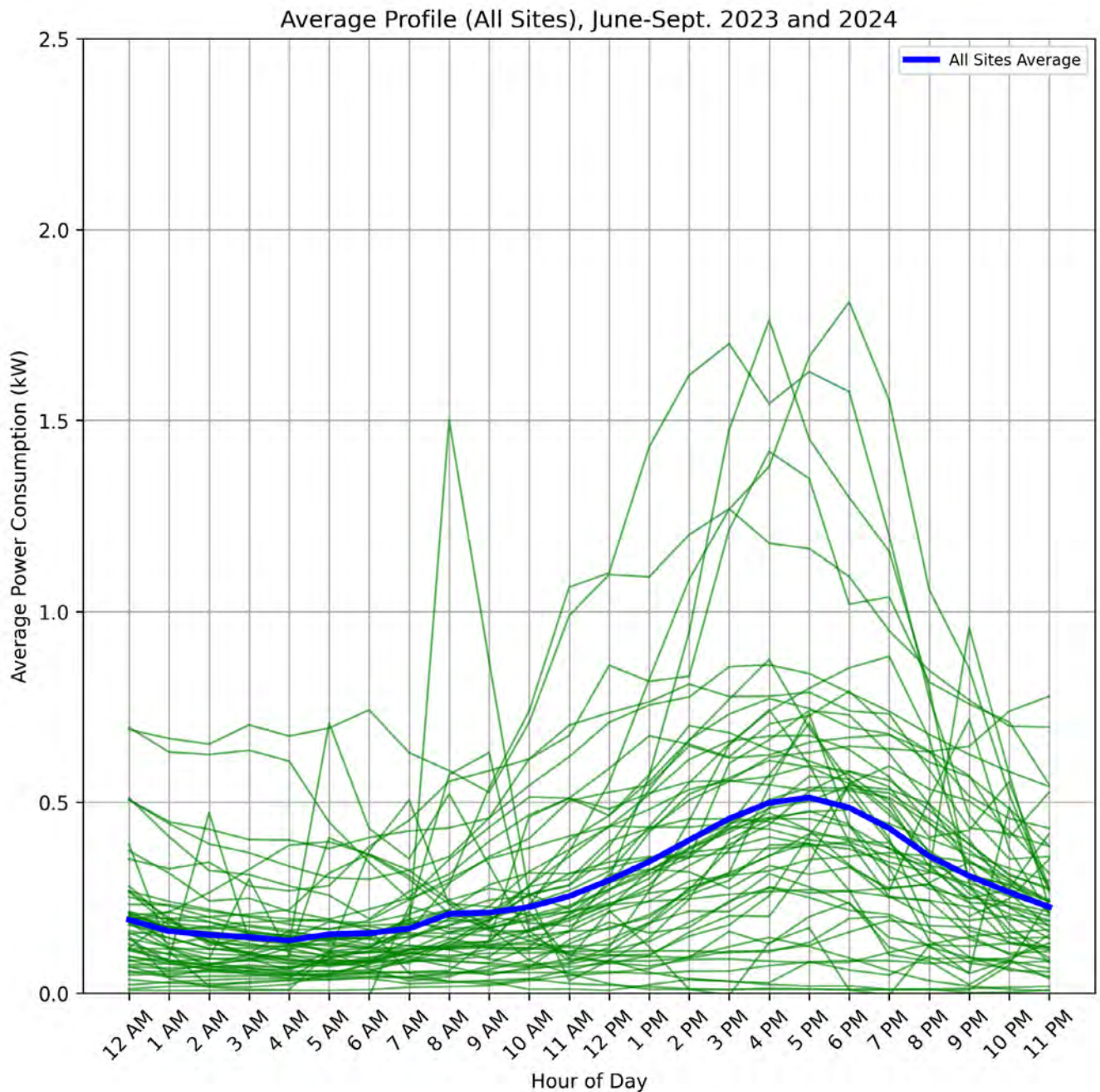


Figure 65. Average Heat Pump and Blower Fan Power Profile for All Sites, June-September 2023 and 2024.

did not. A few had a small amount of heating operation during the coolest hours, even in summer. The result is, much like heating season, a very wide range of outcomes site by site which averages to a predictable and expected overall load shape.

COOLING SEASON, DAILY HIGH TEMPERATURE 60-70°F

Similar to the heating season analysis, to disaggregate their performance the sites are broken out by system type, and the results are graphed below in bins of 10°F for daily high temperature. The first group in **Figure 66** shows the system performance during summer months when the high temperature

was between 60-70°F, very mild weather. The average power profile for each type of system is shown in black, and the number of sites (n) is listed, as well as the number with known alternative heat sources (presented for consistency with heating mode data above, though not expected to play a role in summer). The average power at all sites is quite low, though a few sites have some usage, particularly overnight, which suggests overnight heating may still be occurring at some sites. Indeed, review of the exit survey data confirmed that several of the sites used Auto mode (instead of cooling only mode) during the summer, which permits both heating and cooling.

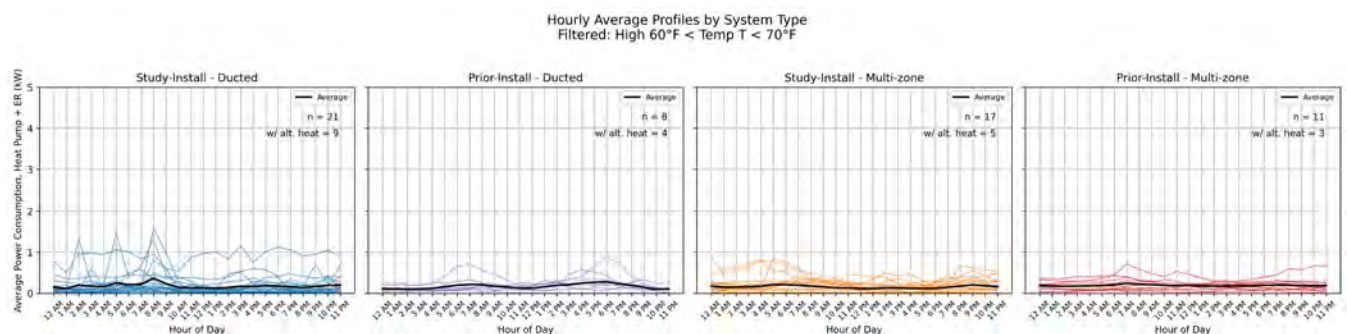


Figure 66. Hourly Average Power Profile by System Type, 60-70°F.

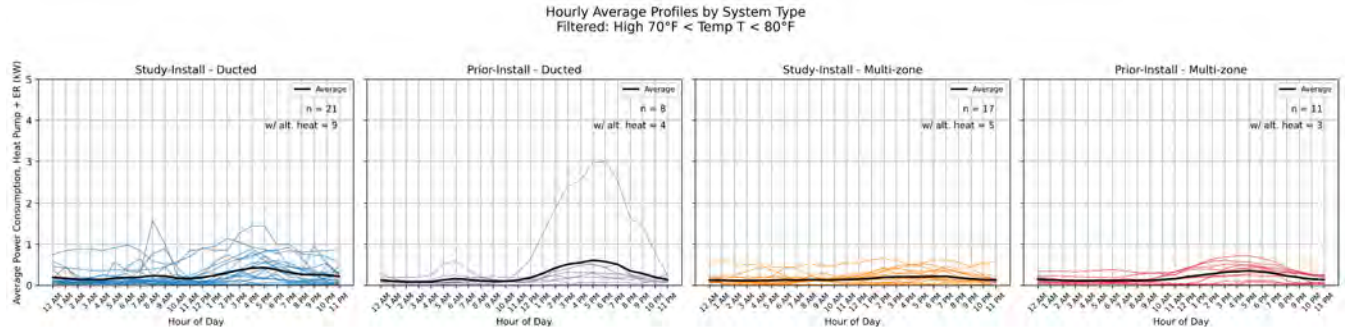


Figure 67. Hourly Average Power Profile by System Type, 70-80°F.

COOLING SEASON, DAILY HIGH TEMPERATURE 70-80°F

In *Figure 67*, the daily outdoor high temperatures were in the 70-80°F range. In this case, there is more power consumption, and in particular a few centrally ducted sites had significant power consumption. SNO 44 in the Prior-Install ducted category stands out. That site appeared to be under manual control; it was frequently off during overnight and morning hours (the average power was below 50 Watts for hours between midnight

and 9 a.m.), and on for sustained periods most days, but not at a consistent start time. This suggests the occupant may have been manually turning the system on when needed each day, and off around bedtime. This system is also a 5-ton HP in a home with over 5,500 square feet of conditioned space, which explains its high average power when running. Importantly, the system runs at a sustained high power level when first turned on, to pull the temperature of the whole home down to set point.

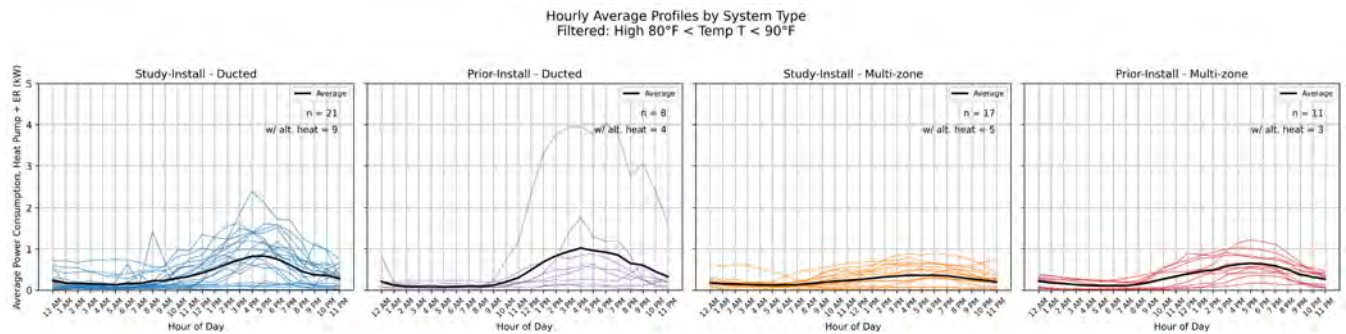


Figure 68. Hourly Average Power Profile by System Type, 80-90°F.

COOLING SEASON, DAILY HIGH TEMPERATURE 80-90°F

Figure 68 shows the data for days with high temperatures between 80°F and 90°F, fairly hot for CZ1. In this case, many of the ducted systems demonstrate relatively high power,

with several hours over 1 kW of power consumed on average during the afternoon hours. SNO 44 is again an outlier in the Prior-Install ducted group. The multizone systems have less peaky power consumption during those same hot afternoon hours.

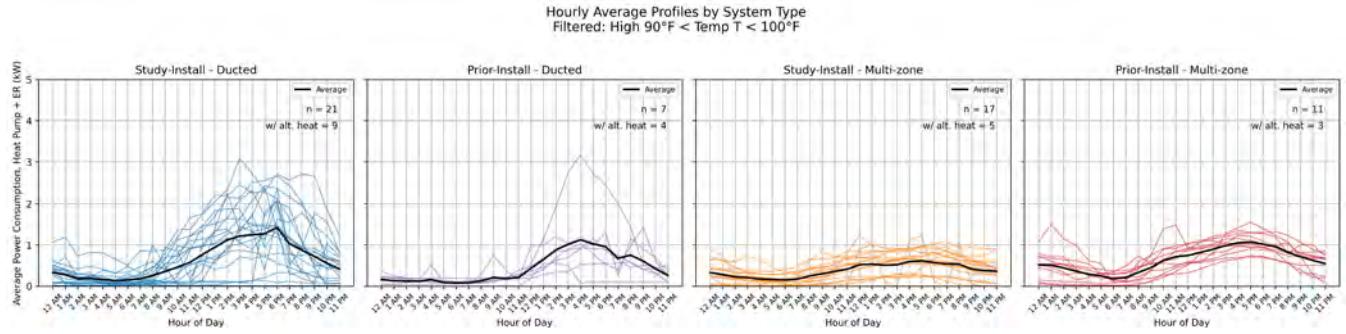


Figure 69. Hourly Average Power Profile by System Type, 90-100°F.

COOLING SEASON, DAILY HIGH TEMPERATURE 90-100°F

Figure 69 shows the power profile for hot days with daily high temperatures in the 90-100°F range. Here, the average power profiles are similar for the ducted sites and the Prior-Install multizone sites, and slightly lower for the Study-Install multizone sites (which are, on average, smaller and have a

lower load). There are a few sites with nearly no power on average during afternoons, but still considerable variation particularly among the ducted sites. Interestingly, the Prior-Install multizone sites have similar average hourly power profiles with 1 less variation. SNO 44 is not present in this graph because of a site data outage that overlapped with the weather in this temperature bin. INL 42 is the site that stands out in the Prior-Install ducted sites.

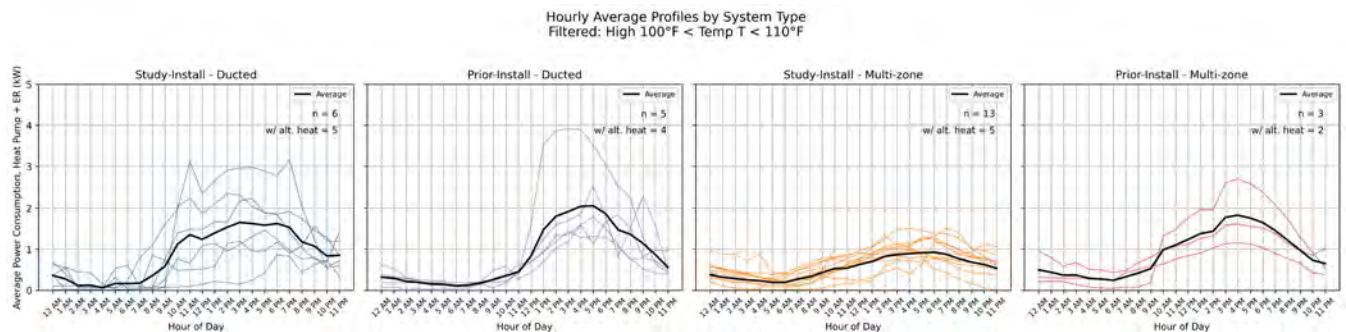


Figure 70. Hourly Avg Power Profile by SystemType100-110°F.

COOLING SEASON, DAILY HIGH TEMPERATURE > 100°F

Figure 70 shows extremely hot days, with daily maximum temperatures over 100°F. Note that fewer sites are available in this bin, as some locations did not exceed 100°F during the study. Here again, the ducted and Prior-Install multizone sites have similar power profiles on average, while the smaller homes in the Study-Install multizone group

had a lower and flatter average power profile. And, again the range from site to site was quite significant, with some sites ramping to much higher power levels during the day, which might suggest thermostat setbacks or user control overrides. INL 42 again stands out among the Prior-Install ducted sites.



POWER PROFILE DIFFERENCES BETWEEN CENTRALLY DUCTED AND MULTIZONE SYSTEMS

The load factors are shown in *Table 31*. To summarize the differences for cooling mode: as with heating mode, we see a peakier load profile for the centrally ducted systems, which can be substantially explained by differences in control and zoning. The multizone systems are capable of cooling a subset of the conditioned space at a given time (for example, cooling the living room and kitchen during the afternoon while not cooling bedrooms to as low a setpoint,

or cooling the side of the house receiving solar gains in a given moment). The ducted systems, on the other hand, provide cooling to the entire home any time there is a call for cooling. There was more variability in the profiles of the centrally ducted systems, which may suggest that the zone-by-zone control in multizone systems has a smoothing effect compared to centrally ducted systems, which are always conditioning either all or no zones. The average load factor for the centrally ducted systems was again generally lower (higher peak loads) than for the multizone systems regardless of whether systems were Study-Install and Prior-Install.

Table 31. Load Factor Of Average Power Profile in Cooling Season.

Temperature Range	Study-Install - Ducted	Prior-Install - Ducted	Study-Install - Multi-zone	Prior-Install - Multi-zone
60-70	2.18	2.46	1.73	1.31
70-80	1.79	2.46	1.41	1.83
80-90	2.16	2.38	1.56	1.96
90-100	2.3	2.17	1.63	1.69
100-110	1.89	2.45	1.69	2

7.6 Thermostat Setbacks

During this study the researchers clearly identified that thermostat setbacks were causing high morning peaks, often triggering ER heat which was not strictly necessary for capacity reasons. To address this issue, in the beginning of 2025 the researchers conducted a thermostat setback study with participation of 14 homeowners recruited from the pool of Prior-Install sites. The participating sites were: TAC 01, TAC 05, TAC 06, TAC 08, TAC 09, TAC 10, YAK 01, YAK 61, SNO 41, SNO 43, SNO 44, INL 02, INL 42, and INL 44.

As described in more detail in *Section 4.5 – Thermostat Setback Study*, the participants were asked to operate their systems normally until January 1, 2025. On January 1, they were asked to switch their thermostats to a set temperature and setback, as well as an 8-hour setback duration. They were to choose from 9 p.m.–5 a.m., 10 p.m.–6 a.m., or 11 p.m.–7 a.m., but two participants asked and were permitted to use different schedules (TAC 01 ending at 3 a.m. and SNO 44 ending at 8 a.m.). Some participants needed assistance or confirmation of their settings, and while most sites started setbacks on January 1 or January 2, the researchers were confident all sites had setback schedules as of January 8. Then, in



February, the participants were asked to run the thermostat at a constant setpoint (no setback).

The weather during the two test periods varied, with January having more consistent mild weather and February having colder and warmer periods.

The combined impact of the thermostat setback change is shown in **Figure 71**, which features, for all the participating sites, a stacked area graph for the HP outdoor and indoor units (including backup heat), as well as the average outdoor temperature at the representative weather. The vertical dashed line on the graphs shows the day the participants switched from with-setback

to flat. The upper graph reveals a significant change in the power profile with, and without, the setback. Visually comparing days with similar weather across the region, the days in January are characterized by high early morning peak power and a trough of low power in the evening. The days in February have lower peaks and higher troughs for similar weather. The highest peak in February occurs in mid-February, with combined power reaching approximately 47 kW; however, this occurs on a day that was significantly colder in Yakima and Inland (outdoor temperatures between 0-5°F) than was reached at any time in January. In January, daily peaks approached or exceeded 50 kW for most of the second half of the month, though outdoor temperatures seldom reached below 15°F.

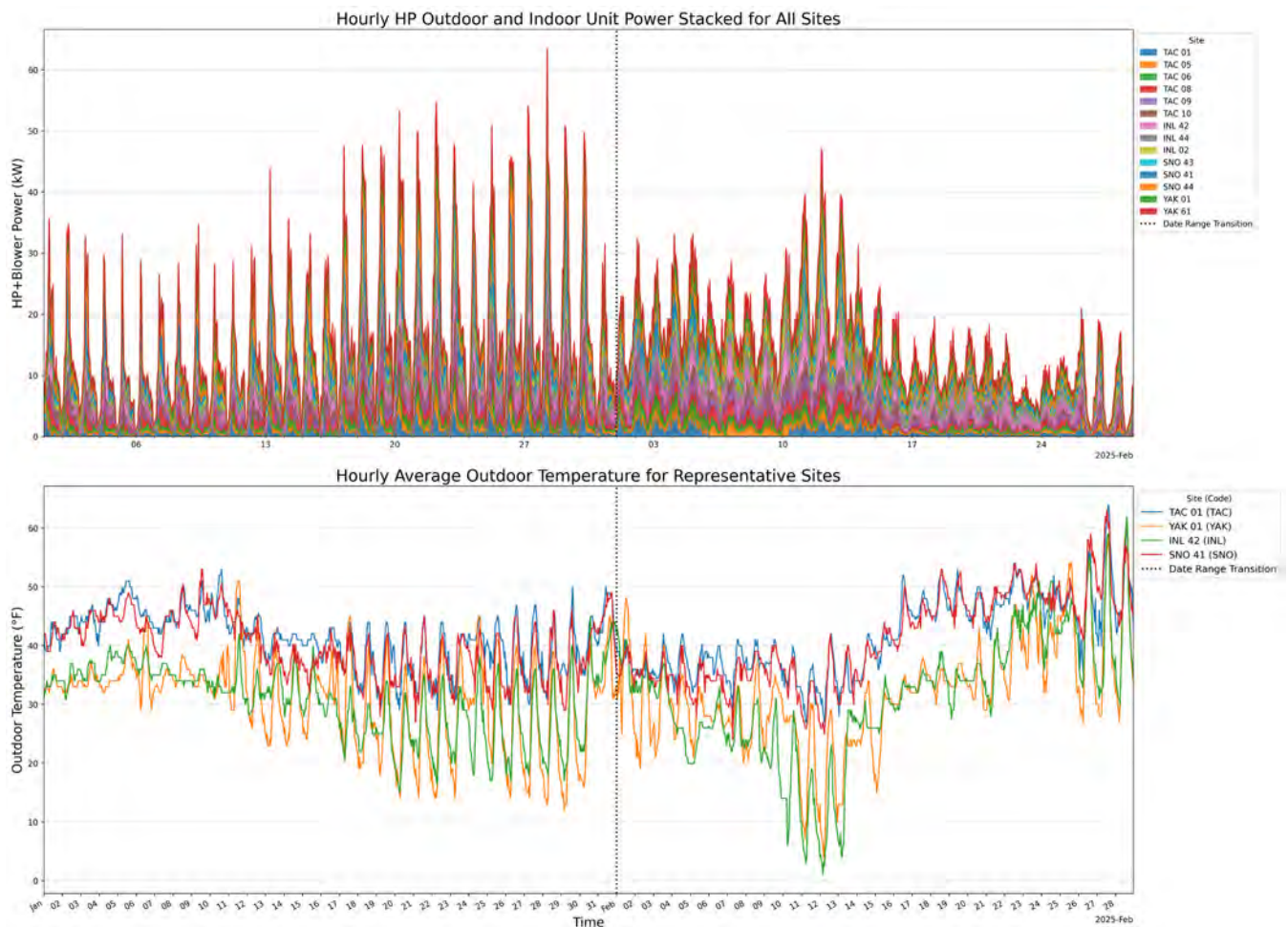


Figure 71. Hourly Heat Pump Outdoor and Indoor Power and Outdoor Temperature before and after Setback.

Site-by-site inspection reveals the drastic change in power profile associated with the controls change. **Figure 72** shows the hourly average power for each site during the range of January 8-31 in blue, and February 1-28 in orange. The shift is visible for all sites but is most pronounced at INL 02 and SNO 44, where very high ER heat power causes the average hourly power during setback recovery to exceed 10 kW at each site in January, compared to average power of approximately 2 kW for the same hours in

February. Other sites also show substantial changes to load shape, but the magnitude of the difference is much smaller. Review of per-site changes showed that all sites selected a flat temperature that was between the two temperatures selected for the January period. TAC 08 was unique in selecting the highest temperature in their setback range as their 24-hour temperature during the no-setbacks period. TAC 08 is also noteworthy for having no ER heat elements installed.

Hourly Average of HP + Backup Power for All Sites

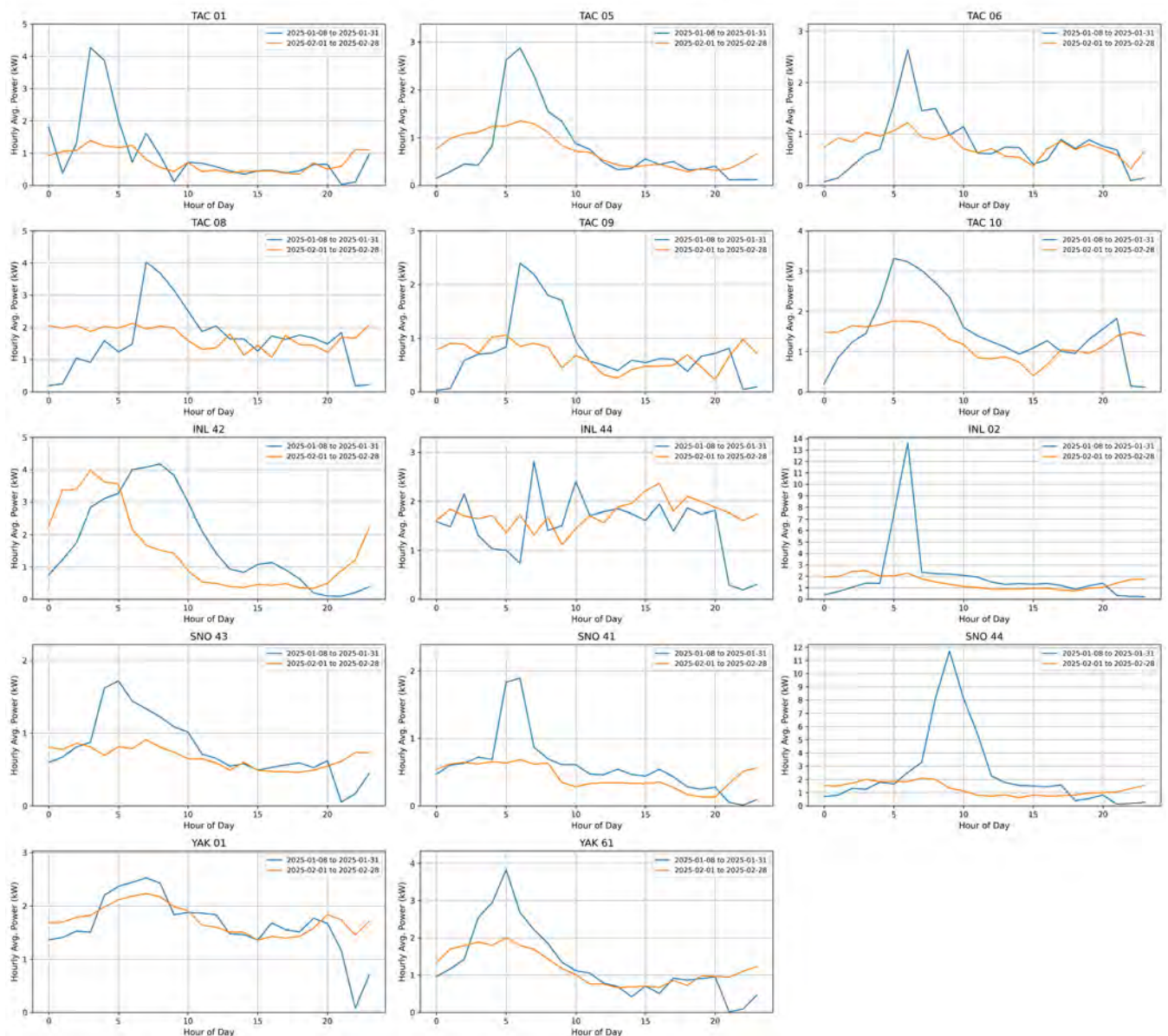


Figure 72. Hourly Average Power Profile of Setback Study Sites with and without Setback.



The above figures and discussion illustrate a clear change caused by thermostat setbacks. The impact of outdoor temperature on peak power is examined below, with and without thermostat setbacks. First, **Figure 73** shows the average hourly power profile for each site, separated by grouping days into bins of average outdoor temperature. This reveals that, across all sites, increased peak power

draw was present even on mild days, but was more significant during colder weather. This aligns with expectation, as the HP will generally have lower capacity and the heat loss rate of the home will be higher with lower outdoor temperature, meaning that a longer run-time, higher power, or both would be expected.

HP+Blower Hourly Avg Power by ODT Bin, 2025-01-08 to 2025-01-31

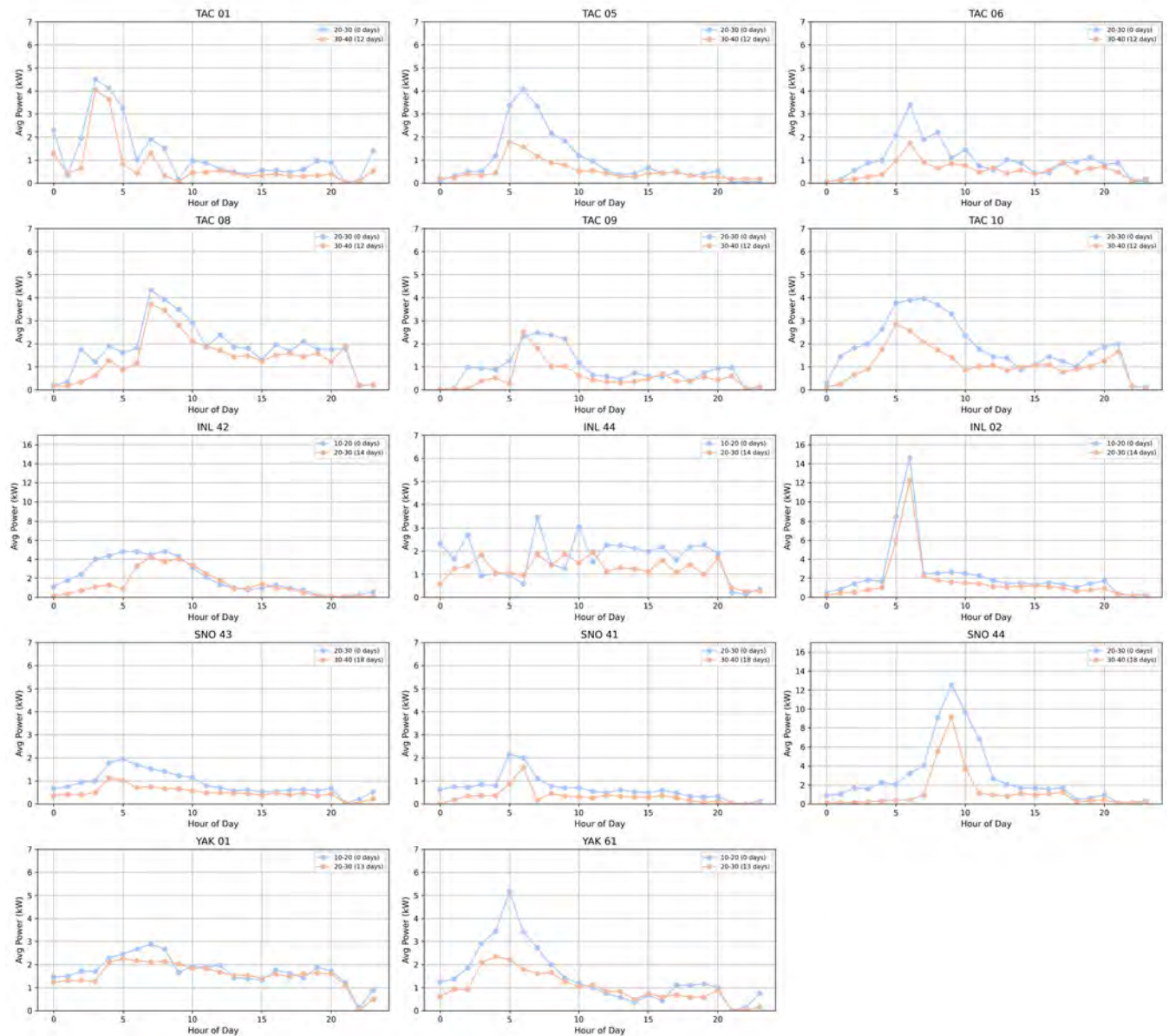


Figure 73. Power Profile by Daily Temperature Bin in January (with Temperature Setbacks).



Figure 74 uses the same format for the February monitoring period with no thermostat setbacks, again by outdoor temperature range. In this case, the power profile is still higher with colder outdoor temperatures, but there is not a distinctive peak period. There was a wider range of weather, and colder weather did cause INL 42 to have higher overnight power, including high ER heat usage for days in the 10-20°F

average outdoor temperature range, which was colder than seen at that site in January. However, this power usage more likely follows the trend of outdoor temperature, rather than thermostat setback. Also, INL 44 indicates nearly zero power in the overnight and morning hours during the coldest outdoor temperatures; this site had natural gas second stage heat, which is most evident during the lowest outdoor temperatures.

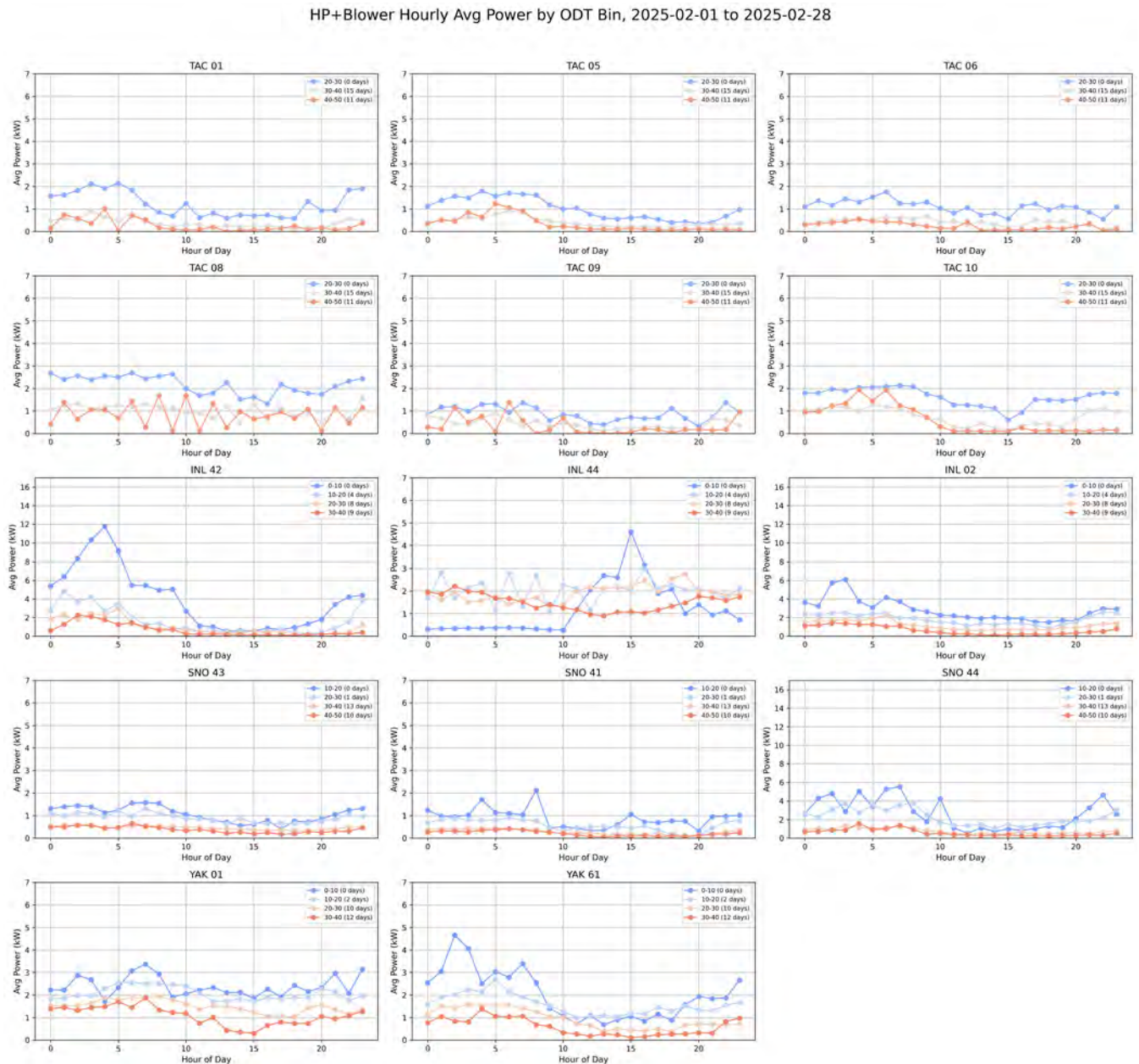


Figure 74. Power Profile by Daily Temperature Bin in February (without Thermostat Setbacks).



Energy savings is the main motivation for homeowners to use a thermostat setback, and **Figure 75** shows the daily HP outdoor and indoor unit energy consumption for each site, plotted as daily kWh vs. daily average outdoor temperature. The graph shows the thermostat setback period in blue, and the flat thermostat setting period in orange. Trend lines for each mode are overlaid

along with the confidence interval for each trendline. With visual inspection it is clear that a few sites trend toward significant energy differences, but most are close and have significant overlap of the confidence intervals. INL 44 stands out for having a vastly different trend; this is the site with natural gas backup heat.

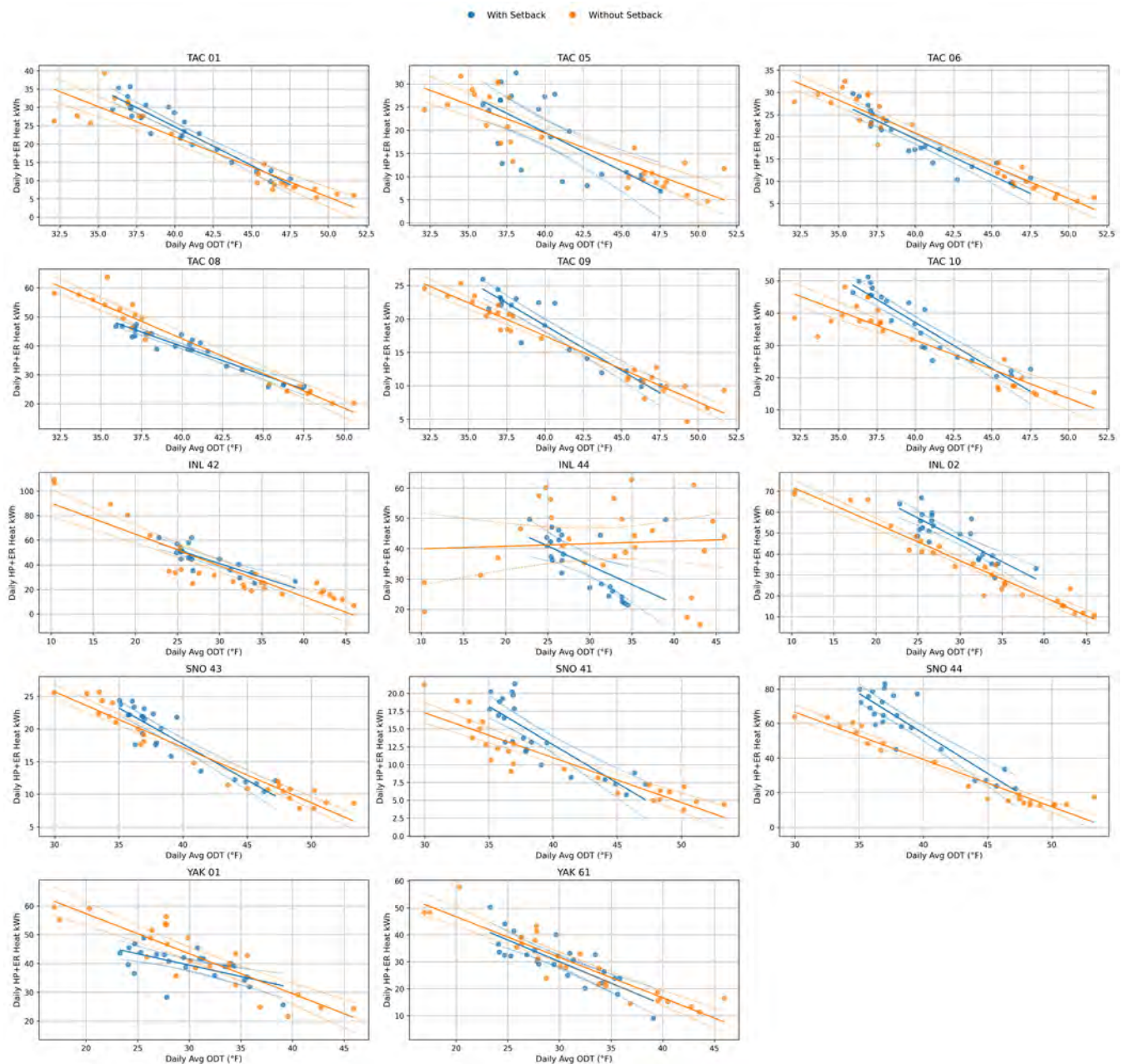


Figure 75. Energy Trends with and without Thermostat Setback Settings.



Weather-Normalized Projected Energy Consumption for January-February Based on Trendlines With or Without Thermostat Setbacks

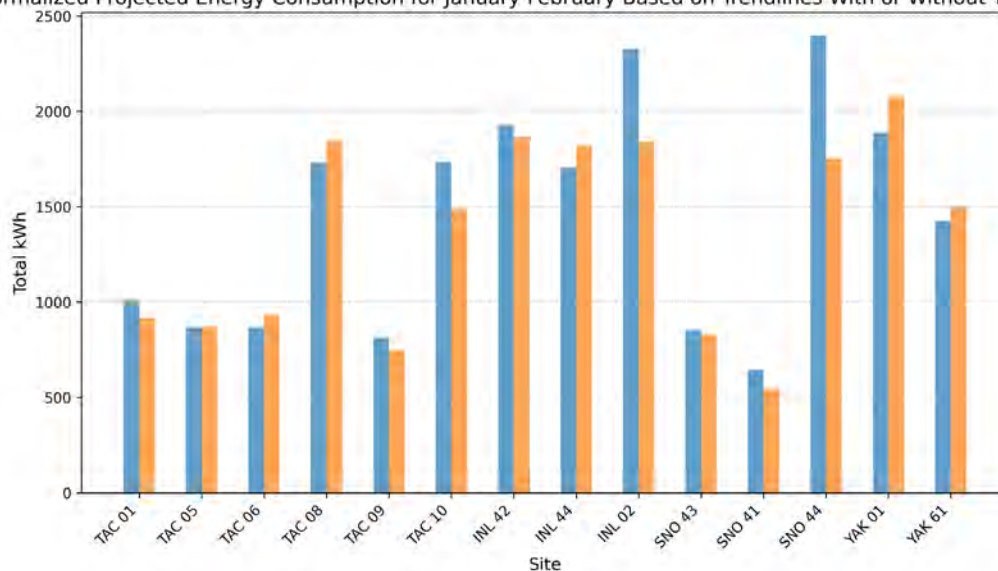


Figure 76. Weather Normalized Projected Energy Consumption for January-February Based on Trendlines with or without Thermostat Setbacks.

The trendlines were used to re-calculate an estimated total energy consumption for the entire duration of January and February as if each home had operated in each mode. The result is in **Figure 76**. This calculation extends the trend lines produced in January into the wider temperature range of February. The results show 10 of the 14 sites within +/- 10% of energy consumption. Of the four sites with projected energy consumption outside that range (TAC 10, INL 02, SNO 41, and SNO 44), all four show projected energy savings with a flat thermostat setting.

One concern the researchers recognized during this study was that more HP run-time can be perceived as the HP running “too much”, causing homeowners to believe the HP may not be running efficiently. The per-day total run time of each system is plotted in **Figure 77** and, for most of the systems, the run time per day was greater without a setback than with, for similar outdoor temperatures. This is to be expected: setbacks prompt the system to turn off while the temperature is allowed to fall in the setback

and then run more when coming out of the setback. However, run time does not directly correspond to energy consumption, since systems may run at different efficiency levels and use ER heat differently. TAC 10 presents a good example: in the coldest overlapping days, the run time without a setback was over 22 hours, compared with 18-21 hours with a setback; but the average energy consumption was approximately 10 kWh lower without a setback, despite the longer total run time. This counter-intuitive concept may need to be clearly expressed to homeowners if behavior changes around setbacks are desired.

The thermostat setback study appears to indicate that thermostat setbacks are not clearly producing energy savings for these homes and, in some cases, are causing energy penalties. The setbacks are also contributing to utility peaks. **Figure 78** shows the aggregated average power profile for the two periods and shows an average power draw at 6 a.m. across the January “with-setback” period, which is approximately double the power at 6 a.m. when the systems were set to

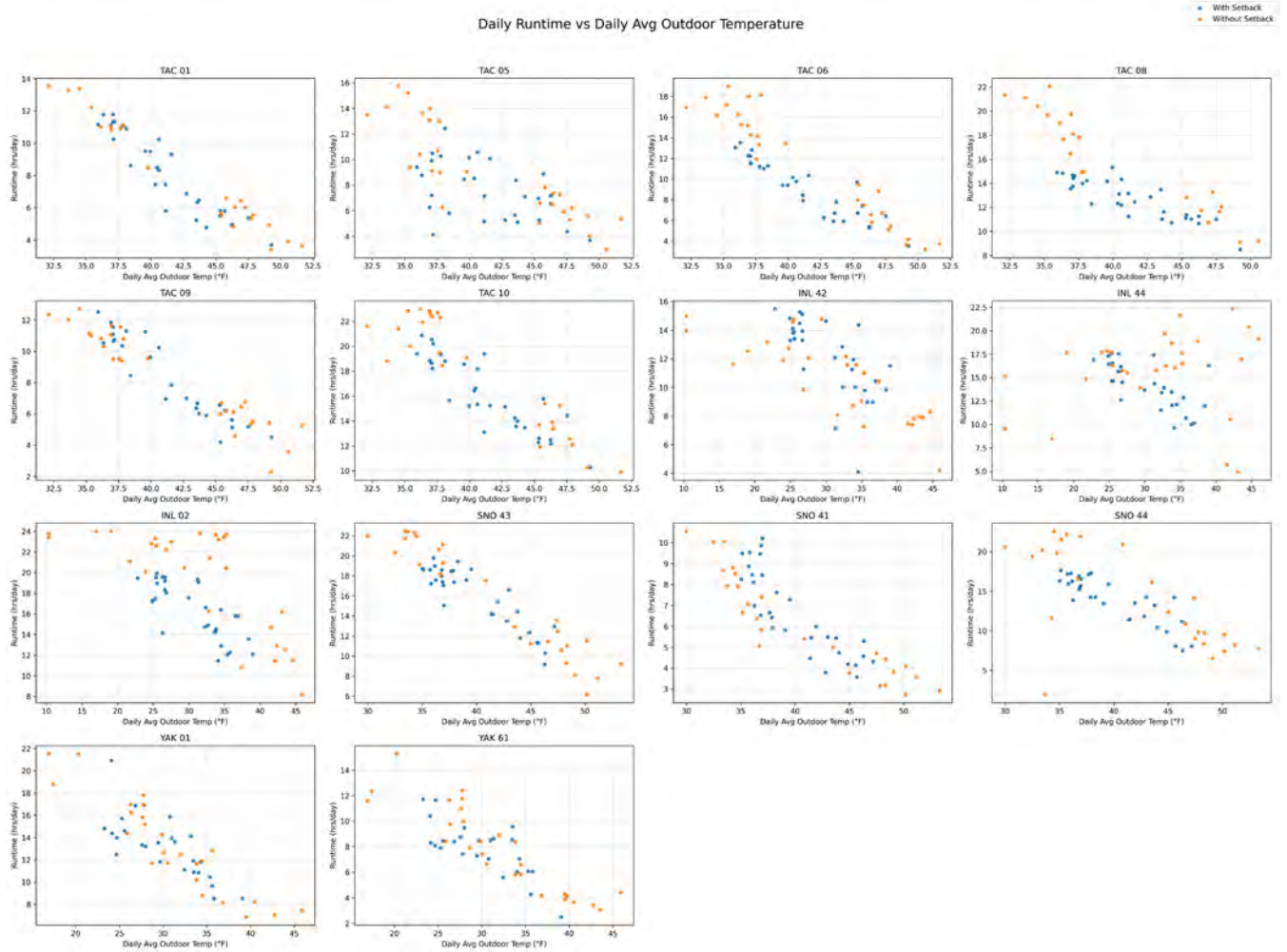


Figure 77. Daily Run Time with and without Thermostat Setbacks.

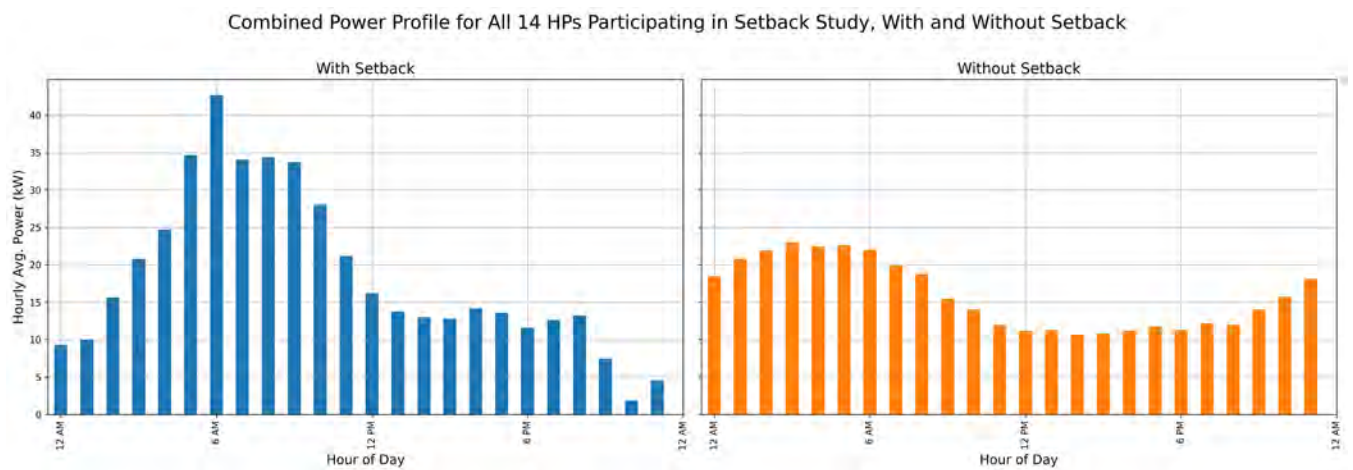


Figure 78. Combined Power Profile of Setback Study Participating Sites with (Left) and Without (Right) thermostat Setbacks.



flat thermostat settings. The issue is largely driven by the use of ER heat to recover from setbacks, an issue which is more significant in colder weather. The issue is also not equally significant across all sites; while all of the sites saw significant changes to their load shape with a thermostat setback than without, a few sites had extreme changes driven by sustained use of large ER elements.

8.0 Determinants of Peak Load Demand Reduction Benefit, Efficiency, and Energy Savings

The prior sections examined, in great depth, numerous aspects of equipment performance. When considered independently, it can be difficult to tease out and generalize what exactly determines efficient operation, energy savings, and a peak load demand reduction. This section seeks to integrate the analysis to first identify, and then quantify, the independent variables that lead to desirable outcomes for energy use, peak load demand reduction benefit, and efficiency.

To better understand the results of the field measurements, the researchers conducted an ordinary least squares (OLS) linear regression approach. This method estimates the coefficients that minimize the sum of squared differences between observed and predicted values, enabling quantification of both the direction and magnitude of each predictor's association with the outcome while controlling for the effects of other variables. An iterative, informed, trial-and-error process was used to select model components, starting from a set of expected contributing variables and aiming to improve model fit while maintaining a credible

technical basis and avoiding overfitting. The researchers tested a large suite of variables for significance. Most were discarded and surprisingly, variables like heat loss rate, were not explanatory. For the sake of brevity, they are not discussed in this section. The researchers gave preference to variables that would be readily available to programmatic decision makers, over variables that might require detailed knowledge of a given home.

It is important to note a few caveats to these results:

- The site sample is not random or representative of the broader region;
- The site sample is relatively small for statistical analysis;
- The systems under test are all expected to be high-performing variable-speed systems, almost all on the NEEP ccASHP list;
- Nearly all the systems in this collection have relatively low balance points (not undersized)

Therefore, the results here should not be extrapolated. A new analysis would be required for comparison with, for example, standard-efficiency single-speed HPs.

8.1 Energy Savings

For energy savings, the researchers scrutinized the billing-based heating-season energy savings for each site. The absolute value was used, though the team also examined models normalized per square foot, per heating degree day, and similar approaches.



An early observation in analysis was that the billed heating energy consumption prior to HP installation was by far the biggest predictor, accounting for about 75% of the savings. This aligns with expectations: homes that used more prior heat present a greater opportunity for savings. The next biggest contributing factor was whether the home received a multizone or ducted heat pump. The model, considering these two factors, explained 80% of energy savings. Beyond that, the researchers found three other factors that meaningfully improved the model: home square footage, a weighted COP, and degrees of under-sizing. The weighted COP is a weighted average of the COP at minimum capacity at 47°F outdoor temperature, and the COP at maximum capacity at 17°F outdoor temperature. This weighting adjusts by outdoor design temperature: weighting the COP at 17°F more heavily with colder outdoor temperatures. The degrees in Fahrenheit of under-sizing – defined by the team as the difference between the estimated balance point of the HP (from measured data) and the outdoor design temperature – is the only variable the researchers added that uses some field measurement. For systems where the balance point was lower than the outdoor design temperature, this value is zero. Otherwise, it is the difference between those two temperatures, with a larger spread contributing more to reduce savings.

The best model for energy savings, which predicts 90% of the bill-based heat energy savings, was:

$$\text{Heating Energy Savings (kWh/y)} = -3434 + 0.90 \times \text{HeatPrekWh} - 143 \times \text{sqft} + 659 \times \text{WeightedCOP} - 310 \times \text{UndersizeDegrees} - 1885 \times [\text{IsMultiZone}]$$

This model suggests that, on average, each multizone system saves 1,885 fewer kWh than each ducted system. Every 1-point increase in the weighted COP predicts an increased 659

kWh of heating season energy savings; every degree of under-sizing predicts an average of 310 fewer kWh saved. Home-specific factors have the largest impact, and square footage and pre-heat pump kWh energy consumption are interconnected. A home with a given pre-heat pump kWh but a larger area (a lower heating energy usage intensity) predicts lower energy savings whereas a home with a given area but larger pre-heat pump kWh (a higher energy usage intensity) predicts higher savings. The magnitude of these changes are considerable: 1,000 kWh more pre-heat kWh predicts an average of 900 kWh savings, compared to 1,430 fewer kWh saved for a 1,000 square foot increase in home size.

8.2 Measured Equipment Efficiency

The OLS model approach was also used to evaluate which parameters predict the field-measured HSPF2 (IV). This value is of interest because it is a seasonal HP efficiency, normalized to a common basis (the Region IV weather bins), and therefore may be less dependent upon home- or location-specific issues. Furthermore, this study sought to identify what made HPs more efficient. Though energy savings did not always correlate directly with the measured efficiency of the HP (due to other factors such as behavior), improved system efficiency would still be an expected benefit for a given home, all other factors being equal. Some of the variables that were expected to be predictive included the COP at minimum capacity, 47°F outdoor temperature and COP at maximum capacity, 17°F outdoor temperature, as well as typical supply air temperature, relative sizing of the HP, and HP turn-down ratio.



Regression analysis confirmed an early suspicion: rated HSPF2 (IV) is a poor predictor of field seasonal efficiency. Surprisingly, the rated EER2 was more strongly correlated with field measured efficiency than was HSPF2 (though still not strong enough to be useful in practice). The researchers also observed some brand-specific clustering in the results, which supports the notion that some factors vary by brand, and theorize that manufacturer control choices play a significant role.

The researchers found that a regression model using only COP at maximum capacity at 17°F predicted approximately 50% of the field-measured HSPF2 (IV) value. This was the strongest individual value in predicting field-observed HSPF2 (IV). This model achieved 80% predicted power when it was further expanded to include some variables that a utility could conceivably impact, including COP at minimum capacity at 47°F, degrees of setback (in Fahrenheit), and fraction of total system energy consumed by the indoor unit and ER heat (FracBF&ER). The proportion of energy consumed by indoor unit and ER heat was more predictive when squared; the researchers hypothesized that small values of this number can be attributed mostly to fan power, or low levels of ER usage (such as during defrost), but that the impact of higher usage may indicate excessive calls for second stage heating.

The best model identified was:

$$\begin{aligned} \text{Field HSPF2 (IV)} &= -5.88 + 0.88 \\ &\times \text{COP}_{\text{Min}47^\circ} + 4.47 \times \text{COP}_{\text{Max}17^\circ\text{F}} \\ &- 15 \times (\text{FracBF \& ER})^2 + 0.48 \times \text{Setback} \end{aligned}$$

This model predicts an average of 1 point of field HSPF2(IV) for each 1.14-point increase in the minimum-capacity COP at 47°F, and 1 point of HSPF2(IV) increase for each 0.22-point increase in the maximum-

capacity COP at 17°F. A 2-degree setback predicts approximately 1 point improvement in the field-average HSPF2(IV). Furthermore, increasing from 10% to 20% of the energy consumed being blower fan or ER heat predicts a 0.45-point reduction in HSPF2(IV), while increasing from 20-30% predicts a 0.75-point reduction, and from 30-40% predicts a 1.05-point reduction (a 10% to 40% change drops the field HSPF2 by 2.25 points). Clearly, the ER use is a gigantic contributor to overall system efficiency.

8.3 Peak Power

The researchers conducted the regression analysis on peak power consumption at three temperature conditions: for bins of 20-25°F, 5-10°F, and 90-95°F over the four-hour average power (5-9 a.m. in winter and 4-8 p.m. in summer). These bins and hours were selected to maximize the number of sites with data and capture the home-specific peaks for as many sites as possible. Further, 20-25°F is the peak heating condition in HZ1, while 5-10°F is near the peak heating condition in HZ2. In the maritime Northwest, 90-95°F is near peak cooling (the researchers did not observe enough hotter temperatures to examine hotter bins).

8.3.1 Heating Power at 20-25°F

Predicting system peak power was also of interest in this analysis. In the 20-25°F outdoor temperature bin the researchers expected that the system's maximum power or capacity at 17°F, COP at 17°F, size of the ER element, and HP-size relative to home-size would be predictive values. For estimates of load on the home variables such as square footage, ACH50, square footage times ACH50, billing-based kWh from the pre-test period, and other similar variables were explored.



The researchers found that the most dominant variables were home square footage, the degree of thermostat setback, and the rated EER2, predicting about 70% of the variation in average power during peak hours. The relative magnitude was that a thermostat setback increase of 5°F corresponds to 0.97 kW higher average power during the morning hours; a 700-square-foot increase in home size drives 0.98 kW higher average power; and 1-point higher EER2 score predicts 0.24 kW lower average power during those hours. It is worth noting that the researchers spent considerable effort trying to identify sizing-related parameters other than square footage which would more clearly separate the house heating load and relative heat pump sizing but found square footage to perform far better in the regression.

The researchers were again surprised to find EER more predictive than metrics for COP at 17°F. They speculate that the EER test is more tightly controlled, and therefore the EER values in the NEEP database may be more consistent than the values provided at manufacturers' discretion.

The researchers theorize that, since nearly all sites in the study had adequate capacity to meet the heating load at 17°F with HP only in absence of a thermostat setback, and since the COPs of these systems are relatively similar (most ranging between 2-3), the differences between HPs specifically is smaller than the impact of a setback (which drives high power for a brief period, often including backup heat) or a large home.

The model with the best fit was:

$$\begin{aligned} \text{Power}_{\text{Early Morning Hours, } 20-25^\circ\text{F Outdoor Temperature}} \\ = 3.48 + 0.193 \times [\text{Degrees of Setback}] \\ - 0.24 \times \text{EER2} + 0.0014 \times \text{SqFt} \end{aligned}$$

8.3.2 Heating Power at 5-10°F

For outdoor temperatures in the 5-10°F range, the modeling approach followed the same framework used for the 20°F bin. The researchers tested whether adding power, capacity, or COP values at 5°F (and other variables) could improve predictive power but found no meaningful benefit from the tested variables. One factor that did improve the model was the size of the ER heating element. Larger elements had a small but statistically significant upward effect on average power use; on average, a 5 kW increase in element size corresponded to a 0.44 kW increase in average power during the period of interest.

This increase may seem counterintuitive, that a 5 kW larger element would raise the average load by less than 0.5 kW. The reason is the values are averaged over several hours. At a given home, assuming perfect control of the HP and resistance heater, a larger-kW element would simply run for a shorter time period, only as much as needed to balance the load, and the average power would be the same with a larger or smaller element. This finding suggests that under real controls, the larger resistance elements may shift a small portion of the heating load from the HP to the backup elements during operation.

The other important variables were the same as for the 20°F bin. A 1,000 square foot increase would correspond to a 1 kW higher peak power, a 5°F greater thermostat setback would contribute 0.83 kW higher average power, and 1-point higher EER2 score predicts 0.15 kW lower average power. Overall, the model predicts about 77% of the average power during winter early morning hours.



The model with the best fit for the 5°F temperature bin was:

$$\begin{aligned} & \text{Power}_{\text{Early Morning Hours, 5-10}^\circ\text{F Outdoor Temperature}} \\ = & 2.92 + 0.166 \times [\text{of Setback}] - \text{EER2} \times 0.1475 \\ \times & 0.0010 \times \text{SqFt} + 0.0876 \times \text{BackupHeatingElementkWh} \end{aligned}$$

PEAK SCORE METRIC

The researchers explored the predictive power of different metrics for predicting average power in decreasing outdoor temperature ranges at all hours (not just peak hours, which are dominated by setback recovery). To predict systems that will perform better in cold weather, the Peak Score conceived at the beginning of the study (*Section 4.4.2 – Specification and HPHC HP QPL Development*) attempts to combine the shape of the capacity line between 17°F and 5°F (giving higher score to systems with higher capacity maintenance into cold weather) and the COP at 17°F. This metric was found to have statistically significant but relatively weak predictive power. Filtering out wood burning homes and examining the temperature bins of 5-10°F, 10-15°F and 15-20°F, a model of peak score alone predicted approximately 30% of the variation in peak power. The effect is modest: in the 5-10°F bin, for example, an increase of 1.0 in the peak score predicts lower average power by 0.63 kW. Scores in the sample population vary from 5.7 to 8.2. The combined metric of Peak Score had a better correlation than was found for the COP or capacity maintenance values alone. Once adjusting for morning hours, as discussed above, other metrics were much more powerful predictors of peak power. However, this finding suggests there may be merit to a metric that attempts to capture the combined effect of high capacity and efficiency in colder temperatures.

The Peak Score metric, when considered alone, had a small predictive power for lower average power, but this finding was narrowly outside the range of statistical significance; the sample size in this range is small, and further sites could have helped clarify its contribution or lack thereof. When considered as part of the model above, its impact was negligible (meaning other factors contributed much more).

8.3.3 Cooling Power at 90-95°F

For the average power during the hours of 4-8 p.m., when outdoor temperature was in the 90-95°F temperature bin, the regression initially presented challenges. The researchers observed that cooling mode operation was highly influenced by user manual intervention. Exit surveys confirmed what was observed in site-by-site analysis: many homeowners turned their systems on in cooling mode only on a case-by-case basis. This means that at some of the sites there were regular occurrences where, even though the outdoor temperature was greater than 90°F, the HP may not have been turned on, or was turned on part of the way through the time period of interest. To address this issue, all sites where the average power during this period was less than 0.5 kW were filtered out, capturing several sites that had low or no usage. This filter is imperfect: if a homeowner usually, but not always, turned their system on during these periods, the data will suggest a lower average power because of the occasions where the homeowner left the system off. The best regression model identified reflects this, having an explanatory power of only 54%. This reflects the high importance of occupant behavior on cooling system behavior.



With the above filters in place, the researchers found two important drivers. As with heating peaks, home square footage is a significant driver. They observed that a 1,000 square foot increase in home size corresponds to an average 0.4 kW increase in average system power during the late afternoon and evening peak hours when outdoor temperature is 90-95°F. The other important driver is whether systems were multizone or centrally ducted: centrally ducted systems on average used 0.66 kW more during this time period than multizone systems. The researchers hypothesized that multizone systems are often only cooling the actively used living space, for example the kitchen and living room but not bedrooms, and this contributes to a significantly lower average power. This also aligns with the observations of the cooling-mode load profile in **Section 7.5.2 – Cooling Season**, which showed lower peaks in multizone systems.

The best fitting model for the 90-95°F temperature bin was:

$$\text{Power}_{\text{late afternoon and evening hours, 90-95°F Outdoor Temperature}} = 1.03 + 0.0004 \times \text{SqFt} + 0.6629 \times [\text{Is Central Ducted?}]$$

9.0 Site-Specific Observations and Illustrations

This section presents a set of observations that did not fit neatly into other parts of the report, illustrated with examples from specific sites. Some are unique to a single site, while others appeared across multiple sites but are highlighted through a representative case. These findings are intended to shed light on details that, while sometimes incidental, may help illustrate key concepts or provide additional context.

GEC 31 - RESIDUAL HEATING POWER, ILLUSTRATED BY EXAMPLE OF EXTREME COLD AT GLACIER, MT

The metering apparatus in this study mostly focuses on the HP itself and on any known ER auxiliary heating equipment, such as second stage ER heat installed with the HP, or electrical circuits dedicated to existing baseboard or cove heaters which the researchers could capture with power meters. It is also important to try to quantify any additional electric heating or cooling equipment that may not have been captured by a dedicated power metering circuit. To accomplish this, the researchers use a simple method: subtracting the average power of the known heating equipment from the average of the whole-home power, adjusting for typical base usage. This allows them to identify any temperature-dependent electricity usage that was not captured by the metering equipment. To quantify the base usage, it's a simple matter of taking the average of electricity usage when outdoor temperatures are above 50°F in heating season and below 70°F in cooling season. For most homes in the study, the result is a residual power vs. outdoor temperature line which is essentially flat. For a few homes, however, some additional heating or cooling is found.

The GEC homes in Babb, Montana provide a simple illustration of this when, during a cold snap, the outdoor temperature reached -40°F. At these homes, power meters were installed on circuits with old, electric resistance heaters, but they were observed not to run as the heat pumps (sized aggressively for high heating capacity) satisfied the entire heating load down to approximately -10°F. However, as the weather became even colder, the heat pump alone was unable to provide adequate heating; its power significantly



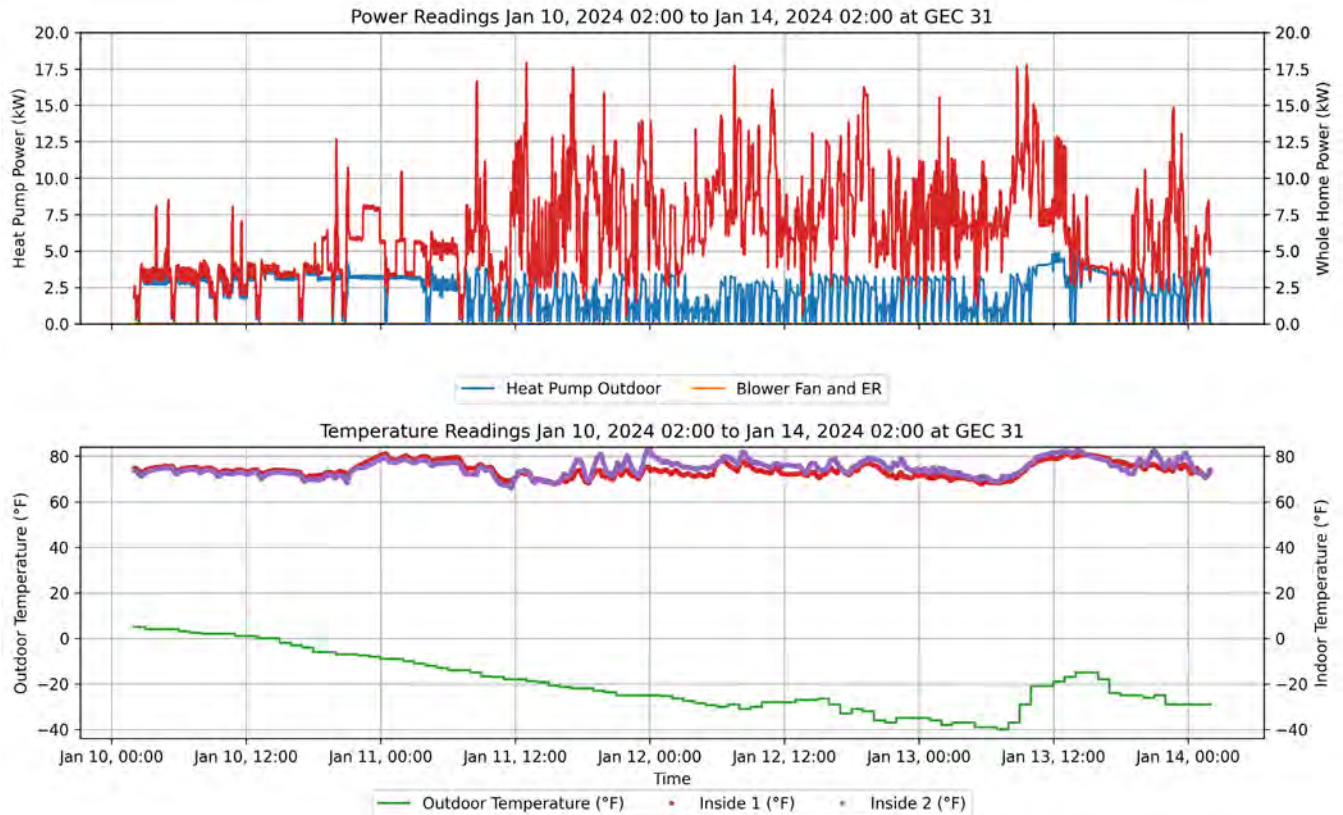


Figure 79. Power and Temperatures at GEC 31 during Cold Snap, Showing Switch to Plug-In Heaters (Residual) In Extreme Cold.

dropped (possibly indicating inability to sustain the necessary operating state to run). The researchers observed the whole-home power increase substantially during this time, proportional to decreasing temperatures. This indicates the occupants used some other heat source, such as plug-in space heaters, to maintain comfort during this time. This power, not captured in isolation on a dedicated power measurement but observed via the whole house measurement, is referred to here as residual electric heating load.

Figure 79 shows the minute-by-minute measured power and indoor temperature at GEC 31 during a January 2024 cold snap, which illustrates this change. As the outdoor temperature dropped, the HP (blue, top axis) ran at high power for a sustained period of time. The whole-home power (red, top axis) roughly followed HP power, as the HP was

the dominant load. Starting late January 10, a gap between whole home power and HP power began to appear, and the two indoor temperatures (blue and purple, bottom axis) rose from approximately 70°F to closer to 80°F. This was around the time when outdoor temperature was approaching -10°F. Subsequently, as it continued to get colder, the HP power continued to decrease and the whole-home power continued to increase.

Figure 80 shows the average power vs. outdoor temperature bin for the same site, with the average GEC power of the HP outdoor unit (blue) and the average power of the whole home, minus the HP and water heater. This shows a steady, relatively low average power of all non-thermal loads as outdoor temperature decreases, and a substantial step-change during temperatures in the -10°F

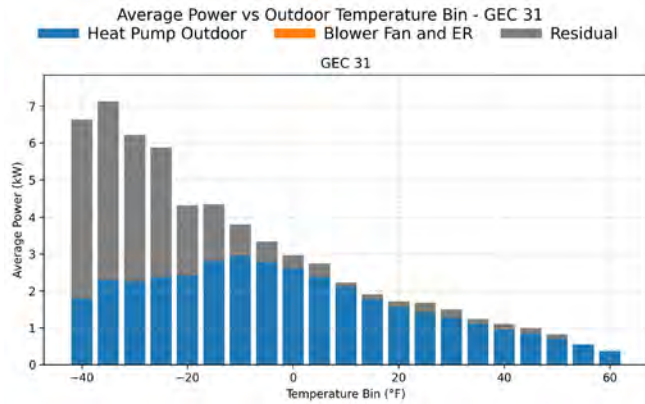


Figure 80. Average Power vs. Outdoor Temperature Bin at GEC 31, Showing Residual Power in Extreme Cold.

bin and lower. That step change is what is captured in the residual power consumption metric.

CEC 41 – UNUSUAL SETBACK SCHEDULE PRODUCES DRAMATIC POWER SPIKES

While the research team sought not to directly interfere with occupant behavior in the study, a homeowner reached out through

their utility to inquire about their unique thermostat setback strategy. The homeowner, believing that a more gradual setback recovery strategy would be easier on their HP, had staged setback recovery into several small steps through the early morning (rather than a single setpoint change). Upon review of the data, the researchers observed that this strategy was causing dramatic increases in ER heat operation and relayed that information through the local utility to the homeowner, suggesting a flat thermostat setting instead. The homeowner changed their thermostat on February 2, 2023. The effect was immediate and dramatic, as illustrated in **Figure 81**. In the days preceding the change, the ER heat spiked several times during the overnight period, producing hourly-average power of 4-6 kW several times per night, even on fairly mild nights. After the change, with similar weather conditions, the ER heat did not run at all.

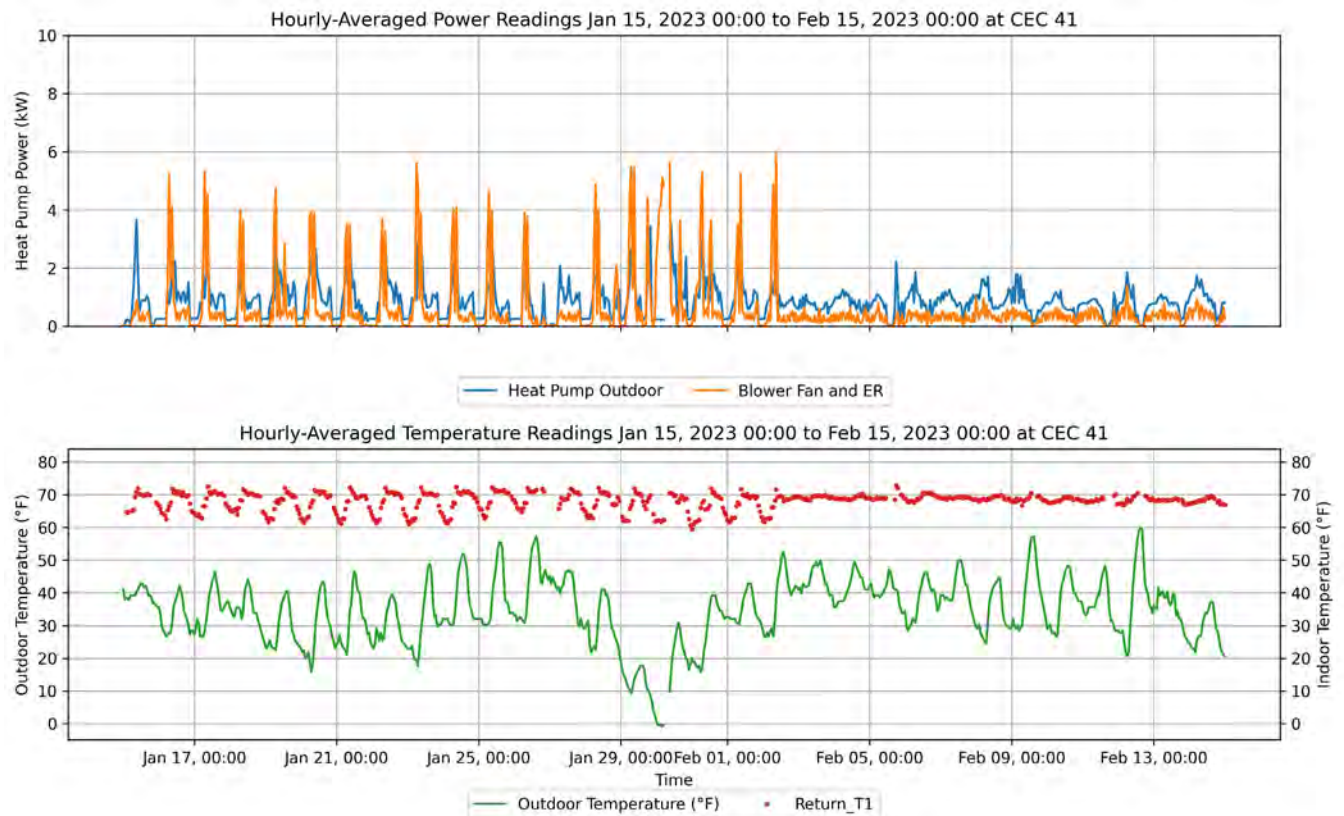
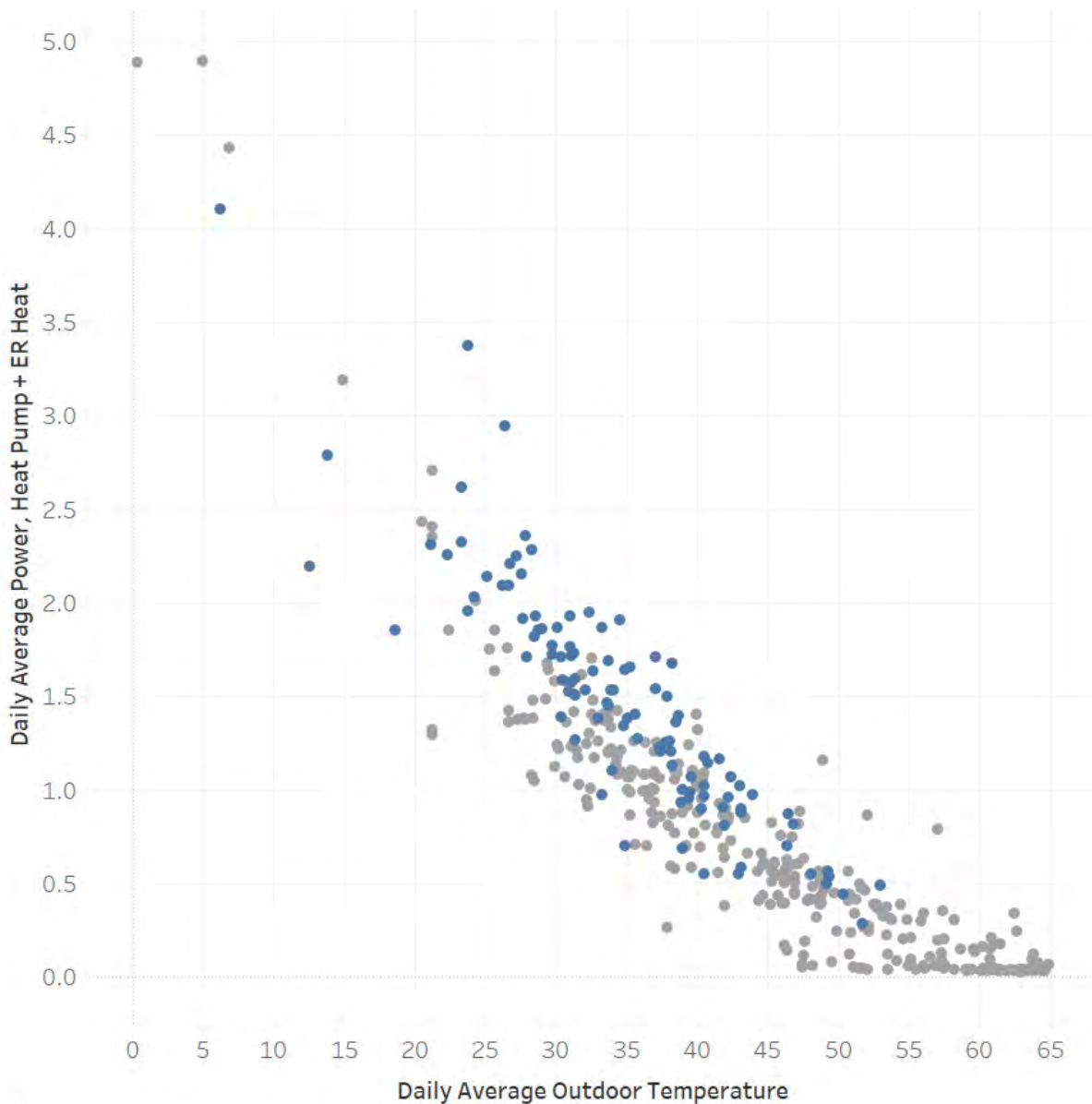


Figure 81. Hourly Average Power and Temperature Leading Up to and After Thermostat Setting Change.





- Before Feb 2, 2023
- After Feb 2, 2023

Figure 82. Daily Energy Before and After Thermostat Setback at CEC 41.

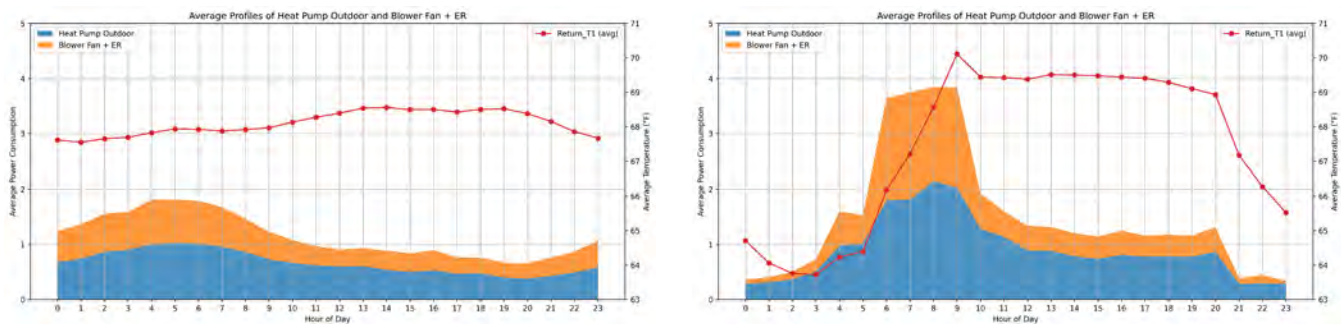


Figure 83. Average Hourly Power and Indoor Temperature Before (Left) and After (Right) Change from Aggressive Thermostat Setback Strategy to Flat Thermostat Setting at CEC 41.



The daily average power consumption of the HP and backup heat system is shown in **Figure 82** with a clear reduction in average power consumption after the change, for a given outdoor temperature.

The hourly average power profile for winter days, along with the indoor temperature profile, is shown in **Figure 83**, illustrating the substantial and sustained high electric heat usage (lasting for approximately four hours) caused by the multi-hour thermostat setback recovery, which was later eliminated with a flat setting. While the setback does reduce overnight power, the change is more than overcome by the resistance heat in morning recovery.

SNO 44 – HIGH CONTRIBUTION TO PEAK IN SUMMER AND WINTER

SNO 44 was shown to be a significant contributor to peak power in both heating and cooling modes. **Figure 84** shows the hourly average power consumption entering a cold snap in January 2024. In the early part of this time period, a thermostat setback is still present, as evidenced by the return air temperature and high average hourly power of outdoor unit and resistance heat at the same time each morning. During the coldest portion in mid-January this problem is more pronounced, with repeated spikes in which the ER heat averages 8-10 kW for an hour each morning.

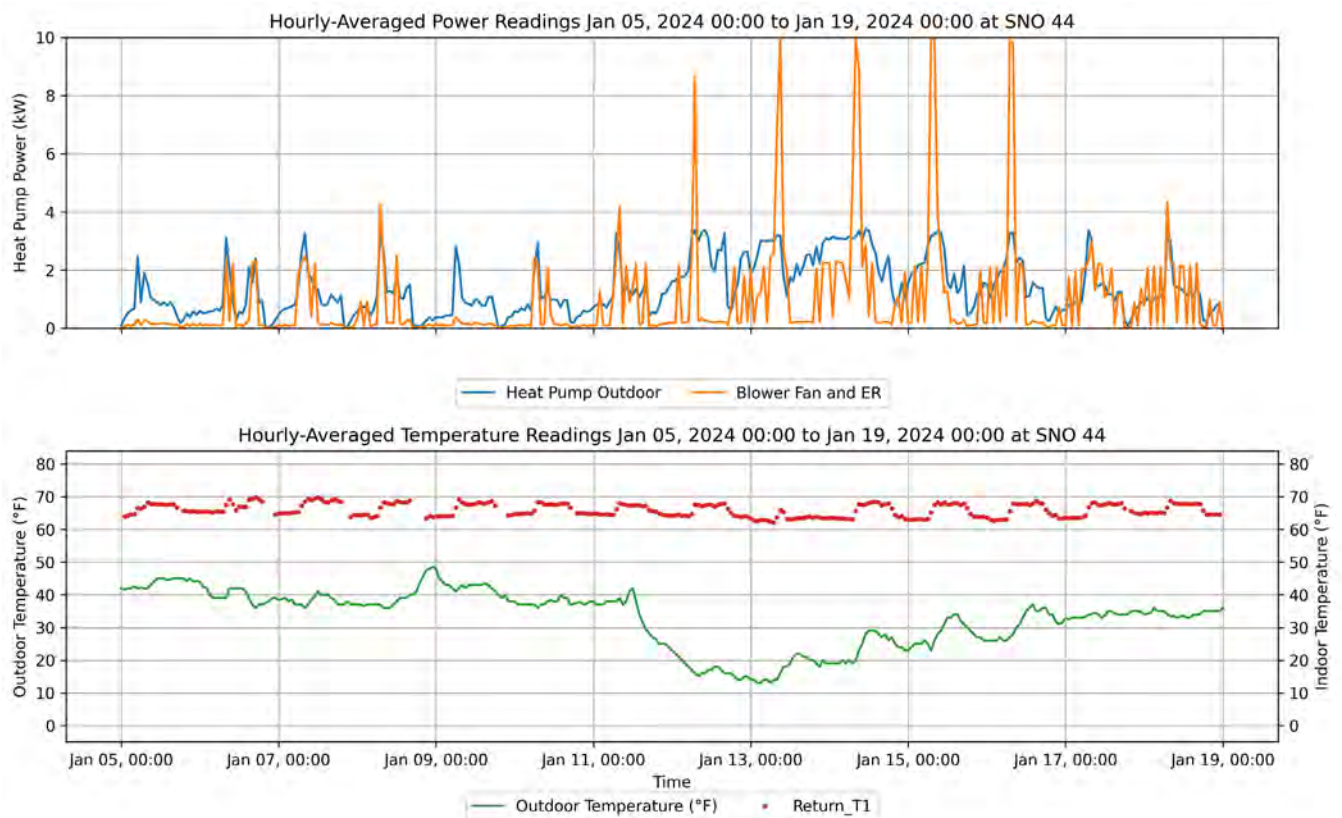


Figure 84. Hourly Average Power at SNO 44 for Two Weeks in January 2024.



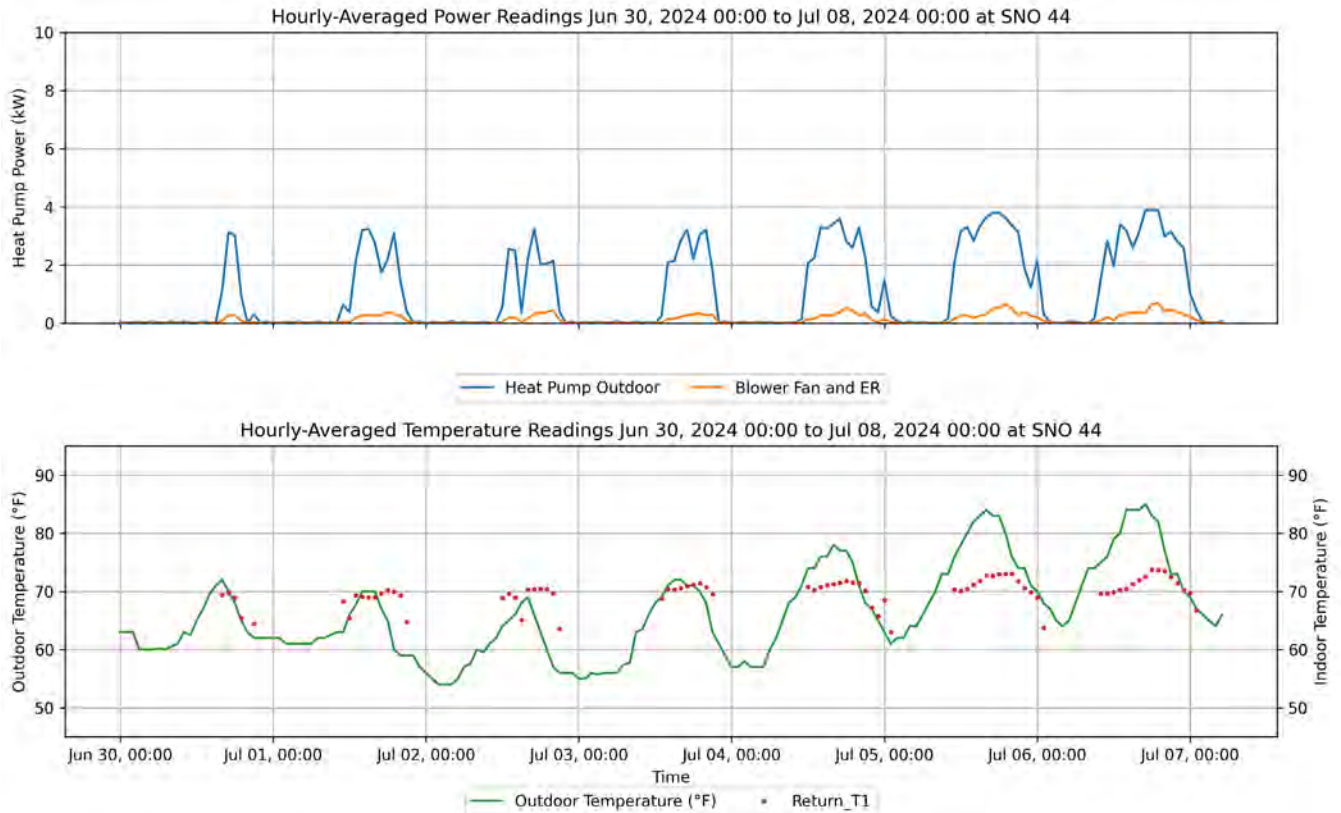


Figure 85. Hourly Average Power at SNO 44 in Early July 2024.

In cooling mode, the behavior is different, as shown in *Figure 85*. The system is turned on each day at approximately noon, having been off. The system is a 5-ton unit and the home is large, over 5,000 square feet. The result is that each day, including mild days, the system runs at fairly high power for a sustained period of several hours. On July 5 and July 6, when the outdoor temperature reached the low 80 degrees Fahrenheit, the system ran at fairly high power for most of the afternoon until approximately midnight. Because the system is called to cool the entire home, the site sees consistently high afternoon power consumption.

TAC 08 – FREQUENT OPERATION, HIGH SUPPLY TEMPERATURES, AND A FEW OPERATING STATES

The system at TAC 08 was observed to behave differently from most of the other systems in the study in a few ways. First, it seemed to frequently run at a handful of discrete states, rather than across a continuously variable spectrum of conditions. For illustration, *Figure 86* shows average power for complete heating cycles in the range of 45°F +/- 5°F outdoor temperature for three sites – TAC 08 (left), TAC 06 (center), and TAC 10 (right). The horizontal axis is outdoor unit power

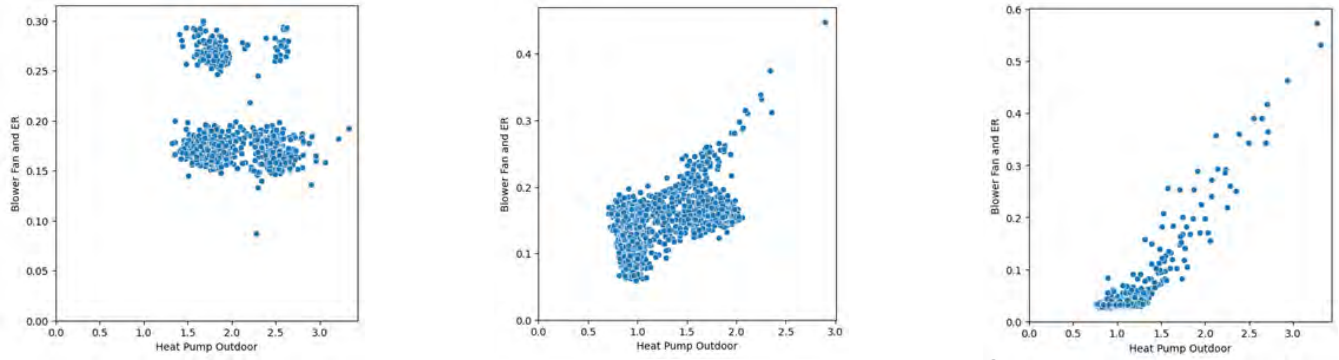


Figure 86. Outdoor Unit vs. Indoor Unit Power when ODT is 45oF +/- 5oF at TAC 08, Left, TAC 06, Middle, and TAC 10, Right.

and the vertical axis is indoor unit power. The right two graphs are more typical of the other sites in the study – a cluster at a common state, and some ramping to higher power occasionally. Not all sites display the ramp. TAC 08, however, appears to have four clusters of operating states in this temperature range.

This clustering can also be seen in time series data in **Figure 87**. In the first day of the shown data, the temperature is mild. The system runs regularly at a nearly constant power level. As temperatures get colder, the system runs again appears to mostly vary between two distinct power levels.

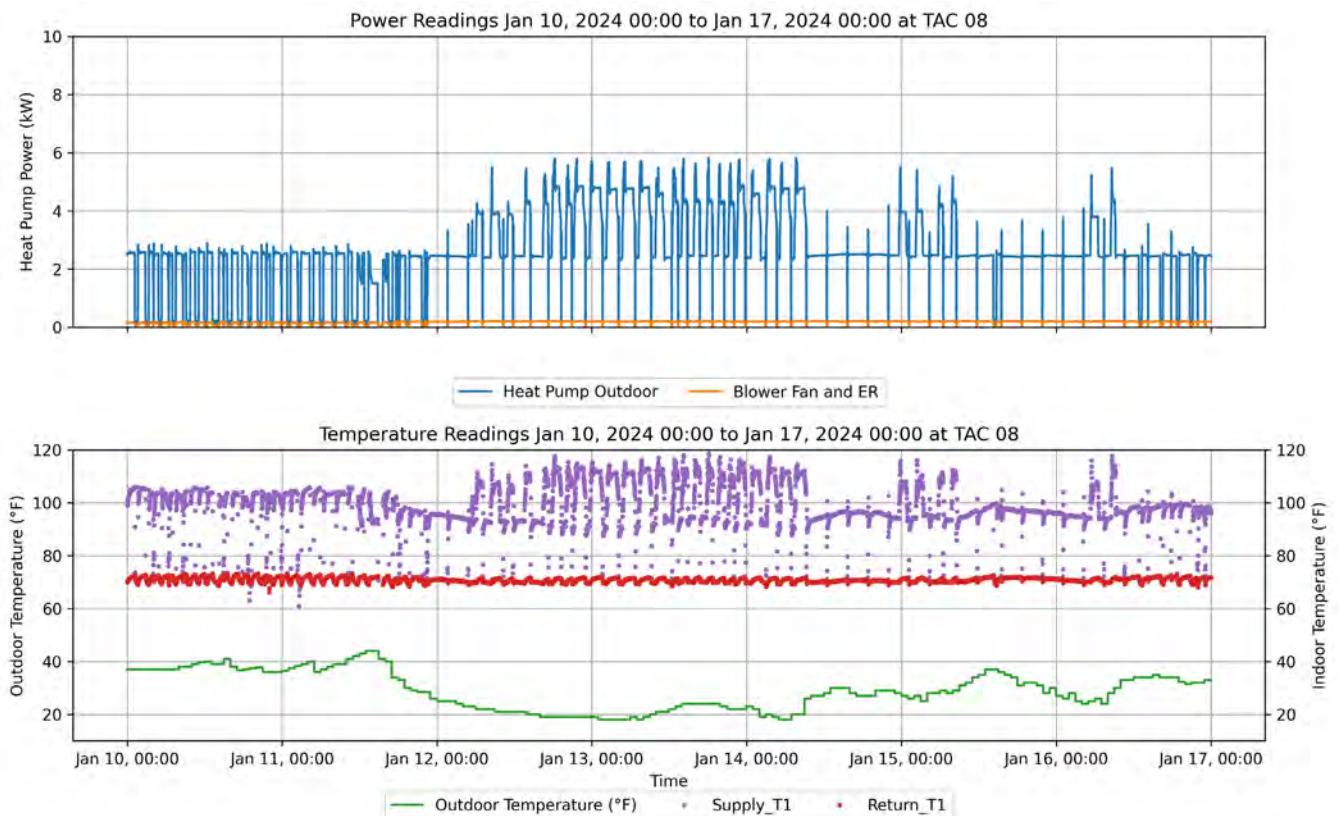


Figure 87. One-Minute Power and Temperature at TAC 08 in January 2024, Showing High Delivery Temperatures During Cold Snap.

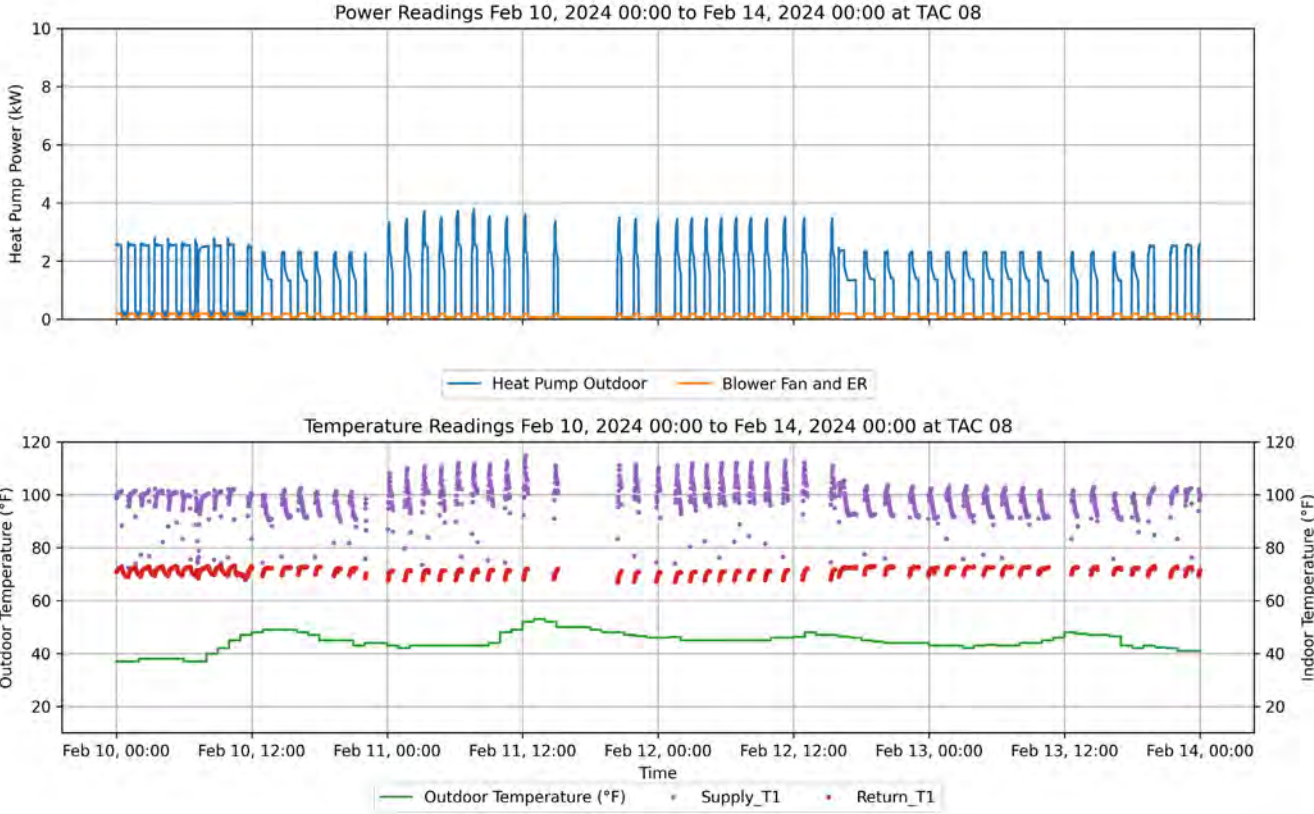


Figure 88. One-Minute Power and Temperature at TAC 08 in February 2024, Showing Mix of Moderate and High Supply Air Temperatures in Very Mild Weather.

This system at TAC 08 also frequently delivered higher supply temperatures than many of the study peers, as seen during the cold snap days of January 12 – 14.

Interestingly, this behavior also happened sometimes in mild weather: **Figure 88** shows a period of mild weather in February 2024. The supply temperature at times reaches 110°F with outdoor temperatures even in the range of 50°F. This is higher than most other systems in the study.

TAC 03 ILLUSTRATION OF LONGER DEFROST

The researchers found a quirk in defrost behavior for one product. Most of the systems that use ER heat during defrost – to provide continued heating – defrost for a relatively short amount of time (often 1-3

minutes), and the electric elements run for approximately the same amount of time. However, the system used at TAC 03 and several other sites often had a different behavior, running the ER heating element for up to ten minutes. **Figure 89** illustrates this. Defrost is evidenced by a dip in outdoor unit power and supply air temperature. During these defrost calls, the ER heater engages at the same time that the initial dip in compressor power begins. However, observation reveals that unless the heat call also ends (total system power going to zero), the ER element stays engaged for a full ten minutes, even though compressor power returns to normal and supply air temperature increases. This means that, if the system is under load (needing to run continuously), a typical defrost may create 5-7 minutes of additional unneeded ER heat operation, compared with if the system simply turned off



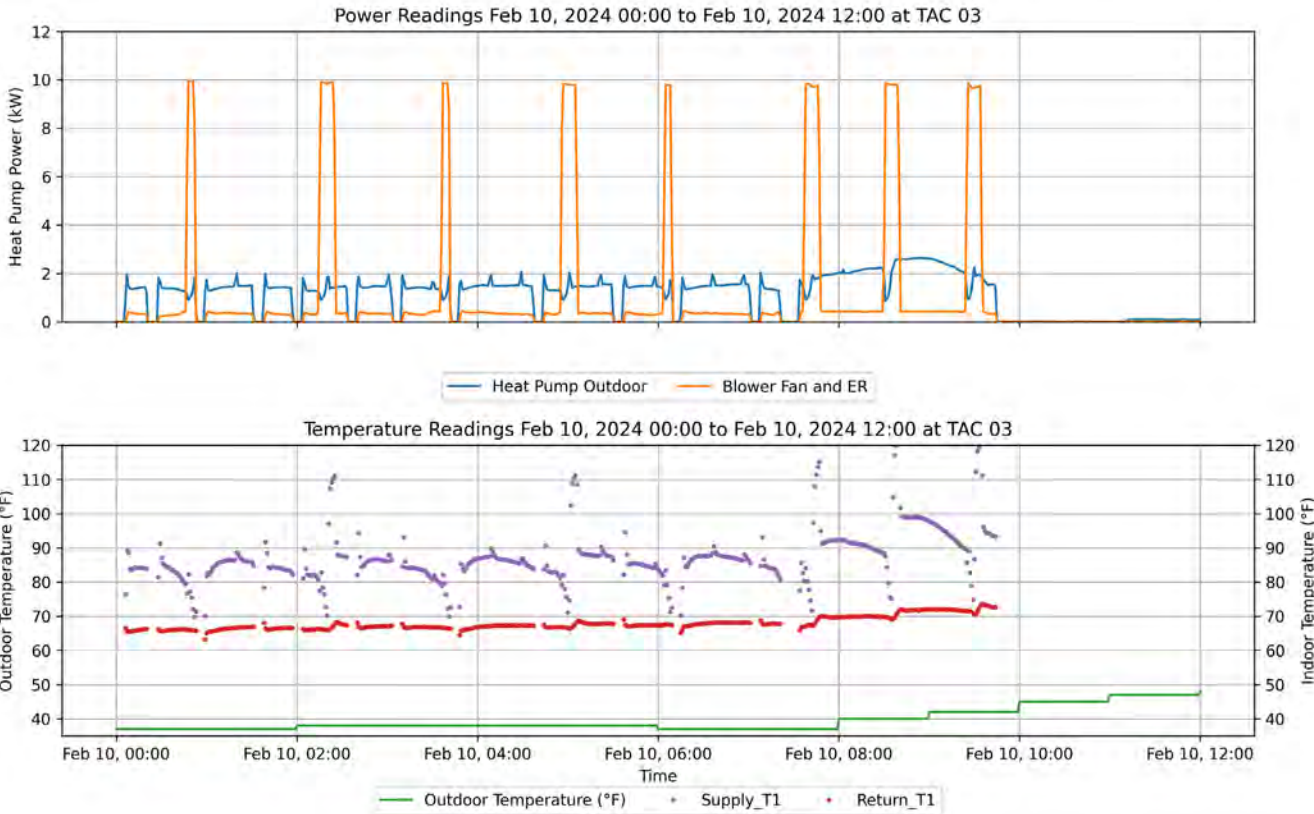


Figure 89. One-Minute Power and Temperature Data at TAC03 Showing Sustained ER Heat Over Defrost Cycles in Moderate Weather.

the resistance heat elements at the end of the defrost cycle.

The impact of this excess resistance heat runtime will vary depending on the size of the heating element and the weather. For the example shown here, the 10-kW element runs for approximately five extra minutes for each defrost cycle that occurs during a continuing heat call, and this occurs five times in this 12-hour period. This amounts to 25 extra minutes of 10-kW resistance heat operation, or an extra 4.2 kWh during this 12-hour window. The heating is not wasted; it is delivered to the space, but drastically reduces the efficiency of the system for those several minutes. This energy difference could amount to a meaningful cost in HZ1, where many hours are spent in defrost temperature ranges.



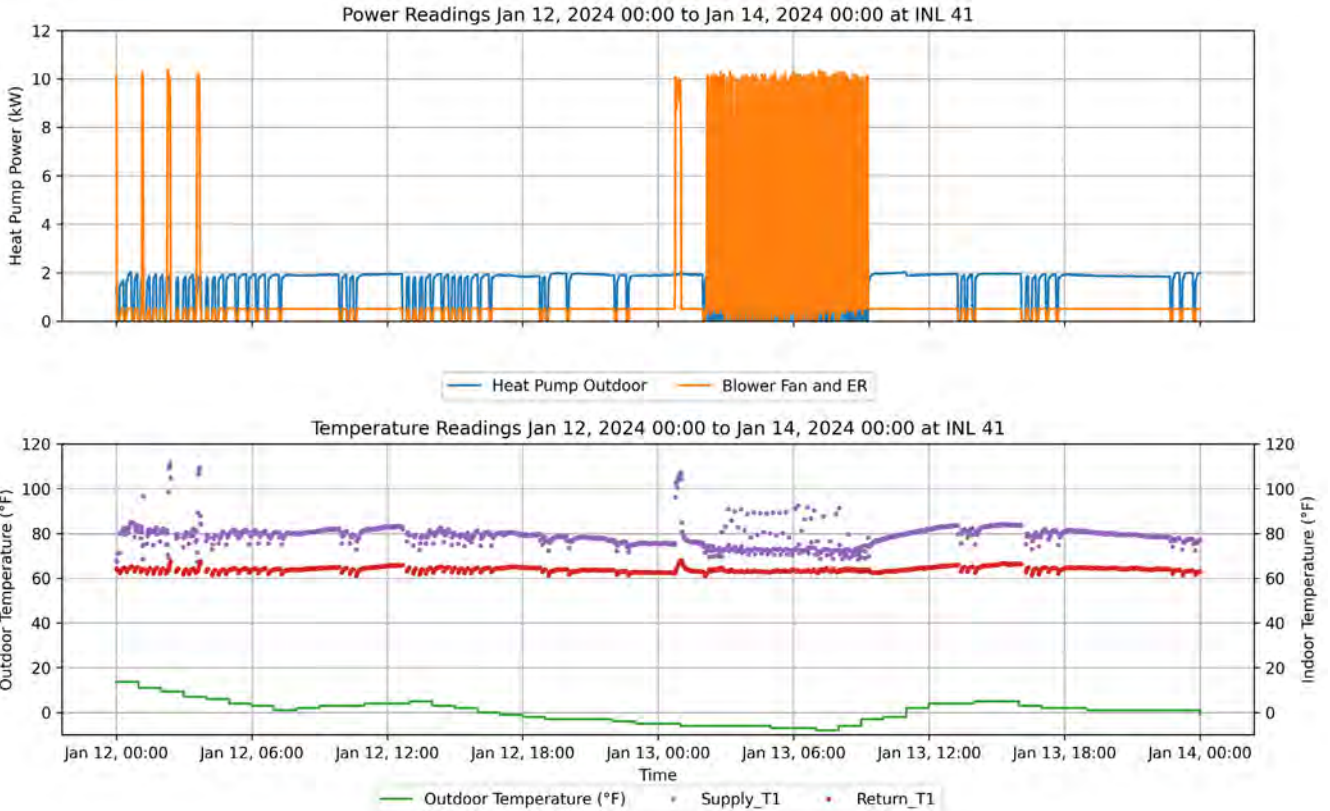


Figure 90. One-Minute Power and Temperature at INL 41 in January 2024 Showing Heat Pump-Only heating to Approx. -5°F.

INL 41: HEAT PUMP PERFORMANCE UNTIL -5°F

INL 41 provides one example of a system delivering steady comfort in HP mode to 0°F and slightly below, before finally needing auxiliary heat at approximately -5°F. **Figure 90** shows steady operation, mostly in HP-only mode, of the HP from midnight on January 12, 2024 until the temperature decreases again overnight on January 13. At that point, supply air temperature had dropped, approaching 70°F, and the system called for second stage heat. As the outdoor temperature increased that morning, HP-only operation resumed. The heating design temperature at this site was 7°F, so this is an example of a site delivering HP-only heating significantly below the design temperature in extreme cold.



10.0 Conclusions

The High-Performance High-Capacity Heat Pump Field Study investigated some of the most promising equipment on the market. The research produced a host of findings from quantifying electric grid benefits and energy savings to the impacts of controls and sizing. It also led to useful recommendations on how to better realize those benefits.

10.1 Unleashing Electric Grid Benefits

HPHC HPs have the potential to meaningfully contribute to electric grid reliability by reducing demand at critical peak times.

In HZ1, this project demonstrated that HPHC HPs can completely meet the building design heating loads. This allows ER to be eliminated from an install in HZ1, meaning it will not run on peak. Alternatively, if ER is installed, it would only ever need to run in the case of an equipment failure.

In HZ2, the regression analysis showed that at 5-10°F outdoor temperature the HPHC HPs – when sized to the 20°F balance point or lower – can offset substantial ER heat. Further, enabled by the heating capacity delivered by a properly sized HPHC HP, reducing the size of the ER elements by 5 kW can reduce the average power draw over a 4-hour peak window by up to 0.5 kW per site.

The thermostat setback study showed how, if the controls are not set up to primarily use the HP for recovery, the ER elements will run, driving the electricity use higher. The regression analysis showed that a 5 degree setback costs 1 kW per home in HZ1 on peak and 0.8 kW in HZ2 on peak. Configuring equipment to not use the setback would

provide substantial peak demand benefit to the grid.

The ducted systems, both Study-Install and Prior-Install, had generally peakier power profiles across the range of weather conditions, and particularly in colder weather, than the multizone systems.

Centrally ducted systems showed higher power load during morning peak demand hours. During both winter and summer peak conditions, the ducted systems had lower load factors (average power/ peak power), meaning higher contributions to peak power. The ability of multizone systems to condition only part of the home, along with disaggregated control of the different heads and backup heat sources, increased their load factor, reducing the impact on peak power demand.

10.2 Dominating Energy Savings

Throughout, the report shows that heating energy savings are strongly proportional to pre-heating energy use. Sites screened for a strong heating signature will deliver more savings than those without.

- The HPs saved 30-50% of the pre-install ER heating energy, on average.
- The savings for Study-Install centrally ducted installs is greater than Study-Install multizone ductless installs.

Centrally ducted systems saved 50% of the pre-heating energy use whereas multizone systems saved 30%. In terms of savings per square foot, the findings are 3.2 kWh/ft² for ducted and 2.2 kWh/ft² for ductless.



10.3 Thermostat Settings, Controls, and Setbacks

In a targeted two-month trial with 14 ducted sites, thermostat setbacks did not appear to save energy. The systems had similar energy consumption and much higher morning peak power with setbacks than with flat thermostat settings. After weather normalization, 9 of the 14 sites had energy use within $\pm 10\%$ regardless of thermostat strategy, while the remaining 5 sites used at least 10% more energy with setbacks than with flat settings.

Across ducted sites, indoor unit energy use (blower plus ER heat) was heavily concentrated in the early morning hours. On average, about 44% of this energy was consumed during only 20% of the day – a five-hour window between 5 a.m. and 9:59 a.m. This was due to the recovery of the thermostat setpoint; it also happened to align with the utility winter peak. However, this pattern was not uniform. It was driven primarily by a subset of homes.

10.4 Performance Metrics

HSPF2 region IV does not reliably predict the savings at a given site, nor does it predict the observed efficiency. Some factors driving this issue include a wide range of in-field HP COPs and ER heat usage. HSPF2, based on laboratory measurements, considers only a very limited use of ER heat.

The regression analysis explored many performance metrics and found that the most predictive of heating use were COP_{max17} and, surprisingly, EER₂. Still, no clear picture emerged to propose an alternate set of performance metrics to confidently predict good or poor performance.

Agreement between the stated values in the NEEP database and field-measured values varied product to product, particularly at low-load conditions. The findings do not suggest that the NEEP data over-estimate a system's maximum capacity, but do indicate that COPs of some systems, particularly at lower loads, are lower than expected in some conditions. The database likely remains viable to support system sizing and selection, since it provides a streamlined and detailed collection of system options and the capacity data appears to be reasonably accurate. However, analysis intended to calculate annual energy savings, for example, is likely to be inaccurate for some products.

10.5 Sizing

The studied sites did not have enough size variation to conclude that a given X tons of under-sizing cost so many kW peak and kWh annually. Although there was some size variation, the HPs generally met or exceeded the researchers' sizing specifications, which meant there were almost no undersized systems to compare.

In HZ1, when equipment is sized to a 20 °F balance point, it is entirely possible to heat without ER.

The ducted HPs generally did deliver the listed maximum heating capacity at 17°F. Achieving this capacity is crucial to realizing the benefits of sizing HPs to minimize ER heat. In HZ1, design temperatures are above 17°F, so the entire home heating load can be met by the HP if the 17°F labeled capacity is above the home heating load.

The study showed a small indication that for this kind of high-performance equipment there may be less of a market problem with under-sizing compared with other HP



products. This needs to be studied further. Two possible explanations are posited:

- HPHC HPs are high-end equipment, which is generally priced higher and installers may be more focused on delivering HP performance rather than minimizing initial install cost.
- The high-performance equipment's ability to maintain capacity to colder outdoor temperatures effectively increases its size relative to the nominal size of a single speed system. To provide a numeric example, a HPHC HP with an actual capacity (at 47°F) of 4-tons may be named and sold as a 3-ton system. For installers using sizing practices based on single-speed systems, and who continue to use the same practices, this may have the somewhat unintended, yet beneficial, downstream effect of increasing the HP capacity at the temperatures that matter most.

10.6 Additional Findings

Much of the “poor” performance is driven by a small number of sites. There is not systematic underperformance – rather it appears that for a given trait/parameter, one quarter to one third of the sites tend to move the needle downward. Inconveniently, these undesirable traits do not always overlap at a site. For example, some systems called for excessive ER in response to thermostat settings, others called for excessive ER in response to defrost controls, and, in other cases, systems underperformed their metrics. These didn't occur all at the same sites, they occurred across the studied cohort. Consequently, these underperforming sites cannot be addressed in one fell swoop.

From a utility conservation program perspective, only some of the traits can be addressed on-site at system install. For a number of others, the burden is on the manufacturers to solve the issues (like defrost, aggressive setback recovery settings, and system efficiency).

Adequate duct sizes are necessary. HPHC HPs can require more airflow than an existing furnace, which operates on a higher delta T. Some homes were excluded from the study because the contractor observed that more airflow would be needed for the size of system the researchers wanted to install. In other cases, the contractor made improvements (at the researchers' request) to the duct system by adding a return. Duct evaluation and improvement cost is often ignored in HP system bidding and installation; failure to address poor ducts can undermine performance and customer satisfaction.

10.7 Equipment Specification Recommendations

The following are the research team's recommendations and observations related to equipment specifications. While these points are informed by the technical content of the report, they also reflect professional judgment and should be taken as such.

Programs seeking to maximize the benefits of HPHC HP deployment should consider the following:

- Promote variable-speed compressor systems.
- Use the NEEP ccASHP List as a framework. The NEEP database is a valuable resource for identifying and sizing systems. Any improvements in the quality and



transparency of the data, the validation of the data, or additional performance data from standardized tests would be highly beneficial. These changes may require the cooperation of manufacturers, NEEP, and industry organizations such as AHRI.

- Performance metrics may provide limited predictive power:
- Data in this study suggest that higher COP_{max17} and higher EER₂ rating may correlate with improved energy savings, and COP_{min47} may weakly correlate with energy savings as well.
- However, the evidence is not strong enough to justify using these metrics for strict programmatic product qualification cutoffs. One reason may be that COP_{max17} and COP_{min47}, as found in the NEEP database, are not currently reliable. Improved data reporting and accuracy could potentially make these metrics viable for specifications.
- Discourage under-sizing. The study population skewed toward systems that were either right-sized or even oversized for heating mode, with few systems undersized. The limited data on undersized systems aligns with expectations: they use more ER heat, reducing energy savings and increasing peak power demand.
- The researchers did not detect a penalty associated with oversizing; however, oversized systems cost more and may create comfort and duct-related (airflow limits) issues. Oversizing should also be avoided.
- Address controls. Controls strongly affected outcomes, particularly on load

factor. While more research is needed to clarify exactly how to improve field controls (and whether reliable fixes are even possible without manufacturer-initiated improvements), a controls-related specification could meaningfully reduce peak power and improve energy savings

- Thermostat setbacks did not appear to save energy in this study, likely because of poor control strategies leading to excessive ER use. Better controls could enable energy savings from setbacks while avoiding sharp morning peaks.

LIMIT EXCESSIVE ER ELEMENT SIZING

- Thermostat setback recovery tends to trigger unnecessary ER heat; larger elements magnify this problem.
- While larger ER elements did not appear to consistently hurt energy savings, there was evidence that, particularly in very cold weather, they may displace HP heating unnecessarily.
- This study skews more toward right-sized systems. The impact of excessive element sizing would be expected to be even greater for undersized HPHC HPs.

In reviewing some of the existing industry specifications— including the NEEP ccASHP Specification⁷, ENERGY STAR and ENERGY STAR Cold Climate⁸, CEE⁹, DOE Cold Climate

⁷ <https://neep.org/heating-electrification/ccashp-specification-product-list>

⁸ <https://www.energystar.gov/sites/default/files/2025-04/ENERGY%20STAR%20Version%206.2%20Heat%20Pump%20Specification%20Rev.%20March%202025.pdf>

⁹ <https://cee1.org/program-resources/tiers-and-energy-star/>



Heat Pump Challenge Specification¹⁰ – the researchers do not strongly favor any particular specification. Instead, the following are some observations relevant to the specifications:

- HSPF2 thresholds that push to variable speed are helpful, but beyond that higher HSPF2 do not appear to predict greater energy savings.
- The researchers did not see evidence that the shape of the HP’s capacity-vs-outdoor temperature line is itself predictive of better performance. In other words, requiring 100% of the 47°F capacity at 5°F merely constrains the equipment design (or labeling) options. What matters is the equipment absolute capacity at the design temperature (or other target) relative to the home load, not the capacity at a given temperature relative to 47°F.

Given equivalent nominal capacity, systems with higher capacity at cold conditions are easier to size to a low target balance point without oversizing for low load conditions. This is beneficial. However, some of the systems marketed as having “100% capacity” at 17°F or 5°F outdoor temperature performed relatively poorly in this study.

Some specifications push for higher COPs at 5°F. The data did not show a significant correlation between this value and savings. However, the analysis was complicated by the small sample size with limited very-cold weather data, and knowledge that the NEEP data is manufacturer-reported and may be inconsistent in accuracy. The equipment in this study typically had a COP at 5°F of 1.9 or higher. The researchers generally support

¹⁰ <https://www.energy.gov/eere/buildings/articles/residential-cold-climate-heat-pump-technology-challenge-fact-sheet>

targeting this, or higher COPs at cold-weather conditions.

10.8 Future Work

This report provides an extensive overview and analysis of the data collected in the High-Performance High-Capacity Heat Pump Field Study. The study dataset is so vast, it calls for further analysis and exploration. Multiple detailed topics warrant further investigation, both within this dataset and in comparison to other datasets, including:

- The creation of a web-hosted, interactive dashboard with key report content to allow wider use of the dataset. Additionally, this would allow easier access to the dataset by other researchers and maximize the investment already made in the field data collection.
- A comparison of all data to lower-rated or “market baseline” HP products. Some of these data can be found in the NEEA Home Energy Use Metering Study (HEMS) while other data for comparison may be available from older studies. Such an analysis would enable quantification of the benefits of higher-performing HPs (typically higher installed cost) to lower-performing ones (typically lower installed cost).
- Further investigation of heat pump sizing to determine its effect on energy and demand impacts. The HP output capacity relative to the home heating load is the primary determinant of whether the HP can heat on its own or needs auxiliary heat. The initial analysis found the HP sizes (balance points) were similar across sites. There was not enough variation to find a clear sizing signal. Expanding to other datasets may help reveal one. Further,



the researchers curiously observed that the home heating load calculated by the study's own field team was generally larger than the load observed through HP output monitoring. This opens the question of how accurate and useful are the industry-standard methods to calculate heating loads. This warrants further investigation; while the problems associated with under-sizing are more obvious, oversizing is expensive and may have subtler but still real impacts on efficiency. Any improvement to accuracy of load calculations would be beneficial. Possible avenues include conducting the heat loss survey again at each site with a different crew and comparing the results. A further dive into the data may also reveal new insights.

- Conduct an in-depth study of the HP controls and thermostat settings. This data (such as deadband, droop, various lockouts, defrost settings, etc.) was collected near the end of the study via the exit survey without sufficient time to incorporate an analysis of this into the report. However, it is clear from observing the unnecessary running of ER heat that these settings have an impact on the equipment operation. A detailed review could reveal optimal strategies to deliver savings.
- Explore peak power reduction in depth:
- Create graphics and tables of average electric demand versus outside air temperature. Conduct this analysis in the context of a comparison to "market baseline" systems in order to fully quantify changes in demand related to HP type.
- Use the above analysis to create a tool that will calculate the HP peak load demand reduction benefits on peak at the utility level or smaller (i.e. climate level and even substation-specific level). The dataset enables calculations of kW reduction for a given HP type, climate, control, etc.
- Engage in coordination and collaboration within the broader industry. Other entities – such as NYSERDA, CEE, NEEA, NEEP, the national labs, and university researchers – are also actively working in this area. Consolidating the latest research findings and collaborating to find unity on key issues could help influence relevant industry decision makers to the benefit of BPA and the public. Some important topics raised in this work – the impact of unnecessary ER heat calls, accuracy and reliability of extended data (such as the NEEP database), accurate load calculation, and sizing for heating – may not have the attention of key industry decision makers because they do not drive day-to-day HP sales but could be addressed if a sufficient consensus existed.



Appendix A: Data Summary

Table 1A. Monitoring Start and End per Site

Ducted Sites			Multizone Sites		
Site Name	Start Date	End Date	Site Name	Start Date	End Date
CEC 01	9/10/2024 9:51	4/1/2025 9:09	CEC 11	10/26/2022 9:53	3/7/2025 12:19
CEC 02	9/11/2024 9:32	4/1/2025 6:42	CEC 12	7/11/2023 10:19	4/1/2025 7:44
CEC 03	9/11/2024 14:52	4/1/2025 9:13	CEC 13	7/11/2023 16:12	4/1/2025 7:48
CEC 04	9/10/2024 14:40	3/3/2025 11:51	CEC 31	10/24/2023 11:48	4/1/2025 8:08
CEC 05	9/12/2024 10:58	4/1/2025 9:17	CEC 32	10/24/2023 15:10	3/29/2025 22:35
CEC 41	10/25/2022 15:03	4/1/2025 9:43	CEC 33	10/25/2023 11:34	4/1/2025 8:17
INL 02	10/3/2023 11:36	4/1/2025 8:07	COL 30	1/26/2024 8:50	3/26/2025 16:09
INL 41	5/23/2023 8:47	3/25/2025 12:57	COL 31	1/26/2024 10:02	3/26/2025 16:11
INL 42	5/23/2023 15:24	3/24/2025 9:30	COL 32	2/12/2024 14:55	3/26/2025 15:52
INL 44	5/24/2023 11:09	3/26/2025 21:00	COL 33	2/12/2024 16:34	3/26/2025 16:11
INL 46	5/26/2023 9:06	3/27/2025 22:11	COL 34	2/13/2024 9:59	2/28/2025 15:13
PLU 01	6/25/2024 10:03	3/6/2025 14:09	COL 35	2/13/2024 10:59	3/13/2025 10:01
PLU 02	6/25/2024 13:33	4/1/2025 9:00	COL 36	1/24/2024 13:45	12/12/2024 12:19
PLU 03	6/25/2024 16:37	3/19/2025 12:53	COL 37	1/25/2024 8:50	3/3/2025 8:59
PLU 04	6/26/2024 9:59	4/1/2025 9:04	COL 38	1/25/2024 8:36	3/19/2025 15:03
SNO 41	8/31/2023 9:46	3/17/2025 9:59	COL 39	1/25/2024 16:15	3/19/2025 15:08
SNO 43	8/30/2023 15:25	3/19/2025 14:13	GEC 31	3/29/2023 8:34	4/1/2025 9:56
SNO 44	9/27/2023 14:38	3/27/2025 20:55	GEC 32	3/29/2023 13:02	4/1/2025 10:04
TAC 01	5/25/2022 14:51	3/27/2025 18:15	SNO 11	8/29/2023 10:16	2/26/2025 10:03
TAC 02	5/25/2022 9:42	6/15/2024 11:34	SNO 53	8/31/2023 15:46	3/19/2025 14:19
TAC 03	6/29/2022 9:42	3/25/2025 22:30	TAC 07	9/14/2022 9:47	3/27/2025 18:17
TAC 04	9/13/2022 10:50	4/1/2025 9:31	TAC 11	5/18/2022 15:09	3/4/2024 20:08
TAC 05	9/15/2022 14:51	4/1/2025 7:08	TAC 12	5/18/2022 10:21	4/9/2024 8:04
TAC 06	9/15/2022 9:32	4/1/2025 9:35	TAC 13	5/17/2022 14:59	5/6/2024 8:03
TAC 08	1/19/2023 10:04	2/25/2025 13:16	TAC 14	5/17/2022 11:18	5/8/2024 18:22
TAC 09	12/14/2022 9:33	4/1/2025 7:29	TAC 15	5/19/2022 9:47	5/10/2024 8:06
TAC 10	12/14/2022 14:47	4/1/2025 9:48	TAC 16	6/29/2022 15:17	5/10/2024 8:07
YAK 01	1/23/2024 10:41	4/1/2025 8:22	TAC 21	12/13/2022 15:01	5/4/2024 6:39
YAK 61	1/23/2024 14:30	4/1/2025 8:26			



Table 1B. Whole House Average Power for Sites with Ducted Systems by Outdoor Temperature Bin, Heating Season.

Site	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60
CEC 01	6.06	8.75	6.09	3.23	5.38	3.95	2.73	2.40	2.07	1.75	1.36	1.04	0.84	0.61	
CEC 02	9.02	9.62	8.61	7.38	6.63	4.49	3.70	3.49	2.89	2.44	2.08	1.57	1.28	1.09	
CEC 03	1.48	1.63	1.40	2.40	1.80	1.53	1.72	1.69	1.62	1.49	1.35	1.18	1.14	1.31	
CEC 04	9.47	8.74	7.91	7.80	5.47	5.18	4.32	3.58	3.30	2.40	1.88	1.68	1.65	1.33	
CEC 05	4.97	4.57	7.90	5.18	2.74	2.69	2.48	2.07	1.81	1.45	1.18	0.95	0.89	0.63	
CEC 41	8.48	6.80	6.13	5.80	4.05	3.33	3.10	2.68	2.56	2.29	2.01	1.87	1.63	1.40	
INL 02	3.96	3.64	4.13	3.42	2.78	3.00	2.24	1.82	1.27	0.97	0.81	0.73	0.66	0.49	-0.03
INL 41	6.07	4.63	3.86	3.49	3.05	3.34	2.95	2.48	2.41	2.07	1.94	1.70	1.43	1.43	0.84
INL 42	13.03	6.53	7.97	7.44	4.78	4.01	3.24	2.71	2.25	1.95	1.80	1.78	1.66	1.39	0.58
INL 44	4.82	4.60	3.33	2.12	2.27	2.76	1.96	2.16	2.77	3.57	3.09	2.70	2.46	2.04	2.09
INL 46	9.59	10.60	10.00	9.38	9.99	9.42	6.85	6.16	4.67	4.45	3.31	2.79	2.18	2.35	0.44
PLU 01	4.34	3.85	4.11	4.02	4.39	4.40	3.51	3.52	3.29	2.97	2.83	2.87	2.26	2.59	1.03
PLU 02	2.95	3.23	3.09	2.84	2.73	2.81	2.55	2.13	1.94	1.67	1.43	1.43	1.02	1.23	0.81
PLU 03	3.83	4.83	4.93	4.03	3.85	4.29	4.07	3.56	3.46	3.17	2.91	2.64	2.79	2.55	6.00
PLU 04	1.42	1.20	1.32	1.65	1.76	1.13	1.45	1.51	1.46	1.74	1.78	1.94	1.52	1.71	2.15
SNO 41					2.34	2.34	1.96	1.79	1.38	1.13	0.94	0.82	0.71	0.62	0.71
SNO 43					1.30	1.31	1.88	0.81	0.75	0.75	0.74	0.71	0.71	0.68	0.53
SNO 44					3.44	3.48	3.35	2.92	2.29	2.14	1.70	1.32	1.22	1.04	0.87
TAC 01							3.83	3.20	2.80	2.46	1.91	1.70	1.50	1.34	1.79
TAC 02							3.35	3.31	2.68	2.43	2.21	1.79	1.56	1.45	1.41
TAC 03							4.92	3.88	3.66	3.33	2.89	2.23	1.82	1.67	1.42



Table 1B. Whole House Average Power for Sites with Ducted Systems by Outdoor Temperature Bin, Heating Season.

Site	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60
TAC 04						2.99	3.58	2.66	2.28	1.93	1.48	1.27	1.11	0.96	0.75
TAC 05						3.48	3.13	2.57	2.12	1.94	1.52	1.27	0.99	0.94	0.58
TAC 06						3.24	3.42	2.52	2.26	2.02	1.72	1.61	1.56	1.30	1.41
TAC 08						4.79	4.25	3.53	3.13	2.90	2.58	2.30	2.13	1.72	1.37
TAC 09						2.22	2.04	1.48	1.43	1.21	0.99	0.88	0.77	0.64	0.92
TAC 10						3.04	3.63	2.90	2.83	2.34	1.98	1.79	1.61	1.66	1.77
YAK 01			3.01	4.19	4.75	3.00	3.32	2.91	3.07	3.00	2.81	2.88	2.58	2.25	2.72
YAK 61			3.88	5.02	5.02	3.96	3.47	3.37	3.46	3.39	3.08	2.84	2.75	2.32	1.99





Table 1C. Whole House Average Power for Sites with Multi-Zone Systems by Outdoor Temperature Bin, Heating Season.

Site	-40	-35	-30	-25	-20	-15	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60
CEC 11							3.95	2.33	2.23	2.20	2.31	2.08	1.56	1.47	1.40	1.33	1.24	1.03	0.87	0.72	
CEC 12							5.20	8.36	5.29	5.17	3.72	3.35	2.65	2.00	1.58	1.31	1.20	1.13	0.92	0.77	
CEC 13							6.16	6.00	6.79	6.26	5.46	5.08	4.92	4.66	4.52	4.11	3.88	3.55	3.05	2.51	
CEC 31							4.34	5.36	4.64	5.62	4.12	3.92	3.66	3.25	3.27	3.11	2.93	2.76	2.87	2.91	
CEC 32							1.69	4.05	4.14	2.88	1.86	1.46	1.53	1.48	1.45	1.36	1.35	1.35	1.30	1.15	
CEC 33							5.19	7.35	6.30	5.88	4.39	3.51	3.21	2.86	2.42	2.25	2.13	2.03	1.97	1.73	
COL 30									2.64	2.31	2.95	2.78	2.73	2.44	2.17	1.91	1.56	1.50	1.25	0.80	0.11
COL 31									3.56	3.35	2.64	2.46	2.34	2.08	1.79	2.04	1.85	1.34	1.16	0.82	0.20
COL 32									2.70	4.01	2.82	3.01	2.73	2.52	2.20	1.89	1.42	1.30	0.95	1.15	0.74
COL 33									2.78	2.35	1.80	2.14	1.50	1.42	1.27	1.29	0.95	1.02	0.96	0.79	0.76
COL 34									4.38	4.24	3.15	3.14	2.69	2.05	1.64	1.47	1.04	0.87	0.73	0.55	0.51
COL 35									4.64	4.87	4.30	3.87	3.67	2.79	2.49	1.84	1.24	1.13	1.10	0.92	0.66
COL 36												1.43	1.53	1.52	1.85	1.44	1.32	1.37	1.25	1.58	
COL 37									1.53	1.48	1.65	1.77	2.07	1.78	1.75	1.65	1.50	1.67	1.61	1.24	1.73
COL 38									2.13	2.17	2.49	2.04	1.75	1.53	1.49	1.16	1.01	0.86	0.87	0.81	
COL 39									0.08	0.07	0.18	0.12	0.15	0.16	0.17	0.19	0.20	0.19	0.19	0.19	



Table 1C. Whole House Average Power for Sites with Multi-Zone Systems by Outdoor Temperature Bin, Heating Season.

Site	-40	-35	-30	-25	-20	-15	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60
GEC 31	7.37	7.87	6.95	6.62	5.05	5.08	4.55	4.09	3.71	3.49	2.97	2.65	2.46	2.42	2.25	1.98	1.85	1.73	1.56	1.17	0.96
GEC 32	7.66	7.22	5.81	5.71	4.26	3.98	3.98	3.68	2.97	2.65	2.54	2.16	2.00	1.85	1.75	1.68	1.46	1.32	1.26	0.80	0.67
SNO 11											3.94	3.68	4.25	4.27	3.24	2.60	2.26	2.04	1.91	1.33	1.49
SNO 53											2.52	4.91	3.59	3.52	2.58	2.71	2.85	2.66	2.68	2.54	3.19
TAC 07												4.00	3.93	3.49	2.96	2.60	2.22	1.95	1.74	1.69	1.67
TAC 11												7.28	7.48	5.92	4.32	3.73	3.17	2.76	2.31	1.93	1.66
TAC 12												5.35	5.45	4.21	3.48	2.91	2.54	2.32	2.06	1.73	1.41
TAC 13												2.19	2.11	2.24	1.83	1.29	1.02	0.87	0.71	0.59	0.54
TAC 14												6.14	6.73	5.53	4.93	4.26	3.79	3.40	3.00	2.48	2.78
TAC 15												5.76	5.02	3.17	2.32	2.05	1.78	1.61	1.48	1.14	1.07
TAC 16													6.73	5.42	4.96	4.33	3.94	3.37	3.05	2.60	1.99
TAC 21												2.77	2.80	2.22	1.87	1.71	1.56	1.44	1.30	0.97	0.76

Table 1D. HVAC-Only Average Power for Sites with Ducted Systems by Outdoor Temperature Bin, Heating Season.

Site	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60
CEC 01	7.85	9.72	6.70	3.19	6.14	4.14	2.40	2.00	1.74	1.27	0.89	0.50	0.34	0.17	
CEC 02	8.80	8.94	6.76	6.31	6.00	3.84	2.71	2.50	1.95	1.43	1.00	0.47	0.32	0.12	
CEC 03	1.49	1.78	1.30	1.45	1.40	1.26	1.14	1.13	1.00	0.85	0.69	0.54	0.50	0.49	
CEC 04	8.92	8.10	7.03	6.77	4.82	4.51	3.38	2.56	2.29	1.31	0.75	0.38	0.28	0.05	
CEC 05	4.70	4.38	7.42	4.76	2.42	2.33	2.00	1.58	1.31	0.93	0.62	0.33	0.22	0.08	
CEC 41	7.84	5.63	4.65	3.98	3.06	2.26	1.97	1.49	1.34	1.07	0.82	0.67	0.51	0.29	
INL 02	4.64	4.04	4.92	3.69	2.22	4.01	2.26	1.83	1.40	0.95	0.58	0.37	0.28	0.16	0.05
INL 41	4.84	3.04	2.48	2.29	1.80	1.82	1.54	1.16	0.93	0.66	0.49	0.32	0.20	0.17	0.06
INL 42	11.99	5.08	6.64	6.05	3.54	2.83	2.20	1.45	1.23	0.87	0.64	0.50	0.43	0.22	0.04
INL 44	0.90	0.40	0.36	0.41	1.11	2.23	1.89	1.88	1.84	2.15	2.03	1.65	1.06	0.58	0.15
INL 46	0.06	0.61	1.18	1.40	1.67	1.73	1.94	1.93	1.71	1.41	1.04	0.68	0.40	0.17	0.07
PLU 01	3.47	3.17	2.97	2.68	2.91	3.04	2.07	1.93	1.65	1.19	0.99	0.71	0.40	0.50	0.13
PLU 02	2.72	2.86	2.68	2.41	2.17	2.20	1.94	1.61	1.28	0.99	0.69	0.49	0.24	0.17	-0.01
PLU 03	3.32	3.50	3.34	2.85	2.95	2.62	2.30	1.74	1.46	1.06	0.90	0.79	0.62	0.48	0.07
PLU 04	0.01	0.01	0.01	0.27	0.34	0.08	0.14	0.24	0.28	0.47	0.50	0.50	0.28	0.38	0.55
SNO 41					1.52	1.65	1.35	1.28	0.80	0.56	0.42	0.31	0.20	0.11	0.09
SNO 43					2.46	1.68	1.66	1.29	1.08	0.77	0.52	0.40	0.31	0.21	0.19
SNO 44					4.33	4.19	3.96	3.66	2.71	2.11	1.40	0.81	0.58	0.36	0.21
TAC 01							2.59	1.74	1.68	1.22	0.66	0.35	0.24	0.12	0.13
TAC 02						2.06	1.62	1.38	1.13	0.96	0.62	0.43	0.31	0.18	0.10
TAC 03						3.79	2.81	2.72	2.48	1.83	1.06	0.57	0.35	0.21	0.15



Table 1D. HVAC-Only Average Power for Sites with Ducted Systems by Outdoor Temperature Bin, Heating Season.

Site	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60
TAC 04						2.30	2.22	1.72	1.49	1.11	0.64	0.42	0.28	0.15	0.08
TAC 05						1.74	1.59	1.48	1.25	0.88	0.53	0.30	0.15	0.08	0.04
TAC 06						2.58	2.17	1.53	1.25	0.85	0.54	0.37	0.27	0.16	0.07
TAC 08						4.14	3.51	2.69	2.18	1.79	1.32	0.98	0.72	0.36	0.21
TAC 09						1.78	1.46	1.16	1.04	0.78	0.53	0.37	0.26	0.15	0.07
TAC 10						2.51	2.54	2.00	1.88	1.45	1.00	0.73	0.50	0.29	0.13
YAK 01			2.70	2.62	2.59	1.90	1.92	1.72	1.59	1.39	1.12	0.89	0.67	0.48	0.38
YAK 61			2.92	3.29	3.37	2.27	1.92	1.56	1.39	1.02	0.82	0.52	0.28	0.11	0.22





Table 1E. HVAC-Only Average Power for Sites with Multi-Zone Systems by Outdoor Temperature Bin, Heating Season.

Site	-40	-35	-30	-25	-20	-15	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60
CEC 11							3.50	3.52	3.45	3.29	2.88	2.51	2.27	2.00	1.83	1.62	1.42	1.18	0.93	0.72	
CEC 12							3.85	6.49	4.32	5.07	3.79	3.69	3.15	2.61	2.21	1.88	1.61	1.32	1.11	0.91	
CEC 13							5.56	4.72	5.41	4.81	4.16	3.86	3.42	3.14	2.88	2.54	2.18	1.86	1.45	1.12	
CEC 31							2.74	2.86	2.61	2.30	2.06	1.82	1.57	1.28	1.04	0.88	0.73	0.60	0.51	0.37	
CEC 32							1.05	2.24	2.04	1.54	0.98	0.73	0.73	0.66	0.59	0.49	0.40	0.32	0.23	0.15	
CEC 33							4.16	4.12	3.96	3.31	2.90	2.34	1.89	1.65	1.37	1.14	0.98	0.81	0.68	0.53	
COL 30									2.14	1.63	1.92	1.74	1.74	1.55	1.24	1.00	0.78	0.56	0.36	0.09	0.01
COL 31									3.48	3.24	2.49	2.31	2.08	1.81	1.54	1.59	1.24	0.75	0.63	0.46	0.00
COL 32									2.57	3.08	2.35	2.17	1.96	1.88	1.53	1.09	0.69	0.46	0.25	0.22	0.01
COL 33									2.39	1.36	1.23	1.41	0.89	0.79	0.54	0.59	0.41	0.38	0.25	0.12	0.17
COL 34									0.79	0.65	1.99	2.55	2.26	1.56	1.37	0.89	0.54	0.38	0.21	0.10	0.07
COL 35									0.37	0.35	0.42	0.37	0.33	0.39	0.34	0.38	0.36	0.28	0.21	0.18	0.11
COL 36											1.15	1.03	0.93	0.72	0.55	0.41	0.41	0.25	0.13	0.04	
COL 37									1.20	1.01	1.05	0.96	0.99	0.84	0.81	0.74	0.64	0.50	0.34	0.25	0.02
COL 38									1.87	1.70	1.69	1.31	1.12	0.88	0.76	0.49	0.32	0.22	0.19	0.09	
COL 39									1.90	1.80	1.60	1.45	1.23	0.95	0.83	0.75	0.63	0.49	0.36	0.26	



Table 1E. HVAC-Only Average Power for Sites with Multi-Zone Systems by Outdoor Temperature Bin, Heating Season.

Site	-40	-35	-30	-25	-20	-15	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60
GEC 31	1.79	2.30	2.26	2.37	2.41	2.82	2.95	2.78	2.61	2.39	2.11	1.77	1.58	1.45	1.29	1.11	0.94	0.84	0.70	0.55	0.37
GEC 32	1.65	1.16	1.64	1.66	1.95	2.68	2.46	2.14	2.11	1.95	1.73	1.53	1.38	1.28	1.14	1.01	0.86	0.77	0.64	0.53	0.49
SNO 11											2.18	2.12	2.09	2.11	1.86	1.52	1.25	1.01	0.76	0.48	0.49
SNO 53											1.02	2.90	1.94	1.73	1.11	1.18	1.14	0.94	0.85	0.67	0.83
TAC 07												3.39	2.95	2.68	2.12	1.68	1.22	0.85	0.61	0.41	0.37
TAC 11												6.62	6.50	4.98	3.38	2.82	2.24	1.82	1.31	1.02	0.70
TAC 12												2.57	2.62	2.32	1.93	1.48	1.26	1.12	0.94	0.80	0.64
TAC 13												1.72	1.71	1.87	1.45	0.94	0.65	0.52	0.35	0.24	0.13
TAC 14												2.48	2.74	2.08	1.97	1.33	1.10	0.83	0.60	0.40	0.53
TAC 15												5.18	4.51	2.49	1.76	1.51	1.24	1.04	0.81	0.52	0.45
TAC 16													1.69	1.54	1.29	1.04	0.77	0.58	0.44	0.30	0.21
TAC 21												2.30	2.13	1.74	1.41	1.24	1.04	0.90	0.73	0.50	0.35

Table 1F. Calculated Residual Heating Power for Sites with Ducted Systems by Outdoor Temperature Bin.

Site	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60
CEC 01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
CEC 02	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
CEC 03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
CEC 04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
CEC 05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
CEC 41	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
INL 02	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
INL 41	0.00	0.36	0.15	0.00	0.02	0.29	0.18	0.09	0.25	0.17	0.22	0.14	0.00	0.02	0.00
INL 42	0.00	0.24	0.12	0.18	0.03	0.00	0.00	0.04	0.00	0.00	0.00	0.07	0.02	0.00	0.00
INL 44	1.72	2.00	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
INL 46	7.87	8.33	7.15	6.32	6.66	6.04	3.26	2.57	1.31	1.38	0.61	0.46	0.12	0.52	0.00
PLU 01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.13	0.00
PLU 02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00
PLU 03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.15
PLU 04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SNO 41					0.14	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SNO 43					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SNO 44					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TAC 01							0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12
TAC 02						0.00	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TAC 03						0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00



Table 1F. Calculated Residual Heating Power for Sites with Ducted Systems by Outdoor Temperature Bin.

Site	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60
TAC 04						0.00	0.42	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TAC 05						0.90	0.70	0.25	0.03	0.22	0.16	0.13	0.00	0.02	0.00
TAC 06						0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TAC 08						0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TAC 09						0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
TAC 10						0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
YAK 01			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
YAK 61			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.12	0.00	0.00





Table 1G. Calculated Residual Heating Power for Sites with Multi-Zone Systems by Outdoor Temperature Bin.

Site	-40	-35	-30	-25	-20	-15	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60	
CEC 11						0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CEC 12						0.50	1.02	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CEC 13						0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CEC 31						0.00	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CEC 32						0.00	0.59	0.87	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CEC 33						0.00	1.38	0.49	0.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COL 30								0.00	0.00	0.31	0.32	0.27	0.27	0.17	0.21	0.19	0.06	0.23	0.17	0.00	0.00	0.00
COL 31								0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COL 32								0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COL 33								0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COL 34								2.99	3.00	0.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COL 35								3.38	3.63	2.99	2.61	2.44	1.51	1.26	0.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COL 36										0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.18
COL 37								0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COL 38								0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COL 39								0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00



Table 1G. Calculated Residual Heating Power for Sites with Multi-Zone Systems by Outdoor Temperature Bin.

Site	-40	-35	-30	-25	-20	-15	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60			
GEC 31	4.35	4.34	3.46	3.01	1.41	1.03	0.37	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
GEC 32	5.09	5.15	3.26	3.15	1.40	0.39	0.60	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
SNO 11										0.19	0.00	0.00	0.58	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SNO 53										0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TAC 07											0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TAC 11											0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TAC 12										1.05	1.09	1.05	1.09	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TAC 13										0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TAC 14										0.91	1.24	0.91	1.24	0.70	0.21	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TAC 15										0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TAC 16											2.49		2.49	1.33	1.12	0.74	0.62	0.24	0.05	0.00	0.00	0.00	0.00	0.00
TAC 21										0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 1H. Whole House Average Power for Sites with Ducted Systems by Outdoor Temperature Bin, Cooling Season.

Site	60	65	70	75	80	85	90	95	100	105
CEC 41	1.10	1.25	1.28	1.18	1.17	1.22	1.41	1.90	2.36	
INL 02	0.56	0.57	0.62	0.70	0.85	0.81	0.93	0.99	1.72	1.53
INL 41	0.95	1.15	1.37	1.68	1.87	2.24	2.49	2.81	3.36	3.62
INL 42	0.63	0.69	0.86	1.10	1.50	1.87	2.53	3.43	4.45	5.51
INL 44	1.89	2.01	2.16	2.16	2.13	2.02	2.32	2.99	3.60	
INL 46	1.15	1.07	1.21	1.20	1.28	1.47	1.70	2.10	2.56	3.11
PLU 01	2.11	2.28	2.39	2.58	2.99	2.92	3.35	3.51	3.94	
PLU 02	0.49	0.64	0.73	0.86	1.06	1.17	1.62	1.57	2.39	
PLU 03	1.86	2.04	2.25	2.24	2.61	2.82	2.20	2.02	3.68	
PLU 04	0.99	1.14	1.28	1.50	1.93	2.06	2.64	2.62	3.11	
SNO 41	0.36	0.41	0.46	0.45	0.46	0.59	0.79			
SNO 43	0.56	0.57	0.73	0.71	0.84	0.54	0.43			
SNO 44	0.89	1.47	2.04	2.73	3.40	3.51				
TAC 01	1.34	1.61	1.61	1.80	2.10	2.30	2.56	3.10		
TAC 02	1.06	1.14	1.37	1.57	1.96	2.68	1.93			
TAC 03	1.07	1.38	1.77	2.14	2.31	2.76	3.37	5.06		
TAC 04	0.74	0.80	0.86	1.29	1.80	1.72	2.15	1.41		
TAC 05	0.82	1.00	1.08	1.47	2.10	2.24	2.36	3.50		
TAC 06	0.98	1.02	1.02	1.09	1.21	1.46	2.25	1.60		
TAC 08	1.66	2.09	2.50	2.91	3.19	3.87	4.24	3.75		
TAC 09	0.64	0.75	0.97	1.08	1.22	1.26	1.20	1.39		
TAC 10	1.16	1.41	1.70	2.02	2.13	2.47	2.56	2.86		
YAK 01	1.63	2.15	2.36	2.63	3.30	3.02	3.42	1.41		
YAK 61	1.84	2.08	2.54	3.27	4.15	4.66	5.45	6.21	7.07	7.64



Table 11. HVAC Average Power for Sites with Multi-Zone Systems by Outdoor Temperature Bin, Cooling Season.

Site	60	65	70	75	80	85	90	95	100	105
CEC 11	0.26	0.30	0.38	0.48	0.59	0.91	1.45	1.88	2.99	
CEC 12	0.88	0.99	1.07	1.12	1.08	1.06	0.94	1.06	1.18	
CEC 13	1.57	1.72	1.95	2.21	2.27	2.28	2.39	2.41	3.53	
CEC 31	1.66	1.66	1.80	2.00	1.99	2.05	2.14	2.25	2.35	
CEC 32	0.79	0.77	0.85	0.96	0.92	1.08	1.14	1.12	2.20	
CEC 33	0.73	0.82	0.85	1.03	1.11	1.16	1.34	1.36	1.77	
COL 30	0.64	0.81	0.91	1.05	1.12	1.22	1.20	1.34	1.58	2.58
COL 31	0.77	0.83	0.87	0.91	1.01	1.06	0.96	1.15	1.58	1.66
COL 32	0.65	0.75	0.96	0.92	0.97	1.14	1.21	1.30	1.43	1.60
COL 33	0.76	0.72	0.81	0.84	0.80	0.87	0.83	0.82	1.22	1.18
COL 34	0.47	0.53	0.62	0.74	0.93	0.97	0.97	1.19	1.51	1.08
COL 35	0.57	0.60	0.63	0.73	0.83	0.77	0.76	0.87	0.76	1.07
COL 36	0.83	1.03	1.19	1.36	1.59	1.90	1.69	1.86	2.64	2.39
COL 37	0.64	0.75	0.83	0.95	1.01	1.45	1.75	1.89	2.17	2.31
COL 38	0.88	0.97	1.02	1.12	1.06	1.13	1.17	1.31	1.64	1.50
COL 39	0.15	0.23	0.27	0.62	0.09	0.15	0.00	0.15		
GEC 31	0.69	0.64	0.62	0.60	0.52	0.66	0.79	0.70		
GEC 32	0.64	0.64	0.59	0.51	0.51	0.67	0.54	0.86		
SNO 11	1.06	1.20	1.23	1.33	1.48	1.27	1.07			
SNO 53	1.64	1.84	2.16	2.35	2.89	2.85	2.92			
TAC 07	1.14	1.35	1.60	1.83	2.03	2.14	2.33			
TAC 11	0.83	0.96	1.10	1.23	1.48	1.89	1.73			
TAC 12	1.14	1.20	1.20	1.31	1.38	1.57	1.47			
TAC 13	0.31	0.49	0.61	0.82	0.98	0.96	1.00			



Table 1J. Calculated Residual Average Power for Sites with Ducted Systems by Outdoor Temperature Bin, Cooling Season.

Site	60	65	70	75	80	85	90	95	100	105
CEC 41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
INL 02	0.00	0.00	0.00	0.04	0.14	0.12	0.16	0.25	0.81	0.66
INL 41	0.00	0.00	0.12	0.35	0.41	0.61	0.66	0.81	1.00	1.28
INL 42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.87
INL 44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
INL 46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.49
PLU 01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
PLU 02	0.00	0.01	0.07	0.18	0.31	0.29	0.47	0.22	0.56	
PLU 03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.53	
PLU 04	0.00	0.00	0.00	0.03	0.15	0.04	0.24	0.00	0.00	
SNO 41	0.00	0.02	0.07	0.02	0.00	0.00	0.09			
SNO 43	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
SNO 44	0.00	0.00	0.00	0.00	0.00	0.00				
TAC 01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
TAC 02	0.00	0.00	0.08	0.11	0.22	0.32	0.00			
TAC 03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00		
TAC 04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
TAC 05	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.15		
TAC 06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
TAC 08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
TAC 09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
TAC 10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
YAK 01	0.00	0.00	0.00	0.19	0.53	0.03	0.35	0.00		
YAK 61	0.00	0.00	0.16	0.56	1.01	1.08	1.30	1.65	2.34	2.61



Table 1K. Calculated Residual Average Power for Sites with Multi-Zone Systems by Outdoor Temperature Bin, Cooling Season.

Site	60	65	70	75	80	85	90	95	100	105
CEC 11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
CEC 12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
CEC 13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	
CEC 31	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	
CEC 32	0.00	0.00	0.06	0.17	0.11	0.20	0.13	0.02	0.44	
CEC 33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	
COL 30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.49
COL 31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COL 32	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
COL 33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
COL 34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00
COL 35	0.00	0.02	0.05	0.15	0.25	0.19	0.18	0.29	0.18	0.49
COL 36	0.00	0.00	0.00	0.07	0.17	0.40	0.17	0.29	0.90	0.63
COL 37	0.00	0.00	0.00	0.00	0.00	0.21	0.22	0.20	0.18	0.05
COL 38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COL 39	0.00	0.05	0.09	0.41	0.00	0.00	0.00	0.00		
GEC 31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
GEC 32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
SNO 11	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
SNO 53	0.00	0.00	0.00	0.00	0.26	0.09	0.22			
TAC 07	0.00	0.00	0.00	0.01	0.00	0.00	0.14			
TAC 11	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
TAC 12	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
TAC 13	0.00	0.00	0.00	0.00	0.01	0.00	0.00			
TAC 14	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
TAC 15	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
TAC 16	0.00	0.00	0.00	0.00	0.00	0.18	0.00			
TAC 21	0.00	0.00	0.00	0.00	0.00	0.00	0.00			



Table 1L. COPs Used for Weather-Normalizing, HSPF(IV) Field Calculation.

Site	Average System COP by Outdoor Temperature Bin														
	-8	-3	2	7	12	17	22	27	32	37	42	47	52	57	62
TAC 01	-	-	-	-	-	3.0	3.2	2.9	2.5	2.6	3.2	3.5	3.3	2.4	3.0
TAC 02	-	-	-	-	-	3.2	3.4	3.4	3.4	3.8	4.5	4.8	4.9	4.7	2.7
TAC 03	-	-	-	-	-	2.2	2.4	2.2	2.1	2.3	3.2	3.6	3.7	3.8	3.7
TAC 04	-	-	-	-	-	2.5	3.3	2.9	2.7	3.2	4.0	4.0	3.7	2.7	0.6
TAC 05	-	-	-	-	-	2.7	2.6	2.5	2.4	2.6	3.0	3.1	2.4	2.1	-
TAC 06	-	-	-	-	-	2.6	3.0	2.9	3.0	3.6	4.1	4.3	4.1	3.6	1.9
TAC 08	-	-	-	-	-	2.4	2.5	2.6	2.6	2.8	3.2	3.4	3.3	2.8	0.9
TAC 09	-	-	-	-	-	2.8	2.9	3.0	3.1	3.2	3.4	3.6	3.6	3.3	2.6
TAC 10	-	-	-	-	-	1.7	1.8	1.8	1.8	2.1	2.4	2.6	2.6	2.5	2.7
INL 02	1.1	1.2	1.3	1.5	1.4	1.3	1.4	1.5	1.8	2.3	2.9	3.3	3.7	3.6	3.6
INL 41	1.1	1.5	2.0	1.8	2.0	2.1	2.2	2.3	2.4	2.7	3.3	3.4	3.1	2.2	2.1
INL 42	1.5	1.5	1.5	1.6	2.4	2.4	2.4	2.5	2.7	3.1	3.9	4.3	4.1	3.6	2.0
INL 46	-	-	-	-	-	3.5	3.7	3.2	3.5	2.9	4.1	4.1	4.0	-	-
SNO 41	-	-	-	-	2.2	2.2	2.3	2.4	2.6	2.8	3.0	3.3	3.4	3.6	3.7
SNO 43	-	-	-	-	2.0	1.9	2.4	2.4	2.4	3.0	3.1	3.2	3.3	3.3	4.7
SNO 44	-	-	-	-	1.9	2.1	1.9	2.0	2.0	2.3	2.9	3.5	3.5	3.4	3.4
CEC 41	0.9	0.9	0.9	1.3	1.5	1.7	1.8	1.7	1.8	1.9	2.2	2.2	2.2	2.1	2.0
YAK 01	-	-	-	-	-	1.7	1.7	1.7	1.7	1.7	1.7	1.8	1.9	1.8	1.5
YAK 61	-	-	-	-	-	2.1	2.2	2.2	2.2	2.4	2.6	2.6	2.8	3.3	4.4
PLU 01	1.4	1.4	1.4	1.5	1.6	1.7	1.9	2.0	2.1	2.4	2.6	2.6	2.9	3.0	-
PLU 02	1.1	1.1	1.1	1.3	1.4	1.5	1.6	1.7	1.8	2.1	2.2	2.3	2.4	2.2	-



Table 1L. COPs Used for Weather-Normalizing, HSPF(IV) Field Calculation.

Site	Average System COP by Outdoor Temperature Bin														
	-8	-3	2	7	12	17	22	27	32	37	42	47	52	57	62
PLU 03	1.2	1.2	1.2	1.4	1.4	1.6	1.7	1.8	2.0	2.3	2.6	2.9	3.4	2.5	-
CEC 01	1.3	1.3	1.4	1.5	1.3	1.6	1.8	2.0	2.0	2.2	2.8	3.3	3.7	4.5	3.5
CEC 02	1.1	1.1	1.1	1.1	1.5	2.1	2.0	1.9	2.0	2.3	2.4	2.2	1.8	-	-
CEC 03	1.9	1.9	1.9	2.2	2.4	2.5	2.4	2.4	2.5	2.8	3.2	3.4	3.3	3.4	3.4
CEC 04	1.1	1.1	1.3	1.3	1.4	1.5	1.7	1.8	1.9	2.6	3.1	3.3	3.1	1.7	3.2
CEC 05	1.0	1.0	1.0	1.1	1.3	1.8	1.9	1.8	1.9	2.1	2.5	3.1	2.1	3.5	3.1

Table 1M. Duct Location Summary

Are the ducts in the conditioned space?	Count
Not Applicable	29
No	18
Mostly no	2
Mix	3
Mostly yes	1
Yes	4

Table 1N. Duct Leakage Summary

Duct Leakage Classification	Count
Not Applicable/No Data	30
Leaky	13
Semi-leaky	4
Average	4
Tight	3
In Conditioned Space	3



Table 10. Duct Insulation Summary

Duct Insulation Quality Estimate	Count
Not Applicable	30
None	1
Low	4
Low-Mid	5
Mid	11
Mid-High	1
High	2
In Conditioned Space	3

Table 1Q. Blower Door Result Summary

Blower Door CFM50	Count
Less than 500	0
500-1000	8
1000-1500	15
1500-2000	13
2000-2500	6
2500-3000	3
3000-4000	3
4000-5000	4
NA	5

Table 1P. Duct Leakage to Unconditioned Space Summary

Duct Leakage to Unconditioned Space @ 25 Pa [CFM]	Count
0/NA	39
Up to 50	2
50-100	3
100-150	5
150-200	5
200-300	2
300-400	1

Table 1R. Blower Door ACH50 Summary

Blower Door Relative Leakage ACH50	Count
Less than 3	0
3-5	3
5-7	15
7-10	22
10-15	13
15-20	2
NA	2



Appendix B: Project Qualified Product List as of February 2023

- Indoor and Outdoor Units should be a NEEP approved Central-Ducted heat pump. Search Here: <https://ashp.neep.org/#/>
- The available nominal capacity table shows which range of capacities are available for a given system; a solid circle indicates a system is available, and a blank means that capacity is not available. An asterisk means a system is available, and our team will review case-by-case

Table 2A. Single-Zone Centrally Ducted System List

Brand	Product Line	Pre-Approved Outdoor Unit models	Available Nominal Cooling Capacity (Tons)					Limited Pairing	Heating Zones
			Up to 1.6	> 1.5 to 2.5	> 2.5 to 3.5	> 3.5 to 4.5	> 4.5		
American Standard	Platinum 19	4A6L9 (all sizes)		●	●	●	●		1,2
	Platinum 20	4A6V0036; 4A6V0048; 4A6V8036; 4A6V8048		*	●	●	*		1,2
Trane	XV19	4TWL9 (all sizes)		●	●	●	●		1,2
	XV20i	4TWW0036; TWV8036; 4TWW0048; TWV8048		*	●	●	*		1,2
Bryant	Bryant® Extreme Heat Pump	280ANV024; 284ANV024; 280ANV036; 284ANV036; 284ANV036*0**A*; 284ANV024*0**A*		●	●	*	*		1,2
Carrier	Infinity® 20 Heat Pump with Green-speed Intelligence	25VNA024; 25VNA424; 25VNA036; 25VNA436; 25VNA436A*030*; 25VNA424A*030*		●	●	*	*		1,2
Coleman/Luxaire/Fraser-Johnson/Champion Heating and Cooling	HC20 / HL20	HC20B4821; HC20B3621; HC20B4821S; HL20B4821; HL20B3621		*	●	●	*		1,2
Daikin Equivalent models with Amana, Goodman or other branding also permitted	Fit	DZ17VSA181; DZ17VSA241; DZ-17VSA301	●	●	*	*	*		1,2
	DZ20VC	DZ20VC (all sizes)		●	●	●	●		1,2
Fujitsu	-	AOUG36LMAS1; FO3620RVJCAB; FO4820RVJCAB		*	●	●			1,2



Table 2A. Single-Zone Centrally Ducted System List

Brand	Product Line	Pre-Approved Outdoor Unit models	Available Nominal Cooling Capacity (Tons)					Limited Pairing	Heat-ing Zones
			Up to 1.6	>1.5 to 2.5	>2.5 to 3.5	>3.5 to 4.5	> 4.5		
Lennox	XP25	XP25-024; XP25-036		●	●	✱	✱		1,2
	SL25XPV	SL25XPV-024; SL25XPV-036; SL25XPV-048; SL25XPV-060		●	●	●	●		1,2
LG		LUU180HHV; LUU189HV; LUU240HHV; LUU249HV; LUU360HHV; LUU369HV	●	●	●	✱			1,2
Mitsubishi Electric (equivalent model numbers under American Standard or Trane also permissible)	M-Series	SUZ-KA12NA2; SUZ-KA18; SUZ-KA18NAH2	●						1,2
	M-Series H2i	SUZ-KA18NAHZ; SUZ-KA30NAHZ; SUZ-KA36NAHZ	●	●	●				1,2
	P-Series	PUZ-A12NKA7; PUZ-A18NKA7; PUZ-A24NHA7; PUZ-A30NHA7; PUZ-A36NKA7; PUZ-A42NKA7	●	●	●				1,2
	P-Series H2i	PUZ-HA24NHA; PUZ-HA30NKA; PUZ-HA36NHA; PUZ-HA36NKA		●	●				1,2
Rheem	RP20	RP20 (all sizes)		●	●	●			1,2
Ruud	UP20	UP20 (all sizes)		●	●	●			1,2
York	YZV Affinity Series	YZV36B21; YZV48B21		✱	●	●	✱		1,2
<p>● = pre-approved for any outdoor/indoor combination that can be found on NEEP list; ✱ = available system, reviewed case-by-case. Please reach out to our team if you have questions or aren't sure if a candidate system qualifies ● For outdoor units with the red dot, some indoor unit combinations listed by NEEP do not satisfy our program criteria. If you wish to specify one of the heat pumps with a red dot, please contact our team to confirm the combination, or if you have further questions.</p>									
American Standard	-	4TXD2036A10NU; 4TXD2060A10NU		●		●		●	1,2
Trane	-	4TXD2036A10NU; 4TXD2060A10NU		●		●		●	1,2
Bosch	IDS 2.0	BOVA-24HDN1-M15G; BOVA-36HDN1-M20G		●	●			●	1



Table 2A. Single-Zone Centrally Ducted System List

Brand	Product Line	Pre-Approved Outdoor Unit models	Available Nominal Cooling Capacity (Tons)					Limited Pairing	Heating Zones
			Up to 1.6	>1.5 to 2.5	>2.5 to 3.5	>3.5 to 4.5	> 4.5		
Bryant	Preferred Series	38MAQB18R--3, 38MAQB30R—3; 38MARBQ24AA3	●	●				●	1
Carrier	Performance Series	38MAQB18R--3, 38MAQB30R—3; 38MARBQ24AA3	●	●	●			●	1
GE	Connect	AUH2436ZGDA*; AUH4860ZGDA*		●		●		●	1,2
Gree/King Home/TOSOT	Flex / Ultra Heat	FLEX36; GUD36W KU36; TU36; FLEX60; GUD60W; KU60; TU60			●	●		●	1,2
Nortek Brands (incl. Broan, Frigidaire, Airtemp, Mammoth, Reznor, Maytag, Nutone)	Ultra Side Discharge	GXH24-36MSK4DH; GXH48-60MSK-4DH		●		●		●	1,2
	FSH1-BG / PSH1-BG	PSH1BG4CVRX48K; PSH1BG-4CVRX60K; FSH1BG4CVRX48K				●		●	1,2
Samsung	Multi-Position Air Handler Max Heat	AC036JXSCCH/AA (*); AC030BX-SCCH/AA; AC018JXADCH/AA; AC036BXSCCH/AA		●	●			●	1
Wabban	-	BB36-24WADU, BB60-48WADU		●		●		●	1,2
LBG Products	GRUN	LCH24036DO; LCH48060DO		●		●		●	1,2
Napoleon/Continental	NS15 / CS18	CS18HV48A60; CS18HV24A36; NS18HV48A60; NS18HV24A36		●		●		●	1,2



- Outdoor Units should be a NEEP-Approved Ductless or Non-Central Ducted heat pump. Search here: <https://ashp.neep.org/#/>
- The available nominal capacity table shows which range of capacities are available for a given system; a solid circle indicates a system is available, and a blank means that capacity is not available. An asterisk means a system is available, and our team will review case-by-case

Table 2B. Multi-Zone Ductless and Non-Centrally Ducted System List.

Brand	Product Line	Pre-Approved Outdoor Unit models	Available Nominal Cooling Capacity (Tons)				
			Up to 1.6	>1.5 to 2.5	>2.5 to 3.5	>3.5 to 4.5	> 4.5
Azur		AZ-42M522SCO		*	*	●	
Bosch	Climate 5000	BMS500-AAM018-1CSXHC, BMS500-AAM027-1CSXHB, BMS500-AAM027-1CSXRA, BMS500-AAM036-1CSXHB	*	●	●	●	
Daikin	MXL Aurora (please check with us for outdoor models with similar model #s not shown here)	2MXL18QMVJU, 2MXL18QMVJU, 3MXL24QMVJU, 3MXL24RMVJU, 4MXL36TVJU	●	●	●		
	MXS Series (please check with us for outdoor models with similar model #s not shown here)	2MXS18NMVJU, 3MXS24NMVJU, 3MXS24RMVJU*, 5MXS48TVJU, 3MXS24RMVJU; 5MXS48WVJU*	●	●	●	●	
Franklin		MST303E23MHAA, MST363E23MHAA		●	●		
Friedrich	Floating Air Pro	FPHMR24A3A	*	●	*		



Table 2B. Multi-Zone Ductless and Non-Centrally Ducted System List.

Brand	Product Line	Pre-Approved Outdoor Unit models	Available Nominal Cooling Capacity (Tons)				
			Up to 1.6	>1.5 to 2.5	>2.5 to 3.5	>3.5 to 4.5	> 4.5
Fujitsu	AIRSTAGE J-II Series	AOU36RLAVM, AOU48RLAVM, AOU60RLAVM			●	●	●
	AIRSTAGE J-IIs Series	AOU36RLAVS			●	*	
	AIRSTAGE J-IV Series	AOU36RLAVM4, AOU48RLAVM4, AOU60RLAVM4			●	●	●
	AIRSTAGE J-IVs Series	AOU36RLAVS4			●	*	
	Halcyon Multi-room Mini-Split Systems	AOU36RLXFZH, AOU45RLXFZ	*	*	●	●	
Gree	GMV5 Mini	GMV-36WL/C-T(U), GMV-48WL/C-T(U), GMV-60WL/C-T(U)		●	●	●	*
Lennox	-	MLA036S4M-1P, MLB018S4M-1P, MLB048S4M-1P , MLB048S4M-2P, MPC018S4M-1P , MPC024S4M-1P, MPC030S4M-1P	*	●	●	●	
LG	Multi F	LMU180HV, LMU240HV, LMU481HV, LMU541HV, LMU600HV	●	●		●	
	Multi F Red	LMU360HHV, LMU361HHV, LMU420HHV, LMU421HHV, LMU480HHV			●	●	
	-	ARUN024GSS4, ARUN048GSS4		●		●	*



Table 2B. Multi-Zone Ductless and Non-Centrally Ducted System List.

Brand	Product Line	Pre-Approved Outdoor Unit models	Available Nominal Cooling Capacity (Tons)				
			Up to 1.6	>1.5 to 2.5	>2.5 to 3.5	>3.5 to 4.5	> 4.5
Mitsubishi	M-Series	MXZ-4C36NAHZ, MXZ-5C42NAHZ	*	*	●	*	*
<i>Equivalent models with American Standard or Trane branding are also permitted</i>	M-Series H2i	MXZ-4C36NAHZ2, MXZ-5C42NAHZ2, MXZ-8C48NAHZ, MXZ-8C48NAHZ2			●	●	
	Smart Multi	MXZ-SM36NAM, MXZ-SM-36NAMHZ, MXZ-SM42NAMHZ, MXZ-SM48NAM, MXZ-SM-48NAMHZ			●	●	*
	S-Series	PUMY-HP36NK-MU1, PUMY-HP48NK-MU1, PUMY-P36NK-MU2, PUMY-P36NKMU3, PUMY-P48NKMU2, PUMY-P48NKMU3, PUMY-P60NKMU*, PUMY-P60NK-MU2, PUMY-P60NKMU3			●	●	●
	S-Series H2i	PUMY-HP36NKMU, PUMY-HP48NKMU			●	●	
NOVAIR Plus		27EVANVMO		●	*	*	
Panasonic	RAC Multi E	CU-3E19RBU-5; CU-2E18SBU-5; CU-4E24RBU-5	●	●			
Rheem	Rheem Multi-room Mini-Split Systems	ROMH36FXZHJ, ROMH45AFXZJ	*	*	●	●	
Ruud	RUUD Multi-room Mini-Split Systems	ROMH36FXZHJ	*	*	●	●	
Samsung	FJM	AJ020BXS3CH, AJ024BXS4CH, AJ024MCS4CH, AJ030BXS4CH, AJ030MCS4CH, AJ036BXJ4CH, AJ036BXS4CH, AJ036TXJ4CH	*	●	●	*	
	FJM Max Heat	AJ020BXS3CH, AJ020MCS3CH, AJ020TXS3CH, AJ024BXS4CH, AJ024TXS4CH, AJ030BXS4CH, AJ030TXS4CH, AJ036BXS4CH, AJ036TXS4CH		●	●		
Sharp/HaxxAir	-	AE-X2M20TU, HVHM-24T2D		●			



Table 2B. Multi-Zone Ductless and Non-Centrally Ducted System List.

Brand	Product Line	Pre-Approved Outdoor Unit models	Available Nominal Cooling Capacity (Tons)				
			Up to 1.6	>1.5 to 2.5	>2.5 to 3.5	>3.5 to 4.5	> 4.5
Toshiba Carrier	Toshiba-Carrier VRF	MCY-MAP0367HS-UL, MCY-MAP0487HS-UL, MCY-MAP0607HS-UL			●	●	●
Westinghouse		WHP24M3A21S	*	●	*		
Zephyr/Azur		AZ-42M522SCO, ZE-42M522SCO		*	●		
Midea	<p><i>Because there are many brands and product lines based on Midea heat pumps, if you wish to specify one of these systems please send us the brand and outdoor unit model number and we will review. We can add the relevant brands to our list if needed.</i></p>						



- Starting in Summer, 2022, as the team updates the list, new brands which are not already in the populated tables on the previous pages will be added to a list on this page. If contractors or utilities express interest in any particular system on this list, it can be verified and added to the appropriate table.
- This is intended to keep the tables on the preceding pages to legible, single-page tables if possible
- Information such as brand name/brand owner is taken from the NEEP database and not explicitly checked. Please advise us of any suspected errors.
- If you see a system with a model number which is close to, but not exactly matching a system in the above tables, please check with us, as many brands are extending their products and there may be too many distinct outdoor models to list

Table 2C. Central Ducted

Additional Products from:	
Brand Owner	Brand Name
Boreal International Corp.	BOREAL
Carrier	Airquest, Comfortmaker, Day & Night, Heil, Keeprite, Smart Comfort, Tempstar
Ecoer	Ecoer
Groupe Distribution Dulac	MAX-R
Innovair	Innovair
Lennox	Ducane, Allied, Concord, Centruy, Comfort-Aire
Midea	(many brands)

Table 2D. Multi-Zone

Additional Products from:	
Brand Owner	Brand Name
HISENSE	HISENSE
Johnson Controls, Inc. (York International Norman)	HITACHI, York
Lennox	Ducane, Concord, Armstrong Air, Allied
Carrier	Airquest, Airquest, ArcoAire, Comfortmaker, Day & Night, Keeprite, Kenmore, Midea, Smart Comfort, Tempstar, Carrier, Bryant, Payne, Weathermaker
Generallux	Generallux
Innovair	Innovair
TRANE US	Trane, American Standard



Appendix C: Site Survey Materials

Site Survey Form #1

High-Performance High-Capacity Air Source Heat Pump Study

1. Site Survey #1 and Support Documentation

Purpose for this process step: The objective of the site survey is to understand home characteristics, document homeowner behavior and provide a detailed site description of the home including the conditions and adequacy of the duct work to assist in several steps: sizing of the equipment; developing the energy usage baseline for the home.

Owner/developer: Ben Larson, LER

Supporting team members: Bob Davis, Ecotope and John Bush, OTS Energy

Who Uses the Documentation?

- Home Specialist Surveyor completes the document and forwards information to the utility to share with their HVAC contractor.
- BPA uses the document to:
 - develop load calculations
 - develop sizing recommendations, and
 - determine if duct work is adequate.

Completed Documents location: HP HC HP Data Site – Utility Site

Date Document Last Updated: 10/6/2021

The following site survey will be completed for each participating site by Keel Energy staff. The goal of the survey is to summarize the following information:

- characteristics of the home – square footage, vintage, number of rooms, etc.
- understanding behavioral aspects of the household – schedule pre and post COVID and
- thermostat settings, if applicable
- heating and cooling set points for the system
- conditions of the duct system including proposed improvements

The site survey will be completed by Keel Energy, a subcontractor to Washington State University Energy Program. The survey process will involve completing the survey document and three tests – duct blaster, air handler TrueFlow, and blower door.

Information and test measurements will be used by both BPA and the HVAC contractor to correctly size the heat pump equipment.



Initial Site Survey (Form #1)

To be performed by 3rd party testing contractor after participation agreement in place and before/during HVAC contractor initial visit.

Purpose

- conduct a short occupant questionnaire on existing system and heating/cooling practices
- collect existing thermostat and equipment information
- collect information on the heat loss rate of the house so the BPA Research Team can determine the heat pump output capacity needed to meet the project’s goals

Site ID:	Utility:
Name of Surveyor:	House Type
Date:	<input type="checkbox"/> Site-Built <input type="checkbox"/> Manufactured Home <input type="checkbox"/> Duplex / Triplex <input type="checkbox"/> Townhome

Occupant Questions

How long have you lived in the house? _____ years

How many occupants live in the house? _____

Occupant Questions: Heating System

Has the current *heating* system kept the house warm to your satisfaction? Yes / No

Are there any uncomfortable cold or warm spots? Yes / No

If yes, where?

What day/month of year do you typically turn the heating system on? _____ and off? _____
 (try to get accurate to half month like mid-November or end April)

Have you changed the thermostat schedule significantly in the past 1-2 years?

Do you use any other heating sources? If so, when, and how?

<input type="checkbox"/> Wood Fireplace – Decorative on special occasions <input type="checkbox"/> Wood Stove – Decorative on special occasions <input type="checkbox"/> Wood Stove – ___ times / week or ___ cords / year <input type="checkbox"/> Gas/Propane Fireplace <input type="checkbox"/> Other:	Electric Space Heaters		
	Output Capacity	Location	Runtime

Special Wood Heat Questions for Sites Known to Heat with Significant Amounts

Approximate square footage or % of conditioned floor area heated by the wood stove _____

List rooms heated and indicate location on floor plan _____

In what part of the day is the wood stove typical used?
 Circle One: Continuous (24hrs)? Evening? Afternoon? Afternoon & Evening? Morning?
 Other (describe):

Occupant Questions: Cooling System

If central *cooling* present:

Has the current system kept the house cool to your satisfaction? Yes / No

Are there any uncomfortable cold or warm spots? Yes / No

If yes, where?

What day/month of year do you typically turn the cooling system on? _____ and off? _____
 (try to get accurate to half month like mid-July or end August)

Do you have a zonal air conditioning system such as window unit or floor unit (on rollers)? Yes / No

Zonal Cooling System Type (window, floor unit, other)	Location (room where used)	Output Capacity (Btu/hr)	Frequency / How Used (ex: Every afternoon/evening in July & August)



Ductless Systems (ask only if applicable – ductless system already in place)

What motivated you to switch from ducted to a ductless system?

In 2020-22, did your routine significantly change because of COVID? (Fill in relevant cells. Examples given in blue.)

Change (circle one)	Approximate timeline	Notes
Significantly more time at home (e.g. work from home, home school)	April 2020-December 2020	Kids home April 2020-December 2020; parents work from home through present
Somewhat more time at home	April 2020-Present	Parents work from home; kids back at school January 2021-present
Normal	N/A	Not yet back to pre-COVID routine
Change in occupancy	September 2020-Present	Child back home from college

Current Heating System

Electric furnace output capacity: ____kW. Make / model: _____

Thermostat make/model: _____ / _____

Air Handler Location

- Garage Inside
- Crawl Basement
- Attic Other _____

Describe location of thermostat

(central hall, living room, etc. Note any potential for vent blowing on it or solar exposure)

Heating Thermostat Setpoints and Schedule

(can ask occupants or collect from thermostat)

Does occupant operate the thermostat on a programmed schedule? Yes / No

If no, does occupant manually adjust the setpoint on a regular schedule? Yes / No

Notes: _____

If set at constant temperature with no adjustments, enter set point: ____ (F)

If operated on a programmed or manual schedule, complete the schedule table. Enter time, in left column, and setpoint in (F) for day of week.

Heating Thermostat Schedule Table

Time	Mon	Tue	Wed	Thu	Fri	Sat	Sun
6AM	68						
10PM	60						



Current Cooling System

Is there a central cooling system? Yes / No

If yes, collect system information from outdoor unit label:

Equipment Make _____ Model _____

SEER or EER (circle one, if listed) _____

Cooling Thermostat Setpoints and Schedule

(can ask occupants or collect from thermostat)

Does occupant operate the thermostat on a programmed schedule? Yes / No

If no, does occupant manually adjust the setpoint on a regular schedule? Yes / No

If set at constant temperature with no adjustments, enter set point: _____ (F)

If operated on a programmed or manual schedule, complete the schedule table below

Cooling Thermostat Schedule Table

Time	Mon	Tue	Wed	Thu	Fri	Sat	Sun



House Heat Loss

Use the *HVAC Sizing Tool* to facilitate data collection that will be used to determine the house heat loss rate.

- Collect information on house envelope component areas and insulation levels
 - Use the Takeoff Template (next page) when on site and then enter data in online tool when back at office.
 - Sketch house plan on graph paper provided. Match house sketch to room entries described on Takeoff Template.
- Measure house leakage (Blower Door) and duct leakage (Duct Blaster) as indicated on subsequent pages.

HVAC Sizing Tool - <https://betterbuiltnw.com/hvac-sizing-tool>

Only parts of the *HVAC Sizing Tool* need to be completed.

- Required Tabs
 - Site
 - Enter Site ID as the “Project Name”
 - Skip from “Subdivision” to end
 - Building
 - All fields required
 - Complete sketch of house plan on provided grid paper
 - Duct Location: select “Custom” and use observations on Duct Network to determine distribution between attic, crawl, and conditioned area
 - Complete duct network sketch on grid paper provided
 - Rooms
 - List all rooms to cover floor area of house. Note that rooms may be combined such as “bedroom suite”: baths, closet, and bedroom or “great room”: living, dining, and kitchen
 - Process Tip – the Takeoff Template will be helpful for collecting information for both Rooms and Windows
 - Windows
 - Enter all square footages
 - Overrides
 - Visually verify all the component insulation values while on site. When observation different from HVAC Sizing Tool default selection, enter an override value.
 - *Duct Leakage*:
 - Take duct blaster flow at 25 Pa (CFM Both Sides) and divide by Combined Duct Surface area (ft²) as determined on Duct Network page. Note value and match to the drop down list in HVAC Sizing Tool
 - *Winter Infiltration ACH*:
 - Take blower door result of airflow at 50 Pa (CFM50) and convert to air changes per hour at 50 Pa, ACH50 (ACH50 = CFM50 * 60 / Volume house).
 - If house 1 story, divide ACH50 by 28 and enter value
 - If house 2 or more stories, divide ACH50 by 21 and enter value
 - *Summer Infiltration ACH*: Enter 40% of the Winter Infiltration ACH
- Not Required Tabs
 - Options, System, Duct Design, Duct Results, Results

Ceiling/Roof Takeoff

Ceiling/Roof Name _____

Orientation (circle): N NE E SE S SW W NW N/A

Ceiling/Roof Type (circle): Vented Attic Unvented Attic Vaulted Rigid Above Roof Deck

Construction: 2x4 2x6 2x8 2x10 2x12 Truss Gross Surface Area (ft²) _____

Insulation: None Batt Rigid Loose Fill Estimated R-Value _____

Skylights:

Qty	Width (ft)	Height (ft)	Area, each (ft ²)	Panes	Frame (circle)	Ins. Spacer	Low-e	Shaded
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			

Floor Takeoff

Floor Name _____

Floor Type (circle): Exposed Slab Over Vented Crawl/Garage Over Unvented Crawl

Joist Floor Characteristics:

Construction: 2x4 2x6 2x8 2x10 2x12 Gross Surface Area (ft²) _____

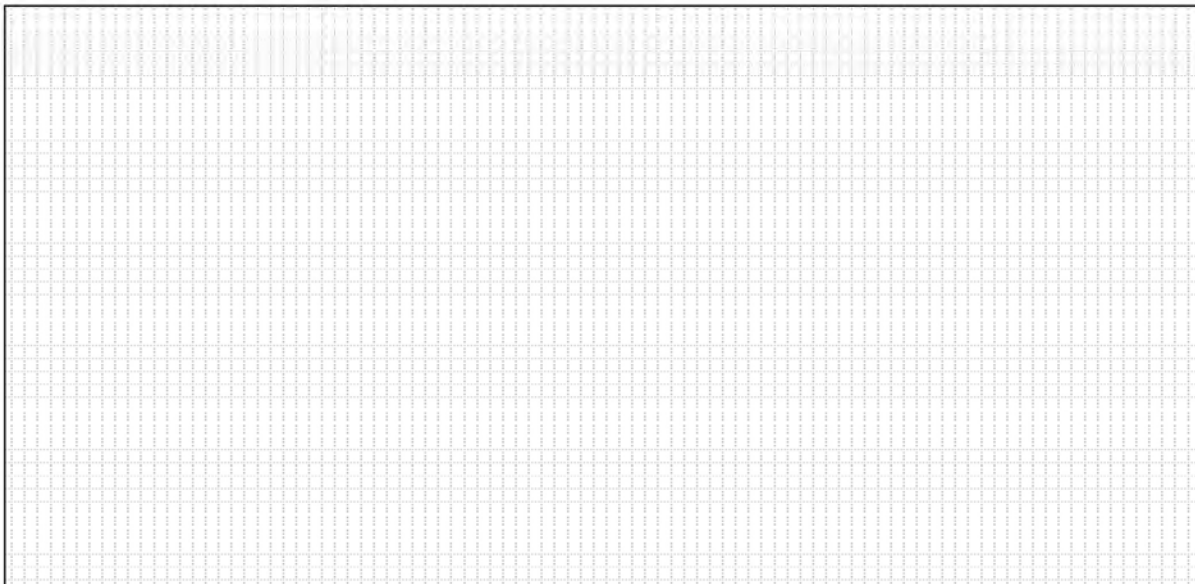
Insulation: None Batt Rigid Loose Fill Estimated R-Value _____

Slab Characteristics:

Length of Perimeter (ft) _____ Estimated R-Value _____

Conditioned Basement Heated Slab Perimeter Insulation Fully Insulated

Sketch (if needed for estimating areas):



Wall Takeoff

Wall Name _____

Orientation (circle): N NE E SE S SW W NW N/A

Surface Type (circle): AG Wall BG Wall Partition

Sketch (include dimensions):

Construction: 2x4 2x6 2x8 Masonry Insulation: None Batt Rigid
 Wall Length (ft) _____ Wall Height (ft) _____ Gross Surface Area (ft²) _____

Windows:

Qty	Width (ft)	Height (ft)	Area, each (ft ²)	Panes	Frame (circle)	Ins. Spacer	Low-e	Shaded
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			

Opaque Doors:

Qty	Width (ft)	Height (ft)	Area, each (ft ²)	Door Type	Insulation
				Wood / Metal / Fiberglass	Hollow / Insulated
				Wood / Metal / Fiberglass	Hollow / Insulated
				Wood / Metal / Fiberglass	Hollow / Insulated



Wall Takeoff

Wall Name _____

Orientation (circle): N NE E SE S SW W NW N/A

Surface Type (circle): AG Wall BG Wall Partition

Sketch (include dimensions):

Construction: 2x4 2x6 2x8 Masonry Insulation: None Batt Rigid
 Wall Length (ft) _____ Wall Height (ft) _____ Gross Surface Area (ft²) _____

Windows:

Qty	Width (ft)	Height (ft)	Area, each (ft ²)	Panes	Frame (circle)	Ins. Spacer	Low-e	Shaded
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			

Opaque Doors:

Qty	Width (ft)	Height (ft)	Area, each (ft ²)	Door Type	Insulation
				Wood / Metal / Fiberglass	Hollow / Insulated
				Wood / Metal / Fiberglass	Hollow / Insulated
				Wood / Metal / Fiberglass	Hollow / Insulated



Wall Takeoff

Wall Name _____

Orientation (circle): N NE E SE S SW W NW N/A

Surface Type (circle): AG Wall BG Wall Partition

Sketch (include dimensions):

Construction: 2x4 2x6 2x8 Masonry Insulation: None Batt Rigid

Wall Length (ft) _____ Wall Height (ft) _____ Gross Surface Area (ft²) _____

Windows:

Qty	Width (ft)	Height (ft)	Area, each (ft ²)	Panes	Frame (circle)	Ins. Spacer	Low-e	Shaded
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			

Opaque Doors:

Qty	Width (ft)	Height (ft)	Area, each (ft ²)	Door Type	Insulation
				Wood / Metal / Fiberglass	Hollow / Insulated
				Wood / Metal / Fiberglass	Hollow / Insulated
				Wood / Metal / Fiberglass	Hollow / Insulated



Wall Takeoff

Wall Name _____

Orientation (circle): N NE E SE S SW W NW N/A

Surface Type (circle): AG Wall BG Wall Partition

Sketch (include dimensions):

Construction: 2x4 2x6 2x8 Masonry Insulation: None Batt Rigid

Wall Length (ft) _____ Wall Height (ft) _____ Gross Surface Area (ft²) _____

Windows:

Qty	Width (ft)	Height (ft)	Area, each (ft ²)	Panes	Frame (circle)	Ins. Spacer	Low-e	Shaded
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			
				1p / 2p / 3p	Wood / Vinyl / Aluminum			

Opaque Doors:

Qty	Width (ft)	Height (ft)	Area, each (ft ²)	Door Type	Insulation
				Wood / Metal / Fiberglass	Hollow / Insulated
				Wood / Metal / Fiberglass	Hollow / Insulated
				Wood / Metal / Fiberglass	Hollow / Insulated



Duct System Characterization

We need information on the duct system to:

- 1) Estimate duct conductive heat loss for heating load calculation
- 2) Estimate whether duct system can convey enough airflow at a reasonable static pressure

This means getting the length and diameter of the ducts in all spaces and insulation levels in unconditioned spaces such as garage, attic and crawlspace. If the ducts run between-floors, also note this. Duct segments fully inside the conditioned space do not need insulation values or lengths and dimensions.

Use graph paper on next page to sketch the duct network.

Ducts running inside house cavities can be tough to observe. Please use best guess and judgement. Can make estimates of locations and lengths based on observations of supply and return grilles relative to air handler.

If ducts damaged, missing considerable insulation, or have obvious holes, record in Notes field.

Supply ducts (list all unique dimensions/insulation levels)

Duct type (metal/flex)	Duct Zone Location (garage, attic, crawl, other)	Dimension (LxW or inside diameter if round)	Length (feet)	Insulation (best guess on R-value)	Notes

Total Supply Duct Surface Area _____ ft²



Return ducts (list all unique dimensions/insulation levels)

Duct type (metal/flex)	Duct Zone Location (garage, attic, crawl, other)	Dimension (LxW or inside diameter if round)	Length (feet)	Insulation (best guess on R-value)	Notes

Total Return Duct Surface Area _____ ft²

Combined (Supply + Return) Duct Surface Area _____ ft²

Notes on duct system:



2-Point Blower Door Test

Depressurize to near 50 and 25 Pa with respect to outside. Note the house pressure WRT outside doesn't have to be exactly 50 or 25 Pa; the actual values will be corrected to 50 Pa during analysis.

Make and model of blower door used _____

Blower Door (BD) Depressurization Test Procedure:

1. Close all windows and doors to the outside. Open all interior doors and supply registers.
2. Close all dampers and doors on wood stoves and fireplaces. Seal fireplace or woodstove as necessary to prevent ash disaster.
3. **Make sure furnace and water heater cannot come on during test. Put water heater and/or gas fireplace on "pilot" setting. Make sure all exhaust fans and clothes dryer are off. Make sure any other combustion appliances will not be backdrafted by the blower door.**
4. **Make sure doors to interior furnace cabinets are closed.** Also make sure crawlspace hatch is on, even if it is an outside access. Check attic hatch position. Put garage door in normal position.
5. Set fan to depressurize house. Run pressure tap out through door shroud.
6. Depressurize house to -50 Pa or thereabouts. Record house pressure, BD flow pressure, and BD ring (below). If you cannot reach -50 Pa, get as close as possible and record information.
7. Now take the house down to -25 Pa WRT outside and record information.

Blower Door Tests	House P near 50 Pa (P ₅₀)	BD fan pressure	BD Ring	BD flow near 50 Pa (Q ₅₀)	House P near 25 Pa (P ₂₅)	BD fan pressure	BD Ring	BD flow near 25 Pa (Q ₂₅)
Test 1								
Test 2								

8. To check test, calculate the flow exponent, n. Use the following formula, $n = \ln(Q_{50}/Q_{25})/\ln(P_{50}/P_{25})$. Note Q₅₀ and Q₂₅ are the flows through the blower door at the testing pressures (which are denoted P₅₀ and P₂₅). Depending on the test, you may not get the house to exactly -50 or -25 Pa WRT outside. Use the exact ΔP you measure when checking the flow exponent. For example, if the house gets to -48 Pa for the high ΔP, use this as the P₅₀ in the equation. If the flow exponent is not between 0.50 and 0.75, repeat the test.

Note testing conditions (if windy, inaccessible room(s), garage door open or closed, etc):



Exterior Duct Leakage Tests at 50 Pa and 25 Pa

Purpose: measure both total duct leakage to outside and supply/return leakage to outside. These two test results will be used to determine house heating load.

Performing exterior duct leakage tests at 50 Pa and 25 Pa:

1. Exterior house doors and garage doors should be closed for exterior duct leakage test.
2. Pressurize the house to about 50 Pascals WRT outside.
3. Pressurize duct system with smallest flow ring possible.
4. Make sure blower door flow does not impinge on pressure tap measuring house pressure.
5. Adjust duct tester speed controller so that duct pressure WRT house is zero or very close.
6. Re-check pressure of ducts WRT outside.
7. Measure duct tester fan pressure. Look up flow in table, use gauge (**make sure gauge is paired with the right duct tester**) or use flow equation. Record duct pressure WRT out, DB fan pressure, DB fan ring.
- 8. If you cannot reach 50 Pa or 25 Pa, test to the highest pressure you can reach and enter this in the 50 Pa column. Use a test pressure of half this pressure for the low pressure test.**
9. Check test by calculating the flow exponent (procedure same as for blower door test): calculate the flow exponent, n. Use the following formula, $n = \ln(Q_{50}/Q_{25})/\ln(P_{50}/P_{25})$. Note Q_{50} and Q_{25} are the flows through the duct blaster at the testing pressures (which are denoted P_{50} and P_{25}). Depending on the test, you may not get the ducts to exactly -50 or -25 Pa WRT outside. Use the exact ΔP you measure when checking the flow exponent. For example, if the ducts get to -48 Pa for the high ΔP , use this as the P_{50} in the equation. If the flow exponent is not between 0.50 and 0.75, repeat the test.
10. Repeat steps 1-9 but for a supply side leakage test (if supply-side measurement not possible, return side is acceptable). Set up for supply-side measurement by separating sides at the filter slot. **Tip: the blanked off TrueFlow plates used in the static pressure measurement work well for this. With return and supply separated, conduct steps 1-9 and record in table below.**

Duct Leakage to Outside Data (note duct pressure WRT outside may not be exactly 50 or 25 Pa)

	<u>Both sides</u>		<u>Supply or Return</u> (circle one)	
	<u>50 Pa</u>	<u>25 Pa</u>	<u>50 Pa</u>	<u>25 Pa</u>
Duct Press= 0 WRT house	_____	_____	_____	_____
Ring	_____	_____	_____	_____
Fan Pa	_____	_____	_____	_____
CFM	_____	_____	_____	_____

Note any unusual testing conditions (wind, etc.):



Measuring Static Pressure and Airflow of Existing Duct System

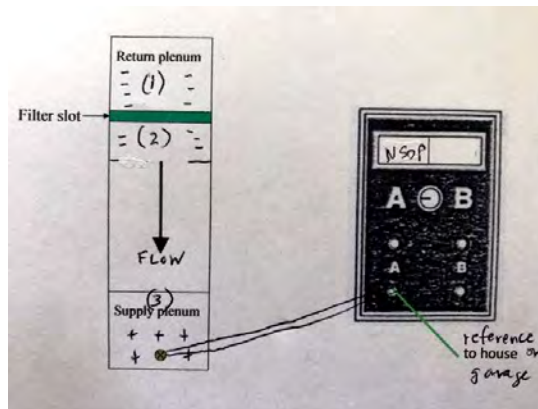
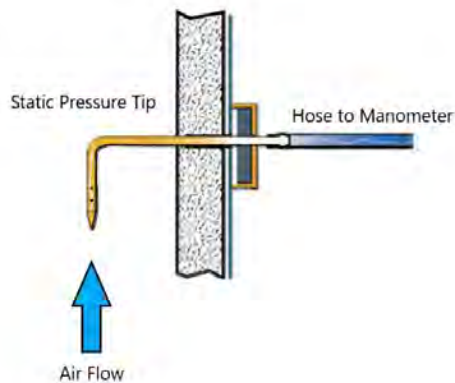
Purpose: measure static pressure inside the duct system upstream and downstream of system filter and in supply plenum.

Tools: static pressure tap or Pitot tube, test tubing, differential digital pressure gauge with known calibration, TrueFlow Air Handler Flow Meter.

We want to get airflow on the highest setting we can achieve for the existing electric furnace. For most electric furnaces, this will be achieved by turning up the heat and allowing the elements to sequence up. This may take as much as 10 minutes. You can also try the Fan On mode since this is usually the highest speed (at least on older systems) but if you aren't sure this is the highest speed, best to use the 'turn up the heat' method.

To get static pressure, use either a static tap or, the *side* tap on a compact Pitot tube (such as the Dwyer 3T086 ; this is recommended since the tip is only 1/8" in diameter and often can fit in cracks in the plenum sheet metal). It is simplest to use flexile silicone tubing to adapt standard test tubing to fit onto the Dwyer Pitot tube.

The following graphic (left) shows how to use the static tap; a Pitot tube would be used similarly, with the hose attached to the tube's side tap. In either case, always point tip towards direction of airflow.



The rightmost graphic shows where to get the NSOP measurement; note since we are measuring static pressure, it is not necessary to measure in the middle of the plenum; anywhere in the plenum will do. Also note that measurements on each side of the system filter are required.

Static Pressure Step by Step Procedure and Data Form

Check condition of system filter. If very dirty it is best to replace it or run the test without the filter in place.

Turn on air handler (by using fan-only switch or by turning on heat with at least 3 F heating call). Drill access hole as needed and point static tap or hooked end of Pitot tube into airflow. Make sure hose connected to side tap of Pitot if using. Do not drill into the duct at any point where you are concerned with hitting something. When finished, place foil faced tape over small hole.

Once system sequenced up, measure static pressure both before and after the filter and record (lines 1 and 2, below). You may have to use averaging on the gauge if measurement is jumpy.

Next, measure static pressure in supply plenum and record as NSOP (line 3).

Place appropriate size TrueFlow plate and spacers into filter slot. Record plate size (line 5).

Record supply plenum static pressure with TrueFlow in place (TFSOP) (line 4) and pressure drop across plate (line 6)

Record the raw flow (line 7).

The ‘correction factor’ and ‘corrected flow’ entries are needed if the NSOP and TFSOP differ by more than 2 Pa. This means the flow plate is creating a different flow from the filter. The TrueFlow has tables showing the correction factor and the math is also shown below (square root of NSOP/TFSOP). Make sure to use the Correction Factor if needed and record both it and the Corrected Flow.

If you need to repeat the tests, you can use the “Test 2” column.

As-found filter condition:	<input type="checkbox"/> New	<input type="checkbox"/> Somewhat dirty		
As-found filter depth: 1" , 2" , 4" , _____	<input type="checkbox"/> Filthy	<input type="checkbox"/> Missing		
Pressure Units:	<input type="checkbox"/> Pascal	<input type="checkbox"/> in. H ₂ O	<input type="checkbox"/> Other:	
	Test 1	Test 2	Test 3	Test 4
1. Return static pressure (upstream of filter)				
2. Return static pressure (downstream of filter)				
3. Normal Supply Operating Pressure (NSOP)				
4. TrueFlow Supply Operating Pressure (TFSOP)				
Correction Factor (NSOP/TFSOP) ^{0.5}				
5. Plate (14 or 20)				
6. Plate Pressure				
7. Raw Flow				
Corrected Flow				

Notes:



TEST RESULTS SUMMARY

Site ID: UTL-##

House Infiltration and Duct Leakage Testing Results

The following data on the site’s air leakage and duct losses were recently collected by a home performance specialist. The testing was conducted with Blower Door and Duct Blaster tools to obtain the most accurate possible measurements. The data were extracted from those testing tools and summarized for conciseness. The results are provided for use in determining the house heating and cooling loads. Should you have any questions about the data or measurements, please reach out to your utility contact.

House Infiltration (aka Blower Door)

Data Point	Value	Definition
CFM50		Blower Door measured ft ³ per minute at 50 Pascals
House Volume		ft ³
ACH50		Air Changes per Hour at 50 Pa
ELA		Calculated Effective Leakage Area, in ² , Blower Door test software output
SLA		Specific Leakage Area – ELA / house floor area in ft ²
ACH Heating Design		Calculated air changes per hour under heating design conditions
ACH Cooling Design		Calculated air changes per hour under cooling design conditions

Duct Leakage (aka Duct Blaster) and Losses

Data Point	Value	Definition
Supply Duct Exterior Leakage, CFM25		Duct Blaster measured ft ³ per minute at 25 Pascals
Return Duct Exterior Leakage, CFM25		Duct Blaster measured ft ³ per minute at 25 Pascals
Supply Duct Surface Area		Observed Duct Surface Area (ft ²)
Return Duct Surface Area		Observed Duct Surface Area (ft ²)
Duct Leakage Classification		CFM25 per square foot of duct surface area (Supply , Return)
Supply Duct R-Value		Average duct insulation R-Value supply ducts
Return Duct R-Value		Average duct insulation R-Value return ducts
Duct Multiplier		Calculated duct system effectiveness. For example, a value of 0.1 means 10% of all heat provided by heat pump is lost through leakage and conduction before reaching house.



Data from Home Specialist Service

[DEVELOPMENT NOTE: Below is for our internal tracking of the development of the form. Only first page will be provided to contractors. For tables below, text in black will be provided to installer in final report. Text in blue is for our internal development purposes. Values currently entered as example only.]

Air Leakage Testing Results

Data to Provide to Contractors

The following data will be provided to HVAC contractor/installer for use in their sizing calculations. Depending on the sizing tool used by the contractor, we are providing more information than needed. However, different sizing tools ask for, or allow, different inputs. Therefore, we are providing a full range of testing outputs. These outputs are what one would typically get from a Blower Door or Duct Blaster testing package from The Energy Conservatory or RetroTec – common testing tools in the industry. The values are also presented in units that will feed directly in to HVAC ST or Manual J tools.

Site ID:

House Infiltration (aka Blower Door)

Data Point	Value	Definition	Notes for internal BPA team
CFM50	1500	Blower Door measured ft ³ per minute at 50 Pascals	
House Volume	12,000	ft ³	
ACH50	7.5	Air Changes per Hour at 50 Pa	
ELA	83	Calculated Effective Leakage Area, in ² , Blower Door test software output	
SLA	0.00038	Specific Leakage Area – ELA / house floor area in ft ²	
ACH Heating Design	0.27	Calculated air changes per hour under heating design conditions	If 1 story, ACH50/28. If 2 story, ACH50/21.
ACH Cooling Design	0.11	Calculated air changes per hour under cooling design conditions	0.4 x ACH Heating Design



Duct Leakage and Losses (aka Duct Blaster)

Data Point	Value	Definition	Notes for internal BPA team
Supply Duct Exterior Leakage, CFM25	35	Duct Blaster measured ft ³ per minute at 25 Pascals	supply
Return Duct Exterior Leakage, CFM25	15	Duct Blaster measured ft ³ per minute at 25 Pascals	return
Supply Duct Surface Area	220	Observed Duct Surface Area (ft ²)	supply
Return Duct Surface Area	80	Observed Duct Surface Area (ft ²)	return
Duct Leakage Classification	Partially Sealed / Semi-Leaky (0.16 , 0.19)	CFM25 per square foot of duct surface area (Supply , Return)	Provided specifically for use with Manual J software if contractor so chooses. See tables below for classification. "Partially Sealed" and "Semi-Leaky" are examples of terms specific to the software being used and have meaning in that context
Supply Duct R-Value	R-4	Average duct insulation R-Value supply ducts	Area-weighted average of all supplies
Return Duct R-Value	R-4	Average duct insulation R-Value return ducts	Area-weighted average of all returns
Duct Multiplier	0.1	Calculated duct system effectiveness. For example, a value of 0.1 means 10% of all heat provided by heat pump is lost through leakage and conduction before reaching house.	Derived by Erin via spreadsheet from various inputs. Providing as fractional value because this is what HVAC ST override input takes (0.1 as opposed to 1.1)



Duct Leakage Classification

The following are the duct leakage classification tables from Manual J and HVAC ST. These are used as “pick lists” in the software implementation. Often, the contractor just selects from “Default Sealed” or “Notably Sealed” so we will reproduce that terminology in our report sheet to them.

Duct Table Leakage Options				
SMACNA Leakage Rate - Cfm/100 SqFt Surface Area				
Tightness	Supply	Return	Notes	HVAC ST Equivalent Name
Default Not Sealed	35	70	Could be worse	Leaky
Partially Sealed	24	47		Semi-Leaky
Default Sealed	12	24	50% to 70% effective	Average
Notably Sealed	9	15	Verify by test	Semi-Tight
Extremely Sealed	6	6	Verify by test	Tight

- **Tight (0.06/0.06) - Extremely sealed ducts (less than 2% CFM25/CFA)**
- **Semi-tight (0.09/0.15) - Notably sealed**
- **Average (0.12/0.24) - Ducts sealed; default value for visually sealed systems**
- **Semi-Leaky (0.24/0.47) - Partially sealed**
- **Leaky (0.35/0.70) - Unsealed system; default value for unsealed systems**

Interpreting these ranges is somewhat ambiguous. Is Extremely Sealed at 6 or less? Or is the cut point half-way between Notably and Extremely, so 7.5 and below? I doubt it matters much. For ease of use, we’ll assume the cut point is at the number provided. This ends up potentially putting things on the higher end of duct leakage in the software sizing calcs which I think is ok.

Tightness	Supply	Return
Default Not Sealed	> 24	> 47
Partially Sealed	> 12 and ≤ 24	> 24 and ≤ 47
Default Sealed	> 9 and ≤ 12	> 15 and ≤ 24
Notably Sealed	> 6 and ≤ 9	> 6 and ≤ 15
Extremely Sealed	≤ 6	≤ 6



1. Site Exit Survey #1 and Support Documentation

Purpose for this process step: The objective of the site survey is to understand home characteristics, document homeowner behavior and provide a detailed site description of the home including the conditions and adequacy of the duct work to assist in several steps: sizing of the equipment; developing the energy usage baseline for the home.

Owner/developer: Ben Larson, LER

Supporting team members: Bob Davis, Ecotope and John Bush, OTS Energy

Who Uses the Documentation?

- Home Specialist Surveyor completes the document and forwards information to the utility to share with their HVAC contractor.
- BPA uses the document to:
 - develop load calculations
 - develop sizing recommendations, and
 - determine if duct work is adequate.

Completed Documents location: HP HC HP Data Site – Utility Site

Date Document Last Updated: 10/6/2021

The following site survey will be completed for each participating site by Keel Energy staff. The goal of the survey is to summarize the following information:

- characteristics of the home – square footage, vintage, number of rooms, etc.
- understanding behavioral aspects of the household – schedule pre and post COVID and
- thermostat settings, if applicable
- heating and cooling set points for the system
- conditions of the duct system including proposed improvements

The site survey will be completed by Keel Energy, a subcontractor to Washington State University Energy Program. The survey process will involve completing the survey document and three tests – duct blaster, air handler TrueFlow, and blower door.

Information and test measurements will be used by both BPA and the HVAC contractor to correctly size the heat pump equipment.

Exit Site Survey

To be performed at removal of data monitoring gear or whenever we deem the data collection period complete.

Purpose

- conduct a short occupant questionnaire on heating/cooling practices during the study period
- collect thermostat information
- collect information to determine if any energy retrofits were conducted during the study period

Site ID:	Utility:
Name of Surveyor:	House Type
Date:	<input type="checkbox"/> Site-Built <input type="checkbox"/> Manufactured Home <input type="checkbox"/> Duplex / Triplex <input type="checkbox"/> Townhome
Heat Pump Install Date:	

Occupant Questions

How long have you lived in the house? _____ years

How many occupants lived in the house during the study period? _____

Occupant Questions: Heating System

Has the *heating* system kept the house warm to your satisfaction? Yes / No

Are there any uncomfortable cold or warm spots? Yes / No

If yes, where?

What day/month of year do you typically turn the heating system on? _____ and off? _____
 (try to get accurate to half month like mid-November or end April)

Did you change the thermostat schedule significantly during the study period?

Did you use any other heating sources? If so, when, and how?

<input type="checkbox"/> Wood Fireplace – Decorative on special occasions <input type="checkbox"/> Wood Stove – Decorative on special occasions <input type="checkbox"/> Wood Stove – ____ times / week or ____ cords / year <input type="checkbox"/> Gas/Propane Fireplace <input type="checkbox"/> Other:	Electric Space Heaters		
	Output Capacity	Location	Runtime

Special Wood Heat Questions for Sites Known to Heat with Significant Amounts

Approximate square footage or % of conditioned floor area heated by the wood stove _____

List rooms heated and indicate location on floor plan _____

In what part of the day is the wood stove typical used?
 Circle One: Continuous (24hrs)? Evening? Afternoon? Afternoon & Evening? Morning?
 Other (describe): _____

Occupant Questions: Cooling System

Has the heat pump kept the house cool to your satisfaction? Yes / No

Are there any uncomfortable cold or warm spots? Yes / No

If yes, where?

What day/month of year do you typically turn the cooling system on? _____ and off? _____
 (try to get accurate to half month like mid-July or end August)

Do you have a zonal air conditioning system such as window unit or floor unit (on rollers)? Yes / No

Zonal Cooling System Type (window, floor unit, other)	Location (room where used)	Output Capacity (Btu/hr)	Frequency / How Used (ex: Every afternoon/evening in July & August)



During the study period, did you carry out any energy efficiency retrofits on the house? For example, replace the windows, insulate the attic, or install a heat pump water heater? (Collect description and date)

During the study period, did your routine significantly compared to the year or two prior? (Fill in relevant cells. Examples given in blue.)

Change (circle one)	Approximate timeline	Notes
More time at home (e.g. work from home, home school)	April 2023-December 2023	Kids home April 2023-December 2023; parents work from home through present
Less time at home	April 2023	Returned to office work three days per week.
No change	N/A	
Change in occupancy	September 2023-Present	Child back home from college

Heating Thermostat Setpoints and Schedule

(can ask occupants or collect from thermostat)

Does occupant operate the thermostat on a programmed schedule? Yes / No

If no, does occupant manually adjust the setpoint on a regular schedule? Yes / No

Notes: _____

If set at constant temperature with no adjustments, enter set point: _____ (F)

If operated on a programmed or manual schedule, complete the schedule table. Enter time, in left column, and setpoint in (F) for day of week.

Heating Thermostat Schedule Table

Time	Mon	Tue	Wed	Thu	Fri	Sat	Sun
6AM	68						
10PM	60						



Cooling Thermostat Setpoints and Schedule

(can ask occupants or collect from thermostat)

Does occupant operate the thermostat on a programmed schedule? Yes / No

If no, does occupant manually adjust the setpoint on a regular schedule? Yes / No

If set at constant temperature with no adjustments, enter set point: _____ (F)

If operated on a programmed or manual schedule, complete the schedule table below

Cooling Thermostat Schedule Table

Time	Mon	Tue	Wed	Thu	Fri	Sat	Sun

