Assessment of Heat Pumps in Maine Homes (2026)

Final Report | January 2026

efficiency MAINE®

Assessment of Heat Pumps in Maine Homes (2026)

Final Report

Prepared for:
Efficiency Maine Trust
Augusta, ME

Lauren Scott
Strategic Initiatives Manager

Prepared by:

Ridgeline Energy Analytics
Stow, MA

David Korn, Vice President
Jacob Jaskwhich, Engineer

Demand Side Analytics
Atlanta, GA

Jesse Smith, Partner
Steve Morris, Principal Consultant

Notice

This report was prepared by Ridgeline Energy Analytics and Demand Side Analytics in the course of performing work contracted for and sponsored by the Efficiency Maine Trust (hereafter "Efficiency Maine"). Reference to any specific product, service, process, or method does not constitute an implied or expressed recommendation or endorsement of it.

Preferred Citation

Efficiency Maine Trust. 2026. "Assessment of Heat Pumps in Maine Homes (2026)." Prepared by Ridgeline Energy Analytics (Stow, MA), Demand Side Analytics (Atlanta, GA).

TABLE OF CONTENTS

Tables

Figures

GLOSSARY

Term	Definition
AMI	Advanced Metering Infrastructure (AMI) is an integrated system of smart utility meters, communication networks, and data management systems. This evaluation uses the term AMI to refer to the source of hourly data received from electric utility meters.
Btu and Btu/h	British Thermal Units and Btu per Hour. A British Thermal Unit is the energy needed to raise the temperature of 1 pound of water one degree Fahrenheit.
COP	Coefficient of Performance. This is the ratio of the amount of heat added or removed by a heat pump to the amount of energy used to move that heat. For example if 9,000 Btu (2.6 kWh) of heat is removed from a home during the cooling season, and this uses 3,000 BTU (0.88 kWh) of electrical energy to accomplish, the COP of the heat pump is (9,000 / 3,000) or 3.0.
CV	Coefficient of variation (CV). A statistical measure of the dispersion of a population of data points relative to the mean. It is calculated by dividing the standard deviation by the mean.
Design Temperature	Temperature threshold at which occurrences below such temperature represent only a small fraction of hours in a year. The rebate program described in the text started with a 99% design temperature (meaning only 1% of hours in a year occur below this temperature), but shortly afterwards changed to a 99.6% design temperature. The sample in this study has both 99% and 99.6% design temperatures.
effRT	The Efficiency Maine Reporting and Tracking System (effRT) is a SQL-based database. Efficiency Maine uses the effRT database to manage and track energy efficiency projects.
HSPF and HSPF2	Heating Seasonal Performance Factor is a heating efficiency rating for heat pumps that has units of BTU/watt-hours. $HSPF = \frac{Heating\ Delivered\ by\ Heat\ Pump\ \ over\ a\ simulated\ heating\ season(BTU)}{Energy\ used\ by\ the\ Heat\ Pump\ over\ the\ simulated\ heating\ season\ (kWh)*1000}$ A newer version of HSPF termed HSPF was released January 1, 2023. HSPF2 changed a number of testing requirements meant to reflect actual field conditions more closely.
kW	A kilowatt (kW) is 1,000 Watts of instantaneous power and is a rate of energy use. This measurement is usually used to show the peak power that a facility or a piece of equipment draws.
kWh	A kilowatt-hour (kWh) is a measurement of electricity consumption equivalent to one kilowatt of demand for one hour.

Term	Definition
MMBtu	1 million BTUs. This convention derives from the Roman numeral M for 1,000, so: a thousand, thousand BTUs. It is equivalent to the heat provided by about 9 gallons of oil used in an 80% efficient furnace or boiler.
Min47 COP	COP at the reported minimum heat output of a heat pump at an outdoor temperature of 47°F.
Multi-zone heat pump	A heat pump with more than one indoor unit working in tandem with a single outdoor unit.
RRV	Residential Registered Vendor. Contractors qualified by Efficiency Maine to install heat pumps rebated through Efficiency Maine programs.
Relative precision	Precision is a measure of uncertainty or error around an estimate. Relative precision is absolute precision divided by an estimate of a mean.
Single zone heat pump	A heat pump that matches a single indoor unit to a single outdoor unit.
TRM	The Technical Reference Manual (TRM) documents Efficiency Maine's methods, formulas, assumptions, and sources that are used to estimate energy and demand impacts of energy-efficiency measures.

1 EXECUTIVE SUMMARY

In September 2023, Efficiency Maine began its rebate program for “Whole-Home Heat Pumps” (WHHP). This program makes rebates available for heat pump systems that will serve as a home’s primary heating system. It rebates one or more single-zone heat pumps (1 indoor-unit to 1 outdoor-unit) in which the capacity of the heat pump system meets or exceeds 80% of the home’s heat load at design temperature, and combined with supplemental heating sources, meets or exceeds 100% of heat load at design temperature. As of September 2025, approximately 98% of rebated heat pumps in Efficiency Maine’s WHHP program were ductless, with the remaining 2% ducted.

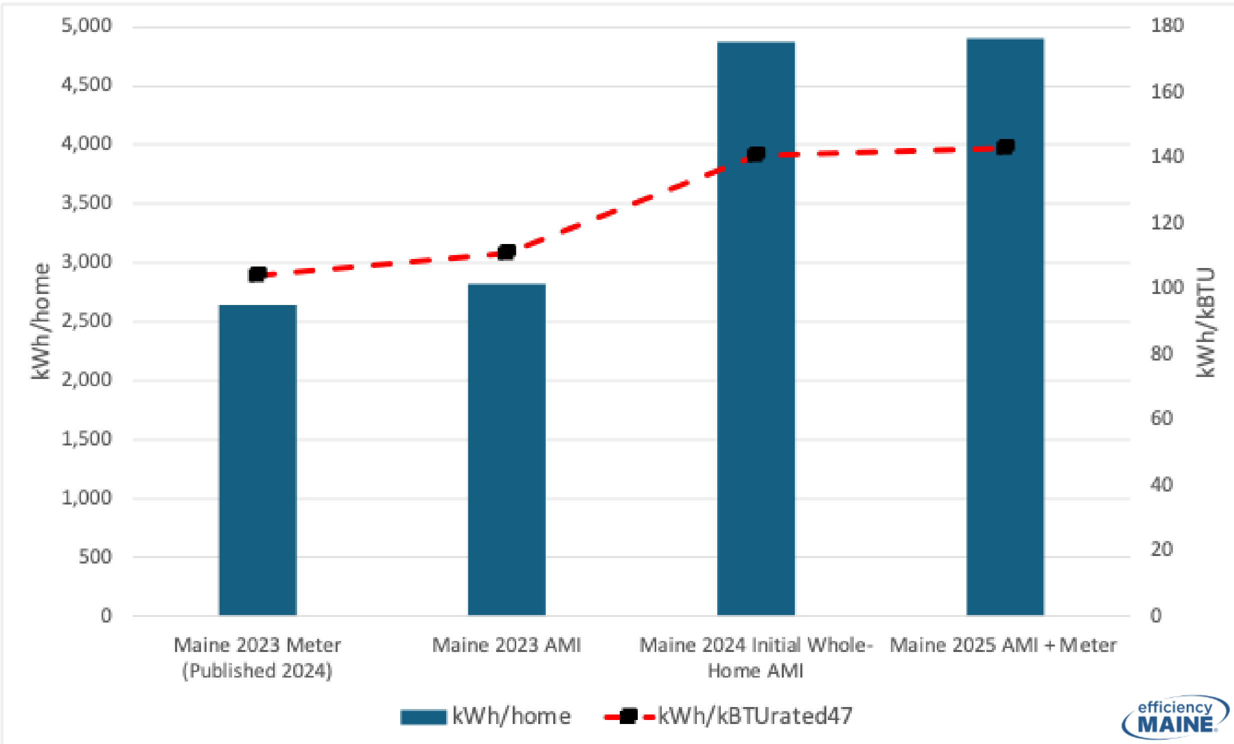
This report presents analyses of WHHP installations that occurred in Maine during the first six months of the WHHP program from 9/18/2023 through 2/28/2024. The first phase of the work included analysis of premise-level interval data on electricity consumption collected through the utilities’ advanced metering infrastructure (AMI) during the spring of 2024. This analysis estimated heat pump usage by isolating cold-weather-dependent electricity consumption (kWh) in each home (referred to as “Initial AMI Analysis” in this report).

Using these results, Ridgeline Energy Analytics (Ridgeline) and Demand Side Analytics (DSA) developed a sample of homes in which to install metering equipment as a subsequent phase of this study. To find out more about suspected underutilization of heat pumps, Ridgeline and DSA drew from the two-thirds of the WHHP population that showed the lowest electricity consumption for cold-weather-dependent kWh. Ridgeline installed metering equipment in homes in late fall 2024 and early winter 2024-2025. Meter removals occurred in spring 2025, and a new batch of utility AMI data was also collected in spring 2025 to run a parallel analysis to the metering data (referred to as “Refresh AMI Analysis” in this report).

This study found that, on average, homes participating in Efficiency Maine’s WHHP program use 4,904 kWh annually for heating with heat pumps, delivering approximately 52 MMBtu of heat. Compared to the earlier generations of Efficiency Maine’s heat pump rebate program, which had smaller incentive amounts and did not establish any minimum requirements for design load capacity, total kWh consumption for heating with heat pumps nearly doubles in the new WHHP program (Figure 1). Under the new WHHP program, electricity consumed per unit of rated heat pump capacity rises from approximately 109 kWh/ $\text{kBtu}_{\text{Rated}}$[47] to 143 kWh/ $\text{kBtu}_{\text{Rated}}$[47] compared to the legacy program design.

Our study finds that the new program design – requiring WHHP systems to serve as a home’s primary heating system in order to be eligible for a program rebate – significantly increased electricity usage for the heat pumps. This higher usage is not an indication that the heat pumps are operating inefficiently; on the contrary, we found their coefficient of performance (COP) has improved. Of greatest importance, the higher usage correlates to a finding that these WHHP systems are operating closer to their full capacity (instead of sitting idle) and are therefore displacing significantly more fossil fuel than the earlier program design. This suggests that, where the homes were previously heated with costlier heating oil, propane, or kerosene, the increased displacement of these fuels translates into significantly improved cost savings for the customer and carbon reductions. Given Maine’s relatively underutilized grid capacity, the higher electrical usage by the heat pump systems will also help depress electricity distribution rates.[1]

Figure 1. Heat Pump Consumption (kWh) Across Multiple Maine Studies[2 3]



Efficiency, expressed as the COP, was metered for the 160 heat pumps in the study. Figure 2 shows the observed relationship between COP and outdoor air temperature. The field-metered COP falls between the COPs claimed by manufacturers (AHRI Reported) for maximum and minimum capacity across a range of outdoor temperatures. The COPs found through our metering in the current study are higher than in previous studies that covered heat pumps installed in Maine from 2014 to 2021. We believe there are several reasons for the findings of improved efficiency:

- New heat pumps have increased their ability to provide partial load heating and have increased their ratings at both warm and cold temperatures.
- Heat pumps in this study are used more continuously than past studies.

[1] Triennial Plan VI Appendix H-1: Beneficial Electrification Plan for Maine. 2024.

[2] The 2023 meter evaluation covers heat pumps installed in 2020 and 2021. The 2023 AMI study covers this same period. Efficiency Maine Residential Heat Pump Impact Evaluation. 2024.

[3] The 2024 AMI study and this study examine heat pumps installed from fall 2023 through spring 2024.

- This study used web-connected meters that provided continuous data with nearly no gaps, reducing the need for data extrapolation.

Figure 2. Average Field-Metered and Manufacturer-Reported COPs vs. Outdoor Air Temperature, with Metered COP from 2024[4] Evaluation and 2019 HESP Evaluation[5]

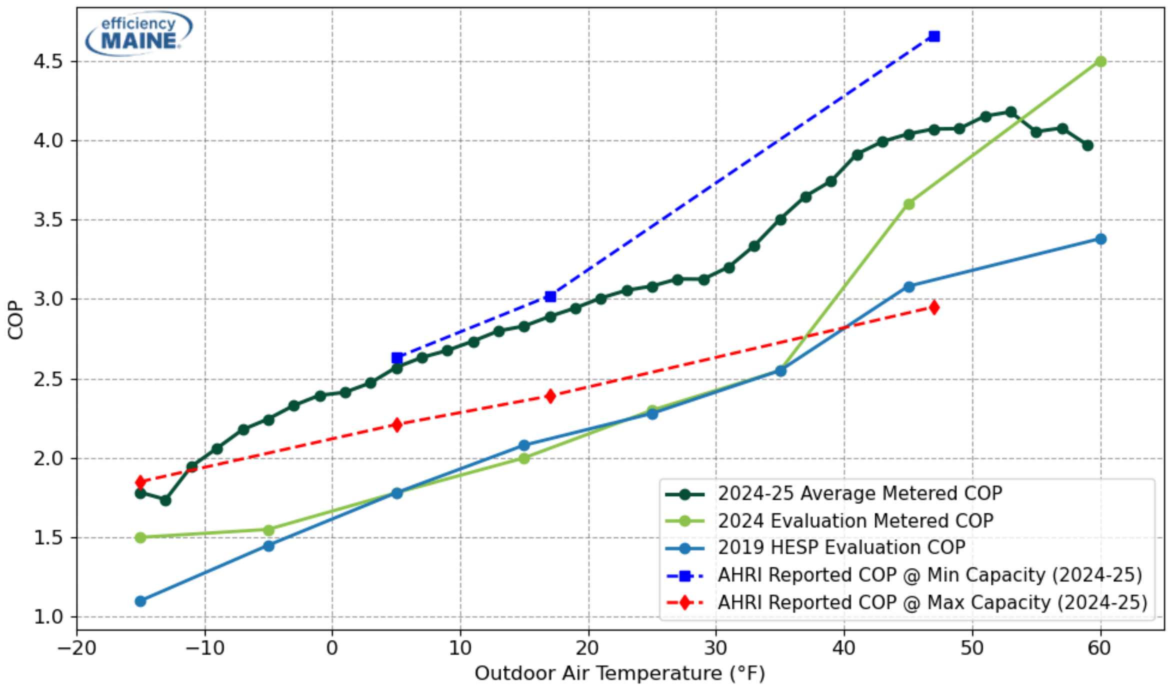
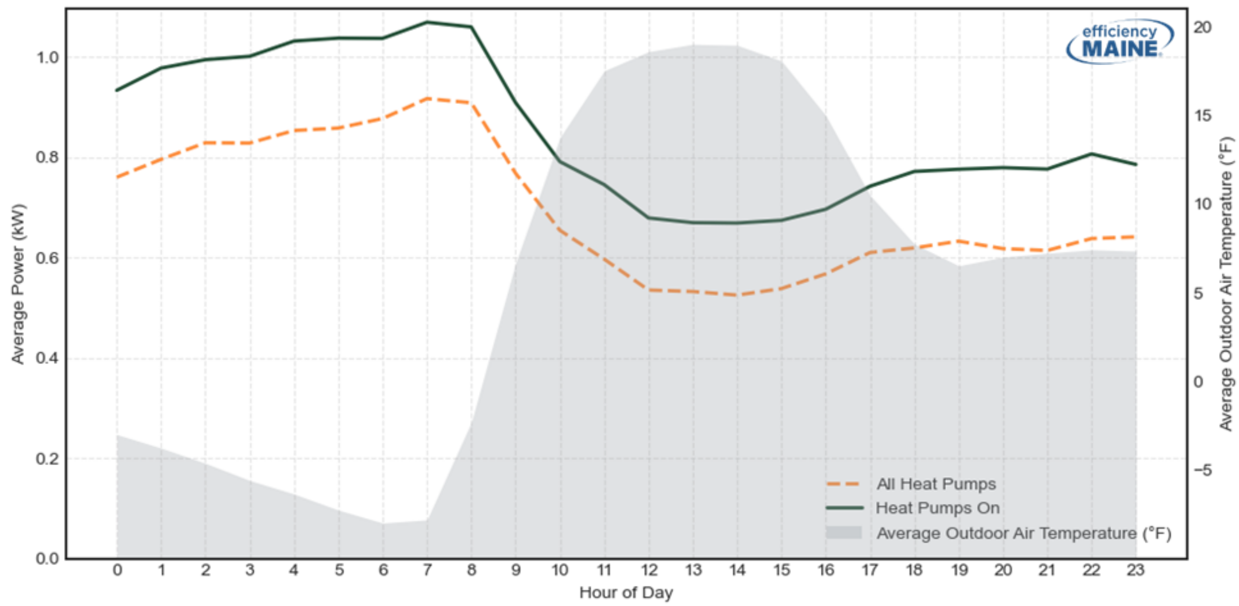


Figure 3 shows the average power consumption per heat pump across all heat pumps in the metering sample for January 22, 2025, the coldest day of the 2024-25 metering period. On this day, average site temperatures fell below -5°F, and peak power draw exceeded 1 kW per heat pump. For regional differences, see Figure 32 in Section 5.

[4] Efficiency Maine Residential Heat Pump Impact Evaluation. 2024. This study evaluated heat pumps installed 2019 - 2021.

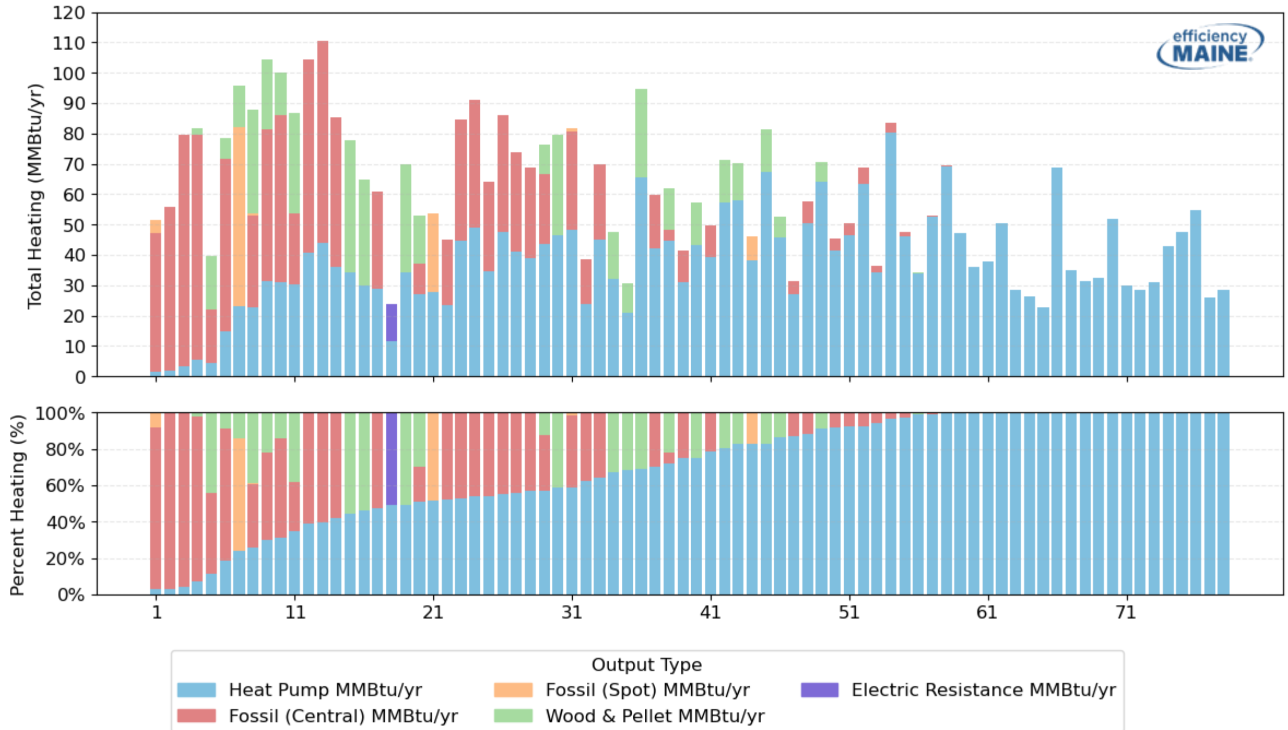
[5] Efficiency Maine Trust Home Energy Savings Program Impact Evaluation. 2019. This study evaluated heat pumps installed 2014 - 2016.

Figure 3. Average Power Consumption vs. Time of Day for Coldest Day (1/22/25) in Metering Period, per Heat Pump (n = 160)



Looking across all 78 metered homes and sorting by percentage of heat load met by heat pumps, we can see (Figure 4) that many of the highest users of heat (of all heat sources), that is >70 MMBtu, correlate to the lowest use of heat pumps to meet their heating load. Moderate consumers of heat (all sources) were more successful than high consumers in fully heating their homes with heat pumps, and homes that consumed the least heat overall were more likely to achieve the highest share of their home's heating needs from their heat pumps.

Figure 4. Total Heating by Home Ordered by Percent Heat Pump Heating (n = 78)



This study found that the WHHP program approach increased the use of heat pumps, and that heat pumps provided over 70% of total heating needs in the homes. Wood heat accounts for 10%, and fossil fuel use accounts for the remaining 19% of total heating needs.

2 BACKGROUND

Efficiency Maine historically offered incentives for heat pump installations that contained minimum requirements for efficiency and cold-climate performance, but did not require that heat pumps serve a minimum capacity of the home's heat load at design temperature.

In 2023, Efficiency Maine contracted Demand Side Analytics (DSA) to perform a pre/post AMI analysis of homes that received a rebate from Efficiency Maine for a supplemental (not whole-home) heat pump installed between 2019 and 2021. Separately, Efficiency Maine contracted Ridgeline Energy Analytics (Ridgeline) to meter residential heat pumps (installed through the Efficiency Maine programs in 2020 and 2021) during winters 2021-22 and 2022-23. Ridgeline's report of the metering results is the Residential Heat Pump Impact Evaluation (2024).[6] The results from both of these analyses indicated that the rebated heat pumps were performing well in Maine's cold climate, but they were underutilized relative to their full potential and many homeowners continued to rely on their central fossil-fueled heating systems to supply varying degrees of the home's heating needs. When the heat pumps are underutilized relative to their full potential, Maine homeowners tend to use more of their traditional fuels to heat their homes, resulting in higher costs. As noted in the prior section, underutilization of heat pumps in Maine also results in higher air pollution levels and a missed opportunity to depress electricity distribution rates.

In response to these findings, Efficiency Maine redesigned the heat pump program by, among other things, limiting rebate eligibility to a "Whole Home Heat Pump" (WHHP) system intended to serve as a home's primary heating system. A WHHP system is one in which the sum of all heat pump(s) in the home are designed and sized to meet at least 80% of the home's peak heating load. The remaining 20% of peak heating load, if not met by heat pumps, may be met by a supplemental system.[7] Efficiency Maine launched its WHHP rebate in September 2023. Hereafter, the term "legacy supplemental" refers to the earlier iteration of Efficiency Maine's program design, discontinued in 2023, in which heat pumps, intended for use as a supplement to an existing, central furnace or boiler were eligible for a rebate.

In the spring of 2024, Efficiency Maine contracted DSA to perform a new pre/post analysis for homes that received a WHHP rebate (referred to as "Initial AMI Analysis" in this report). The Initial AMI analysis found that heat pump utilization was higher under the WHHP rebate design than it had been under the legacy supplemental structure. Figure 5 compares the distribution of post-installation annual heating-related electricity use between the two program designs (i.e., legacy supplemental HP versus WHHP).[8]

---

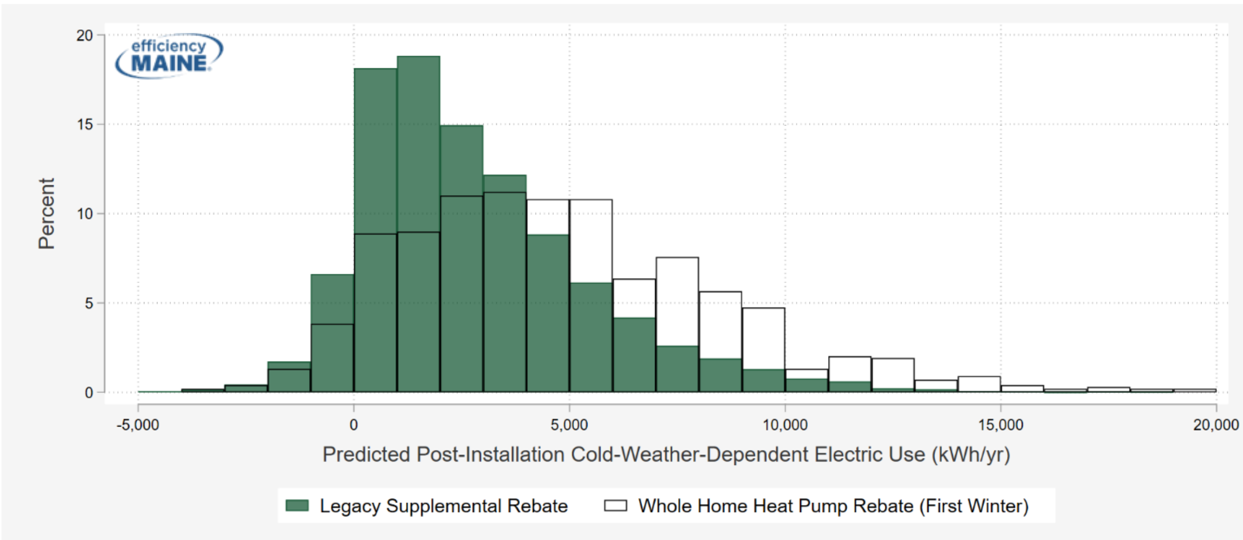
[6] Efficiency Maine Residential Heat Pump Impact Evaluation. 2024.

[7] Subsequent to the launch of the WHHP rebate, Efficiency Maine clarified that a central furnace or boiler is not considered an allowable supplemental heating system.

[8] Electricity used for heating was calculated using outputs from the AMI analysis based on a weather-dependent pattern. If electricity use for a home trends downward with decreasing outdoor air temperature, the predicted cold-weather-dependent electric use is characterized as "negative". A negative electricity use for heating does not make theoretical sense – it just means the relationship between electricity usage and outdoor air temperature is the opposite of the trend we would expect to see in a home that relies on their heat pump for space heating.

The green distribution represents the AMI-predicted electricity use of legacy supplemental HP participants, and the translucent distribution represents the AMI-predicted electricity use by WHHP participants. Temperature-dependent electricity use is clearly greater for WHHP participants than legacy supplemental heat pump participants, but the left half of the WHHP distribution in Figure 5 suggested that many participants would, according to the model, still be underutilizing their heat pumps.

Figure 5. Predicted Post-Installation Heat Pump Electricity by Home



To better understand what was happening in the homes on the left side of the WHHP distribution from Figure 5, Ridgeline performed field metering on a subset of homes. Based on the estimated electricity use distribution above, DSA binned WHHP participants into one of four use bins: negative, low, medium, and high (see footnote 8 for discussion on the negative heating electricity use). WHHP participants with non-negative use were split into bins by thirds rather than using specific kWh or kWh/kBtu of capacity cutoffs. The homes in Ridgeline's metering sample were selected from only the negative, low, and medium bins.

Geographic filters were placed on the dataset to limit technician drive times for metering; however, much of Maine was covered. Table 1 shows the number of homes in each bin in DSA's Initial AMI analysis and Ridgeline's metering sample. The table also shows the range of post-installation heating electricity use and other summary statistics for each bin.

Table 1. Bins by Temperature Dependent Electricity Use (Initial AMI Analysis)

Usage Group Bin	Number of Homes in Initial AMI Analysis	Range of Electricity Use (kWh/yr)	Average Electricity Use (kWh/year)	Average Total Household Max Heat Pump Capacity ($kBtu_{Max}^{Design}$)	Number of Homes in Metering Sample
Negative (01)	57	< 0	-888	31.9	8
Low (02)	312	0 – 3,250	1,713	30.4	34
Medium (03)	312	3,250 – 6,130	4,667	33.6	36
High (04)	311	> 6,130	9,296	42.2	0
Total	**992**	**---**	**4,870**	**35.1**	**78**

Ridgeline metered all heat sources (not just heat pumps) in each home. In metering all heat sources, we could better understand what percentage of each home's heating load was being delivered by the heat pump(s). Chapters 5 through 8 of this report provide additional details regarding the metering methods and findings. Ridgeline metered 160 outdoor units and 166 indoor units in 78 homes. The electricity used by each heat pump, the amperage drawn by each indoor fan, the temperature of the air supplied by each indoor unit, and the temperature of the air returned to each unit were measured. These parameters also allowed the calculation of the efficiency of each heat pump. Research questions for the metering portion of the study include:

- How much power is drawn by each heat pump and how does it vary with outdoor temperature?
- How much heat is provided by each heat pump and how does that vary with outdoor temperature?
- How are other sources of heat used in the home, and at what outdoor temperatures are they turned on?
- What is the ratio of heat provided to electricity used for the heat pumps?

In parallel with metering, DSA refreshed the AMI analysis for early WHHP participants with additional post-installation AMI data (referred to as "Refresh AMI Analysis" in this report). For a portion of homes in the Initial AMI analysis, only a limited timeframe of post-installation AMI data was available because customers had installed their heat pumps in the second half of winter 2023-24. Much of the additional AMI data overlapped with the metering period. One goal of the Refresh AMI Analysis was to compare estimated heat pump electric use produced through regression modeling with actual metered heating kWh. Key research questions for the Refresh AMI Analysis and the AMI/metering comparison include:

- How accurately can heat pump loads be predicted through an AMI analysis?
- Are certain regression model specifications better at estimating heat pump loads than others?
- Are there situations where the AMI approach is more or less applicable than metering?

Additional details regarding the Refresh AMI Analysis including AMI/metering comparison can be found in Chapter 9, Refresh AMI Analysis and Appendix B.

3 INITIAL WHHP AMI INVESTIGATION

In September 2023, the Trust began offering the “Whole Home Heat Pump” (WHHP) rebate through two programs: (1) the Home Energy Savings Program; and (2) Low- and Moderate-Income Initiatives. To be eligible for the WHHP rebate, the newly installed heat pump(s), together with any previously existing heat pump(s), must be sized such that the heat pumps can deliver at least 80% of the home’s peak heating load. DSA performed a pre/post AMI analysis of WHHP participants who installed one or more heat pumps between September 2023 and February 2024. This chapter describes the data sources used for the AMI analysis, our regression approach, and the results.

3.1 DATA SOURCES

At a high level, there were four primary data types used for this analysis:

- Program tracking data from Efficiency Maine’s Reporting and Tracking System (effRT)
- Hourly AMI interval data for homes participating in the WHHP program
- Historical weather data
- Typical meteorological year (TMY3) weather data

These four data streams are discussed in subsequent sections, and the development of the analysis dataset is discussed in section 3.1.4.

3.1.1 Program Tracking Data

The effRT program tracking data captures key information on each home that received a WHHP rebate, including the program pathway (low income, moderate income, or any income), installation date, and details regarding the incentivized heat pump equipment. Two of the key fields regarding the heat pump equipment were (1) the rated heating capacity at 47°F for the rebated units and (2) the sum of the max capacities at the design temperature for all heat pumps at the household (including heat pumps that were previously rebated and heat pumps that were not rebated). This section provides details on relevant program tracking fields used in our analysis.

Figure 6 shows the cumulative count of participants by date. Roughly half of the installations were completed before January 2024, but a notable share were installed after the coldest days of winter had already passed. Any projects completed on or after March 1, 2024, were excluded from the initial AMI analysis due to a lack of sufficient post-installation winter data at the time of analysis (spring 2024).

Figure 6. Cumulative Participation in WHHP by Date

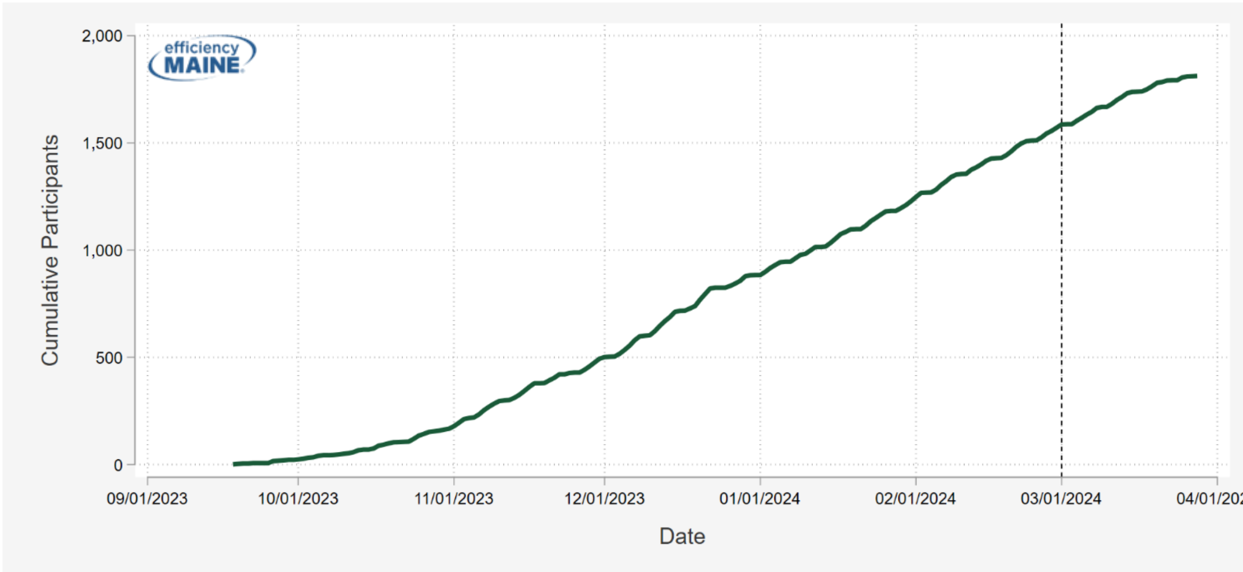


Figure 7 shows the breakdown of the rebated units by manufacturer. Mitsubishi Electric and Fujitsu alone account for about 70% of all units, with Samsung, Daikin, and a handful of other brands making up the balance. The ten most common models were cross-checked against the AHRI directory to confirm ratings and cold-climate eligibility.

Figure 7. Units Breakdown by Manufacturer

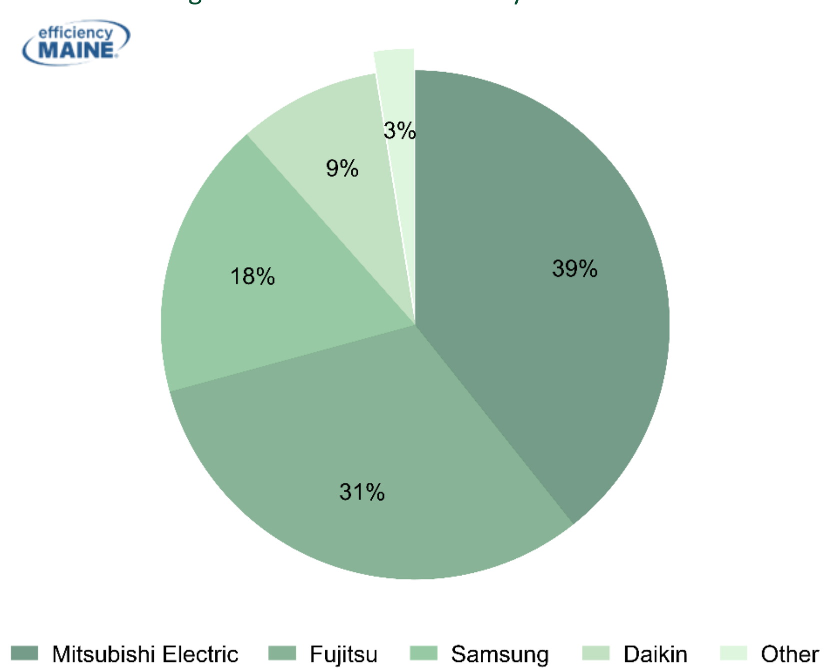


Table 2 summarizes key metrics for homes that received a WHHP rebate during the period of investigation. The average rated heat pump capacity at 47°F for the rebated heat pumps is 14.8 kBtu/h, and the average total household maximum heating capacity at design conditions is 34.6 kBtu/h.[9] This matches well with the fact that on average, participants installed 2 to 3 heat pumps to meet the whole home sizing criteria – either through incentivized WHHP installations only or in total between WHHP incentives, prior heat pump installations, and new non-rebated multi-zone units.

The average rated HSPF2 of heat pumps in homes that received a rebate was 11.3, which is approximately 3.3 times more efficient than electric resistance heating. Even under 5°F conditions, fleet-wide efficiency remains high, with an average rated COP of 2.4. Nearly one-quarter of homes that received a WHHP rebate had also received a prior heat-pump rebate under the legacy program offering for supplemental heat pumps. The incidence of existing, supplemental heat pumps in homes that received a subsequent WHHP rebate is important to consider when comparing "pre" and "post" periods in the AMI analysis.

Table 2. WHHP Tracking Data Summary Statistics (Through 4/7/2024)

Metric	Value
Average Rated Capacity of Heat Pumps Installed through Program (47°F) (kBtu/h)	14.8
Average Total Household Maximum Heating Capacity of Heat Pumps at or Below Design Temperature (kBtu/h)*	34.6
Rated COP @ 5°F	2.4
HSPF2 (Btu/Wh)	11.3
Average Contractor-Calculated Heat Load (kBtu/h)	29.1
Average[10] Annual Heat Load (MMBtu)	75
Percentage of Homes with Prior Heat Pump Rebate (%)	23

*This average capacity reflects all homes in the tracking data. The capacity value shown in Table 1 only reflects homes in the initial AMI analysis.

Figure 8 shows the distribution of total household capacity ($kBtu_{Max}^{Design}$), Figure 9 shows the distribution of living square footage, and Figure 10 shows the relationship between these two variables. According to the 2020 Residential Energy Consumption Survey, Maine's average residential unit has roughly 1,660 ft² of conditioned area (living space).[11] More than 60% of homes in this study have living spaces less than

[9] Design conditions vary by geography with homes mapped to Portland at 0 degrees (F), Bangor at -7 degrees (F), and Caribou at -14 degrees (F). The source of capacity at design conditions is the rebate claim form filled out by the contractor. Manufacturers report capacities at varying conditions and in the NEEP database include capacity at 5°F and at a lower temperature that is often below zero.

[10] As calculated in effRT using the minimum of (installed HP capacity at design temp or reported Heat Load at design temperature) * 186,648 / (Ti-To) / 1,000,000 where 186,648 is the population weighted average TMY3 heating degree hours, Ti - To is assumed to be 70 degrees F, and 1,000,000 converts from Btu to MMBtu.

[11] 2020 Residential Energy Consumption Survey, U.S. Energy Information Administration. "Highlights for square footage in U.S. homes by state".

the state average.[12] Homes in this size range typically install 16–44 kBtu/h of heat-pump design temperature capacity.

Figure 8. Distribution of Total Household Capacity ($kBtu_{Max}^{Design}$)

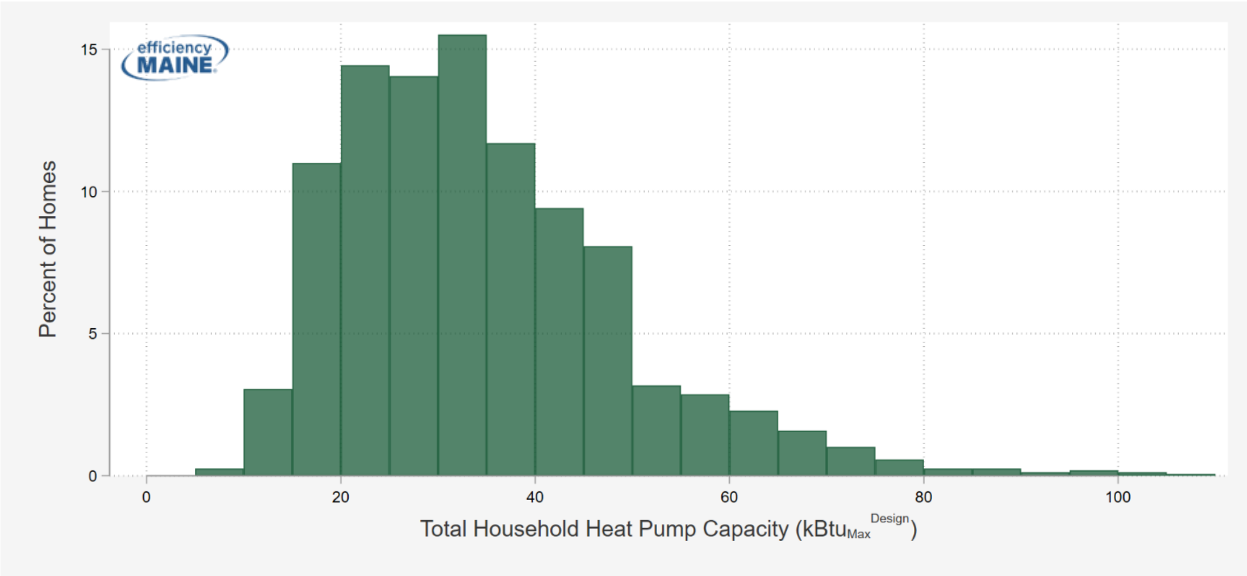
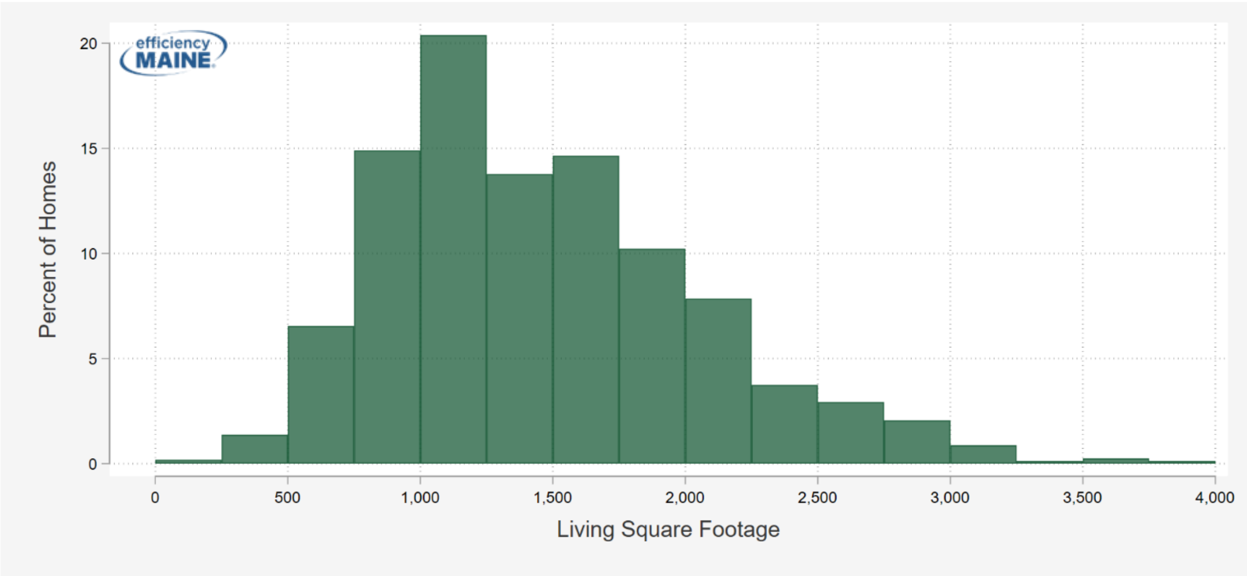


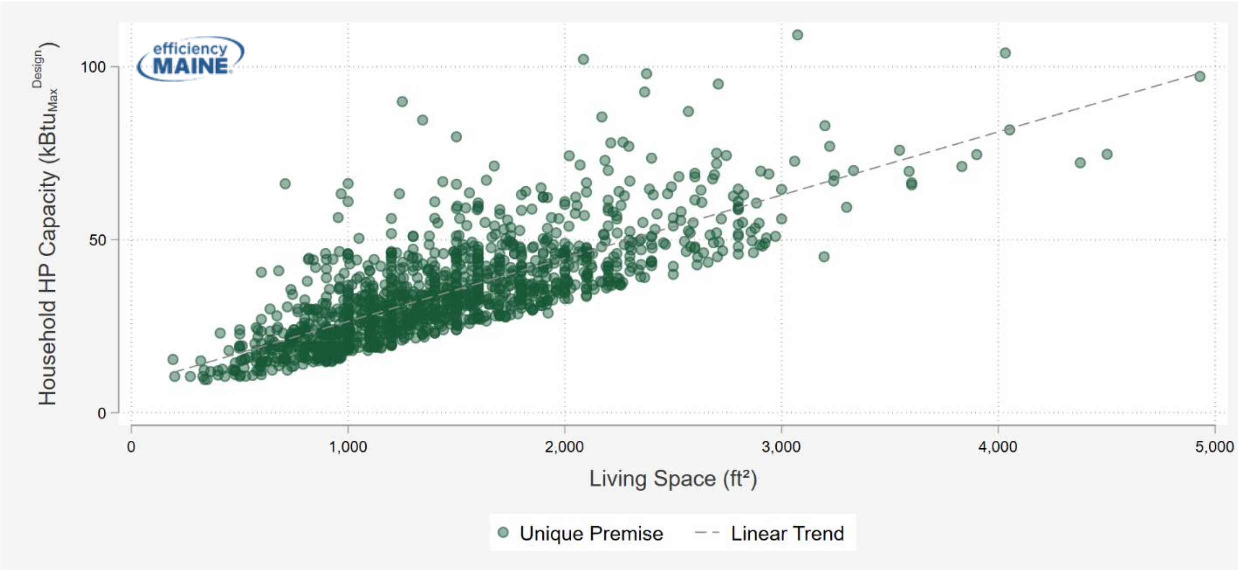
Figure 9. Distribution of Living Square Footage



[12] *Ibid.* According to property tax data, average living square footage was 1,638 for the homes in the AMI analysis of legacy supplemental HPs. For homes included in the Initial AMI analysis, the average is 1,457. For homes included in the Refresh AMI analysis, the average is 1,490. For homes included in the metering sample, the average is 1,337.

Figure 10 shows a near-linear trend where each additional square foot adds roughly 15–20 Btu/h of heat pump capacity. This is not surprising because most contractors calculated heat load using an estimate of 20 Btu/h/ft^2, one of the options in the program application.

Figure 10. Relationship Between Living Square Footage and Capacity ($kBtu_{Max}^{Design}$)



The program tracking data did not contain the electric utility company or the account number for the participants, but it did contain the participants' name and installation addresses. Some records contained a phone number and an email address. We also received program tracking data for Efficiency Maine's electric vehicle offering (EV Accelerator). This data was used to flag homes that installed heat pumps and purchased an EV around the same time. The presence of an EV confounds pre/post AMI analysis for these homes, so they were removed from the analysis in the filtering process described in Section 3.3.1.

3.1.2 Interval Data

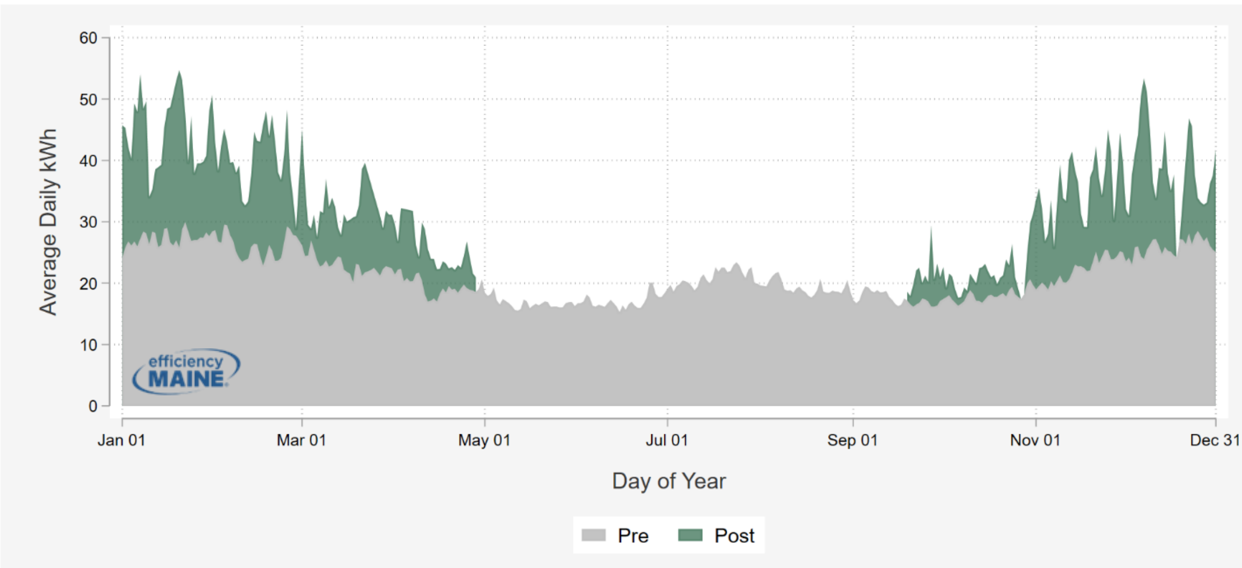
Participant information from the program tracking data was used to map participants to specific account numbers in the Central Maine Power (CMP) and Versant customer databases. After performing this mapping, we requested a history of AMI data from CMP and Versant. Both utilities were able to provide 1-hour interval data for most of the accounts in the data request. Table 3 provides a summary of the data we received. Due to the timing of the analysis, we did not receive any post-installation summer data. This was not an issue since our primary focus was usage during the heating season. On average, we had approximately 2.25 years of pre-participation data and about four months of post-participation data.

Table 3. Count of Service Points

Utility	Number of Accounts	Average Number of Pre-Installation Days	Average Number of Post-Installation Days
CMP	1,195	835	108
Versant	238	827	109
Total	**1,433**	**834**	**108**

Across all homes in the AMI data, Figure 11 shows average daily consumption for the heating season by day of year for both the pre-installation (gray) and post-installation periods (green). The post-period data excludes data from the cooling season. The increase in consumption in the post-period winter months is evident. Note this figure reflects raw consumption, not weather-normalized usage.

Figure 11. Heating Season Average Household Daily kWh by Day of Year and Period*



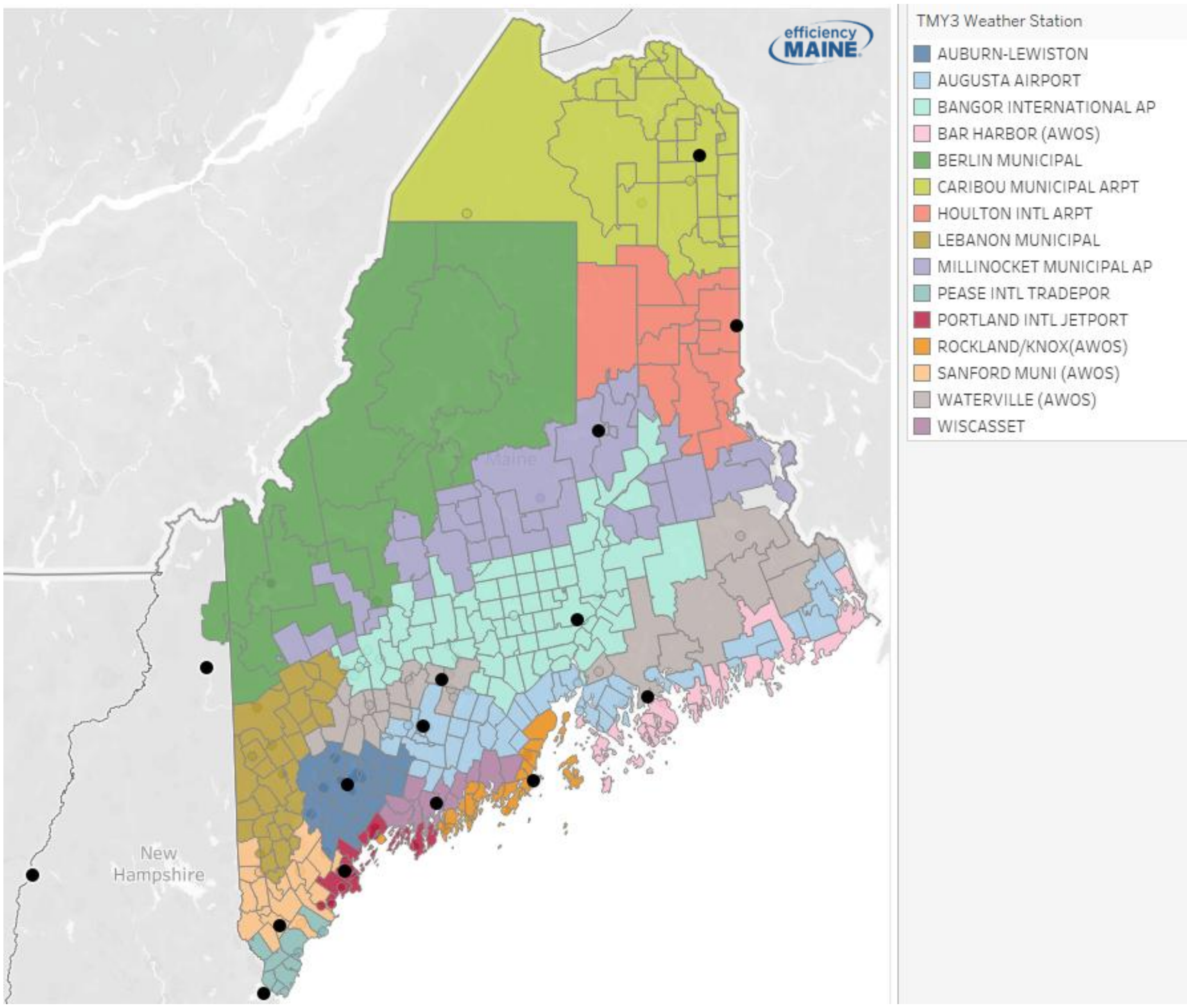
* Analysis of the post period only included data from the heating season. The cooling season was not part of the dataset.

3.1.3 Weather Data

This analysis incorporates two types of weather data: historical weather data and typical meteorological year (TMY3) data. Historical weather data was used to estimate the relationship between temperature and energy use, while TMY3 data were used to predict heat pump usage under typical long-term climate conditions.

Using a zip-to-station map provided by Efficiency Maine (Figure 12), each participant account was mapped to a nearby weather station based on their zip code. In Figure 12, the black dots represent the weather stations. In total, fifteen candidate stations were used. The most common stations were Bangor International Airport (23%), Auburn-Lewiston (15%), Augusta Airport (11%), and Portland International Jetport (10%).

Figure 12. Mapping Zip Codes to Weather Stations[13]



3.1.4 Preparing the Analysis Data Set

The key step in creating the analysis data set was merging the AMI data with the weather data and key characteristics from the program tracking data, such as installation date and zip code. Prior to running the merge, hourly kW readings were aggregated to daily kWh totals, and hourly temperatures were averaged for each day.

Figure 13 shows average daily consumption (gray line) and average daily temperature (green area). Note that the gray line reflects a mixture of both pre-installation and post-installation data, as installations occurred throughout fall of 2023 and winter of 2024. That said, average daily consumption is clearly higher during the 2023-24 winter than either of the prior winters. Many of the rebate recipients had partial or full electric heating (either supplemental heat pumps or primary electric resistance heating) prior to their WHHP installation.

[13] Based on climate data from USDA's 2023 Plant Hardiness Zone Map.

Figure 13. Average Daily Household Consumption Time Series

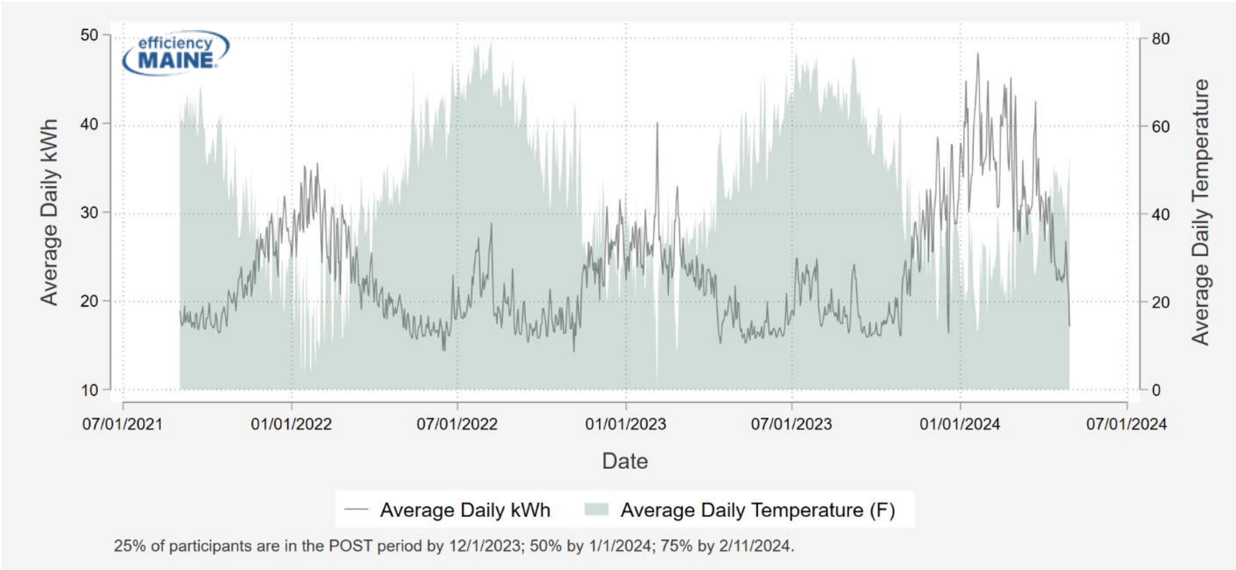


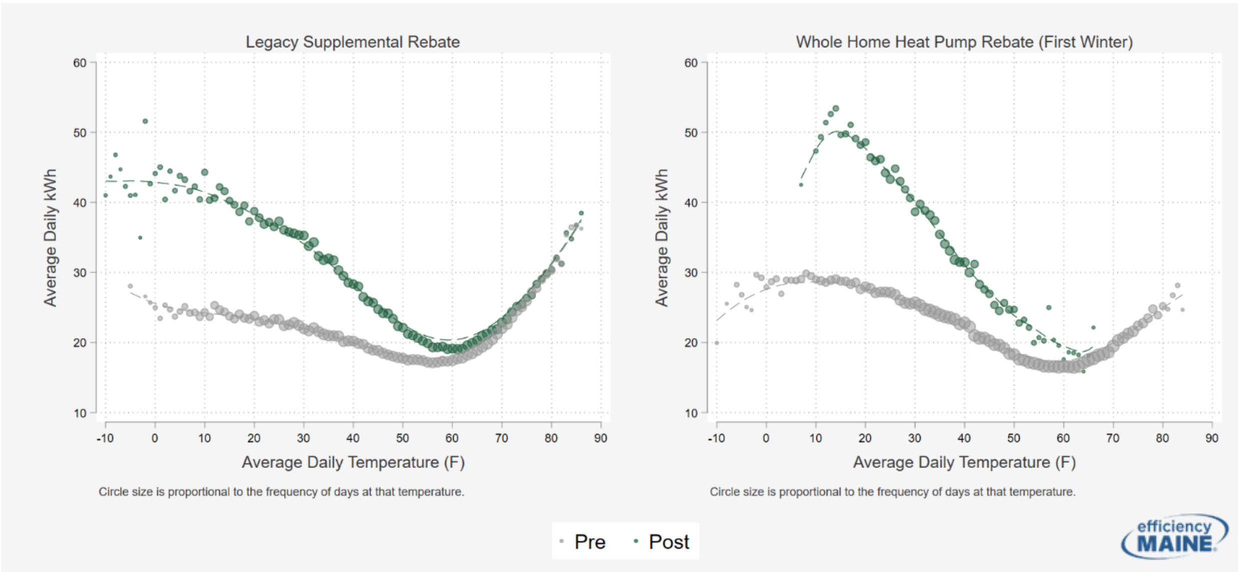
Figure 14 shows average daily consumption across different temperature bins (incremented by 1 degree). The right panel represents WHHP participants, and the left panel represents participants under the legacy supplemental rebate design. See Chapter 2 for discussion on the transition from the legacy rebate design to the WHHP design. Focusing on the right panel, the increase in daily kWh use after WHHP installation is evident. After installation, households were using approximately 50 kWh per day when average daily temperatures were between 10°F and 20°F, compared to approximately 30 kWh per day prior to WHHP installation.

In comparing the two panels, there are a few key takeaways:

- The post-period temperature ranges differed between the two analyses. For the WHHP analysis, which gathered data during the winter of 2023-24, average daily temperatures rarely dropped below 10°F in the post period. For the legacy supplemental rebate analysis, which spanned two winters, average daily temperatures in the post period dropped down to near -10°F. The study had no insight into what electric heating use for WHHP participants would look like between -10°F and 10°F due to the lack of very cold temperatures during the winter of 2023-24.
- Post-installation loads after WHHP rebates are higher than they were after legacy supplemental rebates.
- Pre-installation loads for WHHP rebate reflect considerably more electric heating than the pre-installation loads for the legacy supplemental rebate. (Twenty-three percent (23%) of homes with a WHHP had received a rebate for a supplemental heat pump prior to their WHHP installation.)

Due to the relatively high pre-installation cold-weather-dependent electric use, one of the primary reporting metrics we looked at was the predicted post-installation, cold-weather-dependent electric use only (rather than pre/post). Looking at the delta between the pre period and post period will understate how much the participants rely on heat pumps since the pre-period reflects the use of supplemental heat pumps for nearly one-fourth of participants.[14]

Figure 14. Average Daily Consumption by Temperature



3.2 REGRESSION MODELING

As noted in the prior section, there were two primary metrics we estimated: (1) the post-installation cold-weather-dependent electric use and (2) the delta between the pre- and post-installation cold-weather-dependent electric use. Both metrics can be expressed in kWh, or they can be normalized to maximum heating capacity of the heat pumps at design temperature ($kWh/kBtu_{Max}^{Design}$).

Producing these estimates entails two steps. First, we use historical data to understand the relationship between daily consumption, temperature (in the form of heating degree days and cooling degree days), and period (pre or post). Then, we cast this relationship over a typical meteorological weather year to estimate weather-normalized metrics. We chose to run individual customer regression models (ICRs) rather than one pooled model. The ICR approach enables unlimited slicing of the results across any dimension of interest. We also ran pooled models to check the ICR results, and the average results were quite similar. The model specification for the ICR models is shown below.

$$
\begin{aligned}
kW\mathrm{h_t} \quad = \quad & \beta_0 + \beta_1 * CDD_t + \beta_2 * HDD_t \\
& + \beta_3 * Post_\mathrm{t} + \beta_4 * (Post_\mathrm{t} * CDD_t) + \beta_5 * (Post_\mathrm{t} * HDD_t) \\
& + \beta_6 * Monday_t + \cdots + \beta_{11} * Saturday_t + Error_\mathrm{t}
\end{aligned}
$$

In this model:

---

[14] Suppose a home used 500 kWh for heating in the pre period, then 2,500 kWh for heating in the post period. The pre/post delta is 2,000 kWh and the post-installation cold-weather-dependent electric use is 2,500 kWh. In this hypothetical, the pre/post delta would understate how much of the home's heat load is being delivered by heat pumps by 20%.

- kWh_t represents the daily kWh on day t.
- CDD_t and HDD_t represent the daily cooling degree days (CDD) at base 70 degrees (F) and daily heating degree days (HDD) at base 60 degrees (F) on day t.
- $Post_t$ is an indicator variable that equals one if day t occurs in the post-installation period, and it equals zero otherwise.
- $Monday_t$ through $Saturday_t$ are indicator variables. $Monday_t$, for example, equals one if day t is a Monday, and it equals zero otherwise. (With this approach, Sunday is treated as the baseline day.)
- $Error_t$ represents prediction error on day t.

And the parameters are interpreted as follows:

- β_0 represents the expected base daily kWh (non-weather-dependent) on a Sunday in the pre period.
- β_1 represents the expected change in pre-period daily kWh for each daily CDD.
- β_2 represents the expected change in pre-period daily kWh for each daily HDD. If this coefficient is positive (and statistically significant) for a given premise, then pre-period daily consumption increased as average daily temperatures decreased. This could suggest some form of electric heating (though there are other possible explanations such as hydronic circulator pumps, furnace blower fans, and lighting).
- β_3 represents the expected change in base daily kWh (non-weather-dependent) in the post period.
- β_4 represents the incremental effect of each CDD on daily kWh in the post period. If this coefficient is positive, then the premise used more kWh per CDD in the post period than they did in the pre period. In practice, we observed no CDD in the post-period of the initial AMI investigation, so this coefficient was omitted for each home.
- β_5 represents the incremental effect of each HDD on daily kWh in the post period. If this coefficient is positive, then the premise used more kWh per HDD in the post period than they did in the pre period (i.e., increased load in the winter after installing a heat pump).
- β_6 through β_{11} represent the expected change in base daily kWh for each day of the week (where β_6 corresponds to Mondays, β_7 corresponds to Tuesdays, and so on).[15]

The model estimates can be combined with TMY weather data to predict weather-normalized annual pre and post consumption. Example regression output is shown in Figure 15, and Table 4 illustrates how the metrics are normalized for a location with 6,118 annual HDD60 and 104 annual CDD70. The practical

[15] Note that there is no "day of week" component to TMY weather data. When we cast the relationship between consumption, weather, and day of week over the TMY data, we assign a year to the TMY data to facilitate a "day of week" calculation. The choice of year has a negligible but non-zero effect on weather-normalized pre and post annual consumption but has no effect on the impact estimate.

interpretation of the HDD60 coefficient ($\hat{\beta}_2$ = 0.230) is that predicted pre-period daily kWh increases by 0.230 for each additional HDD60. The practical interpretation of the coefficient for the Post*HDD60 interaction term ($\hat{\beta}_5$ = .424) is that predicted post-period daily kWh increases by 0.654 (0.230 + 0.424 = 0.654) for each additional HDD60. In other words, this account used 0.424 more kWh per HDD in the post period than they did in the pre period.

Figure 15. Example Regression Output

Source	SS	df	MS			
Model	79263.0395	11	7205.73086	Number of obs	=	1,257
Residual	29647.6967	1,245	23.813411	F(11, 1245)	=	302.59
				Prob > F	=	0.0000
Total	108910.736	1,256	86.7123695	R-squared	=	0.7278
				Adj R-squared	=	0.7254
				Root MSE	=	4.8799

	kwh	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
$\hat{\beta}_3$	post	.2468375	.4614978	0.53	0.593	-.6585618	1.152237
$\hat{\beta}_1$	cdd70	.2880586	.1391441	2.07	0.039	.0150758	.5610414
$\hat{\beta}_2$	hdd60	.2297126	.0128751	17.84	0.000	.2044533	.2549718
$\hat{\beta}_4$	post#c.cdd70						
	1	.5606919	.2164841	2.59	0.010	.1359779	.9854059
$\hat{\beta}_5$	post#c.hdd60						
	1	.4243657	.0201802	21.03	0.000	.3847747	.4639568
	dow						
	1	-2.66509	.5147015	-5.18	0.000	-3.674868	-1.655312
	2	-.9025748	.5166223	-1.75	0.081	-1.916121	.1109717
	3	-2.925754	.5144412	-5.69	0.000	-3.935022	-1.916487
	4	-1.833318	.5159446	-3.55	0.000	-2.845535	-.8211013
	5	-3.060826	.5144636	-5.95	0.000	-4.070137	-2.051514
	6	-3.351546	.5165914	-6.49	0.000	-4.365032	-2.33806
$\hat{\beta}_0$	_cons	9.646457	.4267598	22.60	0.000	8.809209	10.48371

Table 4. Example Impact Calculations

Component	Metric	Calculation
Cold-Weather-Dependent Electric Use	Pre	0.230 * 6,118 = 1,407 kWh
	Post	(0.230 + 0.424) * 6,118 = 4,001 kWh
	Impact	4,001 kWh – 1,407 kWh = 2,594 kWh
Warm-Weather-Dependent Electric Use	Pre	0.288 * 104 = 30 kWh
	Post	(0.288 + 0.56) * 104 = 88 kWh
	Impact	88 kWh – 30 kWh = 58 kWh
Non-Weather-Dependent Electric Use	Pre	9.646 * 365.25 = 3,523 kWh
	Post	(9.646 + 0.247) * 365.25 = 3,613 kWh
	Impact	3,613 – 3,523 = 90 kWh

These calculations assume 6,118 annual HDD60 and 104 annual CDD70.

The metrics in the "Cold-Weather-Dependent Electric Use" rows – specifically the post period metric, which accounts for any existing heat pumps in addition to newly installed heat pumps through WHHP – are the metrics of interest for this analysis.

3.3 RESULTS

Overall, we estimated average post-installation cold-weather-dependent electric use to be 4,870 kWh per year. The average maximum heating capacity at design temperature for the homes in this initial AMI analysis, inclusive of heat pumps installed prior to the WHHP installation and/or heat pumps that were not rebated, was approximately 35.1 kBtu/h. This section provides details on filters we applied before calculating these averages as well as some other summary metrics.

3.3.1 Filters

Prior to summarizing the results, we filtered out approximately 20% of accounts. The goal in applying filters is to isolate accounts where we expect (1) the impact of WHHP participation is not confounded with other load modifiers such as the installation of solar panels or charging of an electric vehicle, (2) there are no data quality issues, and (3) the consumption for the home is reasonable for a residential property. The following filters were applied:

- **Insufficient data.** Homes with fewer than 300 days of pre-participation data were filtered out. Homes with installation dates after 3/1/2024 were filtered out as well.
- **Solar power.** Homes with known solar power (per utility database information) or homes with typical solar load shapes were removed.
- **Rebated electric vehicle.** Homes that received an Efficiency Maine rebate for an electric vehicle were removed, as these homes likely charged an EV during the analysis period.
- **Low or high pre-participation annual consumption.** A threshold of 500 kWh was used for the low end, and a threshold of 40,000 kWh was used for the high end.
- **Zero reads.** Homes with several days of 0 kWh were removed. Among other possibilities, no consumption could indicate a data quality issue or a home with solar power. Days with widespread power outages were removed from the entire dataset, separately from the filter for individual homes with several days of 0 kWh.

Table 5 shows the number of accounts that remained in the analysis after applying each filter. If the filters were applied in a different order, the interim table values would change but the final account tally would not.

Table 5. AMI Analysis Filtering

Filter	Accounts Remaining
Total accounts before filtering	**1,433**
Insufficient data	1,378
Solar power	1,284
Rebated EV	1,255
Low or high pre-WHHP annual consumption	1,245
Several days of zero reads	1,141
WHHP installation date on or after 3/1/2024	992

Filter	Accounts Remaining
Total accounts after filtering	**992**

3.3.2 Annual Impacts and Predicted Cold-Weather-Dependent Electric Use

Table 6 shows summary statistics from the initial AMI investigation. Estimated post-installation cold-weather-dependent electric use is shown in kWh and kWh per $kBtu_{Max}^{Design}$.[16] The latter metric (kWh/kBtu) allows for making comparisons across homes of varying sizes, providing insight into the relative intensity of heat pump usage. We found an average pre/post impact of 3,176 kWh and predicted post-period cold-weather-dependent electric use averaged 4,870 kWh (or 147 $kWh/kBtu_{Max}^{Design}$). The distribution of post-installation cold-weather-dependent electric use is shown in Figure 16. There is some discussion in Chapter 3.3.3 on the predictions of negative electric use, which are theoretically implausible. Note that the average of the normalized values ($kWh/kBtu_{Max}^{Design}$) differs from a calculation of the average cold-weather-dependent electric use divided by the average capacity because of the weighting of individual homes.

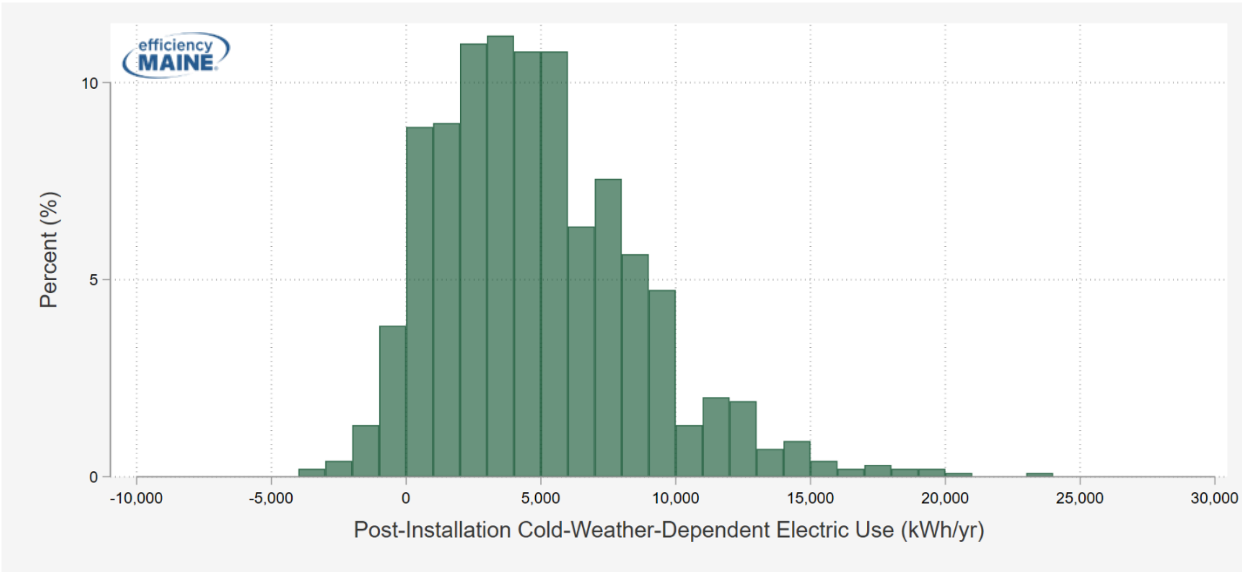
Table 6. Initial AMI Analysis – Results

Metric		P25	P50	P75	Mean
Total Household $kBtu_{Max}^{Design}$		24.0	32.6	42.7	35.1
Cold-Weather-Dependent Electric Use, Post Period	kWh/year	2,148	4,440	7,134	4,870
	$kWh/kBtu_{Max}^{Design}$	71	132	204	147[17]
Pre/Post Cold-Weather-Dependent Electric Use Delta	kWh/year	684	2,695	5,250	3,176
A normalized metric (kWh/kBtu) for the “Pre/Post Heat Pump Heating Impact” was not calculated because the capacity installed between the pre and post periods could not be accurately assessed. Also note that the capacity metric used in this table ($kBtu_{Max}^{Design}$) represents the total for the household.					

[16] $kBtu_{Max}^{Design}$ represents the household sum of the maximum capacity at or below design temperature based on manufacturer reported data as reported on the claim form.

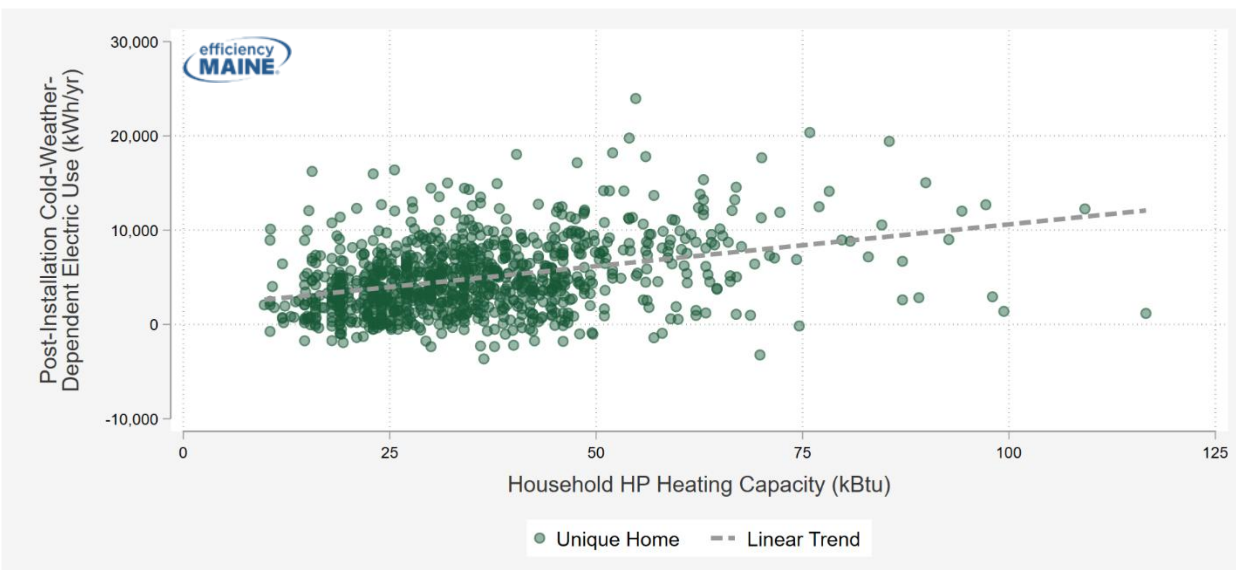
[17] This number is larger than the ratio of the averages because it is an average of the ratios.

Figure 16. Distribution of Post-Installation Cold-Weather-Dependent Electric Use



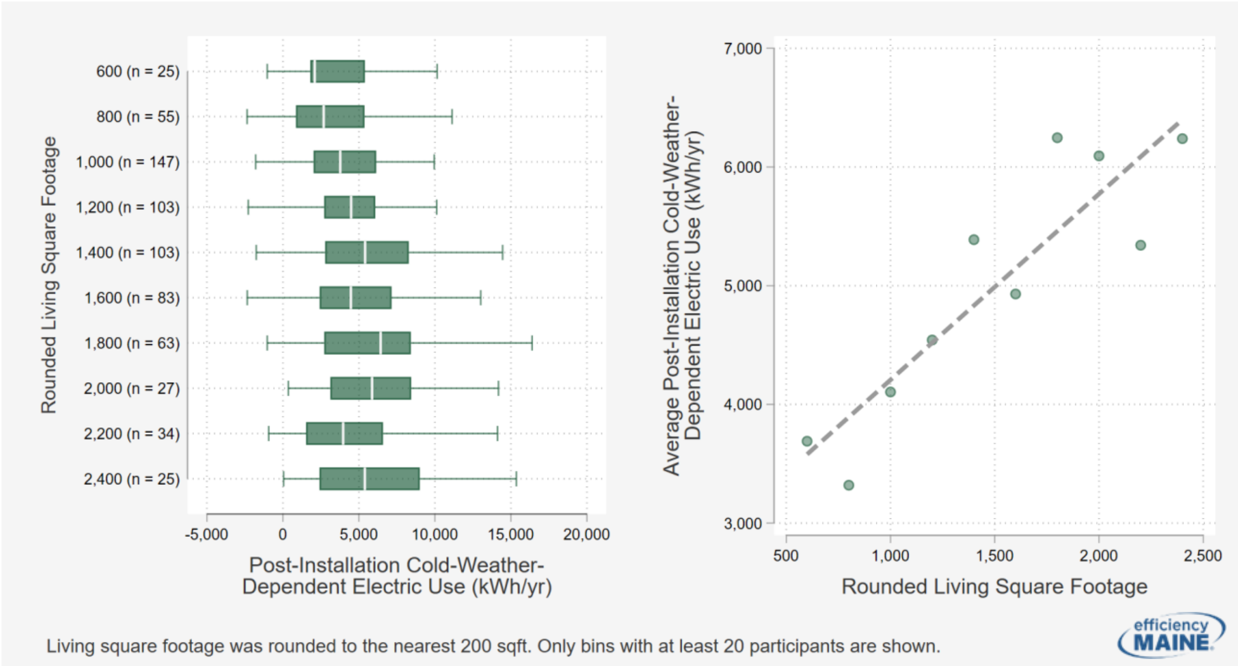
Homes with more heat pump heating capacity generally have higher estimated cold-weather-dependent electric use (Figure 17), though there is considerable variation. Normalized to household heating capacity, average post-installation cold-weather-dependent electric use was 147 kWh per $kBtu_{Max}^{Design}$.

Figure 17. Estimated Cold-Weather-Dependent Electric Use vs. Heat Pump $kBtu_{Max}^{Design}$



Larger homes also generally had higher estimated cold-weather-dependent electric use. The left panel of Figure 18 shows the distribution of predicted post-installation cold-weather-dependent electric use across different home living square footage bins (per property tax data). The right panel shows the average predicted post-installation cold-weather-dependent electric use in each bin.

Figure 18. Estimated Cold-Weather-Dependent Electric Use vs. Home Living Square Footage

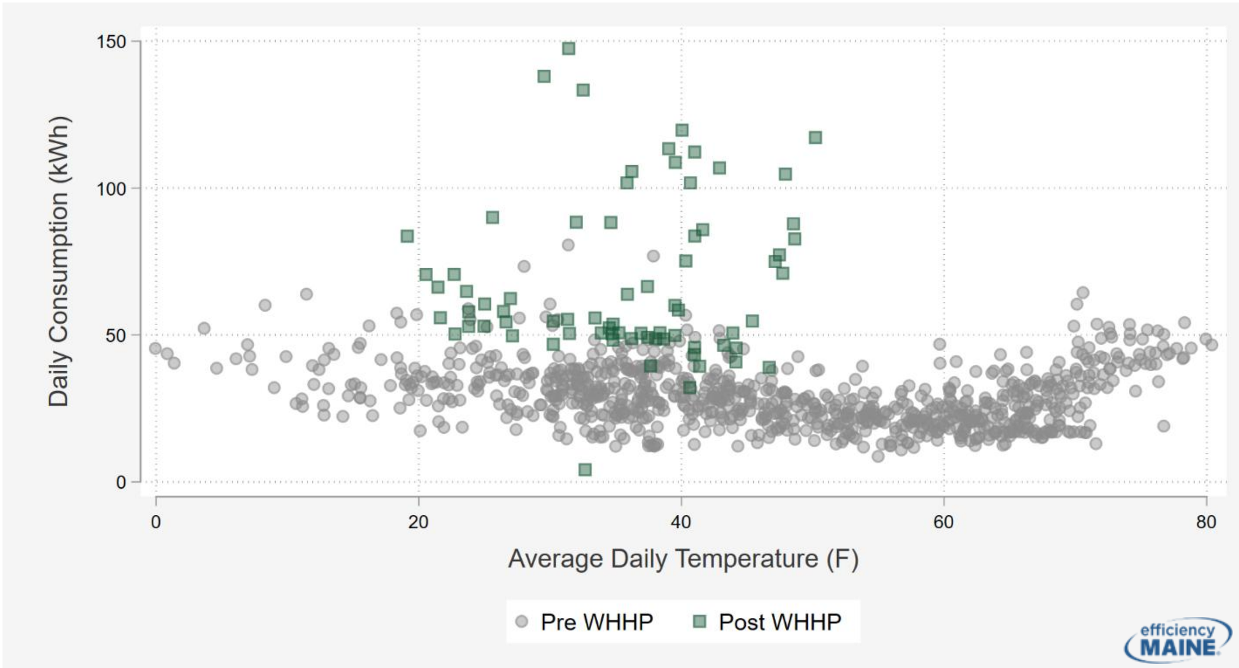


3.3.3 Additional Context

Below we provide some additional context on the findings of the initial AMI investigation.

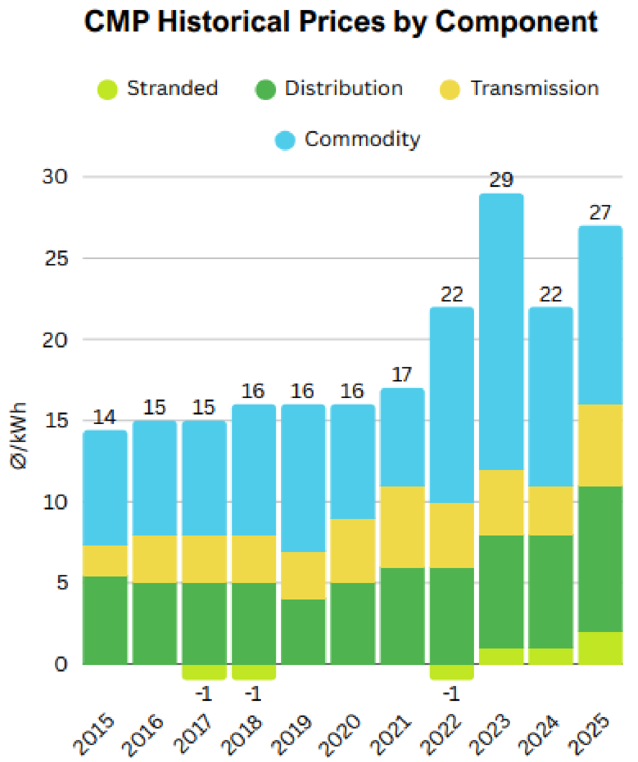
- **Installation dates.** Based on visual reviews, we found evidence that the WHHP installation dates stored in the program tracking data generally corresponded to the start of heat pump use but were occasionally off by a few weeks. In an analysis with more post-installation data, we would typically apply a blackout period around the installation date. Given the limited available post data, we did not apply a blackout period for the initial AMI investigation, but we did apply a blackout period for the Refresh analysis discussion in Chapter 9.
- **Negative cold-weather-dependent electric use.** Our AMI analysis resulted in a prediction of negative cold-weather-dependent electric use for approximately 6% of homes. This seems unusual, and a negative electric use is simply not possible. Our cold-weather-dependent electric use estimates use a linear relationship between daily consumption and average daily temperature. For some edge cases, heat pump usage did not increase as outdoor temperatures dropped. See Figure 19 for an example of a home with a prediction of negative use. Consumption at this home clearly increases after the heat pumps are installed, but the relationship between consumption and outdoor temperature does not conform to what we would expect to see. When heat pump usage is not tied to weather conditions, the estimates from the regression model may become counterintuitive (like predicting negative cold-weather-dependent electric use).

Figure 19. Negative Cold-Weather-Dependent Electric Use Example



- **Electric rates.** Rates are an important factor that aren't controlled for in this analysis. Figure 20 shows an eleven-year history of electricity prices in Maine's largest electric distribution territory. The increase in rates after 2021 could affect participants' willingness to rely on heat pumps to heat their homes.

Figure 20. 11-Year History of Supply Rates in Maine[18]



Data has been rounded to the nearest whole number. The graphic displays an increase in each component's rates over a ten-year period.

[18] Maine Office of the Public Advocate. 2025.

4 METERED HOME CHARACTERISTICS

This section presents a subset of homes with heat pumps installed before March 1, 2024, metered from December 2024 through April 2025, that were initially analyzed using AMI data for winter 2023-24 (Section 3 of this report). As stated earlier in the report, the objective of the metering portion of this study was to determine the driving factors behind lower-than-expected utilization levels observed in the AMI data for certain heat pump installations. Based on the Initial AMI analysis for winter 2023-24, the metering study divided homes into categories of usage level – Low (L), Medium (M), and High (H) use (see Table 1 for details) -- based on their electricity consumption. An additional category of “Negative” (N) was established for homes whose modeled electrical use decreased with decreasing temperatures. The sample used in the metering study focused exclusively on homes segmented as Negative, Low, and Medium, where temperature-dependent electricity use was less than expected.

As described previously, at each home, Ridgeline metered (at one-minute intervals) the power to each heat pump outdoor unit, the amperages to indoor unit fans, the indoor unit supply air temperatures, the indoor unit return air temperatures, and the outdoor temperatures. Additionally, balometer testing was conducted to establish a relationship between fan current and airflow for each indoor heat pump head. Other sources of heating within the home, including boilers, furnaces, wood stoves, spot fossil heating, and electric resistance elements, were also metered to allow a more accurate and comprehensive picture of how homeowners were heating their homes overall. The metering methodology is discussed more thoroughly in Appendix A: Metering Methods.

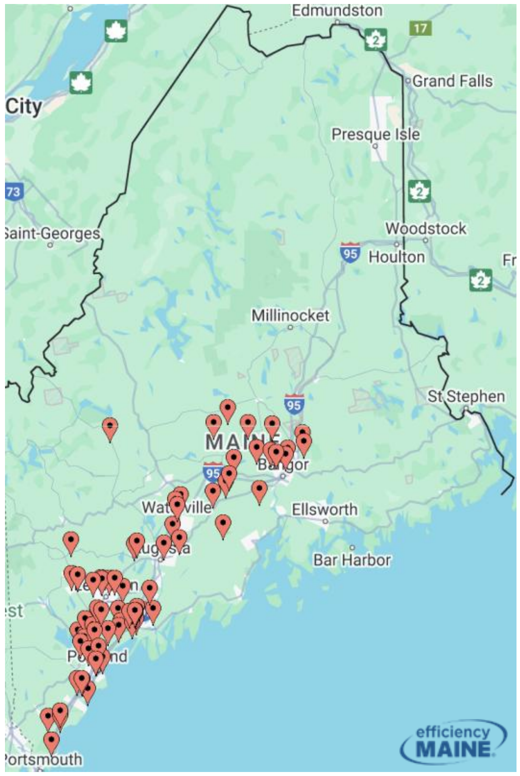
This data would:

- Provide verification for the AMI analysis by checking its accuracy for these categories of homes.
- Give insight at the household level as to why the heat pumps in the Low and Medium (usage) homes consumed less kWh than expected.

4.1.1 Metered Home Locations

The initial sample design for this study was 80 residential homes. Ultimately, this study comprised 78 homes due to one cancellation and one power meter failure. A total of 160 heat pumps (outdoor units) were deployed across these 78 homes. Figure 21 shows the geographic spread of the 78 homes in the metering sample.

Figure 21. Map of Study Area



The study was focused on the more populated areas of Maine as shown in Figure 22. Ten of the 16 Maine counties were represented. Based on the most recent plant hardiness map (Figure 23) issued by the USDA, climates zones 6a, 5b, and 5a were covered by this sample. One home is on the border of zones 5a and 4b. The only populated zone not covered by the study (4a) is at higher elevations in the western mountains and in populated areas in the Caribou and Presque Isle region.

Figure 22. Approximate Study Area Superimposed on Population Density Map

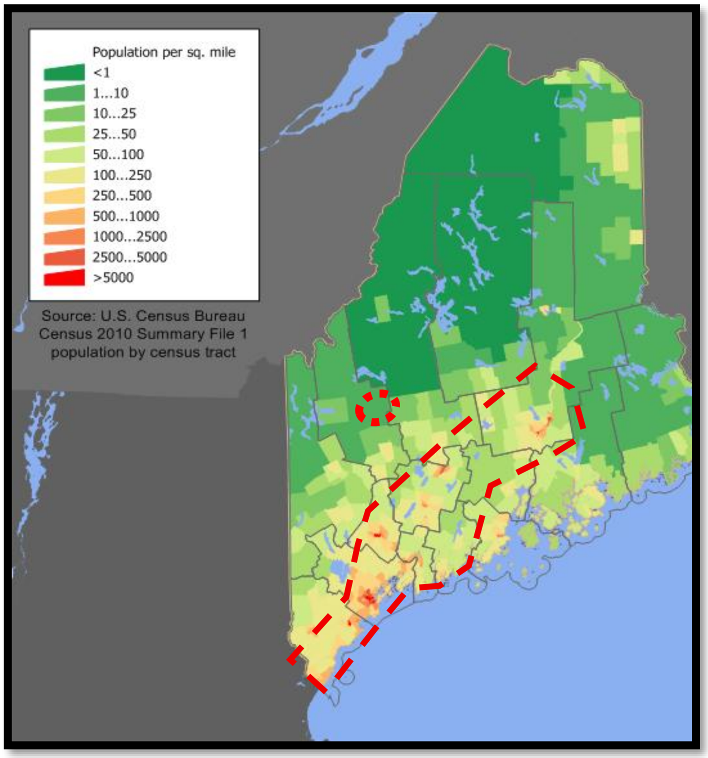
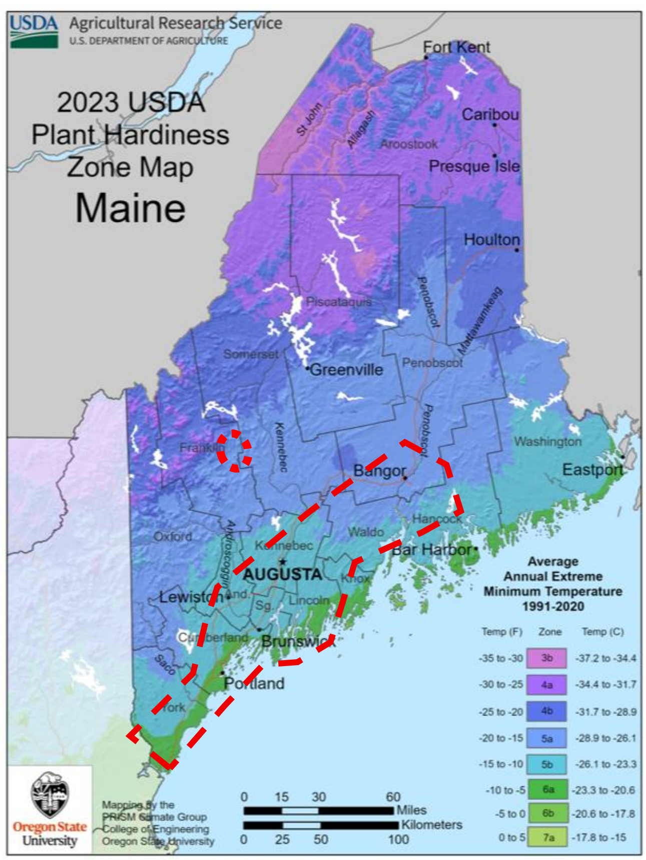


Figure 23. Approximate Study Area Superimposed on USDA Plant Hardiness Zone Map



4.1.2 Metered Home Characteristics

Ridgeline calculated the heat loss from homes using Amply, a software that uses LIDAR[19] sensors built into iPads to efficiently gather dimensions of spaces. It also contains an embedded Manual J model[20] to calculate the heating and cooling requirements of living spaces. The average heat loss for a home in this metering sample was 25.7 kBtu/h at 5°F. These homes were relatively small at 1,337 ft^2, on average. This corresponds to an average heat loss per square foot of approximately 20.3 Btu/h/ft^2 at 5°F. Using the Amply heat loss models and the Efficiency Maine Technical Reference Manual (TRM) equation for annual heat loss mentioned in the Initial AMI Analysis section of this study, Ridgeline estimated the average annual heat loss to be 68.5 MMBtu.[21] (Table 7).

Overall, approximately 63% of the metered homes had a central fossil fuel boiler or furnace, 35% had a wood or pellet stove, 15% had some form of non-central fossil fuel stove, monitor, or through-wall spot heating, and 13% had electric resistance heating in the form of electric space heaters, or baseboard heaters. This does not indicate that all these forms of heating were used at these homes, and sometimes homes had multiple forms of non-heat pump heating available.

Table 7. Characteristics of Homes Metered

Home Summary Statistics	
Count	78
Average Conditioned Square Footage	1,337 ft^2
Average Heat Loss @ 5°F	25.7 kBtu/h
Average Heat Loss per Square Foot @ 5°F	20.3 Btu/h/ft^2
Average Annual Modeled Heat Loss[22]	68.5 MMBtu
Average Annual Metered Heat Delivered (all heat sources)	58.9 MMBtu
Percentage with Two or More Floors Above Grade	41%
Percentage with Wood Heating	35%
Percentage with Electric Resistance	13%
Percentage with Boiler	53%
Percentage with Furnace	10%
Percentage with Non-Central, Non-Wood Heat (Stove, Monitor, or Through-Wall Heater)	15%

[19] LIDAR (Light Detection and Ranging) is a sensing technology that uses pulses of laser light to measure distances and create 3-D models of objects. For this project, LIDAR is constructing 3-D models of rooms.

[20] Manual J is an ANSI-recognized Air Conditioning Contractors of America (ACCA) standard that provides a detailed method for calculating the heating and cooling loads of residential buildings, considering factors like insulation, windows, local climate, and building envelope.

[21] Minimum of (installed HP capacity at design temp or reported Heat Load at design temperature) * 186,648 / (Ti-To) / 1,000,000 where 186,648 is the population weighted average TMY3 heating degree hours, Ti - To is assumed to be 70 degrees F, and 1,000,000 converts from Btu to MMBtu.

The metered heat delivered on average was about 86% of the modeled heat loss extrapolated to the season. This does not necessarily mean that modeling overestimates heat loss. If homeowners turn down temperatures at night or when they leave, they will use less heat than the design load extrapolated to the full season. Similarly, if homeowners only heat certain zones continuously (e.g., they marginally heat a guest bedroom) they will use less heat than the model, but the modeled design load will still be correct.

4.1.3 Metered Heat Pump Characteristics

All but two of the 78 homes that Ridgeline studied had one or more single-zone ductless heat pumps. The other two homes used a central, ducted heat pump. Three of the 78 homes also had a multi-zone heat pump (an outdoor unit that provides heat to more than one indoor unit), in addition to either one or two single-zone heat pumps. In all, the homes contained 160 outdoor units and 166 indoor units (Table 8). The representation of ducted heat pumps in the metering sample reflects that only 2% of the heat pumps in the WHHP population are ducted. In all, 41 different heat pump models were metered.

Table 8. Homes Investigated by Number of Heat Pumps (Outdoor Units and Indoor Units)

Count	Outdoor	Indoor	Heat Pump Type
15	1	1	Single-Zone only
2	1	1	Ducted
41	2	2	Single-Zone only
1	2	3	Both Single-Zone and 2:1 Multi-Zone
1	2	5	Both Single-Zone and 4:1 Multi-Zone
15	3	3	Single-Zone only
1	3	5	Both Single-Zone and 3:1 Multi-Zone
1	4	4	Single-Zone only
1	5	5	Single-Zone only
78	**160**	**166**	

Across the 160 heat pumps, the average rated capacity at 47°F (BTUrated47), which reflects AHRI's definition for the nominal heating capacity in Section 3.2.39 of the *AHRI Standard 210/240,* was 14.5 kBtu/h. The average maximum capacity at 5°F (BTUmax5) was 16.6 kBtu/h. It is important to note that not every heat pump in the metered sample is rated across all these ratings. Some of the older models, which were most likely not rebated by the WHHP program, but were already installed in homes, are not rated for the updated, more stringent HSPF2, SEER2, and EER2 standards. For one such heat pump in the sample, only the rated COP, nominal capacity, maximum capacity at 5˚F, and HSPF are known. Additionally, the average rated capacity at 5°F (BTUrated5) of these heat pumps is marked as an optional test and is not required to be reported by manufacturers for all heat pump models.

Table 9 shows the average characteristics of the installed heat pumps. These values are obtained from the *Air-Conditioning, Heating, and Refrigeration Institute's (AHRI) Directory of Certified Product*

Performance.[23] Across the 160 heat pumps, the average rated capacity at 47°F (BTU_{rated}^{47}), which reflects AHRI's definition for the nominal heating capacity in Section 3.2.39 of the *AHRI Standard 210/240,* was 14.5 kBtu/h.[24] The average maximum capacity at 5°F (BTU_{max}^{5}) was 16.6 kBtu/h. It is important to note that not every heat pump in the metered sample is rated across all these ratings. Some of the older models, which were most likely not rebated by the WHHP program, but were already installed in homes, are not rated for the updated, more stringent HSPF2, SEER2, and EER2 standards. For one such heat pump in the sample, only the rated COP, nominal capacity, maximum capacity at 5°F, and HSPF are known. Additionally, the average rated capacity at 5°F (BTU_{rated}^{5}) of these heat pumps is marked as an optional test and is not required to be reported by manufacturers for all heat pump models.

Table 9. Average AHRI Ratings of Metered Heat Pumps

	Heat Pump Characteristic	Value	Sample Size
	Outdoor Unit Count	160	
	Indoor Unit/Outdoor Unit Ratio	1.04	
AHRI Directory of Certified Product Performance	Maximum Capacity @ 47°F (BTU_{max}^{47})	22,130 Btu/h	159
	Rated Capacity @ 47°F (BTU_{rated}^{47})	14,501 Btu/h	160
	Minimum Capacity @ 47°F (BTU_{min}^{47})	3,694 Btu/h	159
	Maximum Capacity @ 17°F (BTU_{max}^{17})	18,287 Btu/h	159
	Rated Capacity @ 17°F (BTU_{rated}^{17})	9,879 Btu/h	159
	Minimum Capacity @ 17°F (BTU_{min}^{17})	3,594 Btu/h	158
	Maximum Capacity @ 5°F (BTU_{max}^{5})	16,604 Btu/h	160
	Rated Capacity @ 5°F (BTU_{rated}^{5})	15,514 Btu/h	138
	Minimum Capacity @ 5°F (BTU_{min}^{5})	2,945 Btu/h	158

While we observed 5 brands of heat pumps, 81% were Mitsubishi or Fujitsu (Table 10). This closely mirrors the heavy market dominance of these two manufacturers in the overall program data, as discussed in Figure 7 in the initial AMI analysis section of this report. The Mitsubishi units tended to be a bit smaller, but examining brand by capacity did not shift the proportions by much. Samsung, Daikin, and Gree comprised the remaining 19% of the metered sample. In terms of BTU_{rated}^{47}, 23% of the heat pumps in the sample were smaller than 12,000 Btu/h, 46% were between 12,000 and 17,999 Btu/h, and 31% were greater than 17,999 Btu/h.

[23] Air-Conditioning, Heating, and Refrigeration Institute. Directory of Certified Product Performance.

[24] From AHRI Standard 210/240 Section 3.2.39: Nominal Heating Capacity is defined as a capacity approximately equal to the *heat pump* capacity tested at the $H1_{Nom}$ condition which is the test condition for the reported Rated Capacity @ 47°F (BTU_{rated}^{47}).

Table 10. Heat Pumps by Make and Size of Outdoor Unit

	Size Range (Rated Capacity at 47°F (BTU_{rated}[47]))					
(Counts)	Less than 12,000 Btu/h	12,000 to 14,999 Btu/h	15,000 to 17,999 Btu/h	Greater than 17,999 Btu/h	Total	%
Mitsubishi	28	16	20	14	78	**49%**
Fujitsu	0	13	7	31	51	**32%**
Samsung	1	12	2	3	18	**11%**
Daikin	5	3	0	1	9	**6%**
Gree	3	1	0	0	4	**2%**
Total	**37**	**45**	**29**	**49**	**160**	100%
%	**23%**	**28%**	**18%**	**31%**	**100%**	

5 METERED HEAT PUMP ELECTRICAL USE

This chapter discusses the electrical usage of the heat pumps metered from December 2024 through April 2025. Across the 78 homes in the metering sample, the average metered annual heat pump usage was 3,438 kWh per home and 1,676 kWh per heat pump. Since few meters were installed before December 1, 2024, metered electrical use needed to be annualized to the entire 2024-25 heating season to account for the fall 2024 shoulder season.

5.1.1 Annualization of Metered Electrical Use

Using heating degree days (HDD) for the season obtained from local weather stations, a ratio of metered heating degree days to total season heating degree days was calculated and applied to extrapolate the metered data. This metered kWh annualized to 2025 is discussed in this chapter.

Across all 78 homes, 70% of the total HDD for winter 2024-25 were metered. To account for the remaining HDD, each home was assigned to its nearest weather station using EMT's weather station to zip code matching keys. Figure 24 shows the distribution of homes colorized by their matched weather station. Hourly outdoor temperature data was then collected for the full heating season (October 1, 2024, through April 30, 2025) from the 10 matched weather stations. Using a 65°F HDD base, the HDDs measured during the metering period for each heat pump and the total HDDs for the entire season at each weather station were calculated. The metered data was then extrapolated to the full 2024-25 season by applying this ratio of HDDs between the metered period and the entire season.

Figure 24. Map of Homes Binned by Annualization Region

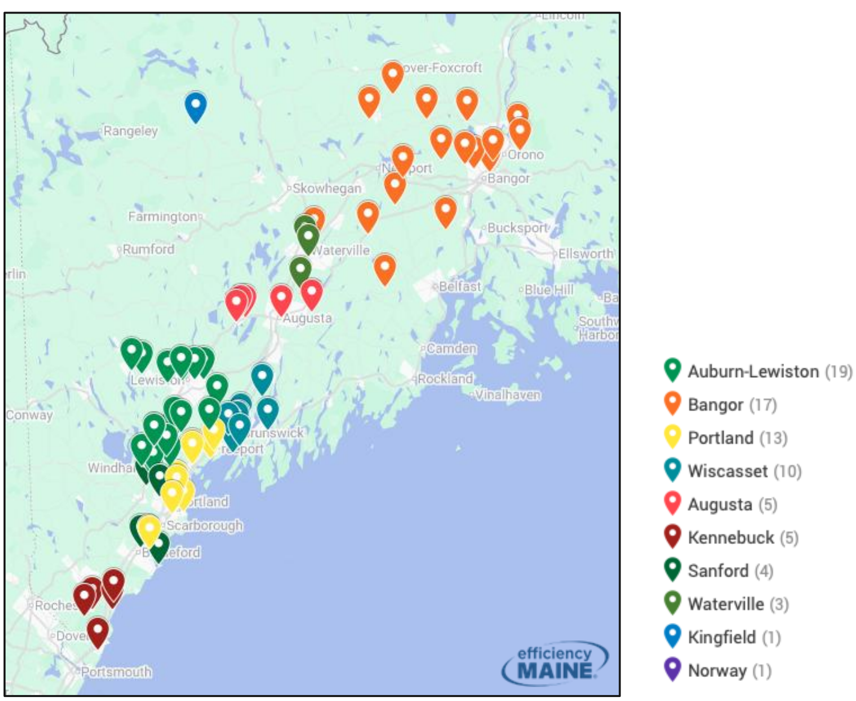
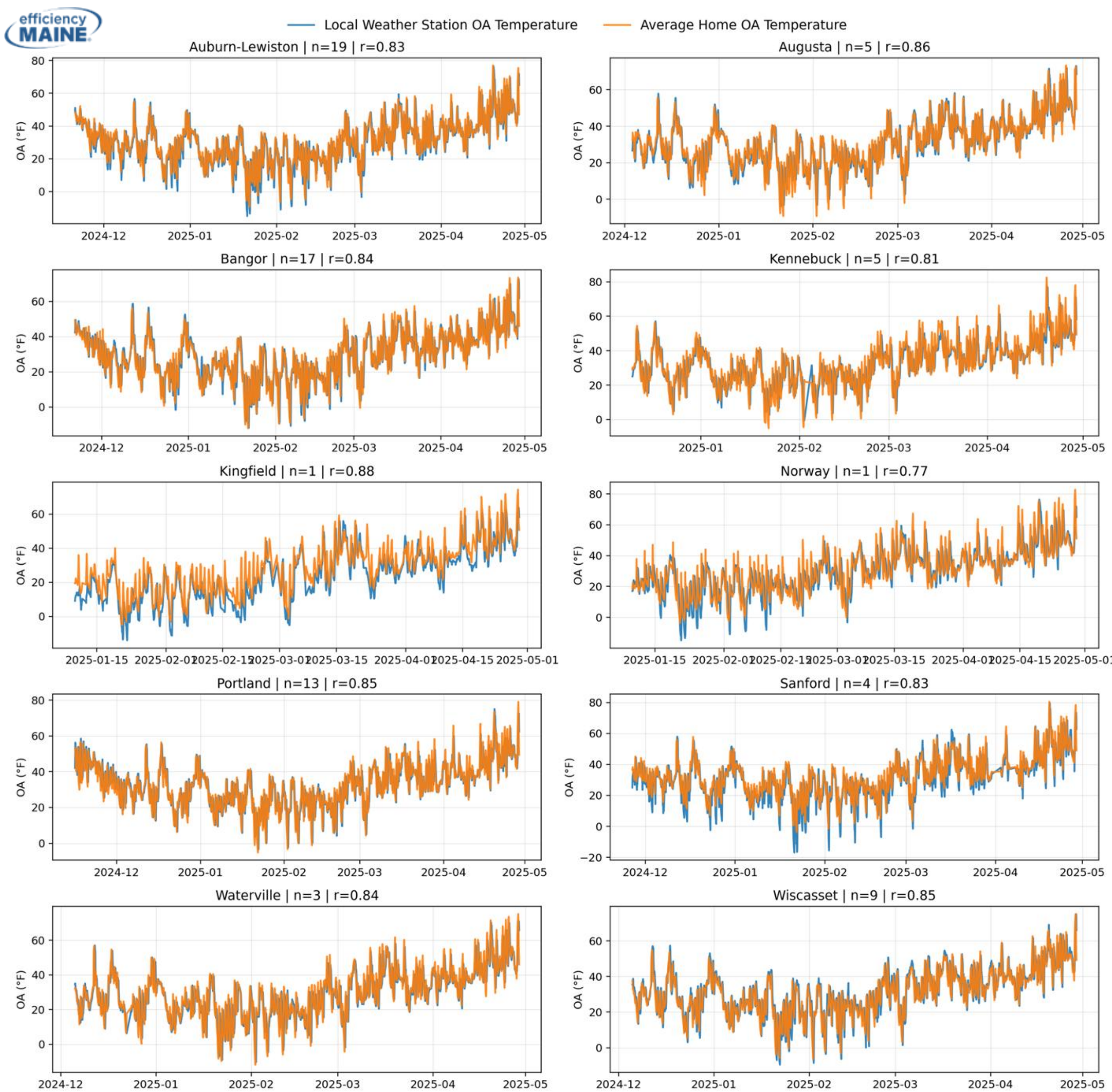


Figure 25 shows the recorded outdoor air temperatures (OA) from the 10 matched weather stations against the average outdoor temperature readings from all homes grouped with each station. As expected, the readings align closely across all weather stations. On average, the correlation coefficient between local weather stations and on-site temperature sensors was 0.83 for overlapping periods. While the metered outdoor temperatures generally aligned closely with the matched weather station data, some variation remains due to localized temperature differences.

Figure 25. Comparison of Outdoor Air Temperature (OA) between Local Weather Stations and the Averages of the Grouped Homes (n = 78)



5.1.2 Trends in Metered Electrical Use

This section shows the heat pump electrical use across the 78 homes and 160 heat pumps metered. The figures in this section use the following lines and markers to show annual electricity consumption by heat pumps as calculated with these methods (Table 11).

Figure 26 through Figure 28 show, as a black line, the 2024-25 metering averages for heat pump kWh at the home for sampled negative, low, and medium heat pump use as identified by the AMI analysis. To compare to the metering data, the weather-dependent regression model from the 2024-25 Refresh AMI Analysis (Chapter 9) was applied to actual weather data for the 2024-25 heating season from October 1, 2024, through April 30, 2025, as opposed to TMY3 conditions. The average results from the Refresh AMI regressions for these 78 sites areshown as a red dashed line in Figure 26. This AMI Refresh analysis and comparison with the metering results are discussed more thoroughly in Section 9.4.[25]

For reference, average results for the total extrapolated WHHP population are shown as the blue dashed line in the figures in this section. Electricity use was extrapolated to the entire population by first developing a ratio of the Refresh AMI analysis to the metering results for the 78 metered homes. These full population extrapolated results are discussed more thoroughly in Section 9.4.1. This sample of 1,003 homes includes homes categorized as Negative, Low, Medium, and High, so the results from this group cannot be directly compared to the other calculation methods, which only include metered homes categorized as Negative, Low, and Medium. Again, the metering was intended to check on the lower users. The total extrapolated WHHP population also represents an annualization based on TMY3 data, not actual 2024-25 weather data.

Additionally, results from the 2023-2024 Initial AMI Analysis (Chapter 3) for 77 out of the 78 metered homes are included in

[25] The results in Section 9.4 may differ to those shown here in Section 5.1.2 due to differences in sample size and filtering.

Table 11 for comparison (and are shown as a yellow dashed line in the following figures). These initial results are annualized using TMY3 data and are therefore not directly comparable to the metering data.

Table 11. Summary Statistics for Electricity Use by Heat Pumps

Method Name	Marker	N	Usage Groups	Calculation Method	kWh / Home	kWh / HP	kWh / $kBtu_{Rated}$[47]
2024-25 Metering	Solid Black Line	78	N, L, M	Measured by on-site metering equipment during winter 2024-25, for homes characterized by 2024 AMI as negative, low, or medium users (annualized to entire heating season 2024-25).	3,438	1,676	115
2024-25 Refresh AMI Analysis	Red Dashed Line	78	N, L, M	Modeled using refreshed AMI data from winters 2023-24 and 2024-25 (annualized to heating season 2024-25). This is discussed in Chapter 9 of this report.	3,403	1,659	114
2023-24 Initial AMI Analysis	Yellow Dashed Line	77	N, L, M	Modeled using AMI data from winter 2023-24 (annualized to TMY3). This is discussed in Chapter 3 of this report.	2,845	1,378	95
2024-25 Metering & AMI (WHHP Population)	Blue Dashed Line	1,003	N, L, M, H	Modeled using refreshed AMI data from winters 2023-24 and 2024-25 (annualized to TMY3). This is discussed in Chapter 9 of this report.	4,904	2,229	143

Figure 26 shows the annual metered electricity consumption by heat pumps per home or household. Usage per metered household averaged 3,438 kWh per year, and it varied somewhat, with nearly 13% of homes using less than 2,000 kWh per year and nearly 33% using more than 4,000 kWh per year. The 2023-24 Initial AMI annual heat pump electricity consumption averaged 2,845 kWh per home, below the other two methods. When extrapolating to the entire program population with the high heat pump usage category included, the average heat pump electricity use increases to 4,904 kWh per household per year. This whole program extrapolation is discussed more in Section 9.4.1.

Figure 26. Heat Pump Heating Electricity Use by Household (n = 78)

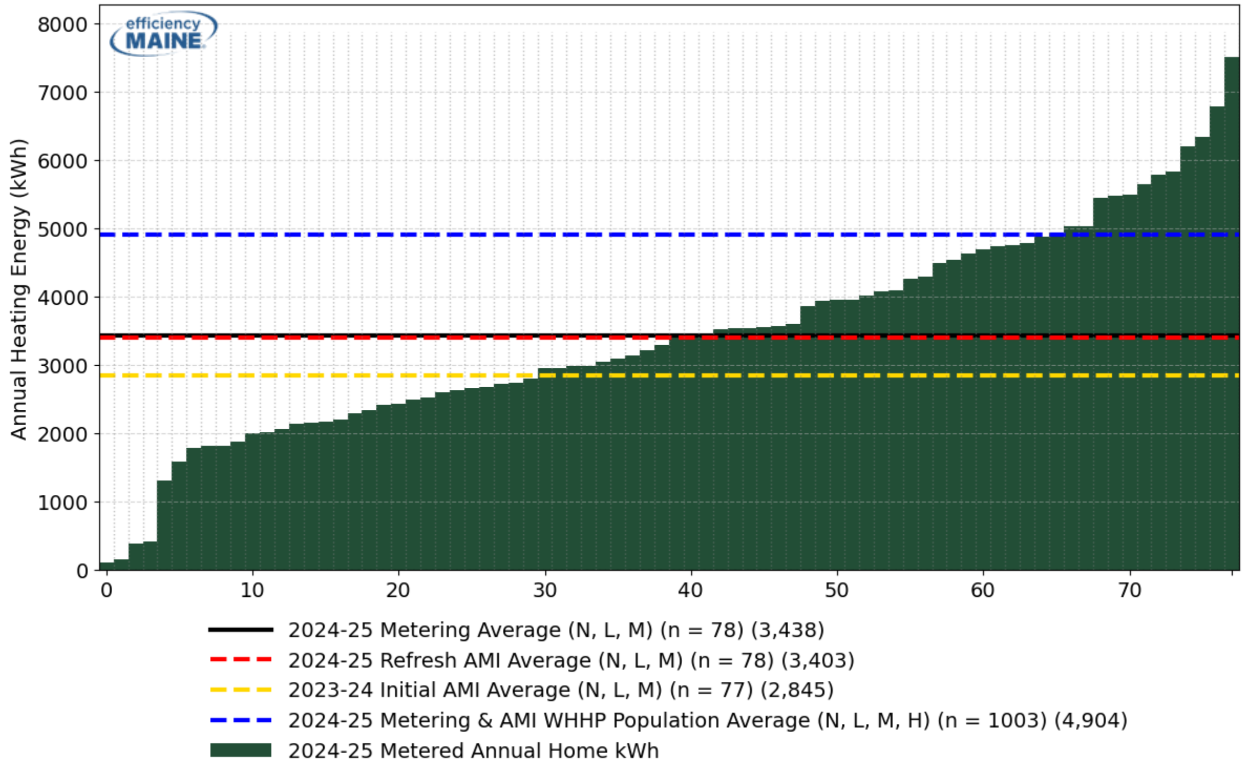


Figure 27 shows annual electricity consumption by heat pumps per household normalized to the household rated capacity of the heat pumps at 47°F as reported by AHRI ($kBtu_{rated}^{47}$). The average household electricity use is 3,438 kWh and the average installed capacity of heat pumps is 29.8 $kBtu_{rated}^{47}$ per household. The average normalized usage is 115 kWh per $kBtu_{rated}^{47}$ for metered homes. We expected that normalizing household electricity use by heat pump capacity would decrease variability and cause the data to revert to the mean. Specifically, we figured that a household with lower electricity use would also have smaller heat pumps and that the largest electricity users would have more heat pump capacity. From the analysis, the coefficient of variation (CV) for kWh is 0.443 and the CV for kWh / $kBtu_{rated}^{47}$ is 0.487, a slight increase in data dispersion. Given that normalization increased the data spread, electricity use does not apparently correlate with heat pump size.

Figure 27. Normalized Heating Electricity Use by Household kWh per $kBtu_{rated}$[47] (n = 78)

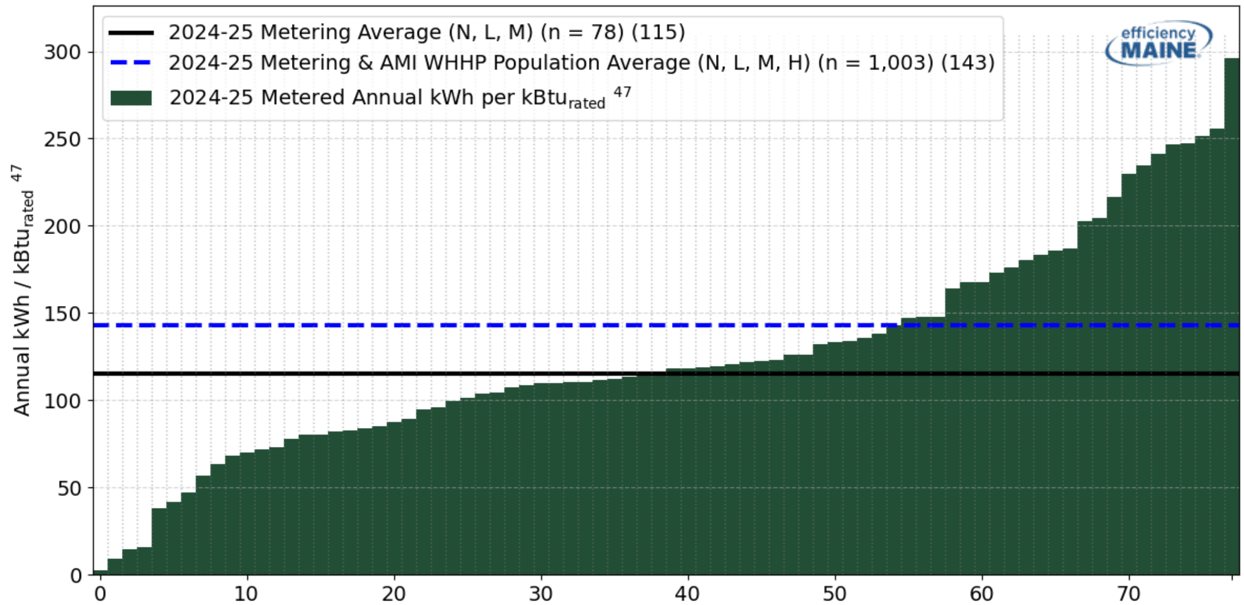
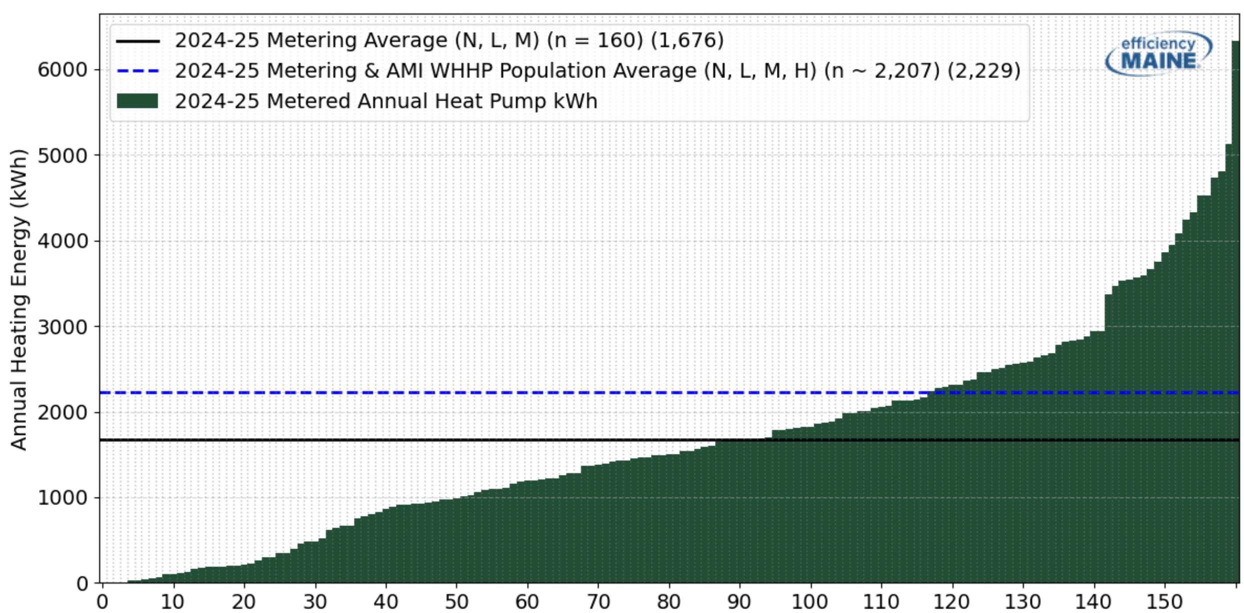


Figure 28 shows annual metered electricity consumption per heat pump. Usage per metered heat pump averages 1,676 kWh per year, where use varies widely among heat pumps. Electricity usage is a function of user behavior, zoning in the home, and the size and efficiency of the heat pump. For example, a 12,000 Btu_{rated}[47] unit operating at half capacity at 30°F, might only draw 600W. Even 3,000 hours at this operating point would barely exceed the mean value on this graph. The average metered usage per heat pump of 1,676 kWh is roughly half of the home-level average of 3,438 kWh as there were approximately 2.05 heat pumps per metered home.

Figure 28. Heating Electricity Use by Heat Pump (n = 160)



Using the metered data, Ridgeline then analyzed trends in heat pump power versus outdoor temperature and time of day. Figure 29 presents the average power usage of metered units versus outdoor air temperature. It shows both the average power of all units across the sample in orange (dotted) and only units that are actively operating in green (solid).

For Figure 29 through Figure 32, heat pumps are considered "actively operating" (or "On") if they draw power greater than a designated power threshold that scales positively with heat pump capacity. These thresholds are greater than zero to discount any small power loads, small metering noise, and low-power fan-only modes. These thresholds were also visually inspected to ensure that they accurately capture operational time only. The average power threshold across all 160 heat pumps was 0.175 kW, with the minimum being 0.150 kW. As heat pump capacity and size increase, this threshold increases. For example, a small unit with a 6,000 Btu_{rated}[47] would have a power threshold of 0.150 kW, but a larger 24,000 Btu_{rated}[47] ducted unit could have a higher power threshold of up to 0.300 kW. This is to ensure that only time periods with relatively significant power draw are considered "on" without unnecessarily discounting operation of smaller units.

Across the entire sample of 160 heat pumps, the average power draw peaks at 0.8 kW, at -10°F. As expected, the average power draw decreases as temperatures increase due to decreasing heating needs and increasing efficiency. Looking at only the heat pumps actively operating, the average power draw follows a similar shape but is higher. The ratio of the average power draw of all heat pumps versus operating heat pumps is about 0.8 at low temperatures, and it is about 0.5 for warm temperatures, showing the impact of load diversity at warm temperatures and low home heating loads. If all heat pumps were used to heat for all temperatures, one would expect the two curves to move closer together at very low temperatures. Instead, the power curve of all heat pumps flattens out at 0°F, possibly indicating that a portion of heat pumps switch off at 0°F.

Figure 29. Average Electrical Power of All Heat Pumps vs. Outdoor Temperature (n = 160)

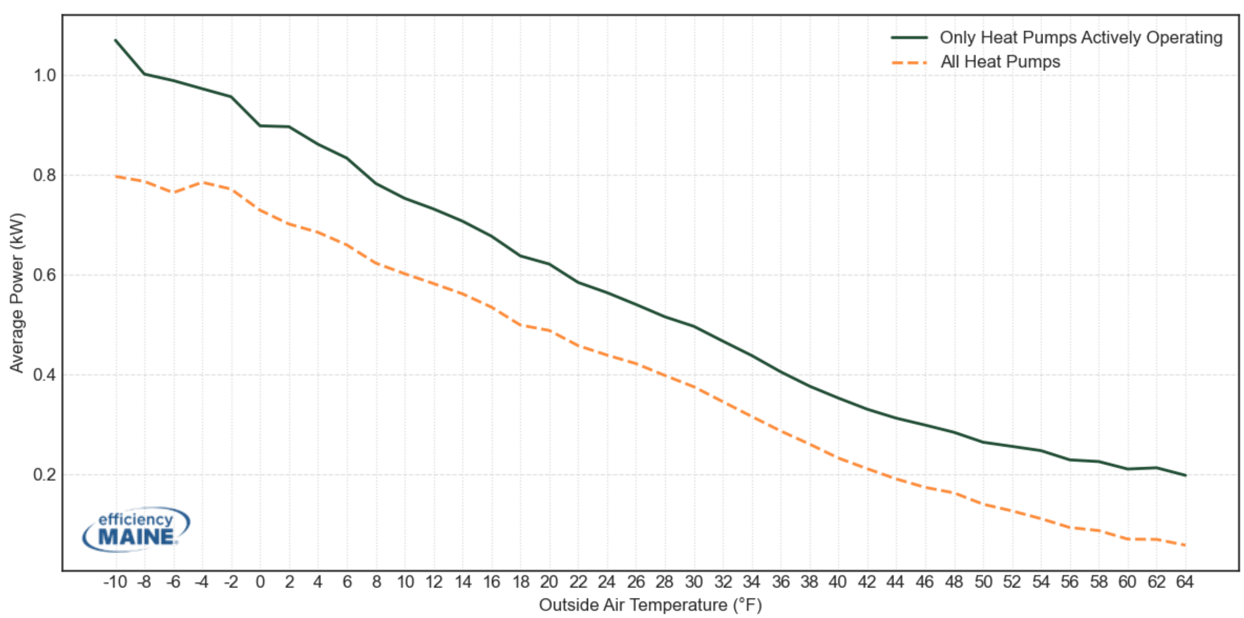


Figure 30 shows the average winter day power usage of metered units by time of day. The "average winter day" is based on temperatures across all metered days from late November through early May. Average heating demand ranges from about 0.3 to 0.5 kW. The peak load occurs from 6 to 7 A.M., which is the coldest portion of most days (around dawn) and is when many families wake up. The minimum load occurs in early afternoon, around 1 to 2 P.M., when many occupants are away from home and outdoor temperatures rise.

Figure 30. Average Power Consumption vs. Time of Day per Heat Pump (n = 160)

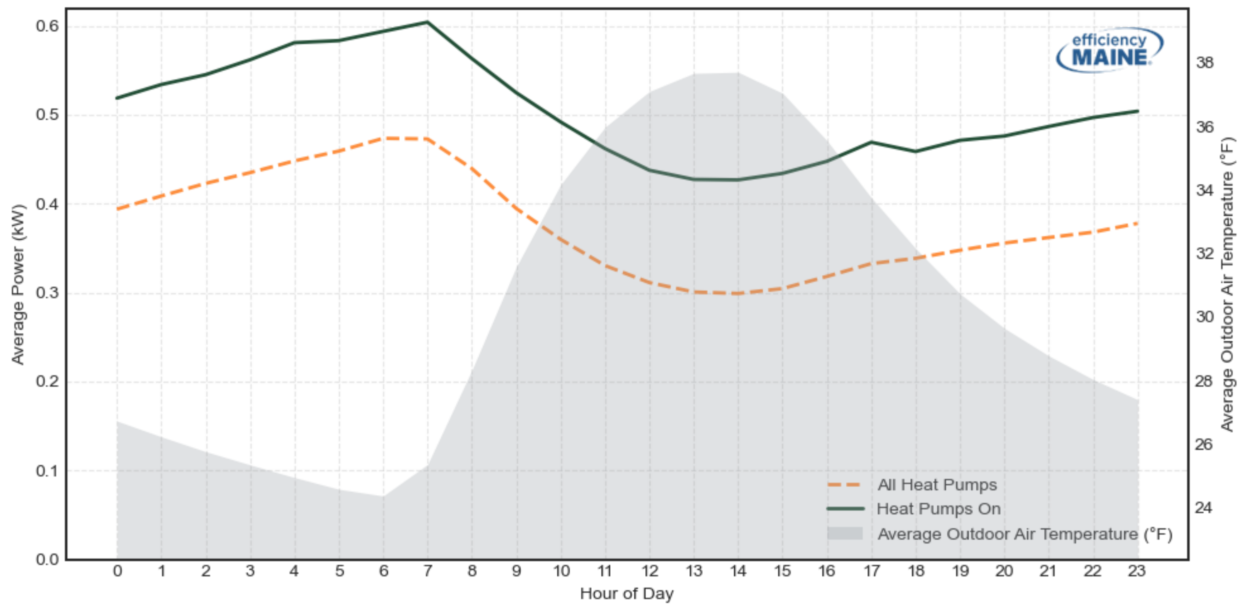
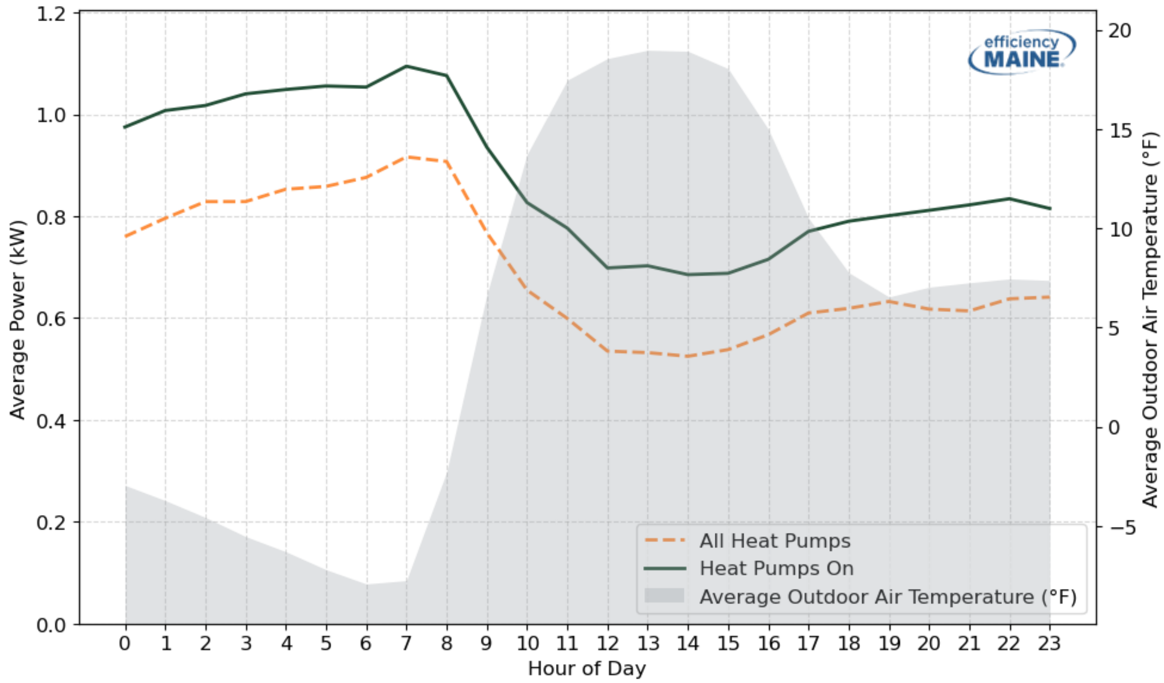


Figure 31 shows the average power consumption across all heat pumps in the metering sample for January 22, 2025, the coldest day of the 2024-25 metering period. On this day, average site temperatures fell below -5°F, and peak power exceeded 1 kW per heat pump, on average. Compared to the average winter day, the peak occurred an hour later, between 7 and 8 A.M.

Figure 31. Average Power Consumption vs. Time of Day for Coldest Day (1/22/25) in Metering Period, per Heat Pump (n = 160)



To investigate potential regional differences in heat pump usage, the time-of-day analysis was replicated on four individual regions within the larger metered sample. Figure 32 shows the average power of all heat pumps grouped into these four regions: Auburn-Lewiston, Augusta, Bangor, and Portland. Although the sites were annualized using 10 unique weather stations, we grouped each site into one of these four regions to preserve the individual group sample sizes for comparison. Heat pumps were assigned to cities based on closest geographic proximity, and the resulting regions closely align with the EffRT WHHP program data design locations. Figure 33 maps the homes by their assigned region: yellow for Portland, green for Auburn-Lewiston, blue for Augusta, and orange for Bangor. Note that these reporting region bins are distinct from the 10 weather stations used in the annualization to the entire winter 2024-25 season.

When comparing the 4 regions, one can see that the Bangor region experienced the coldest average temperatures and that the Portland region experienced the highest on January 22, 2025. Additionally, the average power draw of operating heat pumps in the Bangor region peaked at the highest levels of around 1.3 kW at 8 A.M. The Augusta and Portland regions both experienced the lowest peaks around approximately 1 kW. Notably, there appears to be a smaller difference between the average power draw of all heat pumps and all actively operating heat pumps in the Portland region, suggesting that homes in the Portland region had higher metered heat pump usage rates on the coldest day of the year compared to the other regions. More on these regional differences in heat pump power is discussed in Appendix D: Regional Differences in Heat Pump Operation.

Figure 32. Average Power Consumption vs. Time of Day for Coldest Day (1/22/25) in Metering Period Across 4 Regions (n = 160)

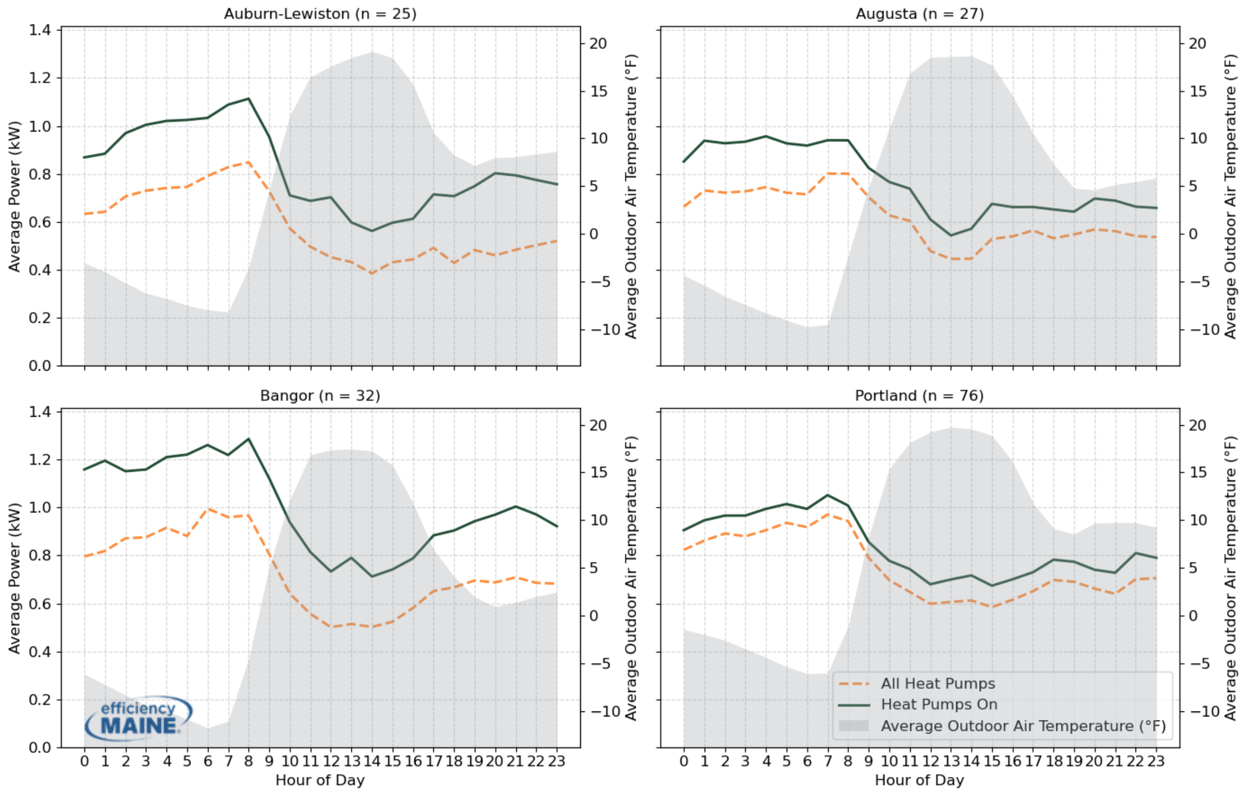
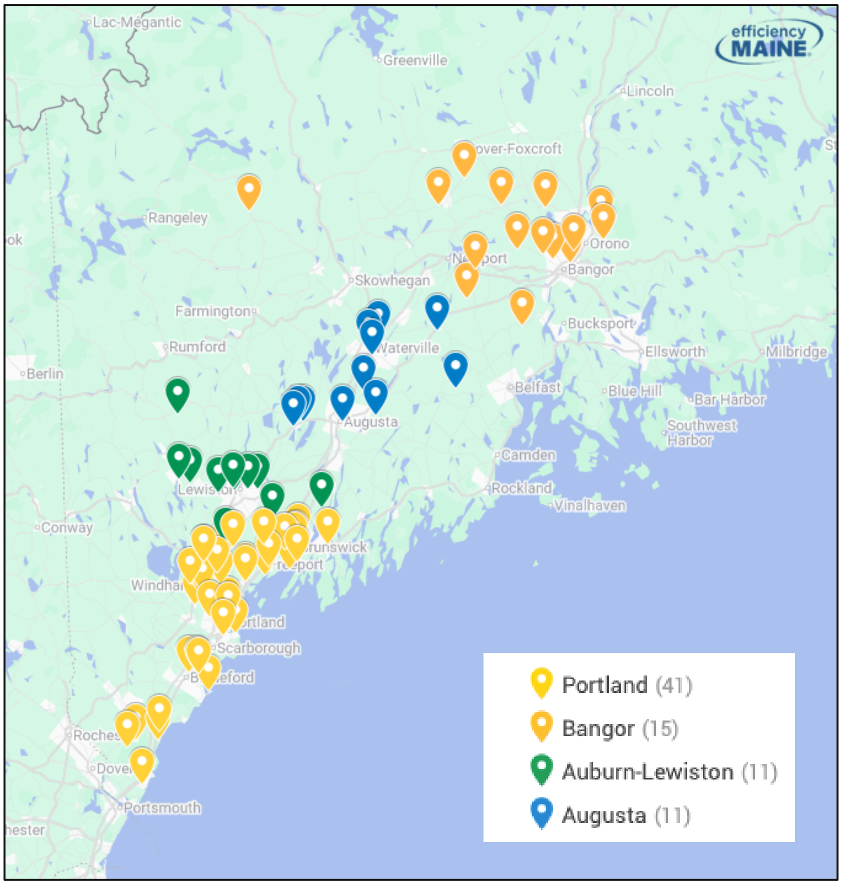


Figure 33. Map of Homes Binned by 4 Reporting Regions



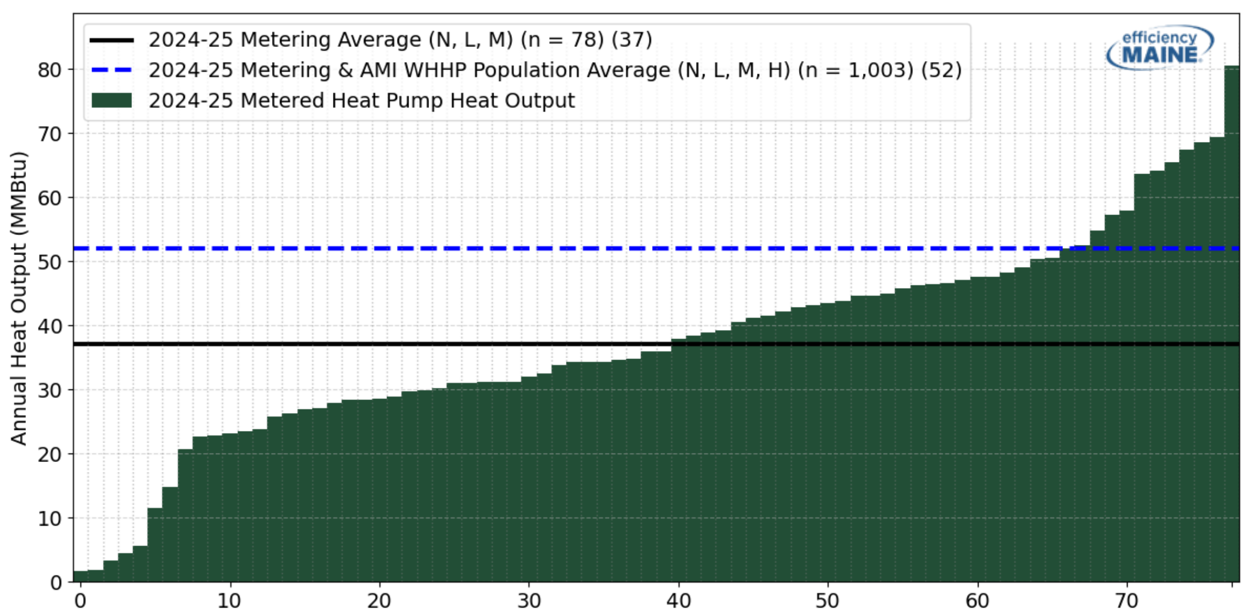
6 METERED HEAT DELIVERED BY ALL HEAT SOURCES

This chapter discusses the heat output metered by Ridgeline across all heating sources at the 78 homes in the metering sample. As previously mentioned, Ridgeline metered the heat output from not only the heat pumps but also across all boilers, furnaces, spot fossil heaters, wood and pellet stoves, and electric resistance elements present at a given home.

6.1 METERED HEAT PROVIDED BY HEAT PUMPS

Firstly, narrowing in on the heat pumps only, Figure 34 shows the heating provided by heat pumps to the 78 metered homes, delivering a mean value of 37 MMBtu per home per year. Extrapolating this value to include homes originally categorized as High users that were omitted from the metering sample, as discussed in Section 9.4.1 of this report, the average heating delivered by heat pumps rises to 52 MMBtu per home per year. For context, 1 MMBtu is equivalent to about 9 gallons of fuel oil at a boiler or furnace effective efficiency of 80%.[26] The average heat provided by these heat pumps is thus equivalent to about 468 gallons of fuel oil. Based on the average home size of metered homes, 1,337 square feet, this is about one-third of a gallon of oil per square foot per year.

Figure 34. Annual Heating Provided by Heat Pumps by Household (n = 78)

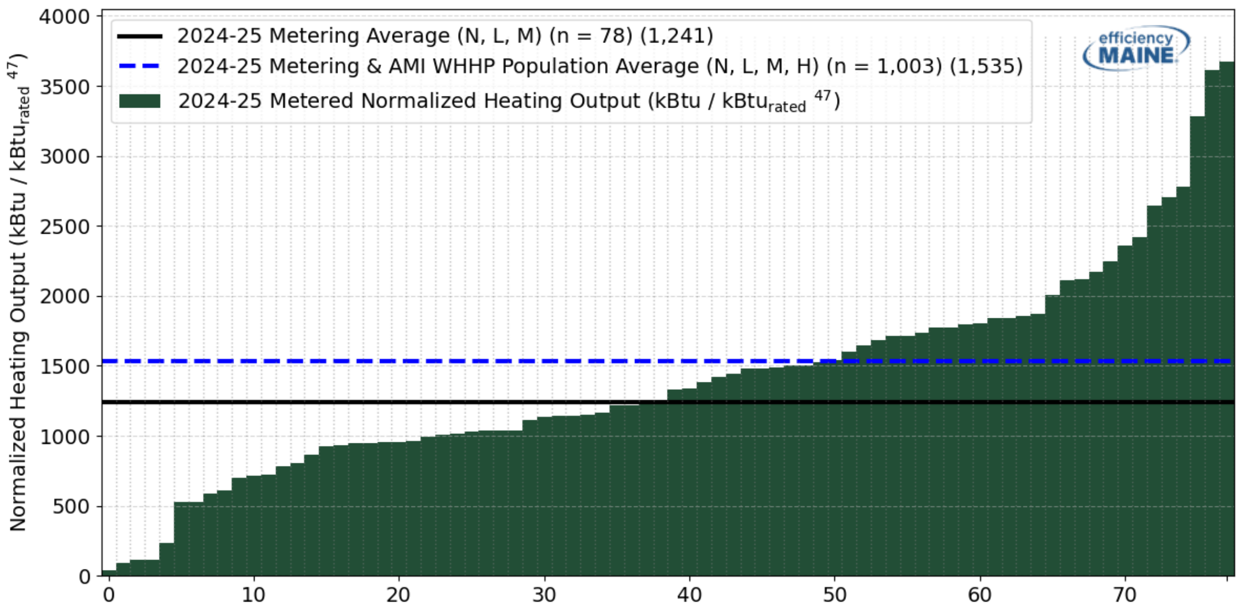


The heating outputs normalized by household $kBTU_{rated}$[47] are shown in Figure 35. The pattern of the curve is similar, but the apparent outlier on the right side of the non-normalized graph is transformed

[26] While nominal combustion efficiencies can be higher than this, heat is lost in piping, duct leakage, and at the furnace or boiler. Effective efficiency reflects how much heat ultimately enters the occupied space.

into a smooth curve of high users. The average normalized heating output to $kBtu_{rated}$[47] was 1,241 hours among the metered sample and 1,535 hours among the entire WHHP population.

Figure 35. Household Heating Provided by Heat Pumps Normalized by $kBtu_{Rated}$[47] (n = 78)



The heating statistics discussed in this chapter are summarized in Table 12. The average heat provided per household in the metered sample of homes previously categorized as Negative, Low, and Medium users was 37 MMBTU per year, and this value increased to 52 MMBTU per year when High users are extrapolated in. The table also shows statistics per heat pump and statistics normalized by heat pump capacity.

Table 12. Summary Statistics for Heating Provided by Heat Pumps

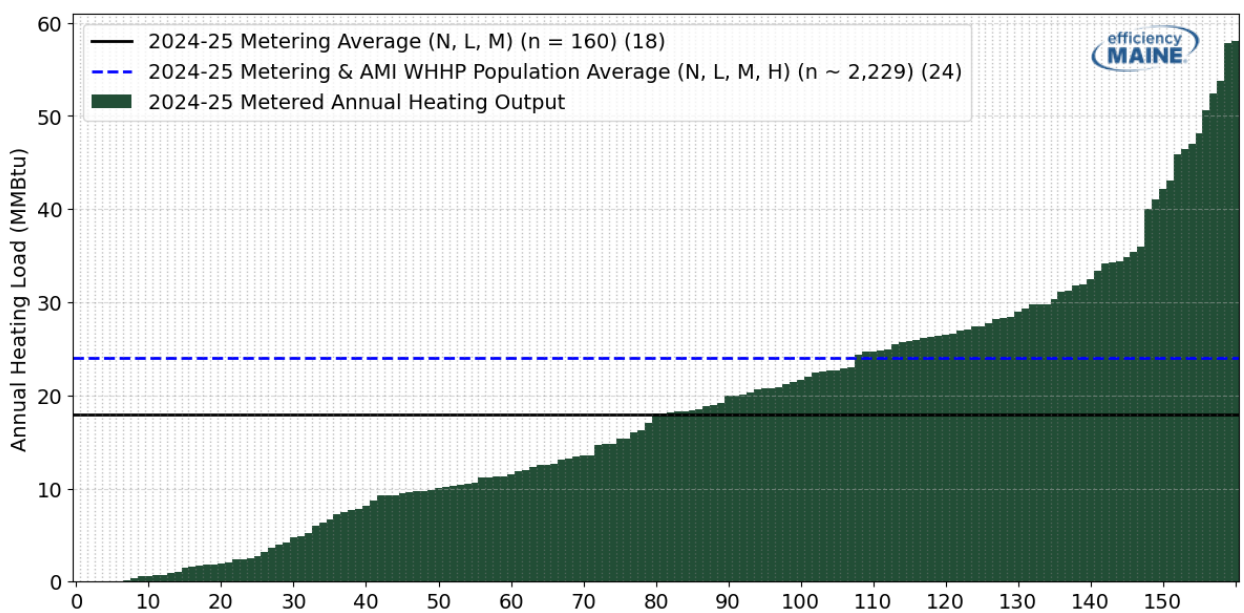
Method Name	Marker	N	Usage Groups	Calculation Method	MMBtu / Home	MMBtu / HP	kBtu / $kBtu_{Rated}$[47]
2024-25 Metering	Solid Black Line	78	N, L, M	Measured by on-site metering equipment during winter 2024-25, for homes characterized by 2024 AMI as negative, low, or medium users (annualized to entire heating season 2024-25).	37	18	1,241

2024-25 Metering & AMI (WHHP Population)	Blue Dashed Line	1,003	N, L, M, H	Modeled using refreshed AMI data from winters 2023-24 and 2024-25 (annualized to TMY3). This is discussed in Chapter 9 of this report.	52	24	1,535

Now, stepping down to the heat pump level, Figure 36 shows the heating provided by all 160 heat pump outdoor units in the metering sample. The mean value was 18 MMBtu per heat pump per year, and there was a large range of heating outputs across the sample. When extrapolating to the entire WHHP population with the High users tied in, this average increases to 24 MMBtu per heat pump per year. Nearly 30% of the heat pumps provided less than 10 MMBtu per year.[27]

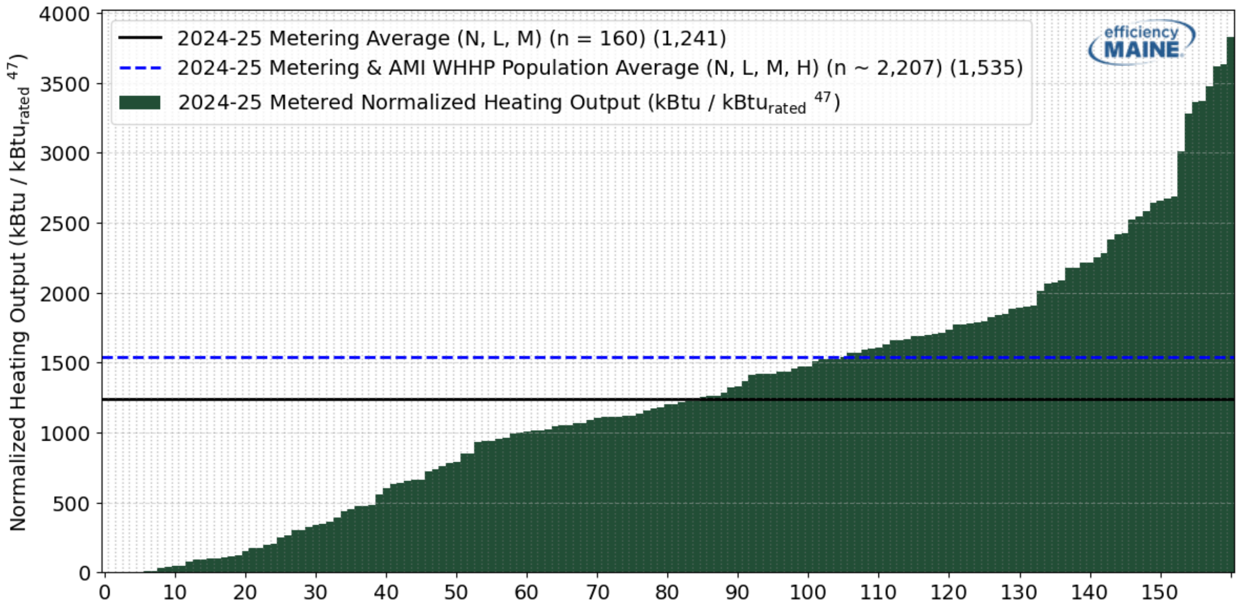
The heating outputs normalized by heat pump capacity are shown in Figure 37. The pattern of the curve is similar. The average normalized heat output by $kBtu_{Rated}$[47] remained at 1,241 hours for the metered sample and 1,535 hours for the entire WHHP population.

Figure 36. Heating Provided per Heat Pump Unit (n = 160)



[27] For reference, 10 MMBtu is equivalent to the heat output of 90 gallons of oil, combusted at 80% effective efficiency.

Figure 37. Heating Provided per Heat Pump by $kBtu_{rated}$[47] (n = 160)

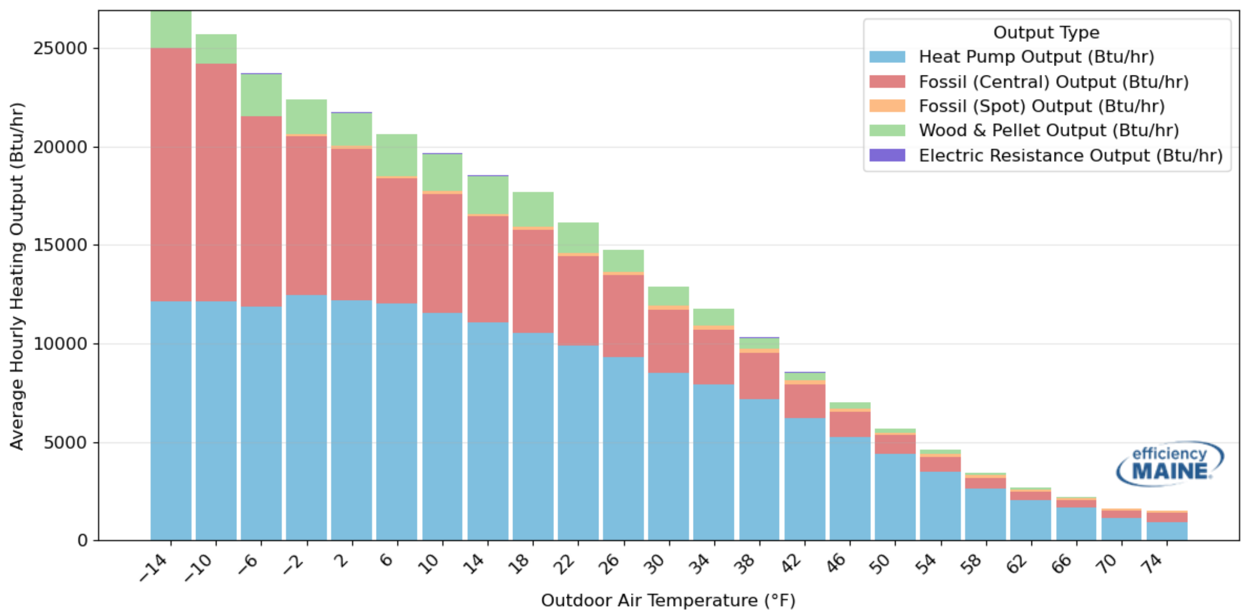


6.2 METERED HEAT PROVIDED BY ALL HEAT SOURCES

6.2.1 Metered Heat versus Outdoor Temperature

Figure 38 shows the rate of metered heat provided by five sources of heat – heat pumps, central fossil fuel systems, spot fossil fuel systems, wood and pellet stoves, and other non-heat pump electric heating systems – across a range of outdoor air temperatures. As expected, the average heat provided to balance a home's heat loss is roughly linear from nearly no heat needed at 62°F to maximum heat needed at -14°F. Heat provided by heat pumps rises linearly until about 6°F, then levels off.

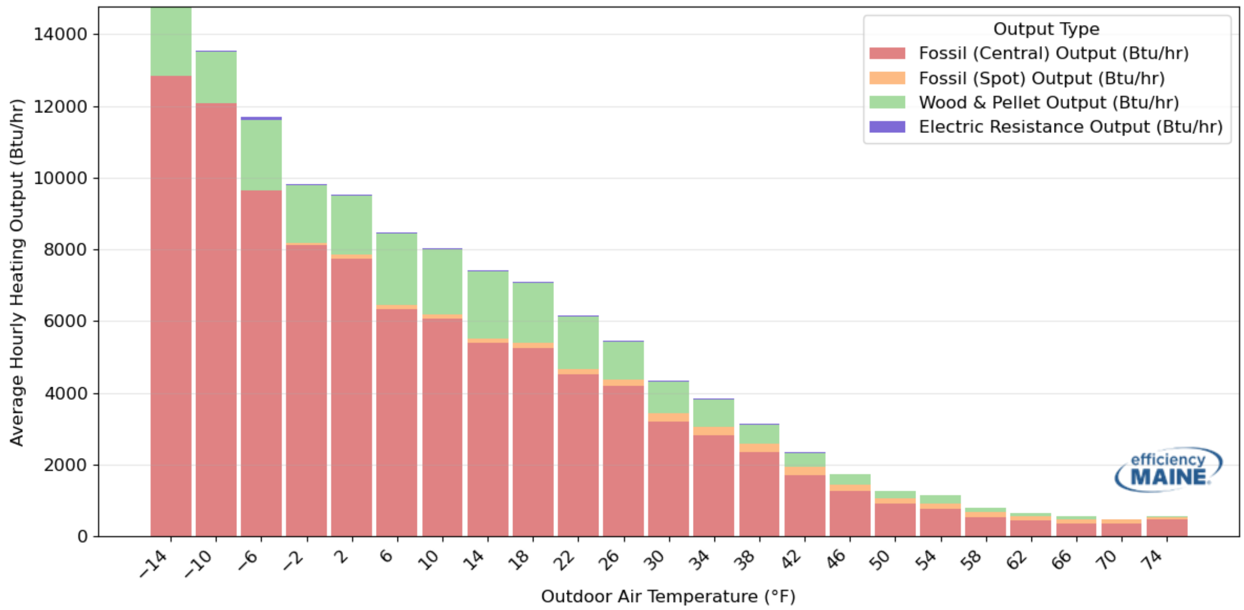
Figure 38. Average Heat Contributed by Heat Source versus Outdoor Temperature (n = 78)



To gain a clearer picture of non-heat pump use, Figure 39 shows the balance of heat (beyond what was provided by the heat pumps) from non-heat pump sources. Very little heat is provided by fossil fuels above 40°F, and this little amount of heating above 40°F is likely from several homes that, even though they have heat pumps, heat exclusively with fossil fuels. Fossil fuel use rises below 10°F, where heat pump utilization plateaus, as shown in Figure 38. Since outdoor temperatures ranging from 10°F to 40°F are the most frequent, increased fossil use at temperatures below 10°F (less frequent) has a modest annual impact. While there are many hours with temperatures above 40°F, little heat is needed. Wood heat is also barely used above 40°F, and wood accounts for a roughly static portion of heat provided below 30°F.

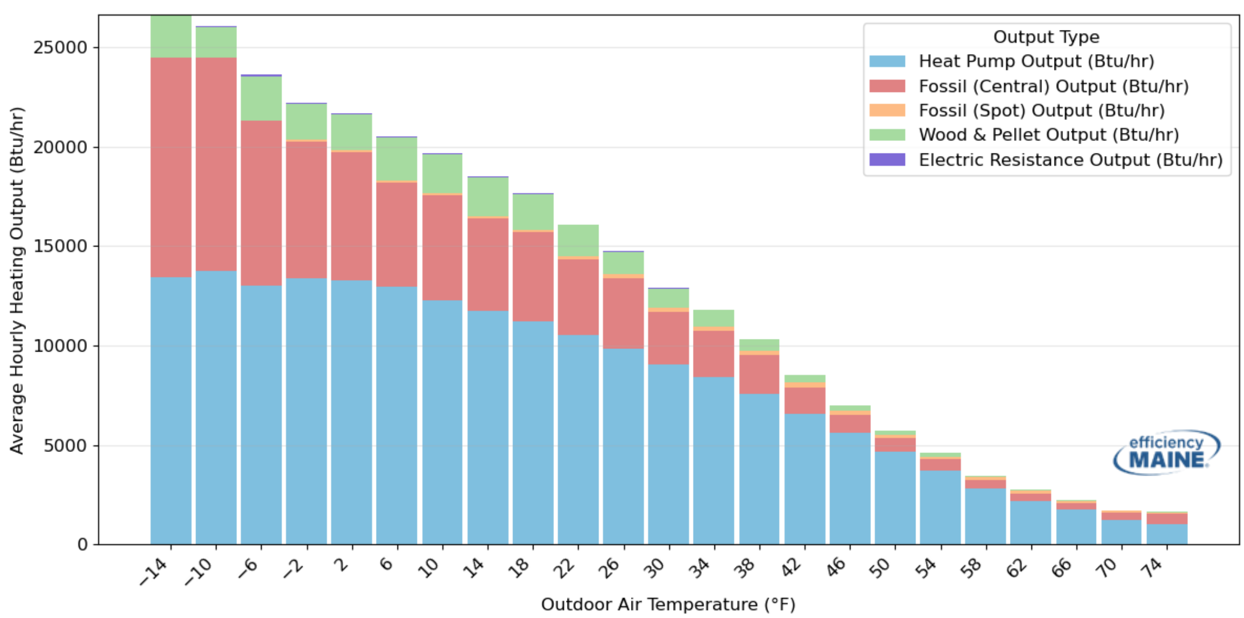
Although 13% of homes in this study possessed some form of electric resistance (ER) heating, only one home regularly used it. Of the two ducted heat pumps in the study, one had auxiliary ER but did not use it based on interviews and metering, and the other did not have any auxiliary ER. Spot fossil fuel heating also had marginal impacts on the total average heating load across the metered sample.

Figure 39. Balance of Heating Provided by Non-Heat Pump Heat Sources versus Outdoor Temperature (n = 78)



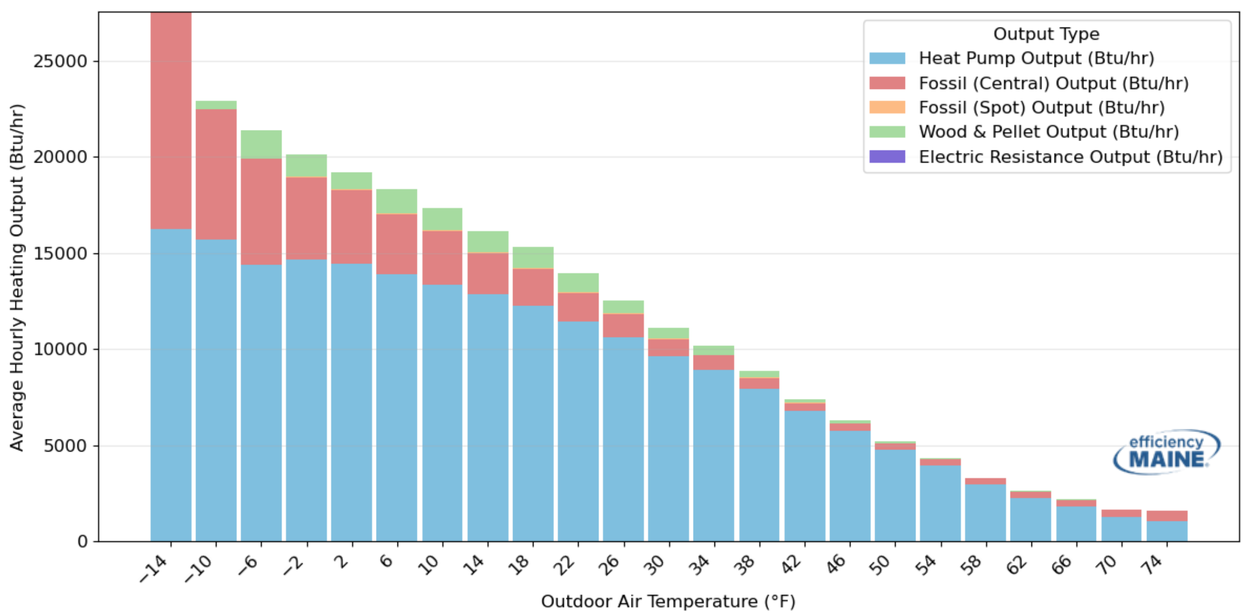
Re-examining Figure 38 and removing the five lowest users of heat pumps that rarely use their heat pumps for heating, shifts the curve slightly, where little fossil fuel use occurs above 30°F (Figure 40). Removing the lowest five homes, a subset of the WHHP population that has less-than-expected heat pump utilization, from the metering sample is representative of removing the lowest 4% from the general WHHP population. These lowest five homes were identified based on the percentage of total household heat provided by heat pumps.

Figure 40. Average Heat Contributed by Heat Source by Outdoor Temperature—Lowest 5 Removed (n = 73)



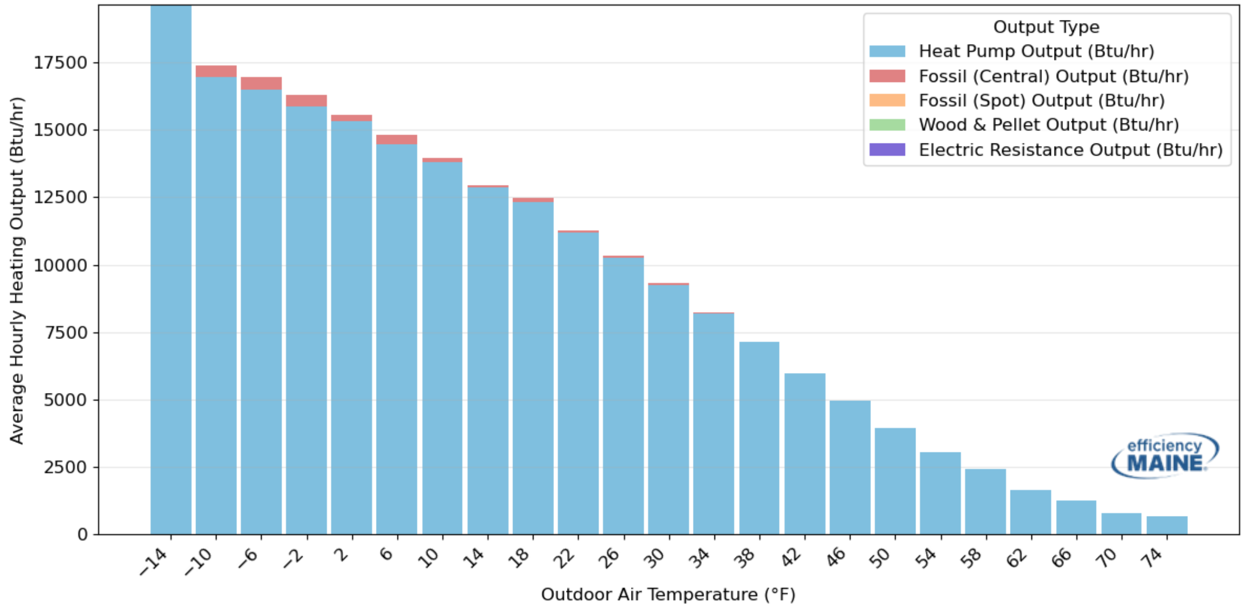
Going further and removing the bottom third of users of heat pumps from the sample of metered homes focuses on the use cases in which behavior and zoning made better use of their heat pumps. Removing the lowest one-third of homes, a subset of the WHHP population that has less-than-expected heat pump utilization, from the metering sample is representative of removing the lowest 22% from the general WHHP population. As shown in Figure 41, there is little fossil fuel use at 10°F, and even at 0°F, fossil use is modest compared to heat pumps among the two-thirds of homes that made better use of their heat pumps.

Figure 41. Average Heat Contributed by Heat Source by Outdoor Temperature—Lowest Third Removed (n = 53)



To examine what is possible in homes that make better use of their heat pumps, we examined the one-third of metered homes that demonstrated a higher percentage of total heat provided by heat pumps and removed the remaining two-thirds of the metered homes. The results are shown in Figure 42. (Recall also that the metered sample represents only the lower two-thirds of the population by heat pump electric use). Removing two-thirds of the metered sample is like removing the lower 45% of the total population, that is, about half. Considered this way, Figure 42 is encouraging. Among this population, the portion of heat provided by fossil fuels is very low, showing that many homes can and do rely completely on heat pumps for heating.

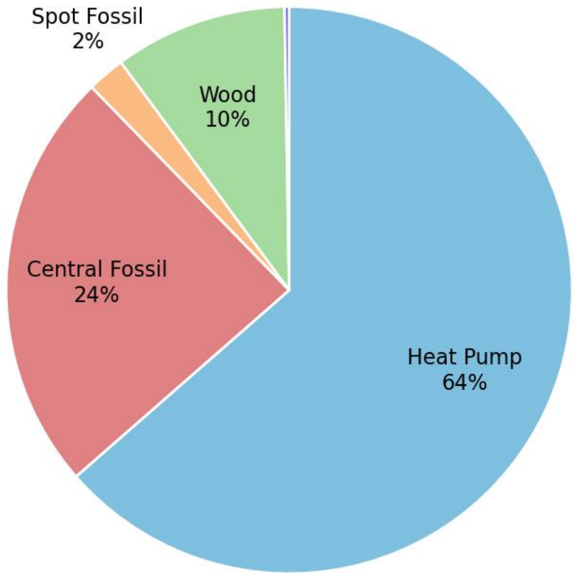
Figure 42. Average Heat Contributed by Heat Source by Outdoor Temperature—Lowest Two-Thirds Removed
(n = 26)



6.2.2 Metered Heat Output by Heat Source

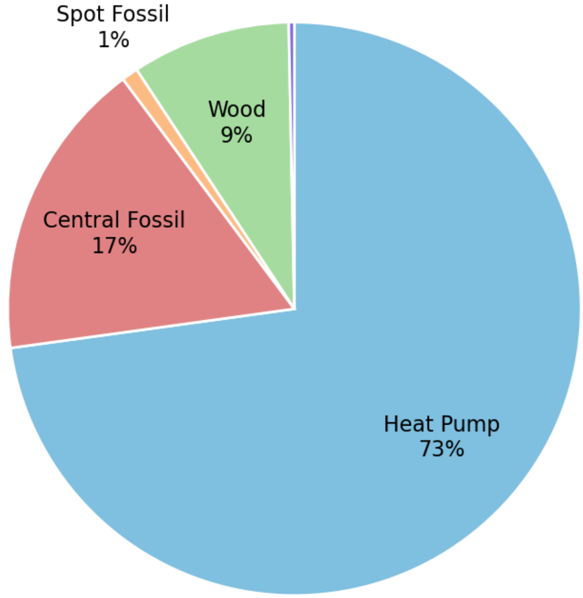
The proportion of heat (MMBtu) provided by the five heat sources noted previously across all temperatures and all homes is shown in Figure 43. As previously discussed, the metered sample is representative of the bottom 67% of the general WHHP population in terms of cold-weather-dependent electric use (since the top-performing one-third of users were excluded from the metering study). Across the sample, including homes that use their heat pumps infrequently, heat pumps provide about 64% of the total heat. Central fossil heating through boiler and furnace use represents the second largest portion at 24%.

Figure 43. Heating Provided to All Metered Homes by Heat Source (n = 78)



Removing the bottom 10 homes that infrequently use their heat pumps for heating (< 0.8 MMBtu / $kBtu_{Rated}$[47]), heat pumps provide about 73% of heat (Figure 44). This value is representative of program results if those homes that effectively do not use their heat pumps for heating could be screened out of the program, or their heat pump use increased to that achieved by the remaining 68 metered homes.

Figure 44. Heating Provided to Metered Homes by Heat Source—Lowest 10 Removed (n = 68)



The percentages in Figure 43 and Figure 44 reflect homes that were originally categorized by AMI as exhibiting negative, low, and medium levels of usage. If we repeat the analysis above and extrapolate to the entire population metered and not metered, we get the heating percentages as shown in Table 13.

Table 13. Relative Contribution to Home Heating, by Heat Source

Analysis	Heat Pump	Wood	Fossil	Usage Groups	Comments
Metering Analysis	64%	10%	26%	N, L, M	Metered lowest two-thirds of heat pump users.
Whole WHHP Population	71%	10%	19%	N, L, M, H	Extrapolated to WHHP program population.
Metering – lowest 10 removed	73%	9%	18%	N, L, M	Removed the lowest 10 users, simulating program incentivizing heating users only, but still for the lowest two-thirds of users.
WHHP Population – bottom 9% removed	77%	9%	14%	N, L, M, H	Removed the lowest 10 users and extrapolated to WHHP program population.

To gain a better understanding of the heating distribution at the individual home level, stacked column charts like Figure 38 were produced for each home in the metering sample. Figure 45 shows the results at a single home (Home # 147) equipped with two heat pumps having capacities of 14 $kBtu_{Max}$[5] and 11 $kBtu_{Max}$[5], respectively. These heat pumps are capable of providing all of the home's heating needs at 5°F, which is roughly 24,000 Btu/h. The graph shows that the home continuously used its heat pumps, even during the coldest temperatures of the winter, but also used the boiler for heating any time the outdoor temperature sank below 40°F. This concurrent operation of the boiler with the heat pumps blunts additional heat pump use below that temperature. In Home #147, the heat pumps provided about 70% of the home's heat in the 2024-25 winter season.

Figure 45. Home #147: Frequently used Mitsubishi 12 $kBtu_{Rated}$[47] unit and less frequently used 6 $kBtu_{Rated}$[47] unit

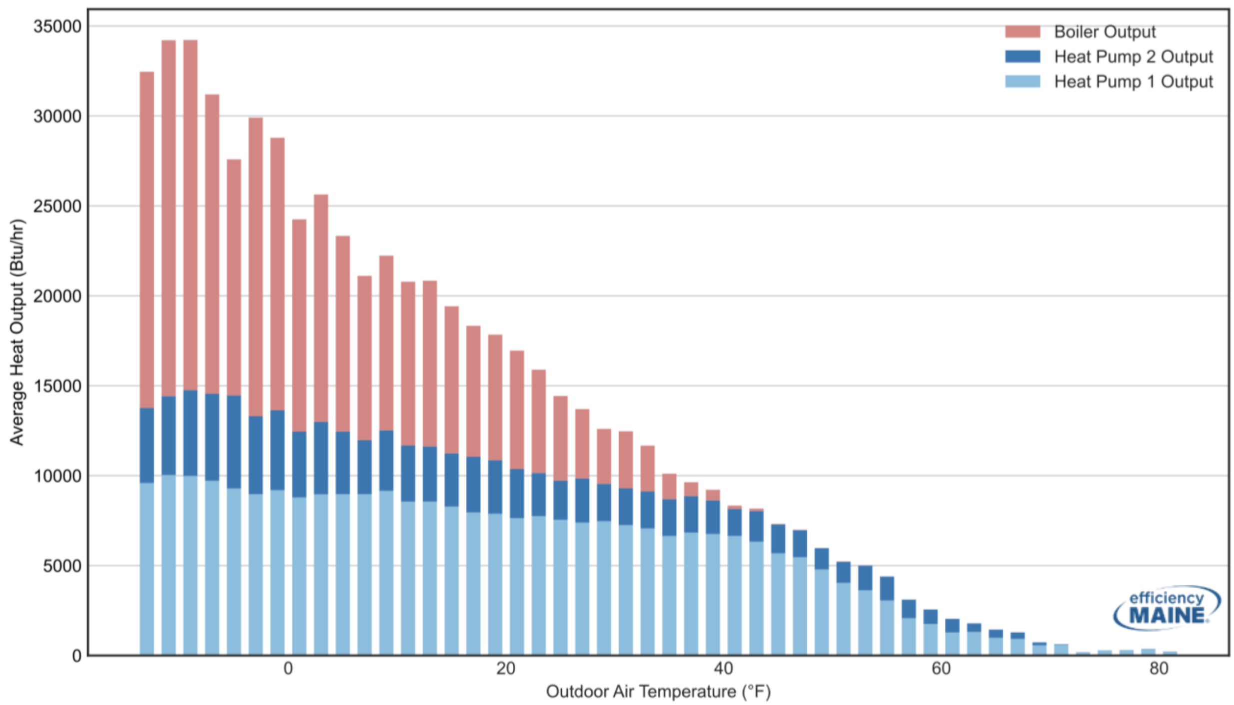
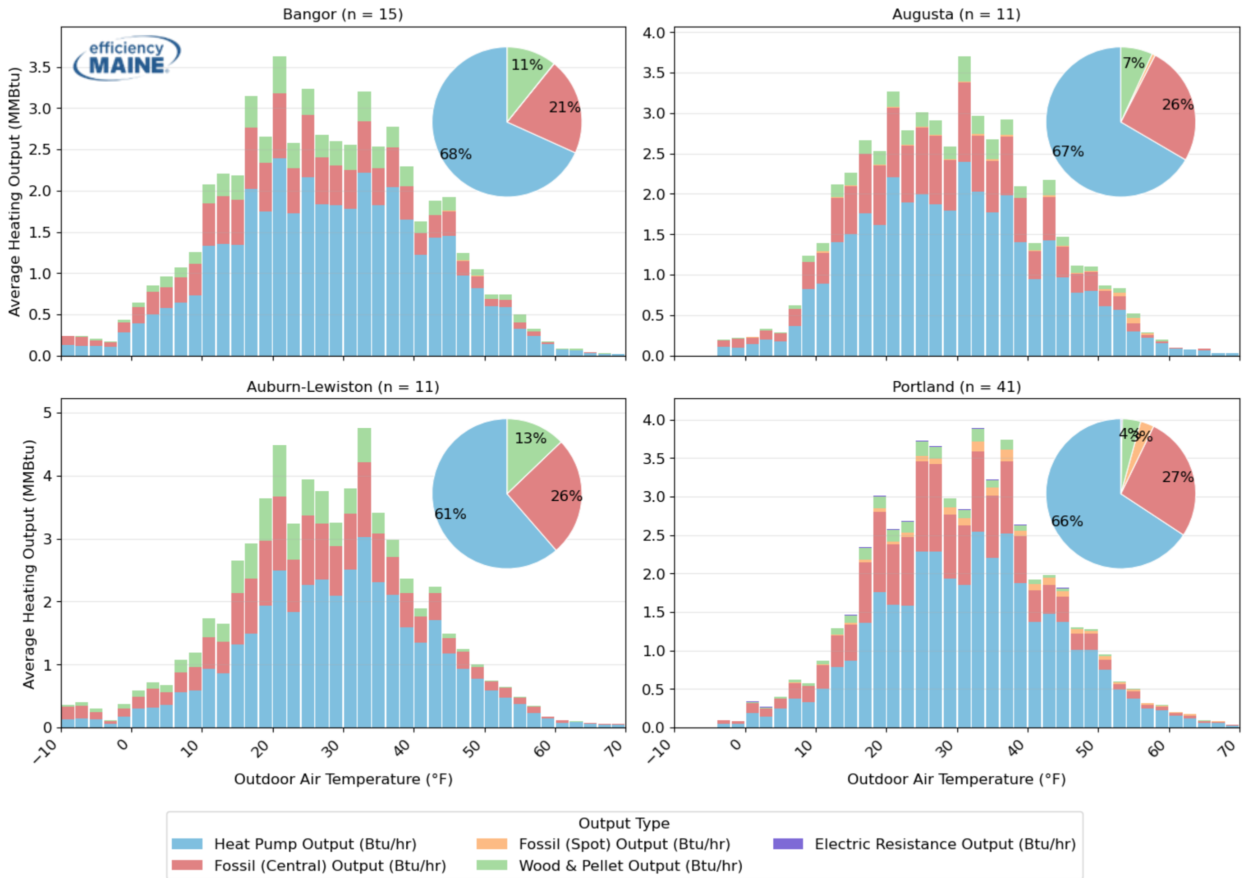


Figure 46 shows the annual heat output distribution (MMBtu) for the four regions binned in Section 5.1.2 of this study. For each region, we calculated a region-specific average heating output distribution in Btu/h and applied it to the outdoor air temperature distribution from the nearest weather station for the 2024-25 heating season.

While the graphs vary slightly, they show that most heat is delivered for temperatures between 10°F and 40°F, and these are the temperatures critical to a heat pump delivering the majority of a home's heat. Home 147 in Figure 45 is located in the Bangor area, and that figure shows that, had the homeowner turned on the boiler at 5°F instead of 40°F, considerably more of the home's annual heat load would have been provided by heat pumps.

Figure 46. Heating Across Cities (n = 78)



Examining the sources providing heat across the 78 metered homes, homes that use the most total heat generally use substantial amounts of heat from other (non-heat pump) sources (Figure 47). Re-sorting homes by amount of heat pump use, homes that use their heat pumps the least make substantial use of other heat sources, as expected (Figure 48). It appears that the lowest users of heat pumps include some of the higher users of total heating.

Figure 47. Contributions to Total Heating by Heat Source, per Metered Home (n = 78)

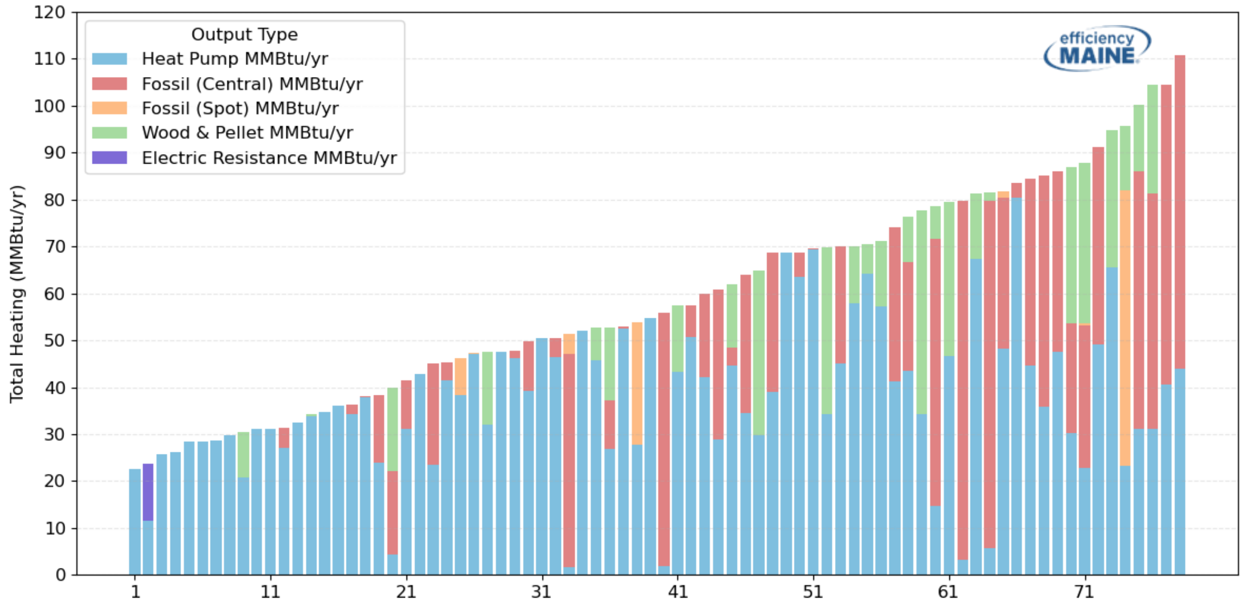
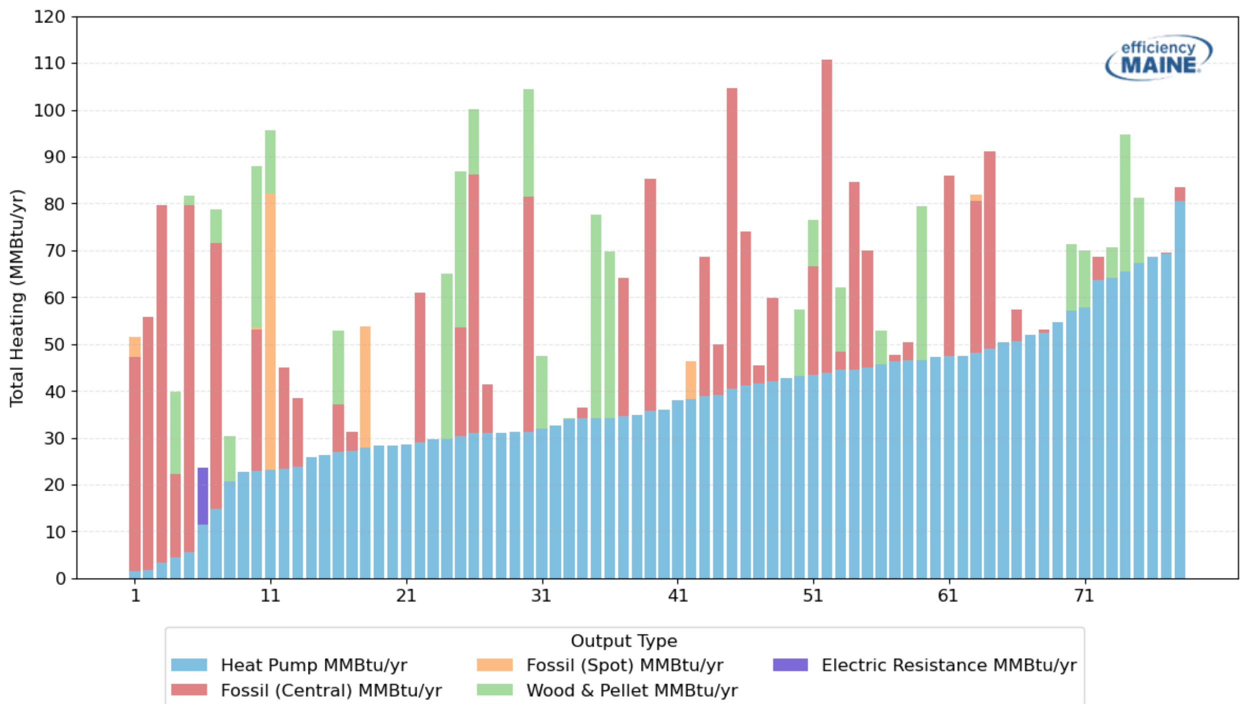


Figure 48. Contributions to Total Heating by Heat Source, per Metered Home, Ordered by Heat Pump Output (n = 78)



Combining the previous graphs with percentage of heat provided by heating source, it is notable that several of the lowest users of heat pumps are among the higher users of total heat (Figure 49). Sorting by percentage of heat provided by heat pumps, the pattern is more pronounced. The lowest users of heat pumps, by percentage of heat load met by heat pumps, include the four highest users of heat and half of the 15 highest users of heat (Figure 50).

Figure 49. Contributions to Total Heating by Heat Source, per Metered Home, Ordered by Heat Pump Output, with Percent Heat Pump Heating
(n = 78)

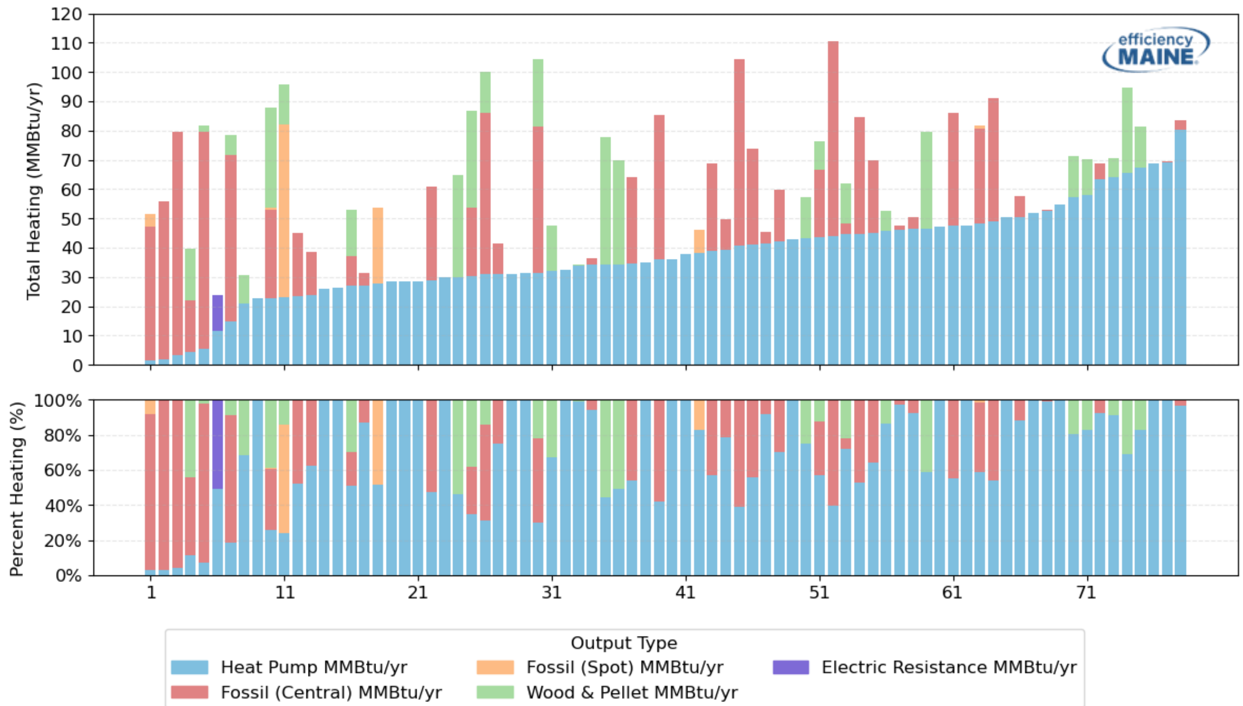
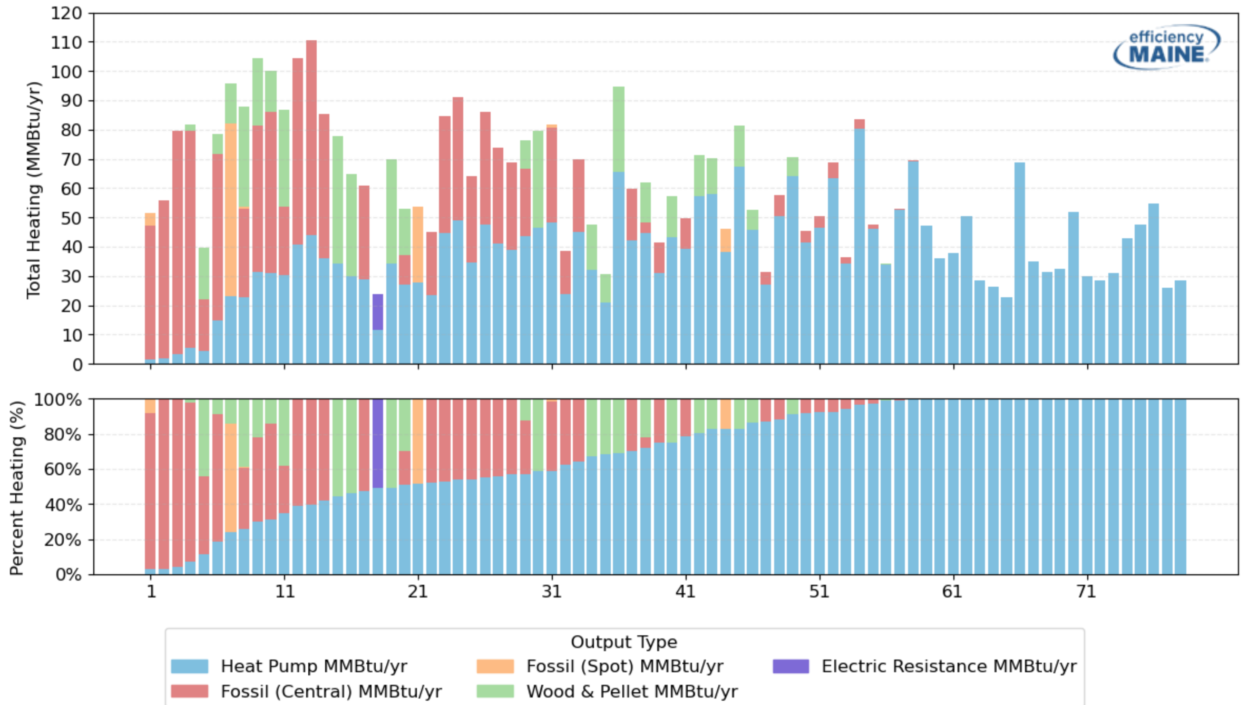


Figure 50. Contributions to Total Heating by Heat Source, per Metered Home, Ordered by Percent Heat Pump Heating (n = 78)

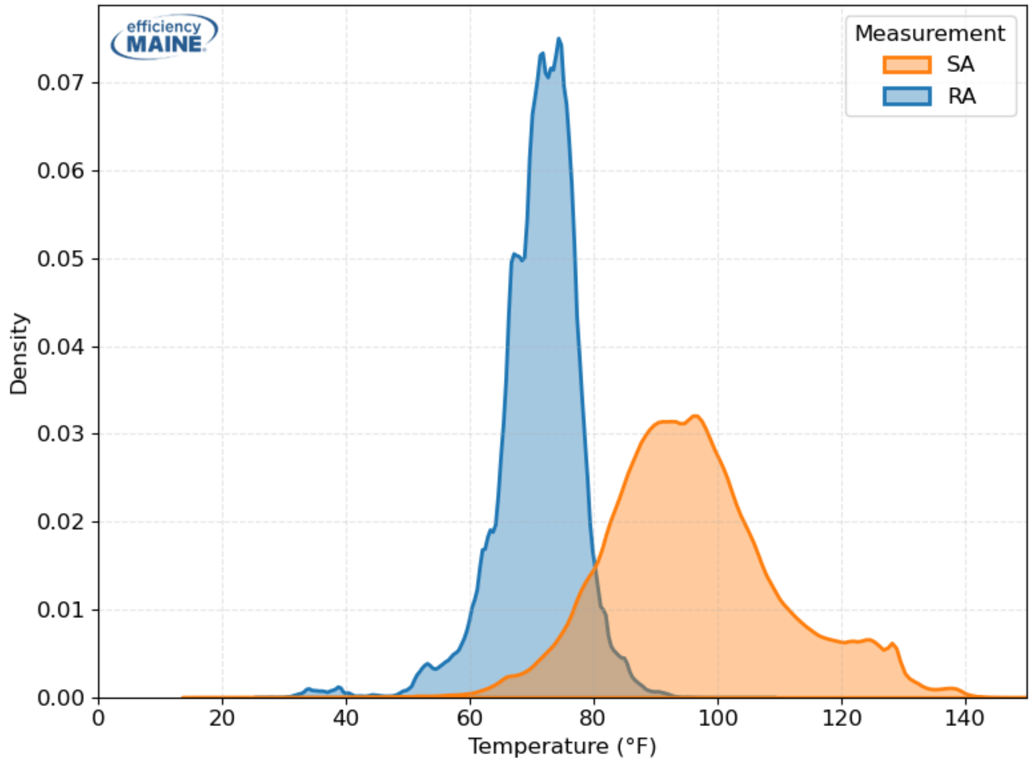


6.2.3 Metered Supply and Return Temperatures

Figure 51 is a histogram that shows the frequency of temperature readings of supply and return air for all indoor units metered. The most frequent return temperature was 72.5°F, with most readings occurring from 68°F to 78°F. Nearly all readings were between 65°F and 80°F. (The small peak at 40°F may indicate that several homes set their temperatures to a minimal setting for a period while the occupants were away from the home.) While the return temperature is indicative of the temperature of the heated space, it is generally higher than the temperature experienced by occupants. This occurs because nearly all units are wall-mounted near the ceiling. Due to stratification of room temperatures, the temperature near the ceiling is typically higher than the temperature nearer the floor where occupants reside.

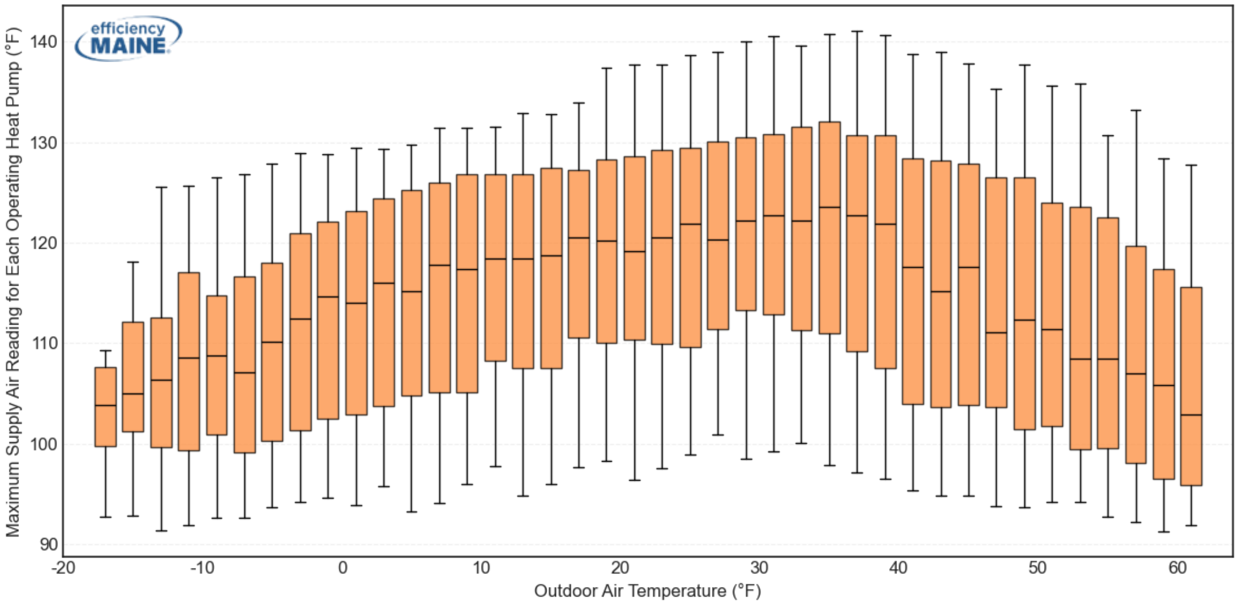
The supply (heating) air temperature had a broad peak between 80°F and 120°F, with warmer temperatures in the 120°F to 140°F range. The heating temperature will depend on internal algorithms of the heat pump and outdoor temperatures. At very cold temperatures, supply temperatures may drop with capacity.

Figure 51. Supply Air (SA) and Return Air (RA) Temperature Frequency (n = 166)



In order to assess the impact of outdoor temperature on heat pump supply temperatures, the metered supply temperatures were also plotted for outdoor temperatures from -18°F to 62°F in Figure 52. Each box and whiskers plot represents the distribution of the maximum supply air temperature recorded across all 166 indoor heat pump units within each 2-degree temperature bin. The intent was to see if the maximum supply temperatures declined with decreasing outdoor temperature as one might expect. Overall, the readings vary because heat pumps have variable speed compressors and fans, and they may ramp temperatures down when setpoints are nearly met. The upper whiskers of the box and whisker plots show that readings above 120°F supply air occur down to -15°F, near the minimum rated temperature for most heat pumps. The median peak supply air temperature is highest at approximately 123°F at outdoor temperatures around 35°F, and the median supply air temperature declines at lower and higher outdoor temperatures. The lower box or 25th percentile temperature is at or above 100°F down to -18°F, the lowest temperature observed.

Figure 52. Maximum Supply Air Temperature Across All Outdoor Air Temperatures for Each Heat Pump Indoor Unit (n = 166)



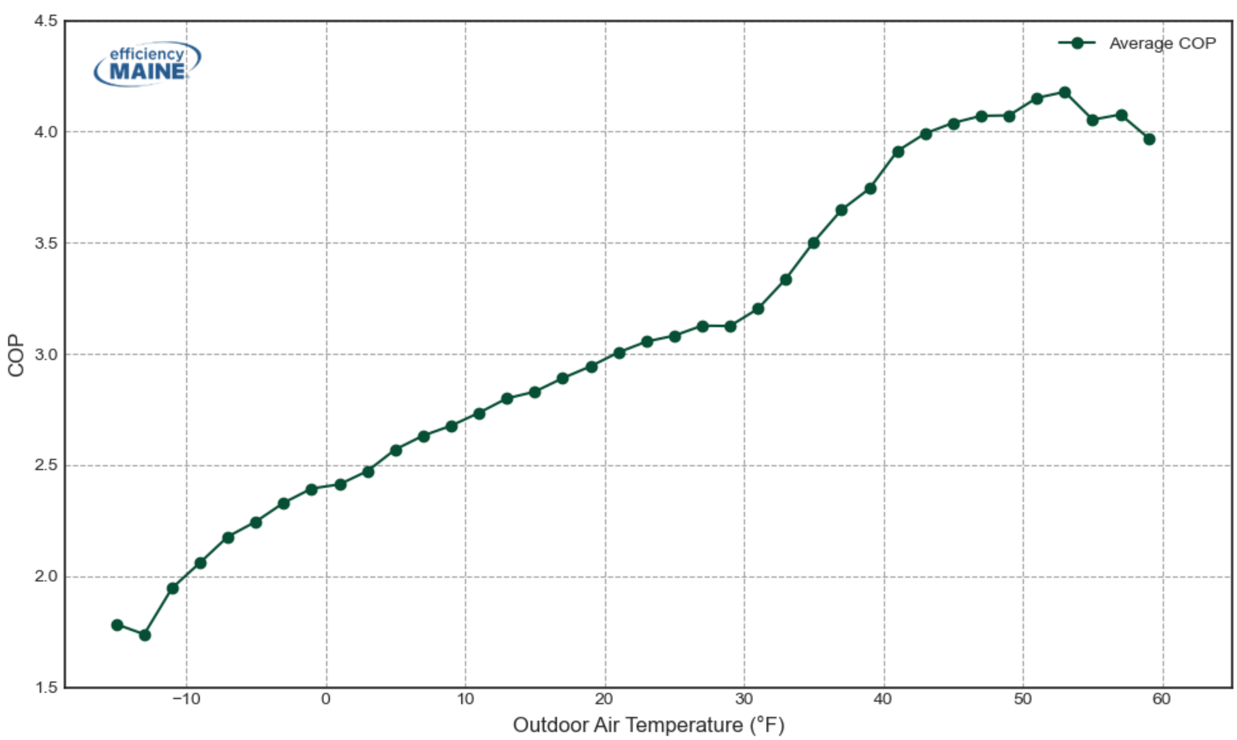
7 METERED HEAT PUMP OPERATING EFFICIENCY

7.1.1 Coefficient of Performance (COP)

The Coefficient of Performance (COP) is the simplest measurement of a heat pump's performance and is equal to the ratio of the energy of heat delivered to the energy of electricity required to achieve this heat transfer (measured in the same units). COP values for heat pumps designed to perform in cold climates typically range from 2 at colder temperatures to 5 at 47°F due to partial loading at low heating loads. This indicates that heat pumps can deliver 2 to 5 units of heat for every unit of energy consumed.

Figure 53 shows the average measured COP across all 166 metered heat pump indoor units. These values were calculated by dividing the total heating energy output across all units by the total electric energy used by all units within each 2-degree temperature bin. The heating COP decreases with decreasing evaporating (outdoor) temperatures primarily due to the increased difference between outside and desired indoor temperatures. Metered COP averaged 2 at-10°F. This means that even for these very cold temperatures, heat pumps are still twice as efficient as electric resistance. The average combined field-metered heating COP across all outdoor temperatures was 3.15, which includes energy used for defrosting.

Figure 53. Average Measured COP vs. Outdoor Air Temperature



7.1.2 Manufacturer-Reported Heat Pump Efficiency Ratings

Heat pumps are rated several ways. Manufacturers publish:

- Coefficient of Performance (COP): This is reported at minimum, maximum, and rated capacities for outdoor air temperatures of 47°F, 17°F, and 5°F. Temperatures at which COPs are reported below 5°F vary between -5°F to -22°F and differ among manufacturers. COPs are unitless.
- Heating Seasonal Performance Factor (HSPF and HSPF2): This is a single seasonal factor that captures a heat pump's overall heating performance over a prescribed set of operating conditions (indoor temperatures, outdoor temperatures, and compressor settings) that represent a full heating season in Region IV (mid-Atlantic). The units for an HSPF or HSPF2 rating are Btu/Wh, and the HSPF and HSPF2 factors can be derived from ~3.412 (Btu to Wh conversion rate) times an equivalent COP. HSPF2 is the more recently updated rating, and it better represents actual heating conditions. For example, the external static pressure is raised from 0.1 to 0.5 inches of water column for ducted systems, which is a more field-representative value. To better simulate performance in colder climates, the average outdoor temperature used in the HSPF2 testing procedures is lower than the one used for the original HSPF calculation.
- Seasonal Energy Efficiency Ratio (SEER2): This is the ratio of the total cooling energy output over a prescribed set of operating conditions (indoor temperatures, outdoor temperatures, and compressor settings) that represent a full cooling season in Region IV (mid-Atlantic) to the total electric energy input over the same period. SEER2 is the more stringent update to SEER.
- Energy Efficiency Ratio (EER2): This is the ratio of cooling energy to electric energy consumed at 95°F. EER2 is the more stringent update to EER.

Manufacturer-reported values for these ratings were obtained for all 160 heat pumps in this study from Northeast Energy Efficiency Partnerships' (NEEP) *Cold Climate Air Source Heat Pump List*.[28] These ratings reflect those discussed earlier in AHRI's *Directory of Certified Product Performance.*[29] Refer to the *AHRI Standard 210/240: Performance Rating of Unitary Air-conditioning and Air-source Heat Pump Equipment* for more information on these tests and ratings.[30]

[28] Northeast Energy Efficiency Partnerships. ccASHP Specification & Product List.

[29] Air-Conditioning, Heating, and Refrigeration Institute. Directory of Certified Product Performance.

[30] Air-Conditioning, Heating, and Refrigeration Institute. AHRI Standard 210/240-2024 (I-P): "Performance Rating of Unitary Air-conditioning and Air-source Heat Pump Equipment."

Table 14 shows the average ratings of all heat pumps in the metering study. It is important to note that not every heat pump in the metered sample is rated across all these ratings. Some of the older models, which were most likely not rebated by the WHHP program but were already installed in homes prior to participating in the WHHP program, are not rated for the updated, more stringent HSPF2, SEER2, and EER2 standards. For one heat pump found in the sample, only the rated COP, nominal capacity, maximum capacity at 5°F, and HSPF are known.

Table 14. Manufacturer-Reported Ratings for Metered Heat Pumps

	Outdoor Air Temperatures (OA)		
Ratings (n = 160)	47°F	17°F	5°F
Min Capacity (Btu/h) (BTU_{min}^{OA})	3,694 (n = 159)	3,594 (n = 158)	2,945 (n = 158)
Max Capacity (Btu/h) (BTU_{max}^{OA})	22,130 (n = 159)	18,287 (n = 159)	16,604 (n = 160)
COP at Min Capacity (COP_{min}^{OA})	4.66 (n = 158)	3.02 (n = 158)	2.63 (n = 158)
COP at Max Capacity (COP_{max}^{OA})	2.95 (n = 158)	2.40 (n = 158)	2.21 (n = 158)
HSPF (Btu/Wh)	12.9 (n = 157)		
HSPF2 (Btu/Wh)	11.4 (n = 146)		
SEER2 (Btu/Wh)	25.9 (n = 146)		
EER2 (Btu/Wh)	14.9 (n = 146)		

Manufacturers also publish engineering tables that show maximum heating capacity and electricity input versus outdoor temperature.[31] Table 15 shows an example of one of these tables for a 12,000 Btu_{Rated}[47], 12 HSPF unit.

Table 15. Example Heat Pump Engineering Data

INDOOR	OUTDOOR TEMPERATURE (°FWB)															
EDB	−13		−4		5		14		23		32		43		60	
°F	TC	PI	TC	PI	TC	PI	TC	PI	TC	PI	TC	PI	TC	PI	TC	PI
59.0	9.73	1.65	12.55	1.68	15.27	1.72	16.23	1.68	17.21	1.63	18.22	1.58	19.45	1.53	23.48	1.65
70.0	8.72	1.70	11.58	1.73	14.33	1.77	15.39	1.72	16.46	1.67	17.52	1.62	18.80	1.56	22.83	1.68
71.6	7.88	1.58	10.93	1.68	13.95	1.79	15.06	1.74	16.16	1.69	17.24	1.64	18.54	1.58	21.97	1.63
75.2	6.55	1.29	9.60	1.46	12.65	1.61	14.73	1.76	15.85	1.70	16.96	1.65	18.28	1.59	20.64	1.51
77.0	5.88	1.15	8.93	1.35	11.98	1.52	14.56	1.77	15.70	1.71	16.82	1.66	18.15	1.60	19.97	1.46
80.6	4.55	0.88	7.60	1.14	10.65	1.33	13.32	1.60	15.40	1.73	16.54	1.68	17.89	1.61	18.64	1.34

In the table at the highlighted heat output of 18,800 Btu/h at 43°F, the COP can be calculated by the following equation:

$$\mathrm{COP} = \frac{\mathrm{TC}}{PI\ x\ 3.412} = \frac{18{,}800}{1{,}560\ x\ 3.412} = \ 3.53$$

Where:

[31] The table shows maximum heating capacity, and the actual operation will follow this table when full capacity is used at colder temperatures. At temperatures above freezing for example, the capacity is not fully used, and one would expect higher efficiencies. Some manufacturers publish a second table showing rated inputs at partial load capacities.

TC =   Total Capacity in kBtu/h
PI =   Power in kW

Only a fraction of the 18,800 Btu/h that the heat pump could provide at 43°F would be needed. If the heat pump were sized to just meet needs at -4°F, then the heat pump would only need to provide (70 - 43) / (70 - (-4)) * 11,580 = 4,225 Btu/h, or about 22% of the heat capacity at 43°F.

7.1.3 Field-Metered COP versus Manufacturer-Reported COP

In Figure 54, the field-metered COPs are compared against the average manufacturer-reported ratings for 47°F, 17°F, and 5°F. The average, field-metered COPs run between the reported manufacturer ratings. The average reported COP at the maximum capacity at the lowest catalogued temperature in the AHRI directory is 1.85 across the sample. The lowest catalogued temperature differs between models and manufacturers and ranges from -4°F to -22°F. The average lowest catalogued temperature was -15°F in the metered sample.

Figure 54. Average Field-Metered COP and Manufacturer-Reported COP vs. Outdoor Air Temperature

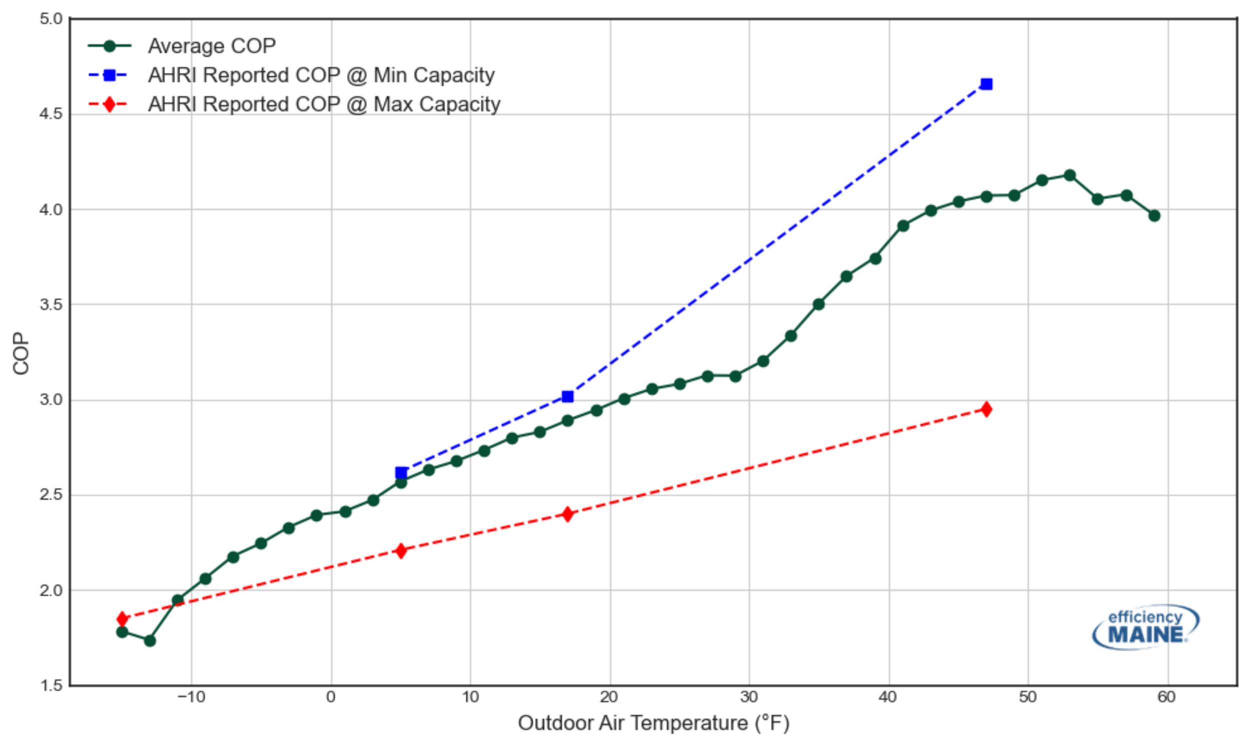
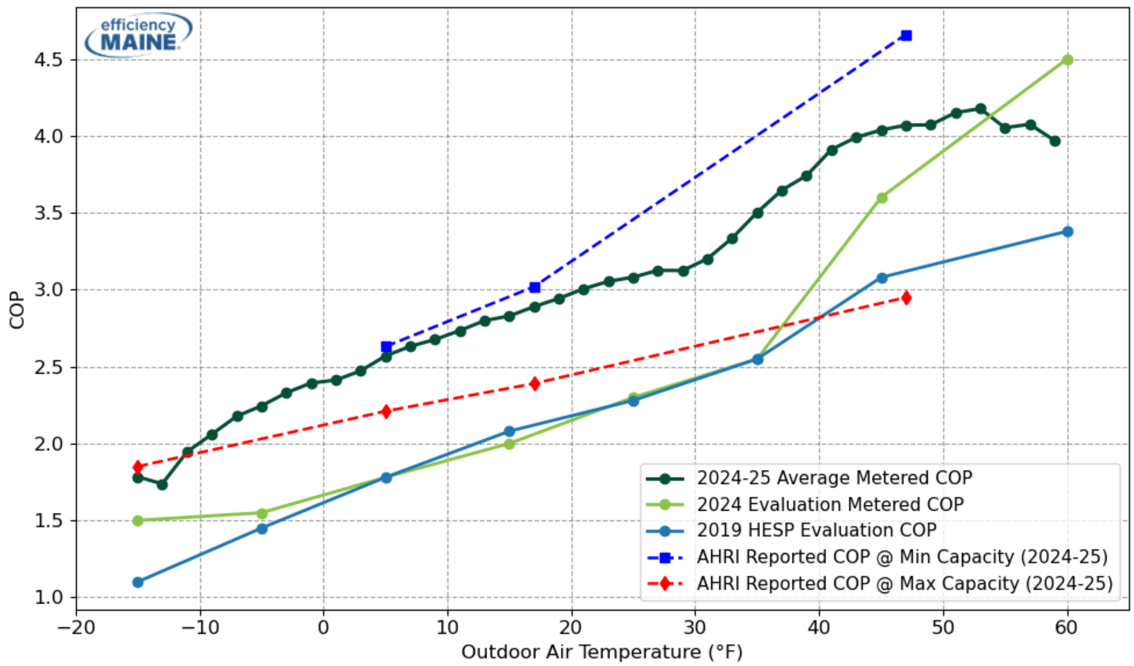


Figure 55 shows both the field-metered COP and the AHRI-reported COPs and two previous studies conducted in Maine. The average metered COP runs between the average minimum and maximum AHRI reported COPs. These metered COPs are higher than previous studies that covered heat pumps manufactured from 2015 to 2021. We believe there are several reasons:

- New heat pumps have increased their ability to provide partial load heating and have increased their ratings at both warm and cold temperatures.
- Heat pumps in this study are used more continuously than past studies.
- This study used web connected meters that provided continuous data with nearly no gaps, reducing the need for data extrapolation.

Figure 55. Average Field-Metered COP and Manufacturer-Reported COP vs. Outdoor Air Temperature, with Metered COP from 2024 HP Evaluation[32] and 2019 HESP Evaluation[33]



7.1.4 Manufacturer-Reported HSPF2 versus Manufacturer-Reported COP

HSPF ratings are calculated using complex formulas and laboratory data. They do not necessarily match actual seasonal efficiency since field conditions are less controlled than a laboratory setting, and the heating needs and temperatures do not always match the assumptions built into the HSPF calculations. Since HSPF is calculated using very specific, limited conditions, the relationship between COP versus temperature and HSPF ratings is not always proportional. Figure 56 shows no clear relationship between manufacturer-reported HSPF2 and COP_{rated}[17]. Figure 57 shows a clearer relationship between manufacturer-reported HSPF2 and COP_{rated}[47]. Of the 41 unique heat pump models metered in this study, 31 of the models had reported HSPF2 factors. The models that did not report HSPF2 were the older heat

[32] Efficiency Maine Residential Heat Pump Impact Evaluation. 2024.

[33] Efficiency Maine Trust Home Energy Savings Program Impact Evaluation. 2019.

pumps in the fleet that were most likely installed before the WHHP rebate program. Most of the heat pumps that lacked reported HSPF2 factors were the only ones of their models within the sample.

Figure 56. Manufacturer-Reported HSPF2 versus Manufacturer-Reported COP_{rated} 17 (n = 31)

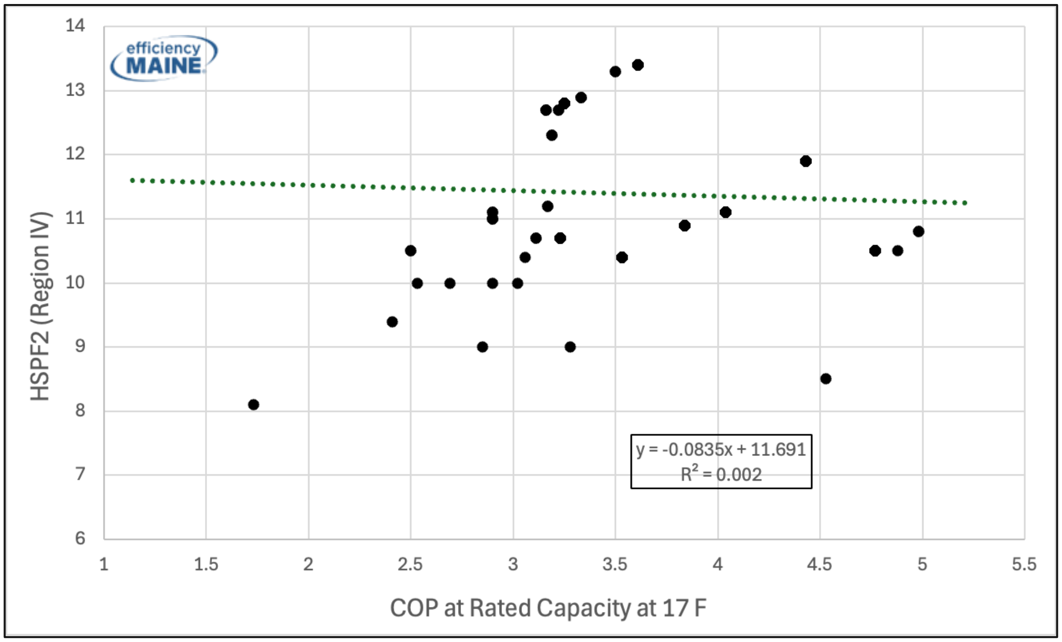
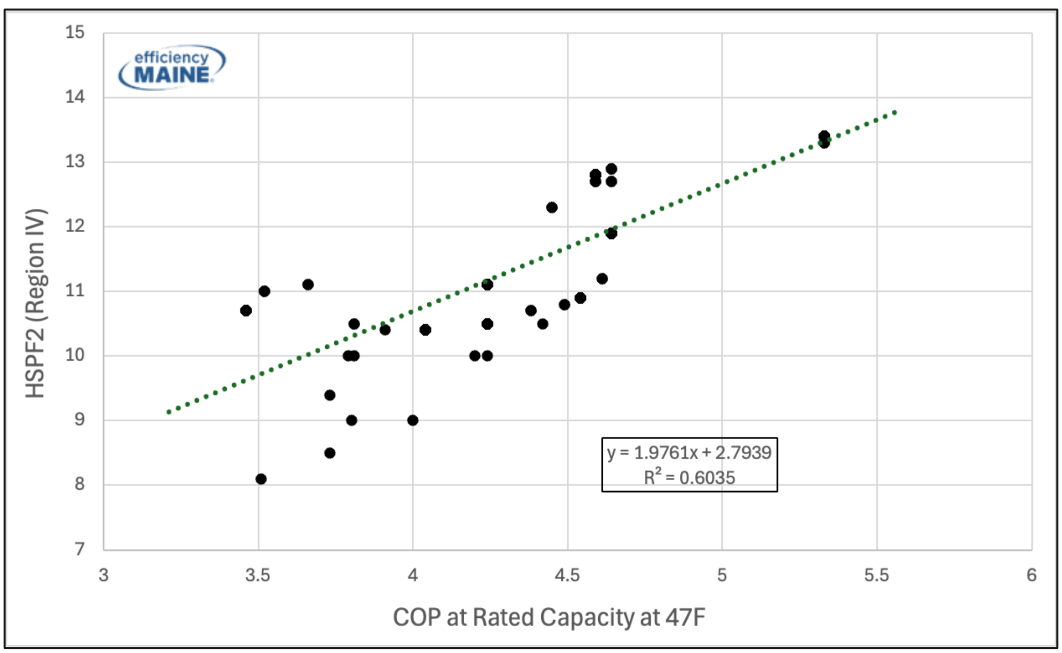


Figure 57. Manufacturer-Reported HSPF2 versus Manufacturer-Reported COP_{rated} 47 (n = 31)



7.1.5 Field-Metered COP versus Manufacturer-Reported HSPF2 and COP_{min} 47

We expected that there might be some relationship between field-metered COPs for heat pumps and their ratings. To test this expectation, we graphed field-metered COP versus HSPF2 and COP_{min} 47 in

Figure 58 and Figure 59. While there are slight upward trends in field-metered COP versus HSPF2 and COP_{min} [47], they are not strong trends. We believe that variability in how heat pumps are operated is a stronger factor impacting field-metered COP than the ratings of the heat pump.

Figure 58. Field-Metered COP versus Manufacturer-Reported HSPF2 (n = 146)

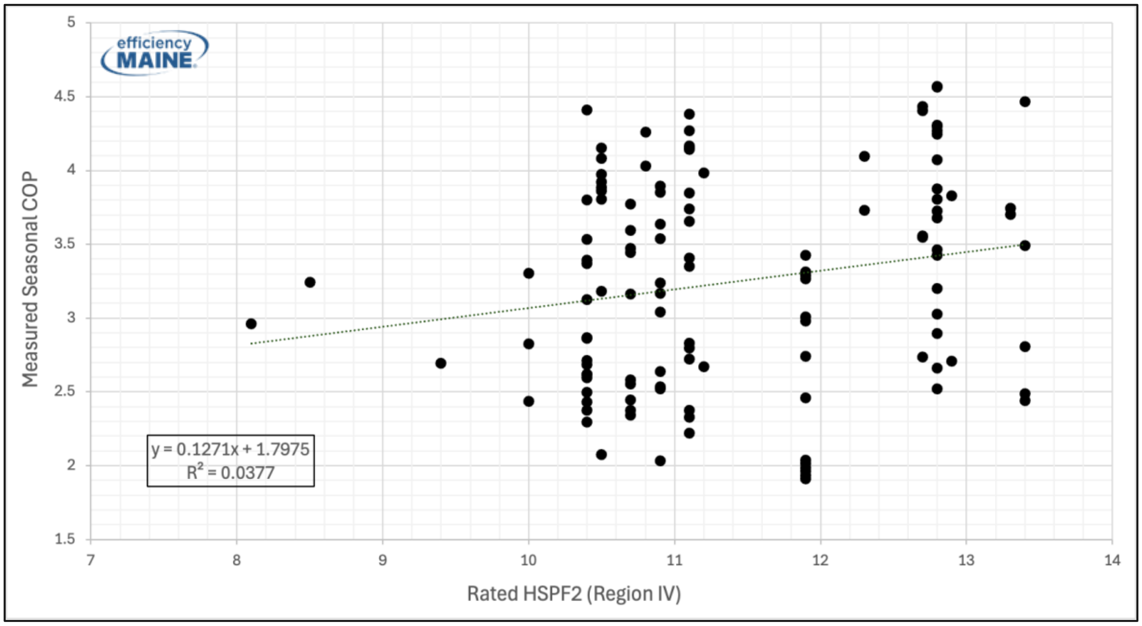
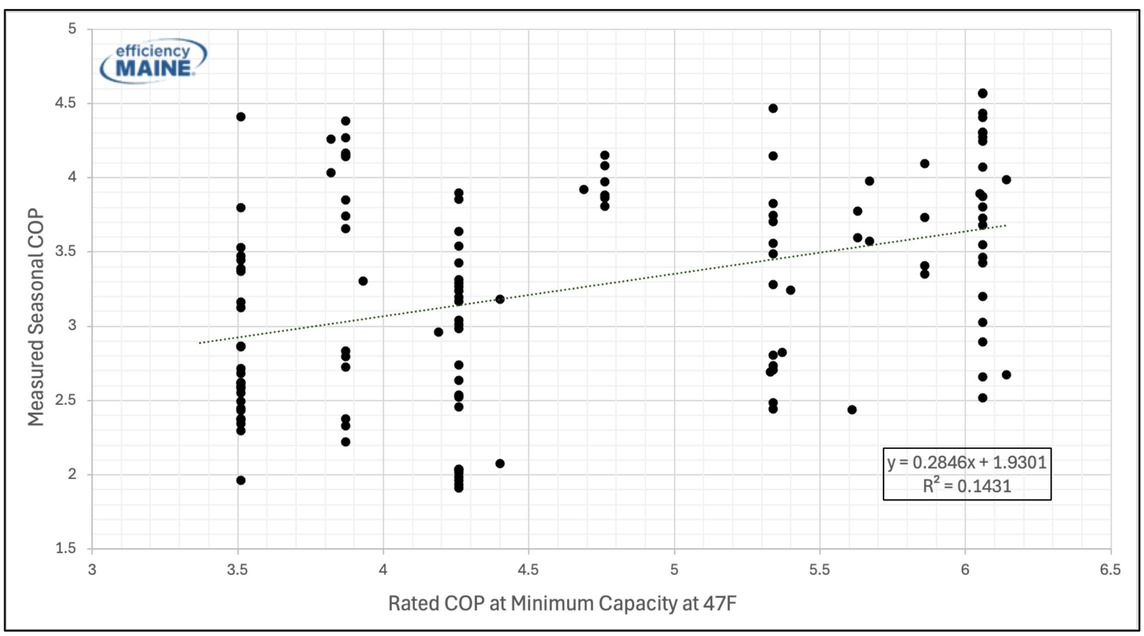


Figure 59. Field-Metered COP versus Manufacturer-Reported COP_{Min} [47] (n = 158)



8 HEAT PUMP OPERATION ANALYSIS

Heat pumps have the potential to provide all or nearly all heat in homes. The portion of a home's heat that heat pumps actually provide depends on several factors. If conditions are optimal, then the heat pump can be used throughout the winter, fully displacing other heat sources. If certain conditions are not optimal, however, usage may be reduced, sometimes substantially. Below are a handful of conditions that this study found to be correlated with increasing (or decreasing) the share of a home's heat load that is provided by a WHHP system.

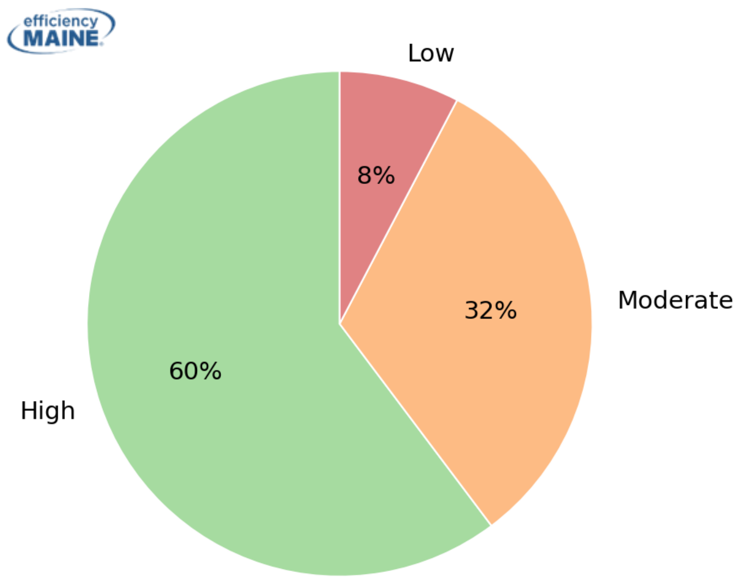
- The owner's intent to use heat pumps as the home's primary heating source is the most closely correlated factor to actual heat pump usage during the heating season. If, however, the owner intends to use the heat pump mostly for cooling, our findings indicate the heat pump will be used little during the heating season, regardless of the design of the heating system.
- Next in importance is zoning of the home's heating system. Non-ducted heat pumps interact with a specific space or "zone" in each home. If individual, non-ducted heat pumps are insufficient to heat a particular zone in a home, homeowners may be uncomfortable and employ other heating sources. The level of overlap, or lack thereof, between the zone of the heat pump and a zone of any pre-existing heating system(s) in the home is important. In the case of a central furnace or boiler serving a home in which the entire space is treated as a single zone, when a system of one or more non-ducted heat pumps is installed to heat the same zone, there is a high risk that the heat pumps will be entirely displaced (i.e., stop operating) any time the central furnace or boiler is on.
- Another factor to consider is how the capacity of a heat pump compares with the size and heat load of the zone in which it is located in the house. If the heat pump has a large capacity compared with a zone, it can provide all of the zone's heat but may still be underutilized.
- How the homeowner sets and operates controls on the home's heating system(s) is another factor that impacts the usage of heat pumps. Controls include the thermostats that signal to the heating system when to produce and when to stop producing, heat. If the heat pump and central system are not controlled correctly, the heat pumps' use can be displaced. During site visits, Ridgeline observed multiple homes where the central system and the heat pump are set to the same temperature. In this study's findings, the control settings and operations have the lowest correlation with the conditions impacting usage of the heat pumps.

How these conditions correlate with increased or decreased heat pump utilization is analyzed below. Heat pump capacity versus modeled heat loss is also explored in this section.

8.1 HOMEOWNER INTENT

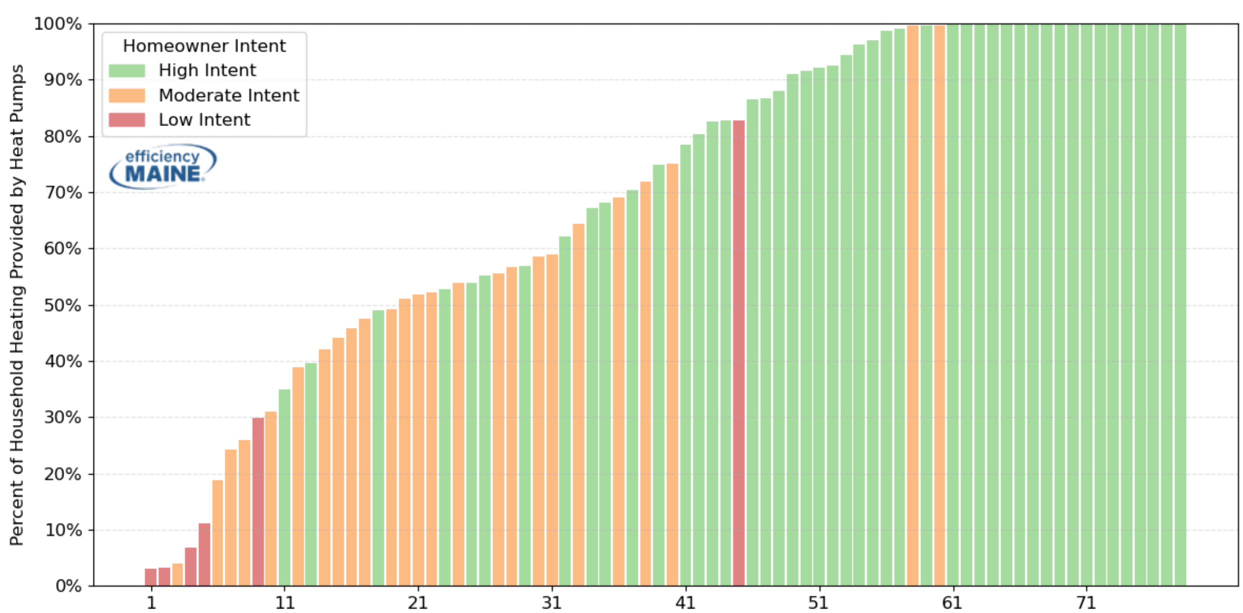
When recruiting homes for metering, Ridgeline discussed with homeowners how they were using their heat pump(s) and other heating systems. Homeowners described a variety of behaviors ranging from "we don't heat with our heat pumps, and we prefer our pellet stove", to "we only heat with our heat pump, and we have no other heating system." We rated homes that clearly showed intent to lightly use their heat pumps for heating as "Low Intent" and homes that either had a clear plan to use the heat pump for most heating or had no alternative heat source as "High Intent." All other homes were classified as "Moderate Intent" homes. Some "Moderate Intent" homes used only heat pumps and wood and did not use fossil fuel, and others had a plan to use heat pumps for most of their heating but would use a central system for either certain zones or low outdoor temperatures. Figure 60 shows the proportions of homes categorized by homeowner use intent and plan based on the results of a phone survey of the homeowners participating in the metered study.

Figure 60. Level of Intent to Use Heat Pumps for Heating, by Category – Metered Homes (n = 78)



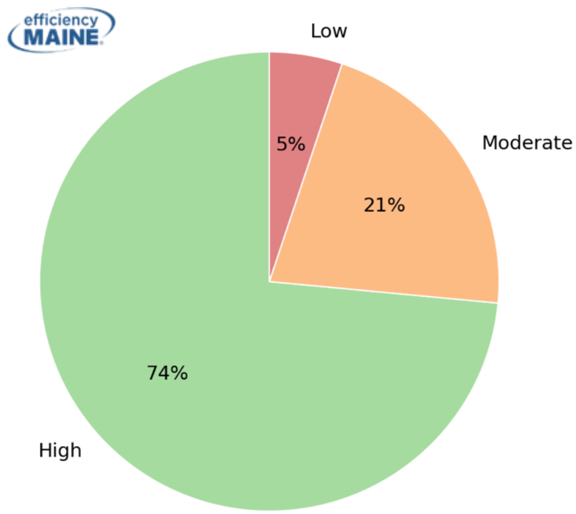
To examine the correlation between homeowner intent and use, the portion of heat provided by heat pumps at each home was plotted in Figure 61 with the associated initial homeowner intent categorization shown by color. The figure shows that intent is important, with most of the high-intent users on the right side of the graph, where heat pump utilization rates are high and all but one of the low users on the far left of the graph, where utilization rates are low.

Figure 61. Comparing Intent with the Portion of Home Heating by Heat Pumps – Metered Homes (n = 78)



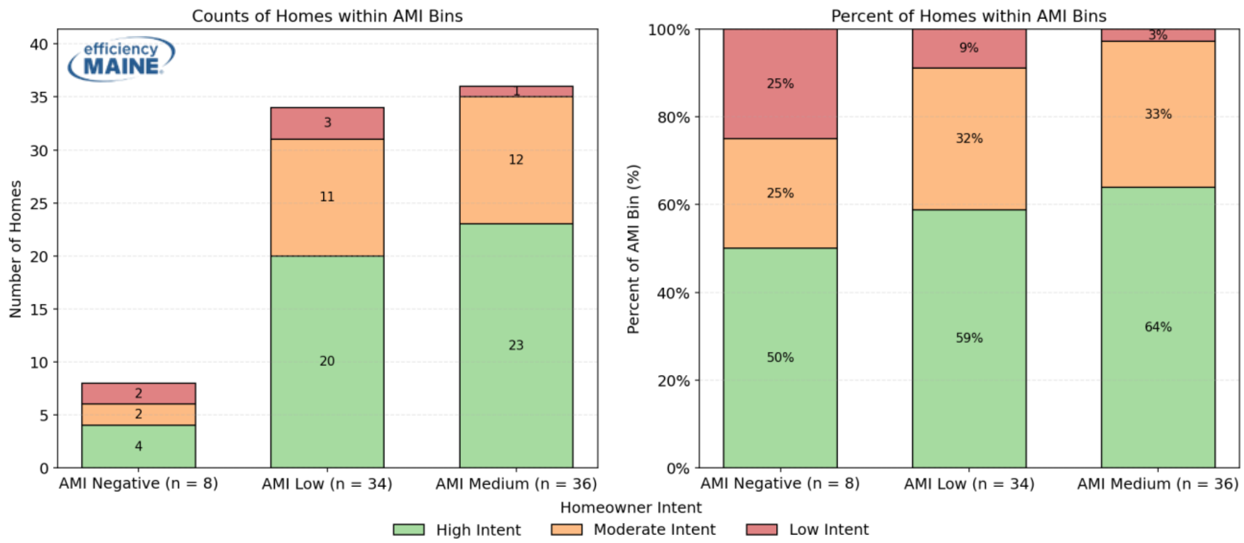
The metering sample only focused on homes previously identified as the bottom-consuming two-thirds of heat pump users using the Initial AMI analysis. Recall from previous descriptions in this report that the metering sample excluded the characteristics or the impacts of the top-consuming one-third of users identified in the Initial AMI analysis. If the top-consuming one-third of users were added back into the sample with the assumption that this population had “High Intent”, 74% of all total WHHP participants would be characterized as having “High Intent.” Figure 62 shows the results of this extrapolation.

Figure 62. Level of Intent to Use Heat Pumps for Heating, by Category, Extrapolated to Population



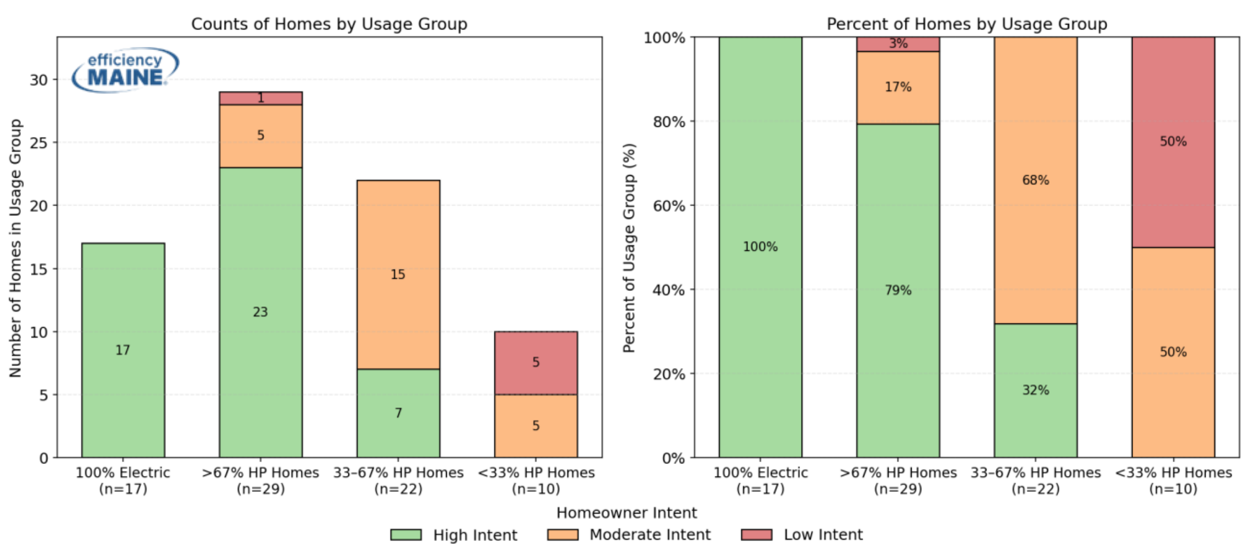
User intent was previously shown to generally correlate with field-metered use as a percentage of total home heating (all heat systems). Grouping user intent (Low Intent, Moderate Intent, and High Intent) with Initial AMI usage bins ((Negative, Low, and Medium) created based on the absolute cold-weather dependent kWh impact from the Initial AMI analysis in Chapter 3) shows little correlation (Figure 63, left side). The AMI bins are shown on the independent axis and are colorized by the category of homeowner intent. Examining user intent by percentage (Figure 63, right side), High Intent users make up 50-64% of each of the Initial AMI bins, illustrating that these AMI usage bins did not match intent, for the metered sample.

Figure 63. Comparing Homeowner Intent with Initial AMI Bins (n = 78)



Matching user intent with the field-metered percentage of heat provided by heat pumps shows some correlation. All homes with 100% heat pump heating had High Intent as did 79% of homes where heat pumps provided greater than 67% of heating. Homes where heat pumps provided 33-67% of heat were made up of 29% of High Intent homeowners and 71% of Moderate Intent homeowners, as one might expect. Similarly, homes where heat pumps provided <33% of heating were made up of equal portions of Low and Moderate Intent homeowners (Figure 64).

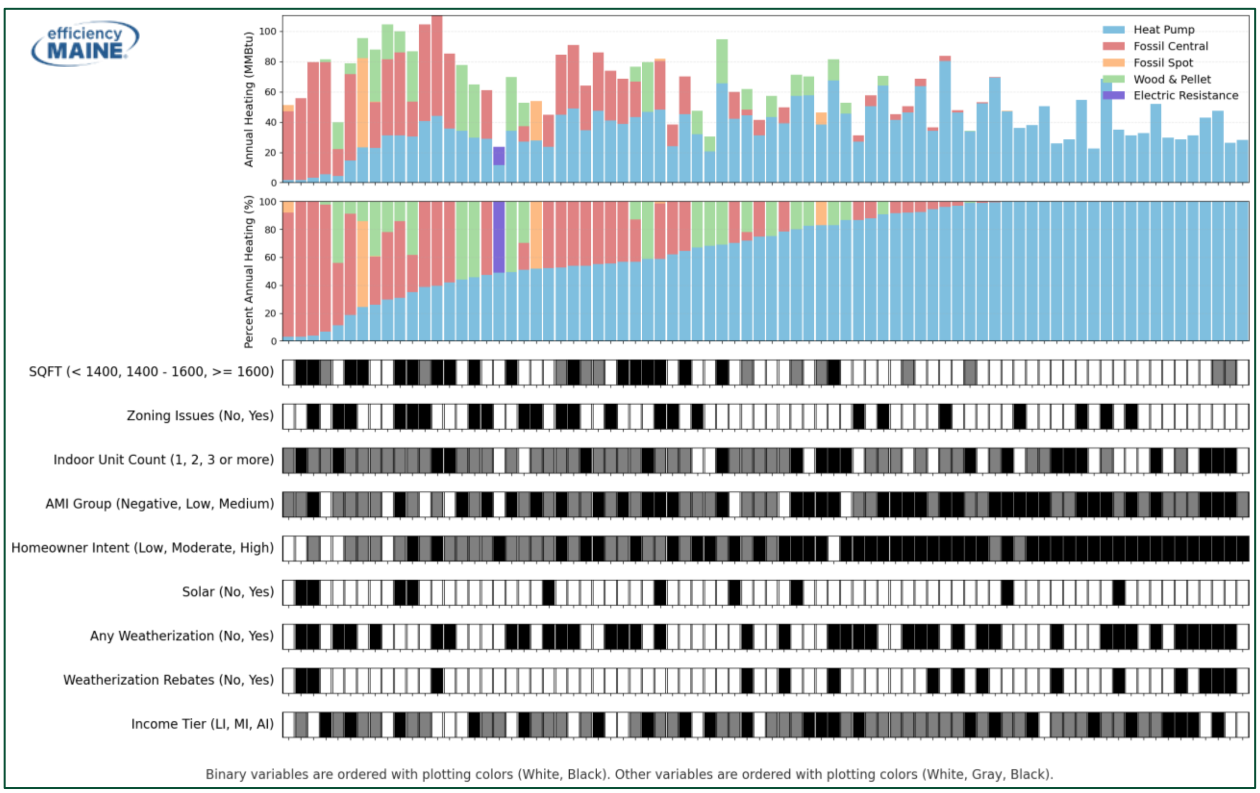
Figure 64. Comparing Homeowner Intent with Portion of Home Heat Delivered by Heat Pumps, Based on Metering (n = 78)



The next series of graphs (Figure 65, Figure 66, and Figure 67) shows the heat provided to each home by source by total MMBtu and by percentage of total home heating. Below each two-graph set is a grid of home characteristics. The graphs are sorted three ways: 1) by percentage of heat provided by heat pumps, 2) by total heat (MMBtu) provided by heat pumps, and 3) by total heat (MMBtu) provided by all sources. For the grid of home-level characteristics in these figures, if a certain factor is a binary variable, then the grid will be black for that given home if it is a "yes" and will be white if it is a "no". For other variables where there are three possible values, the grid is colorized based on the following key: White represents the first response referenced in the list, Gray represents the middle response referenced, and Black represents the third response referenced. For example, if the square footage of a particular home is greater than 1,600 ft^2, then it will be black based on the "SQFT" key "(<= 1400, 1400-1600, >= 1600)" shown in the figures below.

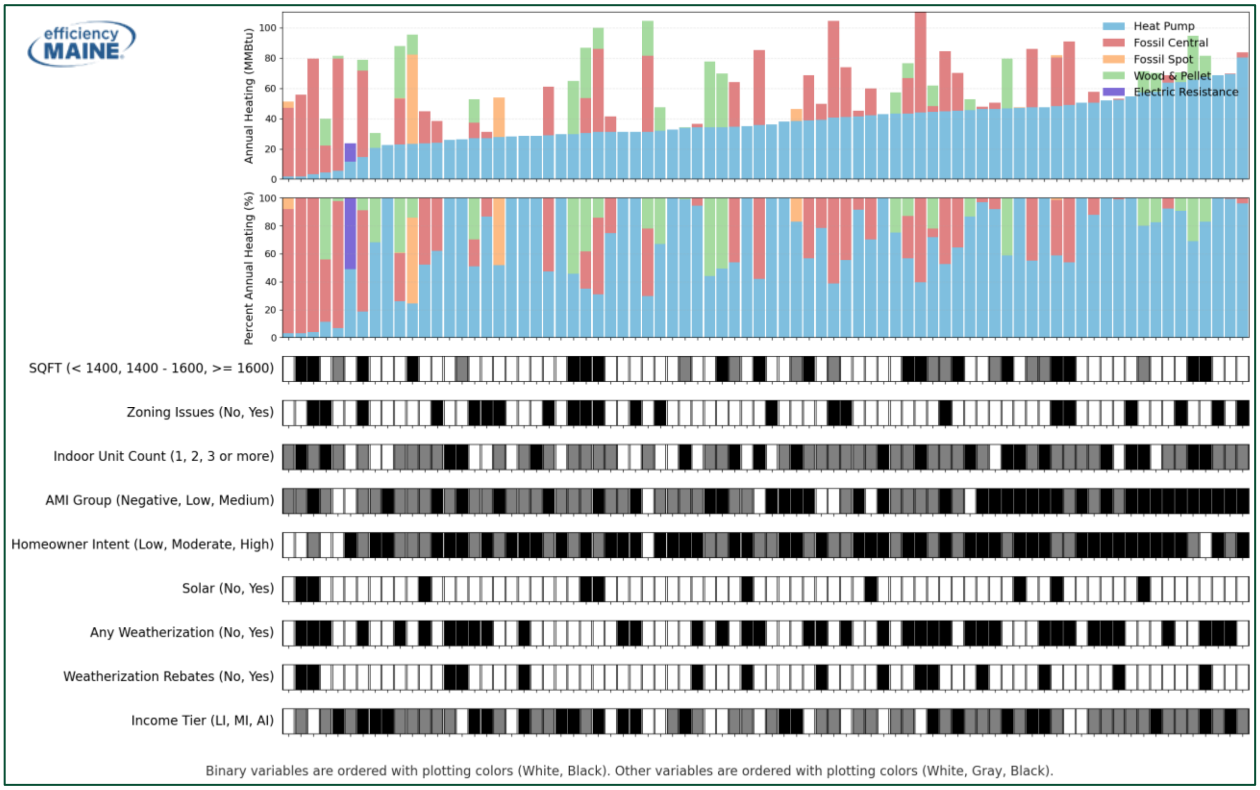
Examining the graph sorted by percentage of heat pump heating (Figure 65), the left side which indicates low percentage of heat pump use, also correlates with moderate and high total heating use. In the characteristics grid below the graph, low heat pump percentage correlates strongly with homes with larger conditioned square footages (see "SQFT") and homeowner intention (see "Homeowner Intent"), and it correlates weakly or moderately with zoning issues (see "Zoning Issues"). Unexpectedly, solar homes clumped towards the left side of the graph (see "Solar"). One might have expected that homes with solar would be more interested in using their heat pumps, or that homes with solar might perceive that the heat pump was using solar, a marginally free source, once the installation is paid for. Anecdotally, we have found a range of strategies by homeowners with both solar and heat pumps. We have heard from a couple of homeowners that they want solar to power their heat pumps and that when their solar surplus from the summer is used, they trim the use of their heat pumps.

Figure 65. Heating by Heat Source per Home, Ordered by Percent Heat Pump Heating with Grid of Home Characteristics (n = 78)



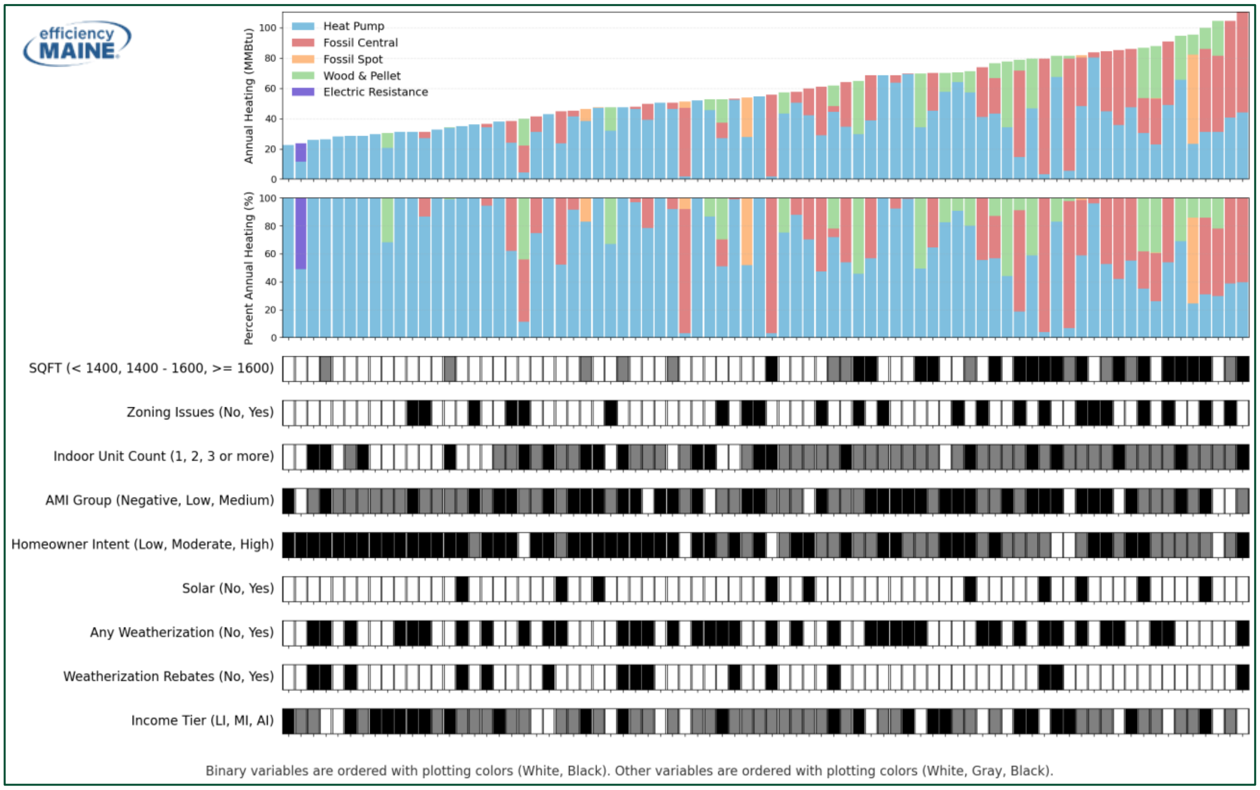
Examining the graph sorted by total heat pump heating in MMBtu (Figure 66), the left side, which indicates low heat pump use, correlates somewhat with a lower percentage of heat provided by heat pumps. In the grid of characteristics below the graph, the left side has no clear correlation, indicating that many factors contribute to the total amount of heat provided by heat pumps.

Figure 66. Heating by Heat Source per Home, Ordered by Heat Pump Heat Delivered (MMBtu) with Grid of Home Characteristics (n = 78)



Examining the graph sorted by total heating in MMBtu across all heating sources (Figure 67), the left side, which indicates low total heat use, correlates with a higher percentage of heat provided by heat pumps. In the grid of characteristics below the graph, the left side appears to correlate with smaller homes with less conditioned square footage.

Figure 67. Heating by Heat Source, Ordered by Total Heating with Grid of Home Characteristics (n = 78)

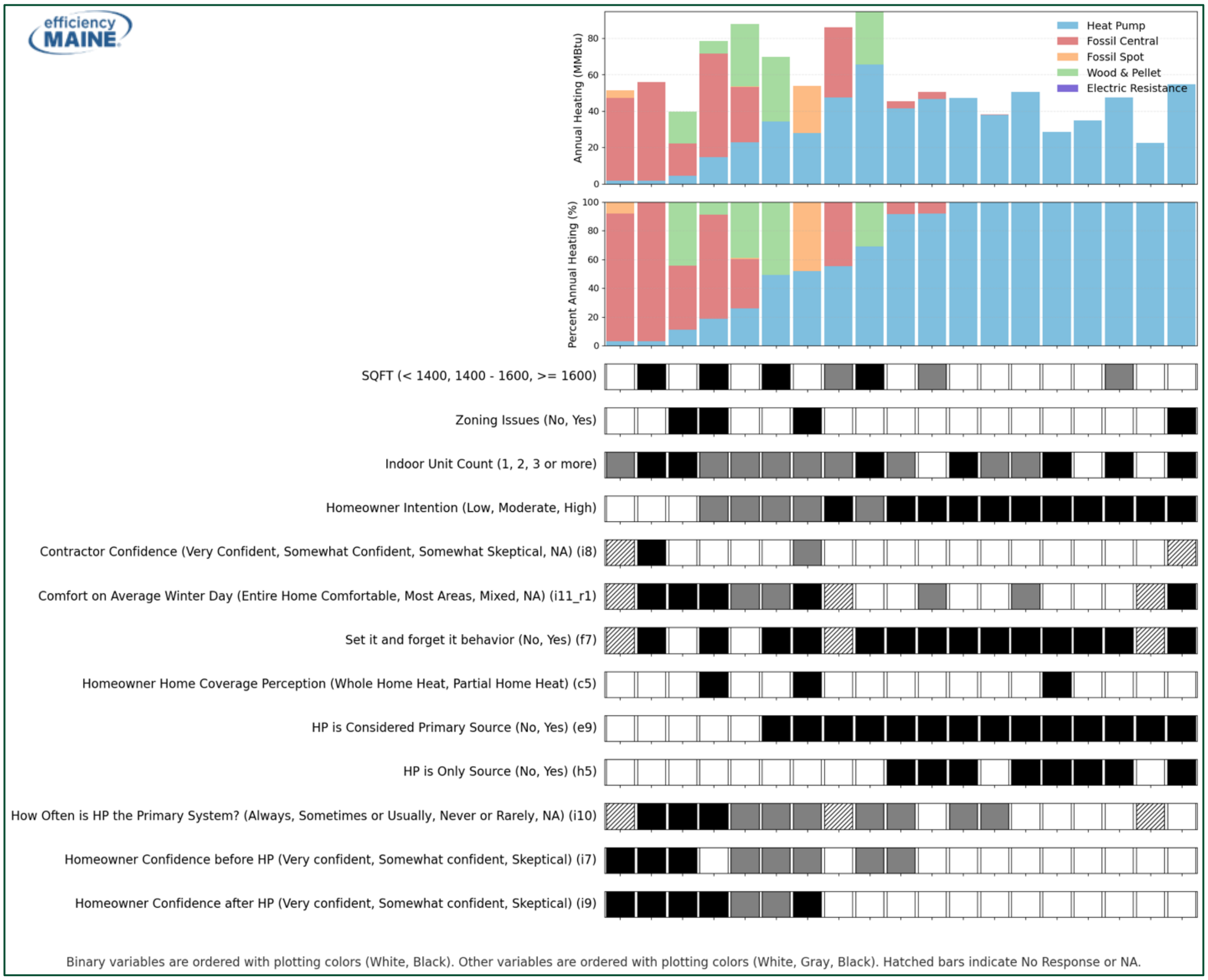


The next set of figures (Figure 68, Figure 69, Figure 70) shows the subset of metered homes that also responded to a separate online Whole Home Heat Pump survey in the summer of 2025.[34] In total, there were 19 respondents to the survey among the 78 homes metered.

Figure 68 is ordered by increasing percentage of heat pump heating. As discussed above, it appears that larger homes are more likely to have lower percentages of heat pump heating. Homeowner intention also appears to be highly correlated with the heat pump's percentage of heating. Other indicators of lower percent heat pump heating are the contractors' confidence in the heat pumps' heating abilities, as perceived by the homeowner (question (i8) in survey), homeowners' reported comfort on an average winter day (i11_r1), the heat pump being considered the primary heating source (e9), the heat pump being the only heating source (h5), how often the heat pump is considered the primary system (i10), and homeowner confidence before and after the heat pump installation (i7, i9). Interestingly, homeowner confidence after the heat pump installation is a better indicator of usage than homeowner confidence before the installation.

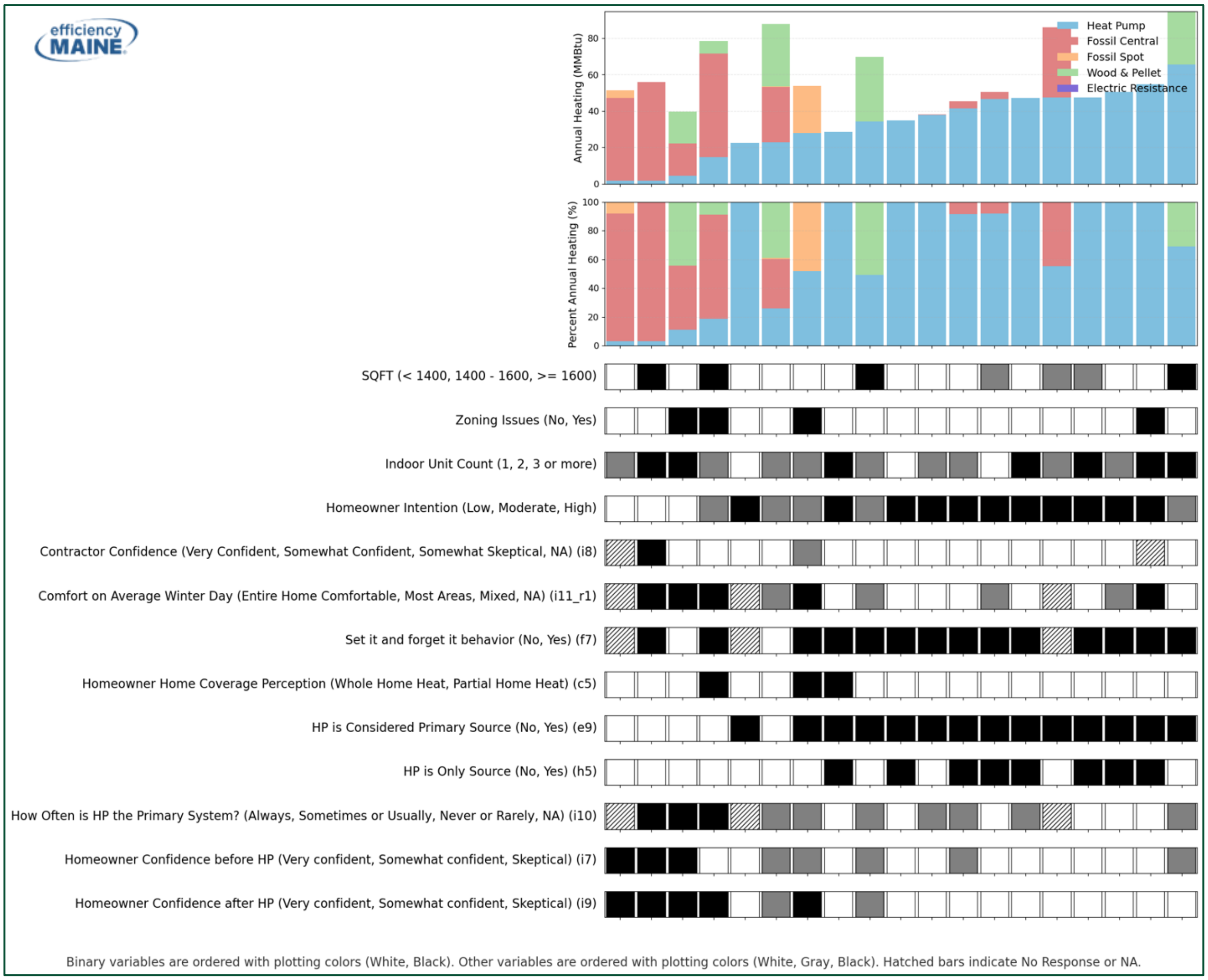
[34] Whole Home Heat Pump Rebate – 2025 Survey Summary Results. November 2025.

Figure 68. Survey Respondents: Heating by Heat Source per Home, Ordered by Percent Heat Pump Heating with Grid of Home Characteristics (n = 19)



Many of the same observations from Figure 68 hold true in Figure 69 below which is ordered by the total heat delivered by the heat pumps in MMBtu.

Figure 69. Survey Respondents: Heating by Heat Source per Home, Ordered by Heat Pump Heat Delivered (MMBtu) with Grid of Home Characteristics (n = 19)



For Figure 70, which is ordered by total heating across all heating sources in MMBtu, there appears to be less correlation between survey responses and ordering. The main correlated variable remains as conditioned home square footage.

Figure 70. Survey Respondents: Heating by Heat Source Ordered by Total Heating with Grid of Home Characteristics (n = 19)

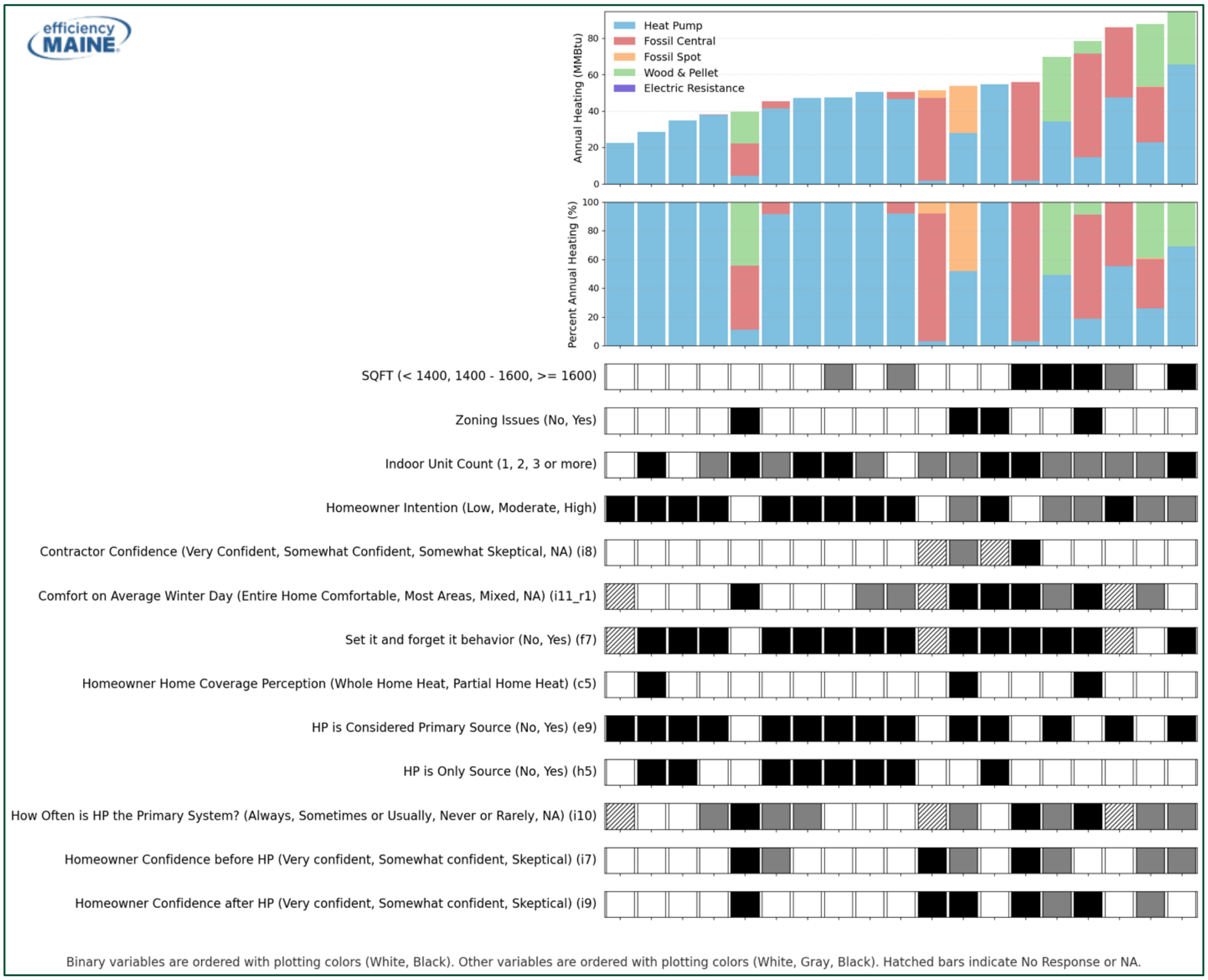
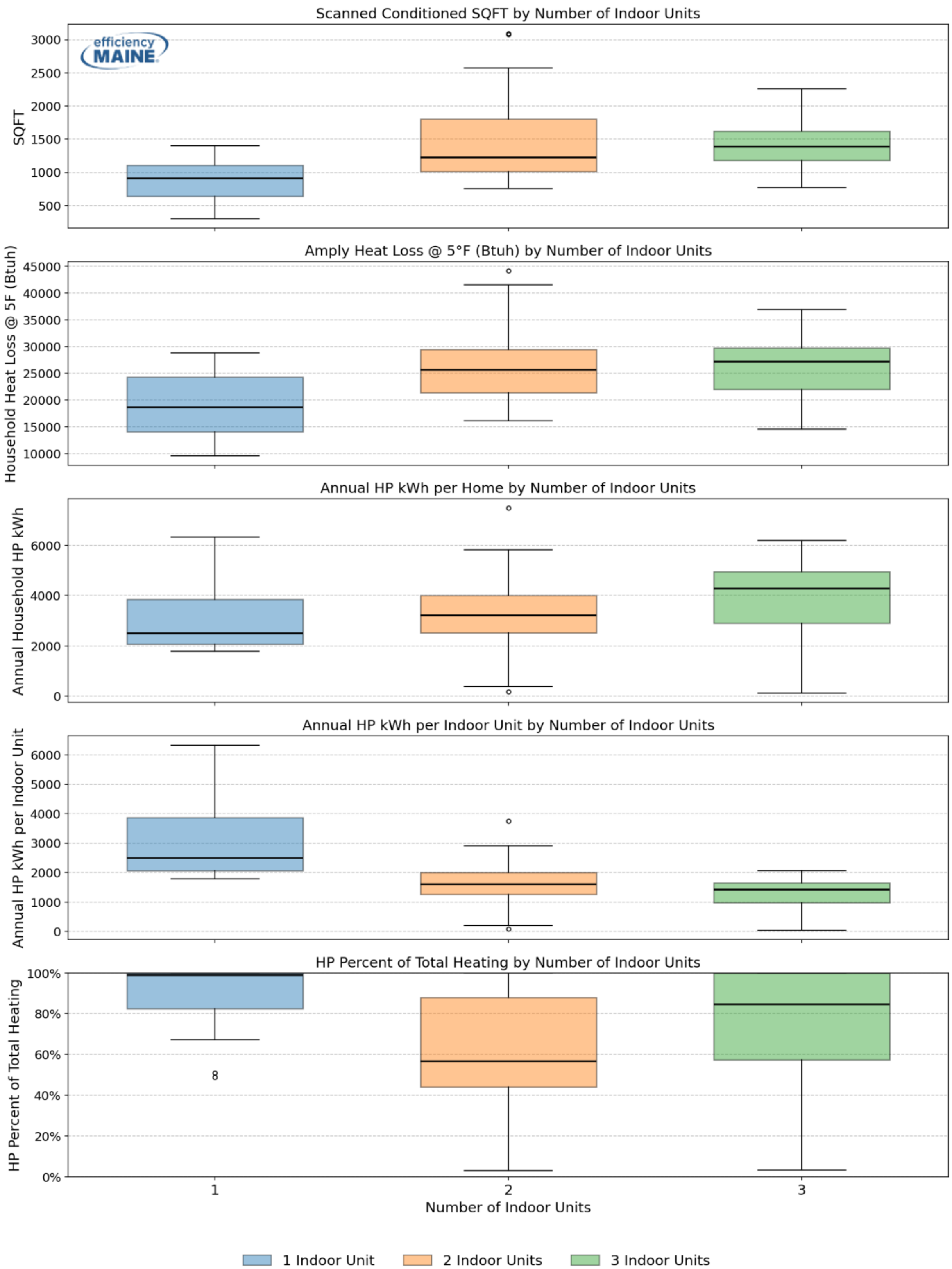


Figure 71 used box and whisker plots to compare homes that have one, two, or three indoor heat pump units. For each of the comparisons, adjacent boxes overlap, and for some, all three boxes overlap. This indicates that while there are trends between the three categories, the differences are more directional than distinct. The homes that had two and three heat pumps were larger than homes with one, and their heat loss was also higher. This shows that in general, contractors are applying more heat pumps to larger, higher-heat-load homes. Electricity use went up shifting from one to three heat pumps, but the marginal increase per heat pump declined from one to two, and from two to three. The last comparison is interesting. It shows that based on the median user, that homes with a single heat pump tended to get all of their heat from heat pumps, that homes with two heat pumps derive just under 60% of heat from heat pumps, and that homes that add a third heat pump derive over 80% of their heat from heat pumps, a rebound with the third added heat pump.

Figure 71. Comparison of Home and Heat Pump Characteristics for Homes with 1 (n = 17), 2 (n = 41), and 3 (n = 16) Indoor Units



8.2 HEATING DISTRIBUTION

An optimally zoned heat pump can run continuously all winter, meet a zone's design heat load (heat load at coldest temperatures), and displace other heating systems all winter. There are several factors that will reduce the use of the heat pump from this optimal situation, including incomplete heating zone overlap and insufficient distribution of heat from heat pumps.

8.2.1 Incomplete Heating Zone Overlap

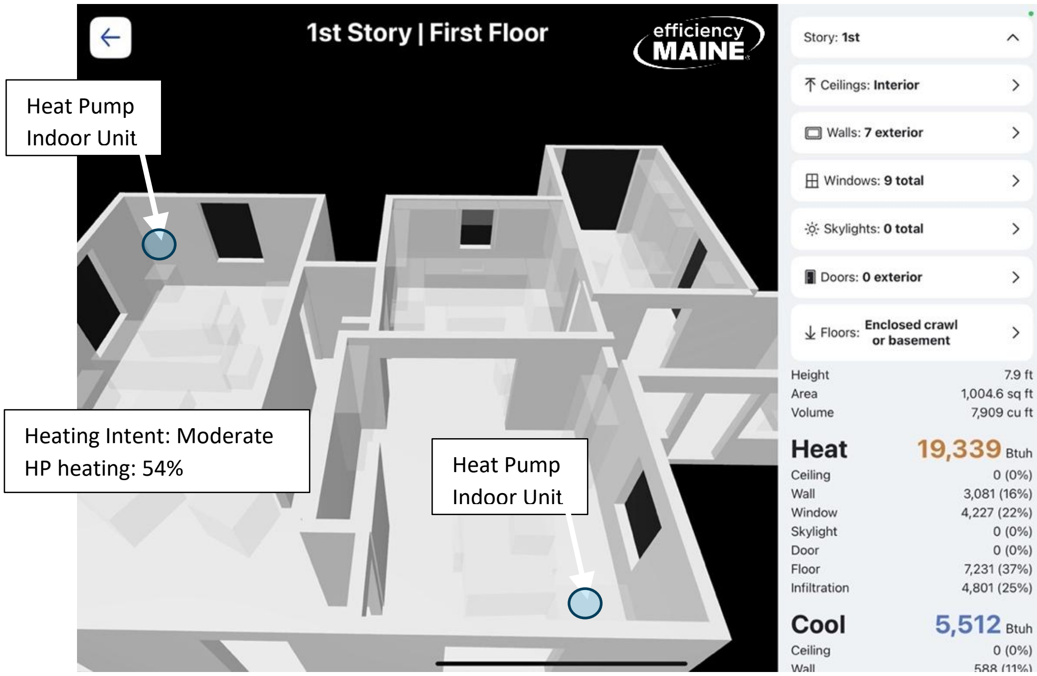
Where a heat pump serves one space, and that space is overlapped by a pre-existing heating system that serves a broader zone, the heat pump will be superseded by the other system whenever other overlapping zones need heat. An example is a furnace-heated home with a single zone (1 thermostat) and two heat pumps that each heat one room. For comfort reasons, the furnace may need to operate to heat the rest of the home, and when it does, it will heat the room served by the heat pump, reducing (often substantially) the use of the heat pump.

House #335 had 3 boiler zones serving the first floor (2 zones) and second floor (1 zone) and had two heat pumps serving the first floor only (Figure 72). Any heat pump heating of the second floor would be only due to buoyant warm air rising up the stairs. This home was judged to be a moderate intent home during the recruitment call because even though the user intended to use heat pumps for the majority of heating, they indicated they sometimes used the boiler to heat the upstairs. During site visits, Ridgeline found that the homeowner used a time clock thermostat to heat the upstairs, but they admitted confusion about the actual setting or whether it worked correctly. Ridgeline also noted a small 1-2°F temperature droop between one of the downstairs heat pumps and the overlapping boiler zone. This insufficiently small droop could cause the boiler zone and the heat pump to both heat the same area. The portion of heat provided by heat pumps based on field metering was 54%.

8.2.2 Home with Capacity and Distribution Challenges

Figure 73 shows a scan of a home (#952) with a different distribution problem. It was originally heated with a ducted furnace that failed and was abandoned. The home is now heated with a heat pump in the far corner of the first floor and a wood stove that is centrally located. The second floor only receives heat by convection. Currently, the heat pump and wood stove are both used. The heat pump maximum capacity at 5°F (BTU_{max}^{5}) is 81% of the modeled heat load of 25,777 Btu/h at 5°F.

Figure 72. Two-Story Home (#335) with Zone Coverage Throughout but Heat Pump Coverage on Floor 1



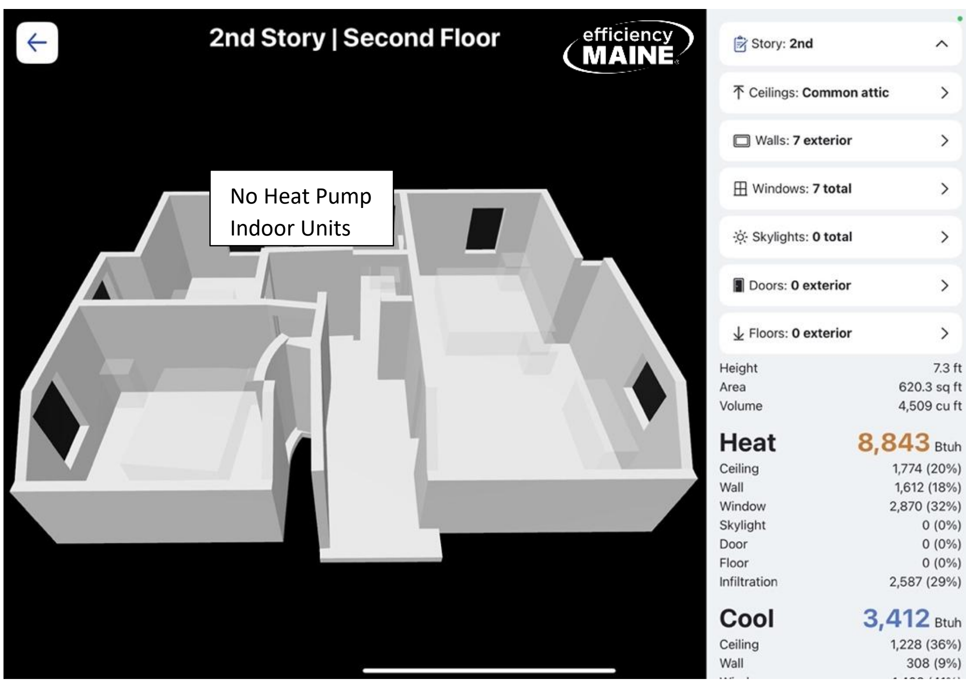
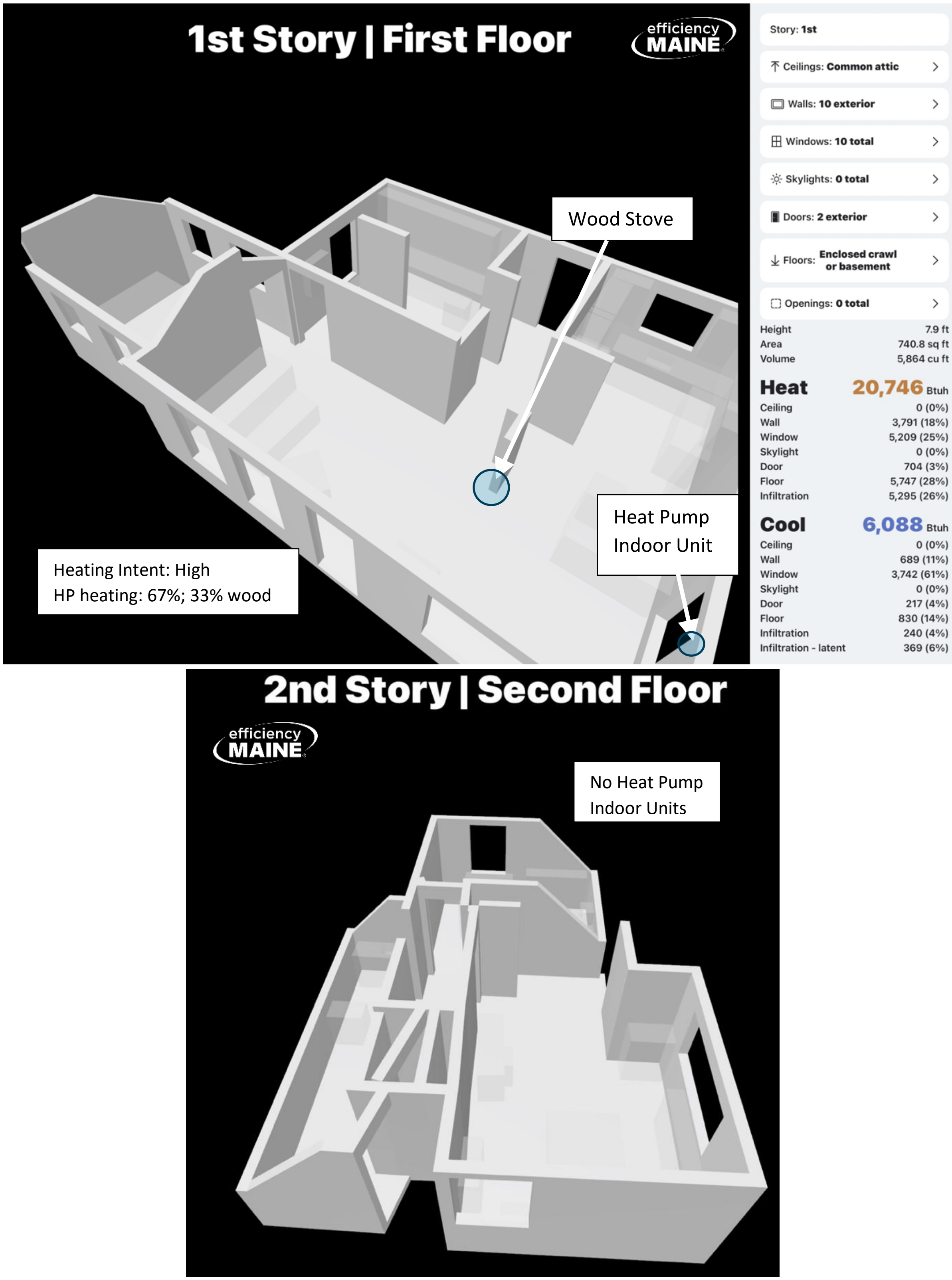


Figure 73. Scan of Two-Story Home (#952) with Wood Stove, Heat Pump, and Abandoned Single Zone Furnace

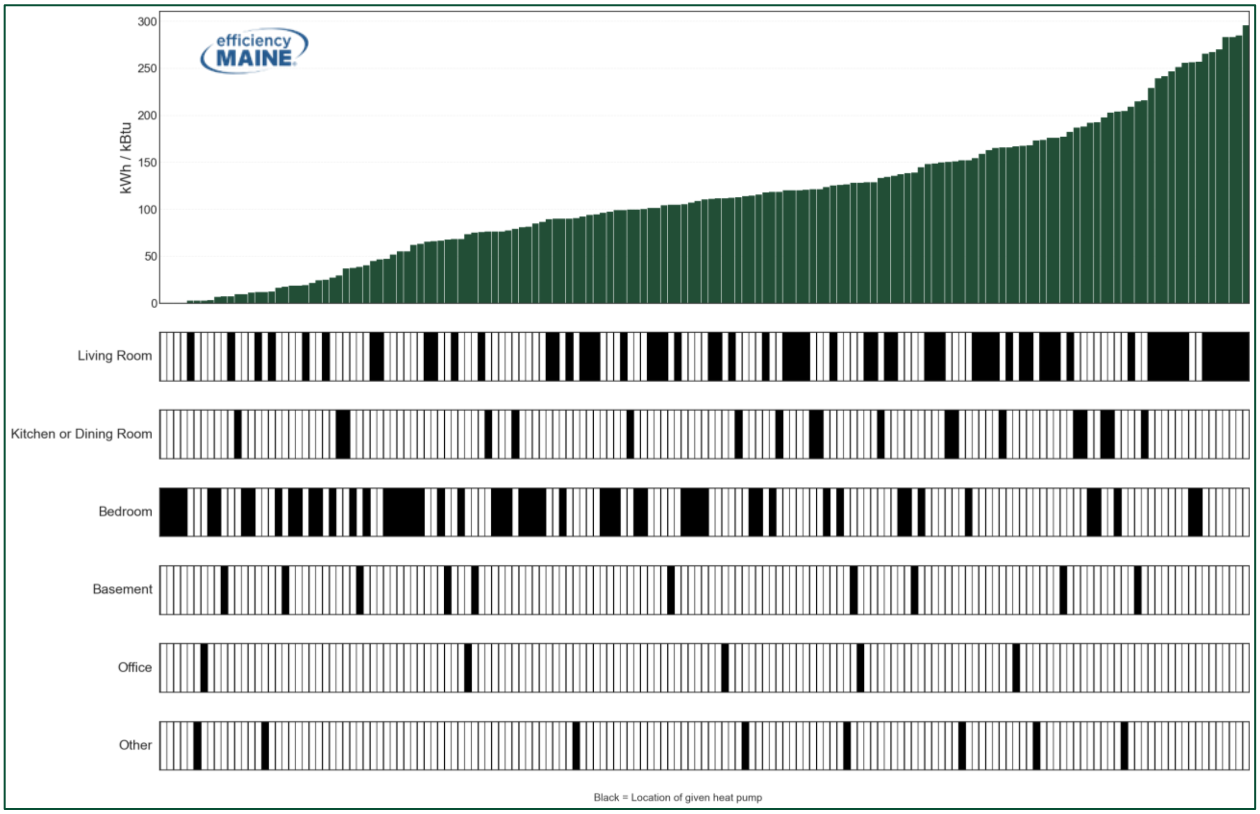


8.3 HEAT PUMP OVERSIZED FOR ZONE

When a heat pump serves a room, and its capacity is greater than the room's heating needs, the heat pump's usage will be limited by the room's low heat loss. This is common when a heat pump is placed in a small bedroom (120 ft^2, for example). For some manufacturers, the smallest indoor units made are 9,000 Btu/h, meaning that the bedroom heat pump is providing 90 Btu/h/ft^2. If the room is well insulated, this could be three or more times the capacity needed for such a small space, even at the coldest temperatures, and 10:1 during moderate temperatures. This will cause the heat pump to be used at a relatively low rate and could cause it to cycle more often during warmer temperatures.

Figure 74 shows the electricity used by a heat pump (kWh) divided by the rated capacity at 47°F ($kBtu_{rated}^{47}$). Below the chart, colored boxes show the locations of the heat pumps. Living room locations skew to the highest used heat pumps, and bedroom heat pumps skew towards low normalized use. Examples of "Other" rooms included playrooms, craft rooms, and conditioned garages.

Figure 74. Normalized Metered Heat Pump kWh by $kBtu_{rated}^{47}$ versus Room Location (n = 160)



8.4 CONTROLS AND HOMEOWNER OPERATION

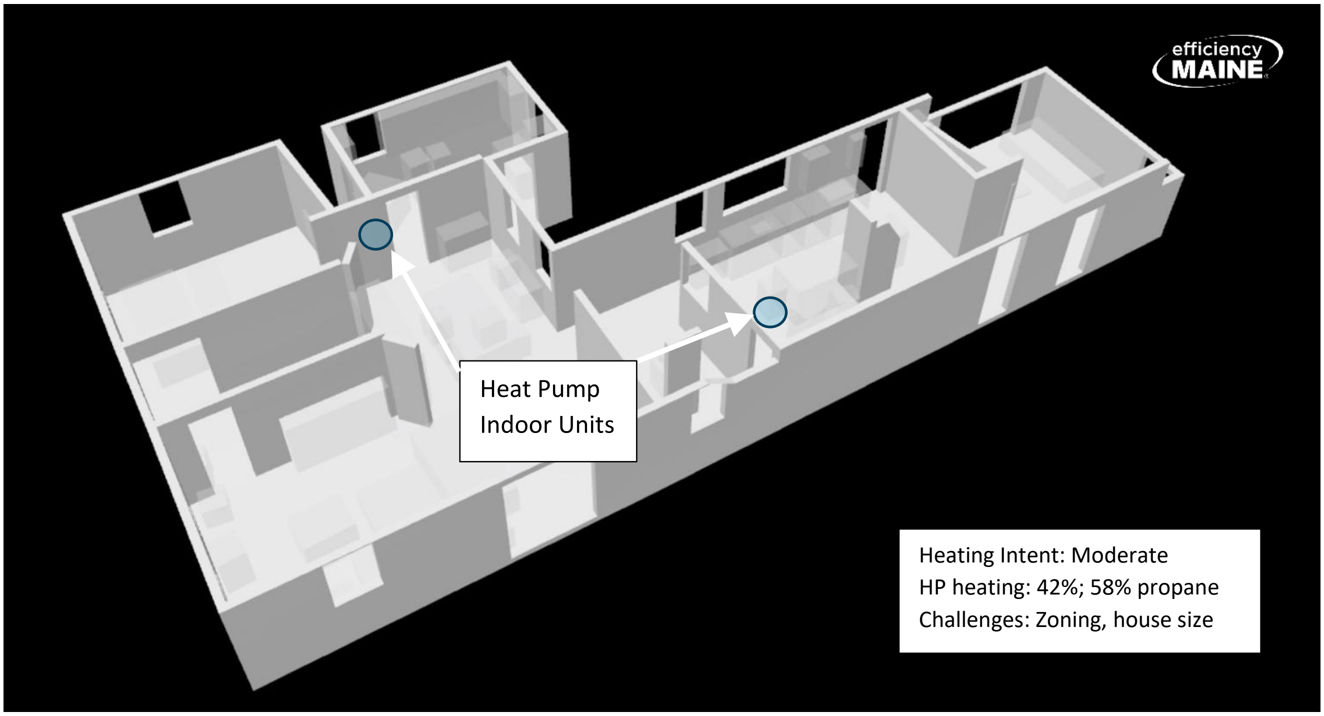
Most of the homes that Ridgeline visited had ductless heat pumps controlled by portable remote controls that would generally be left on a room table or occasionally mounted in a wall holster. Boilers and furnaces are controlled by wall-mounted thermostats located in each zone. Some homeowners understood that to heat with the heat pump, the central system's wall-mounted thermostat needed to be set well below the setpoint of the heat pump remote (known as a temperature "droop") to account for location and accuracy of the temperature readings. Other homeowners thought they were heating with heat pumps but had their central system thermostats set to the same temperature as their heat pump thermostats, which would lead to reduced heat pump use. Others operated their heat pumps like appliances, where they would turn the heat pump on when they entered the room or wanted to adjust their comfort, but otherwise turned the heat pump off.

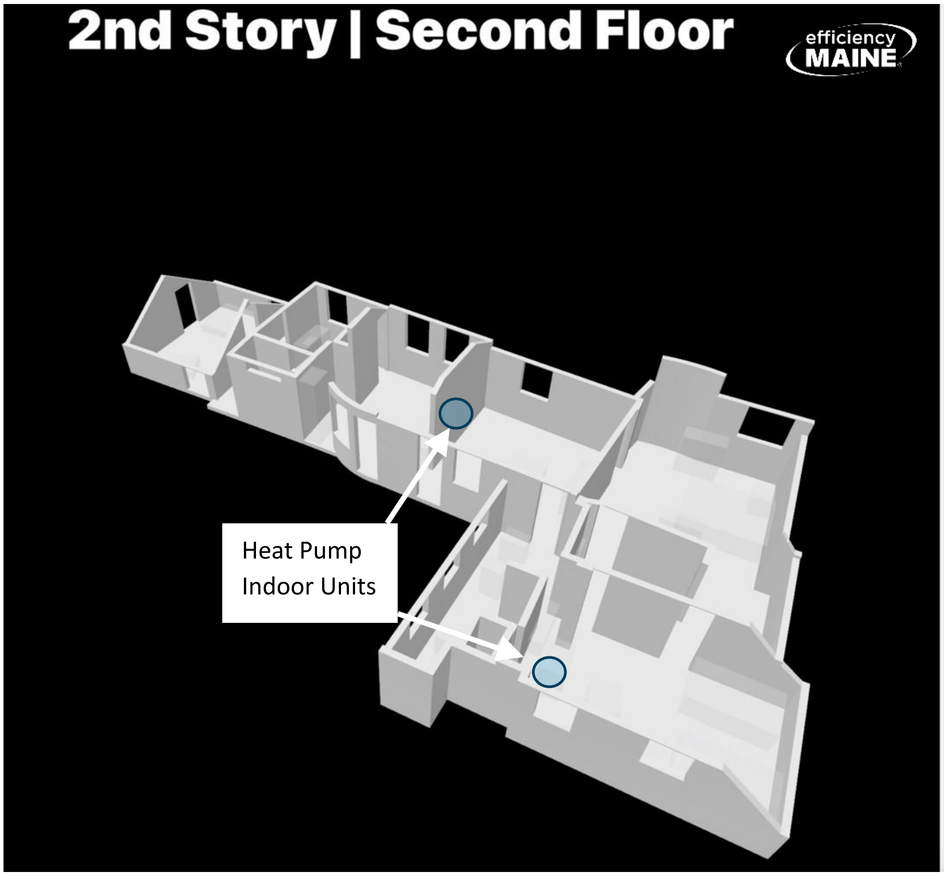
Consider House #398 with a large number of rooms, six boiler zones, and four indoor heat pump units (Figure 75). While the capacity of the heat pumps was close to the modeled heating needs and just below the heat used by the house, the home faced these challenges:

- The home had 10 rooms, not including halls and bathrooms, a challenge for four indoor units to cover.
- The six wall thermostats and four heat pumps, in overlapping zones, were set within 1°F of each other.

The heat pumps in the home met 42% of the heating needs, but the large number of rooms, large number of boiler zones, and minimal to no temperature droop likely all contributed to the relatively low use.

Figure 75. Scan of Two-Story Home (#398) with Four Heat Pumps with Thermostats Set to Match Boiler Zones





8.5 HEAT LOSS MODELING

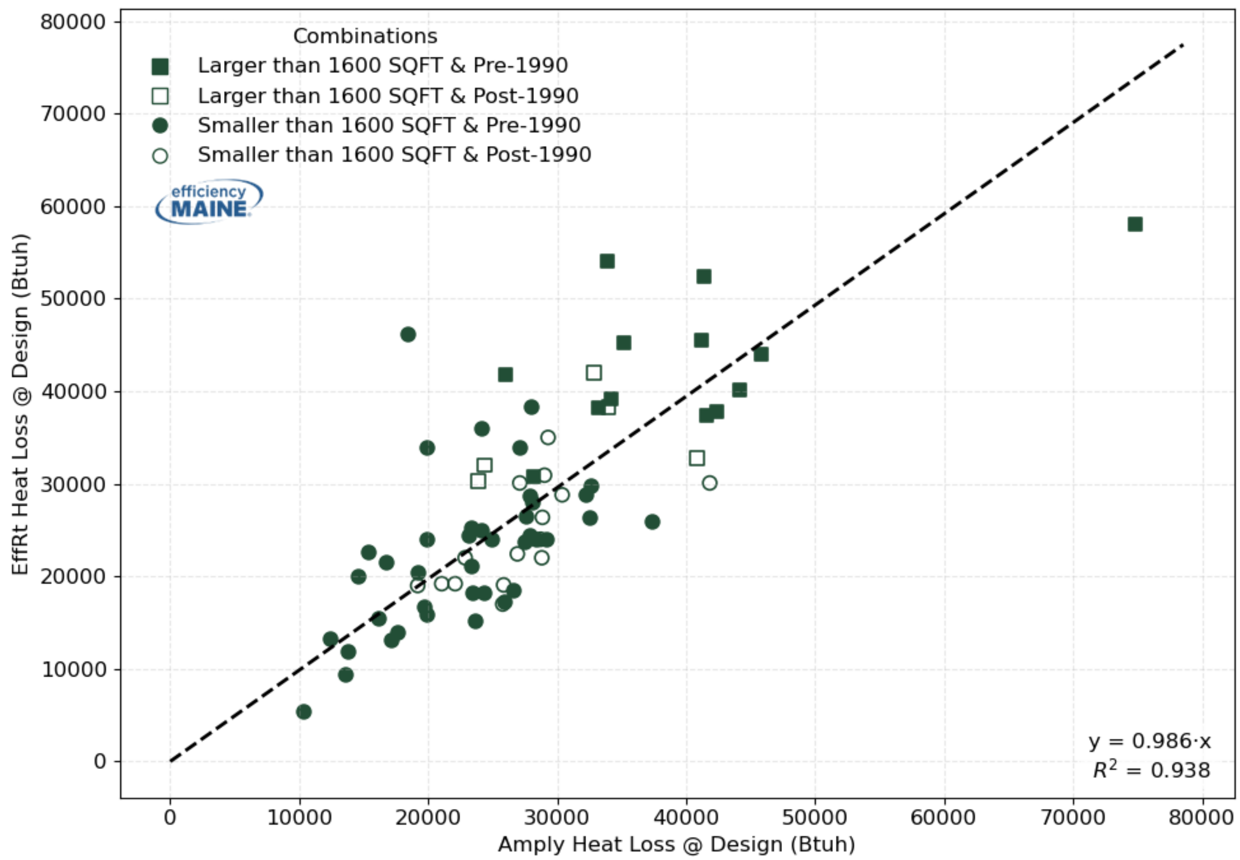
As part of the rebate application, contractors have several options to estimate the heat loss of a home including:

1. Approved software, using an ASHRAE 99.6% design temperature
2. Efficiency Maine Heat Load Estimator[35]
3. Square footage method: >/=20 Btu/hour/square foot of heated space

Most contractors opt to use Option 3, likely because it is the simplest and quickest approach. As described in Sections 4 and 11, Ridgeline scanned and developed a heat loss calculation for homes using Amply software. Figure 76 regresses the contractor heat load estimates onto the Amply modeled values. While there is a good deal of variability in the comparison, in part due to the single point estimates by contractors, contractor estimates are, on average, 98.6% of the Amply modeled values.

[35] Efficiency Maine Heat Load Estimator.

Figure 76. Comparison between Amply Scanned Heat Loss and effRT Heat Loss at effRT Design Temperature (n = 78)



As previously discussed, the total heat used by homes was metered. Figure 77 regresses the metered heat use with the Amply modeled value for each home. There is a good deal of variability among homes. On average, measured heat use is 86% of modeled use. Some of this difference is due to night setback, vacations, and non-uniform use of the home (e.g. a lightly heated spare zone). One other factor is that Manual J is designed to establish the heating need at design temperature. The model can be correct yet not match actual heating use when extrapolated to the whole season. In addition to the reasons above, behavior at temperatures around a home's balance point can also influence seasonal energy use. At warmer temperatures, some homeowners will continue to heat, while others will open windows as daytime temperatures rise. Ridgeline examined the comparison, looking at age and size of home. There is no clear pattern to the variation, but larger, older homes show a wide span using substantially more or less energy than the Amply Manual J model would predict.

Figure 77. Comparison between Amply Scanned Heat Loss and Metered Heat Output at 5°F (n = 78)

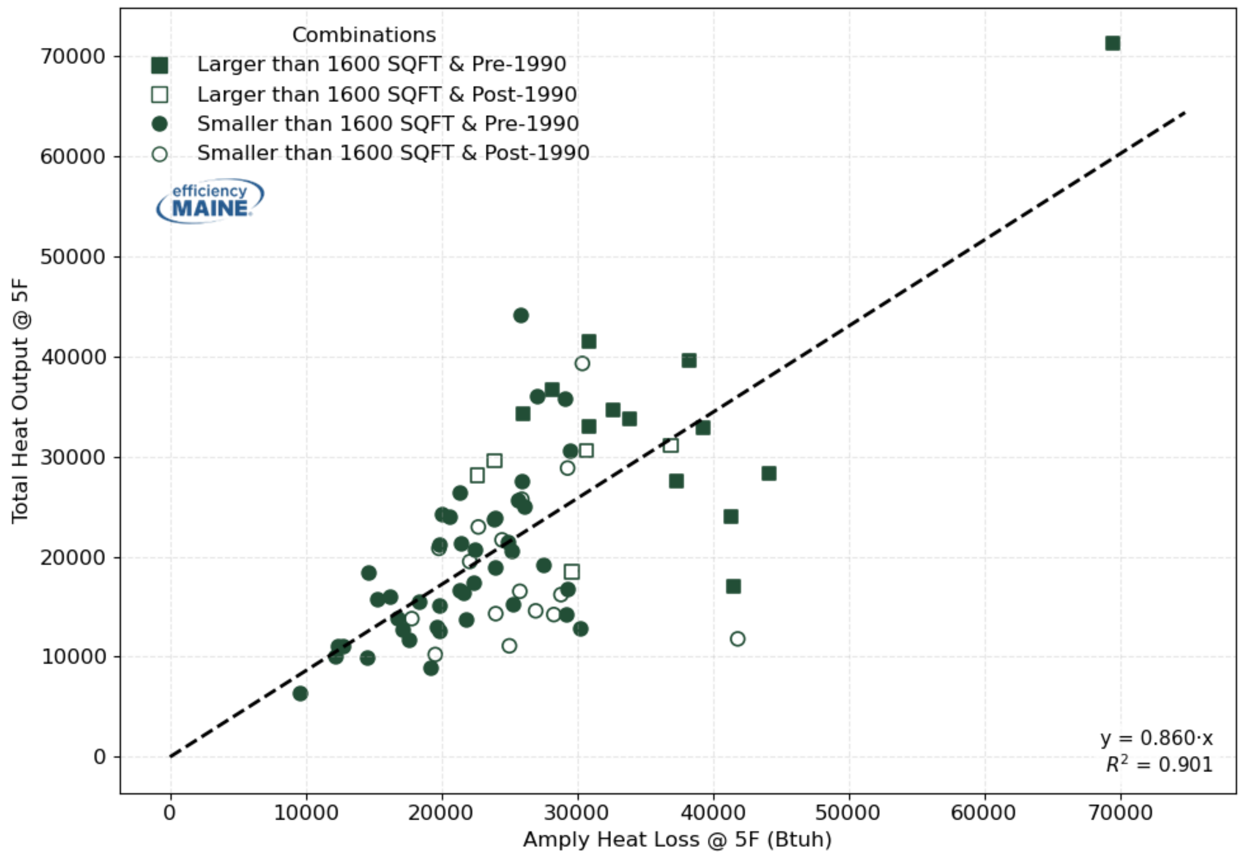


Figure 78 shows box and whisker plots of the Amply models, the effRT contractor load estimates, and the metered heat use of homes. While the medians of the Amply models and contractor estimates are similar, the variation of the contractor estimates is larger than that of the modeling. The metered heating use is lower than the models and estimates (by about 14%), but the span of the data is narrower than the contractor estimates and closer to the model. It is not surprising that actual heat use is somewhat lower than the model since behaviors like nighttime setback, heating selected zones of a home, and going on vacation can all decrease actual heat use below its modeled counterpart.

Figure 78. Comparison between Amply Scanned Heat Loss, effRT Heat Loss, and Metered Heat Output at 5°F (n = 78)

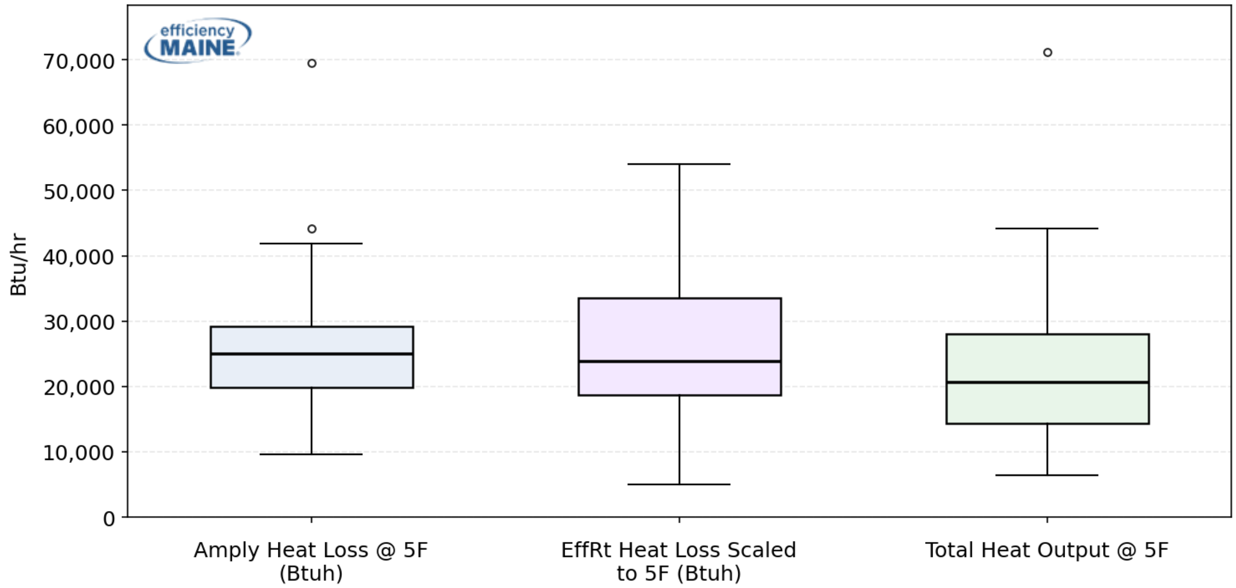
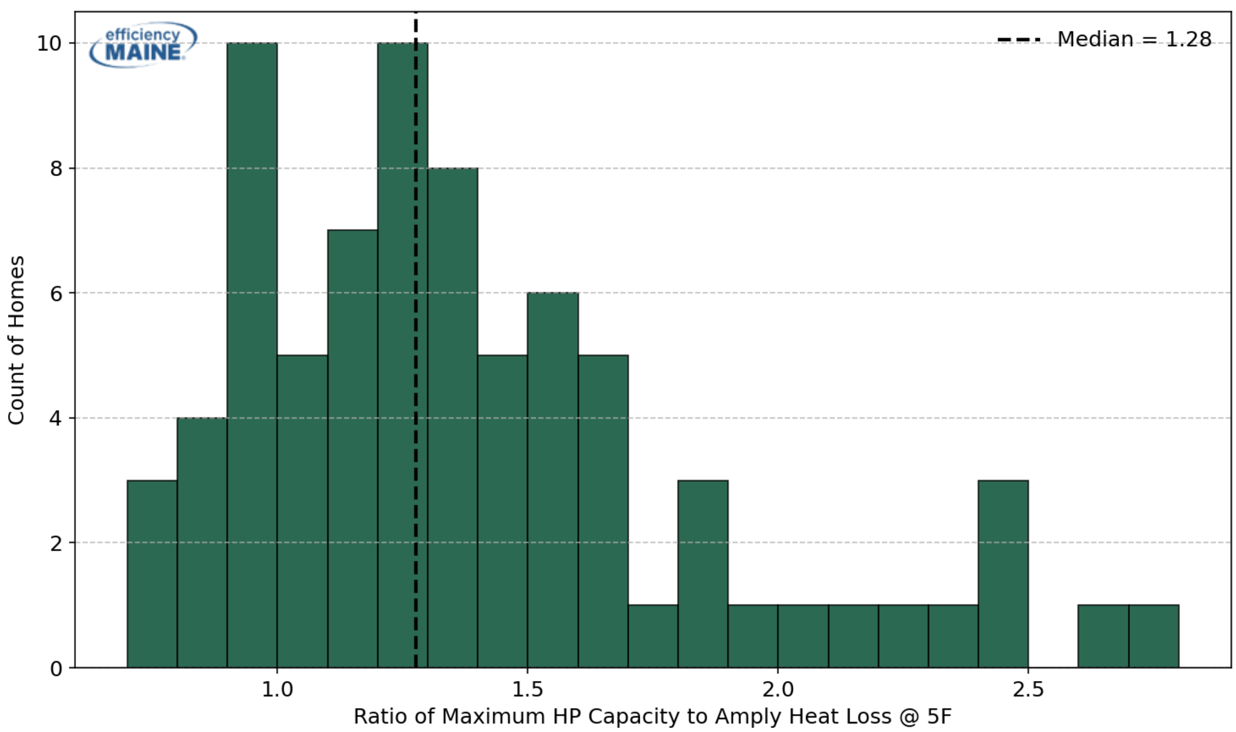


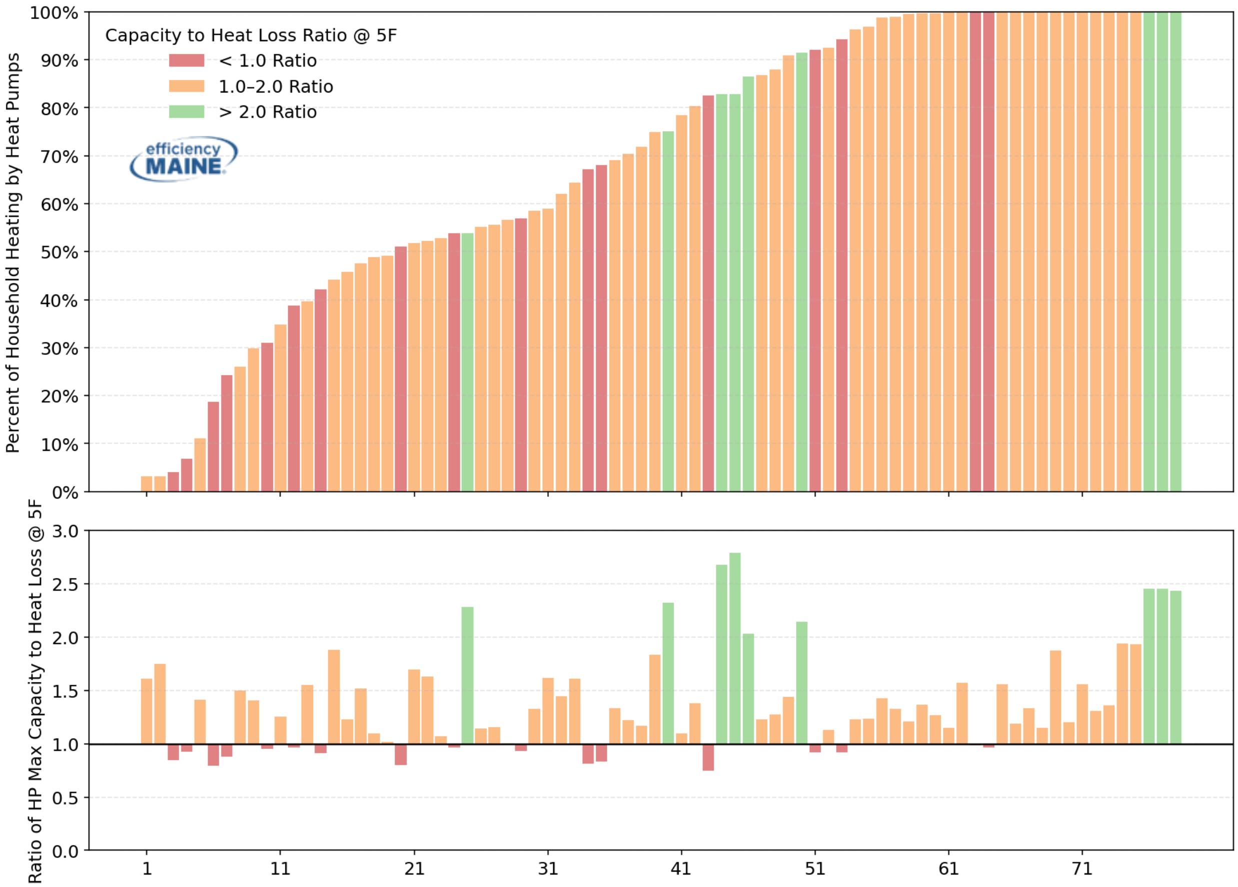
Figure 79 shows the ratio of heat pump capacity at 5°F to modeled heat loss at 5°F. Most homes have ratios greater than 1.0, but 17 (22%) have ratios less than 1.0, and of these, only 7 have ratios less than 90%.

Figure 79. Ratio of Heat Pump Maximum Capacity at 5°F to Amply Heat Loss Model at 5°F (n = 78)



To further examine the importance of the capacity ratio, Figure 80 shows the ratio color-coded and with the range of the percentage of heat that heat pumps provide. While 7 of the 17 homes with ratios below 1 are clustered towards the left side of the graph, the remaining 10 are spread across the range of heat pump use.

Figure 80. Normalized Usage of Heat Pumps with Ratio of Max HP Capacity to Heat Loss at 5°F (n = 78)



9 REFRESH AMI ANALYSIS AND COMPARISON TO INITIAL AMI ANALYSIS AND METERING

In parallel with the metering, the DSA team performed a refresh of the AMI analysis (Refresh AMI Analysis) discussed in Section 3. While the core modeling framework remained consistent with the Initial AMI Analysis, we introduced some refinements for the Refresh AMI Analysis. Table 16 summarizes the key differences between the Initial and the Refresh AMI analysis.

Table 16. Differences between Initial AMI Analysis and Refresh AMI Analysis

Change	Details
Additional AMI data	WHHP installations began in September of 2023, and the Initial AMI Analysis took place in the spring of 2024. This means we had limited post-WHHP data for the initial analysis. In the Refresh AMI Analysis, we had an additional year of post-WHHP AMI data for every participant. The inclusion of additional post data gives the regression model more information about the relationship between electric consumption and weather. We were able to estimate the change in the homes' relationship with cooling degree days (CDD) with the inclusion of summer data, and the change in base daily consumption (non-weather dependent) is more robust due to observing the home through changing seasons.
Blackout period	One finding from the Initial AMI Analysis was that the installation dates in the program tracking data were generally close to in-service dates but not always aligned. Because we had limited post-installation data for the initial analysis, we did not apply a "blackout period" around the installation dates. For the refresh analysis, we applied a two-week "blackout period" on either side of the installation date recorded in effRT for each home (four weeks total). Data within the blackout period was removed from the analysis data set.
Additional regression model specifications	For the Initial AMI Analysis, we used a single regression model specification to estimate impacts and cold-weather-dependent electric use for each participant. For the Refresh AMI Analysis, we used the same model from the initial analysis, but also tested out seven additional model specifications. The additional models, which are described in more detail in Appendix B, include variable heating degree day (HDD) base values and multi-segment HDD terms.
Mix of homes	There were 992 homes included in the Initial AMI Analysis. Reporting for the Refresh AMI Analysis focuses on 1,003 homes. While the counts are approximately the same, there is some variation in the set of homes included for each analysis. Homes with installation dates after 3/1/2024 were excluded from reporting for the Initial AMI Analysis but included in reporting for the Refresh AMI Analysis. We did not apply an installation date cutoff for the Refresh AMI Analysis. On the flip side, additional post-installation AMI data was not available for every home from the initial analysis. Homes without additional post-installation AMI data were not included in the Refresh AMI Analysis.

The homes in the metering sample were drawn from homes included in the Initial AMI Analysis. This overlap allowed us to compare the AMI-based estimates of heat pump consumption with field-metered heat pump consumption. Specifically, there were three research questions we wanted to address with this comparison:

1) Do AMI-based estimates of cold-weather-dependent electric use generally match metered heat pump consumption?
2) Of the models considered in the Refresh AMI Analysis, which specification produces heat pump consumption estimates that most closely mirror metered heat pump consumption?
3) Are there cases when an AMI-based approach is more or less applicable than metering?

Subsequent sections describe the key findings from the AMI/metering comparison.

9.1 FILTERS

The relevant filters for the AMI analysis were discussed in section 3.3.1. We applied the same set of filters to the refresh analysis with one modification. For the Initial AMI Analysis, we removed homes with fewer than 300 days of pre-WHHP data, but we did not apply this filter to the post-WHHP period due to the timing of the analysis (we only had a few months of post-WHHP data for each home). For the Refresh AMI Analysis, we applied the 300-day filter to both the pre-WHHP and post-WHHP periods. Table 17 shows the number of accounts that remained in the Refresh AMI Analysis after applying each filter. Note the total number of accounts for the Refresh AMI Analysis differs from the number of accounts in the Initial AMI Analysis for two reasons: (1) accounts with install dates after 3/1/2024 were excluded from the initial analysis but not the Refresh AMI Analysis, and (2) additional AMI data was not available for some homes that were in the Initial AMI Analysis.

Table 17. Refresh AMI Analysis Filtering

Filter	Accounts Remaining
Total accounts before filtering	**1,334**
Insufficient data	1,280
Solar power	1,114
Rebated EV	1,092
Low or high pre-WHHP annual consumption	1,082
Several days of zero reads	1,003
Total accounts after filtering	**1,003**

9.2 RESULTS

Table 18 shows summary statistics from the Refresh AMI Analysis. Estimated post-installation cold-weather-dependent electric use is shown in both kWh and kWh per total household $kBtu_{Max}^{Design}$. Pre/post heat pump impacts are shown in kWh. At a high level, findings from the Refresh AMI Analysis support the findings from our Initial AMI Analysis – heat pump utilization under the WHHP rebate structure is higher than under the prior supplemental heat pump rebate. The average predicted post-installation cold-weather-dependent electric use was 4,594 kWh/year, and the average normalized heat pump utilization was 136 $kWh/kBtu_{Max}^{Design}$. Similar to what we found in the Initial AMI Analysis, the results for the Refresh AMI Analysis, shown in Table 18, were annualized using TMY3 weather conditions.

Table 18. Refresh AMI Analysis – Results (n = 1,003)

Metric		P25	P50	P75	Mean
Total Household $kBtu_{Max}^{Design}$		25.2	33.9	43.5	35.9
Predicted Cold-Weather-Dependent Electric Use	kWh/year	2,256	4,094	6,504	4,594
	$kWh/kBtu_{Max}^{Design}$	66	122	185	136
Pre/Post Cold-Weather-Dependent Electric Use Delta	kWh/year	797	2,603	4,729	3,034
A normalized metric for the "Pre/Post Heat Pump Heating Impact" was not calculated because the capacity installed between the pre and post periods could not be accurately assessed. Also note that the capacity metric used in this table ($kBtu_{Max}^{Design}$) represents the total for the household.					

Table 19 shows the distribution of predicted cold-weather-dependent electric use by income group. Low-income participants had the smallest average, followed by the moderate-income participants. The distribution of predicted cold-weather-dependent electric use mirrors the distribution of total house capacity ($kBtu_{Max}^{Design}$) for these premises (averages of 38.8, 33.5, and 33.1 for the any-income, moderate-income, and low-income groups, respectively).

Table 19. Results by Income Group (n = 1,003)

Program Pathway	Predicted Cold-Weather-Dependent Electric Use (kWh/year)			
	P25	P50	P75	Mean
Low Income (n = 186)	1,646	3,679	5,498	3,983
Moderate Income (n = 348)	2,508	4,294	6,284	4,679
Any Income (n = 469)	2,160	4,166	7,025	4,774
Overall	**2,256**	**4,094**	**6,504**	**4,594**

9.3 COMPARISON WITH INITIAL AMI ANALYSIS

There were 992 premises included in the Initial AMI Analysis and 1,003 premises included in the Refresh AMI Analysis, but some homes from the initial analysis were not included in the refresh analysis, and vice versa. In total, there were 853 premises that were included in both of the AMI analyses. The summary statistics and figures in this section focus exclusively on these 853 homes. As such, the summary statistics in Table 20 do not mirror the summary statistics in Table 6 or Table 18.

Figure 81 compares post-installation cold-weather-dependent electric use estimates from the Initial AMI Analysis to those derived in the Refresh AMI Analysis (specifically from model 1-A; see Appendix B for all models tested). Each point represents a single participant account, with the X-axis reflecting the estimated cold-weather-dependent electric use from the initial analysis and the Y-axis showing the corresponding estimate from the refresh analysis. Overall, the relationship is tightly clustered along the 45-degree identity line, indicating a high level of agreement between the two sets of estimates. This consistency suggests that the core results from the Initial AMI Analysis were not overly perturbed by any data shortage issues or issues around close-but-imperfect installation dates in the program tracking data. Differences between estimates across periods can likely be explained by (1) additional data in the refresh analysis reduces some noise, (2) possible behavioral changes between winters (i.e., reduced heat pump utilization due to bill concerns or increased heat pump utilization due to running out of a delivered fuel), or (3) degree day base issues that did not materialize in the Initial AMI Analysis due to having limited post-installation data.

Figure 81. Initial AMI Results vs Refresh Results (n = 853)

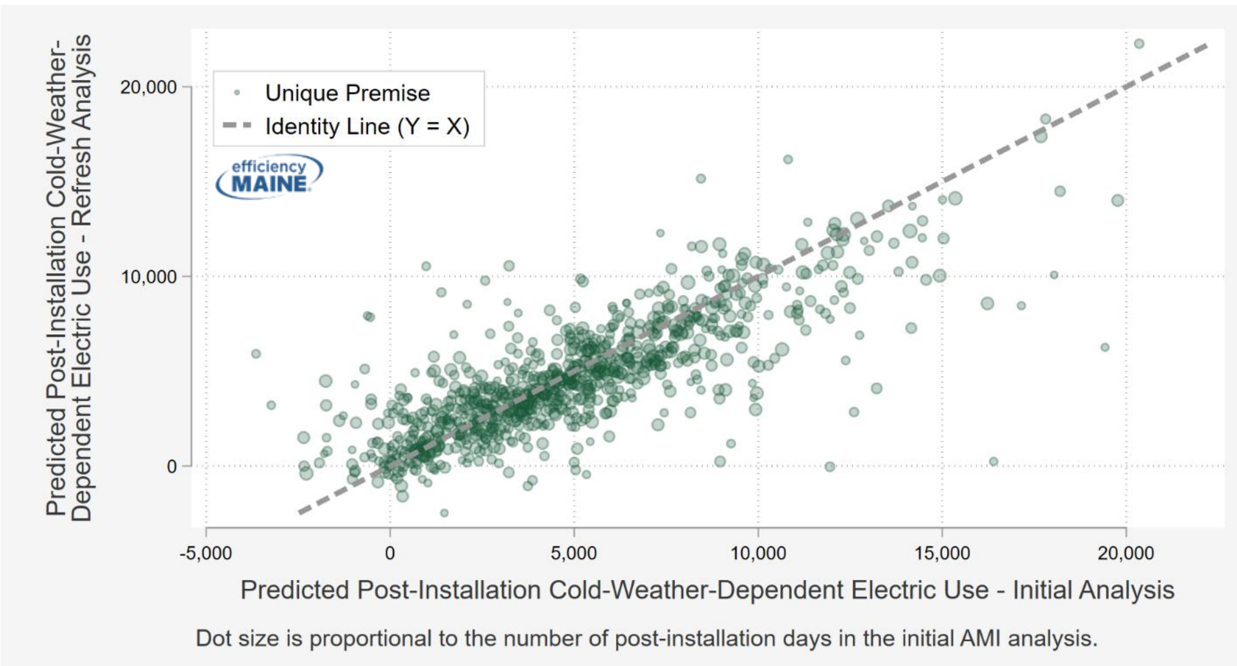


Figure 82 shows the distribution of predicted post-installation cold-weather-dependent electric use for the two AMI analyses. The results from the refresh analysis are represented with green bars, and the results from the Initial AMI Analysis are represented with clear bars outlined in black. The central tendency for the two distributions is similar, but the distribution from the Initial AMI Analysis shows greater spread (more premises fall in the tails of the distribution). The fact that the Refresh AMI Analysis results show less variation can be explained by the fact that we had an additional year of post-installation data for each premise in the refresh analysis. For the Initial AMI Analysis, we only had a few weeks of post-installation data for many premises (often excluding the coldest period of the 2023-24 winter).

Figure 82. Distribution of Predicted Post-Installation Annual Heating kWh by Analysis

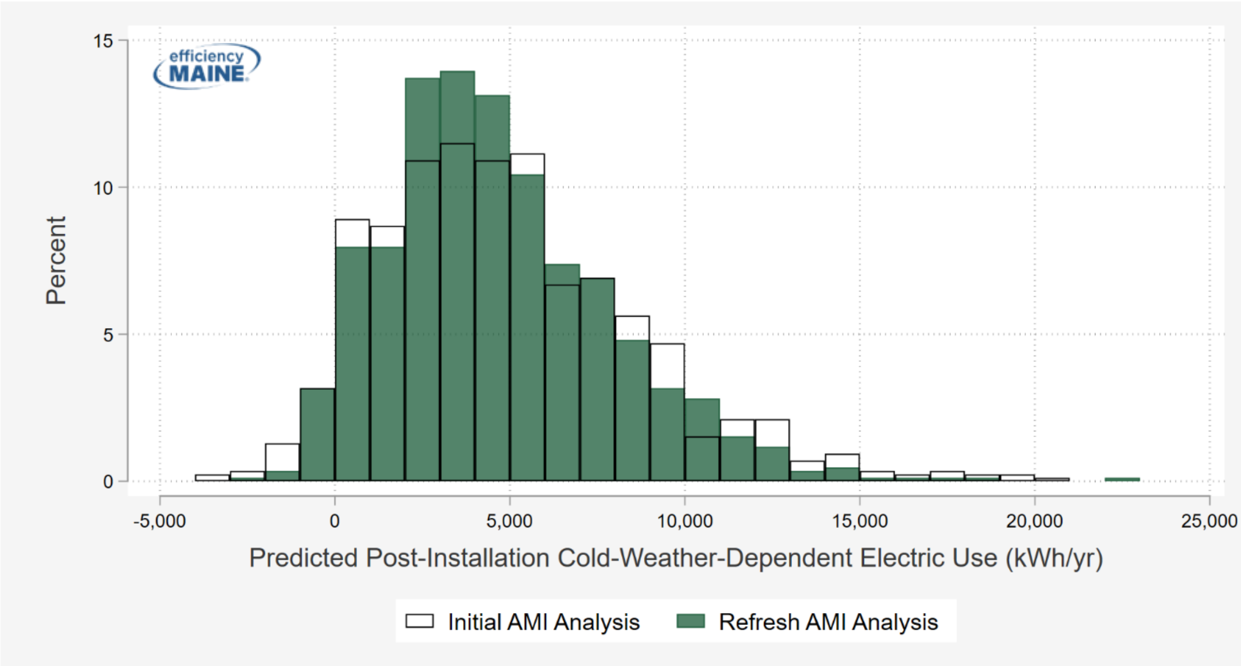


Table 20 provides a quantitative comparison of post-installation cold-weather-dependent electric use estimates across the Initial AMI Analysis and the Refresh AMI Analysis (using Model 1-A). Results are presented both in absolute terms (kWh/year) and normalized to total household heat pump capacity at design temperature (kWh/kBtu$_{Max}^{Design}$). The median and mean values are slightly lower in the Refresh AMI Analysis. The distribution of predicted post-installation cold-weather-dependent electric use for the Initial AMI Analysis showed a slightly stronger right skew than the Refresh AMI Analysis (Figure 82). With more post-installation data for the Refresh AMI Analysis, the right skew (and general spread) of the distribution was reduced. As such, the metrics of central tendency both decreased slightly.

Table 20. Estimated Post-Installation Cold-Weather-Dependent Electric Use – Initial vs Refresh (n = 853)

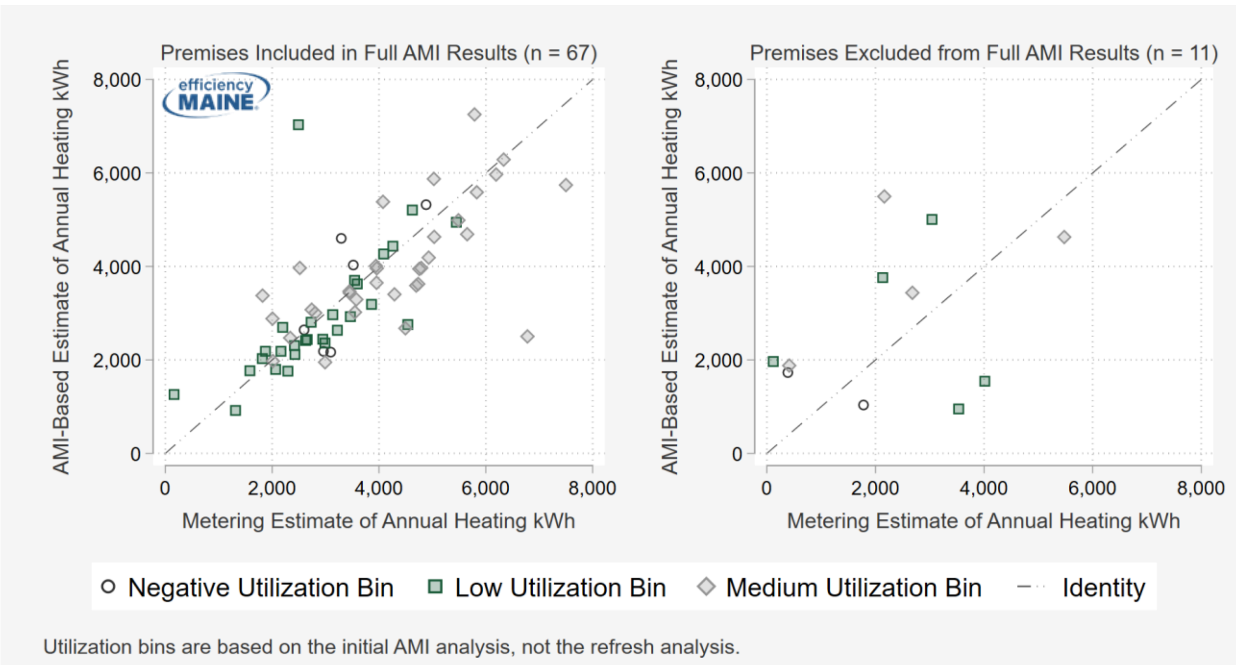
Stage	Unit	P25	P50	P75	Mean
Initial AMI Analysis	kWh/year	2,255	4,500	7,174	4,936
	kWh/kBtu$_{Max}^{Design}$	74	132	204	147
Refresh AMI Analysis	kWh/year	2,456	4,191	6,564	4,675
	kWh/kBtu$_{Max}^{Design}$	74	126	190	140
The summary statistics in this table do not mirror the summary statistics in Table 6 or Table 18 because Table 20 focuses only on 853 homes that were included in both the initial and refresh AMI analyses. Also note that the capacity metric used in this table (kBtu$_{Max}^{Design}$) represents the total for the household.					

9.4 COMPARISON OF AMI AND METERING RESULTS

To understand the strengths and weaknesses of AMI analysis as a method for quantifying heat pump utilization, we compared annualized predictions from the metering and AMI data. Unlike the weather-normalization to TMY3 conditions described elsewhere in this report, this comparison used actual weather conditions. Specifically, we used the observed local weather between October 1, 2024, and April 30, 2025, to calculate annual heating degree days. Coefficients from the AMI regressions were used to estimate heating consumption for the HDD total over this seven-month heating season. For the metering data, we used the ratio of HDD across the seven-month heating season to the local HDD during the site-specific metering window to annualize the metered heat pump consumption.

Figure 83 compares the annualized heat pump heating kWh estimates from the AMI analysis and the metering sample. As described above, these annual heating kWh predictions reflect observed weather during the 2024-25 winter rather than TMY3 conditions. The markers in the figure indicate the utilization bin from the Initial AMI Analysis. Homes from the “High” utilization bin were not metered, so that bin is not represented in these results. The left panel of Figure 83 shows homes that were included in the overall AMI results presented in Section 9.2, and the right panel shows homes that were excluded from the overall AMI results presented in Section 9.2 due to the presence of solar panels, a rebated EV, or other data quality issues.

Figure 83. Comparison of Annualized Heating kWh Estimates from AMI and Metering



Among the homes included in the Refresh AMI Analysis, the average ratio of AMI to metering is similar across the utilization bins. Table 21 shows the average estimated heat pump consumption for winter 2024-25 for the overlapping homes. The ‘Medium’ bin has the lowest ratio of AMI-predicted to metered, and the ‘Negative’ bin has the highest, but all three utilization groups are within ±10%. Notably, all homes that were in the negative utilization group had positive estimates of cold-weather-dependent electric use in the Refresh AMI Analysis. More detail is provided on these homes in Appendix C: Details on Metered Homes in the Negative Utilization Bin.

Table 21. Ratio of AMI to Metering Predictions by Utilization Group

Utilization Group	Number of Homes	Annual Heat Pump Heating kWh			Ratio of Refresh to Metered
		Initial AMI Analysis	Refresh AMI Analysis	Metering	
01 Negative	6	-1,997	3,491	3,391	103%
02 Low	28	2,120	2,899	2,876	101%
03 Medium	33	4,604	3,995	4,288	93%
Bins 01 to 03	**67**	**2,998**	**3,491**	**3,618**	**96%**
Results in the "Initial AMI Analysis" column are annualized using TMY3 data. Primary results for the Refresh AMI analysis were also annualized using TMY3 data (see section 9.2). However, for the AMI-metering comparison, both sets of results ("Refresh AMI Analysis" and "Metering" columns in this table) were annualized as described at the beginning of this section (using local weather between October 1, 2024, and April 30, 2025).					

9.4.1 Extrapolation of AMI-Metering Comparison to the Population

In Table 21, we compared AMI-based estimates of cold-weather-dependent electric use to actual metered heat pump consumption. The table suggests AMI-based estimates generally mirror actual metered consumption, though results varied by premise and utilization bin. We used the findings from this comparison to adjust the findings from the refresh AMI analysis as follows:

1. Binned the 1,003 homes in the Refresh AMI Analysis into Negative, Low, Medium, and High utilization groups. The "Negative" group consists of all premises with negative estimates of cold-weather-dependent electric use (4% of premises). A negative estimate indicates that the heat pump usage – if any – does not scale linearly with decreases in outdoor temperatures. The non-negative homes (96% of premises) were evenly split between the three remaining groups (32% each for Low, Medium, and High).
2. Using the Refresh AMI Analysis results, calculated the average cold-weather-dependent electric use for each of the four bins. These averages are shown in Table 22 – see the 'Average Predicted Cold-Weather-Dependent Electric Use' column.
3. Used the results from Table 21 to adjust the average cold-weather-dependent electric use for each of the four bins.
    a. For the Negative bin, we did not apply an adjustment. Premises in this bin showed atypical results, and an adjustment does not seem warranted. Metered homes in the "Negative" utilization bin all showed positive cold-weather-dependent electric use in the Refresh AMI Analysis.
    b. For the Low bin, the adjustment factor was 101% (meaning we divide the average AMI-based estimate of cold-weather-dependent electric use by 1.01). This factor comes from Table 21.
    c. For the Medium bin, the adjustment factor is 93% (meaning we divide the average AMI-based estimate of cold-weather-dependent electric use by 0.93). This factor comes from Table 21.

   d. For the High bin, we applied the adjustment factor from the medium bin. No homes in the “High” utilization group were metered, so we have no direct comparison of how AMI-based estimates of cold-weather-dependent electric use compared to actual metering results for these homes. We assumed that findings for the medium utilization group are representative of what we would find in the high utilization group.

4. Using the population weights identified in step 1 (4% for Negative and 32% each for Low, Medium, and High), we calculated a weighted average of the adjusted results. See the ‘Adjusted Average Predicted Cold-Weather-Dependent Electric Use (kWh/year)’ column in Table 22 for results by bin.

Table 22 shows the adjusted results. The adjusted estimate of post-installation cold-weather-dependent electric use is 4,904 kWh per year, on average. A 95% confidence interval for the adjusted average spans from 4,683 kWh/year to 5,125 kWh/year. Note that all results in the table are weather normalized using TMY3 weather conditions (but the adjustment factors were developed by comparing results that were both annualized using local weather between October 1, 2024, and April 30, 2025).

The key underlying assumption with this approach outlined above is that the 93% adjustment factor used for the medium group is representative of what we would have seen in the high group had any high utilization homes been metered.

Table 22. Extrapolation of AMI-Metering Comparison to Full Population

Utilization Group	Population Weight	Average Predicted Cold-Weather-Dependent Electric Use (Refresh Analysis)	Metering Adjustment Factor	Adjusted Average Predicted Cold-Weather-Dependent Electric Use (kWh/year)
01 Negative	4%	-502	100%	-502
02 Low	32%	1,708	101%	1,691
03 Medium	32%	4,306	93%	4,630
04 High	32%	8,432	93%	9,067
Weighted Average	**100%**	**4,594**	**---**	**4,904**

9.4.2 Additional Detail on Selected Premises

The next three figures highlight three select premises, one where the AMI-based estimates and metering results were well-aligned, one where the AMI-based estimates overpredict the metering results, and one where the AMI-based estimates underpredict the metering results. Each figure has four panels that should be interpreted as follows:

- The **top left panel** compares the AMI-based predictions of cold-weather-dependent electric use (x-axis) with metered heat pump usage (y-axis).
- The **top right panel** shows a daily time series with lines for whole-household loads (HH Actual), metered heat pump consumption (Metered HP), and AMI-based predictions of cold-weather-dependent electric use (Predicted HP). The whole-household load data only runs through March

2025, while the metering data and predictions of cold-weather-dependent electric use run through April 2025. Predicted cold-weather-dependent electric use was extrapolated for April based on the observed relationship between whole-household loads and outdoor temperatures. The area plot in the background of the figure provides the average daily outdoor temperature at the home.

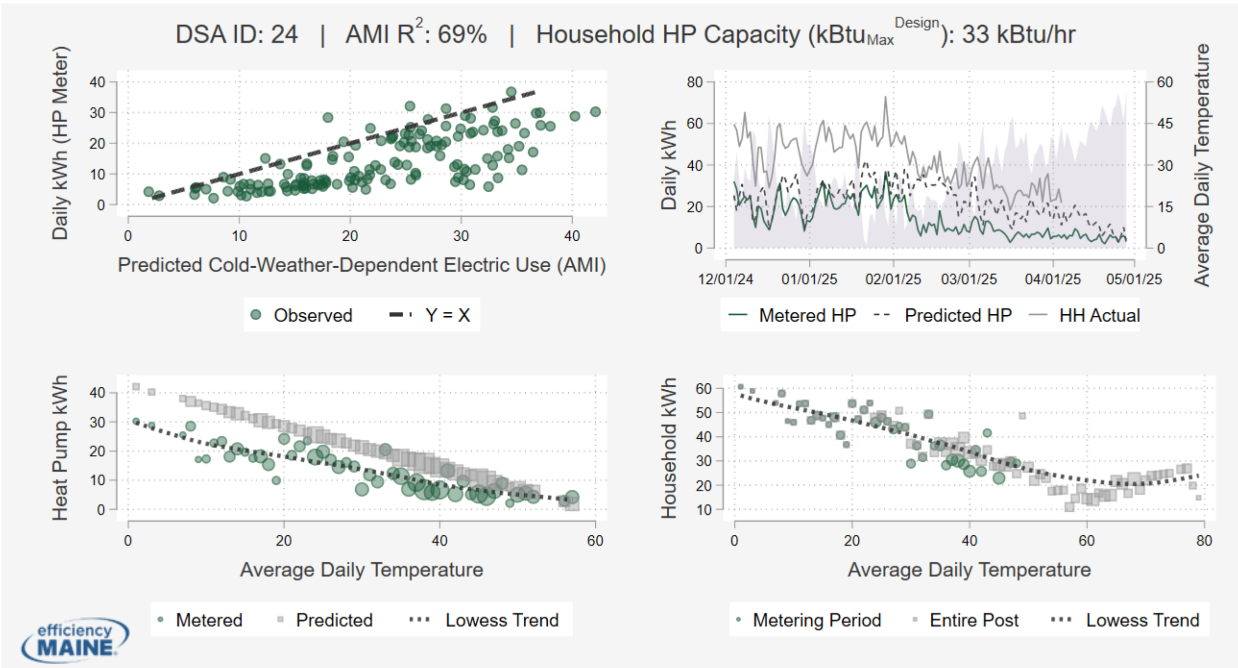
- The **bottom left panel** shows average metered heat pump usage and average AMI-predicted cold-weather-dependent electric use across 1-degree temperature bins. The size of the markers conveys the number of days in each 1-degree bin.
- The **bottom right panel** shows average daily household consumption in the post-WHHP period across 1-degree temperature bins. AMI data from the entire post-WHHP period are represented by green circles (inclusive of metered days and non-metered days), and the gray squares denote days within the metering period.

Figure 84 shows a home where the AMI-based predictions of cold-weather-dependent electric use show strong alignment with actual metered heat pump usage. The errors in the AMI predictions are generally small and centered at zero.

Figure 84. Example Home with Well-Aligned AMI and Metering Results

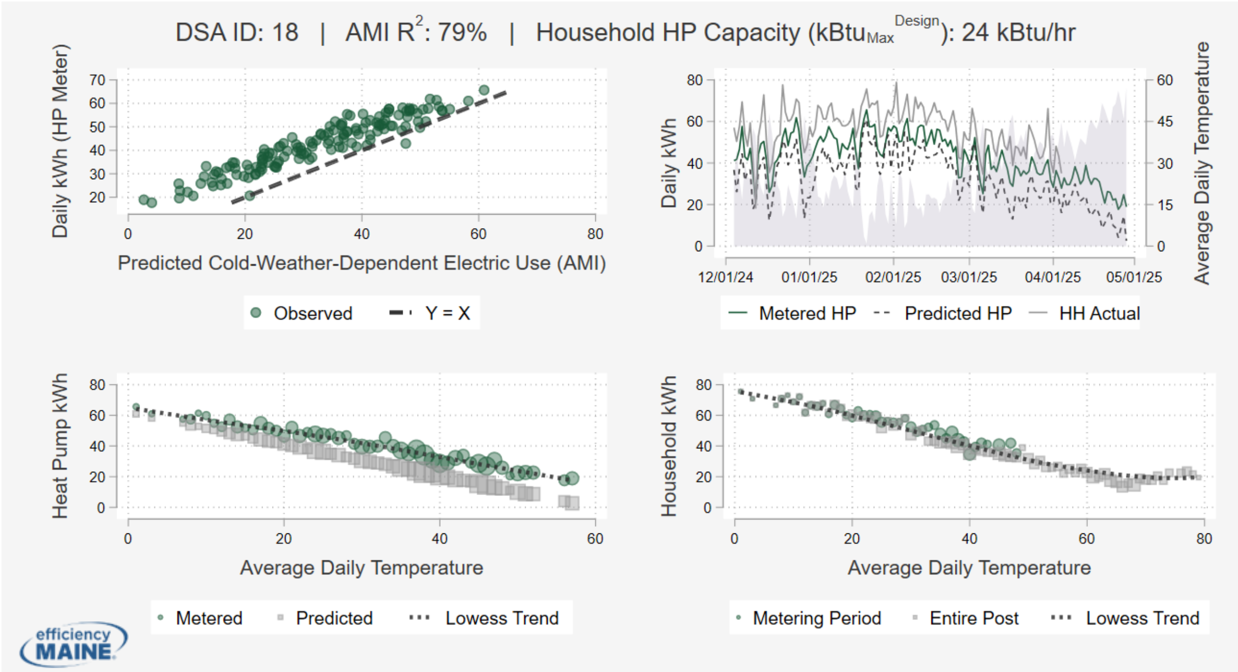
Figure 85 shows a home where the AMI-based prediction of cold-weather-dependent electric use exceeds metered heat pump consumption. Heat pump consumption represents a smaller share of household consumption than the prior example, and heat pump utilization appears to be slightly more erratic. The bottom right panel provides a clue as to why AMI overpredicts heat pump utilization for the home. AMI regressions are trained on all the household AMI data rather than just AMI data overlapping with the field metering period. This home's heat pump usage during the metering period looks slightly lower than the average usage over the entire post-WHHP period. As a result, the AMI regression tends to attribute too much of the whole house load to the heat pumps during the four months of overlapping data.

Figure 85. Example Home Where AMI Overpredicted Heat Pump Consumption



Finally, Figure 86 shows a home where the AMI-based prediction of cold-weather-dependent electric use is less than metered heat pump consumption. For this household, the AMI model consistently underpredicts heating consumption. The change point looks to be the culprit as the home is still using 15-20 kWh per day of heat pump heating as average daily temperatures approach 60°F. Our decomposition of the AMI coefficients forces predicted heating consumption to zero kWh at 60°F. The AMI model performance improves as temperature decreases, and heat pump consumption grows.

Figure 86. Example Home Where AMI Underpredicted Heat Pump Consumption



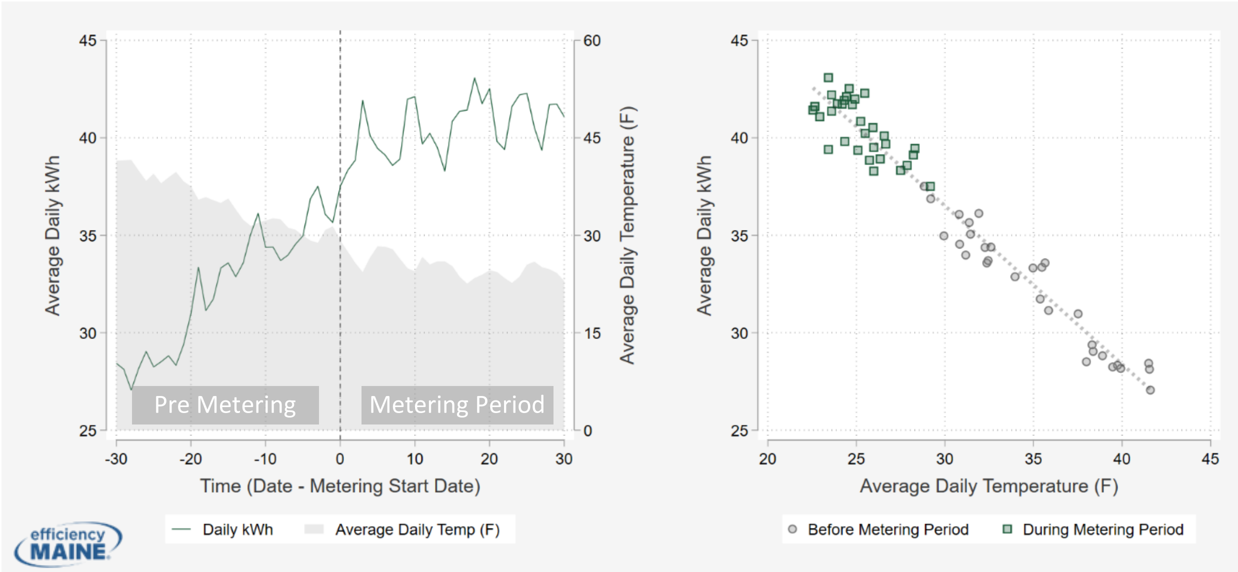
9.4.3 Comparison of Household Electric Usage Across Pre-Metering and Metering Periods

To determine whether the presence of metering equipment prompted any behavioral changes among the metering participants, we compared pre-metering household electric usage patterns with usage patterns during the metering period. Household electric usage was expected to be higher during the metering period simply due to temperature differences between the two periods, but the relationship between temperature and household electric usage should be consistent across periods, assuming no behavioral changes among the participants (e.g., no sudden change in heat pump use). Our findings indicate this relationship was indeed consistent across periods.

For this comparison, we isolated the 30 days prior to the metering period and the first 30 days of the metering period. Meter installation dates varied across premises, so the 60 days included in the comparison varied by premise. To put all premises on a uniform time scale, we created a new time variable as follows: time = metering start date – date. Under this definition, time equals 0 on the metering start date, is positive after the metering start date (time = 1 on the day after meters were installed and increases by 1 each day forward), and is negative prior to the metering start date (time = -1 on the day before the meters were installed and decreases by 1 each day prior).

After creating the uniform time scale, we calculated the average daily household electric usage and average daily temperature for each time level. Figure 87 summarizes the results. The left panel shows a time series of average daily household electric usage (green line) and average daily temperature (gray area). The increased daily usage in the metering period can be explained by a decrease in average daily temperature. This trend is confirmed in the right panel of the figure, which shows that the relationship between usage and average daily temperature is consistent across periods.

Figure 87. Comparison of Pre-Metering Period and Metering Period



9.5 KEY TAKEAWAYS

The metering results are considered the "ground truth" in our comparison of AMI-based predictions versus end-use metering. In most cases, we saw strong alignment between metered heat pump usage and AMI-based predictions of cold-weather-dependent electric use. Table 23 discusses our key questions from this analysis and offers perspectives on how AMI might be applied going forward.

Table 23. Findings from AMI versus Metering Comparison

Question	Discussion
Do AMI-based estimates of cold-weather-dependent electric use generally match metered heat pump consumption?	Yes, in aggregate. While the two methods return very similar estimates of total heating consumption and heat pump utilization across the homes in the metering sample, we see some notable variance on a house-by-house basis. A key advantage of AMI analysis is that it allows researchers to model a large sample of homes at low cost. It is not as precise as metering for specific homes, but we can analyze far more households. Metering is more costly but can answer the question of why households perform the way that they do, albeit for a smaller sample size.
Of the models considered in the Refresh AMI Analysis, which specification produces heat pump consumption estimates that most closely mirror metered heat pump consumption?	The model expansion is discussed in greater detail in Appendix B. Our initial model (1-A) returned estimates of heating consumption that were as unbiased and precise as any of the other model specifications tested. Other models outperformed 1-A for specific homes. For example, models 3-A and 3-B perform well in homes that stop using their heat pump at cold outdoor temperatures. Models 2-A and 2-B perform well for homes that continue to heat their homes when average daily temperatures are above 60°F.

Question	Discussion
Are there cases when an AMI-based approach is more or less applicable than metering?	Several factors impact the ability of AMI analysis to accurately estimate heat pump consumption. Amount of heat pump utilization is the most important factor. Homes that use their heat pumps consistently as a primary heat source are straightforward to model because (a) the heat pump represents a large share of household load, and (b) weather explains the variation across days in a largely linear relationship. Homes that use their heat pump intermittently are challenging for AMI because the model "splits the difference" and estimates moderate utilization on all days. This leads to underpredictions on days when the heat pump(s) are in use and overpredictions on days they are not. The presence of electric resistance heat in the home typically causes AMI analysis to overpredict heat pump utilization because the regression model attributes all weather-dependent electric load to the heat pump and cannot reliably deconstruct the heating usage between heat pump and resistance heaters. The adoption of load modifiers like solar and EVs during the pre- or post-period confounds the AMI analysis and prevents accurate predictions in most cases.

10 FINDINGS

The Initial AMI analysis portion of this study was undertaken in spring and summer 2024 to check the impact of the whole-home heat pump (WHHP) incentives that started in September 2023 (see Initial WHHP AMI Investigation). The field metering portion of the study began in fall 2024 based on some concern over a portion of homes that showed low use or even declining use with decreasing temperature (see “Metering” from Chapters 4-8).

- Initial questions about low heat pump electricity use indicated by AMI were answered by both metering heat pumps and by AMI analysis on more extensive post-installation data (see Refresh AMI Analysis and Comparison to Initial AMI Analysis and Metering). Heat pump utilization was higher and more explainable compared to the initial AMI results for those homes in the bottom two-thirds of the heat pump use categories.

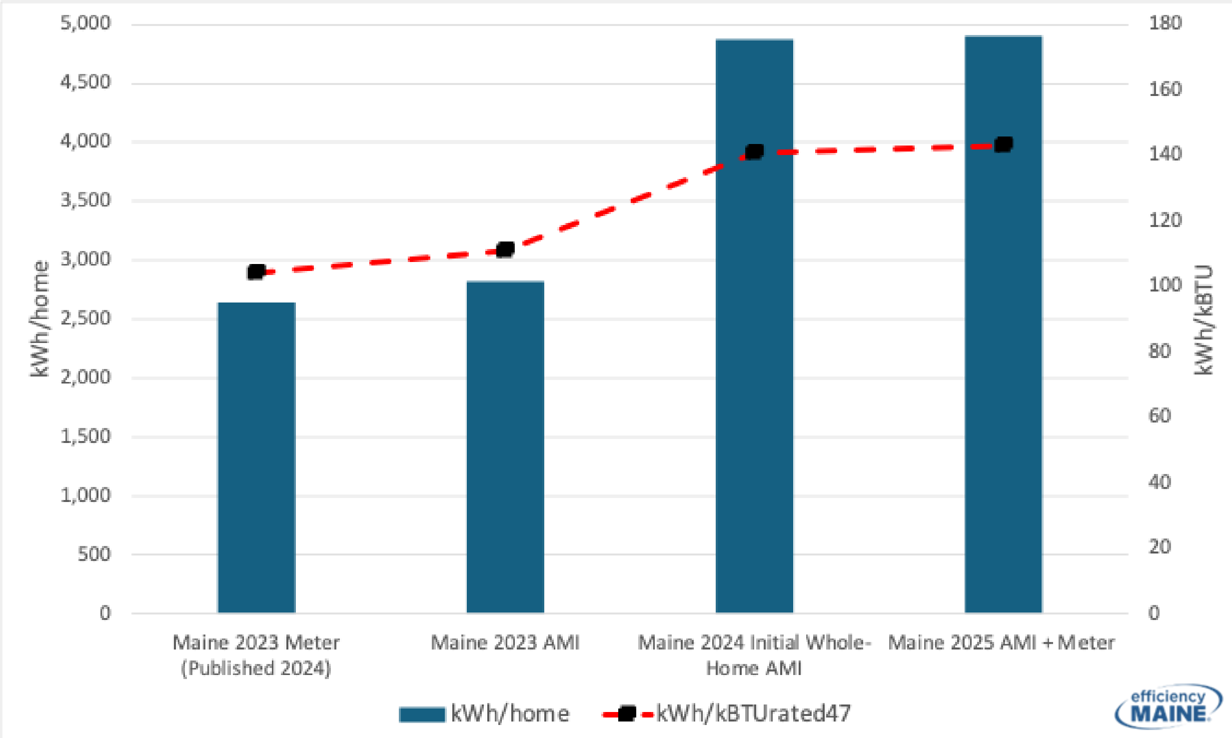
- Since heat pump metering was limited to the lower-consuming two-thirds of heat pump electricity users, extrapolating metering to the entire population was accomplished by calibrating results from the Refresh AMI Analysis. Using calibration factors (see Section 9.4.1 for more details), the population electricity use by heat pumps was calculated to be 4,904 kWh/year (Table 24).

Table 24. Extrapolation of AMI-Metering Comparison to Full Population

Period	Average Predicted Cold-Weather-Dependent Electric Use (kWh/ household/year)	Average Predicted Cold-Weather-Dependent Electric Use (kWh/heat pump/year)
Refresh AMI Analysis	4,594	2,089
Refresh AMI Analysis Calibrated by Metering Results	4,904	2,229

- Reviewing recent studies of the pre-2023 supplemental heat pump program and the post-2023 whole home heat pump program, several trends emerged (Figure 88). Total electricity consumed for household heating nearly doubled from the supplemental program to the whole home program. Electricity used, per unit of heat pump capacity, rises from 109 kWh/ $kBtu_{Rated}$[47] to 143 kWh/ $kBtu_{Rated}$[47]. The electricity use per heat pump unit did not increase as significantly as household heat pump electricity use due to differences in heat pump size and the quantity of homes across the different populations.

Figure 88. Comparison of Recent Studies of Electricity Consumption of Heat Pumps in Maine[36]



- Participation in the WHHP program correlated with a high proportion (74%) of users intending to use heat pumps for most or all of their heating (Figure 62). This is based on combining answers to recruiting call questions, with the assumption that non-metered high users would have the intent to use their heat pumps.
- Looking across all homes during the heating season, heat pumps provided 64% of the total heat used, wood stoves provided 10%, and fossil fuel-fired systems provided the remaining 26%. Removing the 10 homes that showed very low use and reflected homes where heat pumps were only intended for cooling or where there was a different preferred heat source, we see what results would likely occur in a program if it were to screen our participation from low-intent customers (i.e., customers whose intent to use the heat pump system to provide heating is low). If we use the proportions of low-, medium-, and high-consuming homes in the WHHP population and assume that heat pumps in the unmetered highest consuming homes provided 85% of heat, then we get the heating percentages extrapolated to the whole program. Both scenarios are shown in four combinations in Table 25.

[36] Efficiency Maine Residential Heat Pump Impact Evaluation. 2024.

Table 25. Heating Sources by Percentage

Analysis	Heat Pump	Wood	Fossil	AMI Category	Comments
Metering Analysis	64%	10%	26%	N, L, M	Metered, lowest two-thirds of heat pump users.
Whole WHHP Population	71%	10%	19%	N, L, M, H	Extrapolated to WHHP program population.
Metering – lowest 10 removed	73%	9%	18%	N, L, M	Removed the 10 lowest users, simulating a program incentivizing heating users only, but still for the lowest two-thirds of users.
WHHP Population – bottom 9% removed	77%	9%	14%	N, L, M, H	Removed the 10 lowest users and extrapolated to WHHP program population.

- Dividing homes into categories having one, two, or three non-ducted heat pumps allowed us to examine whether there were diminishing returns in adding additional heat pumps (Figure 71). We found that the first heat pump was used the most. While the second heat pump was used less than the first, the third heat pump was used nearly as much as the second (i.e., limited diminishing returns). Homes with two and three heat pumps were similar in both size and heat loss, while homes with one heat pump were smaller and had lower heating needs. The percentage of heat provided by heat pumps had an interesting pattern versus the count of heat pumps. Homes with a single heat pump tended to heat entirely with a heat pump. The median percentage of heat pump heat for homes with two heat pumps was about 55%, but this rose to about 85% for homes with three heat pumps. This implies that there can be heating distribution problems with two heat pumps in medium-to-large-size homes, and a third heat pump can help solve this issue.
- Metered heat use was on average 14% lower than modeled use at design temperature extrapolated to seasonal use (Figure 78). It is not surprising that actual heat use is somewhat lower than the model since behaviors like nighttime setback, leaving portions of a home, like a back bedroom for example, minimally heated, and going on vacation can all decrease actual heat use below its modeled counterpart. In addition, models are generally intended to establish heating needs at design temperatures and extrapolating this design use to a whole season based on degree days is an inexact process.
- Metered seasonal COP was on average about 3.15.
- The metering and AMI studies of the two rebate programs (2023 AMI study of the legacy supplemental rebate, versus the Initial and Refresh AMI Analyses for the WHHP program) generally agree within program (Figure 88). What variation exists is in part due to natural differences and precision between metering and AMI analyses, sample sizes, and the

populations themselves, where metering addresses a small subset of the population analyzed by AMI.

- On average, AMI analysis closely matched metered data, showing the value of its use in monitoring the average usage of heat pumps. Home-by-home predictions are not as accurate, but even so, AMI is a useful check on meter data quality and heat pump user behaviors.
    - The primary results from the AMI analysis are based on a model with a single heating change point. Future AMI analyses could consider adopting a secondary heating change point, as the relationship between daily electric consumption and outdoor air temperature often changes once outdoor air temperatures drop below 20-30°(F). See Section 12.1.2 for additional discussion.
    - The "best" degree day base pair varies by premise, as homeowners heat and cool their homes following their own preferences. On average, we found the best HDD base was 57 degrees, and the relationship between electric use and outdoor air temperature generally shows another change point around 24 degrees. See Section 12.1.1 for additional discussion.

11 APPENDIX A: METERING METHODS

11.1 OVERVIEW

This section describes methods used for sample design, recruiting, home visits, metering, and analysis of homes recruited from the initial AMI analysis. The methods described include pictures to illustrate our approach. Where a procedure needed to change based on issues encountered in the field, that is noted as well.

11.2 HOMEOWNER RECRUITMENT

We recruited using a letter approved by Efficiency Maine, which included Efficiency Maine's letterhead and was signed by Lauren Scott, the Efficiency Maine project manager. We made outbound calls from a (207) area code phone number, leaving the same number for call backs. Homeowners were offered $200 to participate in the study for one year.

11.3 FIELD DATA COLLECTION

We designed a sample to address AMI use categories (negative, low, and medium) and limited the geographical area generally south and west of the Bangor area to limit drive times, developing a sample of 80 homes. Ultimately, we installed meters in 79 homes in winter 2024. In total, we metered 161 outdoor heat pumps serving 167 indoor units.[37] We used photos and tablet-based data collection tools to document the homes and their heating systems.

11.3.1 Data Collection Tool

Ridgeline wrote a custom field data collection form based on Fulcrum,[38] a tablet-based data collection software authoring tool. Ridgeline had used this tool on previous projects, including a study of residential loads in Massachusetts. An example image from the tool customized for this project is shown in Figure 89. Our system allowed field engineers to enter home and heat pump characteristics directly into a database while on the site. Engineers also entered detailed metering data, including meter type, meter serial number, sensor type, and current transformer (CT) size.

To understand the heating zones of each home, field engineers examined each home and scanned living areas using software called Amply[39] that accessed Ridgeline's iPad LIDAR[40] sensors. The software allowed our field engineers to efficiently gather dimensions of spaces. It also contains an embedded

---

[37] One power meter failure dropped the analyzed sample to 160 outdoor units and 166 indoor units.

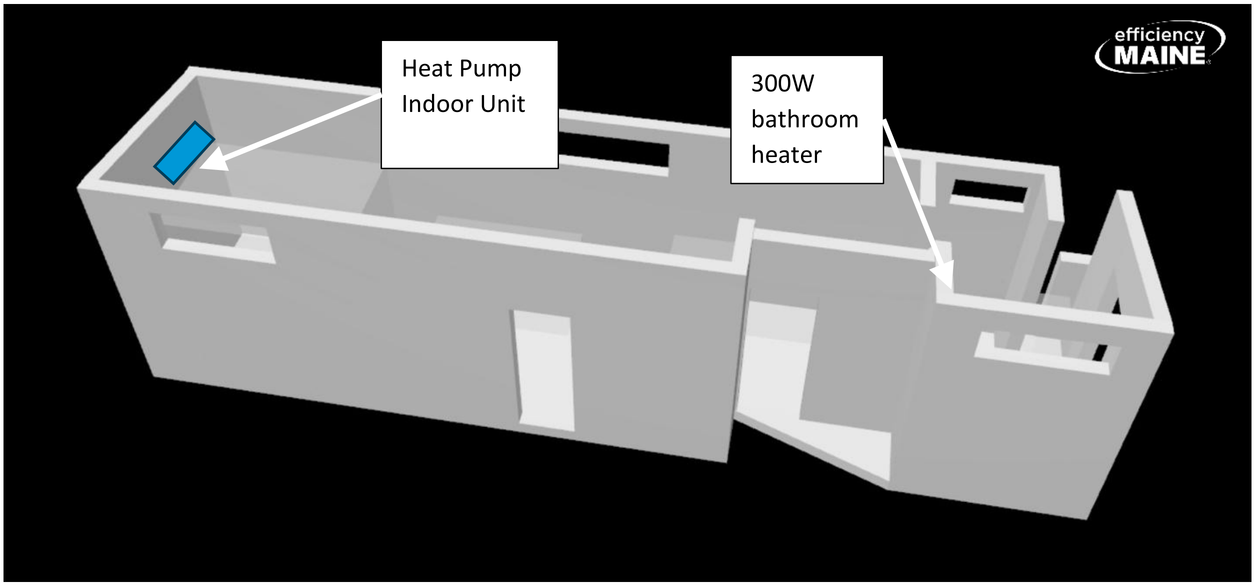
[38] Fulcrum Home Page.

[39] Amply is software designed for contractors to quickly and efficiently calculate heat loss of homes.

[40] LIDAR (Light Detection and Ranging) is a sensing technology that uses pulses laser light to measure distances and create 3-D models of objects. For this project, LIDAR is constructing 3-D models of rooms.

Manual J model[41] to calculate the heating and cooling requirements of living spaces. Figure 89 shows an example of a scan and the locations of the heating systems.

Figure 89. Example of LIDAR Scan of Home



11.3.2 Homeowner Discussions

To set the context of our review of heat loss and zoning and to plan our metering site visits, we discussed the use of heat pumps with each homeowner prior to visiting their home. We asked these questions:

- How many heat pumps do you have, indoor units, outdoor units?
- What other sources of heat do you have in your home? (central boiler or furnace, point source heaters)
- Do you have any wood heating? Is it cord or pellet style?
- How do you use your heat pump vs. other sources of heat at moderate, cold, and very cold temperatures?
- Do you have any issues with or concerns about your heat pump?

The purpose of these questions was to establish context and plan for the metering visit and was not meant to be a definitive assessment of their heating system and operation. For most homeowners, we could discern if their intention was to use their heat pumps for most of their heating, some of their

[41] Manual J is an ANSI-recognized ACCA (Air Conditioning Contractors of America) standard that provides a detailed method for calculating the heating and cooling loads of residential buildings to ensure HVAC systems are correctly sized.

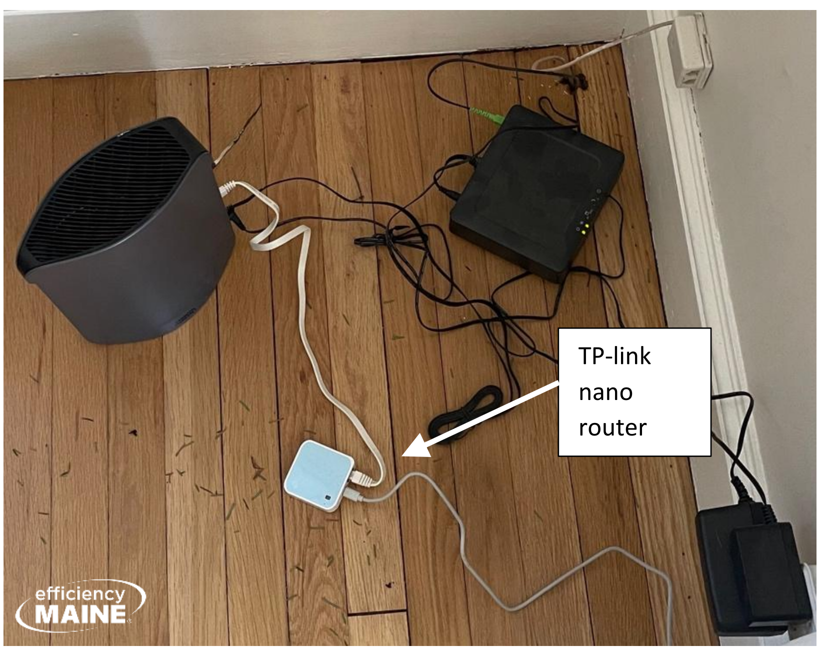
heating, or none of their heating. Indicators of low use include statements that they used the heat pump primarily for cooling, that they were away in the winter, or that they turned the heat pump on to take the chill off but relied on their other system. Indicators of high use would be statements that they set the heat pump to a comfortable temperature and set the other system to well below this setting, that they sought to use the heat pump as much as possible, and that they had either no other heating system or a seldom-used system. Indicators of moderate usage fell in between these extremes, where the homeowner attempted to use the heat pump for most heating but was unclear on exactly how to do that or where they primarily used the heat pump down to a certain outdoor temperature.

11.4 METERING AND MEASUREMENT

11.4.1 Loggers and WiFi

Ridgeline deployed two logging systems for this study: eGauge for metering electrical use at a home's electrical panel and Onset loggers for recording a variety of data. Ridgeline had various data signal converters built so that they could use this logging system to record pulse signals from power meters and alternating-current (AC) from current transformers. The Onset meters also directly record data from temperature sensing thermistors, humidity sensors, and DC output current transformers. Ridgeline attached micro routers to eGauges so that they could connect to Wi-Fi. Onset meters communicated via Bluetooth low energy (BLE) to an Onset gateway. That gateway relayed data to the web via Wi-Fi. Ridgeline constructed a Wi-Fi network in each home using a nano-router that was connected to the homeowner's router via an Ethernet cable (Figure 90) or installed a Sierra cellular router that had an onboard Wi-Fi radio.

Figure 90. Nano Router Plugged into Home Router for Wi-Fi Connected Metering



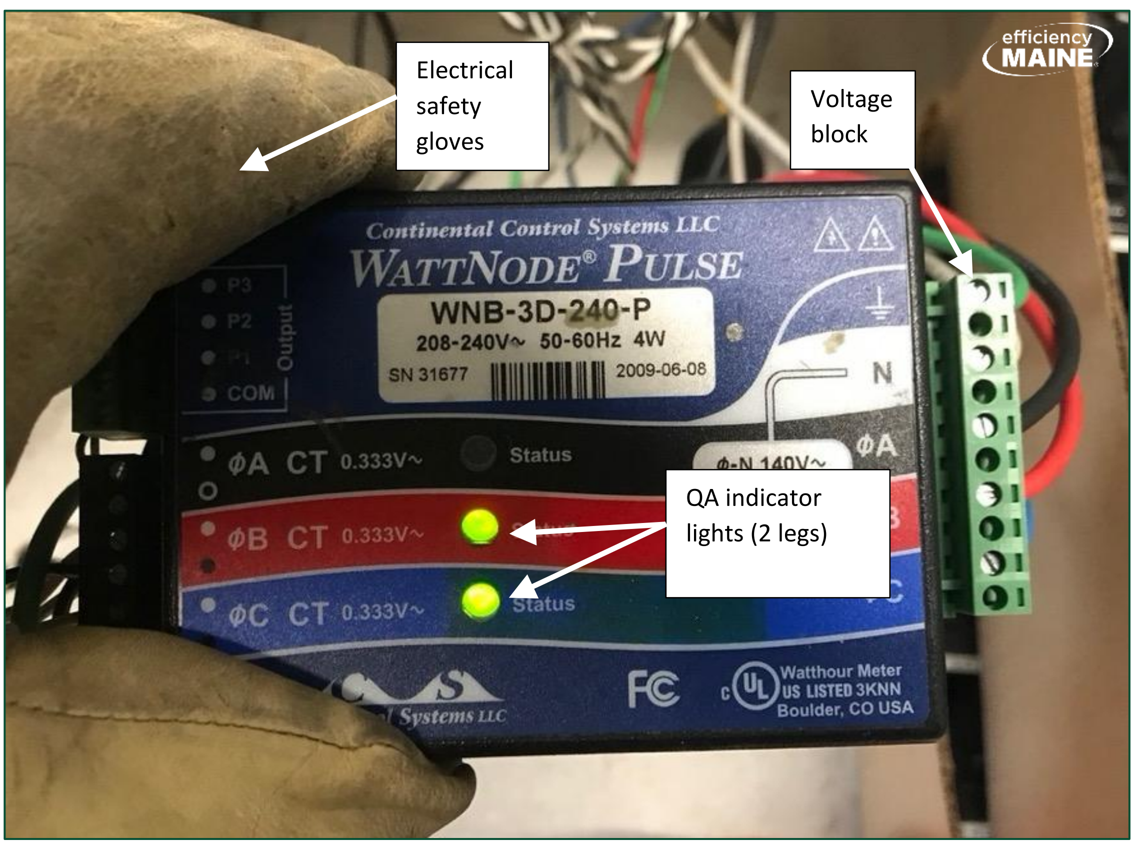
11.4.2 Power

The team installed a power meter to measure each home's heat pump's energy consumption. There are two distinct power meters that Ridgeline used:

1. For homes with 1 or 2 heat pumps, Ridgeline installed a WattNode setup consisting of an alternating-current watt-hour transducer.
2. For homes with 3 or more heat pumps, Ridgeline worked with an electrician to install an eGauge in the home's electrical panel. These units combine the features of a true power meter, a data logger, and a communication device.

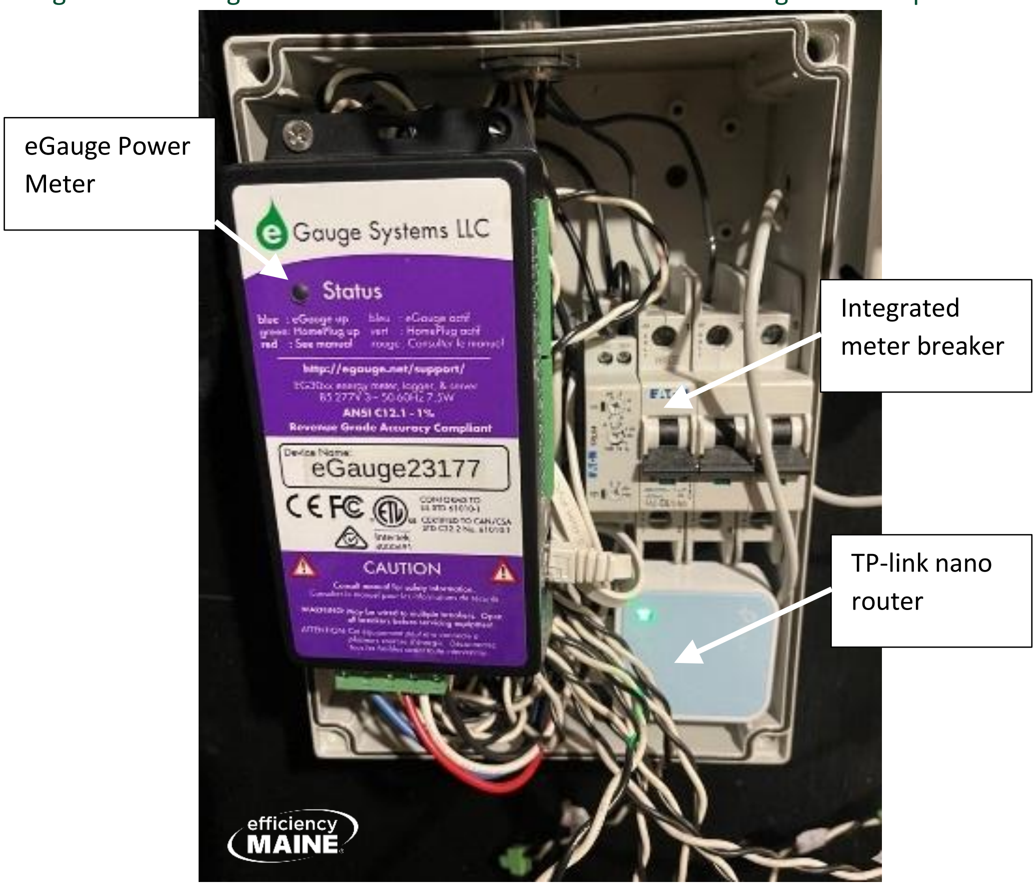
The WattNode setup consists of an alternating-current watt-hour transducer, two 20 Amp current transformers (CTs) sized for the heat pump's full-load operating current, and two voltage taps that allow the transducer to measure real power and energy. The WattNode sends out a pulse signal proportional to the energy used (Watt-hours). A Watt Node is shown in Figure 91. The pulse signal is then converted to a DC voltage value by a Sentient Things data conversion hub. The signal in DC volts is read directly by an Onset MX-1105. The MX-1105 sends data via Bluetooth low energy (BLE) to an Onset gateway. That gateway relays data to the web using Wi-Fi from either the home or from a Ridgeline-installed Sierra cellular gateway. Where there is more than one heat pump, the additional heat pumps are logged using similar equipment, and the data is similarly relayed to the Web via an Onset MX gateway. The team then accesses data from an Onset (Li-Cor) website and transfers it to Ridgeline servers for processing.

Figure 91. WattNode for Metering Heat Pump Power



eGauges are true power meters that hold up to one year of 1-minute data that is saved even if connectivity is lost. The meters are enclosed in a NEMA box and attached to the home's electrical panel using liquid-tight conduit. Since the meters are installed in conjunction with the home's electrical panel and are attached to a breaker in that panel, all eGauge meters were installed by Maine-licensed electricians. Additional 5A breakers are integrated into the metering setup (Figure 92) to provide additional safety.

Figure 92. eGauge in Nema Box with Nano Router for Metering Heat Pump Power



11.4.3 Airflow

The team used balometers (Model Alnor EBT731) to collect volumetric airflow in fan-only mode for each of the speed settings for each of the 5 makes and 41 models of indoor units metered in this study (Figure 93). Coincident with the airflow measurement, the team also collected the amperage of the fan to establish an airflow amperage curve. The reason the evaluation team used the fan-only setting was that in this and previous studies, the team found that in heating and cooling mode, the units often have an automatic fan setting that overrides manual settings, making it very difficult to run the test. While airflow volumes can vary between fan-only and heating and cooling settings, the fan will follow the same airflow versus amperage curve. By establishing this curve, then monitoring amperage, the evaluation team can monitor airflow, whether it is in heating, cooling, or fan-only mode. Metered airflow readings were also compared with manufacturer-rated airflows reported in heat pump submittal forms to verify measurements.

Figure 93. Technician Preparing to Collect Airflow Measurement Using Alnor Balometer

11.4.4 Fan Current

For each unit studied, the evaluation team installed 1 Ampere (A) current transformers (CT) on the wire powering the heat pump's indoor units (Figure 94). The CTs output a signal of 0–333 mV AC voltage proportional to their 0–1A scale. Typical readings of the fan are 0.01 – 0.02A at off, 0.03 – 0.05A at low speeds, and 0.1 – 0.15A at high speeds. The voltage signal is converted to a DC voltage value by a Sentient Things data conversion hub. The signal in DC volts is read directly by an Onset MX-1105. The MX-1105 sends data via Bluetooth low energy (BLE) to an Onset gateway (Figure 95). That gateway relays data to the web using Wi-Fi from either the home or from a Ridgeline-installed Sierra cellular gateway.

Figure 94. 1 Amp Current Transformer (CT) Placed on Wire Powering Indoor Fan

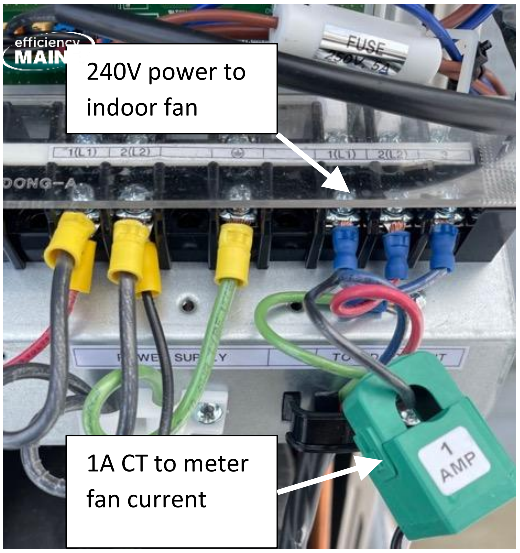
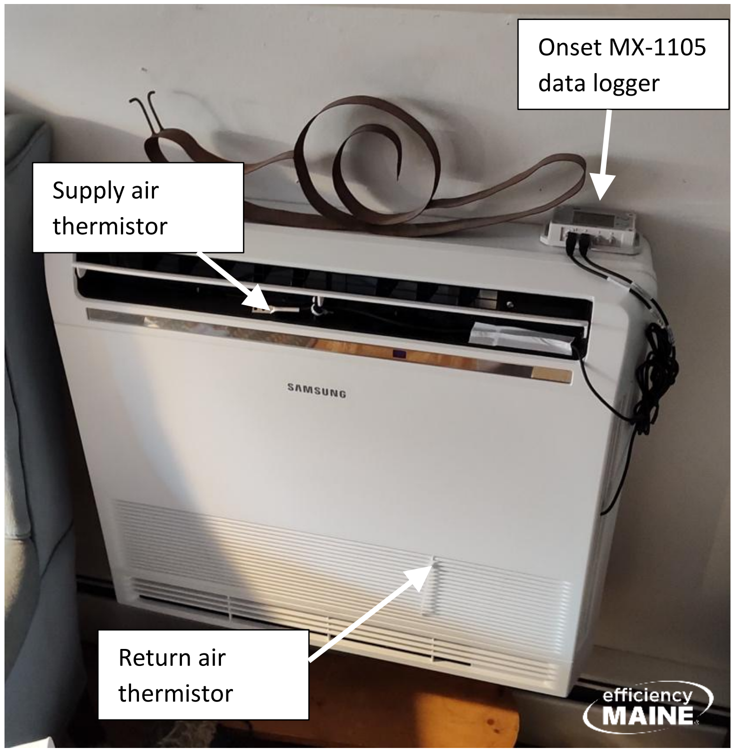


Figure 95. MX Gateway Uses Wi-Fi from Nano Router to Send Metered Data to Web

11.4.5 Temperature and Relative Humidity

The team installed loggers to measure temperature of outdoor air, supply air from the indoor unit, and return air to the indoor unit. At the outdoor unit, the team installed a thermistor, logging outdoor air temperatures at one-minute intervals. At the indoor fan units, the team installed a thermistor each in the supply and return air streams (Figure 96).

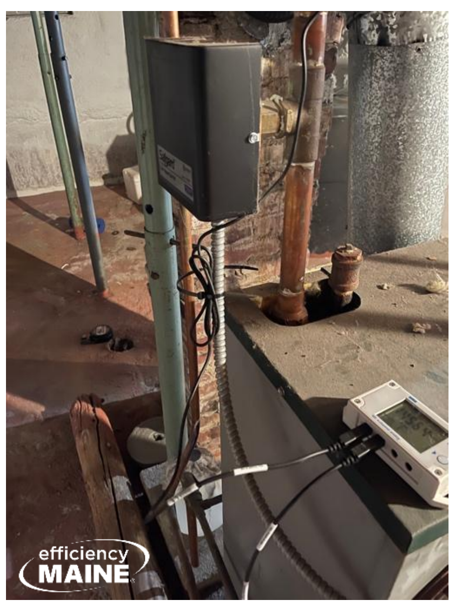
Figure 96. Thermistor and Logger on an Indoor Unit to Meter Supply and Return Temperatures



11.4.6 Combustion Heating Systems

To measure other heating systems' operating times, the field team placed temperature probes on the flue duct or on the supply water pipe where the flue duct was impractical (Figure 97). The team collected nameplate data from all relevant heating system equipment and used this data for various baseline and coincident-heat calculations.

Figure 97. MX 1105 Logger on a Boiler Supply Pipe to Record Boiler Operating Time



11.5 DATA SYSTEM

The Onset meters send data to Hobolink, the Onset metering dashboard[42] that is now operated by Li-Cor. Data is also stored locally on loggers that hold up to one year of 1-minute interval data.

11.6 ANALYSIS OF METERED DATA

The team analyzed the power usage by each heat pump versus time of day and versus outdoor temperature. To examine the heating provided by each indoor unit, we use fan amperage as an analog for airflow. Airflow and the difference between supply and return air temperatures yield heat added.

11.6.1 Logger Data Processing

Each home has the following set of data collected once per minute (Table 26). These seven data streams (plus three for each additional indoor unit) must be aligned for analysis at each home.

Table 26. Data Collected at Each home

Location or Unit	Parameter	Data stored
Outdoor unit	Power	Pulses – DC voltage -- kWh
	Fan current	mV– DC voltage - Amps
	Outdoor air	Temperature (F)
Indoor unit	Return air	Temperature (F)
	Supply air	Temperature (F)
Furnace/ boiler/ wood stove	Temperature adjacent to flue or wood stove indicating operation	Temperature (F)

11.6.2 Airflow versus Current

The analysis team grouped indoor units by manufacturer, capacity, and motor similarity. The team then created scatterplots of airflow versus fan amperage. The best-fit curve for these plots was a natural logarithmic curve of the format:

$$Airflow\ (cfm) = a * \ln(fan\ amperage) + b$$

Where:

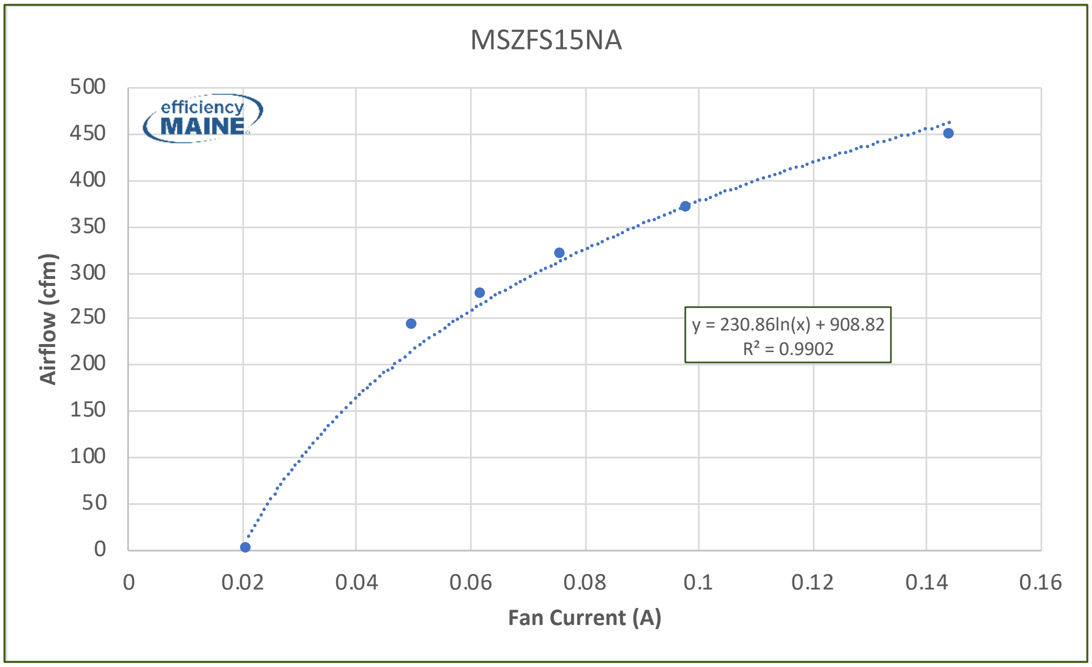
a = constant multiplied by the natural log of the fan amperage and

b = constant that indicates the intercept.

[42] LI-COR Cloud® IoT Platform.

This curve allows for the best fit of the paired current and airflow values. An example curve for a 15,000 Btu/h Mitsubishi unit is shown in Figure 98. The R^2 of 0.99 indicates a close fit for this curve. The team took repeat measurements for some units and found that the curves were repeatable.

Figure 98. Airflow versus Fan Current Curve for 15 kBtu/h Nominal Mitsubishi Unit



For this given heat pump, metered fan current and airflow values resulted in coefficients of a equals 230.86 and b equals 908.82. Where the fan amperage is 0.1A, cfm = 230.86 * ln(0.1) + 908.82 = 230.86 * -2.303 +908.82 = 377 cfm.

11.6.3 Performance

The measurements collected in the study were used to calculate the coefficient of performance (COP) for the heat pumps installed in the 78 homes. The COP is the ratio of the heat delivered or removed from a space divided by the energy consumed by the system. The energy consumed by the system was directly metered as part of our data collection process.

The energy delivered or removed by the system is calculated using an energy balance analysis. Previous sections describe how the team installed meters to collect key measurements to calculate the energy output of the system (the fan current, supply temperature, return temperature, and humidity).[43] The energy provided or removed by the system is equal to the difference between the energy state of the air leaving and entering the system. The equation used to calculate the change in energy is shown below:

[43] Only the sensible heat was considered for the winter analysis. In the cooling season we account for latent heat using humidity measurements.

$$\Delta E = \Delta h_s = V \cdot \rho \cdot c_p \cdot (T_s - T_r)$$

Where ΔE is the energy removed or provided, Δh_s is the change in sensible heat, V is the volumetric flow rate, ρ is the density of air, c_p is the specific heat of air, T_s is the supply temperature, and T_r is the return temperature. In cases where there were multi-zone units, the team added the energy delivered or removed by all of the indoor units and divided by the energy consumed by the respective outdoor unit. This equation simplifies to

$$\Delta(Btu/h) = 1.08 * V\ (cfm) \cdot (T_s - T_r)$$

The team made a couple of assumptions to identify the operating modes for the system. First, the team assumed that the system was operating when the energy input to the system was greater than 100W per ton of capacity. If there was a fan operating during times when the power input was below this threshold, it was assumed the system was in fan-only mode and not actively heating or cooling the space. Temperature sensors had an accuracy of about ± 0.5°F. There are times when heating and cooling by other systems in the house and stratification can cause differences in temperature readings. To account for this, the team only calculated the energy into the system if the temperature differential between the return and supply temperatures was greater than 2°F.

Energy benefit provided by the heat pump is calculated as Btus and divided by the electricity used, converted into Btus.

$$\text{COP} = \frac{\Delta E}{kWh\ x\ 3.412}$$

12 APPENDIX B: COMPARISON OF EIGHT AMI MODELS

The modeling expansion noted in Table 16 of Chapter 9 speaks to one of our key research questions: Are estimates of cold-weather-dependent electric use sensitive to AMI model specification? The answer to this question is that estimates of cold-weather-dependent electric use were similar across model specifications. Additional details are provided in subsequent sections.

12.1 MODELING EXPANSION

We included eight regression model specifications for the refresh AMI analysis. Key differences across the model specifications include the heating degree day base, the number of heating change points, and the number of days included when fitting the model. Table 27 describes the models. The first model in the table (Model 1-A) is identical to the model in the initial AMI analysis. The "B" version of each model is identical to the "A" version, other than the input days.

Table 27. Model Summary

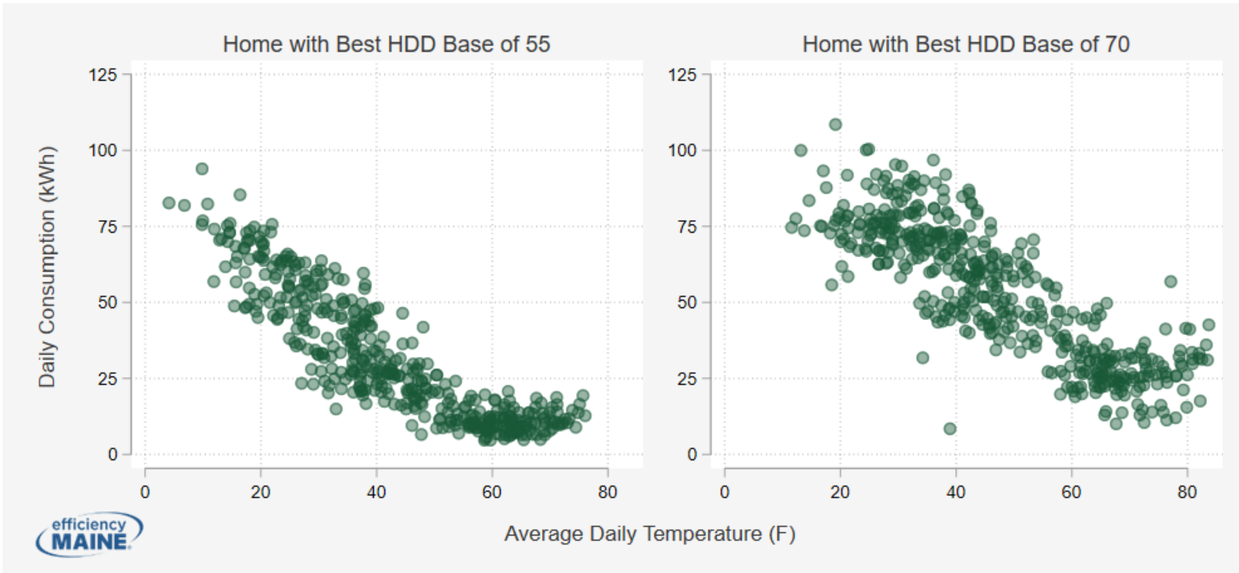
Model Name	Number of Change Points	HDD Base(s)	Input Data
Model 1-A	One	60	All days
Model 1-B	One	60	Only days where HDD60 > 0
Model 2-A	One	Variable	All days
Model 2-B	One	Variable	Only days where VHDD > 0
Model 3-A	Two	25 & 60	All days
Model 3-B	Two	25 & 60	Only days where HDD60 > 0
Model 4-A	Two	Variable	All days
Model 4-B	Two	Variable	Only days where VHDD > 0

Section 12.1.1 provides some additional details on the degree day base testing, and Section 12.1.2 provides some additional details on the additional heating change points.

12.1.1 Variable HDD Base

In the initial AMI analysis, we used a common HDD base of 60°F for all homes. This base choice aligns with the HDD base in Efficiency Maine's TRM and is a reasonable choice for the average home. However, a heating base of 60°F is not the best choice for every single home. Figure 99 shows an example of a home where the best base is 55°F (left panel) and another where the best base is 70°F (right panel). Since our primary modeling approach was to run individual customer regression models rather than a pooled model, it makes sense to allow the heating degree day base to vary across customers.

Figure 99. Best Base Comparison



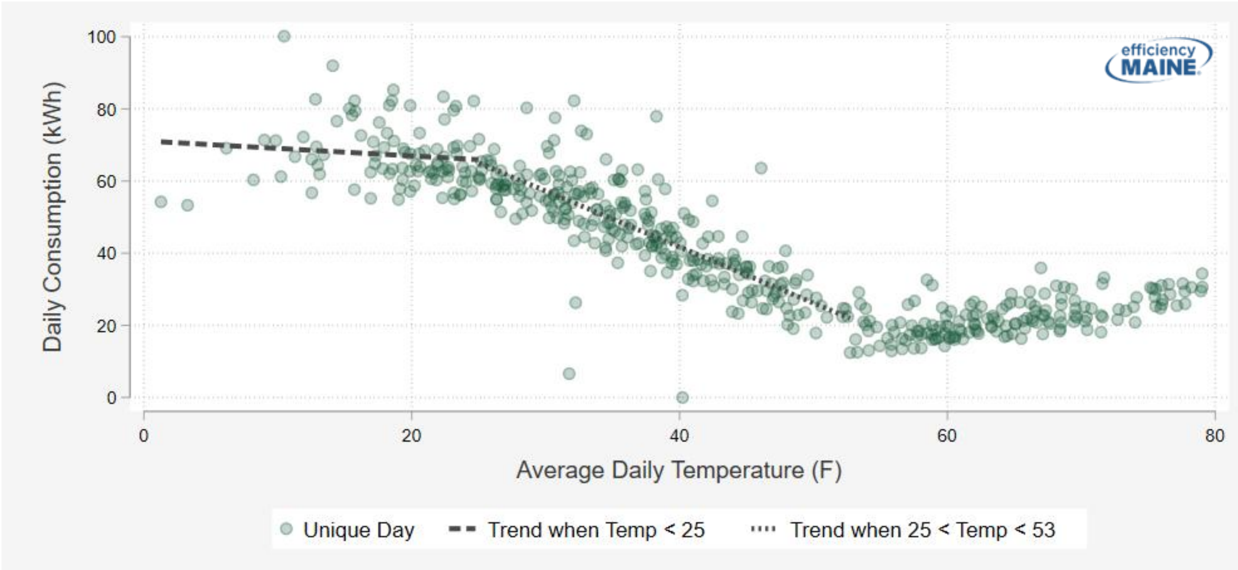
For the refresh analysis, we ran a regression loop to determine which heating degree day base is "best" for each home. In this context, "best" is a function of model fit. The loop entailed fitting 21 different regression models for each home, where each model used a different degree day base for the HDD explanatory variable, and then selecting the model with the highest R^2 value. The HDD bases in the loop ranged from 50°F to 70°F. We used a common CDD base of 70 in each iteration of the loop, and pre-WHHP consumption data for each home was removed before running the regression loop.

For each account, the "best" heating degree day base was retained for use in models 2-A and 2-B. On average, the results from the loop indicated that the best heating base is 57°F.

12.1.2 Secondary Heating Change Point

In some homes, energy consumption plateaus – or even drops off – at lower temperatures. See Figure 100 for an example. At this home, there are two clear heating change points. As average daily temperature drops from about 55°F to about 25°F, electric use steadily increases. Once the average daily temperature is below 25°F, the electric use plateaus at around 70 kWh per day.

Figure 100. Example Home with Two Change Points



To account for this trend, we introduced a few models with multiple heating change points. Models 3-A and 3-B use common change points of 25°F and 60°F for each home. Models 4-A and 4-B use variable change points for each home. To determine the variable change points, we ran an expanded version of the regression loop described in 12.1.1. We included an additional heating change point in the expanded version of the loop. The lower change points ranged from 10°F to 30°F, and the upper change points ranged from 50°F to 70°F. In total, we tested out 441 different models for each account (21 lower change point options * 21 upper change point options = 441 combinations).

On average, 24°F and 57°F were the best heating change points. The home represented in Figure 100 had a best pair of 25°F degrees and 53°F degrees.

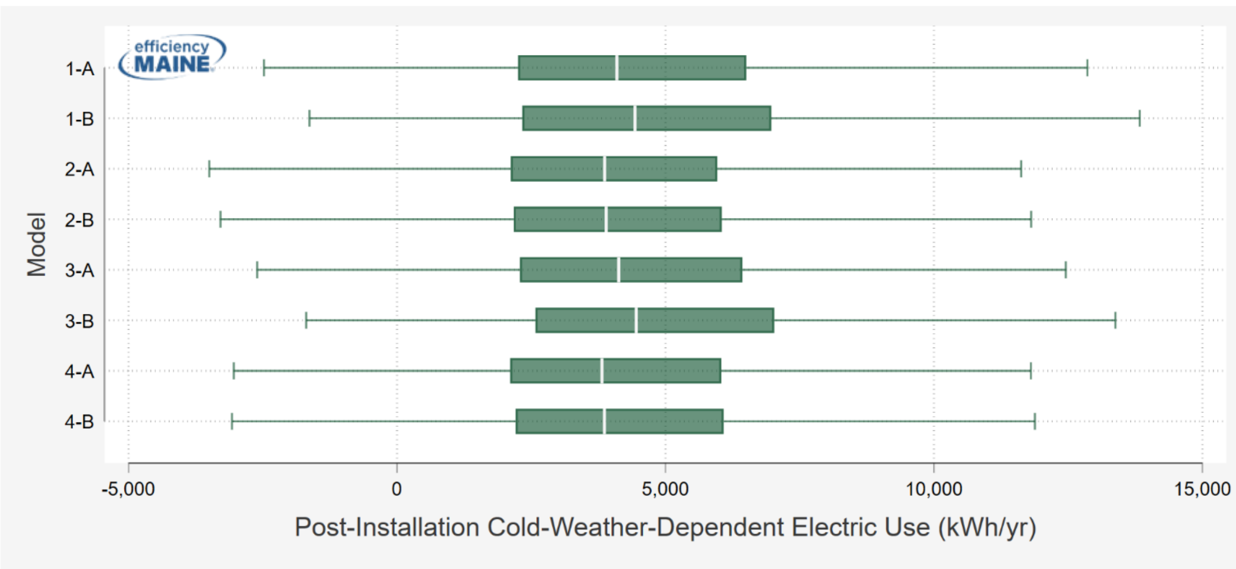
12.1.3 Post-WHHP Cold-Weather-Dependent Electric Use

For each model, Table 28 shows the average estimated post-installation cold-weather-dependent electric use. The overall average was 4,495 kWh, and averages across models are generally similar. Figure 101 compares the distribution of estimated post-installation cold-weather-dependent electric use across the eight model specifications via boxplot. The white line in the middle of each box represents the median (or 50th percentile), and the box itself spans from the 25th percentile to the 75th percentile. There is some variation across the model specifications, but the distributions are fairly similar.

Table 28. Summary Statistics by Model

Model	Post-Installation Cold-Weather-Dependent Electric Use (kWh/year)			
	Mean	P25	P50	P75
1-A	4,594	2,256	4,094	6,504
1-B	5,001	2,332	4,430	6,970
2-A	4,188	2,120	3,867	5,965
2-B	4,244	2,173	3,894	6,046
3-A	4,563	2,288	4,129	6,430
3-B	5,051	2,578	4,456	7,025
4-A	4,179	2,108	3,818	6,038
4-B	4,249	2,211	3,863	6,081
Overall	**4,509**	**2,259**	**4,056**	**6,364**

Figure 101. Distribution of Estimated Post-Installation Cold-Weather-Dependent Electric Use by Model



Capacity-normalized metrics ($kWh/kBtu_{Max}^{Design}$) are shown in Table 29 and were also similar across model specifications. Pre/post impacts are not summarized here, but these were also similar across model specifications, with an overall average around 3,000 kWh.

Table 29. Normalized Summary Statistics by Model

Model	Post-Installation Cold-Weather-Dependent Electric Use ($kWh/kBtu_{Max}^{Design}$)			
	Mean	P25	P50	P75
1-A	136	67	122	186
1-B	148	73	129	200
2-A	125	62	113	171
2-B	127	64	115	173
3-A	136	66	124	184
3-B	150	77	131	203
4-A	124	62	113	173
4-B	127	63	115	174
Overall	**134**	**67**	**121**	**183**

12.2 AMI ACCURACY ASSESSMENT

We assessed the accuracy of the eight different AMI models by comparing metered heat pump heating kWh with AMI-based predictions of heat pump heating kWh. In this assessment, we treated the metered heat pump consumption as ground truth and any difference between the AMI-based prediction and the metered daily total as error. We performed this assessment at the daily level and also at the seasonal level. In turn, these analyses are described in subsequent sections.

12.2.1 Daily Errors

Figure 102 outlines the process we used for the daily error assessment.[44] On average, we had 130 days per premise for 66 premises (n = 8,577 data points).[45] Daily prediction errors were calculated as metered kWh minus AMI-predicted kWh, meaning positive errors imply metered kWh exceeds AMI-predicted kWh, and negative errors imply AMI-predicted kWh exceeds metered kWh.

[44] Note this daily error assessment differs from the AMI-metering comparison in Section 9.4.1. The latter comparison used annualized results. The comparison here focuses explicitly on the metering period, and the timing and length of the metering period varied from premise to premise.

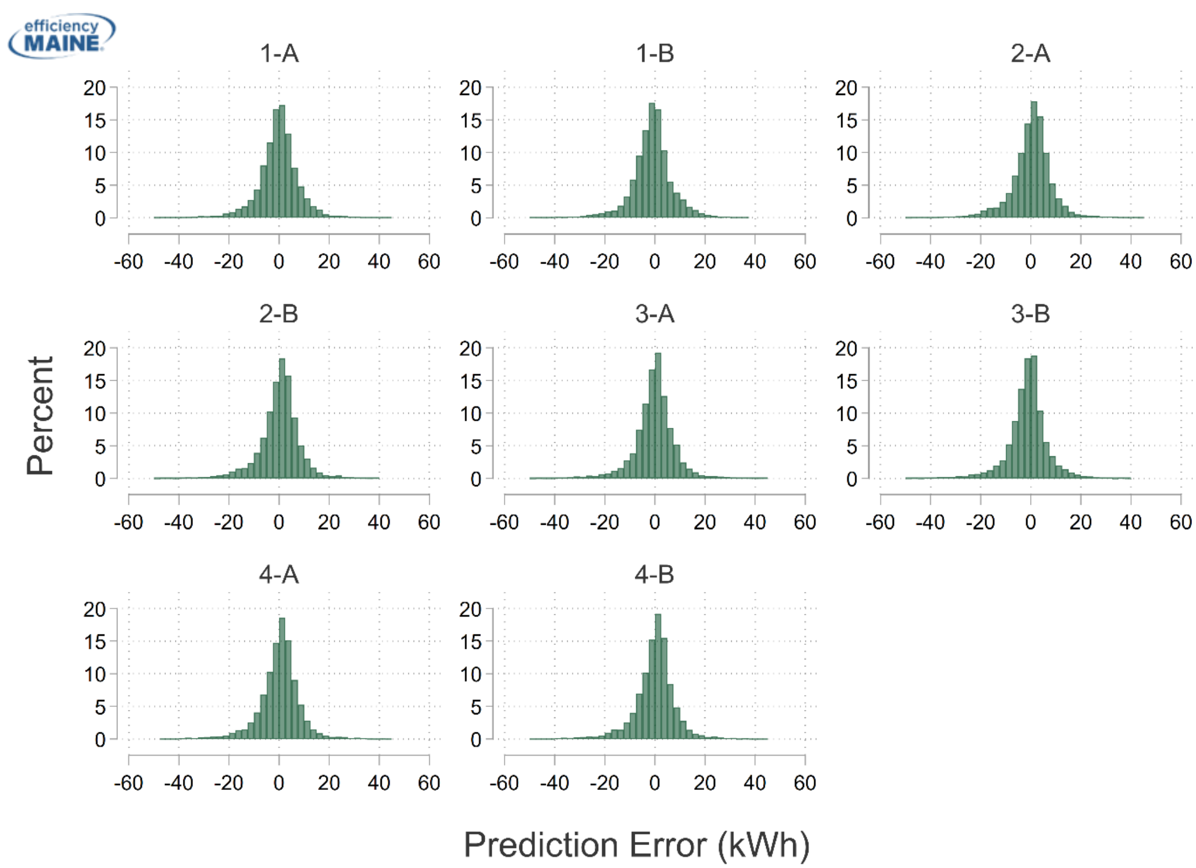
[45] Premises that were excluded from the AMI reporting due to confounding load modifiers or data quality issues were also excluded from this comparison.

Figure 102. Error Analysis

1. For each premise, determine the start and end dates of the metering period.
2. Download actual weather data spanning the metering period and calculate average daily temperature and heating degree days for each day.
3. Use the regression coefficients from the refresh AMI analysis to estimate daily heat pump consumption under actual weather conditions.
4. By date, merge the heat pump consumption estimates with actual metered consumption.
5. Calculate daily prediction error as: metered kWh – AMI-based prediction of kWh. This calculation is repeated for each day/premise/model combination.
6. Assess the distribution of error across model specifications

Figure 103 shows the distribution of daily prediction errors by model specification. For all eight models, the error distribution is clustered around zero and very few errors exceed ±20 kWh.

Figure 103. Histogram of Prediction Errors by Model



The distribution of percent prediction errors is also similar across model specifications (Figure 104). Percent errors are calculated with metered kWh in the denominator. This means that days where metered kWh is zero are not included in the figure (percent error cannot be calculated with zero in the denominator), and days where predicted kWh is zero have prediction errors of 100% (error = metered – predicted = metered – 0 = metered). The spikes at 100% are caused by days where the AMI-based prediction of kWh is zero. Records with percent errors greater than +/-100% were infrequent and are not shown in the figure.

Figure 104. Histogram of Percent Prediction Errors by Model

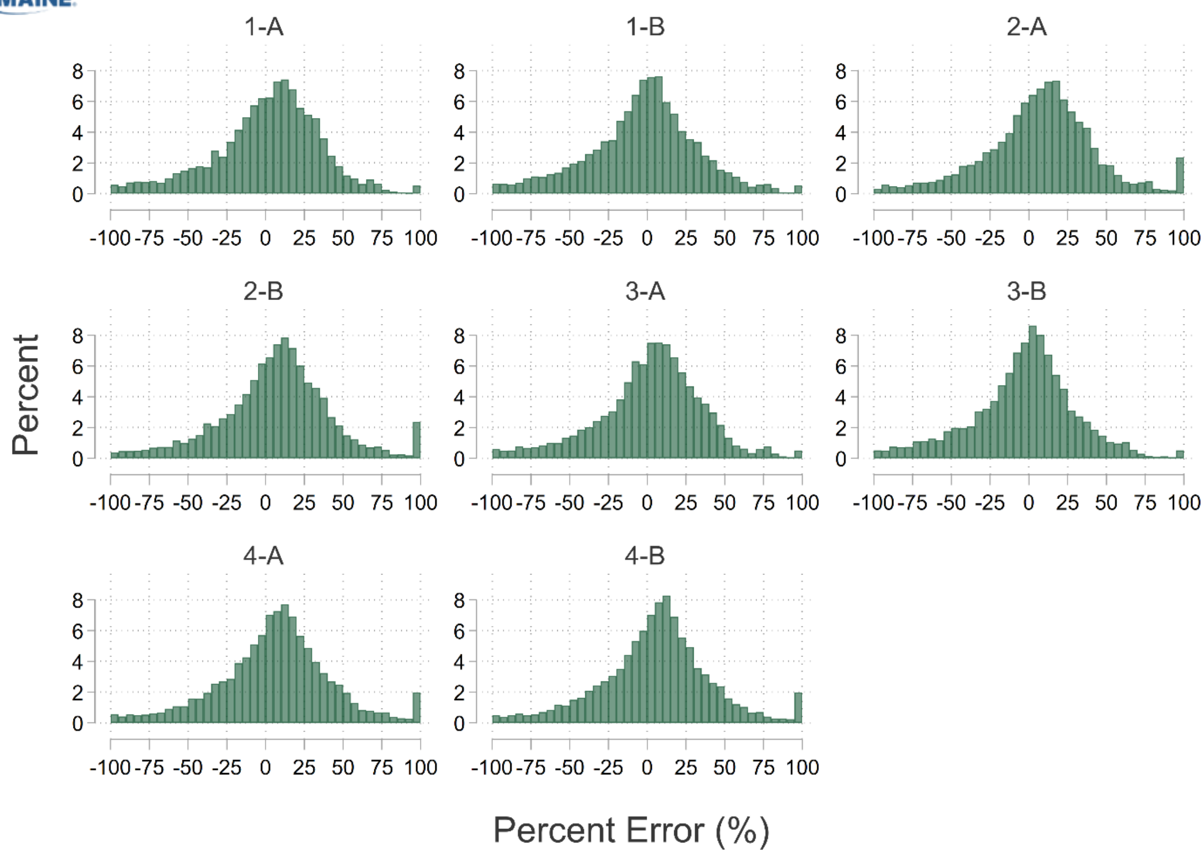


Table 30 presents two formal statistics for the precision of the models. Both the median error and median absolute percent error are close to zero across all model specifications. Based purely on these model fit statistics, we believe model 3-A merits consideration in future AMI analyses. However, the improvement relative to our primary model (1-A) is on the margins.

Table 30. Median Errors by Model

Model	Median Error (kWh)	Median Percent Error (%)
1-A	0.12	1.22
1-B	-0.77	-4.03
2-A	0.94	6.40
2-B	0.83	5.73
3-A	0.22	1.91
3-B	-0.75	-3.79
4-A	0.69	4.79
4-B	0.63	4.32
Overall	**0.21**	**1.95**

12.2.2 Aggregated Errors

While the prior section focused on prediction errors at the daily level, this section examines errors across the annualized heating kWh estimates. Note that the annualizations here were performed as described in Chapter 9.4. In short, the annualization for this comparison is based on local weather between October 1, 2024, and April 30, 2025, rather than TMY3. As in the prior section, errors were calculated as metered – AMI-based prediction, meaning positive errors indicate the AMI-based prediction is less than actual metered consumption, and negative errors indicate the opposite. Figure 105 shows the distribution of errors across models, and Table 31 shows the median error and median percent error by model. The variations of models 1 and 3 tend to outperform the variations of models 2 and 4. For the heating season, the typical error per premise is around 168 kWh (corresponding to an underprediction of 168 kWh).

Figure 105. Distribution of Annual Prediction Error by Model

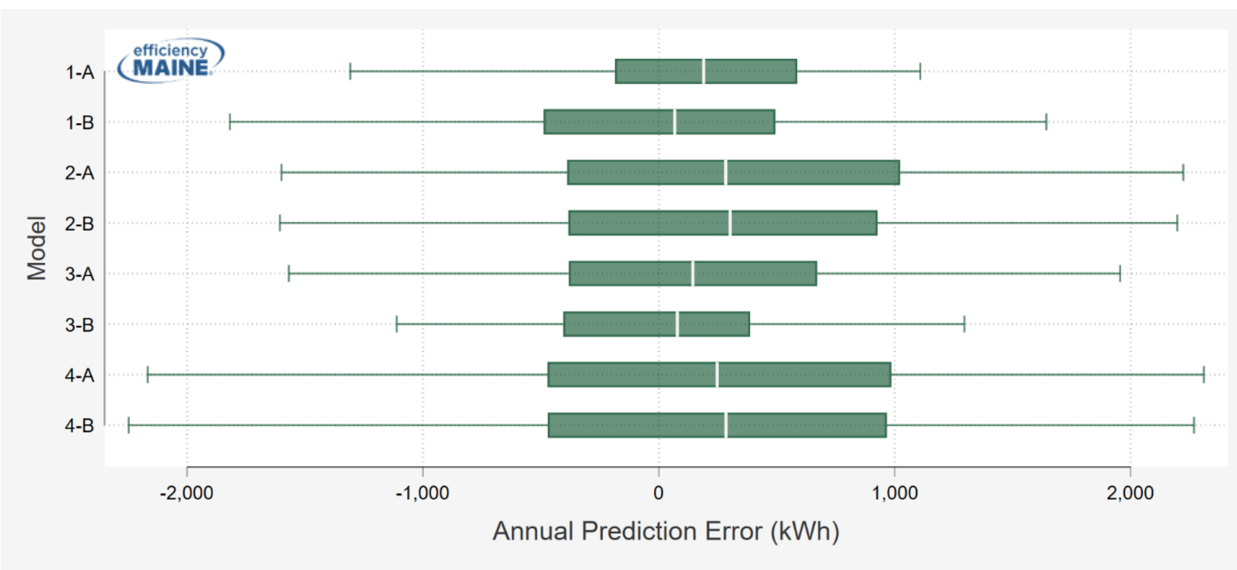


Table 31. Median Errors by Model

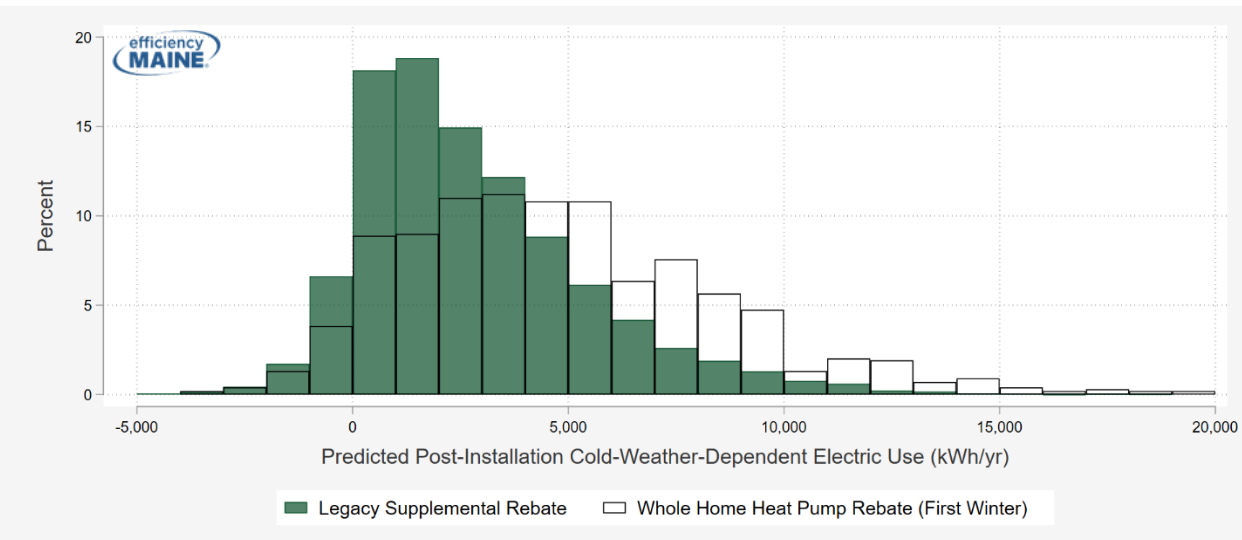
Model	Median Error (kWh)	Median Percent Error (%)
1-A	190	4.77
1-B	67	3.20
2-A	283	9.44
2-B	302	10.28
3-A	144	4.22
3-B	78	2.85
4-A	247	8.38
4-B	284	7.92
Overall	**168**	**5.35**

One important distinction between the results in this section and the prior section is that these results are based on annualized metrics, whereas the results in the prior section were based on just the metering period. Variation in the timing and duration of the metering periods across premises can introduce some inconsistencies between the daily and annualized results. For example, consider a hypothetical case where the metering length for one site is 50 days and 100 days for another site. In the daily analysis, the home with more days effectively has a greater weight. Suppose the prediction error is 1 kWh each day for the site with 50 days and -1 kWh each day for the site with 100 days. The average error at the daily level would be -0.33. When annualized (and assuming the pattern holds), the average error would be zero.

13 APPENDIX C: DETAILS ON METERED HOMES IN THE NEGATIVE UTILIZATION BIN

The metering sample included eight homes that were in the "negative" heat pump utilization bin. The negative bin includes homes that fall to the left of zero in Figure 106 – these are homes that were predicted to have negative cold-weather-dependent electric use based on the results of the initial AMI analysis. (As noted in Chapter 2, the left end of the distribution in Figure 106 was a primary impetus for metering.) Clearly, negative electric use by heat pumps is not possible. The negative prediction indicates heat pumps were not being used during the 2023-24 winter, or their use did not increase, but decreased, as temperatures dropped. This section provides additional detail on the eight aforementioned homes. Note that all eight homes had positive predictions of cold-weather-dependent electric use in the refresh AMI analysis.

Figure 106. Estimated Post-Installation Heat Pump Electricity by Home



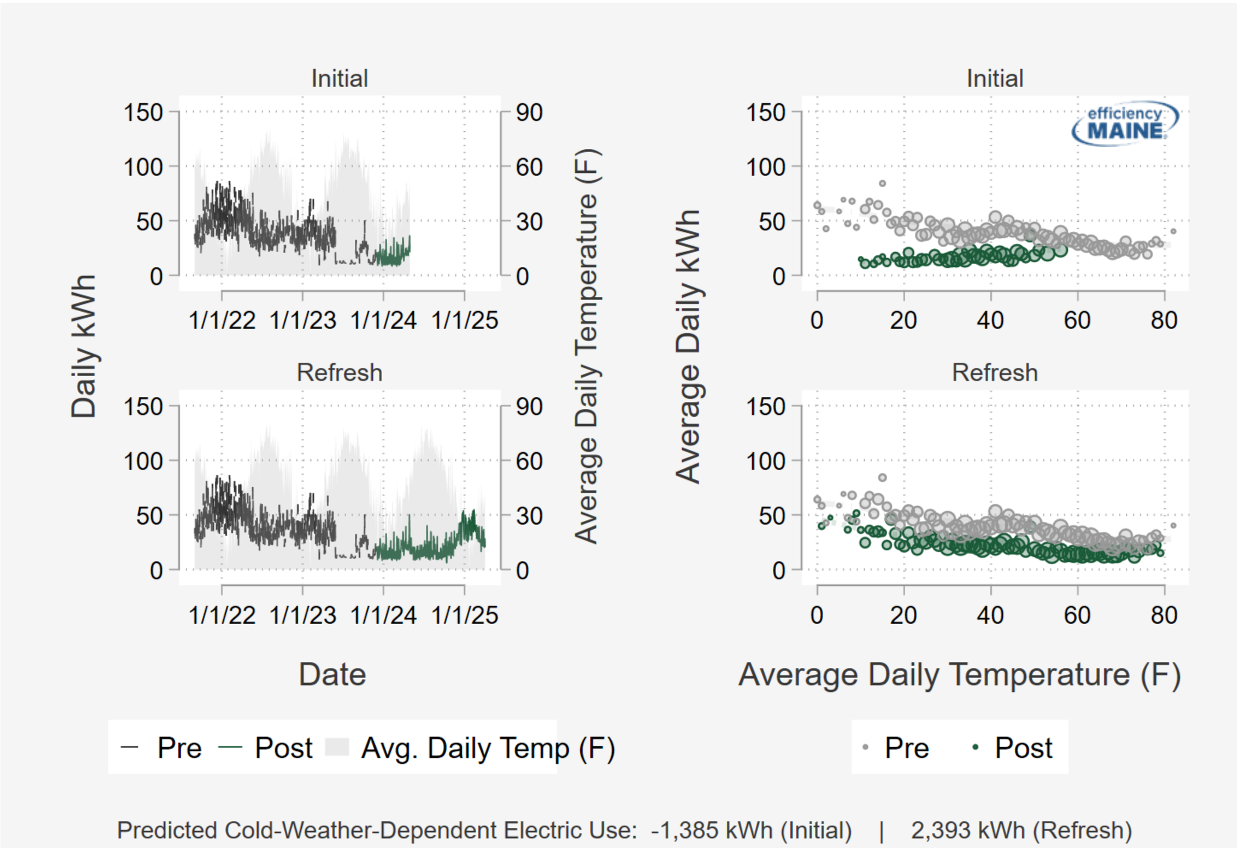
The following figures highlight the relationship between daily electric use, outdoor temperatures, and period (pre-installation or post-installation) for each of the eight sites. Each figure contains four panels, which can be interpreted as follows:

- The **top left panel** is based on the initial AMI analysis. This shows a time series of daily kWh with the pre-WHHP period shown in black and the post-WHHP period shown in green. The gray region in the background shows the average daily temperature (see secondary Y axis on the right). We'd expect to see daily kWh increase when temperatures decrease in the post-WHHP period.
- The **top right panel** is based on the initial AMI analysis. This shows average daily consumption in temperature bins that are incremented by one degree (F). Gray dots represent the pre-WHHP period, and green dots represent the post-WHHP period. Average daily kWh is expected to increase when temperatures decrease in the post-WHHP period.
- The **bottom left panel** conveys the same information as the **top left panel** but includes data from the refresh analysis.

- The **bottom right panel** conveys the same information as the **top right panel** but includes data from the refresh analysis.

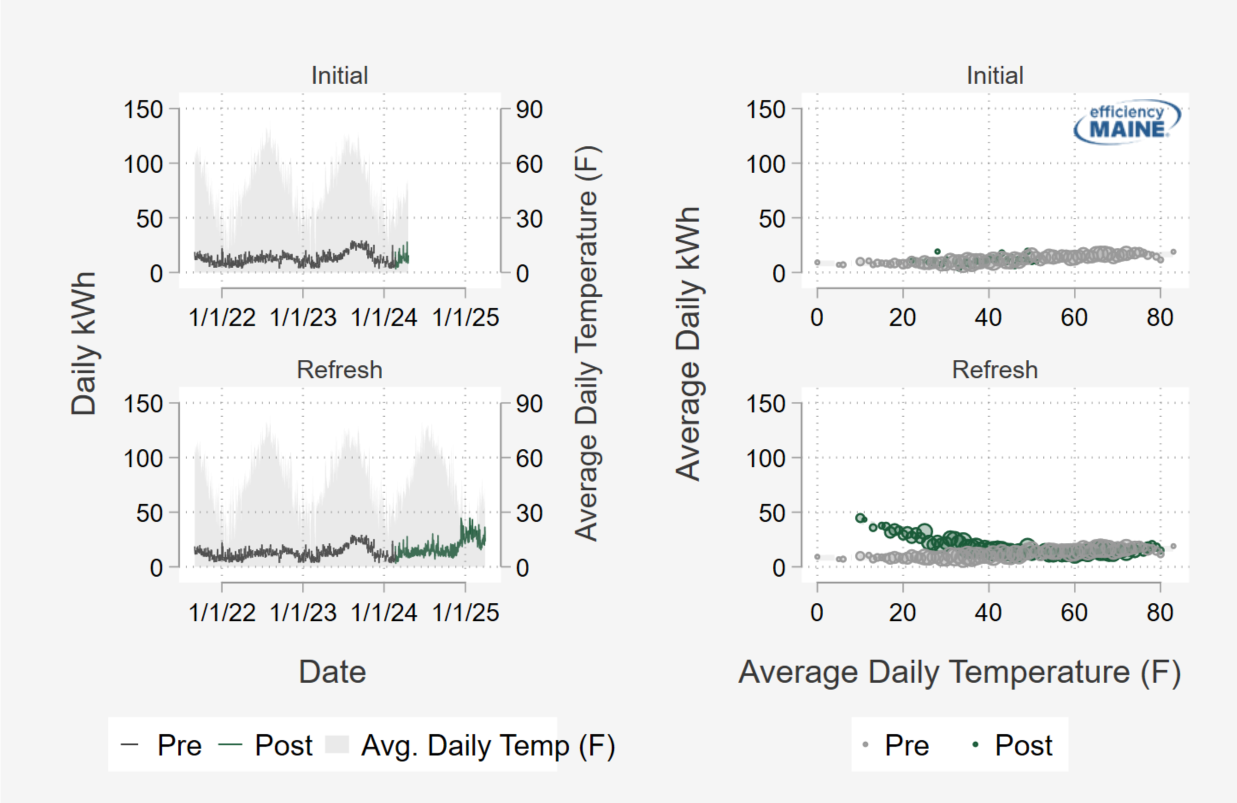
Two common themes for these premises are (1) the actual in-service date of the heat pump(s) lags the installation date and (2) electric use increases post-installation, but usage is lower at low temperatures than it is at moderate temperatures (i.e., the heat pump signature of higher use at lower temperatures is missing). Following each figure are some notes regarding each premise. Figure 107 through Figure 114 show results from House IDs 147, 235, 259, 398, 418, 530, 578, and 609 respectively.

Figure 107. Ridgeline ID 147



Installation Date	Notes
11/27/2023	• Winter 23/24: No/minimal evidence of heat pump usage. • Winter 24/25: Clear temperature response in electric use. • Program tracking data indicates primary heat type prior to WHHP was oil, though AMI indicates electric resistance heating was present in the past (winter 21/22).

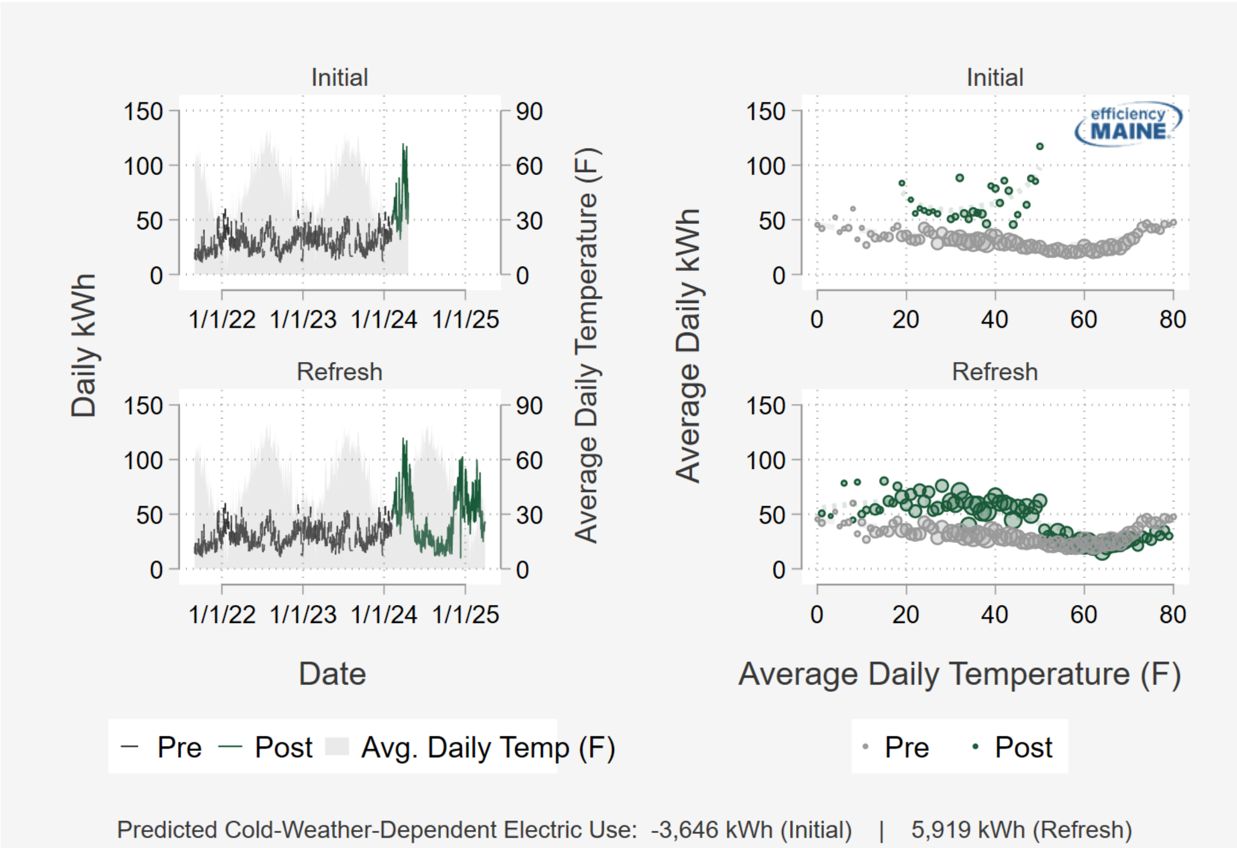
Figure 108. Ridgeline ID 235



Predicted Cold-Weather-Dependent Electric Use: -1,274 kWh (Initial) | 2,648 kWh (Refresh)

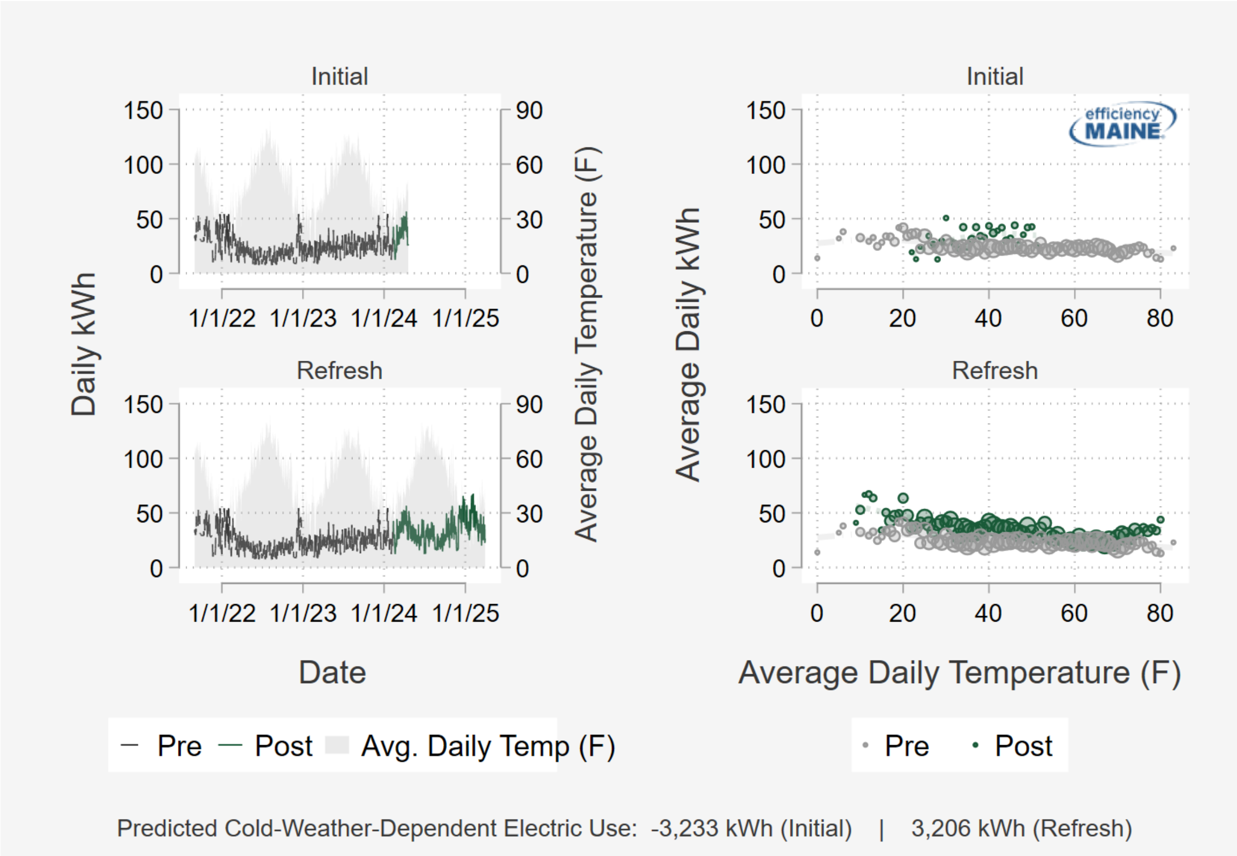
Installation Date	Notes
2/20/2024	• Winter 23/24: No/minimal evidence of heat pump usage. • Winter 24/25: Clear temperature response in electric use. • Program tracking data indicates primary heat type prior to WHHP was oil.

Figure 109. Ridgeline ID 259



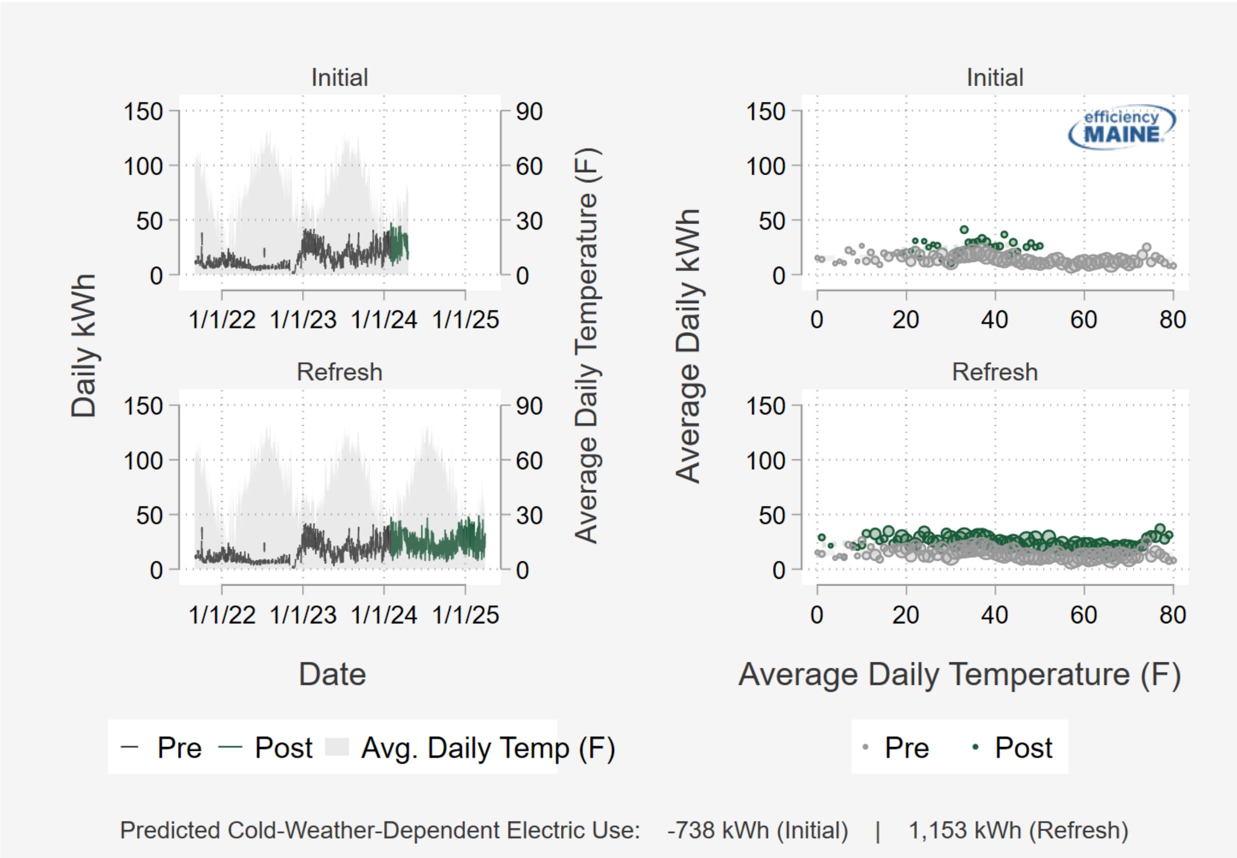
Installation Date	Notes
2/6/2024	• Winter 23/24: Electric use increases after WHHP installation, but use does not show expected temperature response. • Winter 24/25: Electric use is higher in the winter (relative to shoulder/summer) but trend with temperature is relatively flat between 20°F and 50°F • Program tracking data indicates primary heat type prior to WHHP was kerosene.

Figure 110. Ridgeline ID 398



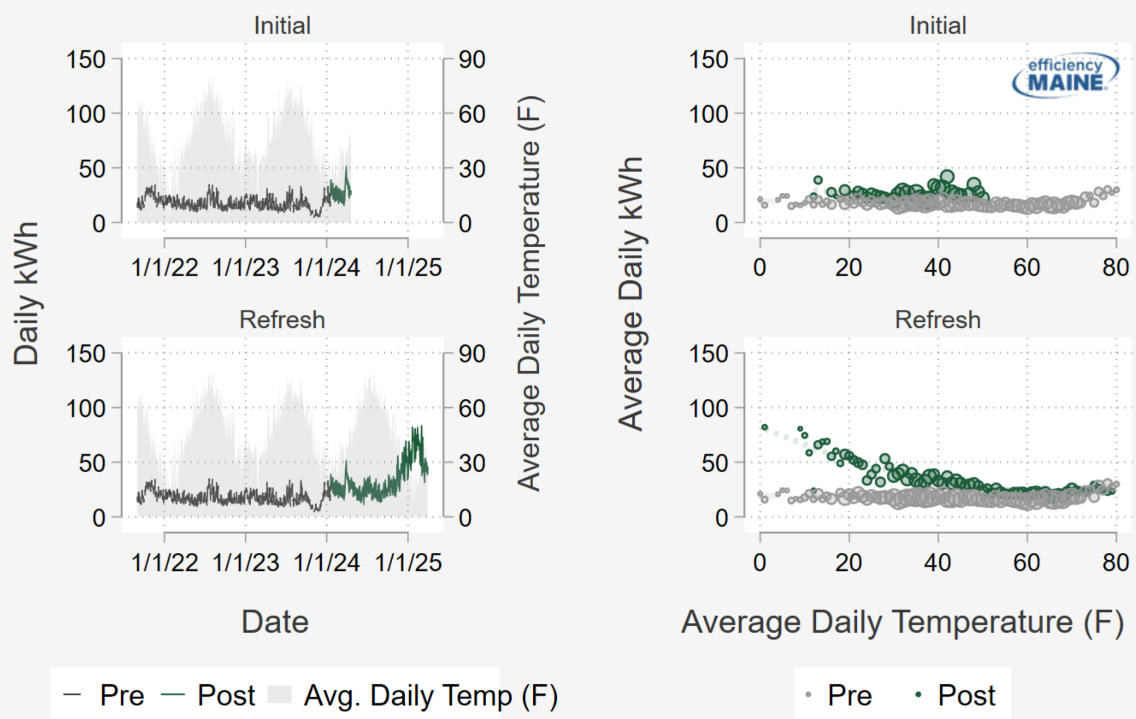
Installation Date	Notes
2/9/2024	• Winter 23/24: Electric use increases after WHHP installation, but use does not show expected temperature response. • Winter 24/25: Clear temperature response in electric use. • Program tracking data indicates primary heat type prior to WHHP was a heat pump. Winter 22/23 does not show heat pump signature but winter 21/22 does.

Figure 111. Ridgeline ID 418



Installation Date	Notes
1/31/2024	• Winter 23/24: Electric use does not show expected temperature response. • Winter 24/25: Some temperature response in electric use. • Program tracking data indicates primary heat type prior to WHHP was electric resistance. • This is a tiny home with around 300 square feet of conditioned living space. The building's heat loss is under 10,000 Btu/h at 5°F and at design temperature.

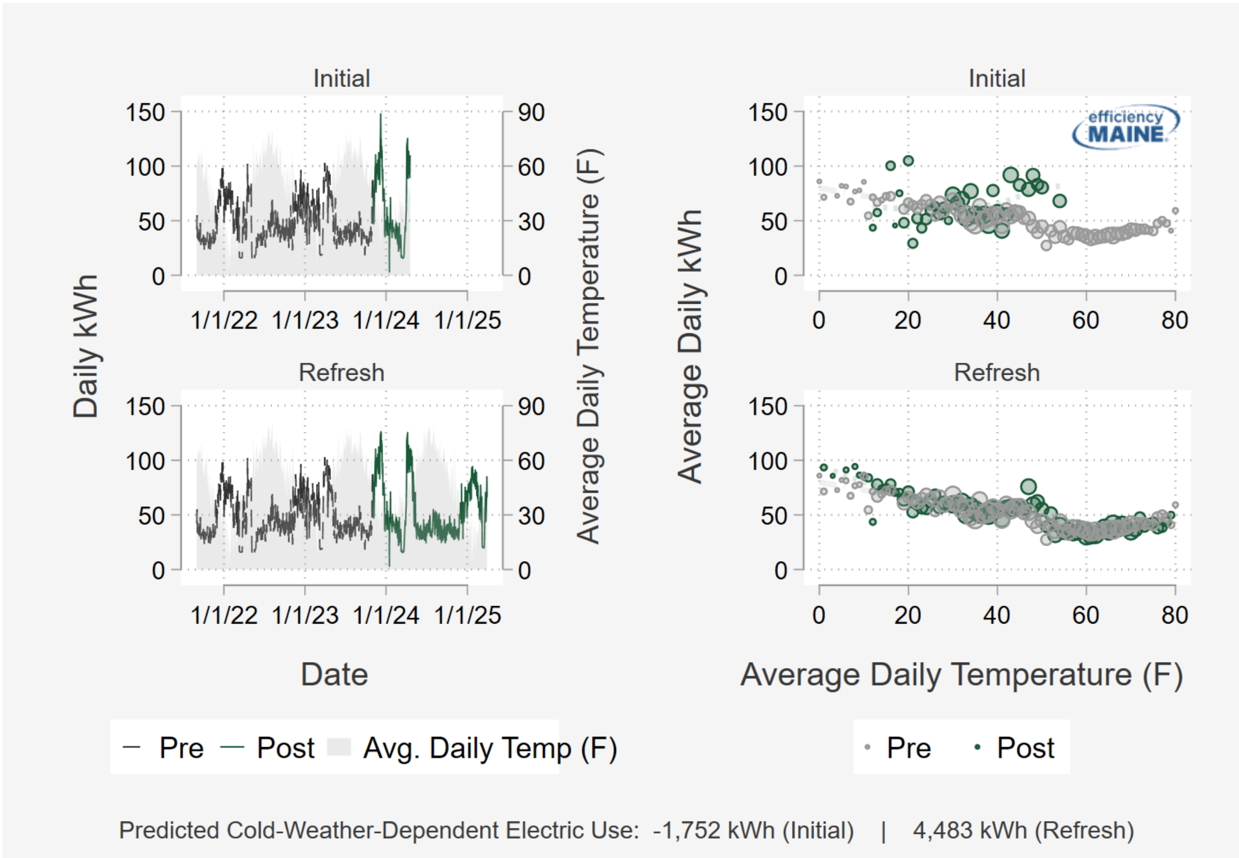
Figure 112. Ridgeline ID 530



Predicted Cold-Weather-Dependent Electric Use: -693 kWh (Initial) | 5,117 kWh (Refresh)

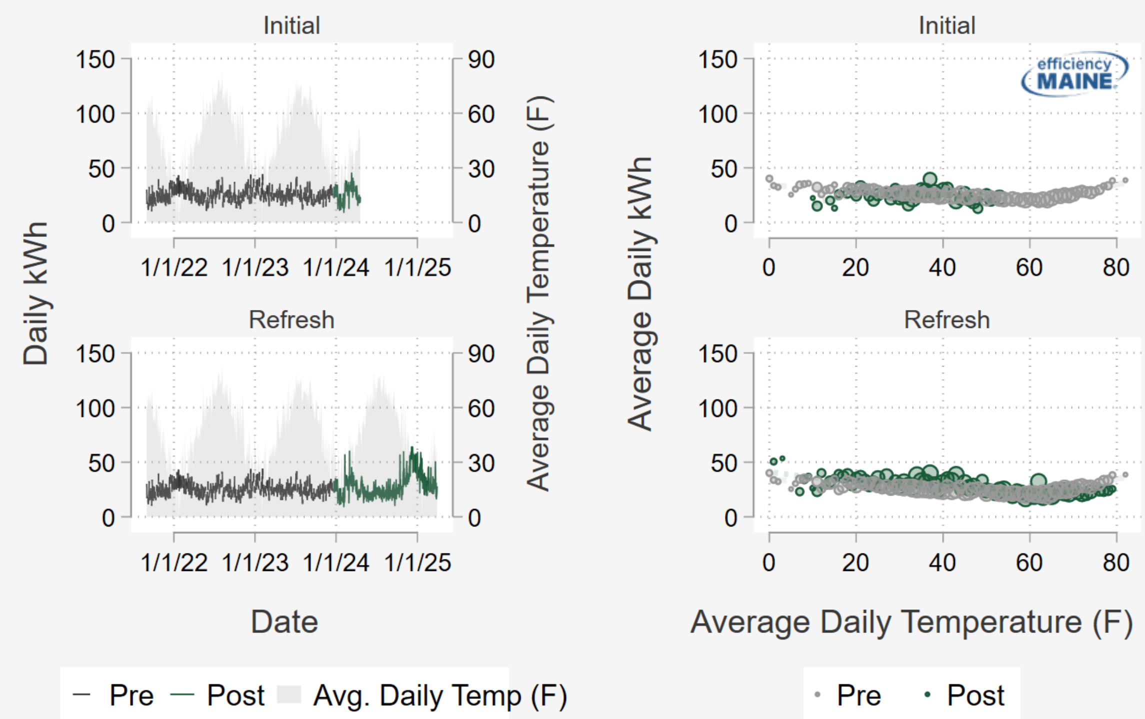
Installation Date	Notes
1/17/2024	• Winter 23/24: Electric use increases after WHHP installation, but use does not show expected temperature response. • Winter 24/25: Clear temperature response in electric use. • Program tracking data indicates primary heat type prior to WHHP was electric resistance, though AMI suggests a non-electric heat type prior to WHHP.

Figure 113. Ridgeline ID 578



Installation Date	Notes
11/1/2023	• Winter 23/24: Minimal usage in January but evidence of heat pump usage in December 2023 and February 2024. • Winter 24/25: Clear temperature response in electric use in December and January but use drops near the end of the AMI period (homeowners out of town). • Program tracking data indicates primary heat type prior to WHHP was oil, though AMI suggests some form of electric heat was also in place prior to WHHP. • Greenhouse on premise that confounds the AMI analysis.

Figure 114. Ridgeline ID 609



Predicted Cold-Weather-Dependent Electric Use: -87 kWh (Initial) | 1,911 kWh (Refresh)

Installation Date	Notes
12/21/2023	• Winter 23/24: No/minimal evidence of heat pump usage. • Winter 24/25: Clear temperature response in electric use in December, but trend with temperature in the remainder of winter is relatively flat between 20°F and 40°F. • Program tracking data indicates primary heat type prior to WHHP was oil.

14 APPENDIX D: REGIONAL DIFFERENCES IN HEAT PUMP OPERATION

To examine regional differences in heat pump operation, more in-depth time of day analysis comparing the four metered regional groups, first discussed in Figure 33 and Section 5.1.2 of this report was performed. As in Section 5.1.2, these heat pumps are considered “actively operating” if they draw power greater than a designated threshold that scales positively with heat pump capacity. These thresholds are greater than zero to discount any small power loads and low-power fan-only modes. These thresholds were also visually inspected to ensure that they accurately capture operational time only. The average power threshold across all 160 heat pumps was 0.175 kW, with the minimum being 0.150 kW. As heat pump capacity increases, this threshold increases. For example, a small unit with a 6,000 Btu_{Rated}[47] would have a power threshold of 0.150 kW, but a larger 24,000 Btu_{Rated}[47] ducted unit could have a higher power threshold of up to 0.300 kW. This is to ensure that only time periods with relatively significant power draw are considered “on” without discounting periods of operation of smaller units that can provide heat with instantaneous power draws of only 0.2 kW.

Figure 115 to Figure 122 below all represent data collected only from December, January, and February (the coldest months of the year). All other metered data outside of these time periods was omitted for this analysis. Looking at Figure 115 and Figure 116, peak power consumption appears to be at 7 AM across the entire metered sample but varies slightly across regions. Power consumption decreases in the warmer, afternoon hours. These power magnitudes differ from those presented in Figure 30 through Figure 32 since the time window analyzed between the Figures varies. Figure 30 presents averages across the entire metering time window from late November to early May. Figure 31 and Figure 32 present averages across the coldest day in the time window (1/22/25), and Figure 115 to Figure 122 present averages across December, January, and February only.

Figure 115. Average Power Consumption vs. Time of Day (Only December, January, & February) (n = 160)

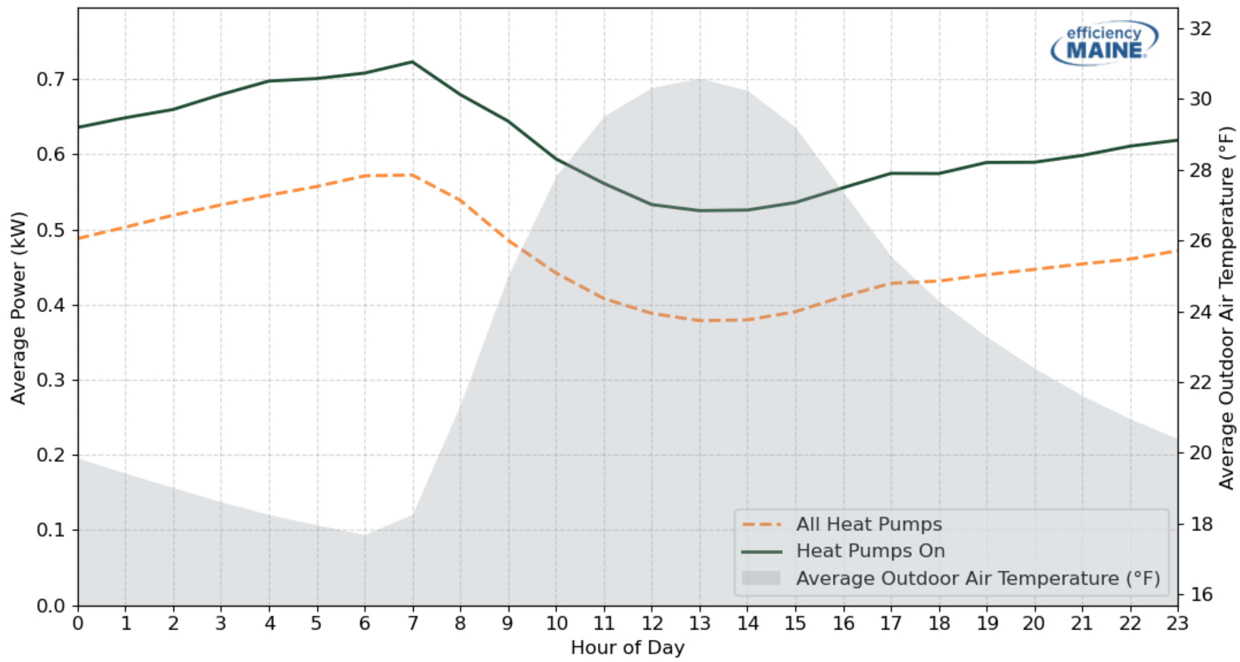
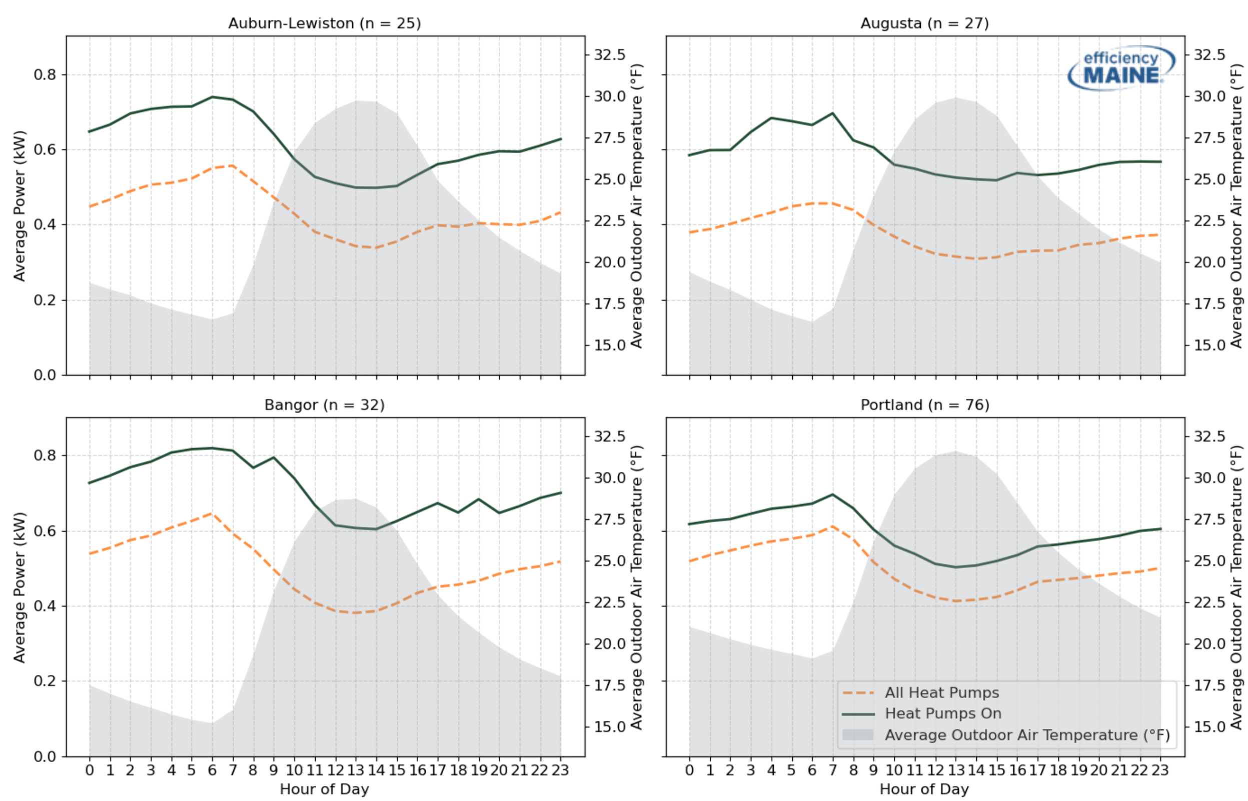


Figure 116. Average Power Consumption vs. Time of Day Across 4 Regions (Only December, January, & February) (n = 160)



The figures below (Figure 117 and Figure 118) show the percentage of heat pumps turned on by time of day. For each hour, the numerator represents the total number of hours that any heat pump across the sample is operating during that particular hour of the day, and the denominator represents the total number of instances that a given hour (ex. 6 A.M.) occurs in December, January, or February (~90 days * 160 heat pumps = ~14,400 hours per hour of the day).

It appears that of the heat pumps that are used, many are used consistently throughout all hours of the day. There is a small decrease in the number of heat pumps operating in the warmer, afternoon hours. The small change in the number of heat pumps operating by time of day indicates that the main driver of changes in power draw by time of day is the negative relationship between outdoor air temperature and heat pump power as opposed to more or fewer heat pumps being operated. Moreover, there appear to be variations in the percentage of heat pumps operating by time of day between the 4 regions. The Portland region shows the highest average percentage of heat pumps operating, which is consistent with the trends seen in Figure 32. Multiple power thresholds and methods were tested to calculate the percentage of heat pumps turned on by time of day, and the results were consistent.

Figure 117. Percentage of Heat Pumps Operating by Time of Day (n = 160)

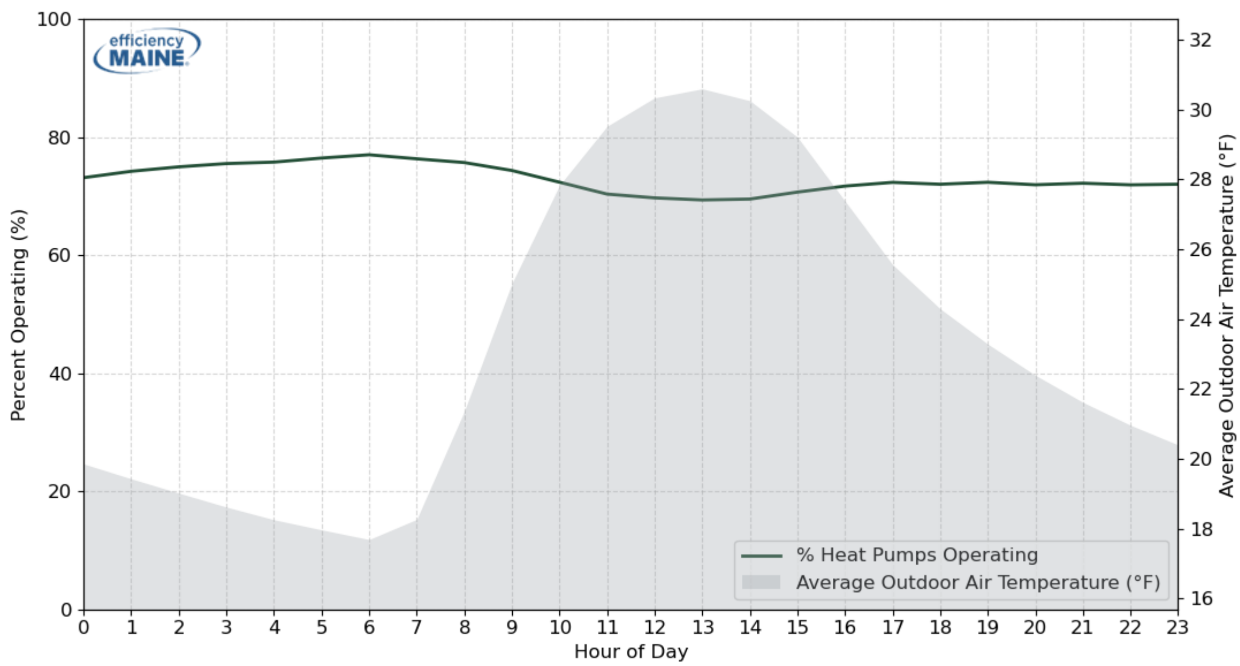


Figure 118. Percentage of Heat Pumps Operating by Time of Day Across 4 Regions (n = 160)

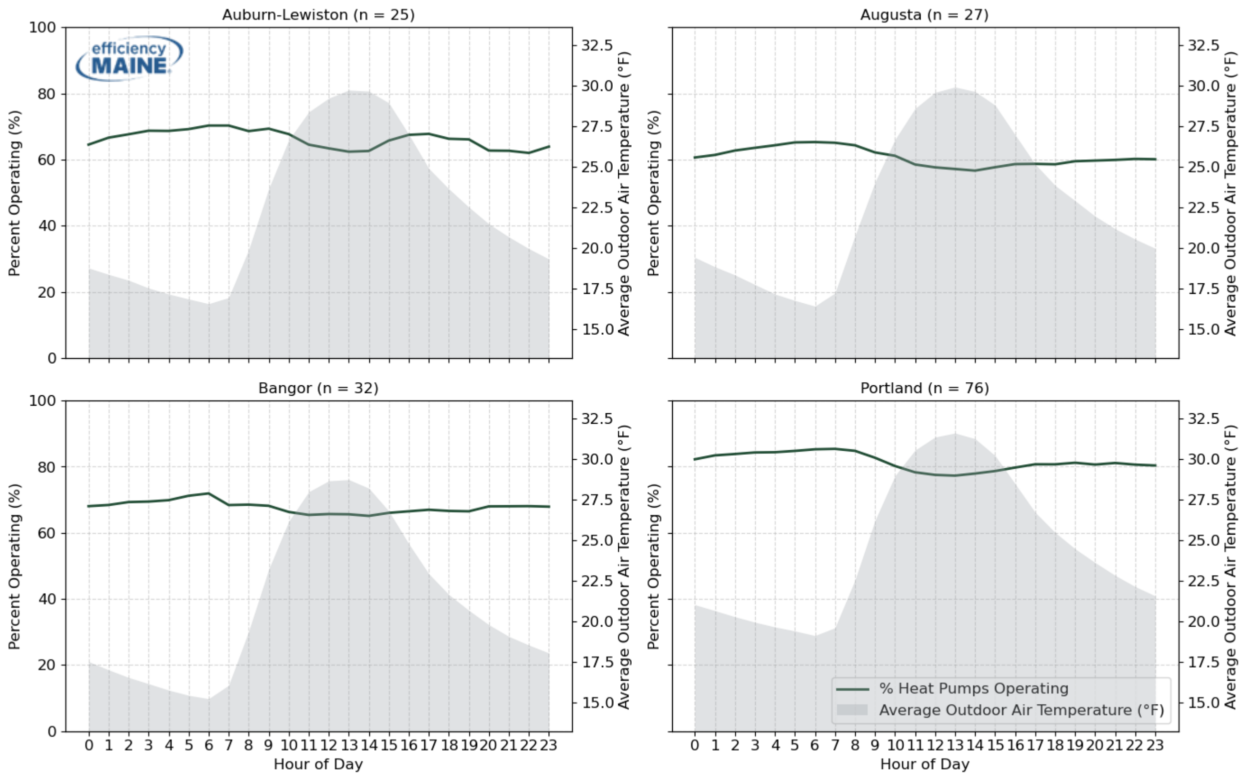


Figure 119 and Figure 120 show the percentage of energy (kWh) from all heat pumps in a given region (or across all total homes) that is used in each hour of the day. The peak energy consumption time appears to remain between 6 and 7 AM. If energy draw was consistent across all hours in a given day, then the percent per hour would be 4.17% for all given hours (100% / 24 hours = 4.17%). The lowest energy appears to be used in the afternoons. These values are relatively consistent across the four regions.

Figure 119. Percentage of Total Energy from Heat Pumps by Time of Day (n = 160)

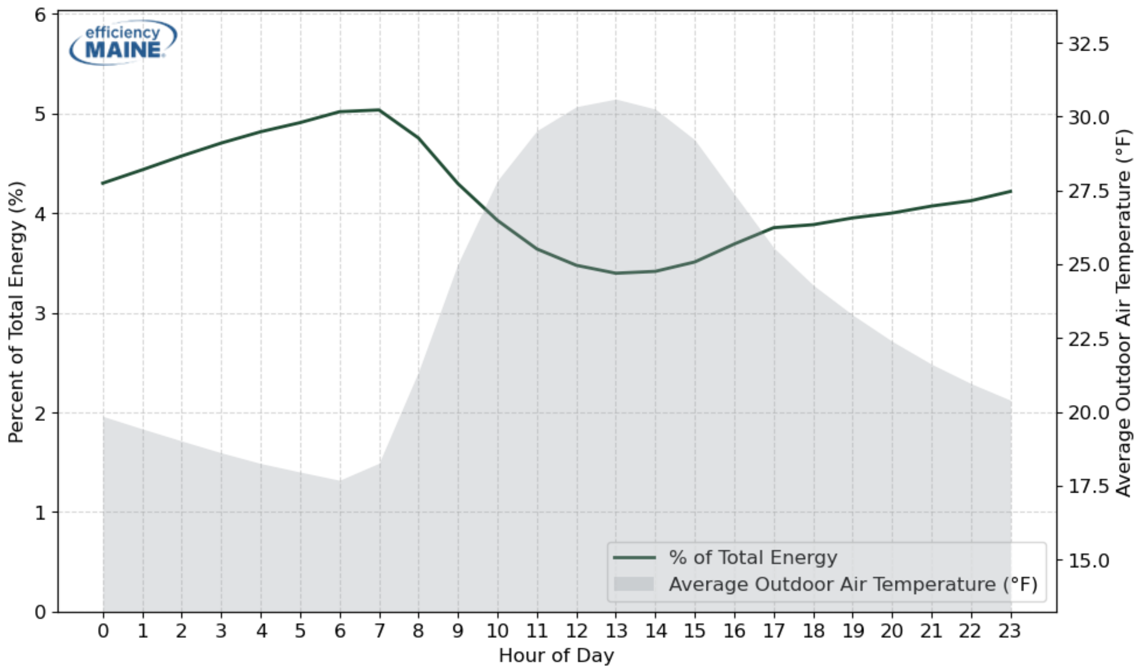
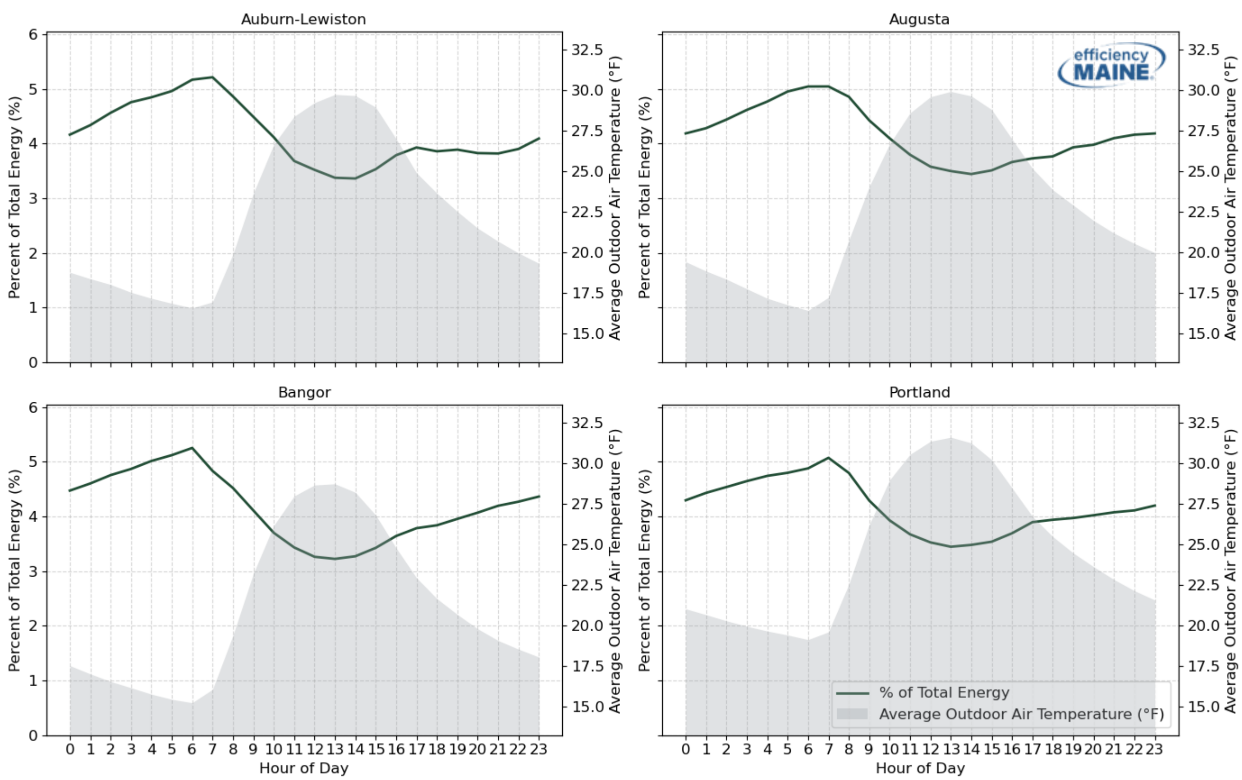


Figure 120. Percentage of Total Energy from Heat Pumps by Time of Day Across 4 Regions (n = 160)



The figures below (Figure 121 and Figure 122) show the normalized 24-hour heating profile in terms of energy (kWh) divided by heating degree hours (HDH65) and heating degree days (HDD65), respectively. So, the numerator reflects the total kWh across all heat pumps within a given hour of day bin, and the denominator reflects the total number of HDH65/HDD65 defined as 65°F minus a given heat pump's associated average outdoor air temperature in that same hour of day bin.

The peak normalized kWh by HDH65 and HDD65 appears to occur between 8 AM and 10 AM, which is slightly later than the other observed peaks in prior Figures. As discussed above in Figure 115, the existing kW peak across all heat pumps occurs at 7 AM. When looking at outdoor air temperatures, however, 7 AM is one of the coldest hours of the day. In these Figures, when the outdoor temperature decreases, the HDD65 or HDH65 denominator increases, resulting in a decrease of the overall ratio of kWh to HDD or HDH. Thus, the peak kWh per HDD65 or HDH65 across all heat pumps occurs an hour later at 8 AM when outdoor temperatures begin to rapidly rise, but average HP power draw is still relatively elevated.

Looking at the peak for actively operating heat pumps only, one can see that the normalized heat pump energy remains elevated through 10 AM as the HDD65/HDH65 denominators shrink with rapidly rising outdoor air temperatures in the morning. This sharp increase in outdoor air temperatures and subsequent decrease in HDD65/HDH65 offsets the observed drop in power draw from 8 AM to 10 AM. For example, if one assumes an HDD/HDH base of 65F, then the average temperature of 21F at 8 AM is 44 HDH, and the average temperature of 28F at 10 AM is 37 HDH. On the other hand, the average power draw at 8 AM is roughly 0.7 kW, and the average power draw at 10 AM is roughly 0.6 kW. This results in ratios of 0.0159 kWh/HDH65 at 8 AM (0.7 kWh / 44 HDH65) and 0.0162 kWh/HDH65 at 10 AM (0.6 kWh / 37 HDH65).

Figure 121. 24-Hour Heating Profile for Energy (kWh) divided by HDH65 (n = 160)

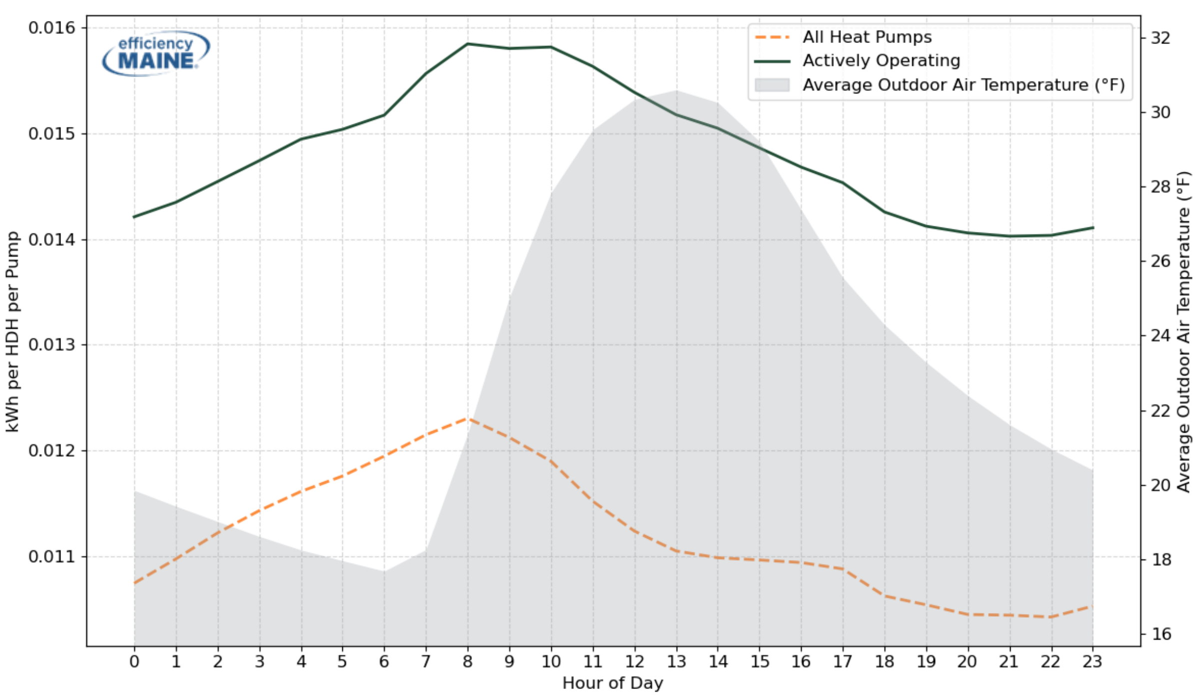
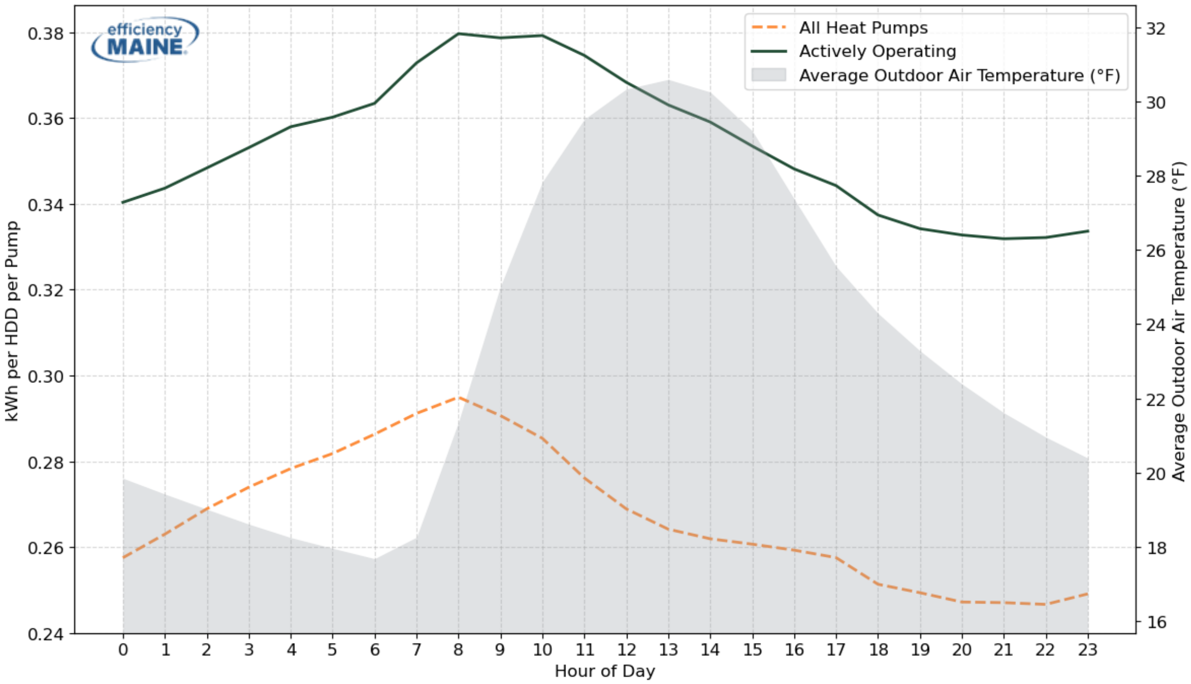


Figure 122. 24-Hour Heating Profile for Energy (kWh) divided by HDD65 (n = 160)



15 APPENDIX E: ADDITIONAL TRENDS IN ALL HEATING SYSTEMS OPERATION

To gain a deeper understanding of the temperature ranges at which different homes begin to use their various heating systems, the "turn-on" temperatures were recorded. Figure 123, Figure 124, and Figure 125 all show the highest turn-on outdoor temperatures for all metered fossil fuel, wood, and heat pump systems, respectively.

These temperatures were manually assigned to bins of 5°F based on visual inspection of each home's individual stacked column chart. This allows evaluators to pick up on consistent operational temperature ranges as opposed to identifying single use-case scenarios. For example, a boiler might fire a single instance at outdoor air temperatures of 70°F because a homeowner turned it on briefly as a test. If one were to automate this process, they might identify this 70°F instance as the highest turn-on temperature for that home's boiler, when in fact, the homeowner really only consistently uses the boiler below 40°F. Additionally, the "Not Used or Marginally Used" category was assigned if the heat output of a given heating source was consistently below 1,000 Btu/h across all temperature ranges. In most cases, these assigned heating systems provided heating much lower than these 1,000 Btu/h thresholds. These heating systems are not viewed as being consistently used according to a schedule and are consequently included in the "Not Used or Marginally Used" category. These systems' use is less weather-dependent and more random in nature. These measures avoid highlighting single instances of heating and more accurately capture consistent trends in homeowner heating behaviors.

Figure 123 shows the highest consistent turn-on outdoor temperature for both central and spot fossil heating systems. In total, there were 56 homes with at least one fossil fuel heating system in the metering sample (56 / 78 = 72%). The pattern of turn-on temperature is relatively flat across all temperatures. We have subsets of homes that turn their fossil fuel systems on between 55°F and 70°F. These homes tend to rely heavily on their fossil fuel systems and use fossil fuels across all temperature ranges. This grouping accounts for 25% of homes with fossil fuel systems. Once a fossil system is turned on, it typically operates at all temperatures under its highest turn-on temperature.

Figure 123. Highest Fossil Fuel Turn-On Temperatures (n = 56)

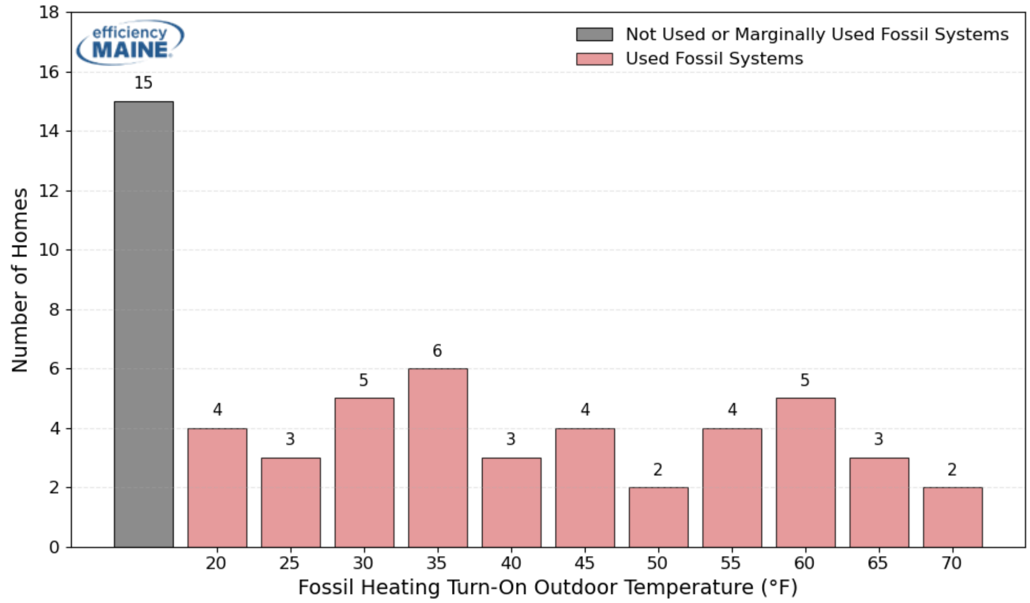


Figure 124 shows turn on temperatures for wood and pellet heating. A handful of homes consistently use wood heating across all outdoor air temperatures. Like with fossil fuel heating, once a wood or pellet system starts being used, it typically operates at all temperatures under its highest denoted turn-on temperature.

Figure 124. Highest Wood Turn-On Temperatures (n = 26)

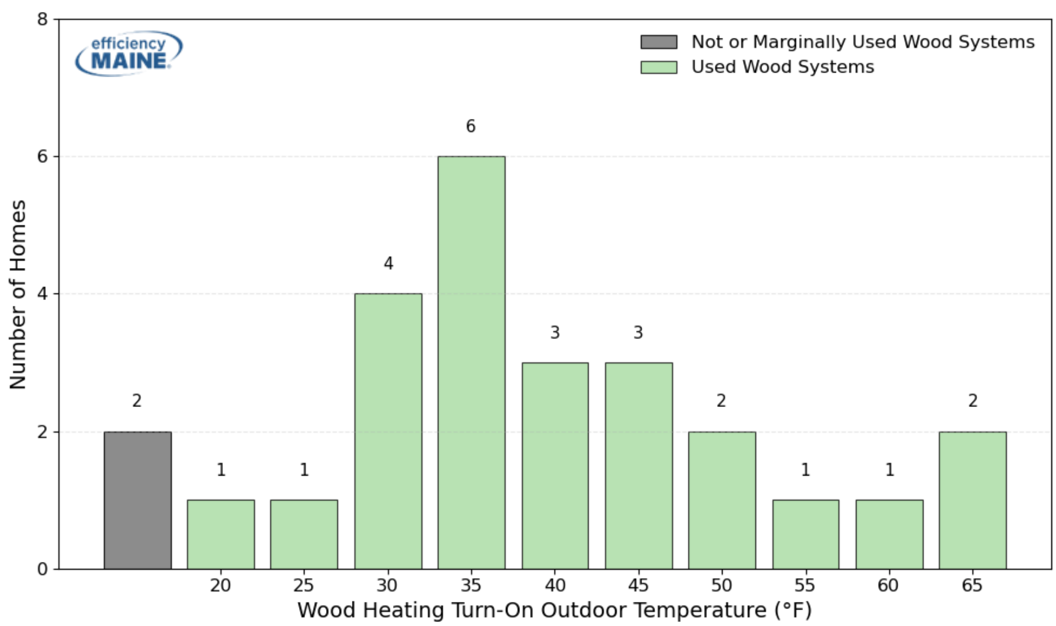
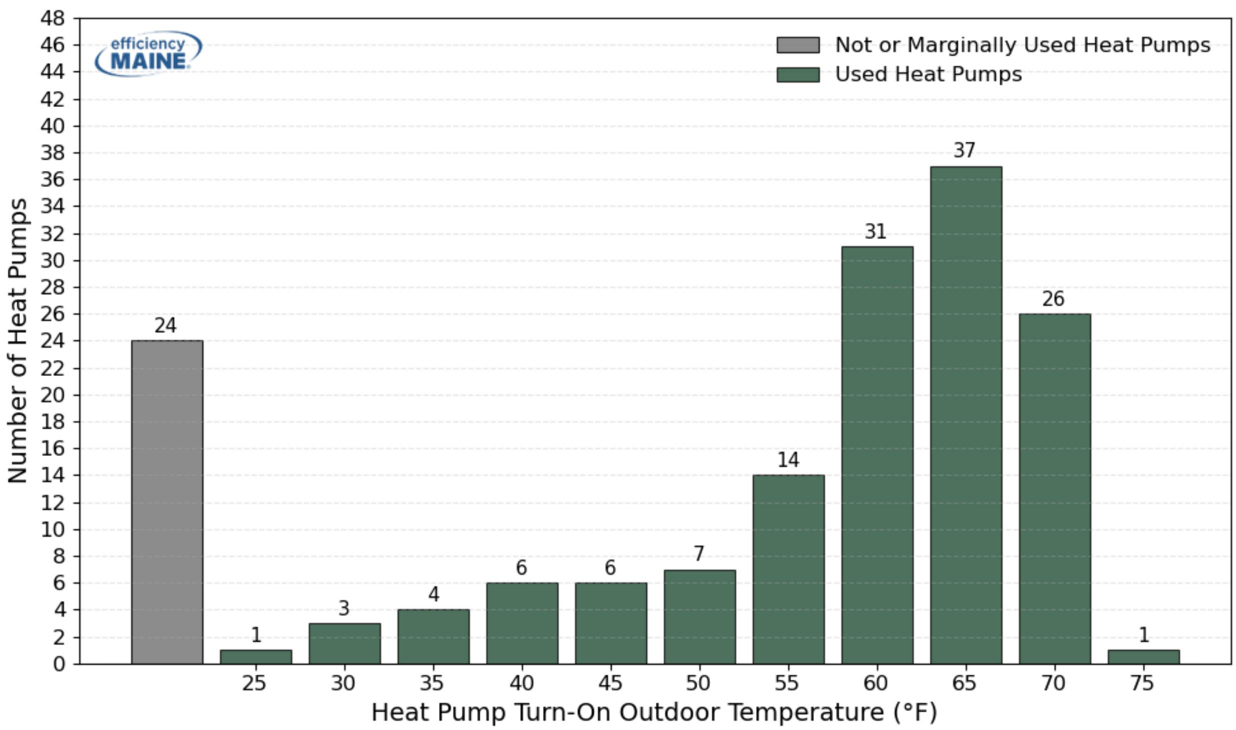


Figure 125 shows the highest heat pump turn-on temperatures across the 160 heat pumps in the sample. The vast majority of heat pumps are first turned on between 60°F and 70°F. 59% (95 / 160) of all heat pumps are turned on at temperatures equal to or greater than 60°F. A subset of heat pumps is then turned on first at colder temperatures to provide additional home heating. Additionally, around 15% (24 / 160) of heat pumps are rarely or never used. In some cases, these heat pumps are used randomly and do not follow any weather-dependent trends. Once a heat pump system is turned on, it typically operates at all temperatures under its highest turn-on temperature. There are a handful of exceptions (discussed below) where the heat pumps are turned off at temperatures under 30°F. Very few heat pumps were completely turned off at lower temperatures that were otherwise used at higher temperatures. For the 6 homes where this is applicable, the turn-off temperature occurs at or below 30°F. Most occur below 20°F.

Figure 125. Highest Heat Pump Turn-On Temperatures (n = 160)



Using the same power thresholds discussed in Appendix D: Regional Differences in Heat Pump Operation, the percentage of heat pumps operating versus outdoor temperatures was also analyzed. Figure 126 shows that the percentage of heat pumps operating increases with decreasing outdoor air temperatures, as expected.

The percent operating represents the heat pump-hours that any heat pump in the metering sample is operating, divided by the total number of heat pump-hours in that given temperature bin (ex. ~150 hours at 10F per pump * 160 heat pumps = ~24,000 heat pump-hours at 10°F = approximate n at 10°F). This example is merely representative, as the number of hours at each given temperature bin will vary for each heat pump due to home location and local weather variation. The data in this Figure is not limited to December, January, and February, but rather the entire metering period to more accurately represent average power and the number of heat pumps operating at higher temperatures.

The percentage of heat pump hours with detected operation appears to plateau just shy of 80% at temperatures below 20°F. This indicates that 20% of heat pump-hours are not considered operating periods out of the total number of heat pump-hours in those given temperature bins (from around -5°F to 20°F). It is important to note that the percent operating shown below may not exactly match the turn-on temperatures above in Figure 125, as the Figure below represents all pump-hours and Figure 125 represents only the highest turn-on temperature. For example, a given heat pump might be turned on for the first time at 68°F, but it will not always be operating for all hours where the temperature is 68°F. The frequency of operation at that given temperature bin is taken into consideration in Figure 126 below, but not in Figure 125.

Figure 126. Percentage of Heat Pump-Hours Operating vs. Outdoor Temperature (n = 160)