

Cool Data. Hot Results. A summary of a comprehensive heat pump metering study across 185 homes in Massachusetts and Connecticut

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ABSTRACT

The energy efficiency Program Administrators in Massachusetts and Connecticut continue to encourage heat pump installation to either partially or fully displace pre-existing natural gas, delivered fuels, or electric resistance space heating. These initiatives are aligned with statewide goals for home heating electrification and greenhouse gas emissions reductions.

This study presents results of a comprehensive heat pump metering and impacts study based on a sample of 185 metered homes in Massachusetts and Connecticut. The study explored ductless, ducted air-source, and ground source heat pump usage and performance characteristics, peak demands, and the portion of heating load met by the installed heat pumps and backup heating systems. The study also explored the ability of heat pumps to keep customers comfortable in low outdoor air conditions along with other customer sentiments, and quantified measure impacts for use in the respective statewide Technical Reference Manuals and Program Savings Documents.

Results from the study suggest that customers are largely satisfied with their heat pump installations. Heat pumps performed well in low outdoor air conditions and were able to keep customers comfortable; however, some customers noted potential concerns regarding system undersizing. The study noted that centrally ducted air source heat pumps were the only heat pump type that saw notable usage of auxiliary electric heating coils at several homes, which contributed to higher peak demands than homes with mini-split heat pump or ground source heat pump installations. The results of this study can be used to inform program design for other utilities offering heat pumps measures.

Background and Introduction

Both Massachusetts and Connecticut have household electrification and greenhouse gas emissions reduction goals. In Massachusetts, the overall emission reduction goal is 80% below 1990 emissions levels by 2050 (MA EOEEA 2022). To help meet the goal, the state's climate plan calls for electrifying 26% of households by 2025 and 38% by 2030. This translates to about 100,000 heat pumps installed by 2025 and 500,000 by 2030 (Massachusetts Office of Climate Innovation and Resilience 2023). In Connecticut, the climate goals are to reduce statewide emissions 45% by 2030 and 80% by 2050 relative to a 2001 baseline, which would also require many homes to electrify (CT DEEP 2018). The heat pump fuel displacement program offerings through Mass Save and Energize CT are aligned with these goals and both states now offer fuel displacement incentives to encourage the adoption of heat pumps for customers with pre-existing gas, propane, oil, and electric resistance heating system types.

The Massachusetts Program Administrators (PAs) and Connecticut Evaluation Administrator (EA) Team commissioned a heat pump metering study to understand how the heat pump offerings were performing. End use metering was conducted across 185 homes for central and mini-split air source heat pumps and ground source heat pumps. The team also fielded customer surveys and performed follow-up phone interviews with select participants. Detailed study objectives included:

- Perform field monitoring to assess the in situ heating and cooling performance and usage of residential heat pumps supported by the programs (this study included heat pumps installed during 2021 and 2022, with most heat pumps installed in 2022).
- Understand the heating loads met by the heat pump and the customer's use of backup heating systems (such as furnaces, boilers, wood stoves, and baseboard heating systems). Understand usage of integrated auxiliary electric resistance heating strips in the heat pump air handling units.
- Understand customer experience with their heat pumps, including overall satisfaction with heat pumps and their ability to meet the heating needs of the home at low temperatures, cost considerations, and any maintenance issues.
- Quantify the gross measure impacts for heat pump installation and inform savings parameter estimates for the Massachusetts Technical Reference Manual and the Connecticut Program Savings document.

The study included installations of heat pumps under two displacement scenarios: full displacement and partial displacement. The following are the definitions of these two displacement types as existed during the 2021/2022 program years.

- Full displacement (FD). The customer removes, disconnects, or indicates that they will not use their pre-existing fossil fuel or electric resistance heating system except in emergencies (extreme weather events, heat pump maintenance or down time) and replaces all space heating needs with heat pumps.¹ Supplemental electric resistance heat is allowed as needed during peak heating periods. Backup heat can also be provided by wood or pellet stoves during peak weather events.
- Partial displacement (PD). The existing fossil fuel-fired system is left in place and an integrated control is used to prioritize the heat pump system's use in milder outdoor air temperatures when the heat pump operates more efficiently. The backup heating systems are typically used at lower outdoor air temperatures when the heat pump efficiency is lowest, when the heat pump cannot meet the full heating loads of the home, or through additional interventions by the customer to meet comfort or other needs. Customers may also operate their units without integrated controls.

Methodology

The following section describes the methodology used by the team to collect customer experience feedback, perform field metering of heat pump installations, and the analysis methods used to summarize heat pump usage, performance, and peak demands.

Customer Surveys and Interviews

Data collection included multiple customer surveys and a customer interview effort. The primary customer survey was fielded to 6,760 heat pump program participants from fall 2022 through spring 2023 and achieved 1,456 total survey responses. A fast feedback interview effort in winter 2023 yielded 13 responses (initial feedback from the sample of 50 homes in the first winter metered sample), and an end-of-season survey yielded 136 responses in winter 2024 (fielded to full metered sample).

¹ Starting in 2023, after the sample was selected, the Mass Save program requires customers to verify the removal of the pre-existing heating system or ensure that it is disconnected at the electric panel or thermostat. The CT program adopted this requirement in 2024.

Metering Methods and Onsite Sample

Onsite Sample

Heat pump usage and performance data were collected at a total of 185 customer homes across Massachusetts and Connecticut and included metering of central heat pumps (CHPs), mini-split heat pumps (MSHPs), and ground source heat pumps (GSHPs), for both full and partial displacement applications. Installations occurred in two waves – Wave 1 installations at 50 sites occurred in fall 2022 (Massachusetts), and the remaining installations at 135 sites occurred in spring and early summer 2023 (Massachusetts and Connecticut). The metered period extended through spring 2024. All sites included heat pump and auxiliary/backup system electric usage data collection, and a subset of 106 sites included additional data collection to calculate the in-situ performance and efficiency of the installed heat pump(s). Table 1 shows the sample distribution for the onsite metering sample. Installations were predominantly in single-family homes (detached and attached), with five multifamily units included.

Table 1. Onsite Metering Sample

System Type	Displacement Scenario*	Sites Installed in Massachusetts	Sites Installed in Connecticut	Total Sites Installed (Usage and Peak Demand)	Total Sites Installed (Performance Sub-Sample)
Mini-Split Heat Pump	FD	35	16	51	38
	PD	23	8	31	7
Central Heat Pump	FD	30	10	40	34
	PD	12	25	37	15
Ground Source Heat Pump	FD	1	25	26	12
Total		101	84	185	106

*FD = Full Displacement, PD = Partial Displacement. Designation of FD or PD based on program data.

Metered Data Collection

The usage sites included measurement of combined power draw of the heat pump and associated equipment (fans, pumps, and any installed auxiliary electric heat) powered through the outdoor unit. The performance sites included the full usage data collection, along with measurements of fan current, indoor temperature and relative humidity at the supply and return air streams, and outdoor temperature. Table 2 summarizes the types of meters used for the study, the data collected for each equipment type, and the location in which they were installed.

Table 2. Metering Equipment for Heat Pump Systems

Measurement	Location	Metering Type	Sensor Type	Equipment
Power (P)	Power supply to outdoor unit	Usage	Watt Transducer	eGauge 3010
Current (i)	Supply Fan	Performance	Current Transducer	Onset MX1105 + 1A CT with converter, or eGauge if air handler had dedicated breaker
Air Temperature & Relative Humidity (T/RH)	Supply Air (SA) Duct, Return Air (RA) Duct	Performance	Thermocouple	MX2302A
Outside Air (OA) Temperature (T)	Outdoor Unit	Performance	Thermocouple	MX1105 + Temp input or MX2302A

Figure 1 shows the installation locations for the meters for central systems (air source and ground source heat pumps),² and mini-split heat pumps.

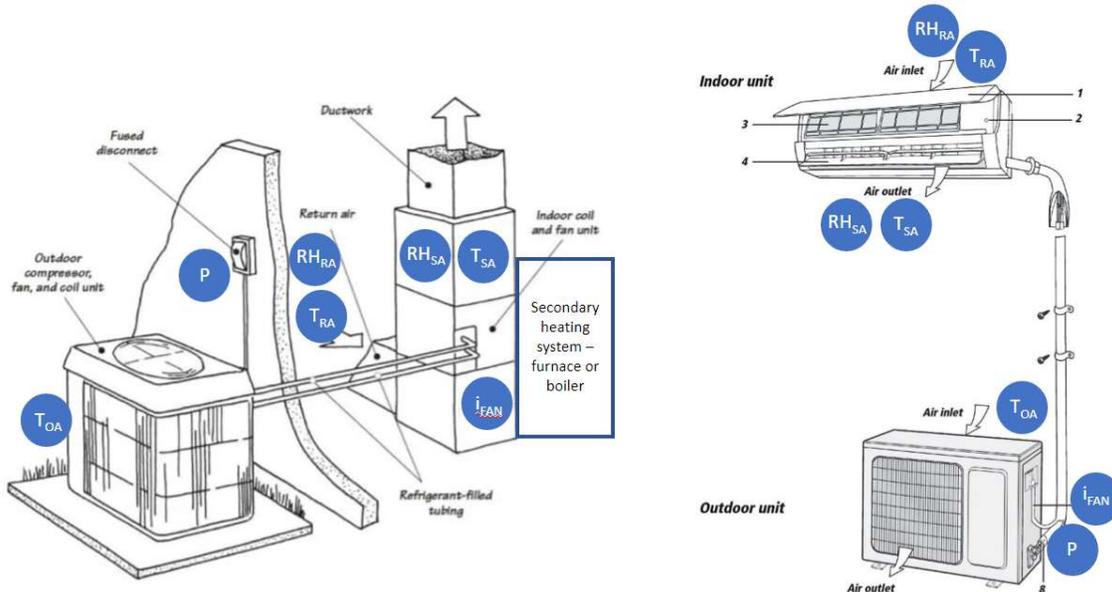


Figure 1. Central and Mini-Split Heat Pump Performance Metering Schematic

Fan Airflow Measurements and Calculation

Fan airflow data for mini-split and central systems were collected on the day of logger installations for sites that underwent performance metering so that analysts could use logged current to estimate air flow. Depending on the system type and the unique air distribution characteristics of the sites, fan airflow data was collected using a flow plate installed in the filter slot for central systems, or a flow hood and balometer (mini-split heat pump systems, or for central systems where the filter return was a custom size that did not accommodate the flow plate).

Data Processing and Analysis

Data Processing

Loggers were installed at a total of 185 sites and metered a total of 246 heat pumps and their associated ancillary systems. Between November 1, 2022, and May 15, 2024, 1.3 billion rows of raw minute-level data were collected from the study sites, which resulted in 760 million rows after data cleaning and consolidation. The team reviewed the raw logger data using a combination of automated checks, visual QC, and cross-checking data with customer reported usage from the field visit interviews. Obvious outliers (i.e., extreme high or low values) were flagged for review and removed. After data cleaning, the usage sample included 175 sites for heating season summaries (169 for cooling season), and the performance metering sub-sample included 60 sites for heating season summaries (66 for cooling season). Reasons varied for logger and site removal, including customer moves, customer errors including turning breakers on or off or fiddling with meters, prolonged periods of internet connectivity loss, inaccurate return or supply air temperature or RH readings (either due to logger placement or sensitivity of the loggers), or malfunctioning loggers.

² Metering setup for ground source heat pumps was functionally the same as air source heat pumps. The power meter collected ongoing power reads for all compressors, pumps, fans, and auxiliary electric heat associated with heat pump system operation. Performance monitoring was conducted on the airside of the system using T/RH readings and current monitoring for the blower fan in the air handling unit.

Usage Analysis

To estimate typical-year heat pump usage and measure impacts, the metered heat pump usage (power) data was converted to typical-year usage for each heat pump system using weather normalization models. The team first aggregated the minute-interval usage data to the hourly level, modeled the relationship between heat pump hourly usage and hourly weather variables, and then predicted typical-year heat pump usage using typical meteorological year weather data (TMYx) and actual meteorological year (AMY) weather data for the past 15 years (for seasonal peak demand) as inputs to the fit models. The study associated each metered site with the closest of seven representative weather stations in the study area: Worcester, Boston, Lawrence, New Bedford, Westfield (Massachusetts); and Hartford and Bridgeport (Connecticut).

Performance Analysis

The performance, or efficiency, of a heat pump is defined as the ratio of the useful energy produced by the system to the energy consumed by the system—that is: the ratio of the heating or cooling energy delivered to the conditioned space over the electrical energy consumed by the heat pump compressor and auxiliary systems. To calculate the energy consumed by the system, the power data from the compressor, air handlers, and auxiliary heating (if any) was summed. The energy removed or delivered by the heat pump is a function of the change in enthalpy across the air handler and the airflow, as described by Equation 1.

Equation 1. Energy Delivered by the Heat Pump

$$E = \Delta t * \Delta H * Q * \rho * \frac{0.9417 \text{ Btu}}{\text{kJ}} * \frac{\text{meter}^3}{35.3 \text{ feet}^3}$$

Where:

E = energy (Btu)

Δt = measurement interval (hours)

ΔH = change in enthalpy (kJ)

Q = volumetric air flow (CFM)

ρ = air density ($1.204 \frac{\text{kg}}{\text{m}^3}$)

Measurements of the fan current were used to calculate the airflow. During site visits the relationship between fan power consumption and system airflow was measured for as many performance-metered sites as possible.³ Whenever possible, at least three data points were collected for each fan. Through ordinary least squares regression, system-specific, exponential models (“fan curves”) were fit to relate the fan power to airflow. Figure 2 shows airflow measurements and fan curve model fits at four example sites. Three curves are shown for the MSHP example system, one for each indoor head.

³ For air handlers in the performance-metered sample where field observations of the fan-curve relationship could not be collected, data from a system with an identical heat pump model was used, when available, or an average of curves from similar heat pump systems when no identical model system was available.

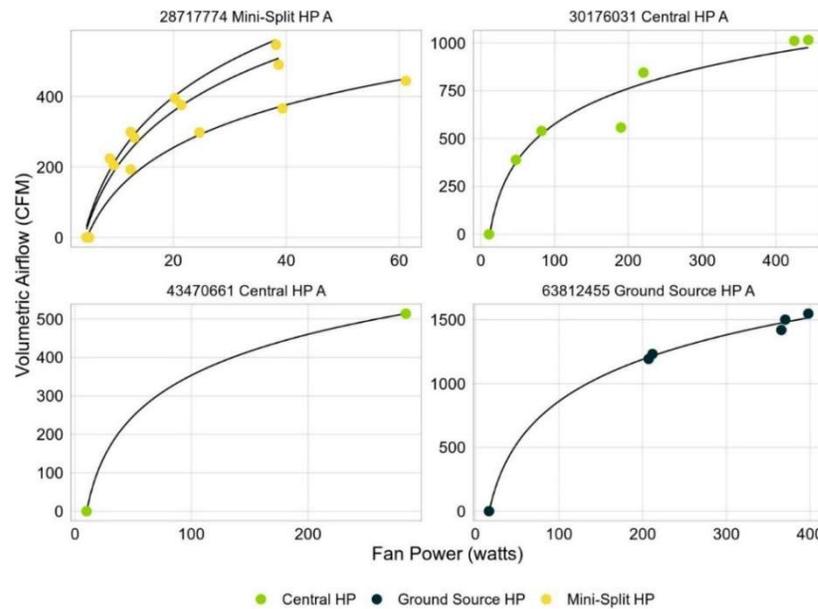


Figure 2. Example Airflow Measurements and Approximate Fan Curves

Heat pump efficiency is expressed as a coefficient of performance (COP), which is the ratio of the useful energy delivered by the heat pump expressed in Equation 1, and energy consumed by the heat pump system components over the same time period. The COP results in this study were expressed for two scenarios of system operation – 1) compressor-only mode, when the heat pump system is actively heating or cooling with the compressor ‘on’, and 2) scenario including all modes of operation, including compressor operation, fan only operation, and any applicable defrost modes.

Heating Load Proportions

To determine the proportion of the heating load met by the heat pumps and backup heating systems, the modeled heating performance data was used to develop models of the home heating load. Initially, average heat pump load was calculated by outdoor temperature, and the temperature range for each site where the heat pump appeared to be meeting the entire home heating load was determined via visual inspection (typically 35°F-50°F). A linear model was then fit for each site using this subset of the data and the model was used to predict the load at colder temperatures. Home heating load is expected to vary linearly with outdoor temperature in the absence of changes to thermostat setpoint or occupancy, and thus a linear model can be used to reasonably extrapolate the loads across temperatures. Next, the heat pump and auxiliary electric heat loads were used with the modeled total home load to calculate the proportion of the load met by heat pumps and auxiliary heat for each temperature at each site, and the remaining proportion was assigned to other backup systems. Six sites were removed from analysis roll up where the heat pump appeared to never meet the full load of the home, and ten sites were removed that were identified as fill displacement of a partial home. Full analysis details are included in the study report.

Results

Heat Pump Performance

Figure 3 shows the Coefficient of Performance (COP) values for the air source heat pump types (central heat pump and mini-split heat pump) for two displacement types (full and partial), for both heating and cooling seasons. These COP values summarize average heat pump efficiencies during compressor 'on' periods in heating or cooling mode, and do not include defrost cycles, auxiliary electric usage, or fan-only operation. As expected in the heating season, COP decreases as outdoor air temperature (OAT) decreases, trending towards a COP of 1.5 to 2.0 at 0 to -10°F.

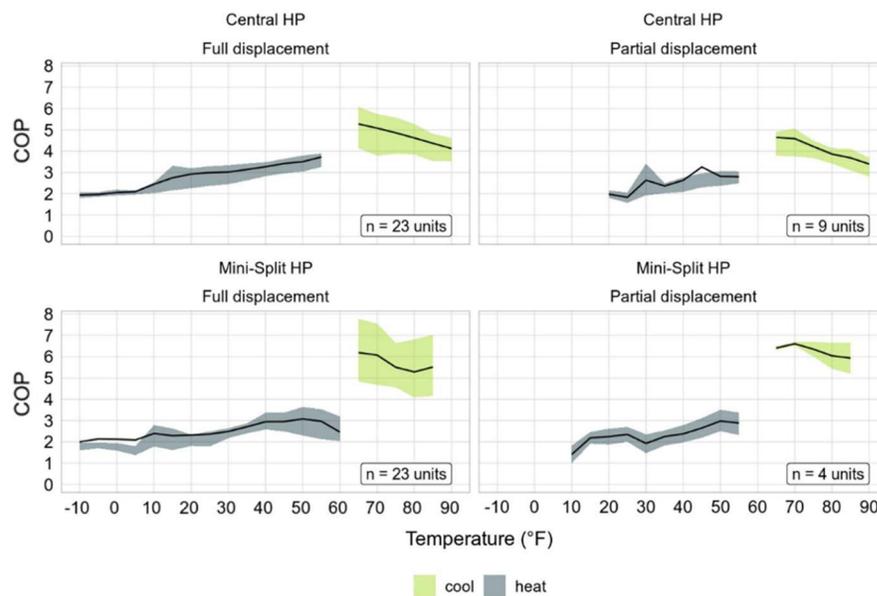


Figure 3. Heat Pump COP vs. OAT During Compressor 'On' Periods – Air Source Heat Pumps

*The black line is the mean COP across all systems. The shaded ribbon is the interquartile range showing the range between the 25th and 75th percentile of units

Figure 4 shows Coefficient of Performance (COP) values for the ground source heat pump for full displacement. Ground source HPs showed consistent COP across the heating season (approx. 3.0).

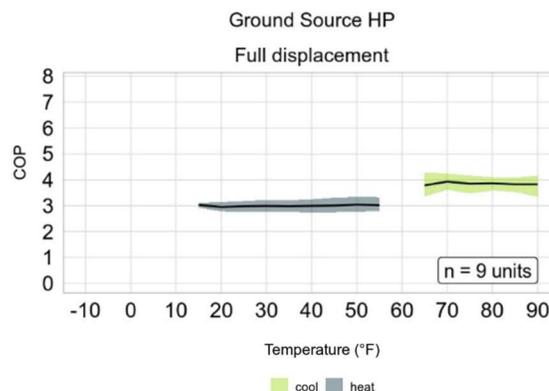


Figure 4. Heat Pump COP vs. OAT During Compressor 'On' Periods – Ground Source Heat Pumps

Table 3 shows the seasonal efficiency metrics for the central and mini-split air source heat pumps. Unlike the COP vs. temperature plot shown above which only considered compressor-on performance, the in-situ Heating Season Performance Values (HSPF) account for all energy consumed and produced by the systems across all modes of operation (heating, cooling, fan only, defrost, standby, dehumidification and integrated auxiliary electric heat). The study suggests that in-situ seasonal heating performance is comparable to HSPF2 rated values. Cooling season results are included in the full study report, and suggest that in-site SEER values are generally lower than both rated SEER and SEER2 values across all units.

Table 3. Heating Season Performance Results vs. Rated

System Type	Displacement Scenario	Average In Situ HSPF	Average Rated HSPF	Average Rated Region IV HSPF2*	Average Rated Region V HSPF2*	Systems Included
Central HP	FD	8.9	10.2	8.9	6.8	44
	PD	8.4	10.1	8.8	6.7	39
	Combined	8.7	10.2	8.9	6.7	83
Mini-Split HP	FD	9.3	10.9	10.0	7.7	69
	PD	9.8	11.3	10.3	7.9	44
	Combined	9.5	11.1	10.1	7.8	113

*The Western portion of MA and the Central/North region of CT are considered Region V in the AHRI test procedure. The Coastal portion of CT and MA are Region IV, along with the western portion of CT.

Note: The seasonal efficiency values in this table include all modes of operation and are weather normalized.

Usage and Peak Demand

Analysis of collected metering data showed that annual heating and cooling season usage of heat pumps (kWh) varied widely across sites in the metered sample, even when normalizing usage per installed capacity (tons).⁴ Some of the variability in site-level usage was driven by manual operations of the heat pumps (such as turning the units on and off), use of customer’s backup heating systems, even for homes that were intended to be ‘Full Displacement’, and use of installed integrated controls (ICs) with varied switchover temperatures. Customer’s home characteristics, occupancy, setpoint preferences, and other operational variables likely contributed to variability in usage as well (details provided in full study report).

Even with the variability in site-level usage, the study found that the majority of the average home’s heating load was met by the heat pumps in Full Displacement applications (86-99%), as shown in Table 4. Partial displacement applications saw 65-79% of the heating load met by heat pumps on average.

Table 4. Proportion of Heating Season Load Met by System Type

System Type	Displacement Scenario*	Portion of Heating Load Met		
		Heat Pump	Auxiliary Electric Heat	Backup Heating Systems
Central HP	FD	86%	4%	9%
	PD	67%	1%	32%
Mini-Split HP	FD	92%	0%	8%
	PD	79%	0%	21%
Ground Source HP	FD	99%	0%	1%

*Based on program data designation of displacement type

⁴ Plots of site-level usage distribution are provided in the full report: https://ma-eeac.org/wp-content/uploads/MA-HPMS-CT-R2246-Heat-Pump-Metering-Study-Final-Report_April_2025.pdf

In Partial Displacement applications, most customers surveyed indicated that an integrated control was installed by their contractor, however most customers also report not knowing what the switchover temperature is or was. By the end of the study (after two to three heating seasons of operation), about half of customers with Partial Displacement installations report still using their ICs. Review of onsite metered data showed about 70% of Partial Displacement sites with central heat pumps showed a consistent switchover temperature throughout the metered period, while 20% of mini-split heat pumps saw a consistent switchover. Switchover temperatures ranged between 15–40°F (average 25°F) for those with oil backup heat, and 20–40°F (average 30°F) for those with natural gas backup heat for those that used them. Customers that do not use a switchover report manual operation of their systems, or using the droop method on their thermostats.⁵

The team also summarized the prevalence of integrated auxiliary (aux) electric heat across heat pump types as well as the usage of the aux heat to meet the heating loads of the home. Based on analysis of the collected field data, the study found that about 33% of homes with central heat pumps had aux heat installed (n=20), and of those homes, 75% used it during the winter heating season. Figure 5 shows the 20 homes with central heat pumps installed with auxiliary electric resistance heating. As outdoor air temperature decreased, aux heat usage increased for these sites. Some sites saw aux heat usage fully take over around or under 0°F. Most sites saw little aux heat usage, or the aux heat was used to boost heat output alongside the heat pump coil.

The team found that 82% of ground source heat pump installations had aux heat installed (n=18). However, only one of those sites saw any usage, which was minimal. Mini-split heat pumps do not typically have aux heat installed.

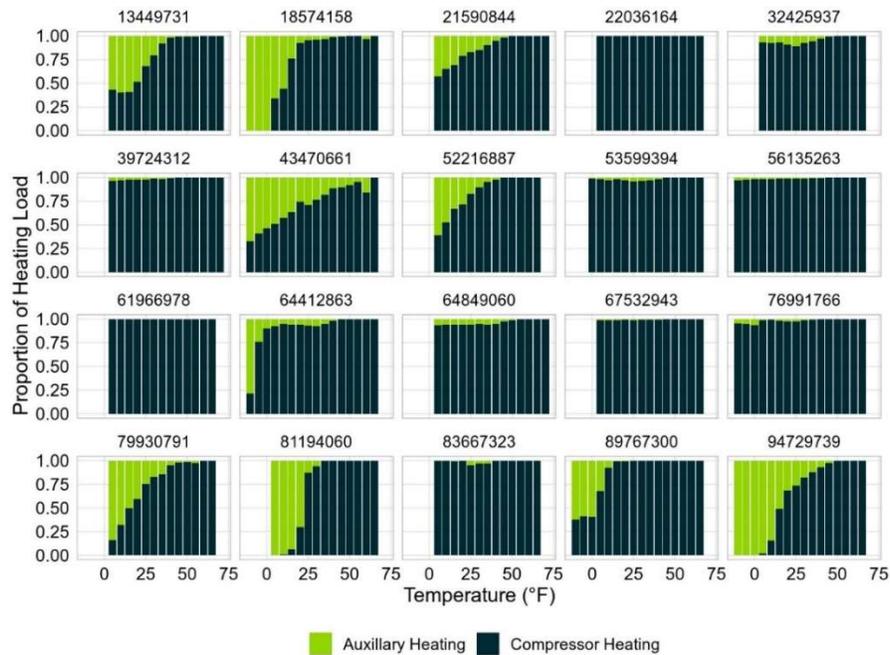


Figure 5. Auxiliary Electric Usage for Central Air Source Heat Pump Sites with Auxiliary Heat Installed

⁵ Droop control utilizes different temperature setpoints on two or more thermostats. Typically, the thermostat controlling the heat pump(s) is set to a higher temperature (e.g., 67°F) than the thermostat controlling the backup heating system (e.g., 62°F). The backup heating system will turn on if the indoor air temperature drops down to 62°F in this example.

The metering period for the study included two winters (2022/2023 and 2023/2024). Figure 6 below shows a comparison of the peak demand on the coldest day of the two metered heating seasons (February 4, 2023 and January 20, 2024). The Figure shows the average hourly demand for the subset of 10 metered homes that had the following conditions: 1) the team verified that the home removed or disconnected any backup heating sources, and 2) homes that had metered data collection during both winter peak day periods.

For central heat pump sites that removed or disconnected their pre-existing heating sources, metered peak demand on the coldest day of 2023 (down to -13°F) was 8 kW, roughly three times as high as the peak demand for the same sites on the coldest day during 2024 (down to 12°F). For these metered sites (n=5), the additional peak demand is largely due to usage of the integrated auxiliary electric heating elements. The mini-split heat pump sites saw higher demand during the colder peak day, but not nearly as high as the central heat pump sites.

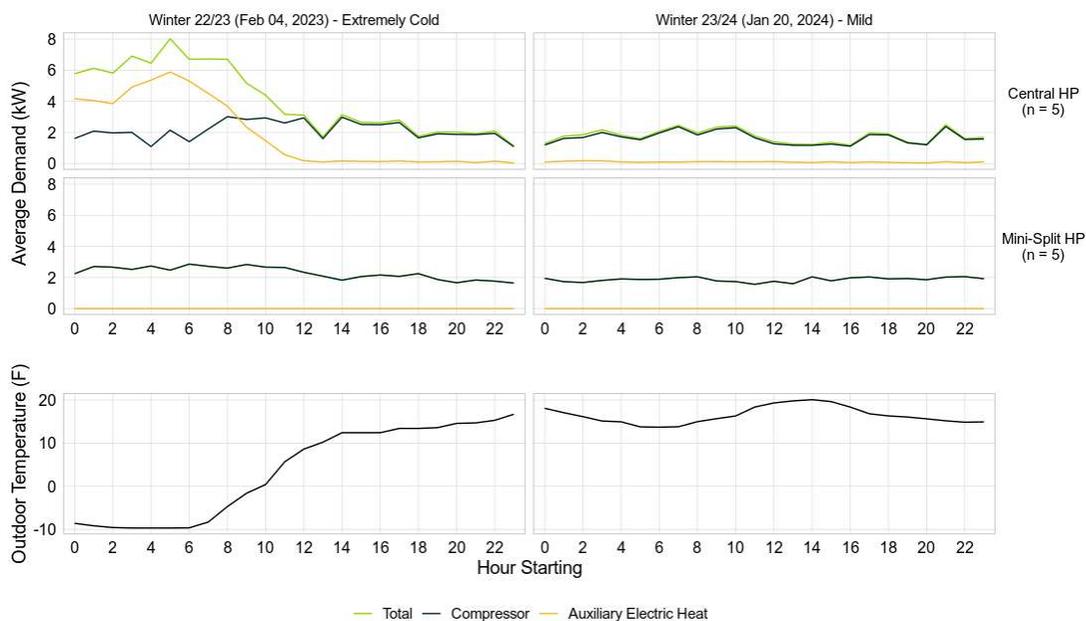


Figure 6. Metered Peak Day Load Shape for Full Displacement Sites that Removed Backup Heat

Customer Feedback

Overall, the study found that most customers are pleased with their heat pump installations. When asked if they would make the same choice again, ninety five percent of respondents said they would install a heat pump. The team noted the following themes in customer sentiment when asked about the greatest advantages and disadvantages of their new heat pump systems.

- **Greatest Heat Pump Advantages**— Customers reported that reduced costs, carbon reduction, and efficiency were the greatest advantages to their heat pumps.
- **Greatest Heat Pump Disadvantages**— Customers also noted that increased electricity cost, poor cold weather performance (for some sites), and difficulty operating the heat pump were some of the greatest disadvantages.

It is interesting to note that cost considerations show up under both the positives and negatives for heat pump installations. Customers in the study had varying pre-existing fuel types (delivered fuels, natural gas, electric resistance), with corresponding differences in fuel costs, so some customers may have seen total heating bills increase while others saw a decrease.

Most customers are satisfied with the ability of their heat pumps to keep them comfortable in the winter (about 93% of Full Displacement installations), however a few customers noted comfort issues. After reaching out to these customers with follow-up phone interviews, the team noted potential under-sizing of heat pump systems at a few of these sites, however this would require further investigation to be able to tell definitively. Some of these customers explicitly said they wished that they had installed a specific cold climate heat pump model.

Most customers did not report maintenance issues with their heat pumps. Of the 9% of CHP and 19% of MSHP customers that indicated a maintenance issue, the reported issues generally fall under these categories:

- Condensate issues such as overflowing or poor condensate routing (3%)
- Circuit board issues caused by electric outages or rodents (2%)
- Refrigerant leaks (2%)

Other less common reported issues include: the inside heat pump vanes malfunctioning, the heat pump going offline during a blizzard, loud sounds when the outside temperature reached freezing, thermostat or control issues, high humidity in the home, and issues with auxiliary heating operating too frequently or not at all. Only 1 GSHP site reported maintenance issues.

Conclusions and Recommendations

The study team completed a 2-year long comprehensive metering study (Winter 2022 through Spring 2024) in Massachusetts and Connecticut for 185 homes that installed heat pumps to fully or partially displace pre-existing fuel-fired or electric resistance heat. The study found that heat pumps are largely meeting the objectives set forth by the fuel displacement program initiatives in Massachusetts and Connecticut. Overall, the study found that:

- Customers are largely satisfied with their heat pump purchases and most installations are meeting their comfort needs down to the lowest observed outdoor air temperatures.
- On average, heat pumps are meeting most of the heating loads in customer homes, and installations are realizing sizable heating fuel displacement.
- Across installations, heat pumps are performing well down to lower outdoor air temperatures, maintaining a COP around 1.5-2.0 at 0°F and below for air source heat pumps, and 3.0 for ground source heat pumps.

The study noted some areas for consideration for program managers and utility staff:

- Some central heat pump installations saw 100% auxiliary electric resistance heating usage at low outdoor air temperatures, causing high peak electric demands during particularly cold winter days. Programs may consider providing guidance on design temperatures and sizing thresholds that contractors must follow to ensure heat pumps can meet home heating loads at the lowest outdoor air temperatures. The guidance could also clarify whether capacity requirements pertain solely to the heat pump compressor or include any installed auxiliary electric heating. Utilities should consider the implications of winter electric peak through heat pump electrification programs.
- Some customers noted frustration that they did not understand how much a heat pump could impact their electrical bill. Programs can consider providing education and tools to help

customers understand how switching to a heat pump could impact their electric bills, especially if their pre-existing system is not electric.

- Heat pump technology is evolving rapidly, with new products entering the market every year reporting higher efficiencies, higher Btu capacities down to low outdoor air temperatures, new controls, and other features. Programs can consider periodic review of the products available in the market and their technical specifications and unit prices to inform potential updates to minimum program requirements and qualified product lists.

The study team provided ideas for future research considerations:

- Conduct additional metering of heat pumps to increase sample size, notably for ground source heat pumps.
- Study energy usage, peak demands, and performance of latest generation of heat pump units being installed in the field. Study portions of heating load displaced as program rules evolve.
- Benchmarking impacts against previous heat pump studies and comparing methodology where appropriate.
- Research into heat pump installation impacts on performance: location of air handling units, orientation of units and exposure of condensers, etc.
- Investigate contractor heat pump sizing practices: are contractors using Manual J sizing calculations? How detailed are they getting and what data or observations are they collecting to use as inputs? How do they choose the system to meet the load, and are they considering capacities of the units at lower outdoor air temperatures (e.g., 5°F)?

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