Massachusetts and Connecticut Heat Pump Metering Study
(MA22R51-B-HPMS) / (CT R2246)

Comprehensive Report

Provided to:

The Electric and Gas Program Administrators of Massachusetts and the Connecticut Energy Efficiency Board and Evaluation Administrator Team

Part of the Residential Evaluation Program Area

Provided by:

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Abstract

Both the Sponsors of Mass Save® and the Sponsors of Energize Connecticut℠ (Energize CT) initiatives have continued efforts to encourage homeowners to meet more or all of their home heating needs with heat pumps. Some of these efforts are structured to support customers that have pre-existing fossil fuel-intensive heating fuels, such as furnaces or boilers that heat with natural gas, fuel oil, or propane as well as electric resistance heating. The Sponsors of Mass Save and the Sponsors of Energize CT have introduced fuel displacement rebates/incentives to encourage the adoption of heat pumps for customers with these pre-existing heating types. These initiatives are aligned with Massachusetts and Connecticut statewide goals for home heating electrification and greenhouse gas emissions reductions.

The Massachusetts Program Administrators (PAs) and the Connecticut Evaluation Administrator (EA) team commissioned this Heat Pump Metering Study to learn about current usage patterns for heat pumps and other heating equipment, electric peak demands for heat pumps, the performance and efficiency of heat pumps, and the ability of heat pumps to meet customers' full heating needs down to low outdoor air conditions. The study also assessed customers' overall experience with heat pumps and feedback on their use. Finally, the study quantified the impacts or savings associated with heat pump installation to update in the Massachusetts Technical Reference Manual (TRM) and the Connecticut Program Savings Document (PSD). Within the report, the team offers multiple scenarios of impact results based on anticipated program changes.

The study conducted research through several modes to address the research questions. For the first mode, heat pump usage data was 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 displacement (FD) and partial displacement (PD) applications[1]. Additional metering to inform performance and efficiency calculations was conducted at a subset of 106 sites. The second mode of data collection included multiple customer surveys (1,399 total survey respondents) and a customer interview effort (13 responses).

The study found that heat pump installations in 2021 and 2022 for FD displaced a large majority of the pre-existing heating delivered by electric resistance and fossil fuel-fired heating sources (approximately 85-90% for CHPs and MSHPs) and more than half of the heating load for PD installations. The majority of customers were satisfied with their heat pump and the ability of their heat pump to keep them comfortable—although a small percentage of study participants reported comfort issues with their heat pumps, concerns about heating costs with heat pumps, and installation or maintenance issues.

[1] See Section 2.3 for sample sizes included in the metering portion of this study.

The study provided the following considerations:

- Establish and enhance program requirements to more clearly identify criteria for FD and PD installations.
- Give additional guidance to installers on switchover temperatures and heat pump sizing.
- Consider adjustments to program requirements for integrated controls, especially for MSHPs.
- Provide customers with additional education on how installing a heat pump will impact their electricity bill and overall heating costs.
- Conduct a heat pump technical assessment periodically (e.g., every couple of years) to inform program requirements.
- Update deemed savings estimates and parameters in the Massachusetts TRM and the Connecticut PSD.

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Executive Summary

Study Goals and Background

This report, developed for the Massachusetts Program Administrators (PAs) and the Connecticut Evaluation Administrator (EA) team, summarizes the usage, peak demand, and performance of heat pumps rebated through the heat pump fuel displacement program offerings, and the measure impacts resulting from heat pump installation to either fully or partially displace pre-existing fuel-fired or electric resistance heating equipment. It also assesses customer experience with the installed heat pumps and the ability of the heat pumps to keep customers comfortable. This evaluation was performed by Guidehouse, with field data collection conducted by Ridgeline Energy Analytics.

The primary goals of this study were to:

- Perform field monitoring to assess the actual heating and cooling performance and usage of the latest generation of residential heat pumps being supported by the programs.
- Understand the heating loads met by the heat pump and the customer's use of backup and auxiliary heating systems. For the purposes of this study, auxiliary heat is defined as an integrated electric resistance heating in the heat pump system. The auxiliary heat operates when compressor can no longer deliver heat. It is typically found in the air handlers of central and ground source heat pump installations. Backup refers to separate conditioning systems independent from the heat pump (boiler, furnace, wood stove, baseboard heating, space heater, window AC unit).
- 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. Quantify impacts for Full Displacement (FD) and Partial Displacement (PD) installations.

Study Methodology

The study included two primary modes of data collection. For the first mode, 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[2]. 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 winter 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).[3]

The second mode of data collection included multiple customer surveys and a customer interview effort. The primary survey was fielded to 5,858 heat pump program participants (1,263 total survey respondents). A fast feedback interview effort in February 2023 yielded 13 responses, and an end-of-season survey yielded 136 responses during February 2024, collected from the onsite metered sample.

Key Findings

Below are key findings that emerged from the various activities, aligned with the study's research topics and questions.

Heat Pump Usage and Peak Demand

The heat pump programs offer rebates to customers to either fully displace (FD) or partially displace (PD) their pre-existing heating systems, though structured differently in Massachusetts versus Connecticut. At the time of installation for the sites participating in study (2021/2022 participants), Massachusetts offered two different pathways of incentives for customers based on their displacement level. Customers opting for FD were not required to remove their pre-existing equipment if the equipment was disconnected and/or only used in emergencies. However, in Connecticut, the rebates were offered through a singular pathway regardless of the level of displacement. Rebates were offered on a per ton basis and customers were required to install an integrated control if their pre-existing system was not removed and it became a backup system. The study sought to understand the prevalence and use of backup and auxiliary heating systems in customer homes that were categorized as either FD or PD, along with the fraction of the home's heating load that was met by backup4 and auxiliary5 heating systems.

[2] See Section 2.3 for detailed sample sizes included in the metering portion of this study.

[3] The participants in this study had their heat pumps installed in 2021 or 2022 (majority of installations were in 2022). During this time period, the Mass Save and Energize CT heat pump full displacement offerings did not fully require the participant to remove or disconnect backup heating sources, rather, the systems were allowed to stay in as emergency backup heat. This report provides measure impact results for two scenarios – 1) scenario using the full metered sample from the 2021 and 2022 installations, and 2) scenario that summarizes usage and measure impacts for Full Displacement sites that removed or disconnected their backup heating system(s).

[4] Backup heating systems include boilers or furnaces (oil, propane, natural gas fuels), wood or pellet stoves, or electric baseboard heaters. Integrated auxiliary electric heating coils are often installed in the air handling unit for ducted HVAC distribution systems to serve as emergency heat.

[5] Auxiliary heating is defined as integrated electric resistance heating in the heat pump system. It operates when compressor can no longer deliver heat. Auxiliary heating is typically found in the air handlers of central and ground source heat pump installations.

Table ES-1 summarizes the proportion of the heating load met by system type across the entire heating season. For the FD sites, the heating load proportion met by the heat pump ranged from 86%-99% based on heat pump type, while for PD sites it ranged from 65%-79%.

Table ES-1. Proportion of Heating Season Load Met by System Type

Heat Pump Type	Displacement Type	Proportion of Heating Load Met – Heat Pump	Proportion of Heating Load Met – Auxiliary Electric Heat	Proportion of Heating Load Met – Backup Heating Systems
Central HP	FD	86%	4%	10%
Central HP	PD	65%	0%	34%
Mini-Split HP	FD	91%	0%	9%
Mini-Split HP	PD	79%	0%	21%
Ground Source HP	FD	99%	0%	1%

Based on full metered sample and program data designation of displacement type

Source: Evaluation team analysis

Full Displacement Usage

- In Massachusetts, the heat pump programs intend for installations of heat pumps as FD to fully replace the home's pre-existing fossil-fuel heating systems. The disconnection or removal of the backup fossil-fuel heating systems was not a strict program requirement in 2021 and 2022 (program years that served as a source for survey responses and onsite data collection in this study). However, the requirement now exists for the programs offered by the sponsors of Mass Save in 2024. As noted above, the heat pump program offered by the sponsors of Energize CT does not have a specific offer based on displacement amount, but it does require the installation of an integrated control if a backup heating system remains installed and connected. The programs do not have any restrictions on the use of auxiliary electric resistance heating or backup heating using wood or pellets.
- Heat pumps met a large majority of the heating load in FD applications despite the prevalence of backup and auxiliary heating sources.[6] Based on analysis of metered data, this study found that, on average, about 85-90% of the home's heating load was met by the heat pump in FD installations for both CHPs and MSHPs. Among this same group, backup heating sources met about 10% of load, while auxiliary heat met a few percent of the load for CHP FD installations. GSHPs met nearly the entire heating load (99%), with backup heating sources accounting for the remaining 1%.

[6] 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. There may have been other un-metered heating sources installed at homes, outside of backup heating systems or auxiliary heating, or a drop in home temperatures that was not accounted for in the load calculations. See Section 2.5.8 for additional details.

- While the heat pumps met most of the load in FD installations, the majority of homes, with the exception of those with ground source heat pumps, needed auxiliary or backup heat during the coldest periods. Of the 50% of customers with backup heat, about 60% of them report using systems to heat during the milder winter periods, and 75% during the coldest periods. Customers report using backup heat for many reasons. Some customers report that they prefer to use wood heat to meet portions of the heating load. Some customers have concerns with electric costs with heating with their heat pumps. Some customers in the study expressed concern that their heat pump was unable to keep them comfortable down to low outdoor air temperatures (a few reporting that they wish they had installed heat pumps better designed for cold temperatures). One customer specifically reported re-connecting their backup heating system.[7]

Partial Displacement Usage

- In PD applications, the programs intend for the heat pump to serve the majority of the heating load of the home, with the backup heating systems meeting load at lower outdoor air temperatures when the heat pump systems are less efficient, or for when heating with backup heating systems and fuels is cheaper than operating the heat pump.[8]
- From survey responses, about 80% percent of customers with PD installations cite that they have additional heating sources in their home, and for those with backup heat, about 80% report using the backup heating systems over the winter period. Some PD customers indicate backup heat usage in parts of the home that their heat pump(s) do not serve.
- For PD installations, analysis of metered data suggests that the heat pump meets about 65% of the homes heating load over the winter for sites with CHPs, and 79% with MSHPs, while backup heating systems meet the remaining load. This could be due to differing use of integrated controls and switchover temperatures across these system types.
- According to survey responses, PD customers were motivated to use backup heat because they were concerned about the costs of heating with their heat pump, their integrated controller was set to automatically switch over, or their backup heat serves parts of their home that their heat pump does not.
- The study found a wide variability in heat pump usage between sites, even when normalizing usage per ton of installed heat pump cooling capacity.[9] The study found that about 10% of PD installations rarely used their heat pumps for heating (less than ~100 kWh per ton of installed capacity).

[7] For additional information on customer experience, see Section 5.

[8] In Massachusetts, PD sites include customers who either fully displaced part of their home (i.e., one zone) or partial displacement of their full home.

[9] Mass Save and Energize CT provide incentives and also track program participation on the basis of installed rated cooling capacity.

- For PD installations, most customers indicate that an IC was installed by their contractor, however, most also report not knowing their IC switchover temperature. After two to three heating seasons of operation, about half of all customers with PD installations report still using their IC to auto-switch system operation, and review of onsite metered data showed about 70% of PD sites with CHPs and 20% of PD sites with MSHPs had a consistent switchover temperature throughout the metered period. 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.[10]

Use of Auxiliary Heating

- About 33% of CHP installations and 82% of GSHP installations had auxiliary heating installed. About 75% of CHP installations with auxiliary heat installed used their auxiliary heat over the metered period, while only 1 out of 18 GSHP sites with auxiliary heat installed used their auxiliary heat.

Peak Demand

- Average peak demand was significantly higher for CHP FD sites relative to MSHP or GSHP due to the additional usage of integrated auxiliary electric heat for CHP installations. Typical year maximum (non-coincident) peak demand was 1.9 kW/ton for CHP FD, 1.0 kW/ton for MSHP FD, and 0.8 kW/ton for GSHP FD.

- Peak demand of auxiliary electric heat in CHPs is also higher on the coldest days. For CHP FD sites that removed or disconnected backup heating sources, metered peak demand on the coldest day of 2023 (February 4th, with outdoor air temperatures down to -10°F) was 8 kW, roughly 3 times as high as the peak demand for the same sites on the coldest day during 2024 (January 20th, with outdoor air temperatures down to 12°F).

Overall Heat Pump Performance

The study also sought to understand the in-situ efficiency of heat pumps, including efficiency of heat pumps across outdoor air temperatures.

Average Compressor-On COPs

- While the heat pumps are in heating mode during compressor-on operation,[11] average COPs for CHP and MSHP equipment were between 2.0 and 3.0 across the outdoor air temperature range, and for GSHP equipment, consistently slightly above 3.0. During cooling season, average compressor-on COPs were between 3.5 and 6.0 for CHP and MSHP equipment across the outdoor air temperature range, and 4.0 for GSHP equipment. Figure ES-1 shows the average COPs as a function of outdoor air

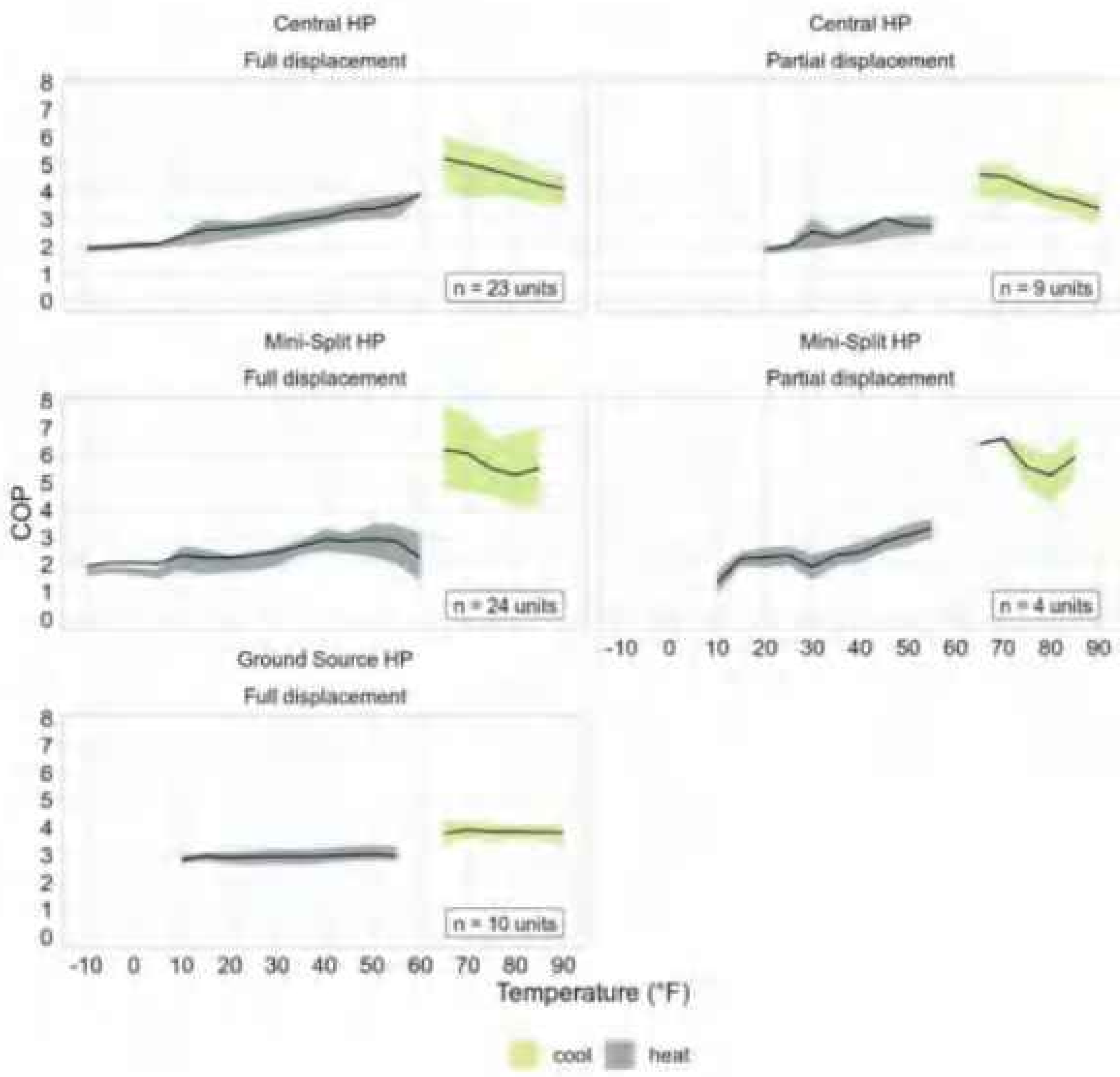
[10] Droop control utilizes different temperature setpoints on two or more thermostats. Typically, the thermostat controlling the heat pump(s) is set to a higher temperature (e.g., 67°F) than the thermostat controlling the backup heating system (e.g., 62°F). The backup heating system will turn on if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

[11] Compressor-on operation does not include periods of time where the unit is in defrost mode, when the unit is operating in fan-only mode, or the unit is 'off'. Seasonal efficiencies for CHPs and MSHPs include all of these operating modes, which has a negative impact on the efficiency value. GSHPs do not need a defrost mode, so their seasonal efficiencies are impacted less.

temperature for periods in which the unit was operating in heating or cooling modes. COPs varied as a function of outdoor air temperature for CHP and MSHP equipment; GSHPs as expected had a consistent COP across the heating season because the temperature of the groundwater is more stable across the season, and also likely due to the fact that GSHP equipment do not require defrost cycles.

- For sites with heat pumps operating in compressor-on mode below 5°F, average central and mini-split heat pump system level COP varied between 1.6 and 2.3, with an average around 2.0.[12]

Figure ES-1. Heat Pump COP vs. Outdoor Air Temperature



Note: This plot shows compressor-on operation from the metering period and is not weather normalized. Auxiliary heat is not included in this figure.

Source: Evaluation team analysis

[12] Twenty sites, 15 MSHP and 5 CHP, had meters transmitting data during the two-day cold spell in February 2023.

Seasonal Performance Metrics

- The study also sought to understand the seasonal efficiency of heat pump systems across all heat pump modes, and accounting for the total energy produced (delivered by the systems) and consumed by the heat pumps over the season.
- For CHPs, the in-site HSPF was generally lower than the manufacturer rated HSPF, but equal to or higher than the HSPF2. For MSHPs, the in-site HSPF was lower than both rated HSPF and HSPF2 ratings. GSHP in-site HSPF was higher than both CHP and MSHP equipment, however, SEER was lower. Across heat pump types and displacement designations, the modeled seasonal energy efficiency ratio (SEER) in cooling season was lower than both the SEER and SEER2 rated values. For additional details see Section 3.5.

Customer Experience with Heat Pumps

The study also sought to understand customer experience with their heat pumps. Overall, 95% of surveyed customers said they would install a heat pump again if they were to go back in time.

Cost of Operation

- Most customers were satisfied with the cost of operating their heat pump, although 29% of respondents claimed that higher energy costs impacted how they ran their heat pumps. Among respondents who changed their heat pump operation based on cost, one third used their backup systems more, either manually or by increasing the switchover temperature on their integrated controller. Two thirds lowered their thermostat setpoints or only heated certain rooms. One respondent avoided using their heat pump entirely in favor of their prior heating system.[13]
- Most customers indicate that heating costs were about what they expected, although about 30% of FD installations and 50% of PD installations indicate that costs were higher than they expected.[14,15,16]

[13] It is evident from many responses that customers do not always distinguish heat-pump use from auxiliary resistance heating, and sometimes lump the two together in their assessments of heat pump performance and costs.

[14] The survey used to inform this finding (Winter 2024 End of Season Survey) was fielded in February 2024. Metering was conducted at all respondents' homes during Winter 2023-2024 and at a subset of homes from Winter 2022-2023. See Section 2.3 for additional details on the End of Season Survey methodology.

[15] Average Massachusetts residential electric rates rose from $0.27/kWh in Winter 2021-2022 to $0.43/kWh in Winter 2022-2023, then dropped to an estimated $0.33/kWh in Winter 2023-2024. "Massachusetts Household Heating Costs", Massachusetts Department of Energy Resources, https://www.mass.gov/info-details/massachusetts-household-heating-costs

[16] Average Connecticut residential electric rates rose from $0.24/kWh - $0.25/kWh in Winter 2021-2022 to $0.32/kWh - $0.34/kWh in Winter 2022-2023, then dropped to $0.28/kWh - $0.33/kWh in Winter 2023-2024. " Energy Price and Supply Information", https://portal.ct.gov/deep/energy/energy-price-and-supply-information

Maintenance Issues

- Most customers report that they did not experience maintenance issues with their heat pump. Of the 9% of CHP and 19% of MSHP[17] customers that indicated a maintenance issue, the reported issues generally fall under these categories:
    - Condensate issues (3%) – This includes condensate build up around the inside of the unit, heavy condensate dripping, overflowing condensate due to poorly installed drains, and poor installation of condensate piping.
    - Circuit board issues (2%) – This includes circuit board issues which caused the unit to not operate. Some examples include an electricity outage which damaged the control panel, and a circuit board which shorted with no known reason, though the customer thinks it might have been a rodent issue. Customers cited long wait times to get replacement parts.
    - Refrigerant leaks (2%) – This occurred more frequently with MSHP units compared to CHPs. A majority of customers reported that they only needed to repair it one time, and that the contractor did it at no charge.
    - Other reported issues include: the inside heat pump vanes staying closed, 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.

Cold Period Performance

- During the Winter 2023-2024 period, about 90% of surveyed FD customers responded "satisfied" with their heat pump's ability to meet the heating needs of their space. During colder periods, this dropped to about 70-80% of customers.[18]

Heat Pump Impacts

Table ES-2 provides the overall annual measure impacts per ton of installed heat pump cooling capacity, including both electric impacts (kWh), and fuel impacts (MMBtu). These impacts are broken out by heat pump type and displacement type, along with the pre-existing heating fuel type. The table includes a comparison of the ex ante and ex post measure impacts for the heat pump types, displacement types, and pre-existing fuel types evaluated in both studies. The table includes the ex ante measure impacts for the 2021 and 2024 program years; the prior study assumed lower average switchover temperatures for partial displacement projects with pre-existing oil and propane heating fuels in the 2022 through 2024 program years, which results in a higher portion of the heating load met by the heat pump, and higher overall MMBtu measure impacts.

[17] Only 1 of 20 GSHP respondents indicated maintenance issues.

[18] As previously noted, customers do not always distinguish heat-pump use from auxiliary resistance heating, and sometimes lump the two together in their assessments of heat pump performance and overall satisfaction.

The table also includes ex post measure impacts for two different measure impacts scenarios evaluated in this study. The first scenario includes weights for all baseline heating types and also includes all metered sample in the Full Displacement category, based on the program data designations of displacement type. The alternative scenario removes heat pumps from the baseline weights, and only includes post-retrofit usage for Full Displacement installations that were verified as having removed or disconnected the backup heating systems.[19,20]

Section 6 provides the full writeup of measure impacts results and includes a summary of the average installed tonnage per site. Site with GSHPs had the highest installed tonnage compared to other system types. Therefore, average measure impacts "per home" are highest for GSHP installations.

Overall, MMBtu measure impacts are lower than ex ante assumptions, however kWh impacts are "less negative" for many of the equipment and fuel types. The ex ante measure impact assumptions are sourced from the Massachusetts Energy Optimization Fuel Displacement study (completed in 2021).[21] Main drivers for these differences include the fact that current study post-retrofit heat pump usage is generally lower than the prior study for FD installations. The prior Fuel Displacement study assumed that FD heat pump installations met the full heating loads of the home with the installed heat pumps. The current heat pump metering study aggregated actual heat pump usage data for a sample of sites in the Full Sample scenario. The results of this analysis showed that many of the installations categorized as FD were partially relying on other heating systems or auxiliary heat to meet portions of the heating load of the home. In addition, for both scenarios, the current study generally assumes higher existing and new unit efficiencies for baseline fuel-fired heating equipment types. All else equal, higher baseline unit efficiencies lower the baseline MMBtu heating equipment usage, lowering overall MMBtu measure impacts. The current study also has differing usage of backup heating systems and proportions of customers using integrated controls and switchover temperatures as compared to the prior study for Partial Displacement installations.

[19] The metered sample for this study includes heat pump installations during the 2021 and 2022 program years (predominantly 2022 program year). Given changes in program design during subsequent program years, the ex post impacts for the Partial Displacement case may be most comparable to the 2021 ex ante assumption, and are not directly comparable to the switchover temperature assumptions in the 2024 ex ante assumption.

[20] The alternative scenario may more closely reflect the current program design in Massachusetts, as the program currently requires customers to remove or disconnect their backup heating systems for Full Displacement projects. However, assumptions for baseline weights should be adjusted based on future program design considerations and any changes to approach for gross baseline assignment assumptions. A summary of baseline weights for the alternative scenario (no heat pump baseline), is included in Section 2.5.5.

[21] Guidehouse (2021). "Energy Optimization Fuel Displacement Impact and Process Study." Provided to the Electric and Gas Program Administrators of Massachusetts. https://ma-eeac.org/wp-content/uploads/MA20R24-B-EOEval_Fuel-Displacement-Report_2021-10-13_Final.pdf. Connecticut references the deemed measure impacts from the 2021 MA Energy Optimization Fuel Displacement report in the current CT Program Savings Document (PSD) for these measures.

Table ES-2. Annual Heating and Cooling Energy Impacts – Ex Ante vs. Ex Post (Per Ton)

Heat Pump and Displacement Type	Pre-Existing Fuel	Ex Ante kWh Electric Savings (2021)	Ex Ante kWh Electric Savings (2024)	Ex Post kWh Electric Savings (All Baselines, Full Sample)	Ex Post kWh Electric Savings (No HP Baseline, FD Remove/ Disconnect)	Ex Ante MMBtu Fuel Savings (2021)	Ex Ante MMBtu Fuel Savings (2024)	Ex Post MMBtu Fuel Savings (All Baselines, Full Sample	Ex Post MMBtu Fuel Savings (No HP Baseline, FD Remove/ Disconnect)
Central Heat Pump – FD	Electric	-	-	32	-44	-	-	7.9	11.4
	Natural Gas	-	-	-1,223	-1,341	-	-	14.3	15.7
	Oil	-1,795	-1,795	-1,269	-1,343	17.9	17.9	15.6	16.6
	Propane	-1,795	-1,795	-1,279	-1,333	17.9	17.9	14.6	15.3
Central Heat Pump – PD	Electric	-	-	-23	-63	-	-	5.2	7.6
	Natural Gas	-	-	-829	-933	-	-	9.3	10.5
	Oil	-795	-900	-857	-933	11.1	12.7	10.2	11.1
	Propane	-795	-1,390	-864	-928	11.6	17.9	9.5	10.2
Mini-Split Heat Pump – FD	Electric	2,316	2,316	1,101	1,126	3.8	3.6	6.5	6.2
	Natural Gas	-	-	-1,199	-1,028	-	-	15.6	14.4
	Oil	-1,508	-1,508	-1,417	-1,225	17.8	17.8	17.2	15.8
	Propane	-1,508	-1,508	-1,133	-1,016	17.8	17.8	15.6	15.2
Mini-Split Heat Pump – PD	Electric	-	-	1,076	1,141	-	-	5.7	6.1
	Natural Gas	-	-	-921	-961	-	-	13.5	14.0
	Oil	-957	-994	-1,111	-1,153	15.0	15.8	14.9	15.4
	Propane	-957	-1,264	-864	-949	14.8	19.0	13.5	14.8
Ground Source Heat Pump – FD	Electric	-	-	-538	-1,011	-	-	8.9	13.9
	Natural Gas	-	-	-572	-1,006	-	-	8	13.4
	Oil	-	-	-574	-1,009	-	-	8.6	14.4
	Propane	-	-	-575	-1,011	-	-	8.1	13.6

Source: Evaluation team analysis

Table ES3 and Table ES4 provide heat pump savings parameter estimates to be used in conjunction with measure savings algorithms in the Connecticut Program Savings Document (PSD). Table ES includes a definition of the parameters, and Table ES provides the parameter values. Section 6.2 provides further detail on the methods used to calculate these values.

Table ES-3. PSD Variables and Descriptions

PSD Variable	Description	Units
$F_{adj,q,c}$	In-situ cooling efficiency adjustment factor of installed unit	N/A
$F_{adj,q,h}$	In-situ heating efficiency adjustment factor of installed unit	N/A
F_{load}	PD Factor to account for the portion of heating load met by the heat pump	N/A
$EFLH_c$	Equivalent Full Load Hours of operation for the average unit during the cooling season	Hours
$EFLH_h$	Equivalent Full Load Hours of operation for the average unit during the heating season	Hours

Source: Evaluation team analysis

Table ES-4. PSD Variable Results

Heat Pump Type	Displacement Category	$EFLH_h$	$EFLH_c$	$F_{adj,h}$	$F_{adj,c}$	F_{load}
CHP	FD	1,397	544	1.03	0.86	0.90
CHP	PD	825	509	1.00	0.81	0.66
MSHP	FD	1,275	499	0.91	0.92	0.91
MSHP	PD	1,025	484	0.95	0.93	0.79
GSHP	FD	1,998	470	0.71	0.59	0.99

Source: Evaluation team analysis

Considerations

Based on the study findings, below are considerations for the utilities and program administrators offering fuel displacement rebates for heat pumps.

C1. Enhance program requirements to more clearly identify criteria for Full Displacement and Partial Displacement installations.

The participants in this study had their heat pumps installed in 2021 or 2022 (majority of installations were in 2022). During this time period, the Mass Save and Energize CT heat pump offerings did not fully require the participant to remove or disconnect backup heating sources, rather, the systems were allowed to stay in as emergency backup heat. Many of the customers used these old units for backup heat to meet part of the heating load, however analysis of metered data for program participants during this time period shows that about 85-90% of the homes heating load was met by the heat pump for both CHP and MSHP Full Displacement installations, and almost 100% for GSHP installations.

In 2024, the sponsors of Mass Save require the removal or disconnection of backup heating systems for a Full Displacement rebate, which should help to minimize the use of backup heating sources in FD installations.

The current program guidelines and Qualified Product Lists (QPLs) also enforce higher thresholds for heat pump maintenance capacities (Btu delivered capacity of the unit at 17°F and 5°F relative to the rated capacity at 47°F) and efficiencies at lower outdoor air temperatures, relative to the minimum requirements in place in 2021 and 2022.

Below are considerations to enhance program guidelines if the program intends for FD installations to maximize the usage of the heat pump and minimize the use of backup heat or auxiliary electric heat:

Full Displacement program qualifications could be further enhanced by:

- Ensure that program criteria make it clear that, for whole home heat pump designations, the newly installed heat pump(s) must serve all of the regularly occupied areas of the home.
- The Sponsors of Mass Save currently require that contractors size the heat pump(s) to meet the full heating load of the entire home per ACAA Manual J Design Conditions, however this documentation is only required upon request. Consider further clarifying the design temperatures and sizing thresholds contractors must use to ensure the heat pump can meet the heating loads of the home down to the lowest outdoor air temperatures. Further clarify whether the capacity requirements are solely for heat pump compressor operation, or for the heat pump and any installed auxiliary electric heat.
- If a customer has an existing heat pump (non-rebated or previously rebated) that will remain installed to serve part of the home, consider if the program intends to allow these homes to qualify as Full Displacement.
- Develop or further enhance random onsite verification of installed heat pump units. For sampled sites, request the Manual J, and during these verification visits, verify the inputs and the load calculations. Ensure that the heat pump(s) serve the intended areas of the homes and that the model specifications and capacity of the heat pump(s) can reasonably meet the heating loads of the home or zones that are intended to heat. Ensure contractors and customers are aware that random verification visits may occur at the premise.
- Update rebate structure to align with heating capacity rather than cooling capacity.

C2. Give additional guidance to installers on switchover temperatures and heat pump sizing.

- Continue to provide and improve criteria and guidance to contractors on what switchover temperature to size the heat pump for, and what switchover temperature to program for Partial Displacement systems. Consider setting maximum switchover temperature(s), so that heat pumps are meeting more of the winter period load.[22]

C3. Consider adjustments to program requirements for integrated controls, especially for MSHPs.

- Installation of integrated controls was a program requirement in 2021/2022 and remain in place in 2024 (MA). Even so, less than half of MSHP installations showed consistent switchover temperatures across the metered period. Many MSHPs are installed to serve spaces not served by a backup system. Integrated controls can and should continue to be required and used in cases where they make sense (CHP installations, MSHP installations where the zoning of MSHP and backup heating systems are aligned, where the IC products work well for the installed systems, and for which the customer is willing to use them). The droop control method may also be a good option for installations that are not a good fit for integrated controls or for which the customer is not willing to use them, however zoning of the heat pumps and backups systems may still be a consideration.

C4. Provide customers with additional education on how installing a heat pump will impact their electricity bill.

- For customers who were dissatisfied with their electricity bill, a common theme was frustration that they did not understand how much a heat pump could impact their electrical bill. Consider providing additional education and tools on how a switch to a heat pump could impact customer's bill, especially if their pre-existing system is not electric. Both Mass Save and Energize CT websites host heating and cooling cost comparison calculators to compare the operational costs of different HVAC systems.[23] These tools can further be promoted to customers and contractors to assist in these cost estimations, especially for potential FD applications.

- Share the customer experience findings of this study with the heat pump installer networks for awareness of maintenance issues that tend to occur in these types of heat pump installations. Consider enhancing quality control checklists for any verification visits, and checking for potential maintenance items such as condensate or refrigerant charge issues.

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[22] Mass Save currently has maximum switchover temperatures based on backup heating fuel type. Energize CT could consider similar program guidelines.

[23] Mass Save calculator: https://www.masssave.com/residential/heating-comparison-calculator
Energize CT calculator:
https://tools.efficiencyestimator.com/ct/renewableheatingcoolingtechnologiesroicalculator/home

C5. Conduct a heat pump technical assessment periodically to inform program requirements.

- Heat pump technology is evolving rapidly, with new product entering the market every year with higher reported efficiency, maintenance capacity (Btu delivered capacity of the unit at 17°F and 5°F relative to the rated capacity at 47°F) at lower outdoor air temperatures, controls, and other features. The Massachusetts Program Administrators and Connecticut utilitiesutilities could conduct periodic review of the product available in the market and their technical specifications and unit prices to inform potential updates to minimum program requirements including heat pump efficiencies and capacity ratios.

C6. Update deemed savings estimates and parameters in the Massachusetts Technical Reference Manual and the Connecticut Program Savings Documents.

- The Massachusetts Program Administrators and Connecticut utilities should update measure savings assumptions using the deemed savings and parameter estimates developed through this study. Measure impacts are provided in Section 6 for two scenarios – 1) using the full metered sample in this study aligned with the program data displacement designations, and 2) subset down to Full Displacement sites that removed or disconnected their backup heating system, with heat pump unit types removed from the baseline weights. The Massachusetts Program Administrators and Connecticut utilities should use the measure impacts that more closely aligns with prospective program requirements in the respective states.

1. Introduction

This comprehensive report, developed for the Massachusetts Program Administrators (PAs), Massachusetts Energy Efficiency Advisory Council Evaluation, Measurement and Verification consultants (EEAC consultants), and the CT Evaluation Administrator (EA) team, describes the Guidehouse team's findings and results for the Heat Pump Metering Study (HPMS), conducted in the states of Massachusetts and Connecticut.

This report provides an overview of the programs, study goals, and evaluation activities in Section 1. Detailed methodology is provided in Section 2. Results for the study are provided in Section 3 (heat pump performance), Section 4 (heat pump and backup system usage), Section 5 (customer experience), and Section 6 (measure impacts). Section 7 describes lessons learned and ideas for future studies. Appendix A details measure impact results for additional scenarios. Appendix B provides the customer and interview guides. Appendix C provides select responses to the customer surveys not provided in the report body.

1.1 Relevance

Both Massachusetts and Connecticut have heat electrification goals. In Massachusetts, the emission reduction goal is 80% below 1990 emissions levels by 2050[24]. The state's climate plan calls for electrifying 26% of households by 2025 and 38% by 2030[25]. This translates to about 100,000 heat pumps installed by 2025 and 500,000 by 2030[26]. In Connecticut, the climate goals are to reduce statewide emissions 45% by 2030 and 80% by 2050, relative to a 2001 baseline[27], which would also require many homes to also electrify. The heat pump fuel displacement program offerings through Mass Save and Energize CT are aligned with these goals.

1.2 Program Description

Both the Sponsors of Mass Save and the Sponsors of Energize CT have continued efforts to encourage homeowners to meet more or all of their home heating needs with heat pumps, especially for customers with pre-existing heating systems that are carbon intensive, such as electric resistance heat, or furnaces or boilers that heat with natural gas, fuel oil, or propane. Both states have introduced fuel displacement rebates/incentives to encourage the adoption of heat pumps for customers with these pre-existing heating types. In addition, the broader market has seen a greater penetration of heat pumps targeted toward cold climates (cold climate heat pumps) and, in the past few years, has seen customer usage behavior change as a result of the COVID-19 pandemic. The Massachusetts PAs and Connecticut EA Team commissioned this study to learn about current usage patterns for heat pumps and other heating equipment, electric peak demands for heat pumps, the performance and efficiency of heat pumps, and the

[24] "Clean Energy and Climate Plan for 2025 and 2030", Massachusetts Executive Office of Energy and Environmental Affair, https://www.mass.gov/info-details/massachusetts-clean-energy-and-climate-plan-for-2025-and-2030#clean-energy-and-climate-plan-for-2025-and-2030-

[25] "Appendices to the Clean Energy and Climate Plan for 2025 and 2030Massachusetts Executive Office of Energy and Environmental Affair, https://www.mass.gov/info-details/massachusetts-clean-energy-and-climate-plan-for-2025-and-2030#clean-energy-and-climate-plan-for-2025-and-2030-

[26] "Massachusetts Climate Report Card - Buildings Decarbonization", Massachusetts Office of Climate Innovation and Resilience, https://www.mass.gov/info-details/massachusetts-climate-report-card-buildings-decarbonization

[27] "Public Act No. 18-82", Connecticut Department of Energy & Environmental Protection, https://www.cga.ct.gov/2018/act/pa/pdf/2018PA-00082-R00SB-00007-PA.pdf

ability of heat pumps to meet customer's full heating needs down to low outdoor air temperatures.
Two displacement scenarios are possible through the fuel displacement program offerings: full displacement and partial displacement:

- **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.[28] 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 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 fuel oil, propane, or gas heating systems are only 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. Partial displacement also includes portions of homes where the heat pump fully or partially displaces the existing heating system.

Both the Mass Save and Energize CT programs have changed requirements each program year. Below summarizes these requirements:

- **2021 Mass Save:** Integrated controls are required unless the central heating system is removed. Rebated amount of $1,250 per ton.
- **2022 Mass Save:** Rebate eligibility added for customers with pre-existing natural gas heating systems. Rebate is split into whole-home and partial-home rebates. Customers could receive a $500 bonus when moving forward with weatherization recommendations made during a Home Energy Assessment prior to installing the heat pump (this incentive was also added for Energize CT).
    - **Whole-home rebate:** Heat pump must be used as the sole source of heating during the heating season. Rebated amount of $10,000 per home[29] for air source heat pumps and $15,000 for ground source heat pumps. Projects may include backup or supplemental heat from non-fossil fuel sources, such as a wood or pellet stove or electric baseboard (resistance) heat, including spaces that are difficult to serve with air source heat pumps such as bathrooms.

    - Project must include either the removal or disconnection of the pre-existing heating system or the homeowner must agree to not use the pre-existing system unless there is an emergency. The pre-existing system can remain in place and operate only if it is used for domestic hot water heating. Homes must also be occupied full time during the winter heating season. Homes must be sufficiently weatherized prior to heat pump installation.

[28] Starting in 2024, Mass Save requires customers to verify the removal of the pre-existing heating system or ensure that it is disconnected at the electric panel or thermostat.

[29] Moderate income customers, in Massachusetts, may receive a heat pump rebate up to $25,000 per home in 2024.

- **Partial-home rebate:** Heat pump must be used to supplement pre-existing heating system during the heating system. If the pre-existing heating system is oil, natural gas, or propane, integrated controls must be installed. Rebated amount of $1,250 per ton, up to $10,000 per home for air source heat pumps, $2,000 per ton, up to $15,000 for ground source heat pumps.

- **2022 and 2023 Energize CT:** In 2022, Energize CT did not include a distinct differentiation between whole-home or partial-home rebated amounts. Both receive a rebate of $1,000 per ton. There was no requirement to remove or disconnect existing system, but if the system is left in place, an integrated control must be installed for all heating zones where the existing system will remain in use.

1.3 Study Goals and Research Objectives

The primary goals of this study were to:

- Perform field monitoring to assess the actual heating and cooling performance and usage of the latest generation of residential heat pumps being supported by the programs.
- Perform field monitoring of baseline HVAC technologies as available and appropriate and estimate baseline HVAC consumption across all fuel categories.
- Analyze and quantify gross baselines for residential heat pumps to derive gross measure impacts.

This study will provide the Massachusetts PAs and Connecticut EA team with combined results for typical performance curves, load shapes, and de-rate factors for central heat pump (CHP), mini-split heat pump (MSHP), and ground source heat pump (GSHP) installations in Massachusetts and Connecticut, typical electric consumption of heat pump equipment in heating and cooling seasons, and measure impacts that represent the range of heat pump installations through the existing homes heat pump program offerings.

The primary research questions are:

1. Heat Pump Performance and Capacity
   - What is the measured efficiency of installed heat pump systems?
   - What is the difference between rated and operational (in situ) performance of heat pump systems?
   - What is the performance and delivered heat of heat pumps down to low outdoor air temperatures?
2. Heat Pump Usage and Peak Demand
   - What is the usage and peak demand of heat pumps in Massachusetts and Connecticut (combined result) during both heating and cooling seasons?
3. Backup and Auxiliary System Usage and Control
   - How are customers using their equipment and does this align with the intended operation (e.g., switchover temperature, heat pump "always on", or manually turned on or off).

- For PD and FD systems, under what conditions are backup systems and auxiliary heating being used?
- What is the primary driver for the backup systems or auxiliary heating being used?
- What improvements could be made to optimize the displacement fraction for FD and PD installations?
- What fraction of total load across the cooling and heating season is being met by the heat pump? What causes homes to have a higher or lower fraction?
- For PD systems, what type of control sequences (i.e., integrated controls, other controls) are employed, and what settings and setpoints are contractors or customers programming?

4. Customer Experience
   - For FD installations, can installed heat pumps keep the customers comfortable during the coldest days?
5. Measure Impacts
   - What is the overall electric, gas, and delivered fuel consumption change due to central heat pump and mini-split heat pump installation for partial and full-displacement of existing oil, propane, gas, and electric resistance baseboard heating systems? Output from this study will inform the Massachusetts Technical Reference Manual (TRM) and Connecticut Program Savings Document (PSD).
   - What are the distributions of gross baseline heating and cooling systems for fuel displacement measure installations? The gross baseline is the heating and cooling equipment the customer would have installed if they didn't install the heat pump they did.

1.4 Summary of Evaluation Activities

Table 1-1 details the activities included in the Heat Pump Metering Study along with their rationale. These tasks were completed over the course of the study.

Table 1-1. Summary of Activities

Activity	Rationale
Program Data Request and Sampling	Gather Massachusetts and Connecticut Heat Pump program data. Determine number of sample points and strata for statistically significant results.
Customer Surveys and Interview	Collect information about use of heat pumps, home characteristics, and collect interest for metering study. For fast feedback interviews and end-of-season survey, collect feedback on whether customers were comfortable during winter peak period, and how they used their HVAC systems.
Field Visits and Equipment Monitoring	Perform spot measurements and collect home characteristic data. Install long term metering equipment for monitoring period. This was done in two waves, with Wave 1 sites installed in November 2023, and Wave 2 sites installed between April and August 2024.

Activity	Rationale
Survey and Metered Data Analysis	Analyze post-retrofit metered data to determine usage, efficiency, and heating/cooling loads for heat pump system installations. Determine usage of both heat pumps and backup HVAC systems for use in impact analysis.
Determine Measure Impacts	Use regression and engineering models to determine weather-normalized post-retrofit HVAC usage, baseline usage, and determine measure impacts.
Reporting	Develop four stages of report deliverables including: 1. Interim PPT including performance and usage findings for Wave 1 sites 2. Interim measure impact results 3. Draft report including draft results, conclusions, and recommendations 4. Final impact results 5. Final report with final results, conclusions, and recommendations

Source: Evaluation team analysis

1.5 Terminology

Throughout this report, the research results are referenced with various terminology:

- **Backup System** – (aka secondary system) used to refer to separate conditioning systems independent from the heat pump (boiler, furnace, wood stove, baseboard heating, space heater, window AC unit, central AC)
- **Auxiliary Heating** – (aka supplemental heating) integrated electric resistance heating in the heat pump system. Operates when compressor can no longer deliver heat. Typically found in the air handlers of central and ground source heat pump installations.
- **Compressor Heating** – heat pump compressor itself is delivering heat.

1.6 Abbreviations

Throughout this report, several abbreviations are referenced. Terms are defined as follows and on first use in the text.

- **Btu**: British thermal units
- **CHP**: Central heat pump
- **COP**: Coefficient of Performance
- **DHW**: Domestic hot water
- **EEAC**: Energy Efficiency Advisory Council
- **EER/EER2**: Energy efficiency ratio
- **EFLH**: Equivalent full load hours
- **FD:** Full displacement
- **GSHP**: Ground source heat pump

- **HPMS**: Heat pump metering study
- **HSPF/HSPF2**: Heating seasonal performance factor
- **HVAC**: Heating, ventilation, and air conditioning
- **IQR**: Inter-quartile range
- **ISO**: Independent System Operator
- **kBtu**: One thousand British thermal units
- **kW**: Kilowatt
- **kWh**: Kilowatt-hour
- **MMBtu**: One million British thermal units
- **MSHP**: Mini-split heat pump
- **PA**: Program Administrator
- **PD:** Partial displacement
- **PSD**: Program Savings Document
- **QC:** Quality Control
- **SEER/SEER2**: Seasonal energy efficiency ratio
- **TRM**: Technical Reference Manual

2. Methodology

The following section outlines the methodological approaches used in this study. The program data for heat pump fuel displacement participants was first requested and then used to pull samples of projects to field the customer survey. The customer survey collected characteristics of the customer homes, HVAC equipment and usage, and other feedback on the equipment. The customer survey also served as a basis from which to recruit participants into the metering portion of the analysis. Data loggers were installed to collect usage and performance for heat pumps and backup heating systems at a sample of customer homes. The data collection period extended for one to two winters and for one summer, depending on the installation date for each metered site. The data collection onsite was used to calculate annual consumption and peak demand of heat pumps and to understand the usage of backup heating systems. Measure impacts results were calculated by modeling the baseline HVAC equipment usage and subtracting the usage of the installed heat pump equipment.

2.1 Program Data Request and Review

A request was submitted (Wave 1) to DNV in August 2022 for Massachusetts program data, covering Heat Pump Fuel Displacement measure records for all of 2021 and the portion available from 2022. In response to the Wave 1 request, DNV provided program data for all 2021 participants and the portion of 2022 participants that had been logged as of August 2022. Table 2-1 shows the number of unique single-family and multi-family customers from the program datasets for each of the major measure categories.

Table 2-1. Wave 1 Population Size (Massachusetts Only)

Building Type	System Type	Displacement Scenario	Wave 1 Massachusetts Program Data Population
Single Family (Detached and Attached)	Mini-Split Heat Pump	FD	522
		PD	2,969
	Central Heat Pump	FD	162
		PD	1,455
	Ground Source Heat Pump	FD	11
Multi-Family (5+ units)	Mini-Split Heat Pump	FD	2
Total			**5,121**

Source: Evaluation team analysis

DNV later provided a full year 2022 dataset (Wave 2), sent to the evaluation team in February 2023. Table 2-2 shows the number of additional 2022 participants in this dataset.

Table 2-2. Wave 2 Population Size (Massachusetts)

Building Type	System Type	Displacement Scenario	Wave 2 Massachusetts Program Data Population
Single Family (Detached and Attached)	Mini-Split Heat Pump	FD	2,201
		PD	2,399
	Central Heat Pump	FD	716
		PD	1,971
	Ground Source Heat Pump	FD	22
Multi-Family (5+ units)	Mini-Split Heat Pump	FD	7
Total			**7,316**

Source: Evaluation team analysis

The evaluation team sent a program data request to Eversource and United Illuminating in January 2023, requesting all 2021 and 2022 heat pump fuel displacement program data. Eversource sent the program data in January 2023 and United Illuminating sent the final program data in March 2023. Table 2-3 shows the number of participants in these datasets.

Table 2-3. Wave 2 Population Size (Connecticut)

Building Type*	System Type	Displacement Scenario	2021 ES Pop. Size	2022 ES Pop. Size	2021-2022 UI Pop. Size^
Single Family (Detached and Attached)	Mini-Split Heat Pump	FD	118	222	3
		PD	3	144	17
	Central Heat Pump	FD	38	80	6
		PD	23	176	11
	Ground Source Heat Pump	FD	109	173	0
Multi-Family (5+ units)	Mini-Split Heat Pump	FD	1	5	0
Total			**292**	**800**	**36**

For the purposes of this table ES = Eversource (CT) and UI = United Illuminating (CT). Pop. = Population
*Assumed based on Massachusetts data, as building type was largely unknown in Connecticut data
**4 'null' heat pump types

Source: Evaluation team analysis

2.2 Customer Surveys and Interviews

Guidehouse fielded three surveys (Wave 1, Wave 2, and End of Season) and one customer interview effort during the study. Table 2-4 shows a brief description for each of the outreach methods and the associated timeline. Appendix B includes the full survey guides.

Table 2-4. Description of Customer Surveys/Interviews and Timelines

Outreach Type	Description of Effort	Outreach Fielding Launch
Primary Survey: Wave 1 # of Responses: 825 Response Rate: 20% Outreach Group: 2021 + partial year 2022 participants (Massachusetts only)	Comprehensive survey sent to 2021 and 2022 Massachusetts program participants to recruit participants to the metering portion of the study, determine the baseline HVAC systems, assess experience with their heat pump(s), and understand behavior at a high level.	October 2022
Fast Feedback Interviews # of Interviews: 13 Response Rate: 52% Outreach Group: FD participants at Massachusetts sites recruited during W1 survey (n = 25)	Interviews conducted with the homeowners at FD sites enrolled in the Wave 1 portion of the metering study. The conversation took place directly after the New England cold snap in February 2023 (where temperatures reached as low as -13°F). Conversations focused on heat pump performance and use of backup systems in extremely cold temperatures.	February 2023
Primary Survey: Wave 2 # of Responses: 644 Response Rate: 28% Outreach Group: Sample of full year 2022 participants (Massachusetts and Connecticut) and select 2021 participants (Connecticut)	Comprehensive survey sent to 2022 program participants in both Massachusetts and Connecticut. Again, this survey was designed to recruit participants to the metering portion of the study, determine the baseline HVAC systems, assess experience with their heat pump(s), and understand behavior at a high-level.	March 2023
End of Season Survey # of Responses: 136 Response Rate: 74% Outreach Group: All metering study participants (Massachusetts and Connecticut)	Survey fielded to all participants in the metering study, with a focus on understanding how participants are using their heat pump(s) and any additional heating source(s) during the winter and cold periods. In addition to behavior, the survey also captured comfort and satisfaction.	February 2024

Source: Evaluation team analysis

The following subsections describe the methodological approaches for conducting the primary customer surveys (Wave 1 and Wave 2 surveys), end of season survey, and fast feedback interviews. In addition to data collection, customer surveys were used to recruit participants for the onsite metering study, as well as to also understand customer HVAC usage characteristics, building characteristics, and to inform gross baseline weighting.

2.2.1 Primary Customer Survey

Customers were recruited using the data from the 2021 and 2022 program years and fielded two primary surveys, the first to collect building and usage characteristics, and the second was to evaluate customer eligibility and gauge interest in the follow-up metering study. The first primary survey (Wave 1) was fielded in fall 2022 using the full 2021 year and the January through August 2022 Massachusetts program participants and was used to recruit customers into the Wave 1 meter installations in fall 2022 through winter 2022/2023. The second primary survey (Wave 2) was launched using the remainder of the full 2022 program participants for Massachusetts and the full 2021 and 2022 program data from Connecticut, to support Wave 2 meter installations in spring and early summer 2023.[30]

Overall, the evaluation team surveyed 6,760 customers who participated in the Massachusetts and Connecticut heat pump programs. The primary customer surveys collected information to meet the following objectives:

- Confirm building type, HVAC equipment types and fuels, and other demographic variables used for designing representative samples and for potential post-weighting variables.
- Assess gross baselines using baseline determination questions, including what type of heating and/or cooling equipment the customer would have installed if they didn't install the heat pump they did.
- Customer installation decisions, control types, HVAC operation practices, and other heating options (wood stoves, fireplaces, portable heaters).
- Metering study recruitment questions, including screener questions for eligibility and willingness to participate.
- Confirm pre-heat pump installation system type and fuel source and obtain delivered fuels purchase orders or volume estimates.

The evaluation team used the provided program tracking data to identify a sample for the participant survey. Each customer was tagged with a survey variable name which allowed separate questions and modules for customers that installed either a CHP, MSHP, or GSHP, either as FD or as PD, and sites with an integrated controller.

Table 2-5 and Table 2-6 show the survey sample disposition for the Massachusetts Wave 1 and Wave 2 surveys, respectively. The tables include the number of customers for each measure category, the number of customers that the survey was fielded to, and the number of customers who completed the survey.[31] All invitations were sent through an initial email, with up to two reminders to customers. A $20 incentive was also offered to respondents.

[30] Onsite meter installations for customers who participated in the heat pump fuel displacement programs in 2022 were prioritized. For Massachusetts, 96 sites in the onsite sample had heat pumps installed in 2022, and five sites in 2021. For Connecticut, 66 sites had projects complete in 2022, and 18 sites with projects complete in 2021.

[31] Given the large number of respondents from Massachusetts who completed heat pump full displacement projects in 2022, the survey data analysis was limited to these customers only and excluded those who participated 2021.

Table 2-5. Primary Survey Sample Disposition – Wave 1 (Massachusetts Only)

Building Type	System Type	Displacement Scenario	Massachusetts Program Data Population*	Wave 1 Survey Sample **	Wave 1 Survey Respondents	Wave 1 Survey Respondents Complete
Single Family (Detached and Attached)	MSHP	FD	522	452	133	118
		PD	2,969	2,224	500	442
	CHP	FD	162	150	52	45
		PD	1,455	1,194	245	213
	GSHP	FD	11	11	6	6
Multi-Family (5+ units)	MSHP	FD	2	2	1	1
Total			**5,121**	**4,033**	**937**	**825**

*Wave 1 population includes 2021 participants and 2022 participants from January through August 2022

**Customers with accurate and complete customer records, with customer emails

Source: Evaluation team analysis

Table 2-6. Primary Survey Sample Disposition – Wave 2 (Massachusetts)

Building Type	System Type	Displacement Scenario	Wave 2 Massachusetts Program Data Population*	Wave 2 Survey Sample**	Wave 2 Survey Respondents	Wave 2 Survey Respondents Complete
Single Family (Detached and Attached)	MSHP	FD	2,201	450	129	104
		PD	2,399	403	96	83
	CHP	FD	716	400	189	157
		PD	1,971	550	90	85
	GSHP	FD	22	20	9	9
Multi-Family (5+ units)	MSHP	FD	7	2	-	-
Total			**7,316**	**1,825**	**513**	**438**

*Wave 2 population includes all customer records from September 2022 through December 2022, and records from January through July 2022 that were not included in the Wave 1 data extract from DNV.

**Subset of customers with complete records (including emails). Number of participants included in sample was reached by applying Wave 1 response rates.

Source: Evaluation team analysis

The Connecticut program tracking data contained a limited number of email addresses. This posed some challenges to the recruitment for the Wave 2 survey. Table 2-7 outlines the number of participants in each measure category by year and the number of available email addresses for outreach. Due to the limited number of email addresses, all the available emails in Connecticut were contacted.

Table 2-7. Primary Survey Sample Disposition – Wave 2 (Connecticut)

Building Type*	System Type	Displacement Scenario	2021 ES Pop. Size	2021 ES Pop. With Emails	2022 ES Pop.	2022 ES Pop. With Emails	2021-2022 UI Pop. Size	2021-2022 UI Pop. With Emails	Total with Emails	Wave 2 Survey Respon-dents Complete
Single Family (Detached and Attached)	MSHP	FD	118	111	222	170	3	3	284	50
		PD	3	3	144	98	17	17	118	24
	CHP	FD	38	36	80	67	6	6	109	24
		PD	23	23	176	136	11	11	170	47
	GSHP	FD	109	83	173	132	0	0	215	48
Multi-Family (5+ units)	MSHP	FD	1	1	5	5	0	0	6	-
Total			**292**	**257**	**800**	**608**	**36**	**36**	**902**	**193****

For the purposes of this table ES = Eversource (CT) and UI = United Illuminating (CT). Pop. = Population
*Assumed based on Massachusetts data, as building type was largely unknown in Connecticut data
**4 'null' heat pump types

Source: Evaluation team analysis

2.2.2 Winter 2023 Fast Feedback Interviews

A historic cold snap occurred the weekend of February 3-4, 2023. Temperatures reached as low as -13°F in certain regions of Massachusetts. Prior to this weekend, the incoming weather was noted, and interviews rather than a survey were conducted to capture any weather response from participants. These interviews were approximately 15-20 minutes and focused on asking customers about their HVAC usage during the cold snap (setpoint adjustments, system operation, use of backup or supplemental heat), their perceived performance of their heat pump, and the ability of their primary heat pump system to keep them comfortable. The full eligible population (25 sites) was contacted, and 13 participants were recruited for interviews. Interviewees were given a $10 incentive for their participation.

2.2.3 Winter 2024 End of Season Survey

Originally, Guidehouse planned to field a short survey, like the interviews conducted in Winter 2023. However, the PAs, EEAC consultants, and EA team expressed interest in a more comprehensive survey to understand customer behavior and satisfaction in more granularity. To address these objectives, Guidehouse increased the length of the survey and adjusted the incentive to $20, rather than the previously planned $10. Additionally, this survey was fielded to all participants in the metering study (n = 185) rather than only the FD subgroup. Overall, the survey received 136 responses (74% response rate). Unfortunately, the weather did not drop below 5°F in Massachusetts during the Winter of 2023-2024, so the survey was launched with questions referring to a cold period at the end of January 2024. The following research areas were addressed through the end of season survey:

- **Backup Heat Usage and Systems Operation—**Understand if customer uses backup heat during the winter and/or identify if they had an emergency situation that warranted their use of backup heat. Gauge customer satisfaction of system's performance in cold temperatures as it is influenced by comfort levels.
- **Impact of Electricity Costs—**Assess relative impact of increased electricity costs on heat pump usage.
- **Thermostat Setpoint—**Understand general customer habits with the thermostat setpoint, how those habits change in the winter, and whether it is similar to previous seasons.
- **Feedback—**Opportunity for heat pump, study team, and program feedback.

2.3 Sample Design and Onsite Sample

The evaluation team designed a sample to collect metered data on heat and backup heating season usage, and to collect data necessary to calculate the performance of heat pumps across heating and cooling seasons. Table 2-8 outlines the sample size as defined in the study plan, and number of onsite sample points that had been installed across Massachusetts and Connecticut, by building type, heat pump type, and displacement type. The planned 185 onsite sample points to collect heat pump usage, peak demands, and backup heating system usage were achieved.

The sample size for the multi-family strata was cut down due to a smaller than anticipated number of multi-family projects being present in the program data. In coordination with the study sponsors, a sample from the original multi-family strata was shifted to the GSHP stratum, which had a larger number of GSHP projects than originally anticipated.

Table 2-8. Onsite Metering Sample – Usage and Peak Demand

Building Type	System Type	Displacement Scenario	Sample Size Planned	Sites Installed in Massachusetts	Sites Installed in Connecticut	Total Sites Installed
Single Family (Detached and Attached)	Mini-Split Heat Pump	FD	37	31	16	47
		PD	48	23	8	31
	Central Heat Pump	FD	37	29	9	38
		PD	36	12	25	37
	Ground Source Heat Pump	FD	5	1	25	26
Multi-Family (5+ units)	Mini-Split Heat Pump	FD	22	4	0	4
	Central Heat Pump	FD	0	1	1	2
Total			**185**	**101**	**84**	**185**

Source: Evaluation team analysis

Additional data was collected at a subset of the 185 sites to support calculation of heat pump performance. Table 2-9 shows the number of sites where data loggers were installed to collect the additional performance data (106 sites total, one higher than planned).

Table 2-9. Onsite Metering Sample – Performance

Displacement Scenario	System Type	Sample Size Planned (n)	Sites Installed in Massachusetts	Sites Installed in Connecticut	Total Sites Installed
FD Installations	Mini-Split Heat Pump	37	25	13	38
	Central Heat Pump	37	26	8	34
	Ground Source Heat Pump	5	1	11	12
PD Installations	Mini-Split Heat Pump	13	5	2	7
	Central Heat Pump	13	6	9	15
	Ground Source Heat Pump	0	0	0	0
Total Mini-Split Heat Pump		**50**	**30**	**15**	**45**
Total Central Heat Pump		**50**	**32**	**17**	**49**
Total Ground Source Heat Pump		**5**	**1**	**11**	**12**
Total Installs		**105**	**63**	**43**	**106**

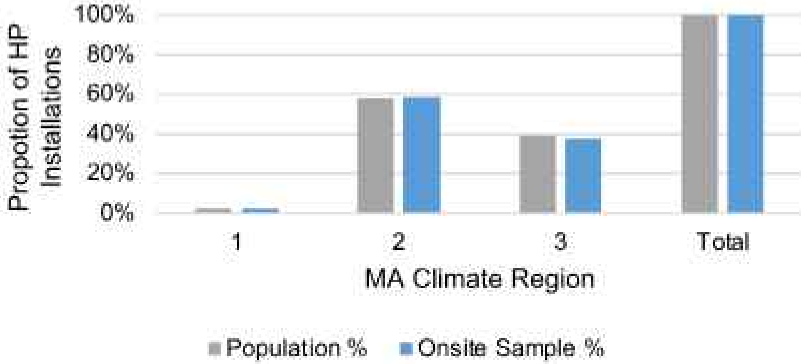
Source: Evaluation team analysis

Figure 2-1 shows the location of onsite meter installation in Massachusetts, indicated by the three major climate regions (Western, Central, and Coastal). Figure 2-2 shows the portion of total installations in these three climate regions as indicated in the customer survey and for the onsite sample. The onsite sample is adequately representative of installations of heat pumps across these three climate regions in Massachusetts.

Figure 2-1. Map of Onsite Installations in Massachusetts

Source: Evaluation team analysis

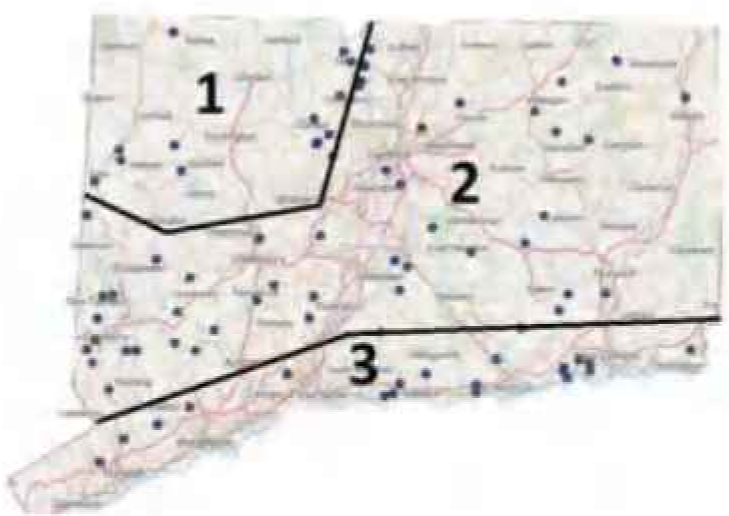
Figure 2-2. Count of Onsite Installations per Climate Region in Massachusetts



Source: Evaluation team analysis

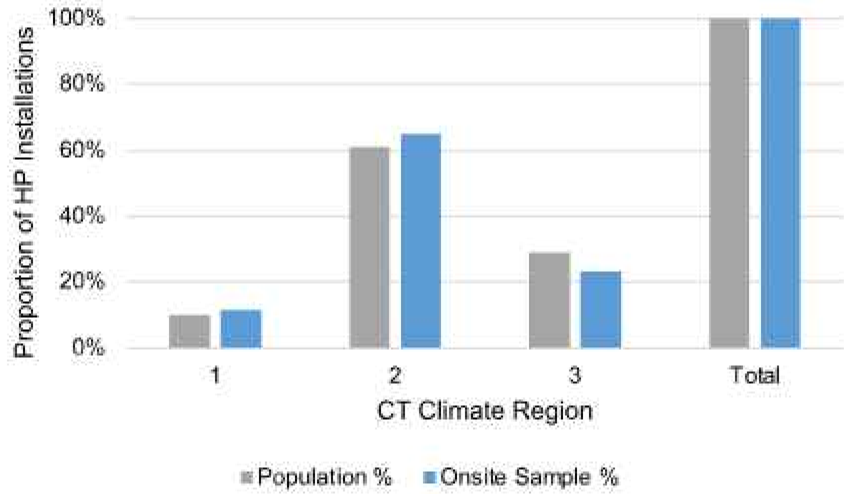
Figure 2-3. shows the location of onsite meter installations in Connecticut, separated by the three major climate regions (Northern, Central, and Coastal). Figure 2-4 shows the portion of total installations in these three climate regions as indicated in the customer survey and the onsite sample. The onsite sample is adequately representative of installations of heat pumps across these three climate regions in Connecticut.

Figure 2-3. Map of Onsite Installations in Connecticut



Source: Evaluation team analysis

Figure 2-4. Count of Onsite Installations per Climate Region in Connecticut



Source: Evaluation team analysis

2.4 Onsite Data Collection

Onsite visits were conducted to collect building characteristics[32], equipment characteristics, and to install a suite of metering/logging equipment to collect all data required for the analysis. The metered equipment included the heat pump compressor, indoor fan units, and supplemental electric resistance heat, as well as any existing electric resistance baseboards, furnace fans, boiler pumps, space heaters, and central ACs. Plug load loggers were used for plug-in equipment such as space heaters. Integrated space and water heating systems utilized surface temperature sensors on the water heating piping to determine when there was demand from the boiler for the water heating separate from space heating. Temperature and humidity loggers were also installed to monitor outdoor air, supply air, as well as return air temperature and relative humidity. While onsite, the quantity and nameplate information for all heating and cooling equipment was recorded to determine equipment characteristics, such as rated capacity and efficiency.

Onsite spot measurements were used to correlate fan airflow versus fan power consumption. Airflow testing methodologies are described further in Section 0.

The field visits and equipment installation took place in two waves. Wave 1 installations took place in fall 2022, and Wave 2 installations occurred in spring and early summer 2023. The sites were further split into two groups: performance and usage. Performance sites collected all the data necessary to calculate heat pump performance as well as heat pump and backup heating system electrical usage. Usage sites only collected electrical consumption data.

[32] There are more than 30 building characteristics that were recorded during the site visit including home square footage, number of permanent residents, age of the home, thermostat setpoints, and fuel sources used in the home.

2.4.1 Metering Setup

The following set of equipment was installed for long-term metering.

Power:

- **Power Meter—**Meter installed at the electrical panel that is used to meter all HVAC power measurements including the outdoor units, air handlers, pumps (for boiler backup systems), and electric resistance supplemental heat. Current transformers were also added on all non-heat pump HVAC circuits in the home, including circuits for furnaces, boilers, and central ACs as applicable.
- **Plug Load Meters—**Installed on plug-in HVAC equipment used in the home at a small, including space heaters and window ACs (installed at 10 homes).
- **Smart Oil Gauge—**Wireless fuel oil tank meter that uses ultrasonic sound waves to determine fuel oil level and transmits the fill level data via Wi-Fi.
- **Copper Labs Logger—**Wireless energy monitor that can deliver whole-home gas meter data at homes with an AMR Type-12 gas meter.
- **Surface Temperature Loggers—**Loggers used to monitor temperature of flues for gas, oil, propane, or wood space heating systems, were used to inform when backup systems were in use.

Performance:

- **Temperature and Relative Humidity Probes—**Meters used to collect outdoor ambient temperature and relative humidity, and for the supply air and return air to the heat pumps(s).
- **Current Monitoring—**Used to continuously monitor fan current. The fan current was correlated with fan airflow measurements during the onsite visit.

Table 2-10 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 2-10. 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

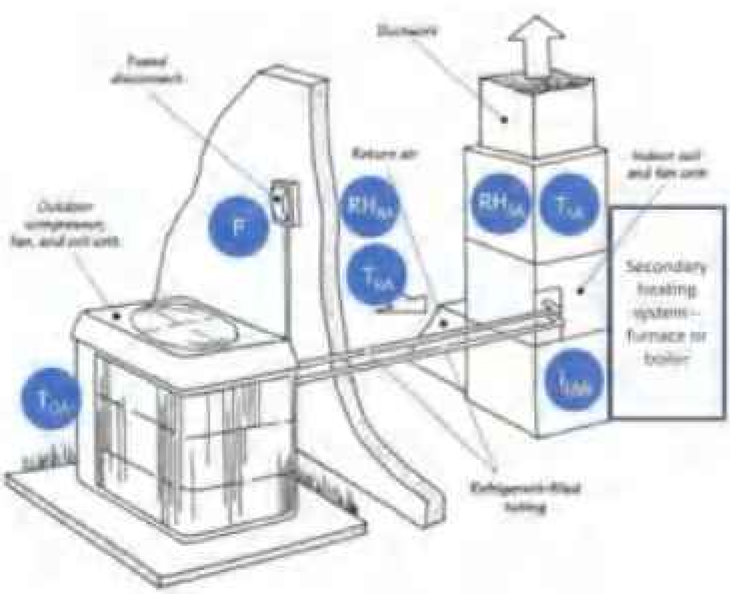
Measurement	Location	Metering Type	Sensor Type	Equipment
Plug Load Usage	Power supply to window or portable AC units and space heaters	Usage	Plug load meter	Onset UX-120-018
Natural Gas Usage	Whole-home gas usage	Usage	Whole-home gas meter	Copper Labs AMR Type 12
Fuel Oil	Delivered fuel heating systems	Usage	NA	Smart oil gauge (fuel oil)

Source: Evaluation team analysis

Figure 2-5. illustrates where each of the meters were installed on a full performance metering site for CHP equipment, as well as the data types they are collecting. Figure 2-6 shows a photo of an example temperature sensor installed at the air handler to collect supply air temperature. Figure 2-7. and Figure 2-8. show the analogous schematics and photos for MSHP equipment. The eGauge, Onset MX, Smart Oil Gauge, and Copper Labs meters were internet connected to enable real-time QC, to be able to troubleshoot any connection issues, and to support interim analyses and deliverables throughout the metered period.

Equipment was installed by licensed professional electricians from RISE Engineering in Massachusetts and Sarracco Mechanical Services in Connecticut (for all equipment installed in the electrical panel), and a field technician from Ridgeline Energy Analytics. During the onsite visits (including install and retrieval), the field team also interviewed the customer to determine how they operated their heat pump equipment in the heating and cooling seasons, how they interacted with their thermostats or integrated controllers, and if they changed switchover temperature settings since installation.

Figure 2-5. Central Heat Pump Performance Metering Schematic [33]

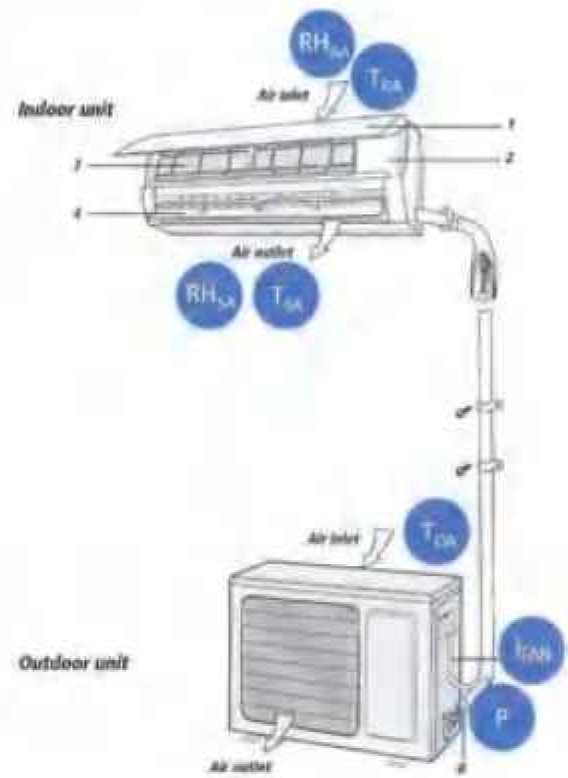


Source: Evaluation team analysis

Figure 2-6. Example of Central Heat Pump Supply Air Temperature Logger Installation

Source: Evaluation team analysis

Figure 2-7. Mini Split Heat Pump Performance Metering Schematic for System with Single Terminal Unit*[33]



**Multi-Split configurations were also widely used and observed*
Source: Evaluation team analysis

Figure 2-8. Example of Mini Split Heat Pump Indoor Unit Logger Installation

Source: Evaluation team analysis

[33] Don Vanderbort (2024). "How a Heat Pump Works." HomeTips. https://www.hometips.com/how-it-works/heat-pumps-air-source.html

The HVAC system power was also metered using an eGauge 3010 with 20- or 50-amp current transformers. As part of the aforementioned field team, composed of an electrician and a field technician, the electrician first identified the circuit breaker(s) that powered the heat pump system(s). In mini-spilt systems and central ducted systems, one two-pole breaker typically served a condensing unit and the indoor units or air handler connected to it.

Following identification, the field technician configured the eGauge device to calculate the power based on the current readings at the breaker. This measurement was used in the analysis as the input power to the heat pump system. Figure 2-9. shows an example eGauge installation. The current transformers are metering the mains of the panel in the example photo.

Figure 2-9. Example eGauge 3010 Installation

Source: Evaluation team analysis

2.4.2 Fan Airflow

Fan airflow data for mini-splits and central systems was collected for sites that underwent performance metering. Depending on the system type, fan airflow was determined in one of the following ways:

- **Mini-Split Systems—**Flow hood and balometer measurements correlated to fan current. The current readings were measured at the outdoor unit, which provides the power to the indoor fans.
- **Ducted Central Systems—**Multiple airflow testing procedures were available with priority given to the procedure that is most applicable based on site-specific characteristics. Options available include:
  - TrueFlow method using the procedures defined in ANSI/RESNET/ACCA (American National Standards Institute/Residential Energy Services Network/Air Conditioning Contractors of America) Standard 310.8F34 This method uses a flow plate installed in the filter slot to measure airflow.
  - Flow Hood method using the procedures defined in ANSI/RESNET/ACCA) Standard 310. Balometer is used to capture airflow through the central return.

2.4.2.1 Mini-Split Systems

As mentioned previously, collecting in-situ air flow data is difficult, as there isn't an effective way to meter air flow over a long period of time without having intrusive meters in a customer's home. To generate a performance curve, airflow versus power readings were collected at each site visit and used to generate a performance curve at the site level.

This was achieved using a calibrated flow hood (i.e., balometer) to capture spot measurements of delivered airflow at each corresponding fan setting. To ensure consistency between sites, the airflow measurements were performed with louvers fixed in place and in fan-only mode when possible. Airflow measurements were taken at each speed setting on the indoor head's controller, creating a matrix of current readings at each airflow reading and allowing the correlation of airflow and amperage. The cleanliness of the filters and coils were noted in the onsite data collection forms, to enable correlation of filter conditions to impacts on airflow rate and cooling performance.

Current transformers were installed on the wire powering the indoor head. These current transformers sense the indoor unit's current draw at one-minute intervals. To verify that the lower amperages seen on mini-split units are accurately captured, the evaluation team used a 0.4" opening 1A Magnelab small format Current Transformers with a custom converter to work with the MX1105. Previous studies conducted by Ridgeline have shown that these current transformers can monitor amperages as low as 0.03 to 0.15A.[35]

[34] Residential Energy Services Network / Air Conditioning Contractors of America (2020). "Standard for Grading the Installation of HVAC Systems." ANSI/RESNET/ACCA 310-2020. https://www.resnet.us/wp-content/uploads/ANSIRESNETACCA_310-2020_v7.1.pdf

[35] Ridgeline (2024). "Efficiency Maine Residential Heat Pump Impact Evaluation." https://www.efficiencymaine.com/docs/Efficiency_Maine_Residential_Heat_Pump_Impact_Evaluation_Report-2024.pdf

2.4.2.2 Ducted Central Systems

A flow hood (balometer) and flow plate are both high-accuracy airflow testing. If the system has a central return, a balometer can be used to record total system airflow at the return grill. The limited ductwork in a central return is assumed to have negligible leakage. If the filter slot is of standard dimensions the TrueFlow can be inserted with minimal setup time. Airflow readings were measured for as many fan speeds as possible. If explicit fan speed controls were not available at the thermostat, then additional strategies including changing the mode and thermostat temperature delta were used to cause the system to change fan speeds.

2.4.3 Temperature and Relative Humidity

To calculate heating and cooling loads and correlate efficiency to outdoor temperature, it is necessary to install a variety of temperature and relative humidity (RH) sensors. For this study, MX2302A probes were used to measure temperature and RH at one-minute intervals.

Measurements were taken for outdoor air, conditioned supply air to the space from the supply duct or the indoor unit and return air from the space through the return duct or to the indoor unit. The outdoor ambient temperature sensor was installed outside next to the condenser.

For ducted central systems one sensor was installed in the supply and return duct (two sensors total). For ductless systems, multiple sensors were originally used to measure supply air temperature and relative humidity across the supply grill to gather an average temperature. This was done because the throw can vary across a ductless unit supply grill which will affect temperature and relative humidity measurements. Analysis of Wave 1 supply air temperature readings for ductless mini-split systems showed no discernable difference between the two sensors. As a result, during Wave 2 installations, ductless mini-split systems were installed with a single supply air sensor. One sensor placed in the center of the return grill was sufficient to measure return or entering air temperature in a ductless system.

2.4.4 Backup HVAC Systems

Metering equipment was also installed to collect usage and runtime for the home's backup HVAC system(s). Table 2-11 contains a list of metering equipment used to measure the consumption of various backup systems.

Table 2-11. Metering Options for HVAC Backup or Supplemental Systems

Backup System	Metering Plan
Cooling – Room Air Conditioner	Onset UX120-018 plug load logger provides runtime and power.
Heating – Space Heater	Onset UX120-018 plug load logger provides runtime and power.
Heating – Electric, Gas, or Fuel-Fired Furnace/Boiler	eGauge at the panel to collect electric usage of electric heating equipment, or fans or pumps for gas or fuel-fired equipment. For gas or fuel-fired units, used to measure on-state and estimate runtime. For oil/gas/propane units, Onset's MX2304 temperature logger installed on system flue to capture runtime. For homes with natural gas, Copper Labs logger to collect whole-home gas usage. For homes with oil, Smart Oil Gauges installed on eligible tanks
Heating – Electric Baseboard Heating	eGauge and current transformer at electrical panel to directly measure power and runtime.

Source: Evaluation team analysis

2.4.5 Logger Installation Counts

Table 2-12 lists the count of meters installed at the 185 homes included in the study sample.

Table 2-12. Count of Loggers Installed

Equipment	Parameter Metered	Count
eGauge 3010	Heat pump, auxiliary heat, backup system, and air handler power	210
Onset MX1105	Fan current and outdoor air temperature (OAT)	80
Onset MX2302	Temperature, relative humidity, OAT, backup system ductwork surface temperature	688
Onset UX-120-018	Room AC and space heater power	13
Copper Labs Gas Meter (AMR Type 12)	Whole-home natural gas consumption	24
Droplet Fuel Oil Logger	Fuel oil tank level	22

Source: Evaluation team analysis

2.5 Metered Data Analysis Methodology

The following steps were used to analyze the metered data to derive the study results:

- Clean and process the metered data.
- Calculate in situ heat pump performance.
- Estimate typical-year heat pump usage with site-specific weather-normalization models.
- Estimate typical-year heat pump energy production using custom-fit models of heat pump performance.
- Estimate typical-year usage of hypothetical baseline heating and cooling systems based on assumed baseline system efficiencies.
- Estimate site-level measure impacts (savings) as the aggregate difference between typical year heat pump usage and typical year baseline usage.
- Aggregate site-level impacts to the stratum level (heat pump type and displacement type) and measure level (heat pump type, displacement type, and pre-existing fuel type). This step also uses weights for the baseline equipment types based on participant survey responses.

These steps are detailed in the following subsections.

2.5.1 Onsite 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 February 1, 2024, 1.3 billion rows of raw minute-level data (equivalent to 2,500 years) were collected from the study sites, which resulted in 760 million rows after the cleaning and consolidating steps described below.

During the metered period, automated and manual processes were used to download raw, minute-level data from the loggers described in Section 2.4.5. Where network connections allowed, the data were downloaded each day from the loggers and ingested into the analytics database. When network connections were either not available or failed, the field team made efforts to retrieve all available data stored on the loggers through additional site visits, both to download the data and to troubleshoot internet connection for devices that had gone offline.[36]

The logger data reviewed 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.

[36] Over the course of the metered period, about 120 revisits were conducted (about 30 visits higher than the 90 planned revisits). These revisits served to download locally stored data on loggers, troubleshoot and re-establish internet connection for loggers that had gone offline, and collect additional field datapoints for the analysis, such as airflow testing. In some instances, the onboard storage reached capacity prior to the revisit date, especially for loggers with limited onboard storage. Onset MX1105 meters and eGauges have a maximum of 1 year of minute level onboard data storage. Onset MX2302 meters have a smaller memory capacity and only have 22 days of onboard storage for all the data channels collected as part of this study.

Any gaps in logger timeseries data were not filled in. While imputing missing values would result in more periods of usable data, the error introduced from the imputation would overshadow the benefits of the increased sample size.

In cases where multiple meters were used to measure the same variable (e.g., two temperature sensors on the supply side of an air handler), the values were averaged across the sensors to arrive at a single estimate for each instant for each variable.

Table 2-13 shows a summary of sites included in the heat pump usage and measure impacts analysis, and a summary of the various site data cleaning steps and drop out points. After data cleaning and QC, data from 169 sites was used to generate the heating season usage and measure impacts savings and data from 168 sites was used to generate the cooling season usage and measure impacts savings.[37]
After meter installation, five participants requested that the meters be removed due to the customer moving or for various reasons.

Eight of the 185 sites had 'insufficient data', defined as having less than four weeks (28 days) worth of usage data for the particular season (heating or cooling). Some of the reasons for having limited usage data collection include:

- Direct power loss at the eGauge due to customer inadvertently flipping the breaker on the circuit that powers the eGauge (one site) or an electrician disconnecting the eGauge in the electrical panel during an unrelated visit (one site).
- Revisit or uninstall visit not completed in time for this report, due to customers being out of town, homeowners moving and not alerting the study team, or other scheduling constraints with the customers (four sites)[38]
- Prolonged periods of connectivity issues spanning longer than the onboard storage of the meters
- A manufacturer defect was discovered in a small portion (<1%) of the temperature/humidity loggers, which caused the battery to die prematurely.

Other miscellaneous data issues also occurred, including:

- Three sites were removed because the metered power data was determined to be erroneous during the QC process.
- One site used their ground source heat pump as a pool heater during the summer season. This use case was deemed as atypical, and the summer season usage was removed from the analysis rollup.

[37] A 10% dropout rate was assumed for the metered usage sample in the initial study planning.

[38] After uninstall visits, data for three to four sites is expected to be recovered and included in final analysis.

Table 2-13. Usage Site Data QC and Resulting Sample

Data QC Step	Heating Season	Cooling Season
Sites Installed	**185**	**185**
Meters removed per participant request	5	5
Remaining sites eligible for usage analysis	**180**	**180**
Insufficient Data (less than 28 days)	8	8
Miscellaneous Data Issue	3	4
Sites with Usage Data Included in Analysis	**169**	**168**

Source: Evaluation team analysis

Table 2-14 provides a summary of the sites with available heat pump performance data and a summary of the various site data cleaning steps and drop out points. After data cleaning and QC, data from 63 sites (65 heat pump units) were used to generate the heating season performance models and data from 66 sites were used to generate the cooling season performance models.

After meter installation, three of the participants with heat pump performance metering requested that the meters be removed due to the customer moving or for various reasons.

Next, units were removed from the performance analysis based on visual QC in cases where there was not enough heat pump runtime to establish performance relationships with input power and outdoor air temperature, either because the customer rarely used the unit in the respective season or because of insufficient data.[39] The usage data from these sites were still used for the usage and measure impacts rollup.

Additionally, data was removed for systems that were determined in the QC process to have incorrect data, including the following cases:

- **Fan CFM curve outside reasonable range**—The airflow values calculated from the fan current to fan CFM relationship were outside reasonable ranges based on the indoor unit or air handler specifications. This includes sites that had only one CFM data point collected at time of install, sites that had test values that appeared outside of range, and sites for which the fan current loggers malfunctioned over the metered period.[40]

[39] Calculation of heat pump performance requires consistent and accurate data collection from the eGauge (heat pump compressor power and fan power), and temperature and relative humidity loggers for both supply and return airstreams. Sites with insufficient data were mainly caused by constraints with maintaining consistent internet connectivity for all loggers (especially for MSHP units with multiple indoor heads, requiring consistent data collection at all heads to include the unit in the analysis), limited onboard storage for the temperature loggers, and battery or wiring failure in some units.

[40] Additional airflow testing will be prioritized at the retrieval site visits for these eight sites. The team expects that with additional airflow testing, up to five of these sites could be pulled into final analysis. Given advanced system control sequences, the team may not be able to manipulate the heat pump fans to collect enough data points to establish an accurate fan curve.

- **Inaccurate supply or return temperature data**—Readings from the temperature or temperature/relative humidity sensors installed at either the return or supply airstream were providing inaccurate readings that prevented calculating the enthalpy at one of the airstreams. For some of these sites the temperature appeared out of range, and for some others the participant moved the logger or probe over the metered period.
- **Compressor power outside of range**—Compressor power readings were flagged as outside of reasonable range, possibly due to malfunction of the current transducers in the electrical panel.

Table 2-14. Performance Site Data QC and Resulting Sample

Data QC Step	Heating Season	Cooling Season
Sites Installed	**105**	**105**
Meters removed per participant request	3	3
Can't derive performance relationship – customer did not use the heat pump in this season, or insufficient data	22	20
Remaining sites eligible for performance analysis	**80**	**82**
Fan CFM curve outside reasonable range	9	9
Inaccurate supply or return temperature data	6	5
Compressor power outside of range	2	2
Sites with heat pump performance data included in analysis*	**63**	**66**

* System count for heating season, by stratum: CHP FD: 21, CHP PD: 8, MSHP FD: 21, MSHP PD: 5, GSHP: 10 (some homes have multiple systems metered)

Source: Evaluation team analysis

Certain steps in the analysis required additional data filtering due to methodological constraints, as discussed in the appropriate sections.

2.5.2 Metered Heat Pump Performance

The performance, or efficiency, of a heat pump is defined as the ratio of the useful energy produced to the energy consumed—that is: the ratio of the heating or cooling[41] energy delivered to the conditioned space over the electrical energy consumed by the heat pump compressor and auxiliary systems.

[41] As per mechanical engineering convention, both energy delivered to (heating) or removed from (cooling) the room are considered "positive" energy flows and thus efficiency is always positive.

To calculate the energy consumed by the system, the power data from the compressor, air handlers, and auxiliary heating (if any) was summed. For mini-split units, the power data for the system at a single breaker at the panel for each system was captured. For central and ground source heat pumps, the outdoor or underground units, air handlers, and auxiliary heat systems associated with the unit were typically metered separately and aggregated at the minute level to calculate the total system power for each minute.

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.

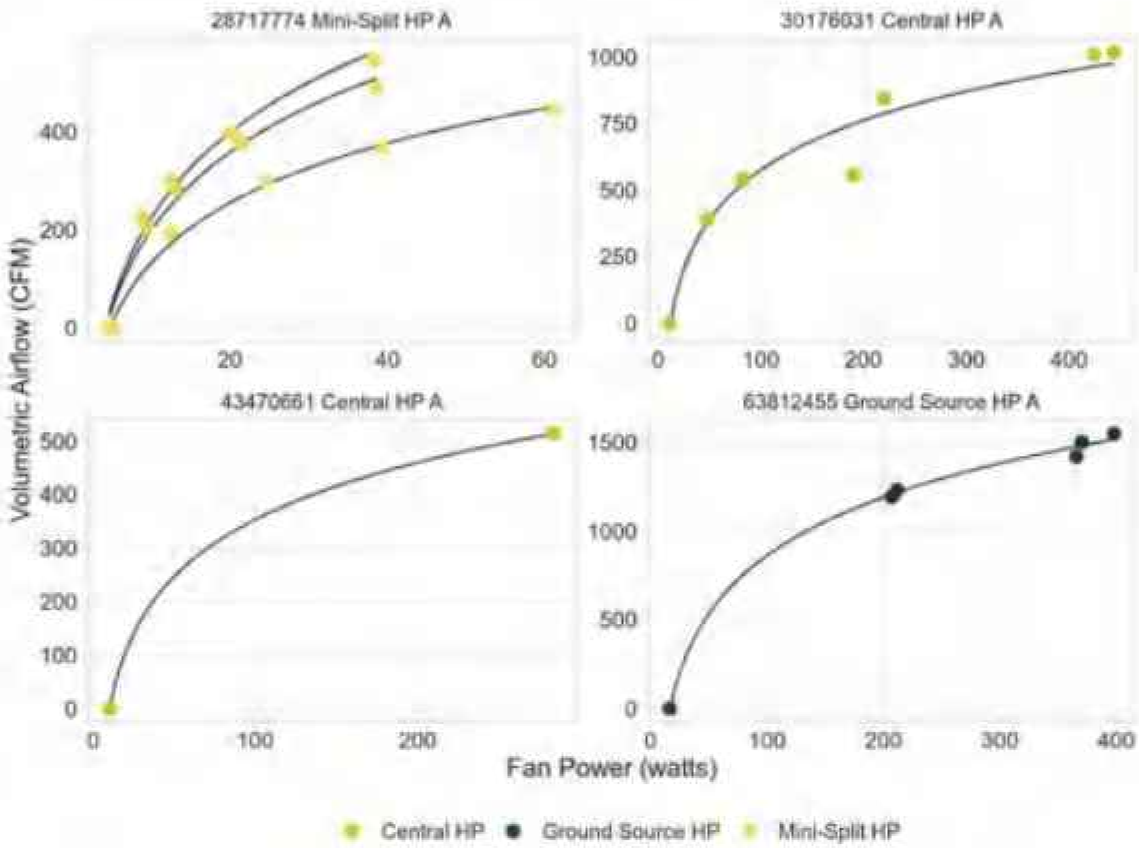
Equation 1. Energy Delivered by the Heat Pump

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

$Where:$
$E = \ energy\ (Btu)$
$\Delta t = measurement\ interval\ (hours)$
$\Delta H = change\ in\ enthalpy\ (kJ)$
$Q = \ volumetric\ air\ flow\ (CFM)$
$\rho = \ air\ density\ (1.204 \frac{kg}{m^3})$

Measurements of the fan power were used to calculate the airflow. As discussed in Section 0, during site visits the relationship between fan power consumption and airflow production was measured for as many performance-metered sites as possible. 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 2-10. shows airflow measurements and fan curve model fits at four example sites.

Figure 2-10. Example Airflow Measurements and Approximate Fan Curves*



*Three curves are shown for this MSHP example system, one for each indoor head.
Source: Evaluation team analysis

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.[42]

The models were used to convert the metered fan power data to minute-interval estimates of volumetric airflow. In cases where fan power could not be directly metered, fan current was metered and converted to power using an assumption of constant 230V.

Volumetric airflow was converted to mass airflow using an assumed constant of 1.204 kg/m^3 (the density of air at 68°F).

[42] Number of systems included in the performance analysis where a fan curve was generated from system-specific data collection: 44 CHPs, 90 MSHPs, 12 GSHPs. Number mapped from analogous systems or system average curves: 2 CHPs and 47 MSHPs.

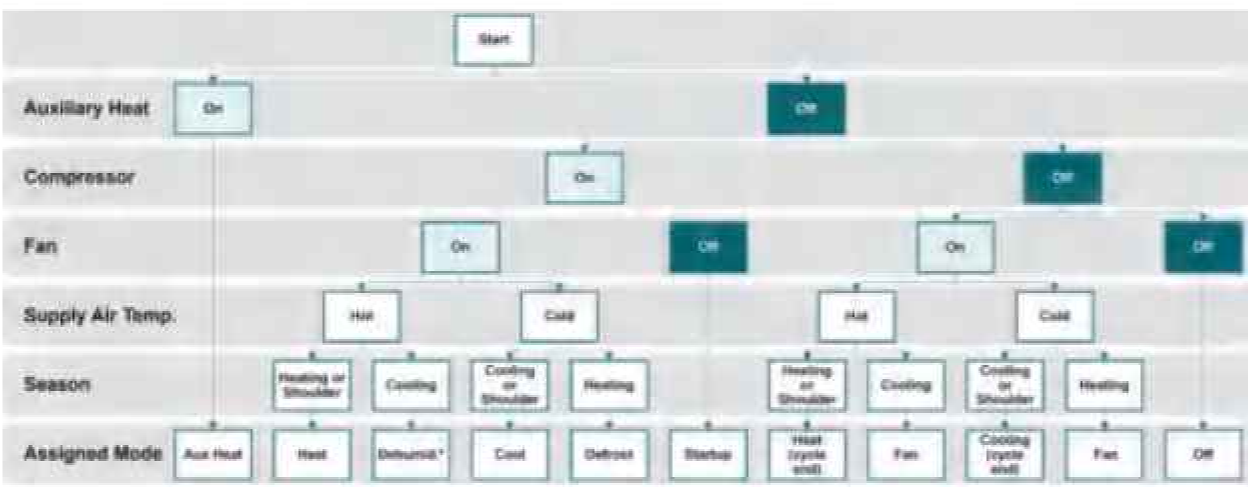
To calculate the enthalpy of the return and supply air streams, the temperature and relative humidity sensors discussed in Section 2.4.3 were used along with standard psychrometric formulas. Note that humidity only factors into the calculation during the cooling season when moisture is removed from the air.

With estimates of the enthalpy of each airstream and the mass flow rate of the air through the air handler, the differences of the enthalpies were multiplied by the airflow to arrive at minute-level estimates of the heating and cooling energy delivered to each space by each air handler as described in Equation 1. For heat pump systems with a single outdoor unit and multiple indoor heads, the delivered energy across all heads was summed for each minute. For minutes where there was insufficient data to calculate energy delivered for any of the heads, that minute was dropped from the analysis for the purposes of performance estimates.

The outcome of this portion of the analysis was a new dataset consisting of estimates of energy consumed and delivered or removed by each heat pump for each minute of the metered period when complete data was available for the actual weather year. This dataset is referred to as the "Performance Data" in subsequent sections of this report.

To facilitate further filtering and aggregation, each observation was labeled in the Performance Data with an estimate of the operational mode of the heat pump. These modes were not directly observed, but rather, inferred based on the available data. The logic shown in Figure 2-11 was used to assign these operational modes.

Figure 2-11. Heat Pump Operational Mode Assignment Decision Tree



*Dehumidification mode is identified for periods of time in the cooling season where supply temperature is cooler than return temperature, and in which the change in enthalpy shows heat added to the space.

Source: Evaluation team analysis

2.5.3 Typical-Year Heat Pump Usage

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. This process is often referred to as weather-normalization. The high-level steps of the weather normalization process are as follows:

6. **Aggregate** the minute-interval usage data to the hourly level.
7. **Augment** the data with temporal and weather variables from the metered year.
8. **Model** the relationship between heat pump usage and those explanatory variables for each heat pump system.
9. **Predict** typical-year heat pump usage by using typical meteorological year weather data (TMYx)[43] and actual meteorological year (AMY) weather data for the past 15 years (for seasonal peak demand) as inputs to the fit models.

2.5.3.1 Aggregate

When averaging the minute-level power data to hourly, any hours that did not have at least 45 minutes of usable data were dropped. This was done to ensure that each hour provided an accurate average of the heat pump power consumption during that hour.

Additionally, the data was split into heating and cooling datasets for each heat pump. Modeling the relationship between heat pump usage and weather separately for the heating and cooling modes allows for better model fits and increased predictive accuracy with lower overall model complexity.

The cooling-mode dataset was defined as all hours of data between June 15 and September 15 (summer) and any hours from April 1-June 14 and September 16-November 30 (shoulder) where the outdoor air temperature was above 65°F. The remainder of the data was used to train the heating-mode model. Note that these modes are defined completely by calendar day and temperature. These modes, applied to the usage data, are independent from the modes discussed as part of the Performance Data dataset.

A filter was implemented to ensure models were only fit for systems which had at least 672 hours (28 days) of data for each modeling mode. Some systems only had sufficient data in the heating mode but not the cooling mode, or vice versa. Others did not have sufficient data for either mode. The number of systems with sufficient data to train models for each mode can be found in Table 2-13.

2.5.3.2 Augment

Actual meteorological year (AMY) weather data was retrieved from a sample of representative weather stations across the study area: Worcester, Boston, Lawrence, New Bedford, Westfield

[43] Typical Meteorological Year (TMYx) weather data are developed by Climate.OneBuilding.Org and use 15 years of recent weather data from weather stations to generate a typical year weather file for that location. The TMYx weather files select the median weather month for each month of the year over a recent 15-year period. The 2007-2021 period was used for this study.

(Massachusetts); and Hartford and Bridgeport (Connecticut). Each study site was matched to the nearest weather station from the sample.

To allow for better model fits, heating and cooling base temperatures were assigned to each system, and where appropriate, heating system switchover temperatures. These were assigned based on visual inspection of each heat pump's heating and cooling energy consumption plotted against outdoor air temperature.

Using the AMY weather data, a set of weather- and time-based predictor variables were derived for use in the models:

- Variable-base heating degree hours (HDH) and cooling degree hours (CDH)
- 4-hour and 24-hour rolling average HDH and CDH
- Normalized heat build up (NHBU) – composite of heat index over the past 72 hours.
- Relative humidity
- Hour of day
- Day type (weekday vs weekend/holiday)
- Season (heating, cooling, shoulder)
- Switchover temperature (if identifiable) with flag for if data is above or below switchover

2.5.3.3 Model

The heating- and cooling-mode data was split into testing and training sets for each system and used cross validation on the training set to try a variety of model formulations for each system, including:

- Polynomial terms of HDH/CDH, rolling average HDH/CDH, and NHBU
- Interactions between HDH/CDH and Hour, Season

The best-fitting model for each mode for each system was chosen based on an aggregate error metric that considers goodness of fit across all training data and within the peak periods, specifically. The fit of the models was confirmed by performing visual inspection of the model predictions across month, outdoor temperature, and hour of day, with a particular focus on outdoor temperature (which is expected to be the primary driver of predicted kW). An example usage model QC plot is shown in Figure 2-12. .

Figure 2-12. Example Usage Model QC Plot

Source: Evaluation team analysis

Once a model formulation was selected for each site and mode, the models were refit using the complete data for that site and mode. These were the final, trained models used for the prediction step.

2.5.3.4 Predict

For the final step in estimating typical-year heat pump usage, TMYx weather data was collected from the same set of weather stations used for the AMY data. TMYx weather was used for the 2007-2021 period. The TMYx data was separated into heating and cooling modes using the same process applied to the AMY data. These datasets were fed into the respective models and the outputs were combined to produce complete, hourly (8760) TMYx heat pump usage (kW) for all systems with complete heating and cooling data (or partial-year datasets for systems with insufficient training data for one mode).

The team also used the models to predict the usage for the seasonal peak period using AMY weather data. Historical ISO-NE system load data was used to determine the Summer and Winter seasonal peak hours for each year, and the models were used to predict the heat pump usage for these hours using AMY weather data from the past 15 years (Summer 2009-Winter 2023/24). The team then selected the year with the median usage (average kW/ton across all systems) to use as the typical year for seasonal peak demand. For heating, the median year was Winter 2019/20, and for cooling the median year was Summer 2013.

2.5.4 Typical-Year Heat Pump Production (Performance)

In contrast to the heat pump *usage* models, which describe heat pump energy *used* as a function of temporal and meteorological variables, the heat pump *performance* models of this section describe heat pump energy *produced* as a function of energy consumed. Where the goal of the usage models is to weather normalize the usage data (converting AMY usage to TMY usage), the goal of these performance models is to estimate the heating and cooling production of the heat pumps during a typical weather year.

Despite the difference in model formulation and use, the overall process of fitting the performance models and predicting typical year heat pump production was largely the same.

2.5.4.1 Aggregate

Following the same process used for the usage-modeling, the minute-level, metered Performance Data was aggregated to the hourly level, then filtered to remove hours without sufficient minute-level data and split into heating and cooling modes based on outdoor temperature. This resulted in a dataset of hourly average kW-consumed and Btu/h-produced for each heat pump in the performance-metered sample of heat pump systems.

2.5.4.2 Augment

Following the same process used for the usage-modeling, AMY weather data from representative weather stations was joined to the hourly Performance Data.

Using the AMY weather data, a set of weather- and time-based predictor variables relevant to the performance models were derived:

- Input power (kW per ton rated capacity)
- Variable-base heating degree hours (HDH) and cooling degree hours (CDH)
- Relative humidity
- Season (heating, cooling, shoulder)
- Rated efficiency – Heating Seasonal Performance Factor (HSPF) for heating and Seasonal Energy Efficiency Ratio (SEER) for cooling (used only in aggregate models, see below for details)

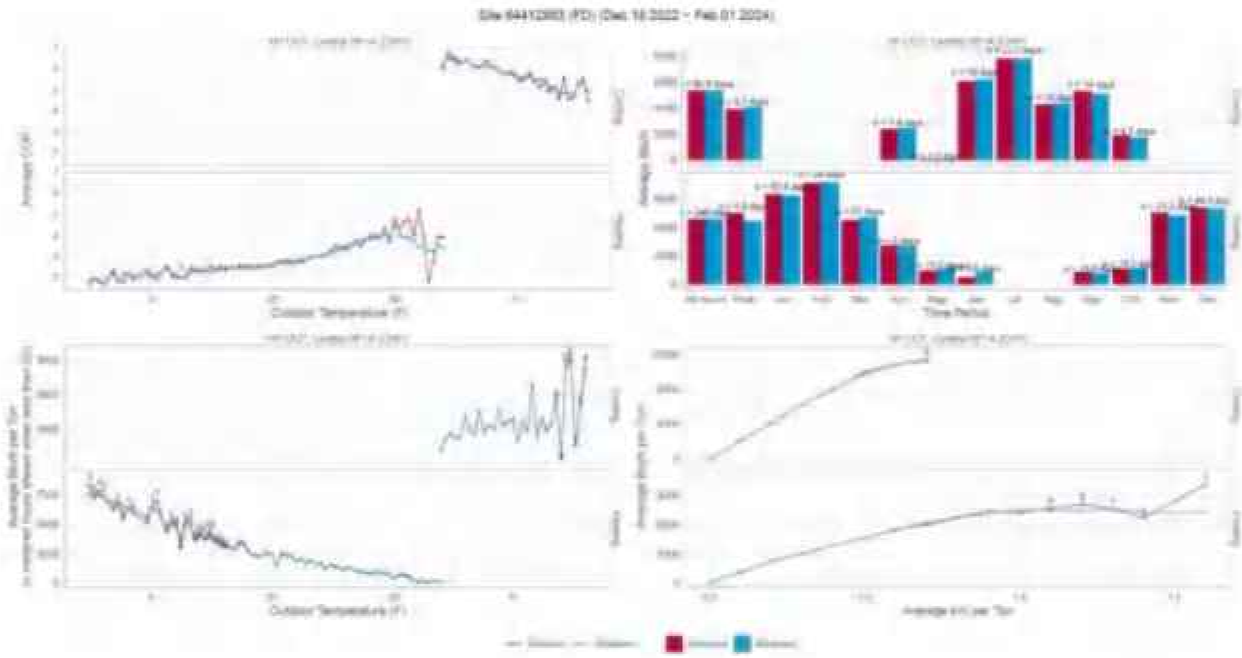
2.5.4.3 Model

Following a similar process used for the usage-modeling, cross-validation was used to test a variety of model formulations for each heat pump system for each mode, including:

- Polynomial terms of input power and HDH/CDH
- Interactions between input power and HDH/CDH, Season, and Rated HSPF/SEER

A similar method was used to select the best model for each system. The fit of the models was confirmed by performing visual inspection of the model predictions across month, outdoor temperature, and input power, with a particular focus on input power (which is expected to be the primary driver of predicted Btu/h). An example performance model QC plot is shown in Figure 2-13.

Figure 2-13. Example Performance Model QC Plot



Source: Evaluation team analysis

In a key deviation from the process used for the usage modeling, aggregate models of heat pump performance were created for each heat pump type (in addition to the system-specific performance models). These aggregate models were used to estimate the typical year heat pump production for systems which did not have performance metering or for which the performance data were insufficient.

2.5.4.4 Predict

After tuning and fitting the performance models using the metered performance data, the predicted, typical year heat pump usage dataset (the output of the previous section) was used along with the same TMYx data previously used as inputs to the models to predict typical year heat pump production. The result of this prediction was hourly estimates of Btu/h heating and cooling production for each heat pump.

It is important to note that these typical-year estimates of heating and cooling production represent the portion of the heating and cooling load met by the heat pump and are not necessarily estimates of the total home heating and cooling loads, which may have been met by other backup or auxiliary systems.

Also note that while the models discussed in this section can be thought of as "performance models" in that they relate energy inputs to energy outputs in the same way any other energy efficiency or performance metrics might, it is important to keep in mind that these models are trained on all available performance data from all operational modes and were tuned specifically for the purpose of estimating the heating and cooling production of the heat pumps given typical-year heat pump usage profiles as inputs. This contrasts with the Performance Results, which in some cases filter the data to specific operational modes (e.g., excluding fan-only or auxiliary heating modes). Although these models use the Performance Data dataset for training and fitting, the outputs of these models were not used for the Performance Results discussed in Section 3.2.

2.5.5 Typical-Year Baseline Usage

After estimating the typical-year heat pump production, the typical year baseline heating and cooling system energy usage that would be necessary to match the typical-year heat pump production was determined.

To estimate baseline energy usage, the modeled Btu/h output for the post-retrofit heat pumps from the prior section was used to estimate the baseline electric and fuel consumption of several baseline system types that would be needed to meet the same Btu/h output as the heat pump.[44]

The following data sources and assumptions were used to inform the baseline equipment efficiency assumptions that Table 2-15 shows.

- **Existing unit efficiency** values are sourced from the most recent Massachusetts Residential Building Use and Equipment Characterization Study (RBUECS), updated in 2023.[45] The existing unit efficiencies are the median unit efficiencies for all HVAC units installed in the 2023 RBUECS onsite metering sample (n=269 sites in onsite sample). The existing unit efficiency values are used for customers who indicate that they would have left their existing HVAC system in place if they did not install the heat pump they did.
- **New unit efficiency** values are sourced from the Massachusetts RBUECS survey data collection and subsequent characterization analysis and are the median efficiency values for all units installed from 2020-2023. These efficiency values are used for customers who indicate that they would have installed an alternative HVAC system if they did not install the heat pump they did. Based on discussions with the Massachusetts PAs, Connecticut EA Team, and EEAC consultants, new unit efficiencies of 15 SEER and 8.8 HSPF for central heat pump based on current code minimum values, and 17 SEER and 9.5 HSPF for mini-split heat pumps were assumed to estimate typical standard efficiencies for mini-split heat pumps available on the market.

[44] Note that the results of this typical-year baseline usage estimation step are estimates of baseline equipment electric and fuel consumption needed to match the estimated production of the heat pump, which is not necessarily equivalent to the whole-home heating and cooling load (especially in the case of partial displacement sites).

[45] The Phase 7 RBUECS for Massachusetts has not been made publicly available at this time of this report submission. The Phase 6 report is available on the MA Energy Efficiency Advisory Council webpage: Guidehouse (2022). "Massachusetts Residential Building Use and Equipment Characterization Study." https://ma-eeac.org/wp-content/uploads/Residential-Building-Use-and-Equipment-Characterization-Study-Comprehensive-Report-2022-03-01.pdf

Assumed derate factors were applied to the rated efficiencies for the purpose of modeling estimated baseline equipment usage, as the situ efficiencies of HVAC equipment are typically lower on average than rated equipment efficiencies. The following derate factors were applied to estimate average derated efficiency:[46]

- Furnaces: 5% derate for existing units, 0% derate for new units
- Boilers: 10% derate for existing units, 5% derate for new units
- Central and Mini-split heat pumps: 20% derate for existing and new units

Table 2-15. Baseline HVAC Unit Efficiency Assumptions*

HVAC Type	Existing Unit Efficiency		New Unit Efficiency	
	Rated	Derated	Rated	Derated
Central AC	13.0 *SEER* 12.4 *SEER2* 11.0 *EER*	10.4 *SEER* 9.9 *SEER2* 8.8 *EER*	15.0 *SEER* 14.3 *SEER2* 11.7 *EER*	12.0 *SEER* 11.4 *SEER2* 9.4 *EER*
Central Heat Pump	13.0 *SEER* 12.4 *SEER2* 11.0 *EER* 7.1 *HSPF* 6.1 *HSPF2*	10.4 *SEER* 9.9 *SEER2* 8.8 *EER* 5.7 *HSPF* 4.9 *HSPF2*	15.0 *SEER* 14.3 *SEER2* 11.7 *EER* 8.8 *HSPF* 7.5 *HSPF2*	12.0 *SEER* 11.4 *SEER2* 9.4 *EER* 7.0 *HSPF* 6.0 *HSPF2*
Mini-Split Heat Pump	20.0 *SEER* 19.0 *SEER2* 12.5 *EER* 11.0 *HSPF* 9.4 *HSPF2*	16.0 *SEER* 15.2 *SEER2* 10.0 *EER* 8.8 *HSPF* 7.5 *HSPF2*	17.0 *SEER* 16.2 *SEER2* 12.0 *EER* 9.5 *HSPF* 8.1 *HSPF2*	13.6 *SEER* 13.0 *SEER2* 9.6 *EER* 7.6 *HSPF* 6.5 *HSPF2*
Ground Source Heat Pump	11.7 *EER* 2.96 *COP*	**	17.1 *EER* 3.65 *COP*	**
Window AC	11.0 *CEER*	8.8 *CEER*	11.3 *CEER*	9.0 *CEER*
Gas Furnace	91.0%	86.5%	96.0%	96.0%
Propane Furnace	91.0%	86.5%	96.0%	96.0%
Oil Furnace	85.0%	80.8%	86.2%	86.2%
Gas Boiler	83.1%	74.8%	95.0%	90.3%
Propane Boiler	83.1%	74.8%	95.0%	90.3%
Oil Boiler	85.0%	76.5%	86.2%	81.9%
Electric Resistance	3.41 *HSPF*	3.41 *HSPF*	3.41 *HSPF*	3.41 *HSPF*

*SEER2 estimated as SEER/1.05, HSPF2 estimated as HSPF/1.17

** GSHPs lack rated seasonal efficiency metrics, so baseline usage was calculated by scaling post-retrofit GSHP usage by the ratio of the rated EER/COP between the post-retrofit and baseline case (effectively assuming that the in-situ efficiency derate was equivalent in both cases)

Source: Massachusetts Residential Building Use and Equipment Characterization Study (2023), evaluation team analysis

[46] Existing unit derate values for furnaces and boilers sourced from Robert Hendron (2006), "Building America Performance Analysis Procedures for Existing Homes - Technical Report," NREL/TP-550-38238. https://www.nrel.gov/docs/fy06osti/38238.pdf. New unit derate values sourced from Cadmus (2015), "High Efficiency Heating Equipment Impact Evaluation," Prepared for the Electric and Gas Program Administrators of Massachusetts. https://ma-eeac.org/wp-content/uploads/High-Efficiency-Heating-Equipment-Impact-Evaluation-Final-Report.pdf
Heat pump unit derate values are estimated based on the average ratio of in situ HSPF to rated HSPF as determined through this study, presented in Section 3.5.

The energy consumption for each baseline equipment type that would be needed to provide the same heating and cooling Btu output as the program-rebated heat pumps at each site were modeled. Afterward, a series of baseline equipment weights were applied to develop the weighted average baseline heating and cooling consumption for each site in the usage sample.

To develop the baseline weights, a series of questions in the primary customer survey were used to determine the baseline heating and cooling equipment type for each survey respondent. The baseline HVAC system types are defined as the systems the customer would have installed if they did not install the heat pump that they did. The customer could have either installed no HVAC system, left their prior system installed, installed an alternative system, or indicate that the installed heat pump was the only HVAC system considered.

The following survey response categories were used to assign the appropriate heating and cooling baseline for each customer:[47]

- **Pre-existing equipment types—**The pre-existing system type is the customer's previous heating and cooling system types. For customers who indicated they had a prior furnace or boiler, the survey asked whether the heat came out of ducts or radiators (and provided a picture example of each type of heat distribution). For customers who indicated their heat is supplied via radiators, the baseline heating system type was assigned as a boiler, irrespective of whether the customer indicated they had a furnace or a boiler. The opposite logic is applied to customers who indicated their heat came out of ducts (the pre-existing heating system type is defined as a furnace).
- **Alternative action—**The alternative action defines what the customer would have installed if they did not install the heat pump that they did. These alternative actions include either taking no action (leaving the existing equipment in place) or installing an alternative system type.

Using the responses to the survey questions, a heating and cooling baseline system type for each unique respondent was assigned before averaging across all respondents to develop baseline weights for each heat pump type. Table 2-16 provides the distribution of baseline cooling equipment types by heat pump type from the customer survey. The no cooling baseline (none) for customers who installed a mini-split heat pump is 52%, indicating that 52% customers did not have pre-existing cooling in their space, and would not have installed an alternative cooling system if they didn't install the heat pump. Per the customer survey, 70% of all customers who installed a mini-split heat pump did not have pre-existing cooling. Existing central ACs are the most common baseline equipment type for customers who installed a CHP or GSHP.

[47] For customers who installed an MSHP, the customer is first asked which space type(s) they installed new heat pump(s), and then a space type is chosen at random by the Qualtrics survey instrument. For the remainder of the survey, the customer is asked to provide their response for the random space chosen by Qualtrics.

Table 2-16. Baseline Cooling Equipment Types and Weights by Heat Pump Type

Existing or New Unit	Baseline Cooling Equipment Type	Central Heat Pump (n=300)	Mini-Split Heat Pump (n=246)	Ground Source Heat Pump (n=62)
Existing Unit	None	16%	52%	8%
	Central air conditioning	37%	8%	31%
	Central heat pump	2%	0%	2%
	Mini-split heat pump	0%	2%	0%
	Room, window, or through the wall air conditioning	1%	13%	2%
	Ground-source heat pump	0%	0%	11%
New Unit	Central air conditioning	30%	10%	19%
	Central heat pump	2%	0%	15%
	Mini-split heat pump	6%	3%	6%
	Room, window, or through the wall air conditioning	6%	13%	6%
Total		100%	100%	100%

Source: Evaluation team analysis

Table 2-17 provides the distribution of baseline heating equipment types for each heat pump type, as determined through the customer survey responses. Additionally, heating weights are also broken out by the pre-existing heating fuel prior to installing the heat pump, as indicated for each customer in the program tracking database.

Table 2-17. Baseline Heating Equipment Types and Weights by Heat Pump Type and Pre-Existing Fuel Type

		Central Heat Pump				Mini-Split Heat Pump				Ground Source Heat Pump			
Unit Type	Baseline Heating Equipment Type	Electric (n=34)	Gas (n=96)	Oil (n=139)	Propane (n=28)	Electric (n=79)	Gas (n=53)	Oil (n=89)	Propane (n=13)	Electric (n=40)	Gas*	Oil (n=19)	Propane*
Existing Unit	CHP	21%	1%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%
	MSHP	0%	0%	0%	0%	3%	0%	0%	6%	0%	0%	0%	0%
	GSHP	0%	0%	0%	0%	0%	0%	0%	0%	20%	0%	0%	0%
	Electric baseboard	21%	0%	0%	0%	58%	2%	0%	3%	0%	0%	0%	0%
	Electric furnace	3%	0%	0%	0%	1%	2%	0%	3%	0%	0%	0%	0%
	Natural gas boiler	3%	17%	1%	0%	0%	49%	0%	0%	0%	5%	0%	0%
	Natural gas furnace	0%	49%	1%	7%	3%	26%	0%	3%	0%	47%	0%	0%
	Oil boiler	12%	0%	25%	0%	4%	2%	42%	0%	8%	0%	16%	0%
	Oil furnace	12%	1%	48%	4%	3%	0%	44%	3%	30%	0%	37%	0%
	Propane/LPG boiler	3%	0%	0%	7%	0%	0%	1%	23%	0%	0%	0%	11%
	Propane/LPG furnace	0%	0%	1%	54%	3%	0%	0%	26%	3%	0%	0%	42%
	Woodstove, pellet stove, or fireplace	3%	1%	1%	0%	9%	0%	1%	9%	0%	0%	0%	0%
New Unit	CHP	6%	5%	3%	7%	1%	2%	3%	0%	8%	32%	32%	32%
	MSHP	6%	5%	6%	0%	1%	2%	0%	3%	8%	11%	11%	11%
	GSHP	0%	0%	0%	0%	0%	0%	0%	0%	3%	0%	0%	0%
	Electric baseboard	0%	0%	0%	0%	4%	2%	0%	0%	0%	0%	0%	0%
	Natural gas boiler	0%	0%	1%	0%	1%	6%	0%	3%	0%	0%	0%	0%
	Natural gas furnace	3%	21%	2%	0%	1%	8%	2%	3%	3%	5%	0%	0%
	Oil boiler	0%	0%	3%	0%	0%	0%	2%	0%	8%	0%	0%	0%
	Oil furnace	3%	0%	6%	0%	5%	0%	2%	0%	5%	0%	5%	0%
	Propane/LPG boiler	3%	0%	1%	0%	1%	0%	0%	6%	0%	0%	0%	0%
	Propane/LPG furnace	3%	0%	2%	21%	1%	0%	0%	11%	8%	0%	0%	5%
	Woodstove, pellet stove, or fireplace	0%	0%	0%	0%	0%	0%	2%	0%	0%	0%	0%	0%
	Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

*Due to low sample, baseline weights for GSHPs with pre-existing oil were assigned to the gas and propane groups, adjusted for proportions of boilers/furnaces.
Source: Evaluation team analysis

Based on discussions with the study sponsors, the study also sought to quantify measure impacts assuming no heat pumps in the baseline assignment weights.

Table 2-18 provides the distribution of baseline cooling equipment types after the heat pump baseline types are removed. The proportion of no cooling baseline was left the same, and the weights for the other non-heat pump equipment types re-weighted to a total of 100% baseline equipment type weight. These weights are used in the alternative scenario for measure impacts.

Table 2-18. Baseline Cooling Equipment Types and Weights by Heat Pump Type – Heat Pump Weight Removed (Alternative Scenario)

Existing or New Unit	Baseline Cooling Equipment Type	Central Heat Pump (n=300)	Mini-Split Heat Pump (n=246)	Ground Source Heat Pump (n=62)
Existing Unit	None	16%	8%	52%
	Central air conditioning	42%	49%	9%
	Central heat pump	0%	0%	0%
	Mini-split heat pump	0%	0%	0%
	Room, window, or through the wall air conditioning	2%	3%	14%
	Ground-source heat pump	0%	0%	0%
New Unit	Central air conditioning	34%	31%	11%
	Central heat pump	0%	0%	0%
	Mini-split heat pump	0%	0%	0%
	Room, window, or through the wall air conditioning	7%	10%	15%
Total		100%	100%	100%

Source: Evaluation team analysis

Table 2-19 provides the distribution of baseline heating equipment types after the heat pump baseline types are removed. The weights for the non-heat pump equipment types were re-weighted to a total of 100% baseline equipment type weight. These baseline weights are used to explore an alternative scenario for measure impacts estimation; results are provided in Section 6.

Table 2-19. Baseline Heating Equipment Types and Weights by Heat Pump Type and Pre-Existing Fuel Type – Heat Pump Weight Removed (Alternative Scenario)

		Central Heat Pump				Mini-Split Heat Pump				Ground Source Heat Pump			
Unit Type	Baseline Heating Equipment Type	Electric (n=34)	Gas (n=96)	Oil (n=139)	Propane (n=28)	Electric (n=79)	Gas (n=53)	Oil (n=89)	Propane (n=13)	Electric (n=40)	Gas*	Oil (n=19)	Propane*
Existing Unit	CHP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	MSHP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	GSHP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Electric baseboard	30%	0%	0%	0%	62%	2%	0%	3%	0%	0%	0%	0%
	Electric furnace	4%	0%	0%	0%	1%	2%	0%	3%	0%	0%	0%	0%
	Natural gas boiler	4%	19%	1%	0%	0%	51%	0%	0%	0%	9%	0%	0%
	Natural gas furnace	0%	55%	1%	8%	3%	28%	0%	3%	0%	82%	0%	0%
	Oil boiler	17%	0%	28%	0%	4%	2%	43%	0%	12%	0%	27%	0%
	Oil furnace	17%	1%	53%	4%	3%	0%	45%	3%	48%	0%	64%	0%
	Propane/LPG boiler	4%	0%	0%	8%	0%	0%	1%	25%	0%	0%	0%	18%
	Propane/LPG furnace	0%	0%	1%	58%	3%	0%	0%	28%	4%	0%	0%	73%
	Woodstove, pellet stove, or fireplace	4%	1%	1%	0%	10%	0%	1%	9%	0%	0%	0%	0%
New Unit	CHP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	MSHP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	GSHP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Electric baseboard	0%	0%	0%	0%	4%	2%	0%	0%	0%	0%	0%	0%
	Natural gas boiler	0%	0%	2%	0%	1%	6%	0%	3%	0%	0%	0%	0%
	Natural gas furnace	4%	24%	2%	0%	1%	8%	2%	3%	4%	9%	0%	0%
	Oil boiler	0%	0%	3%	0%	0%	0%	2%	0%	12%	0%	0%	0%
	Oil furnace	4%	0%	6%	0%	5%	0%	2%	0%	8%	0%	9%	0%
	Propane/LPG boiler	4%	0%	1%	0%	1%	0%	0%	6%	0%	0%	0%	0%
	Propane/LPG furnace	4%	0%	2%	23%	1%	0%	0%	13%	12%	0%	0%	9%
	Woodstove, pellet stove, or fireplace	0%	0%	0%	0%	0%	0%	2%	0%	0%	0%	0%	0%
	Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

*Due to low sample, baseline weights for GSHPs with pre-existing oil were assigned to the gas and propane groups, adjusted for proportions of boilers/furnaces.

Source: Evaluation team analysis

2.5.6 Seasonal Heat Pump Performance

The performance and usage models described in Sections 0 and 2.5.4 were used to calculate the typical year heat pump usage and output at the system level. The operational cooling seasonal efficiency, Season Energy Efficiency Ratio (SEER), was calculated by taking the modeled cooling output of the heat pump over the TMYx cooling season and dividing by the total energy used in the cooling season. For this portion of the analysis the cooling season was defined as June to September.

The heating seasonal efficiency, Heating Seasonal Performance Factor (HSPF) was calculated by taking the modeled heating output of the heat pump over the TMYx heating season and dividing by the total energy used in the heating season. For this portion of the analysis the heating was defined as November through March.

Seasonal heat pump performance is compared to rated SEER/HSPF and SEER2/HSPF2. As of January 1, 2023, the United States Department of Energy (DOE) updated the minimum energy efficiencies standards for central and ductless heat pumps to use SEER2, EER2, and HSPF2 to better represent real world performance. Due to changes in the test procedure, the new versions of the metrics have a lower numerical value. The updated test method and can be found in the Code of Federal regulations, Title 10, Chapter II, Subchapter D, Part 430, subpart B, appendix M1.[48]

2.5.7 Measure Impacts

Measures are defined as the installation of a heat pump (central heat pump, mini-split heat pump, ground source heat pump) to displace a pre-existing heating system using electric resistance, fuel oil, propane, or natural gas fuel types.

As discussed in the prior section, the baseline heating or cooling systems are not necessarily the customers pre-existing system type, but rather what the customer would have installed or used to heat and cool their home if they didn't install the heat pump they did.

To calculate measure impacts, typical-year heat pump usage was subtracted from the modeled typical-year baseline usage. These measure impacts were calculated at the site level and then aggregated to the stratum and measure level for various reporting outputs.

2.5.8 Heating Load Proportions

To determine the proportion of the heating load met by the heat pumps and backup heating systems,[49] the modeled heating performance data was used to develop models of the home heating load. Analysis was performed using data for all 169 sites that had usage data which passed the QC checks and included 106 FD sites as well as 63 PD sites.

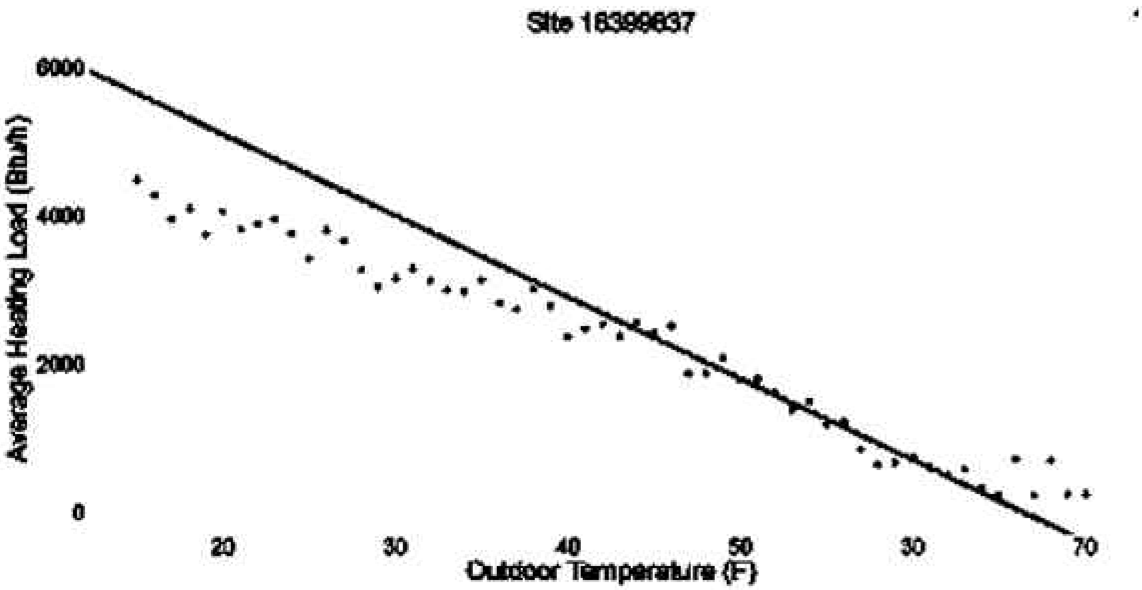
[48] Code of Federal Regulations (2024). "Appendix M1 to Subpart B of Part 430—Uniform Test Method for Measuring the Energy Consumption of Central Air Conditioners and Heat Pumps." https://www.ecfr.gov/current/title-10/chapter-II/subchapter-D/part-430/subpart-B/appendix-Appendix%20M1%20to%20Subpart%20B%20of%20Part%20430

[49] The secondary heating systems encompass both backup heat (boilers, furnaces, wood stoves, baseboard heating, space heaters) and auxiliary heating (integrated electric resistance heating built into the air handler).

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.[50]

An example site heating load model is shown in Figure 2-14, with the points representing average heat pump load, and the line representing the modeled whole home load. The heat pump appears to meet the heating load for this site down to roughly 42°F, below which point a portion of the load is met by the backup heating system.

Figure 2-14. Example Site Heating Load Model with Backup Heating



Source: Evaluation team analysis

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.

[50] This method assumes a constant thermostat setpoint, and thus there is some error introduced in cases where the site implements a nighttime setback.

The next step was to perform QC checks on the site-level results. Several cases were identified in which this method did not produce accurate results, and these sites were removed from the analysis:

- Sites where the heat pump never appeared to meet the full load, based on the metered backup systems data (6 sites)
- Sites that were identified as full displacement of a partial home (10 sites)

In both of these cases it was not possible to estimate the total home heating load, and so this method was not appropriate for determining load proportions.

Additionally, in cases of full displacement installations where the backup systems data and the customer survey responses indicated no backup system usage (or no backup system installed), the load proportion for other systems was set to 0 and the load was split proportionally between heat pump and auxiliary heat. For these sites, it was assumed that any backup heating load shown was due to inaccuracies in the models (e.g., due to the presence of a nighttime setback) rather than backup heating usage.

For a small subset of sites, the models indicated that the proportion of the load met by the heat pump dropped at high temperatures, which is most likely due to the limitations of the model[51], rather than actual backup heat usage at high temperatures. For these sites, the modeled result was adjusted by not allowing the heat pump load proportion to drop at temperatures above 40°F, replacing it with the load proportion from the next coldest temperature bin in cases where it did.

After these adjustments were performed, the site-level load proportions were averaged across sites to determine the average load proportions by temperature bin for each heat pump type and displacement type.

Lastly, typical year seasonal load proportions met by each system type were derived for each site. The load proportions were summarized across the heating season for each site by taking a weighted average, weighting by the total site load in each temperature bin. Finally, the seasonal load proportions for each site were averaged across sites by heat pump type and displacement type.

[51] This could be explained by the site using their heating system intermittently or with a different setpoint at higher temperatures during the shoulder season, which would result in the effective home load being lower on average at high temperatures.

3. Heat Pump Performance Results

This section provides heat pump performance results, including seasonal performance metrics, heat pump performance and efficiency by outdoor air temperature, and performance at the lowest outdoor air temperatures during the metering period.

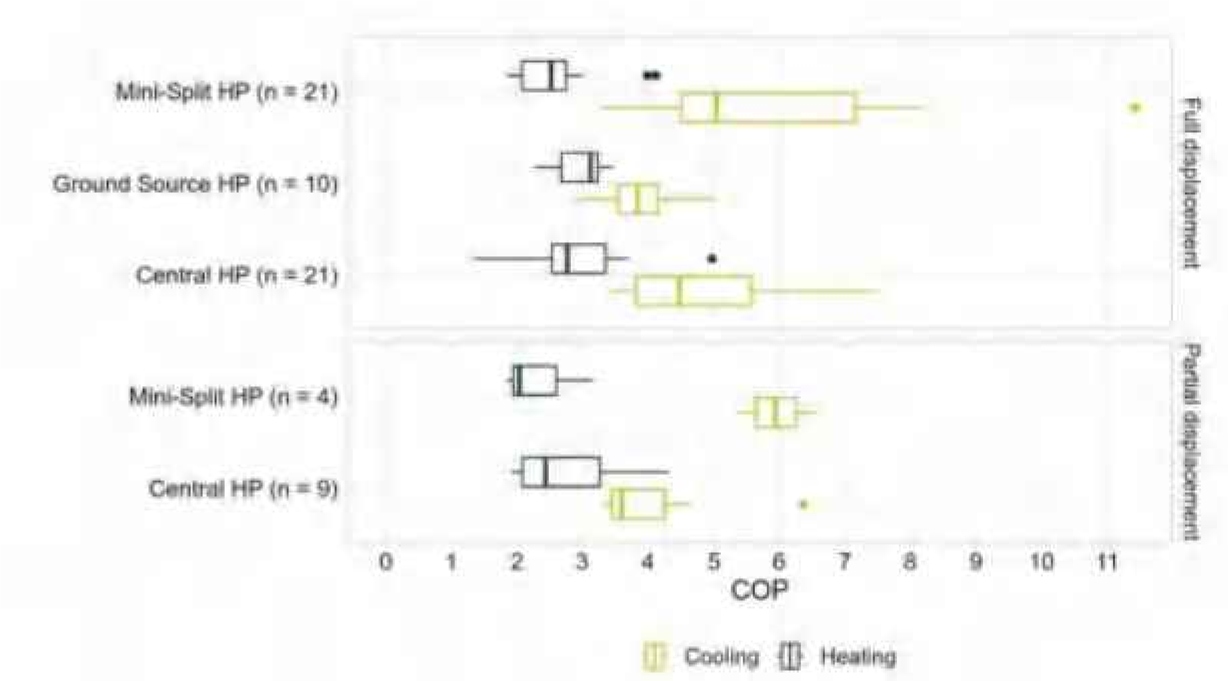
Key Findings Across Performance Analysis:

- Across the metered systems included in the heat pump performance analysis, average CHP heating coefficients of performance (COPs) by temperature ranged from 2.0 at -10°F to 3.5-4.0 at 60°F and the cooling COPs ranged from 3.8-4.0 at 90°F to 4.9-5.1 at 65°F. Average MSHP COPs by temperature ranged from 1.5-2.0 at 10°F to 3.5-4.0 at 60°F and the cooling COPs ranged from 4.0-7.0 at 90°F to 5.0-7.5 at 65°F. GSHPs had a stable COP around 3.0 across the entire heating season and a stable COP around 4.0 across the entire cooling season. The COPs discussed in this section are calculated when the system is either cooling or heating with the compressor. Energy from auxiliary heating and defrost mode operation was not included in the operational COP calculations.
- Many of the metered heat pumps were able to maintain heat delivery during the cold snap on February 3-4, 2023. For heat pump units that operated below 5°F, system level average COP for compressor-on operation varied between 1.6 and 2.3 for CHPs, and 1.9 and 2.2 for MSHPs across the -10°F to 5°F temperature range.
- Of sites with CHPs, 31% had auxiliary electric resistance heating installed. Of these sites, 78% used any auxiliary heating during the metered period, and 44% used auxiliary heating under 15°F to meet at least 25% of the home's heating load.
- Of sites with GSHPs, 80% had auxiliary electric resistance heating installed. Only 1 of 18 GSHP sites used auxiliary heat during the metered period.
- Weather normalized seasonal efficiency values (HSPF and SEER) were typically lower than rated efficiency metrics (HSPF and SEER/SEER2). Seasonal efficiency values were in line with rated HSPF2 on average.

3.1 Average Operational COP

Figure 3-1 shows the distribution of heat pump system average COP during compressor-on periods across heating and cooling periods by heat pump type and displacement type. Average compressor-on COPs for CHP and MSHP equipment are between 2.0 and 3.0, and for GSHP equipment, slightly above 3.0. Cooling season COPs show wider variation and generally fall between 3.5 and 4.5 (MSHP partial displacement stratum average is 6.0 COP, however with low sample size).

Figure 3-1. Distribution of Operational COP (Compressor-On Periods)



Note: This plot shows compressor-on operation from the metering period. Systems with less than 20 hours of heating or cooling operation are not included in this plot. The box and whisker plots show the mean value as a solid vertical line in the boxes. The boxes show the interquartile range between 25% and 75% of observed values, and the lines outside of the box show the remaining distribution of the values for the respective stratum. Outliers are shown as individual points.

Based on full metered sample and program data designation of displacement type

Source: Evaluation team analysis

3.2 Performance by Temperature

This section outlines heat pump performance as a function of outdoor air temperature. Analysis results are shown in Figure 3-2, demonstrating that:

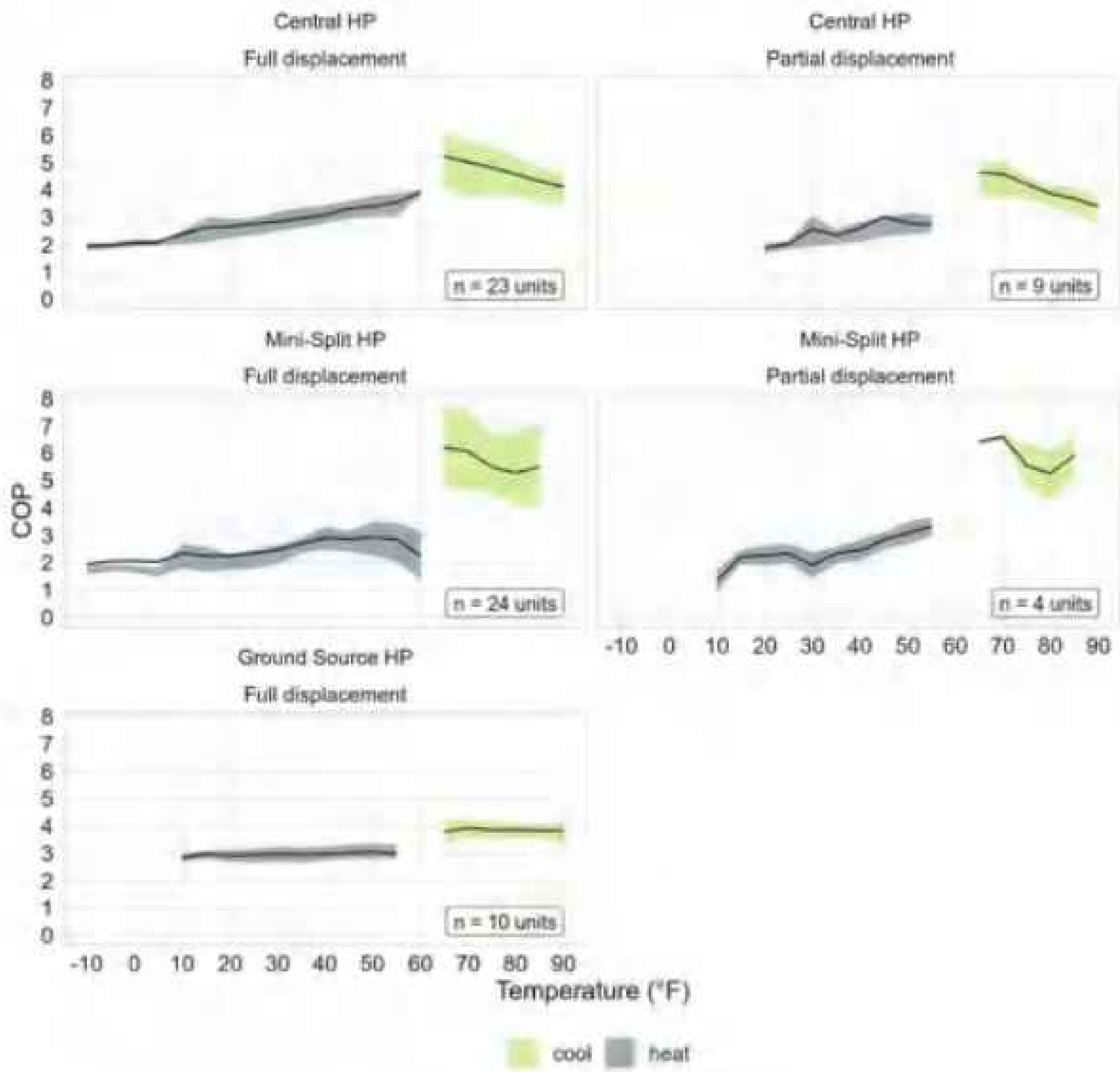
- Both CHPs and MSHPs exhibit outdoor air temperature dependent performance. As expected, system heating COP is higher during warmer portions of the winter season and the system cooling COP is higher during cooler portions of the summer season.
- Across all units, the average heating COPs for CHPs ranged from 2.0 to 3.5 across the outdoor air temperature range, and the cooling COPs ranged from 4.0 to 4.9. MSHP COPs ranged from 2.0 to 3.0 and the cooling COPs ranged from 5.0 to 6.5 across the outdoor air temperature range.
- GSHPs have a stable COP around 3.0 across the entire heating season and a stable COP around 4.0 across the entire cooling season. As expected, GSHP COPs show less outdoor air temperature dependence than air source heat pump type, because the temperature of the ground is more stable across the seasons.

The COP was calculated for heat pumps at sites with sufficient performance data. Using the methodology described in Section 2.5.2, periods when the heat pump systems were heating or cooling were identified, and the energy removed or delivered to the indoor space was calculated. This portion of the analysis only includes periods of time where the compressor was in operation. Weather station data from the metering period was used to summarize data into 5-degree temperature bins.

The operational COP shown in Figure 3-2 was estimated by first calculating the production-weighted COP for each heat pump system for each five-degree temperature bin. Production-weighted COP is the sum of all energy produced in a temperature bin divided by all energy consumed in that temperature bin.

Then, the mean, twenty-fifth, and seventy-fifth percentiles of the system-specific COPs were calculated for each temperature bin. The black line in Figure 3-2 is the mean COP across all systems. The shaded ribbon is the interquartile range (IQR)—showing the range between the 25th and 75th percentile of units. Because not all heat pumps had data available for all temperature bins, the sample size represented by the summary statistics for each temperature bin varies over the range of temperatures. The width of the IQR is a useful proxy for the range of system-level estimates. The sample sizes included in the captions of the figure highlight the maximum numbers of units with data at a single temperature bin for the respective strata. The figure was generated in this way because not all sites experienced the same range of outdoor temperatures and the usage patterns for each site were different. The sample sizes presented in the plot are representative for the majority of temperature bins, but there was some drop off at the low and high ends of each curve.

Figure 3-2. Heat Pump COP vs. Outdoor Air Temperature



The evaluation team did not observe PD GSHP sites during the metering period. Note: This plot shows compressor-on operation from the metering period and is not weather normalized. Compressor-on operation does not include periods of time where the unit is in defrost mode, when the unit is operating in fan-only mode, or the unit is 'off'. Seasonal efficiencies for CHPs and MSHPs include all of these operating modes, which has a negative impact on the efficiency value. GSHPs do not need a defrost mode, so their seasonal efficiencies are impacted less.

Based on full metered sample and program data designation of displacement type

Source: Evaluation team analysis

3.3 Heating and Cooling Btu Output by Temperature During Compressor-On Periods

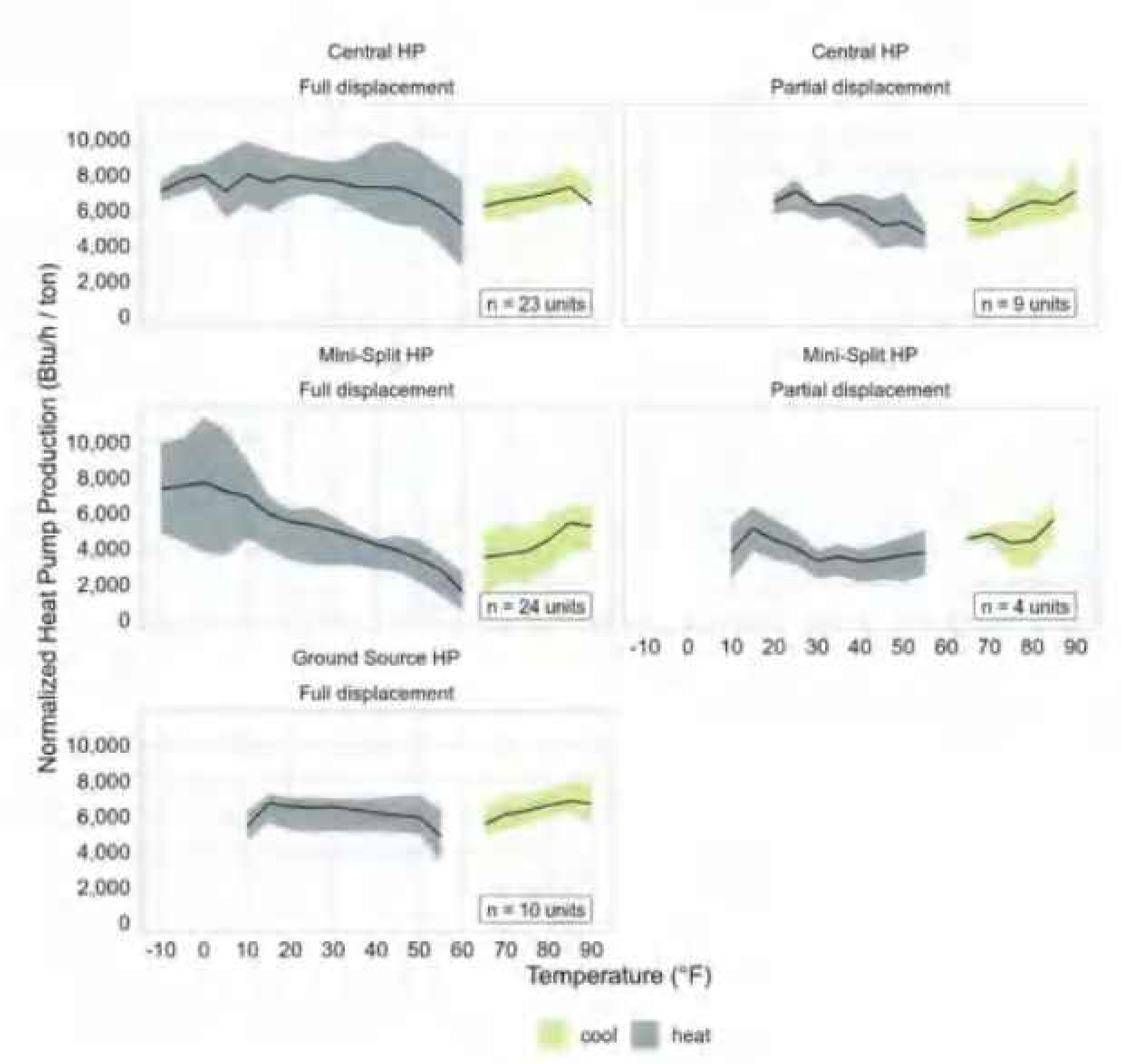
In addition to the COPs, the average heating and cooling output per ton for each stratum was also calculated. The heating and cooling output were calculated during compressor-on periods only and is therefore the average Btu/h output during the compressor-on periods in each temperature bins. This analysis did not summarize the total Btu delivered by the system in the temperature bin, which would multiply the average Btu/h delivered by the unit runtime. The results in Figure 3-3 show that:

- Across the metered period, the average Btu/h during times when the compressor was on did not show significant temperature dependence for FD CHP and GSHP systems, except for FD CHPs where the Btu/h declined at higher temperatures.
- Average Btu/h output during compressor operation for PD MSHPs remained relatively flat as temperature decreased. MSHPs are often installed to serve parts of homes or specific rooms, so there is not as clear of a drop-off in output with temperature. These systems can be toggled on and off as needed.
- FD MSHPs are the only system that show a significant change in average heating output with a change in temperature. Many MSHPs in the sample are multi-zone systems, which operate a subset of indoor heads depending on customer behavior and needs.[52] These systems are operating with multiple thermostats, thus have the ability to control different spaces to differing setpoints. At higher temperatures, only 1 or 2 heads in main living spaces may be on, but at lower temperatures, all heads might be on in both main living spaces and secondary spaces, such as bedrooms. This would cause a much higher Btu/h output at the lowest temperatures. The average number of indoor heads per MSHP outdoor unit in the metered sample was 2.54, and the maximum indoor units attached to one outdoor unit was 6.

The energy produced by the system at the minute level was calculated for each temperature bin, then the energy produced was normalized by the rated tonnage of each system and divided by the number of hours of data in that temperature bin to generate a normalized output for each temperature bin for each system. Like the COP curves, Figure 3-3 shows the mean, twenty-fifth, and seventy-fifth percentiles of the system-specific average outputs for each temperature bin. The black line is the mean across systems. The shaded ribbon is the interquartile range (IQR).

[52] In the metered sample, the average number of indoor heads for every outdoor unit for multi-split MSHP systems was 3.1.

Figure 3-3. Btu/h Output vs. Outdoor Air Temperature During Time of Compressor-On Operation



Note: This plot shows average Btu/h delivered during time periods of compressor-on operation, using the metered data

Based on full metered sample and program data designation of displacement type

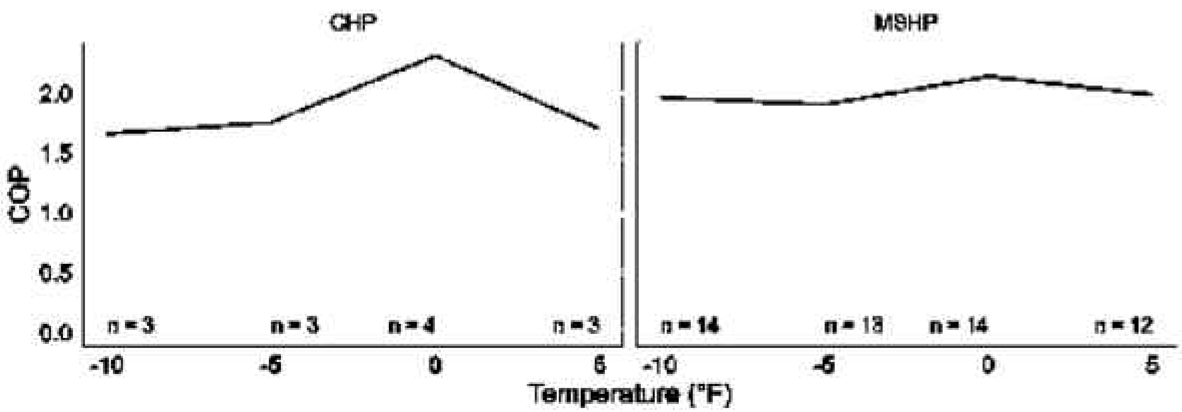
Source: Evaluation team analysis

3.4 Cold Temperature Performance

This section details heat pump operational performance in the coldest outdoor air temperatures, using data available from 20 sites. The results in this section provide compressor-on COPs and do not include the impacts of auxiliary heating or periods of time when the unit is in defrost mode. Friday and Saturday, February 3rd and 4th, 2023, were the only days in the study metering period with temperatures below 0°F. Temperatures on those days dropped to as low as -12°F. Figure 3-4 shows the average performance of five CHP and 15 MSHP units during this temperature range. These results show that:

- For those sites with heat pumps operating in heating mode (compressor-on, no defrost, no auxiliary heat) below 5°F, average system-level COP varied between 1.6 and 2.3 for CHPs, and 1.9 and 2.2 for MSHPs within this outdoor air temperature range. However, multiple sites began to use backup or auxiliary heating at these low temperatures. Findings for auxiliary heat usage are detailed in Section 3.4.1, and for backup heating systems in Section 4.3.

Figure 3-4. Heat Pump Performance below 5°F (Heating Mode Only)



Note: This plot shows compressor-on operation using metered data. Compressor-on operation does not include periods of time where the unit is in defrost mode, when the unit is operating in fan-only mode, or the unit is 'off'. Seasonal efficiencies for CHPs and MSHPs include all of these operating modes, which has a negative impact on the efficiency value.

Source: Evaluation team analysis

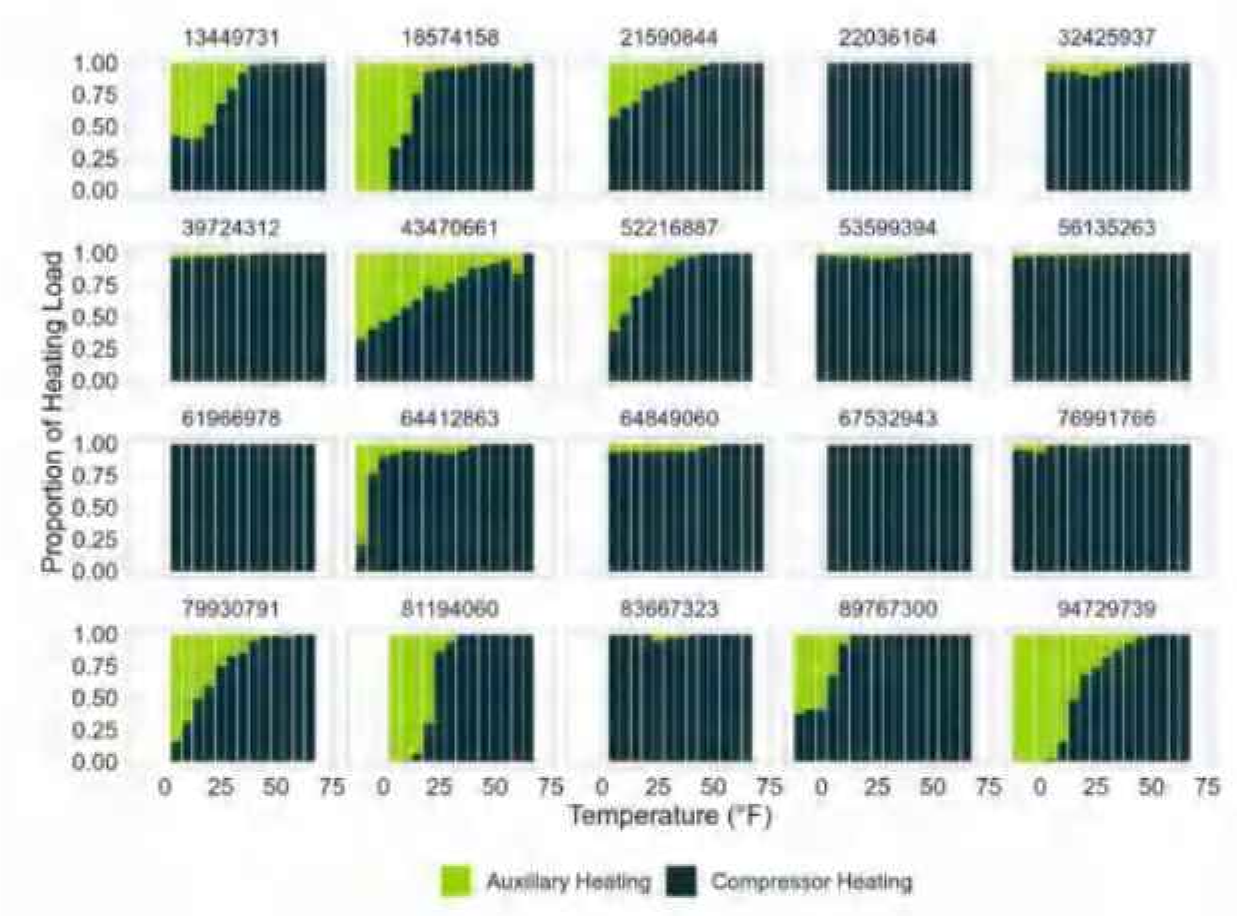
3.4.1 Auxiliary Strip Heat Usage

Some heat pumps are installed with electric resistance elements that are used to supplement heat pump heating at colder temperatures (auxiliary heating). This section summarizes auxiliary usage for the sites included in the "usage sample", which did not receive additional performance monitoring. There are a higher number of sites in the usage sample than the performance sample, as outlined in Section 2.5.1. Of the sites in the usage sample, there were 20 CHPs, 18 GSHPs, and one MSHP with auxiliary electric resistance heating installed and metered. The study looked at the proportion of the heating load met by the heat pump vs. the auxiliary electric heating.

From Figure 3-5 and Figure 3-6 and comparing with the total number of usage sites with data collection available from the onsite sample, we find that:

- 20 out of 60 (33%) of CHP sites had auxiliary heating installed. Of those 20 with auxiliary heating, 15 (75%) used their auxiliary heating during the metered period. Nine of the 20 sites (45%) had periods of time below 10°F-15°F where over 25% of the heat load was provided by auxiliary heating.
- 18 out of 22 (82%) of GSHP sites in the usage sample had auxiliary heating installed. Only one site (5.6%) showed any usage of the auxiliary heating during the metered period.
- One out of 71 (1.4%) MSHP usage sites had auxiliary heating installed, but it was not used.[53]

Figure 3-5. Auxiliary Heat Use vs. Outdoor Air Temperature - CHP Sites



Note: This plot shows compressor and auxiliary heating operation using actual meteorological year data. Some sites had data collection during Winter 2022-2023 with outdoor air temperatures below 0°F, other sites only captured data during Winter 2023-2024 where temperatures only dropped to ~15°F.

Source: Evaluation team analysis

[53] While these sites are categorized as MSHP in the program data, they are twin/combo systems, with both a MSHP and a CHP with an air handling unit.

Figure 3-6. Auxiliary Heat Use vs. Outdoor Air Temperature - GSHP Sites

Note: This plot shows compressor and auxiliary heating operation using actual meteorological year data. Some sites had data collection during Winter 2022-2023 with outdoor air temperatures below 0°F, other sites only captured data during Winter 2023-2024 where the lowest temperatures observed were approximately 15°F.

Source: Evaluation team analysis

3.5 Seasonal Performance

Unlike the COPs discussed in Section 3.2, which only considered compressor-on performance, the operational seasonal efficiency metrics shown in the Table 3-1 and Table 3-2 below account for all energy consumed and produced by the systems across all modes of operation.[54] Table 3-1 and Table 3-2 show the modeled operational seasonal efficiencies compared to the manufacturer rated HSPF and SEER, respectively. The values in the table are shown as simple averages of the systems included in each stratum. For the methodology used, reference Section 2.5.6.

[54] Seasonal efficiencies include all heat pump consumption across all modes of operation, including heating, cooling, fan only, defrost, standby, dehumidification, and integrated auxiliary electric heat.

Key findings include:

- For CHPs, the in-situ HSPF was generally lower than rated HSPF[55] but equal to or higher than HSPF2.
- In situ MSHP HSPF was lower than both HSPF and HSPF2 ratings.
- Across CHP and MSHP, the in-situ SEER was lower than both the rated SEER and SEER2.
- The GSHP in situ HSPF (9.7) was higher than CHP or MSHP while modeled SEER (11.6) was lower.[56]

Table 3-1. Heating Seasonal 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 (n)
Central Heat Pump	FD	9.3	10.3	9.0	6.8	42
	PD	8.8	10.1	8.8	6.6	36
	CHP Combined	**9.1**	**10.3**	**8.9**	**6.7**	**78**
Mini-Split Heat Pump	FD	9.1	11	10.0	7.8	67
	PD	9.8	11.4	10.3	7.9	42
	MSHP Combined	**9.3**	**11.1**	**10.1**	**7.8**	**109**

*Region IV HSPF2 values that were missing from manufacturer documentation were estimated as HSPF/1.17. Missing Region V HSPF2 values were estimated based on the relationship of Region IV HSPF2 to Region V HSPF2 for similar unit types.

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 (including fan-only operation) and are weather normalized.

Based on full metered sample and program data designation of displacement type

Source: Evaluation team analysis

[55] Standard heat pump rating conditions are defined in AHRI Standard 210. Rated HSPF is calculated using weighting factors to reflect seasonal operation across a range of temperatures. Rating conditions have changed between HSPF and HSPF2 and there are also different weighting factors used for different regions. The results here show the metered in field performance compared to various equipment ratings.

[56] Ground source heat pump efficiencies are not listed in Table 3-1 or Table 3-2. GHSPs are not covered by the same rating metrics as CHP and MSHP, and thus it is not possible to make the same comparison with in-situ seasonal efficiency. Instead of seasonal performance efficiencies, GSHP heating and cooling performances are rated with COP for heating and energy efficiency ratio (EER) for cooling.

Table 3-2. Cooling Seasonal Performance Results vs. Rated

System Type	Displacement Scenario	Average In Situ SEER	Average Rated SEER	Average Rated SEER2*	Systems included (n)
Central Heat Pump	FD	15.1	18.7	17.7	44
	PD	14.2	18.4	17.5	35
	CHP Combined	**14.7**	**18.5**	**17.6**	**79**
Mini-Split Heat Pump	FD	18.5	20.2	20.3	64
	PD	19.1	20.6	20.6	42
	MSHP Combined	**18.7**	**20.4**	**20.4**	**106**

*SEER2 values that were missing from manufacturer documentation were estimated as SEER/1.05.

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

Based on full metered sample and program data designation of displacement type

Source: Evaluation team analysis

Manufacturer rated seasonal efficiencies for central and mini-split heat pumps are generated using lab tested measurements at a variety of test conditions to mimic real word performance. However, these procedures may not match the conditions found in actual field operation. Factors that potentially contribute to these differences between modeled efficiency and manufacturer rated efficiency include:

- Amount of time spent in defrost and fan-only modes
- Short cycling at low loads
- Variation in user operational profiles
- Condenser installation details (e.g., direct sun, impeded airflow, soiling on heat exchangers, etc.)
- Potential maintenance issues, such as low refrigerant charge, dirty air filters, or other installation issues
- Differences in the annual temperature profile between actual year and assumptions for the climate region IV and region V HSPF2 and SEER2 calculations.
- Manufacturer reported HSPF2 values are also dependent on the region used to calculate the building load. The standard HSPF2 value for central and MSHPs are based on climate region IV.

- Manufacturer rated efficiencies for ground source heat pumps are generated using lab tested measurements at single point test conditions. The modeled efficiency in this study includes all modes of operation and is weather normalized.

- Increased fan power from in situ static pressure characteristics. Manufacturer efficiency ratings for ground source heat pumps are generated by testing with no external static pressure. The correction factor to account for this underestimates fan power by 50%.

- Average pump power and runtimes were higher than expected for GSHPs. This may be caused by a relatively low average ground loop temperature delta observed in the metered data (ranged between 2°F-6°F), which may lead to higher runtimes and low rates to generate the required heat transfer for these systems.

4. Heat Pump and Backup System Usage Results

This section provides results for heat pump and backup system usage, heat pump peak demand, and backup system controls. In this report, backup system (or "secondary system") is used to refer to separate conditioning systems independent from the heat pump. This includes systems like boilers, furnaces, wood stoves, baseboard heating, and space heaters. Integrated, auxiliary heating (i.e., electric resistance strip heat) is treated separately.

4.1 Heat Pump Usage

This section provides results for the heat pump usage analysis, including average usage at the stratum level (heat pump type and displacement type), and observations of heat pump usage across sites in the metered sample.[57]

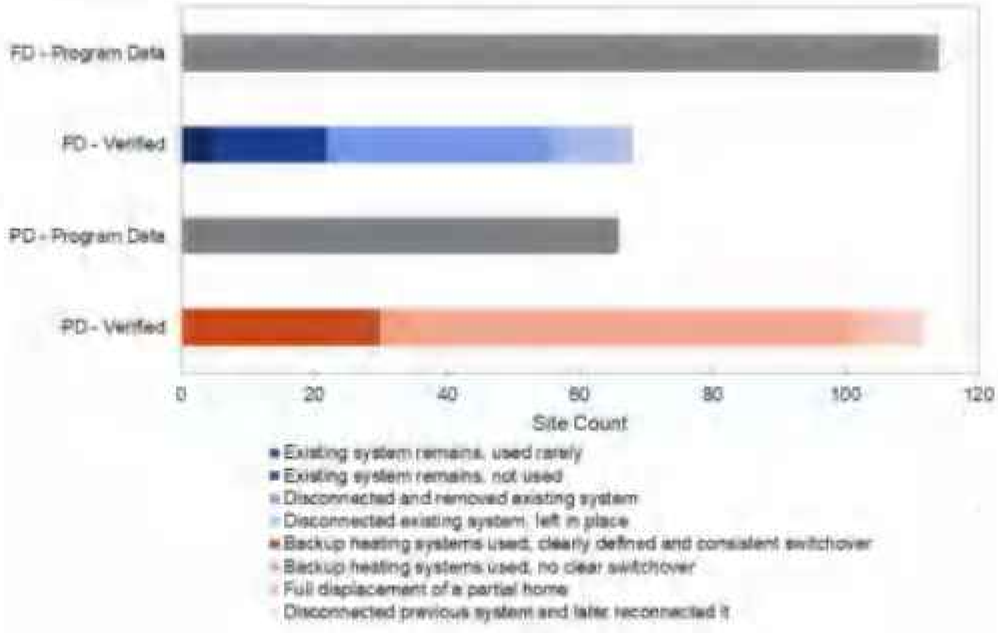
Key Findings:

Full Displacement Sites

Many customers with FD installs used their heat pumps less than anticipated, including many sites that used backup heating systems to meet part of the heating loads for the home. Figure 4-1 shows a summary of the program data displacement categorization and the field-verified displacement categorization for sites across the metered sample, including observations of usage of backup heating systems. Forty-eight of 114 sites (42%) FD sites appear to use backup heat for at least a portion of the heating loads, leading to about 8-10% of heating season load being met by backup heating systems across all FD sites (about 90% of heating load is met by the heat pump in FD installations for CHP and MSHP and nearly all of the heating load is met by heat pump in FD installations for GSHP).

[57] In this report section, the full displacement and partial displacement classification is based on the measure names for each sampled customer from the program tracking databases in Massachusetts and Connecticut (based on the 2021-2022 measure naming convention and program requirements)..

Figure 4-1. Program Data vs. Verified Displacement Type Across Metered Sample



Source: Evaluation team analysis

Partial Displacement Sites

The team cross referenced multiple survey response and metered data. Several customers with PD installs used their heat pumps less than anticipated within the zones they were intended to condition. As a result of the on-site data analysis, the team found that the seven sites with the lowest heating usage are all sites where the heat pump is used either mostly or fully for cooling only. The reasons for this differ from setting very high switchover temperatures for heating, to the customer being concerned about high electricity costs, to the heat pump only being purchased with the intent of using it for cooling.

There is wide variability in heat pump usage between sites, even when normalizing usage per ton of installed heat pump cooling capacity. Beyond the findings provided above, there does not appear to be a common theme for low-usage homes between heat pump type, home size, age of home, thermostat setpoint, occupancy, or weatherization status.

Stratum-level HP usage is provided in Section 0, and site-specific usage findings are included in Section 4.1.2 below.

4.1.1 Heat Pump Usage by Stratum

Table 4-1 shows the average heat pump usage per home by stratum, while

Table 4-2 shows average heat pump usage normalized per ton by stratum. Those who installed CHPs and MSHPs for FD had the highest electric usage when normalized by rated cooling tonnage. However, those who installed GSHPs had the highest annual electric usage for the whole home, since those systems had considerably higher rated tonnage, and were typically sized to meet the whole home load while CHPs and MSHPs relied on integrated electric auxiliary heat and backup heating systems. PD installations had lower annual electric usage, as expected.

Table 4-1. Average Heat Pump Usage (Per Home)

System Type	Displacement Scenario	Average Heating Season Usage Total (kWh)	Average Heating Season Usage Auxiliary Heat (kWh)*	Average Cooling Season Usage (kWh)	Average Annual Usage (kWh)	Relative Precision on Annual Usage**	Average Heat Pump Capacity Per Home (Tons)	Average Home Square Footage (SF)	Tons/ 1,000 SF
Central Heat Pump	FD	5,558	536	1,055	6,612	13%	3.72	2,016	1.84
	PD	4,458	43	1,239	5,697	20%	4.43	2,716	1.63
Mini-Split Heat Pump	FD	5,167	0	783	5,950	16%	3.47	1,791	1.94
	PD	3,224	0	701	3,925	25%	2.98	1,872	1.59
Ground Source Heat Pump	FD	7,189	21	1,403	8,593	16%	6.00	2,803	2.14

Note: *different strata have different average home sizes*
*Auxiliary electric heating usage is a subset of the total heating season usage
**Relative precision calculated at the 90% confidence interval, two-tailed
Based on full metered sample and program data designation of displacement type
Source: Evaluation team analysis

Table 4-2. Average Heat Pump Usage (Per Ton)

System Type	Displacement Scenario	Average Heating Season Usage Total (kWh)	Average Heating Season Usage Auxiliary Heat* (kWh)	Average Cooling Season Usage (kWh)	Average Annual Usage (kWh)	Relative Precision on Annual Usage**	Average Heat Pump Capacity Per Home (Tons)
Central Heat Pump	FD	1,547	145	284	1,831	12%	3.72
	PD	1,027	9	323	1,350	18%	4.43
Mini-Split Heat Pump	FD	1,537	0	238	1,774	14%	3.47
	PD	1,219	0	231	1,450	20%	2.98
Ground Source Heat Pump	FD	1,220	4	222	1,442	13%	6.00

*Auxiliary electric heating usage is a subset of the total heating season usage

**Relative precision calculated at the 90% confidence interval, two-tailed

Based on full metered sample and program data designation of displacement type

Source: Evaluation team analysis

4.1.2 Heat Pump Usage by Site

The data collected from each site was carefully reviewed to understand the drivers for lower or higher than anticipated usage. This included cross-examination of the site-specific usage and performance model results, customer primary survey, end of season survey and fast feedback interview responses, as well as data collected by the field team during install visits and revisits.

Figure 4-2, Figure 4-3, and Figure 4-4 show the post-retrofit heat pump usage normalized per ton of cooling capacity. The dashed line shows the average kWh/ton per stratum. Post-retrofit heat pump usage varies widely across the metered sample.

The team characterized drivers for low usage sites based on review of the site-specific data. While this list is not exhaustive of all sites with these potential drivers, the team identified sites with clear drivers along the categories below:

- **Mostly cooling (blue dot)—**The four lowest usage PD CHP sites and the two lowest usage PD MSHP sites use the heat pump mainly for cooling with little-to-no heating. In these sites, the heat pump is used mainly for cooling with little-to-no heating usage.
- **High switchover temperatures or manual override (orange dot)—**Eight of the low usage sites, mostly PD, were identified as having very high switchover temperatures, of 40-45°F. Three of these sites were categorized as FD in the program data (one for CHP, two for MSHP). On some PD sites, customers indicated that they manually turn the system on/off whenever heat is needed.
- **Partial home (purple dot)—**Some heat pumps were identified as serving only part of a home, including spaces that are not continually occupied during the day, such as

basements, sunrooms, or bedrooms. The team identified 16 sites (10 FD and 6 PD) where the HP served partial homes.

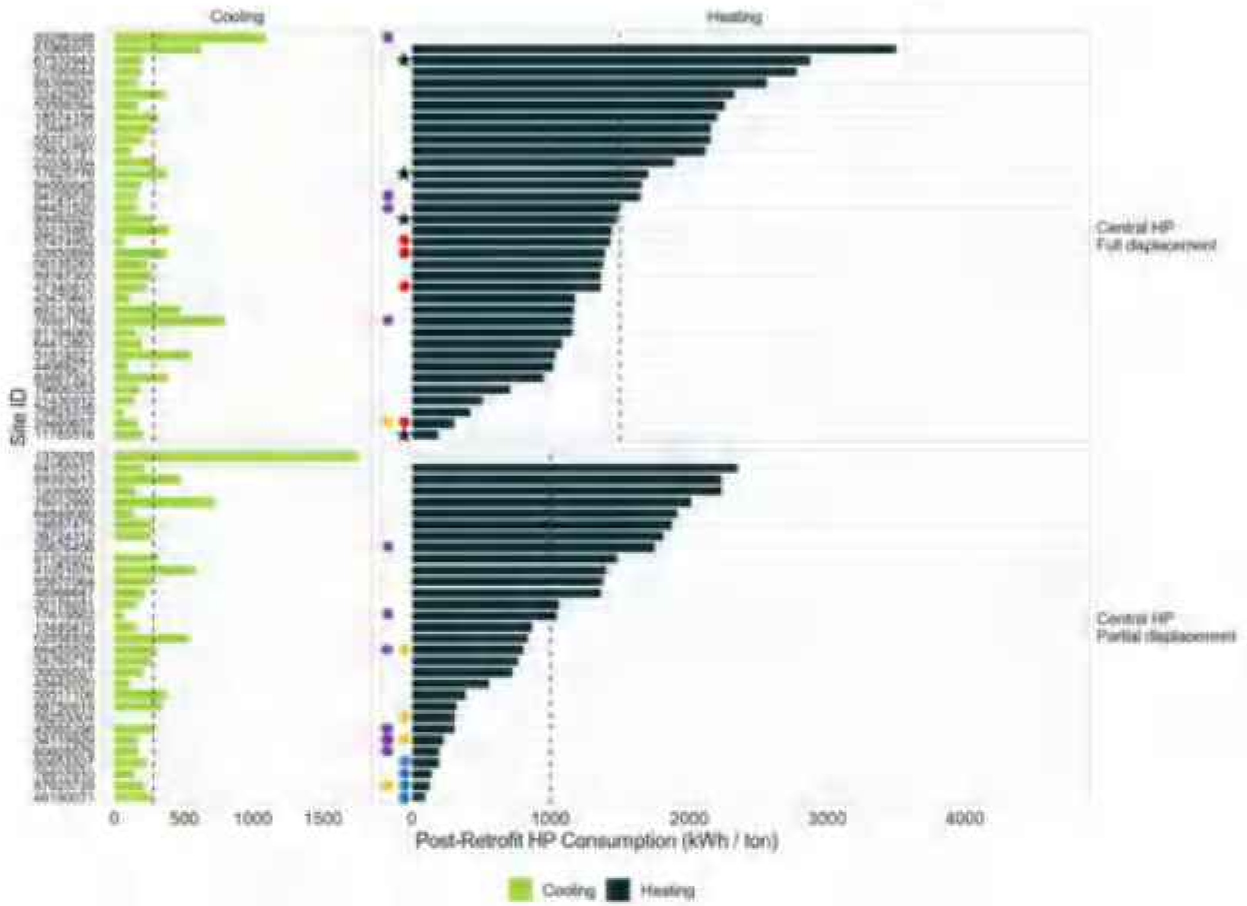
- **Displacement category (red dot)—**15 FD sites appear to operate as PD. Of these sites, five are identified to only serve part of the home. These sites identified as having PD operation but were identified as FD in the program data. These sites had backup system usage.
- **Customer reporting various issue with heating season comfort (black star)—** Seven customers, with varying levels of usage (from low to high), reported some issues with their heat pump keeping them comfortable at colder outdoor air temperatures. One FD customer re-connected their previously disconnected backup heating system.

Below are some verbatim responses from these customers. One common theme that emerged from several customer responses is the fact that they wish they had opted for a heat pump model that was designed to support higher output capacity in low outdoor air temperatures. These heat pumps were installed in 2021/2022, and program guidelines have since changed in recent years (2023/2024) requiring installation of units with higher low temperature output capacity relative to the rated output capacity. This change may reduce the issue in future program years. Only two (17625776 and 72205392) of the seven sites listed below had Energy Star v6.1 rated cold climate heat pumps installed. [58] Both sites had minimal-to-no heat pump usage data below 30 degrees. Due to the lack of data at low temperatures at these two sites, it is difficult to verify whether the systems were in fact not performing well.

- **11785516 (CHP, FD)—**"It's very inefficient when temperatures drop below 40 degrees F."
- **17625776 (CHP, FD)—**"We have to keep the house colder in order for it to not run all the time. The costs are significantly higher than we expected. We also believe the seller sold us a unit that was too small for our house"
- **30700252 (MSHP, FD)—**"We, unfortunately didn't purchase the "hyper-heat" system b/c we were primarily concerned about cooling…During cold periods, the system isn't as able to maintain the heat/temperature throughout all 3 floors of our condo. So we're just using the split system (heat pump) to cool our small finished basement area and our 1st (main floor). We're using the standard electric baseboard heat on the 2nd level, b/c we have a pretty big space in our master bedroom (it has a loft within it)."
- **59919510 (MSHP, FD)—**"My heat pump was significantly undersized, perhaps because the first floor is open to some space on the second floor, perhaps just because it was poorly designed…Not strong enough to heat the house."
- **67532943 (CHP, FD)—**"No Heat when below 25 degrees". Customer stated that they re-hooked up their existing oil boiler to supplement their heat pump.
- **72205392 (MSHP, FD)—**"They don't provide enough heat" I wish I had bought the ones that work in a lower temp"
- **89492022 (CHP, FD)—**"Sometimes it doesn't work as well in extremely cold weather."

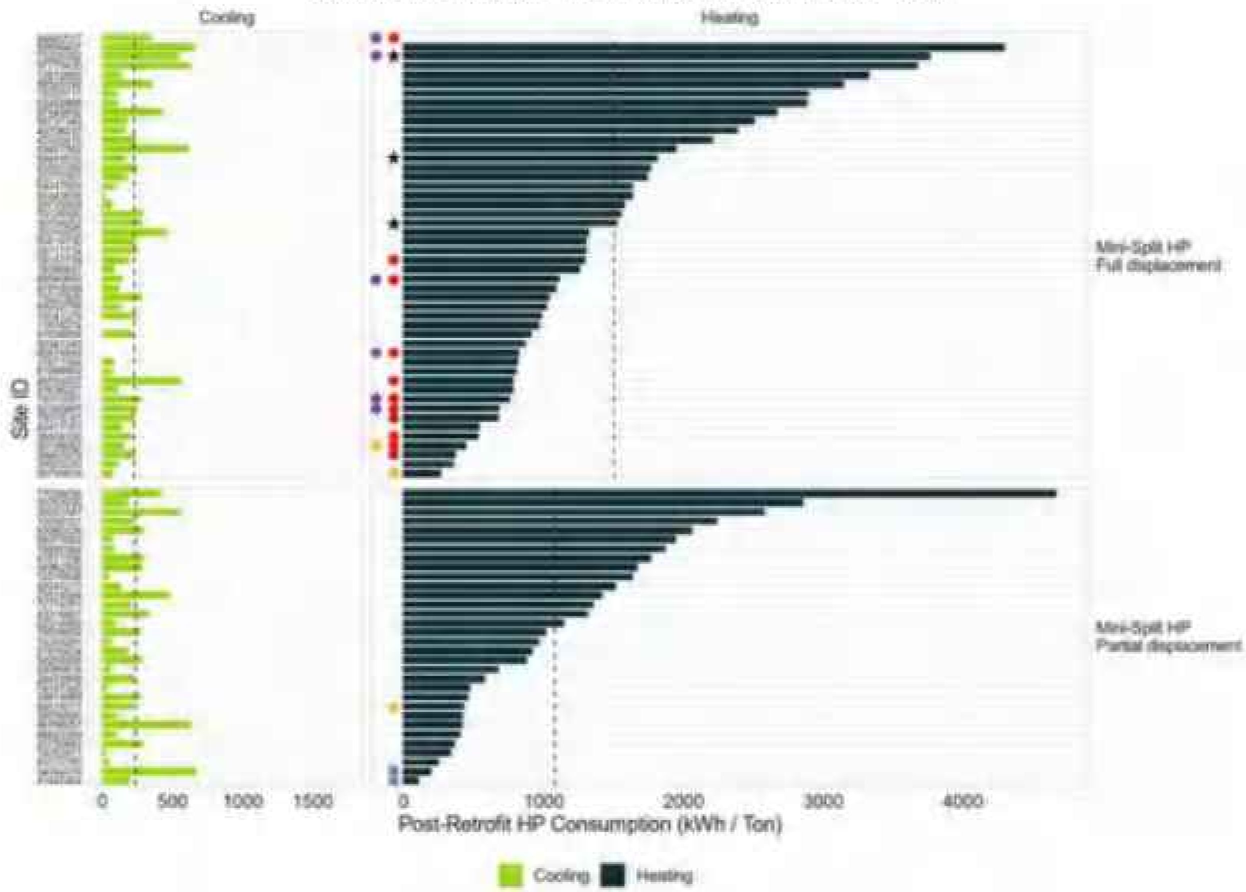
[58] Exact criteria for Energy Star v6.1 Cold Climate designation is provided here: https://www.energystar.gov/sites/default/files/asset/document/ENERGY%20STAR%20Version%206.1%20Central%20Air%20Conditioner%20and%20Heat%20Pump%20Final%20Specification%20%28Rev.%20January%20%202022%29.pdf

Figure 4-2. CHP Post-Retrofit Usage Per Ton



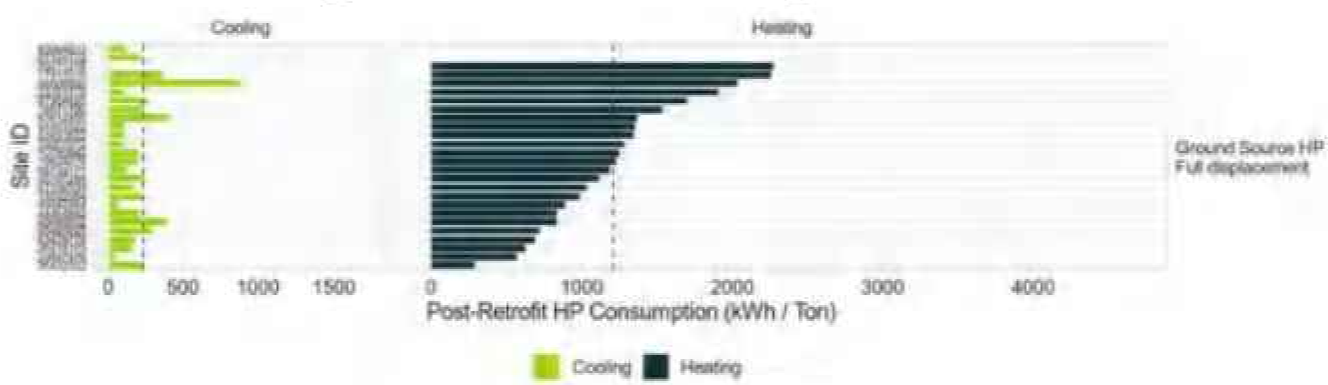
Source: Evaluation team analysis

Figure 4-3. MSHP Post-Retrofit Usage Per Ton



Source: Evaluation team analysis

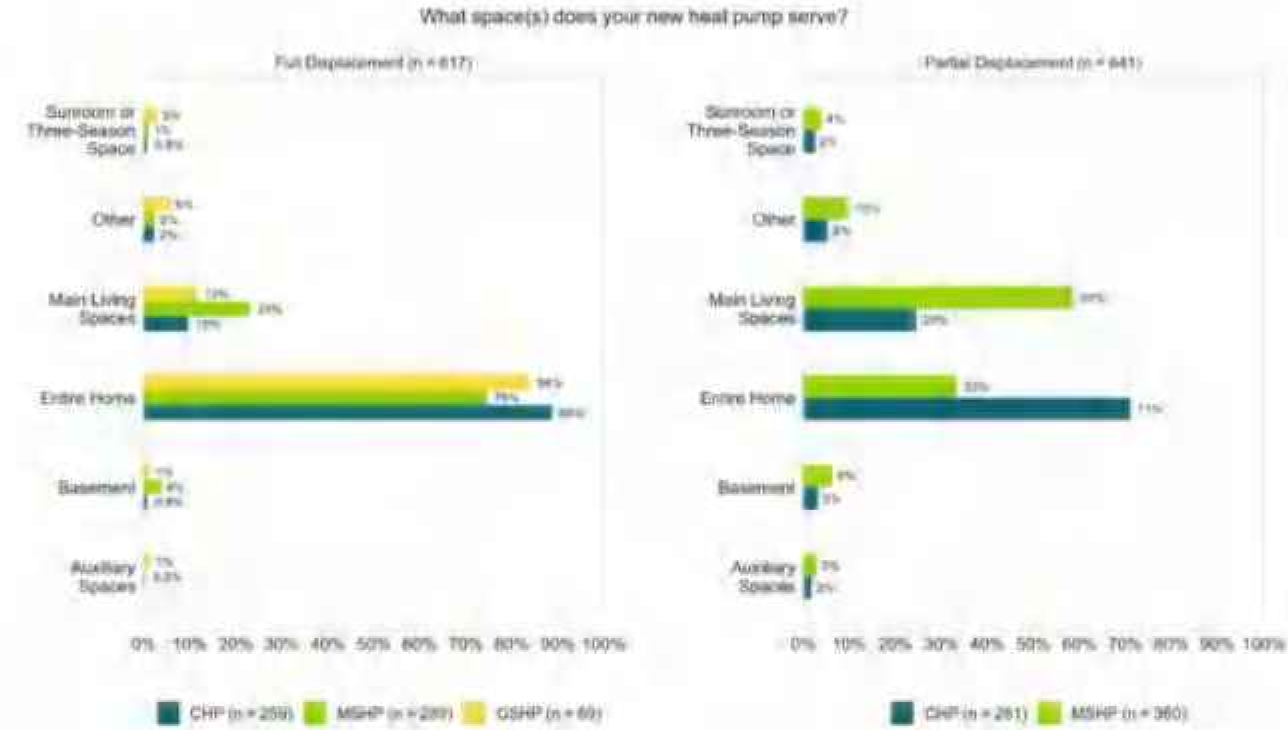
Figure 4-4. GSHP Post-Retrofit Usage Per Ton



Source: Evaluation team analysis

Heat pumps serving partial homes is a common occurrence, as Figure 4-5 shows.[59] For FD installations, customers note that their heat pump serves their entire home for 89% of CHP installations, 75% of MSHP installations, and 84% of GSHP installations. As expected, a smaller proportion of PD installations serve the entire home.

Figure 4-5. Areas of Home Served by Heat Pump



Source: Evaluation team analysis

4.2 Heat Pump Peak Demand

This section provides a summary of peak demand for the heat pumps included in the metered sample, including average peak demand coincident with utility peak periods, as well as the average maximum (non-coincident) demand. This section also shows average hourly demand on the coldest days during winter 2022/2023 and 2023/2204.

Table 4-3 includes an overview of the coincident peak period definitions for both On-Peak and Seasonal Peak savings periods.[60]

[59] This figure displays customer responses from the primary customer survey, which was fielded to all program participants, not just the metered sample. Primary customer survey plots show responses from customers who installed fuel displacement heat pumps in 2021 and 2022 for CT, and only in 2022 for MA.

[60] On-peak and seasonal peak demand savings periods are consistently defined in the MA Technical Reference Manual (TRM) and CT Program Savings Document (PSD).

Table 4-3. Coincident Peak Period Definitions

	Summer On-Peak	Winter On-Peak	Summer Seasonal Peak	Winter Seasonal Peak
Days	Non-holiday weekdays in June, July, August	Non-holiday weekdays in December and January	Non-holiday weekdays in June, July, August	Non-holiday weekdays in June, July, August
Times	1 p.m.-5 p.m.	5 p.m.-7 p.m.	All hours exceeding 90% of the most recent ISO-NE 50/50 system peak load forecast[61]	All hours exceeding 90% of the most recent ISO-NE 50/50 system peak load forecast
Weather Used for Load Modeling	TMYx	TMYx	Actual weather data for the ISO-NE performance period	Actual weather data for the ISO-NE performance period

TMYx typical weather spans the years of 2007-2021, ISO-NE performance period spans Summer 2009-Winter 2023/24.

Source: Massachusetts Technical Reference Manual and Connecticut Program Savings Document

Table 4-4 provides the average peak demand values for the winter season, including winter on peak, seasonal peak, and the average maximum winter peak demand across all sites.[62] The peak demands are summarized for each heat pump type and displacement type, and are normalized per ton of installed heat pump cooling capacity.

[61] Independent System Operator of New England (2023). "Forecast Report of Capacity, Energy, Loads, and Transmission." https://www.iso-ne.com/system-planning/system-plans-studies/celt.

[62] The average maximum peak demand first identifies the highest hourly peak demand during the winter period for each site, and then averages those maximum hourly demand values across all sites in the sample.

Table 4-4. Heat Pump Winter Peak Demand (per Ton)

System Type	Displacement Type	Component	Winter On Peak Demand (kW)	Winter Seasonal Peak Demand (kW)	Winter Average Maximum Peak Demand (kW)	Average Heat Pump Capacity Per Home (Tons)
Central Heat Pump	FD	HP	0.333	0.470	1.351	3.72
		Auxiliary	0.038	0.112	0.672	3.72
		Total	0.371	0.582	1.866	3.72
	PD	HP	0.251	0.205	0.910	4.43
		Auxiliary	0.003	0.004	0.007	4.43
		Total	0.253	0.209	0.917	4.43
Mini-Split Heat Pump	FD	HP	0.392	0.546	1.005	3.47
		Auxiliary	-	-	-	3.47
		Total	0.392	0.546	1.005	3.47
	PD	HP	0.303	0.423	1.048	2.98
		Auxiliary	-	-	-	2.98
		Total	0.303	0.423	1.048	2.98
Ground Source Heat Pump	FD	HP	0.283	0.420	0.809	6.00
		Auxiliary	0.001	0.004	0.030	6.00
		Total	0.283	0.424	0.834	6.00

Based on full metered sample and program data designation of displacement type

Source: Evaluation team analysis

Table 4-5 provides the average peak demand values for the summer season, including summer on peak, seasonal peak, and the average maximum summer peak demand across all sites.[63] The peak demands are summarized for each heat pump type and displacement type, and are normalized per ton of installed heat pump cooling capacity.

[63] The average maximum peak demand first identifies the highest hourly peak demand during the winter period for each site, and then averages those maximum hourly demand values across all sites in the sample.

Table 4-5. Heat Pump Summer Peak Demand (per Ton)

System Type	Displacement Type	Summer On Peak Demand (kW)	Summer Seasonal Peak Demand (kW)	Summer Average Maximum Peak Demand (kW)	Average Heat Pump Capacity Per Home (Tons)
Central Heat Pump	FD	0.159	0.316	0.557	3.72
	PD	0.195	0.407	0.785	4.43
Mini-Split Heat Pump	FD	0.125	0.266	0.426	3.47
	PD	0.128	0.290	0.503	2.98
Ground Source Heat Pump	FD	0.134	0.238	0.406	6.00

Based on full metered sample and program data designation of displacement type.

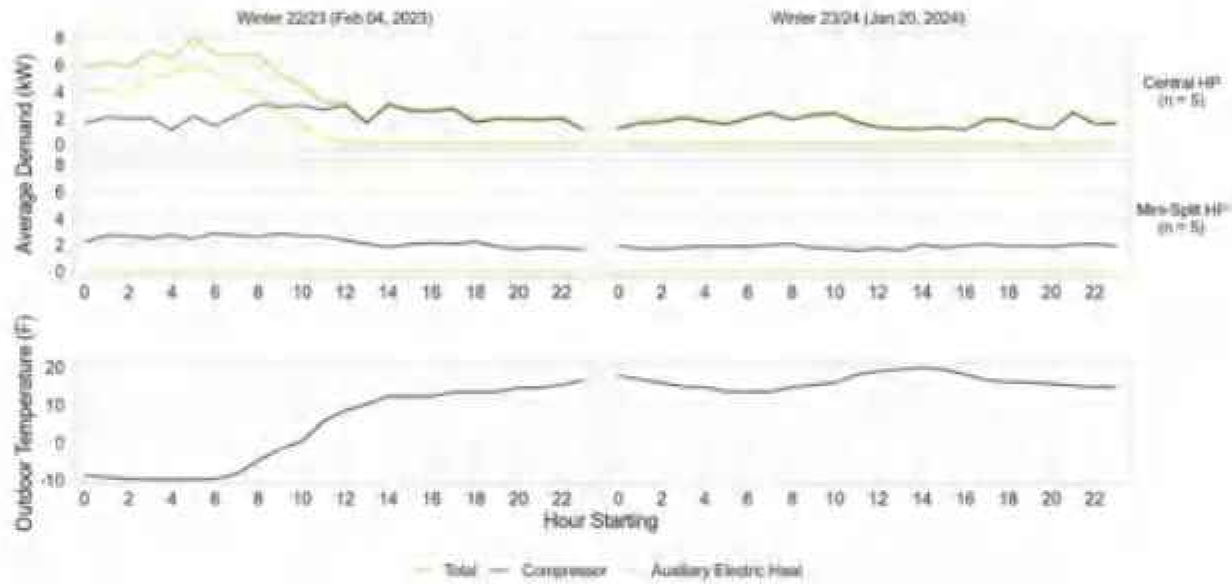
Source: Evaluation team analysis

All peak demand values presented above are for a typical year, based predominantly on metered data collected from a relatively mild winter (23/24)[64]. In order to quantify the potential peak demand impacts in a colder year, Figure 4-6 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), showing the average hourly demand for the FD sites that removed or disconnected any backup heating sources, and for the subset of sites that had metered data collection during both of the winter peak coldest days.

For FD sites, the compressor demand varied between about 2-3 kW across all system types, while the average auxiliary electric resistance heat demand peaked around 6 kW during the morning hours on February 4, 2023, for CHP sites. For CHP sites, the combined system (HP and auxiliary heat) peak was 8 kW in 22/23, compared to only about 2.5 kW in 23/24, which indicates the significant impact of auxiliary heat on peak demand in colder years.

[64] The 50 Wave 1 sites had data in the colder winter of 22/23, but the remaining sites only had data from winter 23/24.

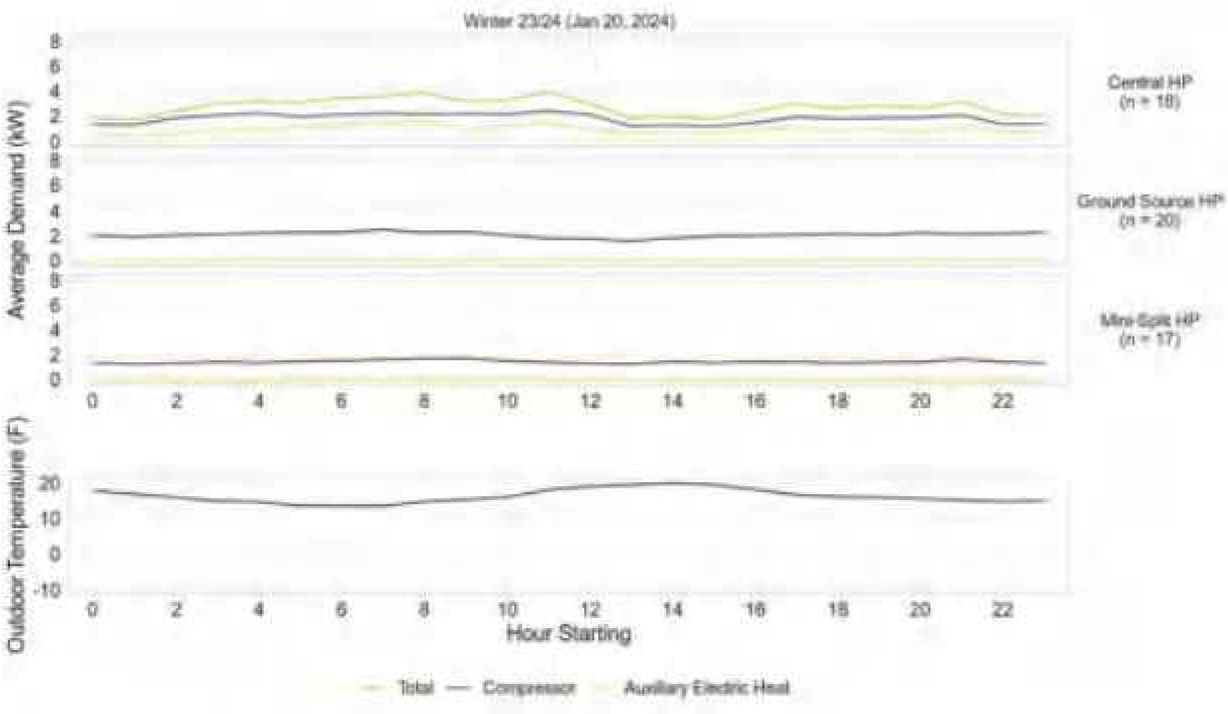
Figure 4-6. Metered Peak Day Load Shape, Full Displacement Sites



Source: Evaluation team analysis

Figure 4-6 only includes data for the subset of sites with metered data in both metered heating seasons. Figure 4-7 below shows the average hourly demand for all FD sites with metered data collection in the Winter 23/24 period. For this relatively mild winter day (temperatures averaging approximately 15 °F), total heating demand was highest for CHP sites with use of auxiliary electric heat as well, and lowest for GSHP sites. Additionally, the peak demand for CHP for this larger set of sites is almost double the peak of the smaller subset in Figure 4-6 for the same day in Winter 23/24, which indicates that the sample included in Figure 4-6 may be biased towards low usage sites. Based on this, it is reasonable to expect that the true average demand on the much colder day in Winter 22/23 may actually be higher than what is shown in Figure 4-6.

Figure 4-7. Average Hourly Demand, Full Displacement Sites



Source: Evaluation team analysis

4.3 Backup and Auxiliary System Usage

This section provides findings for the backup and auxiliary system usage analysis, including the proportion of load in the heating season met by the various heating sources, prevalence of backup heating systems in customer homes, and the control methods for heat pumps and backup heating systems. Findings in this section are derived from the customer surveys, customer interviews, and onsite metering of heat pumps and other systems. Customers included in this section had backup heat (boilers, furnaces, wood stoves, baseboard heating, space heaters), auxiliary heating (integrated electric resistance heating built into the air handler), or a combination of both.

Key Findings:

Full Displacement

- About half of all FD customers reported having a backup heating source in their homes, although those with MSHPs were more likely to report having a backup heating source than those with CHPs. FD customers in Connecticut reported slightly higher prevalence of backup heating systems than those in Massachusetts. At these homes, the backup systems were sometimes whole home backup systems (e.g., furnaces, boilers), and for other homes, there was varying use of pellet/wood/gas stoves or fireplaces (used for both home heating and for ambiance).

- For FD customers with backup heating systems, about 60% reported using them during milder winter periods, and 75% during the coldest periods. Those in Connecticut reported using their backup heat more frequently; those in Massachusetts were more frequently reporting using their backup heating "only in emergencies", while others were reporting a variety of usage across the heating season. Customers with wood heating reported higher frequency of use than those with other heating system types.
- Analysis of the FD metered data suggests that about 85-90% of home heating load was met by the heat pump in FD installations for CHP and MSHP. In these homes, backup heat meeting about 10% of the heating load. Auxiliary electric heat met a few percent of total load for CHP FD installations. For CHP FD installations, auxiliary electric heat meets about 10-20% of the average homes heating load below 0°F.[65]
- Analysis of metered data suggests that GSHPs met almost all heating load of the home (99%).
- For FD customers who used backup heat, about 15% indicated comfort concerns as a reason to use backup heat, and a similar number of customers indicated concerns of heating costs associated with their heat pump (especially during the coldest winter periods). Other customers enjoy using wood heating sources for ambiance.

Partial Displacement

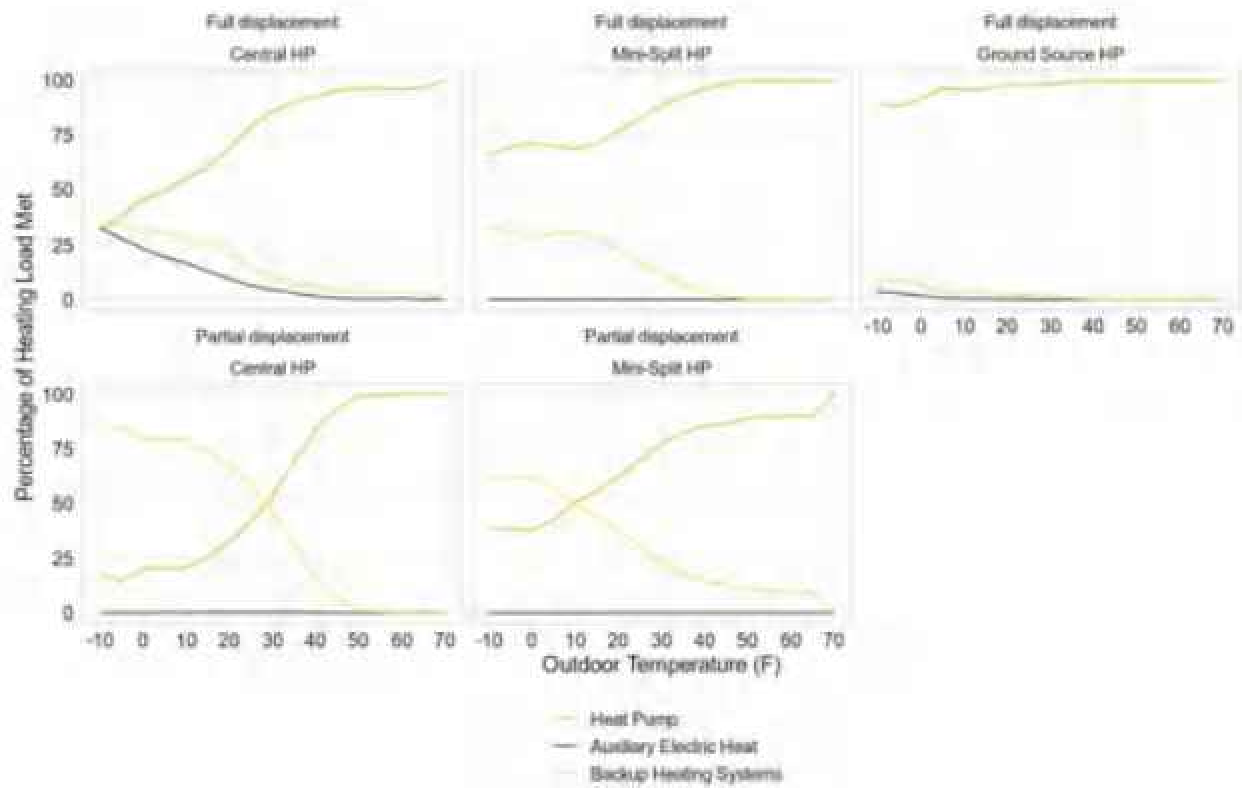
- About 80% percent of customers with PD installations reported having additional heating sources in their home, and for those with backup heat, about 80% reported using the backup heating systems over the winter period.
- For PD installations, analysis of metered data suggests that the heat pump met about 65% of the homes heating load over the winter for sites with CHPs, and 79% for sites with MSHPs, leaving backup heating systems to meet the remaining load.
- PD customers were motivated to use backup heat because they were concerned about heating costs with their heat pump, their integrated controller was set to automatically switch over, or their backup heat serves parts of their home that their heat pump does not.

4.3.1 Backup and Auxiliary Usage by Temperature

Section 2.5.8 details the methods used to estimate the proportion of heating system load met by the heat pump, backup, auxiliary heating systems. Figure 4-8 shows the average proportion of the home heating load that was met by the heat pumps, integrated auxiliary electric resistance heat, and other backup systems, by outdoor air temperature and heat pump type. For both FD and PD installations, customers used heat pumps to meet most of the heating load in the home above 40°F. Below this temperature, the portion of the home's heating load that was met by the heat pump starts to drop while the portions met by backup systems (FD and PD) and electric auxiliary (FD only) rise.

[65] This value has high uncertainty, with limited hours below 0°F during the metered period.

Figure 4-8. Backup and Auxiliary System Usage by Temperature Bin



n=93 FD sites, 60 PD sites
Based on full metered sample and program data designation of displacement type
Source: Evaluation team analysis

For CHP FD sites, the heat pump load decreased from about 90% of the home's heating load at 40°F to about 30% at -10°F. Auxiliary electric heat increased steadily from 0% at 40°F to 30% at -10°F. The remaining load was handled by other backup heating systems, including furnaces, boilers, wood/pellet stoves or fireplaces, and baseboard heat, which increased from about 5% at 40°F to a maximum of about 30% at -10°F.

For CHP PD sites, as expected, the proportion of the load met by the heat pump declined more steeply at lower temperatures, ranging from about 85% of the home's heating load at 40°F to about 20% at -10°F. Backup heating systems made up the remaining load, while auxiliary electric heat usage was negligible for these sites.

MSHP sites showed similar trends, though the heat pump met more of the load on average than the CHP sites. For MSHP FD sites, the heat pump load proportion declined from about 95% at 40°F to 70% at -10°F, while for MSHP PD[66] sites it ranged from about 80% at 40°F to 40% at -10°F. Backup heating systems made up almost all of the remainder of the load at these sites.[67]

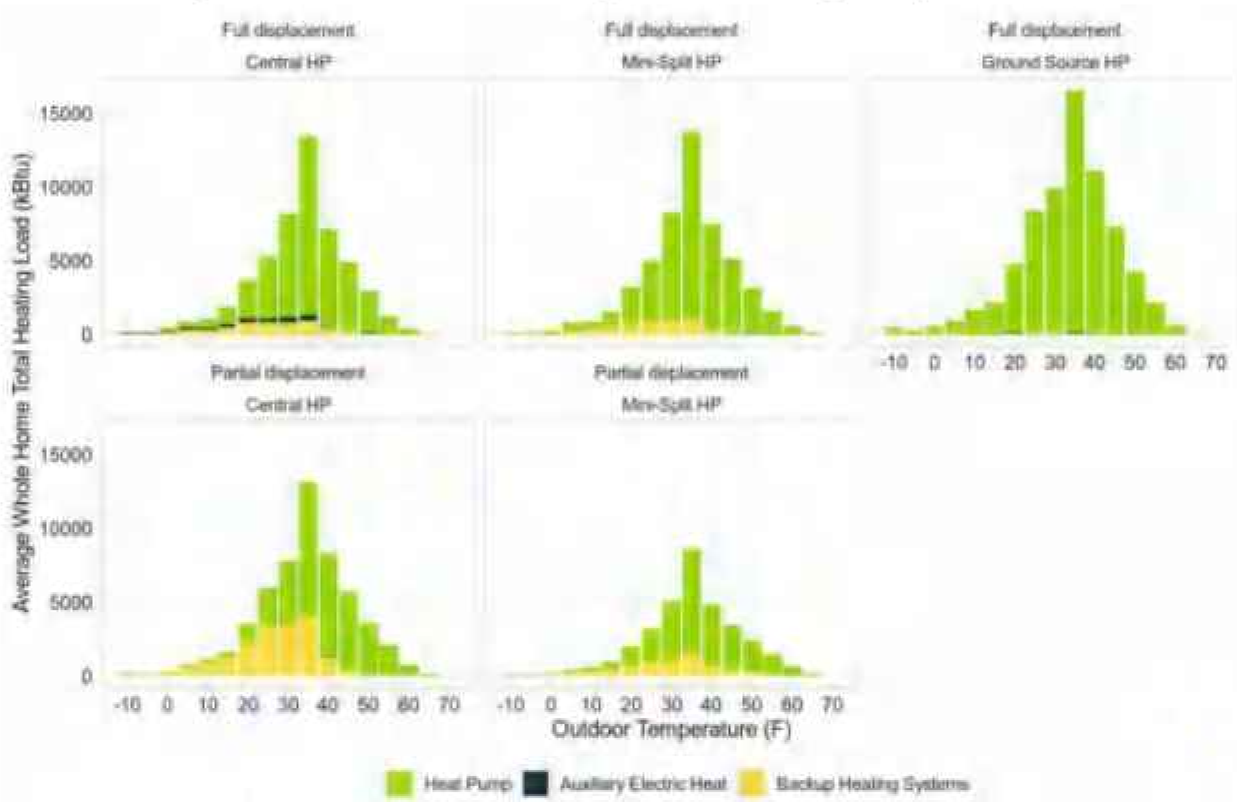
[66] The load is the full home for all heat pump types within this analysis. Sites that were identified in which the installed system only conditioned part of the house were removed from the load proportions analysis.

[67] The small amount of auxiliary electric heat shown for MSHP sites comes from sites that installed both an MSHP and a CHP. The program data classified these as MSHP sites.

Sites with GSHPs showed minimal backup heat usage, with the heat pumps accounting for almost 100% at 40°F and declining only to 90% at -10°F. Backup heat systems were present at about half of GSHP sites.

Figure 4-9 shows the average annual heating load in each temperature bin and the proportion of that load met by each type of heating source (heat pump, auxiliary heat, and backup heating). This figure provides important context for Figure 4-8. For example, while the Figure 4-8 shows that a relatively large *proportion* of FD CHP sites' heating load is met by auxiliary and backup heating at -10°F, Figure 4-9 shows that the overall annual total amount of heating load met by these non-heat pump sources is still relatively small for FD CHP sites. However, it is also important to note that although the seasonal energy consumption due to auxiliary heat usage at low temperatures is small, the associated peak demand impacts are significant, as discussed in Section 4.2.

Figure 4-9. Whole Home Heating Load Source by Temperature Bin



Based on full metered sample and program data designation of displacement type

Source: Evaluation team analysis

Table 4-6 summarizes the proportion of the heating load met by system type across the entire heating season. For the FD sites, the heating load proportion met by the heat pump ranged from 86%-99% based on heat pump type, while for PD sites it ranged from 65%-79%.

Table 4-6. Proportion of Heating Season Load Met by System Type

Heat Pump Type	Displacement Type	Proportion of Heating Load Met – Heat Pump	Proportion of Heating Load Met – Auxiliary Electric Heat	Proportion of Heating Load Met – Backup Heating Systems
Central HP	FD	86%	4%	10%
Central HP	PD	65%	0%	34%
Mini-Split HP	FD	91%	0%	9%
Mini-Split HP	PD	79%	0%	21%
Ground Source HP	FD	99%	0%	1%

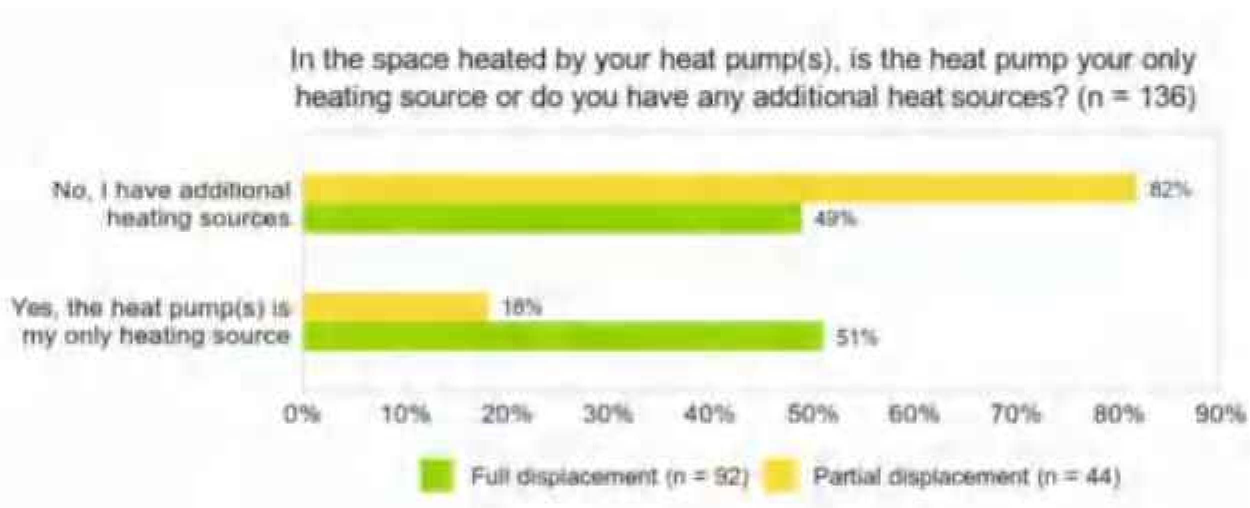
Based on full metered sample and program data designation of displacement type

Source: Evaluation team analysis

4.3.2 Backup System Usage

The findings from the heat pump and secondary heating systems metered analysis are reinforced by responses to the customer surveys. In the end of season survey fielded to the metering study participants, 49% of FD customers and 82% of PD customers indicated that they have additional heating sources, as Figure 4-10 shows.

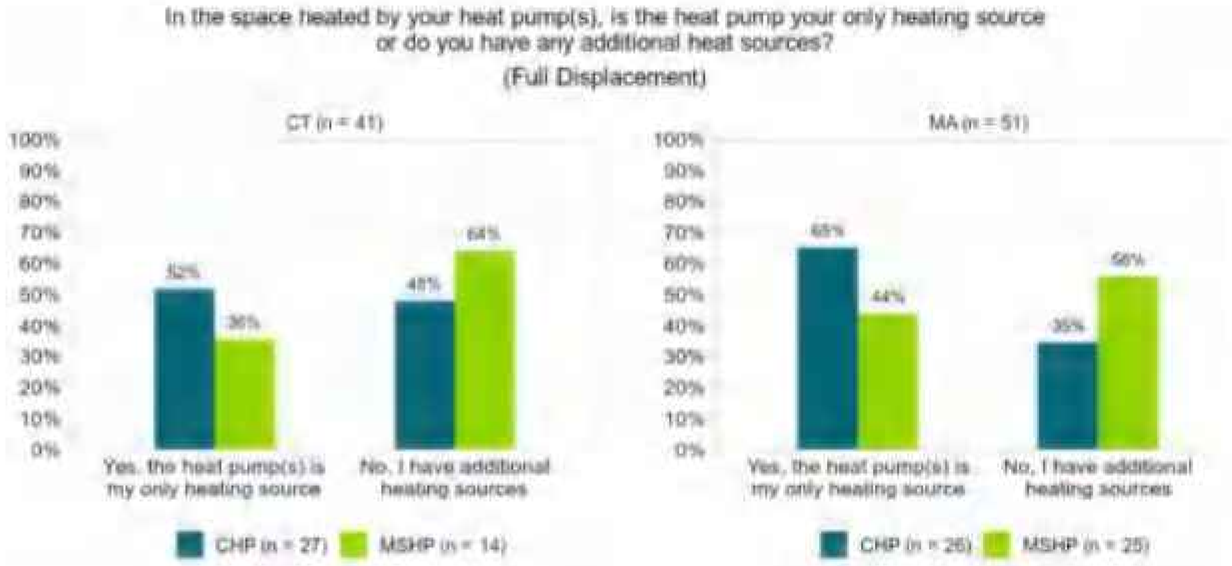
Figure 4-10. Prevalence of Backup Heating Systems



Source: Evaluation team analysis

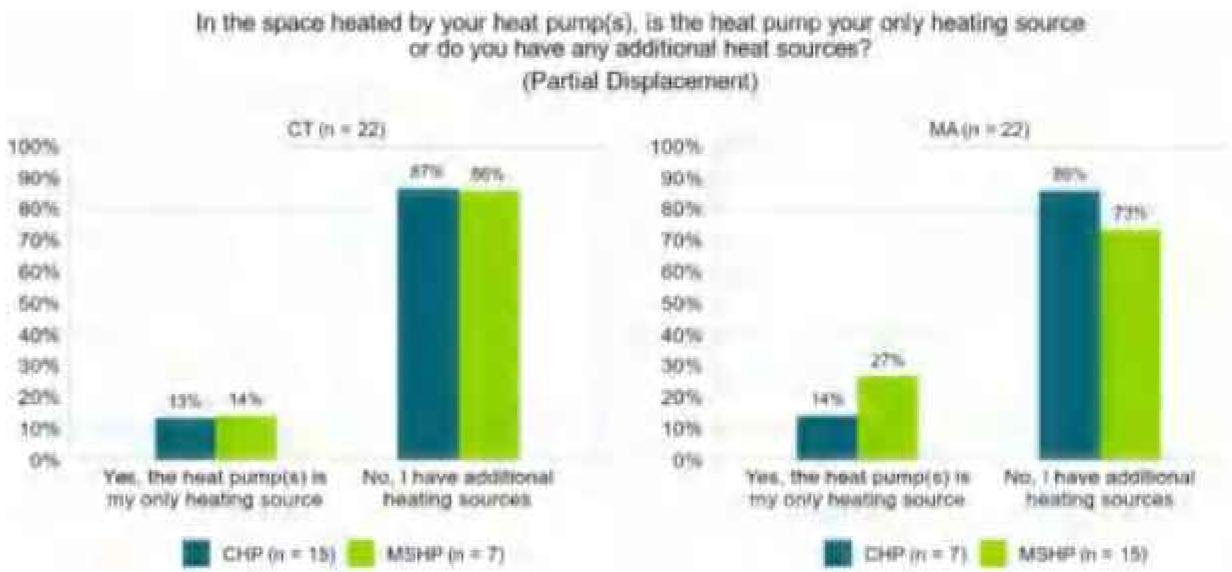
As compared with installations in Massachusetts, those in Connecticut reported an approximately 10% higher prevalence for having backup heating sources across the FD displacement type, for both CHP and MSHP equipment types, as Figure 4-11 and Figure 4-12 show. However, there was not a significant difference reported between states across respondents with MSHPs in the PD displacement type.

Figure 4-11. Home Heating Sources, FD Installs



Source: Evaluation team analysis

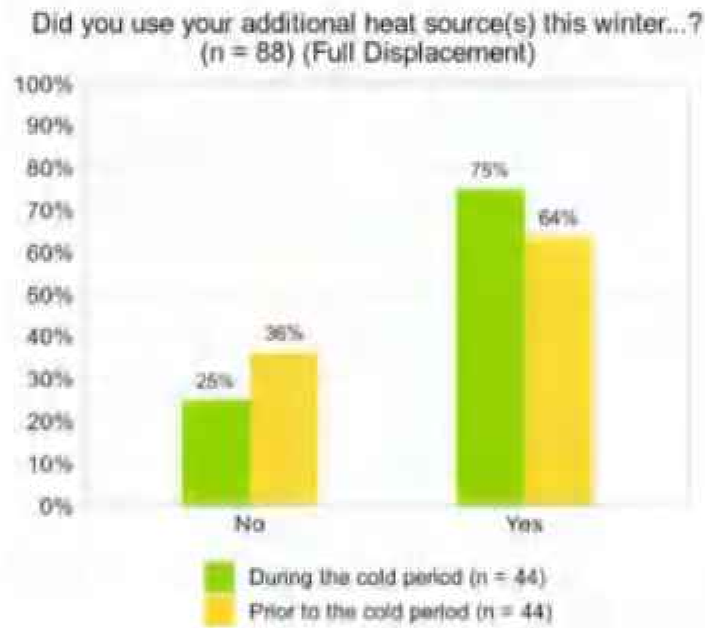
Figure 4-12. Home Heating Sources, PD Installs



Source: Evaluation team analysis

Customers were also asked if they used their additional heat source during the past winter (2023-2024). Of the FD customers in the metering study, 75% responded they used the additional heat source during the recent January 2024 cold period, where temperatures dropped to 14°F, and 64% responded they used the heat source prior to the cold period, as Figure 4-13 shows.

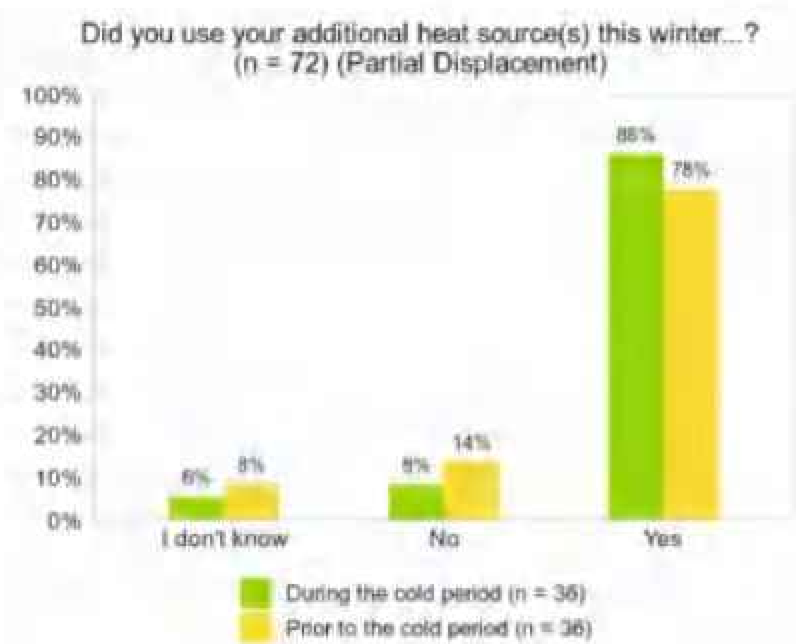
Figure 4-13. Use of Backup Heating Systems During Winter 23-24, FD Installs



Source: Evaluation team analysis

Of the PD customers, 86% responded they used the additional heat source during the recent January 2024 cold period, and 78% responded they used the heat source prior to the cold period, as Figure 4-14 shows.

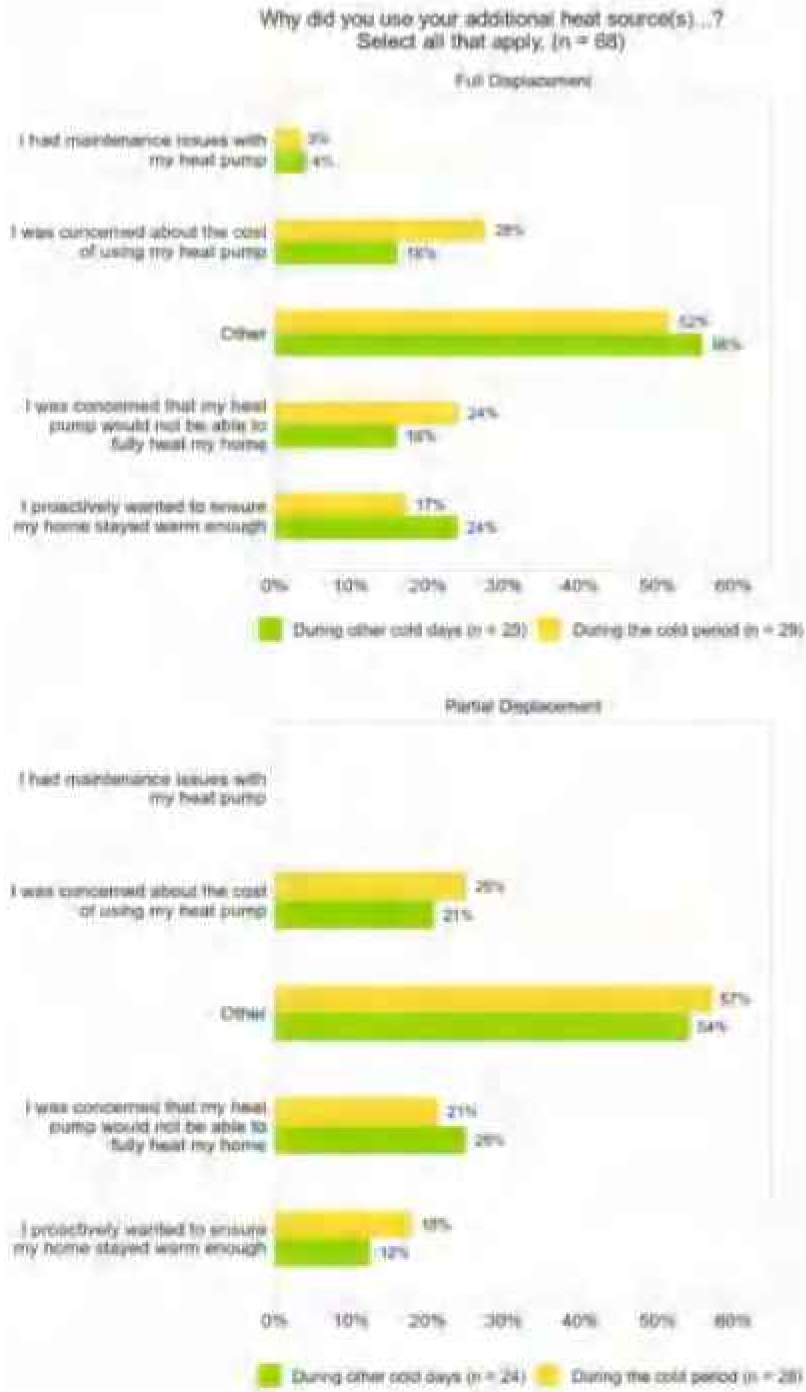
Figure 4-14. Use of Backup Heating Systems During Winter 23-24, PD Installs



Source: Evaluation team analysis

When asked why they used their additional heat source (Figure 4-15), about 20% of respondents indicated concerns that the heat pump would not be able to fully heat the home or that they wanted to be proactive to ensure that their home stayed warm enough. A similar amount expressed concerns about the electricity costs associated with heat pump heating. In review of respondents who indicated "other" reasons for using their backup heating sources, about half of FD respondents with backup heat indicate that they had a wood stove or fireplace that they either used for ambiance, or to heat areas of the home that were not served by their heat pump. Two of the FD respondents said that their heat pump was unable to "keep up" and keep them warm, which spurred their use of backup heat. Many of the PD respondents indicated that they used their backup heat because it was set to automatically turn on.

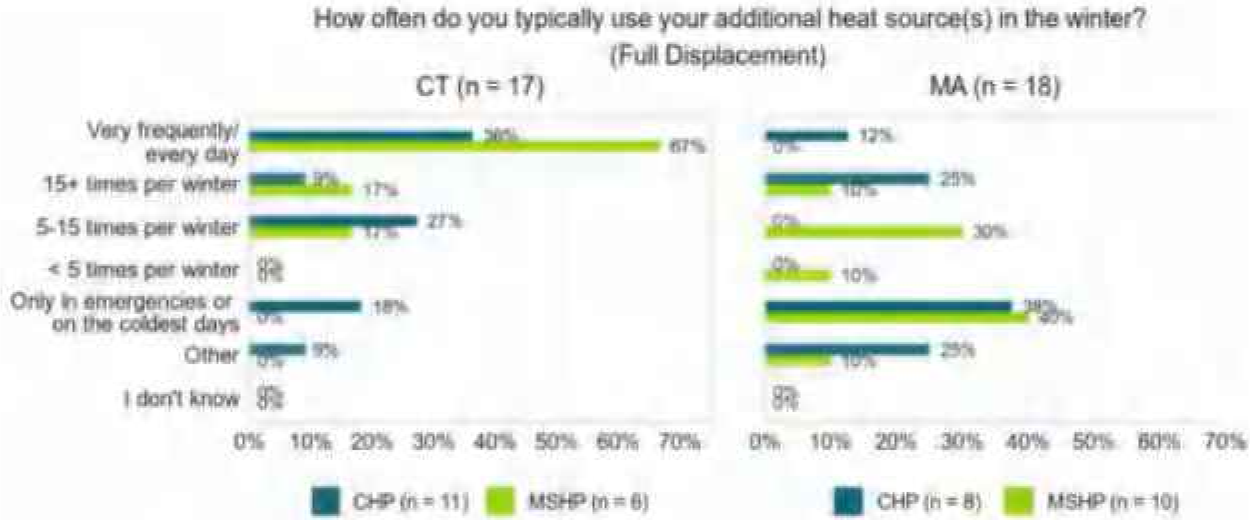
Figure 4-15. Customer Motivations for Use of Backup Heating Systems



Source: Evaluation team analysis

When asked how often the additional heat sources are used, responses varied significantly by state, as Figure 4-16 shows. For this smaller sample from the metering study end of season survey, the FD customers in Connecticut responded that they used the additional heat source "very frequently" at much higher rates. About 40% of the FD customers in Massachusetts responded with "only in emergencies or on the coldest days."

Figure 4-16. Frequency of Backup Heating System Use – FD



Source: Evaluation team analysis

4.3.3 Backup System Control

This section provides findings on backup heating system control strategies and practices.

Key Findings:

- Most customers who initially installed an integrated control (IC) indicated that the IC was still installed (350 of 359), however, fewer (259 of 350) reported still using the IC to automatically switch between their heating systems (especially for those with MSHPs).
- The most common reported switchover temperatures are in the 30°F-45°F range, with 30°F-34°F being the most common, however, a large portion of customers do not know their switchover temperature. Review of onsite metered data showed about 70% of PD sites with CHPs and 20% of sites with MSHPs had a consistent switchover temperature throughout the metered period. Switchover temperatures ranged between 15°F-40°F (average 25°F) for those with oil backup heat, and 20°F-40°F (average 30°F) for those with natural gas backup heat.
- Customers who did not use an IC to auto-switch reported turning on their backup systems manually or using a separate thermostat. Of the customers who reported having multiple thermostats, over half (56%) report using the droop method.

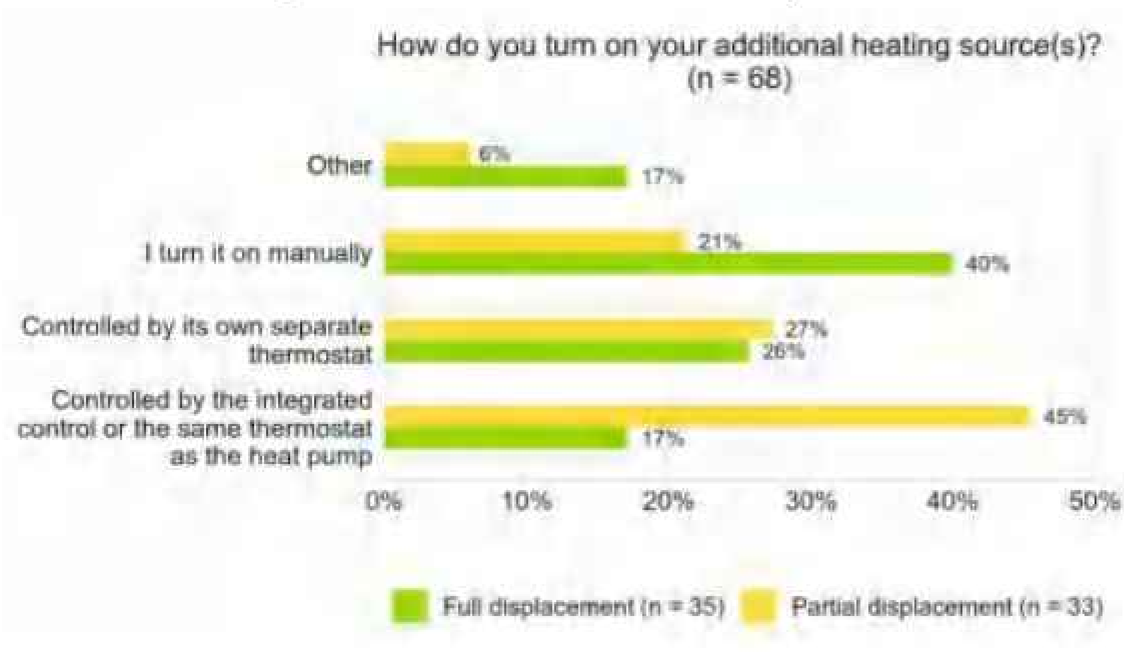
- A majority (83%) of customers reported that their contractor programmed the switchover temperature on their integrated controller during installation. For customers who say the contractor installed the control, 68% reported that the contractor explained how to operate it.
- 83% of PD respondents with installed and working integrated controls (n = 343), said they were satisfied with the operation of their integrated controller.

4.3.3.1 Method of Control

Both the Primary survey and the End of Season surveys asked customers about their method of controlling backup systems. From the Primary survey, about 95% of customers with CHPs indicated as PD reported that the integrated control is still installed, and 90% for MSHPs. For those reporting that they had an integrated control, 90% of those with CHPs and about 65% of those with MSHPs indicated that they used the IC to automatically switch the operation of their heating systems.

From the End of Season survey (n=134), for the customers who responded "yes" to having used their additional heating sources this winter (n=68), 45% of PD customers across all heat pump types responded that they used an integrated control or the same thermostat as the heat pump, as shown in Figure 4-17. About 27% of these customers responded that they used a separate thermostat, and 21% stated that they controlled their backup heat source manually. Most customers who responded "other" indicated they were operating a wood stove.

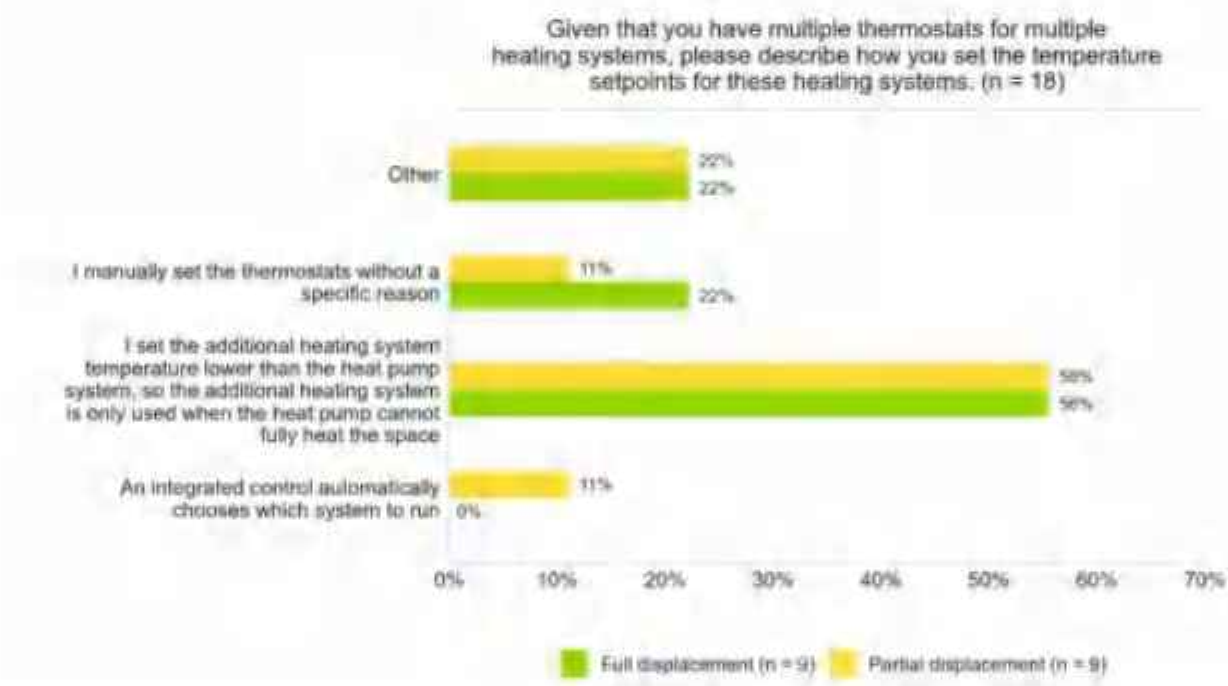
Figure 4-17. Control Method for Backup Heat



Source: Evaluation team analysis

When asked the same question, 40% of FD (mostly MSHP sites – 10 of 14) customers with backup heat indicated they control their backup system manually, and 26% stated that it is controlled by its own separate thermostat. Of the 18 sites (mostly MSHP sites – 13 of 18) that indicated that they use a separate thermostat for multiple heating systems, a majority seemed to use the droop method for operating their systems (56%, or 10 of 18), as Figure 4-18. Control Method for Multiple Thermostats shows.

Figure 4-18. Control Method for Multiple Thermostats



Source: Evaluation team analysis

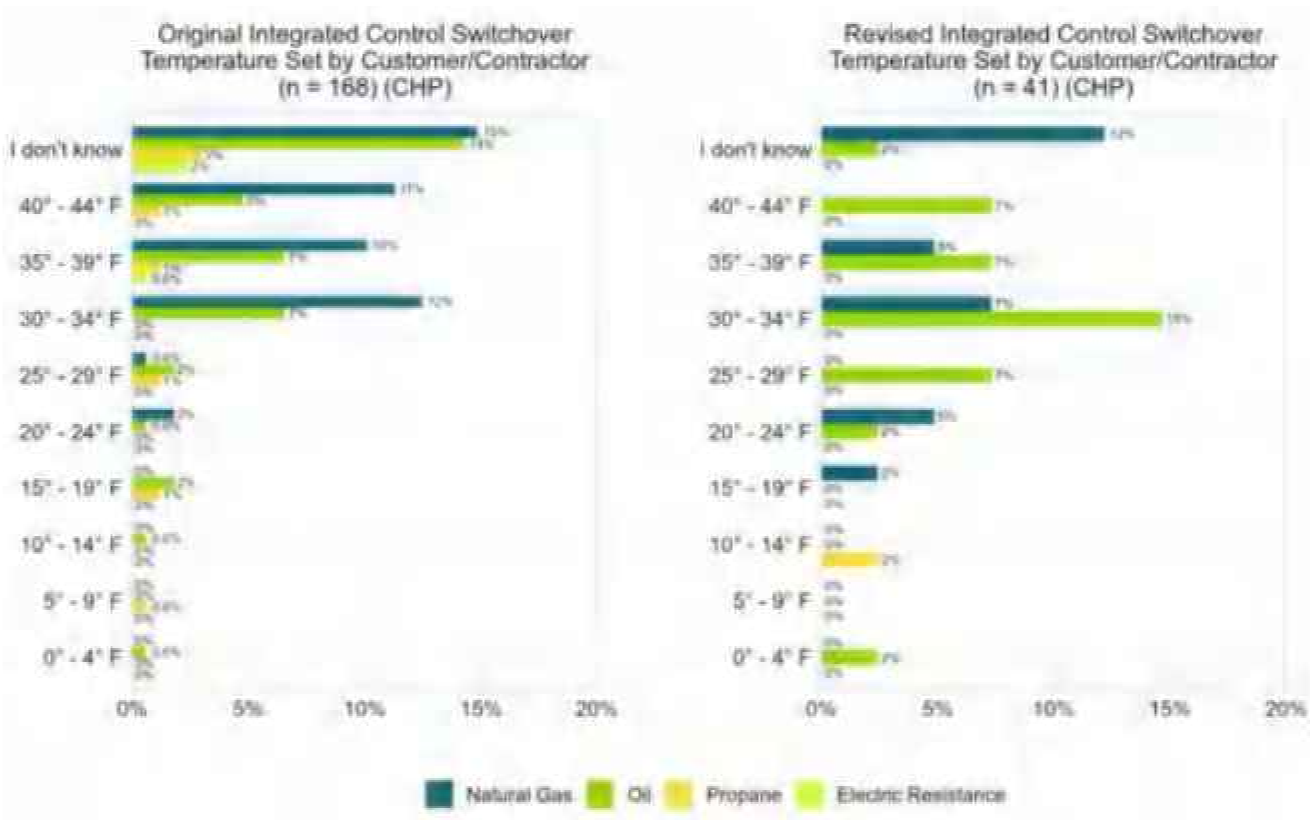
4.3.3.2 Switchover Temperatures

The most common reported switchover temperatures are in the 30°F-44°F range, with 30°F-34°F being the most common, as Figure 4-19 shows. The MA program guidelines dictate different switchover temperatures for customers with backup natural gas, oil, and propane fuel types. As of 2023, the CT program quality guidelines suggest a switchover temperature of 30°F or lower in the Air Source Heat Pump Quality Installation Checklist.[68]

[68] Energize CT (2023). "Air Source Heat Pump Quality Installation Checklist." https://energizect.com/sites/default/files/2023-04/Air%20Source%20Heat%20Pump%20Check-List.pdf

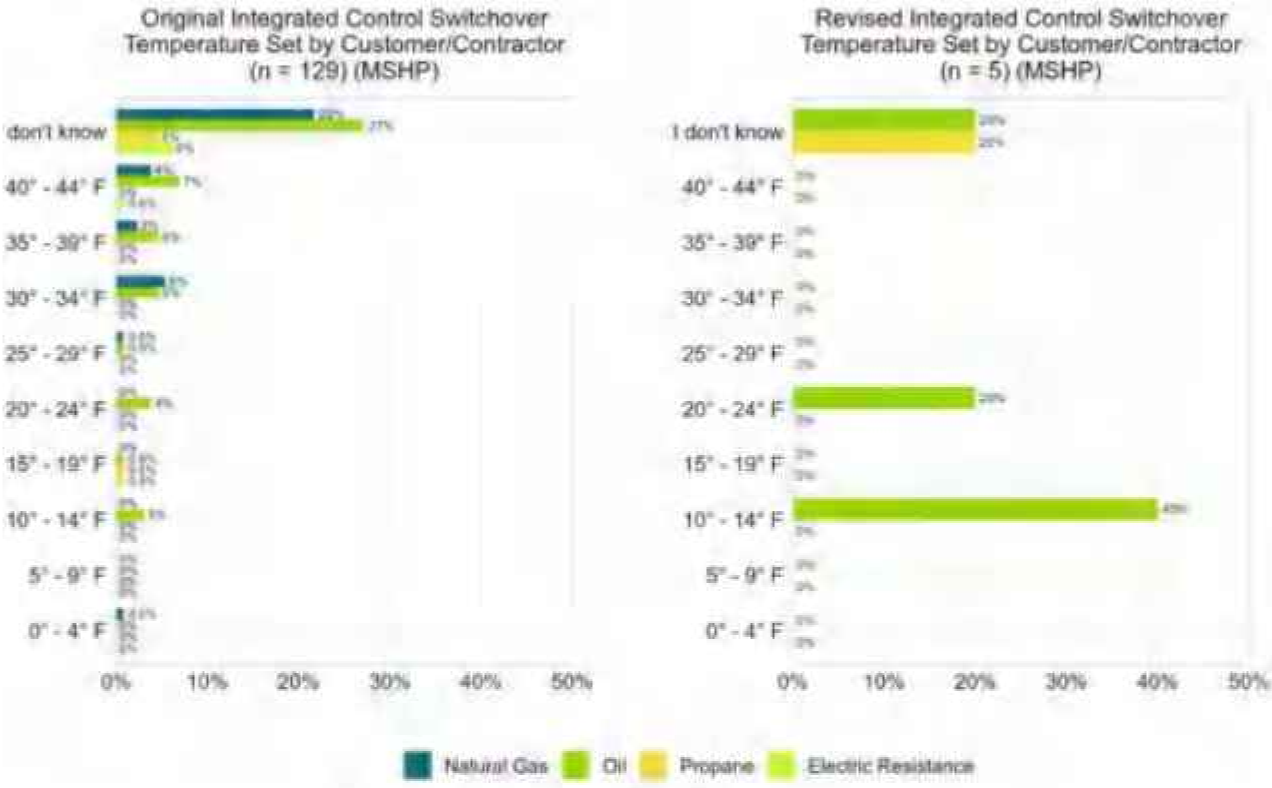
Figure 4-19 and Figure 4-20 show the customer-reported switchover temperature by pre-existing fuel type for CHP and MSHP units, respectively. The plots also show the revised switchover temperatures for customers that changed their IC setting after their heat pump unit(s) was installed. For CHP installs, about 34% of PD customers who reported having an IC installed did not know their IC switchover temperatures. For customers who installed CHPs that did know their switchover temperature, the majority reported settings between 30°F-44°F. About 25% of CHP customers reported changing their switchover temperatures post-install, and they were primarily switched to lower settings in order to use the heat pump more often. For those who reported having ICs installed for MSHPs, about 60% reported not knowing their IC switchover temperature. For those that do know, settings between 30°F-44°F were most common.

Figure 4-19. Original vs. Revised IC Switchover Temperature by Pre-Existing Fuel Type – CHP *



Source: Evaluation team analysis

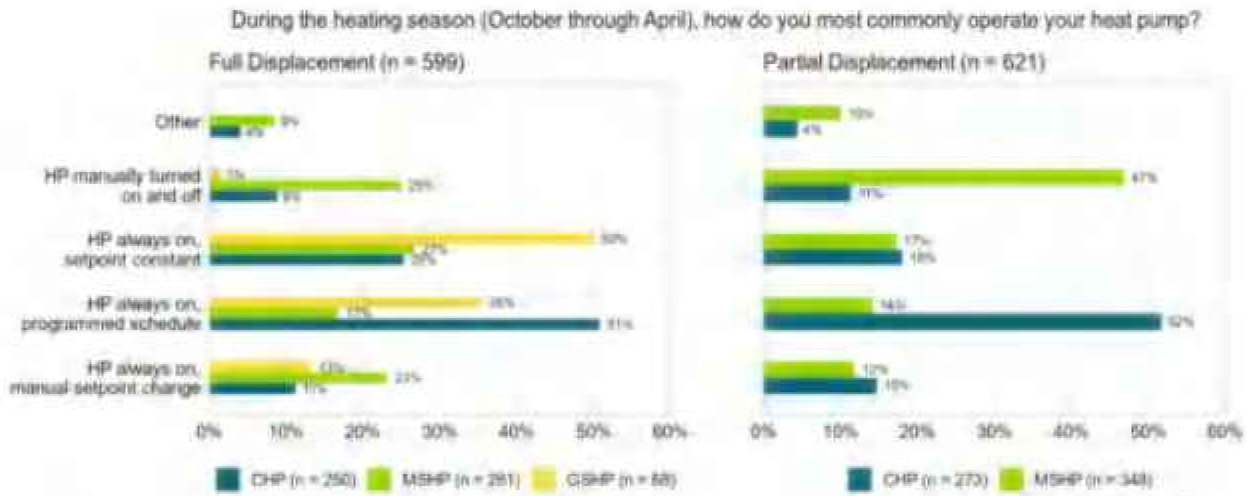
Figure 4-20. Original vs. Revised IC Switchover Temperature by Pre-Existing Fuel Type – MSHP



Source: Evaluation team analysis

Figure 4-21. Operation of Heat Pump System(s) provides an overview of customer reported temperature setpoint operation of their heat pump systems. About 20%-25% of FD customers with CHPs and MSHPs reported using a constant space temperature setpoint, and about 50% for those with GSHPs. A large portion of customers change their temperatures setpoints through a programmed schedule or by manually changing the setpoints over time. It is more common for PD customers, especially those with MSHPs, to manually turn their heat pump on and off.

Figure 4-21. Operation of Heat Pump System(s)



Source: Evaluation team analysis

5. Customer Experience

This section provides findings from the customer surveys and interviews on topics related to customer satisfaction and experience with their heat pumps, customer comfort, heating costs, and any maintenance issues with the heat pumps.

5.1 Overall Experience

The customers in the metered sample who responded to the End of Season survey (n = 134) were asked about the greatest advantage and disadvantage of their heat pumps and if they would install a heat pump again. Overall, customers were satisfied with their heat pumps and if given the opportunity, would install a heat pump again. Detailed responses include:

- **Overall Heat Pump Experience**—95% of respondents said they would install a heat pump again if they were to go back in time. However, 20% of respondents said they would install a different type of heat pump. Overall respondents who indicated that they would install a different type of heat pump did not note changing heat pump types, i.e., MSHP to CHP, but instead that they were interested in performance upgrades (most respondents indicated that they would opt for a heat pump that performs better in the cold weather or has a larger capacity).
- **Greatest Heat Pump Advantage**—When asked about the greatest advantage of their heat pumps, customers responded with cost, carbon reduction, and efficiency (n = 134).
  - **Reduced Overall Cost**—43 out of 134 respondents (32%) cited cost savings alone, or cost savings due to reduction of oil consumption as a benefit.
  - **Carbon Reduction**—33 out of 134 respondents (25%) cited carbon reduction, eliminating fossil fuels, or using a cleaner source of fuel as a benefit.
  - **Efficiency**—28 out of 134 respondents (21%) cited energy efficiency as a benefit.
  - **Heating and Cooling**—20 out of 134 respondents (15%) cited having heating and cooling from one unit as a benefit, while 16 respondents (12%) cited the addition of cooling as a specific benefit.
  - **Other**—Customers responded with a variety of additional benefits, including comfort (13 customers, 10%), benefits of pairing a heat pump with solar panels (11 customers, 8%), quiet operation (8 customers, 6%), and improved indoor air quality from elimination of burning fossil fuels locally (3 customers, 2%).
- **Greatest Heat Pump Disadvantage**—When asked about the greatest disadvantage of their heat pumps, customers responded with increased electricity cost, cold weather performance, and difficulty operating the heat pump (n = 136).
  - **Increased Electricity Bill**—20 out of 136 respondents (15%) cited increased electricity bills, and high electricity rates as a disadvantage for using their heat pumps.

- **Cold Weather Performance Impact**—18 out of 136 respondents (13%) cited poor performance in cold temperatures.
- **Difficulty of Operating**—9 out of 136 respondents (7%) cited difficulty with operating, specifically issues concerning difficulty understanding the integrated control, complex control systems, and poorly designed control software.
- **Installation and Maintenance Costs**—8 out of 136 respondents (6%) cited high installation and maintenance costs, including costs of repairs or replacement parts.
- **Other**—Customers responded with a variety of other disadvantages, including noise (6 customers, 4%), low humidity (2 customers, 1%), discomfort due to defrost cycling (2 customers, 1%), and amount of physical space taken up by the outdoor unit (2 customers, 1%).

5.2 Maintenance

Based on responses from the End of Season survey for the metered participants, most respondents reported no maintenance issues. 18 out of 134 respondents (13%) said that they have experienced maintenance issues with their heat pumps (9% of CHP and 19% of MSHP responses[69]). The issues fall under these main categories:

- **Performance issues**—3 out of 134 respondents (2.2%), said these issues impacted their heat pump's performance during Winter 2023-2024.
- **Condensate issues**—4 out of 134 respondents (3.0%) identified condensate issues. This includes condensate build up around the inside of the unit, heavy condensate dripping, overflowing condensate due to poorly installed drains, and poor installation of condensate piping.
- **Circuit board issues**—3 out of 134 respondents (2.2%) identified circuit board or control panel issues. This includes circuit board issues which caused the unit to not operate, an electricity outage which damaged the control panel, and a circuit board which shorted with no known reason, though the customer thinks it might have been a rodent issue. Customers cited long wait times to get replacement parts.
- **Refrigerant leaks**—2 out of 134 respondents (1.5%) identified refrigerant leaks as their maintenance issue. When reviewing the primary survey responses to a similar question, a slightly higher fraction of respondents (3.4%, 41 out of 1,223) cited refrigerant leaks, with over half having leakage 1 time. Customers with MSHPs were more likely to cite refrigerant leaks than CHPs. A majority of customers reported that their refrigerant leakage repair cost them $0.
- **Other issues**—Respondents identified some other issues. These include the inside heat pump vanes staying closed, 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.

[69] Only 1 GSHP respondents indicated that they had maintenance issues.

5.3 Comfort

Occupants were surveyed on their comfort levels during both the Fast Feedback Interviews (n= 13) and the End of Season survey (n = 136). Details on both of these surveys, including when they were fielded and what portion of the participants they were fielded to, can be found in Section 2.2.

5.3.1 Comfort During February 2023 Cold Snap

The Fast Feedback survey was fielded as a phone interview to Wave 1 FD customers following the weekend of the February 3-5, 2023, cold snap where temperatures reached record lows in Massachusetts (as low as -13°F, with windchill temperatures as low as -41°F). Out of the 25 FD participants, 13 completed the phone interview (52%).

Key findings include:

- Overall, 10 out of 13 (77%) FD customers were satisfied with the performance of their heat pumps during the Feb 2023 cold snap and did not use any backup systems.
- Of the remaining three customers, two used backup systems as a pre-emptive measure or for ambiance (in the case of wood/pellet stoves), not as a result of being too cold.
- Only one customer showed electric auxiliary heating during this period.
- Only one customer reported significant issues with being too cold, however their issue may have been caused by improper configuration of their HVAC controls by the contractor.

Detailed findings include:

Backup heating and system operation:

- Most respondents had some form of backup heat – though not always a whole-home heat source (i.e., pellet stove)
- There was significant variation on the use of backup heat during the sub-zero temperatures on February 3rd through 5th 2023, including many customers that noted the potential automatic kick-on of auxiliary heat (though only one case of auxiliary heat usage was noted). Most respondents noted that they felt warm (or warmer than room temperature) air from the ducts/heads, though some systems were supplemented with backup or auxiliary heat.
- Many of the customers wanted to “test” their heat pumps during this time, so generally they didn’t proactively turn on the backup heat.
- One interviewee explained that their motivation for turning on backup heating was driven by unconditioned basements that are susceptible to freezing pipes.

Thermostat controls:

- Across the group of respondents, there is significant variation in how HP systems are controlled. Some have sophisticated automated controls, whereas others are manually controlling their heat pump.

- Many customers indicated that they adjust the temperature throughout the day. Some customers with MSHPs indicated that there has been a learning curve associated with setpoint selection: learning how heat pump output air temperature impacts room air temperature.

- Some customers explained that they used to change the temperature on their heat pump but heard that it was better to leave it at a consistent temperature and have since changed their behavior.

5.3.2 Comfort During Winter 2023-2024

This section provides a summary of customer comfort during winter 2023-2024, as determined through the End-of-Season customer survey.

- When asked about satisfaction with their heat pumps ability to warm their space during normal winter weather, 84 out of 90 (93%) of FD customers and 38 out of 44 (86%) of PD customers responded "satisfied"[70]. During cold periods, this dropped slightly to 77 out of 90 (86%) of FD customers and 30 out of 44 (68%) of PD customers. This is shown in Figure 5-1.
- Similarly, when asked about satisfaction with their heat pumps ability to meet the heating needs of the space during normal winter weather, 87 out of 90 (97%) of FD customers and 38 out of 44 (87%) of PD customers responded "satisfied". During cold periods, this dropped slightly to 75 out of 90 (84%) of FD customers and 31 out of 44 (70%) of PD customers. This is shown in Figure 5-2.

Overall, respondents indicated that they are satisfied with their heat pump's ability to meet the heating needs of their space compared to their previous heating system. Both FD and PD sites indicated higher rates of "satisfied" during normal winter weather to cold periods. 83 of 90 (92%) FD respondents responded "satisfied" during normal winter weather, while only 73 of 90 (81%) responded "satisfied" during cold periods. This difference was shown even more for PD sites, with 37 of 42 (88%) respondents indicating "satisfied" during normal winter weather and 25 of 42 (59%) noting "satisfied" during cold periods. This is shown in

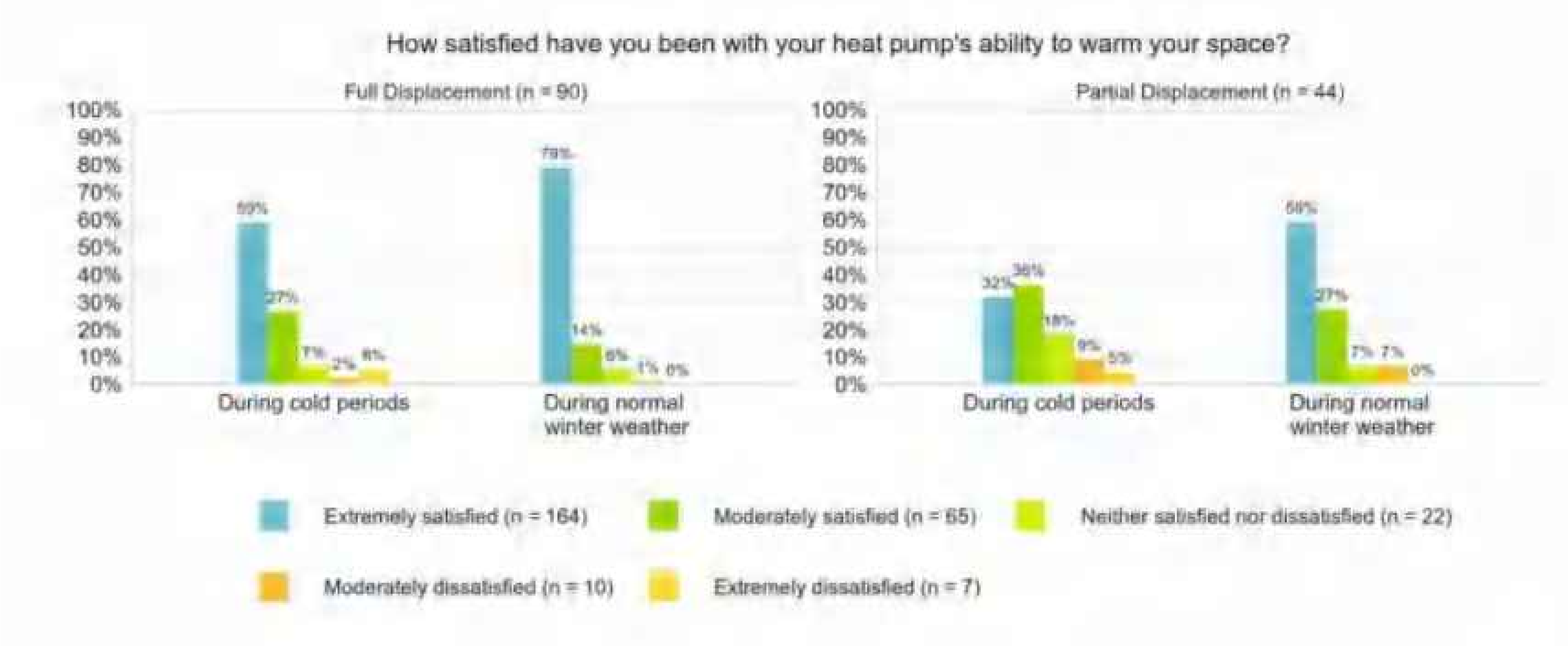
Figure **5-3**.

[70] "Satisfied" includes both "extremely satisfied" and "moderately satisfied" responses.

For customers who responded “dissatisfied” with their heat pump’s ability to warm or meet the heating needs of the space, the reasons listed included:

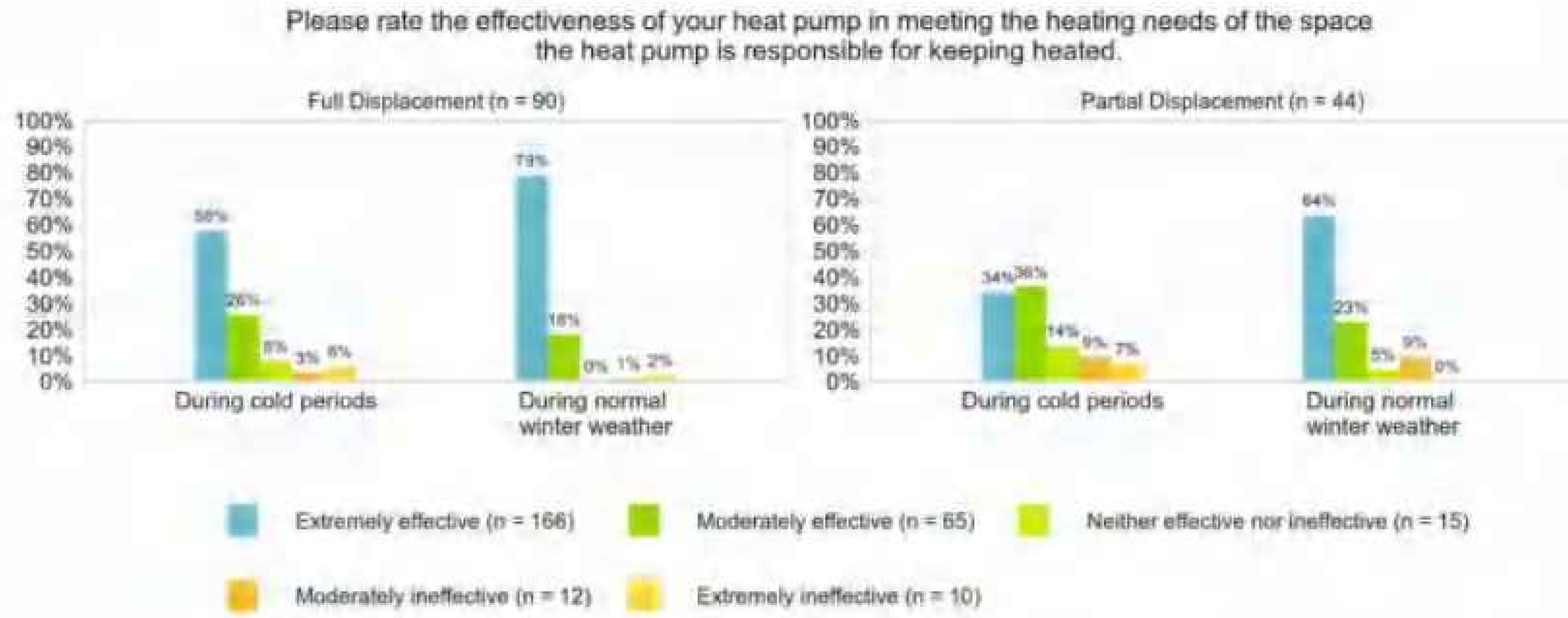
- **Space too cold:** FD customers mostly responded that their homes were too cold, or the heat pump did not heat up the space quickly enough. One PD customer indicated poor circulation of air due to placement of air handler at the top of a vaulted ceiling room.
- **Electricity costs:** Other PD customers indicated high electricity costs.

Figure 5-1 Customer Reported Heat Pump Heating Satisfaction



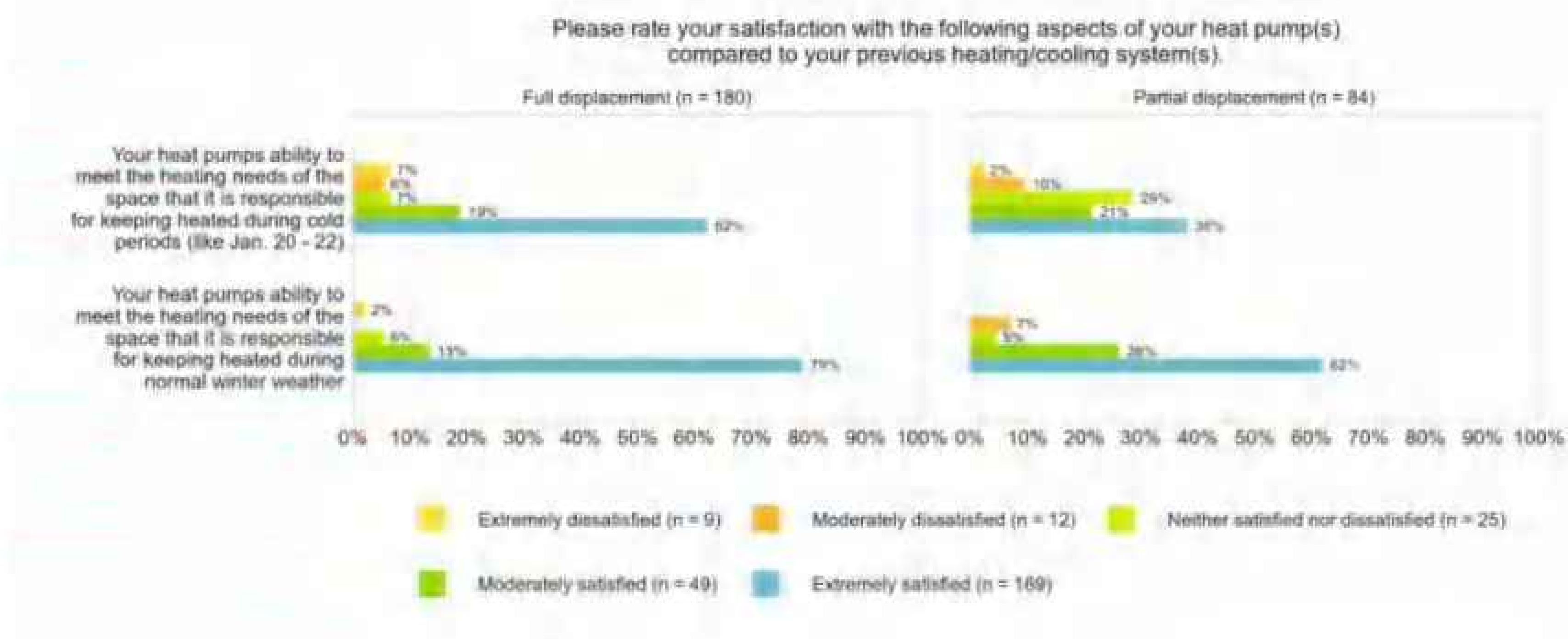
Source: Evaluation team analysis

Figure 5-2. Customer-Reported Heat Pump Heating Effectiveness



Source: Evaluation team analysis

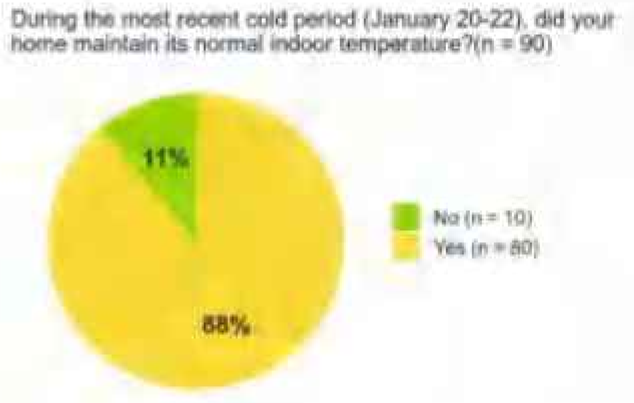
Figure 5-3. Customer Reported Heat Pump Satisfaction Compared to Previous System



Source: Evaluation team analysis

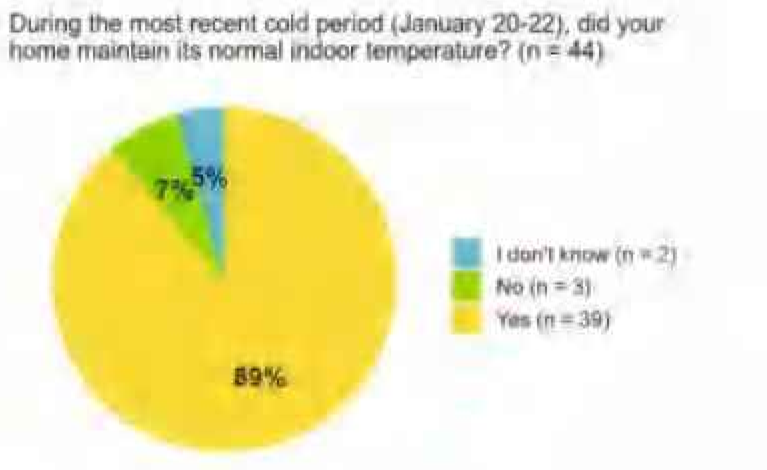
Regardless of displacement type, 88-89% of respondents said their home maintained normal temperature during the most recent cold period. Six percent to 11% of respondants indicated their heat pump did not maintain normal temperature, or indicated they did not know if it did. This is shown in Figure 5-4 and Figure 5-5 below.

Figure 5-4. Home Temperature Maintenance During Cold Period (FD)



Source: Evaluation team analysis

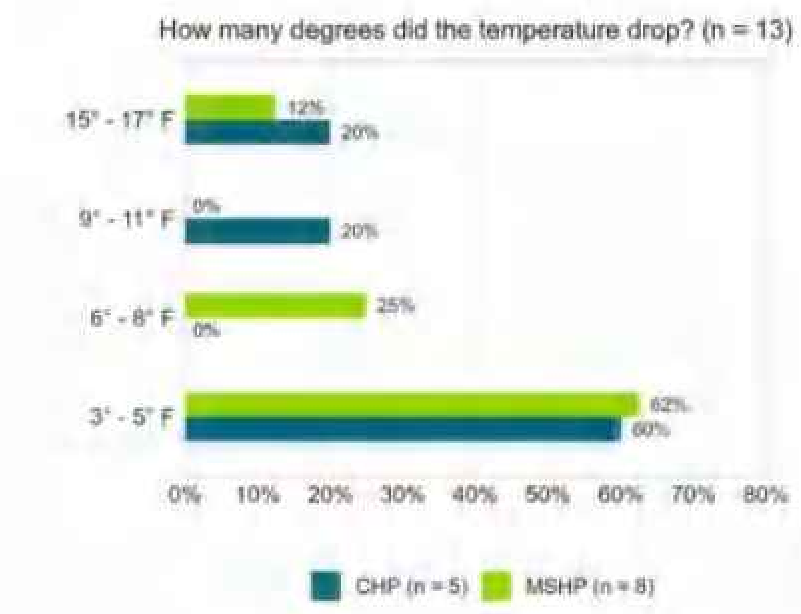
Figure 5-5. Home Temperature Maintenance During Cold Period (PD)



Source: Evaluation team analysis

Of the customers who indicated that their home did not maintain its normal indoor temperature (n=13), 60%-62% (n=8) indicated that temperatures dropped by 3°F to 5°F, as Figure 5-6 shows. The two customers who responded with a 15°F-17°F drop are also customers who were flagged as having potentially undersized systems in Section 4.1.2. The customer who indicated a 9°F-11°F drop is a PD customer with an IC setpoint of 40°F, so the heat pump is not running at cold temperatures, and thus is not the cause of the customer's discomfort.

Figure 5-6. Degree of Temperature Drop in Home*



**1 GSHP respondent indicated that their home's temperature dropped 4°F during the cold period.*
Source: Evaluation team analysis

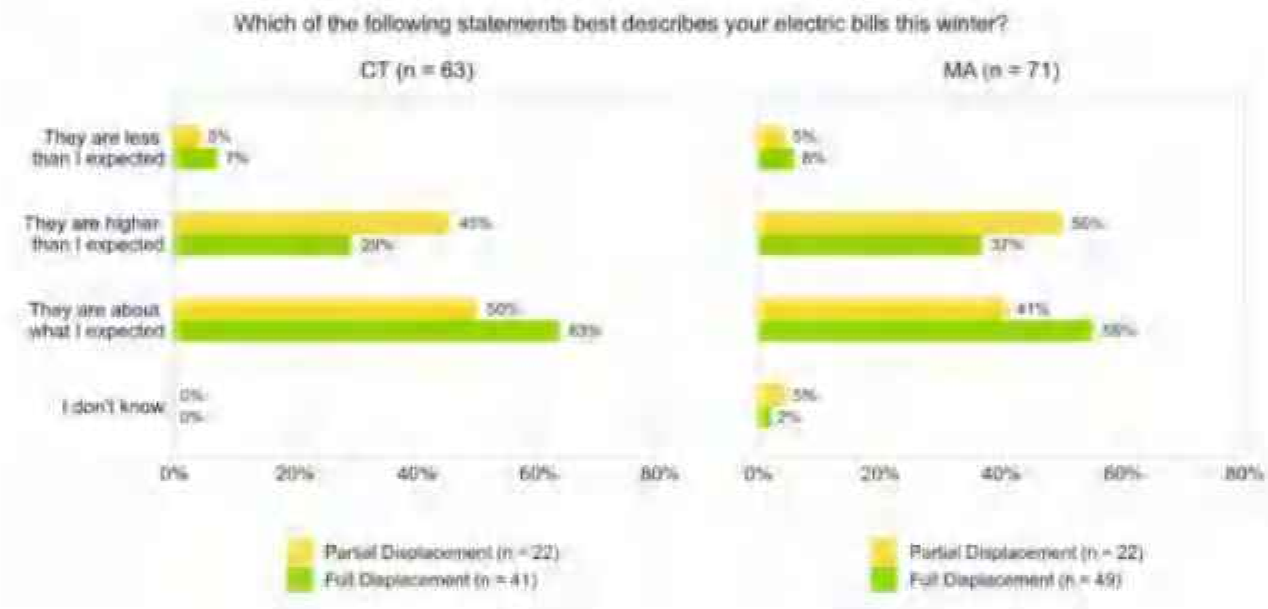
5.4 Cost of Operation

In the End of Season survey, customers were asked about their electricity bill expectations and the impact of electricity cost on their usage of their heat pumps. Figure 5-7 and Figure 5-8 show distributions for electric bill expectations and whether energy costs impacted heat pump operation.

Key Findings:

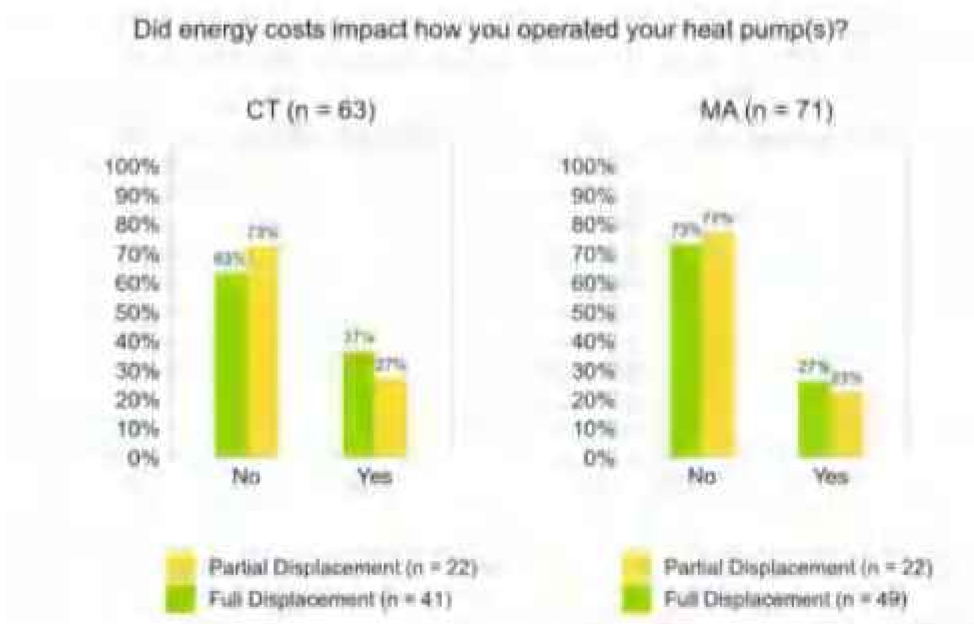
- About 85 out of 134 (63%) of respondents are either extremely satisfied or moderately satisfied with the cost of operating their heat pump(s). 28 out of 134 (21%) are neither satisfied nor dissatisfied.
- The main cause of dissatisfaction was that the cost of electric heating being higher than the cost to operate their previous heating system.
- 39 out of 134 (29%) of respondents claimed that higher energy costs impacted how they ran their heat pumps.
- Among respondents who changed their heat pump operation based on cost, one third used their backup systems more, either manually or by increasing the switchover temperature on their integrated controller. Two thirds lowered their thermostat setpoints or only heated certain rooms. One respondent avoided using their heat pump entirely in favor of their prior heating system.
- Very few respondents indicated that costs were less than expected, but overall respondents indicated that costs were either higher or about what they expected. Respondents with FD systems were slightly more likely than those with PD systems to see their electric bills match their expectations.

Figure 5-7. Electric Bill Expectations



Source: Evaluation team analysis

Figure 5-8. Energy Costs Impact on Heat Pump Operation



Source: Evaluation team analysis

Questions about cost of operation were also asked during the Fast Feedback Interviews conducted with Massachusetts sites in February 2023. Customers reported that:

- Many customers were generally aware of increased electric rates (primarily from media sources). Though customers seem to have a general sense of increased rates, the relative increase and cost between different fuels was not well understood by the interviewees.

- Nearly half of interviewees mentioned that their jurisdiction participates in a community choice aggregation rate, so they may not have seen the full impact of more recent increases in electric costs.

- Customers did not seem overly concerned with their bills and many mentioned that the rates could be comparable to an oil system at this point. Very few changed behaviors due to energy rates. Some said, “Ask me again about how I feel at the end of the winter.”

6. Measure Impacts

This section provides the results of the overall measure impacts, including the change in usage for the typical customer installing heat pump(s) to displace pre-existing electric resistance or fuel-fired space heating systems. The measure impacts account for the overall change in consumption of electricity (kWh) and natural gas, oil, propane, and wood (aggregated to total MMBtu). The measure impacts are provided as overall deemed savings per measure in Section 6.1. Section 6.2 provides parameter estimates to apply to energy savings algorithms for the Connecticut Program Savings Document (PSD).

6.1 Deemed Savings Impacts

This section provides deemed measure impacts for two different analysis scenarios as described below. The measure impacts are the average savings for the typical heat pump installation across the entire program. The deemed measure impacts are the difference between the blended baseline energy consumption and the post-retrofit energy consumption for the average heat pump installation.

The measure impacts values are provided for each program measure, which are categorized by heat pump type, displacement type, and the customer's pre-existing heating fuel type. Section 0 provides an overview of the major analysis and measure impacts rollup steps used to derive these measure impacts. Below is a high-level summary of the various measure impacts data inputs for each of the two scenarios:

- **Post-Retrofit kWh:** For the primary scenario, the average post-retrofit heat pump electrical usage is derived from the full onsite metering sample, and represents the average weather normalized annual electric usage of the heat pump. Per the onsite sample design as outlined in Section 2.3, the post-retrofit heat pump usage is aggregated to the stratum level (defined as each unique heat pump type and displacement category) and is not further broken out by the pre-existing heating fuel type. For the alternative measure impacts scenario, the analysis includes the full displacement sites that removed or disconnected the pre-existing heating system in the home. Appendix A provides additional detail on the methods used to identify sites that met this criteria.
- **Blended Baseline kWh and MMBtu:** The baseline HVAC equipment electric and fuel usage required to meet the same Btu energy output of the metered heat pumps was modeled. The baseline electric and gas usage vary by the measure's pre-existing heating fuel type based on the unique baseline HVAC equipment weights for each combination of heat pump type, displacement type, and pre-existing heat fuel type (as defined in the program tracking database). The baseline weights for heating and cooling are shown in Table 2-16 and Table 2-17.

In the alternative scenario, the baseline weights for heat pump systems were removed, and the non-heat pump baseline system weights were adjusted to total 100%, as shown in Table 2-18 and Table 2-19. The unique baseline HVAC weights have a sizable influence on the overall measure impacts for each measure. Measures with a high proportion of electric heating equipment in their baseline weights (e.g., heat pumps, electric baseboard heaters) and low proportions of fuel-fired heating equipment will show higher electric savings and lower MMBtu savings than measures with a higher prevalence of fuel-fired baseline heating equipment. Conversely in the alternative scenario, a higher proportion of fuel-fired baseline weights result in higher MMBtu impacts.

Table 6-1 shows the annualized electricity and fuels impacts for the primary scenario that includes all baseline HVAC types and the full metered sample. The measure impacts are normalized per ton of installed heat pump cooling capacity. Positive values indicate positive electric or fuel savings going from the average blended baseline heating and cooling equipment to the installed heat pump equipment. The table also includes the average installed tonnage per home for each heat pump and displacement type which can be used to derive the "per home" measure impacts assumptions for the average project. Installations of GSHPs have the highest installed tonnage per home, which will result in higher "per home" measure impacts relative to the other heat pump types. Negative values indicate that consumption increases with the installation of a heat pump for the average installation.

Table 6-1. Deemed Annual Energy Impacts (Per Ton)

Heat Pump and Displacement Type	Pre-Existing Fuel	Blended Baseline kWh	Post-Retrofit kWh	kWh Electric Savings	kWh Electric Savings Relative Precision*	Blended Baseline MMBtu	Post-Retrofit MMBtu	MMBtu Fuel Savings	MMBtu Savings Relative Precision*	Average Installed Tonnage (Cooling)	Sites Included in Rollup (n)
Central Heat Pump - FD	Electric	1,863	1,831	32	610%	7.9	0	7.9	14%	3.7	36
	Natural Gas	608	1,831	-1,223	15%	14.3	0	14.3	14%		
	Oil	562	1,831	-1,269	15%	15.6	0	15.6	14%		
	Propane	552	1,831	-1,279	15%	14.6	0	14.6	14%		
Central Heat Pump - PD	Electric	1,327	1,350	-23	870%	5.2	0	5.2	23%	4.4	30
	Natural Gas	521	1,350	-829	23%	9.3	0	9.3	23%		
	Oil	493	1,350	-857	23%	10.2	0	10.2	23%		
	Propane	486	1,350	-864	23%	9.5	0	9.5	23%		
Mini-Split Heat Pump - FD	Electric	2,875	1,774	1,101	33%	6.5	0	6.5	16%	3.5	46
	Natural Gas	576	1,774	-1,199	20%	15.5	0	15.6	16%		
	Oil	357	1,774	-1,417	16%	17.1	0	17.2	16%		
	Propane	642	1,774	-1,133	21%	15.6	0	15.6	16%		
Mini-Split Heat Pump - PD	Electric	2,526	1,450	1,076	43%	5.7	0	5.7	24%	3.0	32
	Natural Gas	529	1,450	-921	31%	13.5	0	13.5	24%		
	Oil	339	1,450	-1,111	24%	14.9	0	14.9	24%		
	Propane	586	1,450	-864	32%	13.5	0	13.5	24%		
Ground Source Heat Pump – FD	Electric	904	1,442	-538	24%	8.9	0	8.9	15%	6.0	24
	Natural Gas	870	1,442	-572	21%	8.0	0	8.0	15%		
	Oil	869	1,442	-574	21%	8.6	0	8.6	15%		
	Propane	868	1,442	-575	21%	8.1	0	8.1	15%		

*Relative precision calculated at the 90% confidence interval, two-tailed

Based on full metered sample and program data designation of displacement type

Source: Guidehouse analysis, results are normalized using TMYx typical weather spanning the years of (2007-2021)

Table 6-2 provides the seasonal electricity savings for the average installation. The summer on-peak period includes the months of June through September, and the winter on-peak period includes the months of October through May. Both the winter and summer on-peak periods include the hours from 7 a.m. to 11 p.m. on non-holiday weekdays, and the off-peak periods include all other hours.

Table 6-2. Deemed Seasonal Electricity Savings (kWh Per Ton)

Heat Pump and Displacement Type	Pre-Existing Fuel	Winter On Peak Energy Savings	Winter Off Peak Energy Savings	Summer On Peak Energy Savings	Summer Off Peak Energy Savings	Average Installed Tonnage (Cooling)	Sites Included in Rollup (n)
Central Heat Pump - FD	Electric	17	-7	13	9	3.7	36
	Natural Gas	-524	-707	6	2		
	Oil	-543	-733	6	2		
	Propane	-547	-739	6	1		
Central Heat Pump - PD	Electric	-15	-18	6	4	4.4	30
	Natural Gas	-385	-444	2	-2		
	Oil	-398	-459	2	-2		
	Propane	-401	-462	1	-2		
Mini-Split Heat Pump - FD	Electric	514	611	-12	-13	3.5	46
	Natural Gas	-520	-622	-26	-31		
	Oil	-618	-739	-28	-32		
	Propane	-490	-586	-26	-31		
Mini-Split Heat Pump - PD	Electric	521	573	-8	-10	3.0	32
	Natural Gas	-393	-480	-22	-26		
	Oil	-480	-580	-24	-28		
	Propane	-367	-449	-22	-26		
Ground Source Heat Pump – FD	Electric	-254	-338	32	21	6.0	24
	Natural Gas	-268	-357	32	21		
	Oil	-269	-358	32	21		
	Propane	-269	-359	32	21		

Based on full metered sample and program data designation of displacement type
Source: Guidehouse analysis, results are normalized using TMYx typical weather spanning the years of (2007-2021)

Table 6-3 provides the demand impacts for the average installation, using the peak period definitions as defined in Table 4-3 in Section 4.2.

Table 6-3. Deemed Demand Impacts (Per Ton)

Displacement Scenario	Pre-Existing Fuel	Average On Peak kW Savings (Winter)	Average Seasonal Peak kW Savings (Winter)	Average On Peak kW Savings (Summer)	Average Seasonal Peak kW Savings (Summer)	Average Installed Tonnage (Cooling)	Sites Included in Rollup (n)
Central Heat Pump - FD	Electric	0.009	-0.044	0.020	0.051	3.7	36
	Natural Gas	-0.297	-0.471	0.017	0.051		
	Oil	-0.309	-0.490	0.017	0.051		
	Propane	-0.310	-0.493	0.017	0.051		
Central Heat Pump - PD	Electric	-0.012	-0.031	0.011	0.048	4.4	30
	Natural Gas	-0.207	-0.173	0.010	0.048		
	Oil	-0.214	-0.179	0.010	0.048		
	Propane	-0.215	-0.180	0.010	0.048		
Mini-Split Heat Pump - FD	Electric	0.281	0.260	-0.011	-0.003	3.5	46
	Natural Gas	-0.297	-0.429	-0.017	-0.003		
	Oil	-0.351	-0.494	-0.018	-0.003		
	Propane	-0.278	-0.404	-0.017	-0.003		
Mini-Split Heat Pump - PD	Electric	0.298	0.318	-0.007	0.001	3.0	32
	Natural Gas	-0.218	-0.315	-0.012	0.001		
	Oil	-0.266	-0.374	-0.013	0.001		
	Propane	-0.202	-0.292	-0.012	0.001		
Ground Source Heat Pump – FD	Electric	-0.139	-0.212	0.044	0.073	6.0	24
	Natural Gas	-0.147	-0.231	0.044	0.073		
	Oil	-0.148	-0.232	0.044	0.073		
	Propane	-0.148	-0.232	0.044	0.073		

Based on full metered sample and program data designation of displacement type

Source: Guidehouse analysis, results are normalized using TMYx typical weather spanning the years of (2007-2021)

The study sponsors asked the evaluation team to summarize measure impacts for an alternative scenario with the following adjustments to analysis assumptions:

- Heat pumps removed from the baseline system weights, and the remaining HVAC types adjusted to 100% total weight
- Full displacement post-retrofit consumption based on the subset of metered sites where the pre-existing heating system was removed or disconnected. Current program requirements as of May, 2024 require the removal or disconnection of backup heating systems for Full Displacement program rebates.

Table 6-4 shows the deemed measure impacts for this alternative scenario. As expected, the fuel savings (MMBtu) for GSHPs are higher in the alternative scenario, as the baseline weight for heat pumps is removed and the weight for baseline fuel-fired systems increased. This scenario may more closely reflect the design of the heat pump fuel displacement program offerings in future years, however, assumptions for baseline equipment weights should be adjusted to reflect assumptions based on future program design.

Table 6-4. Deemed Annual Energy Impacts (Per Ton) – Remove Heat Pump Baseline Weights, Remove/Disconnect Pre-Existing Heat for FD

Heat Pump and Displacement Type	Pre-Existing Fuel	Blended Baseline kWh	Post-Retrofit kWh	kWh Electric Savings	kWh Savings Relative Precision*	Blended Baseline MMBtu	Post-Retrofit MMBtu	MMBtu Fuel Savings	MMBtu Savings Relative Precision*	Average Installed Tonnage (Cooling)	Sites Included in Rollup (n)
Central Heat Pump - FD	Electric	1,729	1,773	-44	866%	11.4	0	11.4	21%	3.8	14
	Natural Gas	432	1,773	-1,341	23%	15.7	0	15.7	21%		
	Oil	431	1,773	-1,343	23%	16.6	0	16.6	21%		
	Propane	440	1,773	-1,333	23%	15.3	0	15.3	21%		
Central Heat Pump - PD	Electric	1,286	1,350	-63	424%	7.6	0	7.6	23%	4.4	30
	Natural Gas	417	1,350	-933	23%	10.5	0	10.5	23%		
	Oil	417	1,350	-933	23%	11.1	0	11.1	23%		
	Propane	422	1,350	-928	23%	10.2	0	10.2	23%		
Mini-Split Heat Pump - FD	Electric	2,588	1,462	1,126	43%	6.2	0	6.2	22%	4.0	12
	Natural Gas	435	1,462	-1,028	31%	14.4	0	14.4	22%		
	Oil	238	1,462	-1,225	25%	15.8	0	15.8	22%		
	Propane	447	1,462	-1,016	32%	15.2	0	15.2	22%		
Mini-Split Heat Pump - PD	Electric	2,591	1,450	1,141	43%	6.1	0	6.1	24%	3.0	32
	Natural Gas	490	1,450	-961	30%	14.0	0	14.0	24%		
	Oil	297	1,450	-1,153	24%	15.4	0	15.4	24%		
	Propane	501	1,450	-949	31%	14.8	0	14.8	24%		
Ground Source Heat Pump – FD	Electric	391	1,403	-1,011	18%	13.9	0	13.9	19%	6.0	16
	Natural Gas	397	1,403	-1,006	18%	13.4	0	13.4	19%		
	Oil	394	1,403	-1,009	18%	14.4	0	14.4	19%		
	Propane	392	1,403	-1,011	18%	13.6	0	13.6	19%		

*Relative precision calculated at the 90% confidence interval, two-tailed

Based on full metered sample for Partial Displacement, and the subset of Full Displacement installations that removed or disconnected the backup heating system

Source: Guidehouse analysis, results are normalized using TMYx typical weather spanning the years of (2007-2021)

Overall ex post measure impacts are generally lower than the ex ante assumptions, which were derived from the prior Massachusetts Energy Optimization (EO) Fuel Displacement study (completed in 2021) and are currently incorporated into the MA TRM and CT PSD impact assumptions, however measure impacts for PD MSHP are similar.[71] Table 6-5 shows a comparison of the ex ante and ex post measure impacts between the two studies for the heat pump types, displacement types, and pre-existing fuel types evaluated in both studies. The table includes the ex ante measure impacts for the 2021 and 2024 program years; the study assumed lower average switchover temperatures for partial displacement projects with pre-existing oil and propane heating fuels in the 2022 through 2024 program years. The table also includes impacts for both measure impacts scenarios. The first scenario includes weights for all baseline heating types and includes all metered sample in the Full Displacement category. The second scenario removes heat pumps from the baseline weights and only includes post-retrofit usage for Full Displacement installations that removed or disconnected the backup heating systems.[72]

[71] Guidehouse (2021). "Energy Optimization Fuel Displacement Impact and Process Study." Provided to the Electric and Gas Program Administrators of Massachusetts. https://ma-eeac.org/wp-content/uploads/MA20R24-B-EOEval_Fuel-Displacement-Report_2021-10-13_Final.pdf.

The MA EO FD report provides measure impacts for oil, propane, and electric resistance heating fuels and for the 2021, 2022, 2023, and 2024 program years, with varying switchover temperature assumptions for partial displacement projects in each program year. The 2021 program year results are used as the basis of comparison against the current study results.

Connecticut references the deemed measure impacts from the 2021 MA Energy Optimization Fuel Displacement report in the current CT Program Savings Document (PSD) for these measures.

[72] The metered sample for this study includes heat pump installations during the 2021 and 2022 program years (predominantly 2022 program year). Given changes in program design during subsequent program years, the ex post impacts for the Partial Displacement case may be most comparable to the 2021 ex ante assumption and are not directly comparable to the switchover temperature assumptions in the 2024 ex ante assumption.

Table 6-5. Measure Impacts Comparison – Ex Ante vs. Ex Post (Per Ton)

Heat Pump and Displacement Type	Pre-Existing Fuel	Ex Ante kWh Electric Savings (2021)	Ex Ante kWh Electric Savings (2024)	Ex Post kWh Electric Savings (All Baselines, Full Sample)	Ex Post kWh Electric Savings (No HP Baseline, FD Remove/ Disconnect)	Ex Ante MMBtu Fuel Savings (2021)	Ex Ante MMBtu Fuel Savings (2024)	Ex Post MMBtu Fuel Savings (All Baselines, Full Sample	Ex Post MMBtu Fuel Savings (No HP Baseline, FD Remove/ Disconnect)
Central Heat Pump - Full Displacement	Oil	-1,795	-1,795	-1,269	-1,343	17.9	17.9	15.6	16.6
	Propane	-1,795	-1,795	-1,279	-1,333	17.9	17.9	14.6	15.3
Central Heat Pump - Partial Displacement	Oil	-795	-900	-857	-933	11.1	12.7	10.2	11.1
	Propane	-795	-1,390	-864	-928	11.6	17.9	9.5	10.2
Mini-Split Heat Pump - Full Displacement	Electric	2,316	2,316	1,101	1,126	3.8	3.6	6.5	6.2
	Oil	-1,508	-1,508	-1,417	-1,225	17.8	17.8	17.2	15.8
	Propane	-1,508	-1,508	-1,133	-1,016	17.8	17.8	15.6	15.2
Mini-Split Heat Pump - Partial Displacement	Oil	-957	-994	-1,111	-1,153	15.0	15.8	14.9	15.4
	Propane	-957	-1,264	-864	-949	14.8	19.0	13.5	14.8

Source: Guidehouse analysis

Below are drivers that could contribute to some of the difference in measure impacts between ex ante and ex post assumptions:

- Post-retrofit heat pump usage is generally lower than the prior study for FD installations. The prior EO Fuel Displacement study assumed that FD heat pump installations met the full heating loads of the home with the installed heat pumps. The current heat pump metering study aggregated actual heat pump usage data for a sample of sites. For sites included in the first scenario (all metered sample), the results of this analysis showed that many of the installations categorized as FD were relying on other heating systems to meet portions of the heating load of the home. In the second scenario, the subset of homes that removed or disconnected the pre-existing heat has relatively lower sample size for each heat pump type (less than n=20). Variability in usage for the sample may drive changes in post-retrofit consumption compared to the other scenarios.
- The current study generally assumed higher existing and new unit efficiencies for baseline fuel-fired heating equipment types. All else equal, higher baseline unit efficiencies lower the baseline MMBtu heating equipment usage, lowering overall MMBtu measure impacts.
- The current study estimates post-retrofit heat pump usage at the stratum level (heat pump type and displacement type). The prior study also estimated varying post-retrofit heat pump consumption for PD project by the customer's noted pre-existing fuel type in the program data (oil, propane). Therefore, the current study's post-retrofit heat pump consumption does not vary by pre-existing fuel type for PD projects. Only the baseline usage varies based on application of baseline weights by pre-existing fuel type, leading to slight differences in measure impacts between the fuel types.

6.2 Algorithmic Savings for Connecticut PSD

Connecticut has two measures in the Connecticut Program Savings Document (PSD) that are being updated with results from this study. These measures include PSD Section 3.2.16 'Fuel Optimization', which is in the current version of the "Final 2024 Program Savings Document."

This section applies to the "Addition of heat pump partially or fully displacing existing HVAC". The savings were calculated via simulation model runs using a weighted average of survey responses for the most accurate switch over temperature between the installed heat pump and the backup heating source. The annual savings are obtained by multiplying the deemed savings factor by the heat pump capacity. The savings in Section 6.1 will be used to update Table 3-108 Saving Factors in the PSD.

The other measure Connecticut is currently developing for inclusion in a future update to the PSD is the "ASHP, Mini-Spits, PTAC, PTHP" measure. This measure uses an algorithmic approach, as opposed to the deemed saving approach used in the 3.2.16 Fuel Optimization measure. The description of this measure is: "This measure targets the use of air source heat pumps and mini split heat pumps in residential and low-rise multi-family applications…. This measure may apply to early replacement of an existing system, replacement on failure, or installation of a new unit in a new or existing residential or multi-family low-rise building for HVAC applications." This study will inform the inputs required for the new algorithmic savings equations as shown in Table 6-6.

Table 6-6. PSD Variables and Descriptions

PSD Variable	Description	Units
$F_{adj,q,c}$	In-situ cooling efficiency adjustment factor of installed unit	N/A
$F_{adj,q,h}$	In-situ heating efficiency adjustment factor of installed unit	N/A
F_{load}	PD Factor to account for the portion of heating load met by the heat pump	N/A
$EFLH_c$	Equivalent Full Load Hours of operation for the average unit during the cooling season	Hours
$EFLH_h$	Equivalent Full Load Hours of operation for the average unit during the heating season	Hours

Source: Evaluation team analysis

Further description into how each variable was calculated is outlined below:

- **Efficiency Adjustment Factors (Fadj, heating, cooling):** These factors represent the average ratio of the modeled seasonal heating and cooling efficiency for sites with metered performance data to the rated heating and cooling efficiency (HSPF2/SEER2).
- **PD Factor (Fload, heating):** This factor is calculated similarly to the portion of heating load met by the HPs (Table 4-6, Section 4.3.1), but with auxiliary heating also included. These values are based on the portion of the home heated by the heat pump, which may not be the full home.
- **Equivalent Full Load Hours (EFLH, heating, cooling):** EFLH is calculated by dividing annual kWh (calculated from weather-normalized metered data) by full load kW for each heat pump unit. Full load kW is calculated as the rated capacity of the unit divided by rated seasonal efficiency (HSPF2/SEER2). EFLH values are then averaged across all systems in the metered sample.

Table 6-7. PSD Variable Results

Heat Pump Type	Displacement Category	$EFLH_h$	$EFLH_c$	$F_{adj,h}$	$F_{adj,c}$	F_{load}
CHP	FD	1,397	544	1.03	0.86	0.90
CHP	PD	825	509	1.00	0.81	0.66
MSHP	FD	1,275	499	0.91	0.92	0.91
MSHP	PD	1,025	484	0.95	0.93	0.79
GSHP	FD	1,998	470	0.71	0.59	0.99

Based on full metered sample and program data designation of displacement type

Source: Evaluation team analysis

7. Future Considerations

Through this study, the team uncovered best practices for heat pump metering that can be applied to future studies. Through discussions with the study sponsors and stakeholders, the team has also summarized a variety of additional research questions that could be explored through future studies. This section details these items.

7.1 Lessons Learned

This section provides a list of lessons learned from this study.

- **Reassess logger specifications and internet connectivity solutions.** There were interruptions in logger internet connectivity at various sites during this study. Future studies can look to install more redundant loggers on important data streams and look to install cellular WiFi access point(s) at sites in case the customer's WiFi service is interrupted. Study teams could also look into logger models with additional local storage, however these logger types may be more expensive.

- **Allocate additional time for meter installation visits.** Based on experiences from other onsite studies, the team allocated four hours per installation site visit (homes with performance monitoring), which was used to install all data loggers, perform airflow testing, conduct customer interview questions, and record information on heating system and home characteristics. This site installation window also balanced customer experience, as the team did not want to cause undue burden on the customer through longer installation visit windows. The team noted that site visits sometimes required additional time. Allocating more time at each site visit could have potentially improved the study in the following ways:
    - Provided a larger time window to confirm logger connection status and troubleshoot issues, specifically connectivity issues with wireless logger infrastructure and homeplug.
    - Provided an opportunity to review heat pump performance data at the initial installation (e.g., return and supply airstream temperatures).
    - Expanded the level of home characterization, i.e., create floor plans, which could be used to support Manual J inputs, investigate other load impacts such as insulation levels, detail specific spaces or zones served by each system.

- **Additional data collection for geothermal systems.** Future studies can look to install additional water temperature loggers on the ground or water loops. This data can then be used for a more direct comparison of the in-field efficiency to the manufacturer rated efficiencies which are rated at specific entering air and inlet water temperatures. The study can also collect additional characteristics of the ground source heat pump systems, such as the loop design.

7.2 Future Study Ideas

This section provides a list of potential future study ideas. Some of these have been discussed with the study sponsors, and others are provided by the evaluation team.

- The study sponsors could consider a future study exploring the overall customer or utility costs related to heat pump sizing, amount of auxiliary heat installed and used, resulting peak demands for the heating systems of the home, and associated energy and demand costs. The study can also explore impacts to greenhouse gas emissions associated with these variables. The study can investigate the optimization of greenhouse gas emissions and system and operating costs of the HVAC system(s).
- Creation of a predictive model or tool that would estimate the usage and measure impacts for site-specific installation criteria: specific baseline system type, post-retrofit heat pump size, efficiency, compressor type and for different building characteristics, switchover temp, etc. This model or tool can be scaled up or down to specific input variables of interest to the study sponsors.
- Conduct surveys of customers with installation of heat pumps in future years to understand any changes to baseline equipment types.
- Analysis could be done to generate heat pump performance curve coefficients for use in building simulation models.
- Additional research could be done to 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 system to meet the load, and are they considering capacities of the units at 5°F?
- Benchmarking impacts against previous heat pump studies and comparing methodology where appropriate.
- Research could be done to look into the following items:
    - Installation impacts on performance: location of AHU, orientation and exposure of condensers, etc.
    - Part load performance - how the system operates at part load, cycling at full load vs. running longer duration at low speed.

Appendix A. Measure Impacts for Various Full Displacement Scenarios

The study sponsors requested that the evaluation team investigate differences in heat pump usage and measure impacts for different hypothetical scenarios of Full Displacement site characteristics. This section provides results of this investigation.

The team first reviewed primary customer survey responses, winter 2022-2023 fast feedback interviews, end of season (winter 2023-2024) survey responses, and onsite metered data for each site to inform heat pump and backup heating system usage characteristics. Backup heating systems refers to separate conditioning systems independent from the heat pump (boiler, furnace, wood stove, baseboard heating, space heater, window AC unit). Auxiliary electric heating systems are included in the scenarios below. Each site was sorted into one of the following FD categories:

- Site disconnected, and removed backup heating system
- Site disconnected backup heating system, but it was left in place in the home
- Existing heating system left connected, but it was not used during metered period
- Existing heating system left connected, but it was used rarely during metered period

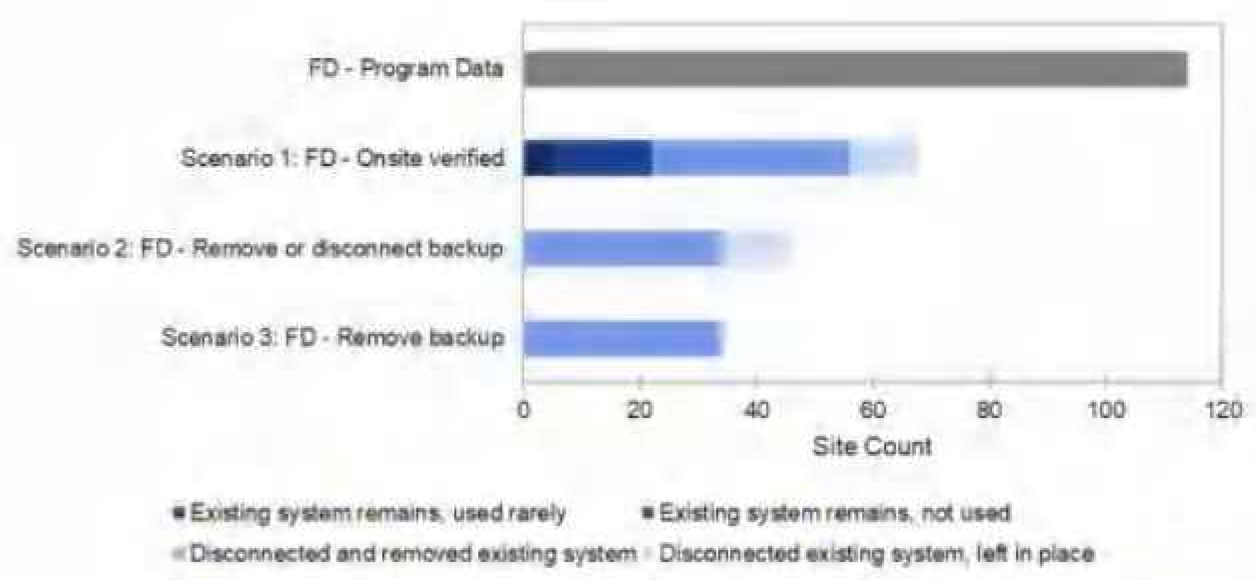
For sites with backup heating sources, the types of heating equipment included the following:

- Boilers—Including fuel oil, propane, and natural gas boilers
- Furnaces—Including fuel oil, propane, and natural gas furnaces
- Wood or pellet stoves—Wood fireplaces used solely for ambiance were not labeled as a backup heating source; wood stoves with significant use were labeled as backup heating
- Electric resistance—Including electric furnace, electric radiant/baseboard, electric space heaters, and electric fireplaces

Figure A-1 summarizes the overall metered sample for each of three scenarios:

- **Scenario 1: Onsite verified FD operation**—Includes sites where the pre-existing heating system was removed, disconnected, or left connected but not used or used rarely (n=68)
- **Scenario 2: Remove or disconnect backup heat**—Includes sites where the pre-existing heating system was removed or disconnected (n=46)
- **Scenario 3: Remove backup heat**—Includes sites where the pre-existing heating system was removed (n=34)

Figure A-1. Full Displacement Site Comparison, Program Data vs. Scenarios

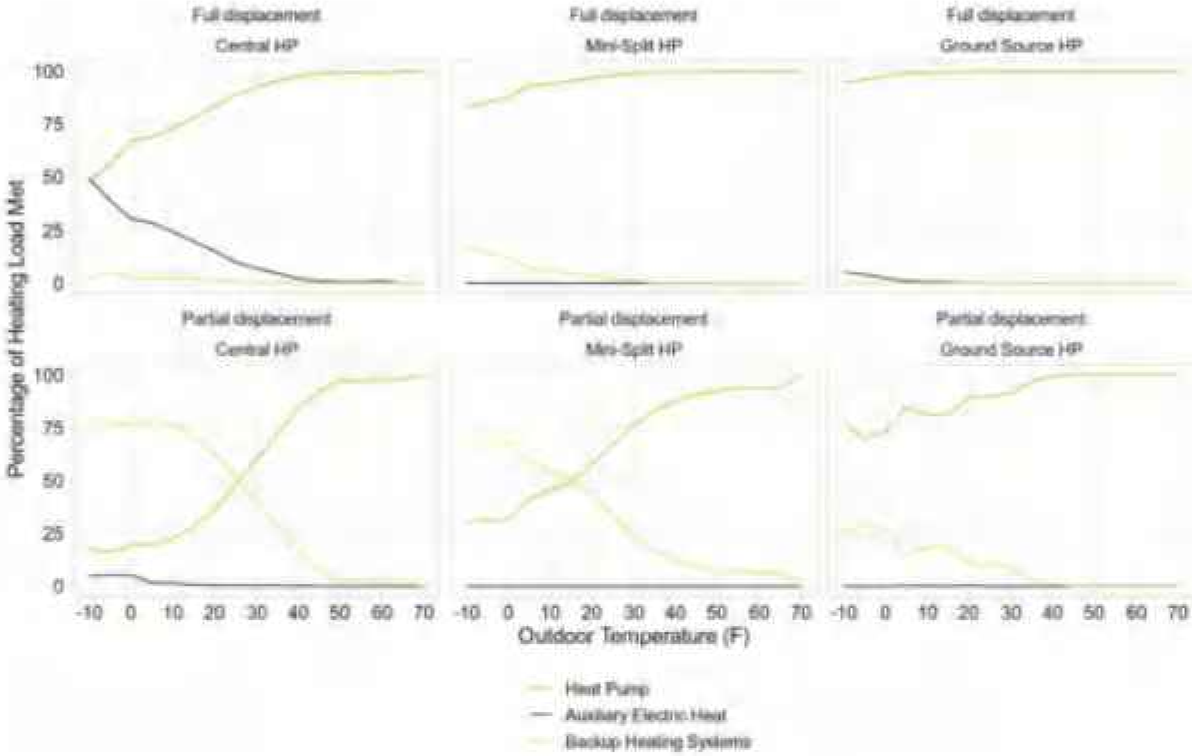


Source: Evaluation team analysis

Figure A-2 shows the comparison of backup and auxiliary system usage by temperature based on the onsite verified displacement type (Scenario 1). As compared to the proportions of heating loads met by the heat pump and backup/auxiliary heat as demarcated in the program data, the portion of the load met by the heat pump in FD applications increases, and the portions for PD applications stays approximately the same.

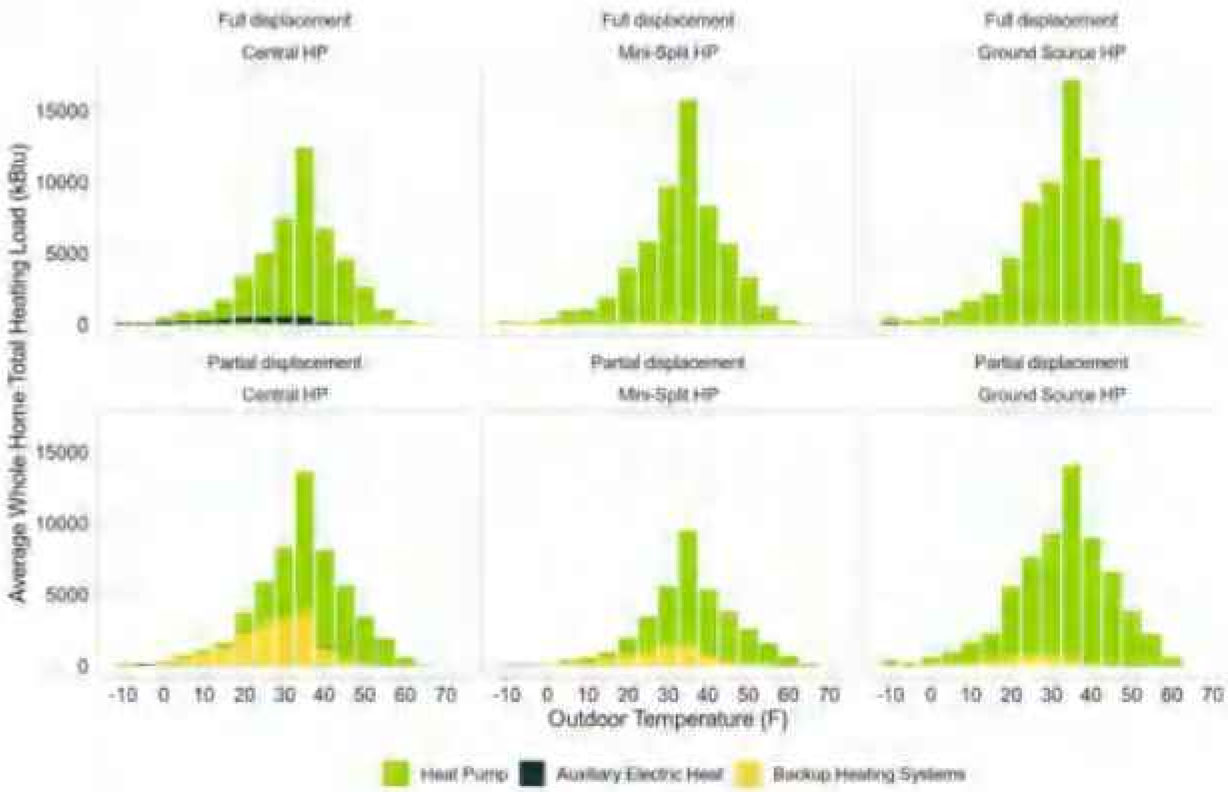
Throughout the three different FD scenarios shown in the following figures, the heating load met by each heat pump type stays relatively consistent. However, it is important to note that the sample size decreases with each scenario as stated in Table A-1.

Figure A-2. Backup and Auxiliary System Usage by Temperature Bin—Scenario 1: Onsite Verified Displacement Type



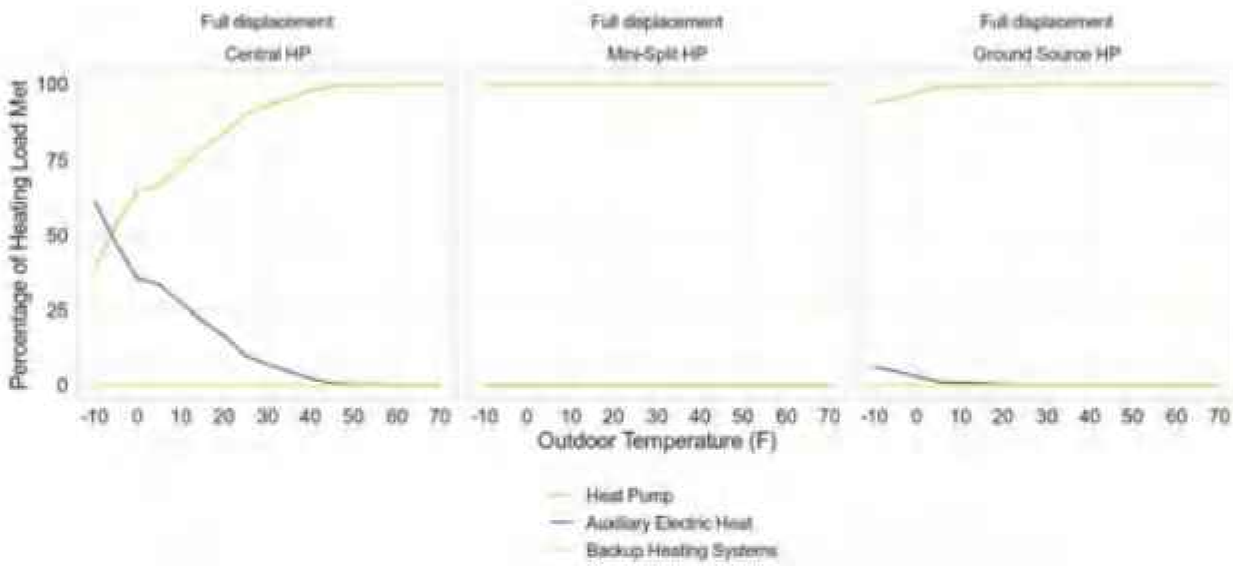
Source: Evaluation team analysis

Figure A-3. Backup and Auxiliary System Portion of Total Heating Load by Temperature Bin—Scenario 1: Onsite Verified Displacement Type



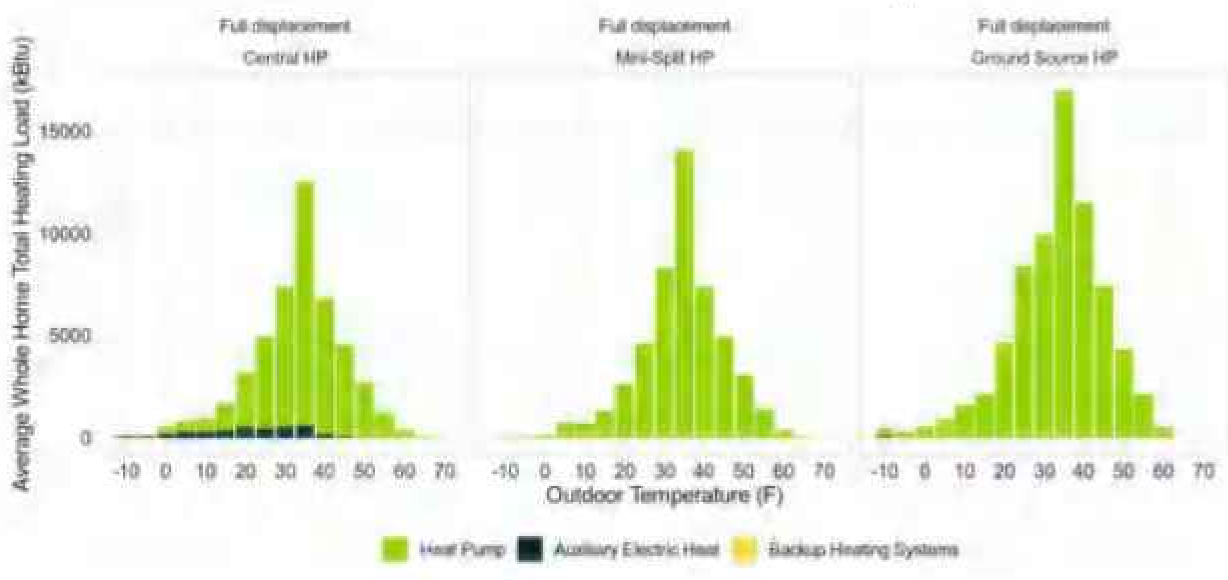
Source: Evaluation team analysis

Figure A-4. Backup and Auxiliary System Usage by Temperature Bin—Scenario 2: Remove or Disconnect Backup Heat



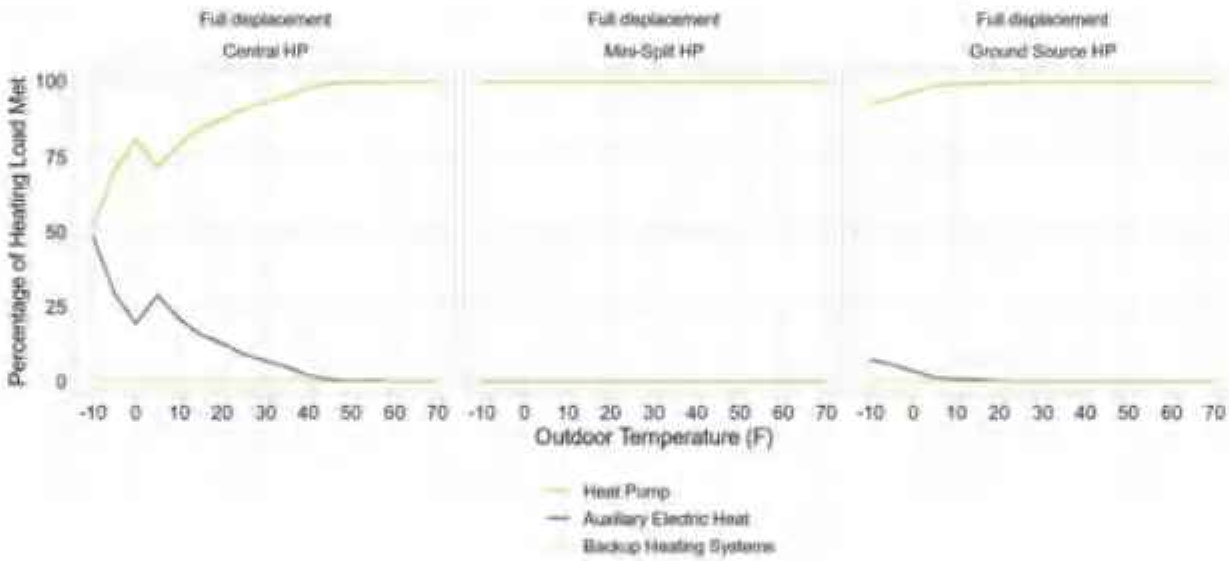
Source: Evaluation team analysis

Figure A-5. Backup and Auxiliary System Portion of Total Heating Load by Temperature Bin—Scenario 2: Remove or Disconnect Backup Heat



Source: Evaluation team analysis

Figure A-6. Backup and Auxiliary System Usage by Temperature Bin—Scenario 3: Remove Backup Heat



Source: Evaluation team analysis

Figure A-7. Backup and Auxiliary System Portion of Total Heating Load by Temperature Bin—Scenario 3: Remove Backup Heat

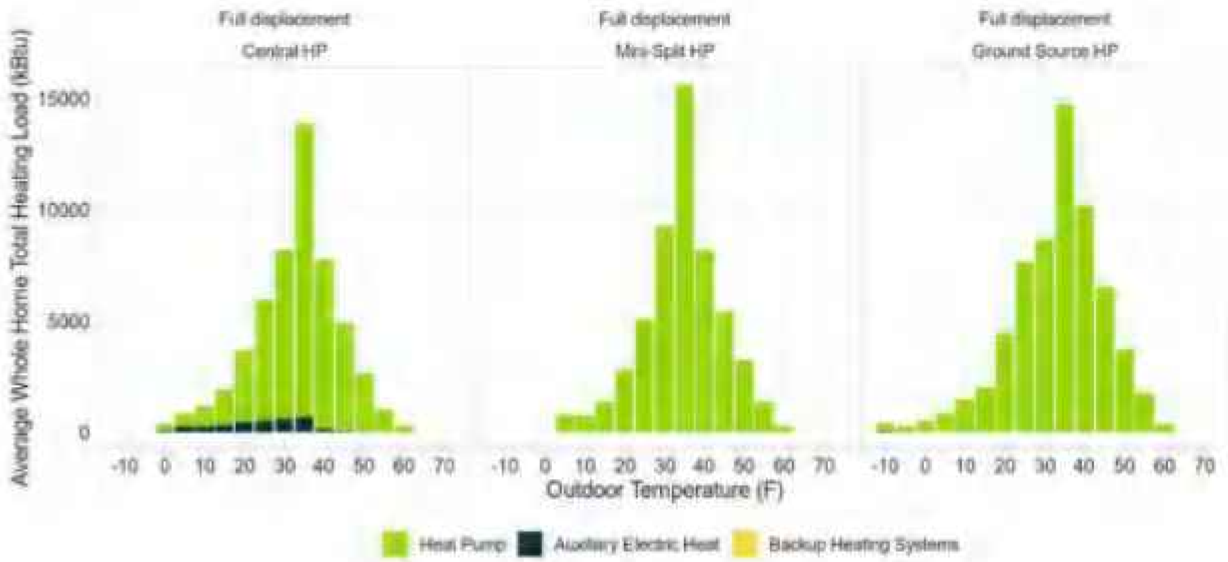


Table A-1 shows the proportion of the heating season heating load met by the heat pump and the backup and auxiliary heating systems for the various FD scenarios. The portion of load met by the heat pump is relatively the same between the Onsite Verified, Remove/Disconnected Backup Heat, and the Remove Backup Heat scenario. As noted above, the sample of sites included in the analysis rollup for each of these scenarios decreases for each scenario based on the FD definitions above.

Table A-1. Proportion of Heating Season Load Met by System Type and FD Categorization Scenario

Heat Pump Type	Full Displacement Scenario	Sample included in Rollup (n)	Proportion of Heating Load Met – Heat Pump	Proportion of Heating Load Met – Auxiliary Electric Heat	Proportion of Heating Load Met – Backup Heating Systems
Central HP	Program Data	30	86%	4%	10%
	Verified	18	93%	6%	0%
	Remove/Disconnect Backup	12	94%	6%	0%
	Remove Backup	8	94%	6%	0%
Mini-Split HP	Program Data	43	91%	0%	9%
	Verified	25	99%	0%	1%
	Remove/Disconnect Backup	15	100%	0%	0%
	Remove Backup	12	100%	0%	0%
Ground Source HP	Program Data	20	99%	0%	1%
	Verified	17	100%	0%	0%
	Remove/Disconnect Backup	14	100%	0%	0%
	Remove Backup	11	100%	0%	0%

Source: Evaluation team analysis

The team used the sites identified in the Remove/Disconnect Backup heat scenario to estimate post retrofit usage for an alternative measure impacts scenario, presented in Section 6.

Appendix B. Customer Survey Guides

B.1 Primary Survey Guide

Massachusetts and Connecticut Heat Pump Performance and Usage Study

(MA22R51-B-HPMS) / (CT R2246)

Customer Survey – Wave 2

Prepared for:

The Electric and Gas Program Administrators of Massachusetts and the Connecticut Evaluation Administrators

Part of the Residential Evaluation Program Area

Provided by:

Guidehouse Inc.
1375 Walnut Street
Suite 100
Boulder, CO 80302

303.728.2500

February 15, 2023

Survey Information

This survey will be delivered in an online format to residential customers who received a heat pump rebate during the 2022 program year. The team will deliver the survey by email.

The team assumes that 20% of sampled customers will respond to the survey, of which 50% will be interested and eligible for the follow-up metering study. For partial displacement installations, the team may sample approx. 2,400 customers to support the onsite recruitment effort. The team assumes that the population of full displacement installations are small enough that a census of projects will need to be surveyed.

Research Objectives

In **Table 8** we outline which survey modules will answer each research question. The main goal of the survey is to recruit metering study participants. Secondarily, the survey will assess baseline, customer decisions, and confirm equipment.

Table 8. Customer Survey Objectives

Research Topic	Section
Metering Study Recruitment	
Recruit metering study participants, including screener questions for eligibility and willingness to participate.	Module B
Customer Equipment	
Confirm building type, HVAC equipment and hot water system types and fuels, and other demographic variables used for designing representative samples and for potential post-weighting variables.	Module A
Confirm pre-heat pump installation system type and fuel source, and obtain delivered fuels purchase orders or volume estimates	Module C
Customer Behavior and Decisions	
Assess gross baselines using baseline determination questions, including what type of heating and/or cooling equipment the customer would have installed if they didn't install the heat pump they did	Module C
Customer installation decisions, control types, HVAC operation practices, and other heating options (wood stoves, fireplaces, portable heaters).	Module C

Table 2. Survey Embedded Variables

Embedded Variable	Source
EQUIPMENT	Sample
BUILDING_AGE	Sample
PA	Sample
EQUIPMENT_REPORTED	A3 Survey Response
INTEGRATED_CONTROLS_REPORTED	A4 Survey Response
YEAR	Sample
Email	Sample
Name	Sample

Survey Introduction

You are receiving this survey because you received a rebate from Mass Save or Energize CT for your heat pump. Thanks for your participation! Your feedback on this survey will help the Sponsors of Mass Save and Energize CT understand your experience to make program improvements in the future. After completing this survey, you may also be eligible to participate in a follow-up metering study to help The Sponsors of Mass Save and Energize CT understand energy usage and performance of heat pumps installed through the rebate program.

There are no right or wrong answers; we want your honest feedback. This survey will take about 20 minutes of your time. To thank you for your feedback, you will receive a $20 e-gift card through Rewards Genius and Tango Card after you have completed the survey, redeemable at numerous retailers or for charitable donation.

If prompted, please enter your PIN. This is the number printed on the postcard you may have received in the mail or in the body of the email you may have received.

PIN: **[8 DIGIT NUMERIC FIELD]**

[IF CARD NUMBER IS ON FILE AND NOT YET USED, SKIP TO QI3]

[IF CARD NUMBER IS NOT ON FILE, ASK QI1]

[IF CARD NUMBER IS ON FILE BUT HAS ALREADY BEEN USED, SKIP TO QI2]

I1. Sorry, but the customer PIN number that you entered cannot be found. Please reenter your customer PIN number from the card that you received in the mail.

PIN: **[8 DIGIT NUMERIC FIELD]**

[IF CARD NUMBER NOT ON FILE, THANK AND TERMINATE]

Unfortunately, we can't find the PIN number that you entered. We appreciate your time and apologize for any inconvenience this has caused. **[CODE AS "TERMINATE"]**

I2. Our records show that a survey has already been completed for the customer PIN you entered. Please reenter your customer PIN number.

Record card number **[8 DIGIT NUMERIC FIELD]**

[IF RE-ENTERED CARD NUMBER ALREADY USED, THANK AND TERMINATE WITH THIS MESSAGE:]

Unfortunately, we are unable to proceed with the customer PIN number that you entered. We appreciate your time and apologize for any inconvenience this has caused. **[CODE AS "TERMINATE"]**

I3. Great, your record has been found.

[GENERAL TERMINATE MESSAGE]

Unfortunately, you are not eligible to complete this survey. Thank you very much for your time and we apologize for any inconvenience this has caused. If you believe this survey was terminated in error, please contact SurveyInfo@guidehouse.com

Module A: Home Characteristics

C1. Our records show that you received a rebate from **<Energize CT or Mass Save>** for installing a heat pump(s) in 2022. Is this correct? **[SINGLE RESPONSE]**

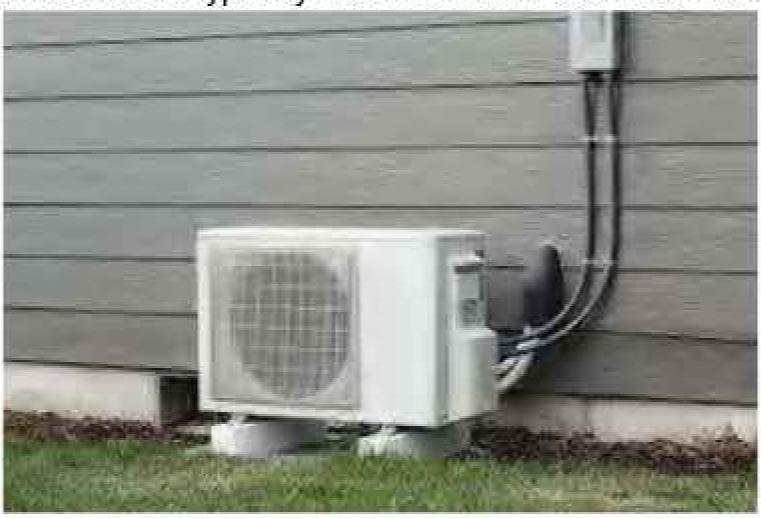
1) Yes **[Continue with survey]**
2) No, I did not receive a rebate on a heat pump **[TERMINATE]**

97) Other **[TEXT]**
98) Don't know **[TERMINATE]**

A3. What type of heat pump did you receive a rebate for in **<YEAR>**? Select all that apply.

1) Mini-split heat pump(s)

Mini split heat pumps typically have smaller outdoor units than central heat pumps and can be ducted or ductless. Ductless systems are the most common. Ductless systems heat and cool using refrigerant lines that lead from the outdoor unit to indoor units that are typically wall mounted in each room being conditioned.



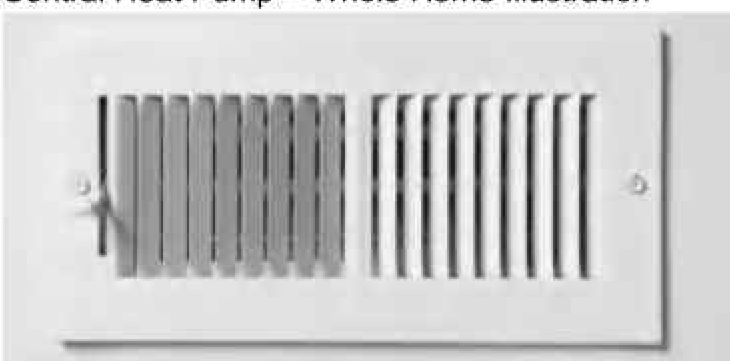
Outdoor Mini Split Heat Pump

Indoor Ductless Mini Split Head

2) Central heat pump

Central heat pumps are a common replacement for a central heating or cooling system. The outdoor units are larger and provide heating and cooling through the ducts of a home/building to a register located in the floor, ceiling, or wall of each room that is conditioned.

Central Heat Pump – Whole Home Illustration



Register

3) Ground source heat pump (i.e., geothermal)

Ground source heat pumps use the ground's heat to both heat and cool the home. Considerable excavation is required to install a ground source heat pump.

Ground Source Heat Pump - Full System Illustration

[LOGIC: If customer selects > 1 equipment type in A3, pipe in random selection as EQUIPMENT_REPORTED]

[LOGIC: Ask A4 IF IC = 1]

A4. Did you install an integrated control on your [EQUIPMENT_REPORTED]?

The control is often programmed as part of a thermostat. An integrated control may be installed to manage your heat pump system. The control is designed to automatically switch between your heat pump system and your fuel-fired heating system when the outdoor temperature drops below a certain point.

1) Yes
2) No
97) I don't know

[LOGIC: Assign A4 response to variable INTEGRATED_CONTROLS_RESPONSE]

A5. We are interested in learning a little bit about the home where you had the [EQUIPMENT_REPORTED] installed. Is this home owned or rented by you or someone in this household? [SINGLE RESPONSE]

1) Owned
2) Rented
3) Other, please specify [TEXT BOX]

A6. Is the home where you had the [EQUIPMENT_REPORTED] installed your primary residence or a secondary/vacation home? [SINGLE RESPONSE]

1) It is my primary residence
2) It is my secondary residence or vacation home
3) I am the landlord/property manager **and** I was the decision maker for installing the rebated heat pump(s)
4) This is not my home [TERMINATE]
97) Other [TERMINATE]

A7. Which best describes this building? [SINGLE RESPONSE]

1) A one-family house detached from any other house
2) A mobile home
3) A one-family house attached to one or more houses (e.g., townhouse)
4) A building with 2 apartments
5) A building with 3 or 4 apartments
6) A building with 5 to 9 apartments
7) A building with 10 to 19 apartments
8) A building with 20 to 49 apartments
9) A building with 50 or more apartments

A8. What is the approximate square footage of your home? If unsure, your best guess is fine [Open-ended text] {validate whole numbers, 300 – 20,000}

A9. In what year was your home built? **[TEXT] {validate whole numbers, 1600 – 2022}**

A10. Did you complete weatherization upgrades, such as air sealing (i.e., weather stripping) or additional insulation in response to a Mass Save Home Energy Assessment / Energize CT Home Energy Solutions service? **[SINGLE RESPONSE]**

1) Yes
2) No
98) I don't know

A11. Do you have a stand-alone heat pump water heater in your home?

1) Yes
2) No
98) I don't know

A12. Do you have solar panels at your home?

1) Yes
2) No

A13. Do you have any <u>additional</u> heating equipment in your home? (In addition to your heat pump(s) that you received a rebate on from Mass Save or Energize CT). Check all that apply.

Ducts (for furnaces)

Radiators (for boilers)

Note: Furnaces typically use ducts to heat the home, as seen on the *left* in the above image. Boilers typically uses radiators or baseboards to heat the home.

1) Electric space heater(s)
2) Electric baseboard heat
3) Electric furnace
4) Oil furnace
5) Oil boiler
6) Natural Gas furnace
7) Natural Gas boiler
8) Propane furnace
9) Propane/liquified petroleum gas (LPG) boiler
10) Woodstove, pellet stove, or fireplace
11) Plug-in wall heater

12) **Additional** mini-split heat pump (that I did not receive a rebate for)
13) **Additional** central heat pump (that I did not receive a rebate for)
14) **Additional** geothermal or ground-source heat pump (that I did not receive a rebate for)
15) I disconnected all additional heating when I received my heat pump(s) rebate **{Mutually Exclusive}**
16) None **{Mutually Exclusive}**
98) I don't know **{Mutually Exclusive}**

A14. **[IF A13 <> 15, 16, 98]** How often do you use this additional heat during the winter? Select the box for frequency on each row of heating equipment.

Heating Equipment [Piped in from A13]	**My thermostat/ control decides**	**Only in emergencies/ extreme temperatures**	**< 5 times per winter**	**5 - 15 times per winter**	**15 + times per winter**	**Very frequently/ Every day**	**I don't know**

A15. Does this equipment heat at least one of the same rooms as your heat pump(s)?

Heating Equipment [Piped in from A13]	**Yes**	**No**	**I don't Know**

A16. Do you have any additional cooling sources? (In addition to your heat pump(s) that you received a rebate on from Mass Save or Energize CT). Check all that apply.

1) Central air conditioning
2) Room, window, or through the wall air conditioning
3) Ductless air conditioner with no heating
4) Central heat pump
5) Portable air conditioner
6) Just using fans
7) **Additional** mini-split heat pump (that I did not receive a rebate on)
8) **Additional** central heat pump (that I did not receive a rebate on)
9) **Additional** geothermal or ground-source heat pump (that I did not receive a rebate on)
10) I disconnected all additional cooling when I received my heat pump rebate **{Mutually Exclusive}**

11)None {Mutually Exclusive}
98) I don't know {Mutually Exclusive}

A17. [IF A16 <> 10,11, OR 98] How often do you use this additional cooling in the summer?

Cooling Equipment [Piped in from A17]	**My thermostat / control decides**	**Only in emergencies / extreme temperatures**	**< 5 times per summer**	**5- 15 times per summer**	**15 + times per summer**	**Very frequently / Every day**	**I don't know**

A18. Does this equipment cool at least one of the same rooms as your heat pump(s)?

Cooling Equipment [Piped in from A16]	**Yes**	**No**	**I don't Know**

Module B: Metering Study Recruitment

B1. [IF A6 = 1 OR 2] In addition to this survey, our team conducts an onsite study for Mass Save and Energize CT to understand how program participants use their HVAC equipment, and its performance. Would you be willing to participate in a study beginning in the next few weeks, where we would visit your home to install data loggers to measure your heat pump's energy usage and performance? The logger installation would include a usage logging device in your electrical panel, and for some homes, additional temperature loggers, energy logger on outdoor fan unit, plug-load logger for moveable equipment and smart oil gauges (as applicable). If you have gas service, we would also install a few loggers that record operation of your gas meter.

If you are selected to participate in the onsite study, you would receive $200 on the initial installation visit and $50 on any follow up visits, which typically occur once per year. The study is expected to last 1.5-2 years. The initial visit to install the logging equipment should take 2-4 hours.

Our onsite team is following all Mass Save and Energize CT COVID-19 safety protocols and State guidelines.

1) Yes, I am interested in participating in the onsite study
2) No, I am not interested in participating in the onsite study

B2. [IF A6 = 4] In addition to this survey, our team conducts an onsite study for Mass Save and Energize CT to understand how program participants use their HVAC equipment, and its performance. Would your tenant(s) be willing to participate in a study beginning in the next few weeks, where we would visit your home to install data loggers to measure your heat pump's energy usage and performance? The logger installation would include a usage logging device in the electrical panel, and for some homes, additional temperature loggers, energy logger on outdoor fan unit, plug-load logger for moveable equipment and smart oil gauges (as applicable). If you have gas service, we would also install a few loggers that record operation of your gas meter.

If you are selected to participate in the onsite study, you and your tentant(s) would each receive $200 on the initial installation visit and $50 on any follow up visits, which typically occur once per year. The study is expected to last 1.5-2 years. The initial visit to install the logging equipment should take 2-4 hours.

Our onsite team is following all Mass Save and Energize CT COVID-19 safety protocols and State guidelines.

1) Yes, I am interested in participating in the onsite study and the team may contact my tenant(s)
2) No, I am not interested in participating in the onsite study

B3. [IF B1 = 1 or B2 =1] To confirm that your home is a candidate for this onsite study and prepare our field team for visiting your home, we would like to ask a few questions. First, do you know where your electrical panel/circuit breaker is located?

1) Yes
2) No
98) Don't Know

B4. [IF B1 = 1] Do you, for any reason, not have access to your electrical panel? An example of not having access would be if its location requires landlord access.

1) I have access to the electrical panel
2) I don't have access to the electrical panel
98) Don't Know

B5. [IF B2 = 1] Do you/your tenant(s) have access to the electrical panel?

1) Yes
2) No
98) Don't Know

B6. [IF B1 = 1 or B2 =1]Do you have internet access through a home WiFi or ethernet network?

1) Yes
2) No
98) Don't Know

B7. [IF B4 = 1 OR B5 = 1] If your home is selected to participate in the onsite portion of the study, our team will contact you to set up an exact time and date for the site visit. However, as we prepare for our scheduling, do you have a preference for what day of the week our team will visit your home? Please select all that apply.

Monday

1) Tuesday
2) Wednesday
3) Thursday
4) Friday
5) No preference

B8. [IF B4 = 1 OR B5 = 1] Do you have a preference for the time of day our team will visit your home? Please select one.

1) Morning
2) Afternoon
3) No preference

B9. [IF B4 = 1] Can you please verify your contact information? Please change as necessary and be sure to add your preferred contact time.

1) Name: **[PIPE FROM TRACKING DATA]**
2) Address1: **[PIPE FROM TRACKING DATA]**
3) Address2: **[PIPE FROM TRACKING DATA]**
4) City: **[PIPE FROM TRACKING DATA]**
5) State: **[PIPE FROM TRACKING DATA]**
6) Zip Code: **[PIPE FROM TRACKING DATA]**
7) Preferred telephone number: **[CUSTOMER RESPONSE]**
8) Preferred contact time: _____:_____ [AM/PM] **[PROGRAMMER: NOT A REQUIRED FIELD.] [CUSTOMER RESPONSE]**
9) Email address: **[CUSTOMER RESPONSE]**

B10. [IF B5 = 1] Can you please verify your contact information? Please change as necessary and be sure to add your preferred contact time. If selected, a member of the team will reach out to you for tenant contact information.

1) Name: **[PIPE FROM TRACKING DATA]**
2) Address1: **[PIPE FROM TRACKING DATA]**
3) Address2: **[PIPE FROM TRACKING DATA]**
4) City: **[PIPE FROM TRACKING DATA]**
5) State: **[PIPE FROM TRACKING DATA]**
6) Zip Code: **[PIPE FROM TRACKING DATA]**
7) Preferred telephone number: **[CUSTOMER RESPONSE]**
8) Preferred contact time: _____:_____ [AM/PM] **[PROGRAMMER: NOT A REQUIRED FIELD.] [CUSTOMER RESPONSE]**
9) Email address: **[CUSTOMER RESPONSE]**

Module C: Baseline and Customer Behavior/Decisions

Next, we would like to understand more about your new heat pump(s) and the heating or cooling system(s) that you had before.

C1. What space(s) does your new heat pump(s) serve? (Select all that apply) **[MULTIPLE RESPONSE]**

1) Entire home (If yes, please select this response only) **[MUTUALLY EXCLUSIVE]**
2) Master Bedroom
3) Other Bedroom(s)
4) Living Room, Family Room or Den
5) Kitchen
6) Office
7) Sunroom or three-season space
8) Auxiliary spaces, such as lofts or attics
9) Basement
10) Other, please specify **[TEXT BOX]**

C2. Was the **[PIPE RANDOM SPACE SELECTED FROM C1]** heated and/or cooled before the installation of the new heat pump(s)? (Select only one response)

1) It was heated only
2) It was cooled only
3) It was heated and cooled
4) It is a brand new space, i.e. installed in addition or new house
5) It was not heated or cooled
6) I don't know

C3. Was the high-efficiency **<EQUIPMENT_REPORTED>** installed as part of a new construction or major renovation project? **[SELECT ONE]**

1) Yes
2) No
3) I don't know

C4. For what purpose did you buy your new heat pump? (Select only one response)

1) I bought it for cooling
2) I bought it for heating
3) I bought it both heating and cooling

C5. Before you decided to install your new heat pump, did you or your contractor consider options other than your new heat pump to heat or cool your **[PIPE RANDOM SPACE SELECTED FROM C1]** ? (Select only one response)

1) Yes, I/we considered both heating and cooling options
2) Yes, I/we considered ONLY heating options
3) Yes, I/we considered ONLY cooling options
4) No, I/we did not consider any other options

C6. **[ASK IF C5 = 1, 2]** What <u>other</u> heating options were considered for your **[PIPE RANDOM SPACE SELECTED FROM C1]**?

Ducts (for furnaces)

Radiators (for boilers)

Note: Furnaces typically use ducts to heat the home, as seen on the *left* in the above image. Boilers typically uses radiators or baseboards to heat the home.

(Select all that apply)

1) Oil furnace
2) Oil boiler
3) Natural Gas furnace

4) Natural Gas boiler
5) Propane furnace
6) Propane/liquified petroleum gas (LPG) boiler
7) Electric baseboard
8) Electric furnace
9) Electric space heater
10) Woodstove, pellet stove, or fireplace
11)Plug-in wall heater
12) Geothermal or ground-source heat pump (outside of the heat pump(s) I purchased)
13) Other mini-split heat pump (outside of the heat pump(s) I purchased)
14) Central heat pump (outside of the heat pump(s) I purchased)
15) Other heat pump (outside of the heat pump(s) I purchased)
97) Other **[TEXT]**

C7. What, if anything, would you have most likely installed to <u>heat</u> your **[PIPE RANDOM SPACE SELECTED FROM C1]** if you hadn't installed the heat pump you did?

1) **[PIPE IN RESPONSES FROM C6 AS SELECTIONS]**
2) I would have continued to use my old heating system
3) I wouldn't have installed a heating system (left space unheated)
4) I would have installed a different heating system, please specify **[TEXT BOX]**

C8. **[ASK IF C5 = 1, 3]** What other <u>cooling</u> options were considered for your **[PIPE RANDOM SPACE SELECTED FROM C1]**?

Ducts (for furnaces)

Radiators (for boilers)

Note that central air conditioning and central heat pumps use ducts and vents to distribute cooled air. (Select all that apply)

1) Central air conditioning
2) Room, window, or through the wall air conditioning
3) Ductless air conditioner with no heating
4) Central heat pump
5) Portable air conditioner
6) Just using fans
7) Other geothermal or ground-source heat pump (outside of the heat pump(s) I purchased)
8) Other mini-split heat pump (outside of the heat pump(s) I purchased)

9) Other central heat pump (outside of the heat pump(s) I purchased)
97) Other, please specify [TEXT BOX]

C9. What, if anything, would you have most likely installed to cool your [PIPE RANDOM SPACE SELECTED FROM C1] if you hadn't installed the heat pump you did?
[PIPE IN ALL RESPONSES FROM C18]

1) I would have continued to use my old cooling system
2) I wouldn't have installed a cooling system (left space uncooled)
3) I would have installed a different cooling system, please specify [TEXT BOX]

Now we would like to understand how your space was heated before the new heat pump was installed.

(Space Previously Heated)

C10. [ASK IF C2 = 1, 3] What was the primary system that heated your [PIPE RANDOM SPACE SELECTED FROM C1] before the new heat pump was installed? (Select only one response)

1) Oil furnace
2) Oil boiler
3) Propane/liquified petroleum gas (LPG) furnace
4) Propane/LPG boiler
5) Electric baseboard
6) Electric furnace
7) Natural gas furnace
8) Natural gas boiler
9) Electric space heater
10) Woodstove, pellet stove, or fireplace
11) Other geothermal or ground-source heat pump (outside of the heat pump(s) I purchased)
12) Other mini-split heat pump (outside of the heat pump(s) I purchased)
13) Other central heat pump (outside of the heat pump(s) I purchased)

C11. [ASK IF C12 = 1, 2, 3, 4, 6, 9, or 11] Did the heat come out of ducts or radiators/baseboards? Select all that apply.


Ducts (for furnaces)


Radiators (for boilers)

1) Ducts

2) Radiators
3) Neither
98) Don't know

C12. When the new heat pump was installed, was the previous heating system removed or disconnected or is it still installed and operating? Please select from the options below. (Select only one response)

1) The previous system was removed or disconnected and not replaced
2) The previous system was removed and replaced with a new piece of equipment of the same type
3) The previous system is still installed and operating
98) Don't Know

C13. **[ASK IF displacement= "full" & C12 = 2 or 3]** How often do you use your additional heating system (not the heat pump you received a rebate on)?

1) Only in emergencies/ extreme temperatures
2) < 5 times per winter
3) 5 - 15 times per winter
4) 15 + times per winter
5) Very frequently/ Every day
98) I don't know

Now we would like to understand how your space was cooled before the new heat pump was installed.

(Space Previously Cooled)

C14. **[ASK IF C2 = 2, 3]** What was the primary system that cooled your **[PIPE RANDOM SPACE SELECTED FROM C1]** before the new heat pump was installed? Note that central air conditioning and central heat pumps use ducts and vents to distribute cooled air. (Select only one response)

1) Central air conditioning
2) Room, window, or through-the-wall air conditioning
3) Portable air conditioner
4) Only used fans
5) Other geothermal or ground-source heat pump (outside of the heat pump(s) I purchased)
6) Other mini-split heat pump (outside of the heat pump(s) I purchased)
7) Other central heat pump (outside of the heat pump(s) I purchased)
97) Other, please specify **[TEXT BOX]**
98) Don't Know

C15. When the heat pump was installed, was the previous cooling system removed or disconnected or is it still installed and operating? Please select from the options below. (Select only one response)

1) The previous system was removed or disconnected and not replaced

2) The previous system was removed and replaced with a new piece of equipment of the same type
3) The previous system is still installed and operating
98) Don't Know

[ASK IF C14 <> Central air conditioning OR Central heat pump] & [A3 = 2]

C16. Before you got your new heat pump, did you already have ducts and vents to distribute heated or cooled air to your **[PIPE RANDOM SPACE SELECTED FROM C1]**?

1) Yes
2) No
98) Don't Know

[ASK IF C16 = 2]

C17. Since you were considering installing a central air conditioner or central heat pump, were you also considering installing ducts?

1) Yes
2) No
98) Don't Know

C18. Since installing your heat pump, have you experienced any maintenance issues?

1) Yes
2) No
98) I don't know

C19. **[IF C18 = 1]** Did your technician identify refrigerant leakage as an issue with your heat pump? Refrigerant leakage is a common problem in heat pumps that may cause your heat pump to pool liquid, produce ice, or run louder and/or less efficiently.

1) Yes
2) No
98) I don't know

C20. **[IF C19 = 1]** How many times has your heat pump had refrigerant leakage?

1) 1 time
2) 2 – 3 times
3) 4 – 6 times
4) 7 + times
98) I don't know

C21. **[IF C21 = 1]** On average, how much does it cost to repair your refrigerant leakage? **[OPEN ENDED, Validation: Numbers, $0 – $10,000]**

C22. **[IF C18 = 1]** Please describe any other maintenance issues which you have experienced **[OPEN ENDED]**

C23. During the heating season (October through April), how do you most commonly operate your heat pump in **[PIPE RANDOM SPACE SELECTED FROM C1]**?

1) Heat pump is always left "on", at the same heating setpoint/temperature at all times of day
2) Heat pump is always left "on", and the heating setpoint/temperature changes automatically based on a programmed schedule
3) Heat pump is always left "on", and I change the heating setpoint/temperature manually, with no consistent schedule
4) I turn the heat pump on and off at difference times of day based on my heating needs

97)Other **[OPEN ENDED]**

[ASK IF C23 – C37 IF A4 = 1]

For the following questions we want to learn more about your experience with the integrated controls that were installed to manage your heat pump.

C24. Is the integrated control still installed and working?

1) Yes
2) No

98) Don't know

[ASK IF C24 = 2]
C25. Why is the integrated control not installed/working? **[Open-ended text]**

[ASK IF C24 = 1]
C26. When you are heating with your heat pump system, do you rely on the integrated control to automatically switch between the heat pump and your other fuel-fired or auxiliary heating system?

1) Yes
2) No

98) I don't know

[ASK IF C26 = 2]
C27. What do you do instead to manage your heat pump and fuel-fired heating systems? **[OPEN RESPONSE]**

C28. Did the contractor program the integrated control, or did you program it on your own?

1) My contractor programmed it
2) I programmed it on my own

C29. **[ASK C24 = 1]** What OUTSIDE temperature did you or your contractor set the integrated control switchover temperature at, where your heat will switch from the new heat pump to the existing fuel-fired or auxiliary heating system? Above this temperature, the backup fuel-fired/auxiliary heat will not operate.

1) _______ Outside Temperature (degrees Fahrenheit) **[Validate: 0 - 40]**
98) I don't know

C30. **[ASK C24 = 1]** Does your integrated controller have a separate heat pump lockout temperature that is different than the stated "switchover temperature" you provided in the prior questions? The heat pump lockout temperature is the temperature under which the heat pump will not operate

1) Yes
2) No
98) I don't know

C31. **[ASK C30 = 1]** What is the heat pump lockout temperature, under which the heat pump will not operate?

C32. Did the contractor that installed the new heat pump explain how to operate the integrated control?

1) Yes
2) No
98) Don't know

C33. **[ASK C24 = 1]** Have you or anyone else changed the integrated control switchover temperature setting since it was first programmed?

1) Yes
2) No
98) Don't know

C34. **[ASK C33 = 1]** What OUTSIDE temperature was the integrated control switchover temperature changed to?

1) _______ Outside Temperature (degrees Fahrenheit) **[Validate: 0 - 40]**
2) My equipment has a range
98) Don't Know

C35. **[ASK C33 = 1]** Why did you change the integrated control switchover temperature setting since it was first programmed? **[Open-ended text]**

C36. **[ASK C24 = 1]** On a scale from 1 to 5, where 1 is "very dissatisfied" and 5 is "very satisfied", how satisfied are you with how your integrated control is working?

C37. **[IF C36<4]** Why did you provide this rating? **[Open-ended text]**

The survey is almost done, we just have a few more questions.

C38. [RESTRICT RESPONSE OPTIONS TO 2 DIGITS] How many people occupied this home in 2022? Enter zero if appropriate. Note, this question is optional.

Occupant Type	Number
Children, under 18	[RECORD NUMBER]
Adults, 18 to 65	[RECORD NUMBER]
Adults, 65 and older	[RECORD NUMBER]

C39. [USE TABLES PROVIDED IN EXCEL FILE TO PROVIDE RANGES BASED ON RESPONSE TO E2. AS AN EXAMPLE, IF E2, 5=1 (SINGLE HOUSEHOLD MEMBER), SHOW THE FOLLOWING] What was your estimated total annual household income in 2022 before taxes (in other words, your gross household income)?

1) Less than $53,999
2) $54,000 -$63,999
3) $64,000 -$73,999
4) $74,000 -$83,999
5) $84,000 -$93,999
6) $94,000 -$103,999
7) $104,000 -$123,999
8) $124,000 -$133,999
9) $134,000 -$153,999
10) $154,000 -$165,000
11) Greater than $165,001
12) Prefer not to answer

C40. Approximately how much did you spend on delivered heating fuel oil (oil, propane, kerosene, etc.) during the winter (October through April)? Please select the appropriate range.

	Before Installing Your Heat Pump	After Installing Your Heat Pump
NA		
$0 - $500		
$500 - $750		
$750 - $1,000		
$1,200 - $1,400		
$1,400 - $1,600		
$1,600 - $1,800		
$1,800 - $2,000		

$2,000 - $2,200		
$2,200 - $2,400		
$2,400 - $2,600		
$2,600 - $2,800		
$2,800 - $3,000		
$3,000 +		

C41. [IF C40 <> N/A] Approximately how much heating fuel (oil, propane, kerosene, etc.) did you use prior to installing your heat pump during the winter (October through April)?

1) Less than 200 gallons
2) 201 – 300 gallons
3) 301 - 400 gallons
4) 401 – 500 gallons
5) 501 – 600 gallons
6) 601 – 700 gallons
7) 701 – 800 gallons
8) 801 – 900 gallons
9) 901 – 1,000 gallons
10) 1,000 + gallons
98) I don't know

C42. [IF C40 <> N/a] Approximately how much heating fuel do you use now, after to installing your heat pump (oil, propane, kerosene, etc.) during the winter (October through April) ?

1) Less than 200 gallons
2) 201 – 300 gallons
3) 301 - 400 gallons
4) 401 – 500 gallons
5) 501 – 600 gallons
6) 601 – 700 gallons
7) 701 – 800 gallons
8) 801 – 900 gallons
9) 901 – 1,000 gallons
10) 1,000 + gallons
98) I don't know

C43. Approximately how many cords of wood did you burn per winter (October - April-) prior to installing your heat pump? [OPEN-ENDED]

C44. Approximately how many cords of wood did you burn per winter (October – April) after to installing your heat pump ? [OPEN-ENDED]

C45. Approximately how much did you spend on wood for heating per winter (October - April) prior to installing your heat pump? [OPEN-ENDED]

C46. Approximately how much did you spend on wood for heating per winter (October – April) after to installing your heat pump ? [OPEN-ENDED]

C47. Please type the email address where you would like us to send your e-gift card. **[OPEN-ENDED]**

CLOSE: This concludes the survey that we have prepared for you today. You can expect to receive your e-gift card directly from noreply@tango.com in 1 – 2 business days.

If you have any questions about this survey or how your responses to this survey will be used, please contact SurveyInfo@guidehouse.com and include your PIN number.

If you are selected for the metering portion of this study, you will receive an email from the scheduling team at Ridgeline Energy Analytics in the next few weeks.

Thanks for your participation in this survey.

B.2 Fast Feedback Interview Guide

Guidehouse

Heat Pump Metering Study

Fast Feedback Customer

Phone Interview Guide

MA22R51-B-HPMS / CT R2246

Prepared for:

The Electric and Gas Program Administrators of Massachusetts and the Connecticut Evaluation Administrators

Part of the Residential Evaluation Program Area

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February 2, 2023

Interview Information

These interviews will be conducted via phone with residential customers who are currently participating in the heat pump metering study (from Wave 1 recruitment) and have been confirmed as "full displacement" sites. The team will invite these customers to participate via email.

The team will send recruitment emails to the full population of eligible respondents, 26 customers. Respondents will receive a $10 e-gift card for participation.

Research Objectives

In **Table 8** we outline which interview guide modules will answer each research question. The main goal of the interview is to understand if customers feel as if their heat pump met their heating needs during one of the coldest days of the year.

Table 9. Customer Phone Interview Objectives

Research Topic	Section
Use of Back Up Heat & Systems Operation	
Confirm customer does not use back-up heat during the winter, or if they have had any emergency situations that warranted back-up heat.	Module A
Gauge customer satisfaction of system's performance in extremely cold temperatures as it is influenced by comfort levels.	Module A
Impact of Energy Costs	
Assess relative impact of energy costs on heat pump usage.	Module B
Thermostat Setpoint	
Understand general customer habits with thermostat setpoint, how it changes in the winter, and if it is similar to previous seasons.	Module C
Feedback	
Opportunity for heat pump, study team, and program feedback.	Module D

Interview Introduction

Hi **[CUSTOMER NAME]** My name is **[INTERVIEWER NAME]** and I am a part of the Heat Pump Metering Study technical team. Thanks so much for being willing to talk with me today!

We really appreciate your participation in this study. We are talking with participants in the study to get a better understanding of how your heat pump has been performing and how you've been using it. I have a series of questions prepared for you today and I may ask some follow-ups just to make sure we're on the same page. There are no right or wrong answers; we want your honest feedback. This call will take about 15 minutes. Do you have any questions before we get started? Also, I know you mentioned this over email, but just to confirm – are you ok with us recording this conversation?

Module A: Use of Back Up Heat & Systems Operation

Key Topics (for interviewer to cover):

- How does the customer use their heat pump?

- Does the customer have whole-home back-up and/or supplemental heat?
    - If so: What is it? Do they use it? Regularly? What about in emergencies? Was the past weekend an emergency?

  Based on comfort-level, is the customer satisfied with heat pump system performance generally? What about in extremely cold weather?

INTRO: First, we'd like to understand how your heat pump is set up. We'll ask some questions about your heating system and how you use it.

A1. Are you using your heat pump to heat your whole home or just parts of your home?

A2. In the space heated by your heat pump, is the heat pump your only heating source or do you have any additional heat sources?

  a. In case of additional heat sources:

    a. What kind of additional heat source? What parts of your home does it heat? How often do you normally use it? *[probe: How did you heat your home over the weekend when temperatures dropped below zero degrees Fahrenheit?]*

    b. *Why do you use it? [probe: is it due to comfort, financial impact, etc.) How do you turn it on? [probe: integrated controller, manual change on thermostat]*

    c. When you purchased your heat pump, did you expect to need to use this back-up heat source?

A3. On Friday and Saturday, how was your comfort level?

  [probe: did you use supplemental heating (e.g., a wood stove, space heater) or more blankets than usual, etc.? did you change the thermostat settings manually?]

A4. Did you install any new heating equipment this winter to supplement your heat pump (such as, a wood burning stove, a propane furnace, gas furnace, space heaters, etc.)?

  [If no, probe: did you consider it? Are you considering it now (after cold)? If yes, probe: what did you install?]

A5. Have you experienced any maintenance issues that have impacted your heat pump's performance this winter?

Module B: Energy Costs

Key Topics (for interviewer to cover):

- What were the customer's expectations on energy costs?
- Has the customer adjusted how they operate their heat pump due to energy costs?
    - Any other cost related impacts?

INTRO: Next, we would like to understand more about how energy costs may have affected your heat pump usage this winter.

B1. Before this winter, had you operated your heat pump(s) during the winter months?

B2. How would you categorize your energy bills this winter *[include oil, gas, etc.]*? Cost-wise, were they about what you expected?

a. If you hadn't operated your heat pump in a winter season, how did you set your expectations?
b. What have you heard about energy costs this year?
c. If costs were higher than expected,
   i. Did you notice a specific increase in electric rates this fall and/or winter? Have you received an electric bill since that increase?

B3. Did energy costs have any impact on how you operated your heat pump?
[probe: Did your electric provider advised you the best way to operate your heat pumps due to higher rates in Winter 2022 - 2023?]

Module C: Thermostat Setpoints

Key Topics (for interviewer to cover):

- How does the customer operate their thermostat?
- Were there any changes to how the customer uses their thermostat during the extremely cold weather on Friday/Saturday?

INTRO: Next, we'd like to know about how you and your household use your main thermostat during the winter (October – April). Generally, we'd like to understand what your typical thermostat usage looks like.

C2. Can you describe how you use your thermostat to control your heat pump(s) by heating zone? Or if you use your thermostat to control your heat pump at all?

[*probe: For example, do you ever make manual changes to the thermostat settings?]*

C3. Some people keep their temperature setting the same throughout the day and night, and some change the temperature to different levels at different times of day. What has your temperature setting generally looked like in your home (by heating zone, as applicable) so far this winter?

a. Is the set point constant or adjusted throughout the day? If adjusted, is that done automatically by thermostat or manually? What are the temperature settings, generally?
b. If applicable:
   i. Do you operate all the thermostats for your other heat pump(s) the same way? *[probe: did you manually change your setpoints over the weekend when it was really could out? Is this something you usually do?]*

C4. When there were sub-zero temperatures on Friday and Saturday, did you make any changes to your thermostat? Was your house able to reach the temperature on your thermostat?

Module D: Feedback

D1. Is there anything else you would like to tell us about your experience with your heat pump so far this winter?

D2. Is there any feedback you would like to share about your experience with the on-site metering study team and metering installation experience?

D3. More generally, is there any other feedback on your experience with the Mass Save heat pump programs that you would like to share?

CLOSE: Thank you so much for your time today, those are all the questions I have. You can expect to receive your e-gift card directly from noreply@tango.com in 1 – 2 business days.

B.3 End of Season Survey Guide

Heat Pump Metering Study

End of Season Survey

MA22R51-B-HPMS / CT R2246

Guidehouse

Prepared for:

The Electric and Gas Program Administrators of Massachusetts and the Connecticut Evaluation Administrators

Part of the Residential Evaluation Program Area

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Survey Information

This survey will be delivered in an online format to residential customers who are currently participating in the heat pump metering study. The team will deliver the survey via email. The team will survey the full population of metered participants. Respondents will receive a $20 e-gift card for participation.

Research Objectives

Table 8 outlines which survey modules will answer each research question. The main goal of the survey is to understand whether customers feel that their heat pump met their heating needs during one of the coldest days of the year.

Table 10. Customer Survey Objectives

Research Topic	Section
Backup Heat Usage and Systems Operation	
Understand if customer uses backup heat during the winter and/or identify if they had an emergency situation that warranted their use of backup heat.	Module A
Gauge customer satisfaction of system's performance in cold temperatures as it is influenced by comfort levels.	Module A
Impact of Electricity Costs	
Assess relative impact of increased electricity costs on heat pump usage.	Module B
Thermostat Setpoint	
Understand general customer habits with the thermostat setpoint, how those habits change in the winter, and whether it is similar to previous seasons.	Module C
Feedback	
Opportunity for heat pump, study team, and program feedback.	Module D

Source: Guidehouse

Table 11 identifies the embedded variables in the survey for programming purposes.

Table 11. Table 2. Survey Embedded Variables

Embedded Variable	Source
EQUIPMENT_REPORTED	Sample
EMAIL	Sample
NAME	Sample

Source: Guidehouse

Survey Introduction

You are receiving this survey because you are participating in the onsite Heat Pump Metering Study through the Sponsors of Mass Save® and the Sponsors of Energize Connecticut℠. Thanks for your participation! Your feedback on this survey will help the Massachusetts Program Administrators understand your experience and satisfaction with your heat pump.

There are no right or wrong answers; we want your honest feedback. This survey will take about 10-15 minutes of your time. To thank you for your feedback, you will receive a $20 e-gift card through Rewards Genius and Tango Card after you have completed the survey, redeemable at numerous retailers or for charitable donation.

Module A: Backup Heat Usage and Systems Operation

First, we would like to understand how your heat pump has been performing in respect to warming your space(s) and/or home. We are particularly interested in days like the past few, when it was exceptionally cold. These questions will focus on your overall satisfaction with your heat pump specifically related to your comfort and the heating effectiveness of your heat pump for both the most recent cold period (January 20 – 22) and more generally this winter.

A1. Are you using your heat pump to heat your entire home or just parts of your home?

1) Entire home/most of my home
2) Just parts of my home (i.e., only some rooms in my home)
98) Don't know

A2. Was the space that your heat pump serves previously cooled?

1) Yes
2) No
98) Don't know

A3. Was the space that your heat pump serves previously heated?

1) Yes
2) No
98) Don't know

A4. **[IF A3= 1]** Did you disconnect or remove your existing heat source(s) when you installed your heat pump?

1) Yes
2) No

A5. In the space heated by your heat pump(s), is the heat pump your only heating source or do you have any additional heat sources?

1) Yes, the heat pump(s) is my only heating source
2) No, I have additional heating sources

A6. **[IF A5 = 2]** What additional heating equipment do you have in your home (in addition to the heat pump(s) for which you received a rebate from the Sponsors of Mass Save / Energize CT)? Check all that apply.

Ducts (for furnaces) Radiators (for boilers)

Note: Furnaces typically use ducts to heat the home, as seen on the *left* in the above image. Boilers typically uses radiators or baseboards to heat the home.

16)Electric space heater(s)
17)Electric baseboard heat
18)Electric furnace
19)Oil furnace
20)Oil boiler
21)Natural gas furnace
22)Natural gas boiler
23)Propane furnace
24)Propane/liquified petroleum gas (LPG) boiler
25) Woodstove, pellet stove, or fireplace
26) Plug-in wall heater
27) **Additional** mini-split heat pump (for which I <u>did not</u> receive a rebate)
28) **Additional** central heat pump (for which I <u>did not</u> receive a rebate)
29) **Additional** geothermal or ground-source heat pump (for which I <u>did not</u> receive a rebate)
17) None **{Mutually Exclusive}**
98) Don't know **{Mutually Exclusive}**

A7. **[IF A5 = 2]** Did you use your <u>additional</u> heat source(s) (other than the heat pump rebated by the Sponsors of Mass Save / Energize CT) this winter, **<u>prior</u>** to the most recent cold period (January 20 – 22)?

1) Yes
2) No
98) Don't know

A8. **[IF A5 = 2]** Did you use your <u>additional</u> heat source(s) (other than the heat pump rebated by the Sponsors of Mass Save / Energize CT) **<u>during</u>** the most recent cold period (January 20 – 22)?

1) Yes
2) No
98) Don't know

A9. [IF A7 = 2 OR A8 = 2] Do you plan to use your additional heating source(s) in the future?
1) Yes
2) No
3) Maybe

A10. [IF A9 = 1 OR A9 = 3] When do you plan to use your additional heating source(s)? [TEXT]

A11. Did you use your heat pump(s) for heating during the most recent cold period (January 20 – 22)?
1) Yes
2) No
98) Don't know

A12. Have you used your heat pump(s) for heating this winter during normal winter weather?
1) Yes
2) No
98) Don't know

A13. [IF A7 = 1 OR A8 = 1] Does your additional heat source(s) run at the same time as your heat pump, or do they always run at different times?
1) Yes, both systems **always** operate at the same time
2) Yes, both systems **sometimes** operate at the same time
3) No, only one system operates at a time
98) Don't know

A14. [IF A7 = 1 OR A8 = 1] How do you turn on your additional heating source(s)?
1) It is controlled by the integrated control or the same thermostat as the heat pump
2) It is controlled by its own separate thermostat
3) I turn it on manually
97) Other [TEXT]
98) Don't know

A15. [IF A14 = 2] Given that you have multiple thermostats for multiple heating systems, please describe how you set the temperature setpoints for these heating systems.

1) An integrated control automatically chooses which system to run
2) I set the additional heating system temperature lower than the heat pump system, so the additional heating system is only used when the heat pump cannot fully heat the space
3) I manually set the thermostats without a specific reason
4) Other: [TEXT]

A16. [IF A7 = 1 OR A8 = 1] When you purchased your heat pump, did you expect to continue to use your additional heat source(s)?

1) Yes
2) No

A17. [IF A8 = 1] Why did you use your additional heat source(s) during the most recent cold period (January 20 – 22)? Select all that apply.

1) My home got too cold, and I needed to use my heat pump to warm it up
2) I proactively wanted to ensure my home stayed warm enough
3) I was concerned that my heat pump would not be able to fully heat my home
4) I was concerned about the cost of using my heat pump
5) I had maintenance issues with my heat pump
6) Other: [TEXT]

A18. [IF A7 = 1] Why did you use your additional heat source(s) during other cold days this winter? Select all that apply.

1) My home was too cold, and I needed to use my heat pump to warm it up
2) I proactively wanted to ensure my home stayed warm enough
3) I was concerned that my heat pump would not be able to fully heat my home
4) I was concerned about the cost of using my heat pump
5) I had maintenance issues with my heat pump
6) Other: [TEXT]

A19. [IF A7 = 1] OR [IF A8 = 1] How often do you typically use your additional heat source(s) in the winter?

1) Only in emergencies or on the coldest days
2) < 5 times per winter
3) 5-15 times per winter
4) 15+ times per winter
5) Very frequently/every day

6) Other: [TEXT]
98) Don't know

A20. During the most recent cold period (January 20 – 22), did your home maintain its normal indoor temperature?

1) Yes
2) No
98) Don't Know

A21. [IF A20 = 2] How many degrees did the temperature drop? (Please use your best estimate below)

1) [Number] Degrees (Fahrenheit)

A22. [A8 = 1] How much of the heating in your home during the cold period (January 20 – 22) was produced by your heat pump(s) (as opposed to your additional heating source(s))?

1) None
2) Some
3) Most
4) All

A23. Did you install any new heating equipment this winter to supplement your heat pump (such as a wood burning stove, a propane furnace, gas furnace, space heaters, etc.)?

1) Yes
2) No

A24. [IF A23 = 2] Did you consider installing any new heating equipment this winter to supplement your heat pump (such as a wood burning stove, a propane furnace, gas furnace, space heaters, etc.)?

1) Yes
2) No

A25. [IF A23 = 1] Please describe the new heating equipment that you installed.
[TEXT]

A26. How satisfied have you been with your heat pump's ability to warm your space during the following situations?
[Scale 1-5, 1 being 'extremely dissatisfied' and 5 being 'extremely satisfied']

	Extremely dissatisfied	Moderately dissatisfied	Neither satisfied nor dissatisfied	Moderately satisfied	Extremely satisfied
a. During cold periods (like Jan. 20 – 22)					
b. During normal winter weather					

A27. **[IF A26a. < 3]** Why are you dissatisfied with your heat pump's ability to warm your home during <u>cold weather periods</u> (like January 20 – 22)? Please describe. **[TEXT]**

A28. **[IF A26b. < 3]** Why are you dissatisfied with your heat pump's ability to warm your home during <u>normal winter weather</u>? Please describe. **[TEXT]**

A29. Please rate the effectiveness of your heat pump in meeting the heating needs of the space the heat pump is responsible for keeping heated during the following situations

[Scale 1-5, 1 being 'extremely ineffective' and 5 being 'extremely effective']

	Extremely ineffective	Moderately ineffective	Neither effective nor ineffective	Moderately effective	Extremely effective
a. During cold periods (like Jan. 20 – 22)					

b. During normal winter weather					

A30. [IF A29a. < 3] Please describe why you indicated that your heat pump is ineffective at keeping your home or space warm during <u>cold periods</u> like we experienced January 20 - 22. [TEXT]

A31. [IF A29b. < 3] Please describe why you indicated that your heat pump is ineffective at keeping your home or space warm during <u>normal winter weather</u>. [TEXT]

A32. [IF A3 = 1] Please rate your satisfaction with the following aspects of your heat pump(s) **compared to your previous heating/cooling system(s).** **[Scale 1-5, 1 being 'extremely dissatisfied and 5 being 'extremely satisfied']**

	Extremely dissatisfied	Moderately dissatisfied	Neither satisfied nor dissatisfied	Moderately satisfied	5- extremely satisfied
a. Your heat pump's ability to meet the **heating** needs of the space that it is responsible for keeping heated <u>during cold periods (like Jan. 20 – 22)</u>					
b. Your heat pump's ability to meet the					

heating needs of the space that it is responsible for keeping heated during normal winter weather					
c. Your heat pump's ability to meet the **heating** needs of the space that it is responsible for keeping heated overall					
d. Your heat pump's ability to meet the **cooling** needs of the space that is responsible for overall					
e. Overall reliability of your heat pump(s)					
f. The cost of operating your heat pump(s)					

g. Your electric bill after installing your heat pump(s)					
h. The frequency of repairs needed for your heat pump(s)					
i. The cost of repairs for your heat pump(s)					
j. The ease of operating your heat pump(s)					

A33. [IF A32a. < 3] Please describe why you indicated that you were dissatisfied with your heat pump's ability to meet the **heating** needs of your space during cold periods (like January 20 – 22) compared to your previous heating system. [TEXT]

A34. [IF A32b. < 3] Please describe why you indicated that you are dissatisfied with your heat pump's ability to meet the **heating** needs of your space during normal winter weather compared to your previous heating system. [TEXT]

A35. [IF A32c. < 3] Please describe why you indicated that you are dissatisfied with your heat pump's ability to meet the **heating** needs of your space overall. [TEXT]

A36. [IF A32d. < 3] Please describe why you indicated that you are dissatisfied with the reliability of your heat pump(s) compared to your previous cooling system. [TEXT]

A37. [IF A32e. < 3] Please describe why you indicated that you are dissatisfied with the reliability of your heat pump(s) compared to your previous heating/cooling system(s). [TEXT]

A38. [IF A32f. < 3] Please describe why you indicated that you are dissatisfied with the cost of operating your heat pump(s) compared to your previous heating/cooling system(s). [TEXT]

A39. [IF A32g. < 3] Please describe why you indicated that you are dissatisfied with your electric bill after installing your heat pump(s) compared to your previous heating/cooling system(s). **[TEXT]**

A40. [IF A32h. < 3] Please describe why you indicated that you are dissatisfied with the frequency of repairs needed for your heat pump(s) compared to your previous heating/cooling system(s). **[TEXT]**

A41. [IF A32i. < 3] Please describe why you indicated that you are dissatisfied with the cost of repairs needed for your heat pump(s) compared to your previous heating/cooling system(s). **[TEXT]**

A42. [IF A32j. < 3] Please describe why you indicated that you are dissatisfied with the ease of operating your heat pump(s) compared to your previous heating/cooling system(s). **[TEXT]**

A43. [IF A3 = 1] Describe how quickly your heat pump responds to increasing the thermostat setpoint to a higher temperature, **when compared with your previous heating system** during the following scenarios.

[Scale 1-5, 1 being much slower' and 5 being 'much faster']

	Much slower	Moderately slower	Neither faster nor slower	Moderately faster	Much faster
a. During cold periods (like Jan. 20 – 22)					
b. During normal winter weather					

A44. [IF A43a. < 3 Please describe your experience with the speed of your heat pump's ability to change your thermostat setpoint compared with your previous heating system during cold periods (like January 20 – 22). **[TEXT]**

A45. [IF A43b < 3] Please describe your experience with the speed of your heat pump's ability to change your thermostat setpoint compared with your previous heating system during normal winter weather. **[TEXT]**

A46. Have you experienced any maintenance issues with your heat pump(s)?

1) Yes
2) No

A47. [IF A46 = 1] When did you experience these maintenance issues?

1) Winter/Fall/Spring (Oct – April)
2) Summer (May – Sept)

A48. [IF A46 = 1] Did the maintenance issues impact your heat pump's performance this winter?

1) Yes
2) No
98) Don't know

A49. [IF A46 = 1] Please describe your maintenance issues here: [TEXT]

A50. Please respond to the following prompts.

If you were to go back in time, would you:

a. Install the same heat pump(s)?	Yes	No
b. Install a different type of heat pump(s)?	Yes	No
c. Install a heat pump(s) at all?	Yes	No

A51. [IF A50a = "No"] Why wouldn't you install the same heat pump(s)? [TEXT]

A52. [IF A50b = "Yes"] Why would you install a different type of heat pump(s)? What type of heat pump(s) would you install instead? [TEXT]

A53. [IF A50c = "No"] What type of heating and/or cooling system would you install instead? [TEXT]

A54. What is the greatest advantage of your heat pump(s)? [TEXT]

A55. What is the greatest disadvantage of your heat pump(s)? [TEXT]

Module B: Electricity Costs

Next, we would like to understand more about how electricity costs may have affected your heat pump usage this winter.

B4. Before this winter, had you operated your heat pump(s) during the winter months?

1) Yes
2) No

B5. Which of the following statements best describes your electric bills this winter?

1) They are about what I expected
2) They are higher than I expected
3) They are less than I expectedd
98) Don't know

B6. Did energy costs impact how you operated your heat pump?

1) Yes
2) No

B7. [IF B6 = 1] Please describe how energy costs impacted how you use your heat pump. [TEXT]

Module C: Thermostat Setpoints

Next, we would like to know about how you and your household use your main thermostat during the winter (October-April). Generally, we would like to understand what your typical thermostat usage looks like, unless we indicate otherwise. Please answer these questions based on the thermostat(s) that controls the heat pump(s) in your home.

C1. Do you or anyone in your household use a thermostat to control your heat pump(s)?

1) Yes
2) No [SKIP to D4]
98) Don't know [SKIP to D4]

C2. Please select the statement that most closely aligns with how your household controls your heat pump(s).

1) My thermostat controls the unit, and I/we never adjust the temperature setting manually
2) My thermostat controls the unit, but I/we occasionally adjust the temperature setting manually
3) I/we frequently adjust the temperature setting manually

C3. [IF EQUIPMENT_REPORTED = CHP] Some households keep their temperature setting the same throughout the day and night, and some change the temperature to different levels at different times of day. What best describes the temperature setting (for the area your heat pump is responsible for heating) in your home so far this winter?

1) Temperature is the SAME all the time (i.e., same temperature day and night)
2) Temperature is DIFFERENT at different times of day or night (i.e., temperature is different when not home or asleep, automatic or manual setback)
97) Other, please specify. [TEXT BOX]

C4. [IF C3 = 2] Why do you/your household change the temperature setting throughout the day? [TEXT]

C5. [IF EQUIPMENT_REPORTED = MSP] Think about the thermostat that controls the space in your home that is heated most frequently by your mini-split heat pump(s). Some households keep their temperature setting the same throughout the day and night, and some change the temperature to different levels at different times of day. What best describes the temperature setting (for the area your heat pump is responsible for heating) in your home so far this winter in this heating zone?

1) Temperature is the SAME all the time (i.e., same temperature day and night) and the unit is left "on" for most of the winter days
2) Temperature is DIFFERENT at different times of day or night (i.e., temperature is different when not home or asleep, automatic or manual setback)
3) Other, please specify. [TEXT BOX]

C6. [IF C5 = 2] Why do you/ your household change the temperature setting throughout the day? [TEXT]

C7. [IF EQUIPMENT_REPORTED = MSP] Does your household operate all the thermostats for your other heat pump(s)/heating zones the same way?

1) Yes
2) No
98) Don't know

C8. [C7 = 2] Please describe how you operate the thermostats linked to other heat pump(s)/heating zones in your home. [TEXT]

C9. During the most recent cold period (January 20 – 22), did your household adjust your thermostat temperature setting compared with other days that were not as cold outside?

1) Yes
2) No
98) Don't know

C10. [IF C9 = 1] Please describe the changes your household made and why. [TEXT]

C11. Generally, do you/your household adjust your thermostat temperature setting more since installing your heat pump(s) compared to your previous heating system?

1) Yes
2) No

C12. [IF C11 = 1] Please describe the changes. Did your household make these changes in summer or winter? Is your thermostat temperature setting generally higher or lower compared to your previous heating system? [TEXT]

C13. Did your home reach the temperature on your thermostat during the most recent cold period (January 20 – 22)?

1) Yes
2) No
98) Don't know

Module D: Feedback

D4. Is there anything else you would like to tell us about your experience with your heat pump so far this winter? **[TEXT]**

D5. Is there any feedback you would like to share about your experience with the onsite metering study team and metering installation experience? **[TEXT]**

D6. More generally, is there any other feedback on your experience with the heat pump programs offered through the Sponsors of Mass Save or Energize CT that you would like to share? **[TEXT]**

CLOSE: This concludes the survey that we have prepared for you today. You can expect to receive your e-gift card directly from noreply@tango.com in 1-2 business days.

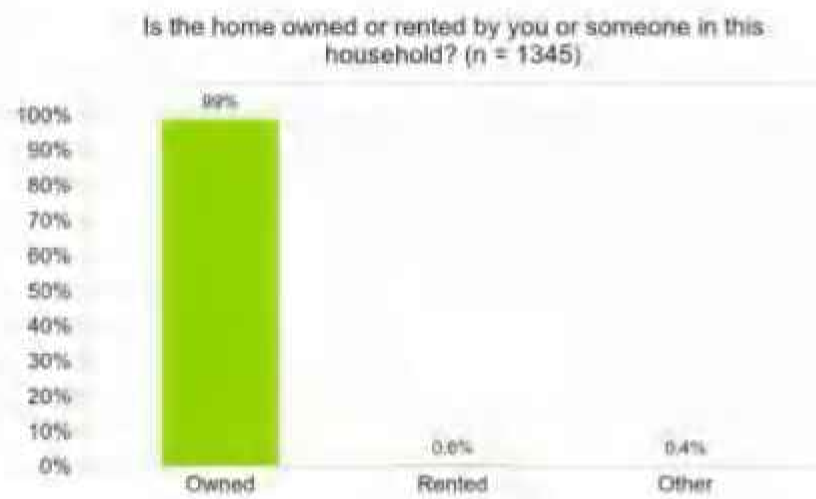
If you have any questions about this survey or how your responses to this survey will be used, please contact HeatPumpStudy@guidehouse.com.

Appendix C. Select Customer Survey Responses

This section provides summary of additional responses to the primary customer survey.

Figure C-1 shows that almost all the heat pump fuel displacement projects were completed in residences that were owned by the occupants.

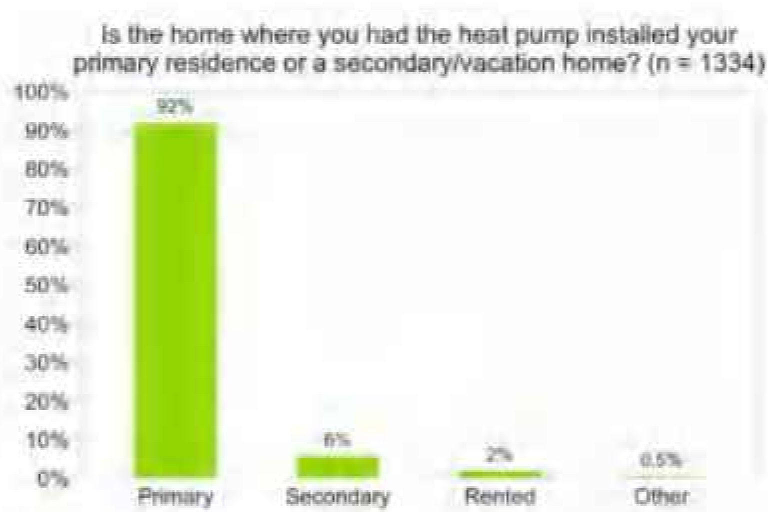
Figure C-1. Homeownership Rate



Source: Evaluation team analysis

Almost all customers (92%) indicate that heat pump(s) were installed in their primary residence, as Figure C-2 shows.

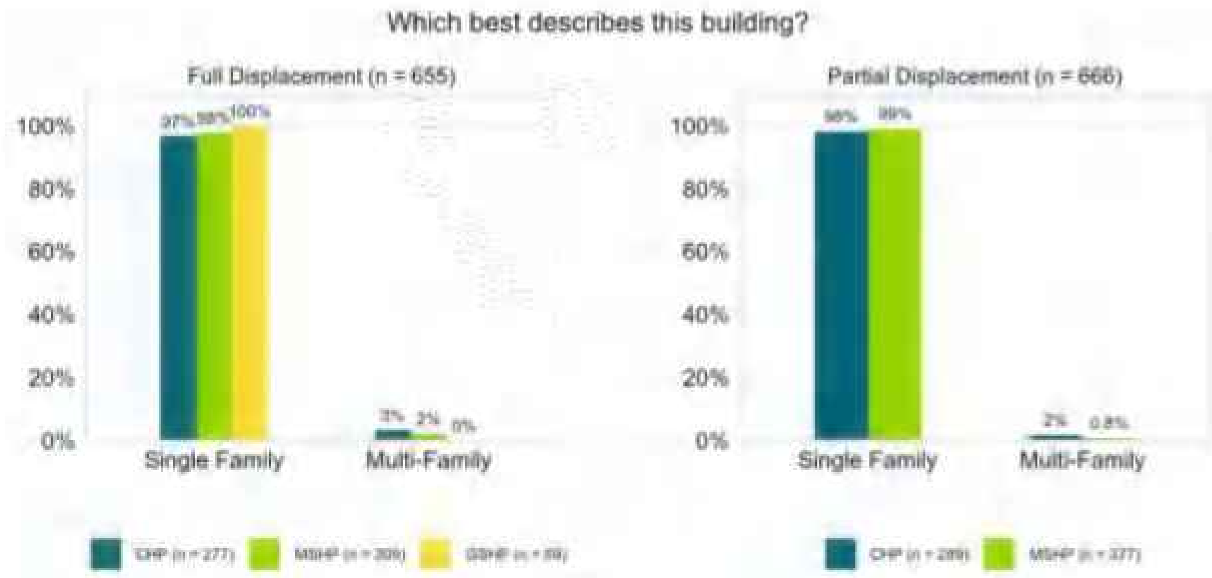
Figure C-2. Residence Type



Source: Evaluation team analysis

Almost all installations went into single family homes (either detached single family homes or attached homes up to 4 units). About 2% of FD installations went into multifamily homes (5+ units), as Figure C-3 shows.

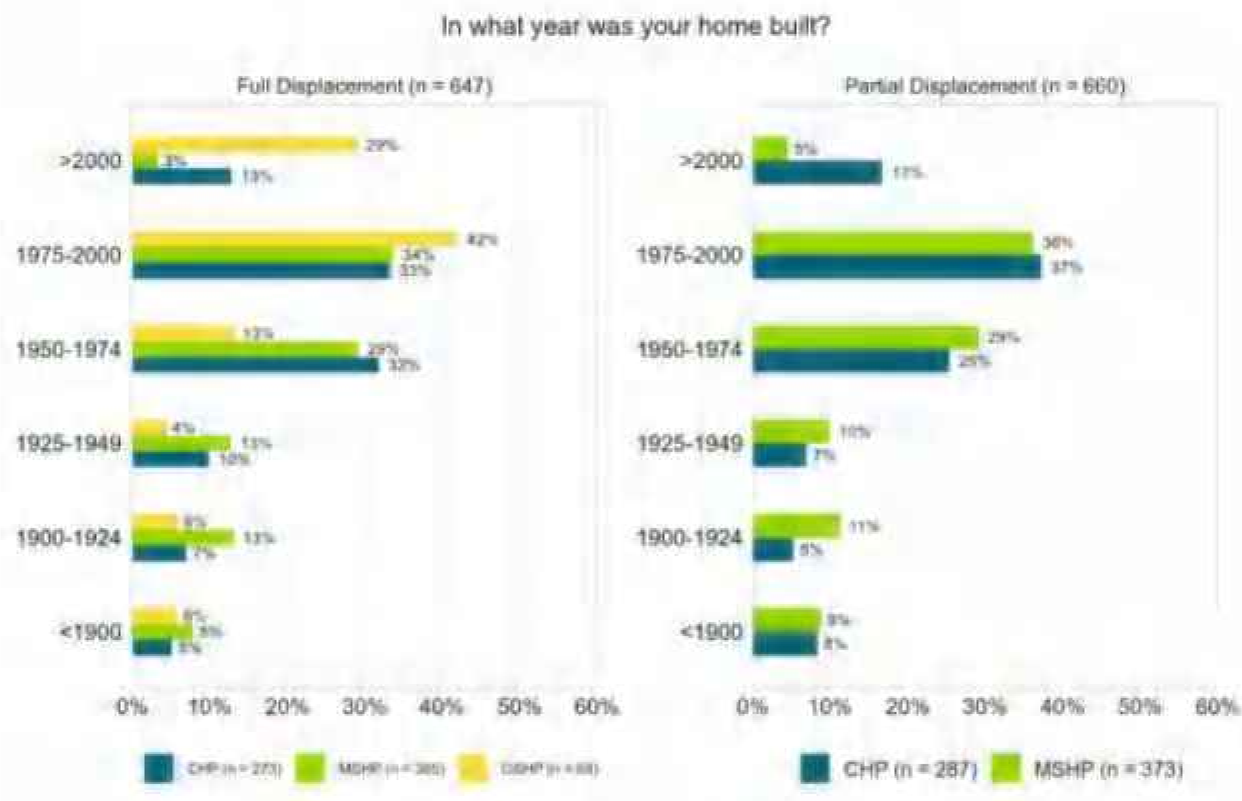
Figure C-3. Building Type by Heat Pump and Displacement Type



Source: Evaluation team analysis

Figure **C-4** shows the distribution of the years which respondents' homes, with heat pump installations, were built.

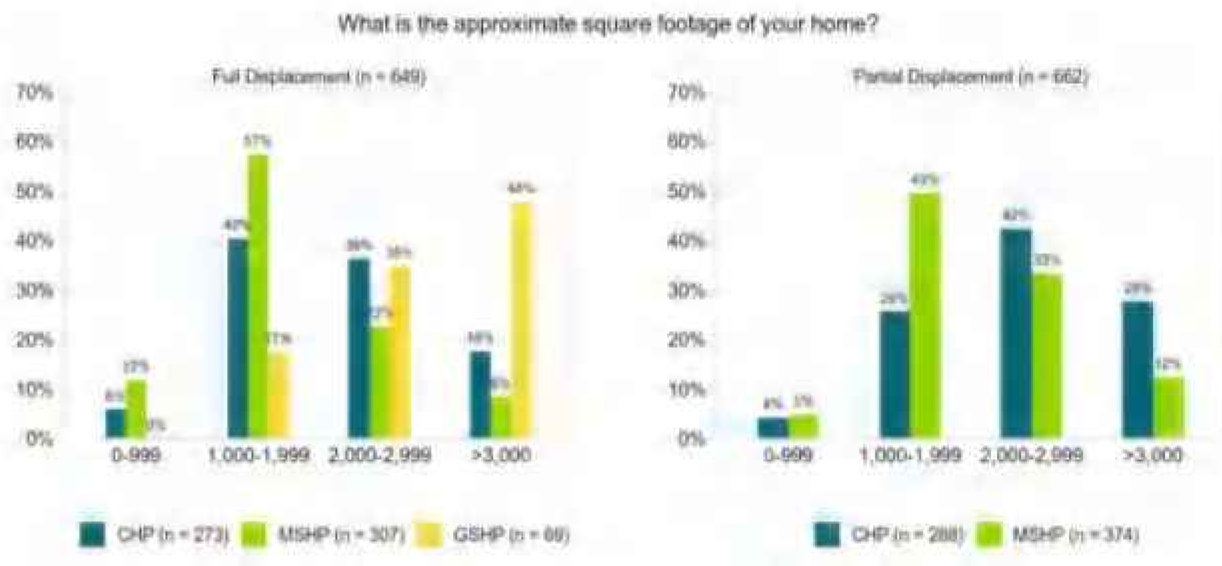
Figure C-4. Year Built by Heat Pump and Displacement Type



Source: Evaluation team analysis

Figure C-5 shows the distribution of installations by home size.

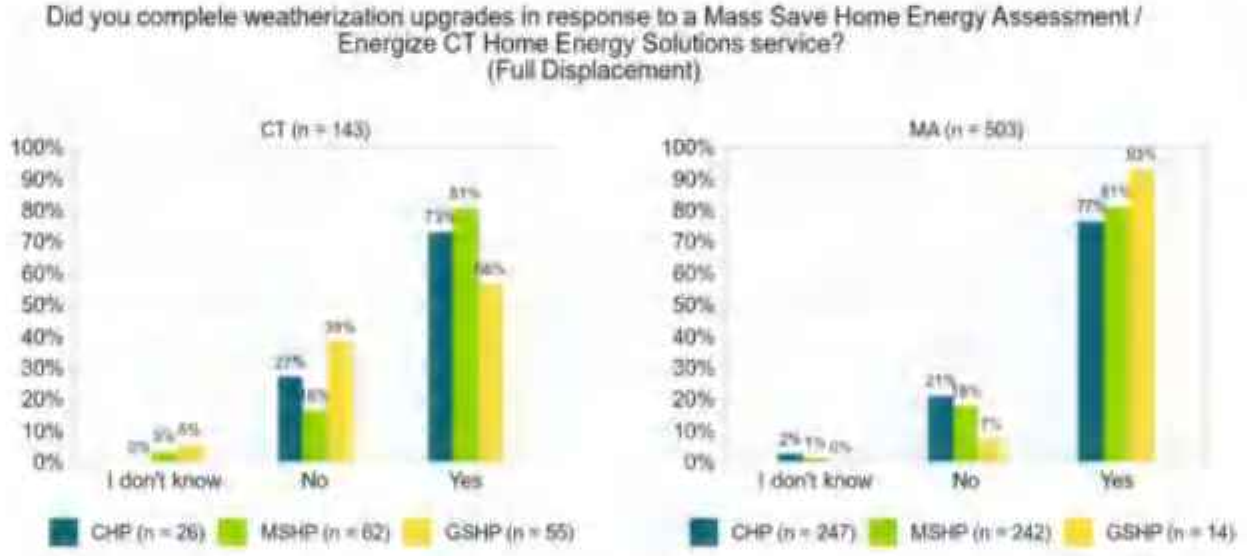
Figure C-5. Home Size by Heat Pump Type and Displacement Type



Source: Evaluation team analysis

Figure C-6 shows that the majority of customers doing a full displacement installation indicate completing home weatherization upgrades in response to a Mass Save Home Energy Assessment or Energize CT Home Energy Solutions service.

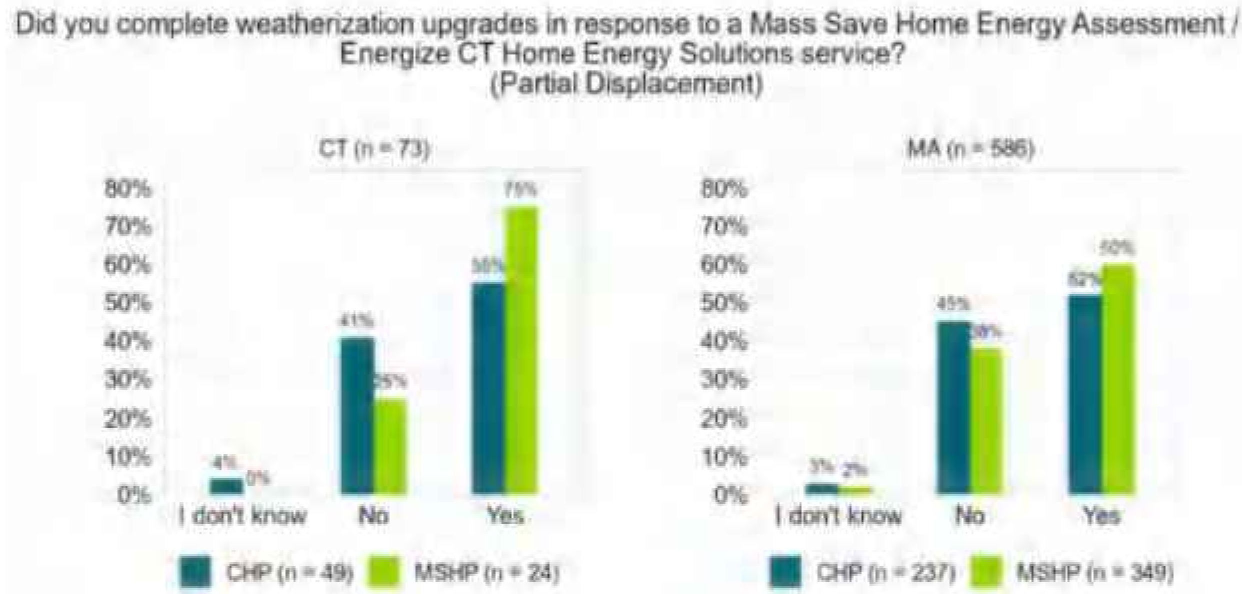
Figure C-6. Weatherization Upgrade by Heat Pump Type (FD)



Source: Evaluation team analysis

A sizable portion of partial displacement installations also received home weatherization upgrades, although fewer than full displacement installations, as Figure C-7 shows.

Figure C-7. Weatherization Upgrade by Heat Pump Type (PD)



Source: Evaluation team analysis