Energy Optimization Fuel Displacement Impact and Process Study (MA20R24-B-EOEVAL)

Final Report

Provided to:

The Electric and Gas Program Administrators of Massachusetts

Part of the Residential Evaluation Program Area

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Abbreviations

Throughout this report, the team references several abbreviations. Terms are defined in the following list.

AC ..... Air Conditioning

ADC ..... Average Daily Consumption

AMY ..... Actual Meteorological Year

BTU ..... British Thermal Unit

CDD ..... Cooling Degree Day

CO_2 ..... Carbon Dioxide

EEAC ..... Energy Efficiency Advisory Council

EER ..... Energy Efficiency Ratio

EFI ..... Energy Federation Incorporated

EUL ..... End of Useful Life

EO ..... Energy Optimization

HDD ..... Heating Degree Day

HP ..... Heat Pump

HVAC ..... Heating, Ventilation, and Air Conditioning

IECC ..... International Energy Conservation Code

IT ..... Information Technology

MA ..... Massachusetts

NREL ..... National Renewable Energy Laboratory

PA ..... Program Administrators

PNNL ..... Pacific Northwest National Laboratory

SEER ..... Seasonal Energy Efficiency Ratio

SF ..... Square Feet

TRM ..... Technical Reference Manual

VBDD ..... Variable Based Degree Day

Executive Summary

The Massachusetts (MA) programs provide rebate for heat pumps (HPs) that displace delivered fuel and electric resistance heating (fuel displacement) in both the residential and income eligible sectors. These measures are part of the broader Energy Optimization (EO) offerings and are applicable to all projects with deemed (non-custom) savings values. The fuel displacement rebate offerings encourage customers to reduce reliance on energy and CO_2-intensive fuel oil, propane, and electric resistance baseboard heating systems and to displace their energy consumption through more efficient heat pump (HP) systems when outdoor weather conditions are favorable to HP operation. Customers either fully replace their existing heating system with a HP (full displacement) or leave their existing heating system installed while also installing either a central HP or mini-split HPs with integrated controls that prioritize resistance, furnace, boiler, or HP operation based on outdoor air and weather conditions (partial displacement). The MA PAs began offering the oil and propane to heat pump measures in 2019 and electric resistance to heat pump measure offerings in 2018.

Objectives and Methodology

The team performed a process and impact evaluation of the EO Fuel Displacement measure offerings. The evaluation's primary goals were to:

- Refine estimates of overall HVAC energy impacts for the EO fuel displacement measures, including electric consumption increases and associated delivered fuel heating (fuel oil, propane) savings for the most prevalent EO fuel displacement measures. The research completed through this study informs savings reporting for the 2021 program year and the subsequent 2022-2024 planning cycle.
- For partial displacement installations with integrated controls, understand how customers are controlling their existing delivered fuel-fired heating system and new HP systems, including programmed and field-verified switchover temperatures and other HVAC operation behavior; and identify opportunities for increased savings from improved control settings, installation practices, or customer or contractor education.
- Understand and offer insights into program processes, customer program satisfaction, potential barriers to participation, contractor and distributor program experience and engagement, and opportunities for improved program delivery.
- Understand customer motivations and decision-making around their energy optimization equipment purchase, including what the customer would have installed if they had not installed the retrofit equipment to determine baseline conditions, and if the customer primarily purchased the HP system(s) for heating, cooling, or both.

The team performed several research tasks in support of the study objectives, including program staff and implementer interviews, contractor and distributor interviews, a customer survey and follow-up interviews, billing analysis, building simulation, and a heating equipment operation metering study. Section 2 outlines these methods and Section 3 details associated results.

Key Findings and Recommendations

This section provides the evaluation team's high-level findings, key recommendations, and considerations as supported by both process and impact research activities. Section 6 details the full study conclusions, recommendations, and considerations.

Customer Satisfaction; Heat Pump and Integrated Control Operation

Findings	Recommendations and Considerations
Finding. Most customers are satisfied with their new fuel displacement equipment—especially their HPs—and are more comfortable than they were before program participation. Customer satisfaction and system operation is described further in Section 5.2.	
Finding. For partial displacement installations in 2019, customers who installed a central HP are largely relying on the integrated controls to auto-switch between their new heat pump and the previous delivered fuel-fired heating equipment (80% of installations in the 2019 program year). About half (40%-60%) of mini-split HP(s) installations are replying on the integrated controls to auto-switch, while the other half are manually operating their systems. Customers using manual operation are using either wall-mounted or app-based controls to operate their heat pumps and existing heating systems based on perceived outdoor air temperatures, or when they would prefer to run their various systems. This study found that customers who are manually operating their systems are largely switching system operation at close to desired temperatures, however, some mini-split HP owners are turning off the units entirely when they are not occupying the zone. These practices have the potential to reduce the efficiency benefits achieved.	**Recommendation 1.** Offer literature directly to customers (including online resources) that summarize the benefits of integrated controls and basic tips on how to operate new systems. Customize literature for central HP and mini-split HP owners. Helping customers build a greater understanding for their new equipment, how to operate it, and how not to operate it, may also increase customer satisfaction and reduce the number of customers switching between their heating systems manually. This will further help customers build a greater understanding for their new equipment, how to operate it, and how not to operate it, and may also increase customer satisfaction and reduce the number of customers manually switching between their heating systems. For example, mini-split HP literature could focus on the cost savings benefits and the ease of "setting and forgetting" with their integrated control. Instead of turning off heat pump when they are not in the room or are not home, they should turn back the boiler setpoint or choose the away setting on their thermostat.

Findings	Recommendations and Considerations
Finding. The results from this study suggest that customers are not using standardized switchover temperatures for either oil or propane systems. For customers who do use an integrated control to auto-switch, they program a variety of switchover temperatures between approximately 5°F and 45°F. Section 5.2 provides further research findings relating to integrated control programming motivations and experience with the controls.	**Consideration.** The program administrators could consider a follow-up study to further explore ideal switchover temperature settings to optimize customer energy bills, reduce fossil fuel usage, and reduce greenhouse gas emissions.
Finding. Contractor and distributor interviews suggest that integrated controls may vary widely in functionality and features depending on the manufacturer. This is common for a developing market. However, this may cause some contractors to be overwhelmed or confused and decide to give up early on the technology. For example, contractors reported experiencing connectivity issues with different brands, and problems with mismatched zoning between the fossil fuel system and new mini-split HPs that may prompt customers to override the controls. Contractor experience is described further in Section 5.2.3.	**Recommendation 2.** The Program Administrators should consider convening a study to gain additional understanding of the functionality and performance of different types of integrated controls, including distinctions between networked and hard-wired controls. Any future metering studies should include a large sample of both networked and hard-wired controls over an extended metering period to capture control and unit operation over a wide range of temperature and weather conditions (including heat pump performance at lower outdoor air temperatures). This type of study may help to further refine program requirements, along with the Qualified Products List (QPL). Additionally, the study may assist the program in producing other guidance for contractors. For example, depending on the study's scope, a guide to accompany the QPL could be produced that identifies which controls are good for different customer types (e.g., tech-savvy customers, set-it and forget-it customers) and the features/functionality offered. As the market matures, controls may align in functionality and features, but until then some contractors may continue to be overwhelmed with the different options and features available.

Contractor Experience

Findings	Recommendations and Considerations
Finding. The program primarily leans on the contractors' relationship with customers to promote the rebate offering. However, many contractors – especially smaller contractors or contractors that have lower participation rates – require more training to be able to provide their customers with the necessary guidance and support so integrated control and HVAC systems operate as intended. Contractor installation experience is described more in Section 5.2.3.	**Recommendation 3.** Provide contractors program support depending on how far along they are on the adoption curve for fuel displacement technologies. Take the following tactics to support the different contractor types: • **Early Adopters:** Highlight their experiences and expertise in case studies or features that can be used to bring along other contractors. These contractors generally represent 20% of the population but perform 80% of the installations and require little to no technical assistance. • **Majority:** Offer technical trainings or field support to increase this groups' capacity to resolve issues and become more confident with the technology. These contractors generally represent the second and third tiers down in project volume from the Early Adopters. They are motivated to offer their customers' the value of the rebate but are still somewhat skeptical of the technology. • **Late Adopters:** Provide sales training and basic information about fuel displacement technologies and the program offering. These low volume EO contractors have little available time and are less likely to seek out resources on their own. The program could consider opportunities to perform additional one-on-one outreach to this group via phone or in-person, emphasizing the value proposition of integrated controls and how controls could benefit both them and their customers.

Multifamily Offerings

Findings	Recommendations
Finding. The four Income Qualified multifamily owners/operators interviewed were very satisfied with their experience.	**Consideration.** The program should review and consider recommendations from the Multi-Family Project Improvement Strategies (RES 42) study, published in October 2018. While not specifically designed for heat pump offerings, these recommendations still apply broadly to the multifamily sector and program offerings.
Interviewed building owners/operators were very happy with their program experience, the performance of the HPs installed at their properties, and the resulting energy cost reductions.	Due to the small sample of multifamily projects included in this evaluation, the team was not able to identify specific recommendations. However, the Multi-Family Project Improvement Strategies (RES 42) study includes recommendations that are applicable to multifamily programs regardless of the measure offering. Future heat-pump research could include interviews with participants, nonparticipants, and contractors that serve multifamily properties.

Baseline Heating and Cooling System Types

Findings	Recommendations and Considerations
Finding. The prevalence of a no cooling baseline assignment is higher for customers who installed a mini-split HP (30% for fuel fired baseline heat, 37% for electric resistance baseline heat) relative to customers who installed a central HP (9%). This suggests that these customers who installed a mini-split HP through the program are motivated to add a cooling amenity to their space (which results in a net cooling energy increase) but are also spurred by the program to displace pre-existing delivered fuel-fired or electric resistance space heating with their new heat pump(s), as the program intended. Thirty-nine percent of customers who installed a central HP indicate that they would have installed a central AC if they did not install the HP they did (which does not provide a heating amenity). This further indicates that the program is having the intended effect: spurring customers to displace delivered fuel heating usage relative to their baseline purchasing decisions. Section 3.1 describes the baseline assignment methodology in detail, along with the detailed baseline heating and cooling distributions for each measure category.	**Consideration.** The program should continue to encourage customers to displace space heating with delivered fuels with heat pumps. The program should continue to encourage contractors to tell customers that the program rebates will afford them both heating and cooling amenities for the same, or slightly lower, unit price as similarly efficient central or mini-split air conditioners.

Fuel Displacement Measure Impacts

Findings	Recommendations and Considerations
Finding. As part of this study, the team performed several research tasks to develop updated energy and demand impacts for fuel displacement measures.	**Recommendation 4.** The MA PAs should use these updated measure impact values for future implementation and planning purposes.

Table 1 summarizes the EO fuel displacement measure impacts at the per installed ton level.[1] MA PAs should use these 'per ton' impact values, as well as the 'per home' impact values in Table 2, as appropriate for the 2021 program year reporting. Table 1 summarizes the average installed tonnage per home, used to convert the 'per ton' impacts to the 'per home' level. Appendix A provides the recommended measure impacts for the 2022-2024 planning years, using updated assumptions for switchover temperature distributions based on recent discussions (held in September 2021) of planned 2022-2024 program changes with the PA program managers and implementation teams.[2]

Table 1. EO Fuel Displacement Measure Savings (Per Ton)

BCR Measure ID	Measure	kWh Heating	kWh Cooling	kWh Total	MMBtu Delivered Fuel	Average Installed Tons per Customer
E19A2c270	Mini-Split HP Integrated Controls Retrofit Oil	-599	-	-599	8.8	2.8
E19A2c269	Mini-Split HP Integrated Controls Retrofit, Propane	-599	-	-599	9.0	2.8
E19A2c266	Central Ducted HP Partially Displacing Existing Furnace, Oil	-838	42	-795	11.1	3.7
E19A2c265	Central Ducted HP Partially Displacing Existing Furnace, Propane	-838	42	-795	11.6	3.7
E19A2c272	Central Ducted HP Fully Displacing Existing Furnace, Oil	-1,831	36	-1,795	17.9	4.7*
E19A2c271	Central Ducted HP Fully Displacing Existing Furnace, Propane	-1,831	36	-1,795	17.9	4.7*
E19A2c268	Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Oil	-843	-114	-957	15.0	2.8
E19A2c267	Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Propane	-843	-114	-957	14.8	2.8
E19A2c273	Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Oil	-1,410	-98	-1,508	17.8	3.9*
E19A2c274	Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Propane	-1,410	-98	-1,508	17.8	3.9*
E19A2c256	Mini-Split HP Fully Displacing Electric Resistance	2,443	-127	2,316	3.8	2.0
E19B1a274	Custom Heat Pumps, Displacing Electric Heat (Multifamily)	1,974	63	2,037	-	1.0

*Due to small sample size for these full displacement installations in 2019, the team assumed typical full displacement capacity (delivered fuel-fired baseline) is 4.5 tons at the 2,400SF EnergyPlus prototype model size, and calculated an assumed average installed tons per participant by applying the ratio of average participant SF to the prototype model SF

Source: Evaluation Team Analysis

[1] See Section 4.2.1 and 4.2.2 for a full summary of measure impacts including electric energy (kWh), peak demand (kW), and delivered fuel (MMBtu) impacts at the 'per ton' and 'per home' levels for average program installations.

[2] The team recommends that PAs and implementers use the 'per ton' results for single-family homes to inform deemed savings planning assumptions for the multifamily segment. The PAs and EEAC could consider a separate study focused on multifamily measure impacts for full and partial displacement with various pre-exiting heating fuel types.

The team scaled the per ton impacts to the per home level using the average tonnage installed per home for fuel displacement installations in the 2019 program year. Table 2 compares the average per home measure impacts between the prior EO Optimization Model and the current EO evaluation study results.

Table 2. EO Fuel Displacement Single-Family Measure Savings Comparison Between Prior and Current EO Study (Per Home, Average Participant)

Measure and BCR ID	Prior Study Results		Current Study Results		Comparison of Study Results	
	kWh Total	MMBtu Delivered Fuel	kWh Total	MMBtu Delivered Fuel	% Difference kWh	% Difference MMBtu
Mini-Split HP Integrated Controls Retrofit Oil E19A2c270	-3,941	49.7	-1,678	24.6	57%	-51%
Mini-Split HP Integrated Controls Retrofit, Propane E19A2c270	-7,106	90.2	-1,678	25.2	76%	-72%
Central Ducted HP Partially Displacing Existing Furnace, Oil E19A2c266	-3,346	42.1	-2,942	41.1	12%	-2%
Central Ducted HP Partially Displacing Existing Furnace, Propane E19A2c265	-5,737	76.5	-2,942	42.9	49%	-44%
Central Ducted HP Fully Displacing Existing Furnace, Oil E19A2c272	-6,082	86.7	-8,437	83.9	-39%	-3%
Central Ducted HP Fully Displacing Existing Furnace, Propane E19A2c271	-6,082	86.7	-8,437	83.9	-39%	-3%
Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Oil E19A2c268	-3,941	49.7	-2,679	42.1	32%	-15%
Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Propane E19A2c267	-7,106	90.2	-2,679	41.4	62%	-54%
Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Oil E19A2c273	-7,468	102.3	-5,882	69.3	21%	-32%
Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Propane E19A2c274	-7,468	102.3	-5,882	69.3	21%	-32%
Mini-Split HP Fully Displacing Electric Resistance E19A2c256	5,039	0	4,631	7.5	-8%	-

Source: Evaluation Team Analysis

The following is a high level summary of the main drivers leading to changes in impacts between the prior study and current study. See Section 4.2.1 for additional details related to these main impact drivers.

- **Baseline heating loads:** The prior EO study heating loads were about 30% higher than those determined through the current study. This is the primary driver behind changes in impacts between the prior and current study. The lower base heating loads in the current

study lead to lower heating impacts relative to the prior study, especially for the mini-split HP measures.

- **Tonnage Assumptions:** The prior study assumed 2.5 tons per home for partial displacement installations and 4 tons per home for full displacement installations. The current study assumes variable average installed capacities per customer, summarized in Table 2-21 in Section 2.6.2. These differences in installed tonnage per home also drive differences in per home impacts between the prior and current studies.
- **Baseline Cooling Assumptions/Weights:** Another driving factor in differences between the current and prior studies is the application of the baseline heating and cooling weights to derive a blended baseline consumption for each measure type (described in Section 3.1). This method was not done in the prior study. This leads to lower baseline cooling kWh consumption in the current study relative to the prior study, which leads to lower cooling kWh impacts.
- **Switchover Temperatures:** The prior EO study assumed a set 30°F switchover temperature for oil baseline systems and 15°F for propane baseline systems. The current study assumed the same switchover temperature distributions between oil and propane baseline system types for the 2021 impact values, based on results from the customer survey and onsite metering. This is consistent with the current program recommendations. Appendix A-1 presents updated switchover temperature assumptions and resulting impact values for the 2022-2024 planning period, which incorporate different switchover assumptions for oil and propane systems based on planned program changes.

1. Introduction

This report presents the evaluation of the 2019 Energy Optimization (EO) Fuel Displacement offerings for the residential and income eligible sectors. This study was conducted by the Massachusetts (MA) Residential Retrofit Research Area team, led by Guidehouse in partnership with ILLUME and the Cadeo Group (referred to as "the team" throughout this document). The team conducted research and analysis on behalf of the MA Program Administrators (PAs) and the Energy Efficiency Advisory Council (EEAC). The PAs participating in this study include National Grid, Eversource, Cape Light Compact, Unitil, Berkshire Gas Company, and Liberty Gas.

This study involved a process and impact evaluation of the EO Fuel Displacement measures, which was first offered by the MA PAs in 2019. As such, this study is the first full process and impact evaluation of these new program offerings. The customer samples drawn for the impact and process evaluation tasks were based on the 2019 program data supplied by DNV; however, the findings and recommendations for this study are not solely based on the 2019 implementation of the program. The team completed several interviews with program staff, implementation staff, contractors, and distributors to provide an accurate picture of the program implementation into 2021. The results of this evaluation serve to provide the MA PAs with actionable findings and recommendation to improve future program delivery and provide current assumptions for measure impacts to inform the next 3-year planning cycle from 2022-2024.

1.1 Program Description

The EO Fuel Displacement measure offerings serve customers of single family homes through deemed measure savings and incentives. All multifamily fuel displacement projects are currently screened through the custom program. The program helps install HPs to provide space heating more efficiently to their homes, provide an improved cooling amenity, and to reduce reliance on energy and CO_2-intensive fuel oil, propane, and electric resistance baseboard heating systems.

Two displacement scenarios are possible through the EO Fuel Displacement measure offerings:

- **Full displacement.** The customer removes or disconnects their existing fossil fuel or electric resistance baseline heating system and replaces all space heating loads with HPs, either for their whole home or for specific heating zones throughout their home.
- **Partial displacement.** The existing delivered fuel-fired system is left in place and either one or multiple HPs are installed. The customer installs an integrated controller, which controls the delivered fuel-fired heating equipment and HP operation to occur during pre-defined outdoor air temperature ranges. The program encourages customers to program an integrated control switchover temperature between 30°F and 40°F as a starting point. Contractors will work with the customer, identify the unique heating and cooling needs of their home, and suggest and program a switchover control setting. The delivered fuel-fired heating systems are prioritized at lower outdoor air temperatures when the HP efficiency is lowest, when the HP cannot meet the full heating loads of the home (e.g., when the heat pump is recovering from a thermostat setback in the morning), or through additional interventions by the customer to meet comfort or other needs. All partial displacement projects included in this evaluation include an integrated control installation.

Both central HPs (ducted) and mini-split HPs (ducted or ductless) are eligible through the program. For the single-family segment in 2019, single-family installations spanned central and mini-split HPs installations with delivered fuel-fired and electric resistance heating baselines. In 2019, all installations within the multifamily segment were full displacements of existing-electric resistance heat with mini-split HPs (impacts determined through custom measure pathway).[3]

The integrated control installation is required to access the energy optimization measure rebates for partial displacement scenarios. In addition, the program provides rebates for standalone integrated controllers that are installed at homes with existing delivered fuel-fired furnaces or boilers and ducted central HPs or mini-split HP systems.

In 2019, the PAs offered an incentive of $1,600 per installed ton of HP capacity for customers that displaced delivered fuel-fired heating and installed a mini-split HP. An incentive of $1,000 per ton was offered for customers displacing electric resistance heat with a mini-split HP, or delivered fuel-fired heat with a central HP. For customers that installed an integrated control on an existing HP system with delivered fuel-fired backup heat, PAs offered $500 per heating zone, up to a $1,500 maximum incentive. In the 2020 and 2021 program years, the PAs offered $1,250 per ton for installed central HPs or mini-split HPs partially or fully displacing delivered fuel-fired or electric resistance heat. The same rebate is offered to customers who install an integrated control on existing HP and delivered fuel-fired heating systems ($500 per heating zone, up to $1,500 max incentive per customer).

1.2 Study Goals and Research Objectives

The primary goals of this study were to:

- Refine estimates of overall HVAC energy impacts for the EO fuel displacement measures, including electric consumption increases and associated delivered fuel heating use (fuel oil, propane) decreases for the most prevalent EO fuel displacement measures. The research completed through this study informs savings reporting for the 2021 program year and the subsequent 2022-2024 planning cycle.
- For partial displacement installations with integrated controls, understand how customers are controlling their existing delivered fuel-fired heating system and new HP systems, including programmed and field-verified switchover temperatures and other HVAC operation behavior; and identify opportunities for increased savings from improved control settings, installation practices, or customer or contractor education.
- Understand and offer insights into program processes, customer program satisfaction, potential barriers to participation, and opportunities for improved program delivery.
- Understand customer motivations and decision-making around their energy optimization equipment purchase, including what the customer would have installed if they had not installed the retrofit equipment to determine baseline conditions, and if the customer primarily purchased the HP system(s) for heating, cooling, or both.

[3] In the 2019 program implementation, all installations in the multifamily segment involved disconnecting prior electric baseboard heaters and sizing and installing mini-split HPs to be able to fully provide both heating and cooling to the space. Electric baseboard heaters are left connected in zones that are not fully served by the mini-split HP heads, such as bathrooms.

1.3 Summary of Evaluation Activities

Table 1-1 details the activities included in the EO Fuel Displacement evaluation. The team first collected program records for the 2019 implementation of the program to support impact and process analyses and to draw samples for the contractor and customer surveys and interviews. The team interviewed program managers, implementation teams, contractors, distributors, and a small sample of customers to gather feedback on the program. The team conducted a utility bill disaggregation analysis to support the calibration of the building simulation models and conducted a remote metering study (surface and air temperatures, total home kWh usage) to identify customer usage behavior of their delivered fuel-fired and HP heating systems and to infer their integrated controller switchover temperatures. The team then used these data in the building simulation task to calculate impacts for the EO fuel displacement measures. The team used the baseline heating and cooling system types determined through the customer survey to apply a final series of baseline weights to the building simulation models to derive gross measure impacts.

Table 1-1. Summary of Activities

Activity	Rationale
Program Records Review	Provide participant, measure, and contractor information to support evaluation tasks.
EO Fuel Displacement Staff, Implementers, Contractors, and Distributor Interviews	Gather key feedback on program processes and participation barriers as well as inputs to inform the assessment of impacts.
Customer Survey and Interviews	Collect information on technology and program satisfaction as well as how customers use their HVAC system(s) and integrated controls. Characterize baseline heating and cooling system types.
Customer Bill Disaggregation and Billing Analysis	Inform and calibrate building simulation models, including both HVAC and non-HVAC end uses. Provide estimated electric impacts for measures with ample participation.
Remote Temperature and Total Home Electric Usage Metering Analysis	Infer HVAC operation and integrated control switchover temperatures. Apply the findings to the building simulation model results to inform measure impacts.
Calibrated Building Simulation	Estimate delivered fuels and electric consumption impacts for the primary building types and measure combinations rebated through the program.
Reporting	Synthesized summary of study findings and recommendations.

Source: Evaluation Team Analysis

2. Methodology

2.1 Program Records Request and Review

The team submitted a program data request to DNV in August 2020 for all 2019 EO Fuel Displacement measure records and participant billing data for 2017-2019. DNV provided several data extracts through the study period. The team performed reviews of the supplied data and identified the following missing or incomplete data fields:

- Installed equipment capacities were missing. The team used the rebate amounts to estimate the installed capacities.
- Manufacturer or model numbers for the installed integrated controls.

Table 2-1 shows the number of unique single-family and multifamily customers from the EO dataset who participated in the EO Fuel Displacement measures in 2019 for each of the major measure categories. Table 2-2 shows the total quantity of units installed for each measure in the EO dataset.

Table 2-1. 2019 EO Fuel Displacement Participation

Measure	Number of Unique Customers		
Single Family	**Electricity**	**Oil**	**Propane**
Central HP (full displacement)		4	
Central HP with integrated controls (partial displacement)		466	103
Mini-split HP (full displacement)	729	5	
Mini-split HP with integrated controls (partial displacement)		1,065	129
Integrated controls installation on existing mini-split HP		12	2
Total	**729**	**1,548**	**234**
Multifamily			
Mini-split HP (full displacement)	7 premises		

Source: Evaluation Team Analysis

Table 2-2. 2019 EO Fuel Displacement Participation

Measure	Total Installed Quantity		
Single Family	**Electricity**	**Oil**	**Propane**
Central HP (full displacement)		5	
Central HP with integrated controls (partial displacement)		534	117
Mini-split HP (full displacement)	960	6	2
Mini-split HP with integrated controls (partial displacement)		1,363	162
Integrated controls installation on existing mini-split HP		13	2
Total	**960**	**1,921**	**283**

Measure	Total Installed Quantity
Multifamily	
Mini-split HP (full displacement)	449

Source: Evaluation Team Analysis

2.2 Program Staff and Implementer Interviews

The evaluation team completed six group interviews with the PA sponsors and program implementation staff to inform the study's research questions and evaluation tasks. Interviews explored goals and objectives of the fuel optimization offerings, how the participation process works, marketing and outreach efforts, successes, challenges, and potential improvements to the program going forward. Table 2-3 shows the stakeholder groups that were interviewed and their roles.

Table 2-3. Stakeholder Interviews

	Stakeholder Group	Role	Interview Timing
1	Heating and Cooling Program Implementation Staff (CLEAResult)	Launched fuel optimization offering in 2019; served in implementation role through June, 2020	June, 2020
2	PA Sponsors from Eversource, National Grid, Unitil, CLC	Oversight of single-family fuel optimization offerings	September, 2020
3	PA Sponsors from Eversource, National Grid, CLC	Oversight of multifamily HP offerings	September, 2020
4	LEAN Multifamily Program Staff (ABCD, Action, Inc.)	Delivers income-qualified multifamily program	October, 2020
5	Market-Rate Multifamily Program Staff (RISE, CLEAResult)	Delivers market-rate multifamily program	October, 2020
6	Heating and Cooling Program Implementation Staff (ICF)	Currently delivers the fuel optimization offering (as of July 2020)	October, 2020

Source: Evaluation Team Analysis

2.3 Contractor and Distributor Interviews

The following sections describe the methodological approaches for completing the contractor and distributor interviews.

2.3.1 Contractor Interviews

The evaluation team interviewed a total of 18 contractors (17 participating, one nonparticipating) over the phone to learn more about the following research areas:

- How contractors discussed HPs and integrated controls with their customers
- The installation process for HPs and integrated controls
- The program participation process for the contractor and customer
- Barriers contractors faced with the fuel displacement technologies

Participating single-family contractors. The contractor sample was derived from the Energy Federation Incorporated (EFI) raw dataset for all 2019 downstream rebate programs. The EFI dataset contained a total of 2,605 accounts associated with the fuel optimization offerings. The team was able to match 2,101 accounts in the EFI dataset back to the original EO fuel displacement tracking dataset. Of these 2,101 records, approximately one-third of them did not contain phone numbers and no records contained email addresses or key contact names.

After cleaning the data for duplicate contractor records, a list of 540 unique participating contractors remained, as Table 2-4 outlines.

Table 2-4. Participating Contractor Sample: Data Cleaning Steps

Data Cleaning step	Number of Contractors
EFI raw dataset (original dataset)	2,605
Matched to participant tracking data	2,101
Unique contractor entries (final sample)	540

Source: Evaluation Team Analysis

Participating multifamily contractors. The contractor sample contained five contractors that were associated with installing a multifamily project in 2019. All five of these contractors were contacted for an interview, but either did not respond to the team's outreach attempts or refused to participate.

Nonparticipating contractors. The team defined nonparticipating contractors as contractors who were listed as a qualified MeasureQuick[4] contractor but did not complete a fuel optimization project in 2019. The cleaned participating contractor list was compared against the list of MeasureQuick contractors, leaving a sample of 19 nonparticipating contractors. These contractors likely participated in other program offerings but had not yet participated in the fuel displacement rebate offerings. The evaluation team only achieved one nonparticipating contractor interview due to the small sample size and hard-to-reach nature of this group.

To confirm the perspectives of those contractors who installed the most projects were represented, the team's sample approach prioritized interviews with high volume participating contractors, while also allowing for broad representation of contractors that install different system types and project volume levels. Table 2-5 shows how the 2019 contractor population varies by volume of accounts served and details the number of interviews the team completed within each group.

Table 2-5. Contractor Groups and Completed Interviews

Group	Volume of 2019 Accounts*	Number of Contractors	Number of Accounts Served	Percent of Total Accounts	Completed Interviews
1	40 or more	5	357	17%	3
2	10 to 39	10	765	36%	7
3	2 to 9	53	701	33%	3
4	1	298	298	14%	3

[4] MeasureQuick contractors must complete a program-approved training, and upon completion are eligible for benefits like the ability to offer zero interest financing to their customers through the HEAT loan offering.

Group	Volume of 2019 Accounts*	Number of Contractors	Number of Accounts Served	Percent of Total Accounts	Completed Interviews
5	0	19	0	0%	1
	Total Contractors	**559**	**2,121**	**100%**	**18**

*Proxy for number of projects completed (or homes served) in 2019
Source: Evaluation Team Analysis

An incentive of $200 was offered to contractors who agreed to participate in an interview. The team contacted 112 contractors and completed 18 interviews, achieving a 16% response rate. The contractors interviewed work primarily in single-family residential homes. Although almost all contractors (n=17) interviewed noted working in multifamily buildings, they said that this was a small portion of their overall work. Five contractors noted they also worked on small commercial buildings, and none served affordable housing.

2.3.2 Distributor Interviews

The evaluation team completed four phone interviews with HVAC distributors serving the MA residential market. These interviews explored market trends for HP systems and integrated controls, how distributors support contractors in the selling and installation of fuel displacement technologies, and potential market barriers.

The team obtained a program-provided list of distributor store locations, including 529 individual contacts with 120 unique distributors. The list did not include key contact names or emails addresses, and about half of the records had no phone number listed.

Table 2-6. HVAC Distributor Sample

Data Cleaning Step	Number of Records
ICF raw dataset: Number of contacts	529
Unique distributor companies	120

Source: Evaluation Team Analysis

The evaluation team prioritized interviews with HVAC distributors that had multiple store locations across the state to ensure broader market representation. The team called 10 distributors and completed four interviews, achieving a 40% response rate. All four distributors interviewed stated that they primarily served the residential sector, with some small commercial work.

2.4 Customer Survey and Interviews

The following sections describe the methodological approaches for completing the single-family customer survey and multifamily owner/operator interviews.

2.4.1 Single-Family Customer Survey

The evaluation team surveyed 328 customers who participated in the 2019 EO Fuel Displacement measure offerings. The team administered the survey online using Qualtrics software, and included questions to explore the following areas:

- Customer awareness and motivations
- Previous heating and cooling equipment installed, what other equipment they considered aside from the program-eligible HP, and what equipment types they would have installed if they did not install the HP they did (informs baseline weightings applied in gross impact analysis)
- Interactions with the equipment and integrated controls
- Experience with the program and their contractor

Net-to-gross and market effects questions were also included in the customer survey to inform other ongoing MA studies.

The evaluation team used PA-provided program tracking data to identify a sample for the participant survey. First, the team tagged each customer with a survey variable name which allowed the team to ask separate questions and modules for customers that installed either a central HP or mini-split HP, either as full displacement or as partial displacement with an integrated controller. Table 2-7 shows the number of customers in the EO fuel displacement dataset for each measure category, the number of customers tagged as do not contact in the utility program data, the number of available customers to field the survey, the number of customers with email addresses, and the number of customers who completed the survey. Each of the 1,452 available customers had a mailing address and 1,029 of those customers also had an email address. The team sent up to two postcard invitations and reminders to all customers, and up to three email invitations and reminders to customers with a valid email address. A $20 incentive was also offered to respondents.

Table 2-7. Customer Survey Sample Disposition

Survey Measure Type	Number of Unique Customers	Do Not Contact Count	Survey Sample Remaining	Has Email	Survey Started	Survey Complete
Central HP (full displacement, delivered fuel baseline)	4	-	4	4	1	1
Central HP with integrated controls (partial displacement, delivered fuel baseline)	569	224	345	293	101	98
Mini-split HP displacing electric heat	729	297	432	275	91	85
Mini-split HP with integrated controls (partial displacement, delivered fuel baseline)	1,199	537	662	452	147	143
Integrated controls installation on existing mini-split HP	14	5	9	5	1	1

Survey Measure Type	Number of Unique Customers	Do Not Contact Count	Survey Sample Remaining	Has Email	Survey Started	Survey Complete
Total	**2,515**	**1,063**	**1,452**	**1,029**	**341**	**328**

Source: Evaluation Team Analysis

The team achieved 328 completed survey responses and a 23% response rate for the customer survey.

2.4.2 Multifamily Interviews

The evaluation team completed four phone interviews with multifamily owners/operators. Multifamily customers are served through either the market-rate multifamily program or the Income-Eligible Multifamily program. Both programs include HP measures and incentives for eligible customers, as well as several other measures and services. The team's interviews explored the owner/operator awareness of HPs, the decision-making process, program experience and satisfaction, experience with the contractor and the equipment, and the equipment being replaced and alternative equipment installation considerations to inform baseline assignments.

The team used the PA-provided program tracking data to identify the sample for the multifamily interviews. Table 2-8 shows the steps taken to identify unique multifamily owners/operators. Of the final nine owners/operators included in the sample, six were served through the income-eligible offering and three were served by the market-rate offering. The evaluation team found minimal contact information in the original program tracking data; however, it did correspond with DNV to identify and provide nine phone numbers and four email addresses through account matching with other data sources.

Table 2-8. Multifamily Owner/Operator Interview Sample

Data Cleaning Step	Number of Records
Records identified as multifamily via sub-offering, BCR, or billing data flags	92
Unique property addresses	11
Unique multifamily owner/operator entries (final sample)*	9

**Two individual customers living in small multifamily (4-8 units) were removed from the multifamily sample, as these customers were individual unit owners who made the decision to participate on their own (rather than through a condo association or housing authority).*

Source: Evaluation Team Analysis

The evaluation team completed four interviews and achieved a 44% response rate. All interviews were with income-eligible multifamily property owners/operators. The team attempted to reach market-rate multifamily owners/operators, but they either did not respond to the outreach attempts or refused to participate.

The multifamily participants interviewed were housing authorities or properties that serve the lower to moderate income population by offering affordable housing services. Other qualifying factors for residency in these properties may have included age (serving senior citizens) and disability status.

2.5 Customer Bill Disaggregation and Billing Analysis

The following sections describe the methodological approach used to estimate monthly and annual heating, cooling and baseload in the pre-retrofit and post-retrofit periods using monthly billing data of customers participating in the EO fuel displacement measures. The pre-retrofit period bill disaggregation results were used to calibrate the baseline building simulation models (as Section 2.6.1 describes). The post-retrofit bill disaggregation (and resulting savings) were used as a comparison against the building simulation savings result but are not used directly to inform measure impacts.

Data Cleaning

The team began by matching the participant billing data with program data; there were 2,549 unique program participants that matched a billing record in the pre-retrofit period. From this point, the team proceeded with the data cleaning process Table 2-9 outlines.

Table 2-9. Participant Billing Data Cleaning

Criteria	Total Remaining	Attrition (% of previous step)
Unique participants in pre-retrofit billing data	2,549	
Remove participants w/ negative consumption data	2,299	-10%
Remove participants with insufficient pre-retrofit data (<12 months)	1,968	-14%
Remove Average Daily Consumption outliers (1st and 99th percentile)	1,926	-2%
Remove participants with insufficient post-retrofit data (<12 months)	1,779	-8%

Source: Evaluation Team Analysis

The team used all billing data before the participants' installation date in the pre-retrofit billing analysis. The team assumed an installation date of January 1, 2019 for any participants that did not have an installation date in the participation data. Finally, the team received post-retrofit billing data in a separate data transfer; Table 2-10 shows the 1,779 participants remaining for the post-retrofit load disaggregation.

Table 2-10 details the breakdown of participants by treatment after the data cleaning process. Three treatments, partial displacement fuel furnace to central HP, electric resistance to mini-split HP, and partial displacement fuel boiler to mini-split HP, made up over 99% of the participants analyzed.

Table 2-10. Participants Analyzed in Bill Disaggregation

Measure	# of Participants in Segment	% of Participants
Partial displacement fuel furnace to central HP	996	56%
Full displacement electric resistance to mini-split HP	472	27%
Partial displacement fuel boiler to mini-split HP	303	17%
Full displacement fuel furnace to central HP	3	0.2%
Full displacement fuel boiler to mini-split HP	3	0.2%

Measure	# of Participants in Segment	% of Participants
Multifamily building	2	0.1%
All segments	**1,779**	**100%**

Source: Evaluation Team Analysis

Combining with Weather Data

After completing the data cleaning process, the team matched each participant with the closest weather station by participant ZIP code. Using daily weather data, the team calculated the average daily temperature for each participant and billing period to use in load disaggregation.

Variable Based Degree Day Regression

To disaggregate consumption into baseload, heating, and cooling, the team fit multiple regression models with floating cooling degree day (CDD) and heating degree day (HDD) bases for each participant. The evaluation team performed this analysis on the pre-retrofit and post-retrofit bills separately.

The team used the average daily temperature for each participant and each billing period to calculate the average number of HDDs and CDDs for each billing period for each combination of HDD and CDD bases between 50°F and 75°F.

The team used a variable base degree day (VBDD) approach that fit regression models for each customer and each combination of CDD and HDD setpoints. Equation 1 shows the general form of the VBDD regession model:

Equation 1.

$$\mathbf{ADC_i = a_i + b_i{*}HDD_{ij} + c_i{*}CDD_{ik} + e_i}$$

ADC_i = average daily consumption for premise i
a_i = intercept for premise i (baseload)
b_i = heating load per HDD
c_i = cooling load per CDD
HDD_{ij} = HDD for premise i at setpoint j
CDD_{ik} = CDD for premise i at setpoint k

In addition, the team fit HDD-only, CDD-only, and intercept-only models for each participant. For each participant, the team selected the best-fit from the universe of VBDD regression models for use in load disaggregation. The team defined best-fit as the model with the highest R-squared value that did not have negative coefficient estimates.

To translate the regression model in annual consumption estimates for baseload, heating, and cooling, the team applied the coefficients from the best VBDD model to a normal weather year. For this analysis, the team elected to define a 15-year normal weather year selected from a set of recent (2005 to 2020) weather years rather than using the typical meteorological year (TMY3) weather file, which spans the years from 1991 to 2005 (Table 2-11).

Table 2-11. Calendar Years Selected for 15-Year Normal Weather

Month	Selected Year
1	2010
2	2010
3	2008
4	2015
5	2015
6	2013
7	2016
8	2015
9	2014
10	2010
11	2017
12	2008

Source: Evaluation Team Analysis

The team selected the calendar year for the 15-year normal by applying the VBDD coefficients to each calendar year's weather (2005 through 2020) and for each month, selecting the calendar year with the median estimated average daily consumption.

Non-HVAC Seasonality Adjustment

The VBDD regression model specification attributes any seasonal consumption patterns into heating and cooling, even if they are not HVAC-related (i.e., seasonal trends in lighting, hot water consumption). To adjust for seasonality of non-HVAC (base) load the team leveraged the metered end use electric data from the MA Residential Baseline Study to create a monthly baseload adjustment factor. To create the monthly baseload adjustment factor, the team summed electricity consumption from non-HVAC related load for each month then divided each month total by the average of the shoulder season months (April and October). The result is the monthly baseload adjustment factor in Table 2-12.

To calculate adjusted baseload, the team multiplied the VBDD estimated baseload for each participant for each month by the baseload adjustment factor for that month. The team calculated the adjusted heating and cooling load by allocating the change in baseload proportionally to the VBDD estimate heating and cooling load.

Table 2-12. Monthly Baseload Factors

Month	Baseload Factor
1	1.084
2	1.007
3	0.982
4	0.934
5	1.051
6	1.130
7	1.229

Month	Baseload Factor
8	1.211
9	1.098
10	1.066
11	1.063
12	1.145

Source: MA Residential Baseline Study

COVID-19-Related Impacts

The time period over which the evaluation team analyzed post-retrofit consumption began in calendar year 2019 and ended in January 2021, and so aligned with the COVID-19 pandemic. The evaluation team conducted an exploratory analysis that sought to determine what, if any, impacts COVID-19 had on energy consumption for year 2019 EO fuel displacement participants. Although the team calibrated its building simulation models to energy consumption in the pre-retrofit period, it used this analysis to inform what total measure impacts including the difference in post-retrofit and pre-retrofit period electricity consumption.

For this analysis, the team used a cohort of 440 EO participants from January to April 2019 (see Table 2-13); each of the 440 participants passed the data cleaning criteria in Table 2-9. The team selected these participants because they had sufficient billing records (20 or more months) to characterize both pre- and post-COVID-19 energy consumption in the post-retrofit period.

Table 2-13. Participant Counts for COVID-19 Impact Analysis

Installed Measure	Number of Participants
Partial Displacement: Delivered Fuel Furnace to central HP	212
Full Displacement: Electric Resistance to mini-split HP	156
Partial Displacement: Delivered Fuel Boiler to mini-split HP	72
Total	**440**

Source: Evaluation Team Analysis

The evaluation team used two approaches to estimate the COVID-19 on energy consumption:

- **Ratio Estimate.** For this approach, the team applied VBDD methods to estimate annual energy consumption based on post-retrofit energy bills from calendar year 2019 (pre-COVID-19) and again to estimate annual energy consumption based on post-retrofit energy bills from calendar year 2020 (post-COVID-19).[5] The evaluation team estimated the ratio of post-COVID-19 to pre-COVID-19 energy consumption for the group of 440 participants described in Table 2-13.
- **Regression Estimate.** The evaluation team pooled the billing data from the 440 participants described in Table 2-13 and fit the regression model with a post-COVID-19 indicator variable, shown in Equation 2.

[5] While calendar year 2020 includes a few months of normal before the COVID-19 pandemic began to change the occupancy characteristics in residential dwelling units, the team intentionally chose this time period to simplify its analysis and maximize the use of available data.

Equation 2. Pooled Regression Model to Estimate COVID-19 Impact

$$ADC_{ij} = a_i + b_1*HDD_{ij} + b_2CDD_{ij} + b_3*COVID_j + b_4*COVID_j*HDD_{ij} + b_5*COVID_j*CDD_{ij} + e_{ij}$$

The evaluation team defined the terms in Equation 2 as follows:

- ADC_i = Average daily consumption for premise i
- a_i = Intercept for premise i
- HDD_{ij} = HDD, base 65°F[6] for premise i in time period j
- CDD_{ij} = CDD, base 65°F for premise i in time period j
- $COVID_j$ = 1 if time period j is after April 1, 2020, 0 otherwise
- b_1, b_2 are pooled estimates of effect of HDD, CDD on electric consumption
- b_3, b_4, b_5 are pooled estimates of the incremental effect of COVID on electric consumption

Using both the ratio and regression approaches outlined above, the team found that the average daily energy consumption increased by 3%-4% during the post-COVID-19, post-retrofit time period. With this marginal increase in mind, the team elected to not adjust its building simulation results to correct for any change in observed energy consumption due to COVID-19.

Specifically, the ratio approach showed post- to pre-COVID-19 consumption ratios ranging from 0.98 to 1.06 across the three measures Table 2-14 shows. On average, this ratio is 1.03, which indicates that after controlling for weather, the team estimates that per-household, post-COVID-19 annual energy consumption is about 3 percent higher than pre-COVID-19 annual energy consumption.

Table 2-14. COVID-19 Energy Consumption Ratios by EO Measure

Installed Measure	Number of Participants	Annual Electric Consumption (kWh), Post-Retrofit, Pre-COVID-19	Annual Electric Consumption (kWh), Post-Retrofit, Post-COVID-19	Ratio: Post/Pre
Partial Displacement: Delivered Fuel Furnace to Central HP	212	11,908	12,567	1.02
Full Displacement: Electric Resistance to Mini-Split HP	156	14,618	14,871	0.98
Partial Displacement: Delivered Fuel Boiler to Mini-Split HP	72	10,517	10,351	1.06
Total	**440**	**12,642**	**13,201**	**1.03**

Source: Evaluation Team Analysis

[6] This regression approach requires a consistent degree-day base across all observations; the evaluation team chose a base of 65°F.

Table 2-15 shows the team's findings from the COVID-19 regression model.[7] The coefficient of the COVID-19 term is 1.30, which indicates that after controlling for weather with the HDD and CDD terms, the average per-household energy consumption increased by 1.30 kWh per day during the post-COVID-19 period, or 3.6% of average daily consumption (36 kWh per day).

Table 2-15. COVID-19 Energy Consumption Regression Results

Model Term	Coefficient Estimate	t-Value of Coefficient	Relative 90% Confidence Interval (+/-)
HDD	0.68	0.01	3%
CDD	1.27	0.04	6%
COVID	1.30	0.27	34%

Source: Evaluation Team Analysis

The scope of this analysis is limited to EO fuel displacement participants from calendar year 2019. The evaluation team will continue to meter residential HVAC end use consumption as part of the ongoing Residential Baseline Study. The MA PAs are also considering a future targeted HP metering study to further understand end use consumption and operating characteristics of HPs.

2.6 Calibrated Building Simulation

The team used calibrated building energy simulation to calculate energy savings and derive impacts for the EO Fuel Displacement measures. The evaluation team calculated savings by comparing the difference in energy consumption between baseline (pre-retrofit) models and post-retrofit models where the customer installed an efficient central HP or mini-split HP, with or without integrated controls for partial or full displacement of the existing heating system, respectively.

The team used the industry-trusted EnergyPlus simulation engine[8] to conduct the building energy modeling and used Pacific Northwest National Laboratory (PNNL) residential prototype models as a starting point prior to calibration of the baseline models.[9] The team used the following prototype models for the single-family and multifamily segments:

- **Single-family prototype model:** The team chose the 2,400 SF single-story detached PNNL prototype model with slab-on-grade foundation[10] for the single-family segment for climate zone 5A, which is the climate zone for the state of Massachusetts. The team chose the 2006 International Energy Conservation Code (IECC) model version, as this is the earliest version available through PNNL. The team then adjusted the insulation values to depict an average EO fuel displacement participant home, as Section 2.6.1 details. The team developed and calibrated two separate models with either an electric

[7] The team tested interaction terms with HDD, CDD, and COVID and found that they were not statistically significant. Thus, the team settled on a simplified model relative the specification shown in the methodology section of this document.

[8] https://energyplus.net/

[9] https://www.energycodes.gov/development/residential/iecc_models

[10] The team recognizes that the prevalent construction type in Massachusetts includes basements (with or without conditioning). The team chose the slab on grade model based on prior experience using both slab on grade and basement model types: the slab on grade model did a better job of modeling heat transfer through the building envelope. The team calibrated the baseline model to pre-retrofit consumption for program participants, which allows for accurate estimate of impacts upgrading the heating system to heat pumps (with or without integrated controls).

or delivered fuel-fired heating system to support development of measure impacts for the delivered fuel-fired furnace/boiler and electric resistance baseline heating types separately.

- **Multifamily prototype model:** The team chose the multifamily low rise apartment building prototype model for the multifamily segment. The team based this selection on the identification of the most common characteristics of seven multifamily program participants in 2019. Due to limited availability of participants' building characteristic data, the team used participants' addresses and various online resources (e.g., mapping tools and facility websites) to identify features such as the number of floors, typical unit sizes, and pre-retrofit HVAC systems for the 2019 multifamily program participants. Based on this research, the team found that most participating multifamily buildings were two story, low rise residential complexes consisting of multiple separate buildings. Of the available prototype models from PNNL, the low rise multifamily residential protype most closely aligned with the identified program participant characteristics.

2.6.1 Baseline Building Development and Calibration

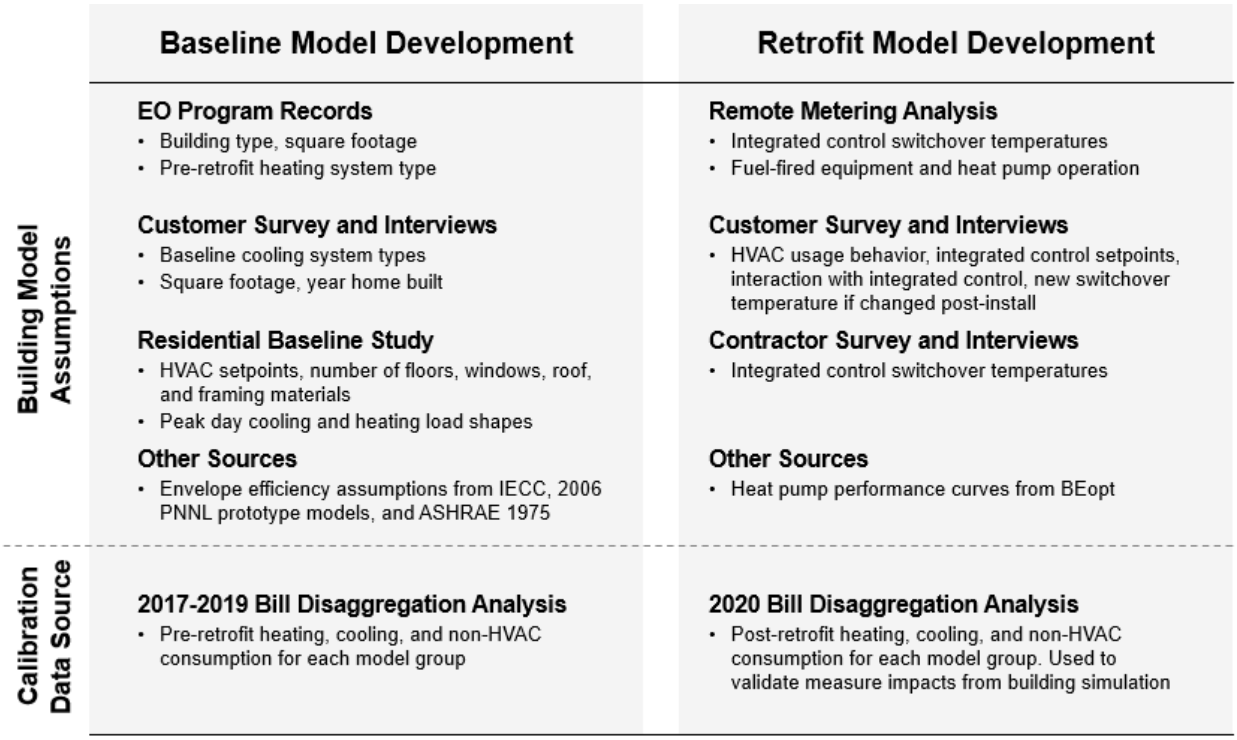
The team calibrated three separate building energy models as part of the baseline calibration task. These three building models encompass the primary combinations of baseline HVAC system fuel types and home types that installed EO fuel displacement measures in 2019, as follows:

- Single-family home with delivered fuel-fired furnace and typical AC (modeled as a blend of central AC and room AC)
- Single-family home with electric resistance heating and typical AC (modeled as a blend of central AC and room AC)
- Multifamily building with electric resistance baseboard heating and room AC

The team calibrated each of these three models to the monthly heating, cooling, and non-HVAC electricity consumption as determined through the bill disaggregation task (Section 2.5 outlines the methods and Section 4.3 includes the results).[11] The team used several data sources to inform the baseline prototype model parameter assumptions, as Figure 2-1 summarizes.

[11] Calibration of the building simulation models to the average energy consumption from the bill disaggregation task represents measure impacts for the average program participant. Baseline consumption, and resulting measure impacts, would differ with homes with different construction characteristics or usage patterns: (e.g., more or less efficient building envelope).

Figure 2-1. Data Sources Leveraged for Building Energy Modeling



Source: Evaluation team analysis

The team summarized the following analysis inputs to support the baseline model calibration:

- **Measure descriptions:** The EO fuel displacement data provided the measure descriptions for each of the participants, which included a summary of the pre-retrofit heating system type, post-retrofit HP installed, and whether the installation was full displacement or partial displacement with integrated controls installation. The team used these flags as filtering variables throughout the analysis.
- **Square footage:** For the square footage assumption, the team referenced values from the program data and the customer survey. To develop the square footage assumptions for the study, the team averaged the median values from both the program data and the customer survey, as Table 2-16 shows.

Table 2-16. Single-Family Square Footage Values

Measure Category	EO Fuel Displacement Program Data (n)	Median SF from EO Fuel Displacement Program Data	Survey (n)	Median SF from Survey	Average of Median SF
Mini-Split HP Full Displacement with Electric Resistance Heating Baseline	729	1,895	81	1,685	1,790
Central HP Partial Displacement with Delivered Fuel-Fired Heating Baseline	569	2,595	87	2,400	2,497

Measure Category	EO Fuel Displacement Program Data (n)	Median SF from EO Fuel Displacement Program Data	Survey (n)	Median SF from Survey	Average of Median SF
Mini-Split HP Partial Displacement with Delivered Fuel-Fired Heating Baseline	1,194	2,205	129	2,000	2,103

Source: Evaluation Team Analysis

- **Year home built:** For the home vintage assumption, the team averaged the median home vintages from the EO fuel displacement data and the customer survey. For all measure categories, the average home age was in the 1970s.
- **HVAC setpoints:** For HVAC setpoints, the team referenced the average logged space temperatures as determined in phase 4 of the MA Residential Baseline Study. In that study, the research team logged typical space temperatures during the winter and summer months for a sample of home across MA. Typical winter space temperatures (used as a proxy for thermostat setpoints) was approximately 67°F, and typical summer space temperatures were 76°F on an average summer day.
- **Envelope characteristics:** The team chose the 2006 IECC prototype model versions as a starting point for the calibration, as these are the earliest model versions available through PNNL. However, 2006 IECC envelope efficiencies do not represent the average envelope efficiency for typical MA residential homes. In coordination with the PAs, the team decided to average the 2006 IECC envelope efficiency values and the ASHRAE 1975 envelope efficiency values to approximate an average home that was built in the 1970s but had undergone some level of envelope upgrades over the home's life. Table 2-17 shows the average efficiency values determined through this process.

Table 2-17. Average Residential Envelope Efficiency Values

Envelope Construction	Efficiency Value
Exterior Wall Insulation	R-7.2
Exterior Floor Insulation	R-9.0
Roof/Ceiling Insulation	R-20.0
Window U-Value	U-0.48

Source: Evaluation Team Analysis

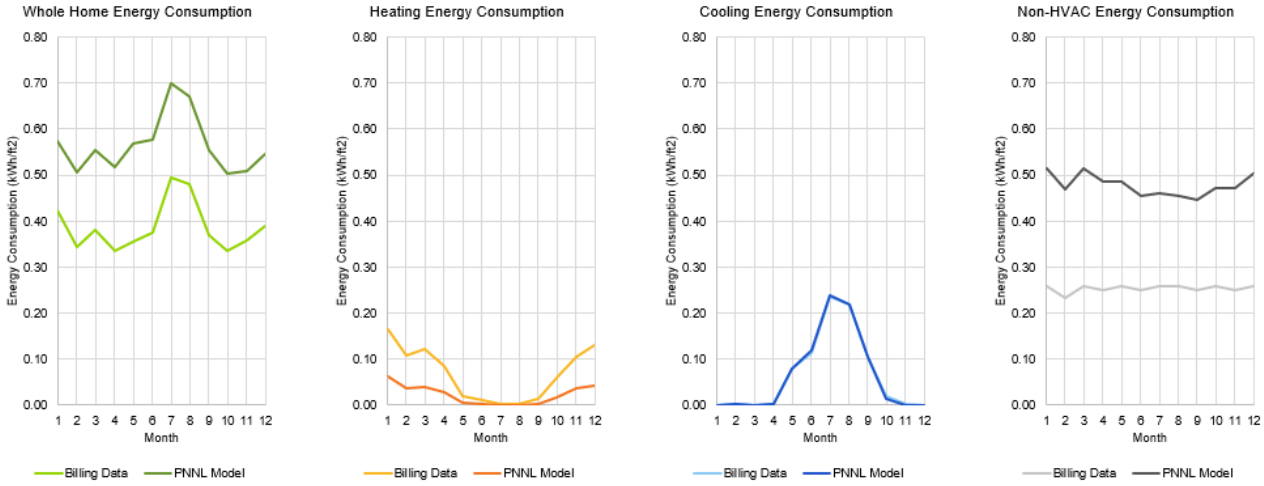
- **Peak day HVAC load shapes:** The team referenced peak winter and summer HVAC load shapes on the peak days from the MA Residential Baseline study. The team then made minor adjustments to HVAC setpoint schedules in the single-family residential model on an hour-by-hour basis to confirm the peak day load shapes from the EnergyPlus models approximately matched those for the typical customer as determined through the MA Baseline Study without any large spike in demand for certain hours of the day.
- **Pre-retrofit monthly heating, cooling, and non-HVAC end use electric consumption:** The monthly bill disaggregation analysis provided the reference heating, cooling, and non-HVAC consumption at the monthly level for the baseline building model calibration.

The team shared interim results of the baseline model calibration with the MA PAs and MA Energy Efficiency Advisory Council (EEAC) consultants for EM&V through three informal calibration working sessions and incorporated feedback from the PAs to inform the final baseline model calibration. Sections 2.6.1.1 and 2.6.1.2 detail the single-family and multifamily specific calibration steps and achieved monthly calibration for each key end use in the home.

2.6.1.1 Single-Family Model Calibration

Figure 2-2 shows the monthly whole home, heating, cooling, and non-HVAC electricity consumption for the default PNNL single-family prototype model with delivered fuel-fired furnace and central AC as compared to the monthly consumption based on the bill disaggregation analysis for the sample of customers with a delivered fuel-fired heating baseline. The team used the 2018 Worcester, MA actual meteorological year (AMY) weather file during the baseline model calibration. Each of the end use consumption values is normalized as kWh/SF, as the home sizes for prototype model and the average program participant homes is different. The default PNNL model over-predicted non-HVAC consumption and under-predicted heating consumption.

Figure 2-2. Default PNNL Single-Family Prototype Model with Delivered Fuel-Fired Furnace and Central AC*

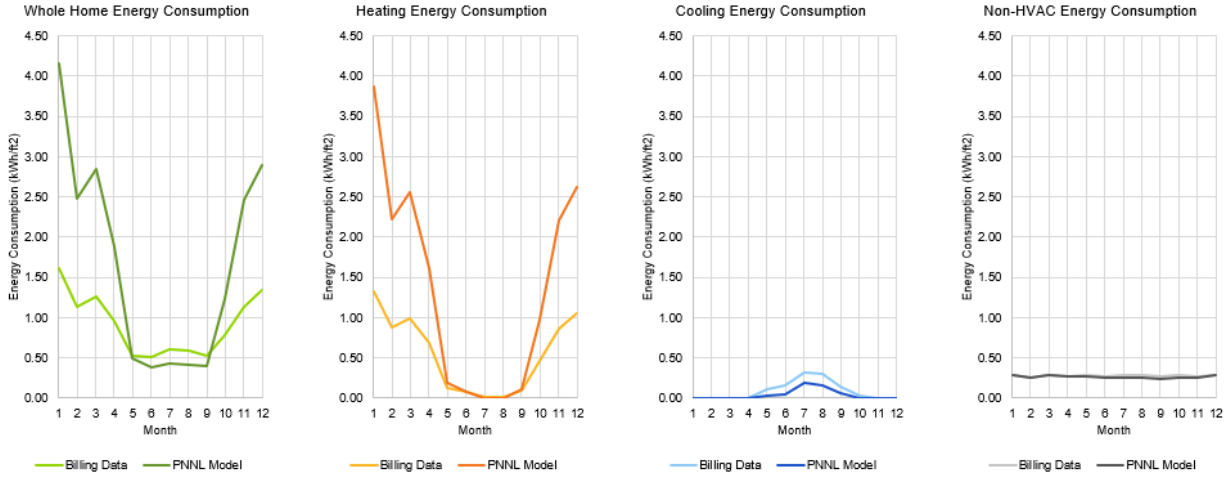


*Baseline cooling consumption is approximately the same between the default PNNL prototype model and the average participant cooling consumption as determined through the bill disaggregation analysis

Source: Evaluation Team Analysis

Figure 2-3 shows the monthly end use electricity consumption for the default PNNL single-family prototype model with electric resistance furnace and central AC as compared to the monthly consumption based on the bill disaggregation analysis for the sample of customers with and electric heating baseline. The default PNNL model over-predicted heating consumption and under-predicted cooling consumption.

Figure 2-3. Default PNNL Single-Family Prototype Model with Electric Furnace and Central AC*



*The team used the prior calibrated delivered fuel-fired furnace model as a starting point in calibration of the electric resistance heating model. Therefore, the non-HVAC consumption is approximately the same between the default PNNL prototype model and the average participant cooling consumption as determined through the bill disaggregation analysis.

Source: Evaluation Team Analysis

The team iteratively changed several of the default PNNL prototype building model inputs for the single-family models to calibrate the baseline models. Table 2-18 details these model input changes along with the associated data source used to inform the model changes.

Table 2-18. Single-Family Baseline Prototype Model Input Parameters

Input	PNNL Prototype Default Inputs	Calibrated Inputs	Data Source
Exterior Wall Insulation	R-19	R-7.2	Average of ASHRAE 1975 and IECC 2006 Standards
Roof Insulation	R-38	R-20	
Floor Insulation	R-31	R-9	
Window U-Value	0.35	0.48	
Window SHGC	0.33	0.59	
HVAC System Type	Central Elec Furnace with DX	Fuel-Fire Furnace with Central AC, Electric Resistance Furnace with AC	EO Participant Data
Heating Setpoint	72°F	67°F from 6 a.m.-9 p.m. 65°F from 10 p.m.-5 a.m.*	MA Residential Baseline Study Phase 4, with minor changes to calibrate models
Cooling Setpoint	75°F	75°F (no change)	
Lighting Power Density	0.67 W/SF	0.65 W/SF	
Non-HVAC Loads		Reduced	Engineering Judgment to Calibrate Models
Hot Water Loads			
Mechanical Ventilation	60 cfm	0 cfm	Engineering Judgment

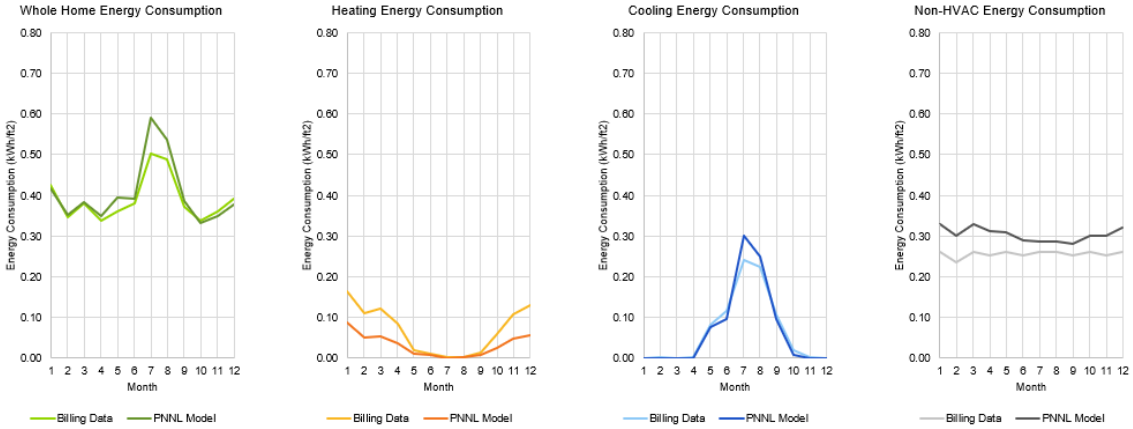
Input	PNNL Prototype Default Inputs	Calibrated Inputs	Data Source
Natural Ventilation	None	Operable Window	

*The team smoothed the step change in setpoint between the two periods by increasing the setpoint by 0.5°F every 30 minutes between 5 a.m. and 7 a.m. and 10 p.m. to 12 a.m.

Source: Evaluation Team Analysis

Figure 2-4 shows the results of the calibration for the single-family home with delivered fuel-fired furnace and average AC consumption. The non-HVAC loads are drastically reduced relative to the default PNNL non-HVAC consumption, and heating and cooling loads are reasonably calibrated.

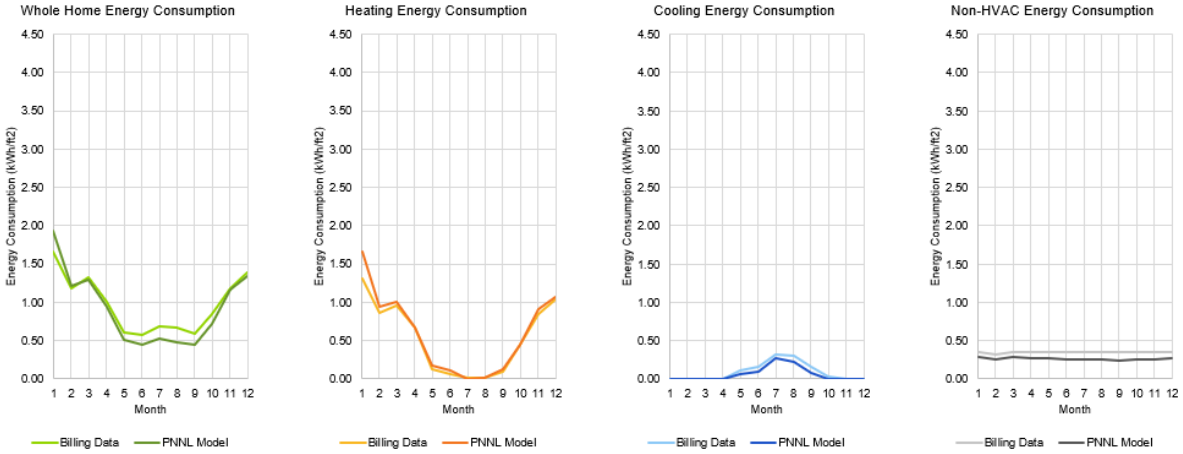
Figure 2-4. Calibrated Single-Family Model with Delivered Fuel-Fired Furnace and Average AC



Source: Evaluation Team Analysis

Figure 2-5 shows the results of the calibration for the single-family home with an electric furnace and average AC consumption. All end uses are well calibrated in the model.

Figure 2-5. Calibrated Single-Family Prototype Model with Electric Furnace and Average AC



Source: Evaluation Team Analysis

2.6.1.2 Multifamily Model Calibration

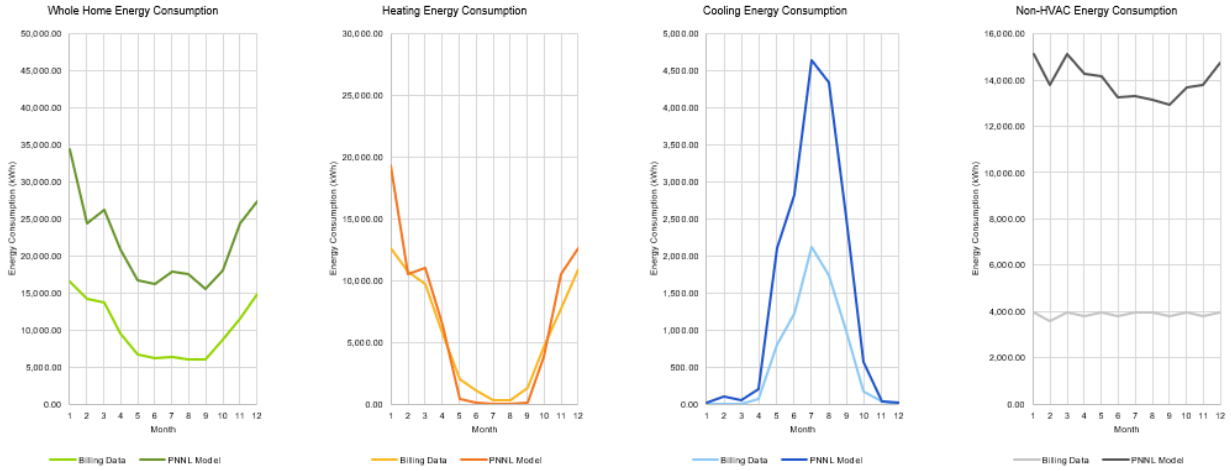
Limited program data relevant to home square footage and year built exists for the multifamily accounts in the program data. However, the team was able to collect the participant characteristics through web searches and by using aerial and street level imagery for the seven participants in the 2019 program offering. Using this web-based data collection, the team identified the building form (number of floors, total floor area, number and size of units, etc.) and pre-retrofit HVAC system types, and inferred the in-unit loads (e.g., presence of clothes washing equipment or dishwashers) and high level occupant characteristics (e.g., seniors versus families) by referencing the building amenities and other characteristics provided on the facility websites.

Relevant to the baseline model calibration, multifamily billing data was only available at the whole facility level for all but one participant address. Without an understanding of the number of dwelling units impacted or the other loads (common areas, exterior lighting) induced in the billing data, it was difficult to properly calibrate the multifamily building model using whole facility data for all seven participants. To resolve this, the team focused the calibration on the one participant address with unit-level billing data. The team compared the form and occupant type for the group of participants with and without unit-level billing data. Of the six multifamily participants without unit-level billing data, three were similar to the participant with unit-level billing data in form (low rise multifamily) and occupancy (elderly/senior hosing). The team was unable to confirm unit form through internet maps and image searches for two locations. Only one multifamily location had a distinct form (high rise residential[12]). Based on these findings, the team proceeded to calibrate the pre-retrofit energy model using data from the single site with high quality billing data.

Figure 2-6 shows the monthly end use electricity consumption for the default PNNL multifamily prototype model with electric resistance furnace and central AC as compared to the monthly consumption based on the bill disaggregation analysis for the reference multifamily building. The default PNNL model reasonably predicted heating consumption and over-predicted both cooling and non-HVAC consumption.

[12] In addition to being distinct in form, the billing data collected for this participant shows very little seasonal variation, possibly indicating that it captures only common area energy end uses.

Figure 2-6. Default PNNL Multifamily Prototype Model with Electric Furnace and Packaged Terminal AC



Source: Evaluation Team Analysis

Although the low rise multifamily prototype model most closely aligned with the participant building characteristics, the team needed to modify the model geometry and envelope to account for differences between the prototype and participant buildings. The team implemented the changes to the multifamily prototype model as Table 2-19 outlines.

Table 2-19. Multifamily Baseline Prototype Model Construction Modifications

Modification	Description
Remove Breeze Way	The PNNL low rise prototype originally contained an unheated breeze way. This was not observed in any of the participant buildings and needed to be removed to ensure a similar amount of wall surface area exposed to exterior temperatures
Reduce Wall U-Value	The exterior wall area per dwelling unit was larger in the prototype than in the participant buildings. To model a similar level of heat transfer though exterior walls, the U-value of the prototype walls was reduced to ensure that the total heat transfer through the walls to the exterior was similar between the prototype model and the average participant (Wall $U{\cdot}A_{Prototype}$ = Wall $U{\cdot}A_{Participant}$).
Reduce Window U-Value and Solar Heat Gain Coefficient (SHGC)	Similar to the exterior walls, the protype had larger windows than were observed in the multifamily participant buildings. Again, the window U-value was increased to ensure similar heat transfer between the walls and exterior (Window $U{\cdot}A_{Prototype}$ = Window $U{\cdot}A_{Participant}$). Similarly, the team adjusted the solar heat gain coefficient of the protype windows by the ratio of window surface areas to ensure that excessive solar gains were not modeled.

Source: Evaluation Team Analysis

The team then adjusted additional building characteristics to ensure the monthly consumption of heating, cooling, and non-HVAC end uses approximately matched the consumption of the reference multifamily building as derived through the bill disaggregation analysis (Section 2.5 outlines the methods and Section 4.3 includes the results). The team primarily adjusted the building model inputs in Table 2-20 to calibrate the models.

Table 2-20. Multifamily Baseline Prototype Model Input Parameters

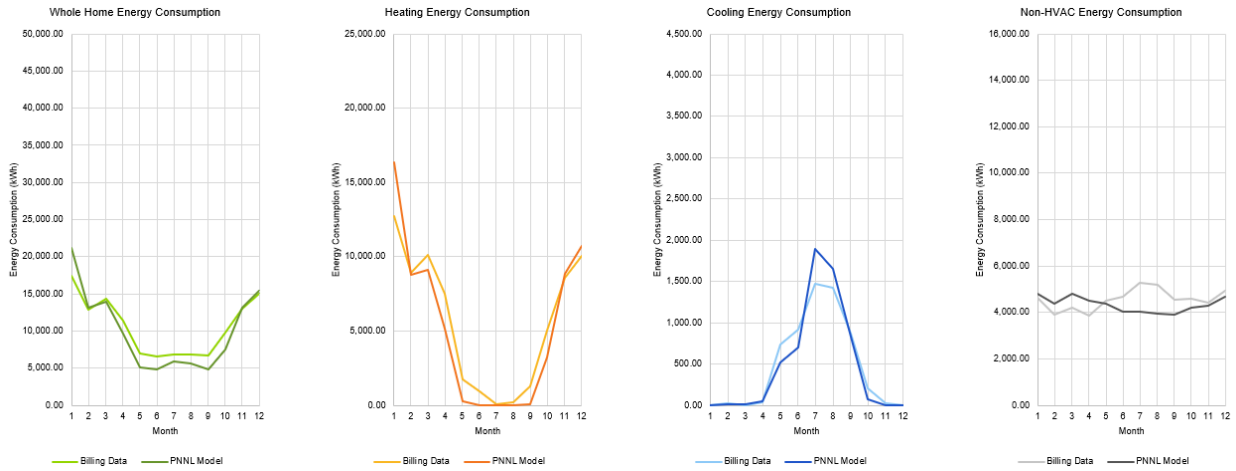
Input	PNNL Prototype Default Inputs	Calibrated Inputs	Data Source
Exterior Wall Insulation	R-19	R-7.5	Average of ASHRAE 1975 and IECC 2006 Standards
Roof Insulation	R-38	R-20	
Window U-Value	0.35	0.48	
Window SHGC	0.33	0.59	
HVAC System Type	Central Elec Furnace with DX	Elec Baseboard with PTAC	EO Participant Data
Heating Setpoint	72°F	69°F	MA Residential Baseline Study Phase 4, with minor changes to calibrate models
Cooling Setpoint	75°F	76.5°F	
Non-HVAC Loads	173,000 kWh	116,000 kWh*	MA Residential Baseline Study Phase 4, EO Participant Data, ASHRAE Fundamentals
Hot Water Equivalent Full Load Hours (EFLH)	180	90	
Natural Ventilation	None	Operable Window	Engineering Judgment

*For the non-HVAC loads, the team performed an attrition process which involved the removal of unit-level washers and dryers, reduction of miscellaneous plug loads, removal of exterior lighting loads, and the modification of hot water use in the model to calibrate the non-HVAC end use.

Source: Evaluation Team Analysis

Figure 2-7 shows the results of the calibration for the multifamily home. The non-HVAC and cooling loads are drastically reduced relative to the default PNNL model consumption. All of the end uses are reasonably calibrated.

Figure 2-7. Calibrated Multifamily Model with Electric Baseboards and Room AC



Source: Evaluation Team Analysis

The team validated the multifamily model calibration for six additional multifamily accounts and found the model reasonably predicted heating, cooling, and non-HVAC consumption for five of the six locations.

2.6.2 Post-Retrofit Model Development

After completing the baseline model calibration, the team implemented several post-retrofit model changes including updating the HVAC system type to include HPs, updating the efficiency levels of the HPs, modifying the default HP performance curves, and applying control strategies to simulate the impacts of the integrated controls on HVAC system energy consumption. The post-retrofit model changes are detailed below.

Update HVAC System Types: For the full displacement model scenarios, the team fully replaced the existing HVAC system in the EnergyPlus models with a HP. For the partial displacement scenarios, the team kept the preexisting system in the model and added a HP coil to the air system to provide heating and cooling based on the specified integrated control strategy. Table 2-21 details the models the team created for each measure. Further, the team hard-sized the HP heating and cooling capacities in the EnergyPlus model to depict typical installations through the Fuel Displacement installations. For each measure, the team used the average participant home size to scale the average installed tons to the default home size of the EnergyPlus prototype models.

Table 2-21. Single-Family Post-Retrofit HVAC System Types and Capacities

Measure	Average Participant SF	Average Installed Tons per Participant	Tonnage Scaled to EnergyPlus Model*
Mini-Split HP Full Displacement with Electric Resistance Heating Baseline	1,790	2.0	2.7
Mini-Split HP Full Displacement with Delivered Fuel-Fired Heating Baseline	2,103^	3.9**	4.5**
Central HP Full Displacement with Delivered Fuel-Fired Heating Baseline	2,497^	4.7**	4.5**
Central HP Partial Displacement with Delivered Fuel-Fired Heating Baseline	2,497	3.7	3.5
Mini-Split HP Partial Displacement with Delivered Fuel-Fired Heating Baseline	2,103	2.8	3.2
Mini-Split HP Full Displacement with Electric Resistance Heating Baseline			1.0***

*2,400 SF for single-family model, 700 SF for each multifamily unit

^Due to a small sample size for these full displacement installations in 2019 (n=4 for Central HP, n=5 for mini-split HP), the team assumes the same average participant home size as the partial displacement measure for central HP and mini-split HP groups, respectively.

**Due to small sample size for these full displacement installations in 2019, the team assumed typical full displacement capacity (delivered fuel-fired baseline) is 4.5 tons at the 2,400SF EnergyPlus prototype size, and calculated an assumed average installed tons per participant by applying the ratio of average participant SF to the prototype model SF.

***Based on auto-sized equipment capacity in the EnergyPlus heating and cooling sizing calculations.

Source: Evaluation Team Analysis

Efficiency Values: Table 2-22 shows the efficiency level assumptions the team applied to the building models for each HVAC unit type. The efficiency levels also support the model runs for the baseline type weightings as Section 3.1 details. The team used the existing unit efficiencies for both the baseline model calibration and to determine impacts for customers that would have left their existing unit installed if they did not install the HP they did. The new unit efficiency levels (market weighted baseline) are used for customers that would have installed an

alternative HVAC system if they did not install the HP they did. The team used the program-rebated efficiency levels for the HP installations incentivized through the EO Fuel Displacement program.

Table 2-22. HVAC Efficiency Level Assumptions

HVAC Type	Existing Unit Efficiency	New Unit (Market Baseline) Unit Efficiency	Program-Rebated Unit Efficiency
Cooling Efficiencies			
Central AC	12 SEER, 10.7 EER	14 SEER, 12.0 EER	
Central HP	12 SEER, 10.7 EER	14 SEER, 12.0 EER	16.9 SEER, 11.2 EER
Mini-Split HP	20.7 SEER, 15.2 EER	15 SEER, 12.5 EER	19.8 SEER, 12.3 EER
Window AC	11.4 CEER	11.0 CEER	
Heating Efficiencies			
Gas Furnace	81.0%	90.1%	
Propane Furnace	81.0%	90.1%	
Oil Furnace	77.7%	83.0%	
Gas Boiler	77.4%	83.7%	
Propane Boiler	77.4%	83.7%	
Oil Boiler	79.4%	86.0%	
Central HP	7.1 HSPF	8.2 HSPF	9.9 HSPF
Mini-Split HP	10.7 HSPF	8.2 HSPF	10.9 HSPF
Electric Resistance	3.41 HSPF	3.41 HSPF	

Source: Existing unit efficiencies informed from the MA Residential Baseline study. New unit efficiencies (market baseline) values are based on either code minimum unit efficiencies sourced from Federal Standards or agreed upon values with the MA EEAC consultants. The program-rebated efficiency levels are based on the average SEER, EER, and HSPF values for units installed through the program.

Performance Curves: The team put considerable effort into researching HP performance curves that may be more representative of typical cold climate HP operation than the default HP performance curves contained in the PNNL prototype models. The team reviewed performance data available in product manuals for program-qualifying HPs and recent reports and presentations based on the CSA EXP-07 HP research[13]; however, the team was unable to find enough publicly available performance data to create a new representative performance curve. Therefore, the team updated the HP performance curves to the latest curves available in the BEopt residential building models, built on the latest research from the National Renewable Energy Laboratory (NREL).[14] The team notes that the performance curve assumption has a marginal impact on the modeled energy consumption of the HP relative to other variables with moderate uncertainty, such as the Seasonal Energy Efficiency Ratio (SEER) and Energy Efficiency Ratio (EER) efficiency levels of the HP.

Switchover Controls: Finally, the team applied the various switchover control strategies and temperatures as determined from the remote metering analysis, as Section 2.7 describes. Section 4.1 summarizes the metering study findings, including the typical switchover

[13] https://neea.org/resources/exp0719-load-based-and-climate-specific-testing-and-rating-procedures-for-heat-pumps-and-air-conditioners

[14] https://www.nrel.gov/buildings/beopt.html

temperatures and strategies used by customers. Table 2-23 shows the switchover temperature weights applied to the partial displacement models in the analysis.[15] The team implemented the switchover controls in the building models by applying custom availability schedules (e.g., for the 5°F switchover scenario, the delivered fuel-fired heating system is available when the outdoor air temperature is below 5°F, and the HP is available when the temperature is above 5°F. For one of the control strategies for the mini-split HP measure, between 25°F and 40°F, the HP is the primary heating system; however, when the system cannot meet load in a specified period of time, the delivered fuel-fired boiler provides backup heat. This is common for the morning warm-up period when the customer raises their thermostat setpoint. Above 40°F, the HP is the only system available.

Table 2-23. Integrated Control Switchover Temperature Weights Applied in Building Simulation for Partial Displacement Measures

Control Strategy	Central HP Partial Displacement	Mini-Split HP Partial Displacement
5˚F Switchover	15%	5%
15˚F Switchover	10%	22%
30˚F Switchover	45%	28%
45˚F Switchover	30%	11%
Boiler below 25˚F, HP primary 25°F-40°F, HP only above 40°F		35%
Total	**100%**	**100%**

Source: Evaluation Team Analysis

The team ran a full set of post-retrofit models for each measure, including building type, HVAC system type, efficiency level, and control strategy. The team then took the difference between the baseline models and post-retrofit models to determine measure impacts, as Section 4.2 outlines.

2.7 Remote Metering Analysis

In this task, the team mailed metering devices to homeowners for self-installation with the specific objective of researching integrated control switchover temperatures and HVAC unit operation for partial displacement installations of central HPs and mini-split HPs with delivered fuel-fired heating baselines (fuel oil and propane).[16]

The research objectives for the task included:

- Infer integrated control operation including switchover temperatures for installed HPs
- Determine how customers are controlling their HP and delivered fuel-fired heating systems and identify opportunities for increased efficiency or energy savings through more optimal control strategies

[15] 6.2Appendix A summarizes updated switchover temperature weighting assumptions for the 2022-2024 program years based on planned program changes.

[16] The metering study did not research integrated control switchover temperatures for customers that installed HPs to fully displace delivered fuel (oil or propane) or electric resistance baseline heating systems, as integrated controls are not applicable to these measure types.

2.7.1 Metering Methodology

The team recruited participants for the metering study from the EO customer survey. At the end of the customer survey, the team included a module with a series of questions that asked customers if they would be interested in participating in a self-installed metering study for a $200 incentive ($100 for agreeing to participate and having the loggers mailed to their home, $100 for successful installation of the loggers). If participants marked that they were interested, they received several additional questions to determine eligibility for the metering study. Eligibility criteria included:

- Having a home Wi-Fi network to install Wi-Fi-enabled meters
- Having a mobile phone or tablet that they could use to take a survey and upload photos or to use for a video call
- Having an electric meter that is located within 20 feet of a wall outlet inside the home to install a Copper Lab meter
- Being able to access a mini-split HP indoor head via step stool or ladder (if applicable)

Guidehouse sent recruitment emails to the interested and eligible survey respondents to verify their interest in the metering study. The team sent out a total of 61 recruitment emails. Of these sites, 41 responded and moved forward with participation in the study. Four sites said they were no longer interested, and the remaining 16 sites were unresponsive to the follow-up recruitment email. The team used a cutoff date of March 10, discontinuing outreach to the unresponsive sites thereafter.

Table 2-24. Metering Study Site Interest and Recruitment

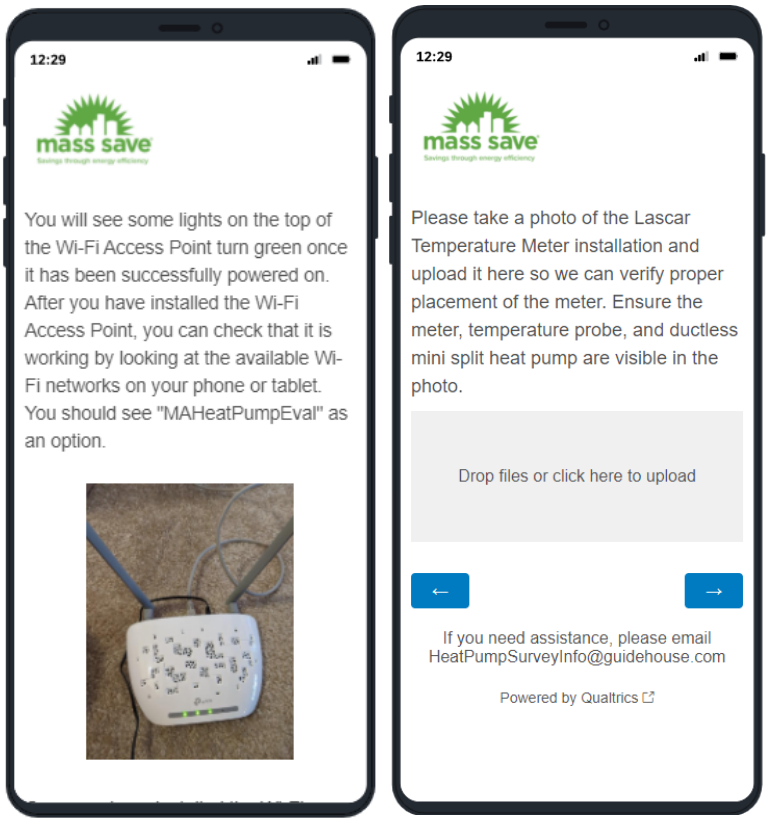
Interested Sites via Customer Survey Response	Sites Contacted via Email	Sites that Attempted Installation	Sites Unable to Install Meters
61	61	41	1

Source: Evaluation Team Analysis

Each of the sites in the metering study self-installed a Wi-Fi access point, two Lascar temperature meters, and a Copper Labs energy meter.

For the device installation, participants either followed a self-install guide via a Qualtrics survey that stepped them through the installation process and prompted them to take photos, or they scheduled a Blitzz virtual installation call with Guidehouse. Figure 2-8 includes examples from the self-install survey guide. In the recruitment process, the team asked participants to schedule a virtual installation call with an experienced field specialist as a default, but also gave customers the option to use the self-install survey if they preferred.

Figure 2-8. Example Installation Instructions from the Self-Install Survey



Source: Evaluation Team Analysis

Customers took photos during installation through the self-install survey, and for customers that installed the equipment through the Blitzz virtual installation call, Guidehouse technicians were able to take screen shot captures during calls. For the customers who took photos through the self-install survey, Guidehouse staff reviewed the photos and verified proper installation of the equipment. Of the 15 customers who self-installed the equipment using the Qualtrics survey, only one site required follow-up after the customer self-install to troubleshoot an installation. For this site, the customer installed one of the meters on their pellet stove instead of their boiler baseboard radiators; the site contact said they use the pellet stove often in the winter, so they thought they should install the meter on the pellet stove instead of on the baseboard radiator, even though the self-install survey specifically instructed them to install on the baseboard. The team followed up with the site and asked them to move the meter and the customer sent a confirmation photo. Overall, the team found that the customer-led self-installations were almost as successful as the calls led with the virtual installation calls.

In total, customers were able to successfully install loggers at 40 sites—15 sites with central HPs and 25 sites with mini-split HPs. Fifteen sites used the self-install survey and the other 25 sites installed the loggers through a Blitzz virtual installation call with a Guidehouse staff member. Table 2-25 includes the site totals and installation methods.

Table 2-25. Summary of Metered Sites and Installation Methods

Installation Method	Central HP Sites	Ductless Mini-Split HP Sites	Total
Self-Install Survey	1	14	15
Blitzz Virtual Installation Call	14	11	25
Total	**15**	**25**	**40**

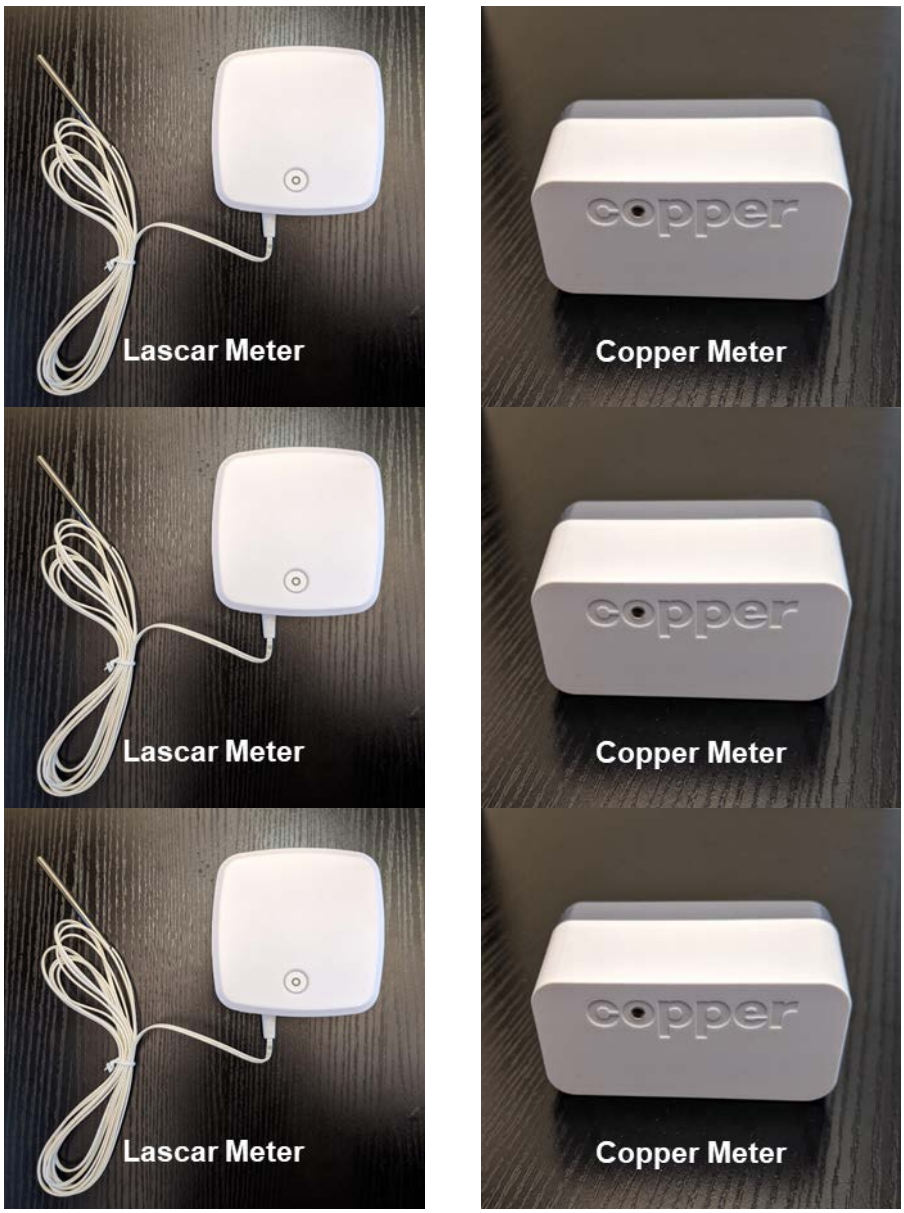
Source: Guidehouse analysis

Only one site interested in participation was unable to complete the installation. The Wi-Fi access point at this site was interacting and attempting to override their mesh Wi-Fi network. When the site had the Wi-Fi access point plugged in, it shut off their home Wi-Fi network. Because of this, they were unable to install the Lascar and Copper meters. This was a site that received a Blitzz virtual installation call. The team did not run into this issue with any other sites that had a mesh Wi-Fi network.

The majority of the installations took place during the first 3 weeks of March 2021. Thirty six of the 40 sites were installed by March 20, with six occurring in the last week of March 2021. The metering period lasted several weeks prior to conducting the meter analysis (as Section 2.7.2 details).

Guidehouse pre-launched the Wi-Fi access points and Lascar temperature meters so the study participants could plug in the Wi-Fi access points and place the Lascar temperature meters with no additional launching steps needed. The study participants followed instructions on the Copper Labs app to install the Copper meters with the assistance of the self-install survey or through the virtual installation call with a Guidehouse staff member.

Figure 2-9. Lascar and Copper Meters

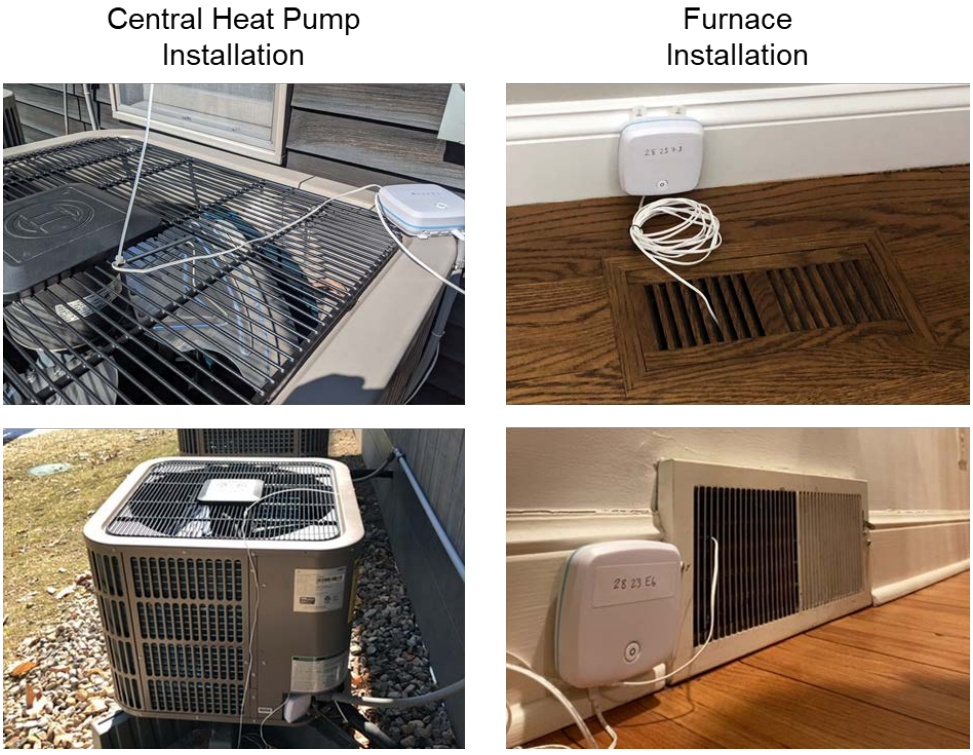


Source: Evaluation Team Analysis

The following meters were installed at sites with central HPs:

- One Lascar temperature meter with probe installed at the exhaust vent for the central HP outdoor condenser unit
- One Lascar temperature meter with probe installed at a furnace supply vent
- One whole home electricity Copper meter

Figure 2-10. Examples of Lascar Meter Installations for Central HPs and Furnaces



Source: Evaluation Team Analysis

The following meters were installed at sites with mini-split HPs:

- One Lascar temperature meter with probe installed at the supply air vent for a mini-split HP indoor head
- One Lascar temperature meter with probe installed on a boiler radiator/baseboard
- One whole home electricity Copper meter

Figure 2-11. Examples of Lascar Meter Installations for Mini-Split HPs and Boilers

Source: Evaluation Team Analysis

During installation, the team asked participants to install the Lascar temperature meters in their largest or most heated room. During the virtual installation calls, the team verified that the metered equipment served the same zone in the home (if applicable). For self-install survey installations, the team checked that all of the temperature meters were installed in the same room or area.[17]

The Lascar temperature logger collects high resolution temperature data that the team used to infer system operation and runtimes. The Copper Labs meters collect high resolution whole home electric usage the team also used to further infer HP system operation.

2.7.2 Analysis Methodology

This section details the methodology used to assign a HVAC control type and switchover temperature setpoint (if applicable) to each site in the metering study sample.

As Section 2.7.1 details, the team installed Lascar temperature meters to collect either air or surface temperatures, which were then used to flag system runtimes for the central HP or mini-split HP and the supplemental heating systems at each home. The Copper meters provided

[17] One site reported installing the mini-split HP meter in the living room and the boiler meter in the bedroom.

secondary data to help verify the operation of the HP. The team performed the following steps as part of the analysis:

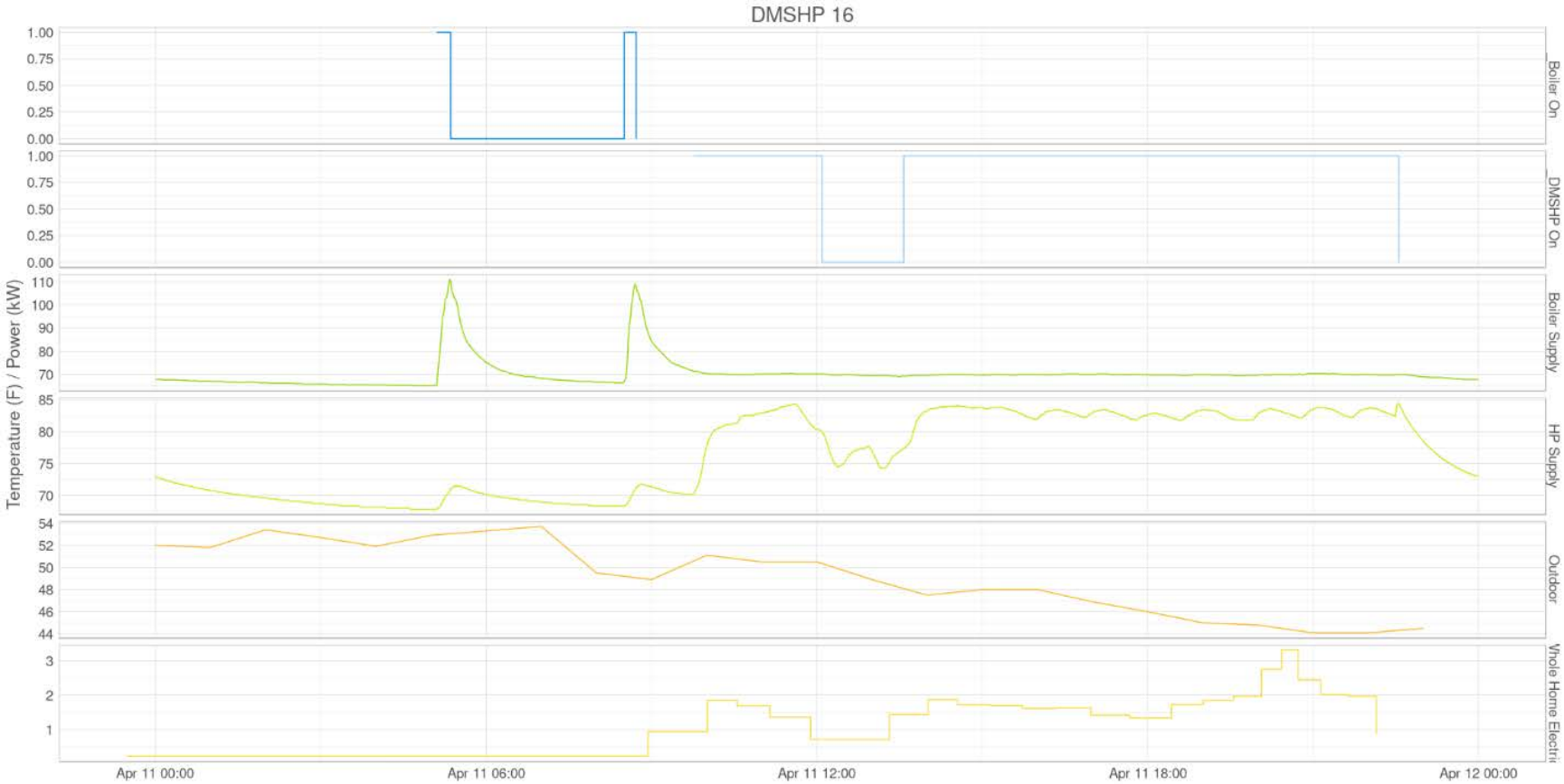
- Connected the temperature and electric meter loggers at each site to the internet. The team downloaded the data from the loggers through each manufacturers' API and stored the data on secure servers.
- Downloaded outdoor air temperature data for five weather stations across Massachusetts (Worcester, Logan [Boston], Barnes [Springfield], New Bedford, and Lawrence). The team then mapped the outdoor air temperature for each of the metered sites based on the closest weather station to each site.
- Labeled run events for the HPs and the secondary heating systems by visually inspecting the data for each site and setting custom thresholds for operation based on range and minimum and maximum temperature readings from the space or surface temperature loggers.
  - For central HP sites, the team classified increases in the supply duct temperature as a heating event that could have been provided by the central HP or the delivered fuel-fired furnace. If there was a concurrent decrease in temperature at the central HP outdoor condenser unit, the team tagged it as a central HP heating event. If there was no decrease in temperature at the outdoor condenser unit, the event was tagged as a furnace event.
  - For mini-split HP sites, the team classified increases in temperature at the mini-split indoor head as a HP heating event. If there was a large temperature increase in the surface temperature logger installed on the radiator or baseboard, the heating event was tagged as a boiler event. The team also noticed a sympathetic heating effect for this logger set-up (e.g., if the delivered fuel-fired boiler was in operation and the radiator surface temp logger was recording a 40°F increase in space temperature, the temperature logger installed at the ductless mini-split HP head may simultaneously show a 5°F temperature increase, when a standard mini-split HP runtime event may show a 15°F temperature increase). The team set thresholds to avoid categorizing these sympathetic temperature reads as runtime events for the incorrect heating system type.
- The team was not able to identify the run events at five of the sites. These sites were not included in the analysis. The reasons for the issues follow:
  - Two sites had sympathetic temperature reads that could not be screened out
  - One site used a pellet stove as the main heat source instead of the furnace
  - One site had incomplete metering data
  - One site had an improper installation

The following figures show examples of the minute-level temperature data collected and the team's assignment of runtime to HPs or secondary heating systems based on the algorithms and methods described above. Figure 2-12 provides an example for a central HP installation, and Figure 2-13 provides an example for a mini-split HP installation.

Figure 2-12. Central HP Installation – Meter Data and HVAC Operation Flags

Source: Evaluation Team Analysis

Figure 2-13. Mini-Split HP Installation – Meter Data and HVAC Operation Flags



Source: Evaluation Team Analysis

After analyzing the meter data and categorizing heating runtime events as either provided by the HP or the secondary heating system, the team performed the following analysis steps to categorize the control strategy at each site:

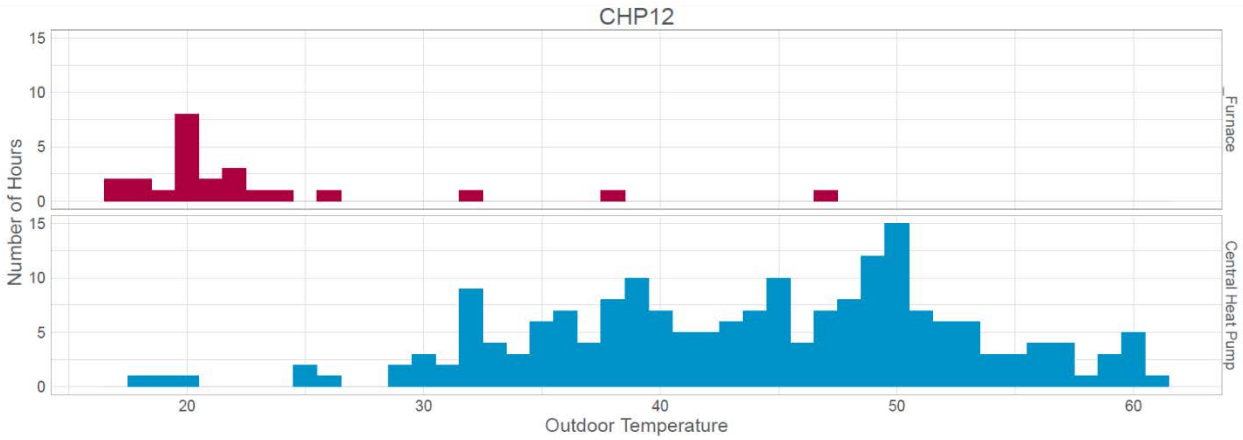
- Flagged each hour throughout the metering period that had more than 2 minutes of runtime and as operation event for the HP or secondary heating system. The team then mapped in the hourly outdoor air temperatures and generated histogram plots summarizing the number of times each system operated at each 1°F outdoor air temperature bin.
- Based on interpretation of these histogram plots showing number of runtime hours for each outdoor air temperature, the team then assigned a field-verified control strategy and switchover temperature setpoint (if applicable) to each site.

The team categorized the control strategies as one of the following:

- **Manual operation:** For this group, the metering results showed operation of both heating system types over the same range of outdoor air conditions.
- **Hard switchover temperature:** For this group, the team discerned a clear switchover temperature, under which the supplementary heating system ran, and over which the HP ran.
- **Switchover with a lead/lag range:** For this group, it appeared that the supplementary heating system was primary under a certain outdoor air temperature, the HP was primary over certain temperature, and there was a range of temperatures where the HP was primary and the supplementary heating system provided backup heat.
- **HP only operation:** At these sites, the customer either only uses the HP for heating, or the switchover temperature was not observed during the metered period of this study.

Figure 2-14 shows an example site that we categorized as a clear switchover control strategy with a switchover temperature of 25°F.

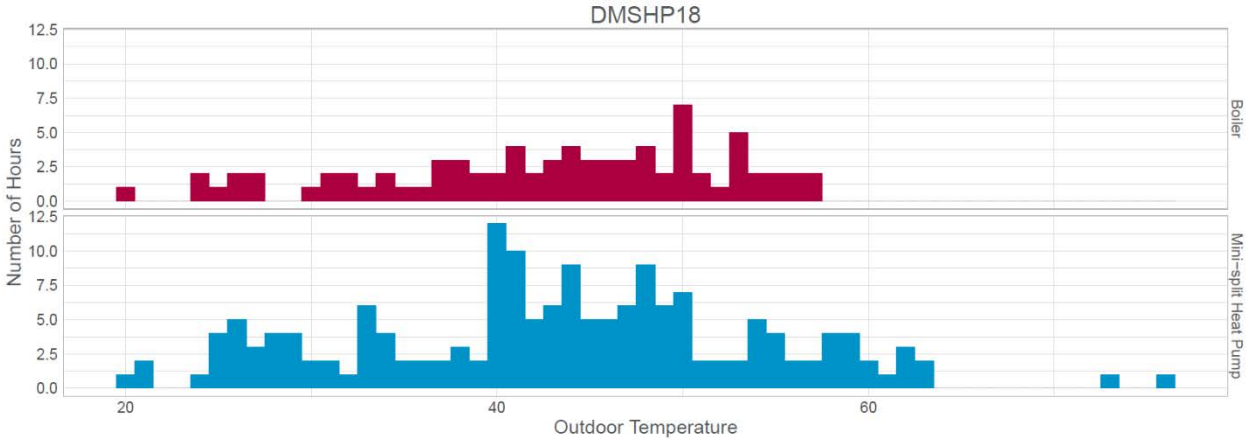
Figure 2-14. Example of Clear Switchover Temperature Setting – Central HP



Source: Evaluation Team Analysis

Figure 2-15 shows an example site that we categorized as manual operation. Both the boiler and the mini-split HP operate over a wide outdoor temperature range.

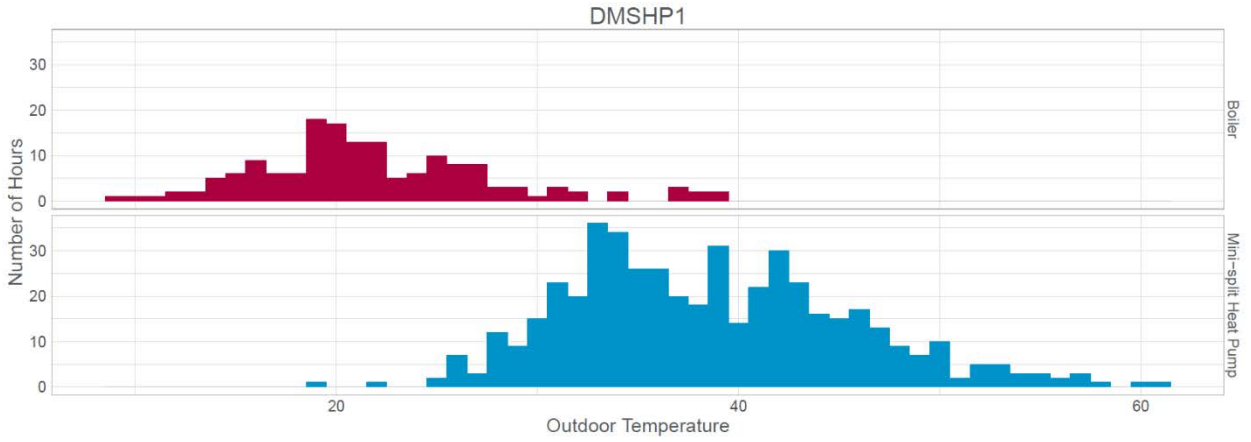
Figure 2-15. Example of Manual System Operation – Mini-Split HP



Source: Evaluation Team Analysis

Figure 2-16 shows an example site that we categorized as having a lead/lag control strategy for a specified temperature range. It appears that for this site, between the outdoor air temperatures of 25°F and 40°F, the HP is the primary heating system, and the boiler will provide backup heat when needed to meet the heating loads of the space. Some of the advanced integrated controllers on the market allow for the programming of these lead/lag temperature ranges. Other controls will call on the backup heat when the HP cannot meet the setpoint within a specified time range.

Figure 2-16. Example of Lead/Lag Range – Mini-Split HP



Source: Evaluation Team Analysis

3. Baseline Determination Results

The team included a series of questions in the customer survey to determine the baseline heating and cooling equipment type for each customer. The baseline HVAC system types are defined as the systems the customer would have installed if they did not install the HP 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 HP was the only HVAC system considered.

Baseline assignments for HPs can be tricky, as they provide both a heating and cooling amenity. The current EO Fuel Displacement design complicates the baseline assignments since customers are only eligible for the elevated EO Fuel Displacement rebate (up to $1,600/ton in 2019) if they either partially or fully displaced existing delivered fuel-fired or electric resistance heating in their home.

The team used the following survey response categories to assign the appropriate heating and cooling baseline for each customer:

- **Purchase intent:** The purchase intent defines whether the customer purchased their new HP to provide cooling, heating, or both. For customers who installed a central HP, they are asked about the purchase intent for their home. For customers who installed a mini-split HP, the customer is first asked which space type(s) they installed new HP(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.
- **Alternative action:** The alternative action defines what the customer would have installed if they did not install the HP that they did. These alternative actions include either taking no action (leaving the existing equipment in place) or installing an alternative system type.
- **Preexisting equipment types:** The preexisting system type is the customer's previous heating and cooling system types. For customers who indicate they had a prior furnace or boiler, the team also 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 team assigned the baseline heating system type as a boiler, irrespective of whether the customer indicated they had a furnace or a boiler. The opposite logic is applied to customers who indicate their heat came out of ducts (the preexisting heating system type is defined as a furnace).

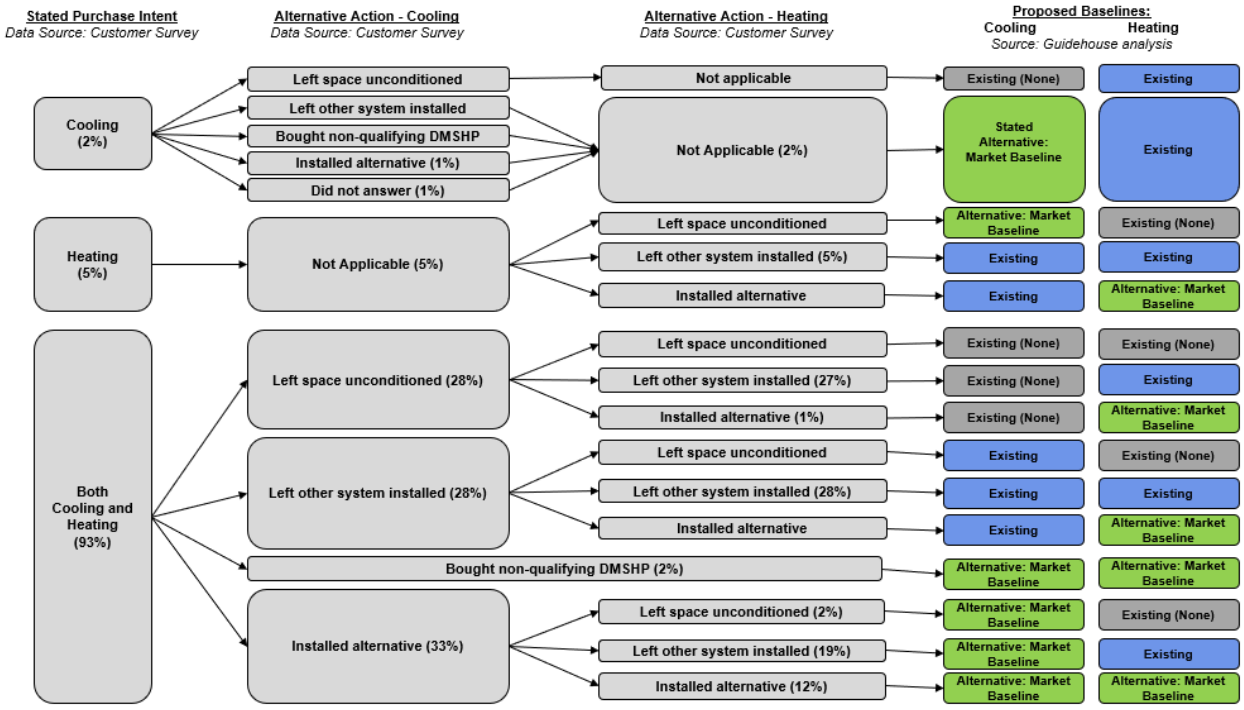
Using the responses to these survey questions, the team assigned a heating and cooling baseline system type using the baseline determination logic as Figure 3-1 through Figure 3-3 show in Section 3.1. Appendix A provides the customer survey instrument. The baseline determination questions are included for both central HPs and mini-split HPs in Module B of the survey.

3.1 Single-Family Gross Baseline Weights

This section details how the team assigned the unique heating and cooling baseline types for single-family customers, and the steps taken to develop a set of baseline weights to apply to the building simulation impact results for gross savings application.

Figure 3-1 shows the baseline determination logic for the group of customers who installed a mini-split HP with an electric resistance pre-retrofit heating system type. The figure also includes the proportion of survey respondents who indicated cooling, heating, or cooling and heating purchase intent, and the percent of survey respondents assigned to each unique cooling and heating alternative action.

Figure 3-1. Baseline Assignment Logic Map and Results for Single-Family Customers with Mini-Split HP with Electric Pre-Retrofit Heating Type



Source: Guidehouse analysis, customer survey

The team applied the following logic exceptions for the mini-split HP measure group:

- If a customer has a cooling purchase intent, chooses a central air conditioner or central HP alternative cooling action, does not have preexisting ductwork, and says they were not considering installing ducts, then the team assigned a code-minimum mini-split AC or mini-split HP as the baseline cooling type. If the customer says they were considering installing ducts, the team assigned a market baseline AC or central HP.
- For customers who install a HP in an attic, sunroom, basement, or loft, indicate a purchase intent for heating, and indicate that the space was not heated previously, the team assumed that the preexisting heating type was the one indicated in the program data measure description, which includes a description of the heating system type displaced. The team assumed that if a customer is heating the space in the post-retrofit case, that the space was at least partially heated in the pre-retrofit case from neighboring spaces in the home (indirect heating).
- If a participant stated that they bought the unit for cooling, the baseline options must include a similar cooling amenity to the mini-split HP. Conversely, if a participant states that they bought the unit for heating, the baseline options must provide a similar heating amenity to the mini-split HP.

Table 3-1 provides the distribution of baseline cooling types from the customer survey, the assignment of baseline cooling type in the building simulation task, and the baseline weights applied to the building simulation results to calculate a weighted gross impact savings for each measure. For the mini-split HP measure with an electric resistance pre-retrofit heating system type, 37% of customers indicated having a non-cooled baseline (they would not have installed an alternative cooling system if they did not install the HP they did). Customers who would have only used fans for cooling are assigned to the uncooled baseline group. Twenty-seven percent of customers would have left their existing system installed, and 36% would have installed an alternative system. The most prevalent existing and new cooling system types are room or portable ACs.

Table 3-1. Baseline Cooling Type and Building Simulation Cooling Weights for Customers Who Installed a Mini-Split HP with an Electric Heating Baseline

Baseline Cooling Type Determined	Survey n	Survey %	Building Simulation Cooling Type	Building Simulation Cooling Weight Applied
Existing (None)	23	28%	None	37%
Existing-Only Used Fans	3	4%		
New Fans	4	5%		
Existing-Central AC	4	5%	Existing-Central AC	6%
Existing-Central HP	1	1%		
Existing-Ductless AC	1	1%	Existing-Ductless AC	1%
Existing-Room AC	12	15%	Existing-Room AC	20%
Existing-Portable AC	4	5%		
Market Baseline-Central AC	4	5%	Market Baseline-Central AC	5%
Market Baseline-Mini-Split AC	2	2%	Market Baseline-Mini-Split AC	10%
Market Baseline-Other Mini-Split HP	6	7%		
Market Baseline-Room AC	10	12%	Market Baseline-Room AC	21%
Market Baseline-Portable AC	7	9%		
Total	**81**	**100%**		**100%**

Source: Evaluation Team Analysis

Table 3-2 provides the distribution of baseline heating types from the customer survey, the assignment of baseline heating type in the building simulation task, and the baseline weights applied to the building simulation results to calculate a weighted gross impact savings for each measure. For the mini-split HP measure with an electric resistance pre-retrofit heating system type, 84% of customers would have left their existing system installed, and 16% would have installed an alternative system. The most prevalent existing heating system type is electric baseboard heaters. Of the 81 installations, 8% of customers indicated they had existing ducts in the space 1% with a forced heating system and 7% with forced cooling system only).

Table 3-2. Baseline Heating Type and Building Simulation Heating Weights for Customers Who Installed a Mini-Split HP with an Electric Heating Baseline

Baseline Heating Type Determined	Survey n	Survey %	Building Simulation Heating Type	Building Simulation Heating Weight Applied
Existing (None)	1	1%		0%*
Existing-Electric Baseboard	60	74%	Electric Resistance Heating	85%
Existing-Electric Space Heater	1	1%		
New Electric Baseboard	2	2%		
Market Baseline-Electric Space Heater	1	1%		
Existing-Other HP or Mini-Split HP	1	1%	Existing-Mini-Split HP	1%
Existing-Oil Furnace	1	1%	Existing-Oil Furnace	1%
Existing-Propane/LPG Boiler	2	2%	Existing-Propane/LPG Boiler	3%
Market Baseline-Natural Gas Furnace	4	5%	Market Baseline-Natural Gas Furnace	5%
Market Baseline-Oil Boiler	1	1%	Market Baseline-Oil Boiler	3%
Market Baseline-Radiant Hydro	1	1%		
Market Baseline-Propane Furnace	1	1%	Market Baseline-Propane Furnace	1%
Market Baseline-Other Mini-Spit HP	2	2%		0%**
Existing-Woodstove, Pellet Stove, or Fireplace	2	2%		0%***
Market Baseline-Woodstove, Pellet Stove, or Fireplace	1	1%		0%***
Total	**81**	**100%**		**100%**

*The team assumes even if the space or zone is unheated, heat will transfer from another heated zone in the home.

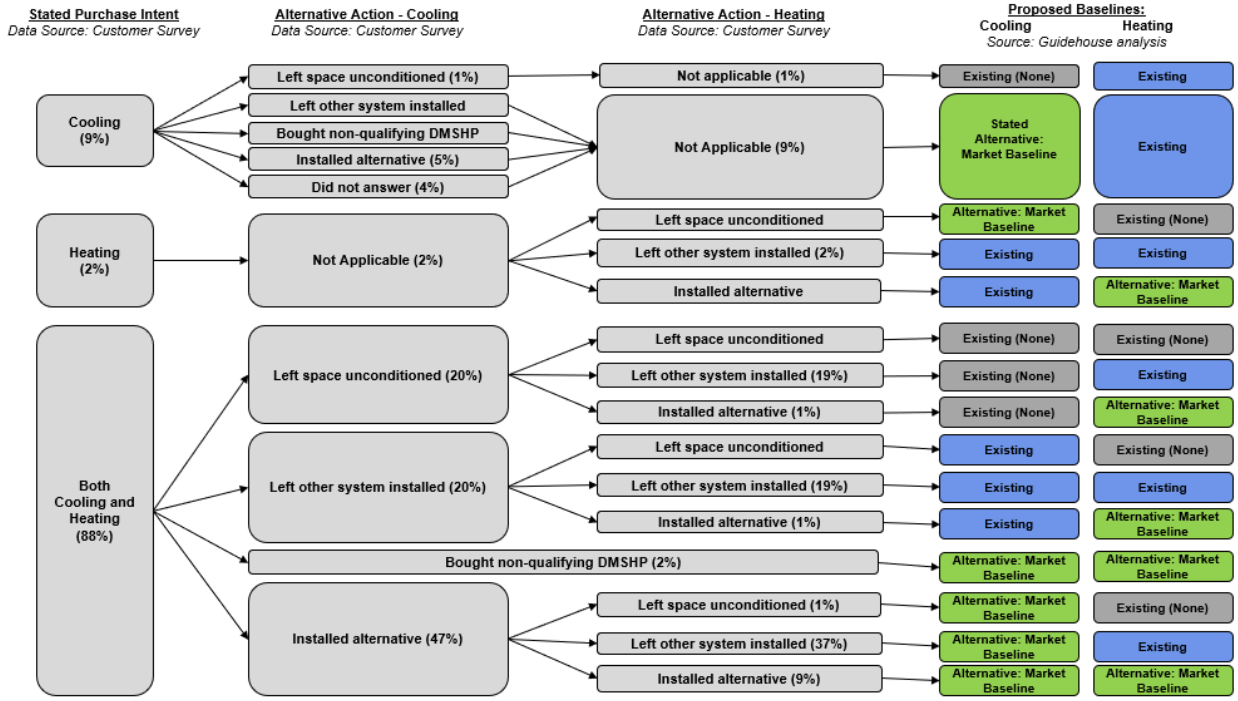
**In discussion with the PAs, the team decided to disallow a HP heating baseline. These customers are likely marked as a free rider in the separate net-to-gross analysis and are therefore removed prior to calculating the gross baseline weights for this analysis.

***Wood heating is removed prior to calculating the baseline weights to apply to the building simulation model results. These cases account for only a few percent of customer responses, so the team made the simplifying assumption to remove them from the analysis.

Source: Evaluation Team Analysis

Figure 3-2 shows the baseline determination logic for the group of customers who installed a mini-split HP with a delivered fuel-fired pre-retrofit heating system type. The figure includes the proportion of survey respondents who indicated cooling, heating, or cooling and heating purchase intent, and the percent of survey respondents assigned to each unique cooling and heating alternative action.

Figure 3-2. Baseline Assignment Logic Map and Results for Single-Family Customers with Mini-Split HP with Delivered Fuel-Fired Pre-Retrofit Heating Type



Source: Guidehouse analysis, customer survey

Table 3-3 provides the distribution of baseline cooling types from the customer survey, the assignment of baseline cooling type in the building simulation task, and the baseline weights applied to the building simulation results to calculate a weighted gross impact savings for each measure. For the mini-split HP measure with a delivered fuel-fired pre-retrofit heating system type, 30% of customers are indicated as having a non-cooled baseline (they would not have installed an alternative cooling system if they did not install the HP they did). Customers who would have only used fans for cooling are assigned to the uncooled baseline group. Seventeen percent of customers would have left their existing system installed, and 53% would have installed an alternative system. The most prevalent existing and new cooling system types are room ACs.

Table 3-3. Baseline Cooling Type and Building Simulation Cooling Weights for Customers Who Installed a Mini-Split HP with a Delivered Fuel-Fired Heating Baseline

Baseline Cooling Type Determined	Survey n	Survey %	Building Simulation Cooling Type	Building Simulation Cooling Weight Applied
Existing (None)	30	23%	None	30%
Existing-Only Used Fans	5	4%		
New Fans	4	3%		
Existing-Central AC	5	4%	Existing-Central AC	4%
Existing-Ductless AC with no heating	1	1%	Existing-Ductless HP	2%

Baseline Cooling Type Determined	Survey n	Survey %	Building Simulation Cooling Type	Building Simulation Cooling Weight Applied
Existing-Other Mini-Split HP	1	1%		
Existing-Room AC	12	9%	Existing-Room AC	11%
Existing-Portable AC	3	2%		
Market Baseline-Central AC	13	10%	Market Baseline-Central AC	10%
Market Baseline- Mini-Split HP	1	1%	Market Baseline- Mini-Split HP	11%
Market Baseline-Ductless AC	4	3%		
Market Baseline-Other Mini-Split HP	9	7%		
Market Baseline-Room AC	36	28%	Market Baseline-Room AC	32%
Market Baseline-Portable AC	5	4%		
Total	**129**	**100%**		**100%**

Source: Evaluation Team Analysis

Table 3-4 provides the distribution of baseline heating types from the customer survey, the assignment of baseline heating type in the building simulation task, and the baseline weights applied to the building simulation results to calculate a weighted gross impact savings for each measure. For the mini-split HP measure with a delivered fuel-fired pre-retrofit heating system type, 90% of customers would have left their existing system installed, and 9% would have installed an alternative system. The most prevalent existing heating system type is an oil boiler. Of the 129 installations, 20% of customers indicated they had existing ducts in the space (18% with a forced heating system and 2% with forced cooling system only).

Table 3-4. Baseline Heating Type and Building Simulation Heating Weights for Customers Who Installed a Mini-Split HP with a Delivered Fuel-Fired Heating Baseline

Baseline Heating Type Determined	Survey n	Survey %	Building Simulation Heating Type	Building Simulation Heating Weight Applied
Existing (None)	1	1%		0%*
Existing-Electric Baseboard	2	2%	Electric Resistance Heating	2%
Existing-Oil Boiler	81	63%	Existing-Oil Boiler	68%
Existing-Oil Furnace	16	12%	Existing-Oil Furnace	13%
Existing-Propane/LPG Boiler	8	6%	Existing-Propane/LPG Boiler	7%
Existing-Propane/LPG Furnace	5	4%	Existing-Propane/LPG Furnace	4%
Market Baseline-Natural Gas Boiler	3	2%	Market Baseline-Natural Gas Boiler	3%
Market Baseline-Oil Boiler	2	2%	Market Baseline-Oil Boiler	2%
Market Baseline-Oil Furnace	2	2%	Market Baseline-Oil Furnace	2%

Baseline Heating Type Determined	Survey n	Survey %	Building Simulation Heating Type	Building Simulation Heating Weight Applied
Market Baseline-Other Mini-Split HP	3	2%		0%**
Market Baseline-Woodstove, Pellet Stove, or Fireplace	2	2%		0%***
Existing-Woodstove, Pellet Stove, or Fireplace	4	3%		0%***
Total	**129**	**100%**		**100%**

*The team assumes even if the space or zone is unheated, heat will transfer from another heated zone in the home.

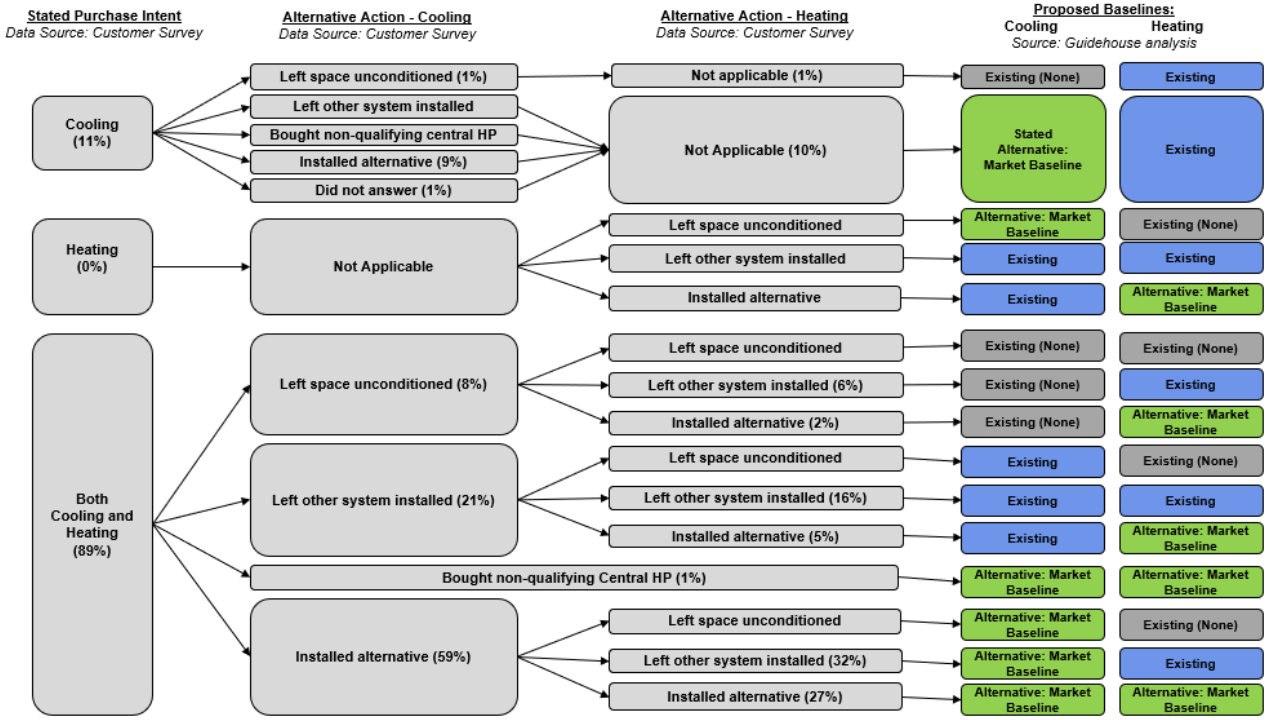
**In discussion with the PAs, the team decided to disallow a HP heating baseline. These customers are likely marked as a free rider in the separate net-to-gross analysis and are therefore removed prior to calculating the gross baseline weights for this analysis.

***Wood heating is removed prior to calculating the baseline weights to apply to the building simulation model results. These cases account for only a few percent of customer responses, so the team made the simplifying assumption to remove them from the analysis.

Source: Evaluation Team Analysis

Figure 3-3 shows the baseline determination logic for the group of customers who installed a central HP with a delivered fuel-fired pre-retrofit heating system type. The figure also includes the proportion of survey respondents who indicated cooling, heating, or cooling and heating purchase intent, and the percent of survey respondents assigned to each unique cooling and heating alternative action.

Figure 3-3. Baseline Assignment Logic Map and Results for Single-Family Customers with Central HP with Delivered Fuel-Fired Pre-Retrofit Heating Type



Source: Evaluation Team Analysis

The team applied the following logic exceptions for the mini-split HP measure group:

- If a customer installed a central HP with integrated controls, and says their alternative action was to install a "other heat pump" (one of the choice options given to customers), the team assumed the baseline heating system also includes the integrated control (partial displacement).

Table 3-5 provides the distribution of baseline cooling types from the customer survey, the assignment of baseline cooling type in the building simulation task, and the baseline weights applied to the building simulation results to calculate a weighted gross impact savings for each measure. For the central HP measure with a delivered fuel-fired pre-retrofit heating system type, 9% of customers are indicated as having a non-cooled baseline (they would not have installed an alternative cooling system if they did not install the HP they did). Twenty percent of customers would have left their existing system installed, and 70% would have installed an alternative system. The most prevalent existing and new cooling system types are central ACs.

Table 3-5. Baseline Cooling Type and Building Simulation Cooling Weights for Customers Who Installed a Central HP with a Delivered Fuel-Fired Heating Baseline

Baseline Cooling Type Determined	Survey n	Survey %	Building Simulation Cooling Type	Building Simulation Cooling Weight Applied
Existing (None)	8	9%	None	9%
Existing-Central AC	15	17%	Existing-Central AC	18%
Existing-Central HP	1	1%		
Existing-Room AC	2	2%	Existing-Room AC	2%
Market Baseline-Central AC	34	39%	Market Baseline-Central AC	41%
Market Baseline-Central HP	1	1%		
Market Baseline-Geothermal or Ground-Source HP	1	1%		
Market Baseline-Room AC	11	13%	Market Baseline-Room AC	13%
Market Baseline- Mini-Split HP	10	11%	Market Baseline- Mini-Split HP	17%
Market Baseline-Ductless AC	4	5%		
Market Baseline-Other Mini-Split HP	1	1%		
Total	**88**	**100%**		**100%**

Source: Evaluation Team Analysis

Table 3-6 provides the distribution of baseline heating types from the customer survey, the assignment of baseline heating type in the building simulation task, and the baseline weights applied to the building simulation results to calculate a weighted gross impact savings for each measure. For the central HP measure with a delivered fuel-fired pre-retrofit heating system type,

65% of customers would have left their existing system installed, and 35% would have installed an alternative system. The most prevalent existing heating system type is an oil boiler and the most prevalent new unit type is an oil furnace.[18]

Table 3-6. Baseline Heating Type and Building Simulation Heating Weights for Customers Who Installed a Central HP with a Delivered Fuel-Fired Heating Baseline

Baseline Heating Type Determined	Survey n	Survey %	Building Simulation Heating Type	Building Simulation Heating Weight Applied
Existing-Oil Boiler	36	41%	Existing-Oil Boiler	47%
Existing-Oil Furnace	20	23%	Existing-Oil Furnace	26%
Existing-Propane/LPG Furnace	1	1%	Existing-Propane/LPG Furnace	1%
Market Baseline-Oil Boiler	3	3%	Market Baseline-Oil Boiler	4%
Market Baseline-Oil Furnace	11	13%	Market Baseline-Oil Furnace	14%
Market Baseline-Propane Furnace	5	6%	Market Baseline-Propane Furnace	6%
Market Baseline-Propane/LPG Boiler	1	1%	Market Baseline-Propane/LPG Boiler	1%
Market Baseline-Central HP	1	1%		
Market Baseline- Mini-Split HP	4	5%		
Market Baseline-Other CHP	2	2%		0%*
Market Baseline-Geothermal or Ground-Source HP	3	3%		
Market Baseline-Woodstove, Pellet Stove, or Fireplace	1	1%		0%**
Total	**88**	**100%**		**100%**

*In discussion with the PAs, the team decided to disallow a HP heating baseline. These customers are likely marked as a free rider in the separate net-to-gross analysis and are removed prior to calculating the gross baseline weights for this analysis.

**Wood heating is removed prior to calculating the baseline weights to apply to the building simulation model results. These cases account for only a few percent of customer responses, so the team made the simplifying assumption to remove them from the analysis.

Source: Evaluation Team Analysis

[18] Despite attempts to add prompts and pictures in the customer survey asking customers to indicate whether heat came out of ducts or radiators, it is likely customers still experienced some confusion indicating whether their heat is supplied by a furnace (ducts) or a boiler (radiators). With this caveat in mind, 70% of customers indicate they already had ductwork in their home (51% with forced air heating, 19% with forced air cooling and not heating). Thirty percent of customers indicate they did not have prior ductwork and needed to install ducts.

3.2 Multifamily Gross Baseline Weights

All of the multifamily projects in 2019 are tagged as mini-split HP installations (full displacement) with an electric resistance pre-retrofit heating system type.

As part of this study, the team interviewed four contractors who completed EO fuel displacement projects for the multifamily housing market. All four of the multifamily contractors indicated that their customers had electric resistance heating equipment and that several customers had window ACs to cool their units prior to installing the new HP units. All four of the multifamily contractors indicated that they did not discuss other heating or cooling options with customers, and that the installed mini-split HPs were the only unit type considered. Therefore, the team assumes that the baseline heating system type for the multifamily mini-split HP measure (full displacement with electric resistance pre-retrofit heating system type) is electric resistance baseline heating and window AC baseline cooling.

4. Impact Analysis Results

This section provides the results of the impact analysis activities, including the metering study, building simulation, and bill disaggregation results.[19]

4.1 Metering Study Results

This section presents the results of the remote metering study, including findings on the field-verified equipment types, control strategies, and switchover temperatures. This section also provides findings from the follow-up customers interviews for the metered sample.

Program Data System Type Categorization

One of the findings from the metering study is that some heating systems were miscategorized in the program data. Of the 40 sites in the metering study sample, three were categorized as central HPs and the team verified the actual equipment installed in the home to be mini-split HPs. The implementation teams should consider quality checks for HVAC system types filled in on the applications and input into the program tracking databases.

Beyond the primary HP type, there were nine sites with secondary backup heating systems miscategorized: seven sites were marked as having backup furnaces but actually had backup boilers, and two were marked as having backup boilers but actually had furnaces. The team recommends that implementers ensure correct HP classification in the program data through additional QAQC of application data entry.

Table 4-1 compares the heating equipment types reported in the program data, those selected by the customer in the customer survey, and the types verified through the metering study.

Table 4-1. Comparison of Equipment: Program Data, Survey Data, and Field-Verified Data

Site ID	Program Data HP	Program Data Secondary Equipment	Survey HP Response	Survey Secondary Equipment Response	Field-Verified HP	Field-Verified Secondary Equipment	Discrepancies in Program Data vs. Field-Verified Data
CHP1	CHP	Furnace	CHP	Furnace	CHP	Furnace	
CHP2	CHP	Furnace	CHP	Furnace	CHP	Furnace	
CHP3	CHP	Furnace	CHP	Furnace	CHP	Furnace	
CHP4	CHP	Furnace	CHP	Furnace	CHP	Furnace	
CHP5	CHP	Furnace	CHP	Furnace	CHP	Furnace	
CHP6	CHP	Furnace	CHP	Furnace	CHP	Boiler	Yes
CHP7	CHP	Furnace	CHP	Furnace	DMSHP	Boiler	Yes
CHP8	CHP	Furnace	CHP	Furnace	CHP	Furnace	
CHP9	CHP	Furnace	CHP	Furnace	CHP	Furnace	
CHP10	CHP	Furnace	CHP	Furnace	CHP	Furnace	

[19] Several impact findings from this study will be used to update the EO Optimization Spreadsheet model assumptions, including the average installed capacities for each measure type and typical control strategies and integrated control switchover temperatures. The EO Optimization Model will support future PA research needs.

Site ID	Program Data HP	Program Data Secondary Equipment	Survey HP Response	Survey Secondary Equipment Response	Field-Verified HP	Field-Verified Secondary Equipment	Discrepancies in Program Data vs. Field-Verified Data
CHP11	CHP	Furnace	CHP	Furnace	CHP	Boiler	Yes
CHP12	CHP	Furnace	CHP	Furnace	CHP	Furnace	
CHP13	CHP	Furnace	CHP	Furnace	CHP	Boiler	Yes
CHP14	CHP	Furnace	CHP	Furnace	CHP	Boiler	Yes
CHP15	CHP	Furnace	CHP	Furnace	DMSHP	Boiler	Yes
CHP16	CHP	Furnace	CHP	Furnace	CHP	Furnace	
CHP17	CHP	Furnace	CHP	Furnace	CHP	Furnace	
CHP18	CHP	Furnace	CHP	Furnace	DMSHP	Boiler	Yes
DMSHP1	DMSHP	Boiler	DMSHP	Boiler	DMSHP	Boiler	
DMSHP2	DMSHP	Boiler	DMSHP	Boiler	DMSHP	Boiler	
DMSHP3	DMSHP	Boiler	DMSHP	Boiler	DMSHP	Boiler	
DMSHP4	DMSHP	Boiler	DMSHP	Boiler	DMSHP	Boiler	
DMSHP5	DMSHP	Boiler	DMSHP	Boiler	DMSHP	Boiler	
DMSHP6	DMSHP	Boiler	DMSHP	Boiler	DMSHP	Boiler	
DMSHP7	DMSHP	Boiler	DMSHP	Furnace	DMSHP	Boiler	
DMSHP8	DMSHP	Boiler	DMSHP	Furnace	DMSHP	Boiler	
DMSHP9	DMSHP	Boiler	DMSHP	Boiler	DMSHP	Boiler	
DMSHP10	DMSHP	Boiler	DMSHP	Boiler	DMSHP	Boiler	
DMSHP11	DMSHP	Boiler	DMSHP	Boiler	DMSHP	Boiler	
DMSHP12	DMSHP	Boiler	DMSHP	Boiler	DMSHP	Boiler	
DMSHP13	DMSHP	Boiler	DMSHP	Furnace	DMSHP	Furnace	Yes
DMSHP14	DMSHP	Boiler	DMSHP	Boiler	DMSHP	Boiler	
DMSHP15	DMSHP	Boiler	DMSHP	Boiler	DMSHP	Boiler	
DMSHP16	DMSHP	Boiler	DMSHP	Boiler	DMSHP	Boiler	
DMSHP17	DMSHP	Boiler	DMSHP	Boiler	DMSHP	Boiler	
DMSHP18	DMSHP	Boiler	DMSHP	Furnace	DMSHP	Furnace	Yes
DMSHP19	DMSHP	Boiler	DMSHP	Boiler	DMSHP	Boiler	
DMSHP20	DMSHP	Boiler	DMSHP	Boiler	DMSHP	Boiler	
DMSHP21	DMSHP	Boiler	DMSHP	Furnace	DMSHP	Boiler	
DMSHP22	DMSHP	Boiler	DMSHP	Boiler	DMSHP	Boiler	

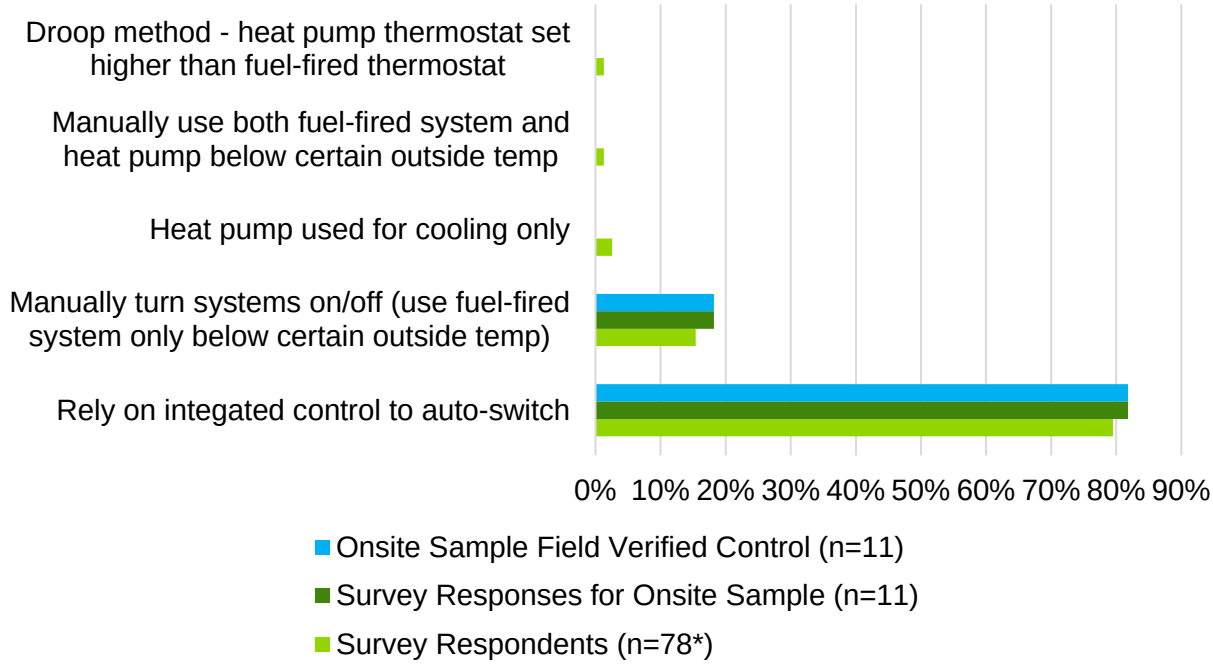
Source: Guidehouse analysis, EO fuel displacement data, EO customer survey, onsite verification

The metering study also found that many homeowners are not familiar with their heating system types. Ten out of the 40 sites reported having a secondary heating system in the customer survey that is different from the equipment the team found during the metering study. Customers can have a hard time identifying whether they have a furnace or boiler, even with survey prompts saying that furnaces typically have ducts and boilers typically have radiators.

Metering Study Control Type and Setpoint Findings

As Section 2.7.2 details, the team categorized the control strategy and switchover temperature setpoint for the central HP sites in the metering study. Figure 4-1 details the control strategies that customers reported using via the customer survey (both for all survey respondents and for the subset of customers verified through the metering study). The figure also details the control strategies verified through the metering study efforts. The majority of customers (approximately 80%) report relying on an integrated control and switchover temperature to auto-switch between their heating system types. This is the same percentage of customers the team verified as having a clear switchover temperature as evidenced in the metering study sample. Approximately 15%-20% of customers manually control their systems and turn them on and off based on customer decision-making criteria (e.g., when it is cold outside). Less than 5% of customers use another control strategy.

Figure 4-1. Survey Reported vs. Field-Verified Control Strategies – Central HP

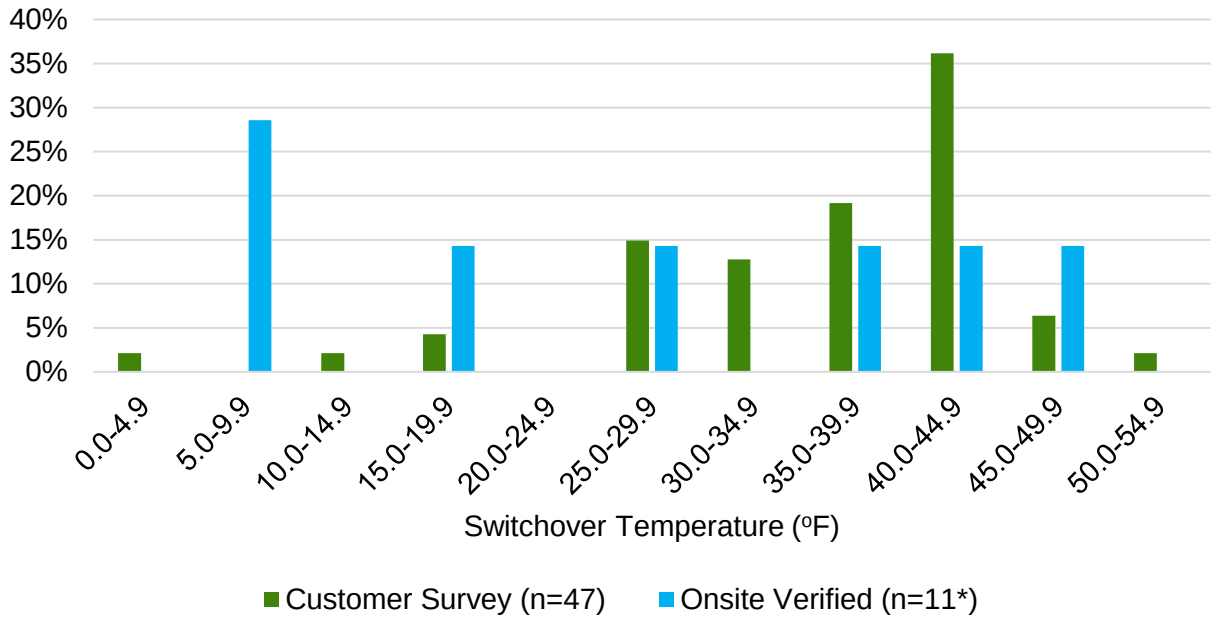


*Survey respondents who knew their control strategy

Source: Evaluation Team Analysis

Figure 4-2 shows the switchover temperatures for the subset of customers that report using a switchover temperature and know what their switchover temperature setting is (customer survey) and the onsite verified switchover temperatures. Customers use a variety of switchover temperatures for their central HP systems with supplemental delivered fuel-fired heat.

Figure 4-2. Survey Reported vs. Field-Verified Switchover Temperatures – Central HP



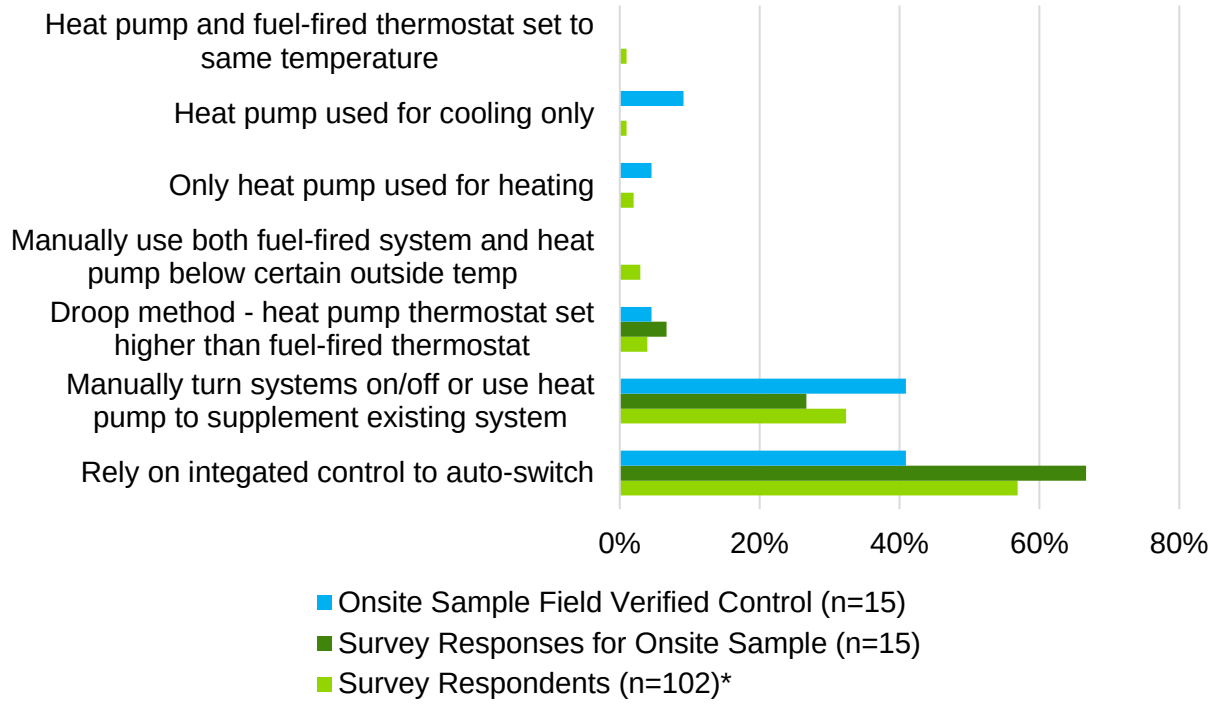
Survey sample includes 37 customers with pre-existing oil heat and 10 with propane heat. The team found no clear trends in differing switchover temperature distributions between the oil and propane groups.

*Onsite sample with clear switchover temperature

Source: Evaluation Team Analysis

Figure 4-3 details the customer-reported and field-verified control strategies for the customer survey and onsite samples for customers who installed a mini-split HP with integrated control. Based on these findings, about 40%-60% of customers rely on the integrated control to auto-switch their systems, while about 25%-40% of customers manually operate their systems without the integrated control auto-switching. About 5% of customers used a droop method, whereby they set their HP thermostat to a higher temperature than their delivered fuel-fired thermostat (usually about 5°F); the delivered fuel-fired system will provide heat if the interior space temperature drops to the setpoint of the lower thermostat, indicating that the HP is unable to fully meet load for a certain period of time. Less than 5% of customers report using their mini-split HP for cooling or heating only.

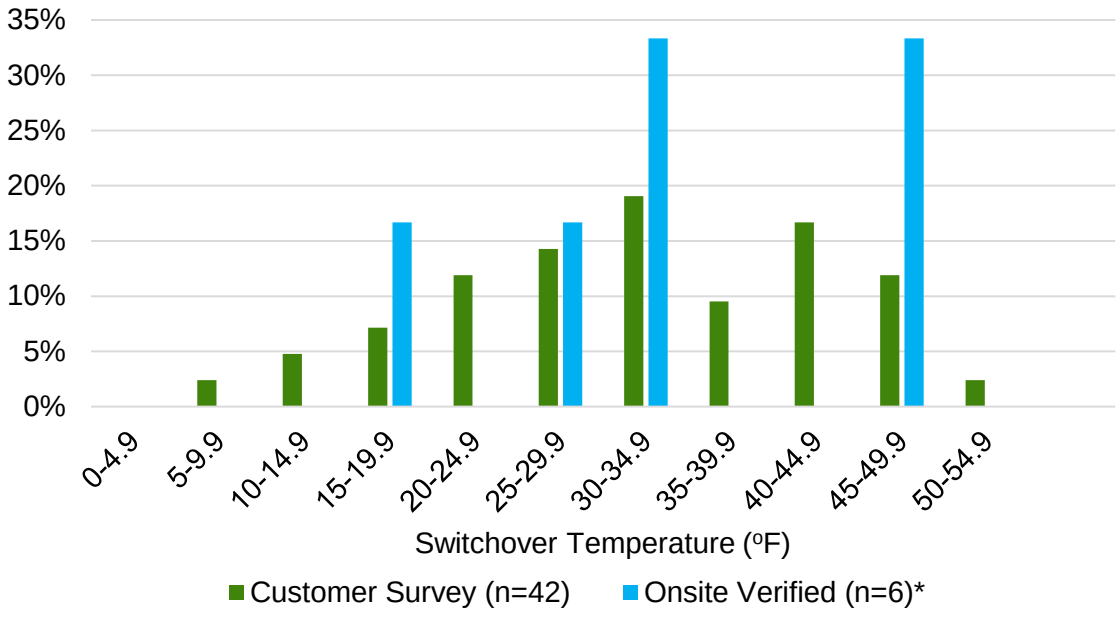
Figure 4-3. Survey Reported vs. Field-Verified Control Strategies – Mini-Split HP



*Survey respondents who knew their control strategy
Source: Evaluation Team Analysis

Figure 4-4 shows the switchover temperatures for the subset of customers that report using a switchover temperature and know what their switchover temperature setting is (customer survey), and the onsite verified switchover temperatures. Customers use a variety of switchover temperatures for their mini-split systems.

Figure 4-4. Survey Reported vs. Field-Verified Switchover Temperatures – Mini-Split HP



Survey sample includes 39 customers with pre-existing oil heat and 3 with oil heat. The team found no clear trends in differing switchover temperature distributions between the oil and propane groups.

*Onsite sample with clear switchover temperature

Source: Evaluation Team Analysis

The evaluation team conducted follow-up phone interviews with five mini-split HP customers that did not have a discernable switchover temperature through the metering study analysis. The purpose of these follow-up interviews was to determine if the customer had integrated controller(s) installed, how they interacted with them, and how they operated their mini-split HP and supplementary heating systems. The customers were able to provide enough detail to discern one of three HVAC operation strategies for this group:

- **Manually turning systems on and off:** Three of the customers used their various thermostats and controller apps to manually control when their mini-split HP and supplementary heating system were used. Two customers indicated they tried to use their mini-split HP for heating when it was warmer outside and use their backup heating systems when it was colder outside. One of these customers uses their home as a vacation home and will switch their heating to the backup delivered fuel-fired heating when they do not occupy the home, as they do not trust the controller system to ensure the home is heated during periods where they are away from the home. They then use the manufacturer-provided app to switch to HP heating mode and raise the heating setpoint before they arrive at their vacation home. Another customer indicated they have an indirect water heater combined with their boiler and will therefore leave the boiler operational with a lower setpoint and use the manufacturer-provided app to control the mini-split HPs and increase temperature in specific zones of their home.

- **Implement a lead/lag control strategy:** One customer indicated that they changed their contractor-programmed hard switchover setpoint and instead implemented two setpoints with an intermediate lead/lag temperature range. In this control strategy, the

boiler is the only heating system operational below a specified temperature (e.g., 25°F), the HP is programmed as the primary (lead) system within a specified temperature range (e.g., 25°F-40°F) wherein the boiler will only provide heat if the mini-split HP cannot meet the heating loads, and the HP is the only heating system operational above the upper setpoint (e.g., 40°F). The team only identified one customer with this control strategy as part of the follow-up phone interviews but believes there to be a sizable frequency of customers with a similar control strategy through review of the site-specific runtime vs. outdoor air temperature plots developed through the metering study analysis (described in Section 2.7.2). Several sites showed overlapping operation with mini-split HP and boiler operation within a range of outdoor air temperatures.

- **Droop control strategy:** One customer indicated they use a droop control strategy for their mini-split HP and boiler systems. They will set the thermostat setpoint for their mini-split HP higher than their thermostat setpoint for their boiler system. The boiler will then provide heat only when the indoor temperature of the home falls to the lower setpoint programmed for the boiler system.

All five of the interviewed customers indicated that they controlled their mini-split HP through the manufacturer-provided apps.

For each of the sites in the mini-split HP metered sample without a clearly defined hard switchover setpoint, the team reviewed the runtime hours plots from the metering study analysis to determine if the majority of the heating load was being met by the HP or by the supplementary heating system and the approximate switchover temperature range (if any). The team them assigned each site to one of the control scenarios implemented in the building simulation models, as summarized in Table 4-2.[20] Each site was assigned to the control strategy scenarios that most accurately reflected the fraction of heating load being met by the mini-split HP and the supplementary heating system, respectively. The team applied these weights to the partial displacement building simulation results detailed in Section 2.6.2.

Table 4-2. Integrated Control Switchover Temperature Weights for Partial Displacement Measures

Control Strategy	Central HP Partial Displacement	Mini-Split HP Partial Displacement
5°F Switchover	15%	5%
15°F Switchover	10%	22%
30°F Switchover	45%	28%
45°F Switchover	30%	11%
Boiler below 25°F, HP primary 25°F-40°F, HP only above 40°F		35%
Total	**100%**	**100%**

Source: Evaluation Team Analysis

The program literature recommended a switchover temperature between 30°F and 40°F for most customers. The program could achieve higher measure impacts for central HP and mini-

[20] 6.2Appendix A summarizes updated switchover temperature weighting assumptions for the 2022-2024 program years based on planned program changes.

split HP measures by moving customers from the 45ºF switchover temperature bin into a lower temperature bin.

4.2 Building Simulation Results

This section summarizes the results of the building simulation analysis and presents the EO Fuel Displacement measure impact results.

4.2.1 Single-Family Building Simulation Results

As Section 2.6 details, the team calibrated the baseline EnergyPlus prototype models to ensure they accurately predicted the electric heating, cooling, and non-HVAC loads as determined from the monthly HVAC load disaggregation analysis for each model group.

After calibrating the baseline model input assumptions, the team then ran an iterative process to swap the HVAC system types in the model and applied the efficiency assumptions for each unique combination of building type, HVAC system type, and baseline case (existing equipment or new market baseline equipment). Table 2-12 in Section 2.6.2 outlines these efficiency values. After running the full set of baseline building models, the team then applied the baseline model weights outlined in Section 3.1 to derive the weighted baseline consumption for each measure type.

Table 4-3 shows the annual end use electricity consumption and delivered fuels energy consumption for the calibrated baseline models, each iterative baseline model run with the various existing and new (market baseline) HVAC system types, the baseline weights applied for each measure group, and the weighted baseline consumption for each measure group by applying the baseline weights to the individual model run results. These results are scaled to the 2,400 SF single family prototype model size.

Table 4-3. Baseline Building End Use Consumption, Normal Year

HVAC Equipment Types and Measure Groups	kWh Heating	kWh Cooling	kWh non-HVAC	kWh Total	MMBtu Fossil Fuels	Baseline Weights		
						Central HP with Fuel-Fired Heating Baseline	Mini-Split HP with Fuel-Fired Heating Baseline	Mini-Split HP with Electric Resistance Heating Baseline
Cooling								
Existing-Central AC		1,590				18%	4%	6%
Existing-Mini-Split HP		1,277					2%	1%
Existing-Room AC		536				2%	12%	20%
Market Baseline-CAC		1,462				41%	10%	5%
Market Baseline-Mini-Split HP		1,467				17%	11%	10%
Market Baseline-Room AC		551				13%	32%	21%
No AC		-				9%	30%	37%
Total Cooling Weight						100%	100%	100%
Heating								
Existing-Propane Furnace	958				78.9	1%	4%	
Existing-Oil Furnace	958				83.2	26%	13%	1%
Existing-Gas Boiler	604				83.4			
Existing-Propane Boiler	604				77.2		7%	3%
Existing-Oil Boiler	604				81.3	47%	68%	
Existing-Mini-Split HP	8,272				-			1%
Market Baseline-Gas Furnace	958				71.7			5%
Market Baseline-Propane Furnace	958				71.7	6%		1%
Market Baseline-Oil Furnace	958				77.8	14%	2%	
Market Baseline-Gas Boiler	604				77.2		3%	
Market Baseline-Propane Boiler	604				81.5	1%		
Market Baseline-Oil Boiler	604				76.9	4%	2%	3%
Market Baseline-Central HP	9,842				-	0%		
Market Baseline-Mini-Split HP	7,931				-	0%	0%	0%
Electric Resistance	17,285				-		2%	85%
Total Heating Weight						100%	100%	100%
Central HP with Pre-Retrofit Fuel-Fired Heat, Blended Baseline*	774	1,218	7,576	9,568	80.5			
Mini-Split HP with Pre-Retrofit Fuel-Fired Heat, Blended Baseline*	952	625	7,576	9,154	79.6			
Mini-Split HP with Pre-Retrofit Electric Resistance Heat, Blended Baseline*	14,969	552	9,402	24,923	10.0			

*The blended baseline consumption applies the baseline weights to the consumption for each individual HVAC equipment type and measure group

Source: Evaluation Team Analysis

After running the series of baseline building models, the team adjusted the building simulation models to add a HP, applied program-rebated efficiency values for the HP, and applied the integrated controller switchover temperature strategies as Section 2.6.2 details.[21] The end use consumption for each post-retrofit model run is provided in Table 4-4 for central HPs, and Table 4-5 for mini-split HPs. Similar to the baseline model runs, the post-retrofit model results are provided for the 2,400SF single-family prototype model.

These results indicate that the average program installation (partial displacement blended result in the tables below) leads to average measure impacts that are between those of the 15°F or 30°F installations, respectively.[22]

Table 4-4. Post-Retrofit Model End Use Consumption, Normal Year – Central HP

Post-Retrofit Model Scenario	kWh Heating	kWh Cooling	kWh non-HVAC	kWh Total	MMBtu Delivered Fuel	Partial Displacement Control Weight
Oil Heating Fuel						
Full Displacement	9,015	1,079	7,576	17,670	-	
Partial Displacement (5°F Switchover)	7,654	1,094	7,576	16,324	0.7	15%
Partial Displacement (15°F Switchover)	6,684	1,094	7,576	15,354	8.4	10%
Partial Displacement (30°F Switchover)	3,249	1,094	7,576	11,919	42.9	45%
Partial Displacement (45°F Switchover)	1,423	1,094	7,576	10,093	70.7	30%
Partial Displacement Blended Result	5,064	1,094	7,576	13,734	29.6	100%
Propane Heating Fuel						
Full Displacement	9,015	1,079	7,576	17,670	-	
Partial Displacement (5°F Switchover)	7,654	1,094	7,576	16,324	0.7	15%
Partial Displacement (15°F Switchover)	6,684	1,094	7,576	15,354	8.0	10%
Partial Displacement (30°F Switchover)	3,249	1,094	7,576	11,919	41.2	45%
Partial Displacement (45°F Switchover)	1,423	1,094	7,576	10,093	67.9	30%
Partial Displacement Blended Result	5,064	1,094	7,576	13,734	28.4	100%

Source: Evaluation Team Analysis

[21] Based on the results of the customer survey and subsequent metering study, the team found no clear trends in differing switchover temperature distributions between the oil and propane groups. Therefore, the team applied the same switchover temperature distributions between the oil and propane measure groups for the 2021.

[22] 6.2Appendix A summarizes updated switchover temperature weighting assumptions for the 2022-2024 program years based on planned program changes.

Table 4-5. Post-Retrofit Model End Use Consumption, Normal Year – Mini-Split HP

Post-Retrofit Model Scenario	kWh Heating	kWh Cooling	kWh non-HVAC	kWh Total	MMBtu Delivered Fuel	Partial Displacement Control Weight
Oil Heating Fuel						
Full Displacement (Elec Resistance Backup)	8,374	909	9,401	18,684	-	
Full Displacement (Fuel Boiler Baseline)	7,298	996	7,576	15,870	-	
Partial Displacement (5°F Switchover)	6,065	920	7,576	14,561	0.7	5%
Partial Displacement (15°F Switchover)	5,463	920	7,576	13,959	8.3	22%
Partial Displacement (30°F Switchover)	2,246	920	7,576	10,742	42.9	28%
Partial Displacement (45°F Switchover)	952	920	7,576	9,448	71.4	11%
Partial Displacement (Under 25°F Fuel-Fired Only, 25°F-40°F HP primary, Over 40°F HP Only)	4,139	920	7,576	12,635	29.6	35%
Partial Displacement Blended Result	3,649	920	7,576	12,145	31.9	100%
Propane Heating Fuel						
Full Displacement (Elec Resistance Backup)	8,374	909	9,401	18,684	-	
Full Displacement (Fuel Boiler Baseline)	7,298	996	7,576	15,870	-	
Partial Displacement (5°F Switchover)	6,065	920	7,576	14,561	0.7	5%
Partial Displacement (15°F Switchover)	5,463	920	7,576	13,959	8.6	22%
Partial Displacement (30°F Switchover)	2,246	920	7,576	10,742	44.0	28%
Partial Displacement (45°F Switchover)	952	920	7,576	9,448	73.2	11%
Partial Displacement (Under 25°F Fuel-Fired Only, 25°F-40°F HP primary, Over 40°F HP Only)	4,139	920	7,576	12,635	30.4	35%
Partial Displacement Blended Result	3,649	920	7,576	12,145	32.7	100%

Source: Evaluation Team Analysis

Next, the team calculated the EO fuel displacement measure impact as the difference between the baseline building simulation model consumption and the post-retrofit model consumption. Table 4-6 provides the electric and delivered fuels impact for each measure at the per home level using the 2,400 SF single-family prototype home size. The table also includes the HP capacity assumption for each model case.

Table 4-6. EO Fuel Displacement Single-Family Measure Savings (Per Home, 2,400 SF Prototype Model, 2021 Program Year)

Measure and BCR ID	kWh Heating	kWh Cooling	kWh Total	MMBtu Delivered Fuel	kW System Peak*	kW System On Peak*	kW Seasonal Peak*	kW Max Peak*	kW System Peak*	kW System On Peak*	kW Seasonal Peak*	kW Max Peak*	Tons Installed Assump-tion**
Mini-Split HP Integrated Controls Retrofit Oil E19A2c270	-2,697	-	-2,697	39.5	-	-	-	-	-1.06	-0.73	-0.80	-1.15	4.5
Mini-Split HP Integrated Controls Retrofit, Propane E19A2c269	-2,697	-	-2,697	40.6	-	-	-	-	-1.06	-0.73	-0.80	-1.15	4.5
Central Ducted HP Partially Displacing Existing Furnace, Oil E19A2c266	-2,932	148	-2,783	38.9	0.16	0.05	0.15	0.18	-1.12	-0.78	-0.82	-1.11	3.5
Central Ducted HP Partially Displacing Existing Furnace, Propane E19A2c265	-2,932	148	-2,783	40.6	0.16	0.05	0.15	0.18	-1.12	-0.78	-0.82	-1.11	3.5
Central Ducted HP Fully Displacing Existing Furnace, Oil E19A2c272	-8,241	163	-8,078	80.3	0.18	0.06	0.17	0.20	-3.21	-2.21	-2.39	-3.38	4.5
Central Ducted HP Fully Displacing Existing Furnace, Propane E19A2c271	-8,241	163	-8,078	80.3	0.18	0.06	0.17	0.20	-3.21	-2.21	-2.39	-3.38	4.5

Measure and BCR ID	kWh Heating	kWh Cooling	kWh Total	MMBtu Delivered Fuel	kW System Peak*	kW System On Peak*	kW Seasonal Peak*	kW Max Peak*	kW System Peak*	kW System On Peak*	kW Seasonal Peak*	kW Max Peak*	Tons Installed Assump-tion**
Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Oil E19A2c268	-2,696	-365	-3,062	48.1	-0.45	-0.15	-0.40	-0.51	-1.00	-0.71	-0.72	-0.97	3.2
Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Propane E19A2c267	-2,696	-365	-3,062	47.3	-0.45	-0.15	-0.40	-0.51	-1.00	-0.71	-0.72	-0.97	3.2
Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Oil E19A2c273	-6,346	-441	-6,787	80.0	-0.55	-0.19	-0.49	-0.61	-2.44	-1.69	-1.80	-2.52	4.5
Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Propane E19A2c274	-6,346	-441	-6,787	80.0	-0.55	-0.19	-0.49	-0.61	-2.44	-1.69	-1.80	-2.52	4.5
Mini-Split HP Fully Displacing Electric Resistance E19A2c256	6,595	-344	6,252	10.1	-0.43	-0.15	-0.38	-0.48	4.35	2.13	3.79	6.93	2.7

*Demand savings calculated as the product of the energy savings (kWh) by the Demand Impact Model peak demand factors for each peak period (Demand Impact Model Update 2021-02-11)

**Tons assumption based average participant installed tonnage in 2019, scaled to 2,400 SF prototype model home size

Source: Evaluation Team Analysis

The team then normalized the measure impacts per ton by dividing the per home impacts by the average installed HP capacity for each measure type at the 2,400 SF home size. Table 4-7 provides the EO fuel displacement measure impacts at the per installed ton level for the 2021 program year.[23] The team recommends that the MA PAs use these impact values for future implementation and planning purposes.[24]

Table 4-7. EO Fuel Displacement Single-Family Measure Savings (Per Ton, 2021 Program Year)

Measure and BCR ID	kWh Heating	kWh Cooling	kWh Total	MMBtu Delivered Fuel	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak
Mini-Split HP Integrated Controls Retrofit Oil E19A2c270	-599	-	-599	8.8	-	-	-	-	-0.24	-0.16	-0.18	-0.26
Mini-Split HP Integrated Controls Retrofit, Propane E19A2c269	-599	-	-599	9.0	-	-	-	-	-0.24	-0.16	-0.18	-0.26
Central Ducted HP Partially Displacing Existing Furnace, Oil E19A2c266	-838	42	-795	11.1	0.05	0.02	0.04	0.05	-0.32	-0.22	-0.24	-0.32
Central Ducted HP Partially Displacing Existing Furnace, Propane E19A2c265	-838	42	-795	11.6	0.05	0.02	0.04	0.05	-0.32	-0.22	-0.24	-0.32
Central Ducted HP Fully Displacing Existing Furnace, Oil E19A2c272	-1,831	36	-1,795	17.9	0.04	0.01	0.04	0.04	-0.71	-0.49	-0.53	-0.75
Central Ducted HP Fully Displacing Existing Furnace, Propane E19A2c271	-1,831	36	-1,795	17.9	0.04	0.01	0.04	0.04	-0.71	-0.49	-0.53	-0.75
Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Oil	-843	-114	-957	15.0	-0.14	-0.05	-0.13	-0.16	-0.31	-0.22	-0.23	-0.30

[23] 6.2Appendix A summarizes updated switchover temperature weighting assumptions and measure-level savings for the 2022-2024 program years

[24] The team recommends that PAs and implementers use the 'per ton' results for single-family homes to inform deemed savings planning assumptions for the multifamily segment. The PAs and EEAC could consider a separate study focused on multifamily measure impacts for full and partial displacement with various pre-exiting heating fuel types.

Measure and BCR ID	kWh Heating	kWh Cooling	kWh Total	MMBtu Delivered Fuel	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak
E19A2c268												
Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Propane E19A2c267	-843	-114	-957	14.8	-0.14	-0.05	-0.13	-0.16	-0.31	-0.22	-0.23	-0.30
Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Oil E19A2c273	-1,410	-98	-1,508	17.8	-0.12	-0.04	-0.11	-0.14	-0.54	-0.38	-0.40	-0.56
Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Propane E19A2c274	-1,410	-98	-1,508	17.8	-0.12	-0.04	-0.11	-0.14	-0.54	-0.38	-0.40	-0.56
Mini-Split HP Fully Displacing Electric Resistance E19A2c256	2,443	-127	2,316	3.8	-0.16	-0.05	-0.14	-0.18	1.61	0.79	1.40	2.57

Source: Evaluation Team Analysis

Finally, the team then calculated the impacts at the average 'per home' level by multiplying the 'per ton' impacts in Table 4-7 by the average 2019 program participant installed tonnage, given in Table 2-21 in Section 2.6.2.

Table 4-8 provides average 'per home' savings for the average 2019 program participant for each measure.[25]

Table 4-8. EO Fuel Displacement Single-Family Measure Savings (Per Home, Average Participant, 2021 Program Year)

Measure and BCR ID	kWh Heating	kWh Cooling	kWh Total	MMBtu Deliver-ed Fuel	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak	Tons Installed Assump-tion*
Mini-Split HP Integrated Controls Retrofit Oil E19A2c270	-1,678	-	-1,678	24.6	-	-	-	-	-0.66	-0.45	-0.50	-0.71	2.8
Mini-Split HP Integrated Controls Retrofit, Propane E19A2c269	-1,678	-	-1,678	25.2	-	-	-	-	-0.66	-0.45	-0.50	-0.71	2.8
Central Ducted HP Partially Displacing Existing Furnace, Oil E19A2c266	-3,099	157	-2,942	41.1	0.17	0.06	0.16	0.19	-1.18	-0.82	-0.87	-1.18	3.7
Central Ducted HP Partially Displacing Existing Furnace, Propane E19A2c265	-3,099	157	-2,942	42.9	0.17	0.06	0.16	0.19	-1.18	-0.82	-0.87	-1.18	3.7
Central Ducted HP Fully Displacing Existing Furnace, Oil E19A2c272	-8,607	171	-8,437	83.9	0.19	0.06	0.18	0.21	-3.35	-2.31	-2.50	-3.53	4.7
Central Ducted HP Fully Displacing Existing Furnace, Propane E19A2c271	-8,607	171	-8,437	83.9	0.19	0.06	0.18	0.21	-3.35	-2.31	-2.50	-3.53	4.7

[25] The team recommends that PAs and implementers use the 'per ton' results for single-family homes to inform deemed savings planning assumptions for the multifamily segment. The PAs and EEAC could consider a separate study focused on multifamily measure impacts for full and partial displacement with various pre-exiting heating fuel types.

Measure and BCR ID	kWh Heating	kWh Cooling	kWh Total	MMBtu Deliver-ed Fuel	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak	Tons Installed Assump-tion*
Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Oil E19A2c268	-2,359	-319	-2,679	42.1	-0.40	-0.14	-0.35	-0.44	-0.87	-0.62	-0.63	-0.85	2.8
Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Propane E19A2c267	-2,359	-319	-2,679	41.4	-0.40	-0.14	-0.35	-0.44	-0.87	-0.62	-0.63	-0.85	2.8
Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Oil E19A2c273	-5,500	-382	-5,882	69.3	-0.48	-0.17	-0.42	-0.53	-2.11	-1.47	-1.56	-2.19	3.9
Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Propane E19A2c274	-5,500	-382	-5,882	69.3	-0.48	-0.17	-0.42	-0.53	-2.11	-1.47	-1.56	-2.19	3.9
Mini-Split HP Fully Displacing Electric Resistance E19A2c256	4,885	-255	4,631	7.5	-0.32	-0.11	-0.28	-0.35	3.22	1.58	2.80	5.13	2.0

*Tons assumption based on average participant installed tonnage (2019 program implementation)

Source: Evaluation Team Analysis

Table 4-9 shows a comparison of the average per home measure impacts between the current EO evaluation study results and the prior EO Optimization Model Impacts delivered to the PAs in March 2021.

Table 4-9. EO Fuel Displacement Single-Family Measure Savings Comparison Between Prior and Current EO Study (Per Home, Average Participant)

Measure and BCR ID	Prior Study Results		Current Study Results		Comparison of Study Results	
	kWh Total	MMBtu Delivered Fuel	kWh Total	MMBtu Delivered Fuel	% Difference kWh	% Difference MMBtu
Mini-Split HP Integrated Controls Retrofit Oil E19A2c270	-3,941	49.7	-1,678	24.6	57%	-51%
Mini-Split HP Integrated Controls Retrofit, Propane E19A2c269	-7,106	90.2	-1,678	25.2	76%	-72%
Central Ducted HP Partially Displacing Existing Furnace, Oil E19A2c266	-3,346	42.1	-2,942	41.1	12%	-2%
Central Ducted HP Partially Displacing Existing Furnace, Propane E19A2c265	-5,737	76.5	-2,942	42.9	49%	-44%
Central Ducted HP Fully Displacing Existing Furnace, Oil E19A2c272	-6,082	86.7	-8,437	83.9	-39%	-3%
Central Ducted HP Fully Displacing Existing Furnace, Propane E19A2c271	-6,082	86.7	-8,437	83.9	-39%	-3%
Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Oil E19A2c268	-3,941	49.7	-2,679	42.1	32%	-15%
Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Propane E19A2c267	-7,106	90.2	-2,679	41.4	62%	-54%
Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Oil E19A2c273	-7,468	102.3	-5,882	69.3	21%	-32%
Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Propane E19A2c274	-7,468	102.3	-5,882	69.3	21%	-32%
Mini-Split HP Fully Displacing Electric Resistance E19A2c256	5,039	0	4,631	7.5	-8%	-

Source: Evaluation Team Analysis

The following is a summary of the main drivers to changes in impacts between the prior study and current study:

- **Baseline Heating Loads:** The prior EO study used heating loads sourced from the RES34 Home Energy Services (HES) Impact Evaluation.[26] The baseline heating loads referenced from this report were about 30% higher than those determined through the current study (e.g., 87 MMBtu vs. 68 MMBtu for a delivered fuel-fired furnace baseline, 102 MMBtu vs. 77 MMBtu for delivered fuel-fired boiler baseline).[27] This is the primary driver behind changes in impacts between the prior and current study. The lower base heating loads in the current study lead to lower heating impacts relative to the prior study, especially for the mini-split HP measures.

    - The prior study performed a gas end use disaggregation to derive space heating loads for customers who participated in the HES program.

    - The current study used electric bill disaggregation from the 2019 EO participants to determine kWh/sf used to heat electrically heated homes and for homes with furnace fan/boiler pumps (methodology described in Section 2.5 with results in Section 4.3). The team then calibrated the building simulation models to this heating kWh consumption (described in Section 2.6.1). The model then predicts the MMBtu for delivered fuels based on the heating loads and efficiency specifications for each unique heating system type.

- **Tonnage Assumptions:** The prior study assumed 2.5 tons per home for partial displacement installations and 4 tons per home for full displacement installations. The current study assumes variable average installed capacities per customer, summarized in Table 2-21 in Section 2.6.2. These differences in installed tonnage per home also drive differences in per home impacts between the prior and current studies.

- **Baseline Cooling Assumptions/Weights:** Another driving factor in differences between the current and prior studies is the application of the baseline heating and cooling weights to derive a blended baseline consumption for each measure type (described in Section 3.1). This method was not done in the prior study. This leads to lower baseline cooling kWh consumption in the current study relative to the prior study, which leads to lower cooling kWh impacts.

- **Heat Pump Efficiency Values:** The prior EO study assumed the program threshold values for HP unit efficiency, whereas the current study uses the average installed unit efficiency values from the 2019 EO fuel displacement installations for both central HP and mini-split HPs. The current study efficiency values for heat pumps are higher than those in the prior study, which indicates the post-retrofit consumption for heat pumps is

[26] https://ma-eeac.org/wp-content/uploads/RES34_HES-Impact-Evaluation-Report-with-ES_FINAL_29AUG2018.pdf
The RES34 study performed a gas end use disaggregation to derive space heating loads for customers who participated in the HES program.

[27] As a point of reference, the Phase 4 Residential Baseline Study performed a gas end use disaggregation on 3,389 baseline study customers with natural gas service and estimated gas heating consumption between 55MMBtu for single-family attached dwellings and 75MMBtu for single-family detached dwellings.
The study also analyzed average delivered fuel oil deliveries for a sample of 55 customers. The weather-normalized annual consumption for fuel oil delivery records collected for the 2016-2019 calendar years was 77 MMBtu, however, the study caveats this value saying this estimate should be treated as a lower bound estimate of annual fuel oil consumption because some customers may have provided incomplete fuel oil delivery records over the data collection period.
https://ma-eeac.org/wp-content/uploads/RES-1-Residential-Baseline-Study-Ph4-Comprehensive-Report-2020-04-02.pdf

lower than those in the prior study. This contributes to higher savings relative to the prior study, but not enough to overcome the decreased impacts due to the changes outlined above.

- Central HP unit efficiencies:
  - Prior study: 15-16 SEER, 9-9.5 HSPF
  - Current study: Current: 16.9 SEER, 9.9 HSPF
- Mini-split HP unit efficiencies:
  - Prior study: 15-18 SEER, 10.0 HSPF
  - Current study: 19.8 SEER, 10.9 HSPF

- **Switchover Temperatures:** The prior EO study assumed a set 30°F switchover temperature for oil baseline systems and 15°F for propane baseline systems. The current study uses the results of the customer survey and onsite metering study to determine a distribution of switchover temperatures and then weights the results of the separate building simulation model runs by these distributions (as Section 2.6.2 describes). The team assumed the same switchover temperature distributions between oil and propane baseline system types, as the customer survey and onsite metered results did not support a separate switchover assumptions between these system types. This is consistent with the current program recommendations, where the recommended switchover temperatures do not vary by oil or propane system types. This change led to lower impacts for propane baseline systems relative to the prior study.

4.2.2 Multifamily Building Simulation Results

Table 4-10 provides the baseline and post-retrofit model end use consumption for the calibrated multifamily building model. The baseline and post-retrofit model consumption values are provided on a per apartment basis. The team assumes a 1 ton mini-split installation per 700 SF unit size, so the mini-split HP full displacement (electric resistance baseline) measure savings are provided on a per ton basis. The team recommends that the MA PAs use these impact values for future implementation and planning purposes.

Table 4-10. EO Fuel Displacement Baseline and Post-Retrofit End Use Consumption and Multifamily Measure Saving, Normal Year (Per Ton)

HVAC Equipment Types and Measure Savings	kWh Heating	kWh Cooling	kWh Total	MMBtu Delivered Fuel	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak
Baseline Model: Electric Resistance Heating, Room AC Cooling	3,648	267	6,806	-	0.32	0.13	0.28	0.35	1.87	1.07	1.53	2.57
Post-Retrofit Model: Mini-Split HP	1,675	204	4,769	-	0.26	0.10	0.22	0.29	0.66	0.45	0.49	0.71
Measure Savings: Mini-Split Full Displacement, Electric Resistance Backup	1,974	63	2,037	-	0.06	0.03	0.06	0.06	1.21	0.62	1.04	1.86

Source: Evaluation Team Analysis

4.3 Bill Disaggregation and Billing Analysis Results

The team used a variable based degree day (VBDD) weather-based regression model to analyze billing data for customers participating in the EO fuel displacement measures. The VBDD model was used to develop typical monthly and annual electricity consumption baselines for both the pre-retrofit period and post-retrofit period, disaggregating consumption into heating, cooling, and the base non-HVAC load. The team the pre-retrofit period bill disaggregation results to calibrate the baseline building simulation models (as described in Section 2.6.1). The post-retrofit bill disaggregation (and resulting savings) were used as a comparison against the building simulation savings result, but are not used directly to inform measure impacts. The team did not use the results of this analysis to update the recommended measure impact values and instead recommends using the results of the building simulation task. This is because the change in electric consumption in the post-retrofit period electric bills can be influenced by several factors beyond the installation of a new HP, including any simultaneous changes to the building or equipment installed alongside the heat pump (e.g., weatherization of the envelope, efficient lighting or water fixtures installed, change to thermostat heating or cooling setpoints). The team uses the building simulation task to isolate the impacts of the HP. The electric load increased in the post-retrofit period for participants in the treatment groups involving a partial displacement from delivered fuel to a mini-split HP or central HP, with the largest increase occurring in the heating load.

Participants who switched from an electric resistance heating system to a mini-split HP, experienced an overall decrease in heating load in the post-retrofit period due to increase efficiency of their heating system.

Table 4-11. Average Annual Household Consumption by Treatment Group in the Pre- and Post-Retrofit Period

Treatment		Base Non-HVAC Load (kWh)	Heating Load (kWh)	Cooling Load (kWh)	Total Load (kWh)
Full Displacement Electric Resistance to Mini-Split HP	Pre-Retrofit	5,927	7,868	959	14,755
	Post-Retrofit	6,197	7,319	1,034	14,550
	Percent Change	4.6%	-7.0%	7.8%	-2.1%
Partial Displacement Delivered Fuel Boiler to Mini-Split HP	Pre-Retrofit	5,903	1,369	920	8,192
	Post-Retrofit	7,219	3,155	1,235	11,609
	Percent Change	22.3%	130.5%	34.2%	41.7%
Partial Displacement Delivered Fuel Furnace to Central HP	Pre-Retrofit	6,500	1,526	1,168	9,195
	Post-Retrofit	7,558	3,736	1,013	12,307
	Percent Change	16%	145%	-13%	34%

Source: Evaluation Team Analysis

5. Process Evaluation Results

This section reviews both the customer and contractor experience with fuel displacement equipment and rebate offerings, providing insights from the customer survey, multifamily owner/operator interviews, and contractor and HVAC distributor interviews.

Figure 5-1 displays the steps in the customer and contractor experience the team explored as a part of the process evaluation.

Figure 5-1. Customer and Contractor Experience

Source: Evaluation Team Analysis

5.1 Market Awareness and Motivations

This section summarizes how customers became aware of the fuel displacement equipment and the rebates, along with what motivated them to install their new equipment. It also details contractor sales tactics and market insights from distributors.

Section Summary

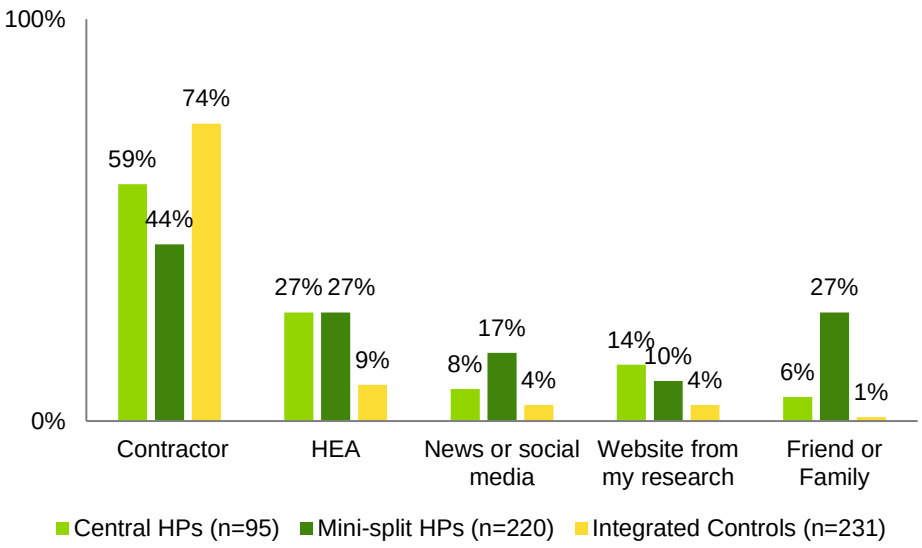
Contractors are a primary source of awareness for customers, and for customers, being able to add or upgrade cooling is a major motivator for installing a HP. In many cases, integrated controls are positioned as a pathway to rebate eligibility and reduced equipment costs.

Distributors see significant growth in the HP market, especially for mini-split HPs, and room for technology advancements for integrated controls as that market matures.

5.1.1 Customer Awareness

Single-family customers rely primarily on their contractor to become aware of the eligible equipment, as Figure 5-2 shows. This is especially prevalent for integrated controls, which almost three-fourths of customers learned about from their contractor.

Figure 5-2. How Customers Learned About the Equipment



Source: Customer survey, "How did you learn about the [equipment] you had installed?", (C12).

Most single-family customers learned about the program rebate from their contractor or a Mass Save-related source like the program website or a program-approved energy auditor (Table 5-1). Supporting these findings about the equipment (Figure 5-2) and the program rebate (Table 5-1), program staff reported they primarily rely on contractors to reach customers and make them aware of the program offering, although they also noted that the website is used as a tool to reach customers performing online research.

Table 5-1. How Customers Learned about the Rebate (multiple response)

Source	N	Percent
From my contractor	**134**	**42%**
Mass Save-related sources	**128**	**40%**
Program website/pages	53	17%
Energy auditor	48	15%
Direct email or mailing from Program Sponsor	20	6%
Utility bill insert	7	2%
Other Sources	**54**	**17%**
Family, friends, word-of-mouth	27	9%
Mass Clean Energy Center HP program	13	4%
On the web or social media	4	1%
Other	10	3%
Total	**316**	**99%***

*Does not total due to rounding

Source: Customer survey, "Where did you first learn about the rebate you got for your [equipment]?", (C12).

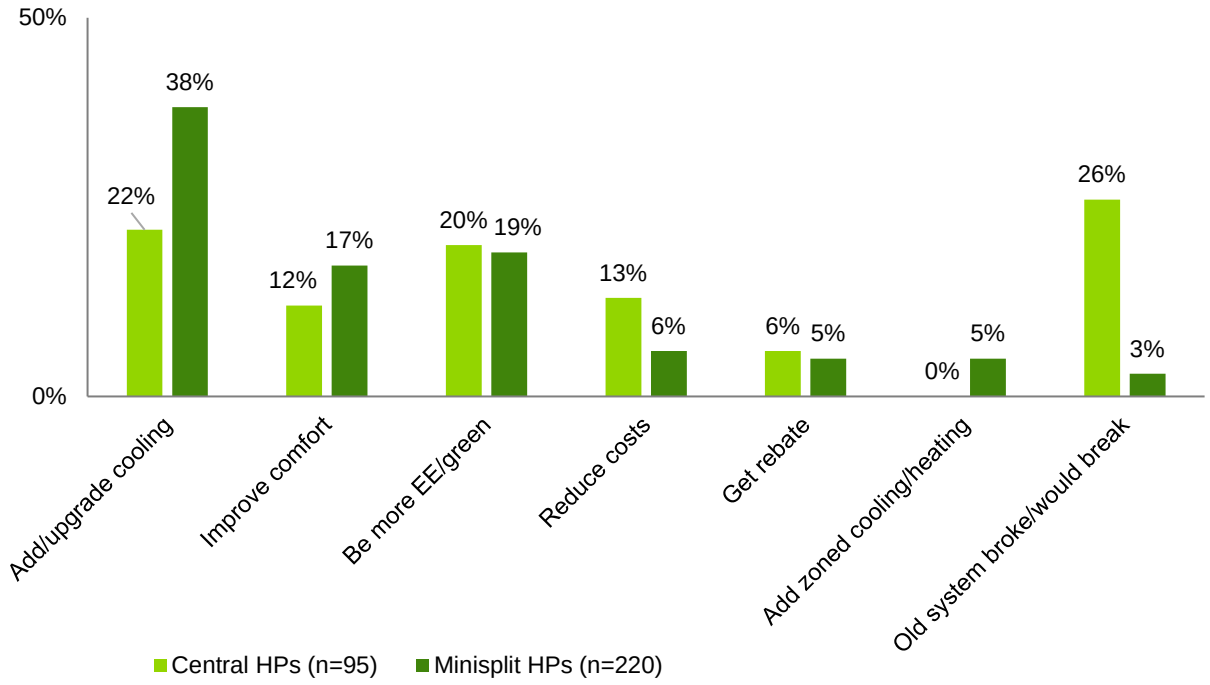
5.1.1.1 Multifamily Awareness

Three of the four interviewed low income multifamily building owners/operators became aware of HPs and the HP offering through a variety of sources, including through a contractor (1), the MA Department of Housing and Community Development (1), and via direct program outreach (1). The fourth organization was unsure of how they became aware. All four multifamily owners/operators reported that contractors for affordable housing properties are typically selected through a bidding process where the project is awarded to the lowest cost bidder.

5.1.2 Customer Motivations

Customers, especially mini-split customers, cited adding or upgrading cooling as a main motivator for installing a HP. The largest share of mini-split owners (38%) said their main reason for installing a mini-split was to add or upgrade their cooling system (Figure 5-3). Central HP owners had a wider variety of reasons for installing their new system, with the highest motivator being that their old system broke or was about to break (26%), followed by adding or upgrading cooling (22%). Another 52% of mini-split customers said that adding or upgrading cooling was a secondary reason for installing the system.

Figure 5-3. Primary Reason for Installing a Heat Pump



Source: Customer survey, "What was your main reason for installing a [equipment]?", (C3 and C5).

Customers with integrated controls (n=231) said they installed the controls to have more efficient heating and cooling systems (44%), because their contractor recommended it (42%), and to get the rebate (41%). A smaller number (28%) also mentioned convenience as a motivator.

5.1.2.1 Multifamily Motivations

The multifamily owners/operators we interviewed said they installed mini-split HPs because they wanted to reduce their energy bills (n=4). All of the multifamily owners/operators interviewed stated that their properties are master-metered, making them responsible for paying the energy bills on behalf of their tenants. The units typically had electric baseboards before the HP installation and owners/operators reported that energy bills were high. The ability to see both a significant reduction in their energy bills and have the program pay for the full replacement of electric baseboards with HPs were strong motivators to participate.

5.1.3 Contractor Sales Tactics

Of the 18 contractors interviewed, efficiency benefits (n=9) and comfort capabilities (n=7) were discussed most often with potential mini-split customers. For instance, contractors mention the ability to individually control the temperature in each room. When ducts are present in the home, contractors will also propose a central HP system (n=10) but will not propose a centralized system when no ducts are present due to increased installation costs.

Contractors reported that, when they speak with customers about integrated controls, they typically put them in context with being eligible for the rebate (n=14) and how the rebate helps them to afford both heating and cooling for the same, or slightly lower, price as an air conditioner (n=10).

5.1.4 Market Insights

Distributors also shared their insights on the market for fuel displacement technologies. They see a maturing market for mini-split HPs, and advances that have led to significant growth. One distributor has seen growth in the sales of central HPs as customers with ducts look to replace their aging fossil fuel equipment.

Table 5-2 summarizes distributor observations on factors that have promoted or inhibited the growth of fuel displacement technologies. These include the following themes:

- Market promoters:
  - **Advances in mini-split technology** contributing to versatility and efficiency
  - **Aging out of ducted fossil fuel systems** opening an opportunity for central HP installations
  - **Program rebates and available financing** to bring down equipment costs
  - **Distributor-provided training and support** to help contractors sell and service systems
- Market detractors:
  - **Ineffective contractor sales strategies** that rely on old, fossil fuel-based system solutions, pointing to a lack of awareness about the value that fuel displacement technologies can offer the customer
  - **Contractor hesitancy** with new or advanced technologies
  - **First generation kinks with integrated controls**, resulting in some contractors being less willing to adopt them or only willing to adopt them in certain circumstances

- **Workforce development needs,** resulting in some contractors turning down jobs or new opportunities to keep up with existing workloads

These observations may point to areas of opportunity the program can leverage to further support the market, like targeting early replacement opportunities, partnering with distributors on contractor training and support, and offering basic sales trainings. Distributors are often a trusted resource for the contractor market, and have access to resources, information, and training facilities that the program does not. The program should continue to leverage its relationships with distributors to partner on identifying and offering contractor trainings and support to further develop the market for fuel displacement technologies.

Table 5-2. Distributor Observations on Fuel Displacement Technologies

Theme	Related Distributor Quote
Market Promoters	
Technology advances in mini-splits	"Ductless has been the **number one selling equipment** across all segments whether it's boilers, anything central heating, anything from unitary heat pumps, air conditioning. **It's the most versatile. It's the most efficient.** The versatility that you get with each individual home is the most attractive, not only to [the] selling contractor, installing contractor, but also to the homeowner."
Aging out of ducted fossil fuel systems	"Ducted has now become something that more contractors are buying every day. And I think that's probably because we have **a lot of houses in Massachusetts that are already have duct work**. And to be able to use the inverter technology in conjunction with the existing duct work, **I think that became very, very easy for contractors to be able to start to install those, be able to talk about the large rebates that Mass Save has to offer.** So I just think it's something that it sort of came together at the same time, with the rebates, the new centrally ducted equipment that was on the market, and the fact that a lot of people in New England already had duct work."
Program rebates and available financing	"It's affordable **because of these rebates**. There are many **financing programs out there** that have come a long way to assist with these large purchases."
Distributor-provided training and support	"HVAC contractors are forced to do continuing education and learn about all these products that are coming out, but **they also depend on us, the distributor, to help them along with that.** With our own training programs and working with the manufacturers to put together a curriculum that is constructive and a good use of their time, **we invest a lot in educating our people, making sure that they're trained and making sure that they're outfitted with all the tools they need** to answer the phone and do technical support in-house so they don't have to always call the manufacturer. **They can just depend on us because ultimately we're the ones that sold them the equipment.** So we'd like to think that we're also the experts with not only selling it, but servicing it."
Market Detractors	
Ineffective contractor sales skills	"A lot of people are just going with the quick cookie cutter system, AC, separate heating system so I think **it really has to do with educating the contractor, [then] the contractor educates the homeowner, [and] that's where the sales I think are being driven**."
Contractor hesitancy with new/advanced technology	"Some guys are **afraid to get into it because all of the controls and the electronics** that are in the new ductless stuff, but as time goes by, I think more and more guys are..."
First generation kinks with integrated controls	"It's relatively new technology. **I'm sure there's going to be improvement down the road.** But this is the kind of the... Right now we're in the first generation of integrated controls…. **There'll be future generations that will be a lot easier to implement and to commission and to hook up**. I mean, it's just mind-boggling the technology."

Theme	Related Distributor Quote
Workforce development needs	"They need resources, they need younger talent coming into the trade. Just like any industry out there, **getting younger professionals to come into the trade is problematic**…. They have a ton of leads coming in, but they just don't have the manpower to get out and schedule them and install them in a timely fashion so they have to pass on a lot of work. But **our industry doesn't do a good job of making it attractive for younger people to go to trade school** or to look at any of the trades for that matter as an attractive career path."

Source: Distributor interviews and analysis.

5.2 Installation Experience

This section describes customer satisfaction with the installation, how customers and contractors report programming the integrated controls, and the contractor experience and barriers faced.

Section Summary

Overall, customers are very satisfied with the installation experience and the majority of contractors are setting the integrated control switchover temperature for them.

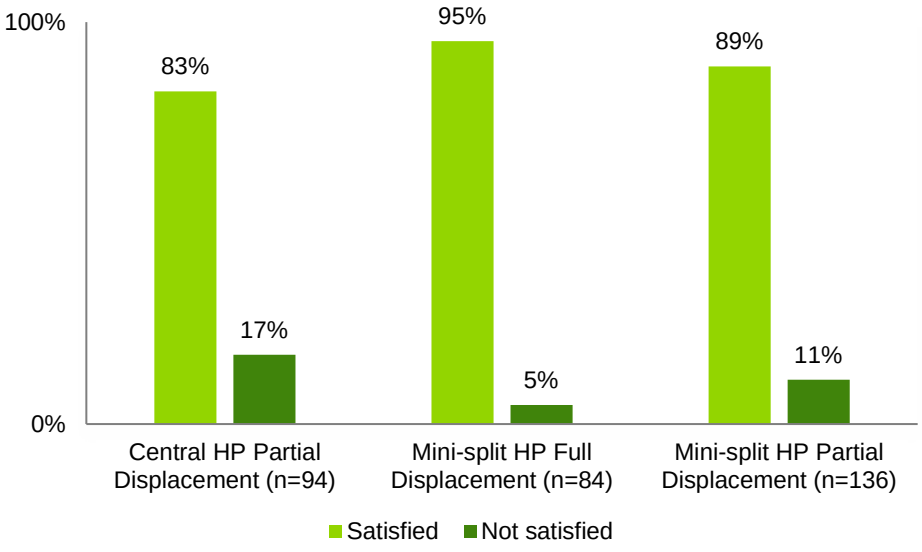
The contractor installation experience depends on where they sit on the adoption curve – while "early adopters" may have faced issues with integrated controls earlier on, they have overcome these and believe in the value that controls deliver and have been able to find solutions.

At the same time, other contractors not as far along the adoption curve face unresolved barriers and require additional program support and training.

5.2.1 Customer Satisfaction with the Installation

Most customers report being satisfied with the overall installation experience with their contractor (Figure 5-4). Mini-split HP owners that have fully displaced their previous system had the highest level of satisfaction with the overall installation experience, with 95% stating that were either satisfied or very satisfied.

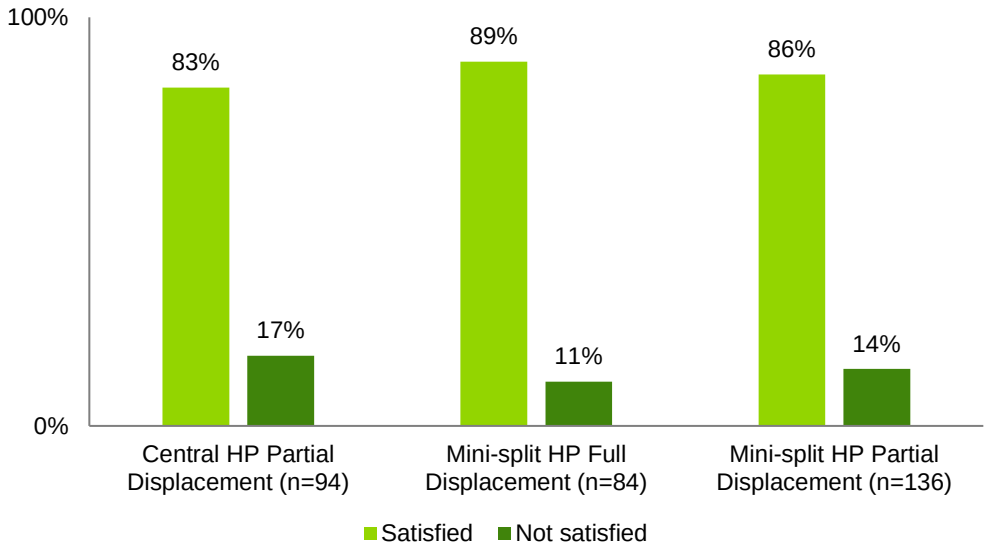
Figure 5-4. Customer Satisfaction with the Overall Installation Experience with their Contractor



Source: Customer survey, "Using a scale of 1-5, with 1 meaning "not at all satisfied" and 5 meaning "very satisfied", how satisfied are you with the following contractor experiences?", (C8c).

Customers are also satisfied with the information that contractors provided them about their new system, as Figure 5-5 shows.

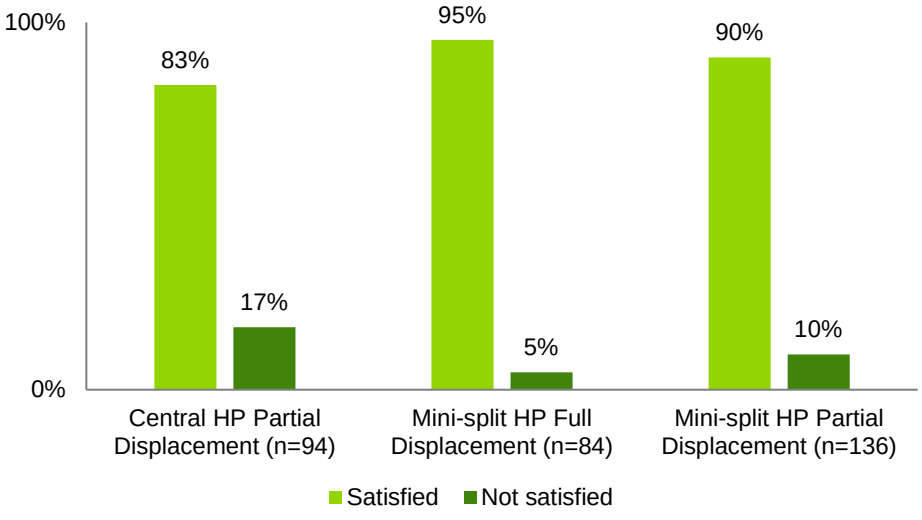
Figure 5-5. Customer Satisfaction with the Information Provided by the Contractor about their New System



Source: Customer survey, "Using a scale of 1-5, with 1 meaning "not at all satisfied" and 5 meaning "very satisfied", how satisfied are you with the following contractor experiences?", (C8b).

Customers were also asked about their satisfaction with the installation process (Figure 5-6). Again, mini-split HP owners that fully displaced their old systems report being the most satisfied (95%) with the installation process.

Figure 5-6. Customer Satisfaction with the Installation Process



Source: Customer survey, "Using a scale of 1-5, with 1 meaning "not at all satisfied" and 5 meaning "very satisfied", how satisfied are you with the following contractor experiences?", (C8a).

5.2.1.1 Multifamily Satisfaction with the Installation

All four multifamily owners and operators interviewed were very satisfied with their installation experience. Minor issues arose during or after installation, but owners/operators noted that these were resolved quickly by the contractor. As described by multifamily owners, these issues were to be expected due to the volume of the units installed and included a few equipment malfunctions or other minor maintenance issues.

5.2.2 Programming the Integrated Controls

The integrated controls are programmed to a specific outside temperature during the winter, at which heating will switch from the HP to the oil or propane system. Most (82%) customers reported that their contractor programmed the control for them (n=130). Customers were also asked what switchover temperature was initially set for their systems. While the program recommended 35ºF in 2019, a sizable group (43%) reported a switchover temperature above this guidance (Table 5-3). The program has since revised this guidance to a recommended setpoint of 30ºF-40ºF for both oil and propane systems.

Table 5-3. Customer-Reported Switchover Temperatures for Partial Displacement Installations (Degrees Fahrenheit)

Temperature Range	Mini-split HPs	Central HPs	Percent
More than 45ºF	1	2	4%
36ºF to 45ºF	10	24	40%
26ºF to 35ºF	11	13	28%
Less than 25ºF	16	8	28%
Total	38	47	100%

Source: Customer survey, "What OUTSIDE temperature did your contractor/you set the integrated control switchover temperature at?", (D9). This table does not include the results of question D13 (if the customer or contractor adjusted the switchover temperature after the initial programming).

The team also asked contractors what switchover temperatures they typically set. The temperatures set and approaches to determine the right temperature varied, with contractors seeking to balance various priorities for the customer, including efficiency and comfort. Of the 18 contractors interviewed, 12 answered. Seven set switchover temperatures between 26°F to 35°F, two set temperatures between 36°F and 45°F, and two contractors set temperatures lower than 25°F. Several contractors reported determining switchover temperature through trial and error to balance comfort, energy efficiency, and cost efficiency (n=7). Some contractors also used calculations or software from the manufacturer that considered the price of the fuels (n=3) or the manufacturer's manual (n=1) to set switchover temperatures.[28] Contractors noted that adjustments might be made based on customer preferences related to comfort, the use of solar, and whether customers are environmentally conscious and would like to avoid the use of fossil fuels.

[28] Only two contractors noted programming separate integrated control switchover temperatures based on the heat pump type (central HP vs. mini-split HP). One indicated they set the central HP at 40ºF and the mini-split HPs at 35ºF, which the other contractors noted the opposite settings for the system types.

A few contractors mentioned that adjusting the switchover temperature to better meet customer's needs is a frequent customer service call (n=3). Additionally, while several contractors (n=8) said that they prefer that customers do not learn how to change the settings to avoid problems with the control's performance, a few contractors (n=3) noted that they do teach their customers how to adjust the settings themselves.

The evaluation team's analysis through both process and impact assessments for this study does not point to an "ideal" switchover temperature setting for central HPs or mini-split HPs. However, our findings suggest that multiple factors must be considered when setting the switchover temperature and that these factors may vary by customer, contractor, or the program perspective, as Table 5-4 shows. Customers want to be comfortable, ensure their system reliability, reduce their overall energy costs, and may note other factors such as reducing greenhouse gas emissions or to be more environmentally conscious. Contractors want to close the project and meet program requirement, be responsive to customer preferences, but also may set switchover temperatures to avoid customer call backs (e.g., may not set the temperature too low). The program goals are to optimize overall energy use and reduce greenhouse gas emissions while reducing the overall energy costs for the customer. The Program Administrators could consider an additional study to explore optimal switchover temperatures further, and how to best balance needs across these different perspectives.

Table 5-4. What Factors are Considered When Setting and/or Adjusting Switchover Temperatures?

Customers want to…	Contractors want to…	Program wants to…
Be comfortable	Reduce customer call-back's	Optimize energy use
Set according to other priorities/preferences (be more energy efficient, reduce fossil fuel use, be environmentally conscious, etc.)	Be responsive to customer preferences and balance the different customer needs (between comfort, energy savings, etc.)	Reduce fossil fuel use and greenhouse gases
Reduce overall energy costs		Reduce overall energy costs for the customer

Source: Evaluation team analysis.

Table 5-5 includes contractor quotes on setting switchover temperatures to further expand on the considerations they make.

Table 5-5. Contractor Quotes: Setting the Integrated Control

Topic Area	Related Contractor Quote
Setting the Integrated Control	"We set it at 30 to 35 degrees. It is a balancing act between **comfort and energy savings**. If you put it lower, their energy bill will go up because the HP has to work harder."
	"We set it at 30 to 35 degrees. We've got some software from the [manufacturer 1]* rep that compares cost per million BTU by fuel type, and so the problem is we don't update it very often for the current price of oil, and different localities have different costs for electricity. So basically**, it comes down to a rule of thumb**. It's something in that range and if the customer's really interested, we can get into it but most people don't seem that interested."
	"With [manufacturer 1]* it's set to 40. With [manufacturer 2]* for central HPs, 30 to 35 degrees, **depends on manufacturer instructions**."

Topic Area	Related Contractor Quote
Guidance on Customer Interaction with Control Settings	"We try not to teach them too much technical within the system. **We don't want them in there because they may change settings that can hurt the system efficiency**. So we do have, there's switches on these controls where they could bypass it if it becomes a problem, and until we can get there. So there is a way, they can almost turn it off, so the old system is running. And then they let us know when we go there and make an adjustment. **So we try not to let them.** There's a few technical people that have done it and figured it out themselves, which is okay. **But it's really something you don't want the customer getting too involved with, because they could create more problems sometimes if they're not tech savvy**."
	"They can [change it], but with the [manufacturer 3]* control, it was not easy to do and it wasn't easy to explain**. It wasn't easy for the homeowner to figure it out. And then when they would try to change it, they would mess up the settings.** We would try to explain over the phone how to reset it, but we'd probably end up having to go there and re-program."

*Manufacturer names are removed from this report

Source: Contractor interviews and analysis.

Two-thirds of customers (66%) with integrated controls said their contractor gave them instructions about how to operate the integrated controls. This guidance may have included a demonstration or tutorial on how the phone application works, talking through how to change the settings, if needed, or telling the customer that the control is automatic so there is not much that they need to do.

- *The contractor "explained how it worked, how I would know if it was working, and to pretty much **let it do its own thing**. Also, with heat pumps to **just pick a temp and leave it** as opposed to going up and down throughout the day." – Survey Participant*
- *The contractor "gave **a quick overview of the functions**, showed us how to access the set-up menu, and left the manual at our house." – Survey Participant*

5.2.3 Contractor Installation Experience and Barriers Faced

The team discussed the installation process with contractors in detail, including what issues they faced and how they resolved those issues. The number of issues faced tended to vary by the contractor's level of experience with the integrated controls, especially with controls for mini-split HPs.

The evaluation team identified four distinct groups of contractors through the interviews, shown in Table 5-6. Early Adopters (group 1) are the most supportive of integrated controls and have the most experience. They generally require minimal program support. The Majority (group 2) are primarily driven to provide the rebate to their customers but may still struggle with controls in various ways. This group needs additional training on the technology and troubleshooting issues in the field. Late Adopters are broken into two sub-groups: contractors who strongly dislike integrated controls and are unwilling to change their positions (group 3), and contractors who are curious about integrated controls but lack awareness (group 4). Although group 3 is likely less reachable for the program, group 4 may be receptive to basic education on the technology and sales training.

Table 5-6. Summary of Contractor Types and Program Needs

Type of Contractor	Defining Characteristics	Program Needs
(1) Early Adopters: Typically higher volume contractors, strongly support controls	• Believe in the value controls can deliver in optimizing energy use automatically • Tried various brands, resolved issues, know what works	• This group requires minimal program support
(2) The Majority: Usually higher or mid-volume contractors, rebate driven	• May not like controls, but want customer to get rebate • Still struggle with issues like connectivity or mismatched zoning • Some may only offer controls for central HPs	• Support on technology and troubleshooting issues
(3) Late Adopters – Strongly Dislike Controls: Mostly low volume contractors, strongly dislike controls	• Faced issues that were never resolved, and may believe they cannot be fixed • Think controls not worth the added effort	• This group may not be open to influence
(4) Late Adopters – Low Awareness: Low volume contractors, lack awareness of controls	• Want to know more about controls, but are very busy and may have a small team • Do not understand how controls work or know how to talk to customers about them • May lack awareness about Mass Save	• Basic education on the technology and sales training

Source: Contractor interviews and analysis.

Outside of experience level with integrated controls, contractors described three key barriers they faced during equipment installations (Table 5-7). The first two issues (connectivity and mismatched zoning) were mentioned more frequently in context with mini-split HP installations because there is more equipment that must be connected and configured. The evaluation team also observed that contractor experiences with different manufacturers varied widely, indicating a lack of consistency in products that is likely challenging for some contractors to deal with.

Table 5-7. Installation Barriers Faced by Contractors

Barrier	N	Description of Barrier	Result
Connectivity Issues	7	• Wi-Fi coverage can be spotty in homes, with limited coverage in basements where the fossil fuel system is located • Signal interruptions could cause system to error or lockout and result in a customer losing heat	• IT issues can be time-consuming and expensive for contractors, and cause customer callbacks later on
Mismatched Zones	4	• Zones for the fossil fuel system (typically just one zone) may not match the number HP zones (mini-splits have one per room)	• Customer comfort issues, like overheating, which can prompt customers to override or disable the controls
Tech-Savviness of Customers	3	• Some customers struggle with how to engage with the controls or phone application	• Customer callbacks to reprogram the system

Barrier	N	Description of Barrier	Result
Wide Variety of Experiences Across Brands	N/A, observed by evaluation team	• Discussions with contractors indicated that there is variety of experiences with different type of controls	• Inconsistent contractor experience and additional time invested in learning about the control options

Source: Contractor interviews and analysis.

Table 5-8 provides contractor quotes that corroborate the barriers in Table 5-7 above.

Table 5-8. Contractor Quotes: Installation Barriers with Integrated Controls

Topic Area	Related Contractor Quote
Connectivity	"Nobody has a perfect mesh Wi-Fi system around their house. Often, nobody worries about coverage in their basement. **We need a good, solid, steady Wi-Fi signal in the corner of their basement where the boiler is**, which is at the opposite end of the house from their Wi-Fi hotspot."
	"I've spent **a lot of time, and a lot of money, having technicians drive around, resetting them up multiple times**, in some houses I've had to pay for wireless routers to be installed. I've had to have IT support come through and fix home internet systems. There's a lot involved in them."
Mismatched Zoning	"So, if you had three heat pumps upstairs, that's three zones, you'd have to have three zones of heat for it really to work right and you don't, you have one. So, **you can either interlock one heat pump and then half the upstairs would have heat or you have to interlock all three and then you get overheating** in areas because of where it's sensing the temperature."
Tech-Savviness of Customer	"I will say, out of everything that we install, the most callbacks we get are for the integrated controls and having to **go back out and again explain how it works**."

Source: Contractor interviews and analysis.

Early adopter contractors typically found solutions to the barriers referenced above, such as having specialized staff to work on integrated controls (n=2), dedicating field managers to troubleshoot issues that may arise (n=1), or using diagnostic tools for Wi-Fi issues and providing their own modems or extenders (n=3). Several contractors tried different types of controls until they found one they felt they could work with (n=6). These contractors also knew that they may receive more callbacks from customers and had the capacity to absorb them. The majority of contractors struggled with how to resolve these barriers and reported that their dissatisfied customers tended to switch manually between systems (n=13). Late Adopter contractors may have tried one integrated control, but never resolved their issues and decided that the effort involved was not worth the value (n=4).

Corroborating the barriers reported by contractors, distributors noted that some contractors may misapply the integrated controls during the system design process and highlighted the need for additional training or support in the field. For example, one distributor mentioned that while integrated controls have many capabilities and can adjust to meet system needs based on indoor and outdoor temperatures, there are limitations in meeting the required capacities if the HP is not sized correctly. This can result in over or underheating certain rooms in the house. Contractors interviewed also acknowledged the importance of sizing the system correctly. Of the 18 contractors interviewed, 10 specified that they use Manual J (or a software that incorporates Manual J) to calculate heating loads. A few other contractors noted that they rarely use Manual J and instead size systems based on experience.

5.3 Application and Program Experience

Nearly two-thirds (61%) of surveyed customers reported that the contractor completed the rebate application for them, while the remainder submitted the application themselves. However, of the 17 participating contractors interviewed, 10 noted that even when the customer submits the application, they are providing significant support to gather the correct information and documentation, either by having the customer on the phone while they fill out the form or filling out or giving the technical information to the customer and letting the customer submit it.

Section Summary

Most customers who submitted the application (39%) found the process easy, but contractors report that even when customers do take the lead, they provide significant support.

The most frequent difficulty cited by customers was gathering the correct equipment information and needing additional back-and-forth.

Of those customers who submitted the application (n=123), nearly two-thirds (65%) said the process was easy but a small number (n=34) noted some issues as shown in Table 5-9.

Customers who did not find the process easy found that the information required to apply for the rebates, such as model numbers of the equipment installed, was difficult to find (n=12). Some customers said that the terminology used in the rebate application form was too technical to understand or confusing (n=11). In both of these cases, customers mentioned that they could not have completed the application without the contractor's assistance. Some customers also mentioned that their initial application was rejected, and that it took significant back-and-forth either by mail, phone, or email to correct the problem and move the process forward (n=5).

Table 5-9. Customer Feedback on the Application Process (n=34)

Feedback Area	Number of Customer Mentions (single response)
Difficulty gathering equipment information	12
It was confusing or complicated and needed additional assistance	11
Multiple back-and-forths required or needed to re-send information	5
Difficulty with online application form	4
Difficulty navigating website	2
Total	**34**

Source: Customer survey, "Why did you rate the process of completing the rebate application this way?", C15.

Although customers who did not find the application process easy focused primarily on issues with completing the paperwork, contractors reported a broader array of issues with the application and program experience. The following list summarizes these issues:[29]

- **Issues with online system:** Contractors mentioned that in some cases, the online application system caused issues such as not being able to read an oil bill, which could cause the application to be rejected. In other cases, the system could not retrieve the

[29] Note that in most cases contractor interviews were with the company owner or a manager, not with administration staff that more often directly process applications. Therefore, observations documented here may not fully represent the contractor application experience.

status of a submitted application but when they checked with the program, the application was there.

- **Inconsistent information provided by customer service:** One contractor noted that they and their customer both unknowingly called Mass Save about the same issue, and each received a different answer.
- **Long rebate timelines and delayed communications:** Contractors found that the length of time to receive a rebate could be long; for example, up to 12 weeks when the website says 6-8 weeks. Several contractors stated that application issues are typically communicated by the program via paper mail, which may take up to 2 months to receive. These contractors thought that communications could be made more speedily by email or by phone. Applications needing corrections are sent to the back of the queue, which adds additional time to the process.
- **Not enough advanced notice of program changes:** Contractors also noted the program does not give them enough time to prepare when changes are introduced. For example, when rebates for integrated controls were first offered by the program, contractors shared that they were not given enough time to prepare and had to adjust quickly. One distributor suggested that the program should provide more advanced notice on program changes, ideally 2-3 months prior to the start of a new program year. Instead, rebate information may not be available until after the program year has already begun. This distributor also stated that it could be difficult to find current rebate information on the program website.

One of the four distributors interviewed thought that the application process could be a major deterrent for contractors to apply for the rebates. This is because adding requirements to the application can cause increased frustration and turn into a drop-off point.

- *"It's just people, I don't think they (contractors) know enough how to do it and when they get into it, they might get frustrated and just say, "Yeah, the heck with this," and just not bother.* ***So just overall making it easier for people to get their rebates*** *when they do the upgrade or whatever. Sometimes they make it too difficult. You need the pertinent information, job site area, what the upgrade was and model, serial number of a piece of equipment and it should be pretty much that simple." – HVAC Distributor*

5.3.1.1 Multifamily Application Process

The four multifamily property owners/operators interviewed thought that the application process for the income-eligible multifamily offering was easy and straightforward to complete. Owners/operators described completing only one application for all units with relevant information about their property and sending the application together with their affordable housing status documentation. They did not mention any significant issues or concerns.

5.4 Satisfaction and Post-Installation Experience

This section discusses satisfaction with the equipment, comfort levels, and how customers are operating the integrated controls after the installation.

Section Summary

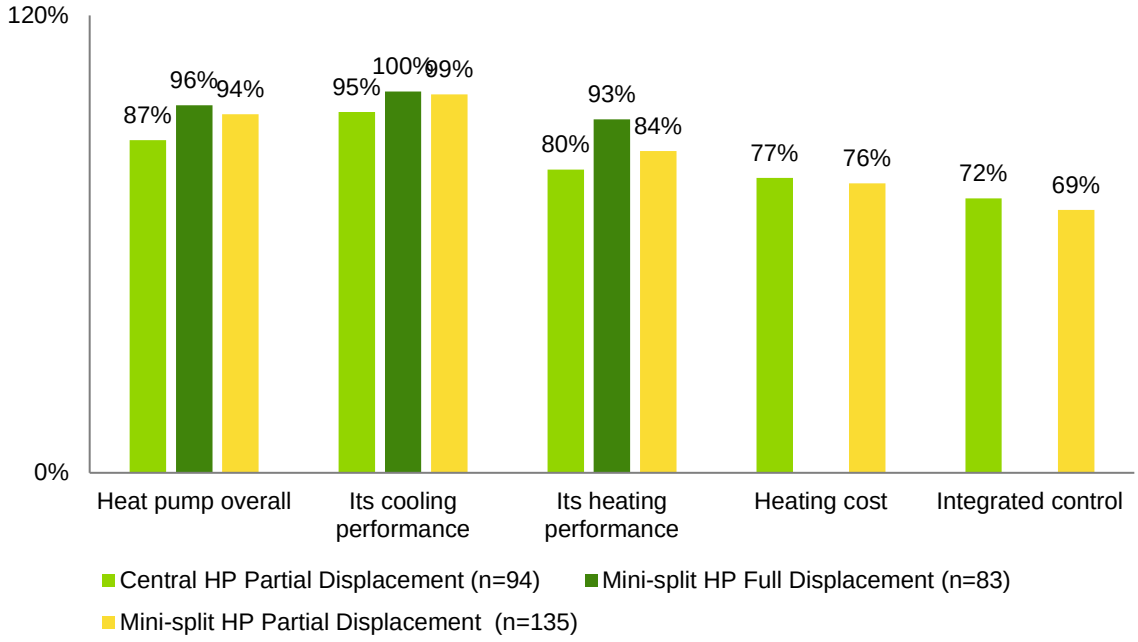
Overall, customers are very satisfied with their HP, satisfied with the integrated controls, and more comfortable than they were before the installation of their new equipment.

Most integrated controls are still installed and working, and most customers say they rely on the control to switch systems. However, mini-split HP customers are more likely than central HP owners to make changes after installation.

5.4.1 Satisfaction with the Equipment and Comfort Levels

Customers are very satisfied with their new equipment (Figure 5-7), especially the cooling performance of their new HPs. Customers are somewhat less satisfied with their heating costs and the integrated controls, but still generally satisfied. Customers less satisfied with their integrated controls had mixed feedback, with some indicating that they had switchover issues or problems with temperature settings (n=17), that the integrated controls do not work properly for various reasons (n=10), that the controls are too complicated or confusing (n=5), or that they had connectivity issues (n=4).

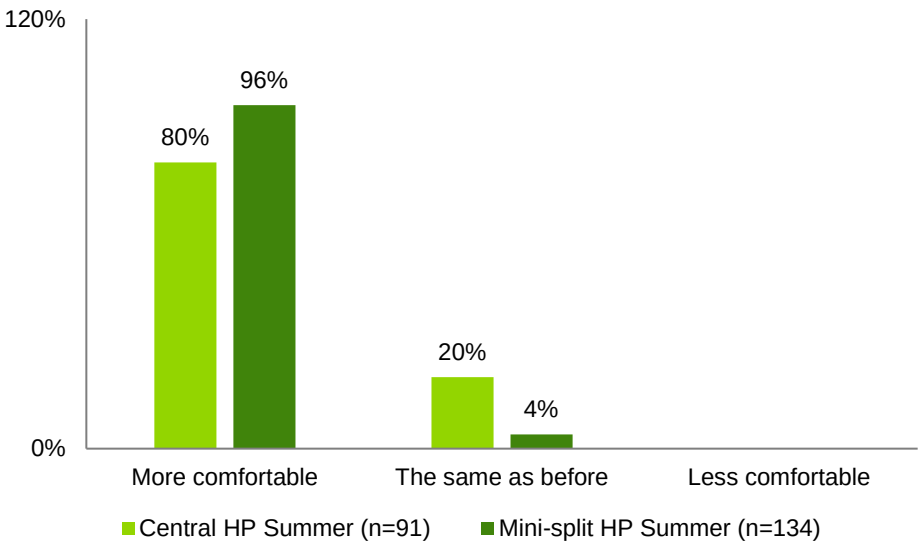
Figure 5-7. Satisfaction with the New Equipment and Features



Source: Customer survey, "Using a scale of 1-5, with 1 meaning "not at all satisfied" and 5 meaning "very satisfied", how satisfied are you with the following aspects of your new heat pump?", (C10). Note: Full displacement customers did not receive a question on heating cost.

Most customers also report being more comfortable in the summer—especially mini-split HP customers—than they were before their new equipment was installed (Figure 5-8). No customers said they were less comfortable in the summer.

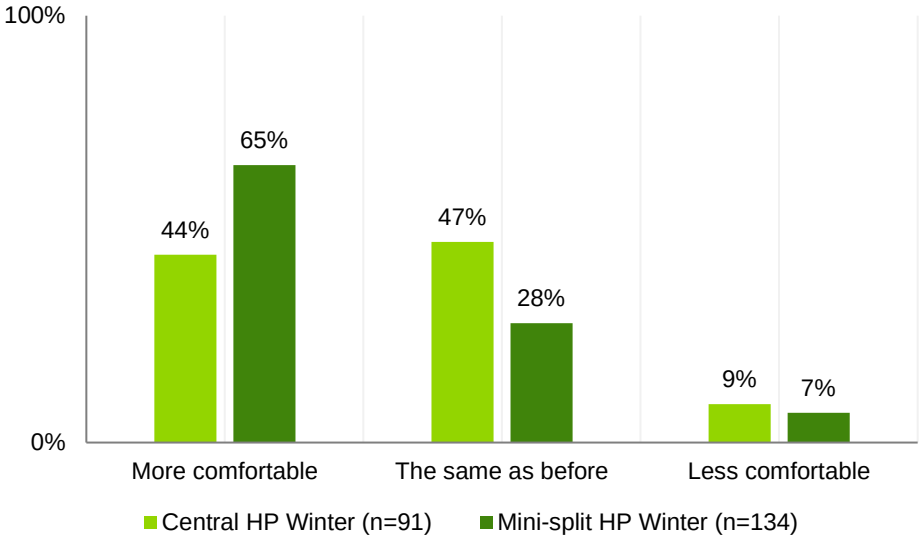
Figure 5-8. Comfort Levels in the Summer



Source: Customer survey, "How, if at all, has your home's comfort level changed since your new [equipment] was installed? My home is ….", (D21).

The majority of mini-split HP customers reported that they were more comfortable in the winter with their new system (65%), while central HP customers were split, with 47% just as comfortable as they were before and 44% more comfortable (Figure 5-9). Only a small portion of customers reported being less comfortable. This question was only asked for partial displacement installations in the customer survey.

Figure 5-9. Comfort Levels in the Winter



Source: Customer survey, "How, if at all, has your home's comfort level changed since your new [equipment] was installed? My home is ….", (D21).

5.4.1.1 Multifamily Satisfaction with the New Equipment

Multifamily property owners/operators reported high satisfaction with their new HPs on behalf of themselves and their tenants. All four owners/operators reported having no issues with HP operation (full displacement installations), and that tenants liked how comfortable they were with the new HPs. Tenants also liked the ability to have both heating and cooling in their homes since in most cases they previously had no cooling or window AC units. Multifamily owners/operators reported electric bill reductions of up to 30% compared to the prior year.

Owners/operators noted that some tenants may desire to adjust HP temperature settings to be more comfortable. However, depending on the property and system, tenants may or may not be allowed to change the settings on their own. In cases where tenants cannot adjust the temperature, internal maintenance staff helps them change the settings.

5.4.2 System Operation Post-Installation

About 87% of central HP owners report that their integrated controls are still installed and working, versus 76% for mini-split owners (Table 5-10).[30] A notable number of customers also said that they did not know whether their integrated controls were installed and working (16% for mini-split HPs and 11% for central HPs). However, this is not unexpected, as the controls are generally intended to be set once and then operate automatically without any necessary intervention, so customers may not be aware that they are installed and working.

More mini-split HP owners tended to change the switchover temperature after the installation than central HP owners (35% vs. 23%, respectively). Some customers report adjusting the original switchover temperature set by their contractor because it was too cold (n=14) or too hot (n=9), due to customer comfort preferences (n=9), because the customer wanted to be more energy efficient (n=9) or for cost-saving reasons (n=4).

Table 5-10. Status of Integrated Controls Post-Installation

Status Topic	Percent of Mini-Split Owners	Percent of Central HP Owners
Still Installed and Working?	**n=136**	**n=94**
Yes	76%	87%
No	8%	2%
Do not know	16%	11%
Adjusted Switchover Temp after Initial Set-up?	**n=125**	**n=91**
Yes	35%[31]	23%
No	55%	62%
Do not know	10%	15%

Source: Customer survey, "Is the integrated control still installed and working?", (D3), and "Have you or anyone else changed the integrated control switchover temperature setting since it was first programmed?" (D12).

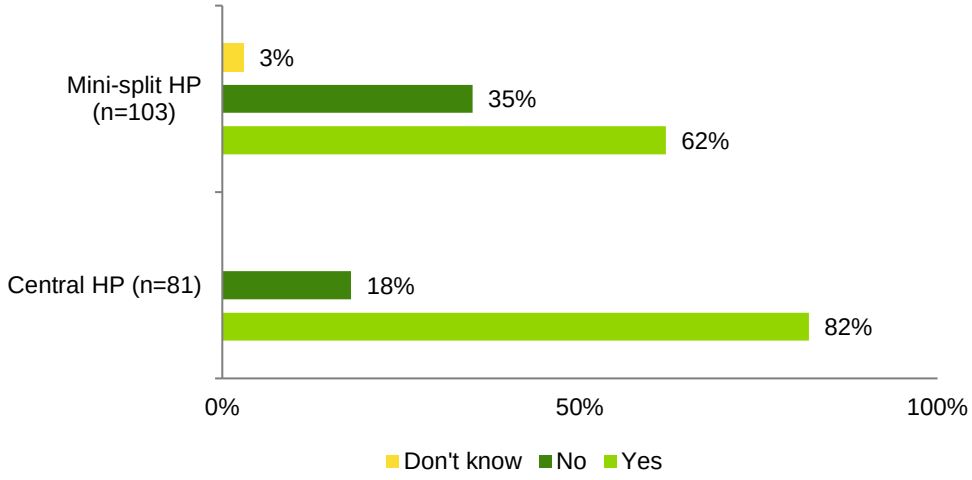
About 82% of central HP owners who reported that their integrated controls are still installed and working say that they rely on them to switch systems. In contrast, 62% of mini-split HP

[30] Statistically significant, p value <.05.

[31] Statistically significant, p value <.05.

owners reported that they rely on the controls to switch systems (Figure 5-10).[32] Since mini-split HPs are more visually prominent in the home, and typically can be adjusted on a room-by-room basis customers may be more likely to adjust or turn off their integrated controls post-installation.

Figure 5-10. Reliance on Integrated Controls to Switch Systems



Source: Customer survey, "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 heating system?" (D6).

Customers who say they do not rely on the integrated controls to switch systems say that they manually switch systems instead (52%, n=33), only use the HP in certain rooms to supplement the delivered fuel-fired system (23%, n=15), or manually operate their HP using other strategies (25%, n=16) like using two thermostats, using both systems at the same time, or only using the HP for cooling.

[32] Statistically significant, p value <.001.

6. Conclusions and Recommendations

This section provides the evaluation team's key findings and related recommendations and considerations, supported by both process and impact research activities. The following sections outline process and impacts findings, recommendations, and considerations for the program's single-family and multifamily offerings.

6.1 Process Evaluation

This section provides key findings, recommendations, and considerations primarily supported by process evaluation activities for both single-family and multifamily offerings.

Single-Family Offerings

Findings	Recommendations and Considerations
Finding. Customers are satisfied with their new fuel displacement equipment—especially their HPs—and are more comfortable than they were before program participation. Integrated controls are largely working as intended for central HP owners, but more mini-split HP owners are switching systems manually instead, which has the potential to reduce the efficiency benefits achieved. Customer satisfaction and system operation is described further in Section 5.2. Section 6.2 below summarizes additional findings regarding heat pump and integrated control operation and switchover temperatures programmed.	**Recommendation 1. Offer literature directly to customers (including online resources) that summarize the benefits of integrated controls and basic tips on how to operate new systems.** Customize literature for central HP and mini-split HP owners. Helping customers build a greater understanding for their new equipment, how to operate it, and how not to operate it, may also increase customer satisfaction and reduce the number of customers switching between their heating systems manually. This will further help customers build a greater understanding for their new equipment, how to operate it, and how not to operate it, and may also increase customer satisfaction and reduce the number of customers manually switching between their heating systems. For example, mini-split HP literature could focus on the cost savings benefits and the ease of "setting and forgetting" with their integrated control. Instead of turning off heat pump when they are not in the room or are not home, they should turn back the boiler setpoint or choose the away setting on their thermostat.

Findings	Recommendations and Considerations
Finding. Contractor and distributor interviews suggest that integrated controls may vary widely in functionality and features depending on the manufacturer. This is common for a developing market. However, this may cause some contractors to be overwhelmed or confused and decide to give up early on the technology. For example, contractors reported experiencing connectivity issues with different brands, and problems with mismatched zoning between the fossil fuel system and new mini-split HPs that may prompt customers to override the controls. Contractor experience is described further in Section 5.2.3.	**Recommendation 2. The Program Administrators should consider convening a study to gain additional understanding of the functionality and performance of different types of integrated controls, including distinctions between networked and hard-wired controls.** Any future metering studies should include a large sample of both networked and hard-wired controls over an extended metering period to capture control and unit operation over a wide range of temperature and weather conditions (including heat pump performance at lower outdoor air temperatures). This type of study may help to further refine program requirements, along with the Qualified Products List (QPL). Additionally, the study may assist the program in producing other guidance for contractors. For example, depending on the study's scope, a guide to accompany the QPL could be produced that identifies which controls are good for different customer types (e.g., tech-savvy customers, set-it and forget-it customers) and the features/functionality offered. As the market matures, controls may align in functionality and features, but until then some contractors may continue to be overwhelmed with the different options and features available.
Finding. The program primarily leans on the contractors' relationship with customers to promote the rebate offering. However, many contractors – especially smaller contractors or contractors that have lower participation rates – require more training to be able to provide their customers with the necessary guidance and support so integrated control and HVAC systems operate as intended. Contractor installation experience is described more in Section 5.2.3.	**Recommendation 3. Provide contractors program support depending on how far along they are on the adoption curve for fuel displacement technologies. Take the following tactics to support the different contractor types:** • **Early Adopters:** Highlight their experiences and expertise in case studies or features that can be used to bring along other contractors. These contractors generally represent 20% of the population but perform 80% of the installations and require little to no technical assistance. • **Majority:** Offer technical trainings or field support to increase this groups' capacity to resolve issues and become more confident with the technology. These contractors generally represent the second and third tiers down in project volume from the Early Adopters. They are motivated to offer their

Findings	Recommendations and Considerations
	customers' the value of the rebate but are still somewhat skeptical of the technology. • **Late Adopters:** Provide sales training and basic information about fuel displacement technologies and the program offering. These low volume EO contractors have little available time and are less likely to seek out resources on their own. The program could consider opportunities to perform additional one-on-one outreach to this group via phone or in-person, emphasizing the value proposition of integrated controls and how controls could benefit them and their customers.
Finding. Distributors have a broad window into market trends for fuel displacement technologies. They have seen HP sales increase substantially over the last few years (especially for mini-split HPs) and recognize the value of integrated controls, but also note that market and product development is still needed to reach their full potential. Distributor insights are discussed further in Section 5.1.4.	**Consideration. Continue to build strong relationships with the top HVAC distributors in the state.** Leverage these relationships to gain insight into how fuel displacement technologies are developing to inform program rebates and equipment offerings.
Finding. Distributors have a unique window into the contractors' perspective. The distributors have relationships with contractors and serve as a collector of product and program information and as a trusted resource that provides training and support. They also have access to resources that the program may not, such as training facilities. Distributor insights are discussed further in Section 5.1.4.	**Consideration. Leverage distributors' relationships with contractors and their position in the market to bring necessary support to its contractor population.** The program should take advantage of distributor access to resources and relationships by partnering with them on contractor support and trainings and consulting them in offering development as updates to requirements and incentives are made.

Findings	Recommendations and Considerations
Finding. Contractors and customers pointed out opportunities to improve communications about the rebate process. Both groups noted that application issues are typically communicated via paper mail, which adds time to the process. Section 5.3 includes application and program experience.	**Consideration. The program should review application process communication points and methods with customers and contractors to simplify and minimize time delays.** Strategies to address delays could include eliminating or reducing paper mail communications and instead relying on phone or email to address application errors or missing information. The program should also ensure that staff are trained on an ongoing basis about program offerings to allow consistency in customer service.

Multifamily Offerings

Findings	Recommendations
Finding. The four Income Qualified multifamily owners/operators interviewed were very satisfied with their experience. Interviewed building owners/operators were very happy with their program experience, the performance of the HPs installed at their properties, and the resulting energy cost reductions.	**Consideration. The program should review and consider recommendations from the Multi-Family Program Improvement Strategies (RES 42) study, published in October 2018. While not specifically designed for heat pump offerings alone, these recommendations still apply broadly to the multifamily sector and program offerings.** Due to the very small sample of multifamily projects included in this evaluation, the team was not able to identify specific recommendations. However, the Multi-Family Program Improvement Strategies (RES 42) study includes recommendations that are applicable to multifamily programs regardless of the measure offering. Future heat-pump research could include interviews with participants, nonparticipants, and contractors that serve multifamily properties

6.2 Impact Evaluation

This section provides key findings, recommendations, and considerations primarily supported by impact evaluation activities for both single-family and multifamily offerings.

Baseline Heating and Cooling System Types

Findings	Recommendations and Considerations
Finding. The prevalence of a no cooling baseline assignment is higher for customers who installed a mini-split HP (30%-37%) relative to customers who installed a central HP (9%). This suggests that these customers who installed a mini-split HP through the program are motivated to add a cooling amenity to their space (which results in a net cooling energy increase) but are also spurred by the program to displace pre-existing electric resistance or delivered fuel-fired space heating with their new heat pump(s), as the program intended. Thirty-nine percent of customers who installed a central HP indicate that they would have installed a central AC if they did not install the HP they did (which does not provide a heating amenity). This further indicates that the program is having the intended effect: spurring customers to displace delivered fuel heating usage relative to their baseline purchasing decisions.	**Consideration.** The program should continue to encourage customers to displace space heating with delivered fuels with heat pumps. The program should continue to encourage contractors to tell customers that the program rebates will afford them both heating and cooling amenities for the same, or slightly lower, unit price as similarly efficient central or mini-split air conditioners.

Table 6-1 summarizes baseline cooling assignments for three primary measure categories (mini-split HP with pre-existing electric space heat, mini-split HP with pre-existing delivered fuel space heat, and central HP with pre-existing delivered fuel space heat). Section 3.1 describes the baseline assignment methodology in detail, along with the detailed baseline heating and cooling distributions for each measure category

Table 6-1. Baseline Cooling System Assignment

Baseline Cooling Type Determined	Mini-split HP with Electric Pre-Retrofit Heating	Mini-split HP with Delivered Fuel Pre-Retrofit Heating	Central HP with Delivered Fuel Pre-Retrofit Heating
Existing (No cooling, only fans)	37%	30%	9%
Existing cooling (central AC, room AC, portable AC, mini-split AC or HP)	27%	17%	20%
New unit, market baseline (central AC, room AC, portable AC, mini-split AC)	36%	53%	71%
Total	**100%**	**100%**	**100%**

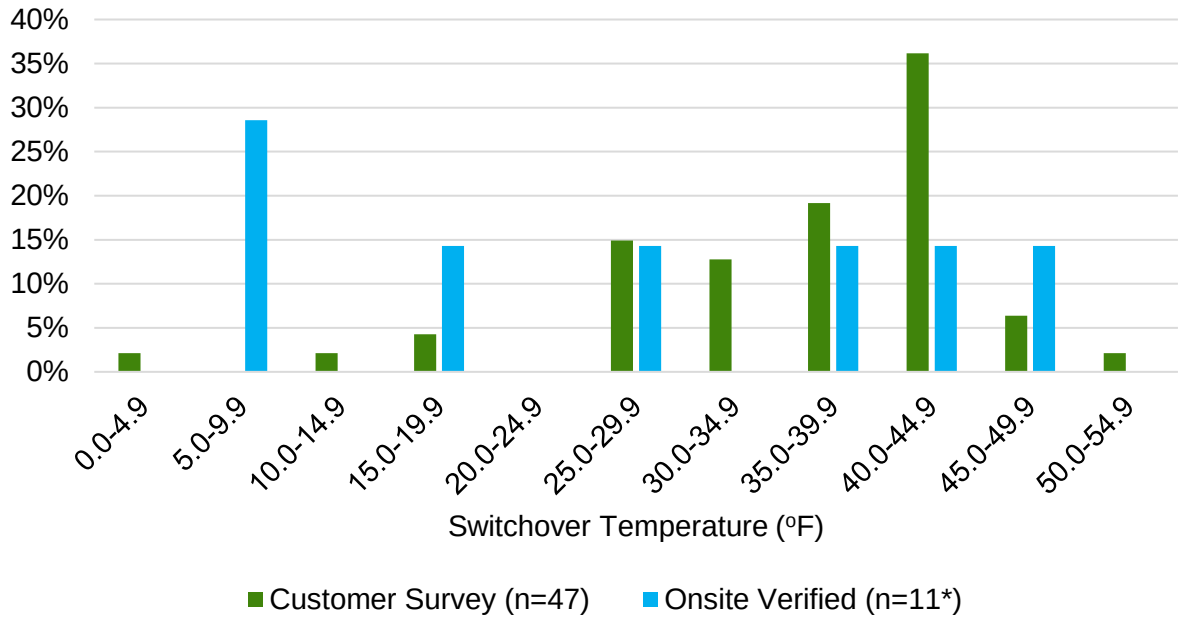
Heat Pump and Integrated Control Operation and Switchover Temperatures Programmed

Findings	Recommendations and Considerations
Finding. For partial displacement installations in 2019, customers who install a central HP are largely relying on the integrated controls to auto-switch between their new heat pump and the previous delivered fuel-fired heating equipment (80% of installations in the 2019 program year). About half (40%-60%) of mini-split HP(s) installations are replying on the integrated controls to auto-switch. For customers who use an integrated control to auto-switch, they program a variety of switchover temperatures between approximately 5°F and 45°F.	**Consideration.** The PAs could consider a follow-up study to further explore ideal switchover temperature settings to optimize energy use, reduce fossil fuel usage, and reduce greenhouse gas emissions

The majority of customers who do not rely on their integrated controls to auto-switch are adjusting operations manually, either using wall-mounted or app-based controls to operate their heat pumps and delivered fuel-fired heating systems, determined based on perceived outdoor air temperatures or when they would prefer to run their various systems. This study found that customers who are manually operating their systems are largely switching system operation at close to desired temperatures, however, some mini-split HP owners are turning off the units entirely when they are not occupying the zone. These practices have the potential to reduce the efficiency benefits achieved.

Figure 6-1 and Figure 6-2 shows the switchover temperatures from the customer survey (for the subset of customers that report using a switchover temperature and know what their switchover temperature setting is) and the onsite verified switchover temperatures (for customers with discernable switchover temperatures), for central HPs and mini-split HPs, respectively.

Figure 6-1. Survey Reported vs. Field-Verified Switchover Temperatures – Central HP

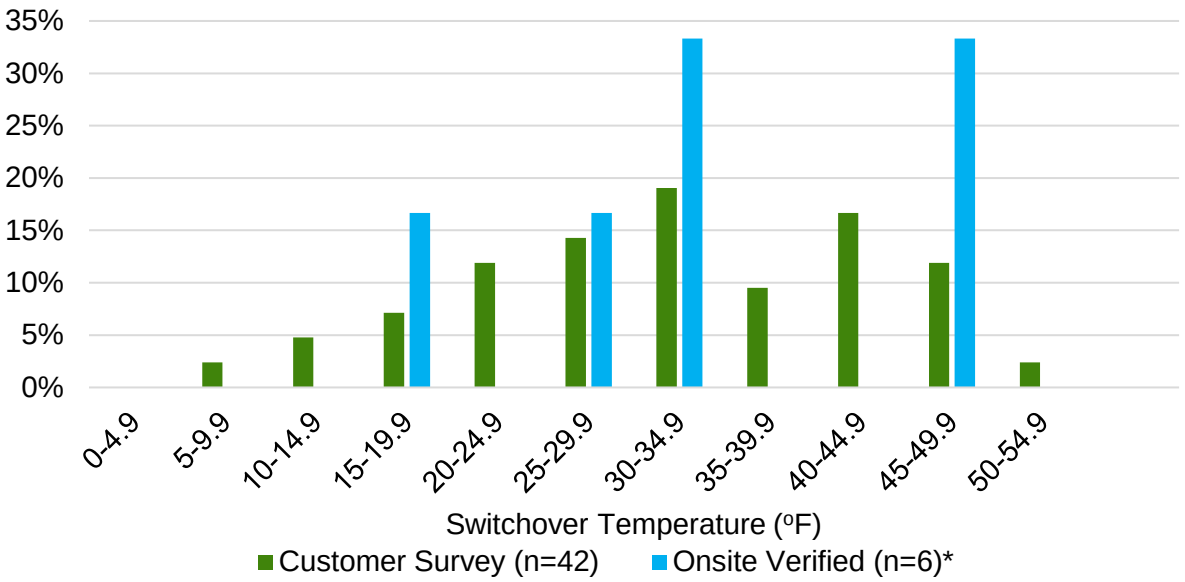


Survey sample includes 37 customers with pre-existing oil heat and 10 with propane heat. The team found no clear trends in differing switchover temperature distributions between the oil and propane groups.

*Onsite sample with clear switchover temperature

Source: Evaluation Team Analysis

Figure 6-2. Survey Reported vs. Field-Verified Switchover Temperatures – Mini-Split HP



Survey sample includes 39 customers with pre-existing oil heat and 3 with oil heat. The team found no clear trends in differing switchover temperature distributions between the oil and propane groups.

*Onsite sample with clear switchover temperature

Source: Evaluation Team Analysis

Section 4.1 describes switchover temperature findings from the metering study and how they are used to inform the switchover temperature assumptions in the building simulation modeling task. Table 4-4 and Table 4-5 in Section 4.2.1 provide the post-retrofit model consumption for central HP and mini-split HP partial displacement installations at various switchover temperatures, as well as the program average blended result. These results indicate that the average program installation (including the distribution of customer reported and observed switchover temperatures) leads to average measure impacts that are between those of the 15°F or 30°F installations, respectively.

Our findings suggest that customers and contractors consider multiple factors when setting their switchover temperature and that these factors may differ from program guidance, as Table 6-2 shows. Section 5.2 provides further research findings relating to integrated control programming motivations and experience with the controls.

Table 6-2. What Factors are Considered When Setting and/or Adjusting Switchover Temperatures?

Customers want to…	Contractors want to…	Program wants to…
Be comfortable	Reduce customer call-back's	Optimize energy use
Set according to other priorities/preferences (be more energy efficient, reduce fossil fuel use, be environmentally conscious, etc.)	Be responsive to customer preferences and balance the different customer needs (between comfort, energy savings, etc.)	Reduce fossil fuel use and greenhouse gases
Reduce overall energy costs		Reduce overall energy costs for the customer

Source: Evaluation team analysis.

Per discussions in September 2021, the PAs implementation teams presented plans to modify the integrated control switchover temperature recommendations and make further program changes to ensure quality heat pump and integrated control installations with the program-recommended switchover temperatures. These changes are expected to go into effect in January 2022 for the 2022-2024 program delivery period and include the following changes:

- **Contractor network:** The program plans to move to a closed contractor network model (instead of the open model in place for 2019-2021). Customers will now need to work with an approved contractor to access fuel-displacement rebates. These contractors will have access to revamped training and educational materials to further support optimal equipment selection based on the customer needs, program-recommended integrated control programming (lower switchover temperature for homes with pre-existing propane heating systems compared to oil systems), proper zoning of systems, and enhanced customer education materials.

Quality control: The implementation teams plan to implement further quality control checks on completed projects to ensure the quality of the installation including proper equipment sizing, control programming (including program-recommended switchover temperature controls), and to ensure the controls and equipment are working currently.

Fuel Displacement Measure Impacts

Findings	Recommendations and Considerations
As part of this study, the team performed several research tasks to develop updated energy and demand impacts for fuel displacement measures.	**Recommendation 4. The MA PAs should use these updated measure impact values for future implementation and planning purposes.**

The team calibrated building simulations to derive impact estimates for the EO fuel displacement measures. Table 6-3 summarizes the EO fuel displacement measure impacts at the per installed ton level.[33] Table 6-3 also summarizes the average installed tonnage per home, used to convert the 'per ton' impacts to the 'per home' level. MA PAs should use these impact values for reporting for the 2021 program year. Appendix A provides the recommended measure impacts for the 2022-2024 planning years, using updated assumptions for switchover temperature distributions based on recent discussions (held in September 2021) of planned 2022-2024 program changes with the PA program managers and implementation teams.[34]

Table 6-3. EO Fuel Displacement Measure Savings (Per Ton)

BCR Measure ID	Measure	kWh Heating	kWh Cooling	kWh Total	MMBtu Delivered Fuel	Average Installed Tons per Customer
E19A2c270	Mini-Split HP Integrated Controls Retrofit Oil	-599	-	-599	8.8	2.8
E19A2c269	Mini-Split HP Integrated Controls Retrofit, Propane	-599	-	-599	9.0	2.8
E19A2c266	Central Ducted HP Partially Displacing Existing Furnace, Oil	-838	42	-795	11.1	3.7
E19A2c265	Central Ducted HP Partially Displacing Existing Furnace, Propane	-838	42	-795	11.6	3.7
E19A2c272	Central Ducted HP Fully Displacing Existing Furnace, Oil	-1,831	36	-1,795	17.9	4.7*
E19A2c271	Central Ducted HP Fully Displacing Existing Furnace, Propane	-1,831	36	-1,795	17.9	4.7*
E19A2c268	Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Oil	-843	-114	-957	15.0	2.8
E19A2c267	Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Propane	-843	-114	-957	14.8	2.8

[33] See Section 4.2.1 and 4.2.2 for a full summary of measure impacts including electric energy (kWh), peak demand (kW), and delivered fuel (MMBtu) impacts at the per ton and per home levels for average program installations.

[34] The team recommends that PAs and implementers use the 'per ton' results for single-family homes to inform deemed savings planning assumptions for the multifamily segment. The PAs and EEAC could consider a separate study focused on multifamily measure impacts for full and partial displacement with various pre-exiting heating fuel types.

BCR Measure ID	Measure	kWh Heating	kWh Cooling	kWh Total	MMBtu Delivered Fuel	Average Installed Tons per Customer
E19A2c273	Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Oil	-1,410	-98	-1,508	17.8	3.9*
E19A2c274	Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Propane	-1,410	-98	-1,508	17.8	3.9*
E19A2c256	Mini-Split HP Fully Displacing Electric Resistance	2,443	-127	2,316	3.8	2.0
E19B1a274	Custom Heat Pumps, Displacing Electric Heat (Multifamily)	1,974	63	2,037	-	1.0

**Due to small sample size for these full displacement installations in 2019, the team assumed typical full displacement capacity (delivered fuel-fired baseline) is 4.5 tons at the 2,400SF EnergyPlus prototype model size, and calculated an assumed average installed tons per participant by applying the ratio of average participant SF to the prototype model SF*

Source: Evaluation Team Analysis

The team then scaled the per ton impacts to the per home level using the average tonnage installed per home for fuel displacement installations in the 2019 program year. Table 6-4 compares the average per home measure impacts between the prior EO Optimization Model and the current EO evaluation study results.

Table 6-4. EO Fuel Displacement Single-Family Measure Savings Comparison Between Prior and Current EO Study (Per Home, Average Participant)

Measure and BCR ID	Prior Study Results		Current Study Results		Comparison of Study Results	
	kWh Total	MMBtu Delivered Fuel	kWh Total	MMBtu Delivered Fuel	% Difference kWh	% Difference MMBtu
Mini-Split HP Integrated Controls Retrofit Oil E19A2c270	-3,941	49.7	-1,678	24.6	57%	-51%
Mini-Split HP Integrated Controls Retrofit, Propane E19A2c270	-7,106	90.2	-1,678	25.2	76%	-72%
Central Ducted HP Partially Displacing Existing Furnace, Oil E19A2c266	-3,346	42.1	-2,942	41.1	12%	-2%
Central Ducted HP Partially Displacing Existing Furnace, Propane E19A2c265	-5,737	76.5	-2,942	42.9	49%	-44%
Central Ducted HP Fully Displacing Existing Furnace, Oil E19A2c272	-6,082	86.7	-8,437	83.9	-39%	-3%
Central Ducted HP Fully Displacing Existing Furnace, Propane E19A2c271	-6,082	86.7	-8,437	83.9	-39%	-3%
Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Oil E19A2c268	-3,941	49.7	-2,679	42.1	32%	-15%
Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Propane	-7,106	90.2	-2,679	41.4	62%	-54%

Measure and BCR ID	Prior Study Results		Current Study Results		Comparison of Study Results	
	kWh Total	MMBtu Delivered Fuel	kWh Total	MMBtu Delivered Fuel	% Difference kWh	% Difference MMBtu
E19A2c267						
Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Oil E19A2c273	-7,468	102.3	-5,882	69.3	21%	-32%
Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Propane E19A2c274	-7,468	102.3	-5,882	69.3	21%	-32%
Mini-Split HP Fully Displacing Electric Resistance E19A2c256	5,039	0	4,631	7.5	-8%	-

Source: Evaluation Team Analysis

The following is a high level summary of the main drivers to changes in impacts between the prior study and current study. See Section 4.2.1 for additional details related to these main impact drivers.

- **Baseline heating loads:** The prior EO study heating loads were about 30% higher than those determined through the current study (e.g., 87 MMBtu vs. 68 MMBtu for a delivered fuel-fired furnace baseline, 102 MMBtu vs. 77 MMBtu for delivered fuel-fired boiler baseline).[35] This is the primary driver behind changes in impacts between the prior and current study. The lower base heating loads in the current study lead to lower heating impacts relative to the prior study, especially for the mini-split HP measures.
- **Tonnage Assumptions:** The prior study assumed 2.5 tons per home for partial displacement installations and 4 tons per home for full displacement installations. The current study assumes variable average installed capacities per customer, summarized in Table 2-21 in Section 2.6.2. These differences in installed tonnage per home also drive differences in per home impacts between the prior and current studies.
- **Baseline Cooling Assumptions/Weights:** Another driving factor in differences between the current and prior studies is the application of the baseline heating and cooling weights to derive a blended baseline consumption for each measure type (described in Section 3.1). This method was not done in the prior study. This leads to

[35] The prior study heating loads were soured from the RES34 Home Energy Services (HES) Impact Evaluation and developed using a gas end use disaggregation to derive space heating loads for customers who participated in the HES program.
https://ma-eeac.org/wp-content/uploads/RES34_HES-Impact-Evaluation-Report-with-ES_FINAL_29AUG2018.pdf
As a point of reference, the Phase 4 Residential Baseline Study performed a gas end use disaggregation on 3,389 baseline study customers with natural gas service and estimated gas heating consumption between 55MMBtu for single-family attached dwellings and 75MMBtu for single-family detached dwellings. The study also analyzed average delivered fuel oil deliveries for a sample of 55 customers. The weather-normalized annual consumption for fuel oil delivery records collected for the 2016-2019 calendar years was 77 MMBtu, however, the study caveats this value saying this estimate should be treated as a lower bound estimate of annual fuel oil consumption because some customers may have provided incomplete fuel oil delivery records over the data collection period.
https://ma-eeac.org/wp-content/uploads/RES-1-Residential-Baseline-Study-Ph4-Comprehensive-Report-2020-04-02.pdf

lower baseline cooling kWh consumption in the current study relative to the prior study, which leads to lower cooling kWh impacts.

- **Heat Pump Efficiency Values:** The prior EO study assumed the program threshold values for HP unit efficiency, whereas the current study uses the average installed unit efficiency values from the 2019 EO fuel displacement program installations for both central HP and mini-split HPs. The current study efficiency values for heat pumps are higher than those in the prior study. With higher efficiency values in the current study, the post-retrofit consumption for heat pumps is lower than those in the prior study. This contributes to higher savings relative to the prior study, but not enough to overcome the decreased impacts due to the changes outlined above.
- **Switchover Temperatures:** The prior EO study assumed a set 30°F switchover temperature for oil baseline systems and 15°F for propane baseline systems. The current study uses the results of the customer survey (descried in Section 2.4) and onsite metering study (described in Section 2.7) to determine a distribution of switchover temperatures and then weights the results of the separate building simulation model runs by these distributions (described in Section 2.6.2). The current study assumed the same switchover temperature distributions between oil and propane baseline system types for the 2021 impact values, based on results from the customer survey and onsite metering. This is consistent with the current program recommendations. This change led to lower impacts for propane baseline systems relative to the prior study. Appendix A-1 presents updated switchover temperature assumptions and resulting impact values for the 2022-2024 planning period, which incorporate different switchover assumptions for oil and propane systems based on planned program changes.

Appendix A. Measure Impacts for 2022-2024 Prospective Application

In September 2021, the team participated in conversations with the MA PAs and fuel displacement program managers and the implementation teams and learned about several planned program changes. These changes are in development in late 2021 and are expected to go into effect for the 2022-2024 program years. These planned program changes are outlined below:

- Contractor network: The program plans to move to a closed contractor network model (instead of the open model in place for 2019-2021). Customers will now need to work with an approved contractor to access fuel-displacement rebates. These contractors will have access to revamped training and educational materials to further support optimal equipment selection based on the customer needs, program-recommended integrated control programming (lower switchover temperature for homes with pre-existing propane heating systems than for oil systems), and enhanced customer education materials.
- Quality control: The implementation teams plan to implement further quality control checks on completed projects to ensure the quality of the installation including proper equipment sizing, control programming (including program-recommended switchover temperature controls), and to ensure the controls and equipment are working correctly.

In collaboration with the PAs and EEAC consultants, the team made the following changes to assumptions for the switchover temperature weights to apply to the building simulation results for the 2022-2024 program years. These modifications are reflective of intended program changes to further shift customers with oil-fired heating systems to a 30°F switchover temperature and those with propane-fired heating systems to a lower temperature assumed to be 15°F switchover temperature for this study. The gradual shifts throughout the 2022-2024 program years assume the program will be able to implement this shift over time.

- For customers with oil-fired heating systems and central HPs, shift 20% of customers from the 45°F switchover category in 2021 to the 30°F category in 2022-2024.
- For customers with oil-fired heating systems and mini-split HPs, shift 8% of customers from the 45°F switchover category in 2021 to the 30°F category in 2022-2024.
- For customers with propane-fired heating systems and either central HPs or mini-split HPs, gradually shift customers from the 30°F and 45°F switchover categories to the 15°F switchover in 2022-2024.

Table A-1 shows the switchover temperature assumptions used for the 2021 program year implementation and measure results as a reference (results presented in main report body). For the 2021 program year, the team used the same setpoint assumptions for systems with oil and propane fuel types, as the program did not recommend different switchover setpoints for these system types, and this study did not support separate assumptions for oil or propane systems based on the customer survey or metering study findings.

Table A-2 through Table A-4 show the integrated control switchover temperature assumptions for the 2022-2024 program years, applying the modifications to the switchover temperature weights as described above.

Table A-1. Integrated Control Switchover Temperature Weights Applied in Building Simulation for Partial Displacement Measures (2021 Program Year)

Control Strategy	Central HP Partial Displacement		Mini-Split HP Partial Displacement	
	Oil	Propane	Oil	Propane
5˚F Switchover	15%	15%	5%	5%
15˚F Switchover	10%	10%	22%	22%
30˚F Switchover	45%	45%	28%	28%
45˚F Switchover	30%	30%	11%	11%
Boiler below 25˚F, HP primary 25°F-40°F, HP only above 40°F			35%	35%
Total	**100%**	**100%**	**100%**	**100%**

Source: Evaluation Team Analysis

Table A-2. Integrated Control Switchover Temperature Weights Applied in Building Simulation for Partial Displacement Measures (2022 Program Year)

Control Strategy	Central HP Partial Displacement		Mini-Split HP Partial Displacement	
	Oil	Propane	Oil	Propane
5˚F Switchover	15%	15%	5%	5%
15˚F Switchover	10%	25%	22%	40%
30˚F Switchover	65%	50%	35%	26%
45˚F Switchover	10%	10%	3%	3%
Boiler below 25˚F, HP primary 25°F-40°F, HP only above 40°F			35%	26%
Total	**100%**	**100%**	**100%**	**100%**

Source: Evaluation Team Analysis

Table A-3. Integrated Control Switchover Temperature Weights Applied in Building Simulation for Partial Displacement Measures (2023 Program Year)

Control Strategy	Central HP Partial Displacement		Mini-Split HP Partial Displacement	
	Oil	Propane	Oil	Propane
5˚F Switchover	15%	15%	5%	5%
15˚F Switchover	10%	50%	22%	50%
30˚F Switchover	65%	25%	35%	21%
45˚F Switchover	10%	10%	3%	3%
Boiler below 25˚F, HP primary 25°F-40°F, HP only above 40°F			35%	21%
Total	**100%**	**100%**	**100%**	**100%**

Source: Evaluation Team Analysis

Table A-4. Integrated Control Switchover Temperature Weights Applied in Building Simulation for Partial Displacement Measures (2024 Program Year)

Control Strategy	Central HP Partial Displacement		Mini-Split HP Partial Displacement	
	Oil	Propane	Oil	Propane
5˚F Switchover	15%	15%	5%	5%
15˚F Switchover	10%	60%	22%	60%
30˚F Switchover	65%	15%	35%	16%
45˚F Switchover	10%	10%	3%	3%
Boiler below 25˚F, HP primary 25°F-40°F, HP only above 40°F			35%	16%
Total	**100%**	**100%**	**100%**	**100%**

Source: Evaluation Team Analysis

The team applied these weights to the building simulation results for each respective switchover temperature model run. Table A-5 through Table A-7 show the measure impacts using the switchover distribution assumptions for the 2022-2024 program years. The team recommends that the PAs and implementation teams apply these assumptions for the 2022-2024 program years.[36]

[36] The team recommends that PAs and implementers use the 'per ton' results for single-family homes to inform deemed savings planning assumptions for the multifamily segment. The PAs and EEAC could consider a separate study focused on multifamily measure impacts for full and partial displacement with various pre-exiting heating fuel types.

Table A-5. EO Fuel Displacement Single-Family Measure Savings (Per Ton, 2022 Program Year)

Measure and BCR ID	kWh Heating	kWh Cooling	kWh Total	MMBtu Delivered Fuel	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak
Mini-Split HP Integrated Controls Retrofit Oil E19A2c270	-599	-	-599	8.79	8.79	-	-	-	-	-0.24	-0.16	-0.18
Mini-Split HP Integrated Controls Retrofit, Propane E19A2c269	-599	-	-599	9.01	9.01	-	-	-	-	-0.24	-0.16	-0.18
Central Ducted HP Partially Displacing Existing Furnace, Oil E19A2c266	-942	42	-900	14.54	12.70	0.05	0.02	0.04	0.05	-0.36	-0.25	-0.27
Central Ducted HP Partially Displacing Existing Furnace, Propane E19A2c265	-1,089	42	-1,047	11.59	14.54	0.05	0.02	0.04	0.05	-0.42	-0.29	-0.31
Central Ducted HP Fully Displacing Existing Furnace, Oil E19A2c272	-1,831	36	-1,795	17.85	17.85	0.04	0.01	0.04	0.04	-0.71	-0.49	-0.53
Central Ducted HP Fully Displacing Existing Furnace, Propane E19A2c271	-1,831	36	-1,795	17.85	17.85	0.04	0.01	0.04	0.04	-0.71	-0.49	-0.53
Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Oil E19A2c268	-880	-114	-994	15.04	15.81	-0.14	-0.05	-0.13	-0.16	-0.33	-0.23	-0.24
Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Propane E19A2c267	-1,008	-114	-1,122	14.78	17.18	-0.14	-0.05	-0.13	-0.16	-0.38	-0.27	-0.27
Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Oil E19A2c273	-1,410	-98	-1,508	17.78	17.78	-0.12	-0.04	-0.11	-0.14	-0.54	-0.38	-0.40
Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Propane E19A2c274	-1,410	-98	-1,508	17.78	17.78	-0.12	-0.04	-0.11	-0.14	-0.54	-0.38	-0.40

Measure and BCR ID	kWh Heating	kWh Cooling	kWh Total	MMBtu Delivered Fuel	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak
Mini-Split HP Fully Displacing Electric Resistance E19A2c256	2,443	-127	2,316	3.75	3.75	-0.16	-0.05	-0.14	-0.18	1.61	0.79	1.40
Custom Heat Pumps, Displacing Electric Heat (Multifamily) E19B1a274	1,974	63	2,036	-	-	0.06	0.03	0.06	0.06	1.21	0.62	1.04

Source: Evaluation Team Analysis

Table A-6. EO Fuel Displacement Single-Family Measure Savings (Per Ton, 2023 Program Year)

Measure and BCR ID	kWh Heating	kWh Cooling	kWh Total	MMBtu Delivered Fuel	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak
Mini-Split HP Integrated Controls Retrofit Oil E19A2c270	-599	-	-599	8.79	-	-	-	-	-0.24	-0.16	-0.18	-0.26
Mini-Split HP Integrated Controls Retrofit, Propane E19A2c269	-599	-	-599	9.01	-	-	-	-	-0.24	-0.16	-0.18	-0.26
Central Ducted HP Partially Displacing Existing Furnace, Oil E19A2c266	-942	42	-900	12.70	0.05	0.02	0.04	0.05	-0.36	-0.25	-0.27	-0.36
Central Ducted HP Partially Displacing Existing Furnace, Propane E19A2c265	-1,335	42	-1,292	16.90	0.05	0.02	0.04	0.05	-0.51	-0.36	-0.38	-0.53
Central Ducted HP Fully Displacing Existing Furnace, Oil E19A2c272	-1,831	36	-1,795	17.85	0.04	0.01	0.04	0.04	-0.71	-0.49	-0.53	-0.75
Central Ducted HP Fully Displacing Existing Furnace, Propane E19A2c271	-1,831	36	-1,795	17.85	0.04	0.01	0.04	0.04	-0.71	-0.49	-0.53	-0.75

Measure and BCR ID	kWh Heating	kWh Cooling	kWh Total	MMBtu Delivered Fuel	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak
Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Oil E19A2c268	-880	-114	-994	15.81	-0.14	-0.05	-0.13	-0.16	-0.33	-0.23	-0.24	-0.32
Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Propane E19A2c267	-1,079	-114	-1,193	18.08	-0.14	-0.05	-0.13	-0.16	-0.41	-0.28	-0.30	-0.40
Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Oil E19A2c273	-1,410	-98	-1,508	17.78	-0.12	-0.04	-0.11	-0.14	-0.54	-0.38	-0.40	-0.56
Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Propane E19A2c274	-1,410	-98	-1,508	17.78	-0.12	-0.04	-0.11	-0.14	-0.54	-0.38	-0.40	-0.56
Mini-Split HP Fully Displacing Electric Resistance E19A2c256	2,443	-127	2,316	3.75	-0.16	-0.05	-0.14	-0.18	1.61	0.79	1.40	2.57
Custom Heat Pumps, Displacing Electric Heat (Multifamily) E19B1a274	1,974	63	2,036	-	0.06	0.03	0.06	0.06	1.21	0.62	1.04	1.86

Source: Evaluation Team Analysis

Table A-7. EO Fuel Displacement Single-Family Measure Savings (Per Ton, 2024 Program Year)

Measure and BCR ID	kWh Heating	kWh Cooling	kWh Total	MMBtu Delivered Fuel	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak
Mini-Split HP Integrated Controls Retrofit Oil E19A2c270	-599	-	-599	8.79	-	-	-	-	-0.24	-0.16	-0.18	-0.26
Mini-Split HP Integrated Controls Retrofit, Propane E19A2c269	-599	-	-599	9.01	-	-	-	-	-0.24	-0.16	-0.18	-0.26

Measure and BCR ID	kWh Heating	kWh Cooling	kWh Total	MMBtu Delivered Fuel	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak
Central Ducted HP Partially Displacing Existing Furnace, Oil E19A2c266	-942	42	-900	12.70	0.05	0.02	0.04	0.05	-0.36	-0.25	-0.27	-0.36
Central Ducted HP Partially Displacing Existing Furnace, Propane E19A2c265	-1,433	42	-1,390	17.85	0.05	0.02	0.04	0.05	-0.55	-0.38	-0.41	-0.57
Central Ducted HP Fully Displacing Existing Furnace, Oil E19A2c272	-1,831	36	-1,795	17.85	0.04	0.01	0.04	0.04	-0.71	-0.49	-0.53	-0.75
Central Ducted HP Fully Displacing Existing Furnace, Propane E19A2c271	-1,831	36	-1,795	17.85	0.04	0.01	0.04	0.04	-0.71	-0.49	-0.53	-0.75
Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Oil E19A2c268	-880	-114	-994	15.81	-0.14	-0.05	-0.13	-0.16	-0.33	-0.23	-0.24	-0.32
Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Propane E19A2c267	-1,150	-114	-1,264	18.97	-0.14	-0.05	-0.13	-0.16	-0.43	-0.30	-0.32	-0.43
Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Oil E19A2c273	-1,410	-98	-1,508	17.78	-0.12	-0.04	-0.11	-0.14	-0.54	-0.38	-0.40	-0.56
Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Propane E19A2c274	-1,410	-98	-1,508	17.78	-0.12	-0.04	-0.11	-0.14	-0.54	-0.38	-0.40	-0.56

Measure and BCR ID	kWh Heating	kWh Cooling	kWh Total	MMBtu Delivered Fuel	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak
Mini-Split HP Fully Displacing Electric Resistance E19A2c256	2,443	-127	2,316	3.75	-0.16	-0.05	-0.14	-0.18	1.61	0.79	1.40	2.57
Custom Heat Pumps, Displacing Electric Heat (Multifamily) E19B1a274	1,974	63	2,036	-	0.06	0.03	0.06	0.06	1.21	0.62	1.04	1.86

Source: Evaluation Team Analysis

The team also developed a set of impact results using the new unit (market baseline) heat pump efficiencies, instead of the average program-rebated efficiencies, in the post-retrofit models. The new unit (market baseline) heat pump efficiencies are summarized in Table 2-22 in Section 2.6.2. Table A-8 through Table A-10 provide the impacts for these new unit (market baseline) building simulation model runs for the 2022-2024 program years. The team recommends that the PAs use these impact results for prospective application if Mass Save provides midstream program incentives for these same measures, in order to avoid double accounting of savings.

Table A-8. EO Fuel Displacement Single-Family Measure Savings, Post-Retrofit Code Minimum Heat Pump Efficiencies (Per Ton, 2022 Program Year)

Measure and BCR ID	kWh Heating	kWh Cooling	kWh Total	MMBtu Delivered Fuel	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak
Mini-Split HP Integrated Controls Retrofit Oil E19A2c270	-848	-	-848	8.38	-	-	-	-	-0.33	-0.23	-0.25	-0.36
Mini-Split HP Integrated Controls Retrofit, Propane E19A2c269	-848	-	-848	8.59	-	-	-	-	-0.33	-0.23	-0.25	-0.36
Central Ducted HP Partially Displacing Existing Furnace, Oil E19A2c266	-1,202	-32	-1,233	13.42	-0.06	-0.03	-0.04	-0.06	-0.46	-0.32	-0.34	-0.47
Central Ducted HP Partially Displacing Existing Furnace, Propane E19A2c265	-1,377	-32	-1,408	15.12	-0.06	-0.03	-0.04	-0.06	-0.53	-0.37	-0.39	-0.55

Measure and BCR ID	kWh Heating	kWh Cooling	kWh Total	MMBtu Delivered Fuel	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak
Central Ducted HP Fully Displacing Existing Furnace, Oil E19A2c272	-2,112	-20	-2,132	17.85	-0.04	-0.02	-0.03	-0.04	-0.82	-0.57	-0.61	-0.87
Central Ducted HP Fully Displacing Existing Furnace, Propane E19A2c271	-2,112	-20	-2,132	17.85	-0.04	-0.02	-0.03	-0.04	-0.82	-0.57	-0.61	-0.87
Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Oil E19A2c268	-1,326	-179	-1,505	16.05	-0.22	-0.08	-0.20	-0.25	-0.50	-0.35	-0.37	-0.51
Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Propane E19A2c267	-1,479	-179	-1,658	17.39	-0.22	-0.08	-0.20	-0.25	-0.56	-0.39	-0.41	-0.57
Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Oil E19A2c273	-1,849	-133	-1,982	17.78	-0.17	-0.06	-0.15	-0.18	-0.72	-0.49	-0.53	-0.75
Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Propane E19A2c274	-1,849	-133	-1,982	17.78	-0.17	-0.06	-0.15	-0.18	-0.72	-0.49	-0.53	-0.75
Mini-Split HP Fully Displacing Electric Resistance E19A2c256	1,866	-196	1,670	3.75	-0.25	-0.09	-0.22	-0.27	1.38	0.63	1.23	2.32
Custom Heat Pumps, Displacing Electric Heat (Multifamily) E19B1a274	1,576	44	1,620	-	0.04	0.02	0.04	0.04	1.05	0.51	0.92	1.69

Source: Evaluation Team Analysis

Table A-9. EO Fuel Displacement Single-Family Measure Savings, Post-Retrofit Code Minimum Heat Pump Efficiencies (Per Ton, 2023 Program Year)

Measure and BCR ID	kWh Heating	kWh Cooling	kWh Total	MMBtu Delivered Fuel	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak
Mini-Split HP Integrated Controls Retrofit Oil E19A2c270	-848	-	-848	8.38	-	-	-	-	-0.33	-0.23	-0.25	-0.36
Mini-Split HP Integrated Controls Retrofit, Propane E19A2c269	-848	-	-848	8.59	-	-	-	-	-0.33	-0.23	-0.25	-0.36
Central Ducted HP Partially Displacing Existing Furnace, Oil E19A2c266	-1,202	-32	-1,233	13.42	-0.06	-0.03	-0.04	-0.06	-0.46	-0.32	-0.34	-0.47
Central Ducted HP Partially Displacing Existing Furnace, Propane E19A2c265	-1,668	-32	-1,700	17.32	-0.06	-0.03	-0.04	-0.06	-0.65	-0.45	-0.48	-0.67
Central Ducted HP Fully Displacing Existing Furnace, Oil E19A2c272	-2,112	-20	-2,132	17.85	-0.04	-0.02	-0.03	-0.04	-0.82	-0.57	-0.61	-0.87
Central Ducted HP Fully Displacing Existing Furnace, Propane E19A2c271	-2,112	-20	-2,132	17.85	-0.04	-0.02	-0.03	-0.04	-0.82	-0.57	-0.61	-0.87
Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Oil E19A2c268	-1,326	-179	-1,505	16.05	-0.22	-0.08	-0.20	-0.25	-0.50	-0.35	-0.37	-0.51
Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Propane E19A2c267	-1,564	-179	-1,743	18.26	-0.22	-0.08	-0.20	-0.25	-0.60	-0.42	-0.44	-0.61

Measure and BCR ID	kWh Heating	kWh Cooling	kWh Total	MMBtu Delivered Fuel	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak
Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Oil E19A2c273	-1,849)	-133	-1,982	17.78	-0.17	-0.06	-0.15	-0.18	-0.72	-0.49	-0.53	-0.75
Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Propane E19A2c274	-1,849)	-133	-1,982	17.78	-0.17	-0.06	-0.15	-0.18	-0.72	-0.49	-0.53	-0.75
Mini-Split HP Fully Displacing Electric Resistance E19A2c256	1,866	-196	1,670	3.75	-0.25	-0.09	-0.22	-0.27	1.38	0.63	1.23	2.32
Custom Heat Pumps, Displacing Electric Heat (Multifamily) E19B1a274	1,576	44	1,620	-	0.04	0.02	0.04	0.04	1.05	0.51	0.92	1.69

Source: Evaluation Team Analysis

Table A-10. EO Fuel Displacement Single-Family Measure Savings, Post-Retrofit Code Minimum Heat Pump Efficiencies (Per Ton, 2024 Program Year)

Measure and BCR ID	kWh Heating	kWh Cooling	kWh Total	MMBtu Delivered Fuel	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak
Mini-Split HP Integrated Controls Retrofit Oil E19A2c270	-848	-	-848	8.38	-	-	-	-	-0.33	-0.23	-0.25	-0.36
Mini-Split HP Integrated Controls Retrofit, Propane E19A2c269	-848	-	-848	8.59	-	-	-	-	-0.33	-0.23	-0.25	-0.36
Central Ducted HP Partially Displacing Existing Furnace, Oil E19A2c266	-1,202	-32	-1,233	13.42	-0.06	-0.03	-0.04	-0.06	-0.46	-0.32	-0.34	-0.47

Measure and BCR ID	kWh Heating	kWh Cooling	kWh Total	MMBtu Delivered Fuel	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak
Central Ducted HP Partially Displacing Existing Furnace, Propane E19A2c265	-1,785	-32	-1,817	18.20	-0.06	-0.03	-0.04	-0.06	-0.69	-0.48	-0.51	-0.72
Central Ducted HP Fully Displacing Existing Furnace, Oil E19A2c272	-2,112	-20	-2,132	17.85	-0.04	-0.02	-0.03	-0.04	-0.82	-0.57	-0.61	-0.87
Central Ducted HP Fully Displacing Existing Furnace, Propane E19A2c271	-2,112	-20	-2,132	17.85	-0.04	-0.02	-0.03	-0.04	-0.82	-0.57	-0.61	-0.87
Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Oil E19A2c268	-1,326	-179	-1,505	16.05	-0.22	-0.08	-0.20	-0.25	-0.50	-0.35	-0.37	-0.51
Mini-Split HP with Integrated Controls Partially Displacing Existing Boiler, Propane E19A2c267	-1,650	-179	-1,828	19.13	-0.22	-0.08	-0.20	-0.25	-0.63	-0.44	-0.46	-0.65
Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Oil E19A2c273	-1,849	-133	-1,982	17.78	-0.17	-0.06	-0.15	-0.18	-0.72	-0.49	-0.53	-0.75
Mini-Split HP with Integrated Controls Fully Displacing Existing Boiler, Propane E19A2c274	-1,849	-133	-1,982	17.78	-0.17	-0.06	-0.15	-0.18	-0.72	-0.49	-0.53	-0.75

Measure and BCR ID	kWh Heating	kWh Cooling	kWh Total	MMBtu Delivered Fuel	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak	kW System Peak	kW System On Peak	kW Seasonal Peak	kW Max Peak
Mini-Split HP Fully Displacing Electric Resistance E19A2c256	1,866	-196	1,670	3.75	-0.25	-0.09	-0.22	-0.27	1.38	0.63	1.23	2.32
Custom Heat Pumps, Displacing Electric Heat (Multifamily) E19B1a274	1,576	44	1,620	-	0.04	0.02	0.04	0.04	1.05	0.51	0.92	1.69

Source: Evaluation Team Analysis

Appendix B. Customer Survey Guide

MA Fuel Displacement Particip

Appendix C. Multifamily Owner/Operator Interview Guide

MA Fuel Displacement_Multifa

Appendix D. Contractor Interview Guide

MA Fuel Displacement_Contra

Appendix E. Distributor Interview Guide

MA Fuel Displacement_Distribu