FINAL REPORT

Energy Optimization Model Version 3.1 Update

MA25C04-B-EOMODEL

Date: October 29, 2026

Report title: Energy Optimization Model Version 3.1

Customer: Massachusetts Program Administrators and Energy Efficiency Advisory Council

Customer contact: Kevin LaFlamme, National Grid

Date of issue: October 29, 2026

Project no.: MA25C04-B-EOMODEL

Prepared by:	Reviewed by:	Approved by:
Miles Ingram Project Manager	Analysts and Subject Matter Experts: Catherine Quiroz, Patrick Hewlett, Kathleen Sturtevant, Nathan Throop, Nathan Caron	Geoff Cooper Portfolio Manager

Rev. No.	Date:	Comments received from (name and organization):
1.0	Sept. 14, 2026	Original Issue
2.0	Oct. 22, 2026	Comments received from EEAC consultants Jen Chiodo, Ralph Prahl; and PA staff and consultants Nate Baker, Kevin LaFlamme, David Jacobson, Justin Spencer.
3.0	Oct. 29, 2026	Comments received from EEAC consultants Jen Chiodo, Ralph Prahl; and PA staff and consultants Nate Baker, Kevin LaFlamme, David Jacobson, Justin Spencer

Table of contents

IMPACT VALUE UPDATES FOR PROGRAM ADMINISTRATORS IV

LIST OF ACRONYMS AND KEY TERMS USED IN THIS REPORT V

EXECUTIVE SUMMARY VI

1 INTRODUCTION 1
1.1 Study purpose and objectives 1
1.2 Program overview 2

2 METHODOLOGY AND APPROACH 4
2.1 Overview 4
2.2 Sample development 7
2.3 Data collection 14
2.4 EO Model tool updates 36

3 ANALYSIS AND RESULTS 45
3.1 Program impacts 47
3.2 Changes in annual program impacts 49
3.3 On-site results 54
3.4 Program tracking and design 62
3.5 Limitations and remaining areas of uncertainty 67

4 CONCLUSIONS, RECOMMENDATIONS, CONSIDERATIONS, AND GUIDANCE FOR FUTURE RESEARCH 69
4.1 Conclusions 69
4.2 Recommendations 70
4.3 Considerations 72
4.4 Guidance 72

APPENDIX A. EO MODEL PROPORTIONS A-1

APPENDIX B. ON-SITE RESULTS DETAILS B-1

APPENDIX C. BUILDING SIMULATION DETAILS C-1

APPENDIX D. STATISTICAL EXPANSION DETAILS D-1

APPENDIX E. PARTICIPANT SURVEY INSTRUMENT E-1

APPENDIX F. CONTRACTOR SURVEY INSTRUMENT F-1

APPENDIX G. EO MODEL V3.1 UPDATE STAGE 3 WORK PLAN G-1

List of figures

Figure 1-1. Downstream and midstream program savings basis 2
Figure 2-1. EO Model v3.1 update study tasks and analysis process 4
Figure 2-2. Calibrated model – small office ASHP 29
Figure 2-3. ASHP heating capacity ratio vs. outdoor air temperature for the EO Model v3.0 and v3.1 31
Figure 2-4. ASHP cooling capacity ratio vs. outdoor air temperature for the EO Model v3.0 and v3.1 32

Figure 2-5. Installed capacity by heat pump type and EO Model version 41
Figure 2-6. Partial displacement share of heating load met by VRF and ASHP and TMYx Weather File Hours by outside air temperature (OAT) 43
Figure 3-1. Data analysis approach flowchart by displacement type, original method 46
Figure 3-2. Data analysis approach flowchart by displacement type, adjusted method with pooling 46
Figure 3-3. Electric impact comparison, v3.0 and v3.1 updates 52
Figure 3-4. Fossil fuel impact comparison, v3.0 and v3.1 updates 53
Figure 3-5. System-level heating consumption and heating EFLH results by system type and confirmed displacement level 57
Figure 3-6. Site-level heating consumption and EFLH per heat pump by load sharing scenario 59
Figure 3-7. Site-level heating consumption and EFLH per heat pump by partial displacement operation category 60
Figure 3-8. 2024–2025 installed program capacity, with and without large (>35 tons per site) projects 65
Figure 3-9. Heat pump share of heating load served by outdoor air temperature (OAT) 67

List of tables

Table 2-1. Summary of EO Model parameters and data sources 6
Table 2-2. Summary of 2023–2024 program heat pumps used to develop sample 8
Table 2-3. Priority sample design variables 8
Table 2-4. EO Model sample design, surveys and on-sites, by equipment and displacement type 11
Table 2-5. EO Model sample design, on-sites (metered & verification only), by equipment and displacement type 11
Table 2-6. EO Model sample design, by displaced fuel 12
Table 2-7. EO Model sample design, by building type 12
Table 2-8. Building type aggregation for sample design 13
Table 2-9. EO Model contractor survey sample design 14
Table 2-10. Participant survey completes 15
Table 2-11. On-site disposition 16
Table 2-12. On-site disposition for metered and verification-only sites, by tracked displacement 17
Table 2-13. On-site disposition for metered and verification-only sites, by confirmed displacement 17
Table 2-14. Summary of site analysis parameter outputs and on-site approaches 19
Table 2-15. Summary of weighted heating kWh per HP with estimated population CV for future sample planning 22
Table 2-16. Contractor survey responses, by measure type 22
Table 2-17. Large sites and systems excluded from building simulations 25
Table 2-18. ASHRAE Guideline 14 calibration metrics 30
Table 2-19. Performance curve sources for simulated VRF and MSHP equipment 32
Table 2-20. Heat pump sizing practices from field data 33
Table 2-21. Baseline HVAC efficiency specification source by baseline event type 34
Table 2-22. Baseline natural gas furnace and boiler efficiency changes by event type 35
Table 2-23. Participant survey results for the change in heating setpoint after installing programmatic heat pump by baseline HVAC fuel type 35
Table 2-24. Changes in total capacity per location and heat pump type for the midrise apartment building type 36
Table 2-25. Survey proportion sources 37
Table 2-26. Count and capacity of incentivized units by EO Model version 40
Table 2-27. Average capacity of incentivized units by EO Model version 40
Table 2-28. Partial displacement change in share of heating load met by heat pump and backup/existing baseline systems by outside air temperature (OAT) across EO Model versions 42
Table 2-29. Ventilation characterization for full displacement VRF and MSHP systems 44
Table 3-1. Annual downstream program prescriptive impacts 47
Table 3-2. Annual midstream PTHP prescriptive impacts 47
Table 3-3. Program-weighted average electric impacts and max kW impacts per ton 48
Table 3-4. Annual impact comparison between EO Model versions, by heat pump type and displaced fuel 49
Table 3-5. M&V site counts by tracked and confirmed heating displacement category* 55
Table 3-6. Comparison of heating consumption results between tracked and confirmed displacement levels 55
Table 3-7. Heating consumption results by confirmed displacement classification 56
Table 3-8. Site-level heating consumption results by load sharing scenario 59
Table 3-9. Site-level heating consumption results by partial displacement operation category 61
Table 3-10. Displacement classifications in tracking data and confirmed on-site, count of projects 63
Table 4-1. Challenges and areas for improvement 69

IMPACT VALUE UPDATES FOR PROGRAM ADMINISTRATORS

The following table lists the measures, BCR measure IDs, and updated impact factors this study produced, for prospective application to PY2026.

Measure update information

Measure*	BCR measure ID**	TRM impact factor		
		kWh/ton	kW/ton	MMBtu/ton
ASHP displacing Gas	GC1c028, *GC1e010* GC1c029, *GC1e011*	-351.61	-0.91	9.78
VRF displacing Gas	GC1c030, *GC1e012* GC1c031, *GC1e013*	-430.94	-1.12	8.18
ASHP displacing Oil	EC1c042, *EC1e019* EC1c046, *EC1e023*	-602.94	-1.57	11.37
VRF displacing Oil	EC1c044, *EC1e021* EC1c048, *EC1e025*	-360.05	-0.94	7.89
ASHP displacing Propane	EC1c047, *EC1e024* EC1c043, *EC1e020*	-359.78	-0.94	12.41
VRF displacing Propane	EC1c045, *EC1e022* EC1c049, *EC1e026*	-454.96	-1.18	7.89
ASHP displacing Electric Resistance***	EC1c038, EC1e014 EC1c040, EC1e016	2,710.35	2.98	0.11
VRF displacing Electric Resistance***	EC1c039, EC1e015 EC1c041, EC1e017	1,861.74	2.05	0.08
Midstream – PTHP	EC1e042	927.71	1.02	N/A

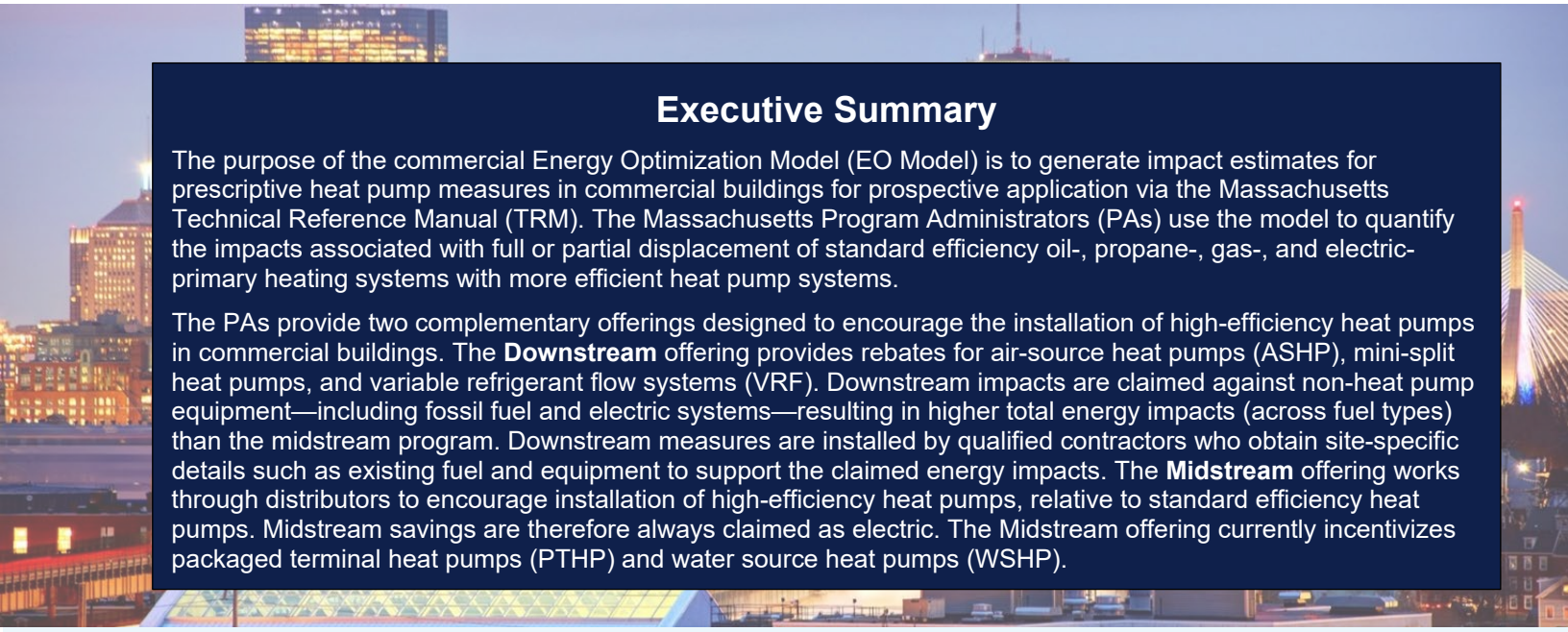
*No GSHP projects were installed through the prescriptive program in 2024 or 2025, and GSHP impacts were not updated as part of this study.
**The recommended impacts reflect pooled displacement impacts for each combination of program heat pump type and displaced fuel. Therefore, BCR measure IDs in each row include IDs for (1) measures that are currently tracked as full displacement, and (2) measures that are currently tracked as partial displacement. BCR measure IDs in italics are in the statewide electrification pool. The IDs above include (1) C&I Equipment Rebates & Instant Incentives (which are part of the statewide pool) and (2) Small Business Turnkey offerings. BCR measure IDs with a lowercase "c" for the fourth digit are part of the Small Business Turnkey Retrofit program, and BCR measure IDs with a lowercase "e" for the fourth digit are part of the Equipment Rebates & Instant Incentives program.
***There are small non-electric savings for measures displacing electric resistance baseline measures due to the Electric Reheat System baseline system types, which appear in a small share of cases based on survey responses. These systems heat using both gas and electric, as they are packaged VAV air handlers with a backup gas burner, DX cooling, and electric resistance reheat at the zone terminals. The heating is primarily served by the zonal electric resistance terminal heaters with the gas only used as backup.

LIST OF ACRONYMS AND KEY TERMS USED IN THIS REPORT

We have provided a list of key terminology as defined by the DNV team, PA evaluation and implementation staff, and the Energy Efficiency Advisory Council (EEAC), here.

Term	Definition
Baseline equipment	The equipment that is the point of comparison for modeling the impact of program-incentivized equipment. It could be either the counterfactual equipment or the pre-program equipment (for the downstream program) or a new standard-efficiency heat pump (for the midstream program).
Case weights	A weight reflecting the prevalence of different segments (defined below), based on program installed capacity, program tracking data proportions, and survey proportions.
Counterfactual equipment	The equipment type that a program participant most likely would have installed if they had not installed what they did (i.e., the program equipment).[1] This is different than pre-program equipment and is considered when assessing impacts for all event types.
Designated equity community (DEC)	Communities selected for targeted program offerings based upon several factors, including the number of low-moderate income customers, renters and historical participation in the programs.
Direct simulation	Estimating the energy use of a segment by simulating the segment characteristics with an EnergyPlus building energy modeling tool.
Displaced fuel	The fuel type of both the pre-program equipment and counterfactual equipment that the program equipment is replacing.
Early replacement	When a participant installs program equipment before their existing equipment has reached the end of its effective useful life.
Energy optimization (EO)	A fuel-neutral approach to energy efficiency that includes strategic electrification—i.e., transitioning buildings from fossil fuels to high-efficiency electric systems like heat pumps for heating and cooling.
Event type	The context in which the program equipment was installed. For the EO Model, this includes early replacement and replace-on-failure instances.
Full displacement	The program-rebated heat pump provides 100% of heating load for the space it serves.
Industry standard practice (ISP)	Equipment characteristics, such as efficiency levels, which reflect current equipment purchases and installation practices across the market without program intervention.
Midstream baseline	The standard efficiency version of the program equipment that a participant installed, used as the baseline to determine midstream program impacts.
Model	In this document, “model” refers to the entire EO tool, including the direct simulation energy models and proxy simulation calculations.
Partial displacement	The program-rebated heat pump provides less than 100% of heating load for the space it serves, with the remainder provided by some other non-heat pump or non-program heating source, such as a separate oil boiler or a backup gas-fired burner within a dual-fuel heat pump.
Pre-program equipment	The components of a participant’s HVAC system that the program equipment replaced. This is different than the counterfactual equipment and is considered when assessing impacts for early replacement events.
Program equipment	The program-incentivized equipment that the participant installed, which serves as the program case used to find midstream impacts.
Proxy simulation	Estimating the energy use of a segment based on the direct simulation results for a different, though similar, segment.
Replace on failure	When a participant installs program equipment after pre-program equipment has reached the end of its effective useful life.
Scenario	Any combination of baseline and program equipment types, displacement type, and building type for which the model estimates energy impact.
Segment	A unique combination of building characteristics that the EO Model accounts for when estimating energy impacts for a measure. Each segment has a case weight (defined above), which reflects the percent of program-participating installed capacity with that combination of characteristics.
Simulation	To avoid confusion with the term “model,” simulation(s) refers to the individual building energy models that serve as inputs to the EO Model.

[1] This study does not assess net-to-gross or program attribution. Therefore, the relevant counterfactual is the gross counterfactual, which is based on the equipment that would have been in place instead of the high-efficiency heat pump customers installed. In contrast, the net counterfactual considers what customers would have done if the program did not exist at all. This counterfactual—which we did not assess—accounts for other complex factors such as free-ridership and spillover.



Executive Summary

The purpose of the commercial Energy Optimization Model (EO Model) is to generate impact estimates for prescriptive heat pump measures in commercial buildings for prospective application via the Massachusetts Technical Reference Manual (TRM). The Massachusetts Program Administrators (PAs) use the model to quantify the impacts associated with full or partial displacement of standard efficiency oil-, propane-, gas-, and electric-primary heating systems with more efficient heat pump systems.

The PAs provide two complementary offerings designed to encourage the installation of high-efficiency heat pumps in commercial buildings. The **Downstream** offering provides rebates for air-source heat pumps (ASHP), mini-split heat pumps, and variable refrigerant flow systems (VRF). Downstream impacts are claimed against non-heat pump equipment—including fossil fuel and electric systems—resulting in higher total energy impacts (across fuel types) than the midstream program. Downstream measures are installed by qualified contractors who obtain site-specific details such as existing fuel and equipment to support the claimed energy impacts. The **Midstream** offering works through distributors to encourage installation of high-efficiency heat pumps, relative to standard efficiency heat pumps. Midstream savings are therefore always claimed as electric. The Midstream offering currently incentivizes packaged terminal heat pumps (PTHP) and water source heat pumps (WSHP).

Methodology and Approach

The v3.1 EO Model update included four primary data collection tasks, detailed below. Most notably, **the v3.1 Model update is the first version to incorporate real-world operation and installation data gathered via on-site visits**, metering and billing data which were used to update building simulations and other EO Model parameters.

Participant survey	On-site verification	On-site metering	Contractor surveys
(n=519)	(n=118)	(n=47)	(n=69)

This evaluation approach consisted of several key steps. They were:

Sample development: The study team designed samples for the participant survey, metering and verification on-sites, and contractor survey based on the 2023–2024 commercial heat pump project tracking data. The team obtained, cleaned, and combined 2023–2024 program data from multiple sources

Data collection: We used a joint data collection approach for the participant web survey and on-site visits, whereby customers were recruited for on-sites from among participant survey respondents who expressed an interest in on-sites. The contractor web survey was independently sampled and fielded.

Building simulation: We updated the existing building simulations—physics-based computer simulation that predict how much energy a building will consume—with real-world operational and field verification data so that they better represent the installed programmatic heat pump systems and behavioral characteristics.

EO Model tool updates: We used survey, field, metered, billing, and program year 2025 tracking data to make several updates to the EO model tool workbook itself, most of which are changes to either weighting or to modeling parameters.

Study Purpose and Objectives

The primary goal of the v3.1 EO Model Update project was to ensure the EO Model's impact estimates reflect real-world operations and other parameters for improved accuracy, by gathering empirical EO project data and improving model functionality and granularity. Specifically, the v3.1 update included the following objectives:

- Evaluate the electric, gas, oil, and propane savings impacts of commercial prescriptive heat pump projects
- Assess how heat pump operations, performance, ventilation, pre-existing conditions and other parameters impact project savings
- Update the EO Model's impact estimates to reflect real-world operations and more granular project characteristics via collection and analysis of on-site metering and verification data.

Model results

The program impact results include electric and fuel impacts for each combination of the following three heat pump installation characteristics:

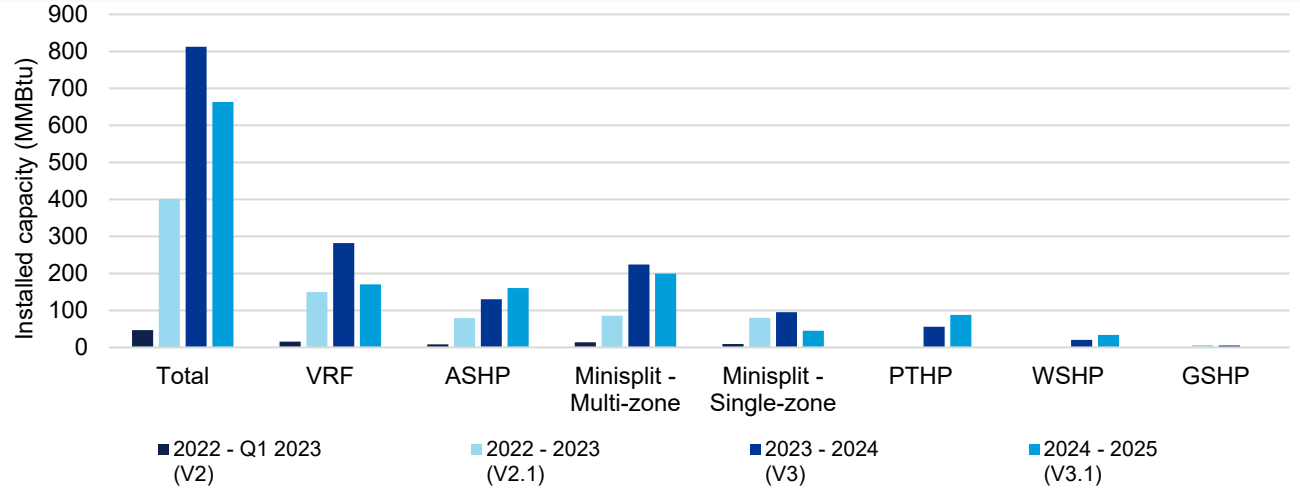
- **Program HVAC equipment type**, including Variable Refrigerant Flow (VRF), Air Source Heat Pumps (ASHP), Packaged Terminal Heat Pumps (PTHP), and Ground Source Heat Pumps (GSHP).
- **Displacement type**, both full and partial displacement.
- **Displaced fuel type**, including electric, gas, heating oil, and propane.

Key Findings

Program impacts

The MA Commercial Heat Pump program has had a meaningful impact on statewide commercial heating and cooling consumption. The v3.1 EO Model results show a small decrease in installed capacity compared to the prior (v3.0) update. However, total installed capacity has nearly doubled since the v2.1 update and increased more than ten-fold since the v2.0 update (which included 15 months of project data rather than two full years).

Figure ES-1. Installed heat pump capacity, by equipment type and EO Model version



Note: No GSHP projects were installed through the prescriptive program in 2024 or 2025, and GSHP impacts were not updated as part of this study. In addition, the program began offering WSHPs during the period covered by the v3.0 Model update, but neither the v3.0 update nor the v3.1 update developed updated WSHP impacts because the resources needed to do so was not merited given their small share of program savings. Specifically, WSHPs accounted for 0.5% of program savings during the 2023–2024 period sampled, and there are no existing building simulations for WSHPs from prior EO Model updates, so updating WSHP impacts would require significant investment to develop new building simulations. Instead, the v3.0 update applied GSHP impacts as a proxy for WSHP impacts, given their technological similarities.

Pooling and adjusting partial displacement impacts

During the survey and on-site data collection tasks, the team encountered a significant number of heat pumps with a heating displacement type (full vs. partial) that was different from the displacement type in the tracking data, as detailed in Sections 3.3.1 and 3.4.1. These classification discrepancies, combined with small sample sizes and substantial variation within displacement categories, limited the precision of displacement-specific estimates and called into question the original approach of deriving partial displacement impacts from full displacement sites. In particular, the approach assumed that full displacement sites provided a reasonable basis for estimating full-season heating use before applying switchover assumptions to represent partial displacement operation. However, some full displacement sites served spaces with low heating needs or irregular occupancy, conditions that may also occur in the partial displacement population. As such, developing partial displacement impacts by applying switchover logic to the modelled impacts from full displacement sites can result in excessively low partial displacement impacts to the extent that full displacement impacts are already influenced

by sites with very low usage. The team's concern is not low usage itself, but whether the additional switchover reductions appropriately represent partial displacement operation when the full displacement impacts already reflect limited heating use. Together, the limited precision of the separate estimates and the uncertainty surrounding this modeling assumption supported developing pooled impacts for full and partial displacement sites together using an adjusted method for calculating partial displacement impacts.[2] *This reflects an interim approach that allows for results in time for prospective 2027 application, but which is expected to be revisited using a more rigorous and time-consuming method for 2028 prospective application (see Section 4.4).*

Downstream impacts

Table ES-1 summarizes the modeled prescriptive per-ton impact for each downstream prescriptive measure. The study team modeled distinct savings impacts by baseline equipment type (pre-existing and counterfactual), building type, and event type (early replacement and replace on failure). The results are weighted to reflect the prevalence of those factors across the program population, based on tracking data, participant and contractor survey responses, and on-site verification data. The downstream summary table includes both total electric impact (kWh/ton) and fuel impact (MMBtu/ton). The electric "savings" are negative—reflecting increased consumption—for measures displacing fossil fuels. This additional electric load is offset by reduced use of fossil fuels. Table ES-1 includes separate full displacement and partial displacement results as well as pooled results, which provide a more accurate representation of the population on average.

Table ES-1. Annual downstream prescriptive impacts

Measure	Displace-ment	Displaced fuel							
		Electric		Natural gas		Oil		Propane	
		kWh/ton	MMBtu/ton*	kWh/ton	MMBtu/ton	kWh/ton	MMBtu/ton	kWh/ton	MMBtu/ton
VRF	Full	1,940	0.08	-449	8.5	-375	8.2	-474	8.2
VRF	Partial	1,786	0.08	-413	7.8	-345	7.6	-437	7.6
VRF	**Pooled**	**1,862**	**0.08**	**-431**	**8.2**	**-360**	**7.9**	**-455**	**7.9**
ASHP	Full	2,825	0.12	-366	10.2	-628	11.8	-375	12.9
ASHP	Partial	2,601	0.11	-337	9.4	-579	10.9	-345	11.9
ASHP	**Pooled**	**2,710**	**0.11**	**-352**	**9.8**	**-603**	**11.4**	**-360**	**12.4**

Note: positive values in this table represent savings; negative values represent increased usage.
*There are small non-electric savings for measures displacing electric resistance baseline measures due to the Electric Reheat System baseline system types, which appear in a small share of cases based on survey responses. These systems heat using both gas and electric, as they are packaged VAV air handlers with a backup gas burner, DX cooling, and electric resistance reheat at the zone terminals. The heating is primarily served by the zonal electric resistance terminal heaters with the gas only used as backup.

Midstream impacts

Table ES-2 provides the weighted average prescriptive impacts for midstream PTHPs. As with the downstream impacts shown above, midstream PTHP impacts are weighted to reflect the relative proportions of baseline equipment types and building types and climate zone observed in the program tracking data and surveys. The midstream summary table only shows positive electric impacts (kWh/ton) because that program's assumed baseline—a standard efficiency heat pump—is always electric.

[2] By the time these issues were fully explored by the study team and the Subcommittee, there was not sufficient time to pool full and partial displacement site analysis results upstream of the building simulations and then re-run and re-calibrate the simulations and update the EO Model. Instead, to produce pooled results in time for 2027 prospective application, the team applied the adjustment approach illustrated in Figure 3-2 in the report body, by directly using on-site metering results. This approach used observed differences in heating consumption between confirmed displacement types in place of the original switchover adjustment. Specifically, the team used the ratio of the metered annualized heating kWh/ton for confirmed full displacement vs. confirmed partial displacement projects to develop an adjustment factor. The team applied this factor to the modeled impacts for full displacement systems to calculate partial displacement impacts. The team then pooled these full and partial displacement impacts into overall impacts via a capacity-weighted average reflecting confirmed full displacement vs. confirmed partial displacement projects.

Table ES-2. Annual midstream PTHP prescriptive impacts

Program equipment type	Electric savings kWh/ton
PTHP	928

Note: The Midstream channel also began offering WSHPs during the period covered by the v3.0 Model update, but neither the v3.0 update nor the v3.1 update developed updated WSHP impacts because the resources needed to do so was not merited given their small share of program savings. Specifically, WSHPs accounted for 0.5% of program savings during the 2023–2024 period sampled, and there are no existing building simulations for WSHPs from prior EO Model updates, so updating WSHP impacts would require significant investment to develop new building simulations.

Changes in annual program impacts

Table ES-3 shows the comparison between the v3.0 and v3.1 electric and fossil fuel impacts, by measure, displacement, and type of fuel displaced. At the highest level, *the v3.1 results show a significant decrease in impacts relative to the v3.0 results, reflecting the general finding that the heat pumps the team observed and metered in the field were used much less than assumed in the prior versions of the EO Model*. Specifically, the v3.1 results show the following changes from the prior model:

- **VRF impacts generally decreased by a larger amount than ASHP impacts.** This includes decreases in fossil fuel savings and electric efficiency savings.
- **For systems displacing fossil fuels, fuel savings decreased for nearly all measures, but corresponding electric penalties decreased by a larger amount**. There was a particularly large difference between the reduction in fossil and electric impacts for ASHPs, which saw reductions in fossil fuel savings of as much as 30%, but reductions in electric impacts (penalties) of as much as 80%.
- **For systems displacing electric resistance, electric savings for ASHPs increased by 16% for partial displacement and 56% for full displacement systems, while electric savings decreased for other measures.** There were decreases of around 30% for full displacement VRF and PTHP systems, and 11% for partial displacement VRF systems.

This report recommends applying pooled displacement results rather than separate full and partial displacement results, so table ES-3 does not reflect the ultimate changes in applied impacts resulting from the study. Rather, the comparison of separate full and partial displacement impacts illustrates the underlying drivers of changes from the prior (v3.0) model, which did not include pooled results. The changes in table ES-3 are shaded based on how large they were. Decreases in savings are shaded red as they are adverse to program savings objectives, while increases in savings are shaded green. Changes (decreases) in electric penalties are shaded orange as they are generally favorable for program net MMBtu savings, but are partly driven by operational factors such as low usage or low heating load sharing (i.e., the heat pump meets a small share of the overall heating needs for a space) that are contrary to program objectives.

Table ES-3. Percent change in annual impacts from EO Model v3.0 to v3.1 unpooled impacts†

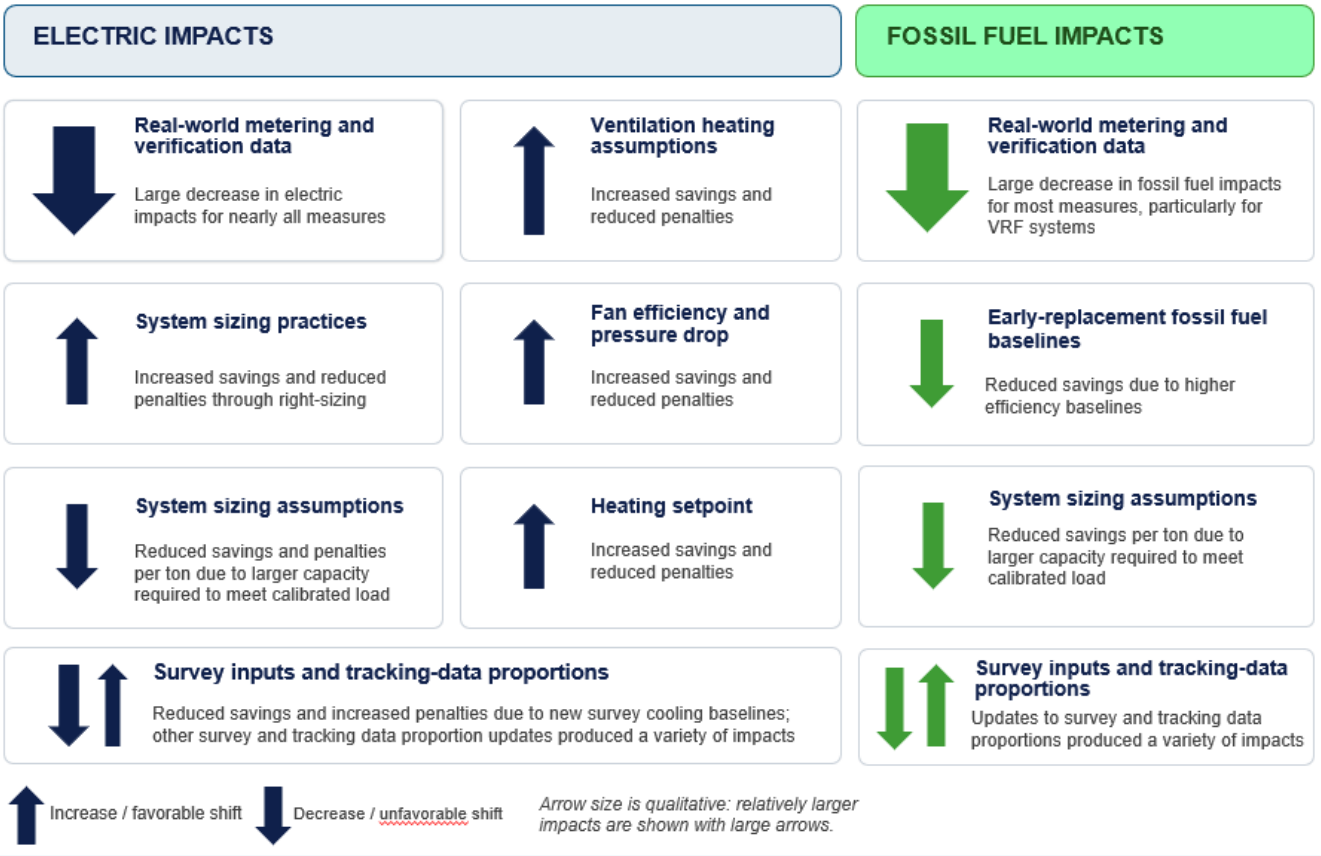
Measure	Displace-ment	Displaced Fuel						
		Electric	Natural Gas		Oil		Propane	
		kWh/ton	kWh/ton	MMBtu/ton	kWh/ton	MMBtu/ton	kWh/ton	MMBtu/ton
VRF	Full	-30%	-64%	-40%	-72%	-45%	-65%	-45%
VRF	Partial	-11%	-43%	-13%	-58%	-23%	-47%	-23%
ASHP	Full	16%	-76%	-28%	-67%	-30%	-80%	-22%
ASHP	Partial	56%	-62%	1%	-49%	-3%	-67%	9%
PTHP*	Full	-31%	N/A	N/A	N/A	N/A	N/A	N/A

Note: The v3.1 impacts reflected in this table are for full and partial displacement projects, prior to pooling, to allow for relevant comparisons across model versions. As detailed above, the report recommends applying pooled impacts. **Red** shading = changes are adverse to program savings objectives; **orange** shading = changes are generally favorable for program net MMBtu savings, but are driven by operational factors (e.g., low usage) that are contrary to program objectives; **green** shading = changes are favorable to program objectives.
*Midstream program only.
†Positive values represent savings; negative values represent increased usage

Drivers of changes

Many inputs and assumptions were updated between v3.0 and v3.1 of the EO Model. Although the team did not isolate the specific impacts of each parameter update, several of the updates contributed significantly to the resulting differences in final impact results between the prior and current version of the model. Figure ES-2 illustrates the direction and relative significance of the drivers of changes between the v3.0 and v3.1 models.

Figure ES-2. Direction and relative significance of changes in v3.1 modeled savings and electric penalties



The following provides further details on these drivers.

- **Real-world metering and verification data.** The v3.1 EO Model is the first iteration to reflect real-world metering and verification data. The metering data revealed far less usage of program heat pumps compared to the assumptions in prior EO Model studies, for both full and partial displacement projects. This updated data drove a *significant decrease* in the impacts (both fossil fuel and electric) across the board.
- **Changes to ventilation heating assumptions**. Based on field observations of the presence (or absence) of ventilation air heating, the v3.1 update removed electric resistance ventilation heating for all mini-split heat pumps (MSHPs) and increased the weighting associated with VRF systems without ventilation heating,

based on survey and on-site data. These changes *reduced electric penalties for systems displacing fossil fuel and increased electric savings for systems displacing electric resistance*.[3]

- **Updates to building simulation assumptions**. Several key updates to building simulation assumptions drove changes in impact results, as follows.
  - Early replacement fossil fuel baselines. The study team reviewed recent Massachusetts building stock and baseline research to assess whether updates were needed for simulated baseline heating system efficiencies. This more recent research found much higher existing system heating efficiencies compared to the efficiencies from earlier baseline research that were used in prior EO Model updates. This increase in baseline efficiency results in *reduced fossil fuel savings for early-replacement systems*.
  - System sizing practices. Contractor survey respondents reported rarely oversizing program heat pumps—a result the team also confirmed from on-site verification data. To align with these results, the team removed the oversizing factors from the modeled baseline and program HVAC systems. This approach effectively "right-sizes" the systems to meet load requirements while reducing how often systems are short-cycling. Reduced short-cycling results in *lower electric penalties for systems displacing fossil fuels, and greater electric saving for systems displacing electric baseline systems*.[4]
  - Fan efficiency and pressure drop. In the prior (v3.0) model, fan efficiency and HVAC system pressure drop was assumed to be the same in both baseline and program conditions. In the v3.1 update, baseline fan performance remained unchanged while program fan efficiency and pressure drop were adjusted during calibration to align with the metered fan end-use target, resulting in greater realized fan savings due to higher fan efficiency and lower HVAC system pressure drop in the program case. This change *reduced electric penalties for systems displacing fossil fuel and increased electric savings for systems displacing electric resistance*.
  - System capacity assumptions. Updates to system capacities reduced savings per ton. The simulation calibration process resulted in increased consumption for program and baseline systems, resulting in an increase in required system sizes in the simulations. Because savings are normalized by installed capacity, the resulting increase in required capacity *lowered overall electric and fossil fuel savings and electric penalties per ton*.[5]
  - Heating setpoint: The participant survey indicated that, on average, participants lower heating setpoints between 1 and 2 degrees after heat pump installation. The team implemented this behavioral change, resulting in *reduced electric penalties for systems displacing fossil fuel and increased electric savings for systems displacing electric resistance*.

- **Changes in survey inputs and tracking data proportions.** Based on PA changes to heat pump project size thresholds for 2026, DNV removed large (>35 ton) projects from the tracking data. The removal of these projects, along with updates to pre-program fuel and building type weighting factors from 2025 program data, *produced a variety of impacts* depending on project characteristics and measure mix. In addition, the v3.1 included new proportions for (1) "no cooling" pre-program and (2) "cooling" and "no cooling" counterfactual baselines, which together *increased electric penalties and reduced electric savings* relative to the prior model baseline cooling assumptions.

[3] Ventilation heating design has not changed for baseline systems since the v3.0 update. For sites assumed to not have ventilation air electric resistance heating, the overall system heating efficiency increases, because the ventilation air heating loads are met using heat pump technology instead of electric resistance
[4] The interaction between right-sizing and then upsizing to meet modeled loads may merit future study, While the team right-sized building simulations when possible per survey insights, some building simulations had to be oversized to manage high unmet load hours and avoid underestimating energy consumption. The fact that oversizing was sometimes needed may be indicative that the commercial building prototypes are too large or unsuitable for representing the stock of commercial buildings where programmatic heat pumps are being installed. Future evaluations could consider scoping a building stock assessment and commercial building prototype development study specific to the prescriptive commercial heat pump program or otherwise explore adjustments to sizing assumptions within the building simulation models.
[5] See prior footnote.

On-site results

The study team deployed metering devices at a sub-sample of 47 participant facilities and collected verification data from a total of 118 facilities (including the 47 metered sites). Section 3.3 of the report details the measurement and verification results that were used to refine and calibrate the EO Model building simulations. In particular, the report provides detailed, statistically representative impact results—particularly heating kWh/ton and equivalent full load hours (EFLH)—across multiple dimensions including system type, heating displacement level, and multiple load sharing scenarios.

Site-specific findings support the ultimate EO Model results showing decreased impacts. For instance, multiple sampled partial displacement heat pumps were primarily used for cooling, and these had the lowest average heating operation of sampled sites. In addition, multiple customers elected to run their heat pumps only at mild temperatures due to utility cost concerns. These findings are inconsistent with program rebate requirements for partial displacement systems. Specifically, the program rebate application requires either (1) installing an integrated control that switches operation from the heat pump to the pre-existing heat source when the temperature of the building falls below a specified set point, or (2) customer certification that a building control system is capable of operating both the heat pump and the existing heating equipment in parallel, subject to a stated switchover temperature. In addition, the application states that control systems must prioritize heat pump operation, and that the PAs may require documentation of control sequence.

The on-site results in Section 3.3 also provide site-specific details on ventilation, including evidence of potentially non-code-compliant ventilation practices at several sampled sites.

Program tracking and design

There were several program tracking data issues and program design changes that materially affected the v3.1 EO Model update study. The two most important issues are as follows.

- **Accurate tracking of displacement type**. During the survey and on-site data collection tasks, the team encountered a significant number of heat pumps with a heating displacement type (full vs. partial) that was different from the displacement status in the tracking data. These discrepancies posed challenges to data collection and analysis as detailed in the report, and they pose significant risks to accurate savings claims if the program does not apply pooled impact values as recommended below. Accurate tracking requires PAs to establish guidance and processes for collecting project data, and contractors to collect sufficient information on the projects they install to correctly classify the displacement type—such as site-specific details on the space served by the program-rebated heat pump and any other supplemental heating systems—which can be challenging to collect.
- **New prescriptive program capacity threshold**. The team made some adjustments to the building simulations and tracking data proportions to account for the new 35-ton capacity threshold for Commercial Prescriptive Heat Pump sites, which became effective on June 1, 2026. However, as this changed happened after analysis was well underway, it created several issues, including decreased applicability of building type mappings used for the building simulations, and decreased applicability of proportions from participant and contractor surveys—both of which were primarily structured around the previous program rules that did not include this threshold.

Limitations and remaining areas of uncertainty

There are several key limitations of the v3.1 EO Model update study that should be considered when interpreting the results, and that can be improved upon in future updates. These are:

- **Available on-site metering data.** During scoping for the study, the Subcommittee and study team developed a sample plan targeting 52 sites for resource-intensive metering, focusing primarily on partial displacement projects based on study priorities. However, as detailed in 2.3.2.3, the on-site sample was small relative to the level of variability across sites, particularly among certain strata, and was not designed to support analysis by building type, and on-sites did not include summer-period metering. As a result, the study provides useful evidence on observed operating behavior, but the findings should be interpreted with caution when applying them to different displacement or building type segments.
- **Aligning commercial building prototypes with available data.** Building simulations always have some extent of inherent limitations due to unquantifiable human behaviors and idealized physical assumptions that create a gap between predicted and actual energy use. In the case of the v3.1 update, there were challenges calibrating certain end-uses and peak loads given prototype characteristics, and as agreed upon with the subcommittee, the team prioritized accurately representing total modeled energy consumption (and therefore savings) as a primary calibration target. Future studies could be scoped to improve end-use-level and peak load calibration.

Conclusions

The MA Commercial Heat Pump program continues to have a meaningful impact on statewide commercial heating and cooling consumption, incentivizing nearly 700 MMBtu/h of capacity and nearly 20,000 heat pump units across nearly 3,000 unique sites in 2024-2025. This is a slight decrease in installed capacity from the prior (v3.0) update, but is more than double the installed capacity of the 2022-2023 period. Such growth has required coordinated effort by program staff and an extensive network of market actors. Given its scale, the program has the potential to significantly advance the commercial heat pump market in Massachusetts.

At the same time, the energy impact estimates from the v3.1 update—based on multiple sources of empirical data from participating end-user and contractor surveys and on-site metering and verification—are lower than the previously estimated energy impacts. Such challenges are not uncommon when rapidly scaling up a new program in a relatively emerging market such as commercial heat pumps. As the first model update to incorporate heat pump operation and installation data gathered via on-site visits, the v3.1 update provides new insights into the real-world operation of program-rebated heat pumps. This newly available information reveals several challenges that PAs and stakeholders will need to address to increase program effectiveness. Addressing the challenges identified in this study will help maximize the impact of the program in contributing to state decarbonization goals.

Recommendations

Recommendation 1. Apply the pooled prescriptive savings values from the v3.1 model prospectively for 2027 commercial heat pump projects. The PAs should update the electric and fossil fuel impact factors in the Massachusetts TRM and BC models for the measure IDs listed in the *Measure Update Information* table on page iv. These values reflect the final impacts based on multiple sources of empirical data from on-site metering and verification visits, participating end-user and contractor surveys, and updated program tracking data. As detailed above, *the study team recommends applying impact values reflecting the pooling of partial and full displacement projects*, for the following reasons.

- Implementers have not consistently and reliably classified or tracked project displacement type.

- The program does not distinguish program incentives by displacement type—all projects receive the same $/ton incentives, regardless of displacement type.[6]
- There is a high degree of uncertainty and variability in energy impacts for both full and partial displacement projects, and direct on-site metering results found that impacts for full and partial displacement projects were not statistically different from each other in most cases. Pooled impacts are more likely to accurately represent the population on average than the separately reported full and partial results.[7]

Pooled impacts should be applied unless and until the programs have been shown to reliably and accurately distinguish between full and partial displacement projects in tracking data (see following recommendation).

Recommendation 2. If the PAs determine that it is important to program objectives to apply separate impact values for full and partial displacement projects in the future, they will need to take several steps to ensure accurate tracking of project displacement type. The 2026 commercial heat pump rebate applications included some clarifications regarding full and partial displacement as detailed in Section 3.4.1. To ensure these definitions are put into effect, the PAs should take the following actions.

- Provide training to program implementation vendors and contractors regarding the need for accurate tracking of displacement type, the technical definitions for full and partial displacement, and the type of site-specific information installation contractors should collect to determine project displacement type.
- Utilize post-inspections to confirm the accuracy of the displacement type in the application (per recommendation 4 below).

Recommendation 3. Enhance contractor training and program guidance to improve project installation quality. The field staff encountered multiple sites with suboptimal project installation quality that pose risks to project savings, customer satisfaction, and code compliance liability. These include multiple projects with unnecessary or inefficient use of backup electric resistance and gas backup heat (including during periods of mild temperatures), several projects with periods of simultaneous heating and cooling within the same space, and evidence of potentially non-code-compliant ventilation practices at several sites. Training and program materials should include additional emphasis on (1) controls systems and strategies for partial displacement sites—which are critical to improving savings impacts for these sites (regardless of whether the program claims impacts or tracks projects by displacement type), and (2) ventilation systems and requirements—which are critical to ensuring code compliance.

In addition, for sites that this evaluation identified as having suboptimal installations and potentially non-compliant ventilation, the team recommends a direct follow-up by program staff to contact these sites and assess their operation and ventilation.

Recommendation 4. Use post-inspections to assess and confirm follow through of key improvements. During the reporting phase of this study, the PAs stated that they plan to begin post-inspecting 100% of commercial heat pump project sites. Based on the site-specific findings from this study, we recommend that post-inspections include the following five items:

- Ensuring heat pump installations do not result in non-compliance with ventilation code
- Confirming that partial displacement control systems and strategies conform to program requirements, including by reviewing documentation of control sequence for a sample of sites to ensure they prioritize heat pump operation
- Checking setpoints and switchover settings where accessible to help ensure optimal system operations
- Assessing overall installation quality
- Confirming the correct classification of displacement type (per recommendation 2 above)

Recommendation 5. Separate the ASHP measure into multiple, more specific ASHP measures. This improvement was also called for in the v2.1 and v3.0 update reports but has not yet been implemented. As in prior years, the PAs currently combine all ASHPs—whether central, ducted, packaged systems or mini/multi-

[6] Since costs (i.e., incentives) are the same for both displacement types, there is no need to track and screen them for cost-effectiveness differently. If costs were different for full and partial displacement, then the programs would still need to track and screen them separately even if savings (i.e., impacts) were pooled.
[7] We did not calculate precisions for the final impact results from this study due to the multiple inputs and additional sources of uncertainty with unknown variation, including the building simulation modelling. However, the direct analysis of on-site metering resulted in heating kWh/ton estimates with precisions of approximately 52% for full displacement and 33% for partial displacement at 80% confidence (see table 3-6), but a much tighter 21% precision when pooled together.

split systems—into a single prescriptive ASHP measure. The study team relied on model numbers and other equipment information to identify more specific equipment types, but this process was limited due to some gaps in this information. There is significant participation associated with this aggregated single ASHP measure (over 60% of 2024-25 capacity), and there are fundamental differences in the design and operation of different ASHP types. For example, on-sites found large differences in metered impacts between packaged and split systems (see Table 3-7). The PAs should split the downstream ASHP program offerings into more specific heat pump types to better capture the inherently different system designs and impact values of these popular measures.

Recommendation 6. Collect information regarding pre-existing equipment in program tracking data. This improvement was also called for in the v2.1 and v3.0 update reports but has not yet been implemented. Downstream program participant data did not contain information on the pre-existing HVAC equipment that the program heat pump replaced. Because the pre-existing equipment type has one of the largest influences on overall measure impacts—and is readily observable by the contractor installing the program equipment—the PAs should consider requiring implementers to track pre-existing equipment as part of program data reporting requirements. The PAs should also collect and track pre-existing equipment status (e.g., whether fully displaced equipment was removed or kept in place), and for partial displacements data on backup heat controls including setpoints, and ventilation details.

Considerations

Consideration 1. Consistently track downstream program data. This was also called for in the v3.0 update report, and the data has improved somewhat, but some inconsistencies and overlap in the data remain. As in the prior update, the study team found that a significant share of downstream projects were not tracked in the downstream vendor data, because the PAs processed them in-house. These projects were often initiated through a separate process involving PA sales or account representative staff, and there can be some barriers to fully integrating them with the vendor-created tracking records. The current study found far fewer records in the separately tracked PA data than in the v3.0 update. However, this data had fewer fields and inconsistencies with the vendor data, including for key fields such as cooling capacity, building types, and equipment details. In addition, the team identified duplicate and overlapping records across PA and vendor data sources, which affected expected equipment counts and required additional cleaning. Consistently tracking this data—and ideally developing a mechanism to directly integrate the PA in-house data into the vendor database—would streamline evaluation and allow mapping of projects to more specific equipment types in the future.

Consideration 2. Collect and track more complete contact information for midstream projects. A lack of contact information in the midstream program data—particularly customer and contractor email addresses—limited the study team's ability to collect survey and other data for PTHPs, which are the largest midstream program offering. According to the PAs, neither customer nor contractor emails are required to be collected in the midstream program. In addition, the team could not survey PTHP contractors due to a lack of contact information, in part because systems were often installed in hotels by facility operations staff. In such cases, improved contact information for customer installation staff would also be useful for future evaluations.

In addition to these recommendations and considerations, Section 4.4 provides guidance to help improve the robustness, comprehensiveness and efficiency of future evaluations of the Commercial Heat Pump program.

1 INTRODUCTION

1.1 Study purpose and objectives

The purpose of the commercial Energy Optimization Model (EO Model) is to generate impact estimates for prescriptive heat pump measures in commercial buildings for prospective application via the Massachusetts Technical Reference Manual (TRM). The Massachusetts Program Administrators (PAs) use the model to quantify the impacts associated with full or partial displacement of standard efficiency oil-, propane-, gas-, and electric-primary heating systems to more efficient heat pump systems.

The EO Model Version 3.1 (v3.1) Update study builds on three prior update projects conducted by DNV and Resource Innovations (formerly Cadeo):

- Version 2.0 (v2.0) Update (November 2023),[8] a comprehensive update to the previous commercial EO Model (Version 1.0). Major improvements in the Version 2.0 model included expanded modeling capabilities using commercial building energy simulations calibrated to non-participant billing data, added C&I HVAC equipment types, updated baseline assumptions, and other major updates.
- Version 2.1 (v2.1) Update (September 2024),[9] which included several substantial improvements to the Version 2.0 model, including updated VRF simulations, improved ventilation heating fuel assumptions, integration of more recent program tracking data (2022–Q12024) and refined model weighting based on installation contractor web survey results.
- Version 3.0 (v3.0) Short-Term Update (September 2025),[10] which updated the model with refreshed 2023–2024 program tracking data and made other improvements to reflect program and policy changes, including integrating savings impacts for ASHP, VRF, and GSHP into downstream program savings values, incorporating program data on PTHPs, and updating baseline assumptions for designated equity communities (DECs).

The primary goal of the v3.1 EO Model Update project was to ensure the EO Model's impact estimates reflect real-world operations and other parameters for improved accuracy, by gathering empirical project data and improving model functionality and granularity. Specifically, the v3.1 update included the following objectives:

- Evaluate the electric, gas, oil, and propane savings impacts of PY2023/2024 commercial prescriptive heat pump projects[11]
- Assess how heat pump operations, performance, ventilation, pre-existing conditions and other parameters impact project savings
- Update the EO Model's impact estimates to reflect real-world operations and more granular project characteristics via collection and analysis of on-site metering and verification data.

[8] Cadeo Group. (November 1, 2023). *Energy Optimization Model Update*. Prepared for the Massachusetts Program Administrators. https://ma-eeac.org/wp-content/uploads/MA22C10-Energy-Optimization-Model-Update-Report_FINAL_01NOV2023_ForEEACWebsite.pdf

[9] Cadeo Group. (September 25, 2024.) *Energy Optimization Model – Version 2.1 Update*. Prepared for the Massachusetts Program Administrators. https://ma-eeac.org/wp-content/uploads/MA24C02-Energy-Optimization-Model-Version-2.1-Update-Report_25SEP2024.pdf

[10] DNV. (November 13, 2025.) *Energy Optimization Model Version 3.0 Short-Term Update*. Prepared for the Massachusetts Program Administrators. https://ma-eeac.org/wp-content/uploads/MA25C04-B-EOModel-Short-term-Update-Final-Report-20251113-clean.pdf

[11] Ground-source heat pumps (GSHP) accounted for 1.0% of program savings from 2023-2024 and there were no GSHPs in the 2024 or 2025 downstream or midstream program data, while water-source heat pumps (WSHP) accounted for 0.5% of program savings from 2023-2024.Given the small portion of capacity installed and program savings, GSHP and WSHP savings impacts are algorithmically estimated as opposed to building simulation-based. This study sought to improve assumptions primarily via on-site data collection and improved building simulations. As detailed in the workplan, sampling and gathering on-site data for GSHP and WSHP and directly simulating these equipment types through building simulations would accrue additional cost that the Subcommittee determined would outweigh the benefit given their share of program activity. As such, this study does not provide updated impact values for GSHP or WSHP.

1.2 Program overview

The PAs provide two complementary program offerings designed to encourage the installation of high-efficiency heat pumps in commercial buildings: a midstream program and a downstream program. The PAs designed these two programs to deliver a range of equipment types through two different channels, using two different baselines,[12] as described below.

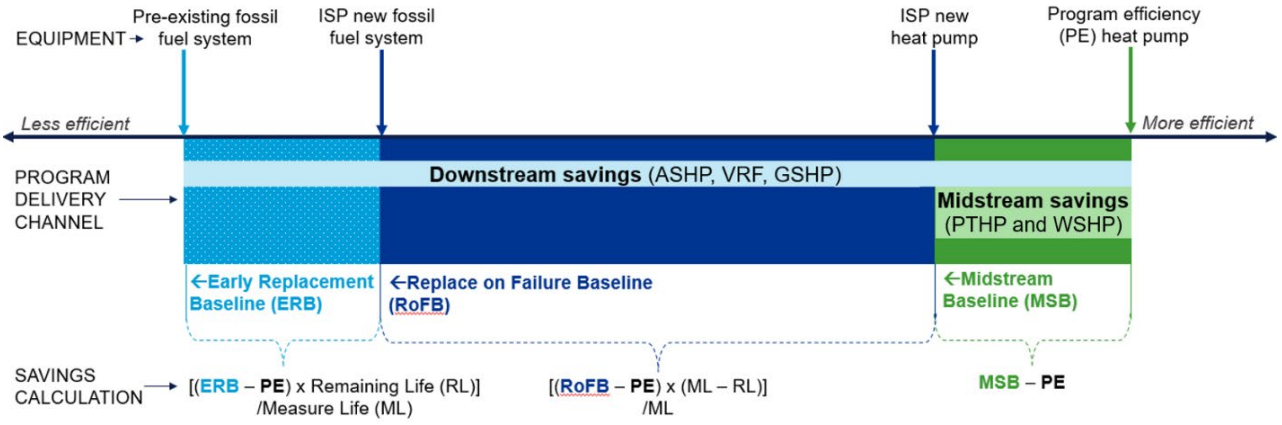
Commercial EO Program Offerings

The Downstream offering claims impacts against non-heat pump equipment, which results in higher total energy impacts (across fuel types) and allows for higher incentives than the midstream program. The downstream program therefore considers fuel switching (i.e., both the change in total cross-fuel and electric consumption) in its impact estimates. Downstream program measures are installed by qualified contractors who obtain site-specific details such as existing fuel, equipment, and displacement types that support the claimed energy impacts. Measures currently offered through the midstream program include air-source heat pumps (ASHP), mini-split heat pumps, and variable refrigerant flow systems (VRF).

The Midstream offering works through distributors to encourage the installation of high-efficiency heat pumps, relative to standard efficiency heat pumps. As a result, the assumed baseline for assessing midstream program impacts is the industry standard practice heat pump efficiency. Also, because the assumed baseline is always a heat pump, savings are always electric and the program is independent of fuel switching. Measures currently offered through midstream include packaged terminal heat pumps (PTHP) and water source heat pumps (WSHP).

For purposes of claiming savings, the PAs calculate downstream program savings as the difference between a program-qualifying, high-efficiency heat pump and either an early-replacement baseline (ERB) of the pre-existing equipment efficiency, or a replace-on-failure baseline (RoFB), reflecting a new, ISP fossil fuel system, as shown in Figure 1-1. They calculate savings for midstream program participants as the difference between a program-qualifying, high-efficiency heat pump and a midstream baseline (MSB) of a new, industry standard practice (ISP) efficiency heat pump, as shown in Figure 1-1.[13]

Figure 1-1. Downstream and midstream program savings basis



[12] As detailed in the call-out box, the baseline for the Midstream program offering is assumed to be a standard efficiency heat pump. There may be some amount of fuel-switching in reality, but this study did not attempt to quantify this for Midstream offerings given the program design and baseline definitions, as well as the prioritization of study resources for ASHPs and VRFs. Future EO Model updates could more fully examine PTHP baselines to determine the extent to which fuel-switching may occur.

[13] Prior EO Model update versions (v2.1 and v2.0) utilized a different savings calculation methodology, in line with the PAs' savings calculations in effect at the time of those model updates. See section 1.2 of the *Energy Optimization Model Version 3.0 Short-Term Update report*, at https://ma-eeac.org/wp-content/uploads/MA25C04-B-EOModel-Short-term-Update-Final-Report-20251113-clean.pdf.

Previous savings approach. The PAs approach to calculating savings for the downstream and midstream program offerings changed prior to the v3.0 model update. Specifically. prior to 2025, the PAs calculated downstream program savings as the difference between the MSB value (a new ISP heat pump) and either an early-replacement baseline (ERB) of the pre-existing equipment efficiency, or a replace-on-failure baseline (RoFB), reflecting a new, ISP fossil fuel system. They separately calculated savings for midstream program participants as the difference between a program-qualifying, high-efficiency heat pump and a midstream baseline (MSB) of a new, industry standard practice (ISP) efficiency heat pump, as shown in the figure. Under this approach—reflected in the v2.0 and v2.1 models—downstream and midstream savings were calculated separately, and the PAs claimed both savings streams for all downstream participants but only the midstream savings for midstream participants. For further details see the EO Model v3.0 Short-Term Update report.[14]

[14] DNV. Energy Optimization Model Version 3.0 Short-Term Update MA25C04-B-EOMODEL, Oct. 30, 2025. See section 1.2. https://ma-eeac.org/wp-content/uploads/MA25C04-B-EOModel-Short-term-Update-Final-Report-20251030-for-filing.pdf

2 METHODOLOGY AND APPROACH

Designed to inform the Massachusetts Technical Reference Manual (TRM) and support PA planning and program delivery, the EO Model quantifies the energy impacts associated with transitioning from standard efficiency heating oil, propane, natural gas, and electric heating systems to more efficient heat pump systems. The model produces prospective impact estimates for prescriptive commercial heat pump measures, using a suite of building simulation results representing multiple baseline and program HVAC system types. The model uses these simulations to estimate measure impacts that account for multiple implementation scenarios, including:

- Event type: early replacement or replace on failure
- Displacement type: full or partial displacement
- Multiple counterfactual fuel and equipment types
- Ventilation heating configuration (i.e., whether or not supplemental heating is provided by the ventilation system).

The model then uses recent participation data to develop weights for all unique combinations of these variables based on the installed program equipment capacity. These weights are applied to building simulation outputs to estimate average program-wide measure impacts for each combination of program heat pump type, displacement type, and displaced fuel (e.g., ASHP fully displacing natural gas). Because the Massachusetts programs apply impact results prospectively, the EO model is designed to be representative of programs moving forward by allowing segment weights to be updated as new program data becomes available.

The v3.1 Model update is the first version to incorporate real-world operation and installation data gathered via on-site visits and equipment metering, which were used to update building simulations and EO Model parameters. The v3.1 Model update also incorporated data gathered through customer and contractor web surveys, as detailed below.

2.1 Overview

The v3.1 EO Model update involved multiple data collection and analysis tasks to develop and integrate evidence to estimate prospective energy impacts for commercial heat pump measures, as illustrated in Figure 2-1.

Figure 2-1. EO Model v3.1 update study tasks and analysis process

The v3.1 EO Model update included four primary data collection tasks covering projects installed in program years 2023–2024, as follows:

Participant survey. The primary purposes of the participant survey were (1) to gather key project information from a large sample of participants, both for primary analysis and to inform subsequent on-site data collection; and (2) to recruit respondents for on-site visits. Survey questions covered the following topics:

- Confirming the participant's building type
- Characterizing the installation, including:
  - The event type—early replacement or replace on failure
  - Whether the system provides cooling and heating
  - Whether the system serves the full or partial heating load (e.g., secondary/backup heating systems and fuels)
- Determining the pre-existing cooling and heating equipment and heating fuel
- Determining the counterfactual heating and cooling equipment (i.e., the equipment that would have been installed instead of the program heat pump)
- Determining heat pump system scheduling and setpoints.

On-site verification. The purpose of the on-site interview and verification inspection was to develop a clear understanding of heat pump operation, seasonal usage patterns, reliance on supplemental systems, and appropriate heating and cooling baselines in consideration of preexisting equipment viability and counterfactual scenarios. We collected the following information for ASHP and VRF project sites:[15]

- **Building characteristics:** facility type (NAICS code), hours of operation, building age, seasonality, location, vintage, square footage (total area and area conditioned by the heat pump), level of weatherization (qualitative).
- **Business characteristics:** number of employees, typical occupancy during business hours, typical work hours or shifts.[16]
- **HVAC characteristics:** fuel mix, primary & secondary heating/cooling equipment (unit types, nameplate data, age of existing equipment, efficiency), distribution system configuration, ventilation system equipment, thermostat or BMS locations/control settings (including switchover temperature and techniques), refrigerant types.
- **Operation characteristics:** Heat pump performance issues, maintenance schedule, refrigerant issues.
- **Preexisting or counterfactual conditions:** heating system type, operational status, fuel type, retention status; cooling system presence, system type, retention status.

On-site metering. On-site metering provided real-world data from ASHP and VRF projects[17] to support updates to the building simulations and EO model tool. In particular, metering provided insight into the actual heating operation of the heat pump as compared with other heating systems such as backups, supplemental systems, or ventilation systems with heating elements. This data informs key parameters such as the switchover temperatures and schedules initially collected during the site visit and customer survey. Meters remained in place for four to six months to capture heating season performance across a representative range of outside air temperatures, generally from December 2025 to April 2026.[18]

[15] PTHPs were included in the survey and program data update tasks, but were not included in on-site data collection, because the study team and Subcommittee determined that ASHP and VRF projects should be prioritized for more resource-intensive site visits.
[16] Business operation information is not a direct model input but could help us extrapolate data from a sampled site to a group of unsampled sites. It is also a low incremental cost to collect in the customer interview.
[17] PTHPs were included in the survey and program data update tasks, but were not included in on-site data collection, because the study team and Subcommittee determined that ASHP and VRF projects should be prioritized for more resource-intensive site visits.
[18] Cooling system characteristics were assessed via field verification, which provides sufficient information for most projects where heat pumps are the sole cooling source.

Contractor surveys. These surveys increased the robustness of the empirical data collected via on-sites and customer surveys by obtaining a broader market perspective and providing corroborating information for key modeling inputs such as:

- Prevalence of event types (early replacement vs. replace on failure)
- Typical system configurations for each installed equipment type
- Typical pre-program equipment types and fuels, for given heat pump and building types
- Equipment sizing and installation practices
- Prevalence and type of supplemental heating fuel
- Common dual-fuel controls and switchover settings
- Ventilation heating configurations

The surveys also covered two market issues similarly included in participant surveys: local emissions reduction ordinances in Boston and Cambridge, and dual baselines for customers in Designated Equity Communities (DECs). Contractors' broader market perspective provides a stronger basis for determining whether, and what, adjustments are needed to future program proportions to reflect increased deployment in Boston and Cambridge; as well as to assess the typical HVAC repair and replacement practices for select customer types[19] in DECs relative to non-DECs.

2.1.1 EO Model parameters and data sources

Table 2-1 provides an overview of the key parameters informing the v3.1 model, and the data sources and associated model and simulation updates the study team made for each parameter.

Table 2-1. Summary of EO Model parameters and data sources

Category	Parameter(s)	Data source	Associated model and simulation updates
Heating operation of heat pump, backup, and supplemental systems	Installation and operability status, nameplate data	Field verification	Key HP characteristics (e.g., nameplate capacity, efficiency)
	HP heating energy consumption	Power metering at HP disconnect	Shares of heating energy consumption and heating output by system type and fuel type
	Backup heating use and fuel type*	Amp metering at combustion air fan** if fossil fuel system or amp metering at electric resistance circuit	
	Supplemental ventilation heating energy consumption*	Amp metering at combustion air fan if gas-fired heating system or amp metering at electric resistance circuit	
	Supplemental heating fuel	Field verification Contractor survey	
	Dual-fuel control and switchover	Power metering & amp metering mentioned above Contractor survey	Switchover temperature and switchover control for partial displacement systems
	Scheduling and setpoints	Field verification	Hourly setpoints and schedules within building simulations
HP performance	Average seasonal coefficient of performance (COP), COP by temperature	Manufacturer specification sheet data for the most prevalent systems identified through field verification	Performance curves (COP vs. outside air temperature) by system type

[19] Per the strategic evaluation plan, these customer types include municipal buildings, schools and small businesses (other than national chains).

Category	Parameter(s)	Data source	Associated model and simulation updates
Ventilation heating configuration	Supplemental heating provided or not provided by ventilation system	Field verification Contractor survey	Weights of ventilation heating configuration by building type among simulation scenarios
Preexisting & counterfactual conditions and event type	Heating fuel Heating equipment condition (e.g., fully operational, nearing end of life), type, age, condition	Field verification Contractor survey Customer survey	Baseline conditions on which savings from program-rebated equipment are quantified (see survey proportions section of APPENDIX A for further detail)
	Cooling equipment condition (e.g., fully operational, nearing end of life), type, age, condition	Field verification Contractor survey Customer survey	

* Field staff metered the ventilation system when it provided heating to the area served by the heat pump—in which case it was considered a supplemental system. Using normalized heat pump operational data compared against normalized supplemental or backup system use, the engineer estimated the percent heating load served by the rebated heat pump and the backup and/or supplemental heating systems by temperature bin.
** If a backup fossil fuel system does not have a combustion fan, the site engineer with meter the gas solenoid valve with a 5-amp current transducer (CT), and verify that the high-low signal is captured to determine system operation.

Additional details on the sources and methods for developing EO Model proportions and weightings—including various program and baseline system proportions—are provided in Section 2.3.10.

2.2 Sample development

The study team designed samples for the participant survey, metering and verification on-sites, and contractor survey based on the 2023–2024 commercial heat pump project tracking data. The team obtained, cleaned, and stacked 2023–2024 program data from the three sources listed below. Overlapping projects between the datasets were de-duplicated so they only appear in the final stacked data once.

- Downstream implementation vendor (Resource Innovations) data, including air source heat pumps (ASHP), ground source heat pumps (GSHP),[20] variable refrigerant flow systems (VRF), and mini-split heat pumps installed through the downstream program
- Midstream implementation vendor (Energy Solutions) data, including packaged terminal heat pumps (PTHP) and water source heat pumps (WSHP)[21] installed through midstream program
- PA in-house data, including VRFs, ASHPs, and mini-split heat pumps tracked and processed by the PAs in-house (not via an implementation vendor).[22]

This combined 2023–2024 program dataset provided the frame used to develop the sample. Table 2-2 summarizes 2023–2024 program heat pumps (installed capacity) by equipment type and delivery channel.

[20] As noted above, no GSHP projects were installed through the prescriptive program in 2024 or 2025, and GSHP impacts were not updated as part of this study.
[21] As noted above, the program began offering WSHPs during the period covered by the v3.0 Model update, but neither the v3.0 update nor the v3.1 update developed updated WSHP impacts because the resources needed to do so was not merited given their small share of program savings. WSHPs accounted for 0.5% of program savings during the 2023–2024 period sampled, and there are no existing building simulations for WSHPs from prior EO Model updates, so updating WSHP impacts would require significant investment to develop new building simulations. Instead, the v3.0 update applied GSHP impacts as a proxy for WSHP impacts, given their technological similarities.
[22] Based on interviews with PA implementers in July 2025, the team identified these 2023 and 2024 projects that were processed in-house and not included in the downstream (Resource Innovations) and midstream (Energy Solutions) implementation vendor data sets. Although a relatively small share of projects were handled this way, these projects are likely to be systematically different from others, as interviewees said they can involve PA sales, account representatives or other staff, meaning a heavier touch involvement by PAs and potentially higher-quality installation and project performance.

Table 2-2. Summary of 2023–2024 program heat pumps used to develop sample

Program HVAC	Downstream (Resource Innovation)		Downstream (PA in-house)		Midstream (Energy Solutions)		Total
	Capacity (MMBtu)	Capacity (%)	Capacity (MMBtu)	Capacity (%)	Capacity (MMBtu)	Capacity (%)	Capacity (MMBtu)
ASHP	63	68%	30	32%	0	0%	93
PTHP	0	0%	0	0%	56	100%	56
Minisplit - Multi-zone	67	40%	100	60%	0	0%	166
Minisplit - Single-zone	38	72%	15	28%	0	0%	53
VRF	102	52%	93	48%	0	0%	195

Note: No GSHP projects were installed through the prescriptive program in 2024 or 2025, and GSHP impacts were not updated as part of this study. In addition, the program began offering WSHPs during the period covered by the v3.0 Model update, but neither the v3.0 update nor the v3.1 update developed updated WSHP impacts because the resources needed to do so was not merited given their small share of program savings. Specifically, WSHPs accounted for 0.5% of program savings during the 2023–2024 period sampled, and there are no existing building simulations for WSHPs from prior EO Model updates, so updating WSHP impacts would require significant investment to develop new building simulations.

Based on input from the EO Subcommittee, we designed the sample to focus on characteristics that were most relevant to the goals of the data collection task. As shown in Table 2-3, we determined equipment type and displacement type to be critical stratification variables, while others were important but less valuable.

Table 2-3. Priority sample design variables

Data collection goal	Stratification variable			
	Equipment type	Displacement type (full/partial)	Building type	Displaced fuel
Understand real-world equipment operation	✓	✓	✓	*
Verify equipment specifications & configurations	✓	✓	**	
Produce savings results for program application (e.g., align with BCR IDs, reflect future offerings)	✓	✓		✓

✓ Stratification priority
* Second-tier priority. The economics of gas will influence the operation of partial displacement, but was expected to be less influential on operations and impacts than the other variables such as heat pump type, displacement type, and building type.
** Second-tier priority. Equipment configurations (including setpoints, switchover temperatures) are expected to differ systematically by building type.

The team designed a sample to produce a manageable number of strata for data collection and target resources on equipment and project types that are most important to the future of the programs and where data collection can provide the most value. This included dropping equipment types and collapsing domains from the 2023–2024 dataset. Specifically, the sample design excludes GSHP and WSHP, because:

- GSHPs accounted for 1.0% of program savings from 2023–2024 and no GSHPs were installed through the prescriptive program in 2024 (or 2025)
- WSHPs accounted for 0.5% of program savings from 2023–2024 and represent a small (albeit growing) portion of capacity installed through the program.[23]

[23] Given the small portion of capacity installed and program savings, GSHP and WSHP savings impacts are algorithmically estimated as opposed to building simulation-based. This study seeks to improve assumptions primarily via on-site data collection and improved building simulations. Sampling and gathering on-site data for GSHP and WSHP and directly simulating these equipment types through building simulations would accrue additional cost that the study team believes would outweigh the benefit given the amount of installed capacity they represent.

Recruitment for this study was at the site (unique address) level. Since many sites (30%) participated in more than one project, we employed a two-stage cluster approach for sampling, where the site served as our sampling unit and data for a single project within a selected site was collected. In addition, sites that participated in more than one project may have installed more than one type of equipment. For sampling, each site had to be placed in a single stratum, requiring the assignment of each site based on its highest priority project type. We established priority based on the scarcity of the project type (defined as the combination of equipment type, displaced fuel, and partial vs full displacement) within the population. Using the scarcest project type as an example, there are only 11 sites in the population that completed partial displacement packaged ASHP projects displacing a fuel other than natural gas. If a site participated in one of those projects, it would be assigned to that stratum even if it had participated in other projects installing other equipment types.

2.2.1 Participant survey and on-sites

The impact evaluation used an integrated sampling approach for (1) participant surveys; (2) on-sites with metering; and (3) on-sites without metering (verification only). Sampling was integrated as the on-sites were recruited from survey respondents, and the sample design prioritized certain types of projects for on-site metering (as opposed to verification-only), as follows:

- Partial displacement ASHP and VRF projects. To help manage study costs, the sample prioritized metering of partial displacement sites, particularly among ASHP and VRF projects, which have had relatively less real-world operational data gathered over time compared to mini-splits (which are commonly installed in residential settings, where they have been previously evaluated via on-site metering and other methods). In addition, partial displacement projects have the greatest uncertainty in operational parameters—in particular the share of heat pump vs. supplemental heating use—and therefore were expected to provide the greatest value from metered data.
- Full displacement, focused on ASHP projects. The rationale for focusing full-displacement metering on ASHPs is that these equipment types have large potential for savings as well as uncertainty around their operations, particularly for RTUs. In addition, there is greater diversity in equipment type and system design among ASHPs than among VRFs, so there is more uncertainty in operations and savings, increasing the value of real-world data collection.

Among ASHPs, the subcommittee expressed a priority for gathering on-site information to better understand RTU operations, due to their large potential for savings as well as uncertainty around their operations, particularly for partial displacement dual-fuel RTUs. The program data does not track RTUs versus other types of ASHPs, so the team targeted the sample of ASHP on-sites on larger, packaged systems. Specifically, the team flagged (1) sites with packaged ASHP systems based on AHRI reference IDs, and (2) sites with an average ASHP capacity per unit greater than 5 tons as eligible for metered site visits.[24]

Based on the considerations above, the team developed the sample design shown in the tables below. The sample design reflects input from the EO Subcommittee on priorities for more resource-intensive metering site visits. Specifically, Table 2-4. and Table 2-5 reflect a sample design entailing 124 on-sites—52 with metering and 72 with verification only. The 72 verification-only sites target most strata from the participant survey, with PTHPs excluded from any on-sites. PTHPs were excluded in order to prioritize resource-intensive site visits for the equipment types of greater interest to the Subcommittee—ASHPs and VRFs—which represent much larger shares of program savings and have greater diversity in operational profiles, displacement types, and building types than PTHPs. The 52 metered on-sites target partial displacement sites with

[24] To identify these sites from among the population of ASHPs, the team first looked up the AHRI reference ID for each project—where available in the tracking data—to determine if the system was packaged or split. We did this using an automated web query of AHRI's database and identified that 52 of the project records were packaged ASHPs based on their AHRI reference IDs. In addition, the team screened projects for average per-unit capacity to identify larger ASHPs to target for metering. Specifically, the team estimated the average capacity per installed unit by dividing the total installed capacity at each site by the number of units installed at that site and identified an additional 122 project records meeting the >5 ton/unit criteria.

ASHPs and VRFs, and full displacement sites with ASHPs. The sample targeted 10% precision at 80% confidence for surveys and 20% precision at 80% confidence for on-sites at the equipment type-displacement type level, assuming a coefficient of variation of 0.7. The study assumed this level of variability through discussions with the subcommittee, acknowledging that a precise estimate of the expected variability for all metrics under consideration was unavailable. Precisions at 90% confidence are also shown for reference.

Table 2-4. EO Model sample design, surveys and on-sites, by equipment and displacement type

Domain (Equipment, Displacement)	**Population**		**Sample**		**Target Relative Precision, 80% Confidence**[1]		**Target Relative Precision, 90% Confidence**[1]	
	Overall Projects	Stratum Sites	Participant survey	On-sites	Participant survey	On-sites	Participant survey	On-sites
Mini-split - Full	1,393	1,157	82	21	11%	23%	14%	29%
Mini-split - Partial	582	476	82	21	11%	24%	14%	31%
ASHP - Full	673	461	98	22	8%	22%	11%	28%
ASHP – Partial	361	277	70	22	10%	25%	13%	32%
PTHP – Unknown	207	207	41	0	12%	N/A	15%	N/A
VRF - Full	363	312	72	22	12%	24%	16%	31%
VRF - Partial	105	85	31	16	13%	24%	17%	30%
Total	**3,684**	**2,975**	**476**	**124**	**5%**	**N/A**	**6%**	**N/A**

[1]Assumed coefficient of variation = .7

Table 2-5 shows the sample for on-sites with metering and without metering (verification only). Since the same non-metered verification information will be captured at both metered and verification-only sites, the targeted precisions for verification estimates are based on the full sample of on-sites.

Table 2-5. EO Model sample design, on-sites (metered & verification only), by equipment and displacement type

Domain (Equipment, Displacement)	**Population**		**On-site Sample**		**Target Relative Precision, 80% Confidence**[1]		**Target Relative Precision, 90% Confidence**[1]	
	Overall Projects	Stratum Sites	Verification only	Metering	Verification only	Metering	Verification only	Metering
Mini-split - Full	1,393	1,157	21	0	23%	N/A	29%	N/A
Mini-split - Partial	582	476	21	0	24%	N/A	31%	N/A
ASHP - Full	673	461	4	18	22%	26%	28%	33%
ASHP – Partial	361	277	4	18	25%	30%	32%	38%
PTHP – Unknown	207	207	0	0	N/A	N/A	N/A	N/A
VRF - Full	363	312	22	0	24%	N/A	31%	N/A
VRF - Partial	105	85	0	16	24%	24%	30%	30%
Total	**3,684**	**2,975**	**72**	**52**	**N/A**	**N/A**	**N/A**	**N/A**

[1]Assumed coefficient of variation = .7

Although not primary stratification variables, the team also estimated sampling precisions for (1) displaced fuel (specifically for natural gas, which has unique economics relative to other displaced fuels, which may influence the operation of partial displacement systems), and (2) building type, as shown in Table 2-6 and Table 2-7.

Table 2-6. EO Model sample design, by displaced fuel

Domain	Population		Sample		Target relative precision, 80% confidence[1]		Target relative precision, 90% confidence[1]	
	Overall projects	Stratum sites	Participant survey	On-sites	Participant survey	On-sites	Participant survey	On-sites
Mini-split - Natural Gas	1,100	907	82	22	11%	23%	15%	30%
Mini-split - Other Fuel	875	726	82	20	11%	27%	16%	35%
ASHP - Natural Gas	604	439	98	25	8%	21%	10%	27%
ASHP - Other Fuel	430	299	70	19	10%	29%	14%	37%
PTHP - Other Fuel	207	207	41	0	12%	N/A	15%	N/A
VRF - Natural Gas	343	300	60	23	12%	24%	16%	31%
VRF - Other Fuel	125	97	43	15	13%	25%	15%	32%
Total	**3,684**	**2,975**	**476**	**124**	**5%**	**N/A**	**6%**	**N/A**

[1]Assumed coefficient of variation = 0.7

Table 2-7. EO Model sample design, by building type

Domain	Population		Sample		Target relative precision, 80% confidence[1]		Target relative precision, 90% confidence[1]	
	Overall projects	Stratum sites	Participant survey	On-sites	Participant survey	On-sites	Participant survey	On-sites
Mini-split - Office	355	286	28	7	22%	44%	28%	57%
Mini-split - Retail/Service/ Supermarket/Restaurant	547	469	38	10	19%	39%	25%	51%
Mini-split - Education	83	66	11	3	27%	58%	35%	74%
Mini-split - Warehouse	183	145	14	4	28%	57%	36%	74%
Mini-split - Residential/Multi-Family	96	79	7	2	36%	80%	46%	103%
Mini-split - Other	547	434	50	13	15%	31%	19%	40%
Mini-split - Unknown Building Type	164	154	16	4	28%	57%	36%	74%
ASHP - Office	240	177	42	11	14%	33%	18%	43%
ASHP - Retail/Service/ Supermarket/Restaurant	249	189	36	9	15%	38%	20%	49%
ASHP - Education	29	17	8	2	24%	60%	31%	77%
ASHP - Warehouse	89	66	18	5	16%	47%	21%	60%

Domain	Population		Sample		Target relative precision, 80% confidence[1]		Target relative precision, 90% confidence[1]	
ASHP - Residential/Multi-Family	62	41	7	2	38%	89%	49%	115%
ASHP - Other	233	168	40	10	13%	35%	16%	44%
ASHP - Unknown Building Type	132	80	18	5	21%	53%	27%	68%
PTHP - Education	1	1	1	0	78%	N/A	100%	N/A
PTHP - Residential/Multi-Family	196	196	39	0	13%	N/A	17%	N/A
PTHP - Other	10	10	1	0	126%	N/A	162%	N/A
VRF - Office	84	71	20	7	21%	42%	26%	54%
VRF - Retail/Service/ Supermarket/Restaurant	88	73	19	7	22%	42%	28%	54%
VRF - Education	25	21	10	4	28%	59%	36%	76%
VRF - Warehouse	72	60	13	5	31%	60%	40%	77%
VRF - Residential/Multi-Family	24	17	4	1	46%	100%	59%	129%
VRF - Other	146	127	28	11	20%	38%	26%	49%
VRF - Unknown Building Type	29	28	9	3	35%	67%	45%	86%
Total	**3,684**	**2,975**	**476**	**124**	5%	**N/A**	**6%**	**N/A**

[1]Assumed coefficient of variation = 0.7

The team aggregated the 15 different building type descriptions in the combined 2023–2024 dataset into six building type categories for sample design purposes, as shown in Table 2-8. This aggregation considered both the prevalence of each building type in the program data (prioritizing building types where the largest share of equipment capacity was installed), as well as similarity in operational profiles. For instance, apartment buildings and hotels were combined into the same grouping based on similar usage profiles.

Table 2-8. Building type aggregation for sample design

Building type in tracking data	Building type for sample design
Office	Office
Retail, service, supermarket, restaurant	Retail/Service/Supermarket/Restaurant
Education	Education
Warehouse	Warehouse
Residential, multi-family, hotel	Residential/multi-family/hotel
All other building types	Other

2.2.2 Contractor survey

DNV administered web surveys to a sample of participating installation contractors,[25] drawn from the same sample frame of 2023–2024 projects used for the customer surveys and on-sites so the results from each task were representative of the same program period and can be appropriately used to corroborate each other and support statistical analyses.

The sample was designed to prioritize a single equipment type for each contractor, based on its prevalence in the population (i.e., contractors who installed multiple heat pump types would be asked about the type that was least prevalent across the population). In addition, the contractor sample excluded PTHP installers, because of the 125 out of 805 installation contractors in the sample that installed PTHPs, none had email addresses available, and nearly all records appeared to name end-use customers rather than contractors in the relevant contractor field (e.g., contact names were for hotels or apartment buildings).[26] Given the response rate for the v2.1 contractor survey of 7.5% and the size of the sample frame, the team planned to survey a census of the contractor population. The sample design is shown in Table 2-9.

Table 2-9. EO Model contractor survey sample design

Domain	Unique count of contractors with email addresses	Projected census attempt sample size (assuming 7.5% response rate)	Estimated precision, 90% confidence
ASHP	254	19	19.8%
MSHP	278	21	18.8%
PTHP	0	0	N/A
VRF	148	11	27.1%
Total	**680**	**51**	**11.7%**

2.3 Data collection

The sections below detail data collection processes for the (1) participant web survey, (2) participant on-sites, and (3) participating contractor web survey. The study team used a joint data collection approach for the participant web survey and on-site visits, whereby customers were recruited for on-sites from among participant survey respondents who expressed an interest in on-sites. This approach reduced the need for a separate recruitment effort and allowed the study team to coordinate the two data collection activities efficiently, leveraging the assumption that a separate follow-on site visit recruitment effort would have been unlikely to generate additional recruitment from participants who indicated they would not be willing to complete a site visit based on the initial survey. Because on-site participants were drawn from survey respondents who volunteered for an additional research activity, the on-site sample may be subject to additional self-selection beyond that associated with survey response.[27] However, the study did not collect information that would allow the team to assess whether survey respondents, respondents interested in an on-site visit, or on-site participants differed systematically from the broader participant population. The contractor web survey was independently sampled and fielded from the participant survey.

[25] The original work plan included contractor interviews. However, after reviewing contractor contact data and developing the instrument, the team determined that the same web survey approach employed for the v2.1 EO Model study would likely result in more consistent data and a larger number of completes, as well as less respondent burden and more efficient use of study resources. In particular, the structure of questions is prescriptive and quantitative, which is better suited for a visual web format with forced choices ensuring specific numeric responses. In addition, nearly 80% of contractor records have an email address, and using a web survey approach, the v2.1 study team completed 70 surveys with installation contractors, well above the targeted 30 completes for that study, and the originally planned 25 interviews for the v3.0 study. The current study team has also leveraged the v2.1 instrument and Qualtrics programming in developing this survey, improving comparability of results across the studies. Finally, respondent burden for web surveys is lower due to avoiding the need to schedule interviews, and shorter time required to complete web surveys compared to interviews.

[26] Instead, for current study inputs for PTHPs such as survey proportions, the team utilized the following sources for PTHP projects: (1) v3.0 participant survey results (which included 38 PTHP responses), and v2.1 installation contractor survey results (which included 19 PTHP responses).

[27] As an example, customers experiencing problems with their installation may have been either more or less likely to agree to on-site participation than those that were not, depending on their attitudes toward the program based on their experience.

2.3.1 Participant survey

The team used a web-based survey, with initial recruitment by mailed letters, supported by email reminders and follow-up phone calls. This multi-mode solicitation along with follow-up calls helped reduce non-response and its effect in subsequent analyses. To encourage participation, the team offered respondents a $150 incentive. Although on the higher side relative to concurrent C&I outreach efforts, the incentive amount was deemed appropriate given the limited population available to survey, historical difficulty soliciting responses from C&I customers, and to limit the volume of telephone follow-ups, which are labor intensive and increase total costs.

The team also leveraged our partnership with APPRISE, who conducted follow-up phone calls with targeted respondent groups with lower-than-desired initial response rates, resulting in achieving or exceeding targets across nearly all strata, particularly those where emails and letters alone had not achieved the targeted number of completes. These phone calls (1) directed customers to the emails and letters already sent, through which some completed the survey online; or (2) offered respondents the chance to complete the survey over the phone with a trained APPRISE survey administrator. While on the phone, the APPRISE staff also recruited participants for on-site visits (see below for further details).

Following this multi-mode solicitation effort, the team exceeded the overall survey target and the target for almost all strata. The only stratum that was substantially below target was PTHP participants. Table 2-10 shows targets, screen-outs, and completes by stratum.

Table 2-10. Participant survey completes

Stratum	Total sample frame[1]	Total sample contacted	Target	Screen outs	Completes	Percent of target achieved	Completion rate
Mini-split - Full	1496	493	82	18	105	128%	21%
Mini-split - Partial	596	299	82	8	90	110%	30%
ASHP - Full	605	434	98	9	104	106%	24%
ASHP - Partial	339	315	70	6	80	114%	25%
PTHP - Unknown	219	124	41	1	27	66%	22%
VRF - Full	420	330	72	11	69	96%	21%
VRF - Partial	101	101	31	5	44	142%	44%
Total	**3776**	**2096**	**476**	**58**	**519**	**109%**	**25%**

[1]2023–2024 participants, de-duplicated by unique mailing address.

2.3.2 On-sites

About 45% of survey respondents (231 out of 519) expressed interest in on-sites, and following the exhaustive recruitment approach described below, about 51% of those respondents (118 out of 231) successfully completed on-sites. On-site recruiting occurred via two processes:

1. DNV staff made follow-up recruitment calls after surveys were complete and respondents had indicated an interest in participating in the site visit portion of the evaluation. Contact with potential metering participants—for which available sample was more limited and fieldling timelines were more constrained—was attempted up to six times via phone and/or email, on different days of the week and at different times of day.
2. APPRISE attempted to schedule on-sites with any customers they reached during the phone call outreach for the participant survey, as noted above.

In addition, to attempt to hit targets for more challenging strata (e.g., VRFs, packaged ASHPs), the team also leveraged PA contacts and assistance via implementation vendors to reach out directly to priority sites and encourage on-site participation. For these priority sites, the team made up to 10 recruitment attempts, including via PA emails. Ultimately, there were nearly 900 recruitment emails/calls made.

Customers participating in metering were offered a $150 incentive upon initial installation of meters and an additional $100 upon completion of metering during equipment retrieval. Customers participating in verification-only on-sites were offered $200 for the visit. The study team subcontracted with electricians or HVAC contractors as required for any behind-panel electrical connections to maintain the highest safety and quality standards.

The team screened out sites who indicated on the survey that a non-routine event (NRE)[28] occurred, so that consumption analysis could be performed on sites without NREs. In some cases, where on-site recruitment was lagging, the team relaxed standards for excluding sites with NREs, for instance for sites where respondents reported minor changes in schedules or operating hours only. Table 2-11 provides the disposition of on-site recruitment by stratum.

Table 2-11. On-site disposition

Stratum[1]	Interested survey respondents	Completed on-sites	Completion rate	Strata complete – stopped outreach	Refused	Exhausted	Bad or duplicate contact[2]
Mini-split - Full	48	30	63%	8	11	1	1
Mini-split - Partial	38	15	39%	14	7	0	2
ASHP - Full	51	24	47%	20	1	0	3
ASHP - Partial	38	17	45%	17	3	0	1
VRF - Full	39	25	64%	0	4	7	3
VRF - Partial	17	7	41%	0	6	4	0
Total	**231**	**118**	**51%**	**59**	**32**	**12**	**10**

[1] Tracking data strata, not updated to reflect actual equipment/displacement.
[2] Survey respondent provided incorrect or bad contact information for site visit, or contact duplicated one provided for another survey response.

Table 2-12 shows the disposition of on-sites separated by metered sites and verification-only sites. As detailed above, the sample targeted (1) partial displacement ASHPs and VRFs, and (2) full displacement ASHPs for metering, and all other strata except PTHPs for verification-only visits.

As detailed in the report body (see Section 3.4.1), there was widespread misclassification in the tracking data of site and system displacement type (full or partial), which the team uncovered during the on-site visits. Because displacement type was a key stratification variable, this misclassification meant that completes by strata were different based on confirmed displacement than based on claimed displacement in the tracking data. As a result, the team re-allocated completes by strata based on confirmed displacement, as shown in Table 2-13. This misclassification created a particular challenge for hitting targets for VRFs, since the planned metering or verification-only approach differed depending on whether the site was a full or partial displacement site. For instance, for sites we expected to be partial displacement based on tracking data, the team planned and scheduled for metering (e.g., by arranging for an electrician to join the DNV field staff on-site), whereas for VRF sites tracked as full verification, no electrician or metering equipment was planned to be utilized on site.[29] When the actual displacement status for such sites differed from what was tracked, this often required re-visits, or led to lost

[28] NREs are changes in typically static factors (e.g., occupancy, equipment failures, process shutdowns) that cause major spikes or drops in energy usage.
[29] As noted above, to help manage study costs, the sample prioritized metering of partial displacement sites, particularly among ASHP and VRF projects, which have had relatively less real-world operational data gathered over time compared to mini-splits (which are commonly installed in residential settings, where they have been previously evaluated via on-site metering and other methods). In addition, partial displacement projects have the greatest uncertainty in operational parameters—in particular the share of heat pump vs. supplemental heating use—and therefore were expected to provide the greatest value from metered data.

opportunities for metering, as detailed below in the tables. After encountering several sites with these issues, the team refined our scheduling and recruitment process to involve more in-depth questioning of the site contact over the phone when scheduling, to attempt to verify the displacement type prior to the on-site and ensure metering equipment and electrician support was planned for as needed. Asterisks and table notes indicate cases where completed sites did not align with the intended strata due to misclassification.

Table 2-12. On-site disposition for metered and verification-only sites, by tracked displacement

Strata	Metered on-sites			Verification only on-sites		
	Target	Completed	Over/Under	Target	Completed	Over/Under
Mini-split – Full	NA	1*	1	21	22	1
Mini-split – Partial	NA	0	0	21	21	0
ASHP – Full	18	17	-1	4	5	1
ASHP – Partial	18	17	-1	4	4	0
VRF – Full	NA	0	0	22	16**	-6
VRF – Partial	16	15***	-1	NA	0	0
Total	**52**	**50**	**-2**	**72**	**68**	**-4**

Notes:
*This project was tracked as an ASHP, rather than a mini-split. This was one of our first visits, and field staff installed meters not realizing it was not eligible. The verification data for this site is counted toward the mini-split verification target in the reallocated table below.
**Two of these sites were tracked as full displacement VRF but determined to be partial once on site. The team attempted follow-up visits to install meters, but customers refused or were non-responsive. Despite the lack of metering data, the verification data for these sites counts toward the target of 16 for the VRF partial sites.
***Three of these projects were tracked as partial displacement and field staff installed meters before subsequently determining they were full displacement sites, not requiring metering. The verification data for these sites is counted toward full VRF verification target in the reallocated table below.

Table 2-13. On-site disposition for metered and verification-only sites, by confirmed displacement

Strata	Metered on-sites			Verification only on-sites		
	Target	**Completed**	**Over/Under**	**Target**	**Completed**	**Over/Under**
Mini-split – Full	NA	0	0	21	23*	2
Mini-split – Partial	NA	0	0	21	21	0
ASHP – Full	18	9	-9	4	6	2
ASHP – Partial	18	23	5	4	4	0
VRF – Full	NA	3**	3	22	15	-7
VRF – Partial	16	12	-4	NA	2***	2
Total	**52**	**47**	**-5**	**72**	**71**	**-1**

Notes:
*Includes two projects tracked as ASHPs, rather than mini-splits, for which field staff installed meters not realizing it was not eligible.
**Includes three projects that were tracked as partial displacement and field staff installed meters before subsequently determining they were full displacement sites, not requiring metering.
***These two sites were tracked as full displacement VRF but determined to be partial once on site. The team attempted follow-up visits to install meters, but customers refused or were non-responsive. Despite the lack of metering data, the verification data for these sites counts toward the target of 16 for the VRF partial sites.

2.3.2.1 On-site M&V

All verification only and metered on-sites included confirmation of heat pump installation and operability along with documentation of facility- and equipment-specific information. The primary objective of the site visit was to develop a clear understanding of heat pump operation, seasonal usage patterns, reliance on supplemental systems, and appropriate heating and cooling baselines in consideration of preexisting equipment viability and counterfactual scenarios. For each site, field engineers collected the following information:

- **Building characteristics:** facility type (NAICS code), hours of operation, seasonality, location, vintage, square footage (total and conditioned), level of weatherization (qualitative).
- **Business characteristics:** number of employees, typical occupancy during business hours, typical work hours or shifts.
- **HVAC characteristics:** fuel mix, primary & secondary heating/cooling equipment (unit types, nameplate data, age of existing equipment, efficiency), distribution system configuration, ventilation system equipment, thermostat or BMS locations/control settings (including switchover (and/or lockout) temperature and techniques), refrigerant types.
- **Setpoints and schedules:** heating and cooling season setpoints by hour and by day type (weekday, weekend, holiday).
- **Operation characteristics:** HP performance issues, maintenance schedule, refrigerant issues.
- **Preexisting or counterfactual conditions:** heating system type, operational status, fuel type, retention status, cooling system presence, system type, including heating/cooling/ventilation, retention status.
- **Non-routine events:** changes in space use, size, occupancy, throughput, or other business conditions, such as other energy efficiency projects or the addition or removal of major energy-consuming equipment, from 2022 to present, to support analysis of pre- and post-project bills for select equipment types.

During each site visit, field engineers collected comprehensive data on all relevant heating, ventilation, and air-conditioning (HVAC) and domestic hot water (DHW) systems, including the rebated heat pump and any backup, supplemental, or ventilation systems with heating elements that overlapped with the rebated heat pump. Engineers also collected preexisting system characteristics when available. The system inventory included make, model, quantity, rated capacities, rated efficiencies, year of manufacture, relevant electrical information (e.g., volts, full-load amps overall and by component as available), load-sharing with other heating or cooling systems by zone, integrated control status, and qualitative notes on load-sharing strategies.

For metered sites, in addition to collecting the information above, engineers deployed metering equipment on the rebated heat pump equipment as well as on any safely accessible backup, supplemental, or ventilation systems with heating elements that served the same space as the heat pump. The primary objective of the metering was to collect operational data and gather insight into the actual heating operation of the heat pump compared with any other heating systems serving the same space(s).

The metering approach included long-term monitoring of total input power to the heat pump outdoor unit(s), amperage to safely accessible indoor units such as air handlers, amperage to auxiliary heating systems (if applicable) via combustion air fan or electric resistance circuit, temperatures of supply air streams to confirm operation, and various space temperatures among zones served by the heat pump.

Table 2-14 summarizes the operational parameters that were collected during metered on-sites and the associated technique.

Table 2-14. Summary of site analysis parameter outputs and on-site approaches

Parameter	Metering				Summary
	Field Verification	Power	Amperage	Temperature	
HP power	✓	✓	✓		Rated power was derived from field verification of the nameplate and make/model lookup. Actual power was derived from real power metering on the outdoor unit and amperage metering of the associated components.
HP capacity	✓				Rated capacity was derived from field verification of the nameplate and make/model lookup.
Backup heating system output	✓		✓	✓	For HPs with electric resistance (ER) backup, rated amperage was confirmed through field verification. Actual amperage was collected by isolating the backup ER circuit and metering the amperage of that circuit. For fossil fuel backups, rated capacity was confirmed through field verification and make/model lookup. Actual heating output was determined through one of the following: combustion air fan amperage metering, gas solenoid valve amperage metering, or temperature metering on the gas heat distribution system, such as a radiator serving a space that overlaps with the rebated HP.
Backup heating fuel	✓				Backup heating fuel was confirmed through field verification and make/model lookup.
Ventilation/ supplemental heating system power	✓		✓		Rated amperage was derived from field verification of the nameplate and make/model lookup. Actual amperage was derived from amperage metering on the resistance circuit (electric) or combustion air fan (fossil fuel).
Ventilation/ supplemental heating system capacity	✓				Rated capacity was derived from field verification of the nameplate and make/model lookup.
Ventilation/ supplemental heating system fuel	✓				Supplemental heating fuel was derived from field verification of the nameplate and make/model lookup.
Outside air temperature					Observed hourly OATs were derived from NOAA. Typical meteorological year data was derived from TMYx.
Indoor air temperature setpoints and schedules	✓			✓	Field engineers investigated setpoints and schedules through inputs programmed into thermostats and/or BMSs and conversations with site personnel. Temperature meters were installed in the inlet/outlet of supply and return ducts, when possible, to capture indoor air temperature. When that was not possible, meters were installed near the thermostat or in an area not directly receiving airflow but being served by the rebated HP.

Meters remained in place for four to six months to capture heating season performance across a representative range of outside air temperatures, generally from December 2025 to April 2026. While the meters were in place, we reviewed the verification data collected from metered sites for gaps and uncertainties. During return site visits to collect metering equipment, engineers collected any remaining verification data that was unclear or missing after the first site visit.

2.3.2.2 Site analysis

After all the metering equipment was collected, all qualitative data from verification-only and metered sites was aggregated; reviewed for gaps, errors, and anomalies; and cleaned. We then provided cleaned data to the RI team to inform the building simulation input parameters.

For the metered on-sites, we created an analysis file for each site, which included raw metered data; relevant qualitative supporting data, such as the site personnel-reported switchover temperature or load sharing strategies; and the system inventory. The objectives of each site analysis were to: correlate HP and supplementary heat operation with outside air temperature (OAT); calculate capacity-weighted values, such as the average annual heat pump heating energy consumption, heating consumption per ton, average heating equivalent full load hours (EFLH); and (if applicable) to determine the displacement scenario, switchover and compressor lockout temperatures, and heating load shares between rebated HPs and supplementary heating systems. To meet these objectives, we followed these analysis steps:

1. Metered data was reviewed for gaps, errors, anomalies, or statistical outliers. The cleaned data disregarded these irregularities.
2. Clean metered data was averaged to an hourly interval and trended against hourly OAT.
3. Power and amperage data was correlated using time-of-week-and-temperature (TOWT) modeling incorporating observed OATs from the most proximate NOAA weather station.
4. Backup or supplemental system data from the combustion air fan, solenoid valve, or distribution system was compared against supply temperature data to determine the operating mode of the backup or supplemental system.
5. Facility schedules, including weekends, observed holidays, shifts, or seasonality, were incorporated by developing multiple TOWT models as needed to represent annualized HVAC operation.
6. Power and amperage versus OAT correlations were extrapolated to typical meteorological year data (from the same weather station as step 3) to mitigate weather-related bias over the metering period.
7. Using the annualized operational profiles over the typical weather year, the following parameters were calculated:
    a. Capacity-weighted average annual HP heating energy consumption,
    b. Capacity-weighted average heating output per ton,
    c. Capacity-weighted average heating EFLH.
8. Based on normalized HP operational data compared against normalized supplemental or backup system use, the engineer estimated the percent heating load served by the rebated HP and the backup and/or supplemental heating systems by OAT bin.
9. Using the heating load shared between the systems, the engineer summarized the heating load sharing strategy and estimated the switchover (and/or lockout) temperatures or ranges.

Consumption analysis

During project planning, it was decided that field engineers would not deploy metering equipment for full displacement VRF projects in part because they were believed to be good candidates for utility consumption analysis. Typically, full-displacement projects are good candidates because they are expected to result in significant energy impacts and, by definition, no longer require the use of supplemental gas heating systems. Therefore, the engineers generally conducted verification-only visits for full-displacement VRF sites.

However, through on-site visits, we identified two issues that hinder the usefulness of a consumption analysis. First, as mentioned previously, full/partial displacement designation was often classified incorrectly within tracking data, including for VRFs. As a result, the sample count of true full-displacement VRF projects decreased from the initial estimate from tracking

classifications. Second, even among the “full” displacement sites, the installed systems often served only a portion of the building—in some cases a relatively small portion—and it was often not possible to map that portion of the building to specific utility meter(s). As a result, consumption analysis results were not conclusive of program heat pump impacts and the team did not use the consumption analysis for impact estimation. For instance, while we expected to see a significant increase in electric energy consumption and associated decrease in gas consumption as a result of the VRF installation, we found that electric consumption increased for only about half of the analyzed sites, with essentially no change at the median, and gas consumption dropped for only about two-thirds of analyzed sites.

Although we did not use consumption analysis for impact estimation, DNV provided consumption analysis results for all sites that we confirmed to be full displacement to the RI team for use in calibrating the building simulations for those sites.

2.3.2.3 Future M&V planning

During sample design, the study team estimated expected precisions using a coefficient of variation (CV) of 0.7 for key analysis variables. This assumption was applied consistently across the participant survey and on-site sample design calculations and reflected the team's best judgment regarding the expected variability of operational and savings-related metrics within the primary sampling domains. Under this assumption, the planned sample sizes were expected to achieve the target levels of relative precision shown in Table 2-4, and the other accompanying sample design tables.

After completing data collection, site verification, and statistical expansion (discussed further in Section 2.3.4), however, it became apparent that the variability of several key metrics was substantially greater than anticipated. The expanded estimates reflected a highly heterogeneous population of commercial heat pump projects. Even within the same equipment category, systems varied considerably with respect to building type, operating schedules, heating load characteristics, system sizing, control strategies, displacement configurations, supplemental heating use, and customer operating practices. This heterogeneity resulted in greater dispersion in observed outcomes than was assumed during sample planning, increasing the variance of many expanded estimates and reducing the precision ultimately achieved at aggregate levels.

The relationship between variability and precision was further complicated by the study's analytical structure. While aggregate domains exhibited higher-than-expected variability because they combined a diverse mix of systems and operating conditions, more granular domains generally exhibited lower within-group variability because they contained more operationally similar projects. Project groupings defined by program system category (PSC, i.e., equipment type) and actual displacement (AD, i.e., confirmed displacement level) often demonstrated more homogeneous characteristics than the broader equipment-level domains used for sample design. However, these more homogeneous groupings also contained substantially fewer completed observations. As a result, the reduction in variability at the PSC × AD level was frequently offset by the smaller effective sample sizes available for estimation.

Consequently, the anticipated gains in precision from analyzing more comparable systems were often not realized in practice. For many PSC × AD combinations, the number of completed observations was insufficient to fully capitalize on the lower within-group variability, resulting in relative precisions that remained broader than originally expected. Table 2-15 below provides estimates of population CV for a key analysis variable (kWh per heat pump) for a set of domain categories based on the collected sample data. These values could be used to better estimate required sample sizes and expected precisions for future studies.

Table 2-15. Summary of weighted heating kWh per HP with estimated population CV for future sample planning

Domain Category	Domain	Sample	Heating kWh per HP	Relative precision @ 80% Conf	Assumed CV	Planning CV
Overall	Overall	47	3,705	22%	0.7	1.5
Actual Displacement (AD)	Full	12	3,470	56%	0.7	1.1
	Partial	35	3,863	38%	0.7	1.6
Primary System Classification (PSC)	ASHP Ducted	21	2,123	28%	0.7	1.1
	HP RTU	11	4,698	34%	0.7	1.0
	VRF	15	8,138	40%	0.7	1.1
PSC X AD	ASHP Ducted - Full	6	2,560	68%	0.7	1.1
	ASHP Ducted - Partial	15	1,751	34%	0.7	0.9
	HP RTU - Full	3	9,117	47%	0.7	0.6
	HP RTU - Partial	8	3,131	39%	0.7	1.0
	VRF - Full	3	6,570	43%	0.7	0.6
	VRF - Partial	12	8,700	49%	0.7	1.1

2.3.3 Contractor survey

Building on the successful recruitment approach used for the v2.1 contractor surveys, the team partnered with program implementation vendors who manage the PA's commercial heat pump contractor distribution list as well as the Heat Pump Installer Network (HPIN). Partnering with those vendors allowed the team to refine the contractor distribution list and outreach emails. This approach was highly effective in achieving the targeted number of responses.

DNV fielded the survey using the web-based Qualtrics platform. The team programmed the survey with embedded data and conducted multiple tests for correct display, skip logic, and overall user experience. We then soft-launched the survey with a subset of contractors and reviewed their response data for completeness before launching the census attempt to the full sample frame. Survey respondents were sent up to four email invitations (one initial email and three reminders), and respondents were offered a $150 incentive. Table 2-16 provides the targets, completes, and response rates by measure.

Table 2-16. Contractor survey responses, by measure type

Measure	Count of contractor	Count with email	Target	Completes	Screened out or incomplete	Response rate
ASHP	254	254	19	26	10	10.2%
MSHP	278	278	22	29	5	10.4%
PTHP	125	0	N/A	N/A	N/A	N/A
VRF	148	148	11	14	5	9.5%
TOTAL	**805**	**680**	**61**	**69**	**20**	**10.1%**

2.3.4 Statistical expansion

The customer, contractor, metered on-site, and verification-only on-site analyses used design weights to expand completed cases to the eligible program population represented by each analysis frame. The common approach was to calculate an inverse response or selection weight within sampling cells. Sparse or empty completion cells were collapsed using adjacent categories before weights were calculated. The analysis generally combined size groups first and, where necessary,

compatible fuel or displacement categories. Separate, broader strata were used for variance estimation when a cell contained only one completed sampling unit. The following generalized formula illustrates this approach.

$$b_h = \frac{N_h}{n_h}$$

b_h: base expansion weight for sampling cell h
N_h: number of eligible population units in sampling cell h
n_h: number of completed sample units in sampling cell h
h: sampling cell after any required collapsing

Where one sampled contact or site contributed more than one analytic record, its base weight was divided equally across those records, as shown in the formula below. This prevents repeated records from multiplying the population represented by the sampled unit.

$$w_i = \frac{b_h}{m_i}$$

w_i: final analysis weight assigned to analytic record i
b_h: base expansion weight for the sampling cell containing record i
m_i: number of analytic records contributed by the sampled contact or site
i: an analytic record

The following subsections describe how this process was applied for each primary data source, and APPENDIX D provides details on statistical weights used for the expansion analysis.

2.3.4.1 Customer survey

The customer survey was linked to the revised 2023–2024 program sampling frame using the unique contact identifier and project characteristics. Twenty-eight responses that could not be linked to the population were excluded after manual review. These were found to be participants in an earlier program year not in scope for this study. Completion counts were reduced to one record per contact before the base weights were calculated. Sampling cells combined heat-pump type, displaced-fuel group, tracked displacement, and size group. Selected low-completion cells were collapsed; repeated response or project records then shared the applicable contact-level weight. The final weight check expanded the responding records to 2,976 eligible population units.

Weighted categorical estimates, including customer-satisfaction results, were produced with SAS survey procedures. Variance estimation incorporated the final analysis strata, clustering by contact, and stratum population totals for finite-population correction. Reported survey-frequency intervals use 90 percent confidence. Satisfaction results use the same weights, strata, and contact clusters.

2.3.4.2 Contractor survey

The contractor frame excludes packaged terminal heat pumps and forms sampling cells by equipment measure and contractor size group. The largest mini-split contractor-size cell was combined with the middle-size cell before weights were calculated. Weighted frequency estimates use the collapsed strata and stratum population totals and report 90% confidence intervals. Rating-scale means are estimated by equipment measure. The current mean routines apply the expansion weights but do not specify the sampling strata, clusters, or finite-population totals; therefore, the point estimates are expanded as intended, but the accompanying standard errors are not fully design based.

2.3.4.3 On-site analyses

Weights were developed independently for the verification-only site file and the on-site metering analysis files. Historical duplicate site identifiers were mapped back to the identifiers and original sampling cells used during selection. Packaged terminal heat pumps were removed because no visits were completed for that technology. For the M&V frame, most mini-split cells were also removed as ineligible, leaving an expansion population of 1,703; the full-site population excluding

packaged terminal heat pumps was 2,769. Within each eligible collapsed cell, the base weight was calculated from its population and completion counts. Multiple records for one site shared the site-level weight, and missing-weight checks were completed before analysis.

M&V site-level means were estimated with SAS survey procedures using the expansion weight, the collapsed variance stratum, the unique site as the cluster, and stratum population totals for finite-population correction. Domain estimation retained the full sample while producing statewide and subgroup means by region, displaced fuel, tracked and observed displacement, system type, displacement scenario, and heating-load-sharing strategy. Site-result confidence intervals use 80% confidence.

2.3.5 Building simulation

Building simulations provide energy consumption values across the EO Model strata and are the basis for estimating prescriptive impact values. For the EO Model v3.1 update, the study team's objective was to update the existing building simulations with real-world operational and field verification data so that they better represent the installed programmatic heat pump systems and behavioral characteristics as the program and statewide market has evolved and matured. The study team used multiple data sources to inform building simulation adjustments including survey, field, metered, billing, heat pump manufacturer, and program tracking data. Our simulation updates primarily focused on adjusting programmatic heat pump equipment, but updates were also made to the baseline HVAC simulations to appropriately account for broader simulation updates (e.g., minimizing energy impacts from differences in non-programmatic heat pump inputs like building envelope) and to represent the latest data collected. This section summarizes the updates made to the EO Model's building simulations, which builds upon previous EO Model versions 2.0 (v2.0) and 2.1 (v2.1), including:

- **Calibration:** The team used all data sources to inform building simulation inputs and calibrated simulated energy consumption to target curves that combine participant electric billing data (monthly load shape) with site metering data (consumption magnitude and end-use shares), as described in Section 2.3.6.2.
- **ASHP performance:** The team used manufacturer specification sheet data for the most prevalent ASHP systems from the field data to update ASHP performance curves.
- **System sizing:** The team used contractor and verification data to inform HVAC sizing decisions.
- **Baseline HVAC simulation updates:** The team used Baseline Study data, field data, and calibrated programmatic heat pump simulations to adjust baseline HVAC simulations.

Across both Baseline and program HVAC simulations, inputs were altered to reflect data collection and analysis findings. Although these data primarily informed adjustments to program HVAC simulations, several changes were also made to the baseline HVAC simulations to minimize any non-program impacts to savings. In addition, several non-HVAC inputs were redefined during the calibration process. Adjustments were made to the following input categories:

- Heat pump efficiency and performance
- Heating and cooling setpoints
- Heating and cooling schedules
- Ventilation
- Occupancy schedules
- Envelope and fenestration
- Infiltration
- Fan efficiency and pressure rise
- Plug loads
- Lighting
- Water heating

As discussed in the Baseline HVAC simulation updates section below, the study team created entirely new baseline HVAC simulations with non-programmatic inputs[30] informed by the calibrated program HVAC simulations.

While this study sought to answer many key simulation questions, it did not aim to restructure the building simulation segmentation that eventually feeds into the EO Model. The detailed methodology on how building types, HVAC types (baseline and program), ventilation design, and more were defined and simulated are available in the v2.0 report.[31] Key simulation updates from the v2.1 update, such as simulation updates made to VRF systems and ventilation fuel assignments, are available in the v2.1 report.[32] All building simulations were run using the EnergyPlus-based tool "Modelkit Flannel." This tool uses EnergyPlus version 9.2.

Note on the new 2026 Commercial Prescriptive Heat Pump Program capacity threshold. The building simulations were adjusted to account for the new 35-ton capacity threshold for the Commercial Prescriptive Heat Pump Program, which became effective on June 1, 2026 (see call-out box). Specifically, metering and billing data was analyzed to ensure target curves were developed in alignment with the program's updated 35-ton installed heat capacity threshold, using a "soft cutoff," so that the analysis excluded data from most sites with a total installed capacity over 35 tons, but still included those sites with over 35 tons of installed capacity where no single units were 20 tons or larger, which are likely to behave similarly to lower capacity sites. The study team and subcommittee agreed on this approach to balance developing results that will be representative of future projects while also allowing the analysis to retain as much of the site metering data as possible. Table 2-17 provides the counts of sites and systems with metering data that were excluded using this "soft cutoff" approach.

Changing Commercial Prescriptive Heat Pump Program threshold

"Effective June 1, 2026, all commercial heat pump projects over 35 tons — including air source, ground source, and variable refrigerant flow systems — will be processed as custom projects…The project size cap is based on the total heat pump tonnage for all projects by customer account as of June 1, 2026."

Table 2-17. Large sites and systems excluded from building simulations

Stratum	Included sites	Included systems	Excluded sites	Excluded systems
VRF full	13	31	2	7
VRF partial	11	23	0	0
ASHP full	7	9	0	0
ASHP partial	20	38	2	3

2.3.6 Calibration

Calibration refers to the process of adjusting the EnergyPlus building simulation inputs (e.g., schedules, loads, and envelope properties) so that its energy and temperature outputs match real-world utility data. This section summarizes the study team's calibration methodology and results. While program tracking data, metered data, and on-site verification data contain

[30] "Non-programmatic inputs" are inputs that should not change in a building because of the program and include envelope, fenestration, infiltration, plug loads, lighting, and water heating.
[31] Energy Optimization Model Update, Massachusetts Program Administrators, https://ma-eeac.org/wp-content/uploads/MA22C10-Energy-Optimization-Model-Update-Report_FINAL_01NOV2023_ForEEACWebsite.pdf
[32] Energy Optimization Model Version 2.1 Update, Massachusetts Program Administrators, https://ma-eeac.org/wp-content/uploads/MA24C02-Energy-Optimization-Model-Version-2.1-Update-Report_25SEP2024.pdf

considerable detail about the installed program equipment, they are limited with respect to non-HVAC aspects of the buildings. This limitation meant we inferred many of the modeling inputs based primarily on building type description, floor area, and the displaced HVAC fuel. To minimize subjectivity, we developed and used a systematic approach to inferring these values, as outlined in this section. Even with this systematic approach, there is an inherent uncertainty to many of the building simulation inputs. To limit this uncertainty, we calibrated our energy simulation inputs based on actual energy use data collected for installed program equipment and commercial buildings having use patterns that align with the building types that we included in the EO Model.

The overall process for calibrating simulations was to:

1. **Develop simulation parameters.** Using various sources of data, the study team characterized and assigned input value ranges for a set of parameters that are most impactful to energy consumption, such as equipment efficiency, ventilation rates, lighting power density, and many more.
2. **Develop target curves.** The study team developed monthly electric consumption calibration target curves using two data sources: monthly program participant billing data and site metered data.
3. **Align simulations to target curves.** The study team systematically adjusted simulation inputs until simulated energy use fell within the acceptance range (± one standard deviation) around each monthly consumption target.
4. **Provide quality assurance and quality control.** Lastly, the study team performed various quality assurance/quality control (QAQC) checks against field data and through using criteria specified in ASHRAE Guideline 14. These criteria set how closely a model must match target data, in both total consumption and temporal shape.

2.3.6.1 Calibration parameter development

To define which simulation inputs we would adjust, and by how much we would adjust them, the study team:

1. Employed an input ranking, starting value assessment, and attribute assessment (categorized by impact, uncertainty and range) for all building simulation inputs.
2. Assigned maximum and minimum values to each simulation input that ranked medium or high in all three attribute categories.
3. Assigned all inputs into impact categories based on the dominant impact by load type (electric baseload, heating load, or cooling load).
4. Further sorted the inputs we assigned to these categories into end-use subcategories (heat pump, backup/supplemental heating, and fans) based on how an input affects consumption as its values are changed.

Each building type was correlated to multiple simulation inputs. As such, each building type has a unique set of inputs. We finalized these inputs in a two-stage process:

1. Defining the expected values based on field data, empirical data, and preliminary building simulations.
2. Adjusting these inputs though a calibration process.

For further detail see APPENDIX C and the EO Model v2.0 report.[33]

2.3.6.2 Calibration target curve development

Target curves are the monthly energy consumption targets that the calibration process aligns the building simulations to. Whereas prior EO Model versions developed these targets from non-participant billing data, for the v3.1 update the study team developed target curves using two data sources, both representing program participants:

[33] Cadeo Group. (November 1, 2023). *Energy Optimization Model Update*. Prepared for the Massachusetts Program Administrators. https://ma-eeac.org/wp-content/uploads/MA22C10-Energy-Optimization-Model-Update-Report_FINAL_01NOV2023_ForEEACWebsite.pdf

- Site metering data: End-use metering was collected at 47 program participant sites over the 2025–2026 heating season, from November through April, and separately metered heat pump, fan, and backup/supplemental heating consumption.
- Billing data: Monthly utility electric billing data for program participants provided whole-building electric consumption over a full post-installation annual cycle. As metering data was not collected in summer months, the billing data was the primary source for developing energy consumption target curves in the summer. Billing data were available for 1,535 of the approximately 4,000 participant sites in the 2023–2025 program tracking data; after the cleaning and screening steps.[34]

The study team developed a target curve for each building type and metered HVAC system type (ASHP and VRF). Each target curve is expressed as whole-building monthly electric consumption, disaggregated into the building base load (non-HVAC end uses) and variable load. The variable load is disaggregated into three heat-pump-related end uses: heat pump, backup/supplemental electric heating, and HVAC fan consumption.

For each building type and system, the study team developed the target curve using the following process:

- Derived a monthly whole-building load shape from the billing data, weather-normalized to a typical meteorological year (TMY) consistent with prior EO Model versions, by taking the median of the normalized monthly profiles across all qualifying sites so that the shape reflects typical seasonal behavior. For VRF target curves, the monthly shape drew on both VRF and mini-split multi-zone billing sites, which share similar staged, variable-capacity operation, to strengthen the sample.
- Scaled the load shape to the consumption magnitude indicated by the metering data, using measured per-installed-ton heat pump consumption level from the metered sites together with the installed heat pump capacity of each building type prototype, where prototype capacity was estimated based on prototype floor area and an estimated square feet per ton of heat pump capacity (based on program tracking data).
- Split the heat pump variable consumption into heat pump, fan, and supplemental electric heating components using observed end use shares from the metered sites. Because the modeled prototype buildings are served entirely by heat pumps with electric backup, supplemental heating was applied seasonally—concentrated in the coldest months and tapering off as outdoor temperatures rise—consistent with how resistance backup engages when heat pump capacity is limited at low temperatures.
- Calculated the month-by-month, site-to-site variability to define an acceptance range of ± one standard deviation around each median target, providing the band within which a calibrated model is considered acceptable.

Consistent with the 2026 program capacity threshold described at the beginning of this section, the metering and billing data underlying the target curves were screened using a "soft cutoff" approach, so that the curves represent installations at or below the 35-ton threshold while retaining sites with a higher total installed capacity where that capacity was composed of many small units. The resulting median target curves and their acceptance ranges are the basis for the calibration described in the following section; an example is shown in Figure 2-2, and all target curves are provided in APPENDIX C.

2.3.6.3 Calibration process

During calibration, we stepped through the following process for each combination of building type and HVAC type (for metered equipment types—ASHP and VRF) where target curves were developed:

[34] Billing data were cleaned at the account level: months with less than 95% of days billed were dropped, and suspicious zero or spike readings were treated as missing. The data were then weather-normalized with a variable-base degree-day model. Sites were retained only if they had (1) post installation electric billing for all 12 calendar months, with every account at the site reporting and the installation month excluded; (2) full displacement in the program tracking data; (3) an ASHP, VRF, or multi-zone mini-split system; (4) installed capacity within the 35-ton soft cutoff; and (5) a building type matching one of the six calibrated prototypes. Of the 1,528 sites with cleaned billing data, 918 had complete post-installation electric data, 637 of these were full displacement, 507 had an eligible system type, and 493 remained after the soft cutoff.

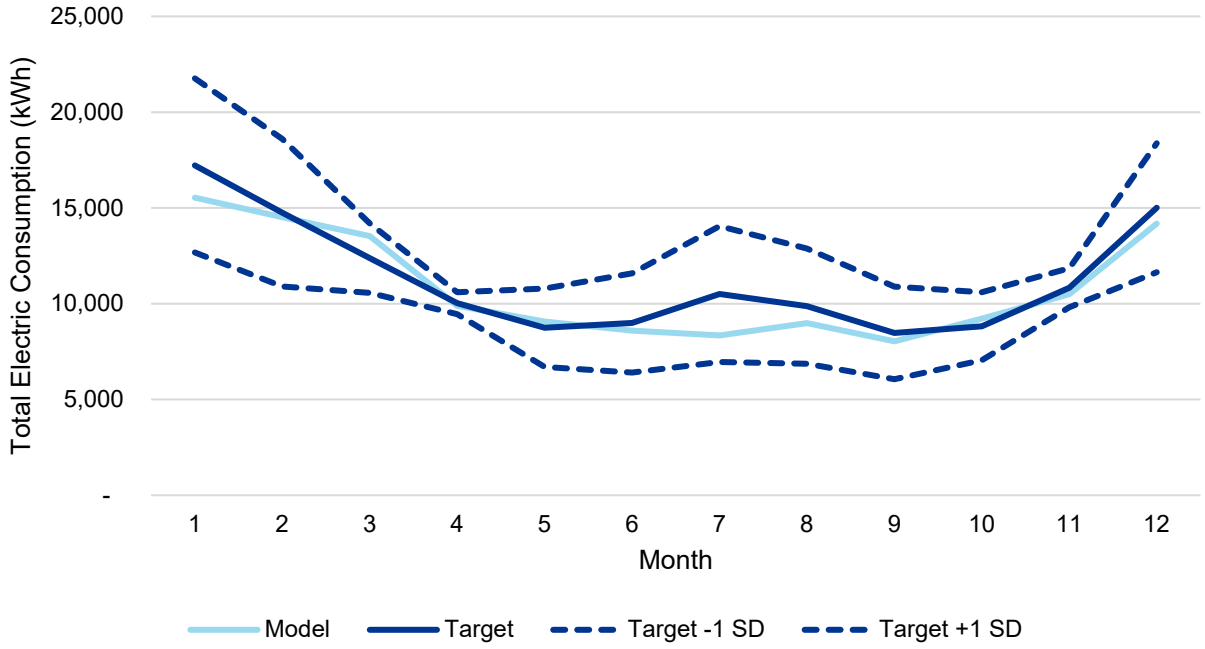
1. Ran two simulations for each case (building type and HVAC system type) for each potential calibration input, one at the maximum allowable level and one at the minimum allowable level.
2. Compared the model results for each max/min run pair to categorize the inputs impact into one of three impact categories (electric baseload, heating load, and cooling load) and three end-use categories (heat pump, backup/supplemental heating, and fans) and the impact direction from the high to the low value.
3. For each case, set up and ran a series of 30 models in which all calibration inputs identified in (2) were varied in equal increments between the two endpoints. One endpoint was the value of each input that produced highest consumption, and the other was the value that produced the lowest consumption, as determined by the max/min comparison in (2).
4. Using the results from the initial run where all calibration inputs were allowed to vary (3), identified which of the 30 runs predicted energy use closest to the target for each end-use category (heat pump, backup/supplemental heating, and fans).
5. For each impact category (baseload, heating load, and cooling load), launched successive runs of 30 models, where only those inputs associated with each impact category were allowed to vary while those for the other three impact categories were locked to those input values that produced results closest to the target.
6. Continue to iterate through impact categories until the calibration targets were met.

After we calibrated each combination of building type and HVAC type where target curves were developed, we used these models to inform inputs for segments that were not calibrated. For MSHP and PTHP simulations, we adjusted (1) HVAC efficiency inputs to reflect data collected in this study, (2) ventilation design inputs to reflect the calibrated VRF models for each building type,[35] and (3) aligned all other HVAC and non-HVAC inputs to the calibrated ASHP models for each building type.[36] For baseline HVAC simulations, we similarly updated all the non-HVAC inputs to reflect the calibrated models while ensuring HVAC inputs reflect data acquired in this study (see the Baseline HVAC simulation updates section) and previous EO Model iterations. The result of this process is that all non-HVAC inputs are constant for all HVAC scenarios accounted for in the model.

An example of a calibrated case is shown in Figure 2-2. This graph provides the annual whole building target curves and simulation results, though the team also aligned as closely as possible end-use categories where target curves were developed (heat pump consumption, backup/supplemental heating consumption, and fan consumption). The median target consumption and acceptance range (± 1 standard deviation) are shown with dashed and dotted lines, respectively. For all resulting calibrated models, refer to APPENDIX C.

[35] Like VRF simulations, MSHP and PTHP simulations utilize Dedicated Outside Air Systems (DOAS) to provide ventilation. As calibrated VRF simulations provide our best estimates for DOAS design inputs, we use these inputs to inform MSHP and PTHP DOAS simulations.
[36] Other than ventilation design and inputs we could acquire directly from field data, the team aligned all other inputs for MSHP and PTHP simulations to calibrated ASHP simulations because individual ASHP units are closer in system size to individual MSHP and PTHP units than VRF systems.

Figure 2-2. Calibrated model – small office ASHP



2.3.6.4 Quality assurance/quality control

Our calibration QAQC process occurred at four key points in the calibration process:

1. **Input Characterization QAQC.** This check occurred after characterizing the calibration input parameters as outlined in the Calibration parameter development section. The team reviewed each input's starting value and calibration range against DOE prototype values, field data, and the ranges used in EO Model v2.0 to confirm they were physically reasonable and correctly assigned to each building type and HVAC system.
2. **Sample Size and Target Curve QAQC.** This check occurred after the target curves were developed and before calibrating simulations to them. For each building type and HVAC system type, the study team reviewed the number of metering and billing sites underlying each curve, confirmed that the data screening steps (billing data 12-month completeness, capacity threshold, and metered end-use screening) had been applied consistently, and verified that the resulting monthly target curves and their acceptance ranges were reasonable and consistent with expected seasonal patterns before they were used as calibration targets.
3. **Input Alteration QAQC.** This check occurred after we finished calibration but before we rolled the calibrated parameters out to the simulations with other HVAC system types. For each calibrated simulation, we reviewed which input values we changed in the calibration process and by how much. This review gave the study team an early indication of the savings to expect for each building type and HVAC system. It also confirmed that the calibration adjustments were reasonable and would not distort those savings once carried into the remaining simulations.
4. **Results QAQC.** This check occurred after we had rolled the calibrated parameters out to the simulations with other HVAC system types and consisted of a detailed review of the model results by end use and seasonal variation.

As a final QAQC check, the team calculated the mean bias error (MBE) and coefficient of variation of the root-mean-square error (CV[RMSE]) for each calibrated model's annual whole-building electric energy consumption following the approach

detailed in ASHRAE Guideline 14.[37] ASHRAE developed this guideline for use in the development and validation of models of individual buildings, typically in the context of investment grade savings impact estimates. While it is not wholly applicable to our calibration efforts (where we are aligning our models to billing data collected across the C&I sector), the metrics outlined in the guideline provide a useful secondary assessment of how well our calibrated models match the available billing data. While the calibrated models do not all conform to the guideline's calibration thresholds of ± 5% for MBE and less than 15% for CV(RMSE), as shown in in Table 2-18, most of our calibrated models are within these ranges and the remaining are close, giving us strong confidence in the outcomes of our calibration process.[38]

Table 2-18. ASHRAE Guideline 14 calibration metrics

Building type	HVAC type	Annual Whole-Building Electric Consumption	
		MBE	CV(RMSE)
apartment-midrise	ASHP	-1.23	8.97
apartment-midrise	VRF	3.41	8.19
office-medium	ASHP	0.86	15.30
office-medium	VRF	-5.91	11.12
office-small	ASHP	4.20	8.90
office-small	VRF	3.95	6.95
retail-strip-mall	ASHP	-1.43	8.91
retail-strip-mall	VRF	0.28	5.74
school-primary	ASHP	-2.75	17.40
school-primary	VRF	-1.55	13.02
warehouse	ASHP	-1.95	30.81
warehouse	VRF	-1.28	23.12

2.3.7 Heat pump performance curves

Prior to calibration, the study team used manufacturer specification sheet data for the most prevalent ASHP systems found through verification site-visits to update ASHP performance curves. Performance curves, also referred to as performance mappings, are mathematical equations (polynomials) used in EnergyPlus to adjust a heat pump's rated heating/cooling capacity and energy efficiency based on changing indoor and outdoor temperatures or part-load conditions. Since equipment does not always operate at its peak rated capacity and efficiency, performance curves act as multipliers or modifiers to scale these rated values under varying conditions. The updated curves are derived from manufacturer-published laboratory performance data, replacing curves from a 2011 NLR study with curves specific to the equipment identified during site visits. EnergyPlus performance curves rely on manufacturer or lab data that sufficiently detail the following performance curve types:

- Efficiency by outdoor air temperature
- Capacity by outdoor air temperature
- Capacity by supply airflow rate

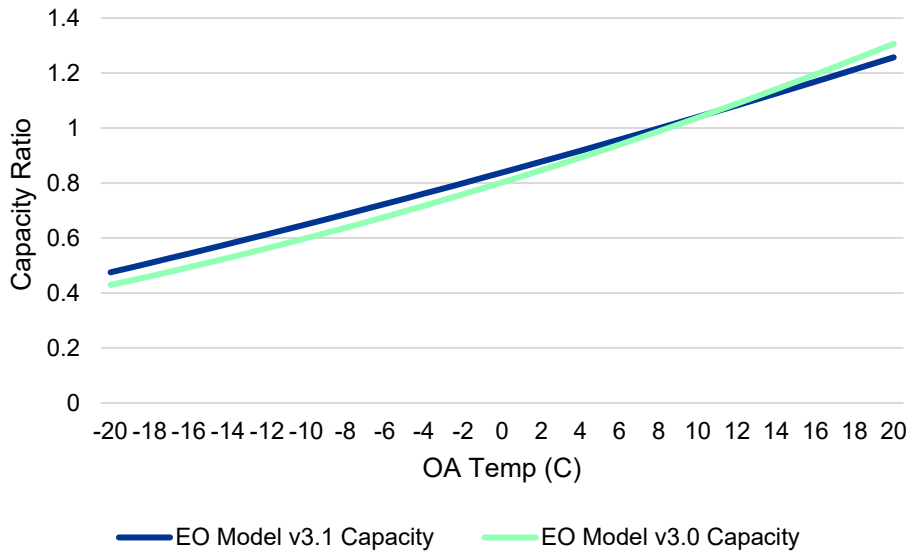
The study team completed manufacturer specification sheet desk reviews for ASHP units that account for about 70% of installed capacity in verification data. As creating performance curves depends on manufacturers publishing abundant lab

[37] ASHRAE, ASHRAE Guideline 14-2002: Measurement of Energy Demand and Savings. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers; 2002.
[38] The only prototype that was significantly outside of the CV(RMSE) threshold were the 'warehouse' models: this is due to the target curves for this building type being very rigid, whereas the modeled energy consumption was much more smooth [CV(RMSE) is a metric that assess calibration precision, which can be negatively impacted if the calibrated model has a smoother curve than the target]. Given this, MBE being within range, and consumption curves matching the targets, we do not have concerns with the CV(RMSE) metric being out-of-range for 'warehouse' models.

data, not all systems have publicly available performance data. However, our ability to capture performance for 70% of installed and verified ASHP equipment resulted in representative performance curves for this heat pump type. Additionally, the study team performed quality control activities to ensure accuracy and representativeness of the new calculated performance curves.[39]

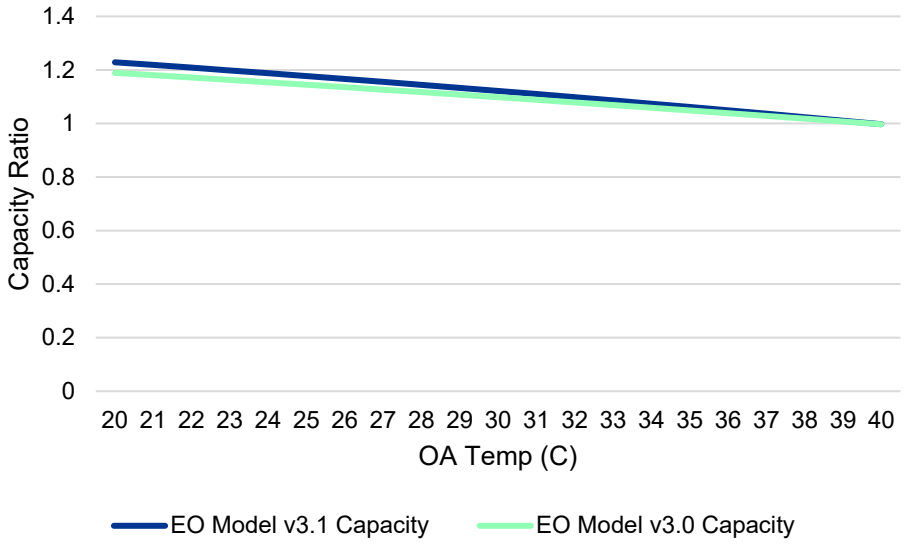
Heating capacity ratio and cooling capacity ratio by outside air temperature are shown in Figure 2-3 and Figure 2-4 , respectively. As demonstrated in these figures, heating and cooling performance had minimal changes between EO Model v3.0 and v3.1, though performance improved very slightly for heating and cooling at low temperatures. Given their magnitude, these changes likely had negligible effects on savings impacts, and the study team recommends that future studies retain the existing curves for ASHPs unless there is a significant change in heat pump performance, such as an increase in program equipment requirements.

Figure 2-3. ASHP heating capacity ratio vs. outdoor air temperature for the EO Model v3.0 and v3.1



[39] The team was able to achieve a coefficient of determination (R^2) value greater than 90%, meaning the resulting performance curves had very strong statistical representation for reviewed ASHP units.

Figure 2-4. ASHP cooling capacity ratio vs. outdoor air temperature for the EO Model v3.0 and v3.1



In addition to ASHP performance curves, the research team performed desk reviews for VRF and MSHP systems that were catalogued in verification site-visit data. As mentioned, robust performance data is required to create new performance mappings for heat pump equipment. The study team found that manufacturers reported only rated conditions in VRF and MSHP specification sheets and did not provide sufficient information needed to characterize variable-speed operation. This results in updated performance curves that have R^2 values that did not meet acceptable limits. The study team concluded that we did not have enough confidence or representativeness in updated MSHP and VRF performance curves to implement in the EO Model v3.1, so MSHP and VRF performance curves have not changed since the EO Model v3.0.

Table 2-19 provides lab data sources for the MSHP and VRF performance curves used in the EO Model v3.1 simulations. VRF performance curves were updated using 2024 National Laboratory of the Rockies (NLR) data as part of the EO Model v2.1 update. MSHP performance curves are based on an older 2011 NLR report and have been employed since the EO Model v2.0. To ensure the MSHP performance curves are not out-of-date, the study team compared the simulated heating and cooling efficiencies by outside air temperature to the 2025 Massachusetts and Connecticut Heat Pump Metering Study[40] and found that simulated efficiencies are similar and within acceptable limits of the metered study results, indicating that the 2011 NLR performance curves for MSHP systems are still representative.

Table 2-19. Performance curve sources for simulated VRF and MSHP equipment

Heat pump type	Performance curve source	Performance curve data source type
VRF	2024 NLR Report: Variable Refrigerant Flow with Heat Recovery and Dedicated Outdoor Air System[41]	Daikin and Mitsubishi manufacturer data analyzed by NLR
MSHP	2011 NLR Report: Laboratory Test Report for Fujitsu 12RLS and Mitsubishi FE12NA Mini-Split Heat Pumps[42]	Fujitsu and Mitsubishi laboratory test data by NLR

[40] Energy Efficiency Advisory Council, Massachusetts and Connecticut Heat Pump Metering Study, https://ma-eeac.org/wp-content/uploads/MA-HPMS-CT-R2246-Heat-Pump-Metering-Study-Final-Report_April_2025.pdf
[41] National Laboratory of the Rockies, Variable Refrigerant Flow with Heat Recovery and Dedicated Outdoor Air System, https://docs.nlr.gov/docs/fy24osti/86103.pdf
[42] National Laboratory of the Rockies, Laboratory Test Report for Fujitsu 12RLS and Mitsubishi FE12NA Mini-Split Heat Pumps, https://docs.nlr.gov/docs/fy11osti/52175.pdf

2.3.8 Heat pump sizing practices

The study team used contractor survey and verification data to inform how heat pumps and baseline HVAC systems are sized in the building simulations. In previous versions of the EO Model, all HVAC systems were oversized in accordance with ASHRAE 90.1 performance-based compliance guidelines.[43] Specifically, the building simulations autosized systems to meet heating and cooling load requirements of the space, then oversized the installed heating capacity by at least 25% and cooling capacity by 15%. This approach also managed unmet load hours and comfort metrics to meet acceptable levels.

A goal of this study was to understand installation practices and incorporate those into how the study team simulates system design. The study team, through the contractor survey, asked contractors how often they oversize heat pump systems. Table 2-20 shows the sizing results from the contractor survey, as well as estimates how often full displacement systems from the site verification visits were undersized, right-sized, and oversized based on the installed tonnage of heat pump systems for the conditioned square footage the heat pump systems are serving. As shown in Table 2-20, contractors—as confirmed through verification data—rarely oversized heat pump systems installed through the program. To align with these results, the study team autosized HVAC systems (baseline and program) as before to meet space conditioning requirements, but removed the oversizing factors. This approach effectively "right-sizes" the systems to meet load requirements while reducing how often systems are short-cycling. During quality control activities, the study team confirmed that this change did not result in unmet load hours or comfort metrics that were outside of acceptable limits for most calibrated ASHP and VRF simulations. However, many MSHP, PTHP (particularly MSHP and PTHP simulations where there is no ventilation backup heating) and some baseline HVAC systems had high unmet load hours when trying to right-size the simulations. We increased system sizing for these simulations as-needed to avoid systems underestimating energy consumption.

Table 2-20. Heat pump sizing practices from field data

	Contractor survey results			Full displacement verification data results			
Heat pump type	n (respondents)	How often contractors are oversizing systems	How often contractors are not oversizing systems	n (sites)[1]	Undersized (>600 sqft/ton)	Right-sized (300-600 sqft/ton)	Oversized (<300 sqft/ton)
VRF	14	15%	85%	15	45%	41%	14%
ASHP (split and packaged)	27	17%	83%	10	43%	21%	37%
MSHP (single-zone and multi-zone)	25	16%	84%	16	42%	53%	5%

[1]Limited to full verification sites where conditioned square footage is available.

2.3.9 Baseline HVAC simulation updates

The study team made three primary changes to baseline HVAC simulations for the v3.1 EO Model:

- Aligned non-programmatic inputs[44] to calibrated program HVAC simulations to ensure that savings reflect only programmatic changes.
- Updated baseline HVAC efficiency values for the early replacement event type (up to end of remaining EUL) based on recent Massachusetts C&I Existing Buildings Baseline Study data.[45]

[43] American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Standard 90.1 Performance Based Compliances (Section 12 and Appendix G), https://www.energycodes.gov/performance_based_compliance

[44] "Non-programmatic inputs" are inputs that should not change in a building because of the program and include envelope, fenestration, infiltration, plug loads, lighting, and water heating.

[45]Massachusetts Commercial and Industrial Existing Buildings Baseline Study, May 2024, https://ma-eeac.org/wp-content/uploads/MA22C05-B-BSLN-Existing-Buildings-Baseline_FINAL_20240506.pdf

- Updated baseline HVAC heating setpoints to reflect participant behavioral changes when installing a programmatic heat pump system.

Baseline HVAC simulations in the EO Model v3.0 were based on a calibration conducted in the EO Model v2.0 update, where gas and electric energy consumption were calibrated to billing data from non-program participants. For this model update, the study team calibrated program HVAC simulations and ensured no non-programmatic input differences between these calibrated program and the new, non-calibrated baseline HVAC simulations. The result of this process is that all non-HVAC inputs are constant for all HVAC scenarios accounted for in the model. This change of approach results in entirely new baseline HVAC simulations.

In addition to reviewing heat pump efficiency and performance information, the study team also reviewed the 2024 Massachusetts Existing Buildings Baseline Study[46] and the 2026 Baseline Repository[47] to assess whether updates needed to be simulated for early replacement and replace on failure baseline heating efficiency.[48] Table 2-21 provides the sources the study team used for defining efficiency for each baseline case/event type modeled.

Table 2-21. Baseline HVAC efficiency specification source by baseline event type

Baseline event type	Efficiency source
Early Replacement (up to end of remaining EUL)	Massachusetts C&I Existing Buildings Baseline Study, 2024
Early Replacement (after end of remaining EUL)	Massachusetts Baseline Repository, 2026[a]
Replace on Failure	Massachusetts Baseline Repository, 2026[a]

[a]In contrast to the Existing Buildings Baseline Study, the Baseline Repository provides guidance when selecting baselines for new construction and lost opportunity measures, according to the latest collection of evaluation research and code stipulations. It is intended to serve as a repository for all industry standard practice research, as well as code-defined baselines where they are recommended, to be used for MassSave projects in an effort to ensure consistency and efficiency of evaluations and to assist implementors with managing the risk surrounding baseline selection.

Table 2-22 provides the changes in baseline heating efficiency for simulated natural gas furnaces and boilers by event type. As shown, the study team did not discover changes in end-of-life or replace on failure heating efficiency in the Baseline Repository. On the other hand, the team found that heating efficiencies in the Existing Buildings Baseline Study—which were based on data collected during 2023—were substantially higher that the efficiencies used in the EO Model v2.0 update, which were based on data collected during 2017-2019.[49] The Subcommittee determined that these updated values were appropriate because they were more recent and have been applied elsewhere including the Massachusetts TRM.

These updated values for early replacement heating efficiency up to the end of remaining EUL result in much lower early replacement fuel savings. However, the overall effect on savings from this change is small, because (1) early replacement savings made up a small portion of fuel savings in the EO Model v3.0 as v2.1 contractor survey results showed equipment were typically installed through replace on failure event types; and (2) the large majority of fuel impacts from electrification

[46] Ibid
[47] Energy Efficiency Advisory Council, Massachusetts 2026 Baseline Repository, https://ma-eeac.org/wp-content/uploads/MA-Baseline-Repository-2026.xlsx.
[48] Cooling efficiency information for baseline systems was not available in the 2025 Massachusetts Baseline Study, so the study team maintained the same cooling efficiency for simulated baseline systems as the calibrated baseline models contained in the EO Model v3.0. The study team found very small differences in cooling efficiency between ComStock data for Massachusetts and the calibrated baseline efficiency values.
[49] The EO Model v2.0 early replacement efficiency values are based on the Massachusetts NRNC Market characterization study: https://ma-eeac.org/wp-content/uploads/MA19C08-B-NRNCMKT-NRNC-Market-Characterization-Study-Final-Report.pdf. The increase of 10 percent in average efficiency is, on the surface, greater than would be expected under normal market conditions. However, as noted in the 2024 Existing Buildings Baseline Study: "*it is important to understand when it is appropriate to make conclusions about trends in the overall market. Past studies used different methods – most notably the sampling unit (account vs. premise vs. parcel) and the source of data collection – which inevitably will yield different results. Additionally, this type of broad market data collection relies on customers with typically low response rates (response bias) and wide ranges of variance. Therefore, it is difficult to draw statistically significant conclusions across years on big market trends*." See Massachusetts Commercial and Industrial Existing Buildings Baseline Study, May 2024, https://ma-eeac.org/wp-content/uploads/MA22C05-B-BSLN-Existing-Buildings-Baseline_FINAL_20240506.pdf.

are a result of switching off of fossil fuel-fired equipment, while the level of efficiency of the existing fossil fuel systems is responsible for a relatively small portion of these overall fuel impacts.

Table 2-22. Baseline natural gas furnace and boiler efficiency changes by event type

Baseline event type	EO Model v3.0		EO Model v3.1	
	Furnace AFUE	Boiler AFUE	Furnace AFUE	Boiler AFUE
Early replacement (up to end of remaining EUL)	73%	73%	83.1%	84.5%
Early replacement (after end of remaining EUL)	85%	85%	85%	85%
Replace on failure	85%	85%	85%	85%

We increased the early replacement efficiencies for oil and propane furnaces and boilers proportionally to the efficiency increases for natural gas systems.[50] Heating efficiencies for all other baseline system types are the same as the EO Model v3.0.

Lastly, we used the participant survey to assess whether participants made any notable changes to HVAC operational parameters as a result of installing programmatic heat pump equipment. Operational parameters investigated include changes in heating setpoints, cooling setpoints, and HVAC schedules. The participant survey indicated that, on average, there are no notable changes in cooling setpoints or HVAC schedules as a result of installing a heat pump, but participants did indicate that they commonly lower heating setpoints as shown in Table 2-23. The study team implemented this behavioral change into the program-level heat pump simulations, reflecting a modest increase in energy savings from installing programmatic heat pump equipment.

Table 2-23. Participant survey results for the change in heating setpoint after installing programmatic heat pump by baseline HVAC fuel type

Baseline HVAC fuel type	n (participants)	Change in heating setpoint after installing programmatic heat pump
Fossil fuel	16	-2
Electric	3	-1

2.3.10 Baseline and program system capacities

In addition to adjusting inputs to alter the simulated consumption, the calibration process also included finding new installed capacity values for the Baseline and program HVAC systems. Savings estimates are normalized by these installed capacities, making these a key model parameter. Table 2-24 provides the assumed installed capacity in the EO Model v3.0 and the new installed capacity in the EO Model v3.1 by location, building type, and heat pump type for the Midrise Apartment building; for all installed capacity results, refer to APPENDIX C.

In previous versions of the EO Model, the team used the average installed capacity across heat pump types for this normalization, resulting in installed capacity only differing by building type and location. In the EO Model v3.1, the study team expanded this capacity normalization to consider heat pump types as well. For each segment, the team uses the

[50] Rather than directly-simulating oil and propane systems, the study team proxy-simulates these system types by applying an efficiency-adjustment factor to simulated natural gas systems. Therefore, any efficiency changes to natural gas systems are captured for oil and propane systems as well. The efficiency adjustment factor is assumed to be 97.6% based on research conducted in the v2.0 update.

higher of the estimated total heating or cooling capacity; normalizing by the higher of heating for cooling capacity aligns with how equipment would typically be selected in the field.

Table 2-24. Changes in total capacity per location and heat pump type for the midrise apartment building type

Climate	Building type	Heat pump type	Total capacity (tons)		Floor area by total capacity (ft^2/ton)	
			EO Model v3.0	EO Model v3.1	EO Model v3.0	EO Model v3.1
Interior	Midrise Apartment	Air Source Heat Pump	90	90	375	375
Interior	Midrise Apartment	Mini-split - Multi-zone	90	109	375	310
Interior	Midrise Apartment	Mini-split - Single-zone	90	110	375	307
Interior	Midrise Apartment	PTHP	90	120	375	281
Interior	Midrise Apartment	Variable Refrigerant Flow	90	61	375	553

Generally, the installed capacity required increased, reflecting that the calibration resulted in a net increase in consumption for baseline and program HVAC systems. Importantly, as savings are normalized by capacity, this increase in capacity requirements also leads to a net decrease in impacts, though it is not possible to measure the combined effect of this change because baseline HVAC systems' capacity requirements also increased and simulation results are weighted across thousands of segments. As installed capacity assumptions in previous EO Model iterations originate from uncalibrated program HVAC models and are averaged across building type and climate zones, these installed capacity values from calibrated models provide a more rigorous impact estimate.

2.4 EO Model tool updates

In addition to updating building simulations, the study team made several updates to the EO Model tool itself. While building simulations are the basis of energy consumption estimates across the EO Model segmentation, these simulation results are also used for post-processing calculations and algorithmic modeling within the Excel-based EO Model, which allows simpler and more cost-effective modifications. The study team used multiple data sources to inform the EO Model tool adjustments including results from survey and field data collection, M&V results, utility consumption data, and program tracking data. This report summarizes the updates made to the EO Model tool, which builds upon previous EO Model v2.0 and v2.1. The updates fall into the following two categories:

> The EO Model tool is an Excel-based interface that uses building simulation results as an input. The EO Model tool houses the calculations and weighting schemes required to produce prospective, prescriptive impact values that the PAs use to claim savings.

- **Weightings:** The team used survey and program tracking data to adjust how the EO Model tool weights building simulation results across program, displacement type, and pre-program fuel. Additionally, the EO model was updated to account for additional pre-existing cooling conditions. [51]

[51] The study team planned to update the EO Model to account for impacts due to local ordinances in Boston and Cambridge. These jurisdictions have ordinances requiring that certain commercial buildings reduce building-related emissions, including through electrification. The team surveyed contractors and participants to assess the impact of these ordinances and provide a basis for potential adjustments to EO Model weights for improved accuracy of prospective results. However, contractor and participant survey respondents reported that these ordinances had a negligible impact on heat pump installations, and therefore the ordinances do not merit updates to the EO Model. See section 3.2.2 for details.

- **Modeling parameters:** The team used survey, on-site verification, and metered data to adjust the EO Model tool's parameters for partial displacement switchover technique and ventilation heating load-sharing design.

2.4.1 EO Model weights

As with prior EO Model updates, the v3.1 Model weights impacts across the many combinations of program heat pumps, building types, climate zones, event types and pre-program and counterfactual HVAC and fuels, using updated (1) customer and contractor survey responses and (2) program tracking data, as detailed in the sections below. In addition, APPENDIX A provides the full set of survey and tracking data proportions used to develop these weights.

2.4.1.1 Survey proportions update

Contractor and participant survey results were weighted according to the sample and expansion methods described in Section 2.3.4 and APPENDIX D. Survey proportions were then developed for each combination of (1) program HVAC and (2) pre-program fuel. Both of those variables are found in the tracking data, however the participant survey also included questions to verify the pre-program fuel. Participants often reported different pre-program fuel than what was in the tracking data, so the survey proportions are based on the pre-program fuel indicated by survey respondents rather than what was in the tracking data for those participants.

A key update in the v3.1 EO model was the addition of (1) "no cooling" pre-program baselines and (2) "cooling" and "no cooling" counterfactual baselines. As noted in the EO Model v3.0 short-term update report,[52] the v3.0 model assumed all baseline systems have cooling capability, in alignment with v2.1 and v2.0. The addition of these pre-program and counterfactual baselines results in a net decrease in electric savings and electric impacts overall, since added cooling loads associated with program heat pumps at sites that previously had no or less cooling are now accounted for in the model.

Table 2-25 provides the sources and other details for each of survey-based proportions in the EO Model. For most proportions, the team used either the contractor or participant survey results, though in some cases the team used a weighted average of both contractor and participant survey results. In addition, APPENDIX A provides a comparison of weighted results for each proportion from the v3.0 model and the v3.1 participant and contractor surveys.

Table 2-25. Survey proportion sources

Survey proportion	Source*
Pre-program HVAC	• **Survey questions**: Contractors and participants were asked what the previous HVAC system was before installation of program heat pumps. • **Analysis notes**: Contractor and participant results were aggregated by program HVAC and pre-program fuel, based on participant-reported fuel. • **Selected source and rationale**: Contractor results were used as they are likely to have a more accurate assessment of previous HVAC systems. Contractor and participant results for pre-program HVAC were closely aligned.
Event Type	• **Survey questions:** Contractors and participants were asked about the status of the pre-program HVAC system and responses were categorized as either replace on failure or early replacement. - Replace on failure survey responses: prior system was not working at all, prior system was damaged or unsafe, prior system was working but needed major repair, and prior system was working but inadequate for the space. - Early replacement survey responses: prior system was working but needed minor repair, prior system was working but old or inefficient, or prior system was working with no need of repair. • **Analysis notes:** Participants were asked about the status of their specific pre-program HVAC, so results were developed by program HVAC and pre-program fuel. Contractors were asked, for a

[52] DNV. (November 13, 2025.) *Energy Optimization Model Version 3.0 Short-Term Update*. Prepared for the Massachusetts Program Administrators. https://ma-eeac.org/wp-content/uploads/MA25C04-B-EOModel-Short-term-Update-Final-Report-20251113-clean.pdf

Survey proportion	Source*
	specific program HVAC type, what portion of the time the previous equipment fell into the various status categories, resulting in data by program HVAC but not pre-program fuel. • **Selected source and rationale:** The team used a weighted average of contractor and participant results to incorporate contractor expertise and broad representation, while also capturing variation in replacement type by pre-program fuel reflected in participant responses.
Counterfactual HVAC	• **Survey questions:** Participants whose equipment was failing (i.e., replace on failure of the previous system) were asked whether they would have installed another version of their pre-program HVAC system if they had not installed the program equipment. If not, they were asked what type of HVAC system they would have installed instead. • **Analysis notes:** The v3.1 participant survey allowed respondents to indicate that the counterfactual HVAC was the same as the program HVAC. For example, an ASHP participant could indicate they would have installed an ASHP outside the program. Such responses create implications for net-to-gross calculations, by introducing the potential for overlap with net-to-gross ratios. In addition, because the EO Model was developed to apply the program's gross baseline of non-heat pump equipment (as illustrated in Figure 1-1), the EO Model is not currently structured to incorporate same-as-program counterfactual baselines. As a result, the team adjusted the v3.1 participant survey results to remove cases where the counterfactual HVAC was the same heat pump technology as the program HVAC. • **Selected source and rationale:** Participant results were used, as contractors were not asked counterfactual HVAC questions. In addition, v3.1 and v2.1 participant survey results were combined and weighted, to increase robustness due to the relatively small set of counterfactual responses in the v3.1 survey and the larger sample size from the v2.1 survey.
Counterfactual fuel	• **Survey questions:** Participants were asked whether they would have continued heating their building with the pre-program fuel. If not, they were asked what fuel they would have switched to. • **Selected source and rationale:** Participant results were used, as contractors were not asked counterfactual fuel questions.
Ventilation approach	• **Survey questions:** Contractors were asked what percentage of the time a separate ventilation air system (e.g., a dedicated outside air system) serves the area conditioned by the heat pump, and when such a system exists, what percentage of the time it tempers the ventilation air. • **Analysis notes:** Ventilation heating (previously called decoupled in the model) and no ventilation heating (previously called coupled in the model) proportions were derived from survey responses for VRFs, and for mini-splits these systems were assumed to have no ventilation heating 100% of the time. ASHPs are all-in-one packaged units that heat and distribute air throughout the system, so questions regarding separate ventilation heating components are not applicable for this heat pump type. Information on PTHP systems was not collected in the surveys so the EO Model v3.1 maintains the same assumption as previous model iterations that PTHPs always have ventilation heating. • **Selected source and rationale:** Contractor results were used because only they were asked about ventilation system configurations, given their technical knowledge.
Baseline cooling *(new in v3.1 update)*	• **Survey questions:** Contractors were asked what percentage of the time the program heat pump systems they install involve adding cooling to previously uncooled or insufficiently cooled areas. Participants were also asked whether the program heat pump they installed added cooling to a previously uncooled or insufficiently cooled area. • **Analysis notes:** Contractor and participant responses regarding added cooling were closely aligned. • **Selected source and rationale:** Contractor results were used for the survey proportions because they provide a broader representation of project installations, and because they were the primary source of equipment-level installation information and were consistent with participant responses.

*Note: PTHP contractors were not included in the v3.1 contractor survey because contact information for contractors was not available in the midstream tracking data. This is in part because systems were often installed in hotels by facility operations staff. In lieu of contractor survey responses, the team used a weighted average of v3.1 participant and v2.1 contractor responses to develop PTHP proportions.

2.4.1.2 2025 program data update

The study team updated the EO Model weighting values with refreshed 2025 program tracking data to ensure that impact estimates reflect the latest program activity and evolving mix of incentivized equipment. The team obtained and processed 2025 data from the midstream and downstream EO program vendors, as well as additional datasets of 2025 projects that were processed in-house by the PAs and were not included in the downstream and midstream implementation vendor data sets The 2025 program data was stacked with the 2024 program data to calculate the tracking data proportions used in the v3.1 model. This program data "refresh" helps ensure the EO Model reflects the most up-to-date proportions and weighting associated with the following parameters:

- Pre-program fuel
- Program HVAC
- Building type
- Displacement type (full/partial)
- Climate (interior/coastal)
- DEC and non-DEC projects[53]

The team utilized the same program data update process as was followed for the v3.0 update report, which is detailed in the v3.0 short-term update report.[54]

New 2026 Commercial Prescriptive Heat Pump Program capacity threshold

In addition to adjusting the building simulations to account for the new 35-ton capacity threshold for the Commercial Prescriptive Heat Pump Program (see section 2.3.4), the study team also adjusted the 2024-2025 tracking data proportions, by removing all downstream program sites where the total installed program capacity was >35 tons. In contrast to the building simulation adjustment, which applied a "soft cutoff" in order to retain more on-site metering data given the relatively limited number of on-sites, the tracking data analysis applied a strict cutoff whereby all ASHP, mini-split, and VRF sites with >35 tons total installed program capacity were excluded. The tables below show counts and capacities both before applying this cutoff (labeled v3.1a) and after (labeled v.3.1). The 35-ton threshold applies only to downstream projects, so midstream PTHPs are unchanged between v3.1 and v3.1a.

Table 2-26 shows the count and capacity of incentivized units, Table 2-27 shows the average capacity per unit, and Figure 2-5 shows total capacity by heat pump type in each model version. The tables also provide capacity and count values reflecting the removal of large (>35 ton) projects (see callout box). As shown below, there was a significant increase—more than doubling—in units and capacity in the participant population included in v3.0, followed by a decrease in the current update. After removing the large projects, the total capacity included in the current model version is about half of that in the prior (v3.0) model version. These updated values reflect several trends:

- PTHPs and WSHPs showed the most significant increase (in both units and total capacity) from the v3.0 model update, and since they are offered midstream, they are not subject to the 35-ton threshold so the total counts and capacities are identical between v3.1 and v3.1a.
- Multi-zone mini-splits also increased slightly (in both units and total capacity) from the prior model update, though after removing large projects, they showed a decrease.
- All other heat pump types decreased significantly between v3.0 and v3.1, with VRF capacity decreasing by the largest absolute amount (about 110 MMBtu/h decrease in total installed VRF capacity), prior to removing large projects. The removal of large projects results in an even greater decrease, in particular among VRF projects.

[53] As detailed in the v3.0 short-term update report (see section 2.4.1), the v3.0 model was updated to include weighted average values reflecting the mix of projects in DEC and non-DEC communities, based on the list of DECs aligned with the 2025-2027 Mass Save plan and associated performance metrics. Specifically, the 2025–2027 Strategic Evaluation Plan states: "…select facilities in equity communities have different HVAC system baselines from the industry standard practice, as these customers are more likely to repair existing equipment than replace it. The working group agreed to a stipulated dual baseline assumption, where the first period baseline reflects the existing conditions for 2/3 the EUL of the installed measure. The second period baseline will be the ISP HVAC system." To calculate the savings in DEC communities using stipulated dual baselines, specific early replacement and replace on failure proportions were calculated. The existing early replacement and replace on failure proportions were based on the remaining life and full effective measure life for each equipment type . The team developed an adjusted measure life calculation tor DEC community projects of 2/3 of the measure life of the installed equipment, based on the Plan language, which results in slightly increased savings for those projects in DEC communities. The v3.1 update reflects the updated proportion of 2024-2025 projects in select facilities, by building type, in DECs.

[54] See Section 2.3 of *Energy Optimization Model Version 3.0 Short-Term Update*. Prepared for the Massachusetts Program Administrators. https://ma-eeac.org/wp-content/uploads/MA25C04-B-EOModel-Short-term-Update-Final-Report-20251113-clean.pdf. DNV (November 13, 2025.)

- No GSHP projects were installed through the prescriptive program in 2024 or 2025, and GSHP impacts were not updated as part of this study.

Table 2-26. Count and capacity of incentivized units by EO Model version

Program HVAC	Count of incentivized units					Total capacity of incentivized units (MMBtu/h)				
	V2.0 (2022–Q1 2023)	V2.1 (2022–2023)*	V3 (2023 – 2024)*	V3.1a (2024 - 2025)	V3.1 (2024 - 2025, <35 tons)	V2.0 (2022–Q1 2023)	V2.1 (2022–2023)*	V3 (2023 – 2024)*	V3.1a (2024 - 2025)	V3.1 (2024 - 2025, <35 tons)
VRF	123	1,318	1,856	983	462	15.4	149.5	281.9	170.6	59.1
ASHP	168	1,827	3,324	2,502	1,781	8.3	79.3	172.9	160.5	90.7
Mini-split–Multi-zone	387	3,294	4,701	4,969	3,242	14.0	85.5	190.7	199.2	126.3
Mini-split–Single-zone	390	3,248	3,127	1,839	1,614	9.0	79.9	85.5	45.1	38.7
PTHP	0	0	6,238	9,545	9,545	0	0	55.6	87.9	87.9
GSHP†	51	179	128	0	0	1.7	6.7	5.2	0.0	0.0
WSHP	0	0	564	1,041	1,041	0	0	20.5	33.9	33.9
Total	**1,119**	**9,866**	**19,938**	**20,879**	**17,685**	**46.8**	**400.9**	**812.4**	**697.2**	**436.6**

* The 2023 downstream implementation vendor data included 284 measures with an unknown equipment type, and insufficient information to determine what the measures were. These were excluded from both the v2.1 and v3.0 Model program data proportions.
† No GSHP projects were installed through the prescriptive program in 2024 or 2025, and GSHP impacts were not updated as part of this study. For the v3.0 update, the team updated the count and capacity of GSHPs from prior updates. Specifically, a large project with 50 units was not originally included in the tracking data in time for the v2.0 study, but is included in the table above, resulting in 51 units in the table above. Also, the v2.1 data originally showed 184 units incentivized in 2023, but 5 of those had zero capacity so are dropped in our current model, resulting in 179 units in the table above.

The values in Table 2-27 show the range of per-unit capacities across different equipment types. Prior to removing the large projects, there continued to be an increase in the average size of installed VRF and ASHP systems from the prior model updates, with VRF projects on average being about 2.5 times the size of ASHP projects. Removal of large projects (>35 tons per site) results in a significant decrease in the average capacity of VRF and ASHP projects, while the average size of mini-split systems (both single- and multi-zone) barely changes with removal of large projects.

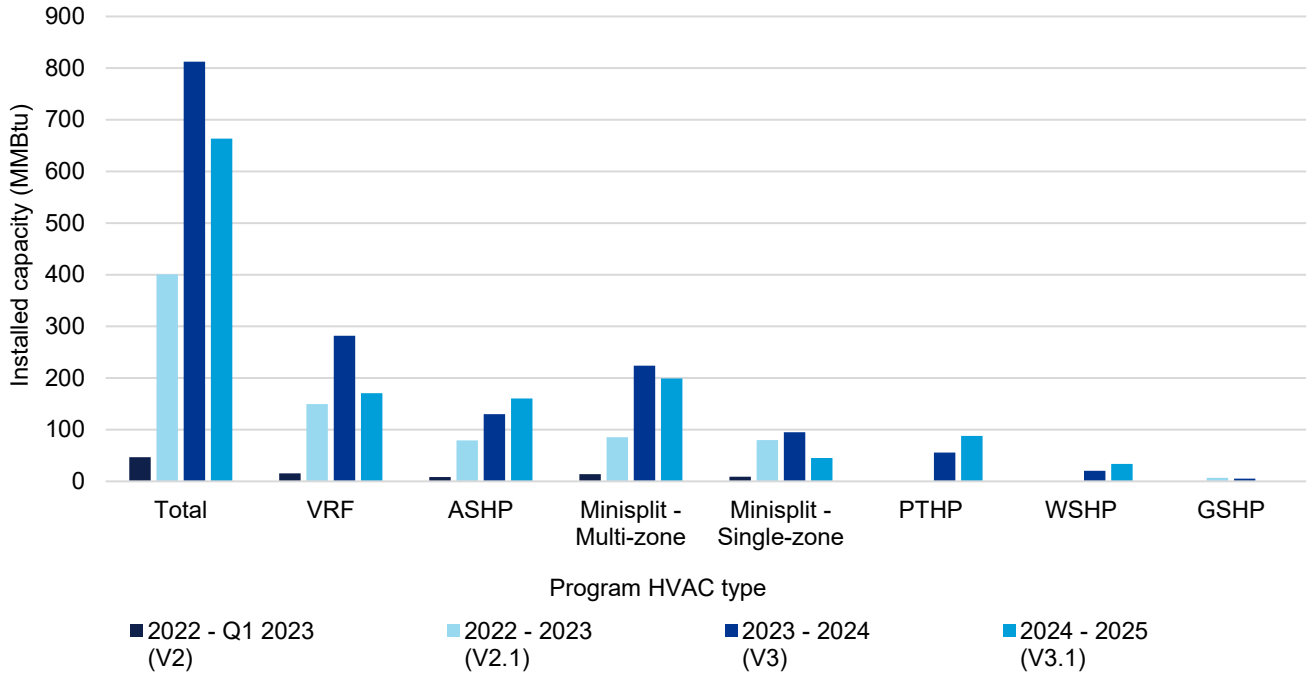
Table 2-27. Average capacity of incentivized units by EO Model version

Program HVAC	Average capacity per incentivized unit (MBtu/h)				
	V2.0 (2022–Q1 2023)	V2.1 (2022–2023)*	V3 (2023 – 2024)*	V3.1a (2024 - 2025)	V3.1 (2024 - 2025, <35 tons)
VRF	125.2	113.4	151.9	173.5	127.9
ASHP	49.4	43.4	52.0	64.2	50.9
Mini-split–Multi-zone	36.2	26.0	40.6	40.1	39.0
Mini-split–Single-zone	23.1	24.6	27.3	24.5	24.0
PTHP	N/A	N/A	8.9	9.2	9.2
GSHP†	33.3	37.4	40.6	N/A	N/A
WSHP	N/A	N/A	36.3	32.6	32.6

* The 2023 downstream implementation vendor data included 284 measures with an unknown equipment type, and insufficient information to determine what the measures were. These were excluded from both the v2.1 and v3.0 Model program data proportions.
†No GSHP projects were installed through the prescriptive program in 2024 or 2025, and GSHP impacts were not updated as part of this study.

Figure 2-5 shows the installed capacity by heat pump type across the current (v3.1) and prior EO Model updates.

Figure 2-5. Installed capacity by heat pump type and EO Model version



2.4.2 Modeling parameters

The EO Model contains post-processing calculations to proxy-simulate and weight results by two key modeling parameters that were updated in this study:

- **Partial displacement switchover** technique, where the study team used metered data to update the EO Model's hard switchover technique to an integrated switchover approach that more accurately characterizes the proportion of heating load served by programmatic heat pump equipment vs. backup or existing baseline systems.
- **Ventilation heating** system design, where the study team used on-site verification and metered data to weight the proportion of systems that do and do not have electric resistance supplemental heating components as part of the ventilation system.

2.4.2.1 Partial displacement switchover

As part of the EO Model v2.0 update, the team developed a proxy-simulation approach to quantify partial displacement impacts by assuming the heat pump system is the primary heating system (as in the system that meets the entirety of the building's heating load requirements) above a certain switchover temperature, then the backup or existing baseline system is the primary heating system below that switchover temperature. The switchover temperature in the model was 30˚F outside air temperature based on survey data. This sudden change in the primary heating system that meets heating load requirements is referred to as a "hard switchover." In contrast, the study team has been interested in the prevalence of "integrated switchover" approaches, where the primary heat pump system and backup or existing baseline systems share heating load requirements. Typically, in an integrated switchover configuration, the heat pump system contributes a decreasing share of heating load as outside air temperature decreases.

Metered data collected for VRF and ASHP partial displacement installations allowed the team to investigate:

- The prevalence of hard switchover and integrated switchover systems.

- The outside air temperature at which switchover occurs.
- For integrated switchover systems, the share of heating load met by the heat pump versus backup or existing baseline system.

For partial displacement installations, the team found that heat pump and baseline systems had a wide array of configurations for meeting heating load requirements, but no sites were found to have a hard switchover approach as previously integrated into the EO Model. System configurations included:

- Standard integrated switchover systems, where the heat pump and baseline system share portions of heating load requirements and the heat pump system contributes a decreasing share of heating load as outside air temperature decreases.
- Non-standard integrated switchover systems, where occupant behavior or system design creates non-uniform or constant heating load shares between heat pump and baseline systems.
- Systems where the heat pump only provides heating during certain times of the year.
- Systems where the heat pump only provides cooling and the baseline system provides the entirety of heating load requirements.

Using metered data, the study team characterized the percent of heating load met by the programmatic heat pump(s) and backup or existing baseline system by outside air temperature across all partial displacement sites metered.[55][56] This was done for VRF and ASHP systems[57] separately and weighted using estimated site-level measurement and verification weights. The resulting configurations were incorporated into the EO Model, replacing the hard switchover technique entirely. Table 2-28 shows how the share of heating load met by the heat pump and baseline systems have changed since previous EO Model versions, and Figure 2-6 provides a visual representation of the percent of heating load requirements met by VRF and ASHP systems and the number of TMYx weather file hours for Boston, MA and Worcester, MA at different outdoor air temperatures. As shown in Figure 2-6, the percent of heating load met by each heat pump type dropped drastically at the outside air temperatures where there are the most TMYx hours, above 30˚F. In total, these proportions are made up of 23 metered VRF and 38 metered ASHP partial displacement units.[58]

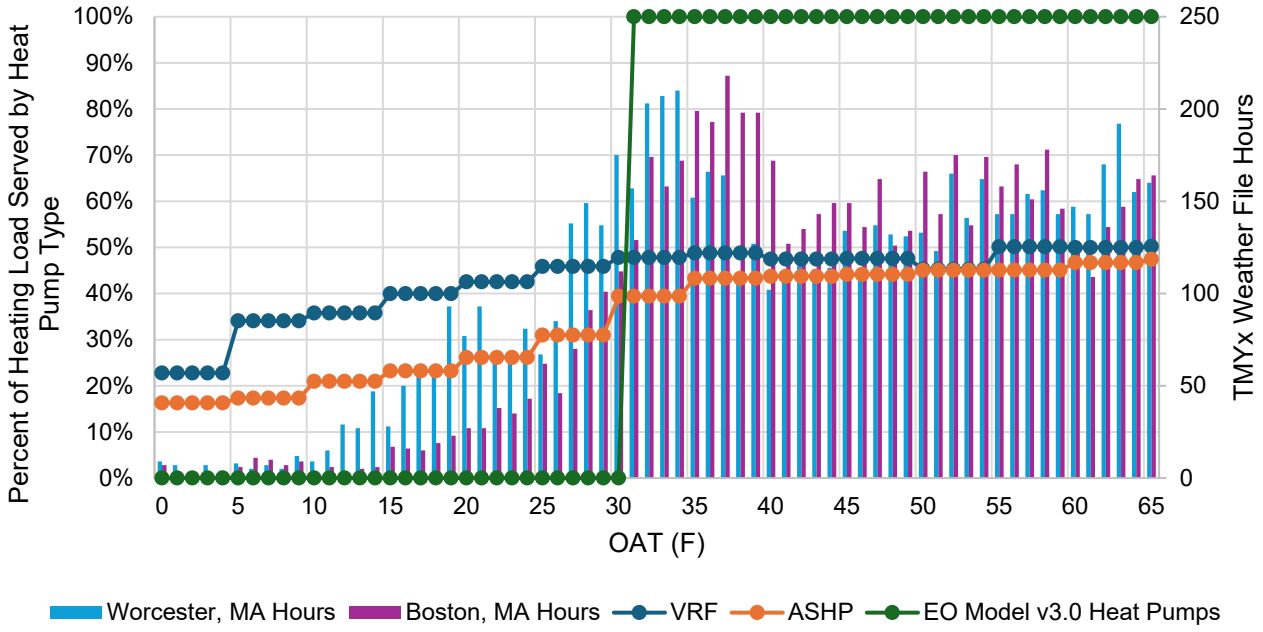
Table 2-28. Partial displacement change in share of heating load met by heat pump and backup/existing baseline systems by outside air temperature (OAT) across EO Model versions

	EO Model v2.0-3.0		EO Model v3.1 VRF systems		EO Model v3.1 ASHP systems	
OAT (˚F)	Heat pump heating load share	Backup/existing baseline system heating load	Heat pump heating load share	Backup/existing baseline system heating load	Heat pump heating load share	Backup/existing baseline system heating load
0	0%	100%	23%	77%	16%	84%
5	0%	100%	34%	66%	17%	83%
10	0%	100%	36%	64%	21%	79%
15	0%	100%	40%	60%	23%	77%
20	0%	100%	43%	57%	26%	74%
25	0%	100%	46%	54%	31%	69%

[55] The study team estimated the percent heating load served by the rebated heat pump and the backup or supplemental system for each individual site by comparing the normalized heat pump operational data against normalized supplemental or backup system use for each temperature bin and supported the estimates using qualitative data collected from the site visit. Using the heating load shared between the systems, the engineer summarized the heating load sharing strategy and estimated the switchover (and/or lockout) temperatures or ranges for each site.
[56] The study team and EO Model subcommittee discussed whether all partial displacement configurations–including systems where the heat pump only provides cooling–should be included in the final, weighted integrated switchover scheme. As these are real equipment installed through the program—which were metered as part of a statistically-selected representative sample of project sites—the study team and Subcommittee agreed that the share of heating load results should consider all partial displacement configurations found among the sampled sites.
[57] The ASHP integrated switchover results include split and packaged ASHPs, in alignment with the simulated system configuration and the prescriptive ASHP measure definition (the PAs currently combine all ASHP and MSHP systems into a single prescriptive ASHP measure). Also in alignment with the ASHP measure definition, the study team assumes the same integrated switchover scheme for partial displacement MSHP systems as ASHP systems.
[58] Like the approach for developing target curves, estimated partial displacement proportions exclude sites where there is greater than 35 tons of installed program heat pump capacity unless the individual installed systems are made up of units that are less than 20 tons.

OAT (˚F)	EO Model v2.0-3.0		EO Model v3.1 VRF systems		EO Model v3.1 ASHP systems	
	Heat pump heating load share	Backup/existing baseline system heating load	Heat pump heating load share	Backup/existing baseline system heating load	Heat pump heating load share	Backup/existing baseline system heating load
30	0%	100%	48%	52%	39%	61%
35	100%	0%	49%	51%	43%	57%
40	100%	0%	47%	53%	44%	56%
45	100%	0%	48%	52%	44%	56%
50	100%	0%	45%	55%	45%	55%
55	100%	0%	50%	50%	45%	55%
60	100%	0%	50%	50%	47%	53%
65	100%	0%	50%	50%	47%	53%

Figure 2-6. Partial displacement share of heating load met by VRF and ASHP and TMYx Weather File Hours by outside air temperature (OAT)



This change in partial displacement switchover approach is a key driver of partial displacement impact changes. Although metered data indicated that heat pumps provide at least a small portion of the heating load well below freezing temperatures, overall heating consumption from both heat pump types even at higher temps where they provide their best performance has decreased significantly from previous assumptions, and therefore the share of heating load served by backup or existing systems increased.

2.4.2.2 Ventilation heating

A key adjustable parameter in the EO Model is the proportion of full displacement VRF and MSHP systems that have supplemental heating provided by the ventilation system (referred to below as "*ventilation heating*") versus no supplemental heating provided by the ventilation system (referred to below as "*no ventilation heating*").[59] In the *no ventilation heating* case,

[59] For ASHP systems other than MSHPs, the team simulated packaged rooftop units (consistent with EO Model v2.0 methods based on a review of program data), which inherently include ventilation and conditioning in an all-in-one packaged unit, so are assumed to have ventilation heating 100% of the time. For PTHPs, we did not collect on-

the ventilation system does not heat the outdoor air it delivers, but that air still enters the building, so the associated heating load remains in the model and is met by the heat pumps.

For the building simulations, the study team simulated Dedicated Outside Air Systems (DOAS) in all VRF and MSHP simulations. The team confirmed that DOAS units are the most common ventilation system type for full displacement VRF systems in the on-site and metered data.[60] Full displacement MSHP systems from the field data, however, were typically residential-style systems where ventilation is not being served by a separate system. However, to ensure code-minimum ventilation requirements are met in our building simulations, we've maintained the same approach as previous EO Model iterations where we simulate MSHP systems with DOAS units. Code-minimum ventilation is applied in both the baseline and program-case simulations, so estimated savings reflect the same ventilation requirement on both sides of the comparison, even though some baseline systems observed in the field did not meet code minimums.

DOAS and other types of ventilation equipment can have onboard heating elements to temper the outside air before supplying it to the conditioned space or reheat air that has been dehumidified. For all-electric (full displacement) systems, this means inefficient electric resistance heating could be providing a share of the heating load to the space. This configuration is used to meet optimal comfort levels but can also have a significant electrical energy usage penalty.

In the EO Model v2.1 update, the study team used a contractor survey to assess the proportion of *ventilation heating* versus *no ventilation heating* VRF systems. MSHP systems were not investigated, so the v2.1 model assumed all MSHP systems were *ventilation heating*. This was also the basis for the ventilation heating assumptions in the v3.0 model update for MSHP systems.

For the current update, the team used on-site verification data to characterize each site by ventilation type and assessed the proportion of installed capacity that is within each ventilation type. Table 2-29 shows how these proportions have changed from the prior model. Three of the 14 full displacement VRF sites were also metered, allowing the team to confirm the characterization of those sites. For VRF systems, the proportion of systems that do not have ventilation heating increased slightly. For MSHP systems, none of these systems in the field had heating load served by ventilation equipment because there weren't separate ventilation systems serving the space whatsoever. In the MSHP simulations, a DOAS unit was added to meet code-minimum ventilation, although the DOAS did not heat the outdoor air it delivered, so the MSHPs themselves served that additional heating load. Overall, this updated configuration reduced the electric penalties for VRF and MSHP systems and increased their savings against electric baseline systems.

Table 2-29. Ventilation characterization for full displacement VRF and MSHP systems

	EO Model v3.0		EO Model v3.1		
Heat pump type	Ventilation heating	No ventilation heating	Verification data sites (n)	Ventilation heating	No ventilation heating
VRF	58%	42%	14	46%	54%
MSHP	100%	0%	23	0%	100%

site data on this system type, so the team continued to use the same conservative assumption as in previous EO Model versions—i.e., that PTHP always have separate ventilation heating.

[60] Partial displacement VRF systems observed on-site contained a mix of ventilation designs including DOAS, AHU, and no ventilation (which, for these systems, may not meet code minimum requirements). As full displacement VRF systems are directly simulated and partial displacement VRF systems are proxy-simulated, the team relies more heavily on full displacement system designs for defining building simulations.

3 ANALYSIS AND RESULTS

This section presents the results of the EO Model v3.1 update, as well as explanations for the underlying drivers of changes, detailed results from on-site data collection and analysis activities, and findings related to program tracking data and key program changes.

The program impact results include electric and fuel impacts for each combination of the following three heat pump installation characteristics:

- **Program HVAC equipment type**, including Variable Refrigerant Flow (VRF), Air Source Heat Pumps (ASHP), Packaged Terminal Heat Pumps (PTHP), and Water Source Heat Pumps (WSHP).
- **Displacement type**, both full and partial displacement.
- **Displaced fuel type**, including electric, gas, heating oil, and propane.

Pooling and adjusting partial displacement impacts

During the survey and on-site data collection tasks, the team encountered a significant number of heat pumps with a heating displacement type (full vs. partial) that was different from the displacement type in the tracking data, as detailed below in Sections 3.3.1 and 3.4.1. These classification discrepancies, combined with small sample sizes and substantial variation within displacement categories, limited the precision of displacement-specific estimates and called into question the original approach of deriving partial displacement impacts from full displacement sites. In particular, the approach assumed that full displacement sites provided a reasonable basis for estimating full-season heating use before applying switchover assumptions to represent partial displacement operation. However, some full displacement sites served spaces with low heating needs or irregular occupancy, conditions that may also occur in the partial displacement population. In particular, developing partial displacement impacts by applying switchover logic to the modelled impacts from full displacement sites (as shown in Figure 3-1 below) can result in excessively low partial displacement impacts to the extent that full displacement impacts are already influenced by sites with very low usage. [61]

The team's concern is not low usage itself, but whether the additional switchover reductions appropriately represent partial displacement operation when the full displacement impacts already reflect limited heating use. Together, the limited precision of the separate estimates and the uncertainty surrounding this modeling assumption supported developing pooled impacts for full and partial displacement sites together and adjusting the method for calculating partial displacement impacts. The team and Subcommittee determined that developing pooled results is appropriate for the following reasons.

- There is a high degree of diversity in heat pump use and uncertainty and variability in energy impacts for both full and partial displacement projects. In addition, direct site metering results found that impacts for full and partial displacement projects were not statistically different from each other in most cases. Pooling allows the team to report an overall population impact without relying on precise separation of impacts between full and partial displacement projects.[62]
- Implementers have not consistently and reliably classified or tracked project displacement type.
- The program does not distinguish program incentives by displacement type—all projects receive the same $/ton incentives, regardless of displacement type.

[61] For instance, for several sites in our sample, heat pumps are the only source of heating—meeting the definition of full displacement—for low-use spaces with irregular occupancy and heating needs such as event halls. This is in part a result of our targeting of partial displacement projects for metered on-sites. Specifically, our on-site recruitment approach prioritized partial displacement sites for metering due to the high targets for those strata, but in cases when our field staff determined that those sites were full displacement because there was no other source of heating for the area served, we re-classified them as full displacement and counted them toward our full displacement strata targets for metering.

[62] The reported precisions/confidence intervals describe sampling uncertainty for the applicable site-level estimates, not total uncertainty in the final adjusted impacts. The team did not calculate precisions for the final impacts because the team did not quantify the uncertainty from the building simulations and subsequent adjustment steps. The adjusted approach addresses the mismatch between the original modeling assumption and observed heating-use patterns, while pooling reduces reliance on separately reported displacement-specific impacts. Neither step should be interpreted as demonstrating a particular improvement in final precision or the complete elimination of potential bias.

However, by the time the team fully understood the effect of these misclassifications on the final impact results and determined that pooling results would provide more representative impacts, there was not sufficient time to pool full and partial displacement site analysis results upstream of the building simulations and then re-run and re-calibrate the simulations and update the EO Model. Instead, to produce pooled results in time for 2027 prospective application, the team applied the adjustment approach illustrated in Figure 3-2 below, by directly using on-site metering results. This approach used observed differences in heating consumption between confirmed displacement types in place of the original switchover adjustment. Specifically, the team used the ratio of the metered annualized heating kWh/ton for confirmed full displacement vs. confirmed partial displacement projects to develop an adjustment factor. The team applied this factor to the modeled impacts for full displacement systems to calculate partial displacement impacts. The team then pooled these full and partial displacement impacts into overall impacts via a capacity-weighted average reflecting confirmed full displacement vs. confirmed partial displacement projects. *This reflects an interim approach that allows for results in time for prospective 2027 application, but which is expected to be revisited using a more rigorous and time-consuming method for 2028 prospective application (see future evaluation guidance in Section 4.4).*

Figure 3-1. Data analysis approach flowchart by displacement type, original method

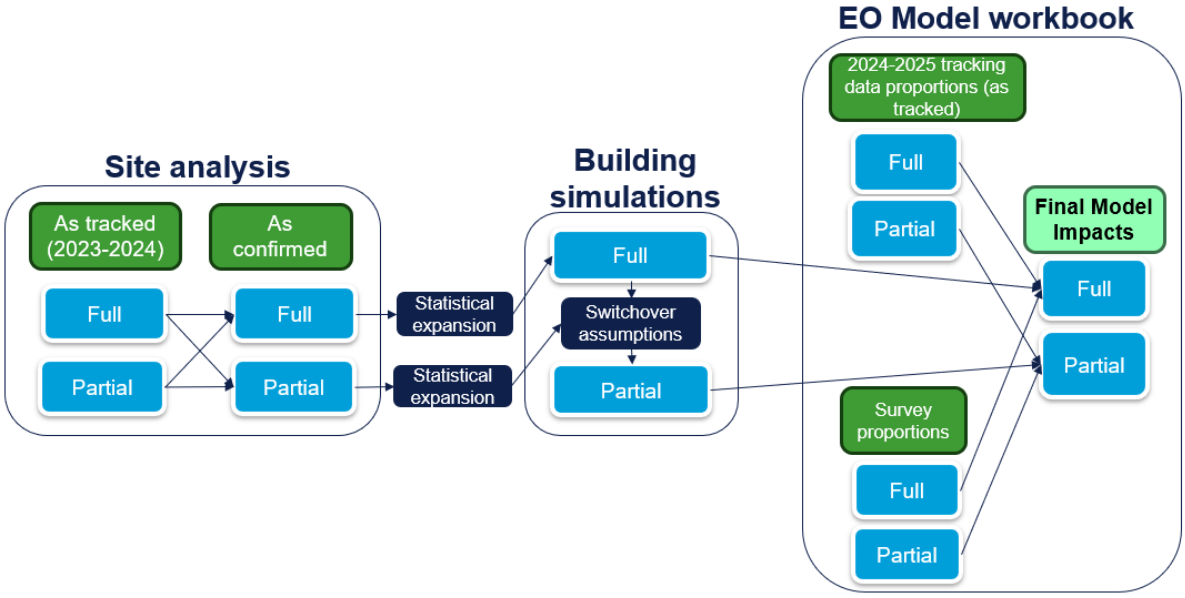
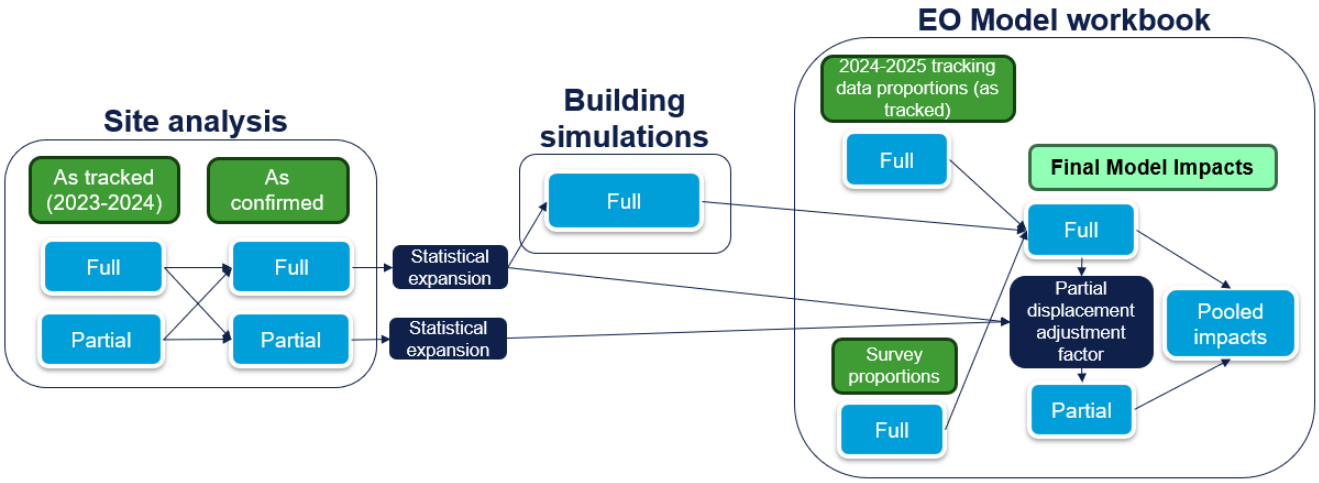


Figure 3-2. Data analysis approach flowchart by displacement type, adjusted method with pooling



3.1 Program impacts

Table 3-1 summarizes the modeled prescriptive per-ton impact for each downstream prescriptive measure. The impacts are weighted to reflect the relevant prevalence of each prescriptive measure's baseline equipment types (pre-existing and counterfactual), building types, and event types (early replacement and replace on failure), based on participant and contractor survey responses and on-site verification data. The downstream summary table includes both total electric impact (kWh/ton) and fuel impact (MMBtu/ton). The electric "savings" in the downstream program are negative—reflecting increased consumption—for all measures displacing fossil fuels, which is a function of the fuel-switching associated with the transition to a heat pump (i.e., electric heating load is being added where there previously was none). This additional electric load is offset by the elimination or lesser use of fossil fuels.[63]

Table 3-1 includes separate full displacement and partial displacement results as well as pooled results, which provide a more accurate representation of the population on average, as detailed in the *Pooling and adjusting partial displacement impacts* section.

Table 3-1. Annual downstream program prescriptive impacts

Measure	Displace-ment	Displaced fuel							
		Electric		Natural gas		Oil		Propane	
		kWh/ ton	MMBtu/ ton	kWh/ton	MMBtu/ton	kWh/ton	MMBtu/ton	kWh/ton	MMBtu/ton
VRF	Full	1,940	0.08	-449	8.5	-375	8.2	-474	8.2
VRF	Partial	1,786	0.08	-413	7.8	-345	7.6	-437	7.6
VRF	**Pooled**	**1,862**	**0.08**	**-431**	**8.2**	**-360**	**7.9**	**-455**	**7.9**
ASHP	Full	2,825	0.12	-366	10.2	-628	11.8	-375	12.9
ASHP	Partial	2,601	0.11	-337	9.4	-579	10.9	-345	11.9
ASHP	**Pooled**	**2,710**	**0.11**	**-352**	**9.8**	**-603**	**11.4**	**-360**	**12.4**

Note: positive values in this table represent savings; negative values represent increased usage.

3.1.1 Midstream program

Table 3-2 provides the weighted average prescriptive impacts for midstream PTHPs. As with the downstream impacts shown above, midstream PTHP impacts are weighted to reflect the relative proportions of baseline equipment types and building types and climate zone observed in the program tracking data and surveys. The midstream summary table only shows positive electric impacts (kWh/ton and kWh/unit) because that program's assumed baseline—a standard efficiency heat pump—is always electric.[64] In addition, because the midstream baseline is a standard efficiency heat pump, all midstream projects are considered full displacement for modeling purposes.

Table 3-2. Annual midstream PTHP prescriptive impacts

Program equipment type	Electric savings
	kWh/ton
PTHP*	928

*The 2025-2027 TRM states: "For PTHPs, savings are calculated as a 50/50 average between a baseline package terminal air conditioner (PTAC) with electric resistance heat and a standard efficiency PTHP." This baseline method was applied in v2.1 and prior. Starting with v3.0, PTHP savings were modeled using pre-program and counterfactual baseline electric resistance systems from participant and contractor surveys. For the v3.1 update, the team weighted the responses from the v2.1 contractor survey and v3.1 participant survey to develop baseline system proportions. The midstream data for the v3.1 update did not include email addresses for contractors, and there were relatively few PTHP participant respondents (n=22), so the team supplemented these with responses

[63] As with the v3.0 update, the downstream program impacts in the v3.1 EO Model incorporate the electric impacts that were previously captured in the midstream program in the v2.1 and prior EO Model updates, which aligns with the PAs' changing savings approach. See DNV. (November 13, 2025.) *Energy Optimization Model Version 3.0 Short-Term Update*. Prepared for the Massachusetts Program Administrators. https://ma-eeac.org/wp-content/uploads/MA25C04-B-EOModel-Short-term-Update-Final-Report-20251113-clean.pdf, section 1.2 (program overview).

[64] Despite this assumed baseline, there may be some amount of fuel-switching in reality, but this study did not attempt to quantify this for Midstream offerings given the program design and baseline definitions, as well as the prioritization of study resources for ASHPs and VRFs. Future EO Model updates could more fully examine PTHP baselines to determine the extent to which fuel-switching may occur.

from the v2.1 contractor survey.
Note: The Midstream channel also began offering WSHPs during the period covered by the v3.0 Model update, but neither the v3.0 update nor the v3.1 update developed updated WSHP impacts because the resources needed to do so was not merited given their small share of program savings. Specifically, WSHPs accounted for 0.5% of program savings during the 2023–2024 period sampled, and there are no existing building simulations for WSHPs from prior EO Model updates, so updating WSHP impacts would require significant investment to develop new building simulations. Instead, the v3.0 update applied GSHP impacts as a proxy for WSHP impacts, given their technological similarities.

3.1.2 Peak demand impacts

The study team developed maximum demand (kW/ton) impact values for prospective application to the TRM by leveraging prior load shape research from Massachusetts.[65] Specifically, the team applied the load factors from the 2024 load shape research to develop maximum demand impacts for each system and displaced fuel, using the pooled displacement impacts detailed above. Table 3-3 provides the electric impacts and max kW per ton results from this analysis. We used the following assumptions and simplifications for the current update:

- Load factors reflect heating and cooling impacts.
- Applied load factors for systems displacing natural gas to systems displacing oil and propane.

Table 3-3. Program-weighted average electric impacts and max kW impacts per ton

Measure	Displacement	Displaced fuel	Electric impacts (kWh/ton)	Load factor	Max kW per ton	Load shape measure category*
ASHP	Pooled	Electric	2,710	0.0011	2.98	Heat pumps: Heating and Cooling (ER + AC) with cooling, Electric baseline
ASHP	Pooled	Natural Gas	-352	0.0026	-0.91	Heat pumps: Heating and Cooling (HP) with cooling, Natural Gas baseline
ASHP	Pooled	Propane	-360	0.0026	-0.94	Heat pumps: Heating and Cooling (HP) with cooling, Natural Gas baseline
ASHP	Pooled	Oil	-603	0.0026	-1.57	Heat pumps: Heating and Cooling (HP) with cooling, Natural Gas baseline
VRF	Pooled	Electric	1,862	0.0011	2.05	Heat pumps: Heating and Cooling (ER + AC) with cooling, Electric baseline
VRF	Pooled	Natural Gas	-431	0.0026	-1.12	Heat pumps: Heating and Cooling (HP) with cooling, Natural Gas baseline
VRF	Pooled	Propane	-455	0.0026	-1.18	Heat pumps: Heating and Cooling (HP) with cooling, Natural Gas baseline
VRF	Pooled	Oil	-360	0.0026	-0.94	Heat pumps: Heating and Cooling (HP) with cooling, Natural Gas baseline
PTHP	Full	Electric	928	0.0011	1.02	Heat pumps: Heating and Cooling (ER + AC) with cooling, Electric baseline

* Load shape measure categories from *MA Impact Shape Final Brief* report, Feb. 9, 2024 (https://ma-eeac.org/wp-content/uploads/LOADSHP-Brief-2.9.2024.pdf. The Massachusetts load shapes for commercial heat pumps were developed by leveraging the 8,760 baseline and efficient savings profiles from the v2.0 EO Model update.

The team initially planned to use site-specific hourly kW data from metered heat pumps to derive peak demand impacts. However, we determined that applying load shapes to annual energy impacts derived from calibrated building simulation models provided a more robust and defensible estimate of peak demand impacts than the use of hourly M&V data from the sampled sites, because: (1) there was a high level of variability in metering results particularly among partial displacement sites (see Section 3.5), and (2) building simulations leverage a larger set of data since they incorporate both metered data from sampled sites and billing data from the full participant population.

[65] See DNV. *MA Impact Shape Final Brief* report, Feb. 9, 2024 (https://ma-eeac.org/wp-content/uploads/LOADSHP-Brief-2.9.2024.pdf)

3.2 Changes in annual program impacts

The section below provides comparisons and further details on the factors contributing to changes in the program impacts between v3.0 and v3.1 of the model, and Section 3.2.1 provides details on the underlying drivers of these changes. At the highest level, *the v3.1 results show a significant decrease in impacts relative to the v3.0 results, reflecting the general finding that the heat pumps the team observed and metered in the field were used much less than assumed in the prior versions of the EO Model.* The impact results for the v3.1 Model show the following changes from the prior model:

- **VRF impacts generally decreased by a larger amount than ASHP impacts.** This includes decreases in fossil fuel savings and electric efficiency savings.
- **For systems displacing fossil fuels, fuel savings decreased for nearly all measures, but corresponding electric penalties decreased by a larger amount**. There was a particularly large difference between the reduction in fossil and electric impacts for ASHPs, which saw reductions in fossil fuel savings of as much as 30%, but reductions in electric impacts (penalties) of as much as 80%.
- **For systems displacing electric resistance, electric savings for ASHPs increased by 16% for partial displacement and 56% for full displacement systems, while electric savings decreased for other measures.** There were decreases of around 30% for full displacement VRFs and PTHPs, and 11% for partial displacement VRFs.

Table 3-4 shows the comparison between the v3.0 and v3.1 electric impacts (including midstream PTHPs), by measure, displacement, and type of fuel displaced. The changes are shaded based on how large they were, and decreases in savings are shaded red as they are adverse to program savings objectives, while decreases in electric penalties are shaded orange as they can be favorable for program net MMBtu savings when fossil fuel savings decrease by less than electric penalties.

Table 3-4. Annual impact comparison between EO Model versions, by heat pump type and displaced fuel

Measure	Displace-ment	Displaced Fuel						
		Electric	Natural Gas		Oil		Propane	
		kWh/ton	kWh/ton	MMBtu/ton	kWh/ton	MMBtu/ton	kWh/ton	MMBtu/ton
EO Model version 3.1 annual impacts†								
VRF	Full	1,940	-449	8.5	-375	8.2	-474	8.2
VRF	Partial	1,786	-413	7.8	-345	7.6	-437	7.6
ASHP	Full	2,825	-366	10.2	-628	11.8	-375	12.9
ASHP	Partial	2,601	-337	9.4	-579	10.9	-345	11.9
PTHP*	Full	928	N/A	N/A	N/A	N/A	N/A	N/A
EO Model version 3.0 annual impacts†								
VRF	Full	2,755	-1,259	14.3	-1,342	14.9	-1,342	14.9
VRF	Partial	2,006	-722	9.0	-826	9.8	-826	9.8
ASHP	Full	2,440	-1,530	14.1	-1,922	16.9	-1,829	16.6
ASHP	Partial	1,668	-893	9.3	-1,143	11.2	-1,053	10.9
PTHP*	Full	1,341	N/A	N/A	N/A	N/A	N/A	N/A
Percent change in annual impacts from v3.0 to v3.1								
VRF	Full	-30%	-64%	-40%	-72%	-45%	-65%	-45%
VRF	Partial	-11%	-43%	-13%	-58%	-23%	-47%	-23%
ASHP	Full	16%	-76%	-28%	-67%	-30%	-80%	-22%
ASHP	Partial	56%	-62%	1%	-49%	-3%	-67%	9%
PTHP*	Full	-31%	N/A	N/A	N/A	N/A	N/A	N/A

Note: **Red** shading = changes are adverse to program savings objectives; **orange** shading = changes are generally favorable for program net MMBtu savings, but are driven by operational factors (e.g., low usage) that are contrary to program objectives; **green** shading = changes are favorable to program objectives.
*Midstream program only.
†Positive values represent savings; negative values represent increased usage.

3.2.1 Drivers of changes

Many inputs and assumptions changed between v3.0 and v3.1 of the model, and it would require a large analytical effort, beyond the scope of the current study, to precisely quantify the extent to which each one contributed to the changes in impact results. However, **several key changes were the largest drivers of the resulting impact differences.**

- **Incorporation of real-world metering and verification data.** The v3.1 EO Model is the first update to reflect on-site metering and verification data. In particular, the on-site data was a critical input for updates on (1) the overall heating usage of the programmatic heat pump(s), (2) the percent of heating load met by and backup or existing baseline systems for partial displacement projects, and (3) the prevalence of different ventilation heating configurations. (Section 3.3 provides additional detail on the findings from the on-site data collection and analysis tasks.) These key updates drove changes to impacts as follows.
  - **Partial displacement switchover assumptions**. The updated switchover technique significantly reduced VRF and ASHP partial displacement measure impacts (and penalties). This is because the heat pump systems provide far less heating load when OAT is above 30 °F relative to the prior EO Model update assumption that partial displacement systems covered the full heating load above 30 °F. The temperatures at which the metered results show an increase in heating load served by the heat pumps relative to the prior EO Model versions (i.e., temperatures below 30 °F) represent a minority of annual heating hours, and the temperatures at which the metered results show a decrease in heating load served by the heat pumps (i.e., temperatures above 30 °F) represent most of the annual heating hours in Massachusetts. As such, this change in heating load results in a *significant decrease in overall impacts for partial displacement sites.* (See Section 2.4.2.1 and Section 3.3 for more detail.)
    - *However, as detailed in the Pooling and adjusting partial displacement impacts section, the team ultimately applied an alternative method for determining partial displacement impacts, by using observed differences in heating consumption between confirmed full and partial displacement types in place of the original switchover adjustment. As such, the switchover methodology was not the basis for the final recommended impact values.*
  - **Changes to ventilation heating assumptions**. Using on-site verification data, the team characterized each site by ventilation type and assessed the proportion of installed capacity with each ventilation type. For VRF systems, the proportion of systems that do not have ventilation heating increased slightly from the prior EO model, and for MSHPs, the v3.1 update removed ventilation heating all together based on on-site data. [66] These changes *reduced electric penalties for systems displacing fossil fuel and increased electric savings for systems displacing electric resistance*. This is especially true for the ASHP measure because MSHP systems, which are part of the ASHP measure, changed from having 100% ventilation heating in the v3.0 model to 100% no ventilation heating in v3.1. (See Section 2.4.2.2 for more detail.)
- **Updates to building simulations**. As a large array of changes were made to the building simulations to reflect the collection and analysis of on-site and survey data, it is not possible to quantify the exact effect to program impacts from any singular change. Moreover, some changes may have differing directional effects to impacts across measures. However, several key updates to building simulation assumptions drove changes in impact results:

[66] Ventilation heating design has not changed for baseline systems since the v3.0 update.

- Early replacement fossil fuel baselines. The study team also reviewed the 2024 Massachusetts Existing Buildings Baseline Study[67] and the 2026 Baseline Repository[68] to assess whether updates needed to be for simulated early replacement and replace on failure baseline heating efficiency.[69] This more recent research found much higher existing system heating efficiencies compared to the efficiencies from earlier baseline research that were used in prior EO Model updates.[70] This increase in early replacement heating efficiency up to the end of remaining EUL results in *reduced fossil fuel savings for early-replacement systems*. (See section 2.3.9 for more detail.)
- System sizing practices. Contractor survey respondents reported rarely oversizing program heat pumps—a result that was confirmed in on-site verification data. To align with these results, the team auto-sized HVAC systems (baseline and program) as before to meet space conditioning requirements but removed the oversizing factors. This effectively "right-sizes" systems to meet load requirements while reducing how often systems short-cycle.[71] Reduced short-cycling results in *lower electric penalties for systems displacing fossil fuels, and greater electric saving for systems displacing inefficient electric resistance baseline systems*. (See Section 2.3.8 for more detail.)
- Fan efficiency and pressure drop. In the prior (v3.0) model, fan efficiency and HVAC system pressure drop was assumed to be the same in both baseline and program conditions. In the v3.1 update, baseline fan performance remained unchanged while program fan efficiency and pressure drop were adjusted during calibration to align with the metered fan consumption target, resulting in greater fan savings due to higher fan efficiency, lower HVAC system pressure drop in the program case. This change *reduced electric penalties for systems displacing fossil fuel and increased electric savings for systems displacing electric resistance*.
- System capacity assumptions. Updates to system capacities also reduced savings per ton. The calibration process included altering the installed capacity values for the baseline and Program HVAC systems. Savings estimates are normalized by these installed capacities, making these a key model parameter. After calibration, the consumption increased for program and baseline systems, resulting in an increase in required system sizes. Because savings are normalized by installed capacity, the resulting increase in required capacity *lowered overall electric and fossil fuel savings and electric penalties per ton*. (See section 2.3.10 for more detail.)
- Heating setpoint: The participant survey indicated that, on average, there are no notable changes in cooling setpoints or HVAC schedules as a result of installing a heat pump, but participants did indicate that they commonly lower heating setpoints as shown in Table 2-23. The study team implemented this behavioral change into the baseline HVAC simulations, reflecting a modest increase in energy savings from installing programmatic heat pump equipment. (See Section 2.3.9 for more detail.)

- **Changes in survey inputs and tracking data proportions.** The removal of large (>35 ton) projects from the tracking data, along with updates to pre-program fuel and building type weighting factors from 2025 program data, *produced a variety of impacts* depending on project characteristics and measure mix. (See Section 2.4.1.2 for more detail.) In addition, the v3.1 update included the following key change affecting survey proportions.

  - Addition of (1) "no cooling" pre-program and (2) "cooling" and "no cooling" counterfactual baselines. As noted in the EO Model v3.0 short-term update report,[72] the v3.0 model assumed all baseline systems have cooling capability, in

[67] DNV, Massachusetts Commercial and Industrial Existing Buildings Baseline Study, https://ma-eeac.org/wp-content/uploads/MA22C05-B-BSLN-Existing-Buildings-Baseline_FINAL_20240506.pdf.
[68] Energy Efficiency Advisory Council, Massachusetts 2026 Baseline Repository, https://ma-eeac.org/wp-content/uploads/MA-Baseline-Repository-2026.xlsx.
[69] Cooling efficiency information for baseline systems was not available in the 2025 Massachusetts Baseline Study, so the study team maintained the same cooling efficiency for simulated baseline systems as the calibrated baseline models contained in the EO Model v3.0. The study team found very small differences in cooling efficiency between ComStock data for Massachusetts and the calibrated baseline efficiency values.
[70] The EO Model v2.0 early replacement efficiency values are based on the Massachusetts NRNC Market characterization study: https://ma-eeac.org/wp-content/uploads/MA19C08-B-NRNCMKT-NRNC-Market-Characterization-Study-Final-Report.pdf
[71] During quality control activities, the study team confirmed that this change did not result in unmet load hours or comfort metrics that were outside of acceptable limits for most calibrated ASHP and VRF simulations. However, many MSHP, PTHP, (particularly MSHP and PTHP simulations where there is no ventilation backup heating) and some baseline HVAC systems had high unmet load hours when trying to right-size the simulations. We increased system sizing for these simulations as-needed to avoid systems underestimating energy consumption.
[72] DNV. (November 13, 2025.) *Energy Optimization Model Version 3.0 Short-Term Update*. Prepared for the Massachusetts Program Administrators. https://ma-eeac.org/wp-content/uploads/MA25C04-B-EOModel-Short-term-Update-Final-Report-20251113-clean.pdf

alignment with v2.1 and v2.0. The addition of these pre-program and counterfactual baselines together results in *increased electric penalties and reduced electric savings* relative to the prior model baseline cooling assumption. (See section 2.4.1.1 for more detail.)

At several key points in the process of updating the v3.1 EO Model, the team produced outputs from the model reflecting the set of changes that had been made up to that point, to allow for comparison of impacts from specific updates. Specifically, the team modelled impacts separately after (1) updating the EO Model proportions based on the 2025 program data and customer and contractor survey results as well as the removal of large (>35 ton) sites; and (2) updating the EO Model with the results of the updated building simulations, reflecting on-site data including partial displacement switchovers and ventilation heating proportions. Finally, the team applied the adjustment approach for partial displacement project impacts detailed in the *Pooling and adjusting partial displacement impacts* section above. Figure 3-3 and Figure 3-4 show the estimated electric and fossil fuel impacts at each stage of the v3.1 update, compared to the impacts from the v3.0 Model.

- **Updating the survey and tracking data proportions (including removing large projects) resulted in a range of electric and fossil fuel impacts depending on equipment type and displaced fuel**. For instance, ASHP electric impacts improved (higher savings, lower penalties) while VRF and PTHP electric impacts became slightly less favourable (slightly lower savings and greater penalties). On the fossil fuel side, gas savings increased, propane savings decreased, and oil savings remained about the same compared to v3.0 model impacts.
- **Updating the building simulations to reflect on-site data and other modeling assumptions—on top of the proportions update—resulted in significant decreases in impacts across the board, but particularly for partial displacement measures**. These decreases affected both electric and fossil fuel impacts, across all equipment types and displaced fuels.
- **Applying the partial displacement adjustment approach resulted in significant increases in fossil fuel savings, electric savings, and electric penalties for partial displacement projects.** In addition to this adjustment, the final impact columns below reflect several minor updates (e.g., added counterfactual cooling proportions and no-cooling pre-program baselines) that were made after the version of results in the "v3.1 building simulation update" columns below.

Figure 3-3. Electric impact comparison, v3.0 and v3.1 updates

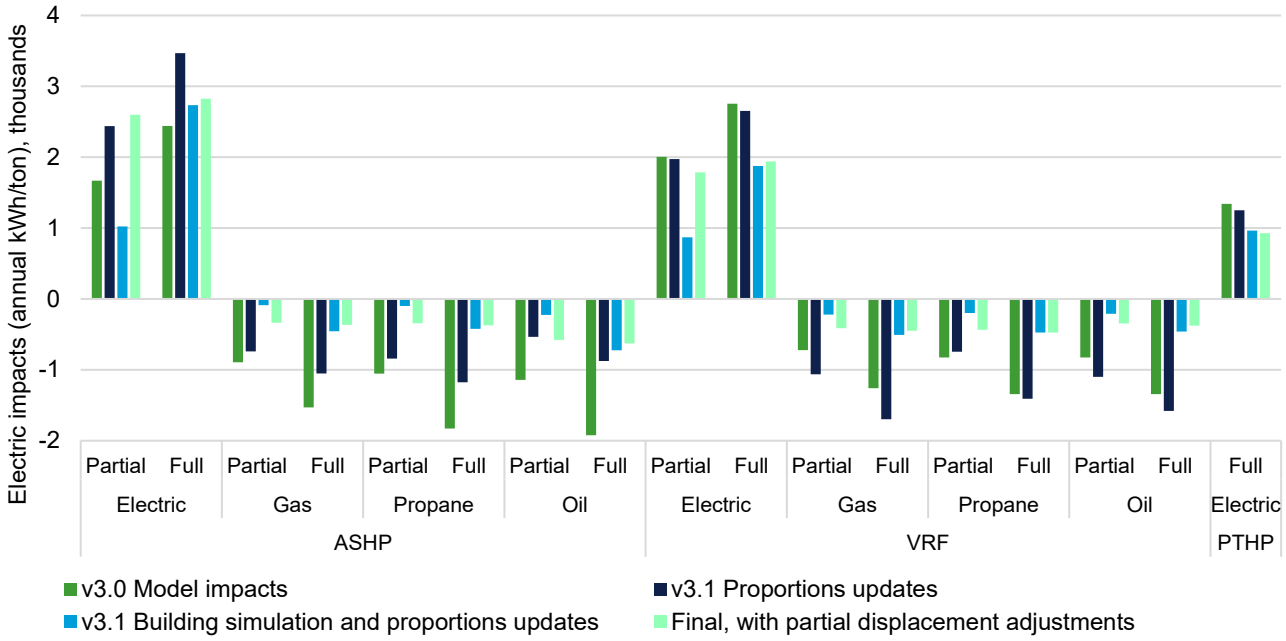
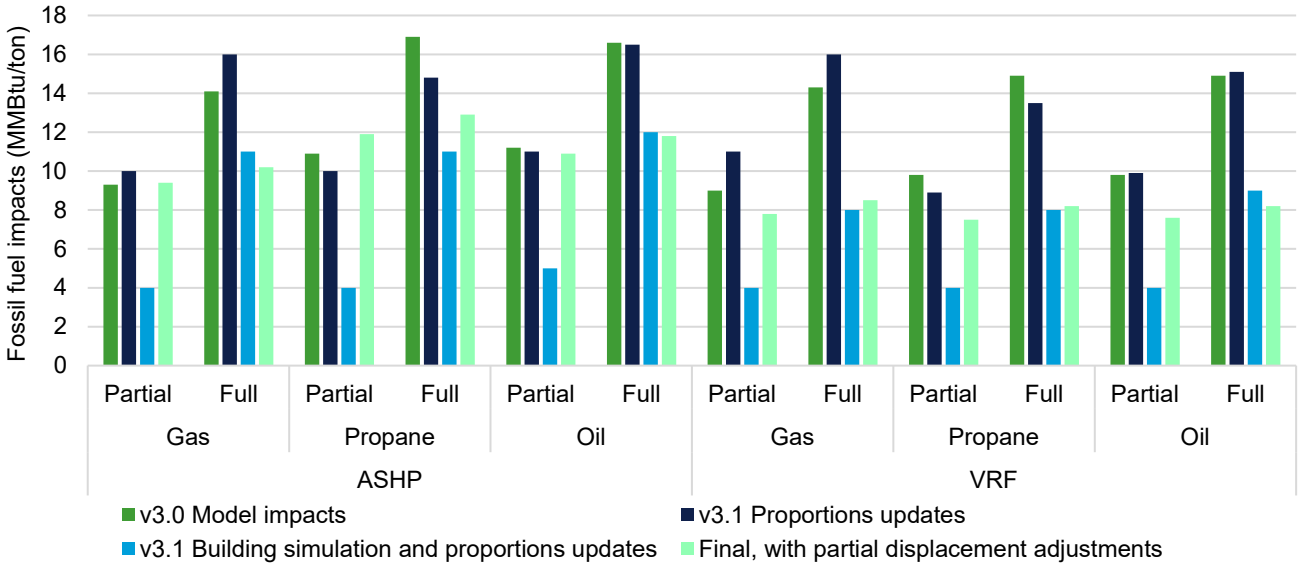


Figure 3-4. Fossil fuel impact comparison, v3.0 and v3.1 updates



3.2.2 Designated Equity Communities and local ordinance impacts

The v3.1 surveys included several question batteries to assess two policy issues raised during EO Subcommittee scoping discussions: Designated Equity Community (DEC) baselines, and local emissions ordinances in Boston and Cambridge.

3.2.2.1 DEC baselines

Contractor survey results support the current EO Model approach of applying distinct dual baselines for customers in DECs.[73] The study team validated this approach by assessing whether DEC customers are more likely than non-DEC customers to repair existing HVAC equipment rather than replace it. Survey responses indicate that this distinction is warranted. Approximately half of the surveyed contractors had installed program equipment in DEC communities, providing a relevant basis for assessing customer behavior in those areas. Among those contractors, a majority reported that when HVAC systems in DECs fail or underperform, DEC customers are generally more likely than non-DEC customers to repair existing equipment rather than replace it. This pattern was reported by 65% of ASHP contractors, 94% of mini-split contractors, and 62% of VRF contractors.

Contractors also indicated that the repair tendency is especially common among certain customer types, including small businesses, municipal customers, and non-profits. Specifically, 74% of ASHP contractors, 81% of mini-split contractors, and 70% of VRF contractors reported that these customer groups are more likely to repair older HVAC equipment instead of replacing it. Small businesses were identified as the customer type most likely to repair old or failing equipment rather than pursue replacement. Together, these findings validate the current EO Model approach by showing that customers in DECs—and particularly small business customers—are more likely to follow a repair path than the industry standard practice baseline assumed for non-DEC customers.

[73] As detailed in the v3.0 short-term update report (see section 2.4.1), the v3.0 model was updated to include weighted average values reflecting the mix of projects in DEC and non-DEC communities, based on the list of DECs aligned with the 2025-2027 MassSaves plan and associated performance metrics. Specifically, the 2025–2027 Strategic Evaluation Plan states: "…select facilities in equity communities have different HVAC system baselines from the industry standard practice, as these customers are more likely to repair existing equipment than replace it. The working group agreed to a stipulated dual baseline assumption, where the first period baseline reflects the existing conditions for 2/3 the EUL of the installed measure. The second period baseline will be the ISP HVAC system." To calculate the savings in DEC communities using stipulated dual baselines, specific early replacement and replace on failure proportions were calculated. The existing early replacement and replace on failure proportions were based on the remaining life and full effective measure life for each equipment type . The team developed an adjusted measure life calculation tor DEC community projects of 2/3 of the measure life of the installed equipment, based on the Plan language, which results in slightly increased savings for those projects in DEC communities. The v3.1 update reflects the updated proportion of 2024-2025 projects in select facilities, by building type, in DECs.

3.2.2.2 Local emissions reduction ordinances

Contractor and participant survey results indicate that local emissions reduction ordinances in Boston and Cambridge[74] have had a limited effect on heat pump installations and do not warrant updates to the EO Model weights at this time. The work plan called for assessing whether these ordinances are materially increasing heat pump adoption in those jurisdictions, since a substantial ordinance-driven shift could justify adjusting model weights to better reflect prospective participation patterns not captured in the retrospective program data. The survey results show that many contractors have direct experience in the affected jurisdictions and are aware of the ordinances. Since 2023, 72% of contractors had installed program equipment in Boston or Cambridge, including 77% of air source heat pump contractors, 69% of mini-split contractors, and 70% of VRF contractors. Among those contractors, ordinance awareness was high: 85% of air source heat pump contractors, 90% of mini-split contractors, and all VRF contractors reported being aware of the requirements.

However, awareness has not translated into a consistent or sufficiently broad change in customer demand. Although 74% of participants in Boston or Cambridge were aware of the ordinances,[75] only 37% of aware participants reported that this knowledge influenced their decision to install a heat pump. Among contractors who had installed program systems in Boston or Cambridge and were aware of the ordinances, 64% of air source heat pump contractors and 55% of mini-split contractors reported observing demand changes that may be related to the ordinances, while no VRF contractors reported such changes. Participant responses similarly suggest a limited effect. Taken together, the findings suggest that the ordinances may be contributing to some heat pump adoption, particularly for air source and mini-split systems, but the evidence does not indicate a strong or consistent enough effect to support adjusting EO Model weights.

3.3 On-site results

As detailed in Section 2.3.2, the study team deployed metering devices at a sub-sample of 47 participant facilities. This section details the measurement and verification results that were used to refine and calibrate the EO Model building simulations.

3.3.1 Heating displacement

The study team explored differences in rebated heat pump operation by heating displacement classification. As defined in this report's glossary, full displacement heat pumps provide 100% of the heating load for the space(s) served. In contrast, partial displacement heat pumps share the heating load within the affected zones with some other non-heat pump or non-program-rebated system.[76] Since displacement classification correlates directly with anticipated heating use, the study team examined differences in M&V results by confirmed heating classification. Section 2.3.2 of this report identified differences between the heating displacement classifications represented in tracking data and heating displacement level confirmed on-site. For example, a project tracked as a full displacement could have been confirmed by field engineers as an actual full displacement or reclassified as an actual partial displacement. Table 3-5 summarizes the site counts of the four possibilities among tracked and actual full and partial displacement classifications.

[74] Boston and Cambridge have ordinances requiring that certain commercial buildings reduce building-related emissions, including through electrification. The team surveyed contractors and participants to assess the impact of these ordinances and provide a basis for potential adjustments to EO Model weights for improved accuracy of prospective results.
[75] 52% said they were specifically aware and 22% said they were generally aware of the ordinances.
[76] "Non-program-rebated" heat pumps are those for which no records were found in the 2023-2025 Commercial Prescriptive heat pump tracking data. It is possible these systems received rebates in 2022, or through another program aside from the Commercial Prescriptive program.

Table 3-5. Metered site counts by tracked and confirmed heating displacement category*

Tracked displacement category	Confirmed displacement category	M&V site count
Full	Full	11
Full	Partial	22
Partial	Full	1
Partial	Partial	13
Total		**47**

*The metered site sample plan specifically targeted partial displacement projects (34 of 52 target sites were partials). During phone recruitment and scheduling of on-sites, team staff gathered details on project configurations to attempt to confirm displacement type. Because of the priority for partial displacement sites, projects that were tracked as full but were actually partial displacement were more often selected for metered site visits than projects that were tracked as partial but were actually full displacement. As such, the table represents a skewed set of displacement misclassifications. Table 3-10 in section 3.4.1 provides the tracked and confirmed displacement status for the complete set of 118 on-sites, which provides a more representative picture of the extent of displacement misclassifications.

Table 3-6 compares two M&V results between tracked and confirmed full and partial classifications: 1) total annualized heating kWh per rebated heat pump and 2) total annualized heating kWh per installed heat pump cooling ton. Each of these results are weighted to represent the full population of EO-rebated heat pump projects in 2023-24. The table provides these results weighted based on (1) the tracked classification of the projects, and (2) the confirmed classification of the projects based on site visits. (See Section 2.2 for detail.)

The table shows that full and partial M&V results generally aligned between tracked and confirmed displacement classifications. However, as shown below in Table 3-7, when disaggregated by equipment type, there are large differences in heating consumption between full and partial displacement projects—although these equipment-level results show a high degree of uncertainty, due to small sample sizes and high variability within equipment strata.

Table 3-6. Comparison of heating consumption results between tracked and confirmed displacement levels

	Tracked classification				Confirmed classification			
Displacement level	Count of sites	Annualized heating kWh	Annualized heating kWh per ton	Relative precision (80%)	Count of sites	Annualized heating kWh	Annualized heating kWh per ton	Relative precision (80%)
Full	33	3,854	667	23.0%	12	3,470	693	51.8%
Partial	14	3,155	634	52.7%	35	3,863	638	32.6%

Table 3-6 shows that, for both tracked and confirmed displacement levels, M&V results for full and partial displacement heating kWh per ton are within 5% and 9% of each other, respectively. Total annual heating kWh for tracked full displacements exceed that of tracked partial displacements, whereas the opposite is true for confirmed displacement levels. The next section further explores this counterintuitive finding.

3.3.2 System type

The study team next explored the M&V results by heat pump type across the three system types prioritized in this study: ducted split ASHP, packaged ASHP, and VRF. Tracking data included limited information on ASHP system types; for example, tracking data does not distinguish between ducted and ductless ASHPs or split and packaged ASHPs. Nonetheless the study team used the prior phases of data collection—participant survey and on-site verification—to filter out projects not prioritized for M&V and to confirm that the M&V sites fit into one of the three system type/displacement level combinations prioritized in this study: ASHP Full, ASHP Partial, and VRF Partial.

Table 3-7 presents the M&V results by heat pump system type, distinguished between full and partial displacement levels as confirmed by the study team. Within the primary ASHP category, the study team differentiated between ducted split systems and packaged systems. As above, the results are weighted to represent the full population of projects completed in 2023-24, which was the period used for the on-site (and survey) sample.

Table 3-7. Heating consumption results by confirmed displacement classification

Heat pump system type	Confirmed displacement classification	Count of primary sites	Metered system count	Annualized heating kWh per heat pump	Annualized heating kWh per installed cooling ton	Relative precision (80%)
Ducted split ASHP	Full	6	12	2,560	630	63.8%
	Partial	15	37	1,751	512	41.7%
Packaged ASHP	Full	3	3	9,117	2,137	47.6%
	Partial	8	12	3,131	348	38.8%
Variable refrigerant flow	Full	3	7	6,570	602	50.8%
	Partial	12	33	8,700	1,000	48.3%

Table 3-7's average values comprise a wide variety in heating season usage across the 104 systems metered by field engineers, as illustrated in Figure 3-5, which presents system-level heating kWh results (dark blue bar, primary y-axis) as well as equivalent full-load hours[77] (EFLH) for heating operation (light blue dot, secondary y-axis), by confirmed displacement classification.

[77] EFLHs are calculated as the ratio between output energy (input electric kWh converted to output Btu using rated efficiency) and rated capacity (in Btu/h).

Figure 3-5. System-level heating consumption and heating EFLH results by system type and confirmed displacement level

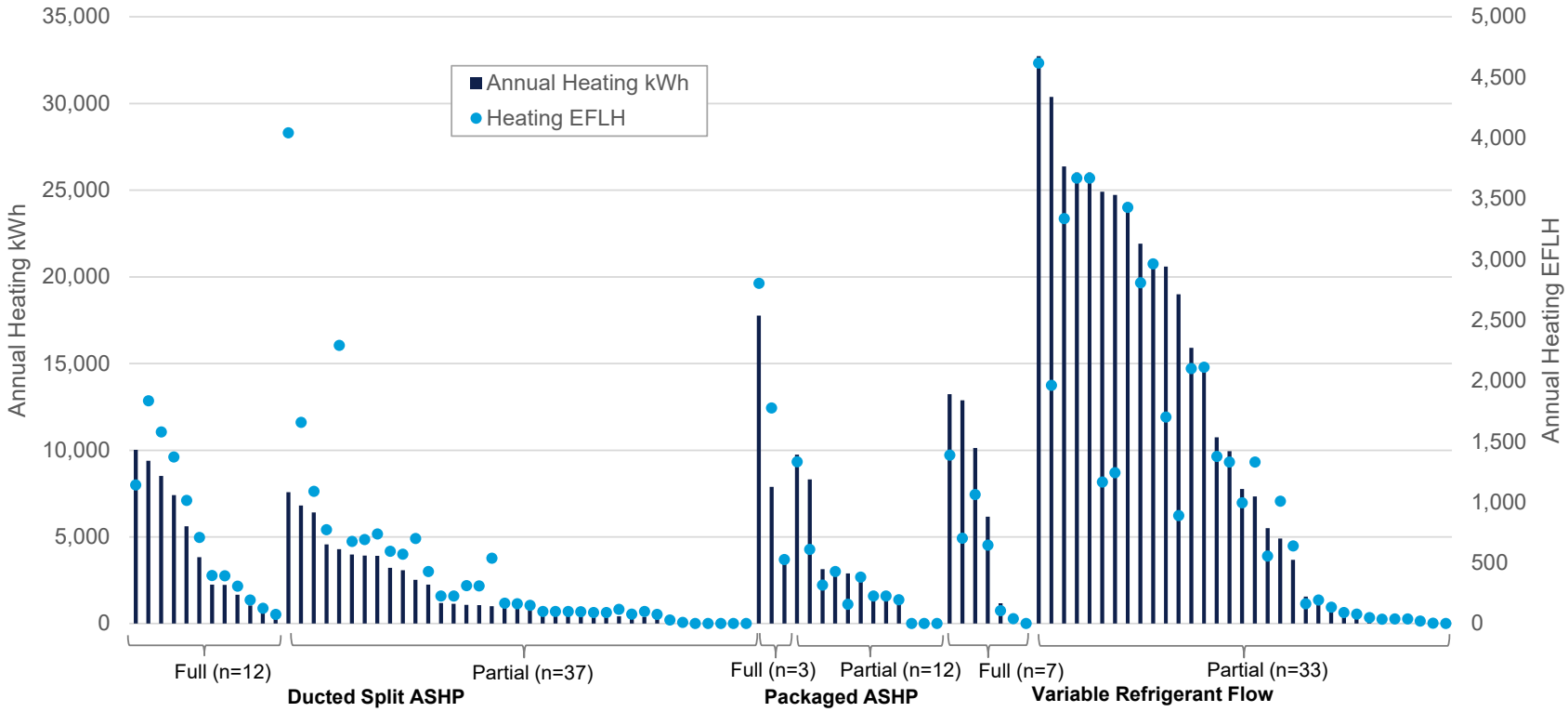


Figure 3-5 illustrates the following key findings by displacement level and system type:

- **VRF systems operate more during the heating season** than ducted split or packaged ASHPs, on average. Counterintuitively, the study team determined that partial displacement VRFs operated more than any other displacement/system combination, including full displacement VRFs. The study team identified several VRF systems for which the conditioned areas included a separate fossil fuel-fired heating source, and therefore are classified as partial displacement, but the fossil fuel systems only minimally operated during the metering period or did not run at all. The counterintuitive results in Table 3-7 for confirmed full vs. partial displacement are primarily due to the prevalence of confirmed partial displacement VRFs in the M&V sample.
- **Partial displacement ducted split ASHPs exhibited the lowest heating season use**, on average, with many of the systems only minimally operating. On-site data collection forms indicate that three such projects (out of 15 partial displacement ducted split ASHP sites in the sample) were characterized by facility staff as being intended for cooling operation only.
- **Several full-displacement systems show relatively low heating use**, despite being confirmed as the lone source of heating within the affected spaces. This occurred most prominently with ducted split ASHPs and VRFs. The corresponding facilities have uniquely low heating loads due to either high internal heat gains (e.g., kitchen, fitness studio, printing press) or intermittent occupancy (e.g., theater).
- **Heating kWh and EFLH generally correlate with each other**, indicating reasonable sizing practices by installation contractors. Systems with significantly higher use than EFLH suggest possible oversizing; however, this occurrence was not very prevalent in the M&V sample. This finding was corroborated by contractor survey respondents who reported rarely oversizing systems.

3.3.3 Load sharing scenarios

To further examine how the rebated heat pumps operated during the winter, the study team developed five load sharing classifications within the full and partial displacement segments to illustrate how the HP interacted with other systems, if any. The five classifications are defined below, and Figure 3-6 illustrates the site-level heating kWh and heating EFLH per heat pump across the five load sharing scenarios.[78]

- **Full displacement: Heat pump + electric resistance (ER) backup** – Heat pumps that rely on backup electric resistance circuits integrated within the heat pump's ductwork to meet the heating load. Since the backup heat is electric, these systems are considered full displacement.
- **Full displacement: Heat pump only** – Heat pumps that require no other backup or supplemental heat to meet the heating load.
- **Partial displacement: onboard gas (dual fuel heat pump)** – Heat pumps that include an integrated gas-fired burner (i.e., a furnace) with which it shares the ductwork.
- **Partial displacement: separate supplemental heating system** – Heat pumps that condition space(s) that include other active heating sources, such as radiators fed by a gas-fired boiler.
- **Partial displacement: air handling unit (AHU) fed with other heating source** – Heat pumps that supply conditioned air through air-handling units that include another heating element, such as a gas-fired burner.

As shown in Figure 3-6, there is wide variation in heating kWh within each displacement type, and a high degree of overlap between full and partial displacement systems generally. This further supports the use of pooled impact values discussed above (see *Pooling and adjusting partial displacement impacts* section).

[78] For sites that included more than one rebated heat pump, the heating kWh and EFLH results reflect average values weighted by heating capacity among the metered heat pumps.

Figure 3-6. Site-level heating consumption and EFLH per heat pump by load sharing scenario

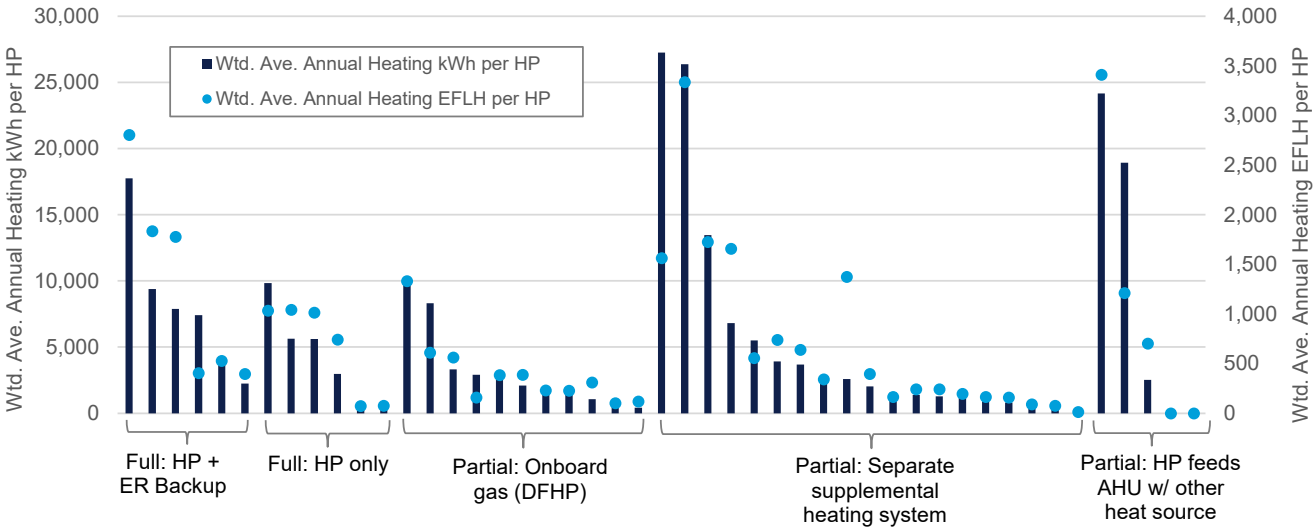


Table 3-8 presents the heating kWh and heating kWh per ton results by load sharing scenario weighted to represent the full population of EO projects completed in 2023-24.

Table 3-8. Site-level heating consumption results by load sharing scenario

Confirmed displacement level	Load sharing scenario	Count of primary sites	Annualized heating kWh per heat pump	Annualized heating kWh per installed cooling ton
Full	Heat pump + electric resistance (ER) backup	6	8,090	1,636
Full	Heat pump only	6	2,663	528
Partial	Onboard gas (dual fuel heat pump)	11	2,271	383
Partial	Separate supplemental heating system	19	3,642	647
Partial	AHU fed with other heating source	5	10,153	1,173

Figure 3-6 and Table 3-8 illustrate the following key findings by load-sharing scenario:

- **Full-displacement heat pumps with ER backup exhibit the highest heating use per ton**, more than tripling that of heat pump-only scenarios. The kWh results include all electric energy consumed by the heat pump during heating mode, not only from the compressor but also from the ER backup. A heat pump's compressor achieves coefficients of performance (COPs) around 3.5, whereas electric resistance corresponds to a COP of 1. This difference in efficiency explains the significantly higher kWh for heat pumps with ER backup—while they exhibit very high heating use, most of it is inefficient compared to their heat pump-only counterparts. Relatedly, the field staff encountered multiple cases in which the backup ER operated outside of the coldest periods, including in shoulder months at mild temperatures. In one example, the field staff determined that ER was constantly running on makeup air units throughout the metering period.
- **Partial displacements with onboard gas backup exhibit the lowest use per ton.** Dual-fuel heat pumps involve complicated digital control systems that sequence the heat pump compressor and integrated gas burner depending on outside air temperature and thermostat readings. The study team encountered several scenarios when the gas backup was unintentionally overriding the heat pump compressor or was activated at milder temperatures than necessary. The field staff provided this feedback to the facility staff, and in some cases those issues were rectified on site.

3.3.4 Partial displacement operation

While the load-sharing scenarios allowed examination of how the presence of other heating sources may have influenced heat pump operation, the actual operation of partial displacement heat pumps varied even within the same load sharing category. The study team therefore classified each of the 35 partial displacement sites sampled for M&V into six operation categories as defined below. Figure 3-7 illustrates the site-level heating kWh and heating EFLH per heat pump across the six partial displacement operation categories.[79]

- **Backup gas used more than anticipated** – This category includes the aforementioned dual-fuel heat pumps for which the gas burner overrode the heat pump compressor more frequently than optimal.
- **Heat pump provided nearly all heating** – Despite other heating sources being connected to the affected space(s), M&V data showed that the heat pump satisfied nearly all of the heating load during the metering period.
- **Heat pump primarily used for cooling** – The facility staff indicated during the on-site interview that the heat pump was installed primarily for cooling reasons, and M&V data showed infrequent heating operation.
- **Heat pump ran only at the coldest temperatures** – Site interview and M&V data indicated that the heat pump was used only to supplement fossil fuel heating to meet the heating load at very cold temperatures.
- **Heat pump ran only at mild temperatures** – Conversely, these heat pumps operated only at mild temperatures before the heating responsibility was transferred to other heating sources at colder temperatures.
- **Simultaneous heating with fossil fuel** – The heat pumps did not exhibit a clear switchover with other heating sources and instead ran in parallel with them.

Figure 3-7. Site-level heating consumption and EFLH per heat pump by partial displacement operation category

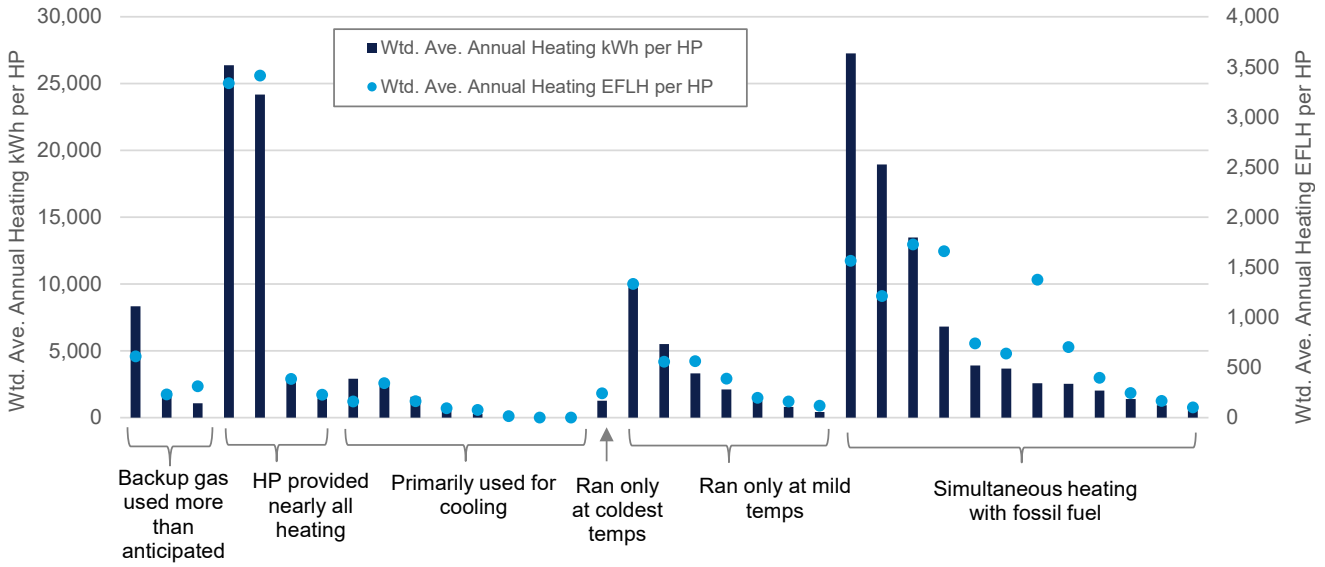


Table 3-9 presents the heating kWh and heating kWh per ton results by partial displacement operation category weighted to represent the full population of EO projects completed in 2023-24.

[79] For sites that included more than one rebated heat pump, the heating kWh and EFLH results reflect average values weighted by heating capacity among the metered heat pumps.

Table 3-9. Site-level heating consumption results by partial displacement operation category

Partial displacement operation category	Count of primary sites	Annualized heating kWh per heat pump	Annualized heating kWh per installed cooling ton
Backup gas used more than anticipated	3	2,304	401
HP provided nearly all heating	4	17,096	2,231
HP primarily used for cooling	8	896	116
HP ran only at the coldest temperatures	1	1,269	293
HP ran only at mild temperatures	7	2,504	410
Simultaneous heating with fossil fuel	12	3,562	675

Figure 3-7 and Table 3-9 illustrate the following key findings by load-sharing scenario:

- **Unsurprisingly, heat pumps primarily used for cooling exhibited the lowest heating operation on average.** The study team classified 8 of the 35 sites sampled for M&V into this category. In one example, the rebated VRF was installed at an automotive repair facility that is also heated by two gas-fired space heaters and a gas-fired dedicated outside air system. M&V data showed that the VRF was only used for heating on a few days in January and March 2026, corroborating the customer's responses to the web survey and on-site questionnaire, which indicated that the VRF was primarily installed for cooling purposes.
- **Conversely, heat pumps that provided nearly all heating exhibited the highest heating operation on average.** While these systems are technically classified as partial displacements, as at least one other active heating source was connected to the affected spaces, the M&V data showed that the heat pump exclusively provided all heating, or close to it. These systems ran more than three times as much as other heat pumps during the heating season.
- **Multiple customers elected to run their heat pumps only at mild temperatures due to utility cost concerns.** In one example, the rebated split ASHP was installed in a 6,000 square-foot office space served by three other (non-rebated) ASHPs and an AHU with a hot water loop. The facility contact mentioned that the rebated ASHP was inefficient and resulted in high energy bills, so they switched to gas heating during the coldest parts of winter (e.g., when temperatures drop below 40°F).
- **Several sites showed evidence of simultaneous heating and cooling**. Of the 47 metered sites, we found three that had periods of simultaneous heating and cooling within the same space. The team used the supply air temperature data to isolate only the heating kWh.

3.3.5 Ventilation

During all 118 site visits (including sites sampled for M&V as well as verification-only sites), the study team characterized the ventilation configuration to inform how ventilation is treated within the EO building simulations (also see Section 2.4.2.2). This assessment allowed the team to qualitatively compare ventilation practices with requirements from applicable code.

Field engineers identified evidence of potentially non-code-compliant ventilation practices at several sampled sites. At least 30% of the 47 metered facilities include no mechanical ventilation. While some of the facilities may have met the requirements for natural ventilation exception per the International Mechanical Code (IMC, see text box to right), the study scope did not include a detailed investigation of these requirements. Nonetheless, qualitative observations are summarized below.

International Mechanical Code (IMC) Section 402 and 403 ventilation requirements: a space may use natural ventilation only if it meets the minimum openable-area and configuration requirements. If it does *not*, then mechanical ventilation is required under IMC 403.

Natural ventilation requirements include several elements, summarized in the bullets below. If these are not met, mechanical ventilation is mandatory.

- Must be through openings to the outdoors
- Minimum openable area: 4% of floor area
- Requirements for interior room ventilation through adjoining rooms
- Requirements for below-grade openings
- Documentation requirements

- One project involved the replacement of several mixed-air rooftop units (RTUs) with a VRF system with several ductless heads. While outside air was previously circulated through the replaced RTUs, no new ventilation was added. The facility contact mentioned a plan to eventually add a mixed-air unit (MAU) to supplement the VRFs with outside air.
- Another project involved the replacement of gas furnaces with ducted split ASHPs that supply conditioned air to an air-handling unit (AHU). The AHU's outside air intake was boarded up at the time of the site visit; as a result, no outside air is circulated through the building.
- Thirteen participating facilities sampled for M&V had no mechanical ventilation before or after heat pump installation. While some may meet the requirements for IMC Section 403 exceptions (see inset), several facilities likely do not meet those requirements. Rebated HPs at three facilities, including a childcare center, serve AHUs with no outside air intake (i.e., full recirculation).

As the project scope did not include detailed assessment of ventilation code compliance, the building simulations described in Section 2.4 reflected full ventilation compliance. Further EO Model research should include more detailed investigation of ventilation practices to not only elevate potential non-compliance with PAs but also ensure that model savings reflect real-world ventilation conditions.

3.4 Program tracking and design

The following sections provide findings related to program tracking data and program design changes that materially affected the v3.1 EO Model update study.

3.4.1 Displacement classifications and tracking

During the process of survey and on-site data collection, the team encountered a significant number of heat pumps with a heating displacement type (full vs. partial) that was different from the displacement status in the tracking data. Currently, the tracked displacement status is determined based on self-attestation on the rebate application form. The program uses the following definitions for full and partial displacement:

- **Full displacement** involves fully removing (or disconnecting) the pre-existing heat source so that the heat pump is fully heating and cooling the space.
  - The 2025 Commercial Prescriptive Heat Pump Rebate application did not explicitly define full displacement, but the 2026 application added the following text: "If fully displacing the existing fossil fuel heating equipment it must either be removed, disconnected from the panel or thermostat, or have the existing fuel line disconnected and capped."

- **Partial displacement** either (1) entails installing an integrated control that switches operation from the heat pump to the pre-existing heat source when the temperature of the building falls below a specified set point, or (2) requires customer certification that a building control system is capable of operating both the heat pump and the existing heating equipment in parallel, subject to a stated switchover temperature. Both the 2025 and 2026 rebate applications state that control systems must prioritize heat pump operation, and that the PAs may require documentation of control sequence.
  - For dual fuel RTUs (which are considered partial displacement), the program allows manufacturer built-in controls to act as the integrated control, eliminating the need for an external control. In 2026, the program rebate application added a specific check-box to indicate installation of a dual-fuel system.

Overall, 47 of the 118 projects in the on-site sample (about 40%) had an incorrect displacement classification in the tracking data. Field staff confirmed the displacement (full or partial) of projects during verification visits, classifying projects as full displacement when the heat pumps were the only source of heating for the area served, and as partial displacement when heat pumps shared the heating load within the affected zones with some other non-heat pump or non-program-rebated system. As described in Section 3.3, the study team encountered a range of partial displacement configurations in the field. Comparing these projects to the tracking data revealed that a large share of them were incorrectly classified as full displacement in the tracking data. At the same time, many projects that were confirmed to be full displacement in the field were classified as partial displacement in the tracking data. Specifically, as shown in the green-shaded cells in Table 3-10:

- 35 of 79 (44%) of projects tracked as full displacement were confirmed as partial displacements in the field
- 12 of 39 (31%) of projects tracked as partial displacement were confirmed as full displacements in the field.

VRFs were the equipment type most likely to be incorrectly classified, with 17 of 32 projects tracked with a different displacement status than was confirmed on-site. It is important to note that the metered electric usage of these projects does not clearly correspond to their displacement status. For instance, many of VRF projects that were tracked as full displacement but were confirmed to be partial displacement on site showed relatively higher use when compared to the VRF projects that were confirmed as full displacement, as detailed in Section 3.3.2.

Table 3-10. Displacement classifications in tracking data and confirmed on-site, count of projects

Displacement in tracking data	Displacement confirmed on-site		Total
	Full	Partial	
Full	**44**	**35**	**79**
ASHP	15	15	30
Mini-split	16	8	24
VRF	13	12	25
Partial	**12**	**27**	**39**
ASHP	0	13	13
Mini-split	7	12	19
VRF	5	2	7
Grand Total	**56**	**62**	**118**

Until and unless the program has been found to reliably and accurately distinguish between full and partial displacement projects in tracking data, the programs cannot accurately apply impact values or claim savings

separately for full and partial displacement projects. Accurate tracking of displacement categories requires PAs to establish guidance and processes for collecting project data, and contractors to collect sufficient information on the projects they install to correctly classify the displacement type—such as site-specific details on the space served by the program-rebated heat pump and any other supplemental heating systems—which can be challenging to collect. It also requires that program implementation vendors and contractors to have a common understanding of the technical definitions of full and partial displacement projects to ensure they consistently apply these definitions.[80]

In addition, one of the largest drivers of reductions in impacts from the v3.0 to the v3.1 EO Model was the partial displacement switchover assumptions and the underlying customer operations of partial displacement projects. Improving the operations and savings impacts of these projects will require implementation changes regarding controls strategies and technologies as well as customer and contractor education and training. Successfully implementing these improvements goes hand in hand with accurately tracking partial displacement projects.

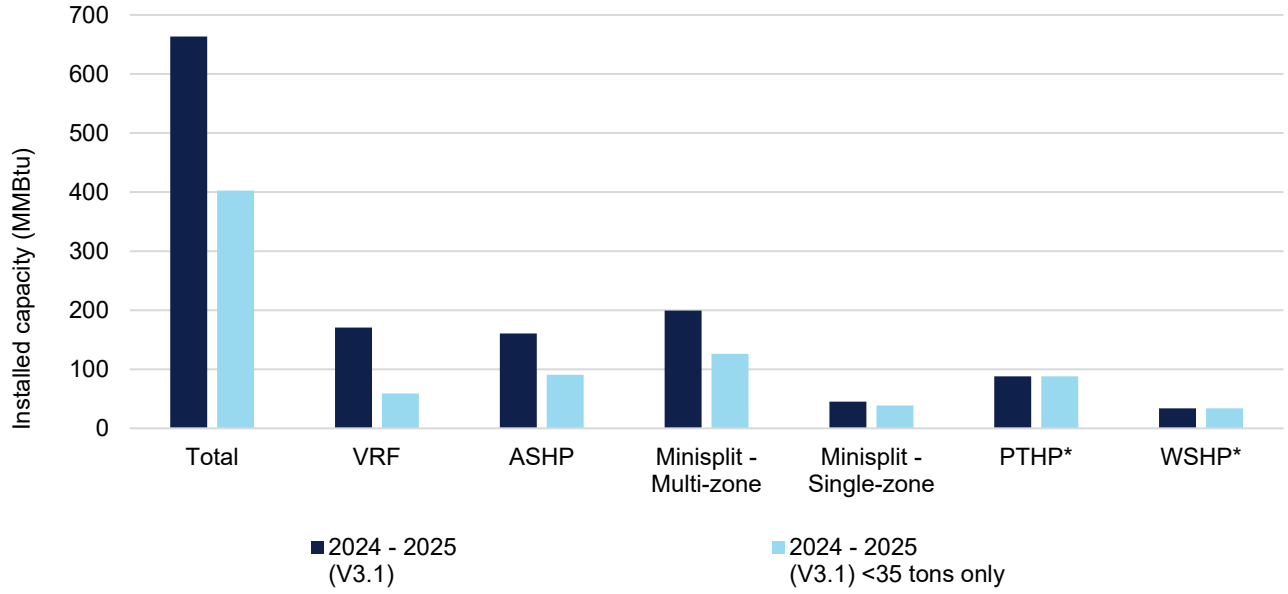
Finally, as with the current study, future evaluations of the commercial heat pump program will likely depend on tracking data records for scoping, sampling, and executing study activities. As the v3.1 update team found, misclassification of displacement type can present significant obstacles to efficient evaluation, particularly when samples and data collection methods are dependent to some extent on the level of displacement. These obstacles result in higher evaluation costs and lower precision due to challenges with sampling efficiency and meeting recruitment targets.

3.4.2 Prescriptive program capacity threshold

The team adjusted the building simulations and tracking data proportions to account for the new 35-ton capacity threshold for the Commercial Prescriptive Heat Pump Program, which became effective on June 1, 2026 (as detailed in Section 2.3.4 and Section 2.3.10). Figure 3-8 shows the total installed capacity for the 2024–2025 program years, with and without large projects (>35 ton sites). Large projects represented nearly 40% of the capacity installed in 2024–2025, and as expected, total VRF capacity decreases the most—about a 65% decrease—when large projects are removed. Note that PTHP and WSHP capacity is unchanged because they are offered through the midstream program and the threshold applies only to downstream projects.

[80] The basic definitions for full displacement—i.e., heat pumps that are the only source of heating for the area served—and partial displacement—i.e., heat pumps that share the heating load within the affected zones with some other system—are straightforward. However, some sites can be challenging to categorize, such as those with unclear boundaries between affected and unaffected heating zones, or where backup systems are still in place but are physically blocked or disconnected from the specific area served. Consistent classification of such sites by a large group of participating contractors requires targeted training and guidance materials to be developed and provided to contractors.

Figure 3-8. 2024–2025 installed program capacity, with and without large (>35 tons per site) projects



*The 35-ton threshold applies to downstream projects only. PTHPs and WSHPs are offered midstream, so no projects were excluded and total capacity is unchanged.

The new capacity threshold was implemented after most of the v3.1 update research tasks were substantially underway, so despite the team's adjustments (exclusion of large project sites) to building simulations and program tracking data proportions described in Section 2.3.4 and Section 2.3.10, there are several ways in which the evaluation results are not fully aligned with the new program threshold.

- **Decreased applicability of building type mappings used for the building simulations.** Smaller (<35 ton) commercial heat pump projects are more likely to involve a relatively more homogenous set of systems in medium-sized buildings, whereas there can be much more diversity among larger custom projects in the types of buildings where they are installed. The v3.1 building simulation prototypes were developed to align with the mix of building types from the program data prior to the new threshold becoming effective. The types of buildings where projects will be installed going forward are likely to differ systematically from the mix of buildings used to inform the prototypes for the current study.
- **Decreased applicability of proportions from participant and contractor surveys.** Unlike the tracking data proportions, the survey proportions could not be disaggregated by project size, since the new threshold had not been announced when the team developed the survey sample and designed the survey instruments. As a result, key survey-based proportions such as event type and pre-program and counterfactual HVAC reflect responses for all project sizes. To the extent there are systematic differences in these proportions for larger projects, the survey proportions in the current study will be less applicable to the program moving forward.

Future EO Model update research that involves building simulations and contractor or participant surveys can improve the applicability and reduce the uncertainty regarding these inputs.

3.4.3 Program data assessment

This section describes the team's assessment of the quality and comprehensiveness of program data, including the extent to which implementers have improved the tracking data in response to recommendations and considerations from the v3.0 short-term update report issued in fall 2025.

3.4.3.1 Displacement classification

As detailed in Section 3.4.1, displacement type was often misclassified, leading to several challenges during the current evaluation. Going forward, accurate tracking of displacement categories will be critical for accurate savings claims, continuous program improvements, and future program evaluability.

3.4.3.2 Other data issues

Several other data issues arose during the course of the evaluation that created evaluability challenges. These issues were present in the 2023-2024 program data included in the v3.0 update as well as the 2025 data included in the v3.1 update.

- **Lack of equipment-specific data for ASHP projects.** As originally reported in the v2.1 and v3.0 short-term updates, the PAs combine all ASHPs—whether central, ducted, and/or mini/multi-split systems—into a single prescriptive ASHP measure. The study team relied on model numbers and AHRI reference numbers to identify more specific equipment types, but this process was limited due to some gaps in this information. Specifically, model numbers and AHRI reference numbers were not available for the projects processed by the PAs in-house. In addition, this resulted in cases of mini-splits being incorrectly assumed to be split ASHP, and vice versa, which created challenges and inefficient use of study resources during site visits due to the different metering and verification approach for the difference technology types. There is significant participation associated with this aggregated measure (over 60% of 2024–25 capacity), and there are fundamental differences in the systems (ducted vs. ductless, single vs. multi zone, etc.). Furthermore, the subcommittee expressed particular interest in the operations and performance of rooftop-units (RTUs) due to their large potential for adoption and uncertainty in how they are currently being operated—but these units are not specifically identified in tracking data.
- **Inconsistent tracking data across multiple sources**. As originally reported in the v3.0 short-term update, the team found that a significant share of downstream projects were processed in-house by the PAs and therefore were not included in the downstream vendor data. The separately tracked PA data contained fewer fields and was inconsistent with vendor data for key variables such as cooling capacity, building type, equipment details, installation dates, addresses, and account numbers. Unlike the vendor data, the PA data often lacked model numbers or AHRI reference IDs, which limited the team's ability to verify equipment characteristics or map projects to more specific equipment categories such as ducted systems, ductless mini-splits, rooftop units, or other equipment types. The team also identified projects that appeared in both the PA data and vendor data, which affected expected equipment counts and required additional cleaning. Some sites visited during onsite verification had less equipment than indicated in the tracking data because of the projects appearing in overlapping sources. The study team made efforts to correct for these issues. Initial duplicate screening removed approximately 200 records based on address, account number, installation date, and equipment type. After onsite visits revealed additional overlap, the team applied stricter criteria, removing another 669 projects out of 4,490 total. These corrections required additional time and budget but were necessary to apply accurate statistical weights to survey and onsite data; without similar corrections in future evaluations, tracking data issues could lead to inaccurate weighting and biased statistical results.
- **A lack of contact information in the midstream program data**. This issue limited the study team's ability to collect survey and other data for PTHPs, which are the largest midstream program offering. According to the PAs, neither customer nor contractor emails are required to be collected in the midstream program. In addition, PTHP contractors were not included in the v3.1 contractor survey because contact information for contractors was unavailable in the midstream data. This is in part because systems were often installed in hotels by facility operations staff, so the contact information was for end-use customers rather than contractors.[81]

[81] In lieu of contractor survey responses, the team used a weighted average of v3.1 participant and v2.1 contractor responses to develop PTHP proportions, as detailed in Section 2.4.1.1.

3.5 Limitations and remaining areas of uncertainty

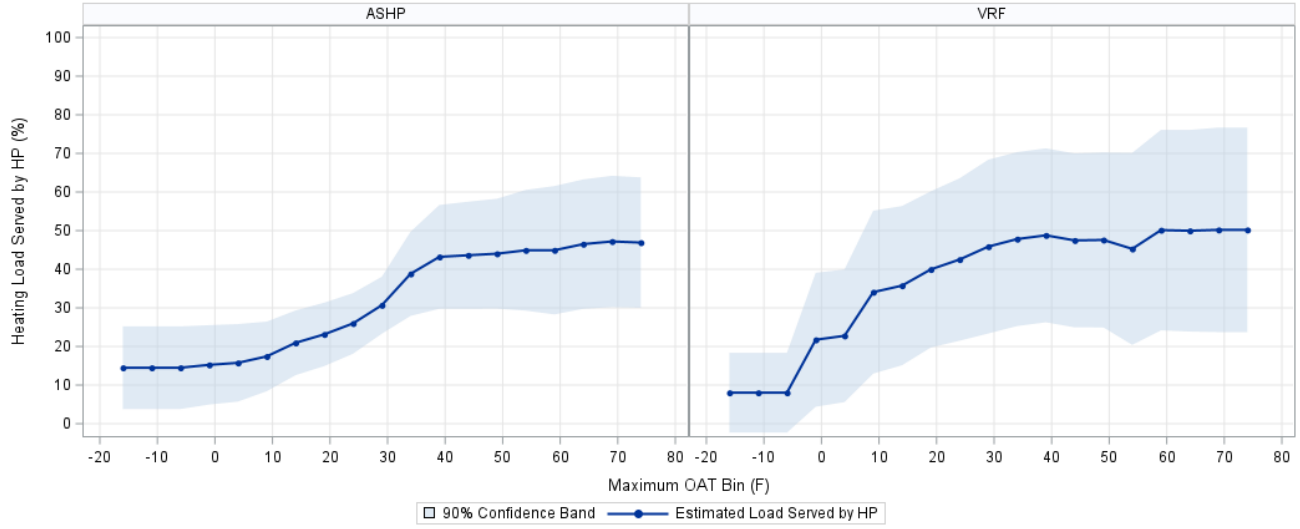
This section describes several key limitations of the v3.1 EO Model update study that should be considered when interpreting the results, and that can be improved upon in future updates. The primary limitations pertain to (1) the amount of on-site metering data collected, and (2) the ability to match building prototypes to the available data.

Available on-site metering data. During scoping for the study, the Subcommittee and study team developed the sample plan detailed in Section 2.2, which targeted 52 sites for metering, focusing the resource-intensive metering on-sites on partial displacement projects (as well as full displacement ASHPs). This target was based on a need to balance available evaluation resources given study priorities to gather real-world operational from equipment types with more uncertainty in operational parameters. However, the resulting metering data had several important limitations:

- The study did not include summer-period metering, which limited the ability to assess seasonal operating patterns across the cooling season.
- The on-site metering sample was also small relative to the level of variability across sites, as detailed in 2.3.2.3. This limitation is particularly important because partial displacement operation is a key driver of evaluated impacts, yet the findings for these systems are based on only 35 metered sites (12 VRF sites and 23 ASHP sites). The wide precision ranges shown in Table 3-6 and Table 3-7 reflect this uncertainty, as do the relatively wide precision bounds around the load sharing estimates shown in Figure 3-9.
- In addition, the metering sample was not designed to support analysis by building type, even though operations and impacts can vary substantially across building types.

Future research could address these limitations by expanding the on-site metering sample and designing the sample to support more precise estimates across equipment types, displacement configurations, and building types. Section 2.3.2.3 provides additional detail on the level of variation encountered in this study which should be considered in developing samples for future evaluations.

Figure 3-9. Heat pump share of heating load served by outdoor air temperature (OAT)



Aligning commercial building prototypes with available data. Building simulations always have some extent of inherent limitations due to unquantifiable human behaviors and idealized physical assumptions that create a gap between predicted and actual energy use. In the case of the v3.1 update, there were challenges calibrating certain end-uses and peak loads given prototype characteristics, and as agreed upon with the subcommittee the team prioritized accurately representing total

energy consumption (and therefore savings) as a primary calibration target. The data limitations described previously could at least partially explain the challenges experienced during calibration; for example: the metering study did not segment by building type and had high variability so there is inherent uncertainty in the magnitude of consumption for some target curves. Additionally, because metering did not occur during summer months there is greater uncertainty for what heat pump peak cooling loads should be. However, some characteristics of the commercial building prototypes also made issues with calibration unavoidable; for example: some prototypes (like the Medium Office prototype) have core zones that could require fan, heating, and/or cooling consumption nearly year-round, resulting in building simulations having meaningful HVAC consumption in shoulder months and a relatively flat energy consumption curve compared to target curves. Attempting to align peak loads to their targets would result in much higher HVAC energy consumption and thus drive down energy savings. As a detailed building stock assessment is required to adjust commercial building prototypes' geometries and zonal configurations, and calibration focused on inputs that could be parametrically and iteratively adjusted, changing commercial building prototype geometries and zonal configurations is outside the scope of this study.

In addition, the removal of large (>35 ton) sites from the program will likely result in decreased applicability of building type mappings by limiting the current prototypes' abilities to represent annual/monthly energy consumption and peak loads going forward. Smaller (<35 ton) commercial heat pump projects are more likely to involve a relatively more homogenous set of systems in medium-sized buildings, whereas there can be much more diversity among larger custom projects in the types of buildings where they are installed. The v3.1 building simulation prototypes were developed to align with the mix of building types from the program data prior to the new threshold becoming effective.

Future evaluators could improve upon these issues by developing Massachusetts-specific and program-specific prototypes for future EO Model updates. Similar studies have been conducted in other parts of the United States, including the California Building Energy Modeling (CalBEM) Prototype Development Project.[82]

[82] California Building Energy Modeling (CalBEM), Prototype Development Project, https://calbem.ibpsa.us/calbem-prototypes/

4 CONCLUSIONS, RECOMMENDATIONS, CONSIDERATIONS, AND GUIDANCE FOR FUTURE RESEARCH

4.1 Conclusions

The MA Commercial Prescriptive Heat Pump program continues to have a meaningful impact on statewide commercial heating and cooling consumption, incentivizing nearly 700 MMBtu/h of capacity and nearly 20,000 heat pump units across nearly 3,000 unique sites in 2024-2025. Although this is a slight decrease in installed capacity from the prior (v3.0) update covering program years 2023-2024, it represents more than double the installed capacity compared to the 2022-2023 program period. Such significant growth in a relatively short period of time has required coordinated effort by program staff and an extensive network of market actors. Given its scale, the program has the potential to significantly advance the commercial heat pump market in Massachusetts.

At the same time, the energy impact estimates from the v3.1 update—based on multiple sources of empirical data from participating end-user and contractor surveys and on-site metering and verification—are lower than the previously estimated energy impacts, reflecting the general finding that the heat pumps the team observed and metered in the field were used much less than assumed in the prior versions of the EO Model. Such challenges are not uncommon when rapidly scaling up a new program in a relatively emerging market such as commercial heat pumps. As the first model update to incorporate real-world heat pump operation and installation data gathered via on-site visits, the v3.1 update provides new insights into the real-world performance of program-rebated heat pumps. This newly available information reveals several challenges that PAs and stakeholders will need to address in order to make meaningful improvements in overall program effectiveness. Addressing the challenges identified in this study will help maximize the impact of the program in contributing to state decarbonization goals. Some of these challenges are more directly in the PAs' control than others, as summarized in Table 4-1.

Table 4-1. Challenges and areas for improvement

Level of PA implementer control	Challenges, risks and areas for improvement	Type of improvement
Direct—primarily PA responsibility	• Accurate tracking of displacement types creates savings accuracy risks • Other data issues (e.g., equipment-specific ASHP data) creates evaluability challenges	• Program guidance, requirements, and processes • Some contractor training and education
Indirect—requires significant contractor involvement, though PAs can establish requirements for participating contractors	• Partial displacement controls strategies and technologies creates customer satisfaction and program savings risks • System installation quality creates customer satisfaction and program savings risks • Potentially non-code-compliant ventilation creates customer satisfaction and liability risks • System suitability for given building/space types creates customer satisfaction and program savings risks	• Contractor training and education • Program guidance, requirements, and processes
Little to no control—depends on actors outside of program implementation	• Customer setpoints and operating schedule issues create customer satisfaction and program savings risks	• Customer education • Future evaluation planning and scoping

Level of PA implementer control	Challenges, risks and areas for improvement	Type of improvement

	• Evaluation assumptions create savings accuracy risks
	  ○ Switchover strategies and temperatures
	  ○ Simulated consumption and system capacity, calibrated to match metered data
	  ○ Baseline fossil fuel efficiencies
	  ○ Ventilation heating
	• Evaluation sample designs and sizes create savings accuracy risks	

4.2 Recommendations

The recommendations below include several areas for improvements to enhance program effectiveness and ensure accuracy in reported impacts and from the Commercial Heat Pump Program going forward.

Recommendation 1. Apply the prescriptive savings values from the v3.1 model prospectively for 2027 commercial heat pump projects. The PAs should update the electric and fossil fuel impact factors in the Massachusetts TRM and PA BC models for the measure IDs listed in the *measure update information* table on page iv. These values reflect the final impact results based on multiple sources of empirical data from on-site metering and verification visits, participating end-user and contractor surveys, and updated program tracking data. As detailed above, the study team recommends applying impact values reflecting the pooling of partial and full displacement projects, for the following reasons.

- Implementers have not consistently and reliably classified or tracked project displacement type.
- The program does not distinguish program incentives by displacement type—all projects receive the same $/ton incentives, regardless of displacement type.[83]
- There is a high degree of uncertainty and variability in energy impacts for both full and partial displacement projects, and direct on-site metering results found that impacts for full and partial displacement projects were not statistically different from each other in most cases. Pooled impacts are more likely to accurately represent the population on average than the separately reported full and partial results.[84]

Pooled impacts should be applied unless and until the programs have been shown to reliably and accurately distinguish between full and partial displacement projects in tracking data (see following recommendation).

Recommendation 2. If the PAs determine that it is important to program objectives to separately track full and partial displacement projects, they will need to take several steps to ensure accurate tracking of project displacement type. The 2026 commercial heat pump rebate applications included some clarifications regarding full and partial displacement as detailed in Section 3.4.1. To ensure these definitions are put into effect, the PAs should take the following actions.

[83] Since costs (i.e., incentives) are the same for both displacement types, there is no need to track and screen them for cost-effectiveness differently. If costs were different for full and partial displacement, then the programs would still need to track and screen them separately even if savings (i.e., impacts) were pooled.
[84] We did not calculate precisions for the final impact results from this study due to the multiple inputs and additional sources of uncertainty with unknown variation, including the building simulation modelling. However, the direct analysis of on-site metering resulted in heating kWh/ton estimates with precisions of approximately 52% for full displacement and 33% for partial displacement at 80% confidence (see table 3-6), but a much tighter 21% precision when pooled together.

- Provide training to program implementation vendors and contractors regarding the need for accurate tracking of displacement type, the technical definitions for full and partial displacement, and the type of site-specific information installation contractors should collect to determine project displacement type.
- Utilize post-inspections to confirm the accuracy of the displacement type in the application (per recommendation 4 below).

Recommendation 3. Enhance contractor training and program guidance to improve project installation quality. The field staff encountered multiple sites with suboptimal project installation quality that pose risks to project savings, customer satisfaction, and code compliance liability. These include multiple projects with unnecessary or inefficient use of backup electric resistance and gas backup heat, several projects with periods of simultaneous heating and cooling within the same space, and evidence of potentially non-code-compliant ventilation practices at several sites. Training and program materials should include additional emphasis on (1) controls systems and strategies for partial displacement sites—which are critical to improving savings impacts for these sites (regardless of whether the program claims impacts or tracks projects by displacement type) and (2) ventilation systems and requirements—which are critical to ensuring compliance with code requirements. In addition, for sites with potentially non-compliant ventilation, the team recommends a direct follow-up by program staff to contact these sites and assess their ventilation.

Recommendation 4. Utilize post-inspections to assess and confirm follow through of key improvements. During the reporting phase of this study, the PAs stated that they plan to begin post-inspecting 100% of commercial heat pump project sites. These post-inspections provide a valuable opportunity to confirm that key improvements are being implemented, including:

- Ensuring heat pump installations do not result in non-compliance with ventilation code
- Confirming partial displacement control systems and strategies conform to program requirements, including by reviewing documentation of control sequence for a sample of sites ensure they prioritize heat pump operation
- Checking setpoints and switchover settings where accessible to help ensure optimal system operations
- Assessing overall installation quality
- Confirming the correct classification of displacement type (per recommendation 2 above)

Recommendation 5. Separate the ASHP measure into multiple, more specific ASHP measures. This improvement was also called for in the v2.1 and v3.0 update reports but has not yet been implemented. As in prior years, the PAs currently combine all ASHPs— whether central, ducted, packaged systems or mini/multi-split systems—into a single prescriptive ASHP measure. The study team relied on model numbers and other equipment information to identify more specific equipment types, but this process was limited due to some gaps in this information. In addition, this resulted in cases of mini-splits being incorrectly assumed to be split ASHP, and vice versa, which created challenges and inefficient use of study resources during site visits. There is significant participation associated with this aggregated measure (over 60% of 2024-25 capacity), and there are fundamental differences in the design and operation of different ASHP types. For example, on-sites found large differences in metered impacts between packaged and split systems (see Table 3-7). The PAs should split the downstream ASHP program offerings into more specific heat pump types to better capture the inherently different system designs and impact values of these popular measures.

Recommendation 6. Collect information regarding pre-existing equipment in program tracking data. This improvement was also called for in the v2.1 and v3.0 update reports but has not yet been implemented. Downstream program participant data did not contain information on the pre-existing HVAC equipment that the program heat pump replaced. Because the pre-existing equipment type has one of the largest influences on overall measure impacts—and is readily observable by the contractor installing the program equipment—the PAs should consider requiring implementers to track pre-existing equipment as part of program data reporting requirements. The PAs should also consider collecting and

tracking pre-existing equipment status (e.g., whether fully displaced equipment was removed or kept in place), and for partial displacements data on backup heat controls including setpoints, and ventilation details.

4.3 Considerations

The following considerations address improvements in program tracking data to help ensure the PAs capture full and accurate savings impacts and allow for robust and efficient oversight and evaluation.

Consideration 1. Consistently track downstream program data. This was also called for in the v3.0 update report, and the data has improved somewhat, but there remains some inconsistencies and overlap in the data. As in the prior update, the study team found that a significant share of downstream projects were not tracked in the downstream vendor data, because they were processed in-house by the PAs. These projects were often initiated through a separate process involving PA sales or account representative staff, and there can be some barriers to fully integrating them with the vendor-created tracking records. The current study found far fewer records in the separately-tracked PA data than in the v3.0 update. However, these data had fewer fields and inconsistencies with the vendor data, including for key fields such as cooling capacity, building types, and equipment details. In addition, the team identified duplicate and overlapping records across PA and vendor data sources, which affected expected equipment counts and required additional cleaning. Consistently tracking these data would help streamline evaluation and allow mapping of projects to more specific equipment types in the future.

Consideration 2. Collect and track more complete contact information for midstream projects. A lack of contact information in the midstream program data—particularly customer and contractor email addresses—limited the study team's ability to collect survey and other data for PTHPs, which are the largest midstream program offering. According to the PAs, neither customer nor contractor emails are required to be collected in the midstream program. In addition, the team could not survey PTHP contractors due to a lack of contact information, in part because systems were often installed in hotels by facility operations staff. In such cases, improved contact information for customer installation staff would also provide a useful source for future evaluations.

4.4 Guidance

The following guidance would help improve the robustness, comprehensiveness and efficiency of future evaluations of the Commercial Prescriptive Heat Pump program.

Guidance 1. Conduct a quick-hit follow-up study to update key impact factors for 2028 prospective application. The challenges the team encountered associated with displacement misclassifications (detailed above) required an adjustment to impact methods and results near the end of the study period. Due to time constraints, the team used an indirect adjustment method for estimating partial displacement impacts and combining them with full displacement impacts to develop pooled results. Specifically, this adjustment and pooling of results was done using the outputs of the building simulations. With more time, the team could implement a more robust adjustment approach, which would include re-analyzing on-site data to develop pooled inputs to the building simulations, re-running and re-calibrating the simulations, and updating the EO Model workbook accordingly. Scoping for this follow-up study should begin in late 2026 to ensure completion in time for 2028 prospective application. The study could also include statistical analysis to develop more comprehensive estimates of variation and uncertainty that reflect the complete analysis process, including quantifying the improvement in precision that is achieved by pooling full and partial displacement projects throughout the analysis process. It could also include other updates to building simulation inputs or assumptions, such as those regarding heat pump sizing.

Guidance 2. Conduct a targeted assessment of implementation of key improvements recommended above, including accuracy of displacement classifications, partial displacement controls systems and strategies, compliance with ventilation code requirements, and tracking data improvements. This could be done alongside or subsequent to the quick-hit follow-up

study mentioned above, and could include identifying associated barriers and challenges to provide program staff and evaluators with more insights on how to advance the improvements. Such an assessment could include desk reviews with phone verification for a sample of projects, and on-site or virtual verification visits for a selected sub-sample of projects, including building owner interviews and supplemental heating system verification data. The team estimates a similar sample size would be required as was used for this study.

Guidance 3. Future EO Model updates should include additional data collection and analysis to reduce uncertainty, while optimizing the use of limited evaluation funding. Large-scale field studies are generally among the highest-rigor approaches, but they typically require substantial resources to cover costs for site visits, metering, and other tasks. The current study found large variation in the operation and use of program heat pumps, and there is a high degree of uncertainty around the final impact results for key strata such as displacement type. Alternative methods could be explored that optimize the use of limited evaluation resources while addressing key areas of uncertainty such as the following.

- Key building types, particularly those that are more prevalent among smaller (<35 ton) projects
- Partial displacement project operation and usage
- Cooling season operation and usage
- More specific equipment types, such as ducted ASHPs, mini/multi-splits, and PTHPs

Future updates could consider approaches such as the following to optimize use of limited evaluation funding:

- Reducing future sample sizes via a rolling average sampling and evaluation approach similar to Massachusetts C&I custom impact evaluations, allowing for regular updates while mitigating costs for data collection.
- Reducing future sample sizes by excluding displacement type as a sample stratification variable, at least until the PAs have implemented improvements in displacement classification and tracking.
- Applying statistical ratio analysis (e.g., realization rates), which result in better statistical precision compared to direct impact estimation.
- Prioritizing less costly data collection approaches such as virtual verification visits, phone interviews, and desk reviews.
- Reducing complexity and increasing transparency by limiting the use of building simulations and the EO Model workbook and relying on alternative methods such as billing analysis combined with site data collection.

Guidance 4. If PAs and stakeholders desire more representative and applicable impacts by building type, and sufficient evaluation resources are available, scope a building stock assessment and commercial building prototype development study specific to Massachusetts and the prescriptive commercial heat pump program. Commercial building prototypes used for building simulations in this study are based on a mapping of DOE commercial prototypes and program tracking data. DOE prototype geometries are designed to be representative for each building type nationally, and as program tracking data does not provide any details on building characteristics, the team did not identify any reasons why building geometries would differ for Massachusetts at the onset of this study. Many of these prototypes are large, ranging from 5,000 sqft to 74,000 sqft, and include core zonal configurations that require fan, heating, and/or cooling energy consumption nearly year-round. The team experienced challenges calibrating certain end uses and peak load energy consumption for these prototypes to field data, resulting in the team opting to prioritize accurately representing total energy consumption (and therefore savings). These challenges could stem from existing data limitations – such as on-site metering variability and the lack of summer metering data – as well as geometric limitations of the prototypes themselves. Additionally, the removal of large (>35 ton) sites from the program will likely result in decreased applicability of building type mappings by limiting the current prototypes' abilities to represent annual/monthly energy consumption and peak loads going forward. Future evaluators could improve upon these issues by developing Massachusetts-specific and program-specific prototypes for future EO Model updates. Similar studies have been conducted in other parts of the United States, including

the California Building Energy Modelling (CalBEM) Prototype Development Project.[85] Such a study would require a building stock assessment of Massachusetts commercial buildings which could include gathering permit data from local Authority Having Jurisdictions (AHJs) as the primary source of data, and identifying a subset of "program candidate" buildings to use for program-specific model input development and construction. These new prototypes could then be calibrated to metering and billing data collected in this study. This update could also explore the interaction between right-sizing, per contractor survey responses, and sizing to meet calibrate loads.

Guidance 5. **For future EO Model updates, if installations of WSHPs continue to increase, it may merit investment in direct building simulation modeling to develop more robust impact estimates for this equipment type**. WSHPs were first tracked as separate measures in the 2024 program data. Because neither the v3.0 or v3.1 model update studies included developing building simulations for WSHPs, the v3.0 update applied the GSHP impacts as a proxy for WSHP impacts, given their technological similarities.[86] However, the GSHP impacts are themselves based on proxy simulations developed in the EO Model v2.0 and v2.1 updates. The 2024 program data showed a meaningful increase in WSHP installations, from 0 MMBtu/h in the prior updates to 20.5 MMBtu/h in the v3.0 update and 33.9 MMBtu/h in the current (v3.1) update. If the program continues to see increasing installations of WSHP, we recommend directly simulating these systems in a future model update to produce more representative and robust impact estimates.

Guidance 6. Future NTG research should be designed to align with the survey responses from the v3.1 update study. A relatively small share of customer survey respondents reported counterfactual systems that would have been the same as what they installed through the program. The survey questions were not intended to get at net impacts, and the study team removed such responses from the analysis in order to maintain the gross baseline and avoid overlap and double counting of net impacts. However, these responses suggest some potential free-ridership. Future NTG research on commercial prescriptive heat pump measures should align with the methods and results of the v3.1 customer survey.

[85] California Building Energy Modeling (CalBEM), Prototype Development Project, https://calbem.ibpsa.us/calbem-prototypes/
[86] This also aligns with how the PAs currently claim WSHP savings.

APPENDIX A. EO MODEL PROPORTIONS

This appendix provides tables reflecting the key v3.1 EO Model proportions, from tracking data and participant and contractor survey data.

Tracking data proportions

The following tables provide the key proportions from the tracking data used to update the v3.1 model, and comparisons to prior model versions.

Table A-1. Installed capacity (MMBtu) by program equipment type, v2.0 through v3.1

Program HVAC	Program years and EO Model version			
	2022 - Q1 2023 (V2)	2022 – 2023 (V2.1)	2023 – 2024 (V3)	2024 – 2025 (V3.1)
Air Source Heat Pump	8.3	79.3	130.2	90.7
Ground Source Heat Pump	0.1	6.7	5.2	0.0
Packaged Terminal Heat Pump	0	0	55.6	87.9
Mini-split - Multi-zone	14	85.5	223.8	126.3
Mini-split - Single-zone	9	79.9	95.2	38.7
Variable Refrigerant Flow	15.4	149.5	281.9	59.1
Packaged Terminal Heat Pump (Midstream)	0	0	55.6	87.9
Water Source Heat Pump (Midstream)	0	0	20.5	33.9
Total	**46.8**	**400.9**	**791.9**	**402.7**

Table A-2. Installed capacity (Btu) by program equipment type and pre-program fuel, v3.0 and v3.1

Program HVAC	Pre-program Fuel	V3.1 installed capacity (Btu)	V3 installed capacity (Btu)	Change between V3.1 and V3
Air Source Heat Pump	Delivered Fuel	11,675,280	21,626,402	-46%
	Electric Resistance	6,699,480	16,655,159	-60%
	Natural Gas	65,198,535	80,683,330	-19%
Mini-split - Multi-zone	Delivered Fuel	23,878,320	44,278,802	-46%
	Electric Resistance	15,746,400	25,350,598	-38%
	Natural Gas	71,780,040	135,426,971	-47%
Mini-split - Single-zone	Delivered Fuel	10,672,440	24,415,081	-56%
	Electric Resistance	6,513,000	16,458,839	-60%
	Natural Gas	19,436,880	48,177,685	-60%

Program HVAC	Pre-program Fuel	V3.1 installed capacity (Btu)	V3 installed capacity (Btu)	Change between V3.1 and V3
Packaged Terminal Heat Pump	Electric Resistance	87,697,900	55,492,300	58%
	Natural Gas	0	0	-
	Delivered Fuel	0	0	-
Variable Refrigerant Flow	Delivered Fuel	9,501,240	22,302,719	-57%
	Electric Resistance	6,376,320	35,806,200	-82%
	Natural Gas	39,515,880	204,937,676	-81%

Table A-3. Tracking data proportions by building type, v3.0 and v3.1

Building Type	V3.1 Proportion	V3 Proportion	Change between V3.1 and V3
Education	4.07%	8.10%	-4.0%
Hotel	23.41%	9.10%	14.3%
Office	16.86%	18.35%	-1.5%
Other	13.94%	22.72%	-8.8%
Outpatient	1.33%	1.42%	-0.1%
Residential	8.52%	11.06%	-2.5%
Restaurant	7.86%	6.20%	1.7%
Retail/Service	16.50%	10.71%	5.8%
Supermarket	0.66%	0.89%	-0.2%
Warehouse	6.86%	11.47%	-4.6%

Survey proportions

The embedded workbook below provides the following:

- weighted results for key survey-based model inputs from the v3.1 contractor survey and v3.1 participant survey
- comparison values from the v3.0 EO Model update
- details on survey questions and weighting
- the final survey-based proportions used to update the v3.1 EO Model

V3.1 Survey Proportions.xlsx

APPENDIX B. ON-SITE RESULTS DETAILS

Table B-1 summarizes key results from each of the 47 sites sampled for metering and verification (M&V).

Table B-1. Summary of site-specific M&V results

Facility Type	Region	Square Footage	Primary HP System Type	# of Outdoor Units	Tracked Displace-ment Category	Confirmed Displace-ment Category	Displacement scenario (most applicable)	Supplemental switchover temperature (or range)	Supplemental heating enabled	HP compressor lock out temperature	Capacity-weighted average annual heating kWh per HP	Capacity-weighted average heating kWh per ton per HP	Capacity-weighted EFLH	Operation Category
Retail standalone	Interior	72000	HP RTU (Packaged)	1	Full	Full	HP + onboard ER backup serves affected zones	N/A	All heating season	No lockout	17761	3739	2804	N/A - Full Disp.
Other	Interior	1800	ASHP Ducted (Split)	1	Full	Full	HP + onboard ER backup serves affected zones	N/A	All heating season	No lockout	9388	2560	1835	N/A - Full Disp.
Office	Interior	2200	HP RTU (Packaged)	1	Full	Full	HP + onboard ER backup serves affected zones	No clear switchover	ER enabled <50ºF	No lockout	7895	2770	1776	N/A - Full Disp.
Multifamily	Coastal	575000	Variable Refrigerant Flow	2	Full	Full	HP + onboard ER backup serves affected zones	No clear switchover	All heating season	No lockout	7415	484	405	N/A - Full Disp.
Other	Interior	1500	HP RTU (Packaged)	1	Full	Full	HP + onboard ER backup serves affected zones	No clear switchover	ER enabled <56ºF	No lockout	3773	526	527	N/A - Full Disp.
Office	Interior	7750	ASHP Ducted (Split)	2	Full	Full	HP + onboard ER backup serves affected zones	No clear switchover	ER enabled <45ºF	No lockout	2248	499	395	N/A - Full Disp.
Office	Interior	35000	Variable Refrigerant Flow	3	Partial	Full	Only HP serves affected zones	N/A - Full Disp.	N/A - Full Disp.	N/A - Full Disp.	9840	1036	1033	N/A - Full Disp.
Public assembly	Coastal	10000	ASHP Ducted (Split)	2	Full	Full	Only HP serves affected zones	N/A - Full Disp.	N/A - Full Disp.	N/A - Full Disp.	5624	1250	1041	N/A - Full Disp.
Multifamily	Coastal	2000	ASHP Ducted (Split)	1	Full	Full	Only HP serves affected zones	N/A - Full Disp.	N/A - Full Disp.	N/A - Full Disp.	5612	1403	1015	N/A - Full Disp.
Public assembly	Coastal	Unknown	ASHP Ducted (Split)	5	Full	Full	Only HP serves affected zones	N/A - Full Disp.	N/A - Full Disp.	N/A - Full Disp.	2980	662	742	N/A - Full Disp.
Education: elementary school	Interior	40000	Variable Refrigerant Flow	2	Full	Full	Only HP serves affected zones	N/A - Full Disp.	N/A - Full Disp.	N/A - Full Disp.	819	71	74	N/A - Full Disp.
Restaurant - Quick service	Interior	3500	ASHP Ducted (Split)	1	Full	Full	Only HP serves affected zones	N/A - Full Disp.	N/A - Full Disp.	N/A - Full Disp.	262	105	76	N/A - Full Disp.
Outpatient	Coastal	7540	HP RTU (Packaged)	1	Partial	Partial	HP + onboard gas backup (DFHP) serves affected zones	55-65ºF	<65ºF	No lockout	9739	1230	1332	Ran only at mild temps
Hotel	Interior	17000	HP RTU (Packaged)	1	Full	Partial	HP + onboard gas backup (DFHP) serves affected zones	No clear switchover	Unknown	Unknown	8321	666	611	Backup gas used more than anticipated
Office	Interior	6500	ASHP Ducted (Split)	5	Partial	Partial	HP + onboard gas backup (DFHP)	30-40ºF	<40ºF	14ºF	3310	709	561	Ran only at mild temps

Facility Type	Region	Square Footage	Primary HP System Type	# of Outdoor Units	Tracked Displace-ment Category	Confirmed Displace-ment Category	Displacement scenario (most applicable)	Supplemental switchover temperature (or range)	Supplemental heating enabled	HP compressor lock out temperature	Capacity-weighted average annual heating kWh per HP	Capacity-weighted average heating kWh per ton per HP	Capacity-weighted EFLH	Operation Category
							serves affected zones							
Other	Coastal	38000	HP RTU (Packaged)	1	Full	Partial	HP + onboard gas backup (DFHP) serves affected zones	Unknown	Unknown	5ºF	2902	145	159	Primarily used for cooling
Outpatient	Interior	4096	HP RTU (Packaged)	1	Partial	Partial	HP + onboard gas backup (DFHP) serves affected zones	No clear switchover	<60ºF	No lockout	2804	354	383	HP provided nearly all heating
Public assembly	Interior	Unknown	ASHP Ducted (Split)	3	Full	Partial	HP + onboard gas backup (DFHP) serves affected zones	30-40ºF	<40ºF	30ºF	2100	485	389	Ran only at mild temps
Manufacturing	Interior	210000	HP RTU (Packaged)	3	Partial	Partial	HP + onboard gas backup (DFHP) serves affected zones	No clear switchover	Unknown	Unknown	1993	218	231	Backup gas used more than anticipated
Public assembly	Coastal	9875	HP RTU (Packaged)	2	Full	Partial	HP + onboard gas backup (DFHP) serves affected zones	Supplemental not used	Supplemental not used	No lockout	1434	218	228	HP provided nearly all heating
Other	Interior	4300	ASHP Ducted (Split)	2	Partial	Partial	HP + onboard gas backup (DFHP) serves affected zones	<50ºF	<50ºF	20ºF	1070	378	312	Backup gas used more than anticipated
Hotel	Interior	37500	ASHP Ducted (Split)	2	Full	Partial	HP + onboard gas backup (DFHP) serves affected zones	44ºF	Unknown	No lockout	519	135	100	Simultaneous heating with FF
Office	Interior	6000	ASHP Ducted (Split)	1	Full	Partial	HP + onboard gas backup (DFHP) serves affected zones	30-40ºF	<40ºF	20ºF	426	149	118	Ran only at mild temps
Other	Interior	13200	Variable Refrigerant Flow	2	Full	Partial	HP and separate supplemental system serve same zones (or whole facility)	No clear switchover	<57ºF	No lockout	27244	1604	1563	Simultaneous heating with FF
Office	Coastal	6800	Variable Refrigerant Flow	2	Full	Partial	HP and separate supplemental system serve same zones (or whole facility)	No clear switchover	All heating season	No lockout	26364	3439	3336	HP provided nearly all heating
Other	Coastal	24000	Variable Refrigerant Flow	3	Full	Partial	HP and separate supplemental system serve same zones (or whole facility)	No clear switchover	<55ºF	5ºF	13471	1757	1727	Simultaneous heating with FF

Facility Type	Region	Square Footage	Primary HP System Type	# of Outdoor Units	Tracked Displace-ment Category	Confirmed Displace-ment Category	Displacement scenario (most applicable)	Supplemental switchover temperature (or range)	Supplemental heating enabled	HP compressor lock out temperature	Capacity-weighted average annual heating kWh per HP	Capacity-weighted average heating kWh per ton per HP	Capacity-weighted EFLH	Operation Category
Office	Coastal	2100	ASHP Ducted (Split)	1	Partial	Partial	HP and separate supplemental system serve same zones (or whole facility)	No clear switchover	<50ºF	5ºF	6809	2334	1659	Simultaneous heating with FF
Other	Interior	3000	Variable Refrigerant Flow	1	Full	Partial	HP and separate supplemental system serve same zones (or whole facility)	20-28ºF	<29ºF	20ºF	5500	579	557	Ran only at mild temps
Office	Coastal	4277	ASHP Ducted (Split)	1	Full	Partial	HP and separate supplemental system serve same zones (or whole facility)	30-45ºF	<45ºF	30ºF	3906	1042	739	Simultaneous heating with FF
Office	Coastal	2400	Variable Refrigerant Flow	1	Full	Partial	HP and separate supplemental system serve same zones (or whole facility)	No clear switchover	All heating season	No lockout	3671	638	639	Simultaneous heating with FF
Warehouse	Interior	17000	Variable Refrigerant Flow	7	Full	Partial	HP and separate supplemental system serve same zones (or whole facility)	No clear switchover	<60ºF	No lockout	2625	342	343	Primarily used for cooling
Education: college/ university	Interior	15188	ASHP Ducted (Split)	5	Full	Partial	HP and separate supplemental system serve same zones (or whole facility)	No clear switchover	Unknown	No lockout	2578	1718	1375	Simultaneous heating with FF
Education: elementary school	Interior	25000	Variable Refrigerant Flow	2	Partial	Partial	HP and separate supplemental system serve same zones (or whole facility)	No clear switchover	<60ºF	No lockout	2023	338	396	Simultaneous heating with FF
Warehouse	Interior	3500	Variable Refrigerant Flow	1	Full	Partial	HP and separate supplemental system serve same zones (or whole facility)	No clear switchover	All heating season	No lockout	1558	164	164	Primarily used for cooling
Public assembly	Coastal	7000	ASHP Ducted (Split)	3	Full	Partial	HP and separate supplemental system serve same zones (or whole facility)	No clear switchover	All heating season	No lockout	1382	346	243	Simultaneous heating with FF
Other	Interior	26756	ASHP Ducted (Split)	4	Partial	Partial	HP and separate supplemental system serve same zones (or whole facility)	No clear switchover	<60ºF	No lockout	1269	293	242	Ran only at coldest temps

Facility Type	Region	Square Footage	Primary HP System Type	# of Outdoor Units	Tracked Displace-ment Category	Confirmed Displace-ment Category	Displacement scenario (most applicable)	Supplemental switchover temperature (or range)	Supplemental heating enabled	HP compressor lock out temperature	Capacity-weighted average annual heating kWh per HP	Capacity-weighted average heating kWh per ton per HP	Capacity-weighted EFLH	Operation Category
Other	Interior	5000	HP RTU (Packaged)	1	Full	Partial	HP and separate supplemental system serve same zones (or whole facility)	No clear switchover	<45ºF	25ºF	1239	261	196	Ran only at mild temps
Public assembly	Interior	2500	Variable Refrigerant Flow	2	Full	Partial	HP and separate supplemental system serve same zones (or whole facility)	No clear switchover	<60ºF	15ºF	917	159	165	Simultaneous heating with FF
Retail standalone	Interior	15000	ASHP Ducted (Split)	2	Partial	Partial	HP and separate supplemental system serve same zones (or whole facility)	No clear switchover	All heating season	20-30ºF	796	222	159	Ran only at mild temps
Other	Interior	6100	ASHP Ducted (Split)	4	Partial	Partial	HP and separate supplemental system serve same zones (or whole facility)	No clear switchover	All heating season	No lockout	490	114	92	Primarily used for cooling
Other	Interior	2000	ASHP Ducted (Split)	1	Partial	Partial	HP and separate supplemental system serve same zones (or whole facility)	No clear switchover	All heating season	22ºF	276	92	77	Primarily used for cooling
Other	Coastal	4000	Variable Refrigerant Flow	2	Partial	Partial	HP and separate supplemental system serve same zones (or whole facility)	No clear switchover	All heating season	No lockout	178	14	13	Primarily used for cooling
Other	Interior	2700	Variable Refrigerant Flow	6	Full	Partial	HP feeds AHU with a hot water coil served by separate supplemental heat	No clear switchover	All heating season	No lockout	24168	3152	3411	HP provided nearly all heating
Other	Coastal	17500	Variable Refrigerant Flow	7	Full	Partial	HP feeds AHU with a hot water coil served by separate supplemental heat	No clear switchover	All heating season	No lockout	18934	1291	1212	Simultaneous heating with FF
Retail standalone	Coastal	1700	ASHP Ducted (Split)	1	Partial	Partial	HP feeds AHU with a hot water coil served by separate supplemental heat	20-50ºF	<55ºF	10ºF	2528	583	702	Simultaneous heating with FF
Manufacturing	Interior	37448	HP RTU (Packaged)	2	Full	Partial	HP feeds AHU with a hot water coil served by separate supplemental heat	No clear switchover	All heating season	No lockout	0	0	0	Primarily used for cooling
Public assembly	Interior	16000	ASHP Ducted (Split)	2	Full	Partial	HP feeds AHU with a hot water coil served by separate supplemental heat	No clear switchover	All heating season	Unknown	0	0	0	Primarily used for cooling

APPENDIX C. BUILDING SIMULATION DETAILS

This Appendix provides details for the following building simulation categories:

- Parameter details
- Targets curves and calibrated results
- Installed capacity results

Calibration parameter development details

To define the expected values related to building type, the study team started with a Department of Energy (DOE) prototype model[87] for each building type. Because the prototypes are fully defined building energy simulations, they define all inputs necessary to run a building energy simulation. These inputs, however, represent typical buildings from across the United States. Therefore we updated the inputs to reflect the program participants' buildings. To do this, we developed a list of all inputs used in the prototypes (along with their values) and ranked each input type based on three attributes:

- **Range** of possible values (how widely the values can range in a typical building). This attribute was developed using professional judgement and confirmed using field data, described below.
- **Impact** on energy use (how much updating the input will change the buildings energy use). This attribute was determined by running a series of simulations for each input in each building type.
- **Level of certainty** (how confident we can be about a value). This attribute was determined by professional judgment.

Table C-1 is an example of this process for two inputs.

Table C-1. Example input assessment

Input Type	Range	Impact	Uncertainly
Ventilation Rate	High	High	High
Lighting Power Density	Low	Medium	Low

With the inputs ranked on these three attributes, we updated the High and Medium starting value inputs and input ranges to reflect field data collected as part of this update if available. If not available in field data, we updated the values with the median values within the input range from state, regional, and national data sources. Other than the field data collected through this study, key sources for developing input starting values and ranges included the DOE Commercial Reference Buildings, DOE prototypes, Massachusetts Baseline Studies, and CBECS.

To determine the impact each input would have on building energy consumption, the team ran a series of simulations for each building type and quantitatively estimated the impact varying inputs within their determined range has on whole-building energy consumption. A high impact input showed significant impact on energy consumption (+/- 20%), a medium impact input showed moderate impact on energy consumption (+/- 10%), and a low impact input showed low or negligible impact on energy consumption.

The team found that there were seven high impact inputs and 16 medium impact inputs across all building type, shown in Table C-2. These inputs were the focal levers in calibrating the models.

[87] Department of Energy (DOE), Commercial Reference Building, https://www.energy.gov/cmei/buildings/commercial-reference-buildings

Table C-2. Inputs initial starting values and ranges for calibration

Object & Characteristic	Impact	Median Starting Value	Input Calibration Range
Infiltration: Rate By Surface Area	High	0.34 cfm/ft2	From 0 to 1.3 cfm/ft2
Ventilation: Rate by Floor Area	High	0.3 cfm/ft2	From 0.08 to 0.6 cfm/ft2
Ventilation: Rate by Person	High	10 cfm/person	From 2.5 to 30 cfm/person
Cooling: Efficiency	Medium	Varied by heat pump type[a]	Varied by heat pump type[a]
Thermostat: Cooling Setpoint	High	74°F	From 70 to 78°F
Thermostat: Cooling Setback	High	77°F	From 71 to 81°F
Heating: Efficiency	Medium	Varied by heat pump type[a]	Varied by heat pump type[a]
Thermostat: Heating Setpoint	High	69°F	From 60 to 72°F
Thermostat: Heating Setback	High	65°F	From 58 to 71°F
DHW Equipment: Hot Water Use Rate	Medium	0.058 gpm	From 0 to 10 gpm
DHW Equipment: Storage Set Point Temperature	Medium	140°F	From 115 to 155°F
Elec Equip: by floor area	Medium	0.63 W/ft2	From 0 to 2 W/ft2
Supply Fan: Pressure Rise	Medium	2.24 in H20	From 0.1 to 6.0 in H20
Supply Fan: Total Efficiency	Medium	57%	From 30% to 95%
Insulation: Roof/Ceiling Cavity R-Value	Medium	20 R-IP	From 0 to 38 R-IP
Insulation: Roof/Ceiling Continuous R-Value	Medium	5 R-IP	From 0 to 20 R-IP
Insulation: Wall Cavity R-Value	Medium	13 R-IP	From 0 to 19 R-IP
Insulation: Wall Continuous R-Value	Medium	2 R-IP	From 0 to 8 R-IP
Insulation: Foundation Wall R-Value	Medium	4 R-IP	From 0 to 20 R-IP
Insulation: Slab R-Value	Medium	3 R-IP	From 0 to 16 R-IP
Lighting: By Floor Area	Medium	1.34 W/ft2	From 0.1 to 3.0 W/ft2
Windows: Solar Heat Gain Coefficient	Medium	0.42 SHGC	From 0.23 to 0.82 SHGC
Windows: Window U-Value	Medium	0.6 Btu/hr·ft2·F	From 0.26 to 1.2 Btu/hr·ft2·F

[a]Heat pump heating and cooling efficiency median starting value and calibration ranges were derived from program tracking data. These values vary by heat pump type.

We developed our input assessment by running two energy models for each potential calibration input, one with the input set to the top of its maximum range and one with it set to the bottom, while all other inputs remained at their default starting values.[88] The result of these simulations allows us to quantify the magnitude and direction of impact that each input had on the different end uses by fuel type. Table C-3 shows an example of what the result of this process looked like. For the full table of calibration parameter categorization, refer to the EO Model v2.0 report.

Table C-3. Example of calibration parameter categorization

Input Category	Input Subcategory	Impact Category	Impact Subcategory	Low Value	Starting Value	High Value
Insulation	Wall	Heat	Down	4	13	21
Plug load Density (W/ft2)	Office	Base	Up	0.3	0.75	1.5
Window SHGC	Entry	Cool	Up	0.2	0.4	0.8

[88] Starting values are based on the DOE's prototype values for each respective building type.

Target curves and calibration results

This section provides the results of creating the target curves and calibrating building simulations to them. Specifically, the study team:

1. Used metered and billing data to create energy consumption target curves by building type, heat pump type (ASHP and VRF), impact categories (electric baseload, heating load, and cooling load[89]) and end-use categories (heat pump, backup/supplemental heating, and fans), then
2. Aligned building simulations energy consumption results to those target curves.

Generally, the study team focused on aligning simulated impact categories to the target, while fitting end-use categories' consumption values to the target as much as possible. The team was generally successful in aligning building simulations impact categories, though as expected there were challenges in aligning more detailed end-use categories' consumption values. The study team does not interpret these challenges as reducing certainty in the final EO Model impact results,[90] however they're worth noting for future work if there is a desire to further improve the calibrated models. These constraints and challenges include the following:

- Building simulation geometries and zonal configurations are based on DOE commercial reference buildings,[91] and therefore are not the same size, shape, etc. as sites included in the metered data. DOE commercial reference buildings are used to create prototypical building simulations representative of a building type for the program. However, this causes limitations in our ability to align end-use consumption to their targets. For example, fan consumption is highly dependent on number of zones, zonal configurations (e.g., interior zone versus perimeter zone), zonal ventilation requirements, and assumed HVAC configuration which causes difficulty in aligning this end-use to the target. Another example is some prototypes have large central zones that require year-round heating and/or cooling.
- Fan consumption was the end-use with the lowest metered sites (N=15), and therefore the highest uncertainty. This end-use also had the highest variance within the metered data results.
- There is a limited number of inputs that can be adjusted to align end-use categories' consumption to the targets.
- There are input range limitations that we've applied during calibration.
- Adjusting inputs can help align one end-use category consumption to the target at the expense of aligning another end-use category.
- Per program requirements and regulations, all building simulations must meet or exceed code-minimum ventilation requirements.

Provided in Table C-4 are the target curves and calibration results, with these calibration results pictured (by monthly electric energy consumption) in Figure C-1 through Figure C-12. As a reminder, the calibrated retail stripmall building was used to inform inputs for the retail standalone building type; the retail standalone building type was not calibrated directly due to lack of available data.

As shown in the following table and figures, all consumption results are within range of the median target consumption and acceptance range (+/- 1 standard deviation). As a final QC check, the team calculated the mean bias error (MBE) and coefficient of variation of the root-mean-square error (CV[RMSE]) for each calibrated model's annual whole-building electric energy consumption following the approach detailed in ASHRAE Guideline 14.[92] ASHRAE developed this guideline for use in the development and validation of models of individual buildings, typically in the context of investment grade savings

[89] Unlike the heating load, cooling load was not metered in this study. Instead, the team inferred cooling consumption targets using available billing data.
[90] Impact values in the EO Model only consider changes in total variable load consumption (i.e., baseload consumption is constant between Baseline and Program models). Additionally, as Baseline Models are entirely different system configurations to Program Models, impact results are agnostic to the detailed end-uses that the study team aligns to available data.
[91] Department of Energy (DOE), Commercial Reference Buildings, https://www.energy.gov/cmei/buildings/commercial-reference-buildings
[92] ASHRAE, ASHRAE Guideline 14-2002: Measurement of Energy Demand and Savings. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers; 2002.

impact estimates. While it is not wholly applicable to our calibration efforts (where we are aligning our models to billing data collected across the C&I sector), the metrics outlined in the guideline provide a useful secondary assessment of how well our calibrated models match the available billing data. While the calibrated models do not all conform to the guideline's calibration thresholds of ±5% for MBE and less than 15% for CV(RMSE), as shown in in Table C-4, most of our calibrated models are within these ranges and the remaining are close, giving us strong confidence in the outcomes of our calibration process.[93]

[93] The only prototype that was significantly outside of the CV(RMSE) threshold were the 'warehouse' models: this is due to the target curves for this building type being very rigid, whereas the modeled energy consumption was much more smooth [CV(RMSE) is a metric that assess calibration precision, which can be negatively impacted if the calibrated model has a smoother curve than the target]. Given this, MBE being within range, and consumption curves matching the targets, we do not have concerns with the CV(RMSE) metric being out-of-range for 'warehouse' models.

Table C-4. Target curve and calibration results

Building Type	Heat Pump Type	Metered Data N	Billing Data N	Total Annual Electric Consumption (MWh)		Total Annual Baseload Consumption (MWh)		Total Annual Heating Consumption (MWh)								Total Annual Cooling Consumption (MWh)					
								Target				Modeled				Target			Modeled		
				Target	Modeled	Target	Modeled	Total	Heat Pump	Backup or Supplemental	Fans	Total	Heat Pump	Backup or Supplemental	Fans	Total	Heat Pump	Fans	Total	Heat Pump	Fans
Small Office	ASHP	6	32	136	130	102	96	30	18	9.1	2.3	30	18	8.7	3.0	4.0	3.7	0.4	4.0	2.7	1.3
Small Office	VRF	7	60	89	85	71	68	15	10	3.8	1.3	15	10	2.6	1.8	2.5	2.3	0.3	2.9	1.8	1.0
Medium Office	ASHP	6	13	817	810	472	479	298	183	93	23	270	161	88	20	47	42	5	61	49	13
Medium Office	VRF	7	67	785	828	611	610	150	100	38	12	148	66	30	52	25	22	2.7	70	30	40
Retail Stripmall	ASHP	6	34	823	834	749	758	26	16	8	1.9	28	12	5	10	49	44	5.4	49	31	18
Retail Stripmall	VRF	7	102	531	530	449	453	59	39	15	4.9	53	32	13	7.8	23	21	2.6	24	17	7.3
Midrise Apartment	ASHP	6	14	1,020	1,032	803	814	171	104	54	13	173	103	48	23	46	41	5	45	31	15
Midrise Apartment	VRF	7	46	760	736	637	608	86	57	22	7.0	90	54	17	20	37	32	4.1	38	24	15
Primary School	ASHP	6	6	965	990	517	542	412	256	125	32	410	239	138	33	36	32	3.9	38	28	9.9

Building Type	Heat Pump Type	Metered Data N	Billing Data N	Total Annual Electric Consumption (MWh)		Total Annual Baseload Consumption (MWh)		Total Annual Heating Consumption (MWh)								Total Annual Cooling Consumption (MWh)					
								Target				Modeled				Target			Modeled		
				Target	Modeled	Target	Modeled	Total	Heat Pump	Backup or Supplemental	Fans	Total	Heat Pump	Backup or Supplemental	Fans	Total	Heat Pump	Fans	Total	Heat Pump	Fans
Primary School	VRF	7	11	965	979	724	720	226	152	53	19	223	122	28	73	16	14	1.7	36	17	19
Warehouse	ASHP	6	13	426	434	96	100	274	175	80	21	282	174	74	34	56	48	6.1	51	37	14
Warehouse	VRF	7	45	293	296	96	100	144	101	36	12	145	104	29	12	53	42	5.8	51	36	15

Figure C-1. Small office ASHP calibration

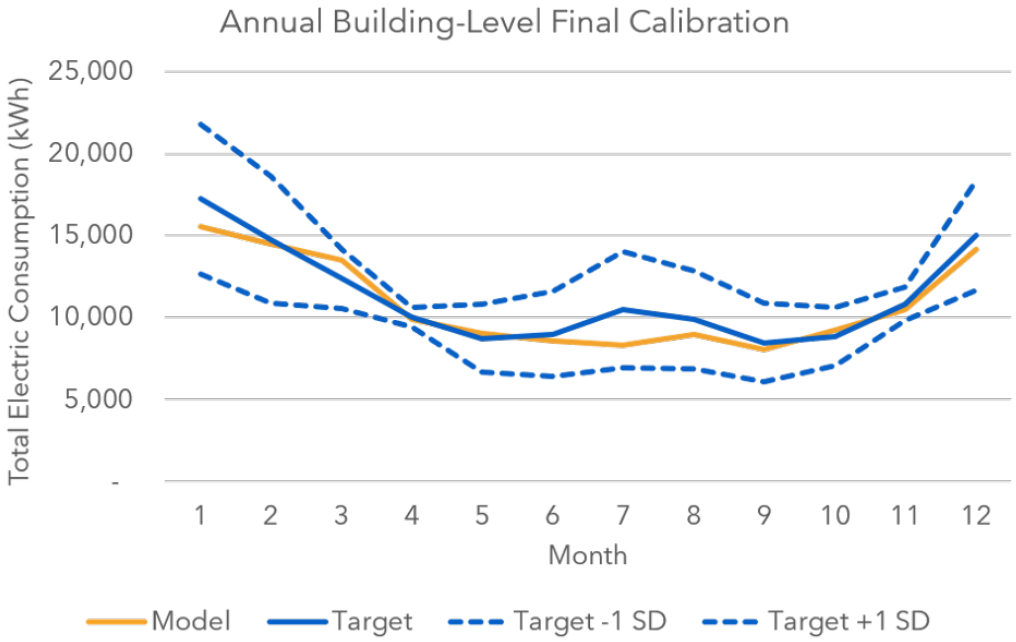


Figure C-2. Small office VRF calibration

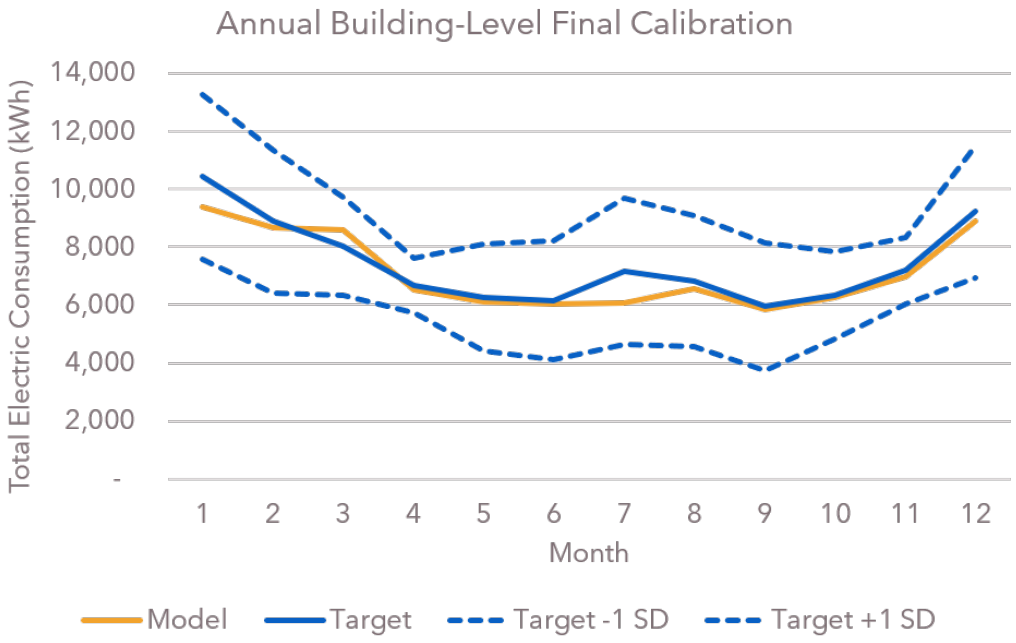


Figure C-3. Medium office ASHP calibration

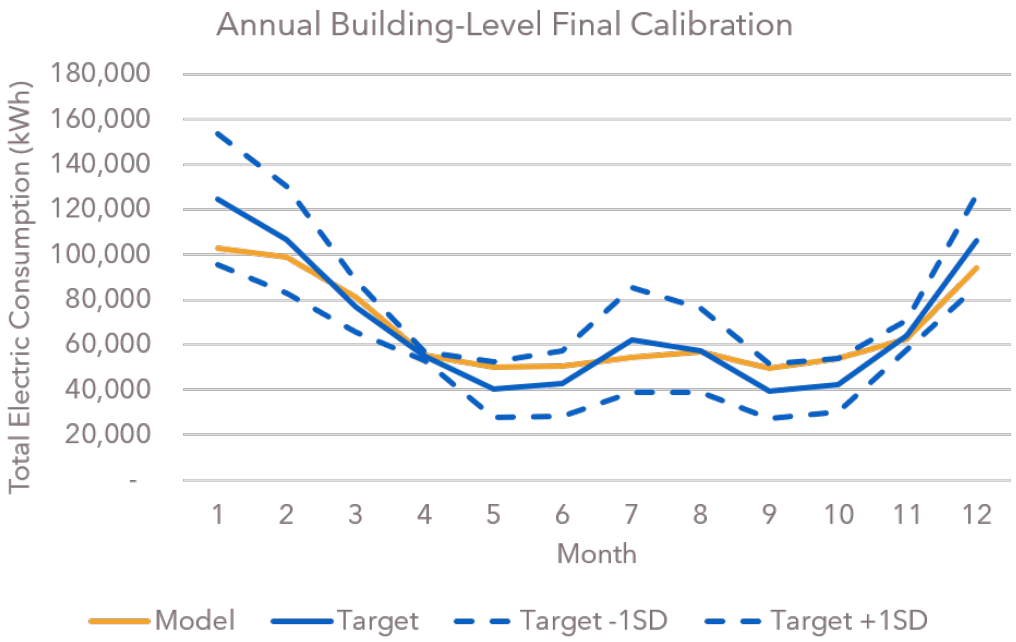


Figure C-4. Medium office VRF calibration

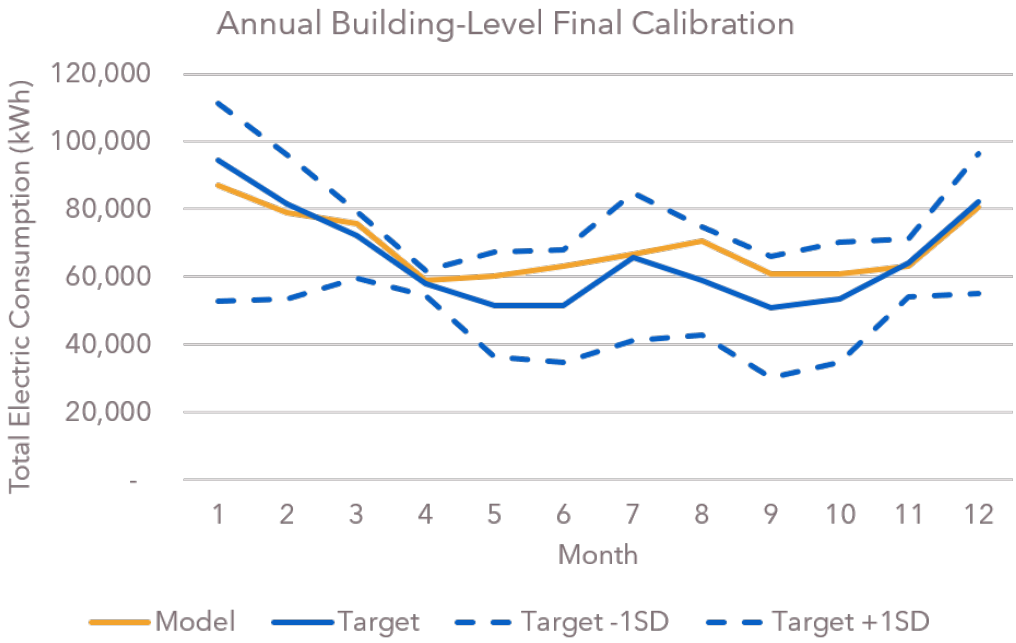


Figure C-5. Retail stripmall ASHP calibration

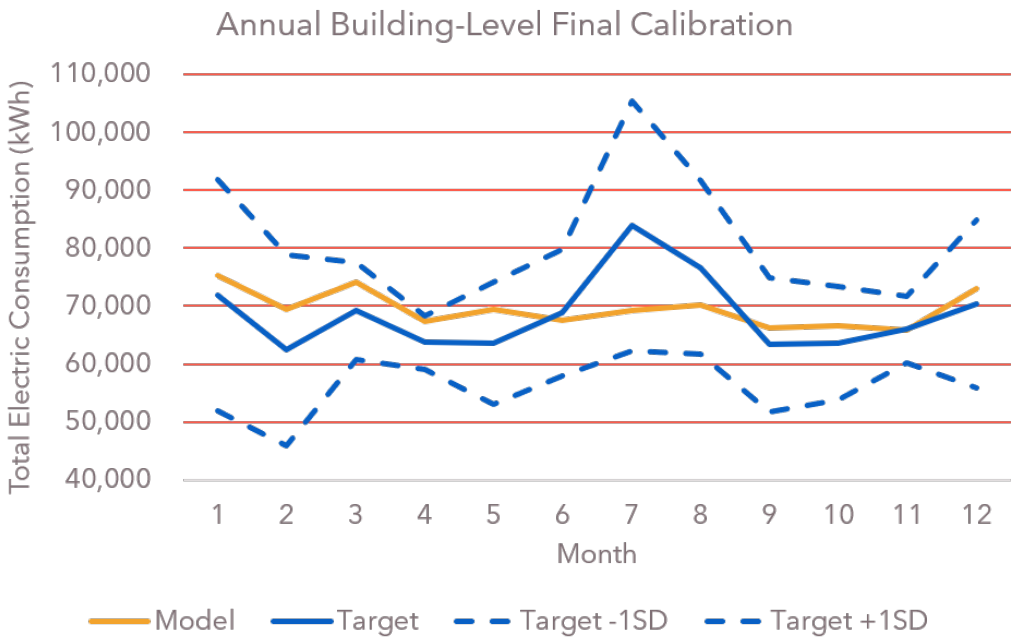


Figure C-6. Retail stripmall VRF calibration

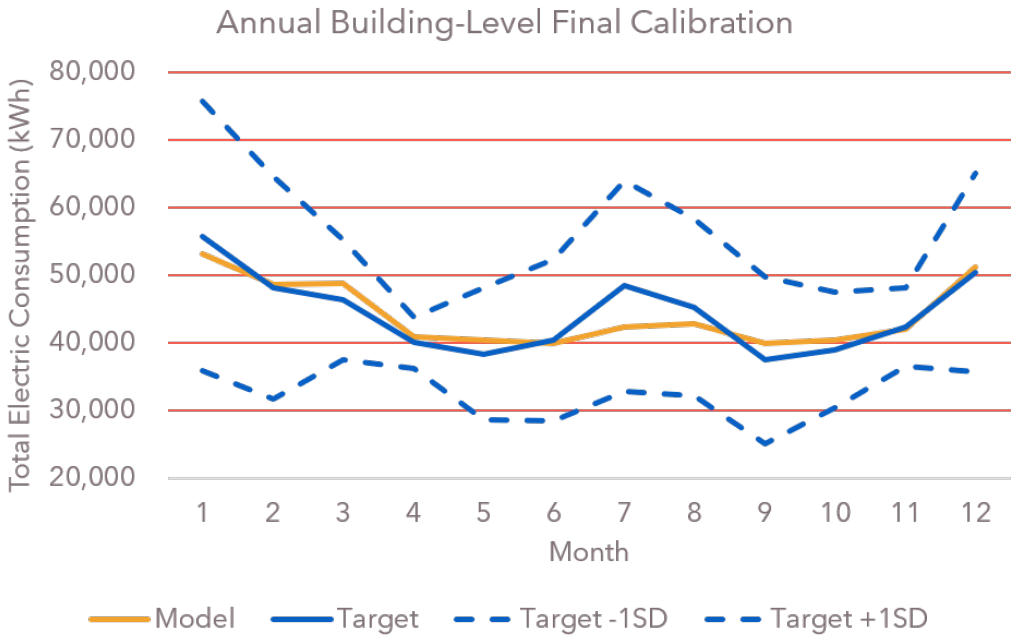


Figure C-7. Midrise apartment ASHP calibration

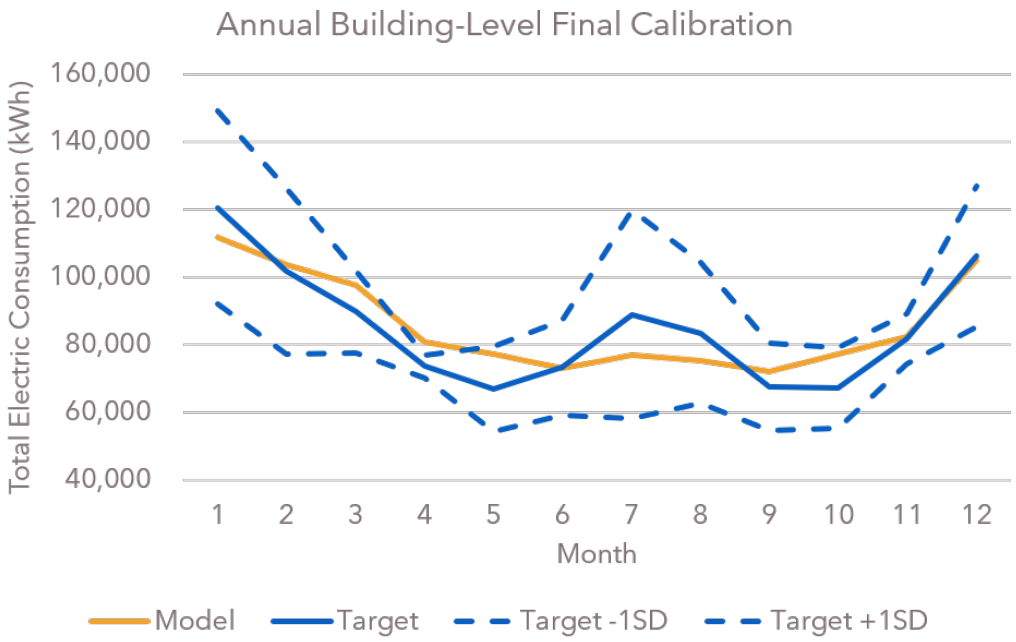


Figure C-8. Midrise apartment VRF calibration

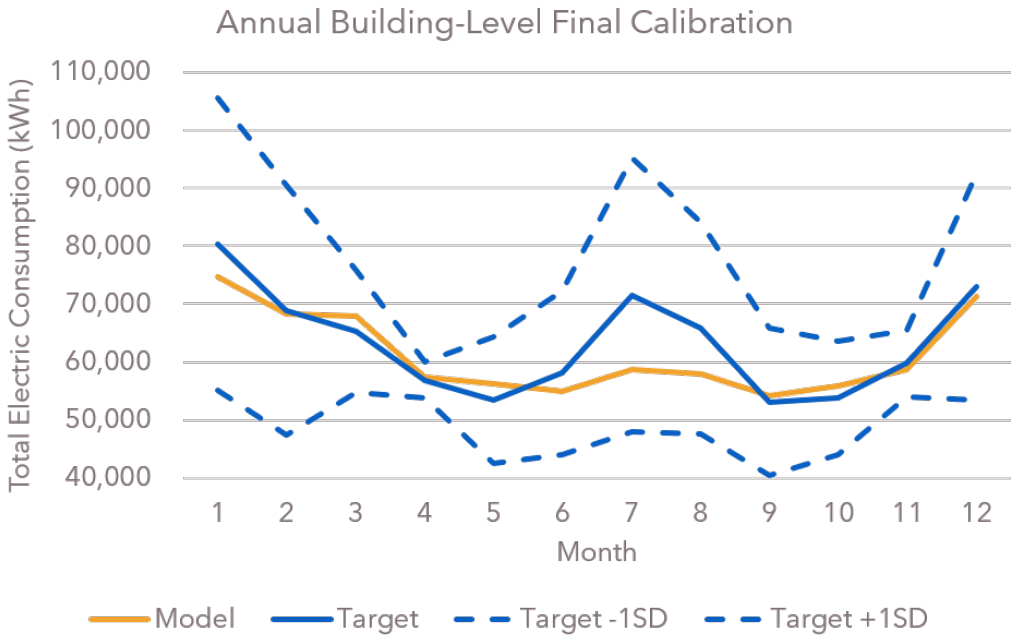


Figure C-9. Primary school ASHP calibration

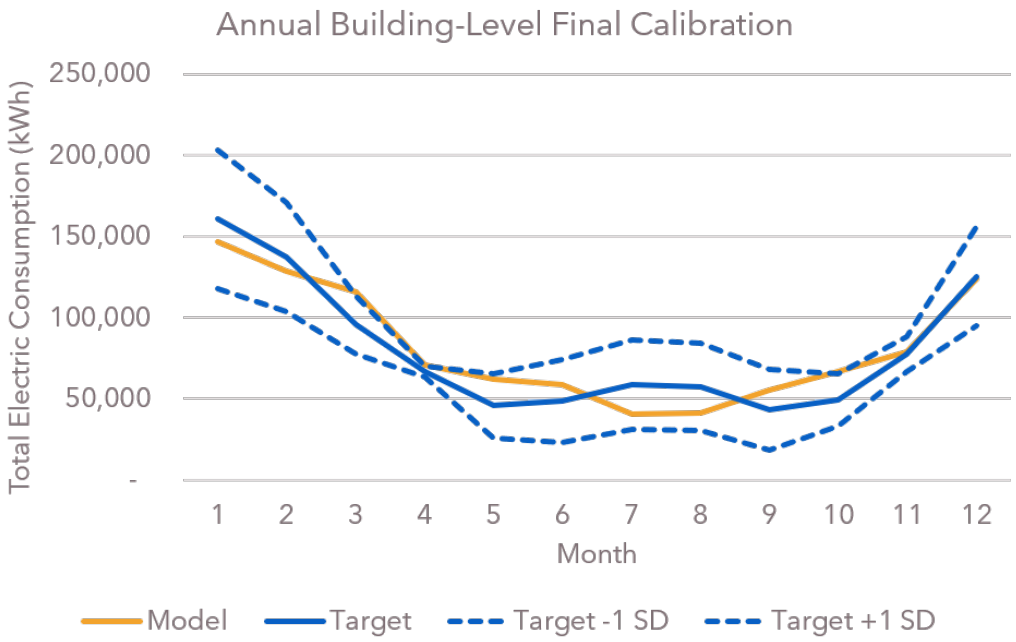


Figure C-10. Primary school VRF calibration

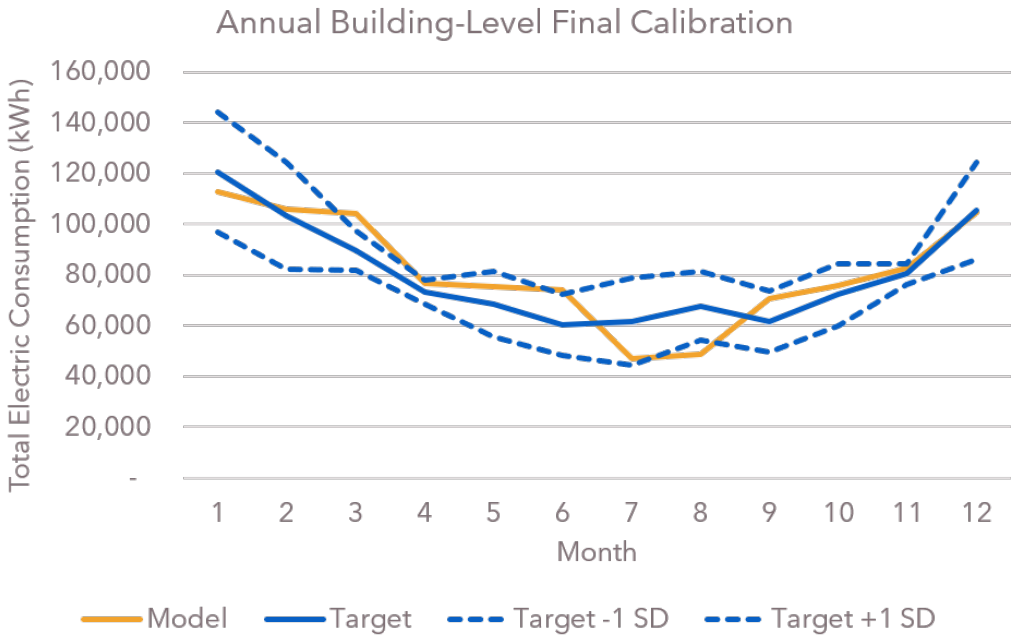


Figure C-11. Warehouse ASHP calibration

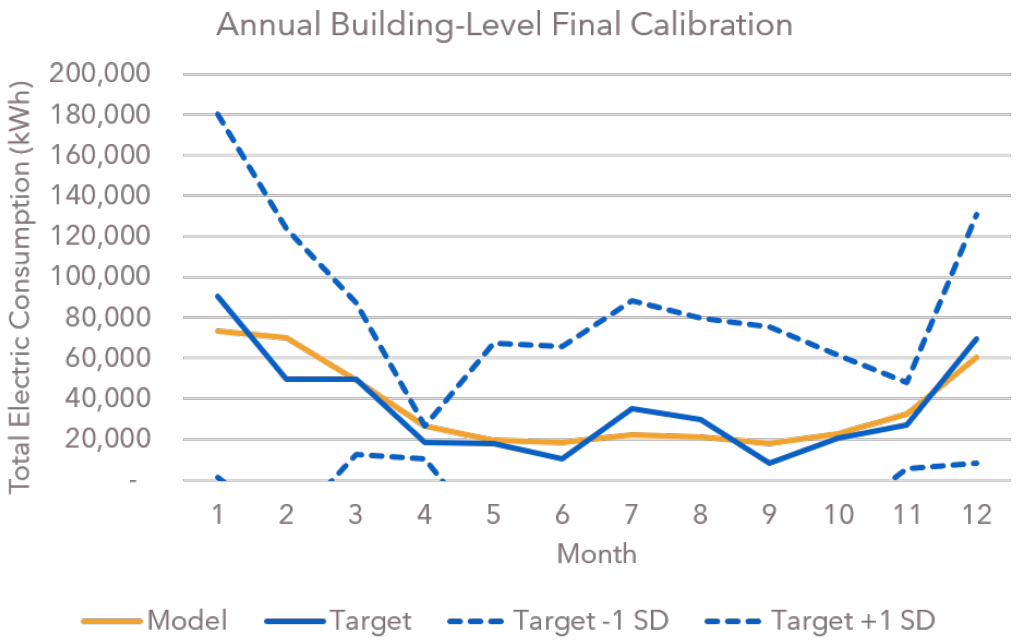
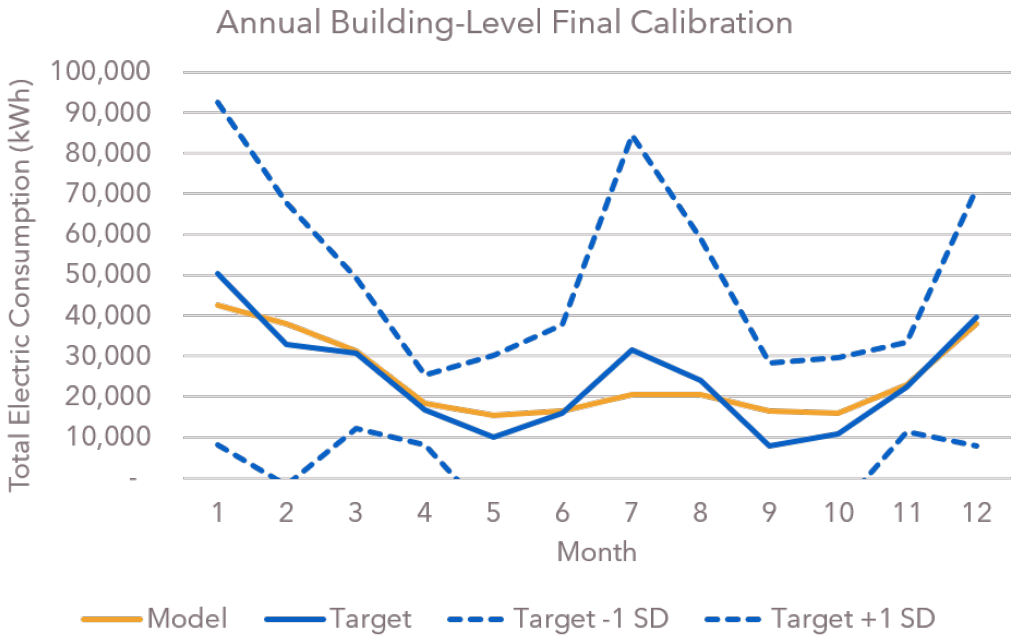


Figure C-12. Warehouse VRF calibration



Installed capacity results

Along with simulation consumption results, installed capacity results were updated in the EO Model as well to reflect changes in installed heat pump capacity after calibration. Table C-5 provides the changes of assumed maximum (between heating and cooling) installed capacity between EO Model v3.0 and EO Model v3.1. As mentioned previously, the EO Model v3.0 applied an average assumed installed capacity across heat pump types for each combination of building type and

climate zone, whereas the EO Model v3.1 more discretely defines installed capacity by climate zone, building type, and HVAC type. Generally, the installed capacity required increased, reflecting that the calibration resulted in a net increase in consumption for baseline and program HVAC systems. In turn, square footage by installed capacity decreased. From a design perspective, the calculated square footage by installed capacity indicates that simulated systems are slightly oversized (defined in this report as less than 300 ft^2/ton). However, the study team does not have concerns with this result given the necessity to ensure calibrated simulations meet target load requirements and because some actual installed systems from site visits had similar sizing characteristics (see Table 2-20).

As a reminder, the calibrated retail stripmall building was used to inform inputs for the retail standalone building type; the retail standalone building type was not calibrated directly due to lack of available data.

Table C-5. Changes in total installed capacity per climate zone, building type, and heat pump type

Climate	Building type	Heat pump type	Total max capacity (tons)		Floor area by total max capacity (ft2/ton)	
			EO Model v3.0	EO Model v3.1	EO Model v3.0	EO Model v3.1
Interior	Midrise Apartment	Air Source Heat Pump	90	90	375	377
Interior	Midrise Apartment	Mini-split - Multi-zone	90	109	375	311
Interior	Midrise Apartment	Mini-split - Single-zone	90	110	375	307
Interior	Midrise Apartment	PTHP	90	120	375	282
Interior	Midrise Apartment	Variable Refrigerant Flow	90	61	375	557
Interior	Medium Office	Air Source Heat Pump	114	178	470	301
Interior	Medium Office	Mini-split - Multi-zone	114	259	470	207
Interior	Medium Office	Mini-split - Single-zone	114	218	470	246
Interior	Medium Office	PTHP	114	218	470	245
Interior	Medium Office	Variable Refrigerant Flow	114	176	470	305
Interior	Small Office	Air Source Heat Pump	14	16	393	336
Interior	Small Office	Mini-split - Multi-zone	14	15	393	361
Interior	Small Office	Mini-split - Single-zone	14	17	393	317
Interior	Small Office	PTHP	14	17	393	315
Interior	Small Office	Variable Refrigerant Flow	14	16	393	345
Interior	Retail Standalone	Air Source Heat Pump	66	137	378	182
Interior	Retail Standalone	Mini-split - Multi-zone	66	119	378	209
Interior	Retail Standalone	Mini-split - Single-zone	66	127	378	197
Interior	Retail Standalone	PTHP	66	129	378	194
Interior	Retail Standalone	Variable Refrigerant Flow	66	89	378	281
Interior	Retail Stripmall	Air Source Heat Pump	57	116	395	194
Interior	Retail Stripmall	Mini-split - Multi-zone	57	86	395	262
Interior	Retail Stripmall	Mini-split - Single-zone	57	86	395	262
Interior	Retail Stripmall	PTHP	57	86	395	262
Interior	Retail Stripmall	Variable Refrigerant Flow	57	52	395	430
Interior	Primary School	Air Source Heat Pump	140	207	528	358
Interior	Primary School	Mini-split - Multi-zone	140	403	528	358
Interior	Primary School	Mini-split - Single-zone	140	358	528	206

Climate	Building type	Heat pump type	Total max capacity (tons)		Floor area by total max capacity (ft2/ton)	
			EO Model v3.0	EO Model v3.1	EO Model v3.0	EO Model v3.1
Interior	Primary School	PTHP	140	358	528	206
Interior	Primary School	Variable Refrigerant Flow	140	225	528	329
Interior	Warehouse	Air Source Heat Pump	86	184	605	283
Interior	Warehouse	Mini-split - Multi-zone	86	123	605	305
Interior	Warehouse	Mini-split - Single-zone	86	130	605	292
Interior	Warehouse	PTHP	86	183	605	284
Interior	Warehouse	Variable Refrigerant Flow	86	232	605	225
Coastal	Midrise Apartment	Air Source Heat Pump	82	90	411	375
Coastal	Midrise Apartment	Mini-split - Multi-zone	82	99	411	341
Coastal	Midrise Apartment	Mini-split - Single-zone	82	99	411	340
Coastal	Midrise Apartment	PTHP	82	113	411	298
Coastal	Midrise Apartment	Variable Refrigerant Flow	82	55	411	610
Coastal	Medium Office	Air Source Heat Pump	108	178	497	300
Coastal	Medium Office	Mini-split - Multi-zone	108	246	497	217
Coastal	Medium Office	Mini-split - Single-zone	108	220	497	243
Coastal	Medium Office	PTHP	108	222	497	242
Coastal	Medium Office	Variable Refrigerant Flow	108	174	497	307
Coastal	Small Office	Air Source Heat Pump	13	16	423	352
Coastal	Small Office	Mini-split - Multi-zone	13	15	423	378
Coastal	Small Office	Mini-split - Single-zone	13	17	423	326
Coastal	Small Office	PTHP	13	17	423	325
Coastal	Small Office	Variable Refrigerant Flow	13	15	423	377
Coastal	Retail Standalone	Air Source Heat Pump	62	139	403	179
Coastal	Retail Standalone	Mini-split - Multi-zone	62	121	403	207
Coastal	Retail Standalone	Mini-split - Single-zone	62	130	403	192
Coastal	Retail Standalone	PTHP	62	132	403	189
Coastal	Retail Standalone	Variable Refrigerant Flow	62	87	403	288
Coastal	Retail Stripmall	Air Source Heat Pump	57	122	395	184
Coastal	Retail Stripmall	Mini-split - Multi-zone	57	90	395	250

Climate	Building type	Heat pump type	Total max capacity (tons)		Floor area by total max capacity (ft2/ton)	
			EO Model v3.0	EO Model v3.1	EO Model v3.0	EO Model v3.1
Coastal	Retail Stripmall	Mini-split - Single-zone	57	90	395	250
Coastal	Retail Stripmall	PTHP	57	90	395	250
Coastal	Retail Stripmall	Variable Refrigerant Flow	57	56	395	404
Coastal	Primary School	Air Source Heat Pump	127	206	582	358
Coastal	Primary School	Mini-split - Multi-zone	127	382	582	194
Coastal	Primary School	Mini-split - Single-zone	127	347	582	213
Coastal	Primary School	PTHP	127	348	582	212
Coastal	Primary School	Variable Refrigerant Flow	127	230	582	321
Coastal	Warehouse	Air Source Heat Pump	72	191	723	272
Coastal	Warehouse	Mini-split - Multi-zone	72	176	723	296
Coastal	Warehouse	Mini-split - Single-zone	72	191	723	272
Coastal	Warehouse	PTHP	72	197	723	264
Coastal	Warehouse	Variable Refrigerant Flow	72	247	723	210

APPENDIX D. STATISTICAL EXPANSION DETAILS

This appendix details the statistical weighting used to expand sampled results to the population level.

Strata and applied base weights

Each row reports a distinct base weight observed within the final analysis stratum and the number of completed sampling units receiving that weight. A repeated stratum label indicates that multiple, more granular weighting cells were pooled into one variance stratum. The represented population equals the completed-unit count multiplied by the base weight, rounded to the nearest whole unit. Customer and site tables show the base weight before any division across repeated analytic records.

Table D-1. Customer survey strata

Final analysis stratum	Completed contacts	Population represented	Base weight
ASHP - Packaged - Natural Gas - Full - 1	14	43	3.071
ASHP - Packaged - Natural Gas - Full - 2	6	19	3.167
ASHP - Packaged - Natural Gas - Partial - 1	7	27	3.857
ASHP - Packaged - Natural Gas - Partial - 2	8	12	1.5
ASHP - Packaged - Natural Gas - Partial - 2	1	2	2
ASHP - Packaged - Other Fuel - Full - 1	8	25	3.125
ASHP - Packaged - Other Fuel - Full - 2	3	13	4.333
ASHP - Packaged - Other Fuel - Partial - 1	1	1	1
ASHP - Packaged - Other Fuel - Partial - 1	1	10	10
ASHP - Split - Natural Gas - Full - 1	21	128	6.095
ASHP - Split - Natural Gas - Full - 2	14	41	2.929
ASHP - Split - Natural Gas - Partial - 1	15	125	8.333
ASHP - Split - Natural Gas - Partial - 2	15	42	2.8
ASHP - Split - Other Fuel - Full - 1	25	148	5.92
ASHP - Split - Other Fuel - Full - 2	7	44	6.286
ASHP - Split - Other Fuel - Partial - 1	9	42	4.667
ASHP - Split - Other Fuel - Partial - 2	7	16	2.286
Mini-split - Natural Gas - Full - 1	31	466	15.032
Mini-split - Natural Gas - Full - 2	18	126	7
Mini-split - Natural Gas - Partial - 1	25	246	9.84
Mini-split - Natural Gas - Partial - 2	22	65	2.955
Mini-split - Natural Gas - Partial - 3	3	4	1.333
Mini-split - Other Fuel - Full - 1	37	434	11.73

Final analysis stratum	Completed contacts	Population represented	Base weight
Mini-split - Other Fuel - Full - 2	32	131	4.094
Mini-split - Other Fuel - Partial - 1	30	117	3.9
Mini-split - Other Fuel - Partial - 2	16	45	2.812
PTHP - Other Fuel - Full - 1	25	168	6.72
PTHP - Other Fuel - Full - 2	11	39	3.545
VRF - Natural Gas - Full - 1	32	179	5.594
VRF - Natural Gas - Full - 2	13	54	4.154
VRF - Natural Gas - Partial - 1	16	45	2.812
VRF - Natural Gas - Partial - 2	11	18	1.636
VRF - Natural Gas - Partial - 2	1	4	4
VRF - Other Fuel - Full - 1	14	52	3.714
VRF - Other Fuel - Full - 2	1	3	3
VRF - Other Fuel - Full - 2	7	24	3.429
VRF - Other Fuel - Partial - 1	6	18	3
Total	**513**	**2976**	**—**

Table D-2. Contractor survey strata

Final analysis stratum	Completed contractors	Population represented	Base weight
ASHP - 1	26	181	6.962
ASHP - 2	4	55	13.75
ASHP - 3	5	18	3.6
MSHP - 1	31	199	6.419
MSHP - 2	4	79	19.75
VRF - 1	10	106	10.6
VRF - 2	5	28	5.6
VRF - 3	4	14	3.5
Total	**89**	**680**	**—**

Table D-3. All on-site strata

Final analysis stratum	Completed sites	Population represented	Base weight
ASHP - Packaged - Natural Gas - Full - 1	7	63	9
ASHP - Packaged - Natural Gas - Partial - 1	2	37	18.5
ASHP - Packaged - Natural Gas - Partial - 2	2	15	7.5
ASHP - Packaged - Other Fuel - Full - 1	3	25	8.333
ASHP - Packaged - Other Fuel - Full - 1	1	13	13
ASHP - Split - Natural Gas - Full - 1	6	128	21.333
ASHP - Split - Natural Gas - Full - 2	4	42	10.5
ASHP - Split - Natural Gas - Partial - 1	4	168	42
ASHP - Split - Natural Gas - Partial - 2	4	58	14.5
ASHP - Split - Other Fuel - Full - 1	6	192	32
Mini-split - Natural Gas - Full - 1	11	464	42.182
Mini-split - Natural Gas - Full - 2	6	126	21
Mini-split - Natural Gas - Partial - 1	4	245	61.25
Mini-split - Natural Gas - Partial - 2	1	4	4
Mini-split - Natural Gas - Partial - 2	7	65	9.286
Mini-split - Other Fuel - Full - 1	5	433	86.6
Mini-split - Other Fuel - Full - 2	6	131	21.833
Mini-split - Other Fuel - Partial - 1	5	117	23.4
Mini-split - Other Fuel - Partial - 2	2	45	22.5
VRF - Natural Gas - Full - 1	14	180	12.857
VRF - Natural Gas - Full - 2	6	54	9
VRF - Natural Gas - Partial - 1	3	45	15
VRF - Natural Gas - Partial - 2	2	22	11
VRF - Other Fuel - Full - 1	2	52	26
VRF - Other Fuel - Full - 2	1	3	3
VRF - Other Fuel - Full - 2	2	24	12
VRF - Other Fuel - Partial - 1	2	18	9
Total	**118**	**2769**	**—**

Table D-4. Metering on-site strata

Final analysis stratum	Completed sites	Population represented	Base weight
ASHP - Packaged - Natural Gas - Full - 1	7	63	9
ASHP - Packaged - Natural Gas - Partial - 1	2	37	18.5
ASHP - Packaged - Natural Gas - Partial - 2	2	15	7.5
ASHP - Packaged - Other Fuel - Full - 1	2	25	12.5
ASHP - Packaged - Other Fuel - Full - 1	1	13	13
ASHP - Split - Natural Gas - Full - 1	4	128	32
ASHP - Split - Natural Gas - Full - 2	3	42	14
ASHP - Split - Natural Gas - Partial - 1	4	168	42
ASHP - Split - Natural Gas - Partial - 2	3	58	19.333
ASHP - Split - Other Fuel - Full - 1	2	192	96
Mini-split - Other Fuel - Full - 1	2	564	282
VRF - Natural Gas - Full - 1	6	180	30
VRF - Natural Gas - Full - 2	3	54	18
VRF - Natural Gas - Partial - 1	1	18	18
VRF - Natural Gas - Partial - 1	1	22	22
VRF - Natural Gas - Partial - 1	1	45	45
VRF - Other Fuel - Full - 1	2	27	13.5
VRF - Other Fuel - Full - 1	1	52	52
Total	**47**	**1703**	**—**

APPENDIX E. PARTICIPANT SURVEY INSTRUMENT

This appendix is included in the following pages.

MA25C04-B-EOModel
Participant Survey Instrument

1 INTRODUCTION (WELCOME PAGE)

Welcome to the Mass Save® Heat Pump Experience Survey!

You received information about the survey because our records indicate you or your organization received an incentive for the purchase and installation of a qualifying heat pump in recent years. On behalf of the Sponsors, DNV Energy Insights and APPRISE are conducting this critical research to help understand how new heat pumps like yours are being used.

This survey should take about 15 minutes to complete. We are offering a $150 e-gift card if you complete the survey.

Please answer the questions to the best of your ability based on your own experience. There are no right or wrong answers; we value your honest feedback and all responses are confidential. Please contact Kyle Bonus at kyle.bonus@dnv.com if you need assistance.

To begin the survey, click “Next”.

2 SCREENER AND INTRO QUESTIONS

S1. [IF MULTIPLE_PROJECTS=0] According to our records, your organization installed the following heat pump that received a Mass Save Commercial Heat Pump Rebate:

Heat Pump Type: [HP TYPE]

Installation Address: [ADDRESS], [CITY], MA

Quantity installed: [Unit_Qty]

Installation Year: [YEAR]

Are you familiar with this heat pump and how it is used at the location?

a. Yes
b. No
c. Don’t know

S1a. [IF MULTIPLE_PROJECTS=1] According to our records, you installed more than one HP project that received a Mass Save Commercial Heat Pump Rebate in 2023 and 2024. Today, our questions will pertain to the following Mass Save rebated heat pump project:

Heat Pump Type: [HP TYPE]

Installation Address: [ADDRESS], [CITY], MA

Quantity installed: [Unit_Qty]

Installation Year: [YEAR]

Are you familiar with this heat pump and how it is used at the location?

a. Yes
b. No
c. Don't know

S2. Are you familiar with the reasons this heat pump was installed?

a. Yes
b. No
c. Don't know

S3. **[IF S1 or S1a = B OR C OR S2= B OR C]** Our questions are best answered by someone familiar with this heat pump and how it is used at the location. Is there someone you can direct us to? If so, please put their name and e-mail address.

- Contact name:
- Contact email:
- I am not comfortable providing this information
  (END SURVEY- TERMINATE 1)

[READ TO ALL] For this survey, please answer all questions thinking about this specific heat pump project, even if you may have installed additional heat pumps at this or other locations.

Heat Pump Type: ${e://Field/HP%20TYPE}
Installation Address: ${e://Field/Full_Address}
Quantity installed: [Unit_Qty]
Installation Year: ${e://Field/Program_Year}

S4. [IF S1 or S1a = A OR S2 = A] Which category best describes the building type where this heat pump was installed?

a. Office
b. Restaurant – Full Service
c. Restaurant - Quick service
d. Education—elementary or secondary school
e. Education—college or university
f. Retail—strip mall
g. Retail—stand-alone
h. Warehouse
i. Manufacturing
j. Hotel
k. Hospital
l. Outpatient
m. Multifamily
n. Public assembly (e.g., religious, entertainment, etc.)
o. Supermarket
p. Other: [OPEN TEXT BOX]

S4a. Was the heat pump installed in an existing building or was it installed in a newly constructed building?

a. The heat pump was installed in an existing building.

b. The heat pump was installed in a new building that was recently constructed *(END SURVEY – TERMINATE 2)*

S4b. Was the heat pump installed as a part of a major renovation or gut rehab project that included structural changes to transform the building's layout or functionality?

a. Yes – part of major renovation / gut rehab project *(END SURVEY – TERMINATE 2)*
b. No – not part of major renovation / gut rehab project

S5. What is the total square footage of the building where the heat pump is installed? Please provide the total square footage of the building even if your heat pump doesn't heat and cool the entire building. Your best estimate is fine.

1. Less than 2,000 square feet
2. 2,001 to 4,000 square feet
3. 4,001 – 10,000 square feet
4. 10,001 – 25,000 square feet
5. 25,001 – 50,000 square feet
6. 50,001 – 100,000 square feet
7. More than 100,000 square feet

Terminate 1: Thank you. This survey is intended for someone familiar with the heat pump and its use. We sincerely appreciate your time and hope you have a great day. If you have any questions or believe there was a mistake, please contact Kyle Bonus at kyle.bonus@dnv.com.

Terminate 2: Thank you. This survey is intended for locations where heat pumps were installed in existing buildings. We sincerely appreciate your time and hope you have a. great day. If you have any questions or believe there was a mistake, please contact Kyle Bonus at kyle.bonus@dnv.com.

S6. [IF ONSITE ELIGIBLE=1] Before moving on, we'd like to share an upcoming opportunity. This fall, our team will be conducting on-site visits to better understand how equipment such as [HP Type]s are being installed and used. Your contribution to this research would help improve the Mass Save program and the energy savings and greenhouse gas impact estimates we use.

a. Yes, I am interested in being contacted

b. No, I am not interested

S7. [IF S6=a] Please provide the contact information of the best person for us to reach out to about scheduling this site visit:

a. Name (first, last): [OPEN TEXT BOX]

b. Email: [OPEN TEXT BOX]

c. number: [OPEN TEXT BOX]

3 QUESTIONS

3.1 Characterizing the Installation

The next questions ask about how the heat pump is used.

1. Do you use the **[HP TYPE]** for heating only, for cooling only, or for both heating and cooling?
   a. Heating only
   b. Cooling only
   c. Both Heating and Cooling
   d. Don't Know

2. Does the **[HP TYPE]** you installed serve the entire building or only a portion of the building?
   a. Entire building
   b. A portion of the building
   c. Don't Know

3. [IF Q2=B] About what percent of your building's square footage is served by the new **[HP TYPE]**? Please answer from 1 percent to 99 percent.
   a. Enter Percent of building served by heat pump: (specify) __%
   b. Don't Know

4. [IF Q1=A OR C AND Q2=A] Thinking about heating for this location, did the **[HP TYPE]**…
   a. Replace your building's previous heating system entirely (i.e., you removed or disconnected your previous system)
      [Indicates full displacement]
   b. Become your building's new primary heating system but you kept your previous heating system as a backup *[Indicates partial displacement; ER baseline]*
   c. Add heating to a building that was not previously heated *[Indicates added load, not replacement; ROF baseline]*
   d. Don't Know

5. [IF Q1=A OR C AND Q2=B or C] Thinking about heating for this location, did the **[HP TYPE]**…
   a. Replace the heating system in that portion of your building entirely (i.e., you removed the previous system heating that space) *[Indicates full displacement]*
   b. Become the new primary heating system for that portion of your building, but you kept your previous heating system as a backup *[Indicates partial displacement; ER baseline]*
   c. Provide additional heating capacity to a portion of your building that wasn't sufficiently heated *[Indicates added load, not replacement; ROF baseline]*
   d. Add heating to a portion of your building that was not previously heated *[Indicates added load, not replacement; ROF baseline]*
   e. Don't Know

6. [IF Q1=B OR C AND Q2=A] Thinking about cooling for this location, did the **[HP TYPE]**…
   a. Replace your building's previous air conditioning system entirely (i.e., you removed your previous system)
      [*Indicates full displacement*]
   b. Become your building's new primary air conditioning system but you kept your previous cooling system as a backup *[Indicates back-up or supplemental system, partial displacement; ER baseline]*
   c. Provide cooling to your building that didn't previously have air conditioning *[Indicates added load, not replacement; ROF baseline]*

7. [IF Q1=B OR C AND Q2=B or C] Thinking about cooling for this location, did the [HP TYPE]…
   a. Replace the cooling system in that portion of your building entirely (i.e., you removed the previous system cooling that space) *[Indicates full displacement]*

b. Become the new primary cooling system for that portion of your building, but you kept your previous air conditioning system as a backup *[Indicates partial displacement; ER baseline]*
c. Provide additional cooling capacity to a portion of your building that had air conditioning but was not sufficiently cooled before *[Indicates added load, not replacement; ROF baseline]*
d. Add cooling to a part of your building that didn't previously have air conditioning *[Indicates added load, not replacement; ROF baseline]*
e. Don't Know

8. [IF Q6=A OR B OR Q7 = A OR B] Which of the following best describes how your space cooling setpoint changed at your business since the [HP TYPE] was installed?
   a. Decreased cooling setpoint by 3°F or more
   b. Decreased cooling setpoint by 1° to 2°F
   c. No change in cooling setpoint
   d. Increased cooling setpoint by 1° to 2°F
   e. Increased cooling setpoint by 3°F or more
   f. Other, please specify; [OPEN TEXT BOX]
   g. Not sure

3.2 Determining Pre-program HVAC System

[SKIP IF Q1=B OR Q4=C OR Q5=D]

9. [IF Q2=A] Prior to installing the **[HP TYPE]**, what kind of fuel did you use to heat your building?
   a. Electric
   b. Natural gas
   c. Oil
   d. Propane
   e. Mixed/Multiple Fuels/Other
   f. Don't Know

10. [IF Q2=B OR C] What kind of fuel did you use to heat the portion of your building that is now served by the new **[HP TYPE]**?
   a. Electric
   b. Natural gas
   c. Oil
   d. Propane
   e. Mixed/Multiple Fuels/Other
   f. Don't Know

11. [IF Q9=E] Please briefly describe the mix of fuel types and HVAC systems used to heat your building.
   (specify): _____[write in]

12. [IF Q10=E] Please briefly describe the mix of fuel types and HVAC systems used to heat this portion of your building.
   (specify): _____[write in]

13. [IF Q9=A OR Q10=A] Which of the following most closely describes your building's previous heating system?
   a. Air source heat pump
   b. Ground source heat pump
   c. Radiant electric
   d. Electric furnace
   e. Electric boiler
   f. Electric reheat
   g. Other (specify): _____[write in]

h. Don't Know

14. [IF Q9=B, C, OR D OR Q10=B, C, OR D] Which of the following most closely describes your building's previous heating system?

a. Unit/Space heater(s)
b. Furnace or packaged unit
c. Boiler
d. Other (specify): _____[write in]
e. Don't Know

3.3 Replacement and Repair

[IF Q1=A OR C AND Q4 = A OR Q5= A]

15. What was the status of the previous heating system when you replaced it with the **[HP TYPE]**?
a. Prior system was working with no need of repair *[Indicates Early Replacement]*
b. Prior system was working but needed minor repair *[Indicates Early Replacement]*
c. Prior system was working but needed major repair *[Indicates Early Replacement]*
d. Prior system was not working at all *[Indicates Replace on Fail]*
e. Other scenario, please specify: [OPEN TEXT BOX]
f. Don't know

16. [IF Q15= B, C, or D] Before you had your old heating equipment replaced, roughly how many years had this equipment required repairs in order to run properly?
a. SLIDING SCALE from 0 to 15 years.

17. [IF Q16 > 1] Why did you choose to repair your old heating system rather than replace it with a new one? Please select all that apply. [ALLOW MULTIPLE RESPONSES]
a. Equipment performance problem wasn't serious enough to justify replacement
b. Financial barriers/budget constraints made it difficult to afford replacement
c. Other building/facility improvement projects were considered a higher priority
d. Couldn't find suitable replacement equipment for the needs of our building
e. Couldn't find reliable HVAC contractor to install the replacement equipment
f. Other scenario [SPECIFY] _____
g. Don't know [exclusive]

18. About how old was your previous heating system when you had it replaced?
a. Greater than 15 years
b. 10-15 years
c. 5-10 years
d. Less than 5 years
e. Don't Know

[IF Q1=B OR C AND Q6 = A OR Q7= A]

19. What was the status of the previous cooling system when you replaced it with the **[HP TYPE]**?

a. Previous system was working with no need of repair *[Indicates Early Replacement]*
b. Previous system was working, but needed minor repair *[Indicates Early Replacement]*
c. Previous system was working, but needed major repair *[Indicates Early Replacement]*
d. Previous system was not working at all *[Indicates Replace on Fail]*
e. Other scenario, please specify: [OPEN TEXT BOX]
f. Don't know

20. [IF Q19= B, C, or D] Before you had your old cooling equipment replaced, roughly how many years had this equipment required repairs in order to run properly?
    a. SLIDING SCALE from 0 to 15 years.

21. [IF Q20 > 1] Why did you choose to repair your old cooling system rather than replace it with a new one? Please select all that apply. [ALLOW MULTIPLE RESPONSES]
    a. Equipment performance problem wasn't serious enough to justify replacement
    b. Financial barriers/budget constraints made it difficult to afford replacement
    c. Other building/facility improvement projects were considered a higher priority
    d. Couldn't find suitable replacement equipment for the needs of our building
    e. Couldn't find reliable HVAC contractor to install the replacement equipment
    f. Other scenario [SPECIFY] _____
    g. Don't know

22. About how old was your previous cooling system when you had it replaced?
    a. Greater than 15 years
    b. 10-15 years
    c. 5-10 years
    d. Less than 5 years
    e. Don't Know

3.4 Determining Counterfactual System

23. [IF Q6=c or Q**Error! Reference source not found.**c or d] If you had not installed the **[HP TYPE]** to provide cooling, would you have installed another cooling technology in that space?
    a. Yes
    b. No
    c. Don't know

24. [IF Q9=A OR Q10=A – RESPONDENTS THAT ALREADY HEATED WITH ELECTRICITY]
    If you had not installed the **[HP TYPE]**, would you have installed another **[Q13 RESPONSE]**?
    a. Yes [Indicates like-for-like replacement
    b. No [Indicates non-like-for-like replacement]
    c. Don't Know

25. [IF Q10=B, C, OR D - RESPONDENTS THAT DID NOT PREVIOUSLY HEAT WITH ELECTRICITY] If you had not installed the **[HP TYPE]**, would you have installed another **[Q9/Q10 RESPONSE] [Q14**

RESPONSE]?

a. Yes [Indicates like-for-like replacement]
b. No [Indicates non-like-for-like replacement]
c. Don't Know

26. [IF Q25=B OR C] Would you have continued to heat your building with **[Q9/10 RESPONSE]**?
    a. Yes
    b. No [Indicates fuel-switching]
    c. Don't Know

27. [IF Q26=B] What kind of fuel would you have switched to? [EXCLUDE Q9 RESPONSE A,B,C, D RESPONSE]
    a. Electric
    b. Natural gas
    c. Oil
    d. Propane
    e. Don't Know

28. [IF Q27=A] What electric heating system would you have **most likely** installed?
    a. Air source heat pump
    b. Ground source heat pump
    c. Radiant electric
    d. Electric furnace
    e. Electric boiler
    f. Electric reheat
    g. Other (specify): ___ [write in]
    h. Don't Know

29. [IF Q27=B, C, OR D] What type of **[Q31 RESPONSE]** heating system would you have **most likely** installed?
    a. Unit/Space heater
    b. Furnace or packaged unit
    c. Boiler
    d. Other (specify): ___ [write in]
    e. Don't Know

3.5 Schedule and Set Points

30. [IF S4 = MULTIFAMILY, HOSPITAL, OR HOTEL, SKIP TO Q35] On average, what time you're your business open, from Monday – Friday? [PROVIDE DROP DOWN OPTION 12:00AM – 11:00PM]

31. [IF S4 = MULTIFAMILY, HOSPITAL, OR HOTEL, SKIP TO Q35] On average, what time you're your business close, from Monday – Friday? [PROVIDE DROP DOWN OPTION 12:00AM – 11:00PM]

32. [IF S4 = MULTIFAMILY, HOSPITAL, OR HOTEL, SKIP TO Q35] On average, what time does your business open, from Saturday-Sunday? [PROVIDE DROP DOWN OPTION 12:00AM -

11:00PM, AS WELL AS A 'CLOSED' OPTION]

33. [IF S4 = MULTIFAMILY, HOSPITAL, OR HOTEL, SKIP TO Q35] On average, what time does your business close, from Saturday-Sunday? [PROVIDE DROP DOWN OPTION 12:00AM - 11:00PM, AS WELL AS A 'CLOSED' OPTION]

34. [IF S4 = MULTIFAMILY, HOSPITAL, OR HOTEL, SKIP TO Q35] In the following scenarios, on average, about how many degrees do you keep the space with the new heat pump equipment?
    a. Heating season – during business hours [SLIDER]
    b. Heating season - during business hours [SLIDER]
    c. Cooling season – during business hours [SLIDER]
    d. Cooling season – outside of business hours [SLIDER]
35. [IF S4 ≠ MULTIFAMILY, HOSPITAL, OR HOTEL, SKIP TO Q37] Who controls the setpoints for the rebated HP?
    a. Occupants and/or guests
    b. Building management
36. [IF Q35 =b] On average, about how many degrees do you keep the space with the new heat pump equipment?
    a. Heating season [OPEN TEXT BOX]
    b. Cooling season [OPEN TEXT BOX]

3.6 NRE [IF HP TYPE = Variable Refrigerant Flow, Air Source Heat Pump]

37. Have there been any changes in ownership, tenancy, or business type at the facility since 2022?
    a. Yes
    b. No
    c. Don't know
38. [IF Q37=a] Please describe the change in ownership, tenancy, or business type that has occurred at the facility since 2022. Please estimate the timing of that change.
    a. Change in ownership, tenancy, or business type: [OPEN TEXT BOX]
    b. Timing of changes: [OPEN TEXT BOX]
39. Has the facility experienced any notable changes in occupancy or staffing, business hours, production, or number of shifts since 2021?
    a. Yes
    b. No
    c. Don't know
40. [IF Q39=a] Please describe the changes in occupancy or staffing, business hours, production, or number of shifts that have occurred at the facility since 2022. Please estimate the timing of the change(s).
    a. Change in occupancy or staffing, business hours, production, or number of shifts: [OPEN TEXT BOX]
    b. Timing of changes: [OPEN TEXT BOX]
41. Excluding the heat pump(s), have there been any additions or removals of major energy-consuming equipment at the facility since 2021?
    a. Yes
    b. No
    c. Don't know
42. [IF Q41=a] Please describe the additions or removals of major energy-consuming equipment that have occurred at the facility since 2022. Please estimate the timing of that change.
    a. Additions or removals of major energy-consuming equipment: [OPEN TEXT BOX]
    b. Timing of changes: [OPEN TEXT BOX]
43. Has the facility expanded or reduced the square footage of heated floorspace since the heat pump was installed?
    a. Yes
    b. No
    c. Don't know
44. [IF Q43=a] Please describe the increase or decrease in heated square footage that has occurred at the facility since the heat pump was installed. Please estimate the timing of that change. If possible, please

estimate the percentage increase or decrease of the heated floorspace.
a. Increase or decrease in heated square footage: [OPEN TEXT BOX]
b. Timing of that change: [OPEN TEXT BOX]
c. Percentage increase or decrease of the heated floorspace: [OPEN TEXT BOX]

45. Has the space heating setpoint changed at the facility since the heat pump was installed?
    a. Yes
    b. No
    c. Don't know
46. [IF Q45=a] Which of the following best describes how your space heating setpoint changed at the facility since the heat pump was installed.
    a. Decreased heating setpoint by 3°F or more
    b. Decreased heating setpoint by 1° to 2°F
    c. No change in heating setpoint
    d. Increased heating setpoint by 1° to 2°F
    e. Increased heating setpoint by 3°F or more
    f. Other, please specify; [OPEN TEXT BOX]
    g. Not sure

3.7 Incentives, Installation & Satisfaction

47. On a scale of 1 to 5, where 1 means not at all important, and 5 means very important, how important were the incentives to your business' decision to install a heat pump?
    a. 1 - Not at all important
    b. 2 - Slightly important
    c. 3 - Moderately important
    d. 4 - Very important
    e. 5 - Extremely important
48. What were your businesses motivations to pursuing a heat pump? Please select all that apply. [ALLOW MULTIPLE RESPONSES]
    a. Reduce energy costs / save on utility bills
    b. Improve building comfort (heating or cooling)
    c. Environmental / sustainability goals
    d. Incentives offered through Mass Save or other programs
    e. Upgrade or replace old equipment
    f. Reduce greenhouse gas emissions
    g. Other, please specify; [OPEN TEXT BOX]
49. How was the incentive you received for the [HP TYPE] paid?
    a. I received a check directly from Mass Save
    b. My installer received the incentive on behalf of my business and deducted it from my bill
    c. Other, please specify;
    d. Don't know
50. How satisfied were you with the following elements of the **[HP TYPE]** process? [MATRIX USE Very satisfied, Somewhat satisfied, Neither satisfied nor dissatisfied, Somewhat dissatisfied, Very dissatisfied, Don't know]
    a. The incentive payment process
    b. The contractor selling/installing the heat pump equipment
    c. The performance of the equipment
51. [IF options = somewhat dissatisfied OR very dissatisfied] Why were you dissatisfied with the following element(s)?
52. How did the installation contractor train your team on using and maintaining the equipment? Please select all that apply [ALLOW MULTIPLE RESPONSES]
    a. In-person training
    b. Provided a manual
    c. Provided written materials (e.g., brochures, handouts)
    d. Video or online training
    e. No training [EXCLUSIVE]
    f. Other, please specify; [OPEN TEXT BOX]

3.8 Local Ordinances

[SKIP FOR BUSINESSES NOT LOCATED IN CAMBRIDGE OR BOSTON, cambridge_boston =0]

53. [For CAMBRIDGE LOCATIONS, cambridge_boston =2] Before now, were you aware that the City of Cambridge has an ordinance that requires large (over 100,000 square feet) non-residential buildings to reduce greenhouse gas emissions and achieve net zero emissions by 2035, and requires mid-size (between 25,000 and 100,000 square feet) non-residential buildings to do so by 2050?

a. Yes, I was aware of these specific requirements
b. Yes, I was generally aware of the requirements, but not the specific details
c. No, I was not previously aware of the requirements

54. [FOR BOSTON LOCATIONS, cambridge_boston =1] Before now, were you aware the City of Boston has an ordinance that requires buildings over 20,000 square feet to gradually reduce their greenhouse gas emissions until they reach net zero emissions in 2050?

a. Yes, I was aware of these specific requirements
b. Yes, I was generally aware of the requirements, but not the specific details
c. No, I was not previously aware of the requirements

55. [IF Q53 OR Q54 = A OR B] Did your knowledge of these emission reduction ordinances from your city/town have any influence in your decision to install your heat pump(s)?

a. Yes
b. No
c. Don't know

56. [IF Q55 = YES] How did your knowledge of these emission reduction ordinances from your city/town influence your decision to install your heat pump(s)? Please select all that apply. [ALLOW MULTIPLE RESPONSES]

a. It was the deciding factor in our choice to install the heat pump
b. It made us more likely to install the heat pump than we otherwise would have
c. It encouraged us to install the heat pump sooner than we otherwise would have
d. It encouraged us to install a larger heat pump than we otherwise would have
e. Other form of influence, please specify; [OPEN TEXT BOX]

f. Don't know [EXCLUSIVE]

4 CLOSING

We just have a few final questions before the survey is complete.[IF S6=NO]

59. As part of our research, we are also conducting on-site visits with a small number of participants to better understand how heat pump equipment is being used at locations like yours. As someone who has direct experience with the equipment your contribution to this research would help improve the program. Participants will receive an additional $200 to $250 incentive or charitable donation for participating in this additional research, and our team can review the process with you to answer any questions.

    Are you interested in learning more about this opportunity?

    a. Yes, I am interested in learning more.

    b. No, I am not interested.

60. [IF 59=a] Great. Please provide your contact information and we will reach out with additional information.

    a. Name (first, last): [OPEN TEXT BOX]

    b. Title: [OPEN TEXT BOX]

    c. Email: [OPEN TEXT BOX]

    d. Phone number: [OPEN TEXT BOX]

61. [IF 59=b] Finally, can you please provide your contact information in case we have any additional follow-up questions?

    a. Name

    b. Title

    c. Email address

    d. Phone

    e. I prefer not to share this

62. This concludes our survey. We are offering a $150 Tango e-gift card as a thank you for your participation. The Tango card gives you the option to select a cash payout, a prepaid debit card, a merchant gift card, or donating to charity organizations.

    Please provide your email address if you would like to receive the e-gift card, or please indicate if you decline to receive it.

    a. Email for e-gift card: [OPEN TEXT BOX]

b. I do not want the e-gift card

**By agreeing to receive an e-gift card from Tango, you agree that DNV may share your email address with Tango. Tango's use, control, and/or processing of your email address (and any other personal information they may require for you to receive or activate a Tango gift card) will be governed by Tango's Privacy Policy.*

You have completed the survey. Thank you! [IF Q62 ≠ B: You will receive an e-gift card within 2 weeks from noreply@tangocard.com.

APPENDIX F. CONTRACTOR SURVEY INSTRUMENT

This appendix is included in the following pages.

MA25C04-B-EOModel
Installation Contractor Survey Instrument

1.1 Overview

The MA EO Model v3.0 long-term update study (MA25C04-B-EOModel)[1] includes a survey of participating installation contractors to validate key savings assumptions, including counterfactual systems, fuel types, and relevant market events. This survey will enhance the robustness of empirical data collected through on-site visits and customer surveys by offering a broader market perspective and corroborating information for the following critical modeling inputs.

- Prevalence of event types, specifically early replacement and replace on failure. (see 1.5.1)
- Common pre-program equipment types and fuels, for specific heat pump and building types (see 1.5.2)
- Typical counterfactual equipment types and fuels, for specific heat pump and building types (see 1.5.3)
- Prevalence of supplemental heating fuel types (see 1.5.2 and 1.5.3)
- Prevailing equipment sizing practices (see 1.5.4)
- Common dual-fuel control strategies and switchover settings (see 1.5.4)
- Variable refrigerant flow (VRF), air-source heat pump (ASHP) and mini-split ventilation practices (see 1.5.4)

The team will also collect insights on two market issues covered in the participant surveys[2]:

- Local emissions reduction ordinances in Boston and Cambridge (see 1.5.5)
- Dual baselines for established customers in Disadvantaged Energy Communities (DECs) (see 1.5.6)

The contractors will be drawn from the same 2023-2024 project cohort as the customer surveys and on-sites, meaning the contractors surveyed are those who worked on the projects from that program period. This alignment ensures that all data collection efforts cover the same program timeframe and population, making the results consistent and comparable. By using the same sample frame for contractors, customers, and on-sites, the evaluation team can directly corroborate findings across datasets (for example, a contractor's description of typical configurations can be checked against on-site data from similar buildings) and support integrated analysis.

[1] The original work plan included contractor interviews. However, after reviewing contractor contact data and developing the instrument, the team determined that the same web survey approach successfully employed for the v2.1 EO Model study would likely result in more consistent data and a larger number of completes, as well as less respondent burden and more efficient use of study resources. In particular, the structure of questions is prescriptive and quantitative, which is better suited for a visual web format with forced choices ensuring specific numeric responses. In addition, nearly 80% of contractor records have an email address, and using a web survey approach, the v2.1 study team completed 70 surveys with installation contractors, well above the targeted 30 completes for that study, and the originally planned 25 interviews for the v3.0 study. The current study team has also leveraged the v2.1 instrument and Qualtrics programming in developing this survey, improving comparability of results across the studies. Finally, respondent burden for web surveys is lower due to avoiding the need to schedule interviews, and shorter time required to complete web surveys compared to interviews.

[2] As stated in the workplan, contractors' broader market perspective will provide a stronger basis for determining whether, and what, adjustments are needed to future program proportions to reflect increased deployment in Boston and Cambridge where local ordinances are in effect; as well as to assess the typical HVAC repair and replacement practices for select customer types in DECs relative to non-DECs.

1.2 Survey Implementation Procedures

DNV will conduct the surveys using our membership with the web-based Qualtrics platform. We will program the survey with embedded data, test for correct display, and ensure skip logic and total sum logic align with the MS Word document. Questions will be programmed with a force response.

Before distributing the survey to the sample frame, we will conduct a user experience (UX) test internally. After the UX test, we will "soft-launch" the survey invitation to a subset of contractors. Once initial responses are collected, we will review the data for completeness and incorporate any necessary feedback and changes deemed appropriate before launching a census attempt to the full sample frame.[3]

Survey respondents will receive up to four email reminders during the study. If response rates or target strata are below expectations, we may email and/or call companies to engage preferred respondents. Respondents will be offered an incentive, which DNV will distribute periodically throughout the survey period.

1.3 Distribution Plan MA EO Survey

DNV will copy the survey instrument for each of the four technology types to improve oversight of sample goals and reminder emails. The data files should be organized accordingly.

Amber plans to send three reminders along with the initial invite -4 days have the last wave distributed.

Geoff Mitchill will serve as the contact for phone calls. – Revise letter, check if he has a Qualtrics account.

- **Thu-Fri 4/2-3:** CQ/MI to create tracker for recruitment emails, completes (& targets) by strata, incentives
- **Fri 4/3:** National Grid supplemental emails by end of week from Erin Crafts
- **Mon 4/6:** Finalize sample frame (CQ and NC)
- **Mon 4/6**: Send NMR full email list to identify overlap (MI, using file from CQ); NMR sends overlap list back to MI by COB
- **Mon 4/6:** AW to send GM the spreadsheet w names/emails/unique URL so he can field calls
- **Tue 4/7 morning**: Send PAs the list of contractor emails for each PA for the advance emails (file from CQ, assign all contractors to only one PA; include DNV dummy email to confirm distribution. MI to send, and copy AW and CQ)
- **Tue 4/7 afternoon**: PA implementers distribute advance email to contractors
- Distribute survey email (Wed AM/Thu AM ET next week)
    - **Wed 4/8 AM:** 20% first wave;
    - **Wed 4/8 PM**: CQ downloads/checks in case of issues to address prior to Apr 9 distribution;
    - **Thu 4/9 AM:** 80% second wave
    - **Tue 4/14:** Reminders to both waves
    - **Fri 5/1**: Tentative date to close survey
- Subcommittee Meetings:
    - **4/14, 4/28, 5/12**: include slide with survey disposition (from tracker—number of emails, completes, and target completes, by strata)

[3] Given the response rate for the v2.1 contractor survey of 7.5%, and the expected size of the sample frame (~750 unique contractors with contact information), the team expects to survey a census of the contractor population.

Dates	Task	Action items	Completion notes
27-Mar	NMR Schedule	Identity their schedule to update the letter (Amber) – get a deadline by Wed 1st.	Sent
27-Mar	Geoff as phone back up	Email Geoff on backup resource - confirmation.	Sent
Monday March 30	Send implementation contractor copy of the letter	**Draft to Miles on Monday** **Miles to send to implementer and CC Amber**	
Tues. March 31	Subcommittee meeting	Final day to deliver files with contact data gaps (Miles to acquire)	
Wed. April 1		Miles to add Amber to project folder on the server.	
		Catherine prepares a tracker with the wave and count for tracking completes and goals.	
Wed. April 1	Send implementation contractor sample that needs to receive the letter	Miles to send and CC Amber and Catherine.	
Thurs April 2	DNV distributes pilot	Amber to issue - 20% of sample for all technology types.	
	Sample design finished by AM	Prepare files by NMR and non-NMR and by technology type. Set aside a wave of sample for testing. (Catherine).	
	Geoff M will be the contact for phone call backups		

Dates	Task	Action items	Completion notes
Monday April 8	Sample distribution 50%; reminders to follow on Tuesday 13th, Reminders to follow on Monday 20th, Final reminder 23rd. Close Survey Friday May 1st.	Amber will distribute	
Tuesday April 14th	Sample distribution last 30%.	Amber will distribute	
	Reminders April 20th, 23th; 28th		
	Close Survey Friday May 1st.		
Dates	Task	Action items	Completion notes

1.4 Advance Email Template – for Implementer

WE ARE MASS SAVE®:

Subject: Advance Notice – Two Opportunities to Share Your Expertise with Mass Save®

Dear Program Partner,

Thank you for your continued partnership with the Mass Save® Commercial Heat Pump Rebate. Program records indicate your organization installed heat pumps in 2023 or 2024. The sponsors of Mass Save® are currently researching heat pump installation practices in commercial and multifamily buildings, **and your company has been selected as a preferred partner** to provide insights to help enhance the program and increase energy savings for contractors and customers.

You will receive email invitations to participate in this research over the next several days. There are **two separate heat pump surveys** being administered. Mass Save® has partnered with DNV Energy and the NMR Group to conduct these independent studies.

To thank you in advance for your time, **you will be offered a $150 e-gift card for each completed survey**. Depending on when you participated and what types of equipment you installed, you may be invited to participate in one or both surveys. If you participate in both, **you can receive $300**.

Your responses will remain confidential and will only be reported in group summaries. To verify the legitimacy of the Mass Save® surveys, please contact Nate Baker at 781-441-5974 or nathan.baker@eversource.com.

Thank you for your time and for supporting the Mass Save® program.

Sincerely,
Implementer name
On behalf of the Sponsors of Mass Save®

1.5 Survey Email Template – Overlapping Sample

From [dnvsurvey@qualitrics.com "Mass Save® Heat Pump Study"]

Email Subject: Reminder: Two Opportunities to Share Your Expertise with Mass Save®

Dear ${e://Field/CompanyName}

According to our records, your organization installed heat pumps in 2023 and/or 2024 that received a Mass Save® Commercial Heat Pump Rebate. Thank you for your continued partnership as a valued HVAC contractor for the Mass Save® program.

On behalf of the Sponsors of Mass Save®, DNV Energy Insights is conducting important research to better understand heat pump installation practices in commercial and multifamily buildings. Your company has been selected as a preferred partner to contribute to this study, which will provide insights to help enhance the program and increase energy savings for contractors and customers.

We recognize that your time is valuable and are **offering a $150 e-gift card** to complete this survey. The survey takes approximately **10–15 minutes** to complete, and you may pause and return at any time. Topics include installation practices, system configurations, and other aspects of your experience delivering heat pump projects.

You can complete the survey using one of the following options:

Option 1
• Follow this link to the survey: *Take the survey*
• Access code: ${e://Field/Authentication%20code}

Option 2
• Complete the survey by phone calling DNV Energy, **Geoff Mitchill** at 860-575-4125

Your responses will be kept completely confidential and reported only in aggregate. A brief follow-up call may be requested to clarify responses.

There is also a second, related Mass Save® survey currently underway. Your company will be contacted separately for that survey, which also offers a **$150 e-gift card** for participating, in appreciation of your time. You will receive an email from NMR Group and M. Davis & Co for this survey in the coming week.

To confirm the legitimacy of this survey, you may contact **Nate Baker** at 781-441-5974 or nathan.baker@eversource.com.

Thank you for your time and continued support of the Mass Save® program.

Sincerely,
DNV Energy Insights
On behalf of the Sponsors of Mass Save®

Follow the link to opt out of future emails:
Click here to unsubscribe

1.6 Survey Email Template – DNV only Sample

WE ARE MASS SAVE®:

From [dnvsurvey@qualitrics.com "Mass Save® Heat Pump Study"]

Email Subject: Share Your Heat Pump Installation Expertise with Mass Save® and Earn a Generous Incentive

Dear ${e://Field/CompanyName},

According to our records, your organization installed heat pumps in 2023 and/or 2024 that received a Mass Save® Commercial Heat Pump Rebate. Thank you for your continued partnership as a valued HVAC contractor for the Mass Save® program.

On behalf of the Sponsors of Mass Save®, DNV Energy Insights is conducting important research to better understand heat pump installation practices in commercial and multifamily buildings. **Your company has been selected as a preferred partner** to contribute to this study, which will provide insights to help enhance the program and increase energy savings for contractors and customers.

We recognize that your time is valuable and are **offering a $150 e-gift card** for completing this survey. The survey takes approximately **10–15 minutes** to complete, and you may pause and return at any time. Topics include installation practices, system configurations, and other aspects of your experience delivering heat pump projects.

You can complete the survey using one of the following options:

Option 1
• Follow this link to the survey: *Take the survey*
• Access code: ${l://SurveyLink?d=Take the survey}

Option 2
• Complete the survey by phone by calling Geoff Mitchill at 860-575-4125

Your responses will be kept completely confidential and reported only in aggregate. A brief follow-up call may be requested to clarify responses.

To confirm the legitimacy of this survey, contact Nate Baker at 781-441-5974 or nathan.baker@eversource.com.

Thank you for your time and continued support of the Mass Save® program.

Sincerely,
DNV Energy Insights
On behalf of the Sponsors of Mass Save®

Follow the link to opt out of future emails:
Click here to unsubscribe

1.7 Survey

1.7.1 Landing Page Survey Introduction

Welcome to the Mass Save® Heat Pump Installation Contractor Survey. Your company has been selected to provide feedback because Mass Save® program records show your company installed heat pumps in commercial or multifamily buildings in 2023 or 2024 that received program rebates. Your responses will help us improve the Commercial Heat Pump Rebate program.

There are no right or wrong answers. We value your honest feedback, and all responses will remain confidential. Your answers will be combined with those of other participants to protect your identity. The survey will take about 10-15 minutes to complete. If you get stuck or have questions, please contact the survey administrator Amber Watkins at amber.watkins@dnv.com or call (707) 205-5502.

To begin the survey, click “Next”.

1.7.2 Screener

First, we would like to ask a couple of questions to confirm your experience working with the types of heat pumps we are studying.

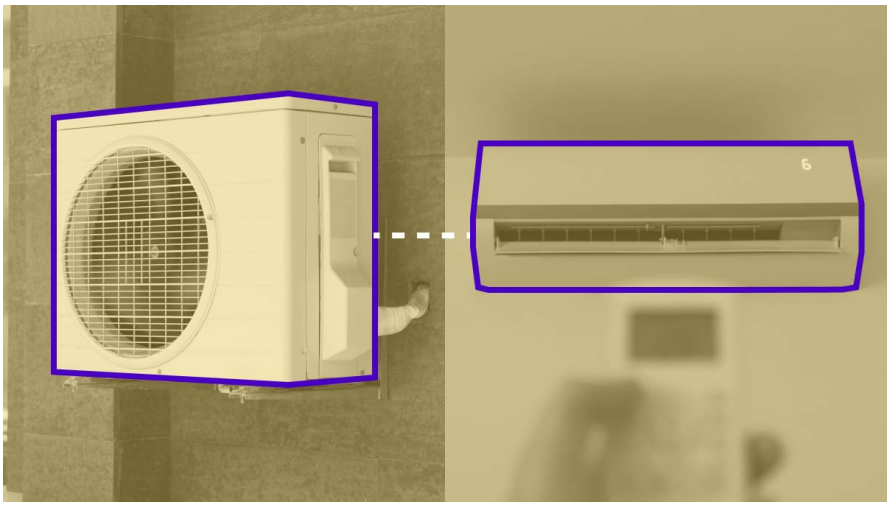
S1. According to Mass Save® program records, your company [name] installed program-rebated [Program HVAC] systems in commercial or multifamily buildings in 2023 or 2024.

[Display associated definition and picture for Program HVAC type from the following]:

Ductless mini-split heat pump (DHP): an all-electric heating and cooling system that moves heat between an indoor space and the outside air. It consists of an outdoor condenser/heat pump and one or more indoor air-handling units connected by a small conduit through the wall. (Note some “ductless” mini-splits may use a ceiling mounted air handler and short duct runs.) This includes:

- Ductless mini-split system, in which one outdoor unit services one indoor unit

- Ductless multi-split system, in which one outdoor unit services multiple indoor units



Source: ReWiring America

Air source heat pump (ASHP): an all-electric heating and cooling system that moves heat between an indoor space and the outside air. This includes:

- Central system in which heating and cooling is typically distributed through ductwork

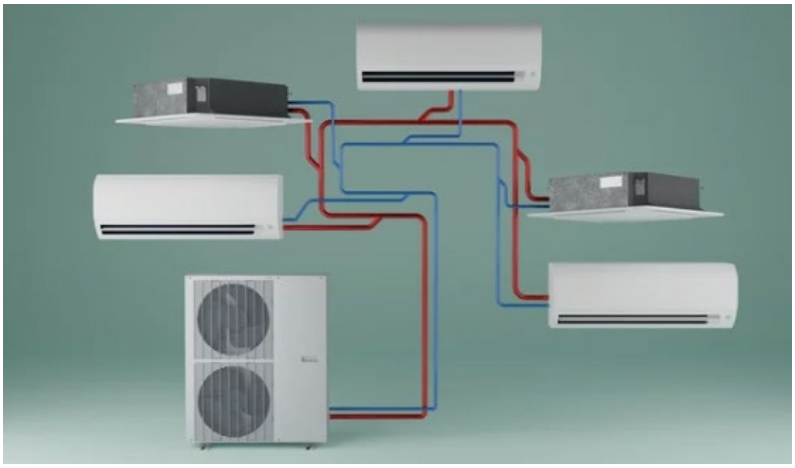
- A RTU (Rooftop Unit) heat pump, which is an all-in-one, self-contained system installed outdoors, typically on a building's roof, that provides both heating and cooling by reversing its refrigeration cycle

Packaged terminal heat pump (PTHP): a self-contained, through-the-wall heating and cooling unit that uses a reversible heat pump system for highly efficient operation in moderate temperatures and includes a backup electric heater for very cold weather.

Photo: Steven Winter Associates

Photo: Steven Winter Associates

Variable refrigerant flow (VRF) system: an advanced HVAC technology that uses one or more outdoor units to provide precise and simultaneous heating and cooling to multiple indoor zones by modulating the amount of refrigerant that flows through the system.



S2. Were you involved with your company installations of rebated ${e://Field/Program%20equipment} in commercial or multifamily buildings?

a. Yes

b. No

c. Don't know

d. My company did not install that type of equipment in 2023 or 2024. [TERMINATE: We sincerely appreciate your time. Our questions are best answered by someone who was involved with installing these types of heat pump systems in commercial or multifamily buildings. If you have any questions or believe there was a mistake, please contact Amber Watkins at amber.watkins@dnv.com.]

S3. [If S2 = B or C] Our questions are best answered by someone who was involved with installing the rebated heat pump systems in commercial or multifamily buildings. Is there someone else in your company you can refer us to? If so, please provide their name and email address.

- Name:
- Email:
- I am not comfortable providing this information [TERMINATE: "We sincerely appreciate your time. Our questions are best answered by someone who was involved with installing these types of heat pump systems in commercial or multifamily buildings. If you have any questions or believe there was a mistake, please contact Amber Watkins at amber.watkins@dnv.com.]

S4. [If S2 = A] Of the rebated heat pumps you installed in commercial or multifamily buildings, please indicate the percentage installed in each of the following situations? The total should equal 100%.

a. New construction buildings: _____ %
b. Existing buildings undergoing major renovations or tenant improvement projects, where code-compliance permitting is required: _____ %
c. Existing buildings NOT undergoing a major renovation or tenant improvement project (i.e., did not require code-compliance permitting): %

S5. [IF S4 OPTION B > 0%] For existing buildings undergoing a major renovation or tenant improvement project, what percentage of the time is the reason for the renovation due to each reason below. The total should equal 100%

a. Participation in the Mass Save program (i.e., the equipment incentivized through Mass Save is the primary reason for the renovation): %
b. Some other building improvements (i.e., the equipment incentivized through Mass Save is not the primary reason for the renovation): %

S6. [IF S4 OPTION A > 5%] You indicated you installed program-rebated heat pumps in new construction buildings. Are you sure these projects received rebates through the Mass Save Commercial Heat Pump Rebate program? Yes/No

S6a. [IF S6 = Yes] When you installed those heat pumps in new construction buildings, were you aware that the Mass Save Custom program offers rebates for heat pump projects in new buildings and major renovations? Yes/No

S6b. [IF S6a = Yes] Why did you choose to receive a rebate through the Commercial Heat Pump Rebate program rather than the Custom program? [Open ended; force response.]

S7. [IF S4 OPTION A = 100%; OR IF S4 OPTION C = 0% AND S4 OPTION B>0% AND IF S5 OPTION A=0%] Our questions are best answered by someone who installs heat pumps in (1) existing commercial or multifamily buildings not undergoing a major renovation or tenant improvement project, or (2) existing commercial or multifamily buildings undergoing major renovations because of Mass Save. Is there someone else within your company you can direct us to? If so, please provide their name and e-mail address.

- Name:
- Email:
- I am not comfortable providing this information (END SURVEY)

S8. [IF S4 OPTION C > 0%; OR IF S5 OPTION A > 0%] For this survey, please focus all your responses on the program-rebated heat pumps you installed:

1) Since 2023
2) In existing commercial or multifamily buildings not undergoing a major renovation or tenant improvement project, and
3) In existing commercial or multifamily buildings undergoing major renovations because of Mass Save.

Click “Next” to continue.

1.8 Questions

1.8.1 Event Type and Displacement

For the next set of questions, we would like to know about the types and condition of pre-existing equipment you have encountered when installing program-rebated [Program HVAC].

Provide additional heating capacity to a portion of the building that had some heating but was not sufficiently heated before

1. What percent of the time do the [Program HVAC] systems that you install …
   a. Entirely replace the heating system in the area of the building where it is installed (i.e., you removed the previous heating system in that space). ___% *[Indicates full displacement]*
   b. Become the new primary heating system in that area of the building, but the previous or a secondary system is retained as a backup for that area of the building. ___% *[Indicates partial displacement]*
   c. Provide additional heating capacity to a portion of the building that had some heating but was not sufficiently heated before *[Indicates added load, not replacement; ROF baseline]*
   d. Add heating to a part of the building that was not previously heated. *[Indicates added load, not replacement; ROF baseline]*

1a. [IFQ1 option a or d >5%; and if Program HVAC = ASHP] When installing [Program HVAC] that do not share the heating load with another existing system, what percent of the time are these [Program HVAC] dual fuel systems (i.e., hybrid systems comprised of both an electric heat pump and a fossil fuel furnace). __%

2. When replacing *existing heating systems* with [Program HVAC] units, what percentage of the time is the heating system still operational? %

3. [IF Q2 <100%] When replacing *non-operational heating systems* with [Program HVAC] units, what percentage of the time could low- or moderate-cost repairs have extended the old system’s operation for several more years? % [Indicates Early Replacement]

4. [IF Q2 >0%] When replacing existing *heating systems* with [Program HVAC] units while the previous systems are still operational, how often are the replacements due to the following reasons? The total should equal 100%.

a. The existing heating system was nearing the end of its service life, and you anticipated replacement would be necessary ___% *[Indicates Replace on Fail].*
b. Changes to the building required a different HVAC system ___% *[Indicates Replace on Fail].*
c. The owner is dissatisfied with the existing heating system's comfort, operating costs, and other factors. ___%
d. The existing system was functioning properly, but you proactively recommended, or the customer requested, a new HVAC system ___% *[Indicates Early Replacement].*
e. Other ___%

5. [IF Q4 c > 0%] When the owner is dissatisfied with the existing heating system, what percent of the time could minor repairs have restored the system to satisfactory operation? % *[Indicates Early Replacement]*

6. What percent of the time do the [Program HVAC] systems that you install are the following:…
a. Entirely replace the cooling system in the area of the building where it is installed (i.e., you removed the previous system cooling that space) *[Indicates full displacement]*
b. Become the new primary cooling system for that portion of the building, but kept the previous air conditioning system as a backup *[Indicates partial displacement; ER baseline]*
c. Provide additional cooling capacity to a portion of the building that had air conditioning but was not sufficiently cooled before *[Indicates added load, not replacement; ROF baseline]*
d. Add cooling to a part of the building that was not previously cooled *[Indicates added load, not replacement; ROF baseline]*

7. Thinking about the type of buildings and customers where you have installed program-rebated [Program HVAC] systems, if they do **not** choose to install a [Program HVAC] system, how often do they instead choose to do the following:
The total should equal 100%

a. Install a different new cooling system instead: %
b. Keep their existing cooling system: %
c. Keep their space uncooled: %

1.8.2 Displaced Heating Fuel and Pre-Program Equipment Types

For the next set of questions, we would like to know about the existing fuel types you have encountered when installing program-rebated [Program HVAC].

8. When installing [Program HVAC] units in existing buildings, please indicate the percentage of projects in buildings that were previously heated by each of the following fuel types. The total should equal 100%. [Indicates Displaced Fuel]

a. Electric: %
b. Natural gas: %
c. Oil: %
d. Propane: %
e. Other: %

9. [IF Q8 OPTION A > 5% - CUSTOMERS THAT ALREADY HEAT WITH ELECTRICITY] When installing [Program HVAC] units in existing buildings heated with *electricity,* what percentage of the time is the pre-existing system heated by one or more of the following fuel tyles?

a. Heat pump: %

b. Zonal heater (baseboard/wall heater): %
c. Furnace (ducted system with central heat): %
d. Hydronic system (boiler serving radiators or fan coils): %
e. Reheat system (ducted system with central cooling and electric reheat at the zone):%
f. Other: %

The total should equal 100%. [Indicates Electric Pre-Program HVAC]

9a. [IF Q9 OPTION F > 0%] Please briefly describe the *other types* of electric heating systems prior to installing heat pumps.

a. (specify): [write in]

10. [IF Q8 OPTION A > 5% - CUSTOMERS THAT ALREADY HEAT WITH ELECTRICITY] When installing [Program HVAC] units in existing buildings heated with *electricity,* what percent of the time was the existing *ventilation system* heated by:

a. Electricity: %
b. Natural gas: %
c. Oil: %
d. Propane: %
e. Ventilation system does not provide heating separate from primary heating system: %

The total should equal 100%.

11. [IF Q8 OPTION B > 5% - CUSTOMERS THAT PREVIOUSLY HEATED WITH GAS] When installing [Program HVAC] units in existing buildings heated with *natural gas*, what percentage of the time is the pre-existing system a natural gas…

a. Zonal heater (unit/wall heater, stove, etc.): %
b. Furnace or RTU (ducted system with central heat): %
c. Hydronic system (boiler serving radiators or fan coils): %
d. Hydronic reheat system (ducted system with central cooling and gas-fired hydronic reheat at the zone): %
e. Other: %

The total should equal 100%. [Indicates Gas Pre-Program HVAC]

11a. [IF Q11 OPTION E > 0%] Please briefly describe the *other* types of natural gas heating systems prior to installing the heat pumps. (specify): [write in]

12. [IF Q8 OPTION B > 5% - CUSTOMERS THAT PREVIOUSLY HEATED WITH GAS] When installing [Program HVAC] units in existing buildings heated with *natural gas,* what percent of the time was the existing *ventilation system* heated by:

a. Electric: %
b. Natural gas: %
c. Ventilation system does not provide heating separate from primary heating system: %

The total should equal 100%.

13. [IF Q8 OPTION C > 5% - CUSTOMERS THAT PREVIOUSLY HEATED WITH OIL] When installing [Program HVAC] units in existing buildings heated with *oil,* what percentage of the time is the pre-existing system an oil…

a. Zonal heater (unit/wall heater, stove, etc.): %
b. Furnace (ducted system with central heat): %
c. Hydronic system (boiler serving radiators or fan coils): %
d. Other: %

The total should equal 100%. [Indicates Oil Pre-Program HVAC]

13a. [IF Q13 OPTION D > 0%] Please briefly describe the *other* types of oil heating systems prior to installing the heat pumps. (specify): [write in]

14. [IF Q8 OPTION C > 5% - CUSTOMERS THAT PREVIOUSLY HEATED WITH OIL] When installing [Program HVAC] units in existing buildings heated with *oil,* what percent of the time was the existing *ventilation system* heated by:

a. Electric: %
b. Oil: %
c. Natural gas: %
d. Ventilation system does not provide heating separate from primary heating system: %

The total should equal 100%.

15. [IF Q8 OPTION D > 5% - CUSTOMERS THAT PREVIOUSLY HEATED WITH PROPANE] When installing [Program HVAC] units in existing building heated with *propane*, what percentage of the time is the pre-existing system a propane…

a. Zonal heater (unit/wall heater, stove, etc.): %
b. Furnace (ducted system with central heat): %
c. Hydronic system (boiler serving radiators or fan coils): %
d. Other: %

The total should equal 100%. [Indicates Propane Pre-Program HVAC]

15a. [IF Q15 OPTION D > 0%] Please briefly describe the *other* types of propane heating systems prior to installing the heat pumps. a. (specify): [write in]

16. [IF Q8 OPTION D > 5% - CUSTOMERS THAT PREVIOUSLY HEATED WITH PROPANE] When installing [Program HVAC] units in existing buildings heated with *propane,* what percent of the time was the existing *ventilation system* heated by:

a. Electric: %
b. Propane: %
c. Natural gas: %
d. Ventilation system does not provide heating separate from primary heating system: %

The total should equal 100%.

1.8.3 Heat Pump Installation Practices

For the following questions, we would like to learn more about [Program HVAC] installation practices including integrated controls, system sizing, and ventilation configurations.

17. [IF Q1 OPTION B > 5%] When installing a [Program HVAC] as the primary heating system with a secondary non-heat pump system that shares the heating load for the same area, what percent of the time is the switchover method used? The total should add to 100%:

a. A hard switchover: the [Program HVAC] serves the full heating load until compressor lockout at a specified outdoor air temperature: %
b. Dual-fuel switchover: [Program HVAC] and non-heat pump system operate together until compressor lockout at a certain outdoor air temperature: %
c. Other switchover control method **not** based on outdoor air temperature: %

18. [IF Q17 OPTION A > 5%] At what outdoor air temperature do you typically set the hard switchover? °F

19. [IF Q17 OPTION B > 5%] At what outdoor air temperature do you typically set the dual-fuel switchover to begin, when the installed [Program HVAC] and the secondary non-heat pump equipment start sharing the heating load? °F

20. [IF Q17 OPTION B > 5%] At what outdoor air temperature do you typically set the dual-fuel switchover to end, when the non-heat pump equipment provides the full heating load? °F

21. When sizing a [Program HVAC] system, how often do you size the units based on heating load and cooling load?

a. Projects sized based on heating load ___%
b. Projects sized based on cooling load ___%
c. Projects sized based on other factors___%

21a. [IF Q21 OPTION C > 5%] Please explain what other factors are considered in sizing [Program HVAC] systems.

22. Do you sometimes oversize [Program HVAC] systems to account for extreme conditions? Yes/No

22a. [IF Q22 = Yes] What percent of the time do you oversize [Program HVAC] systems to account for extreme conditions? (1%-100%)
22b. [IF Q22 = Yes] By what amount do you typically oversize [Program HVAC] systems to account for extreme conditions? (1%-50%)

23. [IF Program HVAC = VRF or minisplit] In your experience, when you install a [Program HVAC], what percent of the time is there a separate ventilation air system (e.g., a Dedicated Outside Air System/Unit) for the area served by the heat pump? ___%

24. [IF Q23 > 5%] Program HVAC = VRF or minisplit] When you install a [Program HVAC] and a separate ventilation system (e.g., a Dedicated Outside Air System/Unit) provides air to the space served by the [Program HVAC], what percent of the time does the system providing ventilation air:

a. Temper (i.e., pre-heat) the ventilation air: %
b. Does not temper the ventilation air: %
c. Other: %

The total should equal 100%.

24a. [IF Q24 OPTION C > 5%] Describe any other ventilation approaches you use when installing [Program HVAC] systems. (specify): [write in]

25. [IF 24 OPTION A > 5%] How often is the ventilation system's heating component fueled by the following fuel types? The total should equal 100%.

a. Electric %
b. Gas %
c. Other %

25a. [IF Q25 OPTION C > 5%] Please describe the other fuel types provide the ventilation system's heating:

a. (specify): [write in]

26. [IF Program HVAC = ASHP] When installing a ducted heat pump in a building with existing ductwork, do you typically…

a. Use existing ductwork as-is.
b. Completely replace the existing ductwork
c. Upgrade/modify existing ductwork
d. I don't install ducted heat pumps

27. [IF Q26 = B] Please select the reasons why you replace the existing ductwork. [multiple response options]

a. Ducts were the wrong size
b. Ducts were in the wrong location
c. Poor duct conditions
d. Tenant improvement or remodel
e. Other: [write in]

28. [IF Q26 = C] Please select the activities you perform when modifying existing ducts. Select all that apply.

a. Reseal ducts
b. Insulate ducts
c. Other: [write in]

29. [IF Q26 = B or C] When insulating existing ductwork, what duct insulation R-value do you install on average?
a. R-4 or 4-2
b. R-6
c. R-8
d. R-12

30. [IF Q26 = A OR C] When reusing existing ductwork, how often do you perform air balancing or commissioning?

__ % of projects

1.8.4 Building Emission Ordinances

31. Have you installed [Program HVAC] systems in Boston or Cambridge since 2023? Yes/No

32. [IF Q31 = yes] These two cities have enacted local climate ordinances targeting building emissions. Boston's law (the Building Emissions Reduction and Disclosure Ordinance, or BERDO 2.0) and Cambridge's law (the Building Energy Use Disclosure Ordinance, or BEUDO) both require large buildings to cut greenhouse gas emissions on a set schedule, aiming for net-zero emissions within the next few decades. Prior to this survey, were you aware of either of these building emissions ordinances?

a. Yes
b. No

33. [IF Q32 = yes] Have you observed changes in customer demand for heat pumps in Boston or Cambridge that may be related to the local emissions reduction ordinances (Boston's BERDO 2.0, Cambridge's BEUDO)? For example, are more commercial or multifamily building owners in those cities now proactively planning HVAC upgrades or heat pump conversions to comply with emissions caps or have owners cited the ordinance requirements as a reason for accelerating heat pump projects or choosing a heat pump system over other system types?

a. Yes
b. No

34. [IF Q33 = yes] To what extent have you seen an increase in heat pump projects in commercial or multifamily buildings in Boston or Cambridge because of the ordinances?

a. Slight increase due to the ordinances (10% or less increase in projects compared to pre-ordinance levels)

b. Moderate increase due to the ordinances (10-25% increase in projects compared to pre-ordinance levels)
c. Significant increase due to the ordinances (over 25% increase in projects compared to pre-ordinance levels)
d. Other. Please specify:___

1.8.5 Designated Equity Communities (DEC) replacement practices

The 2025-2027 Mass Save® Program Plan identified Designated Equity Communities (DECs) across Massachusetts that face disproportionate economic and environmental challenges. These DECs include the following 21 communities with a high share of low- or moderate-income residents and renters: Boston, Brockton, Chelsea, Everett, Fall River, Framingham, Fitchburg, Lawrence, Lowell, Lynn, Malden, New Bedford, Oak Bluffs, Pittsfield, Quincy, Revere, Salem, Springfield, Tisbury, Woburn, and Worcester.

35. Have you installed [Program HVAC] systems in commercial or multifamily buildings in any of these communities since 2023? Yes/No

36. [If Q35 = Yes] In your experience, when an HVAC system in a DEC fails or underperforms, are those customers generally more likely than non-DEC customers to repair the existing equipment rather than replace it? Yes/No

37. [If Q35 = Yes]: Among DEC customers, are there certain types of customers, such as small businesses, municipal customers, non-profits, etc.) that are more likely to keep repairing older HVAC equipment instead of replacing it?
37a. Yes/No; [If Yes, "Please list the types of customers that are more likely to repair older equipment. ____ "]

1.8.6 Closing Statement

38. Can you please provide your contact information in case we have any additional follow-up questions?

a) Name
Title
Email address
Phone

a) I prefer not to share this

This concludes our survey. We are offering a $150 e-gift card as a thank you for your participation. The card gives you the option to select from various choices like Venmo, PayPal, Visa, and vendor gift cards (as either electronic or physical cards), or make a charitable donation.

39. Please provide your email address if you would like to receive the e-gift card, or please indicate if you decline to receive it.

a) Please send the e-gift card to the same email used for this survey ([Email])
b) Please send the e-gift card to a different email address: [TEXT]
c) I do not want the e-gift card

You have completed the survey. Thank you! [IF Q40 ≠ C: You will receive an e-gift card within 2 weeks from [customizable] reward@virtualrewardcenter.com

APPENDIX G. EO MODEL V3.1 UPDATE STAGE 3 WORK PLAN

This appendix is included in the following pages.

DNV

resource innovations

FINAL SCOPE OF WORK

Energy Optimization Model Version 3.0 Update

MA25C04-B-EOMODEL

Date: July 14, 2025

Report title: Final Stage 3 Work Plan, Energy Optimization Model Version 3.0 Update

Customer: Massachusetts Program Administrators and Energy Efficiency Advisory Council

Customer contact: Kevin LaFlamme, National Grid

Date of issue: June 24, 2025

Project no.: MA25C04-B-EOMODEL

Prepared by: Miles Ingram, DNV	Reviewed by: Kristina Kelly and Geoff Cooper, DNV; Marcus Dimeo, RI	Approved by: Kristina Kelly, DNV
Miles Ingram Project Manager	Catherine Quiroz Data Analysis Lead	Kristina Kelly Project Sponsor

Rev. No.	Date:	Comments received from (name and organization):
1.0	May 21, 2025	Kevin LaFlamme (National Grid), Jen Chiodo, Ralph Prahl (EEAC consultants), Matt Siska (GDS), Margaret Song (CLC)
2.0	June 24, 2025	
3.0	July 14, 2025	Updated with additional hours for collecting and processing PA in-house project data

Table of contents

1 INTRODUCTION 1
1.1 Study background 1
1.2 Evaluation objectives 1
1.3 Measure update information 1
1.4 Study team and stakeholders 2
1.5 Overview of approach 3
1.6 Glossary 3

2 SCOPE OF WORK 5
2.1 Task 0: Project management 5
2.2 Task 1: Review recent and planned program and policy changes 6
2.3 Task 2: Update program data 8
2.4 Task 3: Model and report updated program impacts 10
2.5 Task 4: Long-term update scope development 12

3 PROJECT TIMELINE AND BUDGET 15
3.1 Timeline 15
3.2 Summary budget 16
3.3 Detailed budget 17
3.4 Milestone invoice schedule 19

List of figures

Figure 2-1. Downstream and midstream program savings basis 8

List of tables

Table 1-1. Table of stakeholders 3
Table 2-1. Summary of approach 5
Table 3-1. Summary budget 17
Table 3-2. Detailed budget 18
Table 3-3. Milestone invoice schedule 19

1 INTRODUCTION

1.1 Study background

The purpose of the commercial Energy Optimization Model (EO Model) is to generate impact estimates for prescriptive heat pump measures in commercial buildings for prospective application via the Massachusetts Technical Reference Manual (TRM). The Massachusetts Program Administrators (PAs) use the model to quantify the impacts associated with full or partial displacement of inefficient oil-, propane-, gas- and electric-primary heating systems to efficient heat pump systems.

The EO Model Version 3.0 Update project (MA25C04-B) study builds on two prior update projects conducted by Resource Innovations (formerly Cadeo):

- Version 2.0 Update (November 2023),[1] a comprehensive update to the previous commercial EO Model (Version 1.0). Major improvements in the Version 2.0 model included expanded modeling capabilities using commercial building energy simulations, added C&I HVAC equipment types, updated baseline assumptions, and other major updates.
- Version 2.1 Update (September 2024),[2] which included several substantial improvements to the Version 2.0 model, including updated VRF simulations, improved ventilation heating fuel assumptions, integration of more recent program tracking data (2022–Q12024) and refined model weighting based on installation contractor web survey results.

The Version 3.0 project will include additional improvements in the inputs and functionality of the model to improve its future applicability and accuracy, as detailed below.

1.2 Evaluation objectives

The EO Model Version 3.0 Update project (MA25C04-B) includes the following short-term and long-term objectives:

- Ensure the EO Model's **impact estimates reflect the latest program activity and are appropriate for prospective application**, by updating the model with refreshed 2024 program tracking data (short-term)
- Ensure the EO Model's **impact estimates reflect real-world operations and other parameters for improved accuracy,** by gathering empirical EO project data and improving model functionality and granularity (long-term)

This stage 3 work plan details the tasks for the short-term update and includes a separate task for developing the detailed scope for the long-term update.

1.2.1 Equity framework category

The short-term update study is assigned to Category 2 under the Equity Framework, due to the targeted research activity to incorporate dual baselines for customers in equity communities, as described in Task 3 in Section 2.4. Depending on the final scope and work plan for the long-term study, this targeted update activity may be complemented by empirical data collection in the long-term update via an over-sample of site visits, post-metering, or surveys in equity communities.

1.3 Measure update information

Table 1-1 lists the measures and BCR measure IDs for which this study will produce updated impact factors for prospective application to PY2026.

[1] https://ma-eeac.org/wp-content/uploads/MA22C10-Energy-Optimization-Model-Update-Report_FINAL_01NOV2023_ForEEACWebsite.pdf
[2] https://ma-eeac.org/wp-content/uploads/MA24C02-Energy-Optimization-Model-Version-2.1-Update-Report_25SEP2024.pdf

Table 1-1. Measure update information

Measure[3]	BCR measure ID[1]	TRM impact factor
ASHP displacing Gas - Partial	GC1c028, *GC1e010*	kWh/ton, kW/ton, MMBtu/ton
ASHP displacing Gas - Full	GC1c029, *GC1e011*	kWh/ton, kW/ton, MMBtu/ton
VRF displacing Gas - Partial	GC1c030, *GC1e012*	kWh/ton, kW/ton, MMBtu/ton
VRF displacing Gas - Full	GC1c031, *GC1e013*	kWh/ton, kW/ton, MMBtu/ton
GSHP displacing Gas	*GC1e014*	kWh/ton, kW/ton, MMBtu/ton
ASHP displacing Oil - Partial	EC1c042, *EC1e019*	kWh/ton, kW/ton, MMBtu/ton
ASHP displacing Propane - Partial	EC1c043, *EC1e020*	kWh/ton, kW/ton, MMBtu/ton
VRF displacing Oil - Partial	EC1c044, *EC1e021*	kWh/ton, kW/ton, MMBtu/ton
VRF displacing Propane - Partial	EC1c045, *EC1e022*	kWh/ton, kW/ton, MMBtu/ton
ASHP displacing Oil - Full	EC1c046, *EC1e023*	kWh/ton, kW/ton, MMBtu/ton
ASHP displacing Propane - Full	EC1c047, *EC1e024*	kWh/ton, kW/ton, MMBtu/ton
VRF displacing Oil - Full	EC1c048, *EC1e025*	kWh/ton, kW/ton, MMBtu/ton
VRF displacing Propane - Full	EC1c049, *EC1e026*	kWh/ton, kW/ton, MMBtu/ton
GSHP displacing Oil	*EC1e027*	kWh/ton, kW/ton, MMBtu/ton
GSHP displacing Propane	*EC1e028*	kWh/ton, kW/ton, MMBtu/ton
VRF displacing Electric Resistance - Partial	EC1c039, EC1e015	kWh/ton, kW/ton
VRF displacing Electric Resistance - Full	EC1c041, EC1e017	kWh/ton, kW/ton
ASHP displacing Electric Resistance - Partial	EC1c038, EC1e014	kWh/ton, kW/ton
ASHP displacing Electric Resistance - Full	EC1c040, EC1e016	kWh/ton, kW/ton
GSHP displacing Electric Resistance	EC1e018	kWh/ton, kW/ton
Midstream – Water Source Heat Pumps	EC1e041	kWh/ton
Packaged Terminal Heat Pump (PTHP)	EC1e042	kWh/ton

[1]BCR measure IDs in italics are in the statewide electrification pool. The IDs above include (1) C&I Equipment Rebates & Instant Incentives (which are part of the statewide pool) and (2) Small Business Turnkey offerings.

1.4 Study team and stakeholders

Staff from DNV and its subcontractor, Resource Innovations (RI), (together, the study team) will conduct the Version 3.0 update. DNV will serve as the project lead under Contract A, including leading all model update activities and data collection via site visits, metering, or other long-term update tasks. RI staff who were involved in the Version 2.0 and Version 2.1

[3] The 2025-2027 Three-Year Plan TRM lists deemed kWh/ton savings values for midstream ASHP and VRF, but notes that "these savings will be claimed downstream moving forward (i.e. integrated into downstream ASHP and VRF numbers), which will be reflected in future eTRM versions." Based on initial discussions with PA staff, the Midstream program is currently limited to PTHP and Water Source Heat Pump measures. The team will further explore this issue in our Task 1 interviews with program implementation staff and in our review of midstream program data, before updating the model for midstream measures.

updates will, under the direction of DNV, provide legacy expertise and technical support on the EO Model as necessary and will support the long-term update in running building simulation models. The RI team will not be involved in any handling or analysis of program tracking data or model calibration to avoid any real or perceived conflicts of interest.

The key stakeholders for the project are shown in Table 1-2**,** and include the PAs/EEAC Consultants who attend weekly MA CIEC calls, as well as members of the EO Model Subcommittee—a subgroup of evaluation, implementation and oversight consultant stakeholders who meet bi-weekly for more detailed project discussions.

Table 1-2. Table of stakeholders

Stakeholder	Specific personnel	Engagement activities
Weekly C&I EM&V Call	PA and EEAC representatives	Review work plans, interim deliverables, final deliverables, and progress updates.
EO Model Subcommittee Regular Meetings	Subset of PA and EEAC representatives, including PA implementation staff	Detailed discussions of project plans and activities, forum for collaborative decision-making and engaging PA implementation and other staff closely involved in planning and implementing EO programs

Other groups of staff, such as the PA's Engineering Services group, can be informed or consulted on specific stages (e.g., final workplan, draft report) as the members of the EO Model Subcommittee or CIEC deem appropriate.

1.5 Overview of approach

This stage 3 plan includes the following core research tasks for the short-term update, to be completed in time for 2026 prospective application (meeting the October 15 number lockdown date):

1. **Review recent and planned program and policy changes** by interviewing PA implementers, and incorporate changes in modelling assumptions where appropriate, including for measure offerings, program delivery strategies, and policy changes that impact the current model assumptions[4]
2. **Update program data** by obtaining and processing 2024 data from midstream and downstream program vendors
   a. Assess program data for improvements recommended in the v2.1 report, including (1) information on displaced equipment, (2) details on the types of heat pump systems being installed including more detailed descriptions of ASHP types, and (3) contractor names for use in weighting survey response inputs.
3. **Model and report updated program impacts** for all downstream and midstream measures.
   a. To the extent program data recommendations from the v2.1 report have been implemented, update model weights and outputs for improved accuracy and granularity

This stage 3 work plan also includes **a separate task to develop a detailed scope for the long-term update**, which will be informed by and conducted in parallel with the short-term update research tasks. Long-term update tasks will include site-specific data collection and analysis and subsequent EO Model updates, to be completed in time for 2027 prospective application.

1.6 Glossary

We have provided a list of key terminology as defined by the DNV team, PA evaluation and implementation staff, and the Energy Efficiency Advisory Council (EEAC), here.

[4] For details on the current model assumptions and inputs, see the EO Model v2.1 update report, including Appendix C Case Weight Development Results, at https://ma-eeac.org/wp-content/uploads/MA24C02-Energy-Optimization-Model-Version-2.1-Update-Report_25SEP2024.pdf

Term	Definition
Baseline equipment	The equipment that is the point of comparison for modeling the impact of program incentivized equipment, could be either the counterfactual equipment or the pre-program equipment (for the downstream program) or a standard efficiency heat pump (for the midstream program).
Baseload	Energy used in buildings not impacted by seasonal weather variations.
Case weights	The prorated prevalence of different segments.
Counterfactual equipment	The equipment type that a program participant most likely would have installed if they had not installed what they did (i.e., the program equipment). This is different than pre-program equipment and is considered when assessing impacts for all event types.
Direct simulation	Estimating the energy use of a segment by simulating the segment characteristics with an EnergyPlus building energy modeling tool.
Displaced fuel	The fuel type of both the pre-program equipment and counterfactual equipment that the program equipment is replacing.
Early replacement	When a participant installs program equipment before their existing equipment has reached the end of its effective useful life.
Event type	The context in which the program equipment was installed. For the EO Model, this includes early replacement and replace-on-failure instances.
Full displacement	Program equipment provides 100% of space heating.
High-level input	An input to the model used to define other detailed inputs (e.g., building type or HVAC type).
Industry standard practice (ISP)	Equipment characteristics, such as efficiency levels, which reflect current equipment purchases and installation practices across the market without program intervention.
Like-for-like replacement	When a participant's replace-on-failure baseline equipment is the same fuel and equipment type as their pre-program equipment.
Midstream baseline	The standard efficiency version of the program equipment that a participant installed, used as the program equipment to determine downstream program impacts and as the baseline used to determine midstream program impacts.
Model	In this document, “model” refers to the entire EO tool, including the direct simulation energy models and proxy simulation calculations.
Partial displacement	Pre-program equipment remains in place to provide supplemental heat at cold temperatures when the program equipment has insufficient capacity to meet the heating load.
Pre-program equipment	The components of a participant’s HVAC system that the program equipment replaced. This is different than the counterfactual equipment and is considered when assessing impacts for early replacement events.
Program equipment	The program incentivized equipment that participant installed, which serves as the program case used to find midstream impacts.
Proxy simulation	Estimating the energy use of a segment based on the direct simulation results for a different, though similar, segment.
Replace on failure	When a participant installs program equipment after pre-program equipment has reached the end of its effective useful life.
Scenario	Any combination of baseline and program equipment types, displacement type, and building type for which the model estimates energy impact.
Segment	A unique combination of building characteristics that the EO Model will account for when estimating energy impact for a measure. Each segment will have a weight, based on square footage, which gives the percent of program participants with that combination of characteristics and an estimated annual energy impact.
Simulation	To avoid confusion with the term “model,” simulation(s) refers to the individual building energy models that serve as inputs to the EO Model.

2 SCOPE OF WORK

Outside of the work plan development and project management, DNV will complete four research tasks for the short-term update project, each with several specific activities. Table 2-1 connects the project tasks and activities to the research objectives shown above. The short-term update tasks detailed in this work plan will inform the scoping process and the detailed plans for the long-term update tasks, which will be more fully detailed in a future addendum to this work plan. The remainder of this section provides more details about each task and activity to be completed for this study.

Table 2-1. Summary of approach

Task	Research activities	Research objective
1. Review recent and planned program and policy changes	• interview PA implementers • review program planning and implementation documentation	Ensure the EO Model's impact estimates reflect the latest program activity and are appropriate for prospective application
2. Update program data	• obtain and process 2024 program tracking data from the midstream and downstream vendors	
a. Assess program data for recommended improvements	• assess program data for improvements recommended in the v2.1 report, including – information on displaced equipment – details on the types of installed heat pump systems including detailed ASHP types, and – contractor names for use in weighting survey response inputs • update model weights and outputs for improved accuracy and granularity	
3. Model and report updated program impacts	• report impact estimates for all downstream and midstream measures, delivered via updated EO Model and MS Word report	
4. Develop detailed scope for long-term EO Model updates	• determine site-specific data collection approach(es) • refine scope, including segmentation approach, sample design, and key data to be collected • determine additional substantive updates for EO Model functionality and granularity • long-term work plan to be informed by and developed in parallel with the short-term update tasks	Ensure the EO Model's impact estimates reflect real-world operations and other parameters for improved accuracy

2.1 Task 0: Project management and study planning

2.1.1 Project management

Task objective: The objective for this task is to manage internal research activities and coordinate externally with the PAs and EEAC Consultants throughout the duration of the project.

Activities: The principal activities for this task include status updates, budget tracking, invoicing, internal and external meetings, and other activities necessary to manage the project. This will include regular updates on the MA CIEC weekly call to keep the PAs/EEAC Consultants informed on research activities and analysis.

This task also includes activities required to support the EO Model Subcommittee—a subgroup of evaluation, implementation and oversight consultant stakeholders, which meets bi-weekly for more detailed review and input on project progress. EO Model Subcommittee meetings will serve as a foundation for communication, decision-making, and

documentation of project progress. The study team will generally provide agendas, slides, and action items for these meetings, and the EO Model Subcommittee will provide input, guidance, and oversight of the project team.

2.1.2 Study planning and design

Task objectives: The study team will work closely with the PAs and EEAC Consultants to develop and refine the approach for the short-term and long-term updates to the EO Model to optimize the value of the research and ensure the model produces accurate and applicable impact estimates for future program years.

Activities: The planning activities cover the short-term and long-term updates, as follows.

- Short-term update planning. The study team worked closely with the EO Subcommittee to develop a detailed project scope (documented in this work plan) including engaging program stakeholders and EEAC Consultants to prioritize research tasks and scoping details. This task includes defining the project scope, refining the research questions, and detailing the schedule and budget.
- Long-term update planning. The study team will incorporate insights from Task 1 (reviewing recent and planning program changes) and Task 2 (updating program data) to refine the research methods and tasks for the long-term update. The team will also work closely with the EO Model Subcommittee to identify priorities and determine data collection options to pursue (e.g., post-metering, site visits, contractor surveys) for the long-term update.
  - The detailed scope for the long-term update will be provided in a separate work plan, in Q3 of 2025, following collection and analysis of the 2024 program data and interviews with program implementers.

Deliverables: The deliverable for this task is the short-term update Stage 3 work plan (this document), including:

- First draft with solicitation of comments from PAs/ EEAC Consultants
- Revised draft with solicitation of comments from PAs/EEAC Consultants
- Final work plan, indicating approval to begin

2.2 Task 1: Review recent and planned program and policy changes

Objective: Understand recent and planned changes in the Midstream and Downstream Commercial Heat Pump program, including measure offerings and delivery strategies, to ensure results appropriately account for evolving programs.

Activities: There are two activities associated with this task:

- Interview PA implementers and planners, to provide overview of scope of the model and the study, review recent and planned program policy changes and ensure the study aligns with the evolving scope and needs of the programs
- Review program documentation, including application forms and incentive sheets, to understand the specific program measure offerings, delivery channels, and data being collected

PA implementer interviews and documentation review will examine the following issues:

- Recent (since the period covered by the v2.1 model) and planned changes in measure offerings, including
  - technologies
  - incentive levels
  - delivery channels (e.g., midstream vs. downstream)[5]

[5] For instance, during the development of the v2.1 EO Model, the MA PAs were discussing potential redesign of the midstream program, including removal of VRF and ASHP incentives from future midstream programs. More recently, the 2025-2027 Plan TRM notes that ASHP and VRF savings will be claimed downstream moving forward (i.e. integrated into downstream ASHP and VRF numbers), and removed from the midstream program. However, 2024 program data from the midstream vendor still includes ASHPs and VRFs, so the team will further investigate this issue in the Task 1 implementer interviews.

  - targeted customer segments, including small/micro businesses installing residential-style equipment, or new construction market actors

- PA efforts to influence participant and market behaviors, and how that relates to any program logic or goals for market transformation.[6]
- PA efforts to target equity customers, and any related issues that could impact baselines and savings factors for those customers, which could be further explored in the long-term update.[7]

Commercial EO Program Offerings

The PAs run two complementary programs designed to encourage the installation of high-efficiency heat pumps in commercial buildings: a midstream program and a downstream program. The PAs designed these two programs to have different baselines to avoid the double counting of savings.

The Midstream program works through distributors to encourage the installation of high-efficiency heat pumps, relative to "standard" efficiency heat pumps. As a result, the baseline for assessing impacts associated with the midstream program is the industry standard practice heat pump efficiency. Also, because the baseline is always a heat pump, savings are always electric and the program is independent of fuel switching.

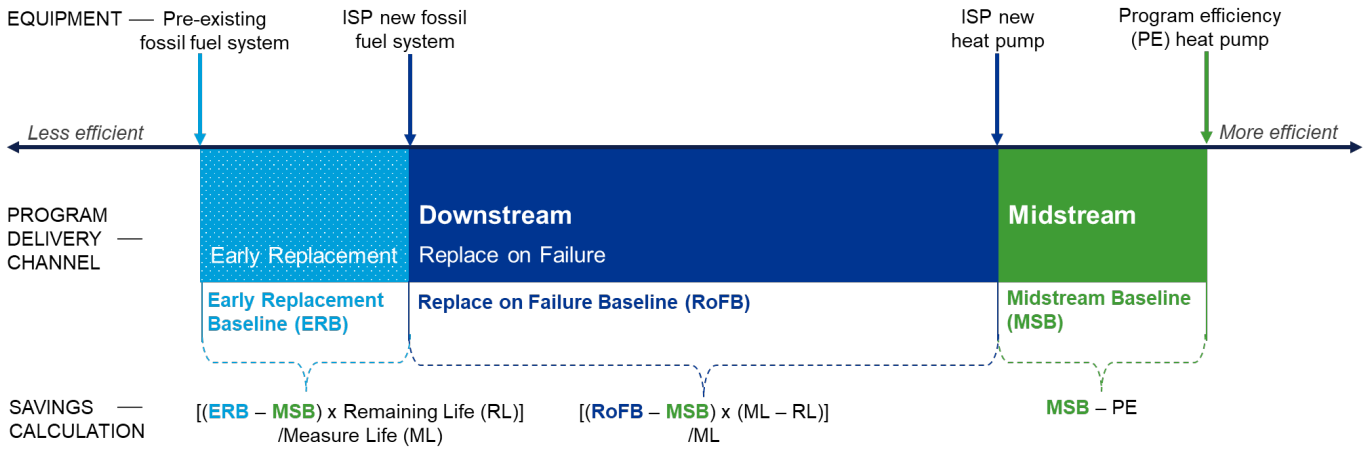
The Downstream program claims impacts against non-heat pump equipment, which results in higher total energy impacts (across fuel types) and allows for higher incentives than the midstream program. The downstream program therefore considers fuel switching (i.e., both the change in total cross-fuel and electric consumption) in its impact estimates. The PAs consider all downstream program participants to also be a part of the midstream program, but not all midstream program participants are part of the downstream program.

For purposes of claiming savings, the PAs consider all downstream program participants to also be a part of the midstream program, but midstream program participants are not considered to be part of the downstream program. Specifically, as shown in Figure 2-1, savings for downstream program participants are calculated against either an early-replacement baseline (ERB) of the pre-existing equipment efficiency, or a replace-on-failure baseline (RoFB), reflecting a new, industry standard practice (ISP) fossil fuel system. Savings for midstream program participants are calculated against a midstream baseline (MSB) of a new, ISP efficiency heat pump. In both cases, claimed savings reflect heating and cooling savings.

[6] From the DOER 2025-2027 Three-Year Plan EM&V Policy Memo: "Market Transformation initiatives may not be subject to net-to-gross factors, or certain impact results that are caused by participant behaviors, or other market factors that are an explicit component of the market transformation theory because these initiatives should be judged on their effectiveness in accelerating market transformation, rather than through a traditional resource acquisition lens." Although these initiatives primarily involve residential customers, small and micro business customers who install small, residential-style equipment in buildings with residential footprints or residential-sized spaces may be a target for market transformation initiatives. https://ma-eeac.org/wp-content/uploads/Appendix-P-2025-2027-Three-Year-Plan-EMV-Policy-Memo.pdf

[7] For example, as noted in the Strategic Evaluation Plan (p.19), "HVAC system baselines for schools, municipal buildings, and local small businesses (non-national chains): There is anecdotal evidence that these select facilities in equity communities have different HVAC system baselines from the industry standard practice, as these customers are more likely to repair existing equipment than replace it." https://ma-eeac.org/wp-content/uploads/Appendix-S-Strategic-Evaluation-Plan.pdf

Figure 2-1. Downstream and midstream program savings basis



Deliverable: Results will be presented to EO Subcommittee members for feedback as part of interim update meetings and will be incorporated in the final report and Model as appropriate. The report will include a section on the key program and policy changes that impact the modeled results.

2.3 Task 2: Update program data

Objective: Update EO Model weighting values with refreshed 2024 program tracking data to ensure that impact estimates reflect the latest program activity and evolving mix of incentivized equipment.

Activity: The primary activity associated with this task is to obtain and process 2024 data from the midstream and downstream EO program vendors. Refreshing program data will ensure the EO Model reflects the most up-to-date proportions and weighting associated with the following parameters:

- Pre-program fuel (also informed by survey results, which will not be updated under the short-term tasks)[8]
- Program HVAC (also informed by survey results, which will not be updated under the short-term tasks)
- Building type
- Displacement type (full/partial)
- Climate (interior/coastal)

The program data refresh will also be used to update (1) the proportions of delivered fuel baselines that are propane or oil, (2) switchover temperatures, and (3) controls for partial displacement installations. The data refresh will ~~also~~ provide an opportunity to update assumptions for PTHPs, which did not have any records of program installation in the tracking data used for the v2.1 model, so the team used proxy data based in part on averages of other program HVAC types. To the extent the 2024 program data includes PTHPs, the team will update the model based on installed program PTHPs.

The team will use program tracking data fields consistent with those used in the v2.1 model, with the addition of certain fields related to the v2.1 report recommendations (e.g., data on displaced equipment, or details on installed ASHP) that may have been added to the 2024 data but were not in the prior model, as described in section 2.3.1 below.

July 2025 scope addition: Based on interviews with PA implementers in July, the team identified an additional set of projects from 2023 and 2024 that were not included in the downstream (Resource Innovations) and midstream (Energy Solutions) implementation vendor data sets. Specifically, several of the PAs processed certain prescriptive commercial heat pump

[8] The Model includes several inputs that are derived from prior survey results. We will not be updating these inputs as part of the short-term update.

projects in-house during that period, and did not process those projects through the implementation vendors. Although a relatively small share of projects were handled this way, these projects may be systematically different from others, as interviewees said they can involve PA sales, account representatives or other staff, meaning a heavier touch involvement by PAs and potentially higher-quality installation and project performance. Because of this, the team will gather these project records and clean and incorporate them with the other projects from the implementation vendor data sets. This task requires additional hours for collecting the data; cleaning, stacking and reconciling it with the existing vendor datasets; and incorporating it into the statewide datasets used in the modelling. The budget in Section 3 has been updated to reflect this addition.

2.3.1 Task 2a: Assess program data for recommended improvements

The program data update will also provide an opportunity for the team to assess the extent to which implementers have improved the comprehensiveness and detail of program data in response to recommendations and considerations from the v2.1 report. Where these improvements have been made, the team will incorporate the updated data in model weighting and outputs for improved accuracy and granularity. Specific improvements include:

- contractor names for use in weighting survey response inputs
- information on displaced equipment
- details on the types of installed heat pump systems including detailed ASHP types.

For reference, the specific data-related recommendations and considerations from the v2.1 report are as follows:[9]

- **Improve collection of customer and contractor information**. Currently, survey results are unweighted for developing case weights (i.e., all survey responses are weighted equally). The team's plan was to match survey respondents' vendor names to vendors in the program data to weigh results by each vendor's installed capacity or count. However, most entries in the program tracking data (~80%) did not include vendor names, thus preventing matching for a representative portion of survey responses. We recommend greater stringency in tracking unique identifiers, such as vendor names, in program data collection.
- **Collect information regarding displaced equipment in program tracking data.** The downstream program participant data provided to our team—one of two primary sources of data for developing case weights in the EO Model—did not contain information on the existing HVAC equipment that the program heat pump replaced. Because the displaced equipment type has one of the largest influences on overall measure impacts—and is readily observable by the contractor installing the program equipment—we suggest the PAs consider requiring implementers to track pre-program equipment as part of the program's data reporting requirements. The PAs should also consider collecting and tracking pre-program equipment status (whether the fully displaced equipment was removed or kept in place), partial displacement backup heat control setpoints, and ventilation details.
- **Separate the ASHP measure into multiple, more specific ASHP measures.** In 2021, the PAs tracked mini/multi-split systems and central/ducted heat pumps separately, but in the same year decided to no longer track these individually given the vast permutations of additional information required for tracking these system types. The PAs currently combine all air source heat pumps—whether central, ducted, and/or mini/multi-split systems—into a single prescriptive ASHP measure. Collectively, these ASHP types represent the overwhelming majority of incentivized commercial heat pump units and savings (79% of all incentivized units in 2022–2023). Given the significant participation associated with this one aggregated measure, as well as the fundamental differences in the systems (single vs. multi zone, coupled vs. uncoupled ventilation, etc.), we suggest the PAs consider going back to the 2021 approach of splitting the downstream ASHP program offering into more specific heat pump types—specifically, separating ductless from ducted heat pumps—to better capture the inherently different system designs and impact values of these popular measures.

[9] See https://ma-eeac.org/wp-content/uploads/MA24C02-Energy-Optimization-Model-Version-2.1-Update-Report_25SEP2024.pdf

- **Collect more detailed information regarding the types of heat pump systems being installed**. The downstream program participant data offers vague descriptions of the types of heat pumps being installed. Tracking more detailed descriptions of heat pumps—for example, packaged ASHP rooftop units versus split systems—could inform and improve the PAs' program, model development, and marketing approaches.

Where improvements have not been made, the team will apply the same assumptions used in the v2.1 model regarding displaced and installed equipment types and other details, and will ask implementers about barriers they face in collecting and tracking these data. If merited, the team will identify and recommend improvements that implementers can make.[10] In addition, the long-term update workplan will consider options for gathering such information from participants and/or contractors that could be used to inform future modelling.

Deliverable:

Results will be presented to EO Subcommittee members for feedback as part of interim update meetings

- Analysis of program data, including trends in equipment type by capacity (tons), building type, and other key data fields
- Assessment of program data for recommended improvements

Results will also be incorporated in the final report and Model as appropriate. The report will include a section on the improvements, if any, made to address these prior recommendations/considerations as well as barriers to addressing them, where relevant.

2.4 Task 3: Model and report updated program impacts

Objective: Produce and report updated impact estimates for prospective application for all downstream and midstream measures.

Activities: The primary activities associated with this task are to (1) streamline and make minor functionality adjustments to the client-facing EO Model workbook, (2) run the updated model to produce impact estimates, and (3) report the results.

In addition to updating the EO Model to include 2024 program data, the team plans to remove the 2022 program data so that the model is weighted with the latest program activity (2023–24) and is more applicable prospectively. This approach results in slightly less data being used in the model—2022 accounts for less than 7% of the projects installed in the 2022-2024 period. However, relative to 2023-24, the 2022 measure mix included more mini splits (73% of projects in 2022 vs. 50% of projects in 2023-24), and less VRFs (9% of projects in 2022 vs. 16% of projects in 2023-24), based on the team's initial review of program data. In addition to the shifting measure mix, other shifting market dynamics related to local ordinances, state and federal policy changes, and the rate environment merit the use of the most recent data available. At the same time, there is a need to balance recency with having sufficient projects included in the data for reliable estimates. For the purposes of this update, and as a default position for future updates, the team believes that modelling two years of program data best strikes this balance.

After processing the program data and loading it into the Model, the team will conduct several post-processing steps to develop program weights and align the outputs with the modelling parameters.

[10] Broader issues such as improving processes for recommendation implementation and follow-through are beyond the scope of this review.

2.4.1 Equity community baselines

The team will also update the model to incorporate a recent policy change from the 2025–2027 Strategic Evaluation Plan related to dual baselines for customers in equity communities, as follows:[11]

> *Stipulated dual baselines: "…select facilities in equity communities have different HVAC system baselines from the industry standard practice, as these customers are more likely to repair existing equipment than replace it. The working group agreed to a stipulated dual baseline assumption, where the first period baseline reflects the existing conditions for 2/3 the EUL of the installed measure. The second period baseline will be the ISP HVAC system."*[12]

To accommodate this change, the team will adjust the post-processing calculations in the EO Model and update Model functionality. The team consulted with PA planning staff to understand how they track and report on project-level savings in their BCR model, specifically related to key performance indicators (KPIs) for equity. Based on the discussion, the team will update the model to produce weighted average values reflecting the retrospective mix of projects in equity and non-equity communities. The team will apply the most up-to-date definition of equity communities that aligns with the 2025-2027 plan and the KPIs that the PAs are measured against.

2.4.2 Local ordinance adjustments

Two local ordinances have recently or are soon coming into effect that are expected to drive heat pump adoption in Boston and Cambridge. These ordinances may affect the future market in a way that reduces the representativeness of the 2023-2024 participant population for purposes of prospective application. These are:

- Cambridge's **Building Energy Use Disclosure Ordinance** (BEUDO): Emissions requirements are set based on the size of your building, with larger buildings (over 100,000 sq. ft.) reporting their first reductions in 2026. These buildings must reduce their emissions 20% by 2026, and reduce an additional 40% every five years until they reach net zero by 2035. For buildings under 100,000 sq. ft., there is no immediate emissions requirement, but starting in 2030 they are required to reduce emissions by 40% and an additional 20% every five years until they reach net zero by 2050.
- Boston's **Building Emissions Reduction and Disclosure** (BERDO): Boston's ordinance sets a schedule of maximum allowable emissions for buildings over 20,000 sq. ft., which will gradually decline to net zero carbon intensity by 2050. Enforcement of this schedule begins in 2025. Annual compliance filings as well as 3rd party verification of building consumption and filing accuracy are required annually.

These ordinances may impact statewide proportions by building type, climate zone, full vs. partial displacement, and event types. The short-term update project tasks do not provide a basis for determining adjustments to account for these potential changes. However, the long-term update may include (1) customer site visit interviews, and/or (2) contractor interviews, which can be scoped to include questions about ordinances to provide a basis for adjusting results for better prospective applicability.

2.4.3 Modelling tool updates

The v.2.1 EO Model tool was provided in the form of a large (~150MB) Excel spreadsheet. Along with the updated program data and functionality described above, the team will also update the EO Model tool to provide a more streamlined user version in Excel with a smaller file size, while retaining the full back-end data for the model in a SAS database. This will

[11] See p.131 of the Strategic Evaluation Plan: https://ma-eeac.org/wp-content/uploads/Appendix-S-Strategic-Evaluation-Plan.pdf. There are two other recent policy changes related to EO offerings that the team determined do not require an adjustment to the EO Model or any further examination in this study. The first is a rule for HVAC controls baselines on page 137 of the Strategic Evaluation Plan, which states that "for custom and prescriptive electrification and non-electrification HVAC projects, the baseline HVAC control system and operation is always the pre-existing control system and operation." There is no change needed to address this, as the EO Model is already in accordance with this rule since it uses the same baseline controls technologies for existing as well as ISP baseline systems. The second is the sshift to statewide pooling of electrification costs and benefits across all gas and electric PAs. There is no change needed to address this, as it does not change modeled impacts—only accounting and reporting in statewide filings.

[12] As discussed with the EO Subcommittee members, the stipulation to use the existing equipment as the baseline for 2/3 of the EUL of the installed measure applies to early replacement projects in specific buildings—specifically, municipal buildings, schools and small businesses (other than national chains). The team will apply this logic in the model.

allow a more user-friendly experience for downloading, storing, and running the model, while maintaining the necessary level of transparency and flexibility.

All data stored in the back-end database will be maintained and made available to PAs and EEAC consultants upon request. In addition, the user-facing Excel Model will include a log of changes made from prior versions and descriptions of all supporting data not included in the Excel Model.

Deliverables:

- Draft and final EO Model, user version (Excel)
- Draft report (MS Word), final report (clean and redlined MS Word versions, PDF)

2.5 Task 4: Long-term update scope development

Objective: Ensure the EO Model's impact estimates reflect real-world operations and other parameters for improved accuracy.

Activities: In parallel with the short-term update tasks detailed above, the team will develop a detailed scope for the long-term update, which will be informed by the short-term update research tasks. Long-term update tasks will include site-specific data collection and analysis and subsequent EO Model updates, to be completed in time for 2027 prospective application. The basic data collection options for the long-term update are as follows:

- Post-metering study (would include a site visit component)
- Site visits with inspection and survey
- Contractor survey

Table 2-2 provides further details on the types of updates each data collection option would support, along with the expected level of effort and impact on savings.

Table 2-2. Potential long-term updates and methods

Potential Update	Description	Potential Savings Impact	Level of Effort to Update EO Model	Data collection method		
				Post metering	Site visits	Contractor survey
Heat pump performance & operations	Currently, performance, usage profiles, and set points are dictated by prototype assumptions, calibration of pre-program participant data and self-reported contractor data. Updates using a metering study could include: (1) Average operational COP, (2) Performance by temperature (including cold temperature performance), (3) Primary, backup, supplemental/ventilation heating annual usage, (4) Primary, backup, supplemental/ ventilation heating usage by temperature (can inform dual-fuel control and switchover assumptions), (5) System sizing, (6) Behavioral decisions, including scheduling, setpoints, etc.	**High** (>25%)	**Very High**. Requires rerunning all simulations and updating simulation results	**Yes**: Best Option.	**Partially**: Can gather info such as behavioral decisions	**No**.
Coupled vs. decoupled ventilation (for VRF systems)	Ventilation (coupled vs. decoupled) has a large influence on impact results. Currently, the EO Model weights the proportion of VRF systems with each ventilation strategy using contractor survey results from the v2.1 model update.	**High** (>25%)	**Moderate**. Requires adding functionality, segments, and post-processing	**Yes**: Second Best Option	**Yes**: Best Option. Provides accurate information at lower cost than metering.	**Yes**: Third Best Option. Less accurate than site visits.
Update hard switchover temperature assumptions & add dual-fuel control scheme	The EO Model currently assumes a hard switchover for all partial displacement cases (informed by program applications and the installation contractor survey). However, some systems have dual-fuel operation capability. Tracking the prevalence of dual-fuel systems, heat pump capacity at certain OAT, and switchover temperatures (for both hard switchover and dual-fuel operation) will improve EO Model assumptions.	**High** (>25%)	**High**. Requires building out post-processing functionality to include complex dual-fuel controls	**Yes**: Second Best Option.	**Yes**: Best Option. Provides accurate information at lower cost than metering.	**Yes**: Third Best Option. Less accurate than site visits.
Determine prevalence of supplemental/ ventilation heating with different fuel than program HP (e.g., gas DOAS)	The EO Model currently assumes that the fuel for any supplemental/ventilation heating is the same as the primary heating system. Additional data collection could inform and improve upon this assumption.	**High** (>25%)	**Very High**. Would require running new simulations and implementing new segments to capture different fuel	**No**.	**Yes**: Best Option. Provides more accurate information than a survey.	**Yes**: Second Best Option. Less accurate than site visits.
Determining pre-existing cooling conditions	The EO Model currently assumes that all buildings prior to program participation have cooling. We know this is not true based on recent survey data. A new survey dedicated to improving pre-existing cooling conditions can improve EO Model assumptions.	**Moderate** (10%-25%)	**Low**. Can leverage existing functionality to weight by pre-existing cooling, though may need to add segments for more granular cooling conditions.	**No**.	**Yes**: Best Option. Provide more accurate information than a survey (assuming discussions with prop. manager).	**Yes**: Second Best Option. Less accurate than site visits.

Depending on the chosen data collection method, the long-term update could address other potential updates not shown in the table. For instance, contractor surveys or site visits could also be used to validate the dual baseline stipulations for equity communities discussed in section 2.4.1. Similarly, contractor visits or site visits could be used to update assumptions related to market events or other model inputs that were derived from the surveys conducted for prior model updates.

In addition, the v2.1 report included two recommendations which would entail more substantial model updates and could be accommodated in the long-term update (as opposed to the other v.2.1 report recommendations that we will address in the short-term update). These were (1) to directly simulate new construction buildings, and (2) directly simulate GSHP HVAC systems (the v2.1 team opted to calculate GSHP impacts using the approach developed in the EO Model 1.0.) As part of Task 1 (see section 2.2), the team will review program data to determine the prevalence of these project types and ask program implementers about plans to encourage such projects going forward. If there is sufficient interest from the PAs and EEAC consultants, the team can incorporate these elements into the long-term update.

The team will work with the EO Subcommittee to determine the data collection approach(es) for the long-term update. Based on this determination, the team will develop a detailed sample design and data collection protocol and provide these details in a separate Stage 3 workplan addendum, including detailed tasks, timeline, and budget. In order to meet timelines for 2025-2026 winter metering (if selected as a method), final workplan approval will be needed by October.

Deliverable: Long-term update workplan addendum, including:

- First draft with solicitation of comments from PAs/ EEAC Consultants (early September 2025)
- Revised draft with solicitation of comments from PAs/EEAC Consultants (late September 2025)
- Final work plan, indicating approval to begin (October 2025)

About DNV

DNV is an independent assurance and risk management provider, operating in more than 100 countries, with the purpose of safeguarding life, property, and the environment. Whether assessing a new ship design, qualifying technology for a floating wind farm, analyzing sensor data from a gas pipeline or certifying a food company's supply chain, DNV enables its customers and their stakeholders to manage technological and regulatory complexity with confidence. As a trusted voice for many of the world's most successful organizations, we use our broad experience and deep expertise to advance safety and sustainable performance, set industry standards, and inspire and invent solutions.