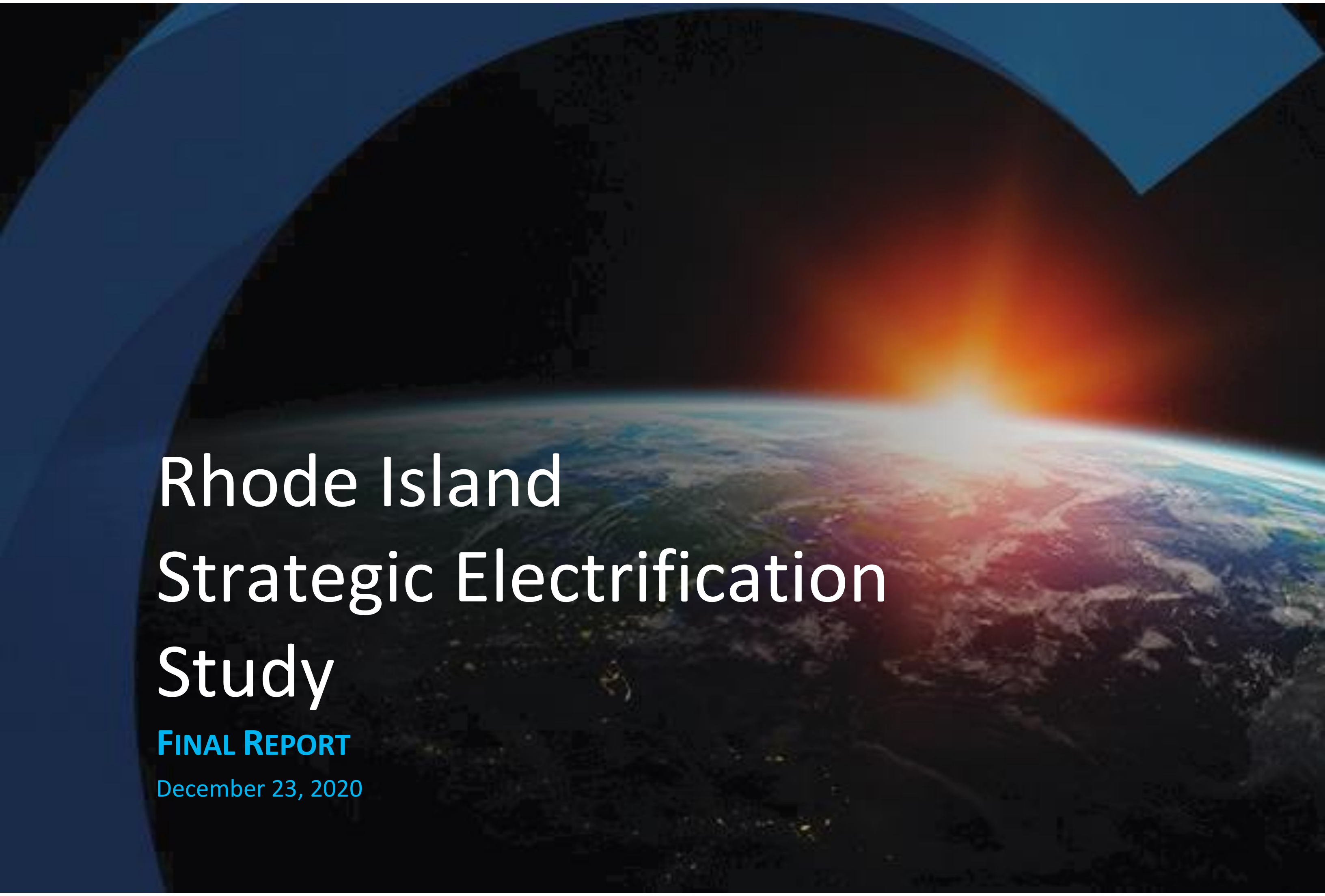
CADMUS



Rhode Island Strategic Electrification Study

FINAL REPORT

December 23, 2020

Prepared for:

National Grid of Rhode Island

Prepared by:

Jacob Erickson

Marisa Hobbs

Connor McCarthy

Ajey Pandey

Acknowledgments:

The authors of would like to acknowledge the valuable guidance and input provided during the preparation of this report. The authors are grateful to the following contributors for their feedback, review, and contributions in preparing this report.

Andrew Grant

Mark Janett

Jeremy Koo

Nelson Lee

Neil Veilleux

Aquila Velonis

CADMUS

Table of Contents

Tables

Figures

Abbreviations

ASHP………………………………. Air-Source Heat Pump

CASHP …………………………… Central Air-Source Heat Pump

ccASHP…………………………… Cold-climate Air-Source Heat Pump

ccDMSHP………………………… Cold-climate Ductless Minisplit Heat Pump

DMSHP…………………………… Ductless Minisplit Heat Pump

WTP………………………………. Willingness to Pay

Executive Summary

The Rhode Island Strategic Electrification Study assesses the cold-climate heat pump market, optimum pathways for heat pump adoption, and opportunities to facilitate market growth. Combining a detailed market assessment with modeling analysis, the study finds that there are significant opportunities for heat pump implementation in the Rhode Island market.

In line with previous research, the study finds there to be generally low awareness of heat pump technology among both residential and commercial customers. Roughly 60% of respondents indicated they had little or no prior knowledge of central heat pumps, and 64% noted they had little to no prior knowledge of ductless heat pump systems. This suggests that the Rhode Island heat pump market is still in a very early stage of growth. As verified by installers and distributors, this lack of customer awareness presents a significant barrier to heat pump adoption. In many cases, installers and current heat pump owners pointed out that HVAC installers are the primary source of heat pump knowledge for customers and are therefore a natural conduit for efforts to increase customer awareness and education.

As found in prior research (Cadmus 2018, EMI Consulting 2014, Meister Consultants Group, 2017), the high cost of heat pump installation also presents a major barrier to adoption, with the average customer noting they were “not very likely” to install a heat pump without incentives. Providing sufficient incentives is therefore needed to encourage customers to consider the technology. The willingness to pay study revealed that incentives of at least $3,600 per system are needed to drive the average consumer to be likely to install a heat pump, with many scenarios requiring significantly higher incentives. However, it also found that incentive levels explain only a small portion of the variability in willingness to pay. This suggests that factors such as building needs, customer knowledge, overall system cost or other variables may play a significant role in customer willingness to pay.

Heat pump costs have been increasing over the last several years at an average of 0.6 – 1.7% per year. The study finds that this is partially attributable to increasing efficiency, new technologies, and the increased adoption of multi-zone ductless systems. Despite the price increase, installers report a notable upswing in ASHP sales in recent years. Reaffirming past research, a survey of heat pump owners found that roughly 35% of these installations are primarily motivated by residential customers’ desire to add cooling to their home, with heating as a secondary benefit. In practice, the majority of residential heat pump owners use heat pumps as the primary form of cooling (88%) and secondary source of heat (51%). Regardless of their reason for installation, heat pump owners’ satisfaction with their systems are very high, with roughly 89% of respondents reporting that they were *“very satisfied”* with their heat pump.

Scenario modeling found that, across building typologies, heat pumps are cost-effective for both customers and program administrators when displacing oil, propane and electric resistance heating, even when new cooling loads are added to a building. Additionally, without significant incentives, just 9 of the 19 scenarios analyzed are found to be cost effective from the customer standpoint. Of these 9 scenarios, 5 model the displacement of electric baseboard heaters and the other 4 model the displacement of oil or propane. In line with past studies, the model does not find any scenarios where displacing natural gas is cost effective for the customer without significant incentives.

Lifetime customer cost savings of a heat pump installations[1] depends heavily on the baseline heating fuel being displaced and the cooling equipment being displaced. Those scenarios displacing electric baseboard heating realize the highest lifetime cost savings. Without incentives, residential customers are shown to realize a lifetime cost savings of $38,400 to $43,600 for partially displacing electric heating and cooling in single-family homes. With incentives equivalent to those offered by Mass Save, which reflect similar values to those offered by National Grid in 2019, these same customers can realize over $46,700 in lifetime cost savings. The Mass Save incentives are benchmarked at $1,250 per ton for heat pumps displacing oil, propane or electric baseboard heat, and $250 per ton for all other scenarios. These savings come from both more efficient heating and cooling, as well as differences in installation costs over the lifetime of the heat pump.

Using the Rhode Island Test to assess program cost effectiveness, the most cost-effective scenarios for program administrators are those installing cold climate DMSHPs to partially replace oil or propane systems, with cost-benefit ratios of up to 8.18 for incentivizing heat pumps in single-family propane homes. Notably, the modeling in this suggests that in smaller structures, the lower potential for energy savings due to lower counterfactual energy consumption means that program cost effectiveness figures tend to be lower for smaller spaces (such as individual multifamily units) relative to single-family homes.

Achievable installation modeling suggests that, without incentives, it is feasible for up to 2,943 new heat pumps to be installed in Rhode Island between 2020 and 2024. This is associated with a reduction in overall electricity consumption of 15,681 MWh as the cost effectiveness of heat pump installation drives the displacement primarily of electric heating. This would also prevent 13,054 tons of CO_2e emissions.

Adding incentives is shown to drive a significant increase in heat pump adoptions. Applying the same incentives currently offered by Mass Save, an additional 1,553 new heat pumps could be installed, totaling 4,497 installations in Rhode Island between 2020 and 2024. This scenario would result in a reduction in overall energy consumption of over 14,105 MWh and prevent the emissions of 18,899 tons of CO_2e. Lower incentives drive heat pump installations in only the most cost-effective scenarios. Therefore, at lower incentive levels, a large percentage of the installs will replace electric baseboard heat and existing, lower efficiency, cooling systems. This results in a relatively high net reduction of total electricity consumption. With higher incentives, more homes with oil or propane heating are likely to install heat pumps to offset fossil fuel consumption. This fuel switching adds to total electricity consumption, offsetting some of the reductions in energy consumption resulting from replacing baseboard heating, but also drives greater average reductions in carbon emissions per installation. The model also finds that, while increased incentives do drive increased heat pump adoption, increasing incentives to 40% above Mass Save levels results in roughly an 10% increase in heat pump adoption. This reflects the diminishing marginal returns on incentives.

[1] Lifetime cost defined as the difference between installation costs and energy savings over the presumed useful lifetime (17-18 years) of the heat pump

As an important note, while the study sought to capture insights from commercial market segments as well as supply chain actors (including installers and distributors), the COVID-19 crisis and subsequent interruption to business across the country greatly limited commercial data collection. The insights included in this report reflect anecdotal reports from select businesses, installers and distributors who were able to be reached during the study. Further research into the willingness to pay, ownership trends and behavior of businesses, and potential installers could highlight valuable insights for the market.

Introduction & Overview

This study sought to provide a better understanding of the current status of the heating and cooling market in Rhode Island and the potential for cold-climate heat pump adoption throughout the state. To this end, the study included three key elements: a broad market evaluation, a scenario modeling for cost effectiveness, and an adoption modeling assessment. The market assessment sought to understand the current status and maturity of the heat pump market in the state, probing for residential and commercial customers' willingness to pay for heat pumps, perceptions and awareness of the technology, and barriers to adoption, as well as heat pump owners' experience with the technology. It also inquired into various market actors' views of the heat pump market, investigating the roles, challenges, and perceptions of HVAC installers, distributors and solar installers. The scenario modeling section aimed to identify and assess the customer and program cost effectiveness of 19 scenarios for heat pump installations in both residential and commercial buildings. Finally, the adoption modeling section compiled this information to project future adoption of heat pumps along an S-shaped curve, aiming to estimate the potential heat pump adoption, energy savings and emissions reductions from heat pumps over the next four years.

This report is organized into three primary sections. It begins with an overview of the market evaluation which includes the literature review, target market survey, heat pump owner survey, ASHP installer survey, distributor interview and solar installer interview results. It is worth noting that, throughout the study, both commercial and residential data and surveys were analyzed. However, due to low response rates from commercial respondents in the initial surveys, much of the commercial analysis remains qualitative. The next section covers the scenario analysis and cost effectiveness modeling and includes a discussion of recent cost trends, identified building scenarios, energy modeling and cost effectiveness testing for all 19 scenarios. Finally, the adoption analysis section discusses the adoption models used in this study under various incentive scenarios. This report concludes with a brief review of overall findings and assessment of future research recommendations.

Market Evaluation

To gain insight into customer cold-climate air-source heat pump[2] (ccASHP) awareness, decision-making processes, and barriers to technology adoption, Cadmus completed a high-level literature review and a series of surveys and interviews with National Grid residential and small business customers, ccASHP installers, solar installers, and heat pump distributors. Table 1 outlines each of these market research activities, target audiences, and sample designs.

The overall objective of this market research was to draw out insights from ccASHP users and industry members on how ccASHPs are used, installed, sold, and promoted and to better inform program design by capturing key inputs for adoption modeling through the willingness-to-pay section of the target-market survey. Specific objectives for each market research survey and interview are noted below.

Literature Review. Cadmus conducted a brief literature review of the existing program and of heat pumps in the Northeast and nationwide. This literature review served to ground the analysis and enable us to identify resources for the later surveys and modeling. In total, Cadmus reviewed 22 sources and identified additional resources for use in later analyses.

Target Market Customer Survey. For this online survey, Cadmus targeted households and small businesses in National Grid's Rhode Island service territory who heat with electricity or delivered fuel and who do not currently have a heat pump. We explored customers' awareness of heat pump technology, as well as their attitudes, perceptions, and barriers to heat pump adoption. Additionally, to assess customer interest and market demand for ccASHPs, we measured willingness-to-pay for heat pumps under different scenarios.

Heat Pump Owner Survey. For this survey, Cadmus targeted residential and small business heat pump owners to gather insights into their decision-making process, satisfaction, usage habits, use of controls, technology preferences, and other relevant factors.

ASHP Installer Interviews. Cadmus conducted these interviews by telephone, targeting registered heat pump installers in the Rhode Island area. We focused on identifying heat pump installer practices, marketing strategies, typical customers interests, and level of interest in additional programming to further assist National Grid in identifying opportunities for more workforce development, outreach, and incentive support.

Supply Chain Installer Interviews. We conducted in-depth telephone interviews with ccASHP manufacturers and distributors that are active in Rhode Island. Cadmus designed and conducted the interviews in partnership with NMR Consulting, which was conducting parallel research in Connecticut,

[2] For the purposes of this study, cold-climate air-source heat pumps are defined as those meeting the specifications to qualify for the NEEP cold-climate certification.

and focused on assessing market growth, costs, and sales rates; upcoming advances in technology; market adoption barriers and opportunities; and potential for partnerships.

Solar Installer Interviews. Cadmus conducted in-depth interviews with solar PV installers to gauge their interest in integrating heat pump installations into their service offerings. We sought to characterize the level of awareness of heat pump technology across the industry and the barriers and opportunities to engaging with this market, as well as the experiences, motivations, and existing business models deployed to incorporate heat pump.

Small business respondents were included in both the target market surveys and owner surveys. For the purpose of this study, Cadmus defined small businesses as National Grid customers using a small business–specific rate, consuming less than 1 million kilowatt-hours per year, and who are not government entities. While we achieved the target sample size for each residential survey, we were unable to gather the target number of responses for most of the commercial surveys and interviews. This is in large part due to the onset of COVID-19 restrictions and the subsequent business impacts beginning in March 2020. While we did gather some responses from commercial respondents, the small sample means these findings should therefore be understood as qualitative, case-specific findings.

Table 1. Primary Research Sample Design

Activity	Methodology	Sector	Subdivision	Target Sample Size	Actual Sample Size
Literature Review	Web Scraping	All sectors	N/A	N/A	N/A
Target Market Customer Survey	Online survey	Residential	Electric heating	68	68
			Delivered fuel heating	68	68
		Small business	Electric heating	68	3
			Delivered fuel heating	68	5
Heat Pump Owner Survey	Online survey	Residential	N/A	68	78
		Small business	N/A	68	6
ASHP Installer Interviews	Telephone interviews	ASHP installers	N/A	68	9
Distributor Interviews	Telephone interviews	Manufacturers and distributors	N/A	8	2
Solar Installer Interviews	Telephone interviews	Solar installers	N/A	15	13

Cadmus conducted a combination of telephone and online surveys, offering a gift card in exchange for participation in the survey. We contacted respondents for the target market and owner surveys via email. We contacted participants in the other three surveys via email (or cold call) to schedule phone interviews.

Literature Review

Cadmus conducted a high-level literature review to inform the assumptions used in this analysis and our approach to the Rhode Island heat pump market.

Methodology and Objective

In conducting the literature review, Cadmus explored 22 distinct sources related to residential and commercial ASHP applications and assessed program evaluations, market research reports, specifications, and past modeling datasets. A full list of sources is in Appendix I.

Key Findings

Prior heat pump research highlights the difference between *in-situ* operation and nameplate efficiency levels. Multiple studies measured heat pump performance as 90% or less of advertised efficiency levels (Cadmus Group 2017, Energy Future Group & Energy and Resource Solutions 2014). The literature also highlighted the impact of user habits and patterns, such as what settings owners use, temperature set points, or how often they used the heat pump, on the overall efficiency of the system (Cadmus Group 2017, EMI Consulting 2014, VEIC February 2018, Cadmus Group 2016, Energy Future Group & Energy and Resource Solutions 2014). Several studies noted that the use of programmable thermostats has a significant, positive impact on the installed efficiency of a system (Cadmus Group 2017, VEIC February 2018, Energy Future Group & Energy and Resource Solutions 2014). It is also notable that prior research in Massachusetts and Rhode Island found that the average heat pump installation was sized to meet an average of 2.6 times a home's *Manual J* cooling need due to higher heating loads relative to cooling in the Northeast (Cadmus 2016).

Market analyses show that heat pump adoption is increasing over time, with variable refrigerant flow and mini-split systems increasing in market share and popularity in recent years (NEEP 2016, NEEP 2017). Many home and business owners are drawn to heat pumps as a way to add or improve building cooling and comfort (Connecticut Green Bank 2018). Although the cost savings of heat pump use can be significant for many homeowners, regional program performance studies still highlight several sizeable barriers to adoption. Principle among these—technology awareness, performance concerns, and installed costs—continue to dampen heat pump market growth. (Cadmus 2018, EMI Consulting 2014, Meister Consultants Group, 2017; Energy Future Group & Energy and Resource Solutions 2014). Where incentives and support are available, research shows that programs that lack clear requirements or require significant administrative effort and costs to participate may discourage installers and distributors from participating (DNV-GL 2018).

In addressing these barriers, state and utility programs have employed a variety of methods to support heat pump adoption, with a varying success. Most utility incentive programs today offer per-ton level incentives with some consideration to system efficiency. By pinning incentives to system size, rather than system efficiency, these incentives appear to favor the less expensive cold-climate systems that just meet efficiency requirements, rather than driving installation of even higher efficiency systems (NEEP February 2019). While size is a significant factor, heat pump costs are also considerably driven by configuration and efficiency, such that targeting incentive dollars to system efficiency may better motivate cold-climate installations (Navigant October 5, 2018; Navigant 2011). Several program assessments highlight that a minimum incentive level over $500 is needed to drive heat pump installations (VEIC September 2018, NEEP February 2019). Interestingly, several studies focusing on the impact of electric rates found that heat pump adoption is more significantly affected by rebate levels than energy prices, but that reduced electricity costs may help in driving long-term heat pump use (DNV-GL 2019, NEEP 2017). In terms of program design, incentives that have targeted mid-stream wholesalers have had reasonable success compared to downstream customer incentives (VEIC February 2018). Commercial programs, on the other hand, have largely failed to achieve expected results due to low participation driven in part by high administrative costs of participation (DNV-GL 2018).

Widespread heat pump adoption is expected to significantly impact energy consumption and the grid over time. Interestingly, because air conditioning use is the single largest contributor to residential peak demand, the use of heat pumps is expected to reduce overall energy consumption and peak demand in many cases due to more efficient cooling relative to older, traditional air conditioners (Navigant July 2018). In New York, one study found that up to 31 TBtu of energy savings could be achieved if heat pumps made up the same proportion of the heating and cooling market as they do in China or Europe (VEIC September 2018). The increased electrification of heating is expected to increase the cost of electricity supply in the short term, particularly after severe winter weather events (DOER 2018). Program administrators may pair electrification efforts with solar incentives and energy efficiency incentives to mitigate the impact to the grid (DOER 2018, VEIC February 2018).

Target Market Survey

Cadmus conducted a general population online survey of households and small businesses in National Grid's Rhode Island service territory that do not currently have a heat pump, but rather are in a target market for installing this technology. The sample included both residential and commercial customers in Rhode Island who do not receive natural gas from National Grid and for whom National Grid had up-to-date email and contact information. The exclusion of natural gas customers was based on the assumption that, given current prices, natural gas is a generally more cost-effective heating fuel.

Overview

Using this survey, Cadmus explored the attitudes perceptions related to ccASHPs, perceived market barriers, and willingness to pay for ccASHPs under different scenarios. We collected survey responses from 136 residential customers and eight commercial customers. The small survey sample size for commercial customers limits the extent to which Cadmus can infer information about the population of commercial customers based on our survey data.

Heat Pump Awareness

Cadmus asked customers whether they had heard of various types of heating technologies before the survey, about their familiarity with ASHP technology, and whether they agreed with various statements about ASHPs. Prior to this survey, most residential and commercial customers (roughly 65%) had a very low level of familiarity with heat pump technology, especially ducted ASHPs. When comparing familiarity of ducted versus ductless ASHPs, both customer segments were notably more familiar with ductless ASHPs (Table 2). While customers agreed most with the idea that ASHPs can offer quiet and efficient cooling and provide spot heating and cooling, they were less certain as to whether ASHPs could adequately heat a Rhode Island home or business. They were also skeptical about whether ASHPs would cost more to run compared to traditional heating and cooling systems.

Table 2. Heat Pump Awareness

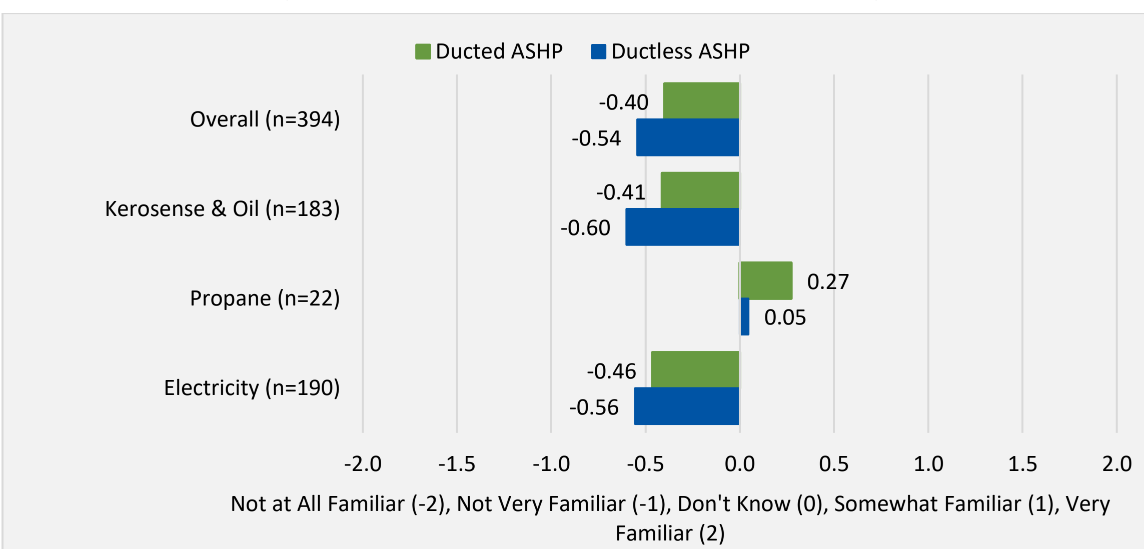
Prior to this survey, had you heard of any of the following types of heating technologies? Select all that apply.	Residential Percentage of Responses (n=394)	Commercial Percentage of Responses (n=21)
Wood burning stove/wood pellet stove/fireplace	74%	81%
Baseboard electric heat	71%	81%
Central forced air furnace with ducts to individual rooms	69%	86%
Steam/hot water system with radiators or baseboards in each room (central boiler)	67%	81%
Portable heater	65%	81%
Ductless mini-split heat pump	53%	76%
Ducted air-source heat pump	40%	52%
Ground-source heat pump	31%	29%
Vented space heater (such as a Monitor or Rinnai)	31%	57%
None of the above	4%	5%

Note: The n values reflect higher values than the total number of responses due to multiple responses per participant.

Overall, the average residential or commercial customer has a relatively low level of familiarity with heat pump technology (Figure 1 and Figure 2). When comparing familiarity of ducted versus ductless ASHPs, both residential and commercial customers were slightly more familiar with ducted ASHPs, although the difference is not statistically significant (Figure 1 and Figure 2). Roughly 38% of residential and 41% of commercial respondents said they are *not at all familiar* (a rating of -2) with ductless ASHPs. Similarly, roughly 31% of residential and 43% of commercial respondents indicated that they are *not at all familiar* with ducted ASHPs. There is little variation in responses between oil and electric customers.

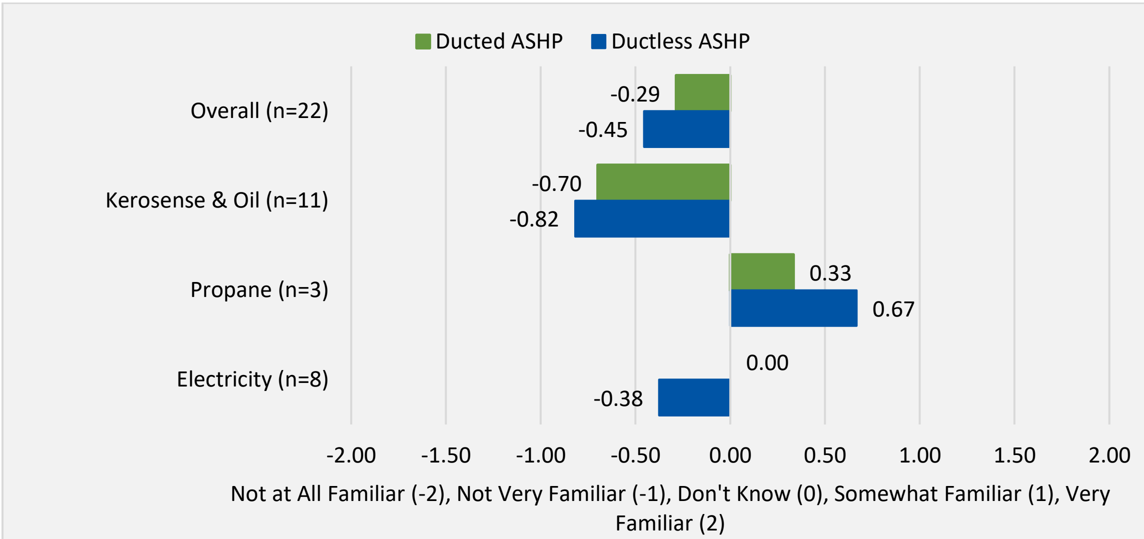
Propane customers, on the other hand, have a significantly higher awareness of heat pump technology. A plurality of residential propane customers (roughly 32%) noted that they were *somewhat familiar* with ductless ASHPs and 46% indicated they were *somewhat familiar* with ducted ASHPs. A similar pattern emerged among commercial respondents, although not enough responses were collected to draw statistical conclusions.

Figure 1. Residential Awareness of ASHP Technology



Note: The n values do not reflect final survey completion count, as many more respondents completed these pre-screening questions than completed the survey overall.

Figure 2. Commercial Awareness of ASHP Technology

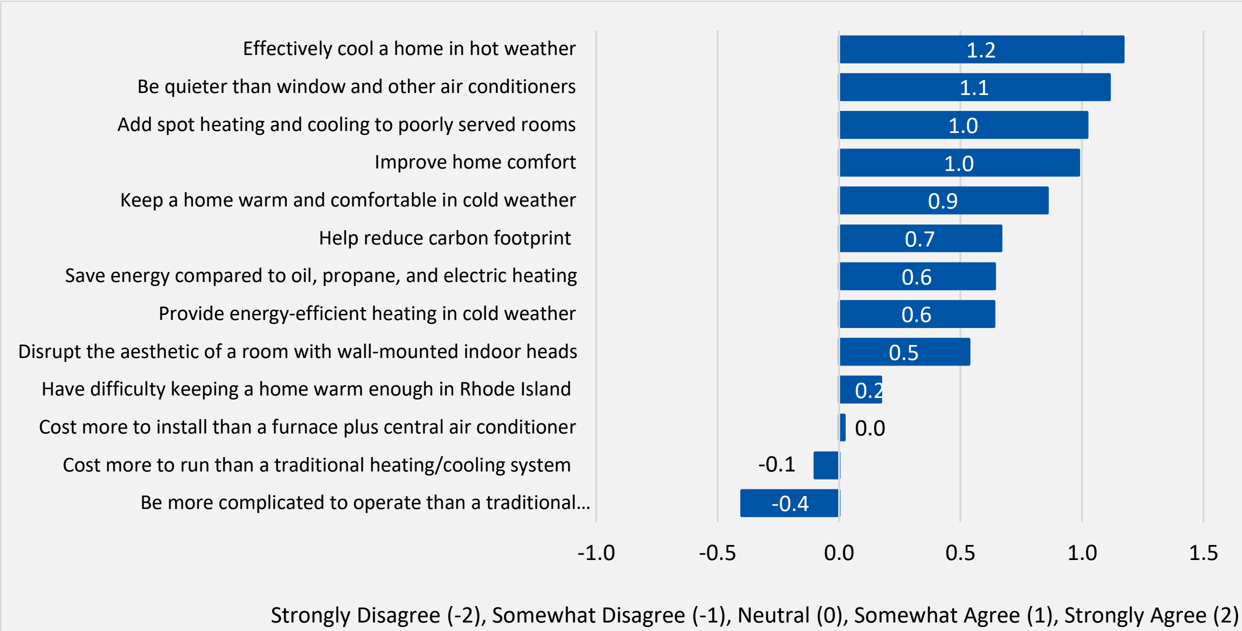


Customers reported that they are, on average, *not very familiar* with (or do not know their level of familiarity with) ducted ASHPs. In comparison, customers are *somewhat familiar* with ductless ASHPs.

When asked to rate how much they agree or disagree with statements about ASHPs, customers agreed most with the idea that heat pumps can offer quiet and efficient cooling and provide spot heating and cooling. Both residential and commercial customers most strongly agree with the statement that ASHPs can “be quieter than window and other air conditioners” (see Figure 3 and Figure 4). Residential customers in particular agree with the statement that ASHPs can “effectively cool a home in hot weather” (Figure 3), while commercial customers in particular agree that ASHPs can “add spot heating and cooling to poorly served rooms” (Figure 4). Note that the small sample size of commercial customers limits Cadmus’ ability to generalize sample-level findings to the overall commercial population.

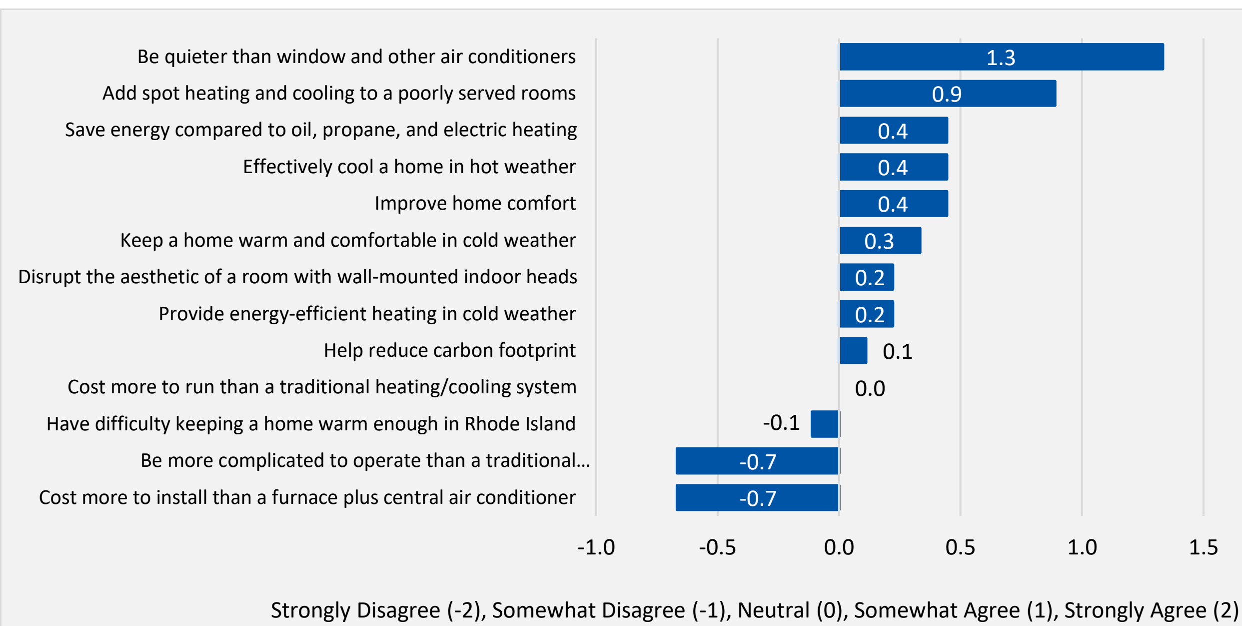
Customers were less certain as to whether ASHPs could adequately heat a Rhode Island home or business, and whether ASHPs would cost more to install or run compared to more traditional heating and cooling systems. Specifically, both residential and commercial customers most strongly disagreed with the statement that ASHPs can “be more complicated to operate than traditional heating and cooling systems.” Commercial customers also disagreed with the statement that ASHPs “cost more to install than a furnace plus central air conditioner.”

Figure 3. Residential Heat Pump Awareness Statement Agreement



Source: Survey question. "Please rate how much you agree or disagree with the following statements. Air-source heat pumps can…" (n=132)
A negative score indicates that respondents, on average, did not agree with the statement.

Figure 4. Commercial Heat Pump Awareness – Statement Agreement

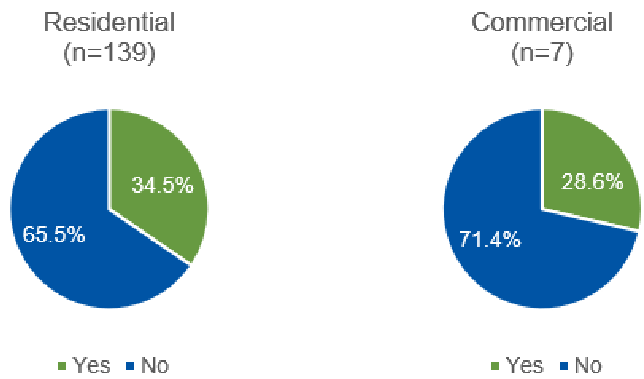


Source: Survey question. "Please rate how much you agree or disagree with the following statements. Air-source heat pumps can…" (n=9)
A negative score indicates that respondents, on average, did not agree with the statement.

Heat Pump Perceptions

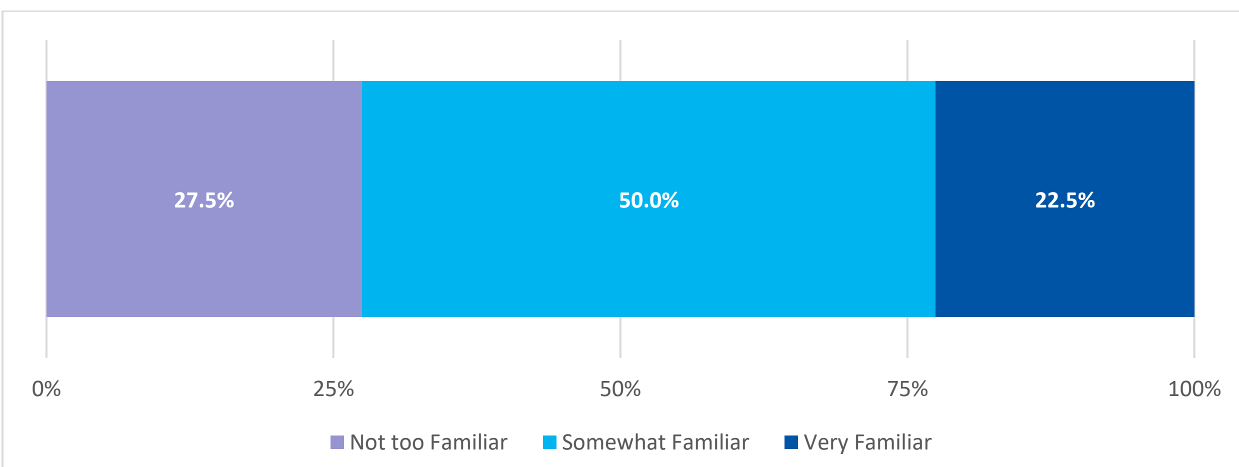
Cadmus also asked both residential and commercial customers a similar set of questions focused on ccASHPs. Specifically, we assessed whether participants had heard of ccASHPs, their familiarity with ccASHP technology, and whether they agreed with various statements about ccASHPs. For both the residential and commercial segments, more than two-thirds of surveyed customers, commercial or residential, had not heard of ccASHPs prior to the survey (Figure 5). Specifically, only 34.5% of residential customers and two of seven commercial customers had heard of ccASHPs prior to the survey. For those who had some familiarity with the technology, most said they were only *somewhat familiar* with ccASHPs, and many were unclear as to whether ccASHPs could perform better than traditional ASHPs.

Figure 5. Pre-Survey Familiarity with Cold-Climate Heat Pumps



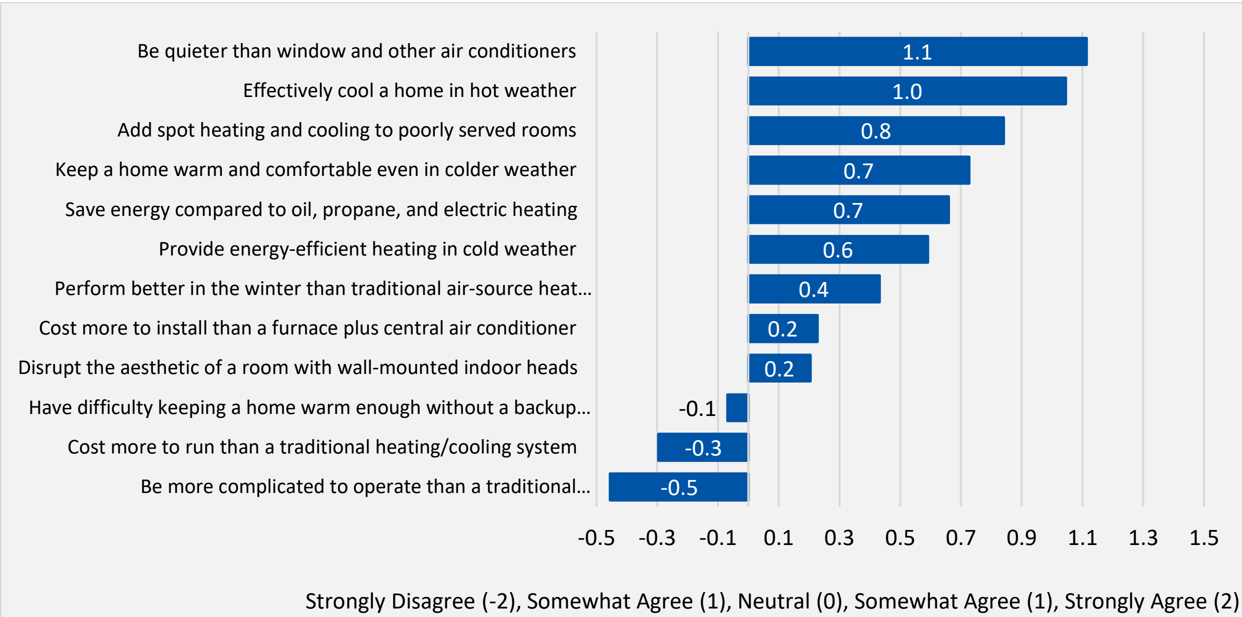
Of those who said they had heard of ccASHP technology, the majority of customers rated themselves as *somewhat familiar* with this technology. Most customers (72.5%) were at least *somewhat familiar* with the technology, while 22.5% claimed to be *very familiar* (Figure 6).

Figure 6. Relative Familiarity with Cold-Climate Heat Pumps



More than half of the surveyed customers said they were neutral or did not know whether ccASHPs could perform better than traditional ASHPs. Much like with traditional ASHPs, residential customers most strongly agree that ccASHPs can "be quieter than window and other air conditioners" and "effectively cool a home in hot weather" (Figure 7). Residential customers were still generally in agreement, though less so, with the statement that ccASHPs can "provide energy-efficient heating in cold weather" and "can perform better in the winter than traditional air-source heat pumps." Residential customers slightly disagreed with the statement that ccASHPs can "have difficulty keeping a home warm enough without a backup heating source."

Figure 7. Residential Cold Climate Heat Pump Performance Perceptions



Source: Survey question. "Please rate how much you agree or disagree with the following statements. Cold-climate air-source heat pumps can..." (n=44)
There was an adequate sample only for residential customers.

Barriers to Heat Pump Use

Cadmus also asked customers about the extent to which they considered making heating and cooling system upgrades, as well as the details and barriers to actions related to those considerations. Roughly 75% of residential customers said they were considering upgrading their home's heating and cooling system in the next several years. The majority of these residential customers reported that they had not yet made these upgrades due to either high upfront costs, a lack of familiarity with the technology, or a lack of time needed to make the upgrade.

For those residential customers who did upgrade their heating system in the last three years, the vast majority (82%) installed the same type of system they replaced (i.e. replacing an old oil furnace with a new, updated oil furnace). Meanwhile, while the number of commercial respondents was too low to draw any major conclusions, it was notable that only half of commercial respondents had considered upgrading their building's system, and none had actually made those upgrades.

Sixty-two percent of residential customers (n=124) had considered upgrading their home's heating and cooling system. More specifically, 30% had considered a complete system upgrade and 32% had considered upgrading a specific component of the system. Home fuel type was statistically related to percentage of residential customers who considered making improvements to their home's heating and cooling system:

- Kerosene and oil: 45% (n=29)
- Propane: 67% (n=6)
- Electricity: 74% (n=42)

Notably, interest in improving home heating systems is positively correlated with the price of fuels, with the most expensive heating fuel (electricity) having the highest percent of homeowners who consider upgrades. In only 25% of cases had customers completed the work they considered. For the eight customers who decided against completing the work, the top reasons were the high initial cost, lack of familiarity with other heating and cooling technologies, and concern that the upgrade may increase monthly energy bills.

Thirty-eight percent of residential customers had not considered improving their home's heating and cooling system, primarily because the existing system was not in need of improvements, the initial cost of a new system is too high, and that they do not plan to stay in their home long enough for the cost to pay off.

Cadmus asked customers who indicated that they considered some form of heating and cooling system upgrade what types of heating and cooling systems they had considered installing. The most common system considered was a ductless mini-split heat pump (DMSHP; 26%), followed by a central AC (16%). Ninety percent of customers who considered installing an ASHP ultimately did not do so due to some combination of high upfront costs, lack of familiarity with the technology, and a lack of time needed to make the upgrade.

Table 3. Heating and Cooling Systems Considered for Installation

Heating and Cooling System Considered	Percentage of Responses (n=94)
Ductless mini-split heat pump	26%
Central air conditioner with ducts to individual rooms	16%
Ducted air-source heat pump	15%
Central forced air furnace with ducts to individual rooms	15%

Most residential customers who upgraded their heating system in the last three years (n=27; 82%) installed the same system they replaced. The majority of these customers had not considered an ASHP when making heating and cooling system replacement decisions. The percentage of respondents who did not consider installing an ASHP was statistically related to the household's fuel type:

- Kerosene and oil: 75% (n=8)
- Propane: 100% (n=5)
- Electric: 44% (n=9)

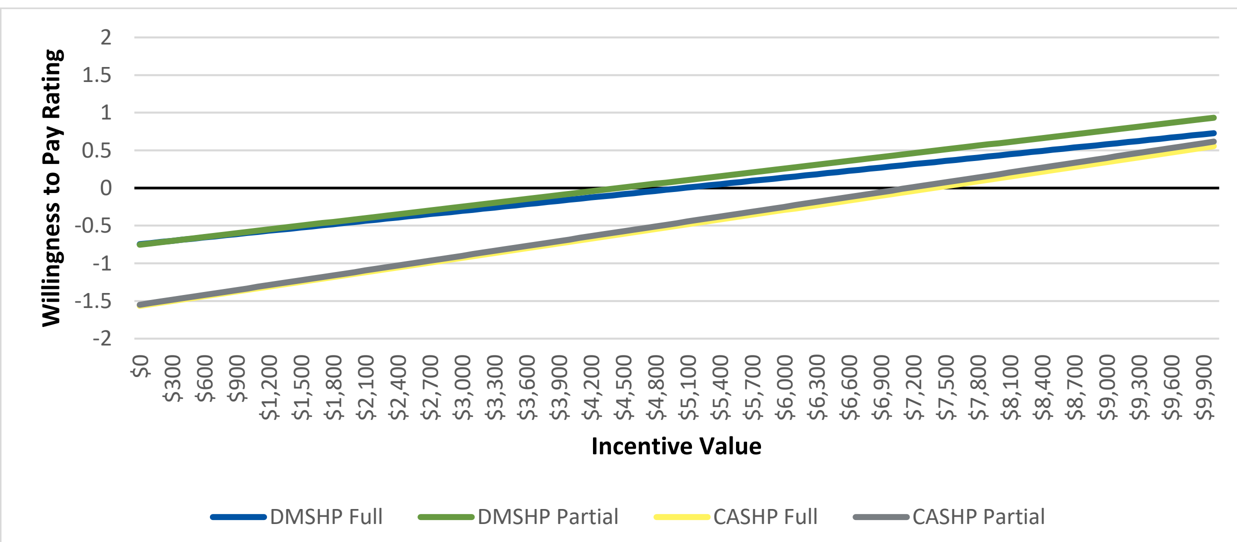
Willingness to Pay

For the willingness-to-pay (WTP) analysis, Cadmus asked participants to rate how likely they would be to install a specific kind of heat pump under different incentive levels. We broke this analysis into four scenarios: installing a DMSHP to partially displace existing heating, installing a DMSHP to fully displace existing heating, installing a centrally ducted heat pump to partially displace existing heating, and installing a centrally ducted heat pump to fully displace existing heating. We informed customers of heat pump prices compared to fossil-fuel systems, then asked them to rate their likelihood to install the technology on a scale of -2 (*not at all likely*) to 2 (*very likely*) under different incentive scenarios covering 0% to 50% of the presumed cost to install each system.

This analysis resulted in a linear regression representing the line of best fit for customers' WTP ratings relative to incentives. With 0 as the neutral point on the scale, this intercept represents a break-even point, revealing the incentive level at which the average respondent was equally likely and unlikely to install the heat pump. Incentives higher than this threshold are notably likely to motivate additional customers to install heat pumps, while incentive levels below this threshold are not likely motivated by the incentive to install heat pumps.

As illustrated in Figure 8 below, the average willingness to pay for a ductless mini-split system (DMSHP) is significantly higher ($p<0.01$), than that for a central system (CASHP) meaning customers generally require lower incentives to consider installing the system. This, however, may be explained by the difference in installation cost and cost savings described for CASHPs versus DMSHPs in the study. As illustrated below, incentives per system need to be relatively high for the average customer to be equally likely and unlikely to install the system (a rating of 0). It is worth noting that, to minimize the confusion for participants, the incentives in this WTP assessment were described on a per-system basis, rather than a per-ton basis.

Figure 8. Average Residential Willingness to Pay by Scenario



Rating: (-2): Not at all likely; (-1): Not Very Likely; (0): Neutral; (+1): Somewhat Likely; (+2): Very Likely

Overall, several key trends emerged from the WTP analysis:

- Where data are available, electric customers appear significantly more willing to pay for heat pumps than oil or propane customers. This is likely due to the relative cost savings of converting to heat pumps from existing electric systems.
- The lowest incentive required to reach neutrality is $3,748 for customers partially displacing electric baseboard heat with a DMSHP. The highest incentive required to reach neutrality is $8,126 for customers fully replacing propane heat with a central heat pump.
- Propane customers generally appear to require higher incentives to achieve neutrality. However, the differences in WTP based on existing fuel are not found to be statistically significant.
- The incentive level needed to achieve neutrality for installing central heat pumps is significantly different from that needed to achieve neutrality for installing ductless mini-split heat pumps. This is largely due to the difference in overall cost as described in the individual scenarios.
- Incentive levels do not appear to explain most of the variability in customers' likelihood to install a heat pump, as reflected in the low R-squared values for each WTP curve. (see sub-sections for further discussion)
- As seen in the graph above, the shape of these WTP curves also illustrates that while WTP increases with incentive amount, the marginal increase in WTP per dollar of incentive is relatively low. For ductless mini-split systems, the WTP rating was shown to increase on average 0.16 points for every $1,000 of incentives, while for central systems, the WTP rating was shown to increase an average of 0.22 points for ever $1,000 of incentives.

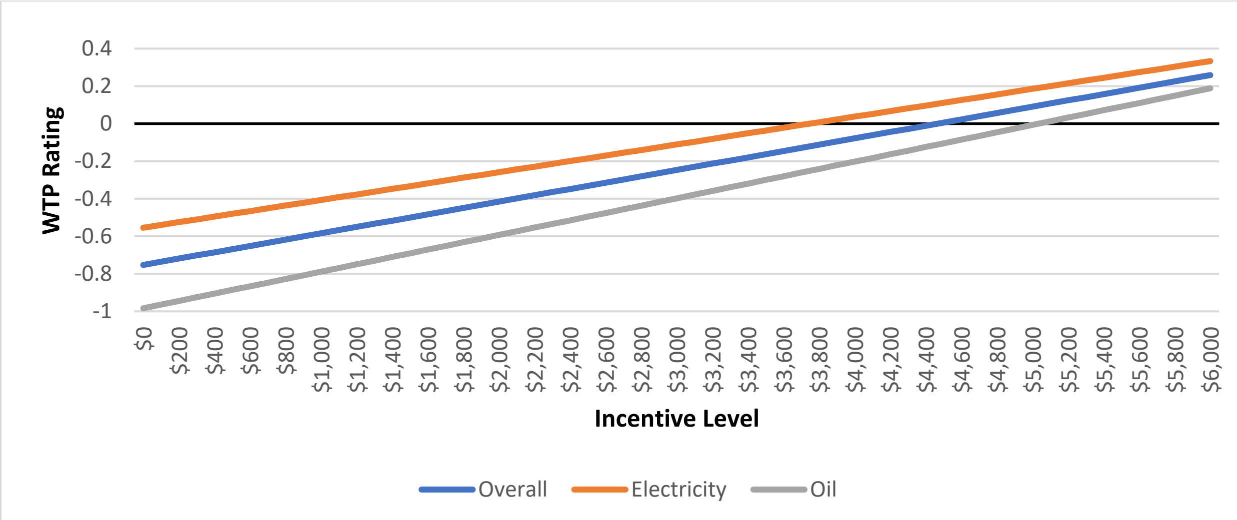
This willingness to pay study was based on the principle of stated WTP. This approach assumes that, provided sufficient information, a customer will accurately assess and respond with their specific preferences (in this case, their likelihood to install a given heat pump). It is worth noting, however, that this approach is not able to control for all variables which may factor into a customer's purchasing decisions. Furthermore, due to the low response rates, the analysis here reflects only residential WTP (not commercial WTP). Collectively, the findings that follow suggest that, while higher incentives are consistently needed to motivate widespread heat pump adoption, factors beyond incentive levels need to change in order to drive significant heat pump adoption, but that higher incentives will consistently be needed to motivate widespread heat pump adoption.

Ductless Mini-Split Partial Displacement

Under this scenario, Cadmus asked participants to consider their WTP to install a $12,000 DMSHP to partially replace their existing heating system, assuming it's still working fine (Figure 9). We informed respondents that this technology would save them between $300 per year (for oil customers) and $2,600 per year (for electric customers). Participants were asked how likely they would be to install the partial displacement heat pump at incentives equal to 0% ($0) 10% ($1,200), 25% ($3,000) and 50%

($6,000) of the installed cost. While no specific size was detailed as part of these WTP questions, a $12,000 DMSHP is roughly equivalent to a 2 to 4-ton DMSHP system.

Figure 9. Residential Willingness to Pay: DMSHP Partial Displacement



Rating: (-2): Not at all likely; (-1): Not Very Likely; (0): Neutral; (+1): Somewhat Likely; (+2): Very Likely

Overall, willingness to pay was rated very low, (-0.92) With no incentives available, WTP remained very low, with the average customer, regardless of fuel type, being unlikely to install the heat pump (-0.92). Only when offered a $6,000 incentive did ratings average above 0, with a standard rating of 0.16 (see Table 4). The slope of the overall WTP curve for partial DSMHP displacement reflects a marginal WTP rating change of 0.17 per $1,000 of total incentives.

Using the linear model from these responses, the typical incentive needed to reach neutrality is about $4,466.33, with electric customers being slightly more willing to adopt the heat pump due to its savings compared to oil customers (see Table 5). However, these differences are not statistically significant. The overall model reflects an R-squared value of 0.068, suggesting that well over 90% of the variation in WTP may be predicted by factors other than incentive levels.

Table 4. Average Rating per Incentive Level: DMSHP Partial Displacement

Incentive Level	Rating (-2 to 2)	Interpretation
$0.00 (0%)	-0.92	Not very likely
$1,200.00 (10%)	-0.37	Not very likely / neutral
$3,000.00 (25%)	-0.16	Not very likely / neutral
$6,000.00 (50%)	0.16	Neutral / somewhat likely

Incentives reflect increasing percentages of the assumed installation cost of $12,000. Note these values are pulled directly from the WTP and do not reflect the line of best fit shown above

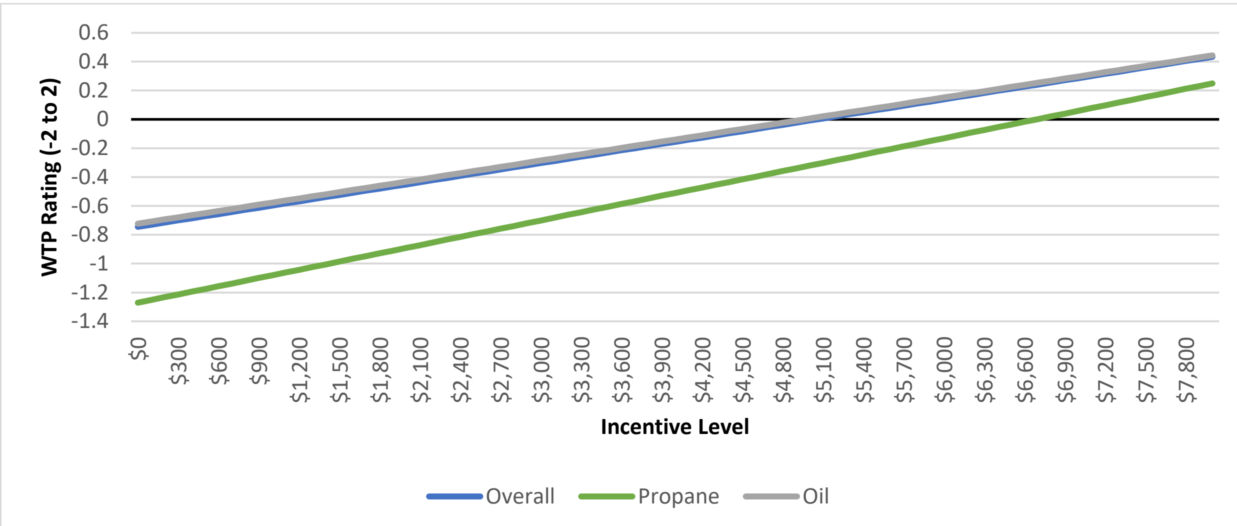
Table 5. Incentive Threshold: DMSHP Partial Displacement

Overall	Oil	Electric
$4,466.33	$5,035.70	$3,748.50

Ductless Mini-Split Full Replacement

Under this scenario, Cadmus asked participants to consider their WTP to install a $16,000 DMSHP to fully replace their existing system (Figure 10). We informed respondents that full replacement would save them between $300 per year (for oil customers) and $1,600 per year (for propane customers). The cost of the system is roughly equivalent to a 3 to 5-ton DMSHP system, although no specific size is noted in the questions used for this analysis.

Figure 10. Residential Willingness to Pay: DMSHP Full Displacement



Rating: (-2): Not at all likely; (-1): Not Very Likely; (0): Neutral; (+1): Somewhat Likely; (+2): Very Likely

With no incentives available, WTP remained very low, with the average customer, regardless of fuel type, being unlikely to install the heat pump (-0.79), which is slightly higher than the rating for partial displacement. Only when offered an $8,000 incentive (50% of the installed cost) did ratings average above 0, with a standard rating of 0.43, which is substantially higher than for partial displacement (see Table 6). The slope of the overall WTP curve reflects a marginal WTP rating increase of 0.14 for every $1,000 of total incentives.

Using the linear model from these responses, the typical incentive needed to reach neutrality is about $5,058.24, with oil customers willing to adopt this heat pump configuration at a very slightly lower incentive level. Meanwhile, propane customers appear to need higher incentives to consider adoption (see Table 7). This is a slightly higher incentive threshold than for partial displacement. Again, however, the difference between fuel types, and the difference between the full and partial displacement systems are not statistically significant. Overall, the model for full replacement DMSHPs, not breaking out by fuel type, has an R-squared of 0.092 reiterating the notion that more than 90% of variation within WTP responses in this survey are predicted by factors other than rebate levels.

Table 6. Average Rating per Incentive Level: DMSHP Full Displacement

Incentive Level	Rating (-2 to 2)	Interpretation
$0.00 (0%)	-0.79	Not very likely
$1,600.00 (10%)	-0.44	Not very likely / neutral
$4,000.00 (25%)	-0.18	Not very likely / neutral
$8,000.00 (50%)	0.43	Neutral / somewhat likely

Incentives reflect increasing percentages of the assumed installation cost of $16,000. Note these values are direct averages, and not derived from the line of best fit noted above.

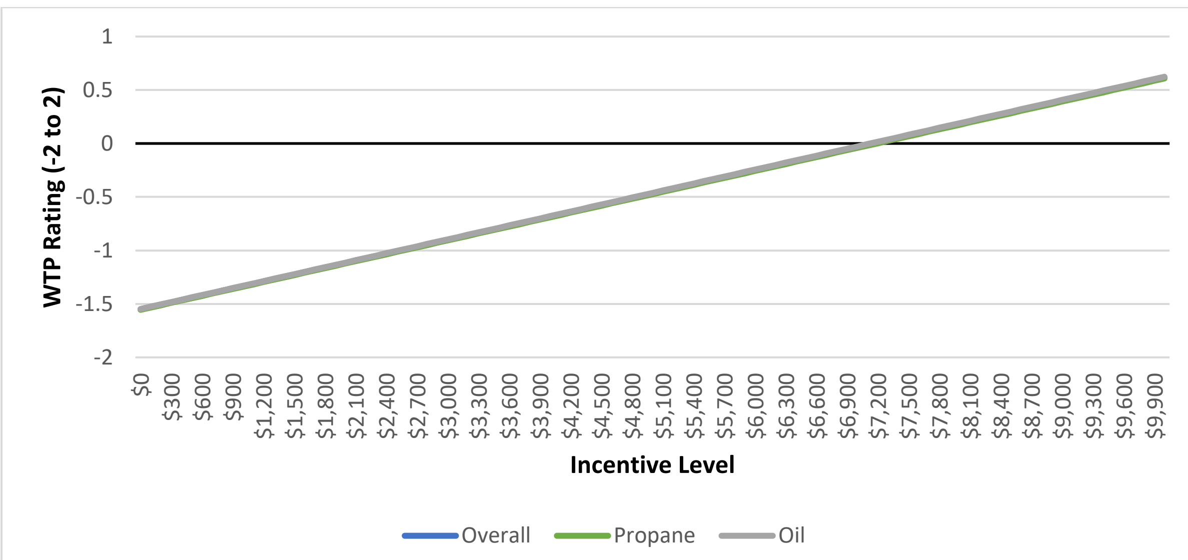
Table 7. Incentive Threshold: DMSHP Full Displacement

Overall	Oil	Propane
$5,058.24	$4,961.05	$6,689.86

Central Heat Pump Partial Displacement

Under this scenario, Cadmus asked participants to consider their WTP to install a $12,500 central heat pump to partially replace their existing system (Figure 11). We informed respondents that this technology would save them between $300 per year (for oil customers) and $1,400 per year (for propane customers). While no specific size was established, the cost of this system is roughly equivalent to that of a 2.5 to 3.5-ton central system.

Figure 11. Residential Willingness to Pay: Central ASHP Partial Displacement



Rating: (-2): Not at all likely; (-1): Not Very Likely; (0): Neutral; (+1): Somewhat Likely; (+2): Very Likely

With no incentives available, WTP remained very low, with the average customer, regardless of fuel type, being very unlikely to install the heat pump (-1.57). This is significantly lower that the likeliness to install the mini-split system, suggesting a significant difference in perception between the DMSHP and the central ASHP. Only when offered an $10,000 incentive (80% of the total installed cost) did ratings average above 0, with a standard rating of 0.62, consistent with expectations (see Table 8). Notably, there is no noticeable difference in willingness to pay between propane and oil customers. This is clearly reflected in the lack of apparent distinction between the "Propane," "Oil," and "Overall" WTP curves seen in Figure 11. The overall curve here reflects a marginal WTP rating increase of 0.22 per $1,000 of additional incentives per system.

Using the linear model from these responses, the typical incentive needed to reach neutrality is about $7,161.67, with both oil and propane customers exhibiting very similar WTP despite differentiated savings values. This finding suggests that the cost, cost savings and details of the central heat pump system has an influence on customers' WTP overall (see Table 9). While the difference between central and ductless systems is significant, the difference between oil and propane customers' wiliness to pay for central heat pump systems is not. Unlike the DMSHP models, the central heat pump model described here has an R-squared value of 0.32, suggesting that just under 70% of variability is predicted by factors other than rebates. This is notably higher than among the DMSHP models and suggests the need for further research into the nature of WTP predictors within the heat pump market.

Table 8. Average Rating per Incentive Level: Central ASHP Partial Displacement

Incentive Level	Rating (-2 to 2)	Interpretation
$0.00 (0%)	-1.57	Not at all likely
$2,000.00 (16%)	-1.00	Not very likely
$5,000.00 (40%)	-0.62	Not very likely
$10,000.00 (80%)	0.62	Somewhat likely

Incentives reflect increasing percentages of the assumed installation cost of $12,500. Note these are direct averages and do not reflect the line of best fit described above.

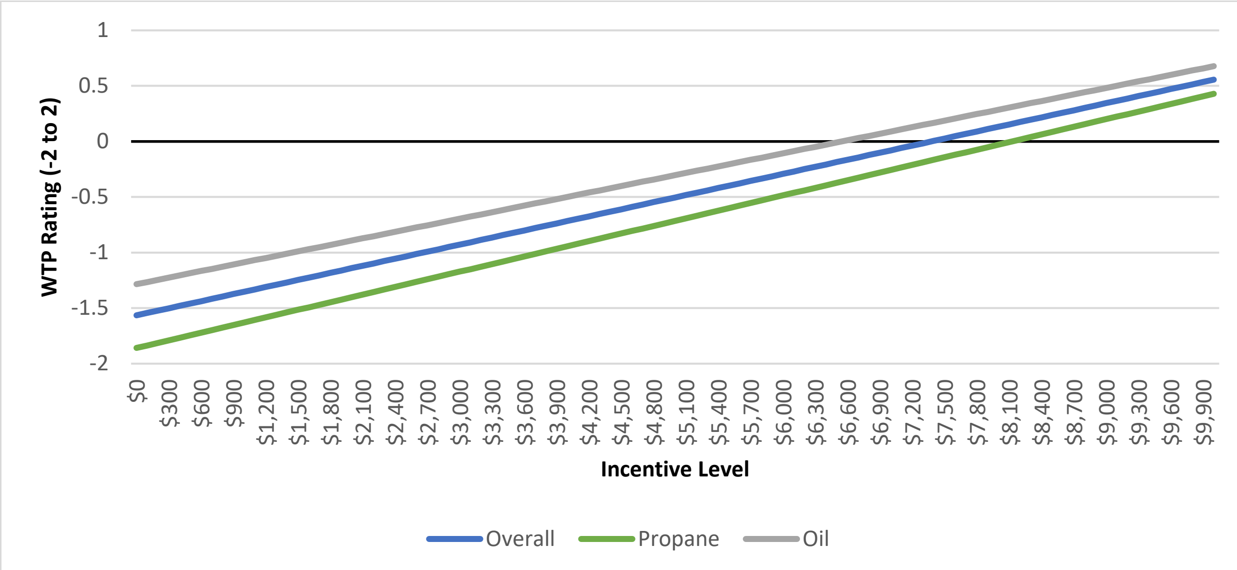
Table 9. Incentive Threshold: Central ASHP Partial Displacement

Overall	Oil	Propane
$7,161.67	$7,127.79	$7,192.59

Central Heat Pump Full Replacement

Under this scenario, Cadmus asked participants to consider their WTP to install a $20,000 central heat pump to fully replace their existing system. We informed respondents that this technology would save them between $200 per year (for oil customers) and $1,100 per year (for propane customers). Based on system cost, this is roughly equivalent to a 3.5 to 4.5-ton central heat pump system.

Figure 12. Residential Willingness to Pay: Central ASHP Full Replacement



Rating: (-2): Not at all likely; (-1): Not Very Likely; (0): Neutral; (+1): Somewhat Likely; (+2): Very Likely

With no incentives available, WTP remained very low, with the average customer, regardless of fuel type, being very unlikely to install the heat pump (-1.59). Like the partial displacement scenario, this is substantially lower than likeliness to install a DMSHP, in part due to the overall cost of the system. Interestingly, this rating is only slightly lower than for the partial displacement scenario, despite being nearly double the cost, indicating that customers may favor full replacement. Only when offered an $10,000 incentive (50% of the installed cost) did ratings average above 0, with a standard rating of 0.59, consistent with expectations (see Table 10). This overall curve, therefore, reflects a marginal WTP rating of 0.21 for every $1,000 of incentives.

Using the linear model from these responses, the typical incentive needed to reach neutrality is about $7,376.44, with oil customers being slightly more likely to install than propane customers. This is somewhat counterintuitive because of the lower cost savings described for oil customers than for propane customers, but does not reflect a significant difference (see Table 11). The standard model for full replacement central heat pumps, not breaking out replaced fuel types, has an R-squared value of 0.29, suggesting that just over 70% of variability is predicted by factors other than rebate values.

Table 10. Average Rating per Incentive Level: Central ASHP Full Displacement

Incentive Level	Rating (-2 to 2)	Interpretation
$0.00 (0%)	-1.59	Not at all likely
$2,000.00 (10%)	-1.04	Not very likely
$5,000.00 (25%)	-0.61	Not very likely
$10,000.00 (50%)	0.59	Somewhat likely

Incentives reflect increasing percentages of the assumed installation cost of $20,000

Table 11. Incentive Threshold: Central ASHP Full Displacement

Overall	Oil	Propane
$7,376.44	$6,544.34	$8,126.10

Environmental Decision Making

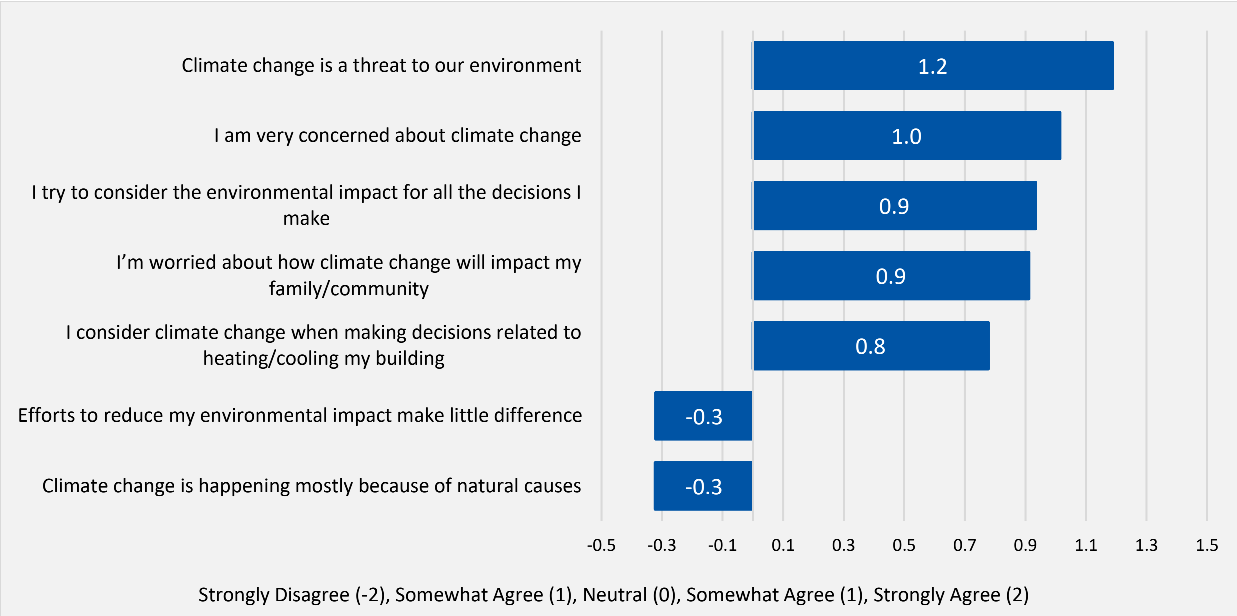
Cadmus asked customers about the extent to which they agreed with several statements about climate change as it relates to their decision making. Based on their responses, most customers—both residential and commercial—are concerned about climate change and the environment. Notably, customers in both segments do consider environmental and climate change impacts when making decisions about heating and cooling systems. However, the two groups are in less agreement about whether their efforts have an impact on the environment.

As shown in Figure 13, the average residential customer either somewhat or strongly agrees that climate change is a threat and is concerned about climate change broadly. Similarly, statements regarding decision making incorporating environmental and climate considerations ranked around 0.85, suggesting that the average customer is somewhat likely to incorporate climate considerations in their decisions, but maybe not as the primary factor.

Notably, surveyed residential customers broadly (albeit less stringently) rejected the idea that climate change is naturally occurring, suggesting that most customers think that climate change is at least somewhat caused by humans. Customers had weak disagreement with the statement, “efforts to reduce my environmental impact make little difference,” suggesting that at least a few customers believe they can reduce their climate impacts through individual action.

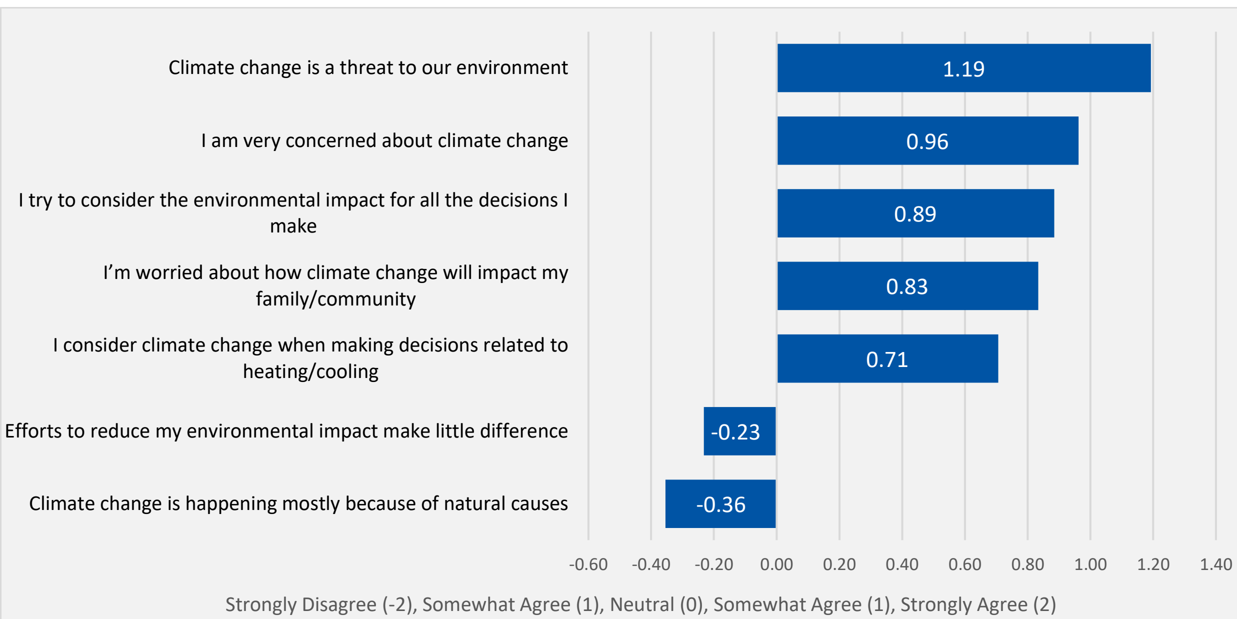
While only a few commercial customers responded to this part of the survey, similar patterns emerged, with notable agreement that climate change is a significant problem and is being considered as part of decision making.

Figure 13. Residential Environmental Decision Making



The only statistically significant difference in responses by fuel type was in regard to whether a customer considers climate change when making decisions. The level of agreement was highest for kerosene and oil customers (0.9).

Figure 14. Commercial Environmental Decision Making



Note, due to low commercial response rates, these findings should be assessed as anecdotal.

This analysis reveals that environmental impact is notably tied to decision making for many customers. However, based on the heating and cooling replacement statistics noted above, it appears that such environmental considerations are often outweighed by price and a general lack of understanding of more efficient heat pump technologies.

Key Findings

Based on results from the survey overall, the Rhode Island market is at an early stage in heat pump market growth. General awareness of heat pumps remains quite low, with few customers receiving information about heating and cooling technologies from anywhere outside their installers. This lack of technical familiarity and the relative upfront cost of these technologies means that many customers need significant incentives to consider heat pumps for their home or business. Meanwhile, while environmental considerations are often involved in heating and cooling decisions, they appear to be significantly outweighed by cost and technological familiarity.

Heat Pump Owner Survey

Cadmus conducted an online survey of current owners of heat pumps in the National Grid Rhode Island territory.

Overview

We identified heat pump owners using past years' rebate data regarding customer installations of HVAC equipment and surveyed customers who had participated in the limited fuel displacement offering, electric resistance to heat pump conversion offering, and the lower rebate standard heat pump offering. Cadmus used the survey to explore owners' decision-making process and experience during ASHP installation. We also assessed customers' satisfaction with the impact of the heat pump on heating and cooling costs, as well as their use habits and control systems.

Cadmus collected survey responses from 78 residential customers and six commercial customers. The small survey sample size for commercial customers limits the extent to which we can infer information about the population of commercial customers based on our survey data.

Decision Making

Cadmus asked customers how they learned about ASHPs and what factors contributed to their decision to install an ASHP. Owners most often heard about ASHPs by word of mouth, either from a friend, family member, neighbor, or colleague (34.5%), or from their HVAC contractor (25%; Table 12). The next-most common sources of ASHP knowledge among residential customers are online research, TV shows, or during an energy audit. Over 8% of residential customers do now know how they first learned about ASHPs. Notably, none of the survey respondents reported first learning about ASHPs from National Grid directly.

Table 12. Air Source Heat Pump Knowledge Source

How did you first learn about ASHPs?	Percentage of Responses (n=84)
From a friend, family member, neighbor, or colleague	34.5%
From a contractor	25.0%
Online research	14.3%
Don't know or don't remember	8.3%
TV show or advertisement	7.1%
Other (please describe)	7.1%
During an energy audit	3.6%
Directly from National Grid	0.0%

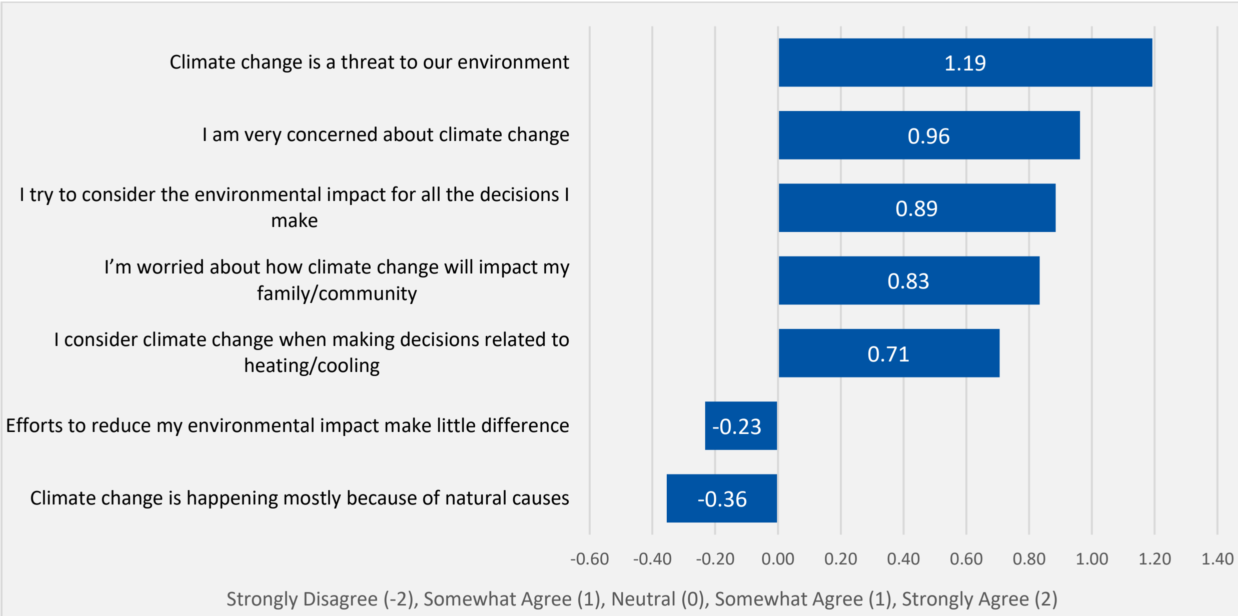
The top reason for installing an ASHP differed by sector. Half the commercial owners most often had an old system in need of repair or replacement, while a smaller proportion wanted a quieter heating and cooling system (Table 13). By comparison, residential customers most often wanted to add cooling, while a smaller proportion wanted to save money on heating and cooling bills. Additionally, roughly 24% of residential customers noted that they wanted a more comfortable heating or cooling system in their home while another 18% said they were motivated to install a heat pump because there was an incentive available.

Table 13. Top Two Reasons for Installing an ASHP

What led to your decision to install an ASHP? Residential	Percentage of Responses (n=110)
Wanted to add cooling	35%
Wanted to save money on heating and cooling bills	25%
Commercial	**(n=6)**
Old system broke down or needed replacing	50%
Wanted a quieter heating and cooling system	33%

Figure 15 shows that ASHP owners are generally concerned about climate change and the environmental impacts of their behavior. The responses among heat pump owners are statistically the same as those from the target market sample. Heat pump owners therefore have roughly the same environmental values as the general population, with strong agreement with the notion that climate change is a threat to the environment and a high level of concern about climate change impacts. While environmental considerations are high among ASHP owners, these considerations do not fully explain the motivation and decision making behind acquiring heat pumps for all owners.

Figure 15. Environmental Considerations of ASHP Owners



Installation Experience

Cadmus asked customers whether they had an energy audit before ASHP installation, whether the auditor recommended ASHP installation, and how the customer had subsequently identified their heat pump contractor. Most owners (60.5%) did not have an energy audit prior to ASHP installation. Among the 39.5% who did have an energy audit, only 7% said their auditor recommend an ASHP. In 88% of cases, the auditors recommended specific energy efficiency measures, specifically insulation, air sealing, or both. Most owners (roughly 65%) completed these recommended upgrades before ASHP installation.

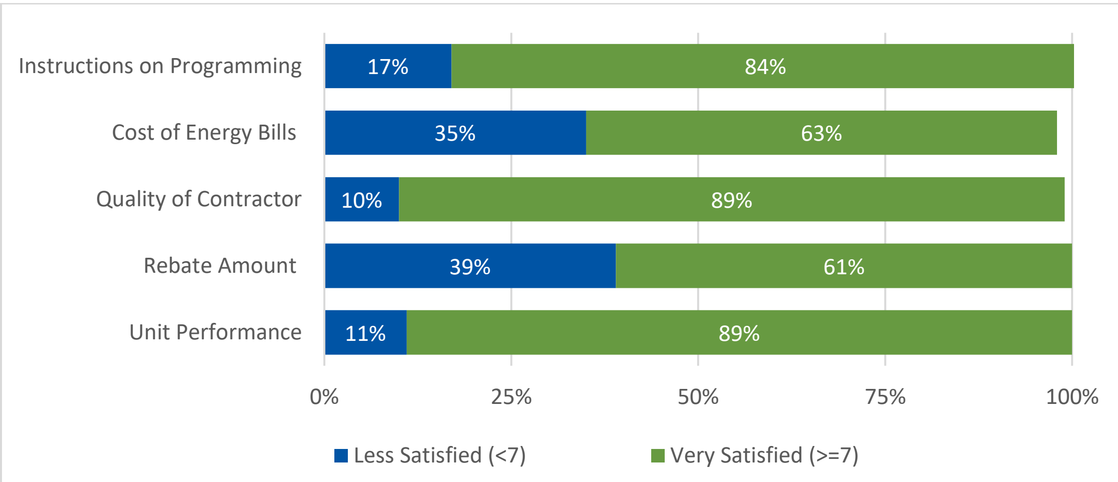
Additionally, the means by which ASHP owners identified their ASHP contractor differed by sector. Residential owners typically received a bid from just one contractor, who they usually identified through word of mouth. Commercial owners most often solicited bids from two or three contractors who they typically had worked with previously.

Residential and commercial customers also had different concerns prior to their ASHP installation. The most common concern among commercial ASHP owners was the cost associated with the time commitment required to install and maintain the system, while the most common concern among residential ASHP owners was the system cost and performance.

Customer Satisfaction

Cadmus asked customers about their satisfaction with various components of the ASHP experience, as well as their likelihood to recommend an ASHP to a friend. Rated on a 0 to 10 scale, with 0 being "*not at all satisfied"* and 10 being "*extremely satisfied,*" the majority of heat pump owners expressed widespread satisfaction with their heat pump and its installation (see Figure 16). Owners were most often the most satisfied with the performance of their ASHP (89% *very satisfied)*, the contractor who installed the ASHP (89% *very satisfied*), and the information and instructions they received from the contractor about system operation and programming settings (84% *very satisfied*; Figure 16). Only a relatively small fraction of heat pump owners expressed even slight dissatisfaction (a rating of less than 7) for any feature of their heat pump and installation experience. While the majority of customers were satisfied with their heat pump overall, the most common point of dissatisfaction was the rebate amount, likely attributable to the number of heat pump owners who did not qualify for the higher rebate, or who installed their heat pump before these higher incentives were available from National Grid.

Figure 16. Residential ASHP Owner Satisfaction (n=57)



Rated on a 0 to 10 scale, with 0 being "*not at all satisfied*" and 10 being "*extremely satisfied,*"

ASHP owners were somewhat less satisfied, however, with other aspects of their ASHP experience. Those who received the smaller, standard rebate from National Grid were somewhat less satisfied with their rebate amount. ASHP owners were also somewhat less satisfied with the amount of their energy bills after installing the ASHP. Table 14 presents a detailed breakdown of ASHP owners' reported changes to their monthly energy bills. For the majority of owners (82%, n=70), energy bills—including electricity, natural gas, and oil—did change.

Table 14. Monthly Energy Bills

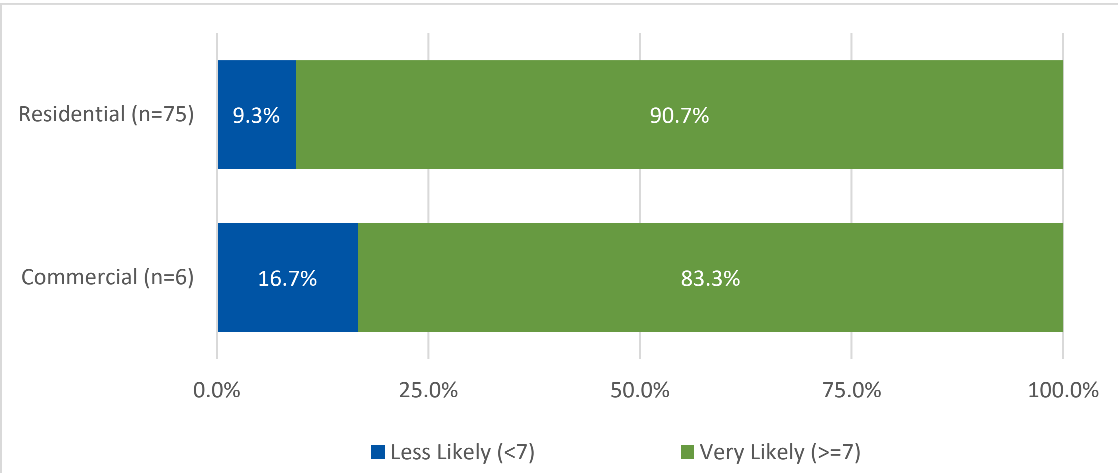
Monthly Energy Bill Changes	Commercial (n=4)	Residential (n=30)	Residential Natural Gas (n=5)	Residential Non–Natural Gas (n=25)
Lower by a large amount ($50 or more lower)	50%	13.3%	20.0%	12.0%
Lower by a small amount ($11 to $49 lower)	25%	43.3%	60.0%	40.0%
Largely stayed the same (within $10 per month)	0%	13.3%	0.0%	16.0%
Higher by a small amount ($11 to $49 higher)	25%	13.3%	0.0%	16.0%
Higher by a large amount ($50 or more higher)	0%	16.7%	20.0%	16.0%

.

Notably, and contrary to expectations, the majority of natural gas respondents said their bills decreased after installing the heat pump. This may be attributable to other energy consumption changes, such as better managing thermostat use or replacing less-efficient cooling systems or may simply reflect the low sample size and should likely be interpreted as anecdotal. Conversely, there are a notable number of non–natural gas owners who said their bills increased after installing a heat pump. Again, this may be attributable to behavior changes or to the addition of cooling, which remains the primary motive for installing a heat pump, or a misrepresentation of savings given that oil and propane are often not billed on a monthly basis. Interestingly, the seven respondents who reported not having previously cooled their home, noted that, on average, their monthly energy bills decreased slightly. All but one of these respondents had also switched from fuel oil or propane to the heat pump.

Cadmus also assessed how likely ASHP owners were to recommend an ASHP to a friend. Most residential ASHP owners (90.7%) reported being very likely to recommend an ASHP to a friend, compared to 83.3% of commercial ASHP owners (Figure 17).

Figure 17. Likelihood to Recommend ASHP to a Friend



Rated on a 0 to 10 scale, with 0 being “extremely unlikely to recommend” and 10 being “extremely likely to recommend,”

This is further confirmation of customers’ overall enthusiasm about their heat pump system. While the survey may reflect some self-selection bias, with only those customers who are most interested in their heat pumps selecting to respond to the survey, the findings offer an encouraging view for helping facilitate heat pump adoption. Because the most common way to learn about heat pumps is through word of mouth, this level of positive response indicates that a growing network of heat pump users may continue to facilitate market growth for the technology.

Heat Pump Use

Cadmus asked customers a broad set of questions related to their ASHP usage habits, interactions with their ASHP contractor, the use of other heating and cooling systems, the use of ASHP controls, and any problems they experienced with their ASHP. Most residential owners intended to use the ASHP as a supplemental heating system, implying that they are using the heat pump either to heat only select areas of the home, or only under certain circumstances. Meanwhile, most commercial owners intended to use their heat pump as their primary heating system (Figure 18), implying that the heat pump is either their only heating system or intended to provide the majority of heating for their space. Notably, fully 14% of residential heat pump owners use their heat pump exclusively for cooling. As shown in Figure 19, most customers, 100% of commercial and 88% of residential, used their heat pump system as their primary source of cooling. This means that they either fully replaced their existing cooling system with the heat pump or did not previously have any cooling and add cooling to their home by installing the heat pump.

Figure 18. Heat Pump Usage Habits: Heating

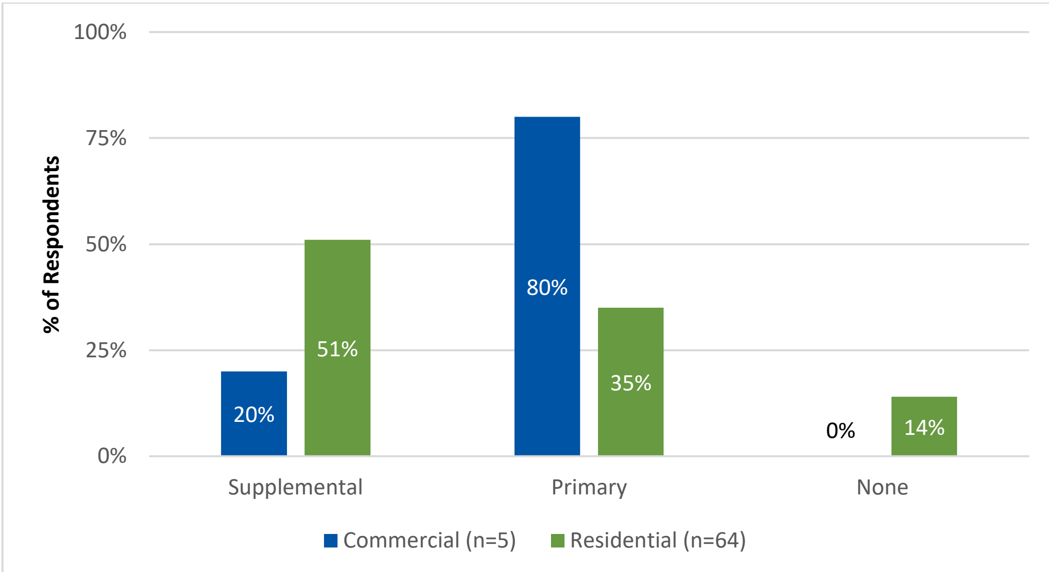
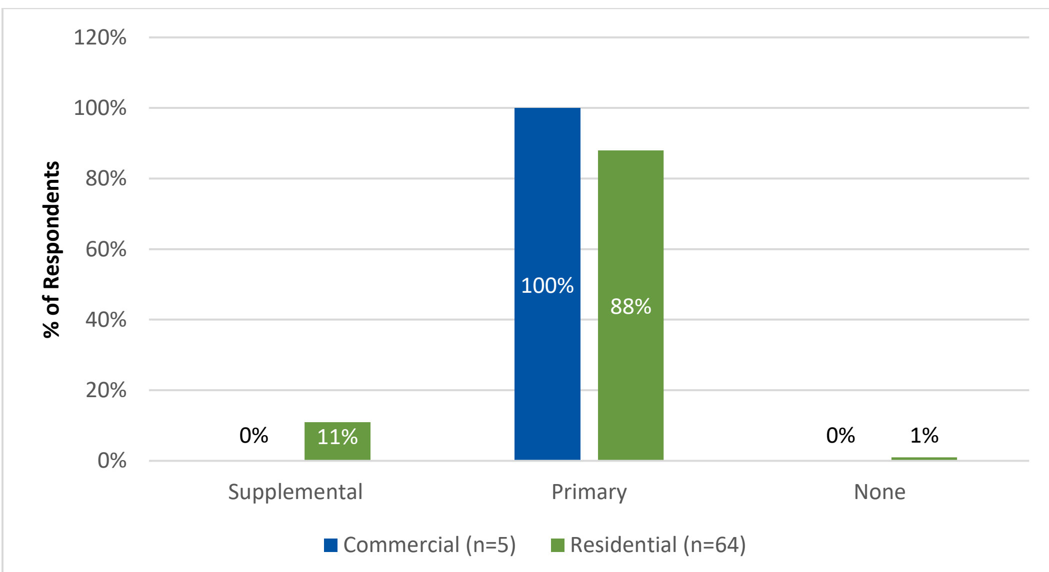


Figure 19. Heat Pump Usage Habits: Cooling



Notably, roughly 11% of residential respondents stated that they did not use their heat pump as their primary source of cooling. A brief follow-up question revealed that 73% of those using their heat pump as supplemental cooling retained their old system and used it to cool the majority of their house while using the heat pump to cool only select rooms. Another 27% of these respondents noted that they ran the heat pump at the same time as an existing system to provide sufficient cooling.

Table 15. Residential Intended Heat Pump Uses

Intended Heat Pump Use		Cooling Use		
		Primary	Supplemental	None
Heating Use	Primary	29.7%	3.1%	1.6%
	Supplemental	46.9%	4.7%	0.0%
	None	12.5%	1.6%	0.0%

Residential respondents only (n=64).

As seen in Table 15, the majority of residential heat pump owners planned to use their heat pumps as the primary source of cooling, while also using the heat pump for some amount of heating. The most common scenario, representing nearly 47% of all residential scenarios, is the installation of a heat pump as the primary source of cooling and as a supplemental, or back-up, source of heating. The next most common scenario is the “whole-home” style installation where the heat pump is the primary source of both heating and cooling for the house.

Within this usage breakdown, there is a notable distinction in responses based on existing heating fuel. Although sample sizes were small, approximately 75% of natural gas residential owners (n=12) intended to use an ASHP as a supplemental system, compared to 51.5% of residential customers who use another fuel type (see Table 16). This follows logically from the relative cost of natural gas and supports the general notion that heat pumps are often installed for supplemental heating but primary cooling.

Table 16. Heat Pump Usage Habits of Residential Owners

How do you use your ASHP and prior heating system?	Overall Residential	Residential Natural Gas (n=12)	Residential Non–Natural Gas (n=33)
I use the prior system as my primary heating source for the majority of my home	57.8%	75%	51.5%
I use the ASHP as my primary heating source for the majority of my home	13.3%	0%	18.2%
I use the ASHP and my prior system equally to heat my home	13.3%	8%	15.2%
I only use my ASHP for cooling my home	15.6%	17%	15.2%
Don’t know	0.0%	0%	0.0%

Note: There were not enough commercial respondents to report relative use statistics. The one propane respondent said they use their prior system as their primary heating source.

Roughly half of all residential owners use their ASHP to service two to four rooms (n=66) compared to approximately one-tenth who use it to service only one room. This is logical given the recent trend toward greater adoption of multi-zone systems as supported by the incentives promoted in the area. Unsurprisingly, customers with natural gas tend to use their ASHP to service fewer rooms than those with propane or fuel oil. Among natural gas customers, roughly 33% (n=12) used their ASHP to service one room, while 25% used it to service two to four rooms. On the other hand, roughly 52% of oil customers used the heat pump to service two to four rooms and only 4% used it to service just one room.

Looking at broader usage patterns, roughly one-third of all customers run their heat pump in a limited number of rooms or only during shoulder seasons, using supplemental heaters in other part of the home and at other times of the year (see Table 17). This limited use is most common among natural gas customers, 40% of who said they only use an ASHP in a limited number of rooms. The shoulder-season use is, interestingly, more common among non–natural gas customers (at over 40%) than among natural gas customers.

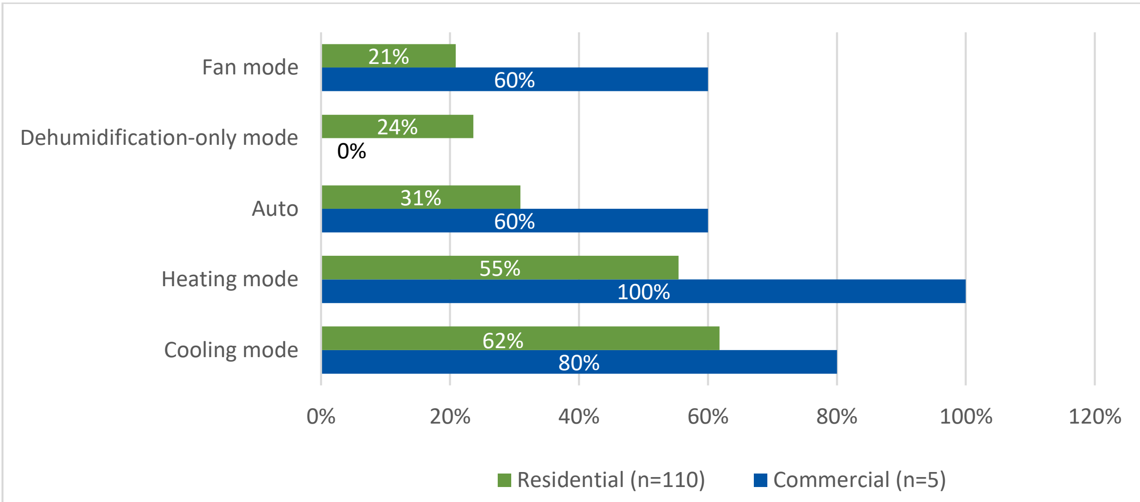
Table 17. Usage Patterns of ASHP among Residential Customers

How do you use your ASHP?	Residential Overall	Residential Natural Gas (n=10)	Residential Non–Natural Gas (n=19)
I use it to heat a limited number of rooms in my home	31.3%	40.0%	27.3%
I run it during the shoulder seasons then switch to my prior system	34.4%	20.0%	40.9%
I run it until a certain temperature then turn it off and switch to my prior system	18.8%	20.0%	18.2%
I run it at the same time as my prior system	9.4%	10.0%	9.1%
Don’t know	6.3%	10.0%	4.5%

Note: There were not enough commercial respondents to report relative use statistics.

Best practice recommendations encourage owners to set their heat pump to either heating or cooling depending on the season to maximize their efficiency. The majority of residential customers primarily use these two settings, indicating reasonable use patterns. About 31% of residential customers use the “auto” setting (Figure 20), which may diminish energy efficiency in some cases. While response rates were too low to draw meaningful conclusions, it is interesting to note that a substantially higher percentage of commercial customers use the “auto” setting, while nearly all use the cooling and heating specific settings. This generally seems to indicate that most commercial customers are, with some exceptions, following heat pump operation best practices, while residential customers seem more likely to use specific preferred settings for their heat pump. Notably, some commercial and residential owners stated that they used both the “auto” mode and either the heating or cooling mode, suggesting that some users may default to the “auto” mode but will occasionally switch on the heating or cooling modes to meet specific, short-term needs.

Figure 20. ASHP Features and Settings Used



Note that percentages do not add to 100% as respondents were able to select more than one option.

With installers and contractors as one of the major sources heat pump awareness, Cadmus also sought to understand the extent to which current heat pump owners learned about the details of the technology from their installers. Roughly 90% of owners (n=82) said they received some type of education from their contractor about their ASHP system. Contractors spent more time educating residential owners (typically 15 to 44 minutes) versus commercial owners (typically under 15 minutes). Contractors also often provided educational materials (80%, n=81), most often an instruction manual or user guide. The vast majority of owners (94%, n=64) said they did use these materials to learn how to use their ASHP systems.

Cadmus also assessed the extent to which ASHP owners needed to perform maintenance on their system. The majority of owners did not have issues with the performance of their ASHP, and many did not seek system maintenance. This is reasonable considering that the median age for heat pumps in the sample was 4-5 years old, with fewer than 25% of respondents reporting that they installed their heat pump prior to 2016. Roughly half of all commercial owners (n=6) receive annual servicing, while 47% of residential owners have not received any maintenance. This is somewhat higher than may be expected given the median system age and lack of reported issues, pointing to more minor, routine maintenance. Indeed, residential customers were shown to more frequently perform small maintenance (such as cleaning or replacing air filters), with 43% conducting basic maintenance every three months compared to 50% of commercial respondents only conducting biannual maintenance. Interestingly, and likely due to sample size, only one commercial respondent reported being dissatisfied with their ASHP. Meanwhile, roughly 11% of residential owners reported experiencing a performance issue with their system, requiring some kind of maintenance. Among this small sub-sample (7 total respondents), 3 respondents noted dissatisfaction with the comfort of the heating and cooling from the heat pump, with only 2 respondents noting that they faced maintenance issues.

Finally, Cadmus assessed ASHP owners' use of controls. Nearly all owners said that the contractor spent time post-installation explaining the new system, including control use. Most residential and commercial owners (54%) use only the most basic controls, most often using the simple hand-held remote that came with an ASHP and have not yet moved toward installing integrated controls that manage both primary and secondary systems. Only a very small proportion of customers (8%) have some kind of smart thermostat system with these integrated control capabilities.

Key Findings

Overall, the owners' survey indicates that current heat pump owners may be a significant asset in the ongoing promotion and adoption of heat pumps in Rhode Island. Given that most customers learned about heat pumps from their peers or contractor and have a high level of overall satisfaction, it is likely that many owners will continue to reinforce efforts to promote this technology. It is also notable that none of the surveyed heat pump owners first learned about heat pumps directly from National Grid. The current study also reinforces the past research finding that the addition of cooling is a primary motivation for installing heat pumps in residential buildings. Meanwhile, using heat pumps to supplement existing heating systems appears popular in residential settings, but not in commercial settings, indicating that different approaches to incenting these systems for different sectors may be appropriate. Finally, while many customers are using their system effectively, the low level of integrated control use indicates that further promotion of smart home and smart thermostat technology could offer some additional energy-saving and integration benefits.

ASHP Installer Survey

Cadmus conducted surveys and interviews with contractors and businesses involved in the installation of air-source heat pumps in Rhode Island.

Overview

These contractors were identified from those who submitted rebates to National Grid in the past. The aim of these interviews was to understand how National Grid can most effectively support and engage installers in promoting heat pump adoption. Specifically, the surveys sought to identify the kinds of training and support that contractors rely on, assess marketing techniques, identify the primary technologies being installed, and confirm price trends and future projections. While the study initially targeted 30 installers for these interviews, due to the COVID-19 crisis, very few respondents were available for comment, and a total of 9 surveys were able to be conducted during the study period by both phone and online survey form. While this does not provide a representative sample, the insights from this analysis do support some critical findings and reaffirm the findings of past research.

Engagement

Only about half of installers surveyed continue to direct customers to the National Grid Electric Heating and Cooling rebate program. Of those installers who conducted outreach and marketing, most include ccASHP-specific marketing, although these installers were not likely to mention National Grid's rebates. This low level of active engagement with National Grid's programs was largely attributed to high barriers to entry, including paperwork and a lack of meaningful incentives. Installers offered several recommendations to these ends, including requesting that National Grid streamline the applications and paperwork, and suggesting higher incentives to match the high cost of installations.

Market Segment

When asked when in the process installers typically introduced the idea of installing heat pumps, many suggested that the technology is discussed in very early conversations. As supported by customer-side research, these conversations often focus on either adding cooling or providing supplemental heat.

Several key factors were commonly noted in determining customer interests in heat pumps, including rebates and general awareness. Many installers echoed the findings of the customer surveys, noting that they were among the first to introduce heat pumps to their customers. When introducing the technology, several installers highlighted how additional education about the technology and its energy and carbon benefits were significant factors in driving customer interest. The primary driver, however, is cost. Several installers that participate in the National Grid programs noted that, once a customer has decided to install a heat pump, the rebates from National Grid, and the specific systems they focus on, are a considerable factor in customers' selection of heat pump technology.

ASHP costs remain a major barrier to installation, however, and most installers expect costs to increase slightly over the coming years.

For most installers, the most common installation is a ductless system, with central heat pumps representing a relatively insignificant portion of installs for most respondents. While both single- and multi-zone installations are common for ductless systems, several installers indicated that they've seen an increase in overall ASHP sales, specifically ductless systems, in recent years and expect that trend to continue.

Trends

Nearly all installers reported that the ASHPs they tend to install are going into middle- and high-income single-family homes built between 1960 and 2000. Installers reported rough cost estimations of several different configurations, reaffirming the prices used later in this study. As can be seen in Table 18, there is a significant jump between typical single and multi-zone installations. The rising costs per system of the typical heat pump installations can be somewhat attributed to the rising prevalence of these configurations.

Table 18. Cost Distribution by Configuration

Heat Pump Configuration	Installed Cost	% Equipment cost
CC single-zone DMSHP	$5,270	60%
CC multi-zone DMSHP	$14,630	64%
CC Central ASHP	$12,170	65%

Notably, most installers highlighted that roughly 60-65% of installed costs come from the equipment itself, rather than labor and other soft costs. It is worth noting that installers were not asked to clarify whether they were including markup in their equipment costs. While past research has indicated that these soft costs are not likely to change significantly in the coming years, nearly all installers suggested that the overall cost of heat pump installation is increasing slightly and expect that trend to continue. One installer noted a potential for high cost increases from tariffs.

Training, Outreach & Customer Engagement

Five of the nine respondents reported participating in a training related to ASHP technology and installation as part of employee education. For most installers, these trainings focused on how to educate and engage with customers, as well as details around the installation, and servicing of technology. Most often, installers indicated that these trainings were sponsored by manufacturers and suppliers with only three respondents indicating they had participated in a third-party training from National Grid or CLEAResult. Most installers also reported that it was relatively easy to retain well-trained, qualified installers.

Of the nine respondents, only 5 participated in the 2019 National Grid Electric Heating and Cooling rebate program for ASHPs. However, four of these indicated a relatively low level of satisfaction with the program. When discussing their recommendations for improving the National Grid program, several pointed to the need to simplify the program, both from the customer and the contractor standpoint. Three installers noted that they would like to see more active outreach by National Grid to inform installers and customers about the incentives available. One specifically suggested that "There should be a tool where you put in the serial number/AHRI number and get the rebate they will receive." Another noted that the Mass Save program could serve as a template for how to improve the program.

Only six of the nine respondents reported conducting outreach and marketing to customers. Of the respondents who conducted marketing and outreach, most included marketing specific to cold-climate ASHPs, although few brought up National Grid rebates. Messaging for outreach typically centered on reduced environmental impacts, improved home comfort, dual heating and cooling ability, and energy and cost savings.

How heat pumps are first introduced to the customer seems to vary widely based on installer preference and experience. Roughly two-thirds of the respondents indicated that they discussed heat pumps with customers during initial conversations or during the proposal phase, while others noted they rarely mention the technology. Of those who do discuss heat pumps, roughly half noted that they prioritize discussing whole-home solutions with their customers, while the other half noted prioritizing zonal heating and cooling options.

During the contracting process, 5 of the installers interviewed noted that they mention the relevant rebates offered by National Grid. However, only 3 of these installers include the rebates in their price offerings. It is also noteworthy that roughly half of the respondents discuss other financing options, including the HEAT Loan and proprietary company financing options, with customers during the contracting process.

Although only anecdotal, the findings from this component of the installer interviews suggests that many customers may not be initially presented with the full range of options for technology, incentives or financing by their installers. As recommended by some of the installers, additional outreach and education targeted toward installers may help facilitate broader awareness of incentives and financing and help promote more detailed discussions between installers and their customers.

Distributor Interviews

Cadmus interviewed heat pump distributors to better understand what guides their purchasing decision and what changes they have witnessed in the heat pump market.

Overview

Through in-depth phone interviews, Cadmus gained valuable insights to the heat pump market. Cadmus had an initial goal of performing eight interviews with distributors and installers but was ultimately only able to interview three individuals from two different heat pump distribution companies.

Cadmus contacted over 20 distributers; however, responses and participation were limited, likely due to the COVID-19 pandemic and the timing of the study. Cadmus contacted manufacturers and distributors servicing the Rhode Island market and greater Northeast region. The list of manufacturers was identified from prior research conducted by Cadmus Group and NMR in the region. The interviews took place over the phone and were conducted by Cadmus using interview guides co-created with NMR. Cadmus focused on interviews in the Rhode Island service territory, while NMR focused their efforts in Connecticut. Each of the 3 interviews lasted between 30 minutes and 1 hour.

Trends

All of the distributors interviewed indicated that there have been substantial changes to the market over the last 5 years. They noted an increase of sales of ASHP with inverter technology[3], and an increase in the sale of ccASHP; however, ground-source heat pump sales have been flat. In regard to ground-source heat pump sales, one distributor said “GSHP are really only purchased by the ultimate ‘green’ consumer [and that] the cost-effectiveness for ground-source heat pumps just isn’t there. The advancements in air-source heat pumps have caused the financial analysis to tilt way in favor of air-to-air systems.”

All of the distributors said that they have seen efficiency improvements for ASHP in the last five years in part due to the increase in products with inverter technology available. One of the distributors also indicated that the physical footprint of the ASHP has reduced in size.

Cold-Climate Standards

The cold climate standards were discussed in depth with both of the distributors. There was consensus that sales of cold climate models have been increasing due to the rebates offered. One of the distributors explained how manufacturers of heat pumps will change what they make based on the incentives available in the market. Both distributors also noted that the costs are higher for ccASHP models.

Both of the distributors did not think that the cold-climate specifications should be incorporated into future RI efficiency programs. One distributor explained said, “The NEEP [Cold-Climate] standards are

[3] Inverter-driven variable speed compressor heat pumps are able to operate at partial capacity depending on the current heating need of a space, improving efficiency. All cold-climate heat pumps are inverter-driven systems with variable speed compressors, but not all inverter-driven systems are cold-climate heat pumps.

focused on the wrong objectives. [...] I think we are going down the wrong path with the NEEP standards." Another respondent noted that when air source heat pumps are designed to meet the cold climate standards, they are less efficient at the more common temperatures.

Market Barriers

The distributors indicated that costs were still a major market barrier, but also indicated that there was a lot of confusion in the market. On distributor had this to say:

> "I think we see a lot of confusion in the market. We would like to see a little clarity. We have the benefit of handling multiple states. Every state seems to have their own spin. I think the utilities in general, and some of the other entities, whether it be NEEP, MassCEC, or Mass Save, have caused some confusion. We spend a lot of time helping to educate contractors about different state programs. We have developed calculators and tools to help assist."

A different distributor noted that changes to the incentive programs where frequent, that there is little help from the utility, and that there is no lead time given about new programs.

Market Role and Interaction

When asked about the role their company plays in the market one distributor said that their main objective is to "to reduce emissions and to keep the consumer comfortable at the lowest operating cost possible."

Solar Installer Interviews

Cadmus interviewed solar installers to better understand what motivates them to diversify their offerings to include heat pump installations.

Overview

Through in-depth phone interviews, Cadmus explored solar installers' familiarity and interest in heat pumps, barriers to diversifying product offerings, and opportunities for utilities and other market actors to support installers with this product diversification. Cadmus conducted phone interviews with installers of solar photovoltaics (PV) systems in the Rhode Island market or greater Northeast region; because Cadmus sought to interview several solar installers who also install heat pumps, the sample needed to include installers beyond just the Rhode Island market. Of the 13 installers interviewed, seven installers had significant business in states other than Rhode Island. Furthermore, 9 out of the 13 installers offered heat pumps in addition to solar.

Familiarity with Heat Pump Technology

Solar installers recognize the symbiotic relationship that exists between solar and heat pump installations and view installing heat pumps as a logical business step. Although a small number of solar installers began offering heat pumps over ten years ago, several others began doing so in the past five years: on average, the interviewed solar installers began offering heat pumps six years ago. Most of the solar installers that offer heat pumps reported a strong technical understanding of heat pumps, although three reported at least some lack of understanding about how this technology works.

Challenges with Participating in the Heat Pump Market

For solar installers who also offer heat pumps, the key challenges they face fall into three categories. Installers elaborated on each challenge, as well as provided possible solutions.

Table 19. Solar Installer Perceived Barriers to Heat Pump Installations

Challenge	Solar Installer Perceptions
Customer Skepticism	Solar installers found that many customers don't believe heat pumps work as well as other HVAC technology. Additional customer-facing heat pump education, such as non-technical, reader-friendly materials, was one solution proposed to improve customer familiarity with heat pumps.
Technical Limitations	Solar installers noted that traditional battery systems cannot meet surges in heating demand, in turn creating a challenge for solar and heat pump pairings that include storage. A publicly available list of low-surge soft-start heat pumps could help installers with finding compatible technology.
Limiting Policies and Incentives	Solar installers noted that Rhode Island policies limit the amount of solar typically installed by placing limits on incentivized capacity, making it challenging to install enough solar to meet the higher electricity demand of heat pumps. In addition to reforming this solar policy, solar installers suggested creating broader HVAC incentives, including for ground-source heat pumps.

Reinforcing the findings of other market research, customer knowledge appears to remain a significant barrier to installation and engagement regardless of the market player. Additional research into low-such soft-start heat pumps and other more solar-friendly configurations could yield valuable insights and pathways for further industry integration. Additionally, should policy makers wish to promote the packaging of solar and heat pumps, specific considerations could be given to array-size maximums to accommodate heat pumps.

Impact on Business Models

All of the solar installers who offer heat pumps agreed that the process of incorporating heat pumps in their business was easy, with three contractors saying there was no influence on their business model and others saying it simply helped the company with market positioning and branding; for instance, installers were able to market themselves as broader energy market experts or appeal to customers looking for "net zero" homes.

Installers were split on how much offering heat pumps affected the bottom line, with four saying very positively and four saying not at all. When asked how significant a portion of the company's revenue heat pumps were, "significant", "20-30%", and "not too big" each made up around one third of responses.

With only three installers saying they installed heat pumps in-house rather than using subcontractors, only half of installers said they pursued training related to heat pumps. Most installers did not see their peers integrating heat pumps into their business models; nonetheless, all 9 of the installers that offered heat pumps said they will continue investing in heat pumps, given customer demand.

Marketing and Outreach

Seven of installers who offer heat pumps said their marketing was limited, even for solar technology. Many businesses do not have the capacity for concentrated marketing, or do not feel it necessary due to the high demand for solar. For the two who said they specifically promote heat pumps, they reported using the company website as the primary source of promotion. In general, however, installers said the focus was on having conversations with customers, so they are aware of all available technology and the best solutions for their home, including heat pumps. Only two of nine installers said they ever "upsell" existing solar customers with heat pump services.

All but one of the 9 installers offering heat pumps focused predominantly on residential buildings, with the best-suited homes often being those that have oil or electric resistance heating, have high electric costs, are old, or lack a cooling system. The idea of installing heat pumps typically arises through conversations between customers and installers about comprehensive home energy solutions; installers often convey several heat pump benefits, including high performance, provision of heating and cooling, lower operating costs, reduced environmental impact, greater home comfort and safety, and advantages for landlords.

When asked what utilities and other market actors could do to help accelerate their ASHP business, installers requested:

Table 20. Solar Installer Requests

Challenge	Details
Training	Installers would appreciate additional in-person and online education, such as seminars on heat pump and solar pairings and an online portal providing comprehensive resources (e.g., qualified installers and customer testimonials) pertaining to this technology.
Incentives and Policies	Installers requested higher heat pump incentives to bring the technology to scale, adequate incentives for compatible battery storage, broader incentives that incorporate air-to-water heat pumps, and fewer restrictions on the kW of solar allowed at residential buildings that can indirectly discourage heat pump installations.
Marketing Support	While installers typically do not advertise themselves, many asked that utilities continue and expand their marketing and advertising initiatives to raise awareness about heat pumps, as well as share marketing collateral with installers.

In addition, several installers expressed interest and willingness to work directly with National Grid to discuss ideas and test programs to help advance heat pump adoption.

Interest and Barriers for Installers Not Offering Heat Pumps

Four solar installers that Cadmus interviewed did not offer heat pumps. Although they all reported being familiar with the functionality and benefits of heat pumps, only two expressed interest in integrating this technology into the company's product offerings; similarly, only two installers said they were interested in partnering with subcontractors to install heat pumps.

Installers reported that they had not diversified to include heat pumps because of insufficient customer demand or wanting to remain focused on their specialty of only solar. Only one of the four installers said they provide customer referrals to fellow contractors for HVAC installations, with one expressing concern about attaching their company to contractors with uncertain reputations.

When probed about factors that may encourage the incorporation of heat pumps into their business, installers suggested:

- Being kept more well-informed about heat pump technology and incentives
- Receiving sales leads, for instance by having access to contact information collected through “Learn More” webpages on state agency or utility websites
- Receiving persuasive materials on why solar installers should offer heat pumps, including cost-effectiveness studies on heat pumps
- Expanding incentives, such as federal tax credits for heat pumps or Rhode Island-specific rebates and financing options for solar and heat pump pairings

Key Findings

Solar installers have a significant opportunity to bolster the adoption of heat pumps by offering packaged installations that reduce household net energy consumption. To date, those installers who offer both technologies tend to be more whole-home solution companies: firms that work in multiple sectors of home renovation to provide wholistic sustainability solutions. While the experience of those firms who have started offering heat pumps and expanding their business model has been largely positive, there are still notable barriers and concerns for solar installers interested in the industry. National Grid may have the opportunity to provide additional training, materials, and policy influence to help craft a more conducive market for paired solar and heat pump deployment in Rhode Island.

Scenario Analysis

Cadmus, in coordination with National Grid and the C-team and alignment with an ongoing potential study led by Dunsky Energy Consulting, identified 19 building typologies to serve as the basis for the analysis. Each scenario is defined by 6 factors:

- Building type: single-family, multifamily, commercial
- Heat pump technology: ductless mini-split, centrally ducted
- Application: existing building, new construction, building addition
- Counterfactual heating fuel: oil, electricity, natural gas, or propane
- Counterfactual heating system: boiler, furnace, baseboard
- Counterfactual cooling system: window AC, central AC, no AC

Leveraging data from the 2018 Rhode Island Residential Appliance Saturation Survey (RASS) by NMR, Cadmus developed a list of each typology present in the Rhode Island market based on building type, counterfactual heating equipment, counterfactual heating fuel and counterfactual cooling system. Each typology was then linked with its corresponding representation in the market as well as representation in the corresponding single-family and multifamily subsets of the market.

Using this market representation data, a list of the most common single-family and multi-family typologies was compiled, including logical heat pump technology to replace or supplement counterfactual heating and cooling systems (this included central ASHPs where furnaces were the counterfactual, and ductless heat pumps where boilers or baseboards were the counterfactual). While the most common typologies often included natural gas heating, the final list of scenarios deliberately excluded several of these typologies to ensure the modeling effort could focus on more cost-effective scenarios, while still representing a significant portion of total residential buildings in Rhode Island.

The RASS database only covers residential scenarios. To account for the small commercial segment of the study, National Grid and the C-team identified 3 scenarios that are common in the Rhode Island market based off past research. In consultation with National Grid and the C-team, the final list of 19 typologies noted in Table 28 was compiled for modeling. Additional building parameters, including number of units per building, unit size, and building age, were subsequently defined using the RASS data for residential buildings and DOE reference buildings for commercial spaces. These are identified below in Table 21.

Table 21. Market Segments Selected

Market Segment	# Scenarios Identified	# units per building	Unit Size (sq. ft)	Building Age (years)	Prototype source
Single-family	12	1	1550*	Existing: 50 New: 0	**RASS 2018 report**. Single-family defined as single-unit, stand-alone building.
Multifamily	4	8	720	Existing: 50 New: 0	**RASS 2018 report.** Multifamily defined as 5-20-unit building.
Commercial	3	5	1100	Existing: 50 New: none	**DOE Reference Building with Pawtucket TMY3.** Defined as DOE small office building.

* One single-family scenario reflects a “building addition” that is assumed to be 169 square feet based on RI / MA averages

Table 22. Scenarios

ID	Application			Counterfactual Equipment		Measure Equipment		Load (MMBtu/year)		RASS Representation		
#	Use	Construction	Replace	Heating	Cooling	Heat Pump	Backup	Heat	Cool	% All	% SF	%MF
1	Single Family	Existing building	Partial	Gas Boiler	Window AC	CC DMSHP	Gas Boiler	76.7	13.1	14%	17%	-
2	Single Family	New construction	Full	Gas furnace	Central AC	Central CC ASHP	None	35.5	8.3	11%	13%	-
3	Single Family	Existing building	Partial	Oil Boiler	Window AC	CC DMSHP	Oil Boiler	76.7	13.1	8%	9%	-
4	Single Family	Existing building	Full	Oil Boiler	Window AC	CC DMSHP	None	76.7	13.1	8%	9%	-
5	Single Family	Existing building	Partial	Electric Baseboard	Window AC	CC DMSHP	Electric Baseboard	76.7	13.1	8%	9%	-
6	Single Family	Building addition	Full	Electric Baseboard	Window AC	CC DMSHP	None	4.6	4.9	2%	2%	-
7	Multifamily	New construction	Full	Gas Furnace	Central AC	Central CC ASHP	None	11.3	4.2	3%	-	25%
8	Single Family	Existing building	Partial	Oil Furnace	Central AC	Central CC ASHP	Oil Furnace	68.4	13.1	3%	3%	-
9	Single Family	Existing building	Partial	Oil Boiler	Central AC	CC DMSHP	Oil Boiler	76.7	13.1	3%	3%	-
10	Multifamily	Existing building	Partial	Electric Baseboard	Window AC	CC DMSHP	Electric Baseboard	15.7	2.7	3%	-	21%
11	Single Family	Existing building	Partial	Electric Baseboard	No AC	CC DMSHP	Electric Baseboard	76.7	13.1	2%	3%	-
12	Multifamily	Existing building	Partial	Gas Boiler	Window AC	CC DMSHP	Gas Boiler	15.7	2.7	2%	-	16%
13	Single Family	Existing building	Partial	Oil Boiler	No AC	CC DMSHP	Oil Boiler	76.7	13.1	2%	2%	-
14	Single Family	Existing building	Partial	Propane Furnace	Central AC	Central CC ASHP	Propane Furnace	68.4	13.1	2%	2%	-
15	Single Family	New construction	Full	Propane Furnace	Central AC	Central CC ASHP	None	35.5	8.3	2%	2%	-
16	Multifamily	Existing building	Partial	Electric Baseboard	No AC	CC DMSHP	Electric Baseboard	15.7	2.7	0%	-	4%
17	Commercial	Existing building	Partial	Oil Boiler	Window AC	CC DMSHP	Oil Boiler	28.7	12.1	-	-	-
18	Commercial	Existing building	Partial	Electric Baseboard	Window AC	CC DMSHP	Electric Baseboard	28.7	12.1	-	-	-
19	Commercial	Existing building	Partial	Oil Furnace	Central AC	Central CC ASHP	Oil Furnace	28.7	12.1	-	-	-

*Building type representation in the Rhode Island Residential Appliance Saturation Survey

%All: Typology's representation % of all residential buildings (SF & MF) based on counterfactual equipment

%SF: Typology's representation % of just Single-Family buildings

*Note that the representation of commercial buildings (#17-19) comes from the DOE Reference building for small office buildings modeled using Pawtucket TMY3 data

*Note that the RASS value noted above for typology 6 (building addition) is modified off the values for electric baseboard existing single-family homes to reflect assumptions about the number of building additions built in a year.

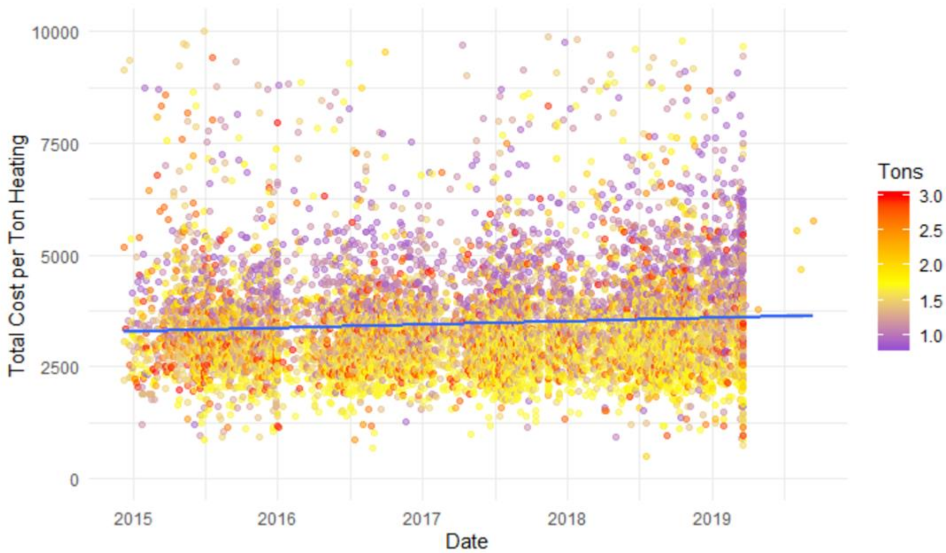
Customer and Program Cost-Effectiveness Analysis

Cadmus analyzed data from the Massachusetts Clean Energy Center's (MassCEC) public Air Source Heat Pump Rebate Program database to assess recent price trends in heat pump installations in the region.

Appliance Cost Analysis

The dataset included over 20,000 ccASHPs that received a rebate from MassCEC from 2015-2019. Figure 21 plots the cost per ton of heating capacity vs. the date the system was installed. We see that there is a large variance in the costs of installed systems and a slight increase in costs over time.

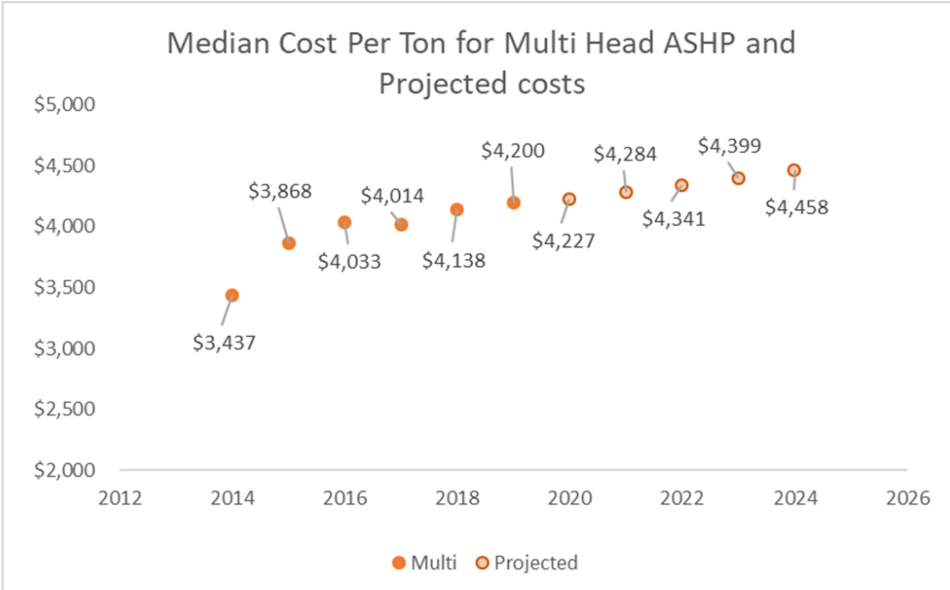
Figure 21. MassCEC 0.75-3 Ton Heat Pump Installed Costs per Ton (2019 $)



A regression analysis found statistically significant year of year cost increases for Central (1.7%) and Multi-Zone (1.3%) and Single-Head (0.6%) installations. These cost increases were supported by conversations with contractors who also noted rising costs.

For this study Cadmus forecast the costs of heat pumps into the future. The projections were based on a log based least squares regression equation of best fit, the cost/ton for heat pumps was projected forward through 2024. Figure 22 shows the median cost per ton for multi head ASHPs from 2014-2019 with projected costs for 2020-2024.

Figure 22. Heat Pump Cost Projection Analysis per Ton



It is anticipated that multi-zone installations will increase $58/ton per year. Single-zone units and central units have projected cost increases of $22/ton per year and $71/ton per year respectively.

Typology Measure & Counterfactuals

Each building typology is analyzed in two "pathways," a counterfactual and a measure, to assess each typology's energy savings. The counterfactual is the "business as usual" scenario, and models the ongoing use of electric or central fossil fuel heating to cover the full heating needs of a building, and either central, window or no AC. The measure "pathway" on the other hand, models the use of an air source heat pump to either fully or partially replace the counterfactual heating system and fully replace the cooling system (or add cooling depending on the counterfactual).

As an example, Typology 1 is a single-family existing building with a gas boiler and window AC. The counterfactual for this typology has all this same equipment: a gas boiler and window AC to cover the full heating and cooling needs of the home. The measure, meanwhile, includes a cold-climate ductless mini-split heat pump as a partial heating provider and only cooling system. Meanwhile, the typology retains the gas boiler as part of the heating system, using it any time temperatures dip below 50 degrees Fahrenheit. A complete list of these measure / counterfactual pairs can be found in Table 23.

Table 23. Measure / Counterfactual Pairs

ID	Counterfactual Equipment			Measure Equipment		
#	Primary Heating	Backup Heating	Cooling	Primary Heating	Backup Heating	Cooling
1	Existing Gas Boiler	None	Existing Window AC	CC DMSHP	Existing Gas Boiler	CC DMSHP
2	New Gas furnace	None	New Central AC	Central CC ASHP	None	Central CC ASHP
3	Existing Oil Boiler	None	Existing Window AC	CC DMSHP	Existing Oil Boiler	CC DMSHP
4	Existing Oil Boiler	None	Existing Window AC	CC DMSHP	None	CC DMSHP

5	Existing Electric Baseboard	None	Existing Window AC	CC DMSHP	Existing Electric Baseboard	CC DMSHP
6	New Electric Baseboard	None	New Window AC	CC DMSHP	None	CC DMSHP
7	New Gas Furnace	None	New Central AC	Central CC ASHP	None	Central CC ASHP
8	Existing Oil Furnace	None	Existing Central AC	Central CC ASHP	Existing Oil Furnace	Central CC ASHP
9	Existing Oil Boiler	None	Existing Central AC	CC DMSHP	Existing Oil Boiler	CC DMSHP
10	Existing Electric Baseboard	None	Existing Window AC	CC DMSHP	Existing Electric Baseboard	CC DMSHP
11	Existing Electric Baseboard	None	No AC	CC DMSHP	Existing Electric Baseboard	CC DMSHP
12	Existing Gas Boiler	None	Existing Window AC	CC DMSHP	Existing Gas Boiler	CC DMSHP
13	Existing Oil Boiler	None	No AC	CC DMSHP	Existing Oil Boiler	CC DMSHP
14	Existing Propane Furnace	None	Existing Central AC	Central CC ASHP	Existing Propane Furnace	Central CC ASHP
15	New Propane Furnace	None	New Central AC	Central CC ASHP	None	Central CC ASHP
16	Existing Electric Baseboard	None	No AC	CC DMSHP	Existing Electric Baseboard	CC DMSHP
17	Existing Oil Boiler	None	Existing Window AC	CC DMSHP	Existing Oil Boiler	CC DMSHP
18	Existing Electric Baseboard	None	Existing Window AC	CC DMSHP	Existing Electric Baseboard	CC DMSHP
19	Existing Oil Furnace	None	Existing Central AC	Central CC ASHP	Existing Oil Furnace	Central CC ASHP

*Note: Existing vs New equipment is designated to indicate whether the equipment modeled is based on new, code-minimum standards or older, lower-efficiency equipment. All existing buildings begin the analysis with existing equipment in the counterfactual. All heat pumps are installed new at the start of the analysis period.

Each building typology is assumed to have a specific heating and cooling load based on the properties of the building. As seen in Table 22 above, Cadmus compiled an annual cooling and heating load for each building using the RES 21 analysis from Navigant and DOE reference buildings for a commercial office building. Using hourly TMY3 data, these heating and cooling loads are distributed across the year based on outside temperature.

Combining this temperature data with the switching temperatures identified in the 2020 Massachusetts Energy Optimization Model, Cadmus identified the portion of each building's annual heating and cooling load covered by each piece of equipment in the measure and counterfactual pathway of each typology. For example, in the Typology 1 measure pathway, 7.6 MMBTU of heating demand is met by the cold-climate ductless mini-split heat pump, while 69.1 MMBTU of heating demand is met by the backup gas boiler. The gas system covers most of the heating load in this case because the temperature where the occupants are expected to switch to natural gas (for economic reasons) is assumed to be 50 degrees. This can be compared to Typology 3 where an existing oil boiler is partially displaced by a heat pump. In this case, the heat pump covers most of the heating load (48.1 of 76.7 MMBTU) because the switching temperature for oil is assumed to be 30 degrees. A complete list of switching temperatures by fuel type can be found in Appendix C.

The heating and cooling loads are then divided by the respective heating or cooling equipment's efficiency assumptions. For example, in Typology 1, the backup gas boiler has an efficiency of 0.8 AFUE, so is shown to consume 86.38 MMBTU of natural gas to meet the 69.1 MMBTU of heating demand it covers. A summary of device efficiencies can be found in Appendix C. This is made more complex by the temperature-dependent performance of heat pumps. Using piecewise linear regressions for COP based on manufacturer data submitted to NEEP for the cold-climate ASHP performance specifications, Cadmus modeled a temperature-dependent COP for each type of ccASHP modeled. The total heating or cooling load covered by the heat pump is then divided by this COP for each hour of use to identify the total energy consumption. Details on this process can be found in Appendix C.

While the analysis is conducted based on measure equipment lifetime, counterfactual heating and cooling equipment as well as backup heating equipment is assumed to need replacement at various intervals throughout the analysis. To capture this nuance, several iterations of each typology pathway was modeled to capture each possible configuration of equipment. These counterfactual configurations assume that, when one piece of equipment dies, a new version of the same equipment will take its place (new oil boiler replacing an old oil boiler). The key difference is that the new equipment is assumed to be slightly more efficient than its older counterpart. For new construction buildings, the analysis assumed that the new version of each equipment type is installed from the beginning. A summary of the new and existing equipment details can be found in Appendix C.

We derived annual fuel and energy savings by comparing measure and counterfactual systems for each typology and determined energy savings over the period of analysis or lifetime of the equipment. A summary of first-year energy consumption for both measure and counterfactual pathways can be found in Table 25 and first-year energy savings can be found in Table 24.

Typology Measure & Counterfactual Performance

The initial typology analysis highlights several of the key patterns that underpin the cost effectiveness of the analyzed scenarios.

First and foremost, even when adding cooling, displacing the use of electric baseboards (Typologies 5, 6, 10, 11 and 16) results in significant electricity savings. Interestingly, as illustrated in Typologies 11 and 16, even when installing a heat pump in a home where no AC had existed previously, electricity use in the measure is significantly lower than the counterfactual because of the replacement of the baseboard heater. First-year energy savings can be found in Table 24, while the specific measure and counterfactual consumption can be found in Table 25.

Table 24. First-Year Energy Consumption Differences

ID	Building	Measure Pathway		Counterfactual Pathway		Fuel & Energy Difference			
#	Typology	Heat Pump	Backup Heat	Heating	Cooling	Gas (MMBTU)	Oil (MMBTU)	Propane (MMBTU)	Electricity (kWh)
1	SF Partial Disp.	CC DMSHP	Existing Gas Boiler	Existing Gas Boiler	Existing Window AC	-9.50	0.00	0.00	-305.14
2	SF Full Disp.	Central CC ASHP	None	New Gas Furnace	New Central AC	-41.76	0.00	0.00	4,173.17
3	SF Partial Disp.	CC DMSHP	Existing Oil Boiler	Existing Oil Boiler	Existing Window AC	0.00	-64.18	0.00	3,541.21
4	SF Full Disp.	CC DMSHP	None	Existing Oil Boiler	Existing Window AC	0.00	-91.31	0.00	7,673.09
5	SF Partial Disp.	CC DMSHP	Existing Electric baseboard	Existing Electric baseboard	Existing Window AC	0.00	0.00	0.00	-13,999.96
6	SF Full Disp.	CC DMSHP	None	New Electric baseboard	New Window AC	0.00	0.00	0.00	-1,034.43
7	MF Full Disp.	Central CC ASHP	None	New Gas Furnace	New Central AC	-13.33	0.00	0.00	1,508.67
8	SF Partial Disp.	Central ASHP	Existing Oil Furnace	Existing Oil Furnace	Existing Central AC	0.00	-55.02	0.00	3,783.64
9	SF Partial Disp.	CC DMSHP	Existing Oil Boiler	Existing Oil Boiler	Existing Central AC	0.00	-64.18	0.00	3,495.34
10	MF Partial Disp.	CC DMSHP	Existing Electric baseboard	Existing Electric baseboard	Existing Window AC	0.00	0.00	0.00	-2,870.75
11	SF Partial Disp.	CC DMSHP	Existing Electric baseboard	Existing Electric baseboard	No AC	0.00	0.00	0.00	-12,444.43
12	MF Partial Disp.	CC DMSHP	Existing Gas Boiler	Existing Gas Boiler	Existing Window AC	-1.94	0.00	0.00	-67.23
13	SF Partial Disp.	CC DMSHP	Existing Oil Boiler	Existing Oil Boiler	No AC	0.00	-64.18	0.00	5,096.74
14	SF Partial Disp.	Central ASHP	Existing Propane Furnace	Existing Propane Furnace	Existing Central AC	0.00	0.00	-82.49	6,327.80
15	SF Full Disp.	Central CC ASHP	None	New Propane Furnace	New Central AC	0.00	0.00	-41.76	4,173.17
16	MF Partial Disp.	CC DMSHP	Existing Electric baseboard	Existing Electric baseboard	No AC	0.00	0.00	0.00	-2,550.96
17	Com Partial Disp.	CC DMSHP	Existing Oil Boiler	Existing Oil Boiler	Existing Window AC	0.00	-24.00	0.00	845.35
18	Com Partial Disp.	CC DMSHP	Existing Electric baseboard	Existing Electric baseboard	Existing Window AC	0.00	0.00	0.00	-5,709.50
19	Com Partial Disp.	Central ASHP	Existing Oil Furnace	Existing Oil Furnace	Existing Central AC	0.00	-23.07	0.00	1,310.79

Note: Calculations and methods can be found in Appendix C. Negative values indicate savings (measure consumes less than counterfactual).
SF: Single-family. MF: Multifamily. Com: Commercial. Partial Disp.: Partial Displacement. Full Disp.: Full Displacement.

Table 25. Measure / Counterfactual First-Year Energy Consumption Levels

ID	Building	Measure Pathway				Counterfactual Pathway			
#	Typology	Natural Gas (MMBTU)	Oil (MMBTU)	Propane (MMBTU)	Electricity (kWh)	Natural Gas (MMBTU)	Oil (MMBTU)	Propane (MMBTU)	Electricity (kWh)
1	SF Partial Disp.	86.38	0.00	0.00	1304.08	95.88	0.00	0.00	1609.22
2	SF Full Disp.	0.00	0.00	0.00	5207.83	41.76	0.00	0.00	1034.66
3	SF Partial Disp.	0.00	38.09	0.00	5159.42	0.00	102.27	0.00	1618.21
4	SF Full Disp.	0.00	0.00	0.00	8908.46	0.00	91.31	0.00	1235.37
5	SF Partial Disp.	0.00	0.00	0.00	10034.12	0.00	0.00	0.00	24034.08
6	SF Full Disp.	0.00	0.00	0.00	753.25	0.00	0.00	0.00	1787.68
7	MF Full Disp.	0.00	0.00	0.00	2230.25	13.33	0.00	0.00	721.58
8	SF Partial Disp.	0.00	32.67	0.00	5487.12	0.00	87.69	0.00	1703.48
9	SF Partial Disp.	0.00	38.09	0.00	5159.42	0.00	102.27	0.00	1664.08
10	MF Partial Disp.	0.00	0.00	0.00	2057.58	0.00	0.00	0.00	4928.33
11	SF Partial Disp.	0.00	0.00	0.00	10034.12	0.00	0.00	0.00	22478.55
12	MF Partial Disp.	17.72	0.00	0.00	306.24	19.66	0.00	0.00	373.47
13	SF Partial Disp.	0.00	38.09	0.00	5159.42	0.00	102.27	0.00	62.68
14	SF Partial Disp.	0.00	0.00	8.71	8031.28	0.00	0.00	91.20	1703.48
15	SF Full Disp.	0.00	0.00	0.00	5207.83	0.00	0.00	41.76	1034.66
16	MF Partial Disp.	0.00	0.00	0.00	2057.58	0.00	0.00	0.00	4608.54
17	Com Partial Disp.	0.00	14.24	0.00	2315.37	0.00	38.24	0.00	1470.02
18	Com Partial Disp.	0.00	0.00	0.00	4135.82	0.00	0.00	0.00	9845.32
19	Com Partial Disp.	0.00	13.70	0.00	2991.15	0.00	36.77	0.00	1680.36

Note: Calculations and methods can be found in Appendix C. Negative values indicate savings (measure consumes less than counterfactual).
SF: Single-family. MF: Multifamily. Com: Commercial. Partial Disp.: Partial Displacement. Full Disp.: Full Displacement.

Looking at Typologies 3 and 4, it is worth noting that the heat pump in Typology 4, which is fully replacing an oil boiler, requires more than twice the electricity compared to a heat pump that is partially displacing an oil boiler (as in Typology 3). This is due to the relatively low switching temperature for oil (30 degrees F) in the partial displacement typology. Although less than half of the heating degree hours of a year are under 30 degrees F, covering heating degree hours below that switching temperature requires more electricity per hour to meet heating demand, thereby increasing electricity consumption to cover the heating for these low-temperature times.

Note that Typology 11, while using similar equipment to Typology 10, uses more total energy in both the counterfactual and measure. This is due to Typology 11 modeling a single-family home with about 5 times the heating and cooling demand, while Typology 10 reflects a multifamily unit. This also results in Typology 11 reflecting a higher energy savings due to the higher counterfactual energy use.

Over the course of the analysis, various pieces of heating and cooling equipment in both the measure and counterfactual reach the end of their useful life and need to be replaced. In most cases, it is assumed that newly installed equipment is slightly more efficient than the equipment it replaces. For example, an existing central AC has a SEER of 10. When it needs to be replaced, a new central AC is installed with a SEER of 13 (See Appendix B). This changes the annual energy consumption and therefore changes the difference in energy consumption between the measure and counterfactual. Table 26 illustrates the lifetime energy consumption differences for each typology accounting for these changes.

Table 26. Lifetime Energy Consumption Difference

Typology #	Measure Lifetime Years	Fuel & Energy Difference			
		Gas (MMBTU)	Oil (MMBTU)	Propane (MMBTU)	Electricity (kWh)
1	18	-169.04	0.00	0.00	250.18
2	17	-710.00	0.00	0.00	70,943.85
3	18	0.00	-1,100.09	0.00	69,484.41
4	18	0.00	-1,643.57	0.00	138,115.57
5	18	0.00	0.00	0.00	-246,256.64
6	18	0.00	0.00	0.00	-18,619.70
7	17	-226.60	0.00	0.00	25,647.38
8	17	0.00	-898.99	0.00	67,942.10
9	18	0.00	-1,100.09	0.00	66,838.00
10	18	0.00	0.00	0.00	-50,492.88
11	18	0.00	0.00	0.00	-223,999.69
12	18	-34.67	0.00	0.00	-29.58
13	18	0.00	-1,100.09	0.00	91,741.36
14	17	0.00	0.00	-1,295.52	111,192.75
15	17	0.00	0.00	-710.00	70,943.85
16	18	0.00	0.00	0.00	-45,917.31
17	18	0.00	-411.31	0.00	20,535.40
18	18	0.00	0.00	0.00	-97,451.86
19	17	0.00	-376.91	0.00	25,636.60

Note: Because of the lifetime of equipment, values reflect the replacement of expired equipment after their RUL and is not equal to 17 or 18x 1-year savings. Methodology can be found in Appendix C.

Cost Effectiveness Analysis

The cost effectiveness analysis for this study was broken into two components: customer cost savings, and utility cost effectiveness.

Approach

These components are analyzed under 5 distinct scenarios, modeling different combinations of high and low incentives, and higher or lower equipment price trends (see Table 27).

Based on the cost analysis described previously, the high cost scenario reflects current price trends, where heat pump costs are steadily increasing over time at different rates based on configuration. The low-cost scenario, in turn, reflects price trends 1.23 percentage points below current trends (meaning some prices are decreasing, and others are increasing, but more slowly). This represents a 5% decrease in prices from 2020 through 2024 which was deemed to be reasonable given prior modeling experience. To maintain consistent nomenclature, the scenarios reflecting current price trends are noted as "high price" while those reflecting a reduced price are noted as "low price." The incentive levels, meanwhile, are based on current offerings from Mass Save. These incentives depend on the fuel being replaced, and whether the building is a new or existing structure. The low incentive scenario matches the incentives from Mass Save, while the high incentive scenario reflects a 40% increase in incentives. This allowed for clean incentive values while providing a noticeable distinction in incentive effects.

Table 27. Cost Effectiveness Scenarios

Scenario	Component	Existing Non-Gas Home	Existing Gas Home	New Single-Family Home	New Multi-Family Home
Name	Item	Incentive $ / ton	Incentive $ / ton	Incentive $ / unit	Incentive $ / unit
Baseline	Price Tend	0% Change relative to current trends			
	Incentive	$0.00	$0.00	$0.00	$0.00
Low Incentive / High Price	Price Tend	0% Change relative to current trends			
	Incentive	$1,250.00	$250.00	$2,000.00	$1,000.00
High Incentive / High Price	Price Tend	0% Change relative to current trends			
	Incentive	$1,750.00	$350.00	$2,800.00	$1,400.00
Low Incentive / Low Price	Price Tend	-1.23% Change relative to current trends			
	Incentive	$1,250.00	$250.00	$2,000.00	$1,000.00
High Incentive / Low Price	Price Tend	-1.23% Change relative to current trends			
	Incentive	$1,750.00	$350.00	$2,800.00	$1,400.00

Benchmarked off the Mass Save program incentives, the incentives used here reflect a slightly different pattern than those noted in the Willingness to Pay portion of this study. In the WTP survey the incentives for whole-home ductless mini-split systems ranged from $1,600 to $8,000 for a $16,000 system. While the permutations used in this portion of the analysis reflect a range of sizes, the average whole-home incentive is for a DMSHP is roughly $3,500 under the low-incentive scenarios, and $4,900 under the high-incentive scenarios. This same pattern holds for central heat pumps and partial displacement installs, with the incentives used in this part of the analysis averaging between 30-40% of the installed cost, with notable variability based on the specifics of the scenario. A summary of the modeled total incentives and heat pump installed costs can be found in Appendix E.

The customer cost savings analysis totals the lifetime energy cost savings for each typology and subtracts total installed costs. A summary of lifetime customer cost savings for each of the 19 typologies under each of the 5 scenarios can be found in Table 28. A summary of the customer lifetime cost savings calculation methodology can be found in Appendix C.

The program cost-effectiveness analysis follows the guidelines of the Rhode Island Test: a modified total resource cost test. Using inputs from the 2020 RI Electric BCR Model, this test accounted for utility costs and a range of utility and societal benefits including consumption savings to water savings, knock-on electricity price effects, CO_2e abatement, as well as several unique factors for economic development and non-energy benefits. A complete list of Rhode Island test factors can be found in Appendix G. A typology with a cost effectiveness ratio greater than 1 is demonstrated to provide net benefits worth greater than $1 for each $1 of program investment and is therefore considered cost effective. A summary of utility cost effectiveness figures for each of the 19 typologies and five scenarios can be found in Table 29.

Table 28. Lifetime Customer Cost Savings

Typology	Baseline	Low Incentive / High Price	High Incentive / High Price	Low Incentive / Low Price	High Incentive / Low Price
ID	Lifetime-year NPV $ Savings				
1	($6,788.47)	($6,163.47)	($5,913.47)	($6,163.47)	($5,913.47)
2	($7,274.77)	($5,274.77)	($4,474.77)	($5,274.77)	($4,474.77)
3	($1,047.46)	$2,077.54	$3,327.54	$2,077.54	$3,327.54
4	($7,571.01)	($2,571.01)	($571.01)	($2,571.01)	($571.01)
5	$43,657.69	$46,782.69	$48,032.69	$46,782.69	$48,032.69
6	$674.04	$2,674.04	$3,474.04	$2,674.04	$3,474.04
7	($447.15)	$552.85	$952.85	$552.85	$952.85
8	$274.81	$3,399.81	$4,649.81	$3,399.81	$4,649.81
9	$7,817.74	$10,942.74	$12,192.74	$10,942.74	$12,192.74
10	$6,368.39	$8,243.39	$8,993.39	$8,243.39	$8,993.39
11	$38,415.56	$41,540.56	$42,790.56	$41,540.56	$42,790.56
12	($3,957.89)	($3,582.89)	($3,432.89)	($3,582.89)	($3,432.89)
13	($6,289.60)	($3,164.60)	($1,914.60)	($3,164.60)	($1,914.60)
14	$16,058.18	$19,183.18	$20,433.18	$19,183.18	$20,433.18
15	$4,899.10	$6,899.10	$7,699.10	$6,899.10	$7,699.10
16	$5,025.06	$6,900.06	$7,650.06	$6,900.06	$7,650.06
17	($11,732.23)	($5,334.00)	($2,774.71)	($5,334.00)	($2,774.71)
18	($457.68)	$5,940.55	$8,499.84	$5,940.55	$8,499.84
19	($6,570.58)	($172.35)	$2,386.94	($172.35)	$2,386.94

Table 29. Program Cost-Effectiveness

Typology	Baseline	Low Incentive / High Price	High Incentive / High Price	Low Incentive / Low Price	High Incentive / Low Price
ID	Lifetime-year NPV $ Savings				
1	0.27	0.93	0.98	0.93	0.98
2	-6.54	0.69	0.81	0.69	0.81
3	76.58	5.11	4.01	5.11	4.01
4	91.56	4.52	3.57	4.52	3.57
5	76.5	5.1	4.01	5.1	4.01
6	1.41	1.13	1.13	1.13	1.13

7	5.07	1.56	1.45	1.56	1.45
8	81.47	5.38	4.21	5.38	4.21
9	100.72	6.38	4.94	6.38	4.94
10	17.01	2.27	1.96	2.27	1.96
11	53.08	3.86	3.11	3.86	3.11
12	1.41	1.2	1.18	1.2	1.18
13	53.16	3.87	3.11	3.87	3.11
14	134.34	8.18	6.24	8.18	6.24
15	57.39	4.37	3.48	4.37	3.48
16	3.06	1.26	1.22	1.26	1.22
17	47.48	2.55	2.15	2.55	2.15
18	96.29	4.06	3.24	4.06	3.24
19	30.39	2.04	1.78	2.04	1.78

Baseline Scenario Cost Effectiveness

The baseline scenario is designed to assess cost effectiveness under a non-intervention assumption. This means that there are no assumed incentives, and no changes to heat pump price trends. This therefore reveals the customer and program cost effectiveness should program administrators and policy makers to take no action at all.

It is immediately apparent that, from the customer standpoint, a narrow majority of typologies analyzed in this report are not cost-effective without incentives or price changes. As seen in Table 28, 10 of the 19 typologies reflect negative lifetime customer savings (net lifetime costs), with two additional typologies reflecting only minimal lifetime savings: Typology 6 (full displacement of an electric baseboard and window AC in a single family house) and Typology 8 (partial displacement of an existing oil furnace and central AC with a central heat pump in a single family house). Notably, Typology 5 and 11 (both partial displacement of existing electric baseboard heat) are highly cost effective, saving customers over $38,000 over the lifetime of the equipment. These typologies may therefore not require extensive financial incentives to drive installation, as the customer-side economics are already very positive without any intervention. Additionally, each of the other electric baseboard typologies (6, 10 and 16) realize lifetime customer cost savings without any incentives. Meanwhile, as expected, typologies displacing natural gas heating do not realize lifetime cost savings.

Program cost effectiveness under the baseline scenario assumes no incentives are distributed by the utility but does include some small program administration costs to accommodate accounting and reporting. By not providing any incentives, per unit program costs are very low, which explains why many of the cost effectiveness figures under the baseline scenario appear exaggerated. From a program standpoint, both Typology 5 and 11 are considered quite cost effective, at 76.5 and 53.08 respectively. However, they are not the most cost-effective typologies under the baseline scenario. As indicated in Table 29, Typology 9 and 14 are considered the most cost-effective scenarios. Typology 9 models the installation of a 2.5-ton CC DMSHP to partially displace the heating of an oil boiler in an existing family home, while Scenario 14 reflects the installation of a central ASHP to partially displace the heating from a propane furnace in an existing family home. On the other end, only Typologies 1 and 2 are shown to be highly cost-ineffective under the baseline scenario. Both reflect the replacement of gas systems and are predictably not likely to incur the utility or social benefits of the other typologies.

Low Incentive / High Price Scenario Cost Effectiveness

The Low-Incentive / High-Price scenario is designed to reflect 2020 Mass Save incentive levels and current price trends for heat pumps.

From the customer standpoint, the addition of incentives results in 12 of the 19 typologies reflecting lifetime customer savings. Typologies 3, 7 and 18 become cost-effective to the customer, as seen in Table 28. These three typologies reflect a wide range of installation situations, including natural gas furnace (Typology 7), oil boiler (Typology 3) and electric baseboard (Typology 18) counterfactual heat, and all three types of buildings (single-family, multifamily and commercial). While none of the buildings are highly customer cost-efficient under this scenario, their change from the baseline scenario reiterates the value of incentives in driving customer cost-effectiveness across the market.

While adding incentives increases program costs, reducing each typology's cost-effectiveness ratio, the same pattern of cost effectiveness remains; Typology 1 (partial displacement of a gas boiler with a ccDMSHP in a single family home) and 2 (full displacement of a gas furnace with a central ASHP in a single family home) are not cost-effective, while Typologies 9 (partial displacement of an oil boiler with a ccDMSHP in a single-family home) and 14 (partial displacement of a propane furnace with a central ASHP in a single family home) are the most cost effective, and all other typologies pass the cost-effectiveness threshold (> 1).

Notably, multifamily typologies appear more likely than single-family typologies to have lower cost effectiveness figures. For example, Typology 12 (partial displacement of a gas boiler with a ccDMSHP in a multifamily unit) and Typology 16 (partial displacement of an electric baseboard with a central ccDMSHP) both have cost effectiveness figures under 2. This may be attributable to the lower total energy consumption of each multifamily unit, and therefore the lower potential for net energy savings from a heat pump installation. This is reinforced by the findings for Typology 6 which represents the installation of a heat pump in a small new building addition. The lower potential for energy savings due to low counterfactual energy consumption means that program cost effectiveness figures for smaller structures with lower heating and cooling demand will remain lower compared to single-family homes.

High Incentive / High Price Scenario Cost Effectiveness

The high-incentive, high-price scenario is designed to model current price trends for heat pumps, while increasing incentives to levels that are 40% higher than 2020 Mass Save offerings.

From the customer standpoint, all of the typologies that are cost effective under the lower incentive level remain cost effective. Only Typology 19 (partial displacement of an oil furnace with a central ASHP in a commercial building) switches from a lifetime loss to lifetime cost savings at the higher incentive level. This suggests that, while increased incentives clearly enable the customer economics to look favorable for a broader segment of the market, even a 40% increase in incentives does not significantly alter the economic landscape for many customers.

From the program standpoint, the same pattern remains in place with the higher incentives, although individual cost effectiveness figures are reduced. As seen in Table 29, all three commercial typologies are considered cost-effective, and multifamily installations remain narrowly cost-effective.

Low Incentive / Low Price Scenario Cost Effectiveness

The Low-Incentive / Low-Price scenario is designed to reflect 2020 Mass Save incentive levels and heat pump prices that are below current trends.

From the customer standpoint, the Low-Incentive scenarios are the same regardless of the price scenario. This is because cost effectiveness is modeled off a first-year installation reflecting 2020 cost assumptions. When the installation is assumed to occur in the future, cost savings are modestly impacted though the same patterns of cost effectiveness arise. As illustrated in Table 30, assuming an install date 2 years in the future does change the customer savings, but the same typologies remain cost effective as in the 2020 installation scenario. Notably, typologies 5 and 11 (both variations on partial displacement of electric baseboard heat with a ccDMSHP in a single-family home), reflect the scenarios with the highest customer cost savings and both see a sizeable drop in lifetime cost savings. This change, however, represents less than a 2% change in lifetime cost savings. Over a longer term of analysis, differences in equipment costs may have greater impacts on cost-effectiveness.

As with customer cost effectiveness, program cost effectiveness figures are altered based on installation year assumptions, as seen in Table 31. Over time, the discount and inflation rates included in the Rhode Island test adjust the cost and benefit values used in the test. Interestingly, Typologies 5, 6, 10, 11, 16 and 18 each see a drop in program cost effectiveness after two years. Each of these typologies are displacing electric baseboard heating. Meanwhile the majority of fossil-fuel displacement typologies see consistent, albeit small, increases in program cost-effectiveness over time.

High Incentive / Low Price Scenario Cost Effectiveness

The High-Incentive, Low-price scenario is designed to reflect the maximum reasonable intervention in support of heat pump adoption with the greatest potential for heat pump cost effectiveness.

For both Customer and Program cost effectiveness, the cost-effectiveness patterns in the High / Low scenario reflect those in the other High-Incentive scenarios when the installation date is assumed to be 2020. The same patterns of cost-effectiveness are also maintained in the short term. As can be seen in Table 30, the specific values change, but the patterns remain the same: Typology 5 and 11 (both partial displacement of electric baseboard heat in single family homes) are the most cost effective, and Typology 19 (partial displacement of an oil furnace with a central ASHP in a commercial space) is only cost effective with high incentive levels. The same pattern arises for program cost effectiveness, regardless of price trends in the short-term. As Table 31 illustrates, within a given install year, program cost effectiveness is only significantly impacted by installation incentives. This generally highlights the minimal impact of the small (1.23% annual) price difference used in these models, suggesting that modeling more significant price differences may result in more noticeable differences in cost effectiveness over time.

Table 30. Difference in Customer Lifetime Cost Savings between 2022 and 2020 Installation

Typology	Baseline	Low Incentive / High Price	High Incentive / High Price	Low Incentive / Low Price	High Incentive / Low Price
ID	Difference in Lifetime-year NPV $ Savings				
1	($27.57)	($44.25)	($50.92)	$177.98	$171.31
2	($296.40)	($349.76)	($371.11)	$22.89	$1.54
3	$83.94	$0.56	($32.80)	$222.79	$189.43
4	$192.80	$59.38	$6.02	$434.20	$380.83
5	($1,064.94)	($1,148.32)	($1,181.67)	($926.09)	($959.44)
6	($113.46)	($166.83)	($188.17)	($52.73)	($74.07)
7	($311.93)	($338.61)	($349.28)	($90.17)	($100.85)
8	($207.13)	($290.51)	($323.86)	($1.44)	($34.79)
9	($148.98)	($232.37)	($265.72)	($10.13)	($43.49)
10	($222.00)	($272.03)	($292.04)	($157.93)	($177.94)
11	($955.48)	($1,038.86)	($1,072.22)	($816.63)	($849.99)
12	($9.64)	($19.65)	($23.65)	$94.45	$90.45
13	$193.40	$110.02	$76.67	$332.25	$298.90
14	$41.37	($42.01)	($75.36)	$247.06	$213.71
15	($200.49)	($253.85)	($275.20)	$118.80	$97.45
16	($192.40)	($242.43)	($262.45)	($128.33)	($148.35)
17	($110.54)	($281.26)	($349.54)	$169.17	$100.89
18	($365.28)	($536.00)	($604.29)	($85.57)	($153.86)
19	($648.25)	($818.97)	($887.26)	($227.12)	($295.40)

Table 31. Difference in Program Cost-Effectiveness between 2022 and 2020 Installation

Typology	Baseline	Low Incentive / High Price	High Incentive / High Price	Low Incentive / Low Price	High Incentive / Low Price
ID	Lifetime-year NPV $ Savings				
1	-0.13	-0.03	-0.03	-0.03	-0.03
2	1.9	0.11	0.08	0.11	0.08
3	3.47	0.18	0.13	0.18	0.13
4	5.93	0.22	0.16	0.22	0.16
5	-7.71	-0.4	-0.3	-0.4	-0.3
6	-0.63	-0.03	-0.03	-0.03	-0.03
7	0.79	0.09	0.06	0.09	0.06
8	5.83	0.31	0.23	0.31	0.23
9	5.85	0.31	0.22	0.31	0.22
10	-1.56	-0.11	-0.09	-0.11	-0.09
11	-7.4	-0.39	-0.28	-0.39	-0.28
12	-0.01	0	0	0	0
13	3.79	0.2	0.15	0.2	0.15
14	7.94	0.42	0.3	0.42	0.3
15	3.2	0.18	0.14	0.18	0.14
16	-1.62	-0.12	-0.09	-0.12	-0.09
17	1.94	0.06	0.04	0.06	0.04
18	-3.35	-0.1	-0.08	-0.1	-0.08
19	6.29	0.19	0.14	0.19	0.14

Adoption Modeling

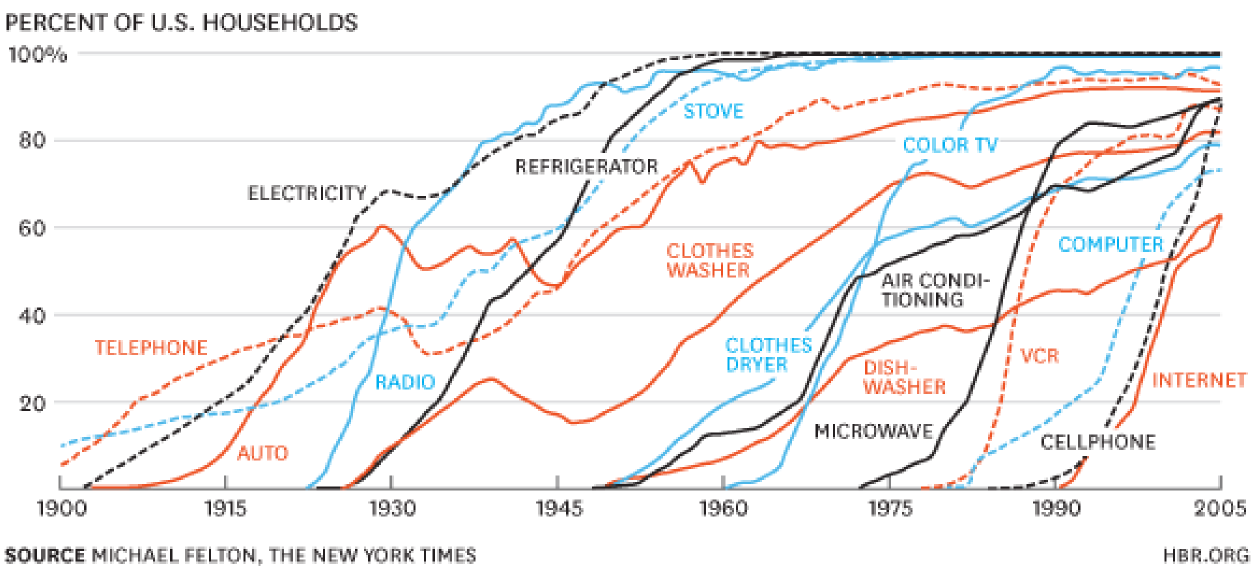
Over time, the total adoption of novel technologies roughly follows an "S-Curve" as more people become aware of new technology. Cadmus utilized a standardized approach incorporating historical adoption data and willingness to pay to model technology adoption to predict the number of heat pumps installed between 2020 and 2024 under each of the 5 scenarios.

Methodology

To project the adoption of cold-climate heat pumps for National Grid, Cadmus followed a standardized process of baselining future projections to historical rebate data and willingness to pay data and leveraging the resulting model to project future trends.

The analysis begins by designing an S-curve model that reflects a line of best fit for the historical rebate data. The shape of the S-curve specifically reflects the initially low rate of adoption as new technology enters the market, followed by more rapid uptake as familiarity with the technology increases and market conditions push further adoption. See Figure 23 for some familiar examples.

Figure 23. Example Technology Adoption S-Curves in the US



To ensure that the S-curve reflect the specific market conditions and customer awareness levels of the Rhode Island Market, Cadmus develops the S-curve as a line of best fit for historical rebate data. This data includes two critical pieces for the S-curve: the number of unique households installing heat pumps each year, and the percent of installed costs covered by rebates (see Table 32 and Table 33 for details). These are split out into rebates for central heat pumps and rebates for ductless heat pumps to provide additional granularity for the analysis. This data is incorporated into a line of best fit using a logistic model as described in Equation 1.

Equation 1. S-Curve Adoption Model Formula

$$f(x) = \frac{WTP}{1 + e^{-k(x-x_0)}}$$

Where:

f(x) = Annual adoption of heat pump (as a percent of possible customers) in year x.

x = Adoption year.

WTP = Willingness to pay factor, varying by historical rebate, or modeled rebate values

k = The logistic growth rate of the s-curve

x_0 = The s-curve midpoint year

By using historical rebate data to create a line of best fit, the resulting model incorporates existing market trends, heat pump awareness and the relative responsiveness of the market to incentives. Using annual heat pump installations (see Table 32) along with regional market share data specific to residential[4] and commercial[5] buildings, and the number of National Grid customer accounts for 2011 to 2018, an annual saturation of central and ductless heat pump was established for each sector. This equates to *f(x)* in Equation 1.

Table 32. Heat Pump Rebates by Year & Configuration

Configuration	2011	2012	2013	2014	2015	2016	2017	2018
Central	95	27	51	37	25	29	106	19
Ductless	441	499	600	630	657	934	676	561

Source: Rhode Island Heat Pump Rebate Data

The other major factor noted in Equation 1 is the *WTP* factor. In establishing the line of best fit, Cadmus used historical rebate data on the percent of installed cost covered by rebates for each year (see Table 33). Formatting the rebate data in this way enables it to be directly compared to the data collected from the willingness to pay survey conducted as part of this study.

Table 33. Average Percent of Installed Price Covered by Incentive

Configuration	2011	2012	2013	2014	2015	2016	2017	2018
Central	4.24%	3.11%	4.39%	4.81%	5.31%	4.23%	4.44%	2.79%
Ductless	12.66%	10.49%	7.45%	7.30%	8.36%	7.86%	3.43%	3.03%

Source: Rhode Island Heat Pump Rebate Data

This historical data is combined with the results of the willingness to pay survey discussed earlier in this study to create the WTP factors for the line of best fit. To make the willingness to pay survey results useful for this analysis, each response was assigned a deemed "likelihood to install" value, expressed as a percentage likelihood to install a heat pump (Table 34).

---

4 NMR, "Residential Appliance Saturation Survey." NMR Consulting Inc. 2018

5 U.S. EIA. "Commercial Building Energy Consumption Survey NE." EIA 2012

Table 34. Likelihood to Install

Response	Deemed Likelihood to Install
"Very Likely"	75%
"Somewhat Likely"	50%
"Not Too Likely"	25%
"Not at All Likely"	0%
"Don't Know"	Excluded

The WTP survey was structured such that incentives were offered at defined percentages of the assumed cost of a system. By assigning each response its corresponding value described in Table 34, it is possible to find the average likelihood of installation among survey participants at each incentive level. (see Table 35 for details.)

Table 35. Willingness to Pay Survey Adoption Percentage Results

Sample Group	System Type	Install Type	0% Incentive	12.5% Incentive	25% Incentive	50% Incentive
Res-Delivered	Ductless mini-split heat pump	Partial	17.4%	30.8%	39.1%	47.8%
Res-Delivered	Ductless mini-split heat pump	Full	22.6%	33.4%	39.6%	53.1%
Res-Delivered	Ducted air source heat pump	Partial	4.4%	21.7%	29.5%	51.3%
Res-Delivered	Ducted air source heat pump	Full	13.7%	16.3%	27.0%	56.0%
Res-Electric	Ductless mini-split heat pump	Partial	26.9%	37.5%	41.0%	45.3%

By plotting the historical rebate percentage data along the scale from 0% to 50% noted in Table 35, it is possible to identify the estimated WTP factor for each year from 2011 to 2018.[6] Note that different WTP values are highlighted in Table 35 for different heat pump installation scenarios. These correspond with the relevant factors for each of the 19 permutations used in the cost effectiveness assessment.

When plotted as a line of best fit using the logistic curve model from Equation 1, these factors create a model that enables forward projection of heat pump adoption for each of the 5 scenarios described previously in Table 27. Note that, because the commercial willingness-to-pay survey could not be completed due to Covid-19, the commercial best fit S-curves could not be created.

Projections

To apply the S-Curves to each of the 19 permutations identified in this study, a stock projection model was developed to identify the achievable installations for each permutation. Cadmus combined various datasets into its stock projection model to estimate the achievable installations over 2020-2024 study horizon. As shown in Figure 24, Cadmus started with National Grid's 2019 residential and small

[6] The willingness to pay study surveyed exclusively customers with some pre-existing familiarity with heat pump technology. Similarly, it is assumed that some level of familiarity with heat pumps is a precondition to adoption. As time progresses, the shape of the S-curve assumes an increase in heat pump awareness across the market, driving some of the increase in adoption over time.

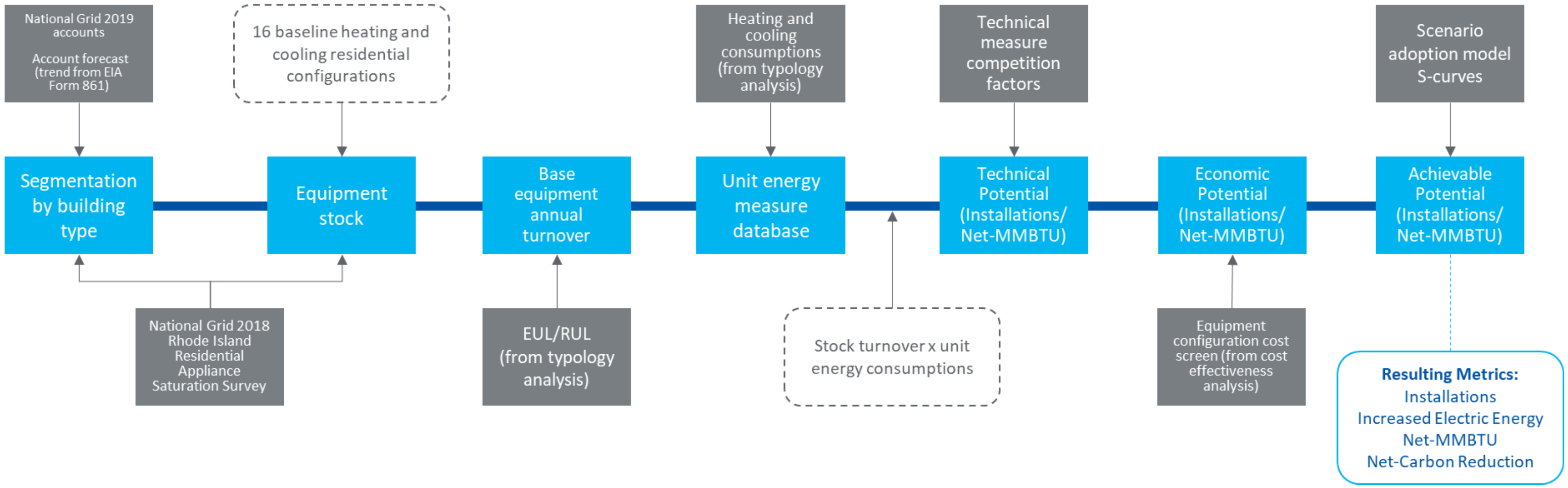
commercial customer accounts and projected the Rhode Island new construction accounts using historical data using EIA data to determine the total eligible customer accounts.[7] Cadmus then used the 2018 RI Residential Appliance Saturation Survey to determine the applicable equipment stock for each configuration. Appling measure life assumptions by each configuration, the baseline annual equipment turnover values were determined. Cadmus used measure level consumption data (from the Typology Measure & Counterfactuals section) to develop unit energy measure database. After applying the unit energy consumptions with the stock turnover projections, Cadmus incorporated technical competition between full-use and part-use applications for the same segmentation application.[8] The resulting calculation, provided the total technical installations over the time horizon.

Next, Cadmus screened the technical installations by data from cost effectiveness analysis (in section Cost Effectiveness Analysis) to determine the total economic installations. Lastly, Cadmus applied the adoption modeling for each configuration to estimate the projected achievable installations over the 5-year period.

7 U.S. EIA, Annual Electric Power Industry Report, Form EIA-861 detailed data files (2010-2018). Online access of "Number of Customers by State by Sector": https://www.eia.gov/electricity/sales_revenue_price/

8 For modeling proposes, Cadmus assumed an even split between full-use and part-use applications. With one exception, for single family full-use existing building and single family part-use building addition Cadmus assumed 95% and 5%, respectively.

Figure 24. Projection Model - Residential Sector Example



Results from the projection modeling for each of the different willingness-to-pay scenarios are found in Appendix J. Potential installations between 2020 and 2024 range from a low of 2,943 under the baseline scenario to 4,992 in the low-cost, high-incentive scenario. Notably, under current price trends, offering incentives equal to those provided by Mass Save results in an additional 1,553 heat pump installations between 2020 and 2024 for total of 4,497 installations. Single-family buildings with electric baseboard and window air conditioning represented the highest number achievable installations for partial and full load equipment replacements. Applications with zero or low installations were either not cost effective (generally where heat pumps are replacing gas heat) or new construction applications with low market share. See Table 36 for details.

Of the incentivized scenarios, lower incentive scenarios are shown to reduce overall electricity consumption the most because they incentivize the highest conversion of electric baseboard heating to heat pumps relative to fossil fuel conversions. In doing so, these lower incentives capture a higher per-installation energy reduction than higher incentives which induce additional fuel-switching installations. The baseline scenario ($0 incentive scenario) is shown to result in the greatest reduction in net electricity consumption. This is largely due to a lack of incentivized fuel switching, while some electric heating continues to be replaced by heat pumps even without incentives. Higher incentive scenarios, on the other hand, result in a greater reduction in overall energy consumption (in terms of MMBTU) combining both fossil fuels and electricity. This is due to incentives driving an increase in the total number of heating systems converted to heat pumps. In Appendix J, detailed results of the increased electric energy, net-MMBTU, and net-carbon reduction are shown across each scenario and permutation.

Overall, the adoption of Mass Save-level incentives significantly increases heat pump adoption above baseline projections. Notably, while the high-incentive scenarios (Low-High and High-High) include incentives 40% higher than Mass Save levels, they do not result in a 40% increase in heat pump adoption. Rather, there is an 9.9 – 10.2% increase for the high and low-cost scenarios respectively. Additionally, typology prevalence in the marketplace plays a significant role in predicting heat pump adoption, with scenarios representing less common or lower-turnover typologies demonstrating significantly lower adoption over the period of the analysis. Details on the results of the annual stock turnover model can be found in Appendix J.

In Appendix J, the impact of heat pump adoption on total annual kWh consumption is highlighted. Due to the high cost-effectiveness of replacing electric heating with heat pumps and the relative prevalence of electric heating in the Rhode Island market, the adoption of heat pumps contributes to a net decrease in annual electricity consumption across all five scenarios. By reducing electric heating load, even when adding cooling to the home, the net reductions in kWh consumption over the 4-year period range from 14.1 to– 15.7 GWh. Under the baseline scenario, the market is expected to install just over 1,900 heat pumps in place of electric heaters, compared to around 1,040 in place of oil, gas and propane heaters, resulting in a significant drop in total electricity consumption of around 15.7 GWh. When Mass Save-level incentives are introduced, the number of baseboard heaters displaced by heat pumps increases to 2,251 (an 18.3% increase) while the number of heating oil, propane and natural gas displacements increases to 2,246 (a 116% increase). As a result, the high-cost / low-incentive scenario has the lowest drop in electricity consumption of around 14.1 GWh over four years.

Inversely, the greatest carbon savings are achieved under the low-cost / high incentive scenario, around 20,870 tons CO_2e, as detailed in Appendix J. As may be expected, this scenario encourages homeowners and businesses to adopt heat pumps in far higher quantities, offsetting substantially more fossil-fuel heating and inefficient electricity than under other scenarios. Predictably, the Baseline scenario sees the lowest carbon savings, with around 13,054 tons of CO_2e saved.

Also, as demonstrated in Table 36, the impact of modeled price trends is minimal. The low-price scenarios are illustrative of heat pump prices falling 5% relative to current trends between 2020 and 2024. However, this drop in prices is highly improbable as it goes against both recent trends and predications offered by heat pump installers and distributors. Additionally, these lower modeled prices are only associated with 35-49 additional installations over 4 years: a 0.78 – 1.00% increase in installations (for low and high incentive scenarios respectively) relative to a 5% drop in price.

Notably, the S-Curve analysis using willingness to pay and cost-effectiveness as parameters leaves out customer behavior that is not purely driven by economics. Customers may not be exclusively driven by economics. For example, roughly 30% of the installations completed through the MassCEC ccASHP Rebate Program were installed in gas homes. Many heat pump installations provide supplemental, shoulder-season heating or are used exclusively for cooling. This highlights the fact that, in addition to the figures noted below, some gas customers may also install heat pumps, motivated by the desire to add cooling capacity or other factors beyond energy savings

Table 36. Achievable Potential Installations of Heat Pumps for 2020-2024

ID	Technology	Base Equipment	Installations (Count) - Cumulative Achievable 2020-2024				
			Baseline: No Change in cost / No Incentives	High-Low: High Cost / Low Incentives	High-High: High cost / High Incentives	Low-Low: Low cost / Low Incentives	Low-High: Low cost / High Incentives
1	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Gas Boiler with Window AC	0	0	0	0	0
2	Single-family New Construction - Central CC ASHP Full Replacement 3 Ton - 9 HSPF	Gas Furnace with Central AC	0	0	0	0	0
3	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Oil Boiler with Window AC	314	654	714	659	720
4	Single-family Existing Building - CC DMSHP Full Replacement 4 Ton - 10 HSPF	Oil Boiler with Window AC	407	689	780	696	790
5	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Electric Baseboard with Window AC	1,158	1,378	1,466	1,385	1,476
6	Single-family Building Addition - CC DMSHP Full Replacement 1.5 Ton - 10 HSPF	Electric Baseboard with Window AC	61	73	77	73	78
7	Multifamily New Construction - Central CC ASHP Full Replacement 1 Ton - 9 HSPF	Gas Furnace with Central AC	0	0	0	0	0
8	Single-family Existing Building - Central ASHP Partial Replacement 2.5 Ton - 9 HSPF	Oil Furnace with Central AC	32	211	275	216	282
9	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Oil Boiler with Central AC	109	241	268	244	271
10	Multifamily Existing Building - CC DMSHP Partial Replacement 1.5 Ton - 10 HSPF	Electric Baseboard with Window AC	354	407	428	409	430
11	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Electric Baseboard with No AC	269	320	341	322	343
12	Multifamily Existing Building - CC DMSHP Partial Replacement 1.5 Ton - 10 HSPF	Gas Boiler with Window AC	90	187	204	189	206
13	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Oil Boiler with No AC	70	145	159	146	160

ID	Technology	Base Equipment	Installations (Count) - Cumulative Achievable 2020-2024				
			Baseline: No Change in cost / No Incentives	High-Low: High Cost / Low Incentives	High-High: High cost / High Incentives	Low-Low: Low cost / Low Incentives	Low-High: Low cost / High Incentives
14	Single-family Existing Building - Central ASHP Partial Replacement 2.5 Ton - 9 HSPF	Propane Furnace with Central AC	18	117	153	120	156
15	Single-family New Construction - Central CC ASHP Full Replacement 3 Ton - 9 HSPF	Propane Furnace with Central AC	0	0	0	0	0
16	Multifamily Existing Building - CC DMSHP Partial Replacement 1.5 Ton - 10 HSPF	Electric Baseboard with No AC	62	73	78	74	79
17	Commercial Existing Building - CC DMSHP Partial Replacement 5.12 Ton - 10 HSPF	Oil Boiler with Window AC	Due to COVID-19 and the resulting low response rates, the team was unable to collect viable WTP data for commercial customers.				
18	Commercial Existing Building - CC DMSHP Partial Replacement 5.12 Ton - 10 HSPF	Electric Baseboard with Window AC					
19	Commercial Existing Building - Central ASHP Partial Replacement 5.12 Ton - 9 HSPF	Oil Furnace with Central AC					
	Total		**2,943**	**4,497**	**4,943**	**4,532**	**4,992**

Note: Typology 1 and 2 were found to not be cost effective and are therefore assumed to not be viable for widespread adoption. However, customers in these typologies may still install ASHPs for non-economic reasons (e.g. adding cooling, reducing fossil fuel consumption and emissions).

Note: Typology 15 and 7, while cost effective, have very low turnovers because they are new construction buildings.

Note: Typology 3 and 4 both represent the same market segment (SF home with oil boiler and window AC).

Conclusions

This study completed a thorough review of ccASHP use, potential, adoption and cost-effectiveness in the Rhode Island market. The findings reveal opportunities for further development of incentives and programming to promote more widespread ccASHP adoption.

While the study was unable to gather sufficient commercial data to draw conclusive insights from the surveys, those responses collected indicate that commercial and residential customers approach heat pumps, their use, and their installation differently and may need to be targeted differently in outreach and incentive programs. While residential customers are motivated by adding cooling, supplementing their heating and considering environmental impacts, business customers appear motivated by maintaining system-wide heating and cooling.

The study also found that word-of-mouth remains one of the primary ways that people learn about heat pumps. Installers were commonly cited as the major source of information about ASHPs for customers (while no customers reported learning about ASHPs from National Grid), suggesting that broader engagement with installers (including providing additional education and resources) would facilitate greater customer awareness. This aligns with many installers' requests for additional support and resources to help promote heat pumps and become better versed in the market. Along similar lines, the study found that many installers are not engaged with National Grid's heat pump program, citing high barriers to entry and paperwork. By streamlining the process for applying for incentives and support, National Grid may expand installer participation, incentive impact, and customer knowledge and awareness of heat pumps.

An analysis of ccASHP prices found that installed costs are expected to continue increasing in the near term. This was corroborated by many installers and distributors, attributable to the installation of higher efficiency systems and more complex configurations. As installation costs continue to be a primary motivator for heat pump installation, incentives are key to driving adoption of the technology.

Under the scenarios analyzed, it was found that most non-gas homes and businesses would realize net financial benefits from partially or fully displacing their heating with a ccASHP system. Most notably, buildings that rely on electric baseboard heating systems stand to benefit the most from heat pump installations. From the program perspective, oil, propane, and electricity-heated buildings offer cost effective options for incentivizing heat pumps, while multifamily and gas-heated buildings offer the least cost-effective options. Targeting existing, fossil fuel and electric-heated buildings will offer the greatest opportunities for ccASHP adoption through future National Grid programs.

If incentives similar to those currently offered by Mass Save are adopted in Rhode Island, there may be a significant increase in annual heat pump adoption (up to a 52.8% increase). Adopting these incentives offers the opportunity to maximize electricity savings as electric heating and cooling is replaced with more efficient heat pump systems. Adopting these incentives will also likely enable higher carbon emissions reductions, with estimated greenhouse gas savings of around 18,900 tons over four years (5,845 tons more than the baseline) if incentives equal to those offered by Mass Save are adopted. Importantly, however, increasing incentives by 40% above Mass Save levels only increases heat pump adoption by around 10% market-wide, suggesting that increasing incentives above a certain threshold offers marginal returns and may not be optimal.

Additional research into the nature of the heat pump market may yield interesting and informative results. As highlighted throughout this analysis, due to Covid-19 insufficient information was able to be collected in this analysis to clearly assess commercial and industrial customers' role in the heat pump market. Further research could investigate the specific motivations for installing heat pumps, willingness to pay for the technology, and use of the technology. Additional investigation into the kinds of businesses, spaces, and structures in which heat pumps are being installed within the commercial and industrial sector may also help inform further targeted incentives and a clearer understanding of the use case for heat pumps among commercial customers. Research into the drivers and barriers for participation in commercial incentive programs may also help inform further changes to more effectively target incentives to commercial participants.

As highlighted in the willingness to pay study, a relatively low portion of the variability in rated WTP appears to be predicted by rebate levels. Additional research and studies into willingness to pay, accounting for other variables beyond rebate levels, may shed light on the key factors driving willingness to pay for heat pumps. Additionally, further studies into the nature and drivers of heat pump prices in the region may also yield valuable insights. While this study found that installed costs are rising, research into the variables involved in heat pump price changes may help identify overall trends as well as areas of focus for program incentives. It was also noted in this study that numerous customers with gas heating have installed heat pumps, presumably as a means for adding cooling. Further research could be conducted into the motivators for installing heat pumps among gas customers as well as the customer and program economics for incentivizing such installations. Finally, additional research into the optimal incentives for heat pumps may highlight the incentive values best situated to maximize carbon reductions, energy demand reductions or other specified goals within the limitations of program budgets.

Appendix A. BEopt Modeling Inputs

Table A-1. Inputs for Multifamily New Construction Building Energy Modeling

Item	Value	Units	Source
Size	720	Square feet	RASS median per unit
Units	8	Units per building	RASS median per building
Air Leakage	7	ACH 50	Massachusetts TRM
Window Ratio	25%	Percent coverage	Updated assumption
Wall Insulation	13	R-value	RI ICC code (fiberglass batt)
Wall Sheathing	10	R-value	RI ICC code (OSB)
Exterior Finish	0.7	R-value	RI ICC code (medium brick)
Finished Roof	30	R-value	RI ICC code (fiberglass batt)
Slab	10	R-value	RI ICC code (4ft perimeter)
Carpet	80%	Percent coverage	BEopt baseline assumption
Duct Leakage (where applicable)	8	CFM 25	RI ICC code (duct leakage)
Duct Insulation (where applicable)	4	R-value	RI ICC code (duct insulation)
Cooling Set point	73	Degrees F	BEopt baseline assumption
Heating Set point	68	Degrees F	BEopt baseline assumption

Table A-2. Inputs for Multifamily Existing Building Energy Modeling

Item	Value	Units	Source
Size	720	Square feet	RASS median per unit
Units	8	Units per building	RASS median per building
Air Leakage	15	ACH 50	Updated assumption
Window Ratio	15%	Percent coverage	Updated assumption
Wall Insulation	4	R-value	Updated assumption
Wall Sheathing	0	R-value	Updated assumption (OSB)
Exterior Finish	0.6	R-value	Updated assumption (vinyl)
Finished Roof	19	R-value	Updated assumption (fiberglass batt)
Unfinished basement	.7	R-value	Updated assumption (uninsulated)
Carpet	80%	Percent coverage	BEopt baseline assumption
Duct Leakage (where applicable)	20%	Percentage loss	Updated assumption (duct leakage)
Duct Insulation (where applicable)	4	R-value	Updated assumption (duct insulation)
Cooling Set point	76	Degrees F	BEopt baseline assumption
Heating Set point	71	Degrees F	BEopt baseline assumption

Table A-3. Inputs for an Addition to an Existing Single-Family Building Energy Modeling

Item	Value	Units	Source
Size	169	Square feet	RASS median per unit
Air Leakage	7	ACH 50	Massachusetts TRM
Window Ratio	25%	Percent coverage	Updated assumption
Wall Insulation	13	R-value	RI ICC code (fiberglass batt)
Wall Sheathing	5	R-value	RI ICC code (OSB)
Exterior Finish	0.3	R-value	RI ICC code (vinyl)
Unfinished attic	38	R-value	RI ICC code (cellulose)
Unfinished basement	10	R-value	RI ICC code (whole wall)
Carpet	80%	Percent coverage	BEopt baseline assumption
Duct Leakage (where applicable)	4	CFM 25	RI ICC code (duct leakage)
Duct Insulation (where applicable)	8	R-value	RI ICC code (duct insulation)
Cooling Set point	73	Degrees F	BEopt baseline assumption
Heating Set point	68	Degrees F	BEopt baseline assumption

0.

Appendix B. Equipment Efficiency

Table B-1. Equipment Components

Item	Unit	Description
Equipment Type	Appliance	Appliance in question including age (new / existing) fuel and mechanism
Remaining Useful Life (RUL)	Years	Number of years until appliance requires replacement
Heating Efficiency	AFUE	Heating efficiency of fossil fuel heating equipment (BTU out / BTU in)
Heating Performance	Seasonal COP	Heating efficiency of electrical heating equipment (BTU out / BTU in)
Heating Performance	HSPF	Heating Season Performance Factor for heat pumps (BTU out / Wh in)
Cooling Performance	EER	Cooling energy efficiency ratio for all cooling equipment (BTU out / Wh in) for peak heating (95 degrees F)
Cooling Performance	SEER	Seasonal energy efficiency ratio for all cooling equipment (BTU out / Wh in) across cooling season (summer averages)
Switching Temp	Degrees F	Temperature at which heat pumps in partial displacement scenarios

Table B-2. Equipment Details

Equipment Type	Remaining Useful Life	Heating Efficiency	Heating Performance		Cooling Performance		Switching Temp
Appliance	Years	AFUE	Seasonal COP	HSPF	EER	SEER	Degrees F
Existing Equipment							
Existing Gas Boiler	10	0.80					50
Existing Gas Furnace	6	0.80					50
Existing Oil Boiler	10	0.75					30
Existing Oil Furnace	6	0.78					30
Existing Propane Furnace	6	0.75					15
Existing Electric Baseboard	5		1.00				15
Existing Window AC	3				8.00	8.40	-
Existing Central AC	5				8.50	10.00	-
New Equipment							
New Gas Boiler	20	0.82					50
New Gas Furnace	17	0.85					50
New Oil Boiler	20	0.84					30
New Oil Furnace	18	0.83					30
New Propane Furnace	18	0.85					15
New Electric Baseboard	15		1.00				15
New Window AC	9				10.00	11.15	-
New Central AC	16				11.00	13.00	-
Heat Pumps							
CC DMSHP	18		2.89	10.00	12.50	18.00	-
Central CC ASHP	17		2.72	9.00	12.50	18.50	-
Central ASHP	17		2.72	9.00	12.50	18.50	-

Table B-3. Equipment Detail Sources

Appliance	Sources
Existing Equipment	
Existing Gas Boiler	ERI 2017 Appliance Estimates & Projections: 2009 Installed Base AFUE for Residential (North). Pump demand assumed to be the same as propane boiler in RES 21
Existing Gas Furnace	RES 21 Value
Existing Oil Boiler	RES 21 Value. Switchover temp from updated Energy Optimization Sheets
Existing Oil Furnace	RES 21 Value. Switchover temp from updated Energy Optimization Sheets

Appliance	Sources
Existing Propane Furnace	RES 21 Value
Existing Electric Baseboard	RES 21 Value
Existing Window AC	RES 21 AC values (only EER provided - assumed EER = –0.02 × SEER^2 + 1.12 × SEER)
Existing Central AC	RES 21 Value
New Equipment	
New Gas Boiler	RES 21 Values. Fan / Pump Demand value assumed to be the same as propane boiler in RES 21.
New Gas Furnace	RES 21 Value
New Oil Boiler	RES 21 Value. Switchover temp from updated Energy Optimization Sheets
New Oil Furnace	RES 21 Value. Switchover temp from updated Energy Optimization Sheets
New Propane Furnace	RES 21 Value
New Electric Baseboard	RES 21 Value
New Window AC	RES 21 AC values (only EER provided - assumed EER = –0.02 × SEER^2 + 1.12 × SEER)
New Central AC	RES 21 Value
Heat Pumps	
CC DMSHP	1st decile of NEEP cold climate multizone ductless heat pumps > 1 Ton capacity with <5F temperature data
Central CC ASHP	1st quartile of NEEP cold climate single zone ductless heat pumps > 1 Ton capacity with <5F temperature data
Central ASHP	Energy Star / rebate EER minimum. Performance is same as ccASHP for values above switching temp (as standard ASHP only used in partial replacement)

Appendix C. Methodology

Degree Hour Calculation

Heating and cooling loads are calculated on an hourly basis based on the outdoor temperature.

1. Set Temperature

A set temperature is selected to identify the heating or cooling temperature to which a building's thermostat is set.

Table C-1. Set Temperatures

Set	Temp	Source
Heating	65° F	RES 21 set temp
Cooling	72° F	BEopt standard input

2. Degree Hours

Using hourly temperature data from the Pawtucket TMY3 dataset, heating (HDH) and cooling degree hours (CDH) are calculated for each hour of the year.

Table C-2. Degree Hour Calculation Sample

Date	Hour	Temp (F)	HDH	CDH
May 12	6:00	57.20	7.80	0.00
May 12	7:00	62.60	2.40	0.00
May 12	8:00	68.00	0.00	0.00
May 12	9:00	71.24	0.00	0.00
May 12	10:00	75.38	0.00	3.38
May 12	11:00	78.26	0.00	6.26

HDH = [Heating Set Temp] – [outdoor Temp (F)]

CDH = [outdoor Temp (F)] – [Cooling Set Temp]

3. Heating/Cooling %

The percentage of total heating (%H) or cooling (%C) degree hours each hour represents is calculated for each of the 8760 hours.

Table C-3. Percent Heating Load Calculation Sample

Date	Hour	HDH	CDH	%H	%C
May 12	6:00	7.80	0.00	0.0049%	0%
May 12	7:00	2.40	0.00	0.0015%	0%
May 12	8:00	0.00	0.00	0%	0%
May 12	9:00	0.00	0.00	0%	0%
May 12	10:00	0.00	3.38	0%	0.0588%
May 12	11:00	0.00	6.26	0%	0.1088%

Fuel consumption is calculated on an hourly basis calculated as the % of total heating or cooling load over time divided by equipment efficiency

4. Building Load

The percentage of heating and cooling degree hours is multiplied by the building's heating and cooling load to identify the load for each hour.

Table C-4. Heating Load Distribution Example

%H	%C	Heat (BTU)	Cool (BTU)
0.0049%	0%	3758.3	0
0.0015%	0%	1150.5	0
0%	0%	0	0
0%	0%	0	0
0%	0.0588%	0	7702.8
0%	0.1088%	0	14252.8

Table C-5. Heating Load Example (Typology 1)

Heating Load	Cooling Load
MMBTU / yr.	MMBTU / yr.
76.70	13.07

5. Set Point Sums

In the counterfactual and full displacement measure pathways, 100% of heating goes is covered by the primary heating equipment (same for cooling). In partial displacement measure pathways, all heating above the switching temperature but below the set point is covered by the heat pump, while all heating below the switching temperature is covered by the backup heating equipment. The load for each equipment is sum of all heating or cooling loads in the respective temperature brackets.

Table C-6. Switching Temperature Example

Heating Fuel	Switching Temp
Natural Gas	50 F
Heating Oil	30 F
Propane	15 F
Electric Baseboard Heat	15 F

Table C-7. Division of Heating Load Example

Heat <50° F	Heat >50 <65
69.104 MMBTU	7.5952 MMBTU
Covered by boiler	Covered by heat pump

6. Equipment Efficiency

The load of each non-heat pump equipment is divided by the efficiency of that equipment to identify the fuel consumption by fuel.

Table C-8. Final Heating Load Coverage

Appliance	AFUE	Load (MMBTU)	Annual Gas Use (MMBTU)
Existing Gas Boiler	0.80	69.104	86.38

However, heat pump performance is assumed to vary significantly with outdoor temperature and is therefore calculated on a per-hour basis with variable efficiencies.

Heat Pump Efficiency Calculation

Heat pump performance depends on outdoor temperature. A formula is used to calculate efficiency for each hour in the TMY3.

A heat pump's COP varies with temperature. Using the median COP values from the NEEP database, a piecewise function was developed to capture differentiated linear curves between -13, 5, 17, and 47 degrees F

Table C-9. Coefficient of Performance

COP at temp:	-13F	5F	17F	47F
CC DMSHP	1.75	2.03	2.19	4.00
Central CC ASHP	1.38	2.04	2.32	3.70
Central ASHP	1.38	2.04	2.32	3.70

The percentage of its maximum output a heat pump can cover varies with temperature. When it is below 100%, the remaining output capacity is covered by built-in electric resistance heating with a COP of 1. The same piecewise format was used.

Table C-10. Heating Output Percentage

% Output at temp:	-13F	5F	17F	47F
CC DMSHP	0.75	1.00	1.00	1.00
Central CC ASHP	0.71	0.77	0.92	1.00
Central ASHP	0.71	0.77	0.92	1.00

In-situ performance has been shown to be ~10% lower than factory rated performance among cold climate heat pumps (Cadmus, 2016). Additionally, the interaction ductless mini-split heat pumps and backup heating systems is not perfect, and some inefficiencies occur. To account for these, hourly heat pump efficiencies are multiplied by the following based on their installation conditions.

Table C-11. Performance Modifiers

Coefficient	Value	Description
In-situ factor	0.9	Applied to all heat pumps regardless of installation to account for 10% performance reduction
Interaction factor	0.98	Applied only to DMSHPs installed in partial displacement measure scenarios.

Calculating heat pump consumption requires that consumption be calculated on an hourly basis and summed to the annual level.

The same steps as for other equipment is followed, conducted on a per-hour basis.

1. Using the Heating % the annual heating load is distributed across the 8760 hours of the year
2. For each hour, the load is divided by the COP calculated for that hour for the electricity input (in BTU)
3. The hourly electricity input is converted to kWh and summed over the year for annual electricity consumption

The below illustrates the calculations for a CC DMSHP covering the full heating load of a home with a 76.7 MMBTU / year heating load.

Table C-12. Hourly Heating Load Example

Month	Hour	Dry bulb (F)	Heating degree hours	Heating %	Heating Load (BTU)	CC DMSHP COP	Electricity input (BTU)	Electricity Input (kWh)
Jan 1	1:00	21.20	43.80	0.03%	21,276.7	2.20	9671.227	2.8344
Jan 1	2:00	23.00	42.00	0.03%	20,402.3	2.30	8870.565	2.5997
Jan 1	3:00	24.80	40.20	0.03%	19,527.9	2.40	8136.625	2.3846
Jan 1	4:00	24.80	40.20	0.03%	19,527.9	2.40	8136.625	2.3846
Jan 1	5:00	24.80	40.20	0.03%	19,527.9	2.40	8136.625	2.3846
Jan 1	6:00	24.80	40.20	0.03%	19,527.9	2.40	8136.625	2.3846
Jan 1	7:00	26.60	38.40	0.02%	18,653.5	2.49	7491.365	2.1955
Jan 1	8:00	26.60	38.40	0.02%	18,653.5	2.49	7491.365	2.1955

Year-over-Year Savings Methods

Energy and fuel savings depend on the equipment in place each year, which is dependent on the remaining useful life of the equipment

Over a 5-year period, some existing equipment is expected to require replacement. New equipment has higher efficiency than old equipment and therefore changes the consumption level after installation.

Table C-13. Scenario 1 Energy Savings Example

Measure		Counterfactual		Consumption Savings (positive values indicate the measure consumes less than counterfactual)			
Heat Pump	secondary heating	Heating	cooling	Gas (MMBTU)	Oil (MMBTU)	Propane (MMBTU)	Electricity (kWh
CC DMSHP	Existing Gas Boiler	Existing Gas Boiler	Existing Window AC	10.42	0.00	0.00	252.97
CC DMSHP	Existing Gas Boiler	Existing Gas Boiler	Existing Window AC	10.42	0.00	0.00	252.97
CC DMSHP	Existing Gas Boiler	Existing Gas Boiler	Existing Window AC	10.42	0.00	0.00	252.97
CC DMSHP	Existing Gas Boiler	Existing Gas Boiler	New Window AC	10.42	0.00	0.00	-129.87
CC DMSHP	Existing Gas Boiler	Existing Gas Boiler	New Window AC	10.42	0.00	0.00	-129.87

The equipment that changes is the cooling system. Therefore, it has no effect on the level of gas consumed, as the existing and new systems are both electric and natural gas is only consumed for heating.

Cost-Effectiveness Calculations

The years of analysis may be fewer than the remaining useful life of a piece of equipment. The analysis uses a percentage lifetime cost discounting formula to ensure benefits and costs match the same timeline.

Table C-14. Partial Lifetime installed cost discounting

Device	Installed Cost	Year installed	RUL	End of analysis	RUL post analysis
New Window AC	$288.07	2023	9 years	2024	7 years

Table C-15. Installed Cost Applying Real Value Discounting

2023	2024	2025	2026	2027	2028	2029	2030	2031
$288.07	$284.20	$280.39	$276.62	$272.91	$269.24	$265.62	$262.06	$258.54
Value during analysis	Value after analysis*							
23.29%	76.71%							

Note: the use of the annual real installed value by year is designed to capture the % of lifetime installed value applicable to the analysis period and does not assume a continually repeated installation cost.

Table C-16. Equipment Lifetime Example

Installed Cost	Analysis Lifetime	Evaluated Cost
$288.07	23.29%	$67.08

Because only 2/9 of the equipment’s lifetime energy savings are being applied in the analysis, a similar discounting must occur for installed cost to not overstate the cost of the energy savings. Because equipment loses value over time, using a percentage of discounted values enables the analysis to account for most of the device’s value up front, better reflecting customers’ experience.

Appendix D. Modeled Energy Savings by Typology

Table D-1. 15 Year-over-Year Savings for Natural Gas Consumption of All 19 Scenarios

Year	Scenario																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	9.49	41.76	0.00	0.00	0.00	0.00	13.33	0.00	0.00	0.00	0.00	1.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	9.49	41.76	0.00	0.00	0.00	0.00	13.33	0.00	0.00	0.00	0.00	1.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	9.49	41.76	0.00	0.00	0.00	0.00	13.33	0.00	0.00	0.00	0.00	1.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	9.49	41.76	0.00	0.00	0.00	0.00	13.33	0.00	0.00	0.00	0.00	1.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	9.49	41.76	0.00	0.00	0.00	0.00	13.33	0.00	0.00	0.00	0.00	1.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	9.49	41.76	0.00	0.00	0.00	0.00	13.33	0.00	0.00	0.00	0.00	1.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	9.49	41.76	0.00	0.00	0.00	0.00	13.33	0.00	0.00	0.00	0.00	1.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	9.49	41.76	0.00	0.00	0.00	0.00	13.33	0.00	0.00	0.00	0.00	1.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	9.49	41.76	0.00	0.00	0.00	0.00	13.33	0.00	0.00	0.00	0.00	1.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	9.49	41.76	0.00	0.00	0.00	0.00	13.33	0.00	0.00	0.00	0.00	1.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	9.26	41.76	0.00	0.00	0.00	0.00	13.33	0.00	0.00	0.00	0.00	1.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	9.26	41.76	0.00	0.00	0.00	0.00	13.33	0.00	0.00	0.00	0.00	1.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	9.26	41.76	0.00	0.00	0.00	0.00	13.33	0.00	0.00	0.00	0.00	1.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	9.26	41.76	0.00	0.00	0.00	0.00	13.33	0.00	0.00	0.00	0.00	1.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	9.26	41.76	0.00	0.00	0.00	0.00	13.33	0.00	0.00	0.00	0.00	1.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note: the existing gas furnace (scenario 12) and existing gas boiler (scenario 1) were assumed to both have a 10-year RUL at the start of the analysis, therefore there is a drop in gas use in year 11 when the old system is replaced with a new one. Meanwhile the new gas furnace (scenario 7) and new gas boiler (scenario 2) have a RUL of 17 and 20 each, so there is no change to equipment in the first 15 years.

Table D-2. 15 Year-over-Year Savings for Oil Consumption of All 19 Scenarios

Year	Scenario																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	0.00	0.00	64.17	91.31	0.00	0.00	0.00	55.03	64.17	0.00	0.00	0.00	64.17	0.00	0.00	0.00	23.99	0.00	23.07
2	0.00	0.00	64.17	91.31	0.00	0.00	0.00	55.03	64.17	0.00	0.00	0.00	64.17	0.00	0.00	0.00	23.99	0.00	23.07
3	0.00	0.00	64.17	91.31	0.00	0.00	0.00	55.03	64.17	0.00	0.00	0.00	64.17	0.00	0.00	0.00	23.99	0.00	23.07
4	0.00	0.00	64.17	91.31	0.00	0.00	0.00	55.03	64.17	0.00	0.00	0.00	64.17	0.00	0.00	0.00	23.99	0.00	23.07
5	0.00	0.00	64.17	91.31	0.00	0.00	0.00	55.03	64.17	0.00	0.00	0.00	64.17	0.00	0.00	0.00	23.99	0.00	23.07
6	0.00	0.00	64.17	91.31	0.00	0.00	0.00	55.03	64.17	0.00	0.00	0.00	64.17	0.00	0.00	0.00	23.99	0.00	23.07
7	0.00	0.00	64.17	91.31	0.00	0.00	0.00	51.71	64.17	0.00	0.00	0.00	64.17	0.00	0.00	0.00	23.99	0.00	21.68
8	0.00	0.00	64.17	91.31	0.00	0.00	0.00	51.71	64.17	0.00	0.00	0.00	64.17	0.00	0.00	0.00	23.99	0.00	21.68
9	0.00	0.00	64.17	91.31	0.00	0.00	0.00	51.71	64.17	0.00	0.00	0.00	64.17	0.00	0.00	0.00	23.99	0.00	21.68
10	0.00	0.00	64.17	91.31	0.00	0.00	0.00	51.71	64.17	0.00	0.00	0.00	64.17	0.00	0.00	0.00	23.99	0.00	21.68
11	0.00	0.00	57.30	91.31	0.00	0.00	0.00	51.71	57.30	0.00	0.00	0.00	57.30	0.00	0.00	0.00	21.42	0.00	21.68
12	0.00	0.00	57.30	91.31	0.00	0.00	0.00	51.71	57.30	0.00	0.00	0.00	57.30	0.00	0.00	0.00	21.42	0.00	21.68
13	0.00	0.00	57.30	91.31	0.00	0.00	0.00	51.71	57.30	0.00	0.00	0.00	57.30	0.00	0.00	0.00	21.42	0.00	21.68
14	0.00	0.00	57.30	91.31	0.00	0.00	0.00	51.71	57.30	0.00	0.00	0.00	57.30	0.00	0.00	0.00	21.42	0.00	21.68
15	0.00	0.00	57.30	91.31	0.00	0.00	0.00	51.71	57.30	0.00	0.00	0.00	57.30	0.00	0.00	0.00	21.42	0.00	21.68

Note: the existing oil boiler (scenarios 3, 4, 9 13 & 17) and existing oil furnace (scenarios 8 & 19) are assumed to have a 10-year RUL and 6-year RUL respectively at the start of the analysis, therefore there is a drop in oil use in year 7 and 11 when the old equipment is replaced.

Table D-3. 15 Year-over-Year Savings for Propane Consumption of All 19 Scenarios

Year	Scenario																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	82.49	41.76	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	82.49	41.76	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	82.49	41.76	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	82.49	41.76	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	82.49	41.76	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	82.49	41.76	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	72.78	41.76	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	72.78	41.76	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	72.78	41.76	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	72.78	41.76	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	72.78	41.76	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	72.78	41.76	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	72.78	41.76	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	72.78	41.76	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	72.78	41.76	0.00	0.00	0.00	0.00

Note: the existing propane furnace (scenario 14) has a RUL of 6 years at the start of the analysis, thus the drop in consumption in year 7. The new propane furnace (scenario 15) has a RUL of 18 years, and therefore no change is reflected in the 15-year timeframe.

Table D-4. 15 Year-over-Year Savings for Electricity Consumption of All 19 Scenarios

Year	Scenario																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	305.13	-4173.17	-3541.21	-7673.09	13999.96	1034.43	-1508.67	-3783.64	-3495.34	2870.75	12444.43	67.23	-5096.74	-6327.80	-4173.17	2550.96	-845.35	5709.49	-1310.79
2	305.13	-4173.17	-3541.21	-7673.09	13999.96	1034.43	-1508.67	-3783.64	-3495.34	2870.75	12444.43	67.23	-5096.74	-6327.80	-4173.17	2550.96	-845.35	5709.49	-1310.79
3	305.13	-4173.17	-3541.21	-7673.09	13999.96	1034.43	-1508.67	-3783.64	-3495.34	2870.75	12444.43	67.23	-5096.74	-6327.80	-4173.17	2550.96	-845.35	5709.49	-1310.79
4	-77.71	-4173.17	-3924.05	-7673.09	13617.12	1034.43	-1508.67	-3783.64	-3495.34	2792.04	12444.43	-11.47	-5096.74	-6327.80	-4173.17	2550.96	-1199.96	5354.89	-1310.79
5	-77.71	-4173.17	-3924.05	-7673.09	13617.12	1034.43	-1508.67	-3783.64	-3495.34	2792.04	12444.43	-11.47	-5096.74	-6327.80	-4173.17	2550.96	-1199.96	5354.89	-1310.79
6	-77.71	-4173.17	-3924.05	-7673.09	13617.12	1034.43	-1508.67	-4085.32	-3797.02	2792.04	12444.43	-11.47	-5096.74	-6629.48	-4173.17	2550.96	-1199.96	5354.89	-1590.22
7	-77.71	-4173.17	-3924.05	-7673.09	13617.12	1034.43	-1508.67	-4085.32	-3797.02	2792.04	12444.43	-11.47	-5096.74	-6629.48	-4173.17	2550.96	-1199.96	5354.89	-1590.22
8	-77.71	-4173.17	-3924.05	-7673.09	13617.12	1034.43	-1508.67	-4085.32	-3797.02	2792.04	12444.43	-11.47	-5096.74	-6629.48	-4173.17	2550.96	-1199.96	5354.89	-1590.22
9	-77.71	-4173.17	-3924.05	-7673.09	13617.12	1034.43	-1508.67	-4085.32	-3797.02	2792.04	12444.43	-11.47	-5096.74	-6629.48	-4173.17	2550.96	-1199.96	5354.89	-1590.22
10	-77.71	-4173.17	-3924.05	-7673.09	13617.12	1034.43	-1508.67	-4085.32	-3797.02	2792.04	12444.43	-11.47	-5096.74	-6629.48	-4173.17	2550.96	-1199.96	5354.89	-1590.22
11	-77.71	-4173.17	-3924.05	-7673.09	13617.12	1034.43	-1508.67	-4085.32	-3797.02	2792.04	12444.43	-11.47	-5096.74	-6629.48	-4173.17	2550.96	-1199.96	5354.89	-1590.22
12	-77.71	-4173.17	-3924.05	-7673.09	13617.12	1034.43	-1508.67	-4085.32	-3797.02	2792.04	12444.43	-11.47	-5096.74	-6629.48	-4173.17	2550.96	-1199.96	5354.89	-1590.22
13	-77.71	-4173.17	-3924.05	-7673.09	13617.12	1034.43	-1508.67	-4085.32	-3797.02	2792.04	12444.43	-11.47	-5096.74	-6629.48	-4173.17	2550.96	-1199.96	5354.89	-1590.22
14	-77.71	-4173.17	-3924.05	-7673.09	13617.12	1034.43	-1508.67	-4085.32	-3797.02	2792.04	12444.43	-11.47	-5096.74	-6629.48	-4173.17	2550.96	-1199.96	5354.89	-1590.22
15	-77.71	-4173.17	-3924.05	-7673.09	13617.12	1034.43	-1508.67	-4085.32	-3797.02	2792.04	12444.43	-11.47	-5096.74	-6629.48	-4173.17	2550.96	-1199.96	5354.89	-1590.22

Notes:

Each of the heat pumps has a RUL greater than 15 years, and each is assumed to be installed on year 1 of the analysis.

The existing electric baseboard heater (scenarios 5, 10, 11, 16 & 18) has a RUL of 5 years and is replaced with a baseboard with the same COP – thus no change in consumption.

The existing Window AC (used in the counterfactuals for scenarios 1,3,4,5,10,12,14,17,18 & 19) has a RUL of 3 years, thus creating a drop in savings as the counterfactual becomes more efficient in year 3.

The existing Central AC (used in the counterfactuals for scenarios 8,9,14 & 19) has a RUL of 5 years, creating a drop in savings in year 6 as the counterfactual becomes more efficient.

The new Window AC and new central AC have a RUL of 9 and 16 respectively, however it is assumed to be replaced by a similarly efficient new Window AC, so no further changes occur for scenarios that are using it in their counterfactual

Negative values represent negative energy *savings* so an increase in energy consumption relative to the baseline

Appendix E. Customer & Program Costs

Table E-1. Heat Pump Equipment Features & Costs

Equipment	Installation Scenario			Equipment Sizing & Demand		2020 Installed cost	Source
	Building	Construction	Replacement	Size	Zones		
Appliance	Type	Variety	Level	Tons	#	US 2020 $	Citation
CC DMSHP	Commercial	Existing Building	Partial	5.12	5	$18,726.16	Ductless Mini-Split Heat Pump Cost Study (RES 28) page 17 Table 11. "Lower Rebate Threshold" adjusted for inflation to 2020 prices
CC DMSHP	Multifamily	Existing Building	Partial	1.5	1	$4,743.57	
CC DMSHP	Single-family	Building Addition	Full	1.5	1	$4,743.57	
CC DMSHP	Single-family	Existing Building	Full	4	5	$15,582.50	
CC DMSHP	Single-family	Existing Building	Partial	2.5	3	$9,239.03	
Central ASHP	Commercial	Existing Building	Partial	5.12		$24,484.15	AC-HP Cost Study Results Memo 3 (RES 23) pg. 4 adjusted for inflation to 2020 prices
Central ASHP	Single-family	Existing Building	Partial	2.5		$11,958.46	
Central CC ASHP	Multifamily	New Construction	Full	2		$10,277.39	AC-HP Cost Study Results Memo 3 (RES 23) pg. 4 adjusted for inflation to 2020 prices
Central CC ASHP	Single-family	New Construction	Full	3		$15,416.08	

Table E-2. Counterfactual Cooling Equipment Features & Costs

Equipment	Installation Scenario		Equipment Sizing & Demand	2020 Installed cost	Source
	Building	Construction	Size		
Appliance	Type	Variety	Tons	US 2020 $	Citation
New Central AC	Commercial	Existing Building	4.57	$18,997.83	AC-HP Cost Study Results Memo 3 (RES 23) pg. 4 adjusted for inflation to 2020 prices
New Central AC	Multifamily	New Construction	1	$4,159.55	
New Central AC	Single-family	Existing Building	2.6	$10,814.84	
New Central AC	Single-family	New Construction	1.5	$6,239.33	
New Window AC	Commercial	Existing Building	4.57	$1,370.18	MA19R16-B-EO_ Energy Optimization Measures and Assumptions Update Model 2020-03-11 Inputs - RES tab
New Window AC	Multifamily	Existing Building	0.75	$225.00	
New Window AC	Single-family	Building Addition	0.46	$137.50	
New Window AC	Single-family	Existing Building	1	$300.00	

Table E-3. Counterfactual Heating Equipment Features & Costs

Equipment	Installation Scenario		Equipment Sizing	2020 Installed cost	Source
	Building	Construction	Size		
Appliance	Type	Variety	Tons	US 2020 $	Citation
New Electric baseboard	Commercial	Existing Building	4.47	$3,488.93	RES 21 Baseline Calculations tab "code replacement costs"
New Electric baseboard	Multifamily	Existing Building	2.4	$1,873.86	
New Electric baseboard	Single-family	Building Addition	1.2	$936.93	
New Electric baseboard	Single-family	Existing Building	3.89	$3,037.49	
New Gas Boiler	Multifamily	Existing Building	5	$6,042.00	Water Heater, Boiler, and Furnace Cost Study (RES 19) pg12
New Gas Boiler	Single-family	Existing Building	6.92	$6,042.00	
New Gas Furnace	Multifamily	New Construction	2.5	$5,227.00	Water Heater, Boiler, and Furnace Cost Study (RES 19) pg10
New Gas Furnace	Single-family	New Construction	5	$5,227.00	
New Oil Boiler	Commercial	Existing Building	5.73	$6,866.00	Water Heater, Boiler, and Furnace Cost Study (RES 19) pg15
New Oil Boiler	Single-family	Existing Building	10.17	$6,866.00	
New Oil Furnace	Commercial	Existing Building	5.73	$5,099.00	Water Heater, Boiler, and Furnace Cost Study (RES 19) pg12
New Oil Furnace	Single-family	Existing Building	8.92	$5,099.00	
New Propane Furnace	Single-family	Existing Building	5.83	$4,886.00	Water Heater, Boiler, and Furnace Cost Study (RES 19) pg11
New Propane Furnace	Single-family	New Construction	5	$4,886.00	

Past research has demonstrated that fossil fuel equipment prices do not significantly change with tonnage. Configuration and efficiency are significantly more predictive of price. Therefore, many differently sized equipment is shown to be the same price above.

Table E-4. Scenario Heat Pump Costs and Incentives

Scenario ID	Building Type	Construction	Counterfactual Heating	Displacement	Heat Pump	Heat Pump Tonnage	Installed Cost	Low Incentive	High Incentive
1	Single Family	Existing Building	Gas Boiler	Partial	CC DMSHP	2.5	$9,239	$625	$875
2	Single Family	New Construction	Gas Furnace	Full	Central CC ASHP	3	$15,416	$2,000	$2,800
3	Single Family	Existing Building	Oil Boiler	Partial	CC DMSHP	2.5	$9,239	$3,125	$4,375
4	Single Family	Existing Building	Oil Boiler	Full	CC DMSHP	4	$15,583	$5,000	$7,000
5	Single Family	Existing Building	Electric baseboard	Partial	CC DMSHP	2.5	$9,239	$3,125	$4,375
6	Single Family	Building Addition	Electric baseboard	Full	CC DMSHP	1.5	$4,744	$2,000	$2,800
7	Multifamily	New Construction	Gas Furnace	Full	Central CC ASHP	2	$10,277	$1,000	$1,400
8	Single Family	Existing Building	Oil Furnace	Partial	Central ASHP	2.5	$11,958	$3,125	$4,375
9	Single Family	Existing Building	Oil Boiler	Partial	CC DMSHP	2.5	$9,239	$3,125	$4,375
10	Multifamily	Existing Building	Electric baseboard	Partial	CC DMSHP	1.5	$4,744	$1,875	$2,625
11	Single Family	Existing Building	Electric baseboard	Partial	CC DMSHP	2.5	$9,239	$3,125	$4,375
12	Multifamily	Existing Building	Gas Boiler	Partial	CC DMSHP	1.5	$4,744	$375	$525
13	Single Family	Existing Building	Oil Boiler	Partial	CC DMSHP	2.5	$9,239	$3,125	$4,375
14	Single Family	Existing Building	Propane Furnace	Partial	Central ASHP	2.5	$11,958	$3,125	$4,375
15	Single Family	New Construction	Propane Furnace	Full	Central CC ASHP	3	$15,416	$2,000	$2,800
16	Multifamily	Existing Building	Electric baseboard	Partial	CC DMSHP	1.5	$4,744	$1,875	$2,625
17	Commercial	Existing Building	Oil Boiler	Partial	CC DMSHP	5.1	$18,726	$6,398	$8,958
18	Commercial	Existing Building	Electric baseboard	Partial	CC DMSHP	5.1	$18,726	$6,398	$8,958
19	Commercial	Existing Building	Oil Furnace	Partial	Central ASHP	5.1	$24,484	$6,398	$8,958

Appendix F. Consumption Costs

Table F-1. Electricity Rate Structure

Billing Item	Residential Rate (A-16)	Commercial Rate (C-06)	Unit
Item	$	$	/ X
Customer Charge	$6.00	$10.00	month
Distribution Charge	$0.06	$0.05	kWh
Renewable Energy Distribution Charge	$0.01	$0.01	kWh
RE Growth Charge	$1.90	$2.95	month
Transmission Charge	$0.03	$0.03	kWh
Transition Charge / Credit	$(0.00)	$(0.00)	kWh
LIHEAP Charge	$0.80	$0.80	month
Energy Efficiency Program	$0.01	$0.01	kWh
Energy Charge	$0.08	$0.08	kWh
Gross Earnings Tax	$0.04	$-	kWh

A-16 rate for National Grid service from RI PUC: http://www.ripuc.ri.gov/utilityinfo/electric/narrelecschedule3a.html
C-06 rate for National Grid service from National Grid: https://www.nationalgridus.com/RI-Business/Rates/Service-Rates.aspx

Table F-2. Gas Rate Structure

Billing Item	Residential On-Peak Rate	Residential Off-Peak Rate	Commercial On-Peak Rate	Commercial Off-Peak Rate	Unit
Item	$	$	$	$	/ X
Customer Charge	$14.00	$14.00	$25.00	$25.00	month
Distribution Charge	$0.58	$0.52	$0.51	$0.45	Therm
Distribution Adjustment Charge	$0.05	$0.05	$0.05	$0.05	Therm
Energy Efficiency Programs	$0.10	$0.10	$0.07	$0.07	Therm
Gas Cost Recovery	$0.53	$0.53	$0.53	$0.53	Therm
LIHEAP Enhancement Charge	$0.80	$0.80	$0.80	$0.80	month

National Grid Rates effective 4/1/20. Assumes heating rates for all due to inclusion of only gas-based heating equipment. Includes Rate 12 (residential heating) and Rate 21 (small business)

Table F-3. Oil & Propane Rate Structure

Billing Item	Residential Rate
Item	$ / Gallon
Oil	$2.94
Propane	$3.09

EIA residential consumer price for heating oil average over Jan 1 - Mar 30, 2020:
https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=W_EPD2F_PRS_SRI_DPG&f=W

Table F-4. Annual Change Rates

Rates	%
Nominal Discount Rate	3.37%
Inflation	2.00%
Real Discount Rate	1.34%
Residential Electricity Price Escalator	0.31%
Residential Natural Gas Price Escalator	0.67%
Residential Fuel Oil Escalator	0.86%
Residential Propane Escalator	1.21%
Commercial Electricity Price Escalator	0.30%
Commercial Natural Gas Price Escalator	0.52%
Commercial Fuel Oil Escalator	0.45%
Commercial Propane Escalator	0.75%

Table F-5. Residential Power / Fuel Consumption Net Present Value Rates

Item	2020	2021	2022	2023	2024
Electricity ($/kWh)	$0.23	$0.23	$0.23	$0.22	$0.22
Electricity ($/year)	$104.40	$103.34	$102.28	$101.24	$100.21
On-Peak Natural Gas ($/MMBtu)	$12.65	$12.56	$12.48	$12.39	$12.31
Off-Peak Natural Gas ($/MMBtu)	$12.04	$11.96	$11.88	$11.80	$11.72
Natural Gs ($/year)	$177.60	$176.75	$175.91	$175.07	$174.24
Fuel Oil ($/MMBtu)	$21.24	$21.14	$21.04	$20.94	$20.84
Propane ($/MMBtu)	$33.86	$33.82	$33.77	$33.73	$33.68

Table F-6. Commercial Power / Fuel Consumption Net Present Value Rates

Item	2020	2021	2022	2023	2024
Electricity ($/kWh)	$0.18	$0.18	$0.18	$0.17	$0.17
Electricity ($/year)	$165.00	$163.30	$161.62	$159.96	$158.31
On-Peak Natural Gas ($/MMBtu)	$11.62	$11.52	$11.43	$11.34	$11.25
Off-Peak Natural Gas ($/MMBtu)	$11.02	$10.93	$10.84	$10.75	$10.67
Natural Gs ($/year)	$309.60	$307.09	$304.59	$302.12	$299.66
Fuel Oil ($/MMBtu)	$21.24	$21.05	$20.86	$20.68	$20.50
Propane ($/MMBtu)	$33.86	$33.66	$33.46	$33.27	$33.07

Appendix G. Costs v. Benefit Components

Table G-1. Program Factors

Cost	Unit	Benefit	Unit
Program Planning	$	Electric Energy	kWh
Program Marketing	$	Electric Generation Capacity	kW
Rebates & customer incentives	$	Electric transmission & Distribution Capacity	kW
Sales & Technical assistance	$	Natural Gas	Therm
Program evaluation	$	Delivered Fuel	Therm
Shareholder Incentives	$	Water & Sewer	Gallon
		Non-Energy Impact	$
		Price Effects	$
		Non-embedded Greenhouse Gases	Tons CO_2e
		Non-embedded Development	GDP $
		Non-embedded NOx Reductions	Tons NOx
		Improved Reliability	$

Table G-2. Customer Factors

Cost	Unit	Benefit	Unit
Installation Cost (after incentives)	$	Change (reduction) in operation costs	$

Program Benefits

- The CE analysis in this study follows the methodology outlined in National Grid's *2020 Rhode Island Test Description.*
- Benefits may be positive and negative. For example, if a measure increases Summer Peak Electric Demand, then the result is a negative benefit
- Future Benefits are included and discounted to present value.
- Electric Energy Benefits (2018 AESC)
- Electric Generation Capacity Benefits (2018 AESC)
- Electric transmission Capacity and Distribution Capacity Benefits (2018 AESC)
- Natural Gas Benefits (2018 AESC)
- Delivered Fuel (Oil and Propane) Benefits (2018 AESC)
- Water and Sewer Benefits (Prov. Water)
- Non-Energy Impacts (2020 RI TRM)
- Price Effects (2018 AESC)
- Non-embedded Greenhouse Gas Benefits (2018 AESC)
- Non-embedded Development Benefits (Review of RI Test and Proposed Methodology 2019)
- Non-embedded NOx Reductions Benefits (2018 AESC)
- Value of Improved Reliability (2018 AESC)

Program Cost Effectiveness Costs

- Program Costs

- The CE analysis in this study follows the methodology outlined in National Grid's 2020 Rhode Island Test Description.
- Future Costs are included and discounted to present value.
- Costs of future equipment purchases are considered and discounted to present value
- For both the counterfactual and the measure, at the end of the study period, equipment that has useful remaining life are credited a percentage of the equipment costs discounted to present value

- Utility Costs (National Grid)
  - Program Planning
  - Marketing
  - Rebates and other customer incentives
  - Sales and Technical assistance
  - Evaluation
  - Shareholder incentives
- Customer Costs (RES 19, RES 28, Mass Save)
  - Capital Contributions to equipment purchases

Appendix H. Scenario Development: Data Details

Table H-1. Rhode Island Test Features and Sources

Source	Items Pulled	Description
Residential Appliance Saturation Survey 2018 Report	• Single-family sq. ft. • Multifamily sq. ft. • Median units per multifamily • Median building age • Scenario market representation	A Rhode Island household survey of appliances including an online questionnaire and in-house verification for a wide sample.
DOE Small Office Reference building	• Commercial sq. ft. • Median units per commercial building • Commercial heating & cooling loads	Energy Plus output based on DOE-defined reference buildings. Re-run with Pawtucket, RI TMY3 data
Rhode Island 2019 Building Code	• Single-family addition envelope standards • Single-family new construction standards	Statewide building code defining code minimums for new construction analysis
BEopt 2.8.0	• Multifamily new construction heating & cooling load* • Single-family addition heating & cooling load*	NREL-developed software based on Energy Plus used to model energy usage and consumption.
RES 21	• Single-family existing building heating & cooling load	Analysis conducted as baseline for Rhode Island TRM (also used elsewhere)

Table H-2. Installation Costs are Determined by Equipment Size and Installation Scenario

Equipment	Installation Scenario			Equipment Sizing & Demand		2020 Installed cost	Source
	Building	Construction	Replacement	Size	Zones		
Appliance	Type	Variety	Level	Tons	#	US 2020 $	Citation
CC DMSHP	Commercial	Existing Building	Partial	5.12	5	$18,726.16	Ductless Mini-Split Heat Pump Cost Study (RES 28) page 17 Table 11. "Lower Rebate Threshold" adjusted for inflation to 2020 prices
Central ASHP	Commercial	Existing Building	Partial	5.12	n/a	$24,484.15	AC-HP Cost Study Results Memo 3 (RES 23) pg. 4 adjusted for inflation to 2020 prices
New Central AC	Commercial	Existing Building		4.57	n/a	$18,997.83	AC-HP Cost Study Results Memo 3 (RES 23) pg. 4 adjusted for inflation to 2020 prices
New Electric baseboard	Commercial	Existing Building		4.47	n/a	$3,488.93	RES 21 Baseline Calculations tab "code replacement costs"
New Oil Boiler	Commercial	Existing Building		5.73	n/a	$6,866.00	Water Heater, Boiler, and Furnace Cost Study (RES 19) pg15
New Oil Furnace	Commercial	Existing Building		5.73	n/a	$5,099.00	Water Heater, Boiler, and Furnace Cost Study (RES 19) pg12
New Window AC	Commercial	Existing Building		4.57	4.5	$1,370.18	MA19R16-B-EO_ Energy Optimization Measures and Assumptions Update Model 2020-03-11 Inputs - RES tab
CC DMSHP	Multifamily	Existing Building	Partial	1.50	1	$4,743.57	Ductless Mini-Split Heat Pump Cost Study (RES 28) page 17 Table 11. "Lower Rebate Threshold" adjusted for inflation to 2020 prices
Central CC ASHP	Multifamily	New Construction	Full	2.00	1	$10,277.39	AC-HP Cost Study Results Memo 3 (RES 23) pg. 4 adjusted for inflation to 2020 prices
New Central AC	Multifamily	New Construction		1.00	n/a	$4,159.55	AC-HP Cost Study Results Memo 3 (RES 23) pg. 4 adjusted for inflation to 2020 prices
New Electric baseboard	Multifamily	Existing Building		2.40	3.4	$1,873.86	RES 21 Baseline Calculations tab "code replacement costs"
New Gas Boiler	Multifamily	Existing Building		5.00	n/a	$6,042.00	Water Heater, Boiler, and Furnace Cost Study (RES 19) pg13
New Gas Furnace	Multifamily	New Construction		2.50	n/a	$5,227.00	Water Heater, Boiler, and Furnace Cost Study (RES 19) pg10
New Window AC	Multifamily	Existing Building		0.75	1	$225.00	AC-HP Cost Study Results Memo 3 (RES 23) pg. 4 adjusted for inflation to 2020 prices
CC DMSHP	Single-family	Building Addition	Full	1.50	1	$4,743.57	Ductless Mini-Split Heat Pump Cost Study (RES 28) page 17 Table 11. "Lower Rebate Threshold" adjusted for inflation to 2020 prices

Equipment	Installation Scenario			Equipment Sizing & Demand		2020 Installed cost	Source
	Building	Construction	Replacement	Size	Zones		
Appliance	Type	Variety	Level	Tons	#	US 2020 $	Citation
CC DMSHP	Single-family	Existing Building	Full	4.00	5	$15,582.50	Ductless Mini-Split Heat Pump Cost Study (RES 28) page 17 Table 11. "Lower Rebate Threshold" adjusted for inflation to 2020 prices
CC DMSHP	Single-family	Existing Building	Partial	2.50	3	$9,239.03	Ductless Mini-Split Heat Pump Cost Study (RES 28) page 17 Table 11. "Lower Rebate Threshold" adjusted for inflation to 2020 prices
Central ASHP	Single-family	Existing Building	Partial	2.50	n/a	$11,958.46	AC-HP Cost Study Results Memo 3 (RES 23) pg. 4 adjusted for inflation to 2020 prices
Central CC ASHP	Single-family	New Construction	Full	3.00	n/a	$15,416.08	AC-HP Cost Study Results Memo 3 (RES 23) pg. 4 adjusted for inflation to 2020 prices
New Central AC	Single-family	Existing Building		2.60	n/a	$10,814.84	AC-HP Cost Study Results Memo 3 (RES 23) pg. 4 adjusted for inflation to 2020 prices
New Central AC	Single-family	New Construction		1.50	n/a	$6,239.33	AC-HP Cost Study Results Memo 3 (RES 23) pg. 4 adjusted for inflation to 2020 prices
New Electric baseboard	Single-family	Building Addition		1.20	1.7	$936.93	RES 21 Baseline Calculations tab "code replacement costs"
New Electric baseboard	Single-family	Existing Building		3.89	5.5	$3,037.49	RES 21 Baseline Calculations tab "code replacement costs"
New Gas Boiler	Single-family	Existing Building		6.92	n/a	$6,042.00	Water Heater, Boiler, and Furnace Cost Study (RES 19) pg13
New Gas Furnace	Single-family	New Construction		5.00	n/a	$5,227.00	Water Heater, Boiler, and Furnace Cost Study (RES 19) pg10
New Oil Boiler	Single-family	Existing Building		10.17	n/a	$6,866.00	Water Heater, Boiler, and Furnace Cost Study (RES 19) pg15
New Oil Furnace	Single-family	Existing Building		8.92	n/a	$5,099.00	Water Heater, Boiler, and Furnace Cost Study (RES 19) pg12
New Propane Furnace	Single-family	Existing Building		5.83	n/a	$4,886.00	Water Heater, Boiler, and Furnace Cost Study (RES 19) pg11
New Propane Furnace	Single-family	New Construction		5.00	n/a	$4,886.00	Water Heater, Boiler, and Furnace Cost Study (RES 19) pg11
New Window AC	Single-family	Building Addition		0.46	0.5	$137.50	MA19R16-B-EO_ Energy Optimization Measures and Assumptions Update Model 2020-03-11 Inputs - RES tab
New Window AC	Single-family	Existing Building		1.00	1	$300.00	MA19R16-B-EO_ Energy Optimization Measures and Assumptions Update Model 2020-03-11 Inputs - RES tab

Appendix I. Literature Review Sources

Cadmus Group, and Sawtooth Analytics (Amy Webb, Hanna Lee, Hope Lobkowicz, Joan Wang, Hugh Ratcliffe, Karen Horkitz, Keith Chrzan). January 17, 2018. “Northwest Ductless Heat Pump Initiative: Market Progress Evaluation Report 6.”

Cadmus Group (John Walczyk). November 3, 2017. “Evaluation of Cold Climate Heat Pumps in Vermont.”

Cadmus Group (Dave Korn, John Walczyk, Ari Jackson, Andrew Machado, John Kongoletos, Eric Pfann) December 30, 2016. “Ductless Mini-Split Heat Pump Impact Evaluation.”

Connecticut Green Bank. November 29, 2018. “Heat Pump Market: Latest Trends and How to Engage Customers.” Green Energy Contractor Conference.

DNV-GL, and Connecticut Energy Efficiency Board (Lisa Skumatz, Robert Wirtshafter, Ralph Prahl). June 20, 2019. “R1617 Connecticut Residential Ductless Heat Pumps Market Characterization Study – Final Report.”

DNV-GL, NMR Group, and TetraTech. September 5, 2018. “Massachusetts Commercial and Industrial Upstream HVAC/Heat Pump and Hot Water NTG and Maker Effects Indicator Study.”

EMI Consulting. November 17, 2014. “Emera Maine Heat Pump Pilot Program.”

Energy Futures Group, and Energy & Resource Solutions (Richard Faesy, Jim Grevatt, Brian McCowan, Katie Champagne). November 13, 2014. “Ductless Heat Pump Meta Study.”

Massachusetts Department of Energy Resources (DOER). December 12, 2018. “Massachusetts Comprehensive Energy Plan.”

Meister Consultants Group, Inc. 2017. “Bringing Renewable Thermal Solutions to Scale in New England.” Carbon Neutral Cities Alliance.

Navigant Consulting, Inc. (Decker Ringo, Theo Kassuga). October 9, 2018. “Energy Optimization Study: Report Findings (RES 21 Task 4).”

Navigant Consulting, Inc. October 5, 2018. “Ductless Mini-Split Heat Pump Cost Study (RES 28).”

Navigant Consulting, Inc. July 27, 2018. “RES 1 Baseline Load Shape Study.” Prepared for Electric and Gas Program Administrators of Massachusetts.

Navigant Consulting, Inc. September 23, 2011. “Incremental Cost Study Report.” Prepared for Northeast Energy Efficiency Partnerships.

NMR Group, Inc. October 11, 2018. “National Grid Rhode Island Residential Appliance Saturation Survey (Study RI2311) Report.”

Northeast Energy Efficiency Partnerships (NEEP). February 2019. "2019 Air-Source Heat Pump Program Incentive Summary."

Northeast Energy Efficiency Partnerships (NEEP). January 1, 2019. "Re: Cold Climate Air Source Heat Pump Specification." Version 3.0.

Northeast Energy Efficiency Partnerships (NEEP). July 2017. "Northeastern Regional Assessment of Strategic Electrification."

Northeast Energy Efficiency Partnerships (NEEP), Energy Futures Group, and Energy & Resource Solutions (David Lis, Richard Faesy, Gabrielle Stebbins, Brian McCowan, Balerie Eacret, Aditi Parlikar). March 31, 2017. "NYSERDA Ductless Mini-Split Heat Pump Market Characterization Study."

Northeast Energy Efficiency Partnerships (NEEP), ERS Consulting, Jacobson Energy Research, and TetraTech (Elizabeth Titus, Brian McCowan, Valerie Eacret, David Jacobson, Denise Rouleau). 2016. "Emerging Technologies: What Will be the Cost of the Next Level of Efficiency?"

Vermont Energy Investment Corporation (VEIC). September 25, 2018. "Ramping Up Heat Pump Adoption in New York State." Prepared for Natural Resources Defense Council.

Vermont Energy Investment Corporation (VEIC; Emily Levin.). February 2, 2018. "Driving the Heat Pump Market."

Appendix J. Adoption & Stock Turnover Modeling

Stock Turnover Results

Table J-1. Percent Annual Possible Adoption

ID	Technology	Scenario Name	2020	2021	2022	2023	2024
1	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Baseline	2.8%	3.0%	3.2%	3.4%	3.6%
		High-Low	2.8%	4.3%	4.6%	4.9%	5.2%
		High-High	2.8%	4.9%	5.2%	5.5%	5.8%
		Low-Low	2.8%	4.3%	4.6%	5.0%	5.3%
		Low-High	2.8%	4.9%	5.2%	5.6%	6.0%
2	Single-family New Construction - Central CC ASHP Full Replacement 3 Ton - 9 HSPF	Baseline	1.6%	1.6%	1.6%	1.7%	1.7%
		High-Low	1.6%	1.8%	1.8%	1.8%	1.9%
		High-High	1.6%	1.8%	1.8%	1.9%	1.9%
		Low-Low	1.6%	1.8%	1.8%	1.8%	1.9%
		Low-High	1.6%	1.8%	1.9%	1.9%	1.9%
3	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Baseline	2.8%	3.0%	3.2%	3.4%	3.6%
		High-Low	2.8%	6.9%	7.4%	7.8%	8.3%
		High-High	2.8%	7.6%	8.1%	8.6%	9.1%
		Low-Low	2.8%	6.9%	7.4%	7.9%	8.4%
		Low-High	2.8%	7.7%	8.2%	8.7%	9.3%
4	Single-family Existing Building - CC DMSHP Full Replacement 4 Ton - 10 HSPF	Baseline	3.6%	3.9%	4.1%	4.4%	4.7%
		High-Low	3.6%	7.2%	7.6%	8.1%	8.5%
		High-High	3.6%	8.2%	8.7%	9.3%	9.8%
		Low-Low	3.6%	7.2%	7.7%	8.2%	8.7%
		Low-High	3.6%	8.3%	8.8%	9.4%	10.0%
5	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Baseline	4.3%	4.6%	4.9%	5.2%	5.6%
		High-Low	4.3%	5.7%	6.0%	6.4%	6.8%
		High-High	4.3%	6.1%	6.5%	6.9%	7.3%
		Low-Low	4.3%	5.7%	6.1%	6.5%	6.9%
		Low-High	4.3%	6.1%	6.5%	7.0%	7.4%
6	Single-family Building Addition - CC DMSHP Full Replacement 1.5 Ton - 10 HSPF	Baseline	4.3%	4.6%	4.9%	5.2%	5.6%
		High-Low	4.3%	5.7%	6.0%	6.4%	6.8%
		High-High	4.3%	6.1%	6.5%	6.9%	7.3%
		Low-Low	4.3%	5.7%	6.1%	6.5%	6.9%
		Low-High	4.3%	6.1%	6.5%	7.0%	7.4%

7	Multifamily New Construction - Central CC ASHP Full Replacement 2 Ton - 9 HSPF	Baseline	1.6%	1.6%	1.6%	1.7%	1.7%
		High-Low	1.6%	1.8%	1.8%	1.8%	1.9%
		High-High	1.6%	1.8%	1.8%	1.9%	1.9%
		Low-Low	1.6%	1.8%	1.8%	1.8%	1.9%
		Low-High	1.6%	1.8%	1.9%	1.9%	1.9%
8	Single-family Existing Building - Central ASHP Partial Replacement 2.5 Ton - 9 HSPF	Baseline	0.5%	0.5%	0.5%	0.5%	0.5%
		High-Low	0.5%	4.1%	4.1%	4.2%	4.2%
		High-High	0.5%	5.4%	5.4%	5.5%	5.5%
		Low-Low	0.5%	4.2%	4.2%	4.3%	4.4%
		Low-High	0.5%	5.5%	5.5%	5.6%	5.7%
9	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Baseline	2.8%	3.0%	3.2%	3.4%	3.6%
		High-Low	2.8%	7.4%	7.9%	8.4%	8.9%
		High-High	2.8%	8.3%	8.8%	9.4%	9.9%
		Low-Low	2.8%	7.4%	7.9%	8.5%	9.0%
		Low-High	2.8%	8.3%	8.9%	9.5%	10.1%
10	Multifamily Existing Building - CC DMSHP Partial Replacement 1.5 Ton - 10 HSPF	Baseline	4.3%	4.6%	4.9%	5.2%	5.6%
		High-Low	4.3%	5.4%	5.8%	6.2%	6.5%
		High-High	4.3%	5.8%	6.1%	6.5%	6.9%
		Low-Low	4.3%	5.4%	5.8%	6.2%	6.6%
		Low-High	4.3%	5.8%	6.2%	6.6%	7.0%
11	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Baseline	4.3%	4.6%	4.9%	5.2%	5.6%
		High-Low	4.3%	5.7%	6.0%	6.4%	6.8%
		High-High	4.3%	6.1%	6.5%	6.9%	7.3%
		Low-Low	4.3%	5.7%	6.1%	6.5%	6.9%
		Low-High	4.3%	6.1%	6.5%	7.0%	7.4%
12	Multifamily Existing Building - CC DMSHP Partial Replacement 1.5 Ton - 10 HSPF	Baseline	2.8%	3.0%	3.2%	3.4%	3.6%
		High-Low	2.8%	6.9%	7.4%	7.8%	8.3%
		High-High	2.8%	7.6%	8.1%	8.6%	9.1%
		Low-Low	2.8%	6.9%	7.4%	7.9%	8.4%
		Low-High	2.8%	7.7%	8.2%	8.7%	9.3%
13	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Baseline	2.8%	3.0%	3.2%	3.4%	3.6%
		High-Low	2.8%	6.9%	7.4%	7.8%	8.3%
		High-High	2.8%	7.6%	8.1%	8.6%	9.1%
		Low-Low	2.8%	6.9%	7.4%	7.9%	8.4%
		Low-High	2.8%	7.7%	8.2%	8.7%	9.3%
14	Single-family Existing Building - Central ASHP Partial Replacement 2.5 Ton - 9 HSPF	Baseline	0.5%	0.5%	0.5%	0.5%	0.5%
		High-Low	0.5%	4.1%	4.1%	4.2%	4.2%
		High-High	0.5%	5.4%	5.4%	5.5%	5.5%

		Low-Low	0.5%	4.2%	4.2%	4.3%	4.4%
		Low-High	0.5%	5.5%	5.5%	5.6%	5.7%
15	Single-family New Construction - Central CC ASHP Full Replacement 3 Ton - 9 HSPF	Baseline	1.6%	1.6%	1.6%	1.7%	1.7%
		High-Low	1.6%	4.1%	4.1%	4.1%	4.1%
		High-High	1.6%	5.8%	5.8%	5.8%	5.8%
		Low-Low	1.6%	4.1%	4.2%	4.2%	4.3%
		Low-High	1.6%	5.9%	5.9%	6.0%	6.1%
16	Multifamily Existing Building - CC DMSHP Partial Replacement 1.5 Ton - 10 HSPF	Baseline	4.3%	4.6%	4.9%	5.2%	5.6%
		High-Low	4.3%	5.7%	6.0%	6.4%	6.8%
		High-High	4.3%	6.1%	6.5%	6.9%	7.3%
		Low-Low	4.3%	5.7%	6.1%	6.5%	6.9%
		Low-High	4.3%	6.1%	6.5%	7.0%	7.4%

Adoption Modeling Projections

Table J-2. Projected Change in Electric Energy Consumption from Heat Pumps for 2020-2024

ID	Technology	Base Equipment	Change in Electric Energy Consumption (MWh) – Cumulative Achievable 2020-2024				
			Baseline: No Change in cost / No Incentives	High-Low: High Cost / Low Incentives	High-High: High cost / High Incentives	Low-Low: Low cost / Low Incentives	Low-High: Low cost / High Incentives
1	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Gas Boiler with Window AC	0	0	0	0	0
2	Single-family New Construction - Central CC ASHP Full Replacement 3 Ton - 9 HSPF	Gas Furnace with Central AC	0	0	0	0	0
3	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Oil Boiler with Window AC	1,132	2,357	2,572	2,374	2,596
4	Single-family Existing Building - CC DMSHP Full Replacement 4 Ton - 10 HSPF	Oil Boiler with Window AC	2,990	5,064	5,737	5,118	5,811
5	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Electric Baseboard with Window AC	(16,209)	(19,296)	(20,530)	(19,394)	(20,668)
6	Single-family Building Addition - CC DMSHP Full Replacement 1.5 Ton - 10 HSPF	Electric Baseboard with Window AC	(63)	(75)	(80)	(75)	(80)
7	Multifamily New Construction - Central CC ASHP Full Replacement 1 Ton - 9 HSPF	Gas Furnace with Central AC	0	0	1	0	1
8	Single-family Existing Building - Central ASHP Partial Replacement 2.5 Ton - 9 HSPF	Oil Furnace with Central AC	126	820	1,067	839	1,094

ID	Technology	Base Equipment	Change in Electric Energy Consumption (MWh) – Cumulative Achievable 2020-2024				
			Baseline: No Change in cost / No Incentives	High-Low: High Cost / Low Incentives	High-High: High cost / High Incentives	Low-Low: Low cost / Low Incentives	Low-High: Low cost / High Incentives
9	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Oil Boiler with Central AC	388	859	953	867	964
10	Multifamily Existing Building - CC DMSHP Partial Replacement 1.5 Ton - 10 HSPF	Electric Baseboard with Window AC	(1,017)	(1,168)	(1,229)	(1,173)	(1,235)
11	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Electric Baseboard with No AC	(3,346)	(3,983)	(4,237)	(4,003)	(4,266)
12	Multifamily Existing Building - CC DMSHP Partial Replacement 1.5 Ton - 10 HSPF	Gas Boiler with Window AC	(1)	(3)	(3)	(3)	(3)
13	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Oil Boiler with No AC	360	750	818	755	826
14	Single-family Existing Building - Central ASHP Partial Replacement 2.5 Ton - 9 HSPF	Propane Furnace with Central AC	115	754	981	771	1,006
15	Single-family New Construction - Central CC ASHP Full Replacement 3 Ton - 9 HSPF	Propane Furnace with Central AC	1	1	2	1	2
16	Multifamily Existing Building - CC DMSHP Partial Replacement 1.5 Ton - 10 HSPF	Electric Baseboard with No AC	(157)	(187)	(199)	(188)	(200)
17	Commercial Existing Building - CC DMSHP Partial Replacement 5.12 Ton - 10 HSPF	Oil Boiler with Window AC	Due to COVID-19 and the resulting low response rates, the team was unable to collect viable WTP data for commercial customers.				
18	Commercial Existing Building - CC DMSHP Partial Replacement 5.12 Ton - 10 HSPF	Electric Baseboard with Window AC					
19	Commercial Existing Building - Central ASHP Partial Replacement 5.12 Ton - 9 HSPF	Oil Furnace with Central AC					
	Total		**(15,681)**	**(14,105)**	**(14,146)**	**(14,110)**	**(14,154)**

Note: values are in terms of statewide increase or decreases in MWh consumed over a given year due to heat pump adoption.

Table J-3. Net-MMBTU Savings Under Achievable Potential Projections

ID	Technology	Base Equipment	Net Energy Savings (MMBTU) – Cumulative Achievable 2020-2024				
			Baseline: No Change in cost / No Incentives	High-Low: High Cost / Low Incentives	High-High: High cost / High Incentives	Low-Low: Low cost / Low Incentives	Low-High: Low cost / High Incentives
1	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Gas Boiler with Window AC	0	0	0	0	0
2	Single-family New Construction - Central CC ASHP Full Replacement 3 Ton - 9 HSPF	Gas Furnace with Central AC	0	0	0	0	0
3	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Oil Boiler with Window AC	16,296	33,939	37,030	34,183	37,372
4	Single-family Existing Building - CC DMSHP Full Replacement 4 Ton - 10 HSPF	Oil Boiler with Window AC	31,387	53,170	60,230	53,729	61,012
5	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Electric Baseboard with Window AC	55,266	65,788	69,997	66,124	70,468
6	Single-family Building Addition - CC DMSHP Full Replacement 1.5 Ton - 10 HSPF	Electric Baseboard with Window AC	215	256	272	257	274
7	Multifamily New Construction - Central CC ASHP Full Replacement 1 Ton - 9 HSPF	Gas Furnace with Central AC	2	2	3	2	3
8	Single-family Existing Building - Central ASHP Partial Replacement 2.5 Ton - 9 HSPF	Oil Furnace with Central AC	1,350	8,813	11,477	9,018	11,764
9	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Oil Boiler with Central AC	5,675	12,568	13,943	12,677	14,097
10	Multifamily Existing Building - CC DMSHP Partial Replacement 1.5 Ton - 10 HSPF	Electric Baseboard with Window AC	3,466	3,983	4,189	3,999	4,212
11	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Electric Baseboard with No AC	11,407	13,579	14,447	13,648	14,544
12	Multifamily Existing Building - CC DMSHP Partial Replacement 1.5 Ton - 10 HSPF	Gas Boiler with Window AC	179	373	407	376	411
13	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Oil Boiler with No AC	3,251	6,771	7,388	6,820	7,456
14	Single-family Existing Building - Central ASHP Partial Replacement 2.5 Ton - 9 HSPF	Propane Furnace with Central AC	1,087	7,098	9,243	7,263	9,474
15	Single-family New Construction - Central CC ASHP Full Replacement 3 Ton - 9 HSPF	Propane Furnace with Central AC	3	8	12	9	12

ID	Technology	Base Equipment	Net Energy Savings (MMBTU) – Cumulative Achievable 2020-2024				
			Baseline: No Change in cost / No Incentives	High-Low: High Cost / Low Incentives	High-High: High cost / High Incentives	Low-Low: Low cost / Low Incentives	Low-High: Low cost / High Incentives
16	Multifamily Existing Building - CC DMSHP Partial Replacement 1.5 Ton - 10 HSPF	Electric Baseboard with No AC	536	638	678	641	683
17	Commercial Existing Building - CC DMSHP Partial Replacement 5.12 Ton - 10 HSPF	Oil Boiler with Window AC	Due to COVID-19 and the resulting low response rates, the team was unable to collect viable WTP data for commercial customers.				
18	Commercial Existing Building - CC DMSHP Partial Replacement 5.12 Ton - 10 HSPF	Electric Baseboard with Window AC					
19	Commercial Existing Building - Central ASHP Partial Replacement 5.12 Ton - 9 HSPF	Oil Furnace with Central AC					
	Total		**130,121**	**206,986**	**229,318**	**208,747**	**231,783**

Note: Positive values in the table above indicate a reduction in consumption (in MMBTU)

Table J-4. Achievable Potential Net-Carbon Reduction

ID	Technology	Base Equipment	Net Carbon Reduction Achievable Potential (Net lbs. CO_2e) – Cumulative 2020-2024				
			Baseline: No Change in cost / No Incentives	High-Low: High Cost / Low Incentives	High-High: High cost / High Incentives	Low-Low: Low cost / Low Incentives	Low-High: Low cost / High Incentives
1	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Gas Boiler with Window AC	0	0	0	0	0
2	Single-family New Construction - Central CC ASHP Full Replacement 3 Ton - 9 HSPF	Gas Furnace with Central AC	0	0	0	0	0
3	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Oil Boiler with Window AC	2,256,116	4,698,657	5,126,626	4,732,504	5,174,011
4	Single-family Existing Building - CC DMSHP Full Replacement 4 Ton - 10 HSPF	Oil Boiler with Window AC	4,079,026	6,909,955	7,827,393	6,982,512	7,928,972
5	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Electric Baseboard with Window AC	14,247,983	16,960,750	18,045,857	17,047,424	18,167,200
6	Single-family Building Addition - CC DMSHP Full Replacement 1.5 Ton - 10 HSPF	Electric Baseboard with Window AC	55,408	65,958	70,177	66,295	70,649
7	Multifamily New Construction - Central CC ASHP Full Replacement 1 Ton - 9 HSPF	Gas Furnace with Central AC	48	53	54	53	55
8	Single-family Existing Building - Central ASHP Partial Replacement 2.5 Ton - 9 HSPF	Oil Furnace with Central AC	176,411	1,151,879	1,500,053	1,178,632	1,537,508

ID	Technology	Base Equipment	Net Carbon Reduction Achievable Potential (Net lbs. CO_2e) – Cumulative 2020-2024				
			Baseline: No Change in cost / No Incentives	High-Low: High Cost / Low Incentives	High-High: High cost / High Incentives	Low-Low: Low cost / Low Incentives	Low-High: Low cost / High Incentives
9	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Oil Boiler with Central AC	787,771	1,744,417	1,935,364	1,759,669	1,956,717
10	Multifamily Existing Building - CC DMSHP Partial Replacement 1.5 Ton - 10 HSPF	Electric Baseboard with Window AC	893,626	1,026,780	1,080,041	1,030,992	1,085,938
11	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Electric Baseboard with No AC	2,940,765	3,500,677	3,724,641	3,518,566	3,749,686
12	Multifamily Existing Building - CC DMSHP Partial Replacement 1.5 Ton - 10 HSPF	Gas Boiler with Window AC	21,911	45,632	49,788	45,960	50,248
13	Single-family Existing Building - CC DMSHP Partial Replacement 2.5 Ton - 10 HSPF	Oil Boiler with No AC	405,926	845,393	922,394	851,483	930,920
14	Single-family Existing Building - Central ASHP Partial Replacement 2.5 Ton - 9 HSPF	Propane Furnace with Central AC	104,424	681,841	887,939	697,677	910,110
15	Single-family New Construction - Central CC ASHP Full Replacement 3 Ton - 9 HSPF	Propane Furnace with Central AC	255	626	891	650	925
16	Multifamily Existing Building - CC DMSHP Partial Replacement 1.5 Ton - 10 HSPF	Electric Baseboard with No AC	138,101	164,395	174,913	165,235	176,089
17	Commercial Existing Building - CC DMSHP Partial Replacement 5.12 Ton - 10 HSPF	Oil Boiler with Window AC	Due to COVID-19 and the resulting low response rates, the team was unable to collect viable WTP data for commercial customers.				
18	Commercial Existing Building - CC DMSHP Partial Replacement 5.12 Ton - 10 HSPF	Electric Baseboard with Window AC					
19	Commercial Existing Building - Central ASHP Partial Replacement 5.12 Ton - 9 HSPF	Oil Furnace with Central AC					
	Total		**26,107,772**	**37,797,012**	**41,346,131**	**38,077,653**	**41,739,028**

Note: values are in terms of statewide pounds of CO_2e reduced relative to baseline projections due to heat pump adoption.