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Heat Pump Water Heaters Impact Study: Volume 1

Final Report

Prepared for:

The Electric Program Administrators of Massachusetts
Part of the Residential Evaluation Program Area

Submitted by:
Navigant Consulting, Inc.
77 South Bedford Street, Suite 400
Burlington, MA 01803
781.270.3800
www.navigant.com

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EXECUTIVE SUMMARY

Starting in 2012, the Electric Residential Heating & Cooling Equipment program (part of Mass Save) has provided residential customers with a rebate for the purchase and installation of qualified heat pump water heaters (HPWHs). The incentive targets customers replacing existing electric storage tank water heaters or those who were in the process of building a new home.[1]

HPWH Impact Study Goals and "Volume 1" Report Scope

The goal of RES 20 HPWH Impact Study is to conduct research to quantify savings associated with HPWHs as well as identify customers' motivations and behavior patterns with respect to their purchase decisions and use of the technology.

The scope of the study as specified in the original Stage 3 Plan (finalized in June 2016) intended to address the quantification of HPWH savings with an in-depth engineering analysis of HPWH data for program participants ("Task 4 Engineering Analysis"). An initial review of program data and available literature ("Task 1 Data Review") and a participant survey ("Task 2 Participating Customer Survey") were conducted in order to lay the groundwork for the engineering analysis.

However, following the completion of Task 1 and Task 2, the engineering analysis (which would use simulations in order to determine savings impacts associated with different installation contexts and baselines) was put on hold in order to leverage the Residential Baseline Study (RES 1). The scope of the baseline study was adjusted to incorporate the metering of 30 HPWHs. Meter data collected through the baseline study will allow for the measurement of energy use of HPWHs installed in Massachusetts with varying installation contexts. This data can be used to update (or verify) the HPWH energy consumption term in the deemed savings calculation.

This report summarizes the results of Task 1 Data Review and Task 2 Participating Customer Survey (HPWH Impact Study "Volume 1"). The findings from these tasks provide context for baseline study findings related to HPWHs. The update to current deemed savings value proposed in this report should be utilized by the PAs to assess retrospective program savings until more robust estimates of energy savings can be estimated using the data from the baseline study.

In summary, the table below provides the primary research questions associated with the HPWH Impact Study objectives, along with the "status" of the research questions (i.e. are they addressed in this report or on hold). Task 1 Data Review provides a basis for some exploration of research questions which will ultimately be assessed using meter data obtained through the baseline study.

[1] http://www.masssave.com/~/media/Files/Residential/Applications-and-Rebate-Forms/CS_MA_HPWH_Rebate_FINAL.pdf.

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Table ES-1. HPWH Research Questions

Research Question	Status
What are the energy and peak-demand impacts associated with heat pump water heaters in Massachusetts in ER, ROB, and NC applications? What is the appropriate baseline in ER, ROB, and NC applications?	Explored in this report but a full analysis is on hold for assessment following Residential Baseline Study data collection.
How do savings vary based on heating, cooling, and dehumidification equipment type, heat pump water heater installation location, and home type? What are the secondary energy impacts on heating, cooling, and dehumidification?	Explored in this report but a full analysis is on hold for assessment following Residential Baseline Study data collection.
What is the value of dehumidification and other comfort impacts of the equipment?	Explored in this report (Task 2 Participating Customer Survey) but a full analysis is on hold for assessment following Residential Baseline Study data collection
Why did participants choose HPWHs? What are their satisfaction levels associated with their decision, the installation process, program incentives and education, equipment performance, etc.?	Addressed in this report (Task 2 Participating Customer Survey)
How do people use their heat pump water heaters? Did they change how they use their heating, cooling, and dehumidification equipment?	Addressed in this report (Task 2 Participating Customer Survey)

The components of this report are:

- **Task 1: Data Review.** This task included a review and summary of available deemed savings assumptions and the HPWH performance characteristics for 50-gallon (nominal) HPWH products qualified under the Electric Residential Heating & Cooling Equipment program, as well as the program data for rebate applications submitted in 2014 and 2015 provided by the Program Administrators (PAs). This task also included a literature review of published laboratory and field performance of qualified products and a comparison of this additional data to available Massachusetts data.
- **Task 2: Participating Customer Survey.** For this task, the Navigant team conducted an online survey of customers who received the HPWH rebate during the 2014 or 2015 program years[2] to improve understanding of their reasons for selecting a HPWH, the role the program played in their purchase decision, and their experience and satisfaction with the unit to date.

Key Findings

The major findings of this study are listed in the following sections.

[2] The population of rebate applications from which the customer survey sample was pulled, contained a small amount of customers who received the HPWH rebate in early 2016.

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Updates to Deemed Savings Estimate

Information obtained in Task 1 and Task 2 through literature review and customer surveys allowed for an adjustment to the current estimate of deemed savings employed by Massachusetts Program Administrators (the PAs) in order to quantify the savings impacts of HPWHs, including the impacts of space conditioning.[3] As a result of Task 1 and Task 2 findings (including the fact that several different home heating sources were cited by survey respondents), a blended deemed savings estimate of HPWHs was developed that is a weighted average of the savings for several types of home heating equipment: an air-source heat pump, electric resistance baseboards, and fossil fuel-fired equipment (natural gas-fired, propane-fired, and oil-fired furnaces and boilers). The weightings for each home heating source are based on the most recent baseline study from MA[4] and the Task 2 survey feedback. The weightings used are presented in Appendix C. Appendix C also includes the individual deemed savings estimates developed for each home heating source. Deemed savings estimates were developed using the equation below.

Table ES-2. HPWH Deemed Savings Calculation

$$Deemed\ Savings = (1\ - S_c)\left(\ ERWH_{consumption,old}\left(\frac{EF_{old}}{EF_{new}}\right)_{ERWH} - HPWH_{consumption,old}\left(\frac{EF_{old}}{EF_{new}}\right)_{HPWH}\right)$$

$$Deemed\ Savings = (1\ - S_c)\left(3330\frac{kWh}{yr}\left(\frac{0.91}{0.945}\right) - 1643\frac{kWh}{yr}\left(\frac{2.35}{2.625}\right)\right)$$

Where

S_c= Percentage of water heater electricity consumption offset by increased electricity consumption for space heating, varies by home heating source. The weighted-average value for all home heating sources is 4.8% (this does not include fossil fuel consumption, see Appendix C for calculation details).

$ERWH_{consumption,old}$ = Annual energy consumption for a 0.91 energy factor (EF) 50-gallon electric resistance water heater (ERWH) [5]

$EF_{old,ERWH}$= Federal minimum EF standard for residential electric storage water heaters manufactured before April 16, 2015

$EF_{new,ERWH}$= Federal minimum EF standard for residential electric storage water heaters with storage volume ≤55 gallons manufactured on or after April 16, 2015[6]

$HPWH_{consumption,old}$ = Annual energy consumption for a 2.35 EF 50 gallon HPWH[7]

[3] The current deemed savings estimate for HPWHs is 1,654 kWh/year and is based on an adjustment to the 2013-2015 Massachusetts Technical Reference Manual (MA TRM). http://ma-eeac.org/wordpress/wp-content/uploads/TRM_PLAN_2013-15.pdf.

[4] http://ma-eeac.org/wordpress/wp-content/uploads/11_MA-Residential-Appliance-Saturation-Survey_Vol_1.pdf

[5] 3330 kWh/year value taken from field testing done by Steven Winter Associates, Inc. (SWA) (2012). HPWH Evaluation of Field Installed Performance. Sponsored by National Grid and NSTAR. http://ma-eeac.org/wordpress/wp-content/uploads/Heat-Pump-Water-heaters-Evaluation-of-Field-INstalled-Performance.pdf.

[6] The current Federal standard for residential electric storage water heaters with storage volume >55 gallons is more stringent and can only be met using HPWH technology.

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$EF_{old,HPWH}$= EF of older generation HPWHs[8]
$EF_{new,HPWH}$= EF of newer generation HPWHs[9]

The equation above can be used to estimate deemed savings for both replacing an ERWH at the end of its life and early replacement of an ERWH. In the case that the ERWH is at the end of its life, the value used for $EF_{new,ERWH}$ is the current Federal minimum EF standard, as shown in the legend above. However, for an early replacement, using the EF rating of the ERWH being replaced as $EF_{new,ERWH}$ in the equation above provides an estimate for the deemed savings of switching to a HPWH that applies for the remaining years of the replaced ERWH's expected life. Because an ERWH being replaced was presumably purchased when the Federal standard was less stringent than the current standard, the efficiency of the replaced unit is likely lower than the efficiency of a new ERWH, resulting in greater deemed savings for early replacement. Beyond the expected life of the replaced ERWH, deemed savings calculated using the current Federal minimum EF standard would represent the savings of switching to a HPWH.

The deemed savings estimates developed from the equations above only apply to the replacement of electric storage water heaters with storage volume ≤55 gallons. Because the current Federal standard for residential electric storage water heaters with storage volume >55 gallons can only be met by HPWHs, there will not necessarily be deemed savings that correspond from moving from an ERWH with a storage volume >55 gallons to a HPWH unless the ERWH is replaced early (in which case the deemed savings that apply for the remaining years of the replaced ERWH's expected life can be calculated as explained in the previous paragraph). The deemed savings for such a scenario depends on consumer behavior in the case of no rebate program – the consumer could purchase a HPWH, downsize to a smaller ERWH, purchase multiple ERWHs, or purchase a different kind of water heater. Navigant did not attempt to predict consumer behavior and therefore did not develop deemed savings estimates for replacing ERWHs with storage volume >55 gallons (unless the ERWH is replaced early).

For the EF of new generation HPWHs, Navigant averaged the EF ratings of HPWHs installed by customers participating in the Mass Save program during the 2014 and 2015 program years. PAs can tailor the above equation by using the average EF of the new generation HPWHs purchased by their customers.

Additionally, PAs can use field COP or UEF instead of rated EF for HPWHs when such data becomes available for newer generation HPWHs (see section 2.3.3), as long as the same metric is used in the numerator and denominator of the EF_{old}/EF_{new} term.

The deemed savings equation above uses HPWH electricity consumption as measured in the 2012 SWA report.[10] However, this measured HPWH electricity consumption may be high because of two caveats

[7] 1643 kWh/year value taken from field testing done by Steven Winter Associates, Inc. (SWA) (2012). HPWH Evaluation of Field Installed Performance. Sponsored by National Grid and NSTAR. http://ma-eeac.org/wordpress/wp-content/uploads/Heat-Pump-Water-heaters-Evaluation-of-Field-INstalled-Performance.pdf.

[8] In the SWA 2012 report, 50 gallon tanks with EFs of 2.35 where tested. Performance in the field yielded lower efficiencies that translate to field COP of 1.61 (this field COP value is provided in case PAs choose to use field COP of newer-generation of HPWHs to calculated deemed savings).

[9] Navigant averaged the EF ratings of HPWHs installed by customers participating in the Mass Save program during the 2014 and 2015 program years. The mean EF for these HPWHs is 2.625.

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noted in the 2012 SWA report: (1) several of the HPWHs were undersized based on daily water consumption averages for the household (meaning that the backup electric resistance elements likely operated more frequently than would have been necessary with a properly sized HPWH), and (2) two of the units did not provide sufficient air volume for the HPWH's air intake, likely leading to sub-optimal operating conditions on the evaporator coil and thus lower HPWH efficiency. Therefore, the HPWH electricity consumption measured in the study likely would have been lower if the HPWHs had been properly sized and installed.

Literature reviews conducted as part of Task 1 identified studies that showed that a HPWH's interaction with a home's heating and cooling system can have an impact on energy savings, depending on the installation location. In the cold months when the home's heating system is active, a HPWH may have a negative impact and force a bigger load upon the heating system, while in the warm months, when the home's cooling system is active, a HPWH may have a positive impact and reduce the load on the cooling system. However, the literature review did not provide a consistent estimate of the impact on the space conditioning load of a HPWH installed in an unconditioned space (e.g., an unfinished basement). Because the space conditioning impact of a HWPH installed in an unfinished basement is somewhere between 0% and 100% of the impact of a HPWH installed in the conditioned space, an impact of 50% of was conservatively assumed for this analysis.

Navigant finds that the blended value (weighted-average across all home heating sources) of the reduction in savings from increased space heating electricity consumption associated with HPWHs is approximately 4.8%. A HPWH cools and dehumidifies the surrounding air and thus would reduce the load and energy consumption of both a dehumidifier if installed in a basement and an air conditioning system – effects that the survey respondents did identify. These energy savings were not included in this analysis due to lack of data, though metering in the Baseline Study may provide an estimate of this effect. In addition to the impact of space conditioning, the new deemed savings estimate accounts for the increase in efficiency in new HPWH models (i.e., a 12% increase in EF).

Based on information obtained from HPWH owners through customer surveys (Task 2), Navigant assumed that 75% of HPWHs were installed in unfinished basements, and 25% were installed in conditioned spaces. The analysis results (i.e., space conditioning impacts and deemed savings estimates) reflect a weighted average of these installation locations.

Navigant developed a blended deemed savings estimate (weighted-average value across all home heating sources) of 1652 kWh/yr for replacing an ERWH with a HPWH.

While fossil fuel-fired furnaces and boilers consume a small amount of electricity when operating, the vast majority of their energy consumption is from fuel consumption. For homes heated with fuels, the deemed savings estimate presented above only includes the small increase in electricity associated with the furnace or boiler operating longer hours to compensate for the space conditioning impacts of the HPWH. Installation of a HPWH in a home heated with a fossil fuel-fired furnace or boiler would also increase fuel consumption to counter the space cooling effect of the HPWH in colder months.

Navigant also estimated a 0.67 MMBtu/yr fuel consumption penalty that accounts for the space conditioning impacts of a HPWH in homes heated with fossil-fuel fired furnaces and boilers.

[10] Steven Winter Associates, Inc. (SWA) (2012). HPWH Evaluation of Field Installed Performance. Sponsored by National Grid and NSTAR. http://ma-eeac.org/wordpress/wp-content/uploads/Heat-Pump-Water-heaters-Evaluation-of-Field-INstalled-Performance.pdf.

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Broken out by fossil fuel type, the blended fuel consumption penalty of 0.67 MMBtu/yr equates to consumption penalties of 0.50 MMBtu/yr oil, 0.10 MMBtu/yr natural gas, and 0.07 MMBtu/yr propane.

These estimates apply to all homes and were weighted by the fraction of homes that use each fuel source for space heating. Appendix C includes further detail on the fuel consumption penalty as well as the estimated penalty for each fuel source (i.e., natural gas, propane, heating oil).

The blended deemed savings estimate presented above is very similar to the value currently used by the PAs, 1,649 kWh/year. However, Navigant recommends using the updated deemed savings estimate and the accompanying average fuel consumption penalty to account for space conditioning impacts of HPWHs.

HPWH Program Application Data Review and Customer Survey Findings

Analysis of rebate application data and customer survey data yielded valuable insights about customer purchase behaviors and satisfaction with the HPWH technology. Key findings are listed in Table ES-4.

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Table ES-4. Customer Application and Survey Data Findings

Evaluation Category	Findings
Replaced Water Heater Characteristics / Purchase Decision	• Half of the water heaters replaced were 12 years old or older. Over 20% of replaced water heaters were less than 9 years old and close to 8% were less than 6 years old, indicating there is some evidence of early replacement. • Survey results indicate that 15% of rebate recipients replaced oil-fired storage water heaters. Another 12% replaced water heaters that were not ERWHs (including indirect, propane storage, electric tankless, and gas storage). • Approximately 40% of all HPWH purchasers downsized, with the main reason cited that a larger water heater was no longer needed. Hot water runouts are not a common problem.
Use of HPWH / Installation Context	• 94% of customers are utilizing the water heater in heat pump mode (39% use “efficiency mode” and 55% use “hybrid mode”). 5% of customers do not know the operational setting of their HPWH. • 16% have HPWHs installed in a basement closet or utility room. • For those who replaced ERWHs, the primary home heating system fuels cited were fuel oil (49%) and electricity (26%) were the top two.
Comfort and Satisfaction	• 76% of respondents have noticed a change in comfort level in their homes; 89% of these customers report that the change has been positive. • 94% of respondents are satisfied with their HPWH. Respondents cited bill savings, energy savings, performance, and dehumidification benefits as reasons for being satisfied. Dehumidification was the most frequently cited comfort benefit.

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Summary of Advantages and Disadvantages of HPWH Technology

Table ES-5 contains a summary of advantages and disadvantages of HPWH technology based on a combination of Task 1 and Task 2 findings.

Table ES-5. Advantages and Disadvantages of HPWHs

Advantages	Disadvantages
• Approximately 50% energy cost savings compared to conventional electric[11] • Reduction in emissions of greenhouse gases[12] • Federal Tax Credit ($300 through end of 2016) • Mass Save rebate for models less than 55 gallons (rebate for models greater than 55 gallons was added in 2017) • Can help cool and dehumidify home • High customer satisfaction	• No energy cost savings compared to natural gas • Blows cool air, adds to home heating load[13] • High first cost:[14] o $500-1,000 cost premium[15] • Noise: o Louder than a refrigerator o Quieter than a dehumidifier • Not good for small space install; manufacturers specify 750 to 1000 cubic feet of air space around the units.

Next Steps, Considerations and Recommendations

Task 1 and Task 2 findings have allowed for adjusted deemed savings estimates by home heating source. **These deemed savings estimates can be used on a retrospective basis to assess program savings until more robust estimates of energy savings can be estimated using the data from the baseline study.** Table ES-6 lists some next steps and recommendations related to HPWHs deemed savings estimates, as well as relating to contractor and customer outreach as part of efforts to increase the adoption of HPWHs.

[11] Based on an updated HPWH deemed savings value of 1,654 kwh/year as described in Section 2.2.2.

[12] Hong, B. and Howarth, R. W. (2016), Greenhouse gas emissions from domestic hot water: heat pumps compared to most commonly used systems. Energy Sci Eng, 4: 123–133. doi:10.1002/ese3.112

[13] Accounted for in deemed savings adjustment described in this report.

[14] Relative to common storage tank water heaters such as electric, natural gas, and fuel, which have costs ranging from $400 to $1,000.

[15] Before incentives.

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Table ES-6. Next Steps, Considerations and Recommendations for HPWHs

Evaluation Category	Next Steps/Recommendation

Updated Deemed Savings	• Next Step: 30 HPWHs will be metered as part of baseline study.
	• Recommendation: Update deemed savings value to assess retrospective program savings (1652 kWh/year with average fossil fuel penalties of 0.50 MMBtu/yr oil, 0.10 MMBtu/yr natural gas, and 0.07 MMBtu/yr propane).
	• Recommendation: Once the HPWH metering data from Residential Baseline study becomes available, determine whether to proceed with the re-scope and execution of Task 4 - Engineering Analysis of the HPWH impact study, which is intended to develop improved and forward-looking energy savings and demand savings values.
	• Consideration: If available before baseline findings, leverage results of testing underway in the Pacific Northwest (NEEA, BPA, PNNL, and Ecotope) to reevaluate assumptions.
	  o Climate is similar to Massachusetts.
	  o Field tests on newer HPWH models are underway.
	• Recommendation: Track Department of Energy (DOE) rulemaking process for transition to uniform energy factor (UEF) metric.

Customer Acceptance and Barriers	• Recommendation: Given the savings and high level of satisfaction expressed by customers, continue to support and encourage the adoption of HPWH technology. • Consideration: Use survey results relating to customer satisfaction to improve program marketing materials. • Consideration: Leverage results of contractor interviews to uncover additional barriers (Res 25).

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1. PROGRAM BACKGROUND AND EVALUATION OBJECTIVES

1.1 Program Background

In the 2014 and 2015 program years, the Electric Residential Heating & Cooling Equipment program offered a rebate to customers of Mass Save program sponsors for the purchase and installation of qualified heat pump water heaters (HPWHs) installed by a licensed plumber. HPWHs eligible for the rebate must be Energy Star qualified HPWHs with an Energy Factor (EF) of 2.3 or greater and a minimum 10-year manufacturer's warranty. Program literature also specifies that rebate must be used to replace an existing electric storage tank water heater or in new construction applications. The 2016 list of qualified HPWHs can be found on the Mass Save website (since updated).[16]

In order to determine the savings attributable to the HPWH rebate program, the Program Administrators (PAs) currently use a deemed savings estimate of 1,654 kWh/year based on the 2013-2015 Massachusetts Technical Reference Manual (MA TRM) and adjusted for the increase in baseline electric resistance water heater (ERWH) efficiency as required by the US Department of Energy's (DOE's) 2010 Energy Conservation Standards for residential water heaters (effective on April 16, 2015).[17]

1.2 HPWH Impact Study Goals and "Volume I" Report Scope

The goal of RES 20 HPWH Impact Study is to conduct research to quantify savings associated with HPWHs as well as identify customers' motivations and behavior patterns with respect to their purchase decisions and use of this technology.

Specifically, the objectives are to:

- Estimate the energy savings and demand impacts associated with ER, ROB, and NC HPWH installations
- Estimate the impact of various HPWH operating characteristics and their impacts on the interactive effects between HPWHs and other residential HVAC and dehumidification systems
- Understand participant behavior to gain context about the interactive effects between HPWHs and other residential HVAC and dehumidification systems
- Explore various program design options to maximize HPWHs' cost-effectiveness and incent greater adoption of the measure

The scope of this HPWH study as specified in the original Stage 3 Plan (finalized in June 2016) intended to address the above-mentioned research objectives with an in-depth engineering analysis of HPWH data for program participants ("Task 4 Engineering Analysis"). An initial review of program data and available literature ("Task 1 Data Review") and a participant survey ("Task 2 Participating Customer Survey") were conducted in order to lay the groundwork for the engineering analysis.

[16] http://www.masssave.com/~/media/Files/Residential/Information-and-Edu-Docs/2016_forms/Mass%20Save%20Qualified%20HPWHs%20v1%207%2016.pdf

[17] Energy Conservation Standards for Consumer Water Heaters Final Rule (April 16, 2010); Docket: EERE-2006-STD-0129, 75 FR 20112.

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However, following the completion of Task 1 and Task 2, the engineering analysis (which would use simulations in order to determine savings impacts associated with different installation contexts and baselines) was put on hold in order to leverage the Residential Baseline Study (RES 1). The scope of the baseline study was adjusted to incorporate the metering of 30 HPWHs. Meter data collected through the baseline study will allow for the measurement of energy use of HPWHs installed in Massachusetts with varying installation contexts. This data will be used to verify and update the HPWH energy consumption term in the deemed savings calculation.

This report summarizes the results of Task 1 Data Review and Task 2 Participating Customer Survey (HPWH Impact Study "Volume 1"). The findings from these tasks provide context for baseline study findings related to HPWHs. The update to current deemed savings value proposed in this report should be utilized by the PAs to assess retrospective program savings until more robust estimates of energy savings can be estimated using the data from the baseline study.

In summary, the table below provides the primary research questions associated with the HPWH Impact Study objectives, along with the "status" of the research questions (i.e. are they addressed in this report or on hold). Task 1 Data Review provides a basis for some exploration of research questions which will ultimately be assessed using meter data obtained through the baseline study.

Table 1-1. HPWH Research Questions

Research Question	Study / Task
What are the energy and peak-demand impacts associated with heat pump water heaters in Massachusetts in ER, ROB, and NC applications? What is the appropriate baseline in ER, ROB, and NC applications?	Explored in this report but a full analysis is on hold for assessment following Residential Baseline Study data collection.
How do savings vary based on heating, cooling, and dehumidification equipment type, heat pump water heater installation location, and home type? What are the secondary energy impacts on heating, cooling, and dehumidification?	Explored in this report but a full analysis is on hold for assessment following Residential Baseline Study data collection.
What is the value of dehumidification and other comfort impacts of the equipment?	Explored in this report (Task 2 Participating Customer Survey) but a full analysis is on hold for assessment following Residential Baseline Study data collection
Why did participants choose HPWHs? What are their satisfaction levels associated with their decision, the installation process, program incentives and education, equipment performance, etc.?	Addressed in this report (Task 2 Participating Customer Survey)
How do people use their heat pump water heaters? Did they change how they use their heating, cooling, and dehumidification equipment?	Addressed in this report (Task 2 Participating Customer Survey)

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1.3 Task 1 and Task 2 Objectives

The goal of this study is to conduct research to quantify savings associated with HPWHs, as well as to identify customers' motivations and behavior patterns with respect to their purchase decisions and use of this technology.

1.3.1 Task 1 Data Review Objectives

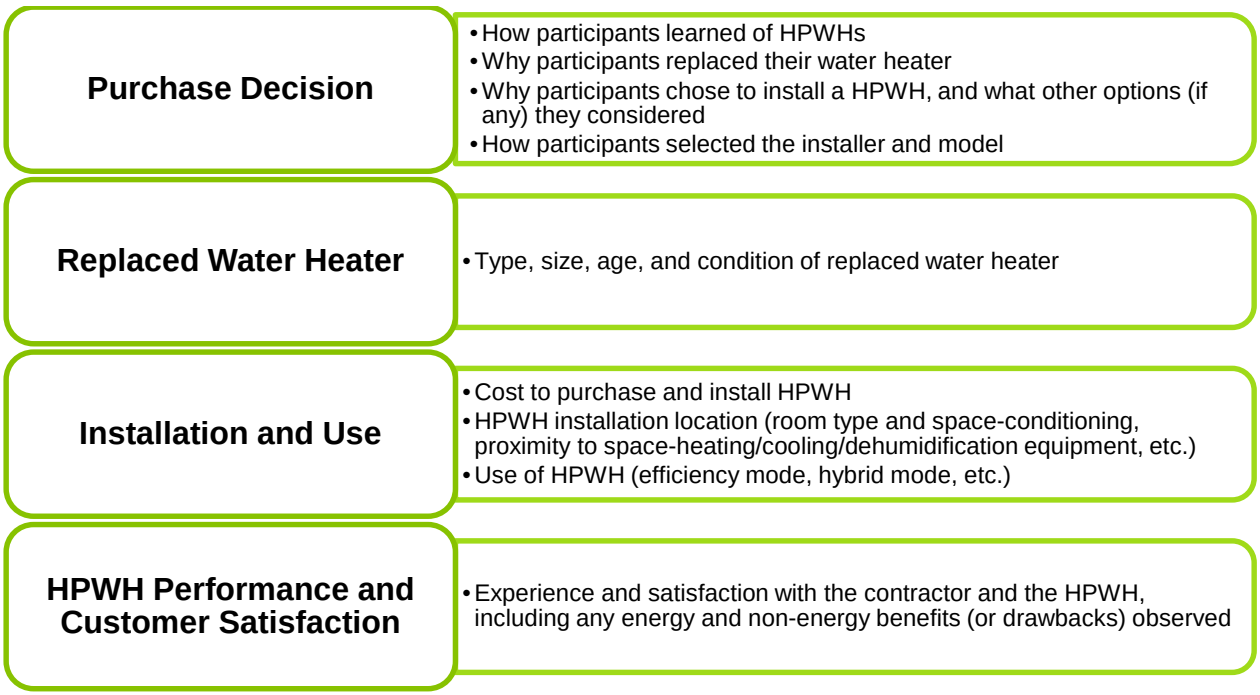
The intent of Task 1 was to lay the groundwork for further refinement of HPWH impact estimates. Task 1 objectives included the following:

- Review and summary of available deemed savings assumptions and the HPWH performance characteristics for 50-gallon (nominal) HPWH products qualified under the Electric Residential Heating & Cooling Equipment program.
- Review and summary of 2014 and 2015 program application provided by the PAs.
- Literature review of published laboratory and field performance of qualified products, as well as a comparison of this additional data with available Massachusetts data.

1.3.2 Task 2 Participating Customer Survey Objectives

Task 2 consisted of a participating customer survey to improve understanding of customers' reasons for selecting a HPWH, the role the program played in their purchase decision, and their experience and satisfaction with the unit to date. Figure 1-1 contains an overview of the topics covered in the customer survey.

Figure 1. Key Questions Addressed in Customer Survey



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2. TASK 1: DATA REVIEW

Task 1 included a review and summary of available deemed savings assumptions and the performance characteristics for 50-gallon (nominal) HPWH products qualified under the Electric Residential Heating & Cooling Equipment program, as well as the program data for rebate applications submitted in 2014 and 2015 provided by the PAs. This task also included a literature review of published laboratory and field performance of qualified products and a comparison of this additional data to available Massachusetts data. This section contains the following subsections:

1. **HPWH Background.** This subsection provides background on the historical and current market for HPWHs, inherent advantages of HPWH technology, DOE regulations related to water heater efficiency affecting the HPWH market, and characteristics of the HPWH models qualified for the Mass Save rebate.
2. **Data Review.** This subsection provides a summary of program rebate application data, as well as a review of the current deemed saving estimate for HPWHs.
3. **Literature Review.** This subsection contains findings of a review of past HPWH field testing and a summary of upcoming HPWH testing. It also contains a summary of findings that will inform adjustments to the current deemed savings value, as described in Section 4.1.

2.1 HPWH Background

This section provides background on the historical and current market for HPWHs, inherent advantages of HPWH technology, DOE regulations related to water heater efficiency affecting the HPWH market, and characteristics of the HPWH models qualified for the Mass Save rebate.

2.1.1 Market Overview

HPWHs were first introduced into the mainstream market in the early 1980s. Over the next 2 decades, the US HPWH market fluctuated between 2,000 and 10,000 units per year.[18] Currently, the US residential market for HPWHs is approximately 60,000 units per year. This equates to a penetration of 1.5% into the current total ERWH market.[19] In Massachusetts, General Electric Appliances (GE, a Haier company) held 61% of the HPWH market, but has ceased production of the technology as of December 2016.[20,21] Other manufacturers are expected to capitalize on the void in the market but need to overcome common barriers. High upfront cost, limited product availability, a lack of customer awareness, and an unengaged installer base have limited the growth of HPWHs. Additionally, the majority of residential water heater purchases are emergency replacements. When old water heaters break, customers are reluctant to move to a less familiar technology (i.e., HPWHs). Thus, HPWHs have yet to penetrate the largest market segment for residential water heaters.

[18] http://www.nrel.gov/docs/fy16osti/64904.pdf

[19] http://pressroom.geappliances.com/news/ge-appliances-makes-moves-to-improve-competitiveness

[20] ibid

[21] 61% number based on 2014-2015 application data.

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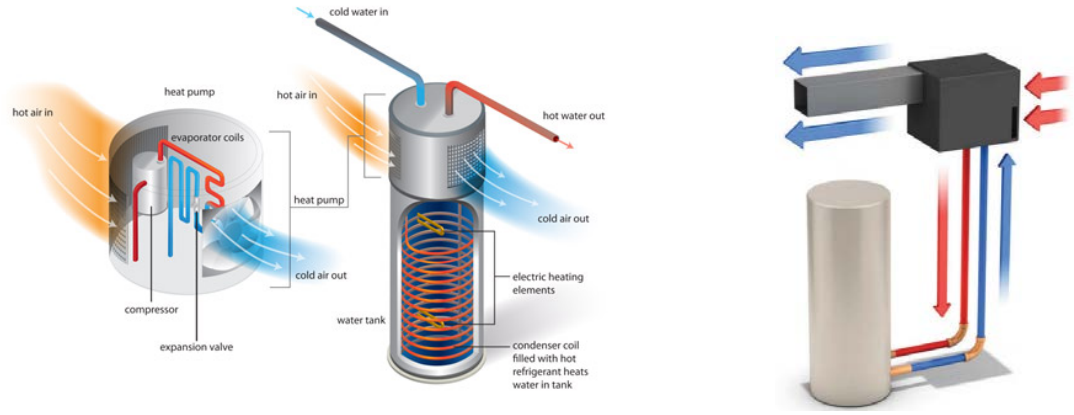
In recent years, federal and state governments and utilities have offered tax credits and incentives in efforts to popularize HPWH technology. In the United States, all ENERGY STAR-certified HPWHs installed between January 1, 2011 and December 31, 2016 qualified for a $300 Federal Tax Credit.[22] In addition to the Mass Save program, rebates are offered throughout the country through state and utility sponsored programs, with an average incentive of approximately $400.[23]

2.1.2 Technology Overview

HPWHs are water heaters that use a vapor-compression heat pump to move heat from surrounding air to the water in the storage tank. These water heaters typically come in one of two configurations (Figure 2-1): integrated (tank and heat pump module combined) or add-on (heat pump module is separate from the tank). Add-on HPWHs are typically used in commercial applications and are not included in the Mass Save list of qualified HPWHs.

Figure 2. HPWH Configurations – Integrated (Left) and Add-On (Right)



HPWH models also vary in the refrigerant used to run the refrigeration cycle. Hydrofluorocarbon (HFC) refrigerants such as R-134a and R-410A are most commonly used, but policy efforts are likely to effectively phase out the use of HFCs in HPWHs. On October 15, 2016, more than 170 countries, including the United States, agreed to the Kigali Amendment to the Montreal Protocol, under which developed countries will start to phase out HFCs by 2018.[24] In addition to the Montreal Protocol, the US Environmental Protection Agency (EPA) has introduced the Significant New Alternatives Policy (SNAP), which identifies and evaluates substitutes in end uses that have historically used ozone-depleting substances (ODS).[25] While HPWHs are not yet targeted by SNAP, the EPA may add them as the market for HPWHs using alternative refrigerants grows to support the Kigali Amendment. Therefore, HPWH manufacturers will increasingly turn to alternative refrigerants.

[22] https://energystar.zendesk.com/hc/en-us/articles/211437758-Is-there-a-tax-credit-for-electric-heat-pump-water-heaters-

[23] http://aceee.org/sites/default/files/files/pdf/conferences/hwf/2016/Reynolds_Lebrasseur_Naleway_Session2C_HWF16_2.22.16.pdf

[24] https://www.nytimes.com/2016/10/15/world/africa/kigali-deal-hfc-air-conditioners.html?_r=0

[25] https://www.epa.gov/snap/overview-snap

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A likely candidate to replace HFCs in HPWH is CO_2. With a global warming potential (GWP) of 1, CO_2 is much less harmful than R-134a (GWP of 1,430) and R-410A (GWP of 2,090).[26] Lab tests from the Northwest Energy Efficiency Alliance (NEEA) report EFs over 3 for HPWHs that use CO_2 as their refrigerant.[27] Sanden CO_2 HPWHs have been certified and are available for purchase in North America.

In terms of advantages of the technology, HPWHs are associated with energy savings (discussed in more detail in Section 4.1) and greenhouse gas emissions reductions.[28] In addition, HPWHs can help cool and dehumidify a home during the non-heating season.

Disadvantages of HPWHs include the fact that they present no energy savings, on a source MMBtu basis, relative to natural gas-fired water heaters and that HPWHs blow cool air (an advantage during the non-heating season), which adds to home heating load and has a negative effect on energy savings relative to ERWHs (accounted for in energy calculations in Section 4.1).[29] Additionally, HPWHs carry higher installed costs than other types of storage tank water heaters, but not tankless heaters. Research indicates that HPWHs carry an installed cost premium of $500-$1,000 relative to other types of storage tank water heaters.[30] Tankless water heaters tend to carry an installed cost premium over HPWHs not due to the cost of the equipment, but due to the cost of retrofitting a home from a storage tank configuration to a tankless system. Also, HPWHs typically need around 1000 cubic feet of air space and room for a condensate drain (or pump), making them not ideal in small space installations. Finally, HPWHs have a noise level ranging from 55 db to 65 db, which may be considered too loud for some consumers.

2.1.3 DOE Rulemaking Timeline

Since 1990, the US DOE has published multiple standards related to the minimum efficiency required for water heaters. As shown in Figure 2-2, the minimum EF of electric water heaters changed from approximately 0.82 to 0.90 (with a slight difference between water heaters of different tank sizes). The DOE's 2010 Energy Conservation Standards (effective in 2015) amended the standards for electric storage tanks, setting the EF for tanks larger than 55 gallons to approximately 2.0.[31] Standard ERWHs with tanks greater than 55 gallons that are currently available on the market have a maximum possible EF of 1. This has effectively forced customers wanting an electric storage tank water heater greater than 55 gallons to turn to HPWHs.

---

[26] https://www.epa.gov/snap/acceptable-substitutes-residential-and-light-commercial-air-conditioning-and-heat-pumps

[27] http://neea.org/docs/default-source/lab-test-reports/laboratory-assessment-of-sanden-gau-heat-pump-water-heater-lab.pdf?sfvrsn=6

[28] Hong, B. and Howarth, R. W. (2016), Greenhouse gas emissions from domestic hot water: heat pumps compared to most commonly used systems. Energy Sci Eng, 4: 123–133. doi:10.1002/ese3.112

[29] According to the NREL paper, HPWHs and natural gas water heaters have the lowest operating costs compared to the other common types of storage tank water heaters. Although natural gas water heaters do not have high efficiencies, the gas source is much cheaper than generating electricity. http://www.nrel.gov/docs/fy16osti/64904.pdf

[30] According to the NREL paper, a 50 gallon HPWH costs around $2,100, which is over twice the cost of other common types of water heaters (electric resistance, natural gas, fuel oil, propane) - http://www.nrel.gov/docs/fy16osti/64904.pdf . Task 2 results show that 60% of installation costs of HPWHs ranged between $1,000 and $1,999.

[31] For tanks with a Rated Storage Volume at or below 55 gallons: EF = 0.960 = (0.0003 x Rated Storage Volume in gallons).

For tanks with a Rated Storage Volume above 55 gallons: EF = 2.057 = (0.00113 × Rated Storage Volume in gallons).

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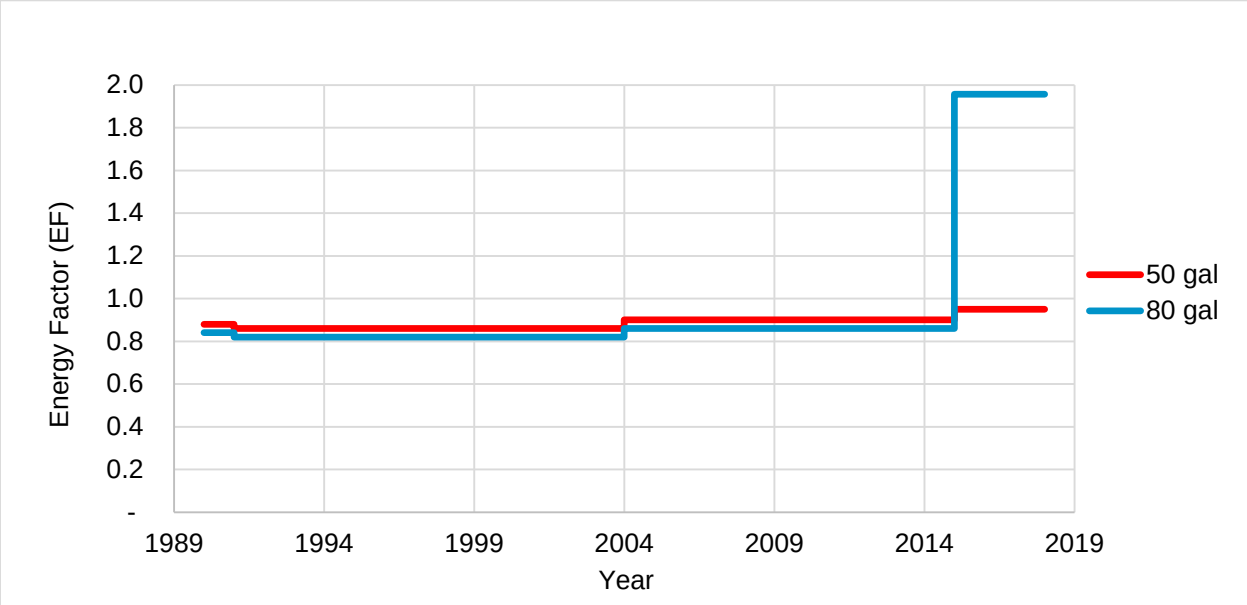
Figure 3. Changes in EF Due to Federal Rulemakings



In the July 2014 Test Procedure Final Rule for Consumer and Certain Commercial Water Heaters, the DOE established the uniform energy factor (UEF) as a uniform efficiency descriptor and adopted a test method for measuring UEF for consumer and certain commercial water heaters (79 FR 40542). The DOE released a cross-walk test procedure final rule on December 29, 2016 establishing conversion factors for the new metric (81 FR 96204). Under the rule, manufacturers can use the conversion factors to adjust from EF to UEF until December 29, 2017. After that, the test procedure based on the UEF metric will be enforced.

2.1.4 Mass Save Qualified HPWHs

The 2016 Mass Save Qualified HPWHs list featured 38 water heaters that represented 10 unique models.[32] The list of qualified Mass Save models was updated at the beginning of 2017 and now includes models greater than 55 gallons, which will qualify for a $150 incentive (HPWH models less than 55 gallons will continue to qualify for the $750 rebate). The old and new lists can be found in 4.4Appendix A (Figure A-1, Figure A-2, and Figure A-3, respectively).

2.2 Data Review

This section provides a summary of program rebate application data, as well as a review of the current deemed saving estimate for HPWHs.

[32] Heat pump water heater must be installed by a MA licensed plumber and installed within the MA electric service area of one of the participating sponsors, be UL listed, and installed in accordance with the National Electric Code and manufacturer's specifications. Must be ENERGY STAR® qualified with an Energy Factor (EF) of 2.3 or greater and have a minimum 10-year manufacturer's warranty. Program literature also specifies that rebate must be used to replace an existing electric storage tank water heater or in new construction applications.

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2.2.1 Program Application Data

On July 11th and August 16th Navigant received initial sets of statewide program application data for the 2015 and 2014 program years, respectively (data was received from the program implementer via the PAs). These initial data sets were limited to participant contact information as well as the cost and size of the purchased HPWH.

In early October, Navigant submitted a request for additional application data fields related to the purchased HPWH (i.e. install date, manufacturer, model, installation location) as well as the replaced water heater. The request was processed on October 14th by the program's implementation vendor.

Comparison of the program application data received in July-August with that received in October revealed discrepancies. The two sets of program data had differences relating to the population of customers who had applied for a HPWH rebate during the 2014-2015 program years. Navigant subsequently worked with the program implementer in efforts to determine the source of the discrepancy. Navigant received an updated set of program application data from the program implementer on November 22nd, but discrepancies persisted.[33]

Therefore, the review and characterization of HPWH rebate program data is based on the overlapping customers (i.e., customers listed in both data sets), over 3,000 Massachusetts residents for 2014 and 2015 program years combined.[34]

As indicated in Figure 2-3, the majority of rebate recipients replaced water heaters that were 46 to 55 gallons or greater than 75 gallons. This aligns with the fact that, historically, storage water heaters have primarily been available with tank sizes of 50 or 80 gallons. **Additionally, a comparison of replaced water heater and HPWH sizes indicates that approximately 40% of recipients downsized.**

[33] Ultimately, the data sets received in July-August (reflecting the 2014-early 2016 program period) from the PAs contained 4,382 unique electric accounts. The data received in November from the program implementer contained 4,563 unique electric accounts for the same program period. There were 3,513 overlapping electric accounts. This overlap was used to summarize the population of HPWH rebate recipients in the remainder of this section.

[34] Application data also included customers who applied for rebates in January 2016.

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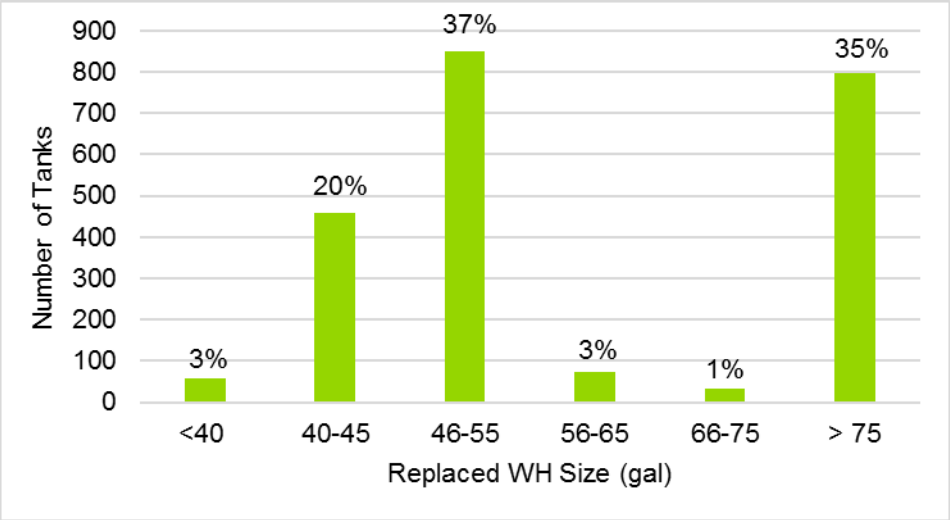
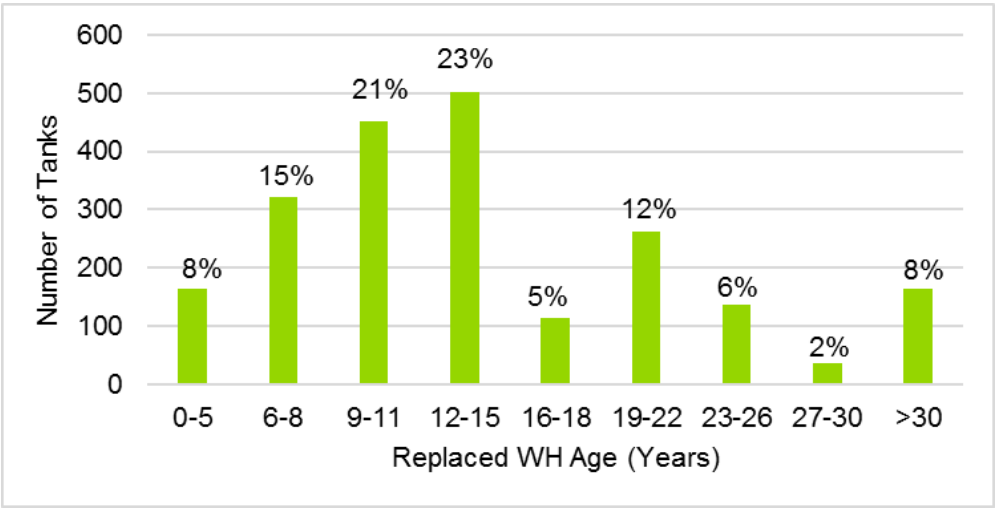
Figure 4. Replaced WH Size (N=2272[35])



As shown in Figure 2-4, **over half of replaced water heaters were 12 years old or older**, a finding that is consistent with survey results showing that approximately 60% of customers purchased a new water heater in order to replace a failed or old water heater. Of note, **over 20% of replaced water heaters were less than 9 years old and close to 8% were less than 6 years old, indicating some evidence of early replacement.**

Figure 5. Replaced WH Age (N=2,152)



Additionally, program application data indicates that **close to all HPWH rebate recipients installed their HPWHs in basements.** As discussed later in section 3.2.3, survey results indicate that approximately

[35] Instances of missing application data for certain data fields indicate certain fields were not mandatory. In the case of replaced water heater size it also reflects the fact that a small segment of customers applied the rebate to the replacement of non-storage tank water heaters. See figure 3-5 in section 3.2.2.

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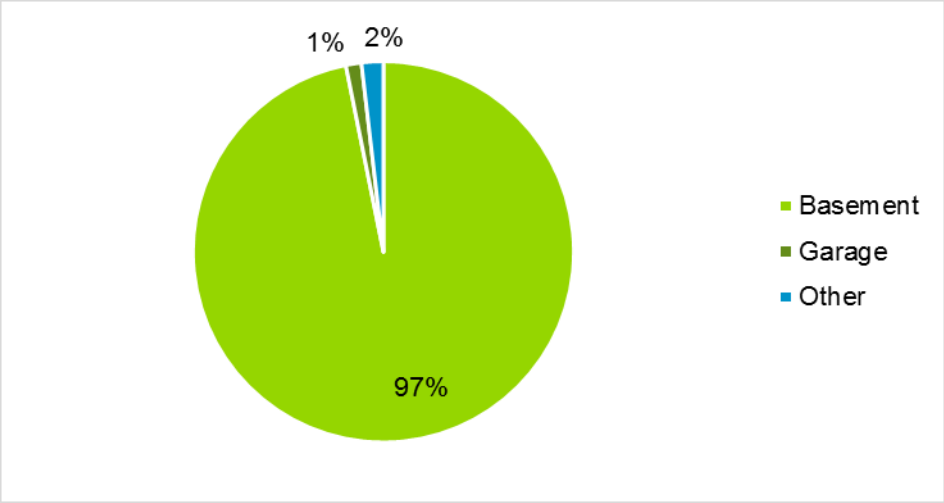
17% of HPWHs installed in basements are installed in closets or utility rooms. Survey results related to the space conditioning of customers' basements are discussed in Section 3.2.3.

Figure 6. Installation Location (N=3,469)



2.2.2 Current Deemed Savings Estimates

The 2013-2015 MA TRM reported a deemed savings of 1,775 kWh/year for a 50-gallon HPWH when compared to an electric storage tank water heater of the same size. For 80-gallon tanks, the TRM deemed savings is 2,672 kWh/year.[36] The original MA TRM deemed savings estimates were made based on a Steven Winter Associates, Inc. (SWA) report. HPWH electricity consumption as measured in the 2012 SWA report may be high because of two caveats noted in the 2012 SWA report: (1) several of the HPWHs were undersized based on daily water consumption averages for the household (meaning that the backup electric hesitance elements likely operated more frequently than would have been necessary with a properly sized HPWH), and (2) two of the units did not provide sufficient air volume for the HPWH's air intake, likely leading to sub-optimal operating conditions on the evaporator coil and thus lower HPWH efficiency. Therefore, the HPWH electricity consumption measured in the study likely would have been lower, and thus the savings higher, if the HPWHs had been properly sized and installed. The results and methods of the SWA paper are described in greater detail in section 2.3.1.1.

In 2016, the Massachusetts PAs made an adjustment to the MA TRM values to account for the increase in baseline efficiency for ERWHs as required by the DOE's 2010 efficiency standard for residential water heaters (as described in Section 2.1.3). The 2010 standard increased the minimum EF of smaller electric storage tanks (<55 gallons) from 0.91 to 0.945. This increase in the baseline efficiency of ERWHs caused the deemed savings to drop from 1,775 kWh to 1,654 kWh.

In this report, Navigant proposes additional adjustments to the TRM deemed savings estimate to account for space conditioning impacts[37] and the increase in performance of newer HPWHs.

[36] These deemed savings were taken from report by Steven Winter Associates, Inc. (SWA) (2012). HPWH Evaluation of Field Installed Performance. Sponsored by National Grid and NSTAR. http://ma-eeac.org/wordpress/wp-content/uploads/Heat-Pump-Water-heaters-Evaluation-of-Field-INstalled-Performance.pdf.

[37] In the SWA report, space conditioning impacts were discussed but not quantified.

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Because HPWHs draw energy from their surroundings, a household's space conditioning system is forced to work harder in the heating season and less in the cooling season—this effect is greater when the HPWH is installed in a fully conditioned space. Generally, the impact is more significant in the heating season and therefore the TRM deemed savings estimate may overestimate savings associated with HPWHs.

Additionally, the SWA report upon which the 2013-2015 TRM value was based was published in 2012 based on field testing done in the 2010 The 50 gallon GE Geospring tanks monitored in the SWA field study had EFs of 2.35. Newer HPWHs with higher EFs (greater than 3) have appeared in the market, which would increase savings.

The following section contains the results of the Task 1 literature review, which provided some insights into how to quantify the above-mentioned deemed savings adjustments.

2.3 Literature Review

In order to verify current savings estimates and assumptions about HPWH performance, Navigant conducted a literature review supplemented with phone interviews.[38] The goals of the review were to compare the PAs' deemed savings estimate with other published field tests and to find data quantifying the impact of HPWH space conditioning interactions. Table 2-1 provides a summary of literature review findings.

[38] Key Resources:

- Field Performance of HPWH in the Northeast, NREL February 2016
  - http://www.nrel.gov/docs/fy16osti/64904.pdf
- Heat Pump Water Heater Model Validation Study. Ecotope Inc. & Northwest Energy Efficiency Alliance 2015
  - http://neea.org/docs/default-source/reports/heat-pump-water-heater-saving-validation-study.pdf?sfvrsn=8
- Heat Pump Water Heater Demonstration at Delaware County Electric Cooperative, Inc. in Delhi, NY. EPRI 2015
  - http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002005495
- Impact of Ducting on Heat Pump Water Heater Space-conditioning Energy Use and Comfort. PNNL. Widder SH, JM Petersen, GB Parker, and MC Baechler. 2014.
  - http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23526.pdf
- Phone interviews with researchers from:PNNL, Ecotope, and Portland General Electric

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Table 2-1. Summary of Data Collected from Literature Review

Source	Year of Publication	Manufacturer (Model[s]) Tested	EF Rating	kWh/yr Savings (Water Heating)	kWh/yr Lost Through HVAC Interaction	Home Heating Source	Net Energy Savings (kWh/yr)	Average Hot Water Draw (Gal/day)	Annual Energy Savings%
SWA[a]	2012	GE (Geospring)[b]	2.35[c]	1,654	N/A	N/A	1,654	43.4	50%[f]
NREL[a]	2016	GE (Geospring)[b]	2.35[c]	1,605	330	Heat pump	1,275	43.4	36.6%
Ecotope[a]	2015	GE (GEH50DEEDSR)[b]	2.4	1,375	272	Heat pump	1,103	40.3[d]	37.4%
Ecotope[a]	2015	GE (GEH50DEEDSR)[b]	2.4	1,375	350	Electric baseboard	1,025	40.3[d]	34.8%
Ecotope[a]	2015	GE (GEH50DEEDSR)[b]	2.4	1,375	15	Gas furnace	1,360	40.3[d]	46.2%
EPRI	2015	Rheem (PROPH50 T2 RH245) GE (GEH50DEEDSR)[b]	2.45 & 2.4	1,382	N/A	N/A	1,382	40[e]	45%[f]
PNNL	2014	GE (GEH50DEEDSR)[b]	2.4	N/A	540 +/- 204[g]	Electric furnace	N/A	65[g]	N/A

a. Average of data provided for 50-gallon tanks: SWA, NREL and Ecotope also analyzed larger tanks

b. GE announced it is ceasing HPWH production by the end of 2016

c. Appears to be an older model

d. Simulation's average household size was 2.57 occupants; draw per day is calculated using 23 gals for the first occupant + 11 gals for any additional occupants

e. Estimated from paper's graph of draw distribution

f. Does not include space heating interaction

g. Adjusted values. PNNL reported losses with respect to a test home with ER space heating and with a large draw profile (130 gallons/day)

2.3.1 Past HPWH Field Testing

National Renewable Energy Laboratory (NREL), Electric Power Research Institute (EPRI), Ecotope, and Pacific Northwest National Laboratory (PNNL) have sponsored studies investigating HPWH performance, potential energy savings, and space conditioning impacts. The following sections provide details and findings related to each organization's study.

2.3.1.1 SWA

SWA ran one of the first publicly available studies to quantify HPWH field performance. The study was published in 2012 and was the source of the 2013-2015 TRM deemed savings estimate.

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The field study took place in 2010 and monitored ten GE Geospring units (50 gallon), two Stiebel Eltron Accelera 300 units (80 gallon), and two A.O. Smith Voltex units (one 66 gallon unit and one 80 gallon unit). The units were primarily installed in unconditioned basements in Massachusetts and Rhode Island and data were collected for over a year. The SWA paper reported some problems with the installation of these monitored HPWHs.[39] As a result, space conditioning impacts could not be determined and were not taken into account for the energy savings reported in this study. Additional information about the tanks tested is provided in Table 2-2.

Using the monitored data, the researchers were able to calculate valuable performance metrics.[40] A coefficient of performance (COP) was calculated for each of the 14 tanks.[41] COP is a performance metric defined as the useful heating energy generated by the HPWH divided by total energy consumed. The higher the COP, the more efficient the HPWH. The COP range for the 50-gallon tanks in this study was between 1 and 2.1.[42] On average, the 50-gallon tanks had a COP of 1.61.[43]

Table 2-2. Tanks Tested in SWA Study

Manufacturer	Capacity (gal)	Units Monitored	FHR (gal/hr)	EF	Average COP[c]	COP Range	% Electric Resistance
GE[a]	50	10	63	2.35	1.82[b]/1.61	1.4-2.1[b]/ 1.0-2.1	32.7%[b]/44%
A.O. Smith	60/80	1/1	68/84	2.33	2.12	2.1-2.1	5.6%
Stiebel Eltron	80	2	79.6	2.51	2.32	2-2.6	5.5%

a. GE announced it is ceasing HPWH production by the end of 2016.

b. Two values/ranges are included – the first omits one test site for the GE model that consistently had lower ambient temperatures under 50°F, resulting in much more operation in electric resistance mode than for HPWHs installed at other sites. The second value/range includes all units.

c. These COP values were calculated based on field data.

Another valuable insight gained from this paper was the estimated energy savings. For each of the field sites, the HPWH energy consumption was monitored and recorded. In addition, the study estimated how much energy the sites would use if equipped with electric resistance, natural gas, fuel oil, or propane storage water heaters. Comparing the actual HPWH energy use to the estimated ERWH energy use provides an indication of deemed savings. SWA reported energy savings of 1687 kWh/year for 50-60 gallon tanks. Those reported savings included one 60-gallon tank. If the one 60-gallon A.O. Smith tank is removed from the average, the savings become 1654 kWh/year for 50 gallon tanks.

[39] Eight units were installed in basements, had good airflow, and saw reasonable ambient temperatures. Five units were installed such that the cool, dehumidified outlet air could potentially be confined to a small space by closing a door. One unit was located in a Massachusetts basement that, during its first winter, consistently saw inlet air temperatures of between 77°F - 81°F due to standby losses for an old boiler located next to the HWPH.

[40] Details about the researchers' experimental method and additional findings can be found on their study website: http://ma-eeac.org/wordpress/wp-content/uploads/Heat-Pump-Water-heaters-Evaluation-of-Field-INstalled-Performance.pdf.

[41] Typically, COP, like EF, is tested in a lab setting; therefore, the SWA paper's COP should be considered a "field COP."

[42] One of the test sites in the study experienced very cold temperatures, causing the HPWH to act as an electric resistance tank (COP = 1).

[43] The A.O. Smith models had an average COP of 2.12 and the Stiebel Eltron models averaged 2.32. A heavier focus was placed on 50-gallon tanks in the literature review due to the Mass Save incentive structure.

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This study also addressed customer concerns related to HPWH technology. All 14 responders were satisfied by the performance of their HPWH. Four people noticed hot water runouts at some point and seven reported noticing a cooling and dehumidifying effect.

2.3.1.2 NREL[44]

In February 2016, SWA prepared an updated version of its study for NREL. This report was based on the same field tests done in 2010 for the original SWA report described in section 2.3.1.1. Therefore, the same installation problems described in the original paper affected this revision. The updated report for NREL provides a more detailed description of the performance of the HPWHs in the field and how variables that were not considered in the original version may have impacted savings.

In the updated version space conditioning impacts were discussed but not experimentally determined. HPWHs in this field study were primarily installed in unconditioned basements, which are not directly connected to HVAC equipment. In unconditioned installations, external impacts would influence the interaction between the HPWH and HVAC equipment, making it difficult to isolate the space conditioning impact.[45] In order to estimate a value for the space conditioning impact, the researchers used a thermodynamic energy balance to solve for the theoretical maximum potential impact.[46] In the NREL report, the calculated maximum cooling load reduction was approximately 1.5 MMBtu (440 kWh) and the maximum heating load increase was approximately 3 MMBtu (879 kWh).[47]

2.3.1.3 Ecotope

In 2015, on behalf of NEEA, Ecotope Inc. conducted a study to evaluate HPWH performance and energy use. Data used for this study included new field testing, laboratory tests, and old field studies conducted by the Bonneville Power Administration (BPA) and NEEA. The study's engineering model used data from over 100 field sites with the following characteristics:

- HPWH models: 46 Airgenerate ATI units (66 gallons), 33 GE Geospring units (50 gallons), and 28 A.O. Smith Voltex units (11 60-gallon units and 9 80-gallon units).[48]
- Region: Oregon, Washington, Montana, and Idaho.
- Installation location: 18 unconditioned basements, 44 garages, 14 interior installations (e.g., utility and laundry rooms), and 31 ducted interior installations.

The methodology behind the data collection and analytical methods can be found in Section 2 of the Ecotope/NEEA report.[49]

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[44] The monitored data for the original SWA report and the updated NREL paper do not match up even though the same water heaters were monitored. This could be due to deviations in the way the data was annualized

[45] External effects include air infiltration into the buffer space, ground coupling, solar gains, and heat transfer from mechanical equipment.

[46] Maximum potential impact = electrical energy used by the HPWH – thermal energy removed from the HPWH

[47] Because HPWHs remove heat from their surroundings, they reduce the load on home cooling systems in the summer but increase the load on home heating systems in the winter.

[48] Only 20 of the A.O. Smith Voltex tanks were provided with gallon size breakdown.

[49] http://neea.org/docs/default-source/reports/heat-pump-water-heater-saving-validation-study.pdf?sfvrsn=8

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In order to quantify HPWH performance, Ecotope developed a measure of system efficiency—average or annual coefficient of performance (aCOP). aCOP is analogous to EF and COP discussed in Section 2.3.1.1, but has a different name to distinguish that different testing conditions are used.[50] For the 50-gallon GE units, the aCOP range observed was 1.24 to 2.68, and the average was 1.85. As expected (and similar to the SWA report in Section 2.3.1.1), this study found that HPWHs in the field did not fully perform to their EF rating.

Space conditioning impacts were also approximated in this paper. Ecotope defined a space conditioning factor, HC_f, as a measure of the degree of "thermal coupling" between a HPWH and a home's heating system. In a "fully coupled system," HC_f =1, meaning that every unit of energy taken out by the HPWH is accounted for and replaced by the heating/cooling system. In a system that is not "thermally coupled," HC_f=0, meaning that the energy taken out by the HPWH has no impact on the heating/cooling system.[51] Ecotope attempted to run five "flip-flop" field tests to determine HC_f.[52] The results from these flip-flop tests were statistically insignificant. Therefore, Ecotope and the RTF (Regional Technical Forum) designated HC_f values for typical installation locations based on their observations during testing. For garages and unconditioned basements, HC_f was set as zero.[53] For interior installations, HC_f was set as 0.65.[54] Ecotope only considered the space conditioning impact on the heating load, as the impact on the cooling load was deemed to be negligible.

For Ecotope's energy savings calculation, a 0.95 EF electric resistance storage water was used as the baseline. Ecotope assumed an average occupant size of 2.57 occupants for household. Ecotope provided a matrix of results for a combination of different inputs such as tank size, home heating system, installation location, and climate. Navigant focused on the savings for the GE Geospring unit in an interior installation located in heating zone 2 (HZ2).[55] In this installation configuration the energy savings are 1375 kWh/year. This value does not account for space conditioning impacts, which are discussed later in this report in section 2.3.2.1.

2.3.1.4 EPRI

In 2012, EPRI was contracted by New York State Energy Research and Development Authority (NYSERDA) and the State of Delaware to investigate the performance of HPWHs. The study included field testing of 45 water heaters: 5 ERWHs and 40 HPWHs. Twenty-four of the HPWHs were first-generation, and 16 were second-generation.[56] The location of the study was Delhi, New York, which is

[50] A description of aCOP can be found on page 41 of the Ecotope/NEEA report.

[51] HC_f has a maximum value of 1 and a minimum value of 0.

[52] The "flip flop" test was forcibly switching the HPWH between operating modes and tracking the change on the HVAC system load.

[53] The study did not feel enough data was available to make a non-zero estimate.

[54] Based on the first law of thermodynamics, the interaction factor for an interior installation would be 1. Navigant conducted a phone interview to clarify Ecotope's reasoning behind their estimate of 0.65. One factor could be latent heat removal not needing to be replaced by the home heating system. Also, localized cooling effects may not reach the thermostat, so the HVAC system may not have to compensate for all sensible heat removal by the HPWH. Finally, shoulder-season gains, such as solar gains could contribute. Shoulder season effects will vary with the home's quality of insulation, windows and air sealing.

[55] Heating zones as defined by the Northwest Power & Conservation Council. The climate zone best representing Massachusetts was HZ2.

[56] The paper did not specify which models were first- or second-generation.

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very similar in climate to Massachusetts. All but one of the water heaters were installed in basements (including both fully conditioned and unconditioned).[57]

The results of this study were mixed:

- First-generation HPWHs performed poorly, with a COP around 1.0.
- Second-generation HPWHs performed well, with a COP around 2.0.

The paper concluded that the annual energy savings for second-generation HPWHs were 1,382 kWh, or 45% savings over an ERWH.

The whole-house heating/cooling load impact was not determined in this study. The EPRI study only assessed how space conditioning affects the performance of the HPWH.[58] Therefore, no conclusions could be drawn about space conditioning impacts on energy use from this study. However, the results of the EPRI paper did provide validation that HPWHs can perform efficiently in cold climates. The second generation HPWHs achieved COPs greater than 1.5 even in average ambient temperatures under 50°F. Although the HPWHs' COPs were lower in colder months, they still provided energy savings over ERWHs.

2.3.1.5 PNNL

In 2014, the DOE published a PNNL study assessing the energy performance and demand response characteristics of GE's second-generation GeoSpring HPWH. Two tests were conducted in PNNL's two identical test homes in Richland, Washington. In one test home, a HPWH with exhaust-only ducting was tested. In the other test home, a HPWH with full ducting was tested. Both HPWHs in this study were installed in conditioned water heater closets on the first floor of the test home.[59]

Fully ducting a HPWH is rarer in Massachusetts than in the Northwest. However, the comparison of a fully ducted HPWH to a non-ducted HPWH does provide insight to the impact of space conditioning on the energy use of HPWHs. In theory, a fully ducted HPWH is isolated from the home's HVAC system. These HPWHs exhaust cold air to the exterior of the home, not in the conditioned space inside the home. Comparing the heating loads of test homes with different ducting configurations provided a good estimate of the maximum space conditioning impact of the HPWH.

The PNNL study determined that fully ducting a HPWH and isolating it from the HVAC system would save 1,079 +/- 408 kWh/year over an unducted HPWH.

[57] One unit was installed in a garage. 15 units were installed in unconditioned basements. 4 units were installed in a conditioned basement with a furnace nearby. 20 units were installed either in a conditioned basement with no furnace nearby or in an unconditioned basement with a furnace nearby.

[58] HPWHs will operate at a higher efficiency if located next to an operating heat source that has on-mode jacket losses (e.g., a boiler).

[59] Installations followed the requirements of the HPWH manufacturer.

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2.3.2 Literature Review Inputs to Adjustment of Deemed Savings

The two goals of the literature review were to examine impact of space conditioning interactions and how HPWHs were performing in the field. Information about space conditioning impacts was gathered from the SWA/NREL, Ecotope, and PNNL papers and is described below.

2.3.2.1 Space Conditioning Impact

Navigant first used the results from the SWA/NREL paper to develop a rough estimate of HPWH space conditioning impact for basis of comparison with other sources. In the paper SWA revised for NREL, the maximum cooling load reduction, for a HPWH installed in the conditioned space, was estimated to be approximately 1.5 MMBtu (440 kWh) and the maximum heating load increase, for a HPWH installed in the conditioned space, was approximately 3 MMBtu (879 kWh).[60] These load increases represent the theoretical worst case scenario (the maximum space conditioning impact). Navigant scaled these loads down based on the COPs of common space conditioning equipment. Navigant assumed homes are cooled in the summer by a 4 COP air conditioning system, yielding a decrease in air conditioning energy consumption of 110 kWh. Assuming homes are heated by a 2 COP heat pump in the winter, the heat pump energy consumption would increase 440 kWh. This equates to a net space conditioning impact of 330 kWh/ year. For a home with electric resistance baseboard heating, the heating system energy consumption increase would be 879 kWh and the net space conditioning impact would be 769kWh/year if the home has air conditioning.

Space conditioning impacts determined in the PNNL study were also considered. The reported impact in the PNNL paper was larger than impacts estimated by NREL and Ecotope in Sections 2.3.1.2 and 2.3.1.3. This was due to PNNL implementing a high demand water draw profile in its testing. A 130 gallon/day water draw profile was more than twice the size of what the other studies observed or simulated. This draw profile in turn exaggerated the space conditioning interaction. Cutting the draw profile by a factor of 2 reduces the impact to 540 +/- 204 kWh/ year for a home with electric furnace heating. If a heat pump heating system is assumed, the impact drops to 270 +/- 102 kWh/year.

The calculation done by SWA for the NREL report was based off a theoretical energy balance and led to impacts that represent the worst-case scenario for space conditioning impacts. PNNL's paper focused more on ducting of HPWHs and only monitored two water heaters. Additionally, only the Ecotope study examined the space conditioning impacts from several different types of home heating systems. Therefore, Navigant used the results from the Ecotope study to provide estimates for the space conditioning impact.

The literature review did not provide a consistent estimate of the impact on the space conditioning load of a HPWH installed in an unconditioned space (e.g., an unfinished basement). The Ecotope study acknowledged that there would be some space conditioning impact of a HPWH installed in an unconditioned basement but nevertheless assumed no impacts in its analysis. In contrast, the NREL study assumed that a HPWH installed in an unfinished basement would have the same space conditioning impact as one installed in a finished basement. Because the space conditioning impact of a HWPH installed in an unfinished basement is somewhere between 0% and 100% of the impact of a

[60] Because HPWHs take out energy from their surroundings, they reduce the load on home cooling systems in the summer but increase the load on home heating systems in the winter.

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HPWH installed in the conditioned space, an impact of 50% of was conservatively assumed for this analysis.

Table 2-3 summarizes the space conditioning impacts found for several home heating systems in the Ecotope study for a HPWH installed in a conditioned space. Navigant used Ecotope's estimates for impact of a HPWH in a conditioned space and applied the 50% factor previously mentioned to reflect installation in an unfinished basement. The results of the customer survey implemented as part of Task 2 allowed Navigant to estimate the ratio of conditioned to unconditioned installation locations for Massachusetts HPWH customers (discussed in Section 3.2.3). All values taken from the Ecotope report correspond to heating zone 2, which best matches the climate of Massachusetts. Reduction in home cooling load due to the HPWH was assumed to be negligible in the Ecotope study. The Ecotope study also did not include the effect of a HPWH on the operating load of a dehumidifier for cases in which the HPWH and dehumidifier are both located in the basement.

Table 2-3 Ecotope Space Conditioning Impact with respect to home heating system

Home Heating System	Space Conditioning Impact	% Impact on Savings
Electric Resistance Zonal Heat[61]	350 kWh/year	25.5%
Heat Pump	272 kWh/year	19.8%
Gas-fired Furnace[62]	15 kWh/year[63]	1.1%

2.3.2.2 Energy Savings in Field

In terms of energy savings associated with HPWHs, the reviewed studies indicate that deemed savings of HPWHs in the field has fallen short of Massachusetts TRM estimated deemed savings. One significant difference is that the MA TRM estimated deemed savings do not include space conditioning impacts. However, even if space conditioning impacts are not considered, the NREL, Ecotope, and EPRI papers report less energy savings than the 1654 kWh/year estimated deemed savings in the MA TRM. A summary of the savings for 50 gallon water heaters based on reviewed studies is shown in Table 2-4, excluding space conditioning impacts.

Table 2-4. HPWH annual energy savings over ERWH excluding space conditioning impacts

Source	Net Savings
SWA	1,654 kWh/year
NREL[64]	1,605 kWh/year

[61] Zonal heat refers to electric resistance baseboard heating.

[62] Ecotope reported the impact for a gas-fired furnace. Navigant assumed the gas-fired furnace simulated by Ecoptope and an oil-fired boiler would have similar on-mode electricity consumption.

[63] This impact reflects only the increase in on-mode electricity consumption. Ecotope did not report the impact on fuel consumption. Navigant converted Ecotope's estimated space conditioning impact for electric resistance baseboard heating from kWh/yr to fossil fuel consumption per year by assuming 100% efficiency for electric resistance baseboards and 80% AFUE for a baseline furnace or boiler (gas-fired or oil-fired).

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Ecotope	1,375 kWh/year
EPRI	1,382 kWh/year

There are several potential reasons for the discrepancy between field performance (reported in the examined studies) and the Massachusetts TRM (and PA-adjusted deemed savings). The lower field test values may be attributable to differences in the water draw profile, water inlet temperatures, and variations in ambient temperature. For example, some of the HPWHs tested in the EPRI study experienced ambient temperatures under 50 degrees. Lower ambient temperatures result in lower efficiency for heat pump mode and increase the likelihood that electric resistance backup element operation will be required. Although there were some discrepancies between the adjusted MA TRM deemed savings and the energy savings reported in each reviewed paper, the energy consumption values measured were of the same order of magnitude– with ERWHs consuming around 3,000 kWh/year and HPWHs consuming around 1,500 kWh/year. The MA TRM values, based on the SWA report, were 3330 kWh/year for ERWH consumption and 1643 kWh/year for HPWH consumption. Because the original SWA numbers come from a study done in MA and RI (rather than the Pacific Northwest), Navigant used the original energy consumption numbers for the basis of their adjusted calculation.

The field tests in the reviewed studies (as well as the Massachusetts TRM) do not reflect the increased efficiency of new HPWH models. EFs of HPWHs tested in the reviewed studies were around 2.35 (see Table 2-1), but some of the newest models of HPWHs have EF ratings exceeding 3. From 2015-2016, the mean EF of HPWHs installed under the Mass Save program was 2.625 (as discussed in Section 2.1.1 of this report). Navigant incorporated an adjustment to the HPWH deemed savings estimate to account for this increase in efficiency in new generation HPWHs (Section 4.1).

2.3.3 Upcoming Testing

Through phone interviews, Navigant learned about upcoming tests being done in the Pacific Northwest that may provide valuable information relating to HPWH deemed savings adjustments. BPA, NEEA, and Portland General Electric (PGE) will be running a 12-month study in order to study demand response events in 300 ERWHs and 300 HPWHs. The focus of the testing will be on CEA2045, a universal appliance device that allows for wireless control of demand response events. Although demand response and verifying the capabilities of CEA2045 are the main goals of this study, valuable performance data of new HPWHs should be available.

Additionally, PNNL and Ecotope will be running tests to better understand the interaction factor, HC_f, discussed in Section 2.3.1.3, which may provide additional data related to the impact of space conditioning on HPWH deemed savings.

[64] Although the NREL and original SWA paper were written based on the same field study, the data reported was different. The NREL paper does not explicitly report a deemed savings estimate – the 1605 kWh/year net savings was calculated by Navigant from the appendix provided in the NREL report. The discrepancy between the NREL and SWA deemed savings could be due to deviations in the way the data was annualized in each report.

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3. TASK 2: PARTICIPATING CUSTOMER SURVEY

For Task 2, the Navigant team conducted an online survey of customers who received the HPWH rebate during the 2014 or 2015 program years in order to better understand customers' reasons for selecting a HPWH, the role the program played in their purchase decision, and their experience and satisfaction with the unit to date. This section provides details related to:

1. **Survey Sample Characterization.** This subsection describes the survey sample selection process and provides a summary of the similarities and differences between surveyed customers and the entire population of HPWH rebate participants.
2. **Survey Results.** This subsection discusses the results of customer surveys.

3.1 Survey Sample Characterization

In an effort to create a survey sample that proportionally represented the various climate regions in Massachusetts, Navigant selected a survey sample using stratified random sampling with proportionate allocation by region. Survey fielding included targets by stratum based on this allocation. Invitations to take the online survey were sent to 2,054 program participants. Of those who received a survey invitation, 339 customers completed the survey (a 17% response rate). Figure 3-1 shows the final proportions of customers by region for the entire population of HPWH rebate recipients and the sample of surveyed customers, respectively.

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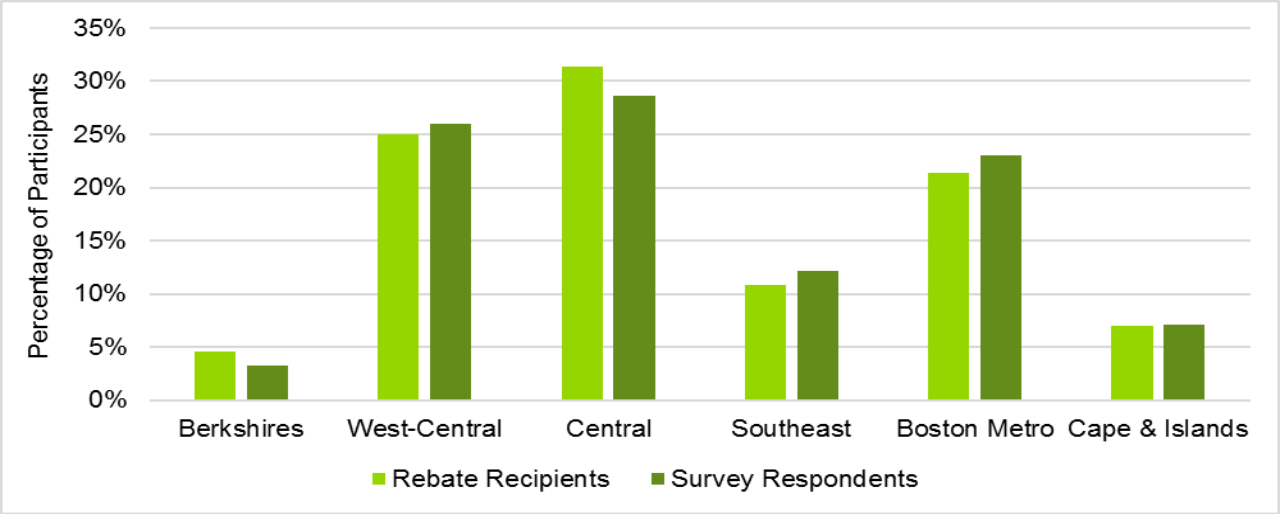
Figure 7. Regional Breakdown for All Rebate Recipients (N=3,513[65]) and Survey Respondents (N=339)



Additional comparisons between the survey sample and the entire population of rebate recipients were made in order to confirm the representativeness of the survey sample. These comparisons relate to the tank size and age of the water heaters replaced by HPWHs, as well as the installation location of HPWHs. In all cases, the survey sample and larger population displayed similar characteristics. Figures showing these comparisons are available in Appendix B (Figure B-1 to Figure B-4).

3.2 Survey Results

This section provides customer survey findings related to the following key research areas:

- Customer purchase decisions
- Replaced water heater characteristics
- HPWH installation and use
- HPWH performance and satisfaction

In addition to the findings described in this section, findings related to other topics addressed in the customer survey can be found in Appendix B.

[65] Navigant received program application data for the 2014 to early 2016 program years directly from the PAs and, subsequently, from the program's implementation vendor. The latter data set contained additional fields related to replaced water heater characteristics and the HPWH installation locations that were not present in the original data set from the PAs. The two sets of program data had differences relating to the number of customers who had applied for a HPWH rebate. Therefore, the final count of rebate recipients and summary of rebate recipient characteristics is based on the overlapping customers (i.e., customers listed in both data sets), n = 3,513.

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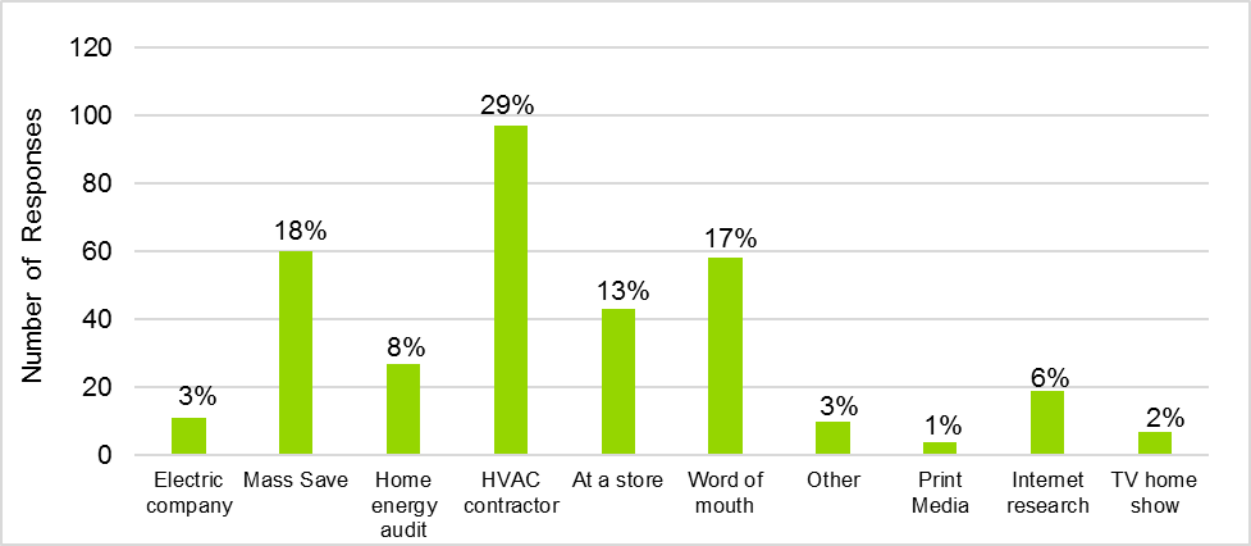
3.2.1 Purchase Decision

Contractors play an important role in exposing participants to HPWHs and recommending specific models. Participants first learned about HPWHs from a variety of sources, with HVAC contractors or plumbers, Mass Save, and word of mouth most frequently cited (Figure 3-2). Similarly, when asked how they chose a specific HPWH model, close to half of survey respondents reported that they chose a specific model based on their contractor's recommendation and half mentioned choosing a model based on those listed as qualified on Mass Save (37 respondents cited both influences).

Figure 8. How did you first learn about heat pump water heaters? (N=336)



More than 75% of survey respondents reported total HPWH purchase and installations costs of less than $2,000 before accounting for the Mass Save rebate and Federal Tax Credit ($300). Interestingly, customers may be unaware of the Federal Tax Credit for HPWHs (discussed in Section 2.1.1), indicated by the fact that only 27% of respondents reported that they had received the Federal Tax Credit in addition to the Mass Save rebate (Figure 3-3). Other explanations for the relatively small proportion of federal tax credit recipients include the fact that residential energy efficiency tax credits were capped at $500 for the 2011-2016 time period and HPWHs installed in new construction did not qualify for the tax credit.[66]

[66] https://energy.gov/savings/residential-energy-efficiency-tax-credit; https://energystar.zendesk.com/hc/en-us/articles/211437758-Is-there-a-tax-credit-for-electric-heat-pump-water-heaters-

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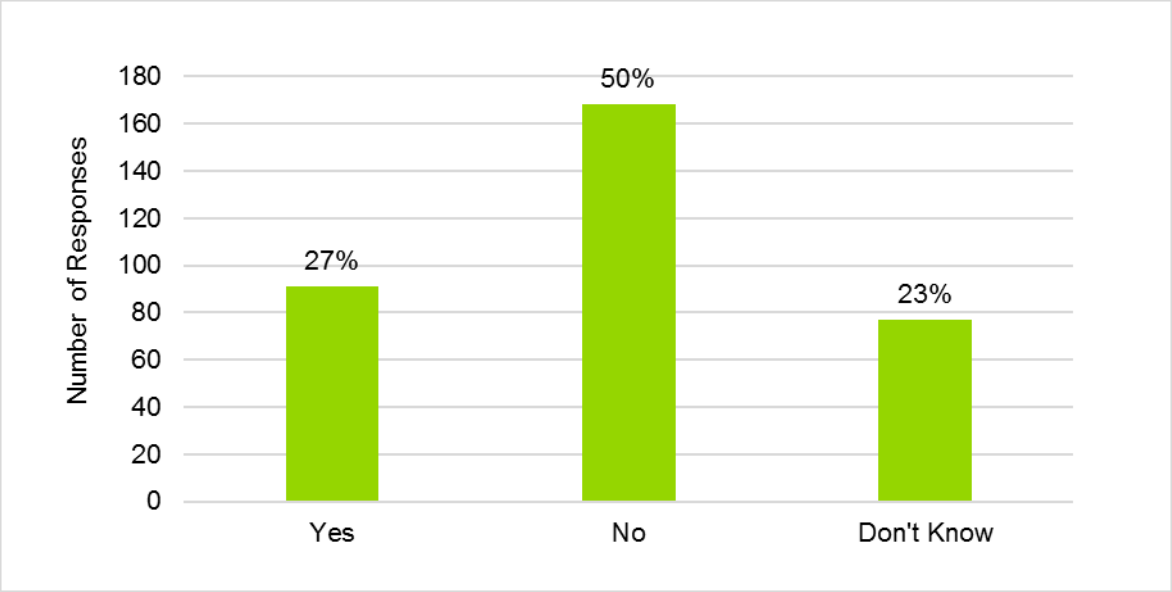
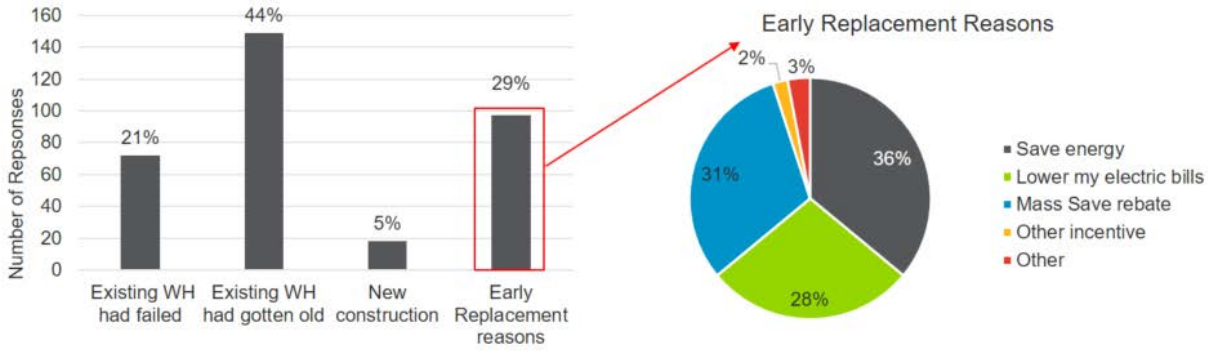
Figure 9. In addition to the Mass Save rebate, did you receive the Federal Tax Credit for the purchase of your heat pump water heater(s)? (N=336)



Approximately 30% of survey respondents indicated that their HPWH purchase was an "early replacement." As indicated in Figure 3-4, close to three-quarters of respondents purchased a new water heater because their previous water heater had failed or gotten old, or because their property was a new construction. Among those whose purchase reason was categorized as early replacement, the reasons for replacing early included the desire for energy and bill savings and because of the availability of the Mass Save rebate. Of note, out of customers whose new water heater purchase was categorized as early replacement, approximately 37% indicated their replaced water heater was over 12 years old and 80% reported that their replaced water heater was 9 years old or older.

Figure 10. Why did you decide to install a new water heater?



N=336

N=200 (Multiple Responses Allowed)

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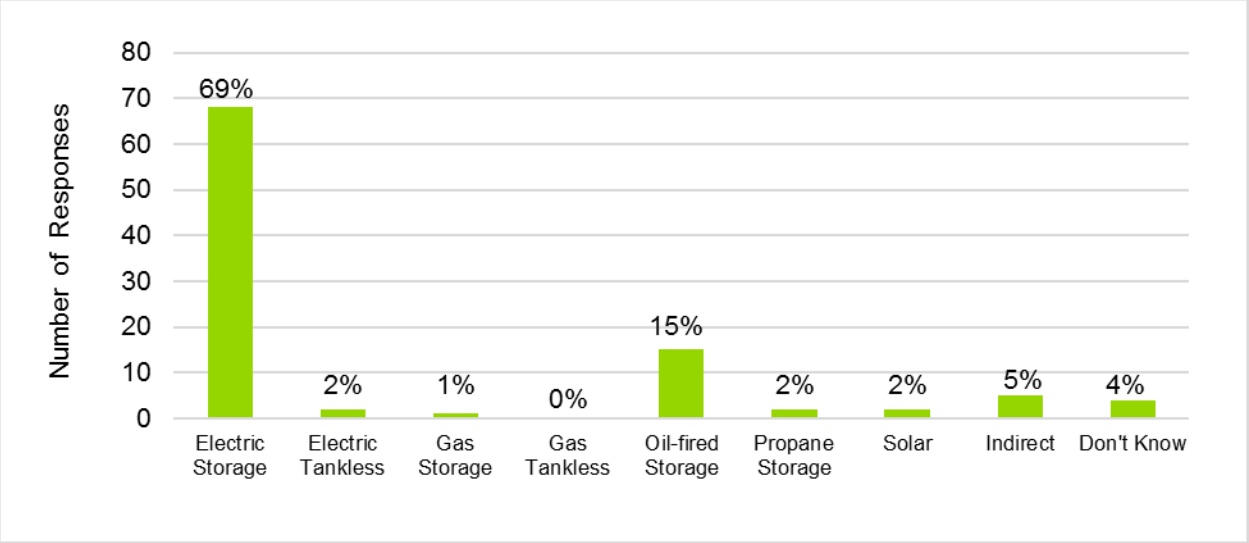
Close to half of survey responders did not consider any alternative water heating technologies. The most commonly cited alternatives considered were electric storage and electric tankless. Figure B-8 in the Appendix B shows the breakdown of alternative water heater types considered by customers (excluding those who did not consider alternatives).

3.2.2 Replaced Water Heater

In order to investigate the baseline for retrofits, questions about replaced water heater characteristics were only asked of those whose new water heater purchase was categorized as early replacement (approximately 30% of respondents).

Of early replacement HPWH purchases, the majority replaced electric storage water heaters (69%). However, 15% of early replacements purchases replaced oil-fired storage water heaters. These findings conflict with rebate criteria listed on the Mass Save website.

Figure 11. What type of water heater was replaced? (N=99, Early Replacement Only)



Of early replacement survey respondents, 21% reported that they installed a HPWH with a tank size that was smaller than that of the replaced water heater. As indicated in Section 2.2.1, when looking at the total population of rebate recipients, the percentage of customers who downsized is approximately 40%. The main reason cited for getting a smaller water heater was that a larger one was no longer needed.

Figure 12. Why did you purchase a heat pump water heater(s) with a tank size (gallons) that was smaller than that of the water heater(s) you replaced? (N=16, Early Replacement Only)

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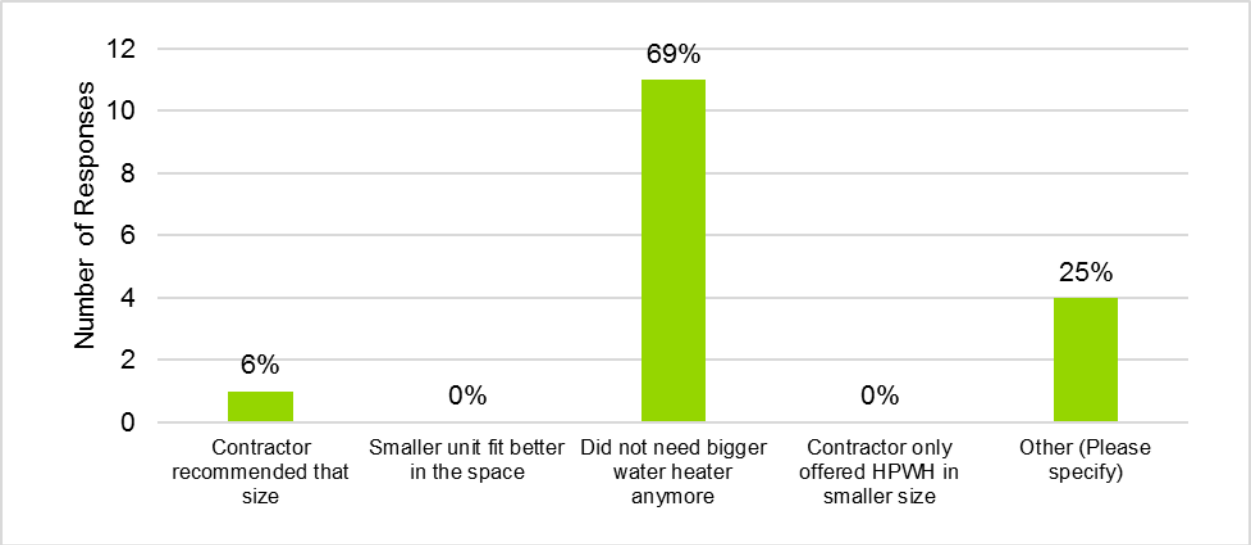

3.2.3 Installation and Use

The majority of HPWHs are installed in unfinished basements. The survey showed 78% of respondents have HPWHs installed in an open basement and 16% have HPWHs installed in a basement closet or utility room (comparatively, 98% of all rebate recipients installed their HPWHs in basements or garages). Of HPWHs installed in a basement or utility closet, 76% were installed in unfinished basements.

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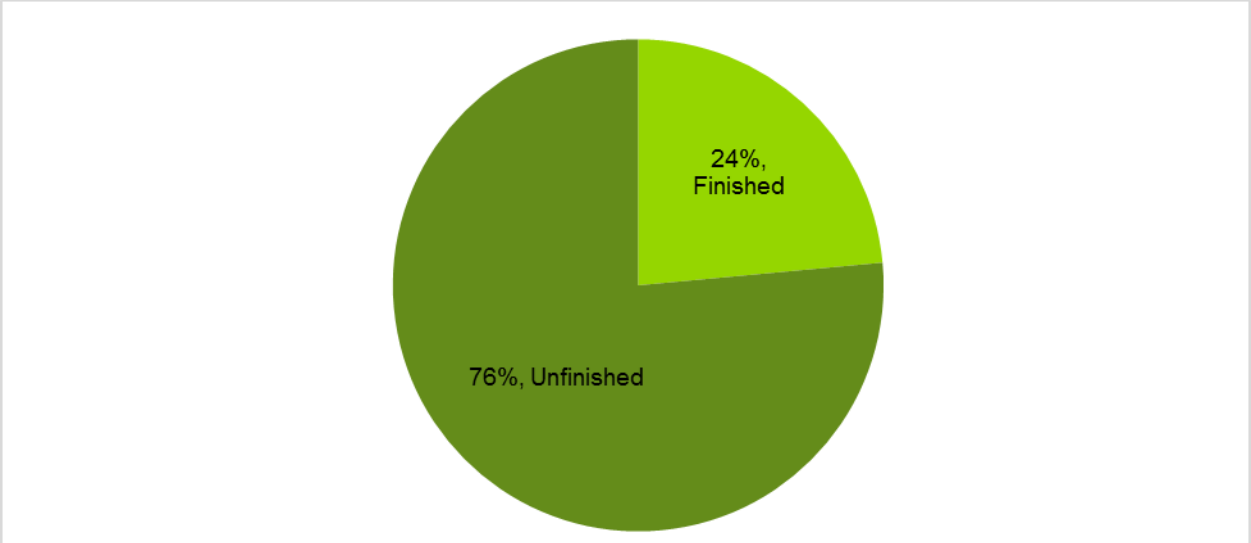
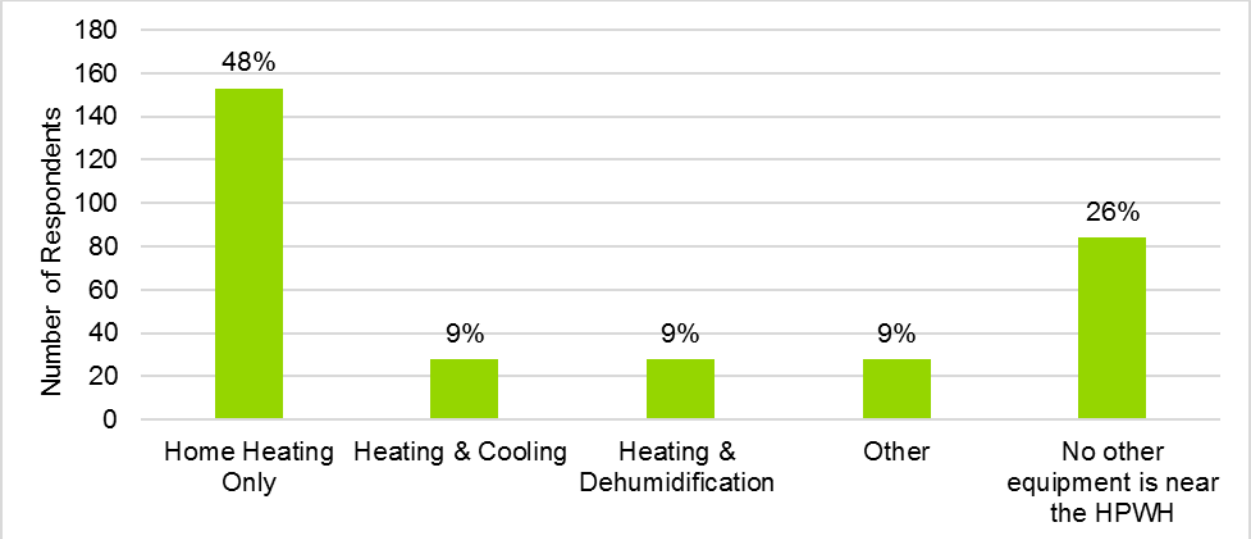
Figure 13. Is the basement finished or unfinished? (N=306)



Home heating equipment is the most common type of HVAC equipment installed near HPWHs. As indicated in Figure 3-8, 60% of customers have their HPWHs installed near heating equipment.

Figure 14. What other equipment is installed near (i.e., same space) the heat pump water heater? (N=325, Multiple Responses Possible)



The primary heating system fuels cited by survey respondents who replaced ERWHs were fuel oil (49%) and electricity (26%). Findings related to other installation characteristics are included in the Appendix B.

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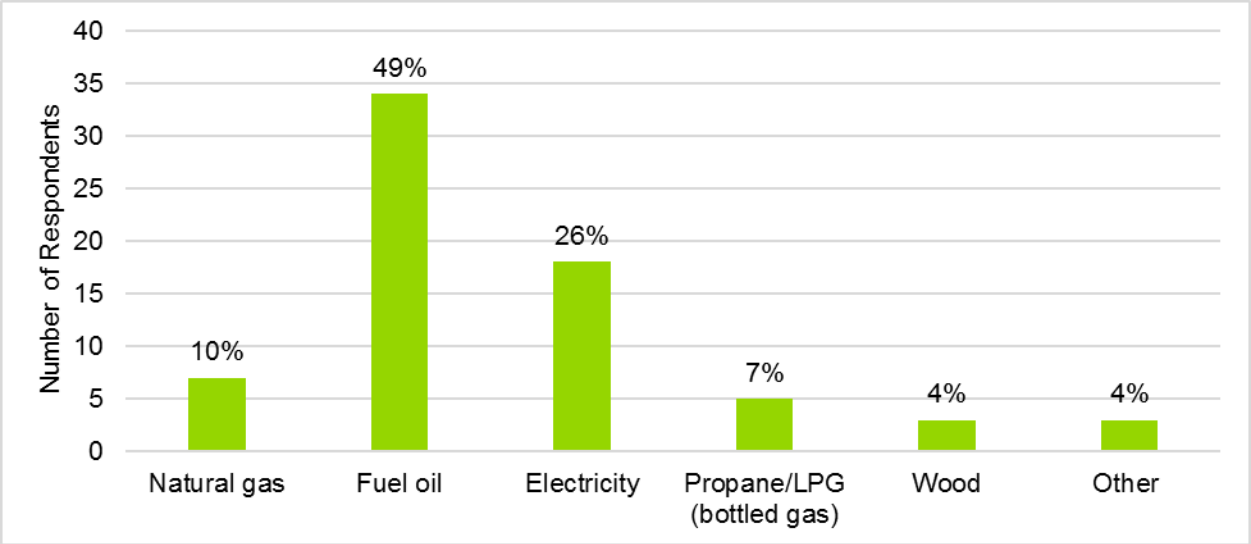
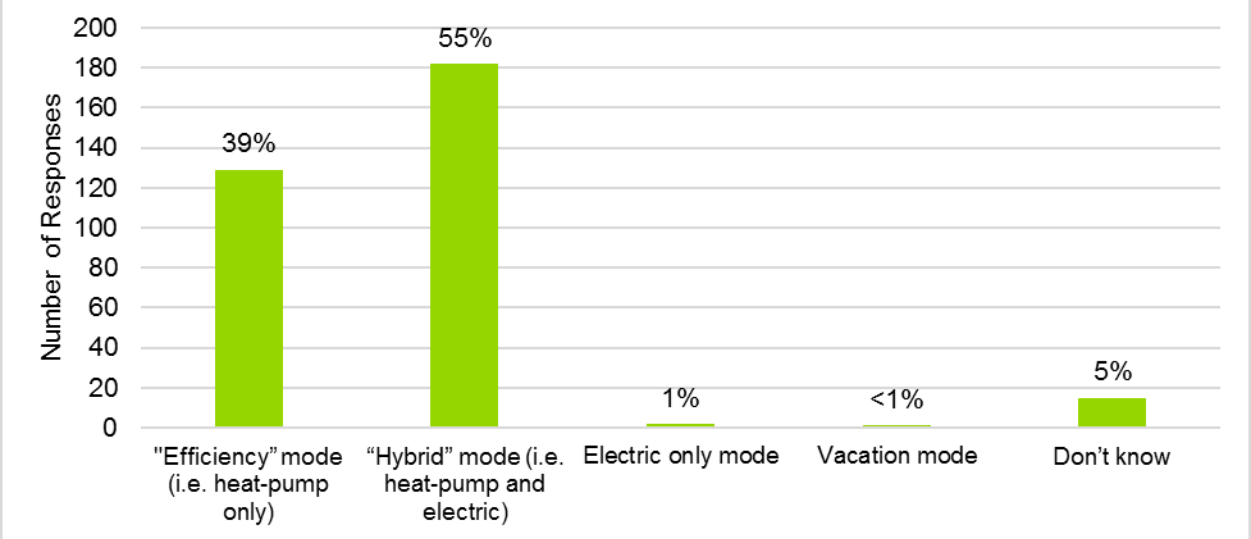
Figure 15. Primary Home Heating Source for Those Who Replaced ERWH (N=70[67])



The majority of HPWH owners utilize the heat pump. As shown in Figure 3-9, 94% of HPWHs are set to utilize the heat pump in some capacity, with close to 40% of customers using "efficiency" mode and 55% using "hybrid" mode. Five percent of customers did not know the operational mode of their HPWH. The operational modes used shows a correlation to customers' perceptions of bill savings due to their HPWHs, with 85% of customers reporting that their HPWH has saved them at least some money on energy bills.

Figure 16. What operational mode is your heat pump water heater set to? (N=329)



[67] The reduced sample size for this figure is associated with that fact that only those categorized as early replacement were asked about the type of water heater they replaced. Additionally, as indicated in section 3.2.2, approximately 30% of respondents replaced water heaters other than ERWHs.

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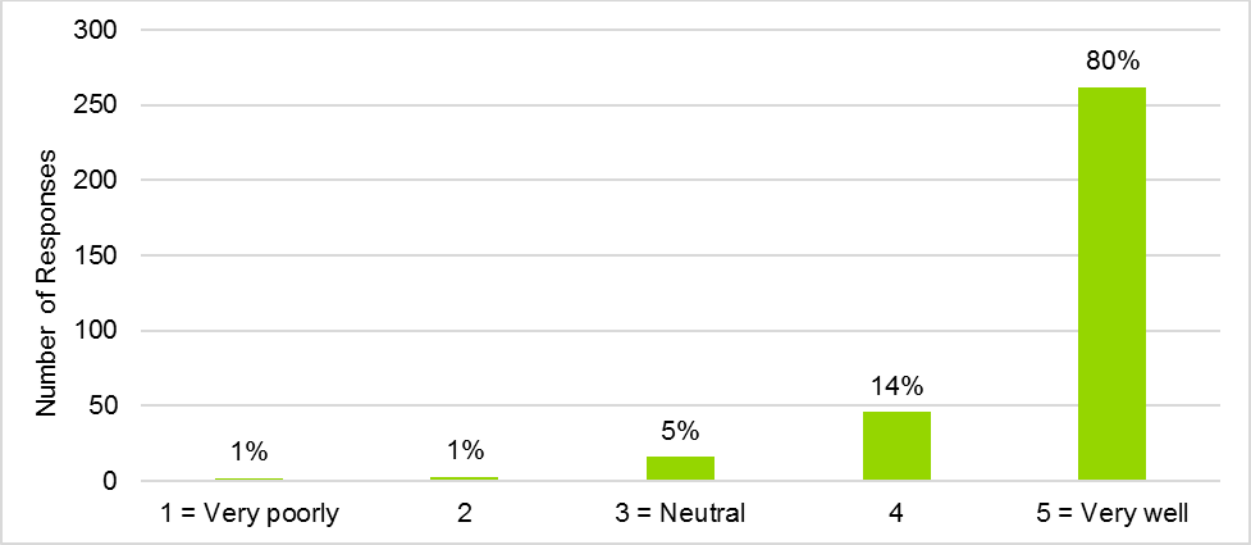
3.2.4 HPWH Performance and Satisfaction

The majority of customers are happy with the performance of their HPWH. As evidenced by Figure 3-10, 94% of customers indicated that their HPWH has performed well. Those who were less satisfied with the performance of their HPWH cited hot water runouts (12 respondents) and broken parts (5 respondents) as the primary reason.

Additionally, 92% of customers who had their HPWH installed by a contractor reported being satisfied with their contractor. For those who were not satisfied with their contractor, improper installation (5 respondents) and non-responsiveness (3 respondents) were the most cited reasons.

Figure 17. Using a scale of 1 to 5 where 1 indicates "Very Poorly" and 5 indicates "Very Well," how well has your heat pump water heater performed since it was installed? (N=329)



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Approximately two-thirds of respondents attributed their HPWH to a positive change in their homes' comfort. As shown in Figure 3-11 and Figure 3-12, 77% of respondents have noticed a change in comfort level in their homes, but 89% of these customers reported that the change has been positive.

Figure 18. How much has your heat pump water heater affected the comfort level of your home or area surrounding your heat pump water heater? (N=329)

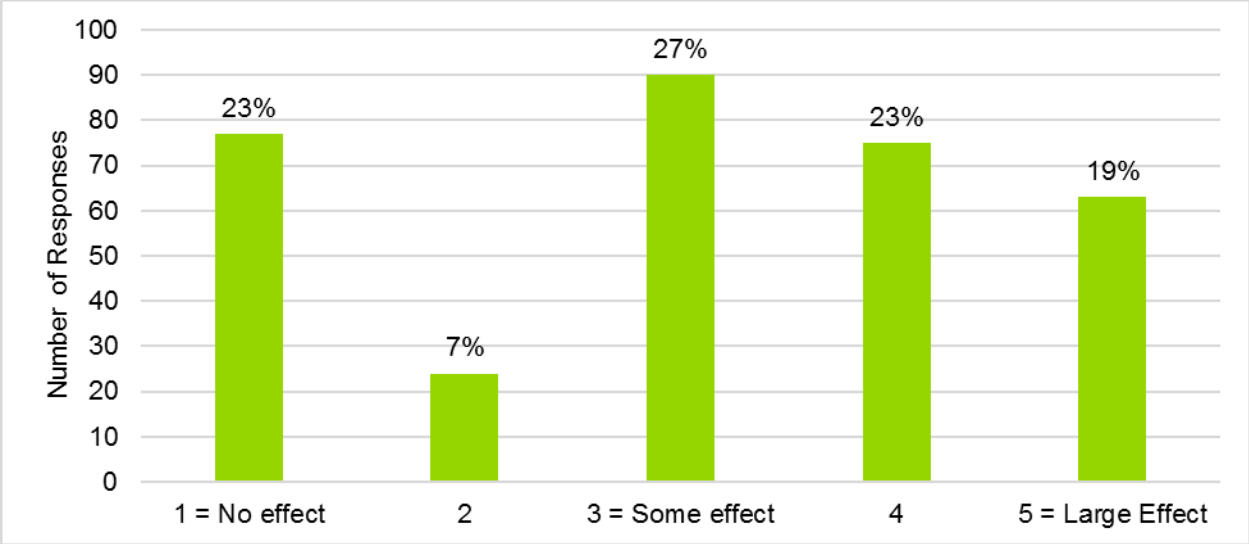
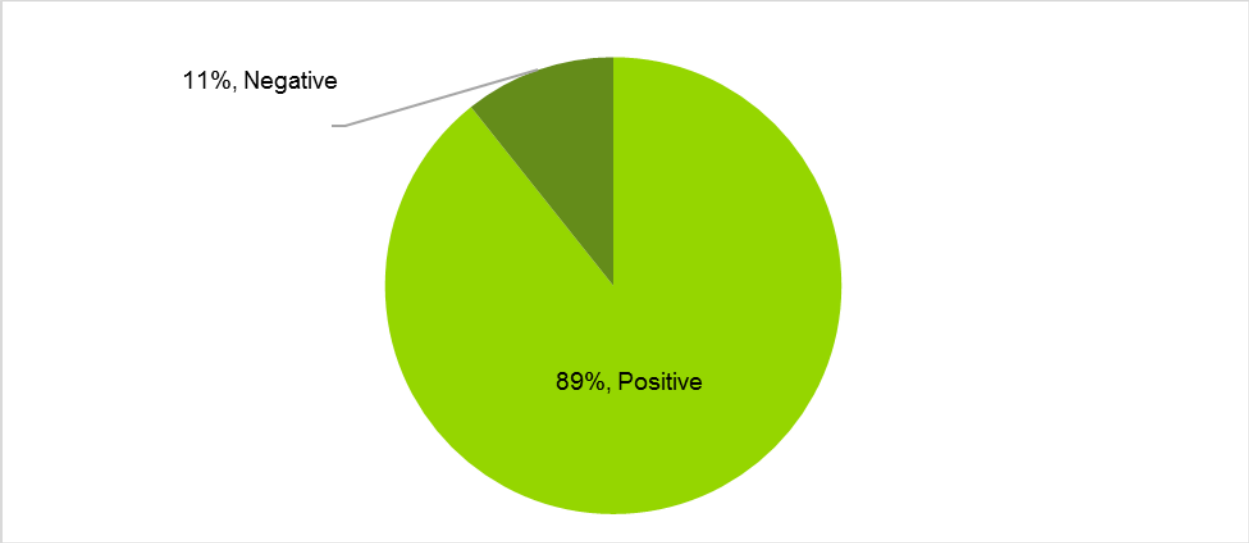


Figure 19. Has this effect been Positive or Negative? (N=252)



As shown in Figure 3-13, respondents whose comfort level was improved due to their HPWH most commonly cited the dehumidifying quality of the HPWH. Those who reported a negative change in comfort most commonly cited the cooling effect of the HPWH (20 respondents), though a greater number of participants (41 respondents) cited the cooling effect as a positive change.

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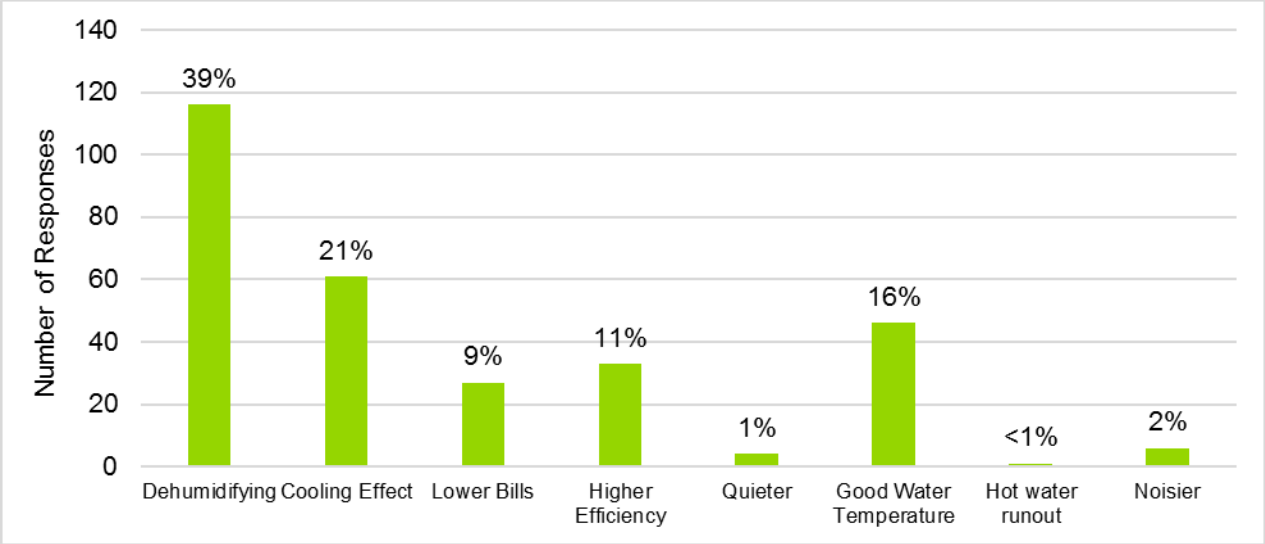
Despite the fact that 40% of participants downsized when they purchased their HPWH, less than 1% cited hot water runouts as a source of discomfort. Noise level was also cited by a small number of respondents as a negative impact (6 respondents).

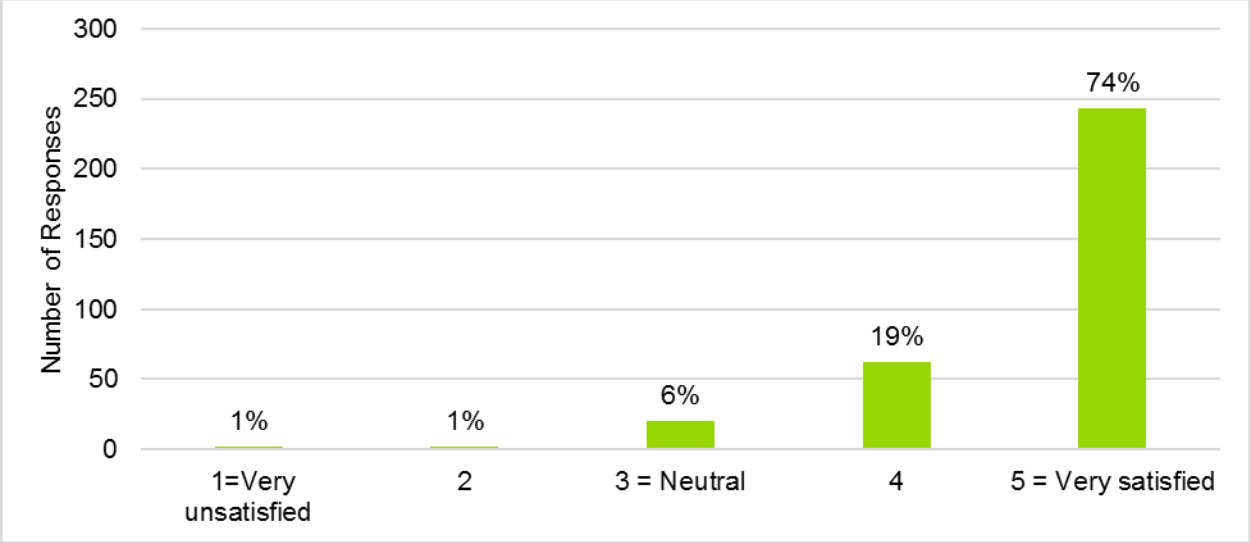
Figure 20. Please describe how your heat pump water heater has had an effect on the comfort level of your home or area of your home? (Open response, Describe all, N=294)



Note: "Cooling Effect" was reported by 41 participants as a positive change in comfort, while 20 participants cited the cooling effect of their HPWH as negative effect. "Hot water runout" and "Noise" were cited as negative effects. The remaining responses were cited as positive effects.

Satisfaction with HPWHs is very high. As shown in Figure 3-14**,** 93% of respondents were satisfied with their HPWHs. In open-ended feedback, customers indicated that they were most pleased with bill and energy savings. Only two customers cited hot water runouts as a reason for being less than satisfied with their HPWHs.

Figure 21. Overall, how satisfied are you with your heat pump water heater? (N=329)



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4. KEY FINDINGS AND RECOMMENDATIONS

4.1 Deemed Savings Adjustment

Information obtained in Task 1 and Task 2 through literature review and customer surveys allowed for an adjustment to the current estimate of deemed savings employed by Massachusetts Program Administrators (the PAs) in order to quantify the savings impacts of HPWHs, including the impacts of space conditioning.[68] As a result of Task 1 and Task 2 findings (including the fact that several different home heating sources were cited by survey respondents), a blended deemed savings estimate of HPWHs was developed that is a weighted average of the savings for several types of home heating equipment: an air-source heat pump, electric resistance baseboards, and fossil fuel-fired equipment (natural gas-fired, propane-fired, and oil-fired furnaces and boilers). The weightings for each home heating source are based on the most recent baseline study from MA[69] and the Task 2 survey feedback. The weightings used are presented in Appendix C. Appendix C also includes the individual deemed savings estimates developed for each home heating source. Deemed savings estimates were developed using the equation below.

Table 4-1 HPWH Deemed Savings Calculation

$$Deemed\ Savings = (1\ - S_c)\left(\ ERWH_{consumption,old}\left(\frac{EF_{old}}{EF_{new}}\right)_{ERWH} - HPWH_{consumption,old}\left(\frac{EF_{old}}{EF_{new}}\right)_{HPWH}\right)$$

$$Deemed\ Savings = (1\ - S_c)\left(3330\frac{kWh}{yr}\left(\frac{0.91}{0.945}\right) - 1643\frac{kWh}{yr}\left(\frac{2.35}{2.625}\right)\right)$$

Where

S_c= Percentage of water heater electricity consumption offset by increased electricity consumption for space heating, varies by home heating source. The weighted-average value for all home heating sources is 4.8% (this does not include fossil fuel consumption).

$ERWH_{consumption,old}$ = Annual energy consumption for a 0.91 energy factor (EF) 50-gallon electric resistance water heater (ERWH) [70]

$EF_{old,ERWH}$= Federal minimum EF standard for residential electric storage water heaters manufactured before April 16, 2015

$EF_{new,ERWH}$= Federal minimum EF standard for residential electric storage water heaters with storage volume ≤55 gallons manufactured on or after April 16, 2015[71]

[68] The current deemed savings estimate for HPWHs is 1,654 kWh/year and is based on an adjustment to the 2013-2015 Massachusetts Technical Reference Manual (MA TRM). http://ma-eeac.org/wordpress/wp-content/uploads/TRM_PLAN_2013-15.pdf.

[69] http://ma-eeac.org/wordpress/wp-content/uploads/11_MA-Residential-Appliance-Saturation-Survey_Vol_1.pdf

[70] 3330 kWh/year value taken from field testing done by Steven Winter Associates, Inc. (SWA) (2012). HPWH Evaluation of Field Installed Performance. Sponsored by National Grid and NSTAR. http://ma-eeac.org/wordpress/wp-content/uploads/Heat-Pump-Water-heaters-Evaluation-of-Field-INstalled-Performance.pdf.

[71] The current Federal standard for residential electric storage water heaters with storage volume >55 gallons is more stringent and can only be met using HPWH technology.

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$HPWH_{consumption,old}$ = Annual energy consumption for a 2.35 EF 50 gallon HPWH[72]
$EF_{old,HPWH}$= EF of older generation HPWHs[73]
$EF_{new,HPWH}$= EF of newer generation HPWHs[74]

The equation above can be used to estimate deemed savings for both replacing an ERWH at the end of its life and early replacement of an ERWH. In the case that the ERWH is at the end of its life, the value used for $EF_{new,ERWH}$ is the current Federal minimum EF standard, as shown in the legend above. However, for an early replacement, using the EF rating of the ERWH being replaced as $EF_{new,ERWH}$ in the equation above provides an estimate for the deemed savings of switching to a HPWH that applies for the remaining years of the replaced ERWH's expected life. Because an ERWH being replaced was presumably purchased when the Federal standard was less stringent than the current standard, the efficiency of the replaced unit is likely lower than the efficiency of a new ERWH, resulting in greater deemed savings for early replacement. Beyond the expected life of the replaced ERWH, deemed savings calculated using the current Federal minimum EF standard would represent the savings of switching to a HPWH.

The deemed savings estimates developed from the equations above only apply to the replacement of electric storage water heaters with storage volume ≤55 gallons. Because the current Federal standard for residential electric storage water heaters with storage volume >55 gallons can only be met by HPWHs, there will not necessarily be deemed savings that correspond from moving from an ERWH with a storage volume >55 gallons to a HPWH unless the ERWH is replaced early (in which case the deemed savings that apply for the remaining years of the replaced ERWH's expected life can be calculated as explained in the previous paragraph). The deemed savings for such a scenario depends on consumer behavior in the case of no rebate program – the consumer could purchase a HPWH, downsize to a smaller ERWH, purchase multiple ERWHs, or purchase a different kind of water heater. Navigant did not attempt to predict consumer behavior and therefore did not develop deemed savings estimates for replacing ERWHs with storage volume >55 gallons (unless the ERWH is replaced early).

For the EF of new generation HPWHs, Navigant averaged the EF ratings of HPWHs installed by customers participating in the Mass Save program during the 2014 and 2015 program years. PAs can tailor the above equation by using the average EF of the new generation HPWHs purchased by their customers.

Additionally, PAs can use field COP or UEF instead of rated EF for HPWHs when such data becomes available for newer generation HPWHs (see section 2.3.3), as long as the same metric is used in the numerator and denominator of the EF_{old}/EF_{new} term.

The deemed savings equation above uses HPWH electricity consumption as measured in the 2012 SWA report.[75] However, this measured HPWH electricity consumption may be high because of two caveats

[72] 1643 kWh/year value taken from field testing done by Steven Winter Associates, Inc. (SWA) (2012). HPWH Evaluation of Field Installed Performance. Sponsored by National Grid and NSTAR. http://ma-eeac.org/wordpress/wp-content/uploads/Heat-Pump-Water-heaters-Evaluation-of-Field-INstalled-Performance.pdf.

[73] In the SWA 2012 report, 50 gallon tanks with EFs of 2.35 where tested. Performance in the field yielded lower efficiencies that translate to field COP of 1.61 (this field COP value is provided in case PAs choose to use field COP of newer-generation of HPWHs to calculated deemed savings).

[74] Navigant averaged the EF ratings of HPWHs installed by customers participating in the Mass Save program during the 2014 and 2015 program years. The mean EF for these HPWHs is 2.625.

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noted in the 2012 SWA report: (1) several of the HPWHs were undersized based on daily water consumption averages for the household (meaning that the backup electric resistance elements likely operated more frequently than would have been necessary with a properly sized HPWH), and (2) two of the units did not provide sufficient air volume for the HPWH's air intake, likely leading to sub-optimal operating conditions on the evaporator coil and thus lower HPWH efficiency. Therefore, the HPWH electricity consumption measured in the study likely would have been lower if the HPWHs had been properly sized and installed.

Literature reviews conducted as part of Task 1 identified studies that showed that a HPWH's interaction with a home's heating and cooling system can have an impact on energy savings, depending on the installation location. In the cold months when the home's heating system is active, a HPWH may have a negative impact and force a bigger load upon the heating system, while in the warm months, when the home's cooling system is active, a HPWH may have a positive impact and reduce the load on the cooling system. However, the literature review did not provide a consistent estimate of the impact on the space conditioning load of a HPWH installed in an unconditioned space (e.g., an unfinished basement). Because the space conditioning impact of a HWPH installed in an unfinished basement is somewhere between 0% and 100% of the impact of a HPWH installed in the conditioned space, an impact of 50% of was conservatively assumed for this analysis.

Navigant finds that the blended value (weighted-average across all home heating sources) of the reduction in savings from increased space heating electricity consumption associated with HPWHs is approximately 4.8%. A HPWH cools and dehumidifies the surrounding air and thus would reduce the load and energy consumption of both a dehumidifier if installed in a basement and an air conditioning system – effects that the survey respondents did identify. These energy savings were not included in this analysis due to lack of data, though metering in the Baseline Study may provide an estimate of this effect. In addition to the impact of space conditioning, the new deemed savings estimate accounts for the increase in efficiency in new HPWH models (i.e., a 12% increase in EF).

Based on information obtained from HPWH owners through customer surveys (Task 2), Navigant assumed that 75% of HPWHs were installed in unfinished basements, and 25% were installed in conditioned spaces. The analysis results (i.e., space conditioning impacts and deemed savings estimates) reflect a weighted average of these installation locations.

Navigant developed a blended deemed savings estimate (weighted-average value across all home heating sources) of 1652 kWh/yr for replacing an ERWH with a HPWH.

While fossil fuel-fired furnaces and boilers consume a small amount of electricity when operating, the vast majority of their energy consumption is from fuel consumption. For homes heated with fuels, the deemed savings estimate presented above only includes the small increase in electricity associated with the furnace or boiler operating longer hours to compensate for the space conditioning impacts of the HPWH. Installation of a HPWH in a home heated with a fossil fuel-fired furnace or boiler would also increase fuel consumption to counter the space cooling effect of the HPWH in colder months.

Navigant also estimated a 0.67 MMBtu/yr fuel consumption penalty that accounts for the space conditioning impacts of a HPWH in homes heated with fossil-fuel fired furnaces and boilers.

[75] Steven Winter Associates, Inc. (SWA) (2012). HPWH Evaluation of Field Installed Performance. Sponsored by National Grid and NSTAR. http://ma-eeac.org/wordpress/wp-content/uploads/Heat-Pump-Water-heaters-Evaluation-of-Field-INstalled-Performance.pdf.

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Broken out by fossil fuel type, the blended fuel consumption penalty of 0.67 MMBtu/yr equates to consumption penalties of 0.50 MMBtu/yr oil, 0.10 MMBtu/yr natural gas, and 0.07 MMBtu/yr propane.

These estimates apply to all homes and were weighted by the fraction of homes heating with fossil-fuel fired systems. Appendix C includes further detail on the fuel consumption penalty as well as the estimated penalty for each fuel source (i.e., natural gas, propane, heating oil).

The blended deemed savings estimate presented above is very similar to the value currently used by the PAs, 1,649 kWh/year. However, Navigant recommends using the updated deemed savings estimate and the accompanying average fuel consumption penalty to account for space conditioning impacts of HPWHs.

4.2 HPWH Program Application and Customer Survey Findings

Analysis of rebate application data and customer survey data yielded valuable insights about how customer purchase behaviors and satisfaction with the HPWH technology. Key findings are listed in Table 4-1 below.

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Table 4-2. Customer Application and Survey Data Findings

Evaluation Category	Findings
Replaced Water Heater Characteristics / Purchase Decision	• Half of the water heaters replaced were 12 years old or older. Over 20% of replaced water heaters were less than 9 years old and close to 8% were less than 6 years old, indicating there is some evidence of early replacement. • Survey results indicate that 15% of rebate recipients replaced oil-fired storage water heaters. Another 12% replaced water heaters that were not ERWHs (including indirect, propane storage, electric tankless, and gas storage). • Approximately 40% of all HPWH purchasers downsized, with the main reason cited that a larger water heater was no longer needed. Hot water runouts are not a common problem.
Use of HPWH / Installation Context	• 94% of customers are utilizing the water heater in heat pump mode (39% use “efficiency mode” and 55% use “hybrid mode”). 5% of customers do not know the operational setting of their HPWH. • 16% have HPWHs installed in a basement closet or utility room. • For those who replaced ERWHs, the primary home heating system fuels cited were fuel oil (49%) and electricity (26%) were the top two**.**
Comfort and Satisfaction	• 76% of respondents have noticed a change in comfort level in their homes; 89% of these customers report that the change has been positive. • 94% of respondents are satisfied with their HPWH. Respondents cited bill savings, energy savings, performance, and dehumidification benefits as reasons for being satisfied. Dehumidification was the most frequently cited comfort benefit.

4.3 Summary of Advantages and Disadvantages

Table 4-2 contains a summary of advantages and disadvantages of HPWH technology based on a combination of Task 1 and Task 2 findings.

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Table 4-3. Advantages and Disadvantages of HPWHs

Advantages	Disadvantages
• Approximately 50% energy cost savings compared to conventional electric[76] • Reduction in emissions of greenhouse gases[77] • Federal Tax Credit ($300 through end of 2016) • Mass Save rebate for models less than 55 gallons (rebate for models greater than 55 gallons was added in 2017) • Can help cool and dehumidify home • High customer satisfaction	• No energy cost savings compared to natural gas • Blows cool air, adds to home heating load[78] • High first cost:[79] o $500-1,000 cost premium[80] • Noise: o Louder than a refrigerator o Quieter than a dehumidifier • Not good for small space install; manufacturers specify 750 to 1000 cubic feet of air space around the units.

4.4 Next Steps, Considerations and Recommendations

Task 1 and Task 2 findings have allowed for adjusted deemed savings estimates by home heating source. **These deemed savings estimates can be used on a retrospective basis to assess program savings until more robust estimates of energy savings can be estimated using the data from the baseline study.** Table 4-3 lists some next steps and recommendations related to HPWHs deemed savings estimates, as well as relating to contractor and customer outreach as part of efforts to increase the adoption of HPWHs.

[76] Based on an updated HPWH deemed savings value of 1,654 kwh/year as described in Section 2.2.2.

[77] Hong, B. and Howarth, R. W. (2016), Greenhouse gas emissions from domestic hot water: heat pumps compared to most commonly used systems. Energy Sci Eng, 4: 123–133. doi:10.1002/ese3.112

[78] Accounted for in deemed savings adjustment described in this report.

[79] Relative to common storage tank water heaters such as electric, natural gas, and fuel, which have costs ranging from $400 to $1,000.

[80] Before incentives.

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Table 4-4. Task 1 and 2 Next Steps, Considerations and Recommendation

Evaluation Category	Next Steps/Recommendation

Updated Deemed Savings	• Next Step: 30 HPWHs will be metered as part of baseline study.
	• Recommendation: Update deemed savings value to assess retrospective program savings (1652 kWh/year with average fossil fuel penalties of 0.50 MMBtu/yr oil, 0.10 MMBtu/yr natural gas, and 0.07 MMBtu/yr propane).
	• Recommendation: Re-scope Task 4 Engineering Analysis, applying data from baseline study in order to develop improved and forward-looking energy savings and demand savings values.
	• Consideration: If available before baseline findings, leverage results of testing underway in the Pacific Northwest (NEEA, BPA, PNNL, and Ecotope) to reevaluate assumptions.
	  o Climate is similar to Massachusetts.
	  o Field tests on newer HPWH models are underway.
	• Recommendation: Track Department of Energy (DOE) rulemaking process for transition to uniform energy factor (UEF) metric.

Rebate Application Review	• Recommendation: Verify that rebates will be used to replace ERWHs only.
Customer Acceptance and Barriers	• Recommendation: HPWH technology should be pushed; high customer satisfaction and savings. • Consideration: Use survey results relating to customer satisfaction to improve program marketing materials. • Consideration: Leverage results of contractor interviews to uncover additional barriers (Res 25).

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APPENDIX A. TASK 1 ADDITIONAL CHARTS

Figure A-1. 2016 Mass Save Qualified HPWH List

Brand Name	Model Name	Model Number	Storage Volume (gallons)	kWh savings / year	Energy Factor (EF)	Warranty
A. O. Smith	Heat Pump Water Heater	HPTU 50 120	50	1516	3.24	10
A. O. Smith	Heat Pump Water Heater	SHPT 50 100	50	1516	2.75	10
American	Heat Pump Water Heater	HPHE10250H045DV 120	50	1516	3.24	10
American	Heat Pump Water Heater	HPSE10250H045DV 100	50	1516	2.75	10
Bradford White Corp	AEROTHERM	RE2H50R10B-1NCWT	50	1416	3.1	10
Bradford White Corp	AEROTHERM	RE2H50R10-1NCWW	50	1830	2.4	10
EcoSense	Hybrid Electric Water Heater	HB50ES	50	1792	2.45	12
GE	GeoSpring	BEH50DCEJSB	50	1295	3.39	10
GE	GeoSpring	GEH50DEEJSC	50	1295	3.39	10
GE	GeoSpring	GEH50DFEJSR	50	1351	3.25	10
GE	GeoSpring	GEH50DEED	50	1830	2.4	10
GE	GeoSpring	BEH50DCEH	50	1830	2.4	10
Kenmore	Heat Pump Water Heater	153.5925	50	1516	3.24	12
Kenmore	Heat Pump Water Heater	153.5926	50	1516	3.17	12
Kenmore	Heat Pump Water Heater	153.5928	50	1516	3.07	12
Kenmore	Heat Pump Water Heater	153.321151	50	1516	2.75	12
Lochinvar	Heat Pump Water Heater	HPA0501KD 120	50	1516	3.24	10
Lochinvar	Heat Pump Water Heater	HPA050KD 100	50	1516	2.75	10
Reliance	Heat Pump Water Heater	10 50 DHPHT 120	50	1516	3.24	10
Reliance	Heat Pump Water Heater	10 50 DHPST 100	50	1516	2.75	10
Rheem	Hybrid Electric Water Heater	HB50RH	50	1792	2.45	12
Rheem	Hybrid Electric Water Heater	PROPH50 T2 RH245	50	1792	2.45	12
Rheem	Hybrid Electric Water Heater	PROPH50 T2 RH245 EC2	50	1792	2.45	12
Rheem	Hybrid Electric Water Heater	XE50T12EH45U0	50	1792	2.45	12
Rheem	Hybrid Electric Water Heater	XE50T12EH45U0W	50	1792	2.45	12
Richmond	Hybrid Electric Water Heater	12E50-HP	50	1792	2.45	12
Richmond	Hybrid Electric Water Heater	HB50RM	50	1792	2.45	12
Ruud	Hybrid Electric Water Heater	HB50RU	50	1792	2.45	12
Ruud	Hybrid Electric Water Heater	PROUH50 T2 RU245	50	1792	2.45	12
Ruud	Hybrid Electric Water Heater	PROUH50 T2 RU245 EC2	50	1792	2.45	12
State	Heat Pump Water Heater	HPX 50 DHPT 120	50	1516	3.24	10
State	Heat Pump Water Heater	SPX 50 DHPT 100	50	1516	2.75	10
US Craftmaster	Heat Pump Water Heater	HPHE2K50HD045VU 120	50	1516	3.24	10
Vaughn	Hybrid Electric Heat Pump DWH	S-50HPT	50	1906	2.32	10
Whirlpool	Heat Pump Water Heater	HPSE2K50HD045V 100 (WP)	50	1516	2.75	10
Whirlpool	Heat Pump Water Heater	HPHE2K50HD045V 120	50	1516	3.24	10
Whirlpool	Heat Pump Water Heater	HPHE2K50HD045VC 120	50	1516	3.24	10
Whirlpool	Heat Pump Water Heater	HPSE2K50HD045VC 100 (WP)	50	1516	2.75	10

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Figure A-2. 2017 Mass Save Qualified HPWH List - Page 1

Qualified Heat Pump Water Heaters (HPWH) This list of equipment is subject to change. (Updated 1/23/17) Up to 55 gallon storage capacity				
Brand Name	**Model Number**	**Storage Volume (gallons)**	**Energy Factor**	**Warranty**
A. O. Smith	HPTU 50 120	50	3.24	10
A. O. Smith	HPTU 50N 120	50	3.24	10
American	HPHE10250H045DV 120	50	3.24	10
American	HPHE10250H045DVN 120	50	3.24	10
American Standard	HPWH50G-AS	50	2.6	10
Bradford White Corp	RE2H50R10B-1NCWT	50	3.1	10
EcoSense	HB50ES	50	2.45	12
GE - GeoSpring	GEH50DFEJSR*	50	3.25	10
GE - GeoSpring	BEH50DCEJSB*	50	3.39	10
GE - GeoSpring	GEH50DEEJSC*	50	3.39	10
GE - GeoSpring	GEH50DHEKSC*	50	3.39	10
Kenmore	153.59280	50	3.07	10
Kenmore	153.59260	50	3.17	10
Kenmore	153.59250	50	3.24	10
Lochinvar	HPA051KD 120	50	3.24	10
Lochinvar	HPA052KD 120	50	3.24	10
Reliance	10 50 DHPHT 120	50	3.24	10
Reliance	10 50 DHPHTNE 120	50	3.24	10
Rheem	HB50RH	50	2.45	12
Rheem	PROPH50 T2 RH245	50	2.45	12
Rheem	XE50T12EH45U0	50	2.45	12
Rheem	XE50T12EH45U0W	50	2.45	12
Rheem	PRO H50 T2 RH245 BM	50	2.45	12
Rheem	PROPH50 T2 RH350 D	50	3.5	12
Rheem	XE50T10HD50U0	50	3.5	12
Richmond	12E50-HP	50	2.45	12
Richmond	HB50RM	50	2.45	12
Richmond	10E50-HP4D	50	3.5	12
Ruud	PROUH50 T2 RU245	50	2.45	12
Ruud	HB50RU	50	2.45	12
Ruud	PRO H50 T2 RU245 BM	50	2.45	12
Ruud	PROUH50 T2 RU350 D	50	3.5	12
State	HPX 50 DHPT 120	50	3.24	10
State	HPX 50 DHPTNE 120	50	3.24	10
US Craftmaster	HPHE2K50HD045VU 120	50	3.24	10
US Craftmaster	HPHE2K50HD045VUN 120	50	3.24	10
Vaughn	S-50HPT	50	2.32	10
Whirlpool	HPSE2K50HD045V 100 (WP)	50	2.75	10

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Figure A-3. 2017 Mass Save Qualified HPWH List - Page 2

Greater than 55 gallon storage capacity				
Brand Name	**Model Number**	**Storage Volume (gallons)**	**Energy Factor**	**Warranty**
A. O. Smith	HPTU 66 120	66	3.17	10
A. O. Smith	HPTU 66N 120	66	3.17	10
A. O. Smith	HPTU 80 120	80	3.07	10
A. O. Smith	HPTU 80N 120	80	3.07	10
American	HPHE10266H045DV 120	66	3.17	10
American	HPHE10266H045DVN 120	66	3.17	10
American	HPHE10280H045DV 120	80	3.07	10
American	HPHE10280H045DVN 120	80	3.07	10
Bradford White Corp	RE2H80R10B-1NCWT	80	3.1	10
GE - GeoSpring	GEH80DFEJSR*	80	3.12	10
GE - GeoSpring	BEH80DCEJSB*	80	3.26	10
GE - GeoSpring	GEH80DEEJSC*	80	3.26	10
GE - GeoSpring	GEH80DHEKSC*	80	3.26	10
Lochinvar	HPA067KD 120	66	3.17	10
Lochinvar	HPA068KD 120	66	3.17	10
Lochinvar	HPA081KD 120	80	3.07	10
Lochinvar	HPA082KD 120	80	3.07	10
PHNIX	PASHW008-270LD	71.3	3.01	10
Reliance	10 66 DHPHT 120	66	3.17	10
Reliance	10 66 DHPHTNE 120	66	3.17	10
Reliance	10 80 DHPHT 120	80	3.07	10
Reliance	10 80 DHPHTNE 120	80	3.07	10
Rheem	PROPH65 T2 RH350 D	65	3.5	12
Rheem	XE65T10HD50U0	65	3.5	12
Rheem	PROPH80 T2 RH350 D	80	3.5	12
Rheem	XE80T10HD50U0	80	3.5	12
Richmond	10E65-HP4D	65	3.5	12
Richmond	10E80-HP4D	80	3.5	12
Ruud	PROUH65 T2 RU350 D	65	3.5	12
Ruud	PROUH80 T2 RU350 D	80	3.5	12
State	HPX 66 DHPTNE 120	66	3.17	10
State	HPX 66 DHPT 120	66	3.17	10
State	HPX 80 DHPT 120	80	3.07	10
State	HPX 80 DHPTNE 120	80	3.07	10
Stiebel Eltron	Accelera 220 E	58.1	3.05	10
Stiebel Eltron	Accelera 300 E	80	3.39	10
US Craftmaster	HPHE2K66HD045VU 120	66	3.17	10
US Craftmaster	HPHE2K66HD045VUN 120	66	3.17	10
US Craftmaster	HPHE2K80HD045VU 120	80	3.07	10
US Craftmaster	HPHE2K80HD045VUN 120	80	3.07	10
Whirlpool	HPHE2K80HD045VN 120	80	3.07	10

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Figure A-4. Replaced Water Heater Manufacturer (N=2,605)[81]

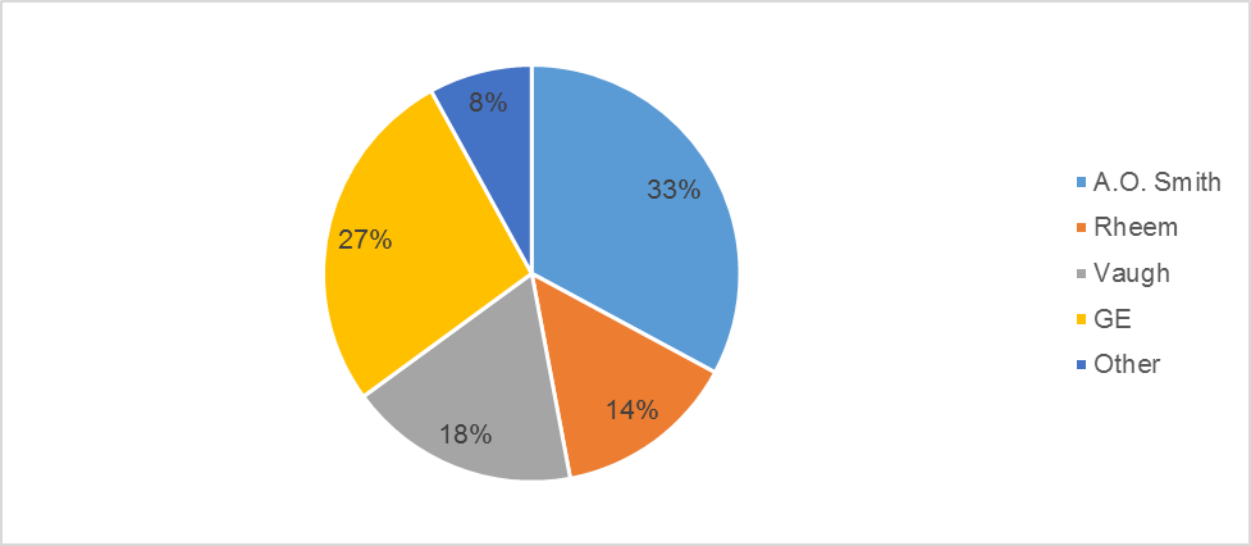
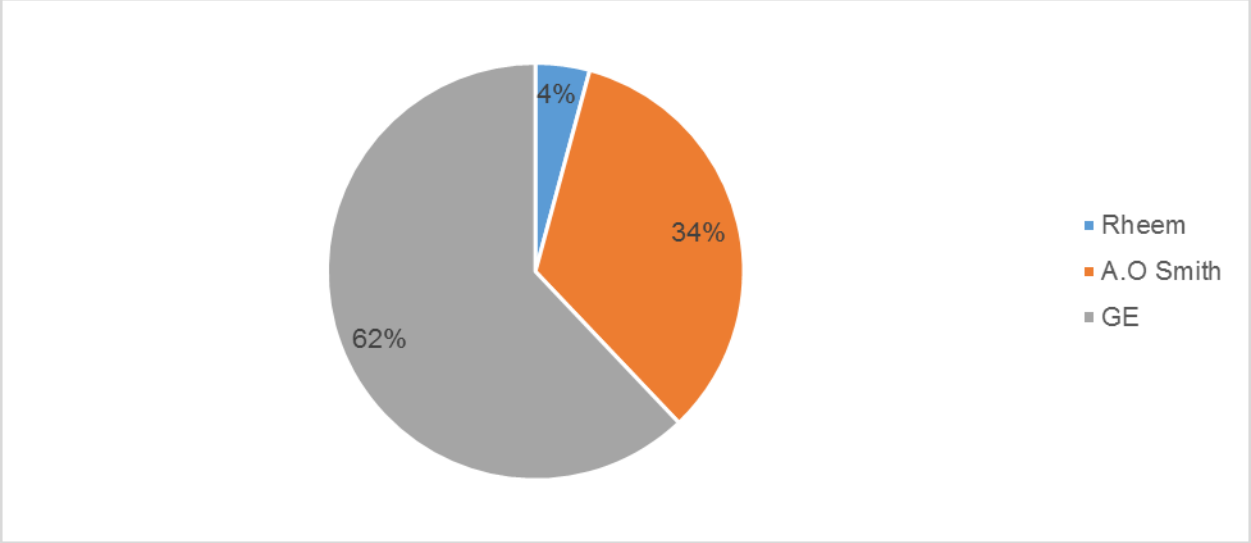


Figure A-5. Installed HPWH Manufacturer (N=3,450)



[81] Model numbers for replaced water heaters were not provided in the application data. Brands of water heaters were consolidated using current-day branding and subsidiaries.

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APPENDIX B. TASK 2 ADDITIONAL CHARTS

Figure B-1. Size of the Replaced Water Heater (Rebate Recipients N=2,272; Survey Respondents N=152)

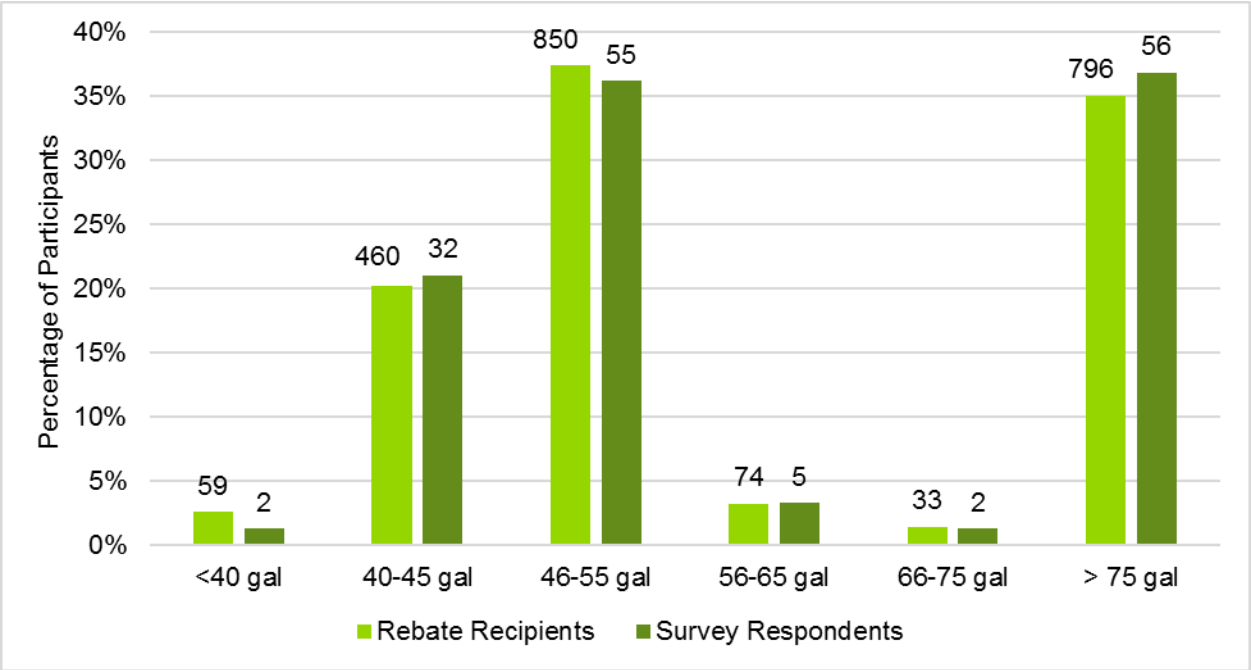

Figure B-2. Age of the Replaced Water Heater (Rebate Recipients N=2,152; Survey Respondents N=151)

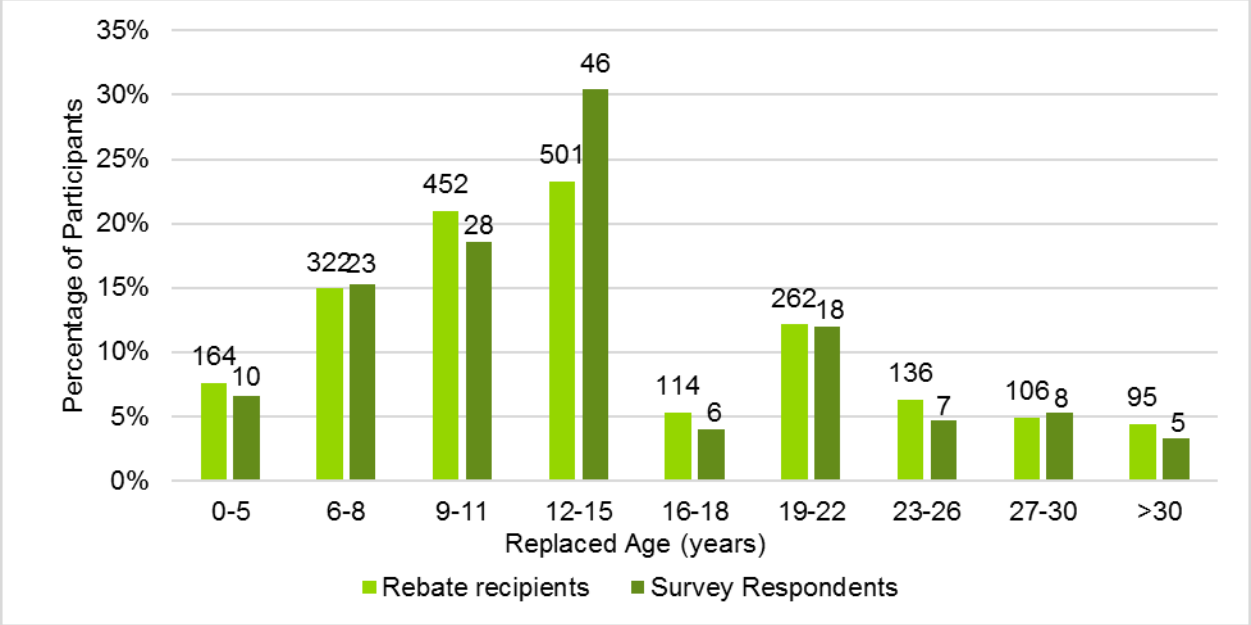

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Figure B-3. HPWH Installation Location (Rebate Recipients N=3,469)

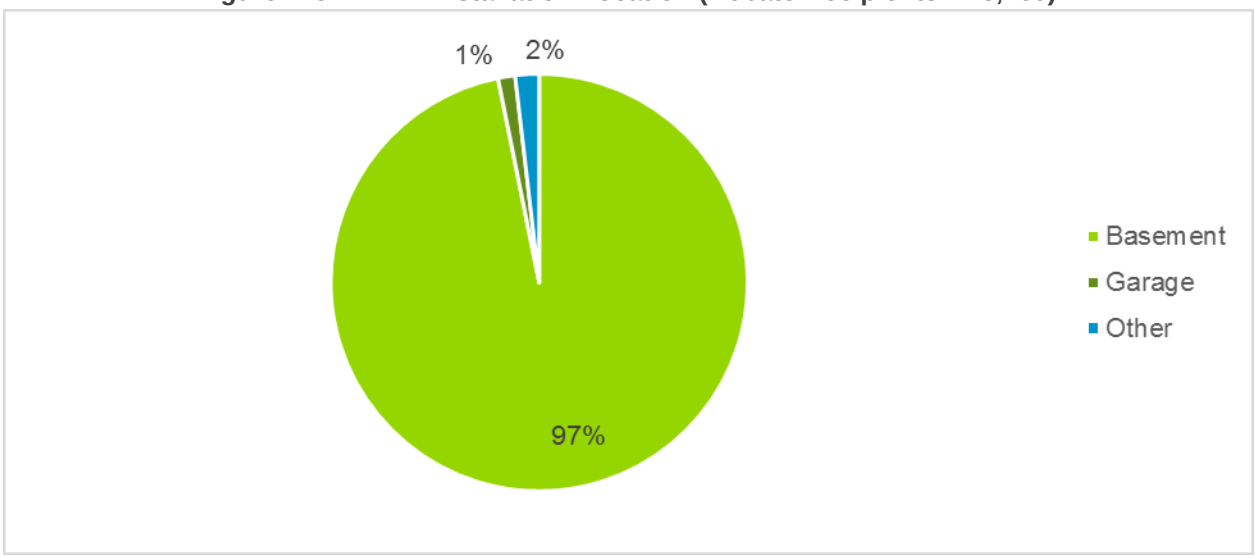

Figure B-4. HPWH Installation Location (Survey Respondents, N=283)

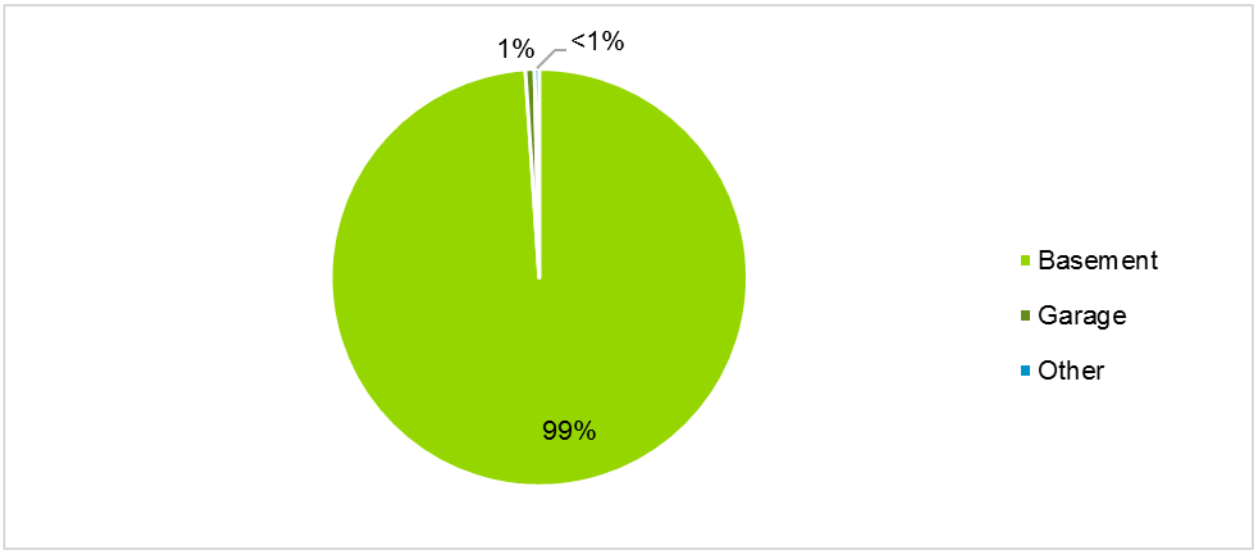

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Figure B-5. How did you select the model(s) of heat pump water heater that you purchased? (N=531, Multiple Responses Allowed)

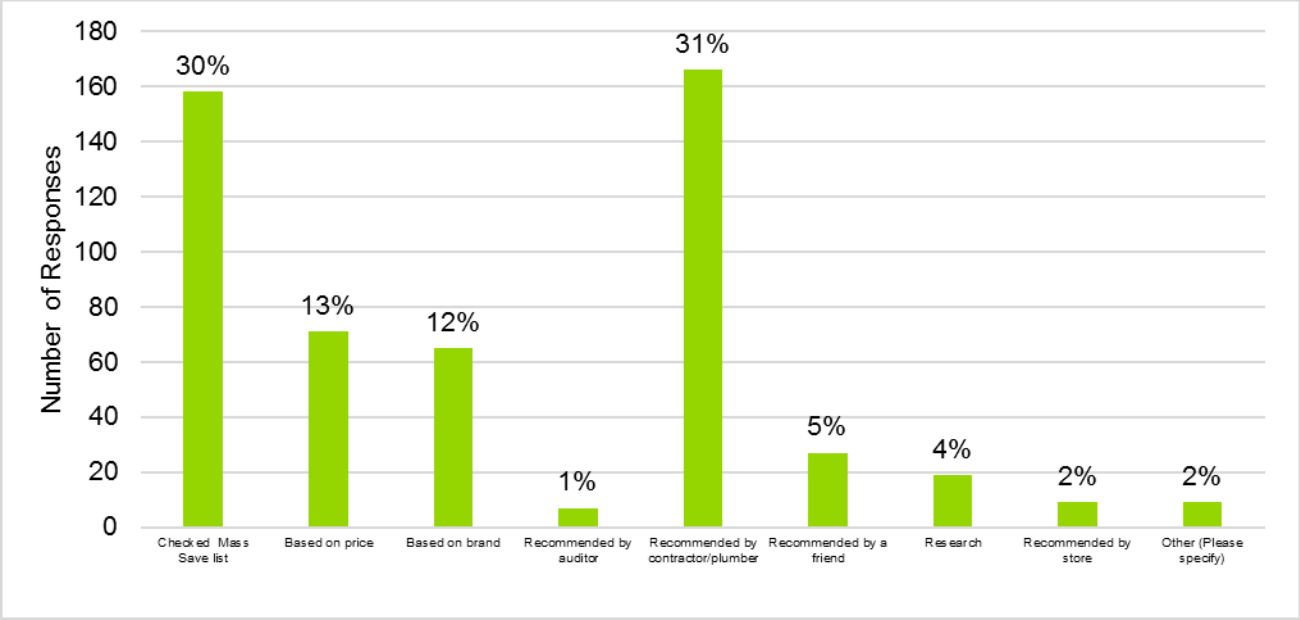

Figure B-6. What was the total cost of installation (excluding rebates and credits) (N=220, Open Response)

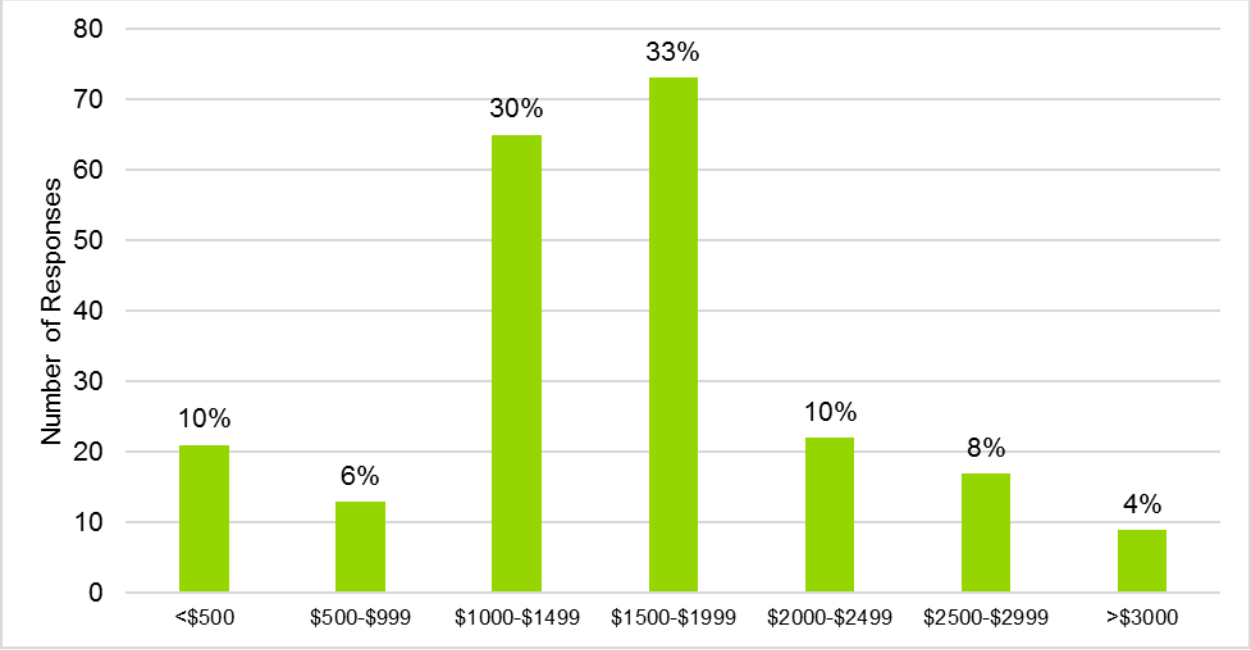

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Figure B-7. How old was the replaced water heater? (N=85)[82]

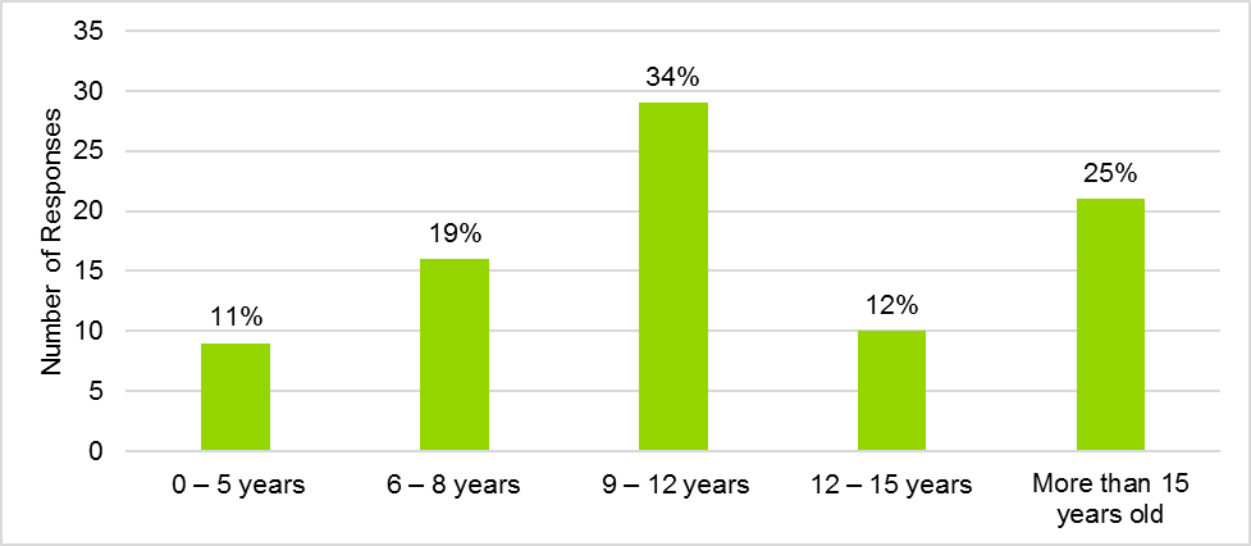
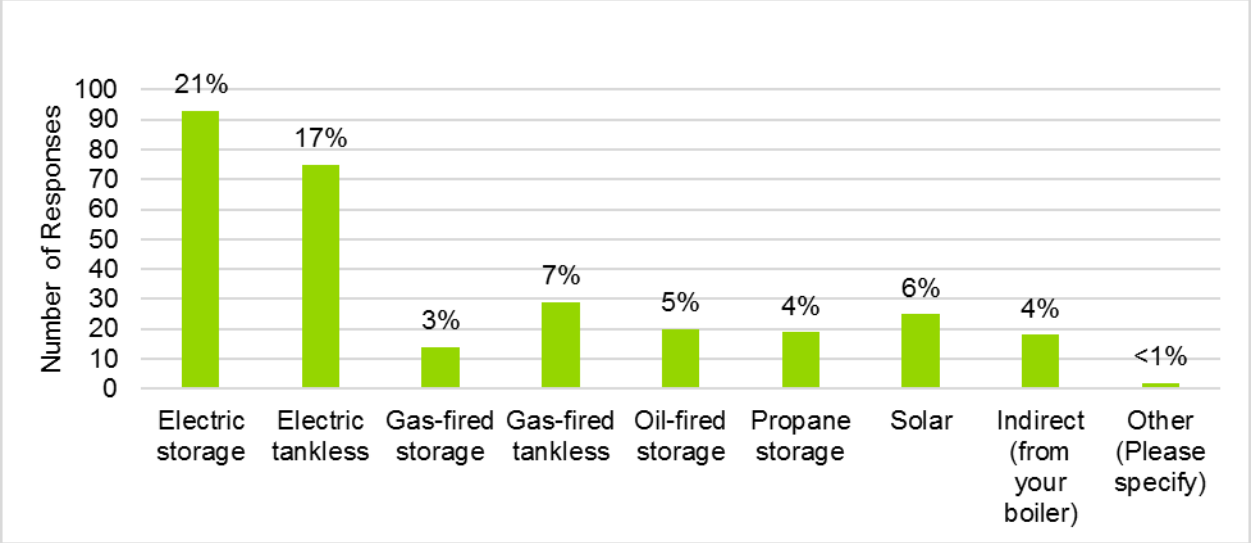


Figure B-8. Before purchasing your heat pump water heater(s), what other type(s) of water heaters did you consider? (N=295, Multiple Responses Allowed)



[82] Question only for customers who were classified as early replacements. 12 responses of "don't know" were omitted from this figure.

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Figure B-9. Relative to the tank size of the water heater(s) you replaced, did you purchase a heat pump water heater(s) with a tank size (gallons) that was: (N=73)

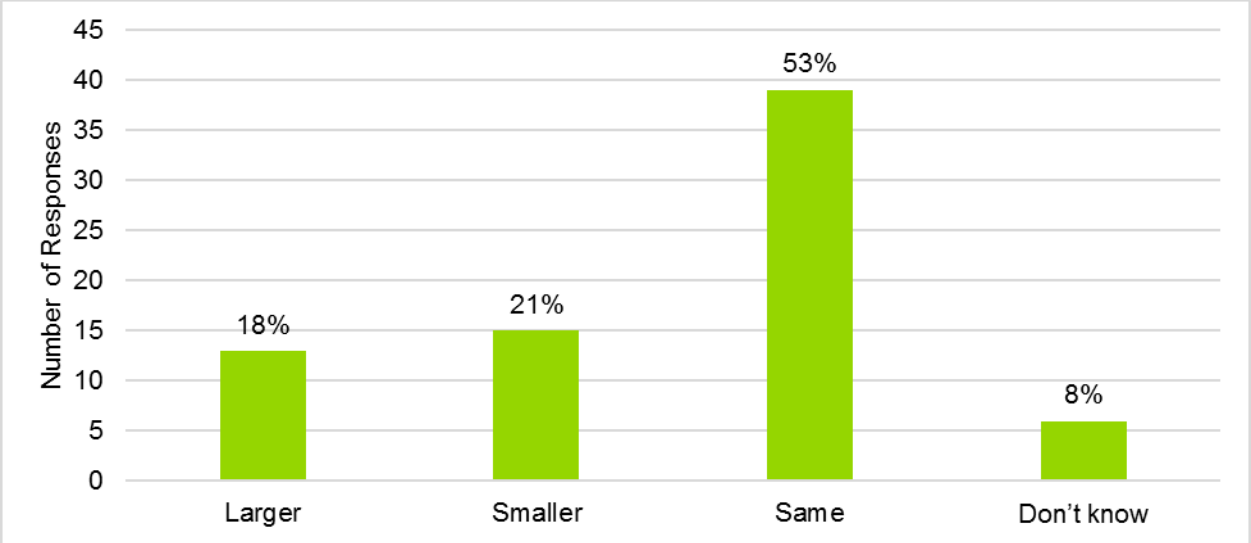

Figure B-10. Where is the HPWH installed? (N=329)

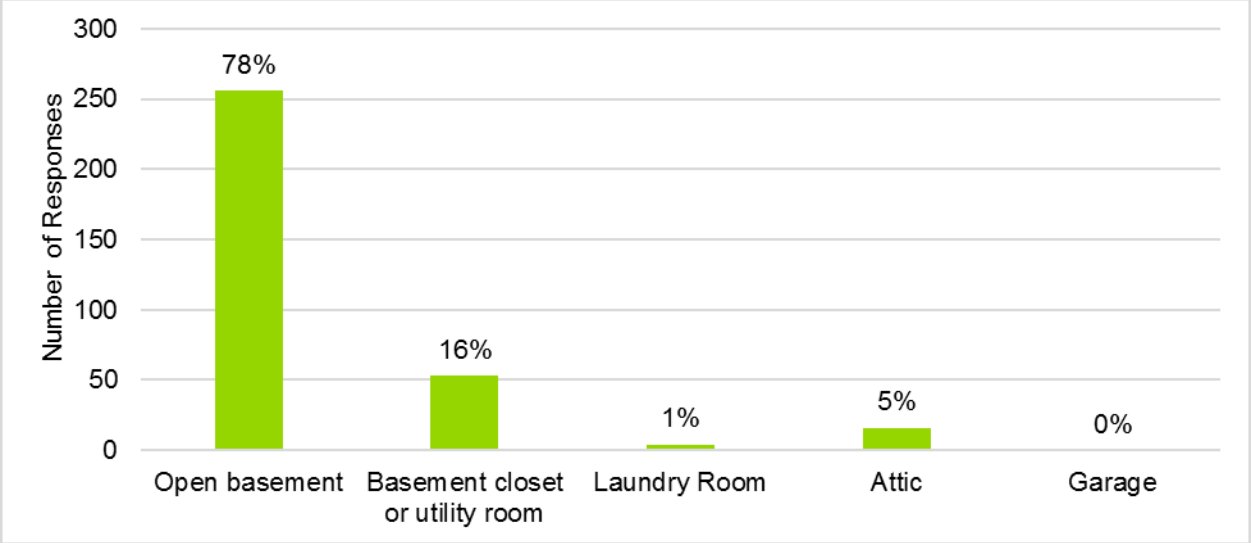

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Figure B-11. What type of fuel does your home heating system use? (N=394, Multiple Responses Allowed)

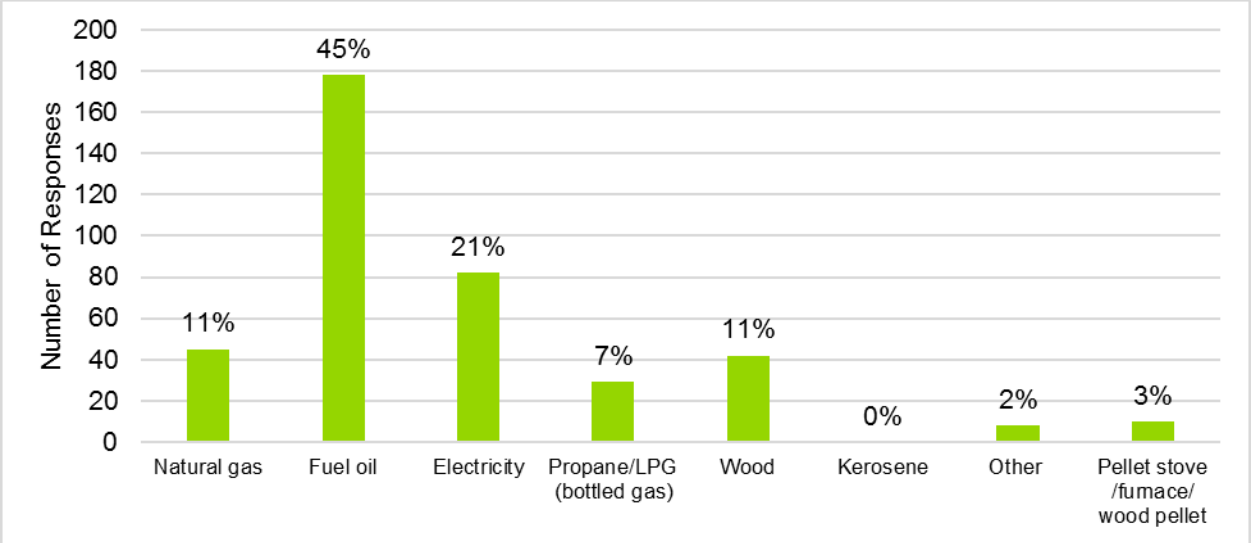

Figure B-12. Who installed your HPWH? (N=336)

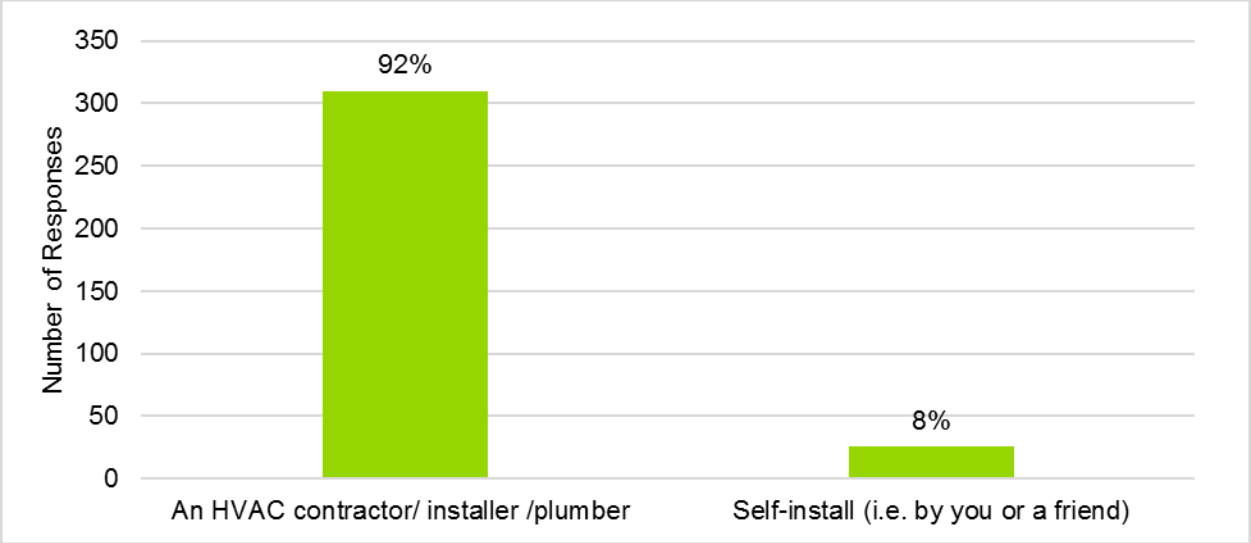

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Figure B-13. Has your heat pump water heater saved you money on your monthly energy bills? (N=329)

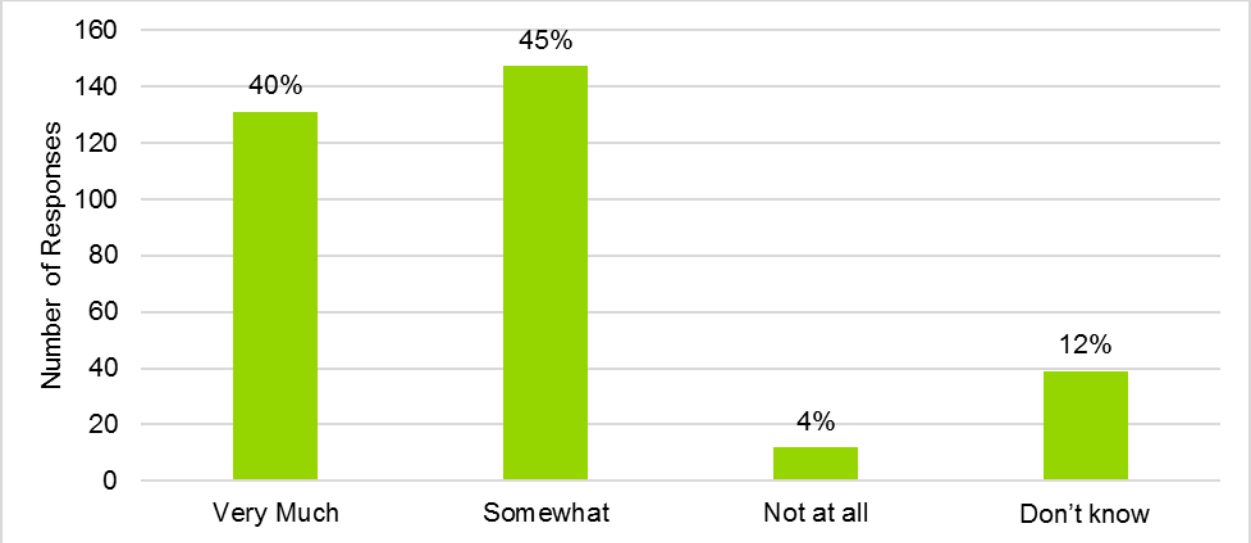

Figure B-14. Please describe the performance issues you've encountered when using your heat pump water heater. (Open Response, N=17)

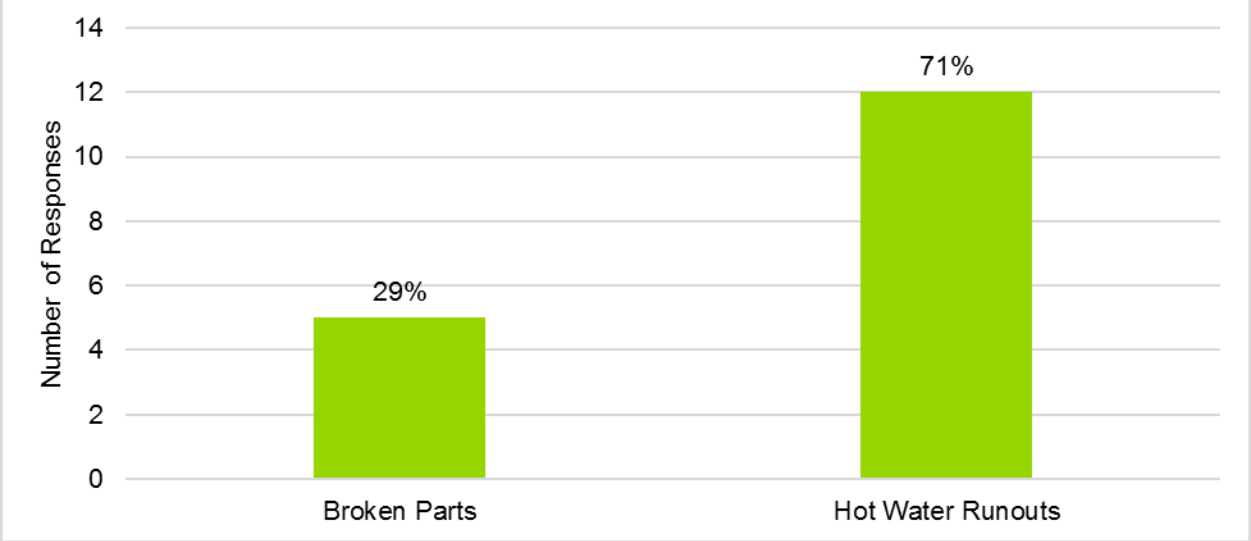

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Figure B-15. How satisfied are you with the contractor/plumber who installed your heat pump water heater? (N=300)

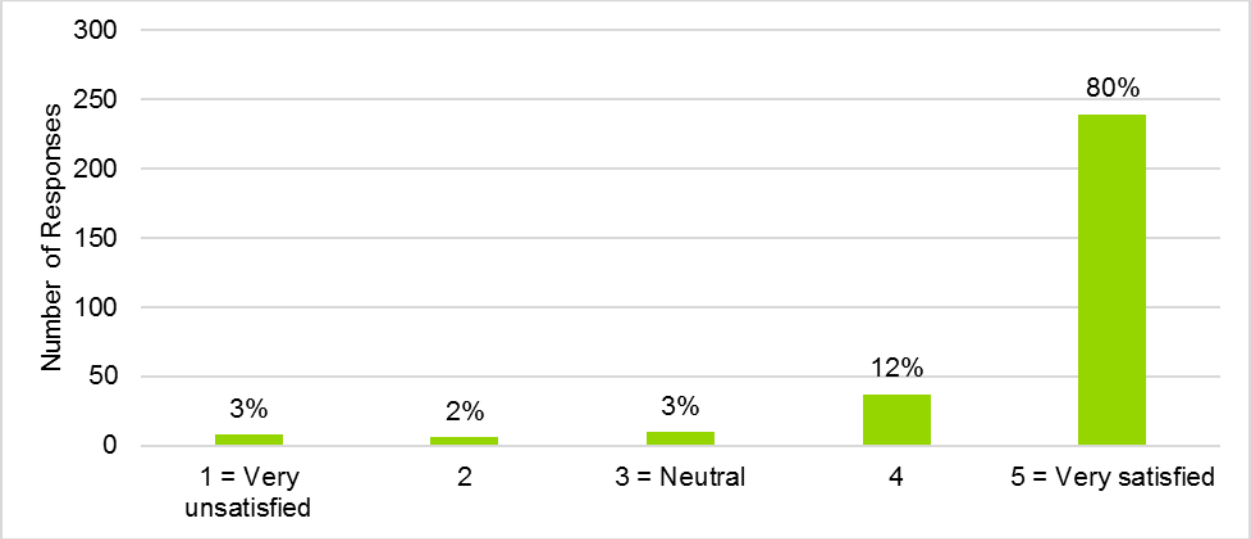

Figure B-16. Please describe why you are not completely satisfied with the contractor/plumber (Open Response, N=13)

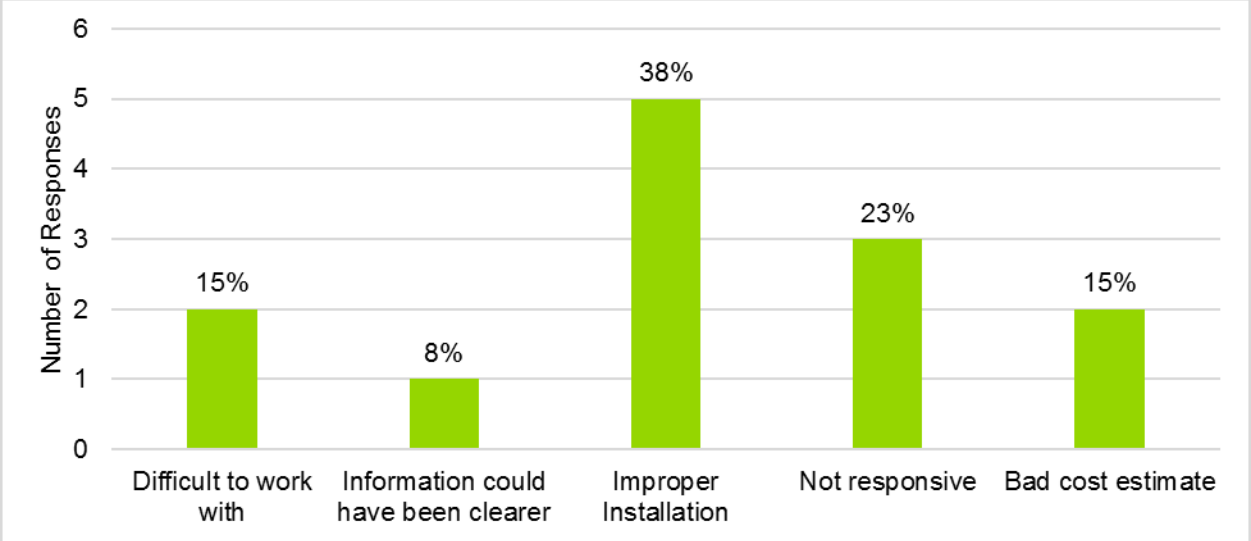

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Figure B-17. Please describe why you are satisfied with your heat pump water heater. (Open Response, N=481)

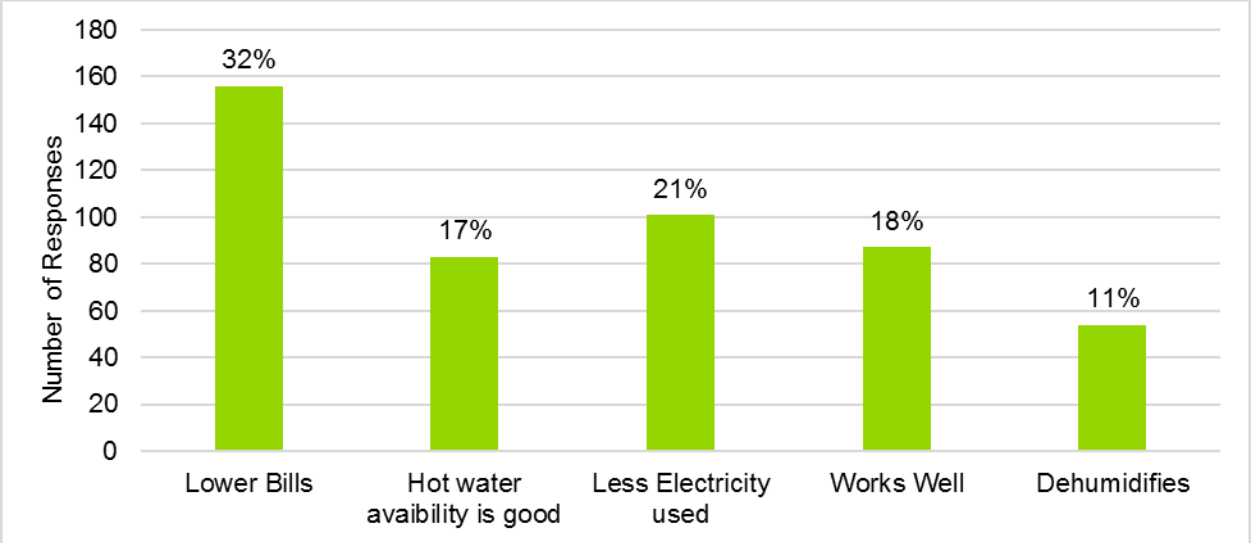
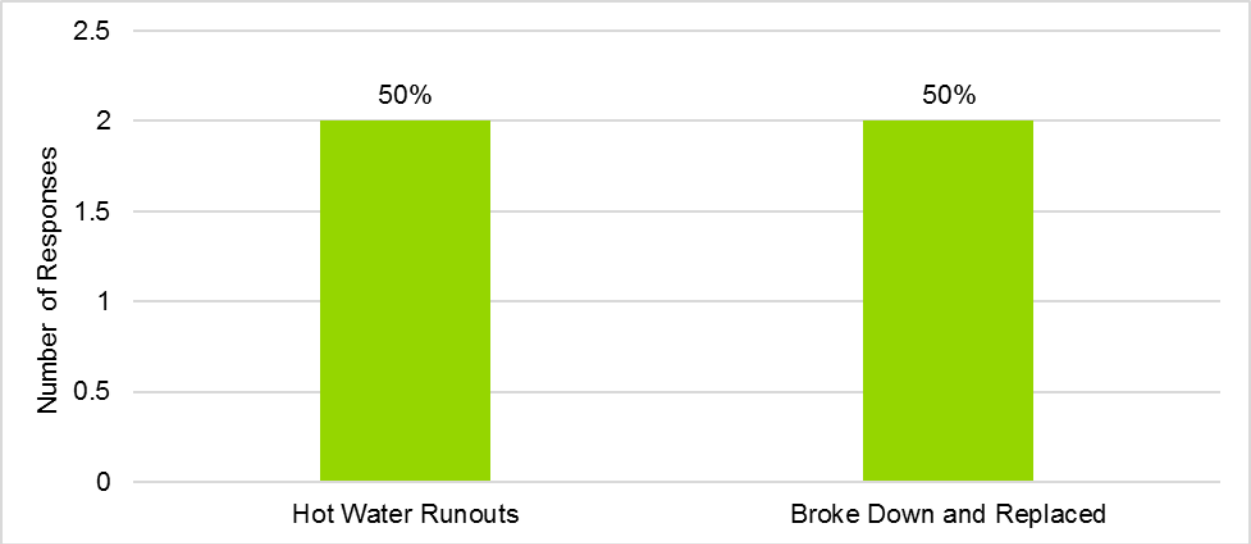


Figure B-18. Please describe why you are not completely satisfied with your heat pump water heater. (Open Response, N=4)



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APPENDIX C. SPACE CONDITIONING IMPACTS AND DEEMED SAVINGS ESTIMATES

Navigant finds that increased space heating electricity consumption reduces savings associated with HPWHs by an average of approximately 12.4%, 15.9%, and 0.7% for homes heated with a heat pump, electric resistance baseboards, and a fossil fuel-fired furnace or boiler (excluding increased fuel consumption), respectively. The blended (weighted-average) value for all home heating sources is 4.8%.

To determine blended space conditioning impacts and deemed savings estimates, Navigant developed weighting factors for each home heating source, based on the most recent baseline study from MA[83] and the Task 2 survey feedback. Specifically, the results from the Task 2 survey feedback were used to determine the weightings for natural gas, oil, propane, and overall electric heating. The results from the most recent baseline study from MA were used to determine the weightings for electric resistance baseboards and heat pumps (in the baseline study, 6% of homes were heated with electric resistance baseboards and 1% of homes were heated with heat pumps). The weightings used for each home heating source are shown below.

Figure C-1. Home Heating Source Weights

Home Heating Source	Fraction of Homes
Natural Gas	11%
Oil	53%
Propane	8%
Electric Resistance Baseboards	24%
Heat Pump	4%

Data from the Ecotope study[84] were used to develop space conditioning impact estimates, as discussed in section 2.3. Data used are shown below and correspond to HPWHs installed in the conditioned space and in Heating Zone 2, as specified in the Ecotope study. In the Ecotope study, the ERWH annual energy consumption was 2946 kWh and the GE Geospring HPWH annual energy consumption was 1571 kWh, yielding an annual savings value of 1375 kWh. This annual savings value was used to determine the space conditioning impacts in terms of % of savings.

[83] http://ma-eeac.org/wordpress/wp-content/uploads/11_MA-Residential-Appliance-Saturation-Survey_Vol_1.pdf

[84] http://neea.org/docs/default-source/reports/heat-pump-water-heater-saving-validation-study.pdf?sfvrsn=8

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Figure C-2. Space Conditioning Impacts from Ecotope Study by Home Heating Source for HPWHs Installed in a Conditioned Space

Heating Type	Savings from HPWH, Including Space Conditioning Impact (kWh)	Space Conditioning Impact (kWh)	Space Conditioning Impact for HPWH Installed in Conditioned Space (% of Savings)
Heat Pump	1103	272	19.8%
Gas Furnace[85]	1360	15	1.1%
Zonal Heat (Electric Baseboards)	1025	350	25.5%

As discussed in section 4.1, the literature review did not provide a consistent estimate of the impact on the space conditioning load of a HPWH installed in an unconditioned space (e.g., an unfinished basement). Because the space conditioning impact of a HWPH installed in an unfinished basement is somewhere between 0% and 100% of the impact of a HPWH installed in the conditioned space, an impact of 50% of was conservatively assumed for this analysis. Further, based on survey feedback, it was assumed that 75% of HPWHs are installed in unfinished basements, and 25% are installed in conditioned spaces. These factors were used to adjust the space conditioning impacts in % of savings shown in Figure C-2 above for each home heating source. Finally, the home heating source weightings shown in Figure C-1 above were used to develop a weighted-average space conditioning impact for all homes of 4.8%.

Deemed savings estimates calculated for each home heating source are shown below.

Figure C-3. Adjusted Deemed Savings Estimates by Home Heating Source

Home Heating Source	Deemed Savings Estimate (kWh/year)
Heat Pump	1521
Electric Resistance Baseboards	1460
Fossil fuel-fired furnace or boiler*	1724

*Only includes electricity consumption

Navigant estimated the increased fossil fuel consumption of the space heating system resulting from space conditioning impacts of a HPWH, as shown in the tables below. Navigant assumed an AFUE of 80% for furnaces and boilers and used the space conditioning impact from the Ecotope study corresponding to a HPWH installed in the conditioned space of a home with electric baseboard heating (350 kWh) for fuel consumption calculations. Specifically, this space conditioning impact value was

[85] Data for homes heated with gas furnaces were used for oil-fired boilers, because it was assumed that gas furnaces and oil boilers would have similar on-mode electricity consumption. The Ecotope study did not examine space conditioning impacts for fuel consumption.

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weighted to include the impacts of unfinished basements (as described above) and then converted to MMBtu/yr and fuel-specific units (i.e., gallons/yr and therms/yr).

The first set of values below shows the constants used in these calculations for fuel-fired home heating sources (Figure C-4). The second set of values (Figured C-5) presents results for homes with the HPWH in a conditioned space. The third set of values (Figure C-6) is a blended average of results impacts of HPWHs installed in conditioned spaces and unconditioned basements. These values apply only to homes with space heating systems that use each fuel source and are not weighted by the fraction of homes that use each fuel source for space heating. The fourth set of values (Figure C-7) applies to all homes and these values are weighted by the fraction of homes that use each fuel source for space heating. When all of the impacts are weighted according to the installation characteristics from the survey (i.e., installation location and home heating source), the resulting annual fossil fuel heating increase is 0.67 MMBtu per HPWH.

Figure C-4. Conversion Factors used for Space Conditioning Impact Fuel Calculations

Constant	Value
Btu/kWh	3,412.142
Btu/gallon for No. 2 Heating Oil	140,000
Btu/therm for Natural Gas	100,000
Btu/gallon for Propane	91,600

Figure C-5. Additional Annual Fuel Consumption for Each Home Heating Source for HPWH Installed in Conditioned Space

Fuel Source	Additional Annual Fuel Consumption (MMBtu/year)	Additional Annual Fuel Consumption (Fuel-Specific Units)
Natural Gas	1.49	14.9 therms/year
Propane	1.49	16.3 gallons/year
Heating Oil	1.49	10.7 gallons/year

Figure C-6. Additional Annual Fuel Consumption for Each Home Heating Source for HPWH Weighted by Installation Location

Fuel Source	Additional Annual Fuel Consumption (MMBtu/year)	Additional Annual Fuel Consumption (Fuel-Specific Units)

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Natural Gas	0.93	9.3 therms/year
Propane	0.93	10.2 gallons/year
Heating Oil	0.93	6.7 gallons/year

Figure C-7. Additional Annual Fuel Consumption for All Homes, Weighted Across All HPWH Installation Locations and Home Heating Sources

Fuel Source	Additional Annual Fuel Consumption (MMBtu/year)	Additional Annual Fuel Consumption (Fuel-Specific Units)
Natural Gas	0.10	1.0 therms/year
Propane	0.07	0.8 gallons/year
Heating Oil	0.50	3.5 gallons/year

The following tables show each step of the calculations made to determine space conditioning impacts, deemed savings estimates, and fuel consumption penalties. The first set of values (Figure C-8) shows the calculations for determination of space conditioning impacts and deemed savings estimates. The second set of values (Figure C-9) shows the calculations for determination of fuel consumption penalties.

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Figure C-8. Intermediate Results for Calculation of Space Conditioning Impacts and Deemed Savings Estimates

Home Heating Source	Heat Pump	Fossil Fuel Furnace/ Boiler	Electric Baseboard
HPWH Savings over ERWH (from Ecotope study) (kWh)	1375	1375	1375
Space Conditioning Impact for HPWH Installed in Conditioned Space (from Ecotope study) (kWh)	272	15	350
Space Conditioning Impact for HPWH Installed in Conditioned Space (from Ecotope study) (% of Savings)	19.8%	1.1%	25.5%
% Space Conditioning Impact for HPWH Installed in Conditioned Space Assumed for Unconditioned Spaces	50%	50%	50%
% of HPWHs Assumed in Unconditioned Spaces	75%	75%	75%
Weighted Average Space Conditioning Impact for All Locations (% of Savings)	12.4%	0.7%	15.9%
Deemed Savings Estimate (kWh)	1521	1724	1460
Home Heating Source Weights	4%	72%	24%
Deemed Savings Weighted by Home Heating Source (kWh)	61	1241	350
Weighted Average Space Conditioning Impact for All Locations and Home Heating Sources (% of Savings)		4.8%	
Total Deemed Savings Estimate (kWh)		1652	

Figure C-9. Intermediate Results for Calculation of Additional Annual Fuel Consumption

Home Heating Source	All	Natural Gas	Propane	Heating Oil
Additional Fuel Consumption for HPWH Installed in Conditioned Space (Fuel-Specific Units)**	1.49 MMBtu/yr	14.9 therms/yr	16.3 gallons/yr	10.7 gallons/yr
% Space Conditioning Impact for HPWH Installed in Conditioned Space Assumed for Unconditioned Space	50%	50%	50%	50%
% of HPWHs Assumed in Unconditioned Spaces	75%	75%	75%	75%
Weighted Average Additional Fuel Consumption for All Locations (Fuel-Specific Units)	0.93 MMBtu/yr	9.3 therms/yr	10.2 gallons/yr	6.7 gallons/yr
Home Heating Source Weights		11%	8%	53%
Weighted Average Additional Fuel Consumption for All Locations and Home Heating Sources (MMBtu/yr)	0.67	0.10	0.07	0.50
Weighted Average Additional Fuel Consumption for All Locations and Home Heating Sources (Fuel-Specific Units)		1.0 therms/yr	0.8 gallons/yr	3.5 gallons/yr

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*All fuel consumption values assume an AFUE of 80% for furnaces and boilers.
**Equivalent to 350 kWh, the conditioning impact determined for baseboard heating in the Ecotope study.

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