National Grid Rhode Island Residential Appliance Saturation Survey (Study RI2311) Report

Final

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SUBMITTED TO:
National Grid Rhode Island

SUBMITTED BY:
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National Grid Rhode Island Residential Appliance Saturation Survey Report

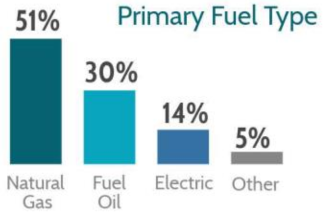
In early 2018, NMR fielded a Residential Appliance Saturation Survey (RASS) study with National Grid Rhode Island customers. This study, consisting of web surveys and on-site verification visits, resulted in the following report and a comprehensive database of results. We sought to estimate penetration and characterize a variety of end-uses among the customer population. The on-site visits enabled us to also estimate the technical potential for mini-split heat pumps.

Approach

- 10,000 recruitment letters
- 900 web surveys
- 75 on-site verification visits

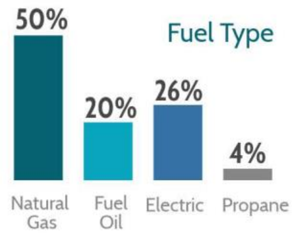
Select Key Findings

Heating



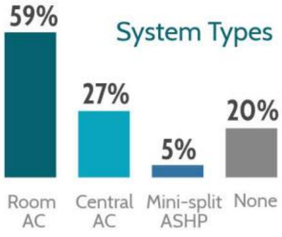
Most often customers use natural gas boilers (**37%**) and oil boilers (**28%**).

Water Heating



Homes most often have natural gas standard tank water heaters (**40%**). Only **1%** of homes have heat pump water heaters, but **36%** could readily accommodate them.

Cooling



Opportunities for MSHPs appear plentiful. Three-fifths (**60%**) of an average home's floor area is high feasibility.

Thermostats

Customers most often have standard thermostats (**61%**). Only **60%** of the **51%** with programmable thermostats use the programmable features.

Consumer Electronics

Laptop (**81%**) penetration overshadows desktop (**44%**) penetration. Given their newness, advanced power strips have relatively high penetration (**27%**) -- likely due to National Grid support.

Solar and Electric Vehicles

Only **1%** of homes have photovoltaic solar panels and **1%** of customers have plug-in electric or hybrid vehicles.

Average Equipment Age (years)

Furnaces	Boilers	Central ACs	Room ACs	Water Heaters	Fridges	Dishwashers	Washers	Dryers	Dehumidifiers
14	14	13	8	9	11	11	10	11	7

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Executive Summary

In early 2018, NMR Group, Inc., fielded a Residential Appliance Saturation Survey (RASS) study using 900 web surveys and 75 follow-up on-site verification visits with National Grid Rhode Island customers. This report provides an overview of the study methodology and an analysis of results. We also prepared and delivered an Excel database that included all primary research data points and detailed analyses. This report provides a database user guide. We sought to develop an inventory of residential end-uses, including appliances, consumer electronics, heating and cooling equipment, thermostats, water heating, and building characteristics. We also used the on-site verification visit data to conduct a mini-split heat pump (MSHP) technical feasibility analysis. Additionally, we used the visits to collect lighting data for an upstream program net-to-gross analysis, but we analyzed those results in a separate report.

METHODOLOGY

Here we summarize the research methodology described in Section 2:

Topics. The web survey asked about appliances, consumer electronics, HVAC, water heating, building characteristics, demographics, and program participation. The on-site visits took place for a subset of web survey respondent households and verified select self-reported data and collected additional information on various end uses, including lighting, shell characteristics, efficiency levels, and ages.

Sampling and fielding. We pulled a sample frame of 10,000 customers from National Grid's residential customer database of over 400,000 customers. Between March 27 and April 30, 2018, we sent 10,000 letters to National Grid customers inviting them to respond to the web survey and then followed up with reminder emails. We provided respondents with a $10 Amazon gift card for completing the survey. We completed 900 web surveys and 75 on-site verification visits.

Weighting. The sample overrepresented customers with higher levels of education (Section 5) and those who participated in a National Grid program since 2015 (Appendix D). Using an iterative proportional (raking) approach, we developed weight factors that accounted for these two parameters along with dwelling and fuel types.

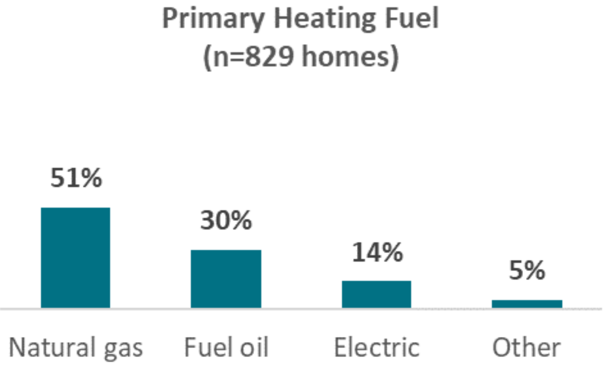
Adjustment factors. Using self-reported (web-survey results) and observed (on-site results) end-use equipment, we developed adjustment factors – ratios – to correct self-reported data. We applied adjustment factors in cases where on-site verified results differed statistically significantly from the web-survey results at the 90% confidence level.

Database development. NMR combined the web-survey and on-site verification data as well as anonymized respondent billing data in an Excel database. NMR designed the database to provide additional details and breakdowns not presented in this report. Appendix E (provided separately) includes a database user guide.

Below, we present the key findings.

HEATING AND COOLING

Section 3.1 details the following heating and cooling findings:



Fuel. The slight majority (51%) of customers' primary heating fuel was natural gas. While single-family customers were next most likely to primarily use fuel oil for heating (36%), multifamily customers were next most likely to primarily use electric heat (33%).

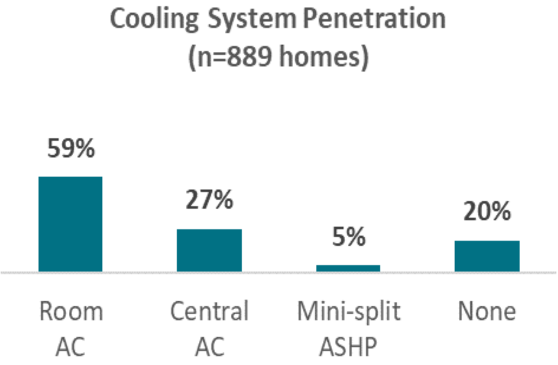
Boilers. Boilers were the most common heating system and were 14 years old, on average across all fuel types. Natural gas boilers were most common, with penetration reaching 37%. Oil boilers had the next highest penetration (28%), yet they were much more common in single-family (33%) than in multifamily (2%) homes.

- The average rated (not tested) annual fuel utilization efficiency (AFUE) among the boilers observed on site was 83 for natural gas boilers (n = 33) and 84 for oil boilers (n = 16).[1] These values are in line with federal standards (80-84) but notably lower than the minimum AFUE requirement for National Grid natural gas boiler rebates (90). See Table 6, in the body of the report, for more AFUE details.

Furnaces. Furnaces were the next most common heating system. Natural gas furnaces were most common (23%) followed by fuel oil (6%) and propane (2%). Furnaces were 14 years old, on average across all fuel types.

- The average rated AFUE among the furnaces observed on site was 85 for natural gas furnaces (n = 11), 81 for oil furnaces (n = 3), and 86 for propane furnaces (n = 4). These AFUEs are above the federal standard (80), but well below the minimum program requirement for natural gas furnaces (95).

Electric heat sources. The most commonly reported electric heating equipment was space heaters (13%) followed by baseboard heaters (11%), central air source heat pumps (3%), and MSHPs (2%).



Cooling. One-fifth of customers have no cooling systems. Room air conditioners were the most commonly reported cooling systems (59%), followed by central air (27%) and MSHP or air source heat pumps (5%). Room air conditioners were newer than central air conditioners (eight versus 13 years old, on average). In accordance with age, the average central air conditioner seasonal energy-efficiency ratio (SEER) was below the federal

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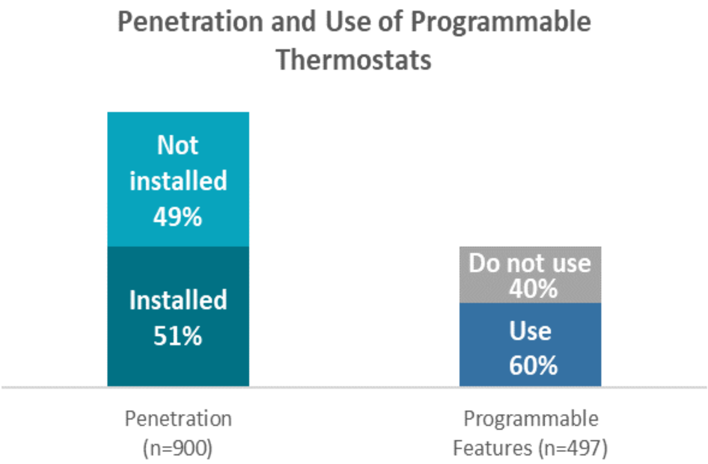
[1] Note that rated AFUE can and often does differ from tested efficiencies.

standard as well (11 versus 13), but the average room air conditioner energy-efficiency ratio (EER) was in line with federal standards (10 versus 9-11).

THERMOSTATS

Section 3.2 reports these and other findings about thermostat penetration and usage:



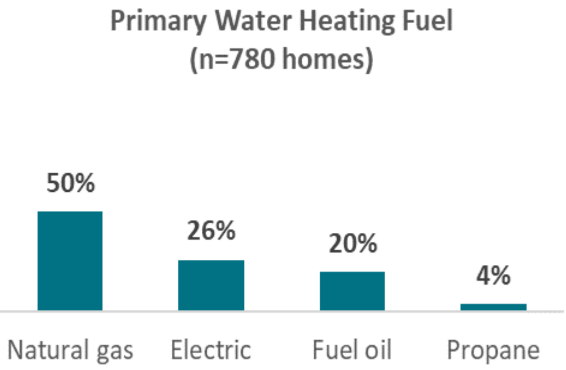
Programmable. While programmable thermostats are in more than one-half (51%) of homes, two-fifths of those who have them say they do not use the programmable features.

Wireless. Only one in ten homes (9%) have adopted smart wireless (Wi-Fi) thermostats.

Settings. Depending on the time of day, customers set their thermostats to between 66°F and 68°F in the winter, on average. Those who have cooling systems, set their thermostats on average to 70°F during the cooling season. Comparing their minimum setpoints to their maximum setpoints, customers change their thermostat set points by 3°F on average over the course of typical winter day and 1°F on average on a typical summer day.

WATER HEATING

Section 3.3 includes details on water heating findings:



Fuel. Natural gas was the most commonly used water heating fuel source (50%) followed by electricity (26%), fuel oil (20%), and propane (4%).

System. Water heaters were most often natural gas standard tank units (40%), followed by standard electric storage tank units (23%).

Age. While the average age of water heaters was only nine years, nearly one in five (17%) were 18 years old or older and one-half were manufactured before 2011.

Efficiency. Aside from inefficient tankless coil systems, the average Energy Factor (EF) among fossil-fuel based units ranged from 0.61 to 0.91. The average EF among the 12 electric units observed on site was 1.07 – the one heat pump water heater observed on site had an EF of 2.40.

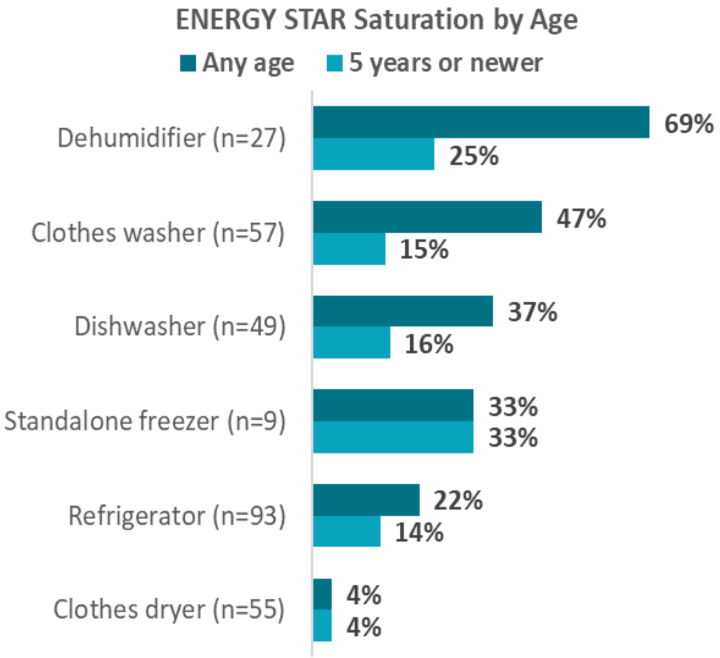
Heat pump water heaters. Only 1% of homes had heat pump water heaters (HPWHs), but an additional one-third (36%) of homes had water heaters installed in locations that could technically readily accommodate a HPWH because they were sufficiently large, warm, and had a drain to handle condensate.[2] The lack of a drain is the most common reason why a space was not currently suitable for a HPWH – ignoring the drain issue, 56% of spaces would have been suitable for a HPWH installation. Nonetheless, we did not estimate the cost-effectiveness of installing HPWHs.

APPLIANCES

Section 3.4 details these appliance results:

Refrigerators. The average home had 1.19 refrigerators, with 16% of homes having more than one. Fourteen percent of refrigerators were new (manufactured after 2012) and ENERGY STAR® labeled. The average refrigerator was 11 years old.

Dishwashers. Two-thirds (67%) of homes had dishwashers. Sixteen percent were new and ENERGY STAR labeled. The average dishwasher was 11 years old.



Clothes washers and dryers. Nearly four-fifths of homes had in-unit clothes washers (78%) and dryers (78%). Fifteen percent of clothes washers were new and ENERGY STAR, but only 4% of clothes dryers were. The average clothes washer was ten years old and the average clothes dryer was 11 years old. Dryers were most often electric – 64% of customers had electric clothes dryers. Based on self-reported data, the average home runs 4.6 loads of laundry per week.

Dehumidifiers. More than one-quarter (28%) of customers had dehumidifiers, and one-quarter of dehumidifiers were new and ENERGY STAR labeled. Where age was discernable, dehumidifiers were seven years old, on average (n=24).

Freezers. Standalone freezers were uncommon (9% penetration); three of nine observed on site were new and ENERGY STAR.

CONSUMER ELECTRONICS

Section 3.5 details these consumer electronics results:

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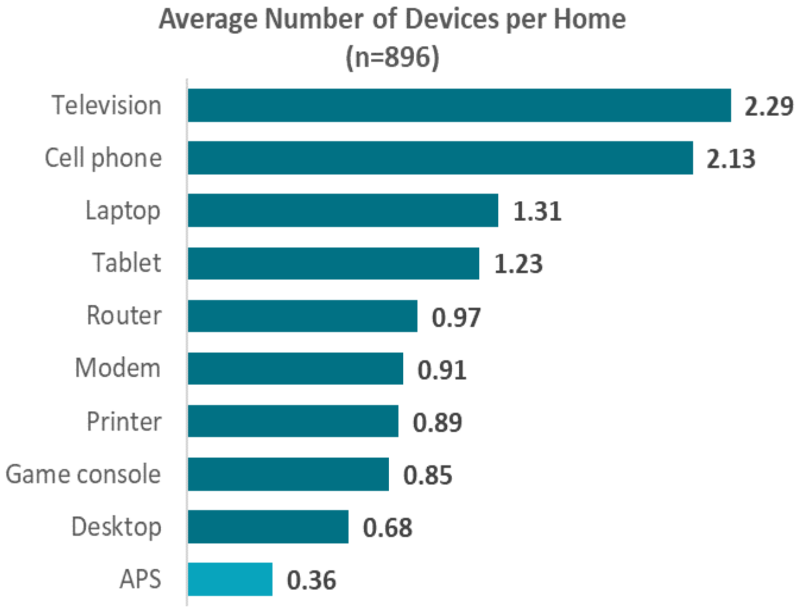
[2] To accommodate HPWHs, rooms must be kept at 50°F in winter, greater than 750 cubic feet in volume, have ceiling height of 6.5’ or taller, and have a drain present.



Electronics. With high penetration levels, the average home had 2.13 cell phones, 2.29 televisions, and 1.31 laptop computers. Laptop computer (81%) penetration was particularly high compared to desktop computer (44%) penetration, with the average home owning 0.52 desktop computers.

Advanced power strips. More than one-quarter (27%) of customers had advanced power strips (APS). That penetration level was higher than initially expected since APS are generally considered an emerging technology, not often available outside of energy-efficiency programs. The high APS penetration is likely attributable to National Grid's aggressive programs, which have distributed or rebated over 80,000 APS in Rhode Island since January 2016.[3] While weights account for program participation, it is worth noting that downstream participants were over represented in the web and on-site survey samples.[4] Note, however, APS penetration was high amoung both confirmed downstream participants and non-participants (28% versus 25%). As National Grid provides incentives for APS devices through its retail program, this may be an indication that National Grid's upstream program efforts are also driving adoption.

MISCELLANEOUS END-USES

Photovoltaic (PV) solar panels have not penetrated the market: only 1% of homes have them installed. Their average installed capacity was 6.11 kW. One in ten of homes with PV solar panels had energy-storage batteries. As shown in Section 3.6, most miscellaneous end-uses, such as pools (8%), air purifiers (6%), and electric cars (1%), also had limited penetration.

BUILDING CHARACTERISTICS

Section 4 provides details on these results:

Type, Age, Size. Compared to the population, the web-survey sample oversampled homes in buildings with two to four units (33%) and under-sampled single-family detached homes (44%). On-site visits more closely resembled the population, with single-family detached homes

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[3] For perspective, National Grid has roughly 400,000 residential customers in Rhode Island.

[4] We were unable to account for upstream participation as no customer tracking data exist for upstream APS participants and customers themselves may have been unaware of participation in upstream programs.

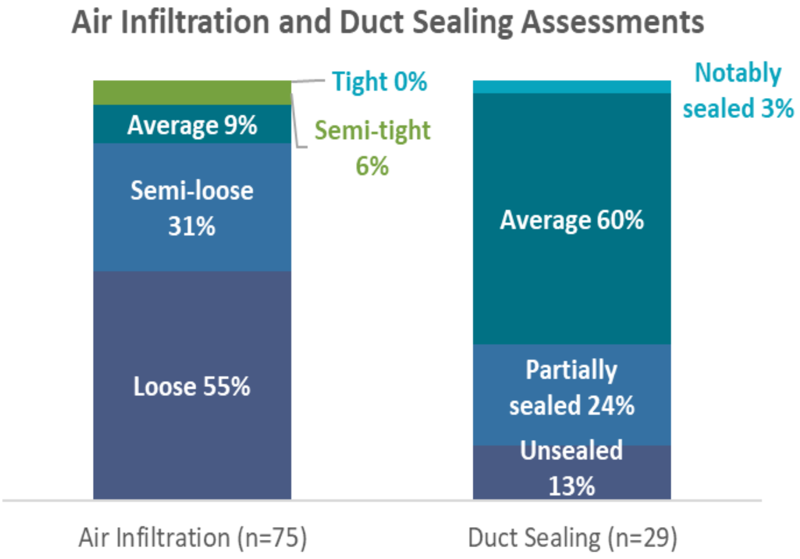
comprising more than one-half (53%) of the sample and homes in buildings with two to four units comprising roughly one-quarter (23%) of the sample. The population (85%) has a slightly older building stock than the web (62%) and on-site (69%) samples, with more homes built before 1990.

Insulation. While the average R-value for on-site homes' exterior above grade walls is about 9, when we group all walls to unconditioned space, including walls to garages, unconditioned basements, and so forth, their average R-value drops to about 7. These buffer spaces are often inconsistently insulated, resulting in lower overall R-values.

Windows. Most window glazing was double paned (89%) and most had vinyl frames (64%) – 44% of total glazing area across all homes was composed of vinyl-framed double-paned windows. About one-fifth (19%) had a low-emissivity coating and less than 4% were filled with insulating gas.

Air infiltration. The majority of homes (86%) received the two lowest air infiltration rankings – *loose* or *semi-loose,* based on Manual J's qualitative assessment criteria.

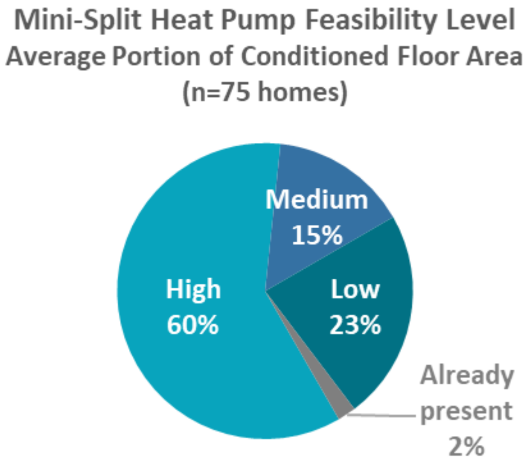
Duct sealing. More than one-third of ducts are either entirely unsealed (13%) or sealed to below-average standards (24%), again using Manual J qualitative assessment criteria.



MINI-SPLIT HEAT PUMP TECHNICAL FEASIBILITY ASSESSMENT

Our analysis focused on the technical feasibility of MSHP. That is, if it was technically possible for a MSHP to be installed in a space to meet heating or cooling needs. Our analysis does not consider other factors that might limit the applicability of MSHP such as cost, customer preferences or needs (marketability), or any site-specific conditions which may prevent installation of MSHP (ownership structures, external zoning restrictions, etc.).

Section 6 explains these findings:



Ranking. The on-site verification visits included a room-level assessment of how much of each home's floor area fell into one of four categories: Tier 1 (high MSHP feasibility), Tier 2 (medium feasibility), Tier 3 (low feasibility), and Tier 4 (no feasibility because a heat pump was already installed). We identified the rooms' suitability for MSHPs based on factors such as room type, HVAC system age, and whether they were too hot in the summer or too cold in the winter. Opportunities for MSHP installations appear plentiful given that three-fifths (60%) of an average home's floor area is Tier 1. Of the homes we visited, 98% had a Tier 1 space.

Load. We then calculated the heating and cooling loads for each home using Manual J, and apportioned the load based on how much of the home's floor area fell into each tier. Heat pump systems could supply much of the average home's heating and cooling needs (the average heating load was 39 kBTUh and about 19 for cooling). One or two MSHP systems could serve a substantial portion of many homes.

National Grid should consider conducting future research that leverages these technical feasibility results to study the cost-effectiveness of MSHP incentives.

PROGRAM PARTICIPATION

Though not the purpose of this research, web surveys offered us a chance to ask some questions about National Grid's home energy assessment offering (Energy Wise and Income Eligible Energy Services programs). Appendix D presents more findings and context on these findings:

Familiarity. Respondents were not overwhelmingly familiar with it. When asked to rate their familiarity on a scale of 1 to 5, where 1 is *not at all familiar* and 5 is *extremely familiar*, they rated their familiarity 2.9, on average. Of course, participants' average familiarity ratings (4.2) were statistically significantly higher than non-participants (2.4).

Installations. Nearly four-fifths (79%) of those who participated, self-reported that they installed the measures that the energy specialist recommended (we did not verify this on site), with nearly all citing that their motivation was to lower their energy bills (98%). Those who reportedly did not install the measures most often pointed to high upfront costs (44%) and insufficient prospective savings (18%) as their main rationales.

Section 1 Introduction

Contracted by National Grid Rhode Island, NMR Group, Inc. performed a statewide Residential Appliance Saturation Survey (RASS) study using web surveys and follow-up on-site verification visits. This report provides an overview of the study methodology, a high-level analysis of results, and a database user guide (provided as a standalone appendix). Data collected as part of this study was also used to estimate upstream lighting net-to-gross and is presented under a separate cover (*RI2311 National Grid Rhode Island Lighting Market Assessment*).

1.1 STUDY OBJECTIVES

Using web-based surveys with 900 National Grid Rhode Island residential customers and follow-up on-site verification visits with 75 of those customers, we accomplished several goals:

- **Baseline characterization.** The results established a sector-wide baseline characterization of Rhode Island households by researching a select set of end-uses, building characteristics, and demographics.
- **Database.** We built a comprehensive database housing all survey and on-site data and appended it with respondents' billing data. We delivered this database to the PAs for stakeholders to conduct any additional analysis to meet their varied needs. In other words, it offers anyone the ability to drill down as needed – a more efficient and user-friendly alternative to a report with innumerable tables.
- **Mini-Split heat pump (MSHP) feasibility.** Results from on-site visits allowed us to assess the market and program potential for MSHPs by measuring how well-suited homes are for installing MSHPs.
- **Lighting market assessment.** Though the results are not reported here, we estimated lighting saturation and other lighting elements (e.g., storage behavior and LED satisfaction).

1.2 REPORT ORGANIZATION

This report includes findings from both the web surveys and on-site verification visits. Table 1 outlines the structure of the report.

Table 1: Report Organization

Section	Purpose/Contents
Methodology	
Section 2	Recounts the methodology we undertook to design the web survey, field and sample for the web-survey and on-site verification visits, analyze data, and develop the database.
Appendix A	Lists end-uses and attributes studied and offers more fielding and sampling details.
Appendix B	Gives further insight into analytical methods, including weighting, adjustment factors, and MSHP feasibility assessment.
Appendix C	Summarizes the approach for cleaning primary data and attaching billing data to develop the database.
Analysis	
Section 3	Analyzes penetration and other key characteristics of the end-uses.
Section 4	Presents sample building characteristics.
Section 5	Characterizes the sample demographics.
Section 6	Assesses MSHP feasibility.
Appendix D	Summarizes program participation questions.
Reference Materials	**(Provided in separate documents)**
Appendix E	Consists of the database user guide.
Appendix F	Includes the web-survey instrument.

Section 2 Methodology

This section details the study methodology including survey design, fielding, sampling, on-site verification, analysis, and database development.

2.1 DATA COLLECTION INSTRUMENTS

The web survey asked about appliances, consumer electronics, HVAC, water heating, building characteristics, demographics, and program participation. The on-site visits, verified much of this self-reported data and collected additional information on various end uses, including lighting, shell characteristics, efficiency levels, and ages. Appendix A.4 lists the end-uses and attributes that the web survey and on-site verification visits examined and Appendix F (in a separate document) includes the web-survey instrument itself.

2.2 FIELDING AND SAMPLING

Using the National Grid residential customer database of 418,478 customers, we pulled a sample frame of 10,000 customers. Between March 27 and April 30, 2018, we sent approximately 10,000 letters to National Grid customers inviting them to respond to the web survey and then followed up with two reminder emails (where available) to non-responsive customers. We provided respondents with a $10 Amazon gift cards for completing the survey. In addition to asking questions about their household, the web survey also asked respondents if they were willing to participate in on-site verification visits. Nearly two-fifths of the 900 web-survey respondents (56%) were willing to have us visit their homes in exchange for a $150 gift card.

We sought to complete 500 web surveys and 75 on-site verification visits, however, given email addresses available from National Grid, as well as stronger than expected initial response rates, we were able to allocate funds initially budgeted for follow-up mailings on additional gift cards. We exceeded the web-survey goal and achieved 900 completed web surveys (a 9% response rate). As planned, we completed 75 verification visits (Table 2). Future evaluations may wish to weigh the pros and cons of increased sample size versus higher response rates. As discussed below, while we nearly doubled the number of completes, allowing us to provide additional data breakdowns, a response rate of 9% introduces more opportunity for non-response bias. The issue of response rates and sample quality is an issue facing evaluations throughout the United States, as response rates continue to decline.[5]

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[5] https://www.aapor.org/Education-Resources/For-Researchers/Poll-Survey-FAQ/Do-Response-Rates-Matter.aspx

Table 2: Completed Surveys and On-Site Verification Visits

Dwelling Type	National Grid Customer Population (n=347,248)[1]	Web Survey		On-Site Verification Visits	
		Completed	Sampling Error	Completed	Sampling Error
Single-family, 1-4 units	86%	751	2.2%	63	7.6%
Multifamily, 5+ units	14%	149	5.0%	12	17.4%
Total		**900**		**75**	

[1] While the National Grid Rhode Island database consisted of over 400,000 customers, approximately 16% of customers were not characterized by dwelling type, so this table shows only valid percentages.

The customer database indicated that, since 2015, 14% of all customers have taken part in one of National Grid Rhode Island's programs.[6] Our sample frame mirrored this proportion, but – not unusual – response rates were higher among participants: based on National Grid's customer database 23% of web-survey respondents and 28% of on-site homes (unweighted) participated in National Grid programs in or after 2015. After weighting (described below), participants accounted for 18% of the samples.

Appendix A.1 recounts additional fielding and sampling steps and considerations.

2.3 ANALYSIS

Below we discuss (1) how we weighted results, (2) development and application of adjustment factors, and (3) the MSHP feasibility assessment approach.

2.3.1 Weighting

Sampling targets aimed to represent the program participation status, dwelling stock, education level, and fuel type of National Grid Rhode Island customers. Appendix B.1 describes the process of segmenting the population and developing the weights using a raking approach.

2.3.2 Adjustment Factors

As described, on-site visits yielded the opportunity to verify web-survey results. Comparing self-reported and observed end-use equipment, we developed adjustment factors to correct for erroneous self-reported data. For example, if 12% of on-site participants reported an end-use in the web-survey, and on-site we found that 21% of homes had the end-use, we would adjust web survey results by a factor of 1.75 (21% divided by 12%). Adjustment factors were only applied in cases where on-site verified results differed statistically significantly from the web survey results at the 90% confidence level. Readers should note that sometimes when adjustment factors are applied, the penetration and average units per home statistics appear incongruous, because one (e.g., penetration) showed a significant difference but the other (e.g., average units per home) did not. The *Adjustment Factor* tab in the database reports adjustment factors by measure and

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[6] The customer program database does not account for all upstream lighting participation; though, online lighting channels collect customer information even if the customer does not directly receive the incentive.

indicates if we applied adjustment factors for the measure-level analysis; throughout this report, we denote if we have applied adjustment factors to the results. For additional details on adjustment factors, please see Appendix B.2.

2.3.3 Mini-Split Heat Pump Technical Feasibility Assessment

MSHPs can be installed in a variety of configurations, including ducted varieties and multi-split systems with multiple indoor blowers attached to a single outdoor unit.[7] Rapid advancement in heat pump technology, increasing efficiency, and configuration options mean that nearly all homes could accommodate a heat pump system to provide some amount of heating or cooling. With that in mind, **this assessment focused on identifying the spaces where systems are technically most feasible or most likely to be installed**. Our analysis does not consider other factors that might limit the applicability of MSHP such as cost, customer preferences or needs (marketability), or any site-specific conditions which may prevent installation of MSHP (ownership structures, external zoning restrictions, etc.).

The feasibility assessment used a room-level tiered ranking system which estimated how much of a home's conditioned floor area was well suited to an MSHP installation. Using a tier scale of one to four, the ranking system leveraged sequential adjustments to identify the feasibility of a MSHP for a given room. Details regarding the assessment protocols are included in Appendix A.2.

2.4 DATABASE DEVELOPMENT

Our primary deliverable for this project, the database, includes all primary research data points and detailed analysis such as penetration (with precision) by dwelling type, income, tenure, participation, and fuel type.

The database combines web-survey and on-site verification data as well as anonymized respondent billing data. The Excel database has been designed to provide additional details and breakdowns not presented in this report. This database should allow National Grid or other interested stakeholders to conduct additional analysis, using simple filtering or more advanced methods, to meet their varied needs, offering users the ability to drill down as desired. Appendix C describes the data processing and Appendix E (provided separately) includes a database user guide**.**

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[7] We use the acronym MSHP rather than "ductless mini-split," given the flexibility of these systems.

Section 3 End-Use Results

This section presents combined key web-survey and on-site results for appliances, consumer electronics, heating and cooling, thermostats, water heating (including a heat pump water heater [HPWHP] feasibility analysis), and miscellaneous end-uses. The database provides comprehensive data points, standard errors, and analyses. The reader should note a few details when reviewing these results:

- **Adjustment factors.** Data are unadjusted unless noted otherwise.
- **Weighting.** Data are unweighted only where specified or if sample sizes are less than 20.
- **Sample sizes.** These vary because we removed invalid responses such as, *don't know*, from the denominator (i.e., base).
- **Dwelling type.** We categorize respondents as multifamily respondents if they live in buildings with five or more units.
- **Dashes.** Dashes in penetration tables indicate that penetration or average units per home are equal to 0.
- **Penetration and Saturation.** Throughout the report we refer to the penetration of end-uses and occasionally to the saturation of ENERGY STAR® products. **Penetration** is the percentage of homes with one or more of a particular end-use. **Saturation** is the percentage of end-use products that share a specific characteristic (for example, ENERGY STAR labeled).

3.1 HEATING AND COOLING

3.1.1 Penetration

The slight majority (51%) of customers' primary heating fuel was natural gas (Table 3). While single-family customers were next most likely to primarily use fuel oil for heating (36%), multifamily customers were next most likely to primarily use electric heat (33%).

Table 3: Primary Heating Fuel

(Source: web-survey and on-site visits)

Heating Fuel	Single-family, 1-4 units (n=708)	Multifamily, 5+ units (n=121)	Overall (n=829)
Natural gas	48%	65%	51%
Fuel oil	36%	2%	30%
Electric	10%	33%	14%
Propane	3%	-	3%
Other	2%	-	2%

Table 4 presents heating systems' penetration. Single-family customers were most likely to heat their homes with natural gas boilers (35%), oil boilers (33%), and natural gas furnaces (21%). While multifamily customers were slightly different; they most often used natural gas boilers (43%) and furnaces (34%) and electric baseboard heating (19%). Customers rarely used heat pumps for heating purposes, with only 3% of homes using central air-source heat pumps and 2% using ductless MSHPs. While 11% of multifamily customers reported using central air source heat pumps for heating, we should consider that multifamily customers are likely less knowledgeable about their heating systems than single-family customers; in fact, 18% of multifamily customers did not know their primary heating system while only 7% of single-family customers did not know. Hydronic systems (i.e., boilers) comprised about three-fifths (62%) of natural gas heating systems and four-fifths (82%) of fuel oil systems.

Table 4: Heating System Penetration

(Source: web-survey and on-site visits)[1]

Heating System	Single-family, 1-4 units (n=708)		Multifamily, 5+ units (n=121)		Overall (n=829)	
	Customers	Fuel Type	Customers	Fuel Type	Customers	Fuel Type
Natural Gas						
Boiler[2]	35%	63%	43%	56%	37%	62%
Furnace	21%	38%	34%	44%	23%	38%
Fuel Oil						
Boiler[2]	33%	89%	2%	100%	28%	82%
Furnace[2]	7%	18%	-	-	6%	18%
Electric						
Space heater[2]	13%	52%	4%	11%	13%	45%
Electric baseboard	9%	36%	19%	54%	11%	38%
Central air source heat pump	1%	4%	11%	31%	3%	10%
Ductless MSHP	2%	8%	1%	3%	2%	7%
Ground source heat pumps	<1%	<1%	<1%	<1%	<1%	<1%
Propane						
Furnace	2%	67%	-	-	2%	67%
Boiler	1%	33%	-	-	<1%	33%
Other						
Fireplace or heating stove	6%	100%	2%	100%	5%	100%

[1] Surveys did not ask for heating system quantities. Percentages do not sum to 100% because some customers had multiple types of heating systems. Fuel Type columns present percentages which exclude uncommon systems such as electric boilers and natural gas wall heaters.

[2] Adjustment factor applied. Natural gas systems (60%) and fuel oil systems (34%) sums differ from the primary heating fuel sums (51% and 30%, respectively) shown in Table 3 due to adjustment factors and – to some extent – the fact that a small share of homes do not use these as their primary systems.

Not uncommon in New England, customers most often cooled their homes using room air conditioners (59%; Table 5). Likely owing to a relatively mild cooling season and the expense of installing duct work in an existing home, less than one-third of homes (27%) have central air conditioners. One-fifth of respondents reported having no cooling system.[8] Among respondents with a cooling system, 17% had at least one other type of cooling system.

Table 5: Cooling System Penetration

(Source: web-survey and on-site visits)[1]

Cooling System	Single-family, 1-4 units (n=774)	Multifamily, 5+ units (n=145)	Overall (n=889)
Room air conditioner	62%	41%	59%
Central air conditioner	24%	41%	27%
Mini-split air source heat pump (ducted or ductless)	5%	2%	5%
No cooling system[2]	20%	20%	20%

[1] Percentages do not sum to 100% because customers had multiple cooling systems.
[2] This also includes respondents who reported having only ceiling or portable fans.
Note: Surveys did not ask about quantities for these systems.

3.1.2 Efficiency and Age

Comparing them to federal standards, Table 6 summarizes the annual fuel utilization efficiency (AFUE)[9] of furnaces and boilers, the seasonal energy-efficiency ratio (SEER) of central air conditioners, energy-efficiency ratio (EER) of room air conditioners, the heating seasonal performance factor (HSPF) of ductless MSHPs and ducted ASHPs, and the EER and coefficient of performance (COP) of GSHPs observed on site. Note the low sample sizes.

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[8] Survey respondents could specify portable fans and ceiling fans as cooling systems. On-site, the team collected data on room and central air conditioners and heat pumps only. In this analysis, we consider respondents that cool their homes exclusively with a portable or ceiling fan as having no cooling system in order to make accurate comparisons with on-site data. Overall, 9% of respondents reported that they exclusively cool their home with a portable or ceiling fan.

[9] On-site technicians recorded the efficiency ratings shown on units' energy labels. Technicians did not test actual performance.

Table 6: Heating and Cooling System – Efficiency Levels

(Source: on-site visits; n = 75)

End-Use		Quantity (n)	Average	Minimum	Maximum	Federal Standards[1]
Furnace (AFUE)	Oil	3	**80.7**	77.0	85.0	80
	Natural gas	11	**85.4**	78.0	96.1	80
	Propane	4	**85.9**	75.0	96.1	80
Hot water boiler (AFUE)	Oil	14	**83.4**	75.0	87.0	84
	Natural gas	29	**83.2**	77.0	95.1	82
Steam boiler (AFUE)	Oil	2	**84.0**	84.0	84.0	82
	Natural gas	4	**79.8**	77.0	82.0	80
All boilers (AFUE)	*Oil*	*16*	***83.5***	*75.0*	*87.0*	*See above*
	Natural gas	*33*	***82.9***	*77.0*	*95.1*	*See above*
Air conditioner	Central (SEER)	23	**10.9**	7.4	15.5	13
	Room (EER)	83	**10.1**	8.0	12.1	9 to 11[2]
Ductless MSHP	HSPF	2	**11.1**	10.6	11.5	8.2
	SEER		**19.8**	19.0	20.5	14
Ducted ASHP	HSPF	1	**9.6**	9.6	9.6	8.2
	SEER		**14.0**	14.0	14.0	14
GSHP	COP	2	**4.7**	4	5.3	3.1 to 4.1[3]
	EER		**21.5**	17.5	25.2	16.0 to 21.1[3]

[1] *Source*: Electronic Code of Federal Regulations. https://www.ecfr.gov/cgi-bin/text-idx?SID=a9921a66f2b4f66a32ec851916b7b9d9&mc=true&node=se10.3.430_132&rgn=div8. August 24, 2018.

[2] Values range by size and other features. Federal standards began using combined EER (CEER) in 2014, but the team did not collect CEER data. However, using the U.S. Department of Energy's Compliance Certification Database we ran a regression modeling suggesting that CEER is equal to 99% of EER.

[3] Values range by open/closed loop and other features. These values come from ASHRAE because there are not federal efficiency codes for GSHPs.

Table 7 characterizes the ages of the common heating and cooling systems on site. Both 14 years old, on average, boilers (67%) and furnaces (67%) were most often between eight and 28 years old – more than two-fifths were manufactured in the 1990s or earlier. Cooling systems were newer: central air conditioners (65%) were most often between eight and 17 years old, and room air conditioners tended to be even newer, with 78% manufactured in the past 12 years. On average, central air conditioners were 13 years old while room air conditioners were eight.

Table 7: Heating and Cooling System – Ages

(Source: on-site visits; n = 75)

Year Manufactured	Heating[1]		Air Conditioning	
	Boiler (n=42)[2]	Furnace (n=15)[2]	Central (n=23)	Room (n=71)
2016 or newer	1%	13%	4%	10%
2011 -2015	15%	7%	17%	34%
2006-2010	14%	7%	31%	34%
2001-2005	24%	27%	34%	10%
1991-2000	29%	33%	12%	12%
1981-1990	13%	7%	2%	-
1980 or earlier	5%	7%	-	-
Average Age (years)	**14**	**14**	**13**	**8**

[1] While common, electric baseboards are not typically marked with model/serial numbers, making age unclear. Note: Not shown, the two ductless MSHPs were six years old on average, the ducted ASHP was 12 years old, and the two GSHP were three years old.

[2] Does not sum to 100% due to rounding.

3.2 THERMOSTATS

The average home had 1.46 thermostats. They most often had standard thermostats (61%) installed, followed by basic programmable thermostats (44%) (Table 8). About one in ten homes (9%) had a smart wireless (Wi-Fi) thermostat.[10] Of the 94 respondents who reported having a smart Wi-Fi thermostat, Nest was the most popular brand (62%), followed by Honeywell (19%) and Ecobee (9%). In total, 51% of homes had at least one type of programmable thermostat. Of the homes with programmable thermostats (both basic programmable and Wi-Fi), three-fifths reported using the programmable features.[11]

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[10] A Wi-Fi thermostat allows users to monitor, control, and program their thermostats through web browsers or mobile devices. A *smart* Wi-Fi thermostat adds to those features by automating control of HVAC systems based on data from occupancy or proximity sensors, weather data, and/or machine-learning algorithms.

[11] Fewer respondents (65) reported having a separate programmable cooling thermostat, but the percentage using the programmable features on cooling thermostats (55%) was similar to the percentage that reported using the feature on heating thermostats (60%).

Table 8: Thermostat – Penetration and Average Units per Household

(Source: web-survey and on-site visits)

Thermostat	Single-Family, 1-4 units			Multifamily, 5+ units			Overall		
	n	Pen.	Units	n	Pen.	Units	n	Pen.	Units
Standard	751	61%	1.08	149	57%	0.83	900	61%	1.04
Basic programmable	751	45%	0.78	149	37%	0.48	900	44%	0.73
Wi-Fi smart	751	8%	0.14	149	11%	0.12	900	9%	0.13
Wi-Fi not smart[1]	751	3%	0.06	149	4%	0.07	900	3%	0.06
Overall[2]	**751**	**99%**	**1.52**	**149**	**97%**	**1.12**	**900**	**98%**	**1.46**

[1] A *not-smart* Wi-Fi thermostat does not include the advanced automation features that a *smart* Wi-Fi thermostat has. None of the on-site respondents reported these in the web survey, but on-site, we found that 4% had them – a statistically significant difference. However, we cannot apply an adjustment factor to 0%, so we report the unadjusted penetration, but it is worth considering that penetration may be higher than 3%.

[2] Adjustment factor applied.

Note: n = number of respondents; Pen. = penetration; Units = Average units per household.

As shown in Table 9, web-survey respondents reported that, in the winter, depending on the time of day, they set their thermostats to between 66°F and 68°F, on average. Comparing their maximum settings with their minimum settings, the typical respondent varies their temperature set points by 3°F on a given winter day. While set points do not vary greatly, generally heating thermostat set points are highest during the evening (5pm to 9pm) and decrease during the day (9am to 5pm) and at night (9pm to 6pm).

Those who have cooling systems, set their thermostats on average to 70°F during the cooling season. Their cooling thermostat set points do not vary by time of day. However, looking at the variation for each respondent's high and low temperature, on average, they change their set points by 1°F on a given summer day.

Table 9: Average Temperature Setting

(Source: web-survey)

Time of Day[1]	Single-family, 1-4 units	Multifamily, 5+ units	Overall
Heating Season	(n=684)	(n= 128)	(n=811)
Morning (6am to 9am)	66	68	67
Day (9am to 5pm)	66	67	66
Evening (5pm to 9pm)	68	69	68
Night (9pm to 6am)	66	67	66
Average Setpoint Change	**3**	**3**	**3**
Cooling Season	(n=379)	(n=91)	(n=470)
Morning (6am to 9am)	70	70	70
Day (9am to 5pm)	70	71	70
Evening (5pm to 9pm)	70	70	70
Night (9pm to 6am)	70	70	70
Average Setpoint Change	**1**	**2**	**1**

[1] Heating season refers to December through February and cooling season refers to June through August. Values exclude outliers three standard deviations from the mean. Cooling sample sizes exclude respondents who did not have cooling systems.

3.3 WATER HEATING

3.3.1 Penetration

One-half of primary water heaters used natural gas and slightly more than one-quarter (26%) used electricity. While one-fifth used fuel oil, this was considerably more common among single-family (23%) than multifamily (<1%) homes (Table 10).

Table 10: Primary Water Heating Fuel

(Source: web-survey and on-site visits)

Fuel Type	Single-family, 1-4 units (n=674)	Multifamily, 5+ units (n=106)	Overall (n=780)
Natural gas	49%	60%	50%
Electric	23%	39%	26%
Fuel oil	23%	<1%	20%
Propane	4%	-	4%

Water heaters were most often natural gas storage tank units (40%), followed by storage tank electric units (23%). Only 1% of homes had heat pump water heaters (Table 11).

Based on the on-site verification visits, it was clear that some web-survey respondents struggled to accurately identify their water heaters' fuel *and* system types. For example, a respondent may have correctly identified that his water heater used natural gas, but he may not have known that it is a storage tank unit (or vice versa). The differences in knowledge compelled us to estimate adjustment factors for fuel types and system types separately (none were needed for water heater fuel types). As such, proportions across end-use attributes do not always align given that adjustment factors are applied to *proportions* not individuals.[12] This type of scenario also occurred with space heating.

Table 11: Water Heating System Penetration

(Source: web-survey and on-site visits)

Water Heater	Single-family, 1-4 units (n=645)	Multifamily, 5+ units (n=91)	Overall (n=736)
Natural Gas[1]			
Storage tank	41%	40%	40%
Tankless[2,3]	1%	4%	2%
Indirect	4%	5%	4%
Electric			
Storage tank	21%	39%	23%
Heat pump[4]	1%	-	1%
Tankless	1%	-	1%
Fuel oil[1]			
Storage tank	8%	-	7%
Tankless[3]	7%	-	6%
Indirect[2]	20%	-	18%
Propane			
Storage tank	4%	-	3%
Tankless[3]	1%	-	1%

[1] Combination water heater systems had a penetration of less than 1% in each fuel category.
[2] Applied adjustment factor.
[3] Includes tankless coils and instantaneous, on-demand systems. Though, fuel oil systems are likely only tankless coils.
[4] None of the on-site respondents reported these in the web survey, but on site we found that 1% had them – a slight but statistically significant difference. We cannot apply an adjustment factor to 0% penetration, however, so we report the unadjusted penetration, but it is worth considering that penetration may be higher than 1%.

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[12] For example, 50% of homes have natural gas water heaters, but at the system type level – due to adjustment factors – 46% appear to be natural gas (40% were storage tank, 2% were tankless, and 4% were indirect).

3.3.2 Efficiency and Age

Table 12 shows the Energy Factors (EF) of the water heaters observed on site, but readers should note small sample sizes. Looking at average EF by fuel type, the average EF among fossil-fuel based units ranged from 0.61 to 0.68. The average EF among electric units was 1.07 – the one HPWH had an Energy Factor of 2.40.

Table 12: Water Heaters – Energy Factors

(Source: on-site visits; n = 75)

End-Use		Quantity (n)	Average	Minimum	Maximum
Standalone storage	Natural gas	33	**0.62**	0.56	0.76
	Electric	11	**0.91**	0.84	0.93
	Propane	3	**0.61**	0.53	0.70
	Oil	1	**0.64**	0.64	0.64
Indirect with storage	Natural gas	6	**0.82**	0.74	0.87
	Oil	5	**0.77**	0.74	0.79
Tankless coil	Oil	7	**0.47**	0.45	0.50
	Natural gas	1	**0.45**	0.45	0.45
Combination appliance	Natural gas	3	**0.90**	0.85	0.95
Instantaneous	Natural gas	1	**0.83**	0.83	0.83
Heat pump water heater	Electric	1	**2.40**	2.40	2.40
Overall by Fuel Type					
Natural gas		44	**0.68**	0.45	0.95
Electric		12	**1.07**	0.84	2.40
Propane		3	**0.61**	0.53	0.70
Oil		13	**0.60**	0.45	0.79

Considering the standard lifetime of water heaters,[13] a notable share of water heaters we observed on site were fairly old, with one-half manufactured before 2011 (Table 13). On average, they were nine years old.

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[13] The 2017 Rhode Island Technical Reference Manual assumes a ten-year lifetime for water heaters.

Table 13: Water Heaters – Age

(Source: on-site visits; n = 75)

Year Manufactured	Percentage of Units (n=62)[1]
2016 or newer	17%
2011 to 2015	33%
2006-2010	26%
2001-2005	7%
1991-2000	9%
1981-1990	3%
1980 or earlier	5%
Average Age (years)	**9**

[1] Age was not decipherable for some units.

3.3.3 Heat Pump Water Heater Feasibility

As noted, only 1% of customers had HPWHs. During on-site visits, auditors assessed each water heater location against four key criteria to determine if it could accommodate a HPWH.[14] HPWHs transfer heat from the surrounding air to the water in a storage tank and therefore work best when installed in spaces with a volume of at least 750 cubic feet and that maintain a year-round temperature of at least 50°F. They are usually tall, so they require a ceiling height of at least 6.5 feet. Lastly, the heat pump functionality produces condensate, requiring a nearby drain.

Thirty-six percent of on-site homes met all conditions to readily accommodate a HPWH, meaning the space was sufficiently large, warm, and had a drain (Table 14). Most often homes were unsuitable for a HPWH because they did not have a nearby drain, with fewer than one-half (46%) having a nearby drain. If all spaces had a drain, 56% of homes could accommodate a HPWH (though adding a drain could be expensive in many cases).

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[14] Example of programs providing these criteria as general requirements for HPWH installation: https://www.masssave.com/en/shop/equipment/electric-water-heaters/

Table 14: Heat Pump Water Heater Feasibility

(Source: on-site visits; n=70)[1]

Conditions	Count (unweighted)	Percentage of Homes
All conditions met	**28**	**36%**
Drain present	39	46%
Room 50°F + in winter	51	68%
Volume > 750 cubic feet	57	83%
Ceiling height = > 6.5 feet	68	96%
HPWH already installed	1	1%

[1] Five homes had inaccessible water heaters.

3.4 APPLIANCES

3.4.1 Penetration

Table 15 presents the penetration and average number of units per household for kitchen and other appliances:

- As expected, refrigerator (100%), oven (97%), and stove (100%) penetration were high. On average, households had 1.19 refrigerators, with 16% of the sample having more than one refrigerator.
- In-unit clothes washers (78%) and dryers (78%) were somewhat less common, but even less common among multifamily homes with five or more units (56% and 56%, respectively).
- Dryers were most often electric, with 64% of respondents having electric dryers, 13% having natural gas dryers, and only 1% having propane dryers.
- More than one-quarter (28%) of customers had dehumidifiers and slightly fewer had humidifiers (22%). In our experience multifamily occupants often do not have sole usage or access to their basements and dehumidifiers are generally used in basements, so it is not surprising that only 4% of multifamily respondents had dehumidifiers.
- Standalone freezers were the least common appliance (9%).

Table 15: Appliances – Penetration and Average Units per Household

(Source: web-survey and on-site visits)

End-Use	Single-Family, 1-4 units			Multifamily, 5+ units			Overall		
	n	Pen.	Units	n	Pen.	Units	n	Pen.	Units
Kitchen									
Refrigerator	748	100%	1.22	144	100%	1.03	892	100%	1.19
Standalone freezer[1]	734	10%	0.11	146	5%	0.05	880	9%	0.10
Dishwasher	738	66%	0.68	145	73%	0.73	883	67%	0.69
Stovetop[1]	745	100%	1.02	144	100%	0.98	889	100%	1.01
Oven	747	97%	1.05	145	99%	1.00	892	97%	1.04
Electric stovetop/oven[1]	*750*	*52%*	*0.64*	*144*	*56%*	*0.7*	*894*	*53%*	*0.65*
Natural gas stovetop/oven[1]	*750*	*41%*	*0.40*	*144*	*39%*	*0.38*	*894*	*40%*	*0.39*
Propane stovetop/oven	*750*	*6%*	*0.13*	*144*	*1%*	*0.01*	*894*	*5%*	*0.11*
Clothes									
Clothes washer	747	83%	0.85	147	56%	0.56	894	78%	0.80
Clothes dryer	746	83%	0.85	147	56%	0.56	893	78%	0.80
Electric	*738*	*68%*	*0.69*	*143*	*44%*	*0.44*	*881*	*64%*	*0.65*
Natural gas	*738*	*13%*	*0.14*	*143*	*11%*	*0.11*	*881*	*13%*	*0.13*
Propane	*738*	*2%*	*0.02*	*143*	*-*	*-*	*881*	*1%*	*0.01*
Humidity Control									
Dehumidifier	751	33%	0.36	149	4%	0.04	900	28%	0.30
Humidifier[2]	751	24%	0.30	149	15%	0.15	900	22%	0.28

Note: n = number of respondents; Pen. = penetration; Units = Average units per household

[1] Adjustment factor applied.

[2] Not verified on site.

3.4.2 Efficiency and Age

Table 16 shows ENERGY STAR saturation among on-site appliances by age. ENERGY STAR saturation among clothes washers (47%) and dishwashers (37%) were notably high. However, ENERGY STAR specifications advance over time, so the label among older appliances loses significance. With that in mind, only 15% of clothes washers and 16% of dishwashers were ENERGY STAR-labeled and manufactured recently (2013 or sooner). One-quarter of the 27 dehumidifiers were ENERGY STAR and manufactured recently.

Table 16: Appliances – ENERGY STAR Saturation

(Source: on-site visits; n = 75)

Appliance	Year of first ENERGY STAR Specification[1]	Quantity (n)[2]	ENERGY STAR Certified	
			Any Age	Manufactured in or after 2013
Clothes washer	*1997*	57	47%	15%
Clothes dryer	*2014*	55	4%	4%
Dishwasher	*1996*	49	37%	16%
Refrigerator	*1996*	93	22%	14%
Standalone freezer	*1996*	9	33%	33%
Dehumidifier	*2001*	27	69%	25%

[1] Source: https://www.energystar.gov/

[2] Bases vary depending on the availability of age and/or ENERGY STAR status. Note the particularly small freezer sample size.

Appliances on site were generally manufactured within the last 18 years. However, more than one-half of refrigerators (58%), clothes washers (65%) and dryers (71%), and dishwashers (56%) were manufactured before 2011; on average, units were between ten and 11 years old (Table 17). Dehumidifiers were newer: they were seven years old, on average, and 62% were manufactured in 2011, or more recently (though n = 24).

Table 17: Appliances – Ages

(Source: on-site visits; n = 75)[1]

Year Manufactured	Refrigerator (n=95)[2]	Clothes Washer (n=59)[2]	Clothes Dryer (n=59)	Dishwasher (n=52)	Dehumidifier (n=24)[2]
2016 or newer	10%	4%	8%	10%	12%
2011- 2015	34%	32%	21%	34%	50%
2006-2010	13%	31%	33%	15%	20%
2001-2005	28%	25%	23%	24%	16%
1991-2000	14%	9%	14%	13%	-
1981-1990	1%	-	1%	4%	3%
1980 or older	2%	-	-	-	-
Average age (years)	**11**	**10**	**11**	**11**	**7**

[1] Sample sizes differ from previous on-site appliance table due to unknown ages.
[2] Does not sum to 100% due to rounding.

3.4.3 Habits

Web-survey respondents most often wash their clothing in cold water. On average, they reported that they used cold water for nearly three-fifths (57%) of their laundry loads (Table 18). They run an average of 4.6 loads of laundry per week.

Table 18: Clothes Washing Habits

(Source: web-survey)

Habit	Single-family, 1-4 units (n=640)	Multifamily, 5+ units (n=79)	Overall (n=719)
Average Water Temperature			
Hot	12%	20%	13%
Warm	31%	21%	30%
Cold	57%	59%	57%
Average Loads per Week	**4.8**	**3.1**	**4.6**

3.5 CONSUMER ELECTRONICS

3.5.1 Penetration

When asked to quantify the consumer electronics in their homes, web-survey respondents most frequently reported having cell phones (99%) and televisions (96%) – the average homes had 2.13 cell phones and 2.29 televisions. Laptop computer (81%) penetration was particularly high, especially compared to desktop computer penetration (44%); moreover, homes had 1.31 laptop computers and only 0.52 desktop computers, on average. Table 19 compares these results by dwelling type. With the exception of advanced power strips (APS),[15] on-site visits did not verify the presence of consumer electronics. We discuss APS penetration below.

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[15] “Advanced power strips” is a generic term that we use to refer to Tier 1 and Tier 2 products.

Table 19: Consumer Electronics – Penetration and Average Units per Household

(Source: web-survey)

Device	Single-Family, 1-4 units			Multifamily, 5+ units			Overall		
	n	Pen.	Units	n	Pen.	Units	n	Pen.	Units
Communication									
Cell phone	747	99%	2.23	149	100%	1.66	896	99%	2.13
Router[1]	741	94%	0.98	149	89%	0.90	890	93%	0.97
Modem[1]	740	88%	0.91	149	88%	0.90	889	88%	0.91
Combined modem and router	*707*	*51%*	*0.51*	*144*	*56%*	*0.58*	*851*	*52%*	*0.52*
Entertainment									
Television	748	96%	2.37	149	97%	1.87	896	96%	2.29
Tablet	743	77%	1.28	147	72%	0.99	890	76%	1.23
Game console	737	50%	0.89	148	35%	0.64	885	47%	0.85
Stand-alone sound equipment	723	36%	0.54	148	29%	0.42	871	35%	0.52
TV sound system	736	38%	0.47	148	32%	0.36	884	37%	0.45
Office									
Laptop	744	82%	1.36	148	77%	1.04	892	81%	1.31
Printer	733	75%	0.93	148	66%	0.68	881	73%	0.89
Monitor	733	47%	0.66	148	40%	0.46	881	46%	0.68
Desktop computer	739	46%	0.55	147	35%	0.36	886	44%	0.52
Advanced power strip[2]	**700**	**27%**	**0.38**	**143**	**27%**	**0.30**	**843**	**27%**	**0.36**

Note: n = number of respondents; Pen. = penetration; Units = Average units per household

[1] Includes combined modems and routers.

[2] Verified on site and adjustment factor applied.

3.5.2 Advanced Power Strips

APS adjusted penetration (27%) was higher than we might expect given the relative newness of this energy-saving measure. The majority of APS penetration may be attributable to National Grid's aggressive support of APS. National Grid Rhode Island has supported APS as part of their programs since 2012.[16] Based on program records, between January 1, 2016 and May 29, 2018, they have distributed or rebated over 80,000 APS through all programs combined. For reference, National Grid serves over 400,000 households in Rhode Island. While downstream participants were overrepresented in the sample, weights accounted for participation (see Section 2.3.1); APS penetration did not vary by downstream program participation: penetration was 28% among customers who have participated since 2016 and 25% among those who have not. Note that we were unable to account for upstream participation as no customer tracking data exist for upstream APS participation and customers themselves may have been unaware of participation in upstream programs.

On-site visits allowed us the opportunity to (1) verify the installation of APS and (2) identify what was plugged into those APS.[17] Many web-survey respondents had mistaken surge protectors for APS. When asked on the web-survey, 71% of on-site customers said that they used APS, but when we went on site, we found that only 27% (weighted) of them had APS (this resulted in an adjustment factor of 0.38 that decreased overall penetration from 71% to 27%). Therefore, when we analyzed what was plugged into APS, we disregarded web-survey responses and focused on on-site observations only. As shown in Table 20, we saw that customers most commonly use their APS with their televisions and set-top boxes:

- Of the 22 on-site homes with APS, 86% plugged televisions into their APS. This means that one-quarter of all on-site homes (n=75) used APS for their televisions.
- More than two-thirds (71%) of customers with APS plugged set-top boxes into their APS, meaning that roughly one-fifth of on-site homes (21%) have set-top boxes plugged into APS.

We also saw sound systems (37%) and DVD players (34%) plugged into APS in more than one-third of the 22 homes.

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[16] The majority (96%) of APS that the program has distributed or rebated were Tier 1. None of the on-site APS appeared to be Tier II APS.

[17] None appeared to be Tier II APS. Tier II APS provide more savings than traditional APS by "monitoring a user's engagement with their electronics or presence in a room." *Source*: Northeast Energy Efficiency Partnerships. *Advanced Power Strips*. http://www.neep.org/initiatives/high-efficiency-products/advanced-power-strips. Accessed July 26, 2018.

Table 20: Consumer Electronics Plugged into Advanced Powers Strips

(Source: on-site visits)[1]

End-Use Connected to APS	Homes with APS (n=22)
Television	86%
Set-top box	71%
Sound system	37%
DVD player	34%
Game console	28%
Computer	17%
Printer/office equipment	14%
Smart home device (e.g., Google Home)	8%
Fan	6%
Kitchen appliance	3%
Lighting	2%

[1] Percentages represent the proportion of homes with at least one of the specified end-uses plugged into an APS. Percentages do not total to 100% because multiple end-uses may be plugged into a single APS, and homes may have had more than one APS.

3.6 MISCELLANEOUS END-USES

Electric and plug-in hybrid cars are uncommon with only 1% of respondents reporting each (Table 21).

One percent of respondents (18 households – all single-family) had photovoltaic (PV) solar panels. Based on their attempts to estimate the capacity or size of their panels, we estimate that the average installed capacity among that subset of customers was 6.11 kW (not shown). Only two of those respondents had energy-storage batteries to accompany their panels.

Table 21: Vehicles and Solar – Penetration and Average Units per Household

(Source: web-survey and on-site visits)

End-Use	Single-Family, 1-4 units			Multifamily, 5+ units			Overall		
	n	Pen.	Units	N	Pen.	Units	n	Pen.	Units
Electric-only vehicle	738	1%	0.02	144	1%	0.01	882	1%	0.01
Plug-in hybrid vehicle	736	<1%	<0.01	142	-	-	878	<1%	0.01
PV panels[1]	751	2%	0.12	149	-	-	900	1%	0.10
Energy-storage battery	751	<1%	<0.01	149	-	-	900	<1%	<0.01

Note: n = number of respondents; Pen. = penetration; Units = Average units per household

[1] Average units per household refers to average installed capacity per household in terms of kW.

When presented with a list of (what we considered) common miscellaneous measures, customers most often reported having pools (8%) and air purifiers (6%) (Table 22). A small percentage (4%) reported having whole-home generators; of those 36 respondents, roughly one-half (51%) used bottled gas such as propane, while others mainly used gasoline (29%) and natural gas (16%) to fuel the generators.

Table 22: Miscellaneous Measure Penetration Rates

(Source: web-survey)

End-Use	Single-family, 1-4 units (n=751)	Multifamily, 5+ units (n=149)	Overall (n=900)
Pool	9%	3%	8%
Air purifier	6%	5%	6%
Aquarium with pump	5%	1%	4%
Whole-home generator	4%	1%	4%
Spa	2%	<1%	2%
Terrarium with heat lamp	1%	-	1%
Pool sweep	1%	-	1%

Section 4 Building Characteristics

4.1 TYPE, AGE, AND SIZE

As shown in Table 23, on-site verification visits took place most often at single-family detached homes (53%) and homes in buildings with two to four units (23%). These proportions are different from the web-survey sample (44% and 33%, respectively) – on-site dwelling types better represent the population (56% and 23%, respectively). Though we targeted advance letters for web surveys (see Appendix A.1), that mode relied more heavily on respondent self-selection and more limited dwelling type data. Conversely, we leveraged web-survey responses to selectively develop our on-site sample to better represent the population and were able to more aggressively recruit customers to participate using phone calls and follow-up emails to ensure a better representation.[18]

The population (85%) has a slightly older building stock than the web (62%) and on-site (69%) samples, with more homes built before 1990.

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[18] Our weighting approach accounted for this discrepancy (see Appendix B.1).

Table 23: Dwelling Type and Age (Unweighted)

(Source: on-site visits and U.S. Census)

Characteristic	Web-Survey Responses (n=900)	On-Site Observations (n=75)	Population (n=410,240)[1]
Dwelling Type[2]			
Single-family detached	44%	53%	56%
Single-family attached	7%	8%	4%
Single-family (2-4 units)[3]	33%	23%	23%
Multifamily (> = 5 units)	17%	16%	17%
Year Built[4]			
Before 1920	13%	15%	37%
1920 to 1949	12%	12%	
1950 to 1979	23%	31%	37%
1980 to 1989	14%	11%	11%
1990 to 1999	6%	8%	8%
2000 to 2010	7%	7%	7%
2011 to 2014	2%	-	1%
2015 or after	2%	3%	0.02%

[1] Source: U.S. Census Bureau. ACS 2012-2016. Proportions are based on occupied housing units.
[2] Due to vague answers, we conducted secondary research to determine dwelling types for some homes.
[3] This study's analyses – in line with the National Grid program definition – considers properties with two to four units as single-family.
[4] More than one-fifth of web-survey respondents did not know the age of their home, so n=693.

On average, the on-site homes' conditioned floor area was 1,365 sq. ft.[19] This is somewhat smaller than we might expect, but the unweighted size was slightly larger (1,449 sq. ft) and in line with regional statistics.[20] Table 24 compares it by income-category and dwelling type. Not surprisingly, low-income customers live in smaller spaces than non-low-income customers (960 versus 1,710 sq. ft.). Similarly, single-family homes are, on average, roughly 1,000 sq. ft. larger than multifamily homes with five or more units.

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[19] Web survey respondents who could provide precise estimates of their homes' sizes, estimated that their homes were 1,511 sq. ft., on average (n=582).

[20] Census data do not report the average housing unit size in Rhode Island. However, the 2013 American Housing Survey data show that the median home size in the nearby Boston, MA and Hartford, CT metropolitan areas are somewhat larger (1,467 and 1,518 sq. ft., respectively). (The National Center for Health Statistics considers all counties in Rhode Island to be metropolitan, so these appears to be the best available regional reference points).

Table 24: Conditioned Floor Area by Income and Dwelling Type

(Source: on-site visits)

Income Category	Single-Family		Single-Family, 2-4 units		Multifamily, 5+ units		Overall	
	N	Average Sq. Ft.[1]	n	Average Sq. Ft.[1]	n	Average Sq. Ft.[1]	n	Average Sq. Ft.
Low-income	10	1,062	12	993	4	609	26	960
Non-low-income	36	1,971	5	1,354	8	754	49	1,710
Overall	**46**	**1,774**	**17**	**1,099**	**12**	**705**	**75**	**1,365**

[1] Because sub-group sample sizes are small, we show unweighted averages. However, we show weighted overall values.

4.2 INSULATION

Table 25 shows the average R-values for above grade walls, ceilings, and frame floors.[21] When grouping all walls abutting unconditioned space (including basements, garages, attic spaces, etc.), the average per-home R-value drops from about 9 to around 7, and the maximum falls from 24 to 19. This reduction is due to inconsistently insulated building shells; walls to basements and garages are often framed and insulated differently than the main exterior walls of a home. The team observed that ceilings, in comparison to exterior walls, were more consistently insulated: 11 ceilings were uninsulated, while 18 homes had fully uninsulated exterior walls.

As a point of comparison, we present state energy conservation code R-value requirements for new homes.[22]

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[21] R-values are measurements of an insulation’s ability to resist the flow of heat. A high R-value is indicative of a high insulating ability.

[22] Rhode Island uses an amended version of the 2012 IECC. Note that the amended code contains one table (R402.1.1) with R-values equivalent to the 2009 IECC and another table (R402.1.3) with U-factors from the 2012 IECC, creating inconsistent requirements for the same measure.

Table 25: Insulation R-Values

(Source: on-site visits)

Location		On-Site Observations (n=75)			Current New Homes Code Requirement (2012 IECC-RI)[4]
		Quantity (n)	Average	Maximum[3]	
Above grade walls[1]	Exterior	75	**9**	24	**20** for cavity insulation *or* **13** cavity insulation with **5** continuous insulation
	All to unconditioned space	75	**7**	19	
Ceiling[2]	Flat	57	**23**	46	**38** or **49** (inconsistent code)
	Vaulted	31	**18**	38	
Frame floor	To unconditioned basement	36	**9**	32	**30** or insulation sufficient to fill the framing
	All over unconditioned space	46	**9**	32	

[1] On-site estimates use an area-weighted calculation across all walls in the home.
[2] Flat ceilings have attic space between floor joists and roof decks; vaulted ceilings do not.
[3] Minimum was always *0*.
[4] *Source*: Rhode Island State Building Code. SBC-8-2013. Effective July 1, 2013. http://sos.ri.gov/assets/downloads/documents/SBC8-RI-state-energy-conservation-code.pdf

4.3 WINDOWS

Table 26 characterizes on-site homes' window glazing and frames. Most glazing was double paned (89%) and most had vinyl frames (64%); not shown, 44% of total glazing area across all homes was composed of vinyl-framed double-paned windows. Some windows had additional energy-efficiency features: 19% had a low-emissivity (lo-e) coating and less than 4% were filled with insulating gas (typically argon) – note, however that the presence of this gas is difficult to confirm through visual means only, and this may be a low estimate.[23]

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[23] Low-emissivity coatings minimize ultraviolet and infrared lights' ability to pass through glass, improving a window's insulating ability. Inert gases such as argon gas – when filled inside double-pane windows – insulate and minimize heat transfer.

Table 26: Windows – Glazing and Frames

(Source: on-site visits; n = 75)

Material	Percentage of Total Glazing Area[1] (n=14,467 sq. ft.)
Glazing	
Double pane	73%
Double pane, lo-E	16%
Single pane	8%
Triple pane, lo-E, gas-filled	3%
Double pane, lo-E, gas-filled	<1%
Frame	
Vinyl	64%
Wood	26%
Fiberglass	6%
Metal	5%

[1] Total glazing area equals the sum of window area across all sites.

4.4 AIR INFILTRATION

Because this study did not include diagnostic tests, auditors used a qualitative scale codified by the Manual J to assess air infiltration for visited homes.[24] Manual J's air infiltration classifications are based on home size, rise, type (e.g., single-family detached), construction quality,[25] insulation type, presence of fireplaces, and HVAC equipment location and type. Based on these factors, Manual J modeling tools create an estimated air infiltration rate for each home.

Table 27: Building Winter Infiltration Rates presents the on-site homes' average air change per hour (ACH50[26]) by home size associated with each classification. For example, a *loose* home between 901 and 1,500 sq. ft. had an infiltration rate of 16.5 ACH50, while a *semi-tight* home of equal size had a 5.4 ACH50.

None of the on-site homes were *tight* (based on Manual J criteria). Some nearly attained that ranking but fell short; if those homes had used closed-cell spray foam, which has high air and vapor barrier qualities, that factor would have pushed them into the *tight* category, per Manual J

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[24] Air infiltration assessments informed the Manual J load calculations used in the MSHP feasibility analysis (Section 6).

[25] In some cases, age is a proxy for quality. Generally, air infiltration increases (worsens) with size and/or age. Common construction practices that correspond to each of the Manual J air infiltration classification are included in Appendix A.3.

[26] Technically these values are air changes per hour at a 50 Pascal pressure difference between the inside of the home and ambient conditions, circumstances that would be created with a blower door fan.

criteria. Considered *loose* or *semi-loose*, most homes (86%) had high air infiltration, and the average rate of infiltration for the on-site sample was 13.4 ACH50 (12.8 unweighted).

Table 27: Building Winter Infiltration Rates

(Source: on-site visits; n = 75)

Home size (sq. ft.)	Loose		Semi-Loose		Average		Semi-tight	
	n	ACH50	*n*	ACH50	*n*	ACH50	*n*	ACH50
900 or smaller	*13*	20.9	*6*	14.5	-	-	*1*	4.6
901 to 1,500	*15*	16.5	*9*	10.7	*3*	6.4	*2*	5.4
1,501 to 2,000	*5*	12.2	*2*	7.8	*3*	6.7	*2*	3.6
2,001 to 3,000	*5*	11.0	*4*	7.9	*1*	5.6	-	-
Larger than 3,000	*1*	9.8	*3*	6.5	-	-	-	-
Percentage of homes[2] (weighted)	**55%**		**31%**		**9%**		**6%**	

[1] Infiltration rates have been converted from the natural air changes per hour specified in Manual J's reference tables to ACH50 for the on-site homes. Summer infiltration rates used by Manual J are approximately half those in winter (53%), although the exact proportion depends on the presence of a fireplace and other factors.

[2] Row sums to greater than 100% due to rounding.

4.5 DUCTS

As with air infiltration, this study did not include diagnostic tests for duct leakage. Therefore, auditors assessed duct leakage based on Manual J's qualitative duct leakage criteria.[27] Manual J load calculation tools assign a duct leakage rate to a duct system based on the designated qualitative assessment. The Manual J duct leakage classifications are based on the presence of insulation and the estimated thoroughness of duct sealing measures (e.g., the level of sealing achieved by duct tape and/or mastic).

Table 28 presents the distribution of qualitative duct leakage rates in on-site homes assigned to homes based on auditors' qualitative assessments. It also shows the quantitative duct leakage rates assigned to the homes based on Manual J's load calculation formulas (based on the auditors' qualitative assessments). For reference, Rhode Island code allows duct leakage of up to eight CFM/100ft^2 of conditioned floor area.

Of the 29 homes with duct systems in the sample, nearly two-thirds were either at an *average* (60%) level of sealing or *notable* (3%) level of sealing; however, one-quarter (24%) were only *partially sealed* and the remaining 13% were entirely *unsealed*.

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[27] These assessments informed the Manual J load calculations used in the MSHP feasibility analysis (Section 6). Additional detail can also be found in Appendix A.3.2.

Table 28: Duct Leakage Rates

(Source: on-site visits; n = 29)[1]

Assessment	Percentage of Homes	CFM/100 sq. ft. of Conditioned Floor Area[2]
Notably sealed	3%	4.3
Average sealed	60%	6.2
Partially sealed	24%	12.4
Unsealed	13%	18.2

[1] The sample size decreases to 29 because not all homes have duct systems.

[2] Rhode Island energy code allows up to 8 CFM/100 ft^2 of conditioned floor area (CFA).

Table 29 shows the average R-values among ducts in unconditioned spaces.

Table 29: R-Values of Ducts in Unconditioned Spaces

(Source: on-site visits; n = 75)

Location	n	Supply	Return
Exposed attic[1]	11	5.5	5.9
Unconditioned basement	10	2.6	2.0
Enclosed crawl space	2	4.5	4.5

[1] Attic insulation was largely comprised of flex duct covered in a fiberglass wrap insulation.

Section 5 Demographics

The web surveys asked customers demographic questions – adjustment factors do not apply because on-site verification visits did not address demographics. The following offer a snapshot of the respondent demographics (weighted):

- Identical to Census statistics for Rhode Island, roughly three-fifths (58%) of survey respondents owned their homes.
- The vast majority (96%) answered questions about their primary residence. The average single-family respondent lived in their home for 11 years while the average multifamily respondent lived in theirs for almost six years.
- A small share (15%) worked from home, and those who did, did so for 28 hours per week, on average. Not surprisingly, respondents hesitated to share their daily schedules. Over two-thirds of those who would answer confirmed that someone was at home during the workday.
- Respondents (63%), like Census households (64%), were most likely to live in homes with two or fewer occupants. Multifamily household sizes were noticeably smaller than that of single-family households – 75% of multifamily homes consisted of one or two occupants while 52% of single-family homes had that few occupants.
- Similar to the population (58%), slightly more than one-half of respondents' homes (53%) were in Providence County.
- Homes were most likely to have occupants between 35 and 54 years old (38%) and 19 and 34 years old (35%). Though, single-family homes were nearly twice as likely as multifamily homes to have occupants between 35 and 54 (41% versus 21%) and considerably more likely to have children in the home – bearing in mind that the average single-family household was larger (2.6 versus 1.8 occupants).
- Similar to Census data, 30% of respondents (excluding refusals) confirmed that their gross household income in 2017 was less than 60% of the area median income (AMI).[28]
- Similar to the population (31%), one-third of respondents attained their bachelor's degree or more education. Before weighting results, however, more than two-fifths of respondents (63%) attained this level of education; our weighting approach described in Appendix B.1 accounts for this overrepresentation.

Table 30 compares our sample to Census statistics for Rhode Island.

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[28] Low-Income Home Energy Assistance Program (LIHEAP). *Rhode Island State Median Income for FFY 2017*. https://liheapch.acf.hhs.gov/Tribes/Tables/povertytables/FY2017/rismi_tribal.htm

Table 30: Demographic Comparison to Population

(Source: web-survey and U.S. Census)

Demographic	Sample (n=900)[1]		Population (n=410,240)[2]
	Weighted	Unweighted	
County			
Providence	53%	52%	58%
Washington	15%	17%	12%
Kent	17%	16%	17%
Newport	8%	9%	9%
Bristol	7%	7%	4%
Tenure			
Own	58%	62%	59%
Rent	42%	38%	41%
Household Size			
2 or fewer	63%	65%	64%
3	17%	16%	16%
4	11%	12%	13%
5 or more	8%	8%	7%
2017 Gross Household Income			
Less than $40,000	33%	25%	37%
$40,000 to $69,999	29%	26%	22%
$70,000 to $99,999	15%	18%	16%
$100,000 to $149,999	16%	18%	15%
$150,000 to $199,999	4%	6%	6%
$200,000 or more	3%	6%	5%
60% Area Median Income			
Above	70%	78%	65%
Below	30%	22%	35%
Highest Level of Education[3]			
High school/Less than HS	19%	10%	42%
Some college or associated degree	48%	27%	27%
Bachelor's degree or higher	33%	63%	31%

[1] Percentages exclude refusals so sample sizes differ by demographic.

[2] Source: U.S. Census Bureau. ACS 2012-2016. Proportions are based on occupied housing units.

[3] Respondents (survey) and residents (Census) are the units of analysis for education (not households).

Figure 1 illustrates the distribution of the 900 web-survey and 75 on-site sample homes.

Figure 1: Sample Geography

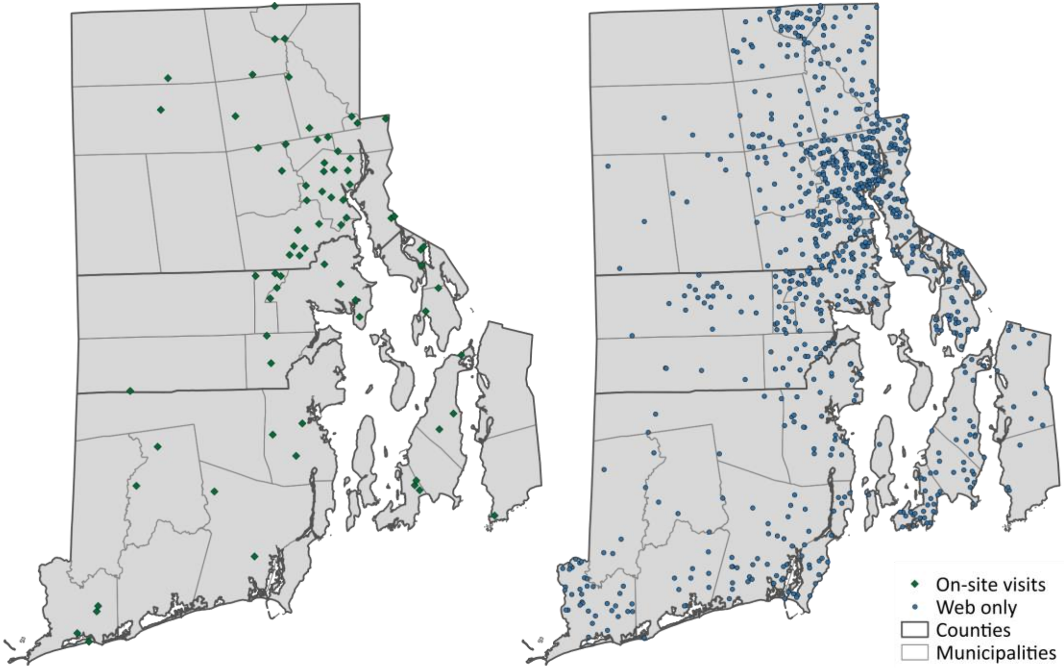

Table 31 through Table 33 compare web-survey responses by dwelling type.

Table 31: Household Occupant Age

(Source: web-survey)

Age	Single-family, 1-4 units (n=751)		Multifamily, 5+ units (n=149)		Overall (n=900)	
	Weighted	Unweighted	Weighted	Unweighted	Weighted	Unweighted
5 years or younger	14%	15%	4%	3%	12%	13%
6-18 years old	21%	20%	3%	3%	18%	17%
19-34 years old	35%	36%	34%	39%	35%	37%
35-54 years old	41%	42%	21%	22%	38%	39%
55-64 years old	24%	23%	23%	17%	24%	22%
65-74 years old	15%	15%	18%	17%	15%	15%
75-84 years old	4%	4%	7%	7%	4%	5%
85 years and older	1%	1%	<1%	1%	1%	1%

[1] Percentages represent the proportion of homes with at least one occupant in the respective age range; as such, percentages do not sum to 100%.

Table 32: Home Occupancy

(Source: web-survey)

Demographic	Single-family, 1-4 units (n=751)		Multifamily, 5+ units (n=149)		Overall (n=900)	
	Weighted	Unweighted	Weighted	Unweighted	Weighted	Unweighted
Tenure						
Own	63%	66%	37%	38%	58%	62%
Rent	37%	34%	63%	62%	42%	38%
Residency						
Primary	96%	95%	96%	96%	96%	95%
Secondary	4%	5%	4%	4%	4%	5%
Years in Home						
Average[1]	11.3	10.3	5.5	5.3	10.4	9.5
Months Occupied						
Average[1]	11.7	11.6	11.5	11.6	11.7	11.6
Day Time Occupancy[2]						
9am to 12pm	73%	70%	62%	56%	71%	68%
12pm to 4pm	74%	70%	52%	52%	70%	67%
4pm to 7pm	95%	94%	87%	87%	93%	93%
7pm to 10pm	100%	99%	98%	98%	99%	99%
Work from Home						
Yes	16%	19%	11%	17%	15%	19%
No	71%	69%	76%	70%	72%	69%
Refused	13%	11%	12%	13%	13%	12%
Average hours per week[1]	**29.5**	**28.8**	**20.5**	**20.7**	**28.3**	**27.6**

[1] Sample sizes vary.

[2] Over one-fifth of respondents refused to answer this question, likely out of concern for safety. So, calculations exclude refusals from the base.

Table 33: Socioeconomic Indicators

(Source: web-survey)

Demographic[1]	Single-family, 1-4 units (n=751)[2]		Multifamily, 5+ units (n=149)[2]		Overall (n=900)	
	Weighted	Unweighted	Weighted	Unweighted	Weighted	Unweighted
Number of Occupants						
1	19%	20%	41%	42%	23%	23%
2	32%	35%	35%	37%	33%	36%
3	17%	16%	8%	7%	15%	14%
4	12%	13%	3%	1%	10%	11%
5 or more	9%	8%	1%	1%	7%	7%
Refused	*11%*	*8%*	*14%*	*12%*	*12%*	*9%*
Average	**2.6**	**2.6**	**1.8**	**1.8**	**2.5**	**2.2**
2017 Gross Household Income						
Less than $40,000	23%	18%	26%	20%	23%	18%
$40,000 to $69,999	19%	17%	29%	27%	20%	19%
$70,000 to $99,999	11%	13%	8%	11%	10%	13%
$100,000 to $149,999	13%	14%	6%	9%	12%	13%
$150,000 to $199,999	3%	5%	2%	2%	3%	4%
$200,000 or more	2%	5%	1%	1%	2%	4%
Refused	*30%*	*28%*	*28%*	*30%*	*30%*	*28%*
60% Area Median Income[3]						
Above	47%	55%	57%	59%	49%	56%
Below	23%	17%	15%	11%	21%	16%
Refused	*30%*	*28%*	*28%*	*30%*	*30%*	*28%*
Highest Level of Education						
High school or less	18%	10%	14%	8%	17%	10%
Some college or associates degree	46%	25%	42%	27%	45%	25%
Bachelor’s degree or higher	30%	61%	37%	60%	31%	61%
Refused	*7%*	*4%*	*8%*	*5%*	*7%*	*4%*

[1] Note that percentages differ slightly from Table 30 due to the inclusion of refusals.

[2] Some percentages do not sum to 100% due to rounding.

[3] Source: LIHEAP. *Rhode Island State Median Income for FFY 2017*. https://liheapch.acf.hhs.gov/Tribes/Tables/povertytables/FY2017/rismi_tribal.htm

Section 6 Mini-Split Heat Pump Technical Feasibility

As detailed in Appendix A.2, this study created a methodology that allowed us to estimate the proportion of a home's floor area that would be a good candidate for a MSHP installation. We did a room-level assessment and calculated how much of each home's area fell into one of four technical feasibility categories: Tier 1 (high MSHP feasibility), Tier 2 (medium feasibility), Tier 3 (low feasibility), and Tier 4 (no feasibility because a heat pump was already installed). We identified the rooms' suitability for MSHPs based on factors such as room type, HVAC system age, and whether they were too hot in the summer or too cold in the winter. We then calculated the heating and cooling loads for each home using Manual J, and apportioned the load based on how much of the home's floor area fell into each tier. We found:

- On average, 60% of a home's floor area would be a good candidate for a MSHP installation (i.e., 60% was identified as Tier 1 space).[29] Nearly all homes (98%) have some amount of Tier 1 space.
- Heat pump systems could supply much of the average home's heating and cooling needs (the average heating load was 39 kBTUh and 18.6 for cooling). One or two MSHP systems could technically serve a substantial portion of many homes.

National Grid should consider conducting future research that leverages these technical feasibility results to study the cost-effectiveness of MSHP incentives.

6.1 PREVALENCE OF SPACES WITH HIGH TECHNICAL FEASIBILITY

Homes tended to have a lot of space that could be served by heat pumps. Three-fifths (60%) of the floor area of a given home fell into the high feasibility (Tier 1) category and 15% fell into Tier 2 (Table 34). This indicates that heat pumps could readily serve a sizeable portion of a typical (small) Rhode Island home, including high-occupancy rooms and spaces in need of additional heating or cooling. However, about one-fourth (23%) of a home's floor area was represented by low feasibility (Tier 3) areas on average, though areas already served by heat pumps (Tier 4) were rare (2%). Nearly all homes (98%) have some amount of Tier 1 space. Appendix B.3 describes the characteristics of the assessed rooms that factored into their final technical feasibility assessments.

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[29] As noted in Section 4.1, on-site homes were somewhat smaller than we might have expected.

Table 34: Average Floor Area by Technical Feasibility Tier

Technical Feasibility Tier	Overall (n=75)			
	Weighted		Unweighted	
	Square Feet	Percent	Square Feet	Percent
Tier 1 (High)	819	60%	843	58%
Tier 2 (Med)	204	15%	201	14%
Tier 3 (Low)	319	23%	361	25%
Tier 4 (N/A: heat pump present)	22	2%	44	3%
Total	**1,365**		**1,449**	

6.2 MANUAL J CAPACITIES

Developed by the Air Conditioning Contractors of America, the Manual J is a protocol used to determine how much heating/cooling a home needs to be cool and dry in the summer and warm in the winter. Using Manual J energy models created for the visited homes, this study estimates that the average National Grid Rhode Island home[30] has a heating load of 39 kBTUh and a cooling load of about 18.6 kBTUh (around 1.5 tons) (Table 35).[31] These are loads that many commercially available heat pump systems could easily satisfy,[32] particularly in multifamily homes, as those have substantially lower heating and cooling needs than single-family homes, which tend to be larger.[33]

The average Tier 1 home heating load is 22.6 kBTUh on average, and 10.7 kBTUh for cooling, capacities that could likely be easily delivered in most homes by one or two heat pump systems, based on commercially available equipment. Among homes with a cooling load (i.e., those that need mechanical cooling to meet comfortable Manual J design conditions), the average Tier 1 cooling load is a bit higher, at about 12.6 kBTUh.

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[30] Includes single- and multifamily homes.

[31] Eleven of the seventy-five homes had no cooling load based on Manual J calculations. These are homes that are predicted to be able to stay comfortable in the summer (75 degrees Fahrenheit and 50% relative humidity) even without mechanical cooling. Such homes tend to be energy efficient, located in moderate climates, and/or have limited exposure to ambient conditions (e.g., multifamily units with shared walls, ceilings, and floors). Those 11 homes without cooling loads are included in these averages. Average cooling load when omitting those homes is a bit higher.

[32] The AHRI database includes performance data on commercially available equipment, a great deal of which would satisfy these load requirements. https://www.ahridirectory.org/

[33] Note that the multifamily on-site sample site in this study was small, only 12 homes.

Table 35: Average per Home Heating and Cooling Loads by Tier

Feasibility Tier	Single-family, 1-4 units (n=63)	Multifamily, 5+ units (n=12)	Overall (n=75)	
	Weighted	Weighted	Weighted	Unweighted
Total Heating Load (BTUh)	**42,225**	**22,067**	**39,000**	**39,642**
Tier 1 (High)	23,981	15,253	22,585	21,913
Tier 2 (Med)	7,285	1,907	6,424	6,018
Tier 3 (Low)	9,594	4,907	8,844	9,564
Tier 4 (N/A: HP present)	1,365	-	1,147	2,147
Total Cooling Load (BTUh)	**20,097**	**10,525**	**18,565**	**18,954**
Tier 1 (High)	11,292	7,708	10,719	10,597
Tier 2 (Med)	3,730	342	3,188	2,982
Tier 3 (Low)	4,776	2,474	4,407	4,906
Tier 4 (N/A: HP present)	299	-	251	470
Total Cooling Load (BTUh) – Homes *with* Cooling Load (n=64)	**23,020 (n=55)**	**14,033 (n=9)**	**21,756 (n=64)**	**22,212 (n=64)**
Tier 1 (High)	12,935	10,278	12,561	12,418
Tier 2 (Med)	4,273	456	3,736	3,495
Tier 3 (Low)	5,470	3,299	5,165	5,749
Tier 4 (N/A: HP present)	342	-	294	550

Based on these findings, we estimate an overall heating load for National Grid Rhode Island homes of 13.8 billion BTUh, 55% of which (7.6 billion BTUh) is in Tier 1 spaces, meaning it could technically be readily served by heat pumps. For cooling, we estimate loads of 6.6 billion BTUh overall, 56% of which (3.7 billion BTUh) in Tier 1 space. More precise figures are included in Table 36, which is derived from unweighted single-family and multifamily load calculations and scaled to the National Grid Rhode Island service population.

Table 36: Statewide Load in Each Feasibility Tier (Unweighted)

Feasibility Tiers	Load (n=347,248 customers)	
Heating Load (MMBTUh)	**13,766**	
Tier 1 (High)	7,609	55%
Tier 2 (Med)	2,090	15%
Tier 3 (Low)	3,321	24%
Tier 4 (N/A: HP present)	746	5%
Cooling Load (MMBTUh)	**6,582**	
Tier 1 (High)	3,680	56%
Tier 2 (Med)	1,035	16%
Tier 3 (Low)	1,704	26%
Tier 4 (N/A: HP present)	163	2%

Table 37 presents customers' total heating loads by primary heating fuel. Overall heating loads ranged from about 33 kBTUh for electric-heated homes to 51 kBTUh for oil-heated homes. Oil-heated homes had the highest overall heating loads. Given that this feasibility study used the presence of electric resistance heating as one of the criteria that would indicate that a room is a good candidate for a heat pump installation, it is not surprising the nine electric-heated homes had the highest portion of their heating loads as Tier 1 (73%).

Table 37: Average per Home Heating Loads by Fuel

Feasibility Tiers	Electric (n=9)		Natural Gas (n=43)		Oil (n=19)		Propane (n=4)	
Total Heating Load (BTUh)	**32,814**		**34,661**		**50,500**		**44,943**	
Tier 1 (High)	24,052	73%	19,788	57%	28,366	56%	21,885	49%
Tier 2 (Med)	465	1%	5,963	17%	9,600	19%	9,699	22%
Tier 3 (Low)	8,296	25%	7,987	23%	10,631	21%	10,810	24%
Tier 4 (N/A: HP present)	–	–	923	3%	1,903	4%	2,550	6%

6.3 HOME-LEVEL FEASIBILITY ASSESSMENTS

We gave a total composite score to each home based on the percentage of floor area in each tier and then divided the 75 homes into groups of 25 based on their scores: High, Medium, and Low Feasibility.

Table 38 compares the three groups in terms of their tier mean classifications. On average, two-thirds (66%) of the High Feasibility group's conditioned floor area was comprised of Tier 1 area. High Feasibility homes of course had the largest composition of Tier 1 area, but even the Low Feasibility homes had a substantial amount of Tier 1 area (56%).

Table 38: Overall Technical Feasibility Assessment

Overall Technical Feasibility Assessment		Average Percentage of Conditioned Floor Area (Weighted)			
	n	**Tier 1**	**Tier 2**	**Tier 3**	**Tier 4**
High	25	66%	7%	19%	-
Medium	25	57%	14%	21%	4%
Low	25	56%	24%	31%	1%

6.4 CONTIGUOUS HIGH FEASIBILITY ROOMS

A home may be a particularly strong candidate for a heat pump installation if it has a large amount of contiguous Tier 1 floor area, meaning it has multiple Tier 1 rooms that are open to or abutting one another. In this situation, an HVAC professional could offer a system that can cost effectively or relatively unobtrusively condition multiple key spaces. For example, a single ductless mini-split could serve multiple rooms in an open layout home, reducing installation and equipment costs.

Additionally, a mini-duct system could serve multiple abutting rooms with minimal aesthetic impact, which may appeal to some customers.

This study measured the largest single, contiguous Tier 1 floor area in each home, because if a homeowner wanted to choose one portion of their home to condition with a new heat pump system, this portion of the floor area could be a good choice. On average, about one-half (47%, weighted) of the floor area in homes was made up of contiguous Tier 1 floor area, totaling 574 square feet.[34]

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[34] Oil and electric-heated homes have higher amounts of contiguous Tier 1 floor area (56% of floor area on average for each), versus 42% for natural gas and 45% for propane.

Appendix A Methodology Details

This appendix details fielding and sampling approaches and the end-uses and attributes that web surveys and on-site visits examined.

A.1 FIELDING AND SAMPLING

Between March 27 and April 30, 2018, we sent approximately 10,000 letters in two waves of 5,000 letters to National Grid customers inviting them to respond to the web survey in exchange for a $10 Amazon electronic-gift card. We then sent email reminders (where email addresses were available) to non-responsive customers following the letter invitation. We achieved a response rate of 9%, with 900 customers completing the survey.

Some customers called, explained they did not have internet access, and asked to respond to the survey via paper or telephone. We suggested they visit a local library for internet access. This may have contributed to somewhat lower survey-sample representation among low-income customers (as compared to Census data).[35] We did not ask *respondent* age, so it is unclear if the web-only mode impacted response rates among older customers. Research from mixed-mode surveys conducted via web and telephone in Massachusetts in 2015, showed that web and phone respondents differed primarily for three parameters: age, home ownership status, and income.[36] With web respondents being significantly more likely than phone respondents to be younger than 45 years old, homeowners, and non-low-income.

Comparing outreach timing with web-survey response rates, shows that response rates were highest approximately four days after the initial mailing. Customer visits to a temporary informational webpage – which we developed and designed – only appeared somewhat correlated with response rates (0.49 positive correlation). Figure 2 charts response rates and webpage visits over time in respect to the two mailing waves.

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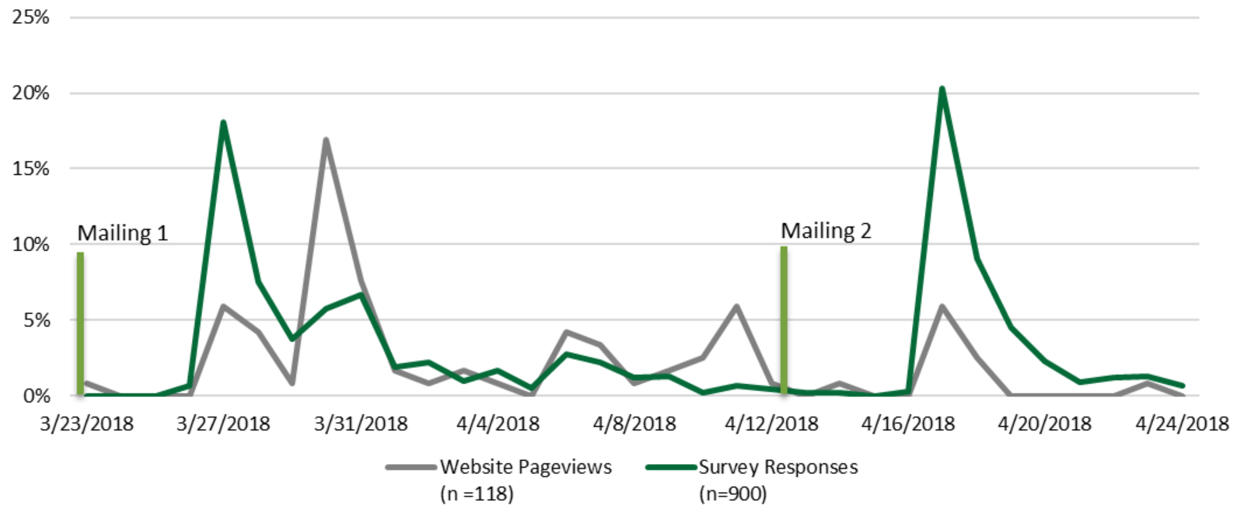
[35] We binned respondents who refused to answer income questions into the non-low-income group, which also contributes to the underrepresentation of low-income customers.

[36] http://ma-eeac.org/wordpress/wp-content/uploads/MA-2015-16-Lighting-Market-Assessment-Final-Report-08August2016.pdf

Figure 2: Web-Survey Response Rates and Webpage Visits



After removing non-residential customers and duplicated service addresses, the National Grid database included 418,478 residential homes. Using a stratified random sampling approach, we ensured that our sample frame of 10,000 customers mirrored the distribution of the customer database across 160 strata based on five parameters: county, dwelling type, income, fuel type, and energy-efficiency program participation.

Table 39 characterizes the National Grid customer database (blue and white cells) and the sample frame (grey cells).

Table 39: National Grid Population by Web-Survey Sampling Strata

County	Sector and Home Type[1]	NGRID Population	Electric				Electric/Gas			
			Participant		Non-Participant		Participant		Non-Participant	
Total		**347,248**	LI	Non-LI	LI	Non-LI	LI	Non-LI	LI	Non-LI
Bristol	**MF All**	**3,116**	**19**	**164**	**32**	**774**	**41**	**378**	**136**	**1,572**
	MF 2-4 Units	1,166	0	2	0	20	4	6	10	74
	MF 5+ Units	1,950	0	14	4	50	2	26	6	66
	SF All	**15,411**	**201**	**1,775**	**159**	**4,589**	**161**	**2,494**	**233**	**5,799**
	SF Attached	1,730	0	2	2	20	4	8	6	66
	SF Detached	13,681	4	30	2	70	4	40	4	86
Newport	**MF All**	**6,027**	**89**	**753**	**91**	**2,403**	**12**	**493**	**57**	**2,129**
	MF 2-4 Units	1,774	0	10	2	54	0	4	2	52
	MF 5+ Units	4,253	6	40	4	106	0	28	2	90
	SF All	**27,429**	**491**	**5,161**	**428**	**14,229**	**63**	**1,744**	**95**	**5,218**
	SF Attached	3,181	2	10	2	64	2	12	2	60
	SF Detached	24,248	6	68	6	176	0	20	0	54
Kent	**MF All**	**10,670**	**196**	**1,766**	**210**	**3,716**	**71**	**1,622**	**142**	**2,947**
	MF 2-4 Units	1,143	0	4	2	32	0	4	4	30
	MF 5+ Units	9,527	12	110	10	212	4	102	6	162
	SF All	**50,643**	**811**	**6,021**	**512**	**16,108**	**698**	**7,978**	**764**	**17,751**
	SF Attached	2,978	2	8	4	56	2	10	4	56
	SF Detached	47,665	10	80	6	204	10	106	10	226
Providence	**MF All**	**49,556**	**354**	**3,366**	**868**	**12,870**	**916**	**4,401**	**2,612**	**24,169**
	MF 2-4 Units	21,048	4	10	14	212	40	52	116	852
	MF 5+ Units	28,508	16	190	36	562	16	210	44	626
	SF All	**134,153**	**2,391**	**11,045**	**1,348**	**31,012**	**4,683**	**20,063**	**4,011**	**59,600**
	SF Attached	27,181	10	22	16	202	52	88	82	720
	SF Detached	106,972	26	124	12	312	42	212	26	508
Washington	**MF All**	**6,054**	**88**	**963**	**171**	**2,092**	**44**	**809**	**76**	**1,811**
	MF 2-4 Units	1,139	4	6	6	52	2	6	10	98
	MF 5+ Units	4,915	6	72	10	142	4	64	4	130
	SF All	**44,189**	**862**	**8,152**	**508**	**23,172**	**228**	**3,531**	**190**	**7,546**
	SF Attached	2,873	6	10	6	72	4	12	8	92
	SF Detached	41,316	12	124	8	338	6	72	4	152

[1] Single-family detached homes include mobile homes. Approximately 16% of customers were not characterized by dwelling type. For the purposes of analysis in this report, we consider homes with fewer than five units as single-family.

A.2 MINI-SPLIT HEAT PUMP TECHNICAL FEASIBILITY ASSESSMENT

A.2.1 Assessment Protocols

The room assessment protocols entailed the following steps:

1. **Assign initial tier based on room type**. Key room types were based on the NMR Northeast Residential Lighting Hours-of-Use (HOU) Study.[37] Room types with the highest rates of daily lighting use are high occupancy spaces and thus strong candidates for HVAC system upgrades. As shown in Table 40, based on the HOU study results, we initially classified higher use room types as Tier 1 (high feasibility), bedrooms as Tier 2 (medium feasibility) and others as Tier 3 (low feasibility). We assigned all rooms with heat pumps already installed as Tier 4 (no feasibility, given the preexisting heat pump).

Table 40: Initial Tier Classifications based on Room Type and Hours of Use

Room Types	Daily Lighting Hours of Use[1]	Initial Feasibility Tier Based on HOU	Key Room Type for MSHP Feasibility Study?
Kitchen	3.8	Tier 1	**Yes**
Dining Room	3.5	Tier 1	**Yes**
Living Space	3.4	Tier 1	**Yes**
Bedroom	2.6	Tier 2	**Yes**
Other	1.6 or less	Tier 3	No
Any room with a HP installed	N/A	Tier 4	No

[1] Estimated by NMR's 2014 Hours-of-Use Study.

2. **Adjust initial tier designation.** As shown in Table 41, we adjusted the room's initial tier assessment based on the following sequential adjustment criteria.[38]
   - **Adjustment 1: New HVAC system already present.** Rooms served by new (less than two years old) heating *and* cooling systems are unlikely candidates for upgrades, so we downgraded them to Tier 3.
   - **Adjustment 2: Supplemental heating or cooling needed.** Rooms that need supplemental heating or cooling are strong candidates for MSHPs, so we upgraded their feasibility Tier (except for *other* room types smaller than 100 sq. ft.). They included:
     - Rooms not served by the main heating/cooling system (e.g., additions or recently finished rooms).

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[37] The HOU study included Rhode Island-specific estimates. Source: NMR Group, Inc. "Northeast Residential Lighting Hours-of-Use Study. May 5, 2014. http://www.neep.org/sites/default/files/resources/Northeast-Residential-Lighting-Hours-of-Use-Study-Final-Report1.pdf

[38] To keep this analysis forward-looking, we did not factor the openness of a space into the assessment because we determined that an open floorplan is not a requirement for high MSHP feasibility. ASHP systems have advanced to offer far more installation flexibility. They can incorporate wall-mounted or in-ceiling blowers and ducted configurations to serve adjoining rooms with reduced aesthetic impact – a single system can incorporate multiple such configurations.

    - Rooms identified by occupants as particularly warm in the summer, cold in the winter, or where they often use space heaters or room air conditioners.
  - **Adjustment 3: Electric resistance heating present.** We upgraded rooms with electric resistance heating to Tier 1 (excluding *other* room types).

Some adjustments applied to all rooms, others only applied to rooms 100 sq. ft. or larger. Regardless, if any type of permanent heat pump was already installed, we kept that room in Tier 4.

Table 41: MSHP Feasibility Assessment by Room

Room Type		Initial Feasibility Based on Lighting HOU	Sequential Adjustments			
			1) New Heating & Cooling System?	2) Supplemental Heating or Cooling Needed?	3) Electric Resistance Present?	4) Permanent Heat Pump Present?
Key rooms	Kitchen	1 (High)	If Yes: ↓ to Tier 3	If Yes: ↑ one Tier	If Yes: ↑ to Tier 1	If Yes: ↓ to Tier 4
	Dining					
	Living					
	Bedroom	2 (Medium)				
Other	100+ sq. ft.	3 (Low)	No change		No change	
	<100 sq. ft.			No change		

After assigning rooms to tiers, we calculated the portion of the home's conditioned floor area that fell into each tier.

We also collected onsite data to create Manual J energy models for each visited home, including conditioned floor area, shell characteristics, duct insulation, and qualitative assessments of air infiltration and duct leakage. Manual J uses these home characteristics to estimate the heating and cooling design loads of the home.[39] We used these results to estimate the load that could readily supplied by a heat pump system by multiplying the proportion of floor area in each MSHP feasibility tier by the total heating and cooling loads for the home. Appendix B.3 provides additional details about the characteristics of the assessed rooms that determined their final feasibility assessments.

While this report assesses MSHP feasibility, we provided digital home schematics in an electronic format to National Grid, should they desire to leverage this information for further analyses.

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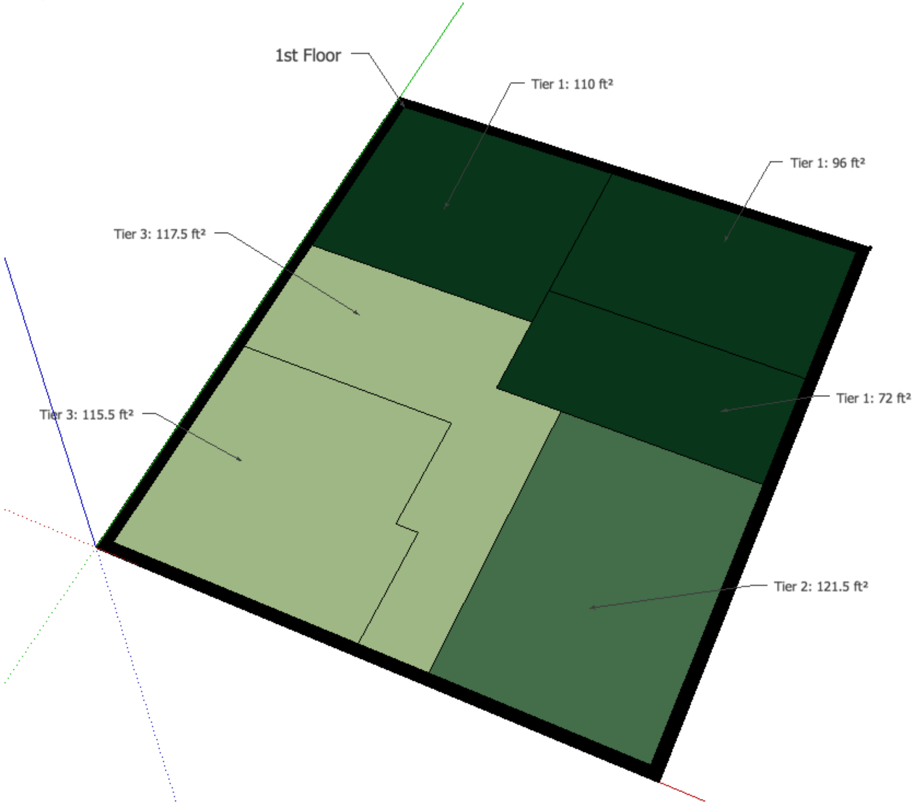
[39] Developed by the Air Conditioning Contractors of America, the Manual J is a protocol used to determine how much heating/cooling a home needs to be cool and dry in the summer and warm in the winter.

A.2.2 Digital Home Floorplan Schematic Snapshots

Technicians created digital floorplans of the visited homes using SketchUp 3D modeling software.[40] The floorplans divided each story of a home into its respective rooms, and color-coded and labeled the rooms based on their MSHP feasibility tier. Figure 3 shows an example screenshot of a floorplan schematic of a single-floor home. Figure 4 shows an example of a home that also had conditioned floor area in the basement.

Figure 3: Example Schematic 1 with Room-Level MSHP Tiers



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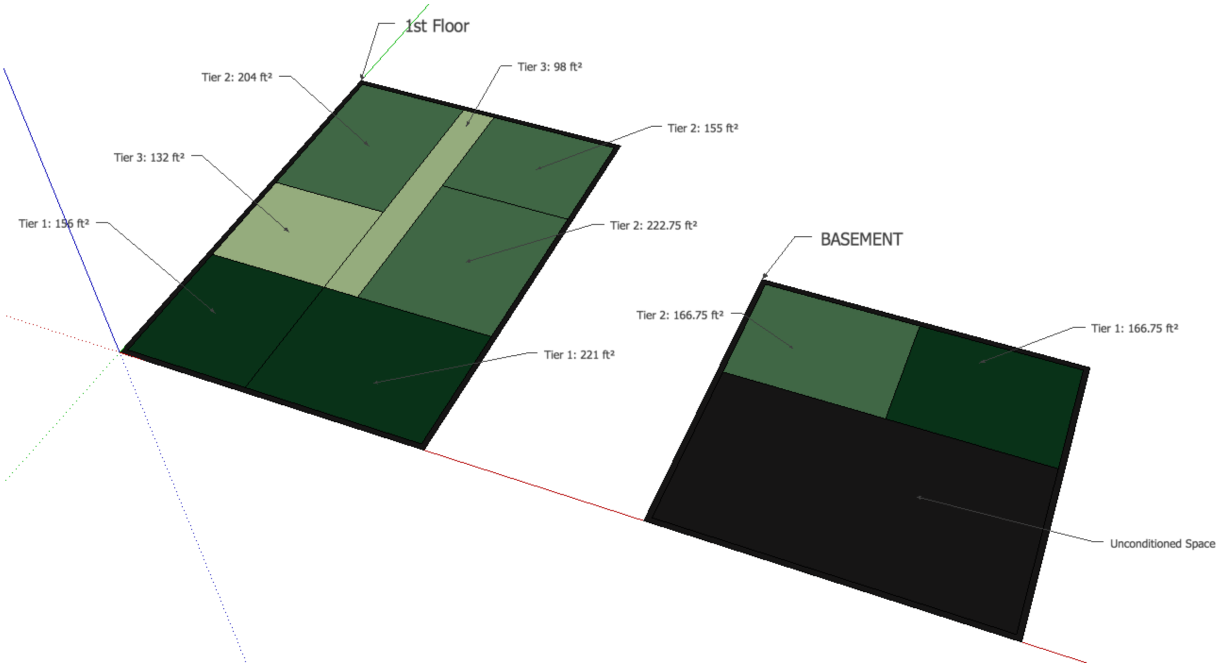
[40] https://www.sketchup.com. The full digital files can be manipulated in SketchUp software and were provided separately to National Grid Rhode Island.

Figure 4: Example Schematic 2 with Room-Level MSHP Tiers



A.3 QUALITATIVE ASSESSMENTS

A.3.1 Air Infiltration

As discussed in Section 4.4, Manual J provides assessment factors that can be used to create air infiltration assessments in the absence of diagnostic tests (as was the case in this study). The estimated leakage values are based on home size, rise, type, construction quality, insulation type, presence of fireplaces, and HVAC equipment location and type. The classifications range from *tight* to *loose*. Table 42 provides a summary of language Manual J uses to describe the construction practices that are common for each air infiltration tier.

Table 42: Manual J Qualitative Air Infiltration Assessment Criteria

Classification	Summary of Manual J Air Infiltration Qualitative Criteria
Tight	Corners, cracks, joints and penetrations are meticulously sealed using air barrier, taping, packing and caulking. Exhaust fans and vents are equipped with backdraft dampers. No recessed light fixtures or, if so, negligible leakage around the fixtures. No non-direct-vent combustion equipment (furnaces, dryers, etc.) within the conditioned space. The house does not have powerful (i.e., 150 CFM or greater) range hoods, or they have dedicated makeup air.
Semi-tight	Between Tight and Average.
Average	Corners, cracks, joints and penetrations reasonably sealed adequately using air barrier, taping, packing and caulking. Exhaust fans and are equipped with backdraft dampers. The home does not use ceiling recessed light fixtures or, if so, there is a minor amount of leakage around the fixture. The house does not have powerful (i.e., 150 CFM or greater) range hoods, or they have dedicated makeup air.
Semi-loose	Between Average and Loose.
Loose	There has been no effort or inadequate effort to seal the structural panels, the associated corners, cracks, joints and penetrations and/or there is a large amount of ceiling recessed light fixture (or light-can) leakage. Some exhaust fans and vents lack backdraft dampers. Powerful (i.e., 150 CFM or greater) range hoods are used that do not have their own source of makeup air.

A.3.2 Duct Leakage

As discussed in Section 6, Manual J provides estimated duct leakage rates that can be used in Manual J models based on an auditor’s qualitative assessments. Auditors made estimates of duct leakage given the lack of diagnostic testing in this study. Table 43 shows the estimated leakage rates and associated qualitative descriptions provided in Manual J load calculation tools for these leakage tiers. The team also developed more detailed guidance on how to assign these leakage values to a given duct system; a summary of that guidance is also included in the table for each classification.

Table 43: Manual J Qualitative Duct Leakage Assessment Criteria

Classification	Manual J Leakage Rates and Assessment			
	Supply (CFM/sq. ft of Duct Area)	*Return* (CFM/sq. ft of Duct Area)	MJ Description	NMR Specific Guidance to Auditors[1]
Unsealed	0.35	0.70	-	No visible effort to seal joints, or visible openings in ductwork
Partially sealed	0.24	0.47	Fabrication conforms to standards	Signs of attempts to seal, but incomplete coverage/degraded materials, or minor cuts in otherwise average ductwork
Average sealed	0.12	0.24	Average sealed system (MJ default)	Sealed with appropriate materials and no visible deterioration or gaps
Notably sealed	0.09	0.15	Verification by leakage test recommended	Ducts and registers sealed as in new construction
Extremely sealed	0.06	0.06	Verified by leakage test	N/A – only attainable via testing
Duct below slab	0.03	0.03	Some surface area may be above grade	-

[1] Auditors relied on this more detailed guidance from NMR regarding how to assign ducts into these qualitative tiers.

A.4 END-USE AND ATTRIBUTE LIST

Table 44 through Table 48 identify the end-uses and other characteristics asked about in the web survey and/or on-site verification visits. We examined fuel types, presence, counts, ages, efficiency levels, and elements indicative of energy consumption. The level and mode of research varied by measure, however. Numbers in the table columns indicate the modes used: 1 means we asked about it only in web-survey, 2 means we examined it only on site, and 3 means we collected it through both modes.

This report does not analyze all characteristics. However, the database houses all data listed below.

As shown in Table 44, after asking on the web survey about quantities, ages, configurations, and habits associated with appliances, we verified that information on site. Technicians also recorded other characteristics indicative of energy consumption by logging things like make, model, and ENERGY STAR-labeling.

Table 44: Appliances – Details Collected by Data Collection Modes

End-Use	Fuel Type	Presence	Count	Age	ENERGY STAR	Details
Clothes washer	2	3	3	3	2	Loads per week and temperatures^1 IMEF^2
Clothes dryer	3	3	3	3	2	Location^2 Moisture sensing^2
Dishwasher	-	3	3	3	2	-
Refrigerator	-	3	3	3	2	Type^3 Refrigerator volume and consumption^2 Location^3 Use^1
Freezer	-	3	3	3	2	
Oven/Range	3	3	3	-	-	-
Ice maker	-	3	-	-	-	Integrated or stand alone^3
Dehumidifier	-	3	3	3	2	Level of use^1 Auto-setting^1
Humidifier	-	1	1	1	-	-

1=web only, 2=on site only, 3=both web and on site

Consumer electronics research captured presence, count, and if equipment was plugged into APS (Table 45). While web surveys asked respondents to enumerate their consumer electronics and about APS usage, on-site verification did not take a full inventory of consumer electronics; instead, technicians only logged equipment plugged into APS.

Table 45: Consumer Electronics – Details Collected by Data Collection Modes

End-Use	Fuel Type	Presence	Count	Age	ENERGY STAR	Details
Desktop computers	-	3	3	-	-	-
Laptops	-	3	3	-	-	-
Computer monitors	-	3	3	-	-	-
Advanced power strips	-	3	3	-	-	Plugged-in devices[3]
TVs	-	3	3	-	-	-
Game consoles	-	3	3	-	-	-
Sound systems	-	3	3	-	-	-
Cell phones	-	1	1	-	-	-
Modem/Router	-	3	3	-	-	-
Printer	-	3	3	-	-	-
Standalone sound equipment	-	3	3	-	-	-
Tablets	-	1	1	-	-	-
Wi-Fi connected devices	-	1	1	-	-	-

1=web only, 2=on site only, 3=both web and on site.

As shown in Table 46, on-site verification visits again offered the opportunity to hone-in on energy consumption factors. On site, we collected make and model of heating, cooling, and water heating equipment; output capacity of heating and cooling units; and gallons and/or EF of water heating equipment.

Table 46: Heating, Cooling, Thermostats, Water Heating – Details Collected by Data Collection Modes

End-Use	Fuel Type	Presence	Count	Age	ENERGY STAR	Details
Heating system	3	3	3	3	2	Use[1] AFUE/COP[2]
Cooling system	3	3	3	3	2	Use[1] SEER/EER/COP[2]
Thermostats	-	3	3	-	-	Type [3] Settings[1]
Ducts	-	3	3	-	-	Insulation type R-value
Radiators	-	1	1	-	-	-
Whole-house fan	-	3	3	-	-	-
HRV/ERV	-	2	2	2	2	-
Water heater	3	3	3	3	2	Conditioned space[3] AHRI[2]
Pipe insulation	-	2	2	-	-	R-value
Water heater blanket	-	2	2	-	-	R-value

1=web only, 2=on site only, 3=both web and on site.

Table 47: Miscellaneous End-Uses – Details Collected by Data Collection Modes

End-Use	Fuel Type	Presence	Count	Age	ENERGY STAR	Details
Electric vehicles	-	3	3	-	-	Charging station presence and power level
Photovoltaics	-	3	-	-	-	Capacity (kw)
Energy-storage batteries	-	3	-	-	-	-
Pool	-	1	-	-	-	Heater fuel type Sweeps presence
Whole-home generator	1	1	-	-	-	-
Air purifier	-	1	-	-	-	-
Waterbed	-	1	-	-	-	-
Aquarium with pump	-	1	-	-	-	-
Terrarium with heat lamp	-	1	-	-	-	-
Spa	-	1	-	-	-	-

1=web only, 2=on site only, 3=both web and on site.

Table 48 lists the building characteristics studied. Note, web surveys asked respondents to quantify rooms in their homes by type and estimate the square footage of their homes. However, on-site verification visits limited that investigation only in relation to MSHP feasibility; for example, we only enumerated rooms that could potentially support a MSHP. Web surveys also asked about home occupancy, education, and income. On-site verification visits did not address demographics.

Table 48: Building Characteristics – Details Collected by Data Collection Modes

Characteristic	Data Collection Mode(s)	Details
Home type	3	-
Stories	3	-
Age of home	3	-
Conditioned area	3	-
Last major renovation	2	-
Rooms	3	
Windows	2	E-coating and argon Pane Frame material
Insulation	2	R-Value

1=web only, 2=on site only, 3=both web and on site.

Appendix B Analysis Details

B.1 WEIGHTING

To develop weights, we used statistical software to create iterative proportional (i.e., raking) weights based on four demographic variables:[41]

- **Participation.** Using National Grid program tracking data, we flagged respondents who participated in a program since 2015 as participants. If respondents reported having recently participated in a program but were not flagged as such in the program tracking data, we still considered them non-participants.
- **Dwelling type.** Counter to our sampling scheme, we considered homes with one to four units as single-family and homes with five or more units as multifamily (the National Grid program definition).
- **Education.** Respondents who reported having a bachelors' degrees or more education into one group and respondents with associate degrees or less education into another group.
- **Fuel type.** We split customers by their National Grid service – electric versus combination gas and electric.

We generated the raking weights by adjusting individual respondents by weighting variables to proportionally mimic the larger population. This process is repeated multiple times for each weighting variable and produces respondent level weights and not the typical cell weight (or weight by weighting variable group).[42]

B.2 ADJUSTMENT FACTORS

Adjustment factors leverage three statistics: (1) self-reported values from the full online sample, (2) self-reported values from the on-site sample, and (3) verified values from the on-site sample. The adjustment factors are the ratio between self-reported values from the on-site sample and verified values from the on-site sample. These ratios are applied to the full web-survey sample values.

Table 49 provides an example of how we calculated an adjustment factor for oil boilers and the influence it had on overall penetration. In this example, 17% of *all* web-survey respondents reported having an oil boiler and – when responding to the web survey – 16% of 68 on-site

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[41] While we originally intended to base weighting on county, dwelling type, fuel type, and income, we found that participants and respondents with high education levels were overrepresented, so we included participation and education into the weighting scheme and set aside county and income – which we found were less relevant variables than participation and education.

[42] For more information on raking, see https://www.stata-journal.com/sjpdf.html?articlenum=st0323.

respondents reported having them. On-site technicians found that 26% of on-site homes *actually* had oil boilers, yielding an adjustment factor of 1.63 (26% divided by 16%). Applying that adjustment factor to the full web sample revises the penetration rate from 17% to 28% (17% times 1.63). Calculations for average number of units per household uses the same formula.[43]

Table 49: Adjustment Factor Calculation Approach – Example

End-Use	Penetration[1]			Adjustment Factor	Revised Penetration (n=829)
	Full Web Sample (n=829)	On-Site Sample (n=68)			
		Web Reported	On-Site Verified		
Oil boiler	17%	16%	26%	**1.63**	28%

[1] Percentages are weighted statistics.

For many end-uses we did not apply adjustment factors because the on-site verified results did not significantly differ from the web-survey results at the 90% confidence level. The *Adjustment Factor* tab in the database reports adjustment factors by measure and indicates if we applied adjustment factors for the analysis; throughout this report, we denote if we have applied adjustment factors to the results.

B.3 MINI-SPLIT HEAT PUMP FEASIBILITY

Table 50 includes information about rooms in the sampled homes by their final, assigned heat pump feasibility tier and type of room. The prevalence figures show the proportion of each room type that we classified into each tier. The remaining three segments indicate for what fraction of rooms in a given tier the following questions were true:

1. Is the space under-conditioned? *Yes* if any of the following were true:
    a. Occupant reported the space is uncomfortable (based on auditor questioning)
    b. Space is not served by the central HVAC system
    c. The space is served by the central HVAC system, but supplementary conditioning equipment is used (i.e., space heaters or room air conditioners).
2. Is the space served by an HVAC system that is less than two years old?
3. Is electric resistance heating used in this space?

For example, one-half of all bedrooms were Tier 1, of which 81% required additional conditioning and 23% were heated with electric baseboard heating.

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[43] A common misconception is that we use adjustment factors to change individual's responses. However, adjustment factors are only applied to results for summary statistics.

Table 50: Room Characteristics by Use and Tier (Unweighted)

Room	n	Percentage of Rooms in Each Tier (Prevalence)				Percentage of Rooms in Each Tier with Characteristic											
						1. Additional Conditioning Required				2. Served by New HVAC				3. Electric Resistance Heating			
		Tier 1 (High)	Tier 2 (Med)	Tier 3 (Low)	Tier 4 (N/A)	Tier 1 (High)	Tier 2 (Med)	Tier 3 (Low)	Tier 4 (N/A)	Tier 1 (High)	Tier 2 (Med)	Tier 3 (Low)	Tier 4 (N/A)	Tier 1 (High)	Tier 2 (Med)	Tier 3 (Low)	Tier 4 (N/A)
Bathroom	6	–	33%	67%	–	–	100%	–	–	–	–	–	–	–	–	50%	–
Bedroom	180	50%	43%	2%	6%	81%	1%	–	20%	–	1%	100%	30%	23%	–	–	–
Dining	36	94%	–	3%	3%	29%	–	–	–	–	–	100%	–	3%	–	–	–
Kitchen	74	93%	–	3%	4%	26%	–	–	–	–	–	100%	–	10%	–	–	–
Living	113	87%	3%	3%	8%	41%	100%	–	–	–	33%	33%	–	12%	–	–	–
Office	17	–	18%	76%	6%	–	100%	8%	–	–	–	–	100%	–	–	–	–
Other	3	–	67%	–	33%	–	100%	–	–	–	–	–	–	–	–	–	–

Appendix C Data Processing

This appendix details steps taken to clean, process, and merge data to prepare the database's Raw Data tab which partners web-survey data, on-site data, and National Grid Rhode Island customer electric billing data. The methodology (Section 2) and database user guide (Appendix E) describe the analysis processes and protocols which leverage these data.

C.1 WEB-SURVEY DATA CLEANING

After fielding, we modified web-survey variables into clean binary and categorical variables to facilitate database-user friendliness. Because adjustment factors corrected for erroneous estimates at the aggregate level, the team only revised responses for clarity, consistency, and overtly incorrect responses; here are some examples:

- In addition to being coded themselves, open-ended responses necessitated revising other responses. For example, a customer mentioned having a pool pump in an open-ended question, but when directly asked, they responded that they did not have one. The team changed that response to reflect the presence of a pool pump.
- Some outlier responses implied respondents misinterpreted questions. For example, if a respondent lived in a home with five units and reported they had five dishwashers, the team assumed they had one dishwasher per housing unit and revised the quantity from five to one.
- When asked about temperature setting behavior, some respondents likely responded in terms of Celsius instead of Fahrenheit; we converted those responses to Fahrenheit (e.g., 20°C to 68°F). However, some gave very unlikely responses such as 5°F, so we discarded those responses.
- If respondents enumerated the various rooms in their home and then provided a much higher, or a lower, total rooms count, we revised their responses to reflect numbers that better corresponded with their previous answers. The team also identified responses that referred to the entire building (e.g., five bathrooms in a five-unit building) and recoded room counts accordingly.
- If a respondent recorded a vehicle model that is not offered in electric or hybrid forms, we revised their responses to indicate that they did not have an electric or hybrid vehicle.
- When asked about cooling systems, people mentioned opening their windows as a form of cooling. We cleaned out those responses.

C.2 ON-SITE VERIFICATION DATA CLEANING

After completing the 75 on-site verification visits, we thoroughly reviewed the data collected at each home and compared entries with on-site photographs to verify data were entered correctly. The details allowed us to look up additional information (e.g., model numbers implying age or efficiency levels). We used photos taken at the site to verify all end-uses. We then merged that data with the web-survey data (at the customer level), aligning web-survey responses with on-site responses alongside each other or simply adding new variables.

C.3 BILLING DATA ATTACHMENT

After developing the web-survey sample frame, we isolated and processed the billing records associated with the sampled accounts. The sample frame only had customers with a minimum of one to two months of billing data and excluded extremely large users that were determined to be non-residential sites. We took the following steps to process and clean the customer billing records:

- Checked for duplicate reads or billing records for the same timeframe and location.
- Removed master metered accounts, if detected.
- Disaggregated monthly usage to daily kWh based on the number of days between meter reads
- Aggregated daily usage into calendar monthly kWh[44]

After cleaning and merging the web-survey and on-site data, we appended the cleaned monthly billing data.

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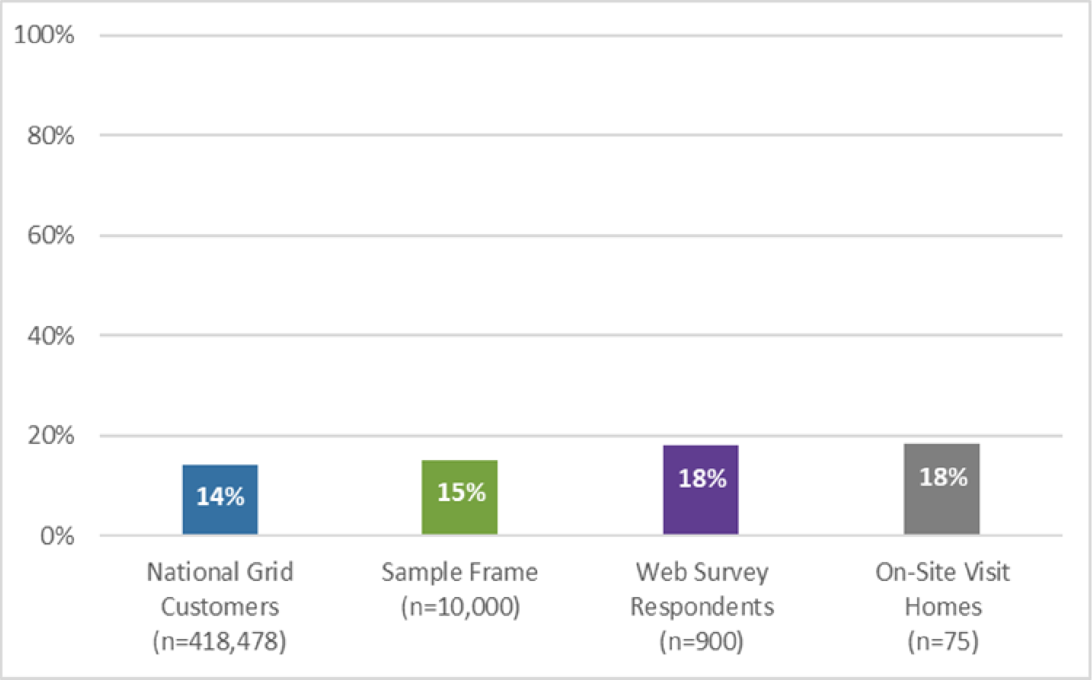
[44] If the first or last month in the customer billing series contained less than 21 days, it was coded as missing and left out of the alignment of billing data to calendar months.

Appendix D Program Participation

The National Grid program database indicated that, since 2015, 14% of customers have taken part in one of its programs. Our sample frame mirrored this (15%). However, response rates were higher among program participants: 18% of our web-survey respondents and on-site homes were flagged as program participants in the National Grid customer database (Figure 5). However, before weighting 23% of homes had been flagged as participants; our weighting approach described in Appendix B.1 accounted for this overrepresentation.

Figure 5: National Grid Program Participation

(Source: program participation database – January 2015 through May 2018)



Twenty-five percent of web survey respondents self-reported or confirmed that they had participated in one of National Grid's energy-efficiency programs at some point (though 18% were flagged as participants). The web survey asked both participants and non-participants a series of questions about their familiarity with the home energy assessment, reasoning for participating or not participating in it, recommendations they received for energy-efficiency upgrades, and decision making behind installing recommended measures. Their responses, shown in Table 51 and Table 52, indicate the following key findings (weighted):

- Respondents were less than somewhat familiar with the home energy assessment program. When asked to rate their familiarity on a scale of 1 to 5, where 1 is *not at all* *familiar* and 5 is *extremely familiar*, they rated their familiarity 2.9, on average.[45] One might expect greater familiarity given relatively high program participation levels. Respondents flagged as participants rated their familiarity as a 4.2 while those who were not flagged as participants rated it a 2.4, on average (a statistically significant difference at the 90% confidence level).

- Nearly one-fifth (17%) reported that they received a home energy assessment. Most often they did so out of desire to reduce their energy bill (80%). While those who did not participate most often did so because they were unaware of the program (44%) or were too busy (28%).
- Nearly four-fifths (79%) of those who participated installed the measures that the energy specialist recommended, with nearly all citing that their motivation was to lower their energy bills (98%). Those who did not install the measures, most often pointed to high upfront costs (44%) and insufficient prospective savings (18%) as their main rationales.

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[45] Instead of referring to it as Energy Wise or Income Eligible Energy Services Program, the web survey defined the home energy assessments as follows: “National Grid offers home energy assessments that involve energy specialists visiting customers’ homes to evaluate their homes’ energy efficiency and to educate customers about ways to save energy. During the visit, the energy specialist will offer to install no-cost energy savings products, such as efficient light bulbs, low-flow showerheads and smart power strips.”

Table 51: Program Familiarity and Reasons behind Participation

(Source: web-survey)

Survey Question	Single-family, 1-4 units	Multifamily, 5+ units	Overall
Confirmed or Self-Reported Participation	**(n=751)**	**(n=149)**	**(n=900)**
Home energy assessment	19%	10%	17%
Rebate program	14%	7%	13%
Either	27%	14%	25%
Familiarity with Home Energy Assessment Program (1 to 5 scale)	**(n=751)**	**(n=149)**	**(n=900)**
Average rating	2.8	2.7	2.8
Reasons for Participating in Home Energy Assessment Program[1]	**(n=163)**	**(n=16)**	**(n=179)**
To learn about how I can reduce my energy bill	80%	83%	80%
To learn about my home's energy use	49%	68%	51%
To help the environment	44%	40%	44%
To improve home comfort	36%	47%	37%
To increase the value of my home	21%	16%	21%
Other	3%	4%	3%
Reasons for Not Participating in Home Energy Assessment Program[1]	**(n=475)**	**(n=99)**	**(n=574)**
Not aware of the program	43%	37%	44%
I was too busy	30%	22%	28%
My landlord would not allow	19%	26%	22%
Have a new or already efficient home	7%	8%	7%
Not interested	4%	6%	4%
Too much paperwork	5%	2%	4%
In process of making appointment for assessment	4%	5%	4%
Other	2%	5%	2%
Don’t know	<1%	<1%	<1%

[1] Multiple response, so percentages do not sum to 100%. Only asked of respondents who knew if they did or did not (respectively) participate.

Table 52: Measure Recommendations and Installations

(Source: web-survey)

Survey Question[1]	**Single-family, 1-4 units**	**Multifamily, 5+ units**	**Overall**
Installed Recommended Measures	**(n=163)**	**(n=16)**	**(n=179)**
Yes (complete or in progress)	81%	63%	79%
No	19%	37%	21%
Reasons for Installing Recommended Measures[1]	**(n=128)**	**(n=9)**	**(n=137)**
To lower my bills	98%	100%	98%
To improve home comfort	54%	61%	55%
To help the environment	38%	33%	37%
To increase the value of my home	24%	26%	25%
Top Reason for Not Installing Recommended Measures	**(n=31)**	**(n=7)**	**(n=38)**
Upfront cost too high	51%	20%	44%
Energy savings are not big enough	20%	12%	18%
I was too busy	18%	-	14%
My landlord would not allow the upgrade	7%	52%	16%
Didn't think I needed to replace a working unit	5%	15%	7%
Other Reasons for Not Installing Recommended Measures[1]	**(n=31)**	**(n=7)**	**(n=38)**
Didn't think I needed to replace a working unit	29%	40%	32%
Upfront cost too high	19%	-	15%
Energy savings are not big enough	13%	-	10%
My landlord would not allow the upgrade[2]	-	-	-
I was too busy	3%	28%	8%
Equipment did not qualify under the program	13%	-	11%

[1] Multiple response, so percentages do not sum to 100%.