MASSACHUSETTS RESIDENTIAL BASELINE STUDY

Prepared for:
The Electric and Gas Program Administrators of Massachusetts
Part of the Residential Evaluation Program Area

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NAVIGANT navigant.com || April 30, 2019

STUDY OVERVIEW

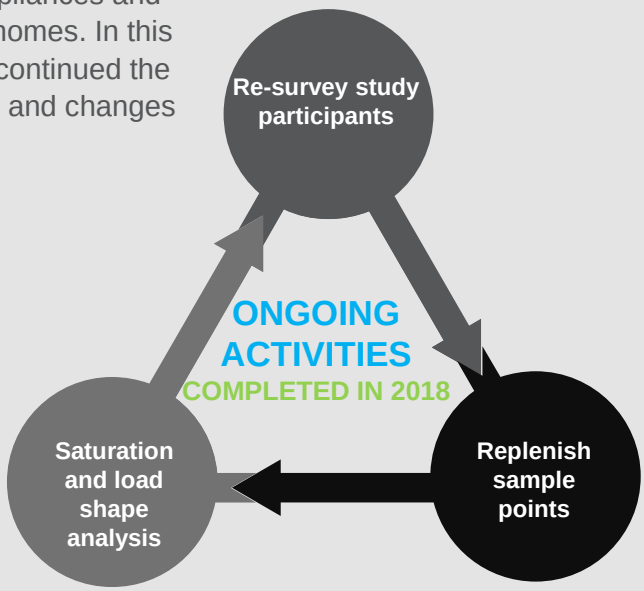
The primary goal of the Massachusetts Residential Baseline Study is to collect saturation, penetration, and usage behavior data for all major electric and gas appliances, mechanical equipment, and electronics in Massachusetts homes.

This data supports energy and peak demand savings calculations for program evaluation and design, and provides additional insight on the savings potential in the existing residential buildings market.

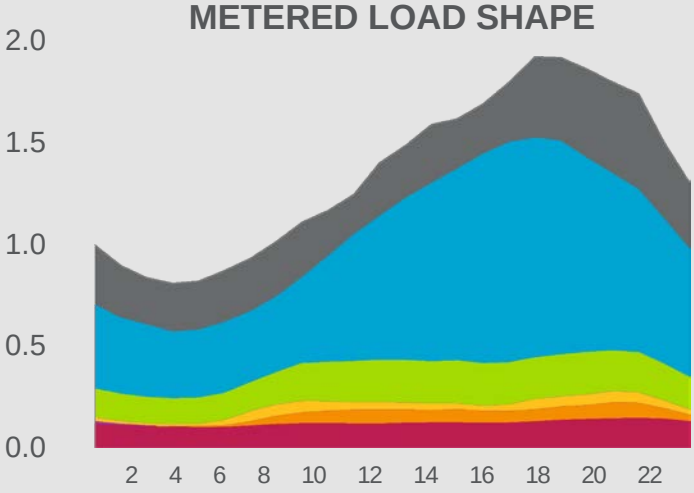
In the **first year** of the study, Navigant surveyed thousands of Massachusetts residents about their household appliances and energy use and metered 25 end uses at over 350 homes. In this **second year** of the study, Navigant repeated and continued the same data collection activities to calculate updates and changes in saturation and load shapes.

INITIAL ACTIVITIES
COMPLETED IN 2017

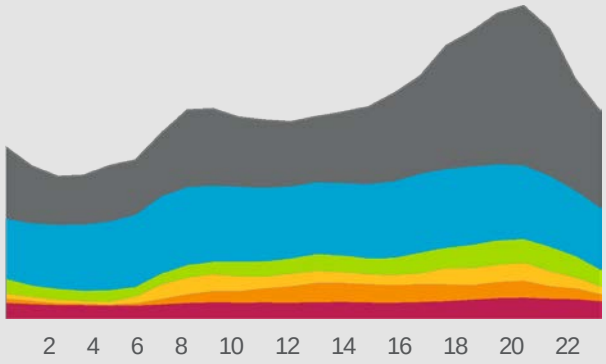
- Conduct online survey
- Draw onsite sample
- Install meters at sampled homes



SUMMER PEAK DAY METERED LOAD SHAPE



WINTER PEAK DAY METERED LOAD SHAPE



LIGHTING + OTHER | HVAC | MISC | WATER HEATING | LAUNDRY | KITCHEN

CONCLUSIONS

COOLING

Central air conditioners (AC) are the single most important end use driving summer peak demand.

Central AC should be the focus of efforts to reduce peak demands, but ductless heat pumps and room AC are also important to a comprehensive program offering.

HEATING

Hardwired electric heat, plug-in electric heat, ductless heat pumps, furnace fans, and boiler distribution systems all consume energy within the same order of magnitude, and are equally important as other prevalent non-HVAC end uses. Ductless heat pump saturation is increasing.

KITCHEN

Refrigerators are the second largest individual consumers of electricity, but peak impacts from kitchen equipment are negligible.

LIGHTING AND OTHER

Lighting is assumed to be the largest portion of the remaining load, but its energy intensity is falling quickly due to program interventions and federal standards.

WATER HEATING

Heat pump water heaters consume about half of the energy and peak demand of regular electric water heaters, providing potentially significant reductions in peak demand.

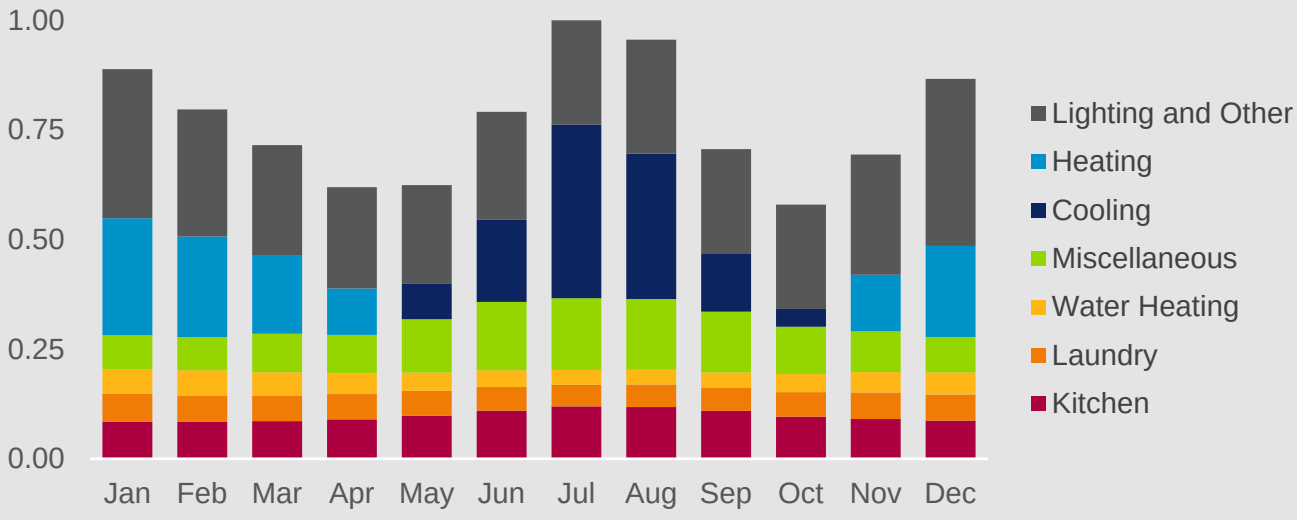
LAUNDRY

Clothes dryers are used throughout the day, including during afternoon and evening peak.

MISCELLANEOUS

Pool pumps have the largest non-cooling summer peak demand of any metered end use.

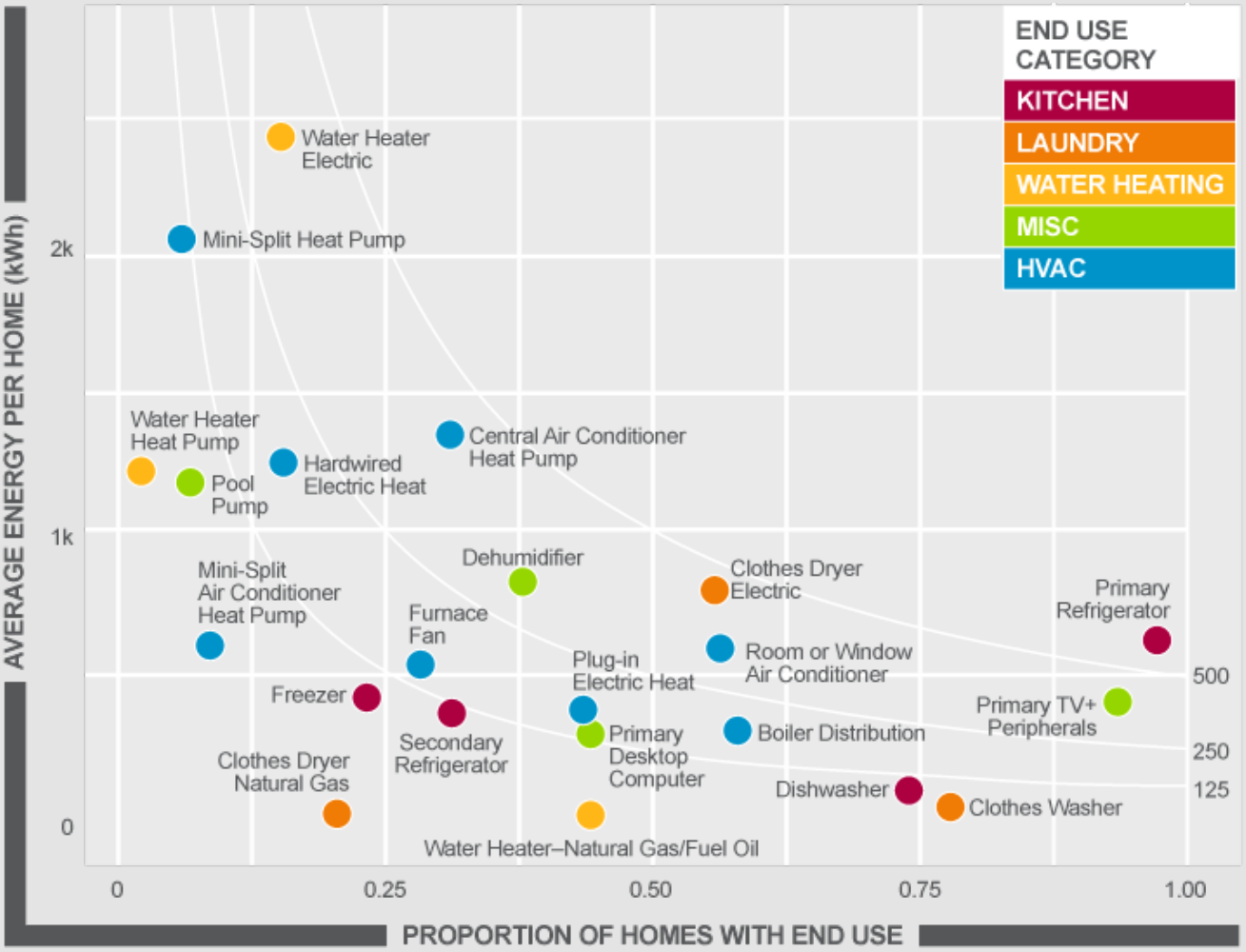
Program administrators should consider targeting dehumidifiers and pool pumps for peak demand savings with low customer impacts.



ANNUAL ENERGY CONSUMPTION

Electric heating and hot water (including heat pumps) are anticipated to increase in saturation. As saturations of these end uses go up, statewide electricity consumption will increase.

Refrigerators consume more electricity in Massachusetts than any other appliance.



Dryers and dehumidifiers are both medium energy consumers and present in many but not all homes.

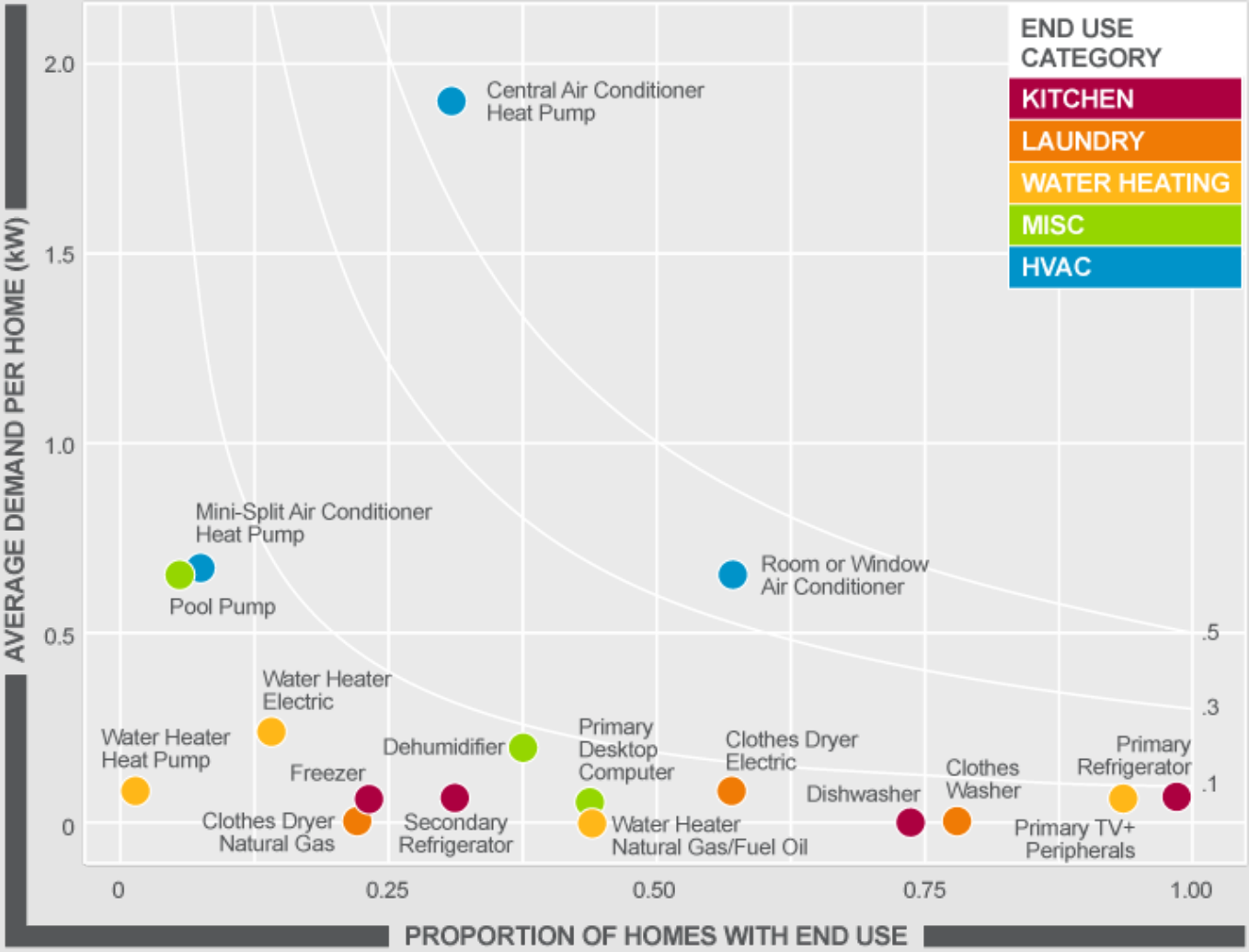
High saturation end uses such as refrigerators and TVs are ripe for broad-based behavior or upstream/midstream programs to save energy.

Each point in this plot shows the household consumption and the fraction of households with a given end use. As you move up and to the right, the aggregate consumption per Massachusetts household goes up, as shown by the lines of constant aggregate Massachusetts consumption. For example, primary refrigerators are found in 99% of homes and have an annual consumption of 557 kWh per home with a refrigerator, so the statewide average is 547 kWh per Massachusetts household, while Central AC is found in 31% of homes and has an annual consumption of 1390 kWh per home with a Central AC. This yields 431 kWh per Massachusetts household.

SUMMER PEAK DEMAND

Pool pumps are uncommon, but they offer a high quality peak saving opportunity. Dehumidifiers offer a more common medium-sized opportunity.

Central air conditioners are the single most important end use driving summer peak demand, and their saturation is increasing. Room ACs are the next largest contributor. These two end uses are the best opportunity for near-term peak demand savings.



While typical electric water heaters and electric clothes dryers do not offer significant demand savings, a small portion offer high quality peak savings opportunities.

Ubiquitous end uses like TVs, refrigerators and lighting are candidates for behavior-based DR, or upstream/midstream programs.

Each point in this plot shows the household demand and the fraction of households with a given end use. As you move up and to the right, the aggregate demand per Massachusetts household goes up, as shown by the lines of constant demand. For example, primary refrigerators are found in 99% of homes and accounts for 0.088 kW per home, so the statewide average is 0.087 kW per household. Central AC is found in 31% of homes and has an average demand of 1.93 kW per home with a central AC. This yields 0.6 kW per Massachusetts household.

END USE SATURATIONS

ELECTRIC END USE SATURATIONS

End Use	Saturation
Central Air Conditioner (Ducted)	30%
Mini-Split Air Conditioner (Ductless)	2%
Room or Window Air Conditioner	57%
Central Heat Pump (Ducted)	2%
Mini-Split Heat Pump (Ductless)	6%
Ground Source Heat Pump	< 1%
Furnace - Electric	2%
Electric Baseboard Heat	14%
Thermostat	87%
Dehumidifier	38%
Refrigerator	99%
Freezer	23%
Dishwasher	74%
Oven or Range - Electric	47%
Cooktop - Electric	12%
Water Heater - Electric	14%
Tankless Water Heater - Electric	2%
Water Heater - Heat Pump	1%
Clothes Washer	78%
Clothes Dryer - Electric	57%
Pool Pump	7%
Electric Vehicle Charger	3%
Electric Vehicle	2%
Solar Photovoltaic System	7%
Solar Photovoltaic Batteries	1%
TV	92%
Smart Phone	93%

NON-ELECTRIC END USE SATURATIONS

End Use	Saturation
Furnace - Natural Gas	24%
Furnace - Fuel Oil	4%
Boiler - Natural Gas	35%
Boiler - Fuel Oil	14%
Fireplace - Natural Gas	5%
Fireplace or Heating Stove - Other Fuel	9%
Oven or Range - Natural Gas	57%
Cooktop - Natural Gas	10%
Water Heater - Natural Gas	40%
Tankless Water Heater - Natural Gas	3%
Water Heater - Indirect	18%
Clothes Dryer - Natural Gas	22%

INTERNET-CONNECTED END USE SATURATIONS

End Use	Saturation
Clothes Dryer - Electric	4%
Clothes Dryer - Natural Gas	< 1%
Clothes Washer	6%
Water Heater - Electric	5%
Irrigation System	3%
Lighting Controls	13%
Outlets	10%
Refrigerator	5%
Thermostat	16%
TV	41%

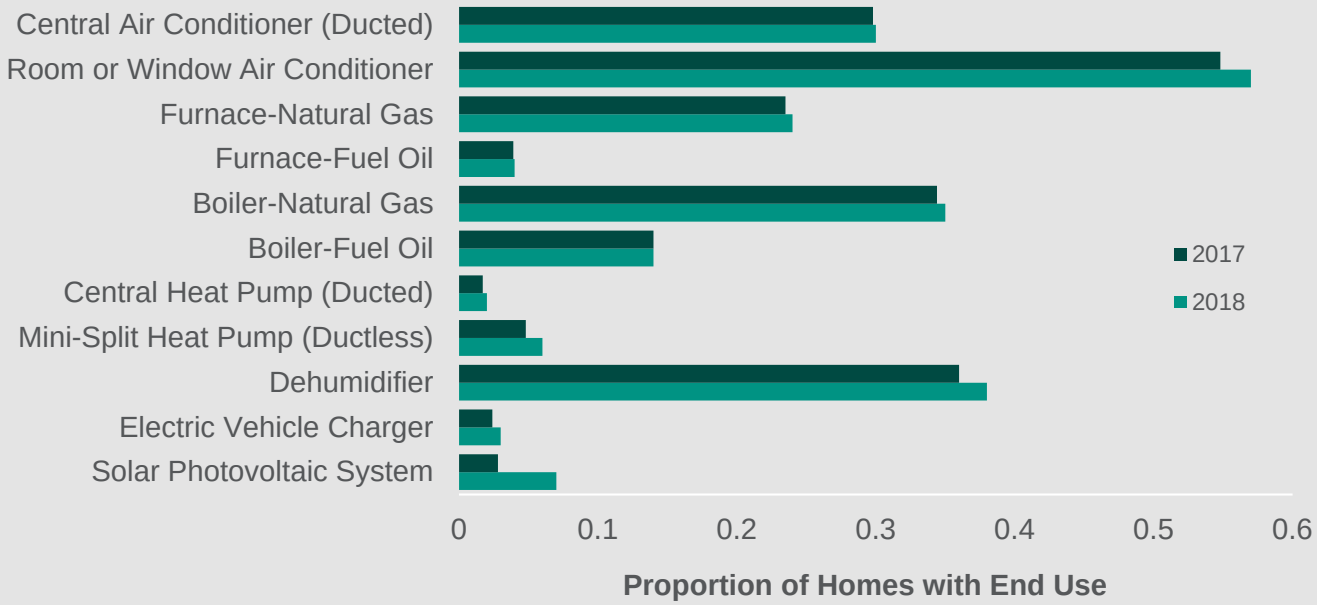
Compared with the previous saturation study completed in Massachusetts about ten years ago, the state has seen a dramatic reduction in saturations of fuel oil end uses, which have been offset by an increase in natural gas end uses.

The saturation of cooling equipment has increased in the last ten years, potentially due to more extreme and consistently high summer temperatures.

Emerging technologies such as heat pump water heaters, electric vehicles, heat pumps, and internet-connected devices are starting to gain adoption in Massachusetts.

The increasing prevalence of internet-connected devices represents an opportunity for new demand response and load shifting program design options.

CHANGES FROM LAST YEAR



The online surveys conducted this year showed notable increases in the saturation of room ACs, dehumidifiers, and electric vehicles. The hot moist weather in summer of 2018 appeared to motivate people to purchase room ACs and dehumidifiers. Gas end uses increased in saturation in the last year, while oil end uses remained constant.

Meanwhile, the hot summer caused consumption from air conditioning measures to increase significantly in 2018, compared to 2017.

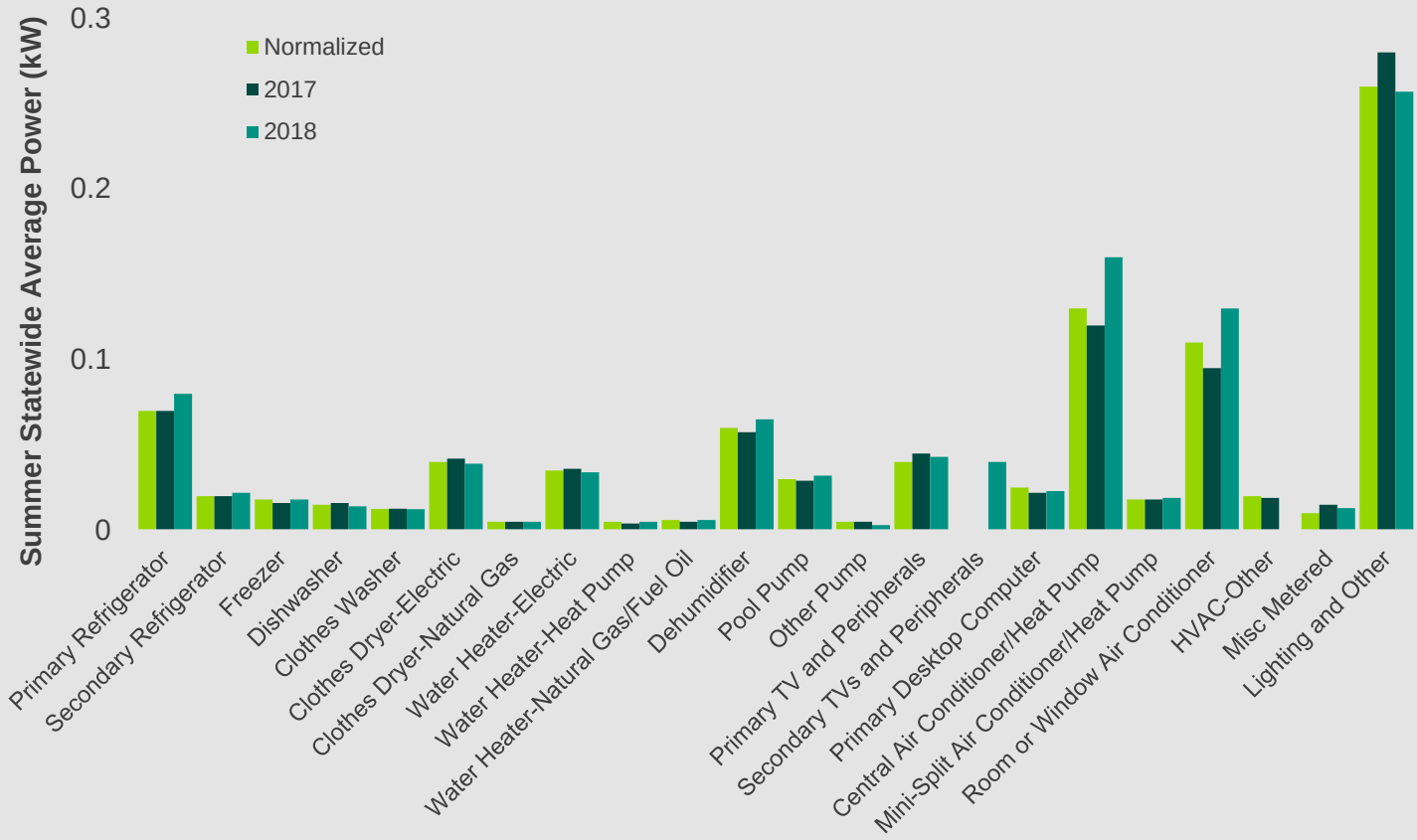


TABLE OF CONTENTS

1. Introduction 10
1.1 Study Goals 10
1.2 Summary of Research Activities 10
1.3 Updates from Previous Comprehensive Report 12
1.4 Terminology 13
1.5 Abbreviations 14
2. Results and Key Findings 15
2.1 Range of Summer Weather Events Observed 15
2.2 Saturation of Key End Uses 16
2.2.1 Saturation Changes of Notable End Uses (All Fuels) 17
2.2.2 Saturation of Gas and Oil End Uses 17
2.3 Annual Energy Consumption 21
2.4 Peak Demand 28
2.4.1 Summer Peak Demand 29
2.4.2 Winter Peak Demand 38
3. Overall Conclusions and Considerations 44
Appendix A. Detailed Findings A-1
A.1 End Use-Specific Findings A-1
A.2 Delivered Fuels A-36
A.3 Internet-Connected End Uses A-36
A.4 TRM Inputs A-37
Appendix B. Methods B-1
B.1 Online Survey B-1
B.2 Onsite Sampling and Precision B-3
B.3 Onsite Metering B-6
B.4 Delivered Fuels Data Collection B-7
B.5 Data Analysis B-8
Appendix C. Supporting Data C-1

LIST OF FIGURES

Figure 1-1. Panel Study Approach for the Residential Baseline Study 10
Figure 2-1. Summer 2017 and Summer 2018 Cooling Degree Days, Comparison by Month 15
Figure 2-2. Histogram of Average Summer Daily Temperature 16
Figure 2-3. Updated Saturation and Change in Saturation for Select End Uses....17
Figure 2-4. Gas End Uses Saturation and Change in Saturation....18
Figure 2-5. Proportion of Homes that Purchased Gas End Uses in the Last Year....18
Figure 2-6. Proportion of Gas End Uses Removed in the Last Year....19
Figure 2-7. Oil End Uses Saturation and Change in Saturation....19
Figure 2-8. Proportion of Homes that Purchased Oil End Uses in the Last Year....20
Figure 2-9. Proportion of Oil End Uses Removed in the Last Year....20
Figure 2-10. Population Annual Energy Consumption by End Use Category....21
Figure 2-11. Population Annual Energy Consumption by End Use....22
Figure 2-12. Population Average Energy Consumption by Month and End Use Category....23
Figure 2-13. Population Average Energy Consumption by Month Split by End Use Category....24
Figure 2-14. Average Annual Energy Consumption by End Use Category and Building/Occupancy Demographics....25
Figure 2-15. End Use Saturation and Annual Energy Consumption for Homes with End Use....26
Figure 2-16. Average Weather-Normalized Demand for Five Periods by End Use....28
Figure 2-17. Summer and Winter Weather-Normalized Peak Load by End Use Category....29
Figure 2-18. Weather-Normalized Summer Peak Day End Use Category Load Shapes....30
Figure 2-19. Weather-Normalized Summer Peak Day End Use Load Shapes....31
Figure 2-20. Whole Summer Average Demand Comparison for Population....32
Figure 2-21. Whole Summer Average Demand Comparison per Home with End Use....32
Figure 2-22. Summer Peak Average Demand Comparison for Population....33
Figure 2-23. Summer Peak Average Demand Comparison per Home with End Use....33
Figure 2-24. Weather-Normalized Summer Peak Demand by End Use Category and Building/Occupancy Demographics....34
Figure 2-25. End Use Saturation and Summer Demand for Homes with End Use....35
Figure 2-26. Weather-Normalized Summer Peak Demand for Top 25% of Users of Each Metered End Use....36
Figure 2-27. Proportion of Homes with Weather-Normalized Summer Peak Demand....36
Figure 2-28. Weather-Normalized Winter Peak Day End Use Category Load Shapes....38
Figure 2-29. Weather-Normalized Winter Peak Day End Use Load Shapes....39
Figure 2-30. Weather-Normalized Winter Peak Demand for Top 25% of Users of Each Metered End Use....40
Figure 2-31. Proportion of Homes with Weather-Normalized Winter Peak Demand Greater than 0.2 kW for Each Measured End Use....40
Figure 2-32. End Use Saturation and Weather-Normalized Winter Demand for Homes with End Use....41
Figure 2-33. Weather-Normalized Winter Peak Demand by End Use Category and Building/Occupancy Demographics....42

Figure A-1. HVAC Cooling Equipment Saturation and Change in Saturation....A-2
Figure A-2. Proportion of Homes that Purchased Cooling Season HVAC End Uses in the Last Year....A-3
Figure A-3. Proportion of Cooling Season HVAC End Uses Removed in the Last Year....A-3
Figure A-4. Histogram of New Central Air Conditioner/Heat Pump Efficiencies....A-4
Figure A-5. Histogram of Mini-Split Air Conditioner/Heat Pump Efficiencies....A-4
Figure A-6. Histogram of New Room/Window Air Conditioner Efficiencies....A-5
Figure A-7. Histogram of New Room/Window Air Conditioner Efficiencies as a Ratio of Standard Room AC Efficiency....A-5
Figure A-8. HVAC Heating Equipment Saturation and Change in Saturation....A-6
Figure A-9. Proportion of Homes that Purchased Heating Season HVAC End Uses in the Last Year....A-7

Figure A-10. Proportion of Heating Season HVAC End Uses Removed in the Last Year A-7
Figure A-11. Histogram of New Furnace Efficiencies A-8
Figure A-12. Miscellaneous HVAC Equipment Saturation and Change in Saturation A-8
Figure A-13. Proportion of Homes that Purchased New Miscellaneous HVAC Equipment A-9
Figure A-14. Proportion of Miscellaneous HVAC End Uses Removed in the Last Year A-9
Figure A-15. Population Annual End Use Energy Consumption – HVAC End Uses..... A-10
Figure A-16. Weather-Normalized Summer Peak Day HVAC End Use Load Shapes for Homes with End Use A-11
Figure A-17. Cooling System Use Motivation A-12
Figure A-18. Weather-Normalized Winter Peak Day HVAC End Use Load Shapes for Homes with End Use A-13
Figure A-19. Secondary Heating Use Motivation..... A-14
Figure A-20. Rated vs. Measured Boiler Efficiency A-14
Figure A-21. Kitchen End Use Saturation and Change in Saturation..... A-15
Figure A-22. Proportion of Homes that Purchased New Kitchen End Uses in the Last Year A-16
Figure A-23. Proportion of Kitchen End Uses Removed in the Last Year A-16
Figure A-24. Secondary Refrigerator Types A-17
Figure A-25. Population Annual End Use Energy Consumption – Kitchen End Uses A-17
Figure A-26. Weather-Normalized Summer Peak Day Kitchen Load Shapes for Homes with End UseA-18
Figure A-27. Weather-Normalized Winter Peak Day Kitchen Load Shapes for Homes with End Use.. A-18
Figure A-28. Dishwasher Use A-19
Figure A-29. Laundry End Use Saturation and Change in Saturation..... A-20
Figure A-30. Proportion of Homes that Purchased New Laundry Equipment in the Last Year..... A-20
Figure A-31. Proportion of Laundry End Uses Removed in the Last Year A-21
Figure A-32. New Clothes Washer Efficiencies A-21
Figure A-33. Population Annual End Use Energy Consumption – Laundry End Uses (kWh)..... A-22
Figure A-34. Weather-Normalized Summer Peak Day Laundry Load Shapes for Homes with End Use . A-23
Figure A-35. Weather-Normalized Winter Peak Day Laundry Load Shapes for Homes with End Use. A-23
Figure A-36. Laundry Use Motivation A-24
Figure A-37. Water Heating End Use Saturation and Change in Saturation..... A-25
Figure A-38. Proportion of Homes that Purchased New Water Heating Equipment in the Last Year... A-25
Figure A-39. Proportion of Water Heating End Uses Removed in the Last Year A-26
Figure A-40. Population End Use Annual Energy Consumption – Water Heating End Uses A-27
Figure A-41. Weather-Normalized Summer Peak Day Water Heating Load Shapes for Homes with End Use A-28
Figure A-42. Winter-Normalized Winter Peak Day Water Heating Load Shapes for Homes with End UseA-28
Figure A-43. Hot Water Use Motivation A-29
Figure A-44. Miscellaneous End Use Saturation and Change in Saturation – Outdoor..... A-30
Figure A-45. Miscellaneous End Use Saturation and Change in Saturation – Electronics A-30
Figure A-46. Proportion of Homes that Purchased New Miscellaneous Equipment - Outdoor A-31
Figure A-47. Proportion of Miscellaneous Outdoor End Uses Removed in the Last Year A-31
Figure A-48. Proportion of Homes that Purchased Miscellaneous Equipment - Electronics..... A-32
Figure A-49. Proportion of Miscellaneous Electronics End Uses Removed in the Last Year A-32
Figure A-50. Histogram of New EV Battery Sizes..... A-33
Figure A-51. Population End Use Annual Energy Consumption – Miscellaneous End Uses..... A-34
Figure A-52. Weather-Normalized Summer Peak Day Miscellaneous Load Shapes for Homes with End Use A-35
Figure A-53. Weather-Normalized Winter Peak Day Miscellaneous Load Shapes for Homes with End Use A-35
Figure A-54. Saturation of Internet-Connected End Uses A-36
Figure A-55. Proportion of Homes that Added Internet-Connected Equipment in the Last Year A-37
Figure B-1. eGauge Energy Metering Setup in Customer Homes..... B-6

Figure B-2. Onset Plug Load Logger Used in Customer Homes B-6
Figure B-3. Saturation and Load Shape Analysis Map B-10
Figure B-4. Weather Normalization Test Results B-12

LIST OF TABLES

Table 1. Measured End Uses by Category 12
Table 2. Annual Energy Consumption by End Use 27
Table 3. Peak Period Definitions 28
Table 4. Weather-Normalized Summer Peak Demand by End Use 37
Table 5. Weather-Normalized Winter Peak Demand by End Use 43

Table A-1. RASS Comparison – Heating Systems A-1
Table A-2. RASS Comparison – Cooling Systems A-1
Table A-3. RASS Comparison – Kitchen Appliances A-15
Table A-4. RASS Comparison – Laundry A-19
Table A-5. RASS Comparison – Water Heating Systems A-24
Table A-6. EFLH and CF by End Use A-38
Table B-1. Follow-Up Survey Recruitment Summary B-2
Table B-2. Survey Recruitment Summary B-3
Table B-3. Targeted Sampling Assumptions and Achieved Sample B-5
Table B-4. Combined End Uses for Load Shape Analysis B-10
Table B-5. Weather Years Used by Time Period B-16
Table C-1. Appendix D Supporting Documents File Names and Contents C-1

1. INTRODUCTION

Navigant is conducting a large multiyear residential baseline saturation and load shape study in which data is collected via online survey, onsite validation, and long-term metering. Through this research, the Navigant team strives to provide the Massachusetts Program Administrators (PAs) and Energy Efficiency Advisory Council (EEAC) consultants more granular data about the energy consumption of residential buildings and their occupants. The PAs and EEAC also want to learn more about relevant opportunities for reducing overall energy consumption and consumption during peak periods/hours. This report reflects all study findings to date, including all survey and metered data collected from inception in January 2017 through Fall 2018.

1.1 Study Goals

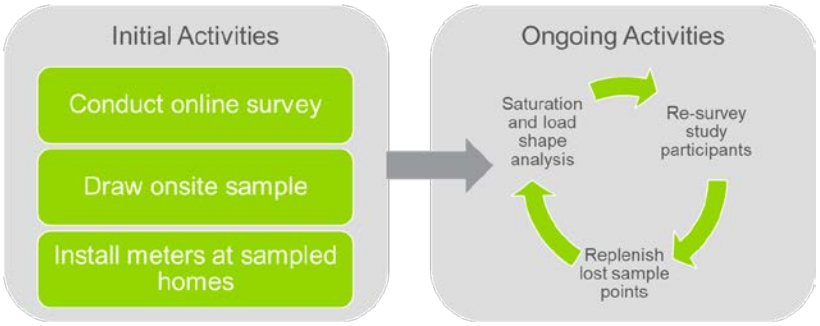
The primary goal of the Residential Baseline Study is to collect saturation, penetration, characterization, and usage data for all major electric and gas appliances and equipment in Massachusetts homes. This data supports energy and peak demand savings calculations for program evaluation and design and provides additional insight into the savings potential in the existing residential buildings market. The secondary goal of this study is to support other research that the PAs are undertaking—such as energy efficiency potential studies and market effects research—by providing comprehensive data for the sampled customers.

This report is intended to answer the primary research question stated in the study's Stage 3 Plan: "How and when are people using the electric equipment in their homes?" [1] The Navigant team presents key findings from the data collected between January 2017 and October 2018.

1.2 Summary of Research Activities

This study's research approach and activities followed the step-by-step process outlined in Figure 1-1. Navigant completed each of the initial activities in the first year of the study, while the second year and subsequent years will include the ongoing activities completed by Navigant. Information for each step is provided below the figure, and additional details on the study's methodology are contained in Appendix B.

Figure 1-1. Panel Study Approach for the Residential Baseline Study



Source: Navigant analysis

[1] The Residential Baseline Study has two primary research questions and three secondary research questions. All research questions can be found in the study's Stage 3 Plan.

- **INITIAL: Conduct online survey** to inventory saturation of several key end uses in Massachusetts residences. The initial survey asked questions related to the respondents' demographics, home characteristics, and home appliances. In the initial phase, 6,673 online surveys were completed (February-June 2017).[2] The general population survey was supplemented by targeting geographies that had a higher saturation of underrepresented priority characteristics such as renter, low income, multifamily, and non-English speaking households. The surveyed sample served as the population frame for the metered sample.
- **INITIAL: Draw onsite sample** to meet end use confidence and precision targets determined during the project's planning phase. The core sample was drawn to maintain several representativeness quotas. The oversample includes homes with specific under-sampled end uses, which ensures that all end uses meet the confidence and precision targets.
- **INITIAL: Install meters** to measure all end uses at core sampled homes and the sampled end use for oversampled homes. This study uses both meters installed in the panel that communicate remotely via powerline carrier and non-communicating plug load meters installed at the end use. The initial site visits were completed between March and June 2017. Data from the plug load meters has been downloaded every 6 months since the meters' installation.
- **ONGOING: Analyze data** to determine statewide saturations, equipment characterizations, typical year load shapes, and peak year load shapes by end use. To calculate load shapes, site-level data was aggregated to the hourly level to generate per home average load shapes and peak period consumption for each end use after being rigorously checked for quality and completeness. Saturations from survey data were used in conjunction with site-level metered data to generate both actual and weather-normalized aggregate (statewide) average load shapes and peak period results.
- **ONGOING: Re-survey study participants** to determine what changes they had made to the end uses of interest in their home. The 2018 follow-up survey received 3,055 completes. Survey respondents who indicated they purchased new equipment within the last year were offered an additional incentive to take a picture of their new equipment's nameplate or invoice for characterization. Of the 1,865 respondents eligible for this survey module, 1,200 provided additional information on their new equipment.
- **ONGOING: Replenish lost sample points** to maintain a robust and representative sample of study participants in both the survey-based and onsite data collection samples. The replenishing survey—called the new customer survey throughout this report—effectively turned the survey portion of the Residential Baseline Study into a classic panel study and aimed to recruit the remaining 3,245 respondents to achieve a total surveyed sample of 6,300 for 2018. The recruitment for this survey was completed via postcards and was targeted to subpopulations that were underrepresented by the follow-up survey. This survey achieved 3,506 completes with a response rate of 4.6%. The team also installed meters at 60 new sites to replace sites where occupants moved or otherwise left the study.

Table 1 shows the measured end uses that Navigant is providing load shape results for in this report. Most end uses on this list were identified by the Navigant team, the PAs, and the EEAC during study planning as high priority end uses to measure. End uses that proved to be inconsequential to the overall

[2] This does not include the additional 228 Cape Light Compact oversample completes.

load due to either small sample size or small loads were combined as other heating and cooling,[3] other pumps,[4] and other miscellaneous metered loads.[5] Unmetered loads, which includes lighting, were calculated by subtracting the metered end use loads from the metered whole premise loads.

Table 1. Measured End Uses by Category

End Use Category	Measured End Uses	
HVAC	• Central air conditioner (AC)/heat pump • Room AC • Mini-split AC/heat pump* • Furnace fan	• Hardwired electric heat • Plug-in electric heat • Boiler distribution system • Ductless heat pump* • Other heating and cooling
Kitchen	• Dishwasher • Refrigerator	• Second refrigerator • Freezer
Laundry	• Electric clothes dryer • Gas clothes dryer*	• Electric washer
Water Heating	• Electric water heater • Heat pump water heater	• Gas water heater*
Miscellaneous	• Pool pumps • Other pumps • Primary TVs and peripherals* • Secondary TVs and peripherals[6]	• Dehumidifiers • Computers and peripherals* • Other miscellaneous metered loads

*End uses with enough metered data to report on even though they were not identified as high priority end uses.

1.3 Updates from Previous Comprehensive Report

The previous comprehensive report for the Residential Baseline Study was finalized in July 2018.[7] Since then, the following changes have been made to the study, which may materialize in changes to the outputs reported in this document:

- In May 2018, the team started metering secondary TVs and their peripherals.
- The definitions of the peak periods have changed to provide one value consistent with how resources are currently bid into the ISO-NE forward capacity market and another value that represents ISO-NE and traditional electric utility system peak impacts.

[3] All cooling-only end uses (room air conditioners (ACs), central ACs, ductless ACs), central heat pumps, whole house fans, and ground source heat pumps are combined as other heating and cooling.

[4] Pool pumps were the only type of pump found to have significant electricity consumption. All other pumps were combined into the other pumps group, which includes well pumps, booster pumps, sump pumps, and ejector pumps.

[5] The other miscellaneous metered loads group includes a long list of rare end uses that were metered but cannot be statistically extrapolated individually. These end uses include electric vehicle (EV) chargers, hot tubs, pool heaters, water beds, large battery chargers, and large fish tanks.

[6] The research team started metering secondary TVs and their peripherals in May 2018. Data was retrieved from the metered sites in September 2018. Because this end use does not have a full year's worth of data, it has been excluded from some results to not misrepresent the magnitude of the consumption when compared with other end uses. Data for the summer of 2018 has been included.

[7] The 2017 comprehensive report can be found at http://ma-eeac.org/wordpress/wp-content/uploads/RES-1-FINAL-Comprehensive-Report-2018-07-27.pdf.

- Individual lighting load shapes have been removed from the overall results tables and figures because they are incongruent with the rest of the metered data. Lighting energy consumption is now being included with the other remaining load in a category called lighting and other, which should be mostly lighting.
- All previously surveyed study participants were recruited to take a follow-up survey indicating what they have changed in their residence over the past year. Additionally, new customers were surveyed with the same survey that was used in the first year.
- The team added a new module to the follow-up survey that asked survey respondents who indicated they had purchased a new piece of equipment to take pictures of their new equipment's nameplate or invoice.
- Starting in October 2018, the research team collected data about recent fuel deliveries for oil and other delivered fuels.
- The team removed the behavior-related questions from the survey instrument.
- The team did not measure the operating efficiency of boilers.

1.4 Terminology

Throughout this report, the research results are referenced with various terminology:

- **Population:** These results are scaled by saturation and show the overall impact to the system, on average, by home but do not represent the impact from an individual appliance.
- **For homes with end use:** These results only include homes with the relevant end use installed, irrespective of the saturation of that end use in the population.
- **Summer system peak:** For the purposes of this report, summer system peak is defined as the 2-hour period on a non-holiday weekday in June, July, or August with the highest average ISO-NE system peak load. The weather-normalized summer system peak was derived from model simulations using the previous 15 years of weather data, and the year that resulted in the median demand was selected.
- **Summer on-peak:** Summer on-peak is consistent with the ISO-NE summer on-peak definition: all hours 1 p.m.-5 p.m. on non-holiday weekdays in June, July, and August. This is weather normalized the same way as summer system peak.
- **Summer residential peak:** For the purposes of this report, summer residential peak is defined as a forward-looking evening peak, set for 5 p.m.-7 p.m. on the date of the ISO-NE peak load. This is weather normalized the same way as summer system peak.
- **Summer peak day:** These results only include data from the date of the summer system peak. This is weather normalized the same way as summer system peak.
- **Winter system peak:** For the purposes of this report, winter system peak is defined as the 2-hour period on a non-holiday weekday in December or January with the highest average ISO-NE system peak load. The weather-normalized winter system peak was derived from model simulations using the previous 15 years of weather data, and the year that resulted in the median demand was selected.

- **Winter on-peak:** Winter on-peak is consistent with the ISO-NE winter on-peak definition: all hours 5 p.m.-7 p.m. on non-holiday weekdays in December and January. This is weather normalized the same way as winter system peak.
- **Winter residential peak:** For the purposes of this report, winter residential peak is defined as 7 p.m.-9 p.m. on the date of the winter ISO-NE peak load. This is weather normalized the same way as winter system peak.
- **Winter peak day:** These results only include data from the date of the winter system peak. This is weather normalized the same way as winter system peak.
- **Building type:** Either single-family detached, single-family attached (2-4 units), or multifamily (5+ units).
- **Number of occupants:** Number of permanent residents (adults and children) living in the home.
- **Top 25%:** Results are presented for homes that fall in the top 25% of energy consumers for a given end use.
- **Lighting and other:** This is the unmetered portion of the total household electricity use, composed of all of the end uses that did not get metered, including lighting.

1.5 Abbreviations

Throughout this report, the team references several abbreviations as defined below. Terms are also defined on first used.

- **AC:** Air conditioner
- **ACS:** American Community Survey
- **CF:** Coincidence factor
- **DHW:** Domestic hot water
- **EEAC:** Energy Efficiency Advisory Council
- **EER:** Energy efficiency ratio
- **EFLH:** Equivalent full load hours
- **EV:** Electric vehicle
- **HOU:** Hours of use
- **HP:** Heat pump
- **HVAC:** Heating, ventilation, and air conditioning
- **ISO-NE:** Independent System Operator New England
- **PAs:** Program administrators
- **SEER:** Seasonal Energy Efficiency Ratio
- **TRM:** Technical reference manual

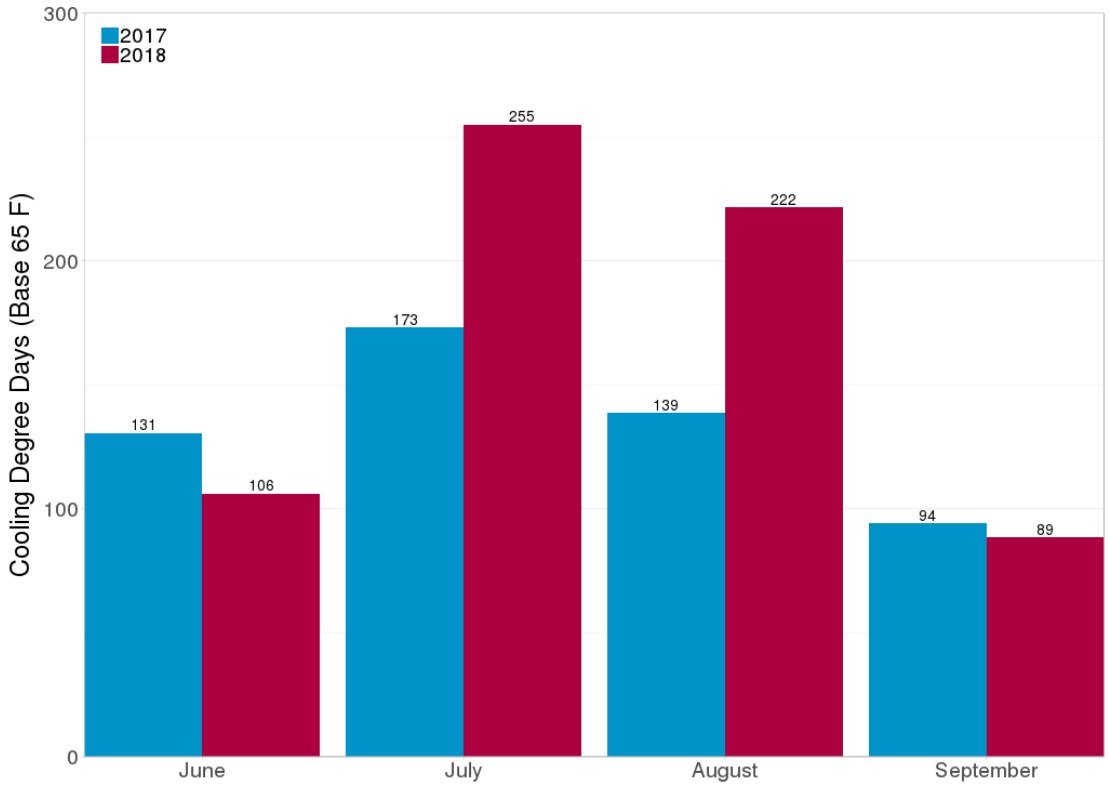
2. RESULTS AND KEY FINDINGS

This section contains weather-normalized annual energy consumption (expressed as average power), summer peak demand, and winter peak demand findings by end use category. Further end use-specific results are available in 3.Appendix A. The full accompanying datasets, including additional charts and graphics, are provided as Appendix C to this report. Metered data was collected from March 2017 through October 2018 and adjusted according to the methodology laid out in Appendix B.4.

2.1 Range of Summer Weather Events Observed

The longitudinal nature of this study allows the research team to observe the effects of various extreme weather events on the energy consumption and peak demand of each end use among Massachusetts residents. As shown in Figure 2-1 and Figure 2-2, the summer of 2018 had more sustained higher temperatures than the summer of 2017.[8] The orange box in Figure 2-2 highlights the difference in the number of days at extreme high temperatures between the two years. The effects of this will be discussed further in the section on HVAC end uses, 3.A.1.1. Additionally, the summer of 2018 had more high temperature evenings and overnights, which increased evening loads.

Figure 2-1. Summer 2017 and Summer 2018 Cooling Degree Days, Comparison by Month

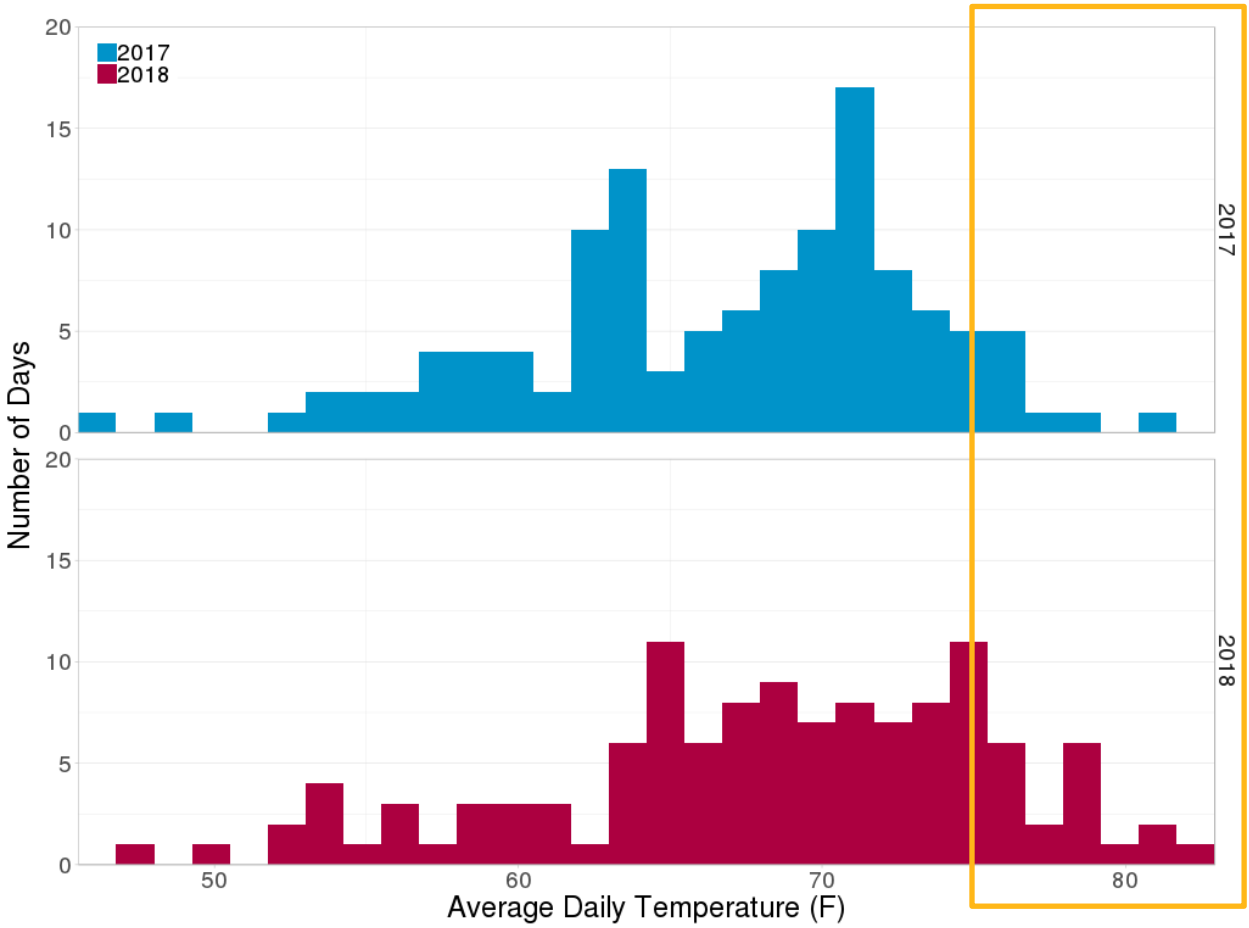


Source: Navigant analysis

[8] This report does not include a comparison of two winters because the metered period ended in October 2018, before the study's second winter had taken place.

Key Finding: *Massachusetts experienced higher average temperatures and more extreme peak temperatures in summer 2018 compared with summer 2017.*

Figure 2-2. Histogram of Average Summer Daily Temperature



Source: Navigant analysis

2.2 Saturation of Key End Uses

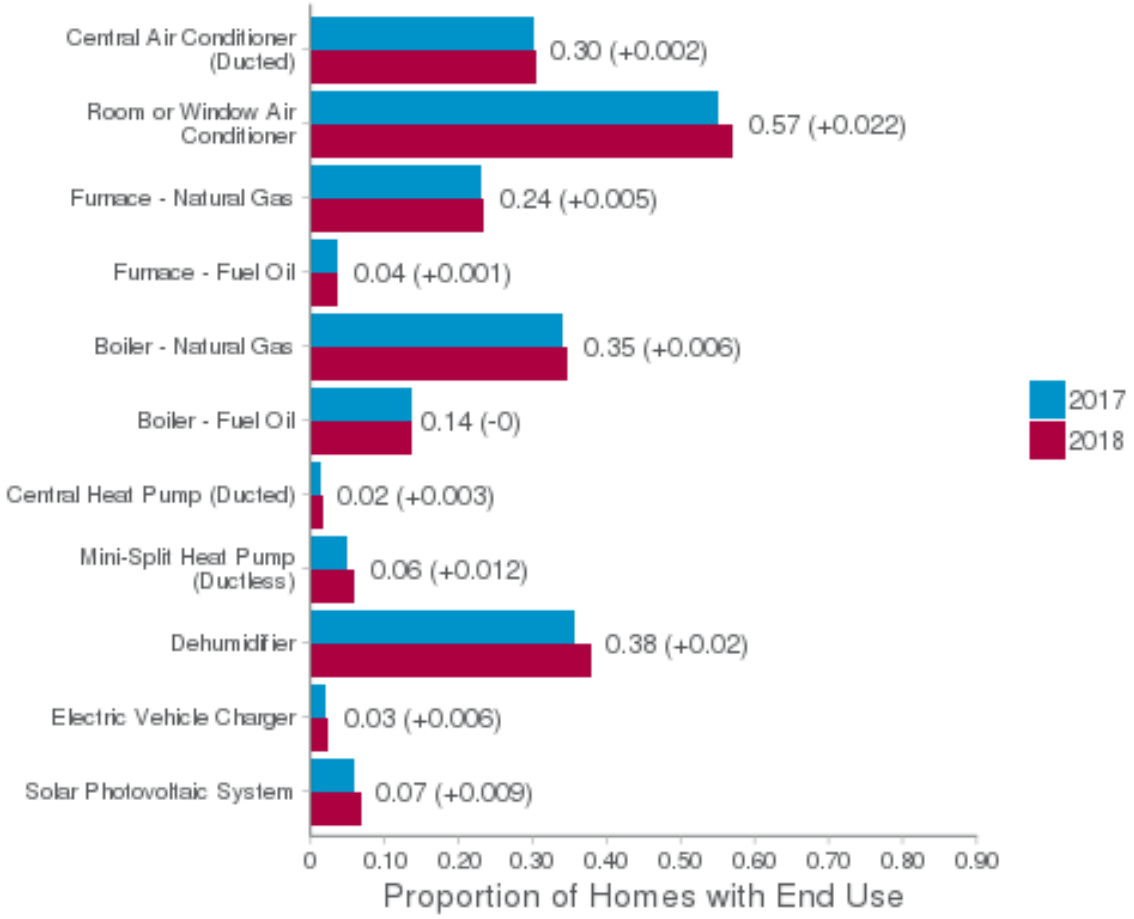
This section highlights some updated statewide saturations for key end uses and notable changes in saturations that have occurred since the previous comprehensive report.

Key Finding: *The saturations of cooling end uses are increasing. The saturation of natural gas heat is increasing, while the saturation of fuel oil heat has remained constant.*

2.2.1 Saturation Changes of Notable End Uses (All Fuels)

Figure 2-3 shows the year over year saturations—with the 2018 saturation indicated in the data label and the absolute change in saturation over the last year in parentheses—for select end uses. The full record of updated saturations and changes in saturations are available in Appendix C. The characterization data collected from survey respondents who indicated they had purchased new equipment in the last year is summarized in the end use-specific sections for end uses with adequate data.

Figure 2-3. Updated Saturation and Change in Saturation for Select End Uses



Source: Navigant analysis

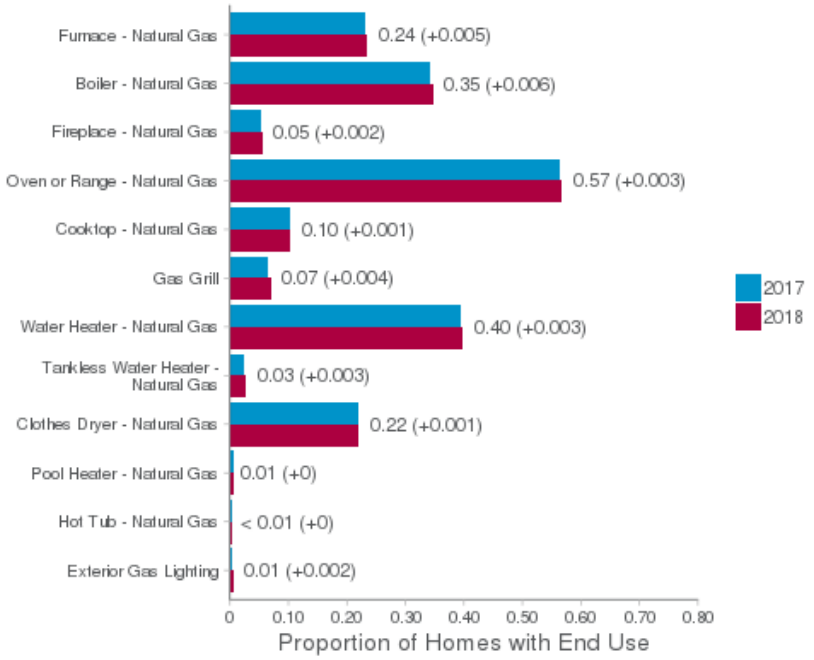
> ***Key Finding:*** *Emerging technologies such as EVs and solar PV systems are increasing in saturation.*

2.2.2 Saturation of Gas and Oil End Uses

This section shows the saturation findings for all gas- and oil-specific end uses that were studied in this research.

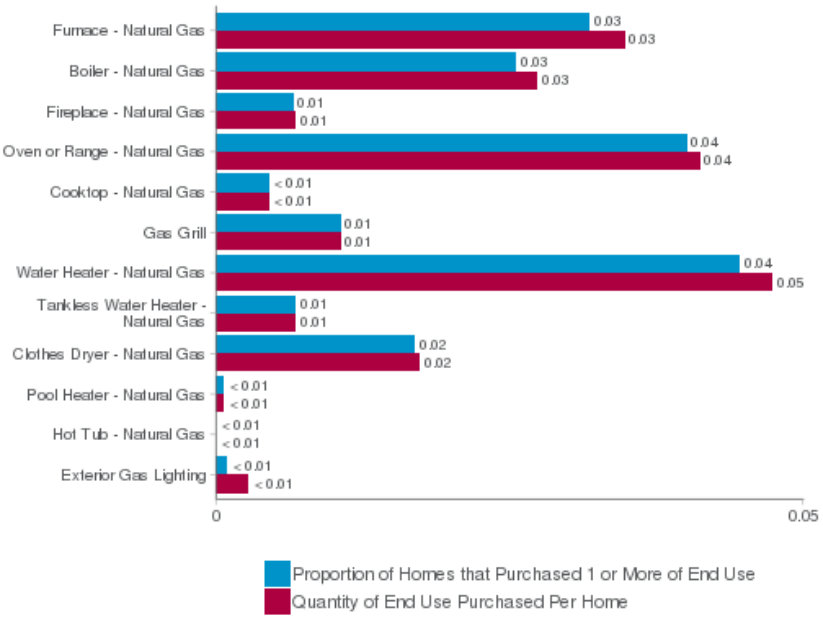
Figure 2-4 shows the current saturation of gas end uses with the red bar and the data label, as well as the change from the previous saturation in parentheses. The previous year's saturation is represented by the blue bar. Figure 2-5 and Figure 2-6 provide supporting documentation for the current saturations by showing the number of residents that purchased new gas equipment and the proportion of removed equipment in Massachusetts.

Figure 2-4. Gas End Uses Saturation and Change in Saturation



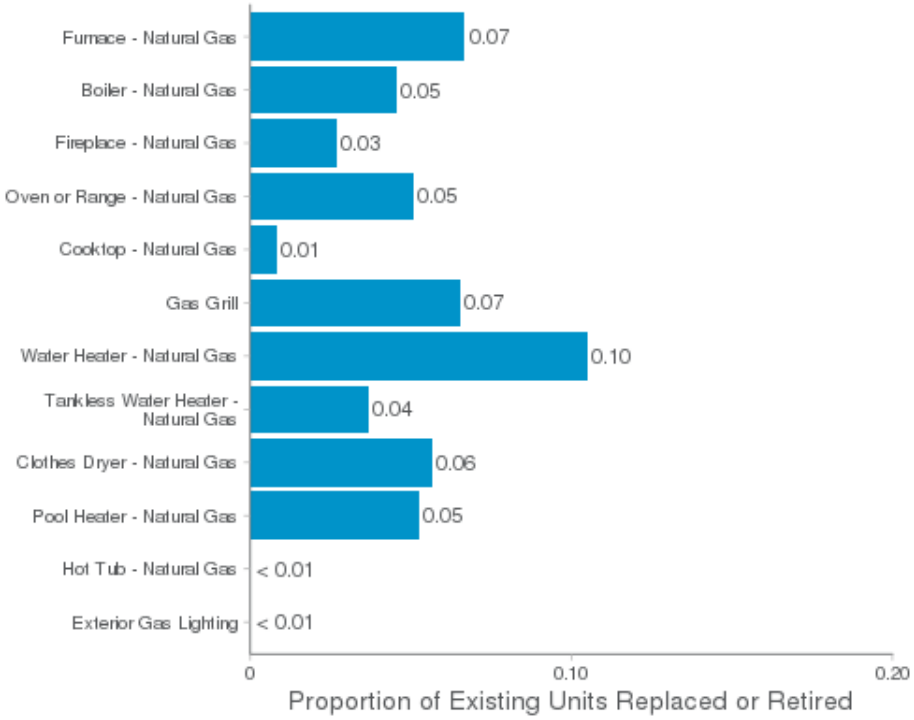
Source: Navigant analysis

Figure 2-5. Proportion of Homes that Purchased Gas End Uses in the Last Year



Source: Navigant analysis

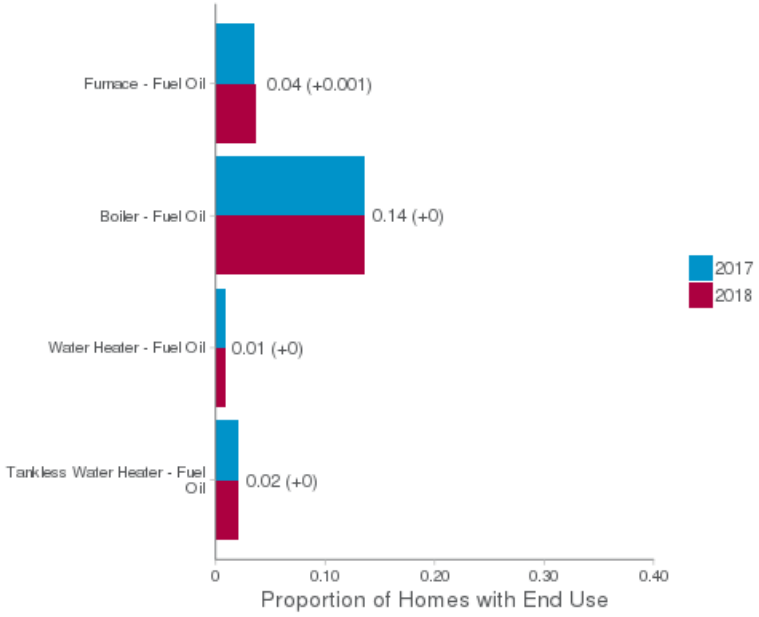
Figure 2-6. Proportion of Gas End Uses Removed in the Last Year



Source: Navigant analysis

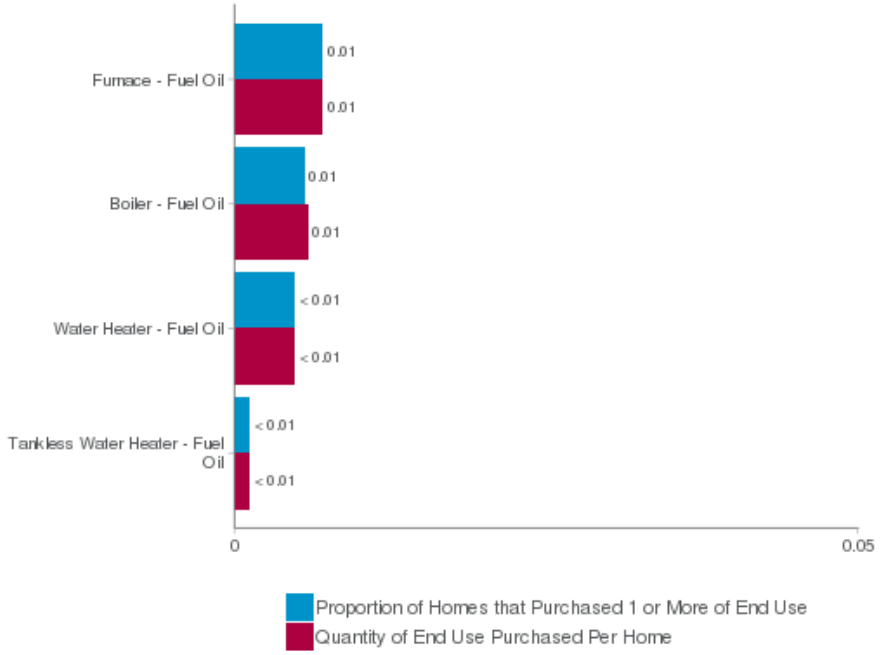
Figure 2-7 shows the current saturation of oil end uses with the red bar and the data label, as well as the change from the previous saturation in parentheses. The previous year's saturation is represented by the blue bar. Figure 2-8 and Figure 2-9 provide supporting documentation for the current saturations by showing the number of residents that purchased new oil equipment and the proportion of removed oil equipment in Massachusetts.

Figure 2-7. Oil End Uses Saturation and Change in Saturation



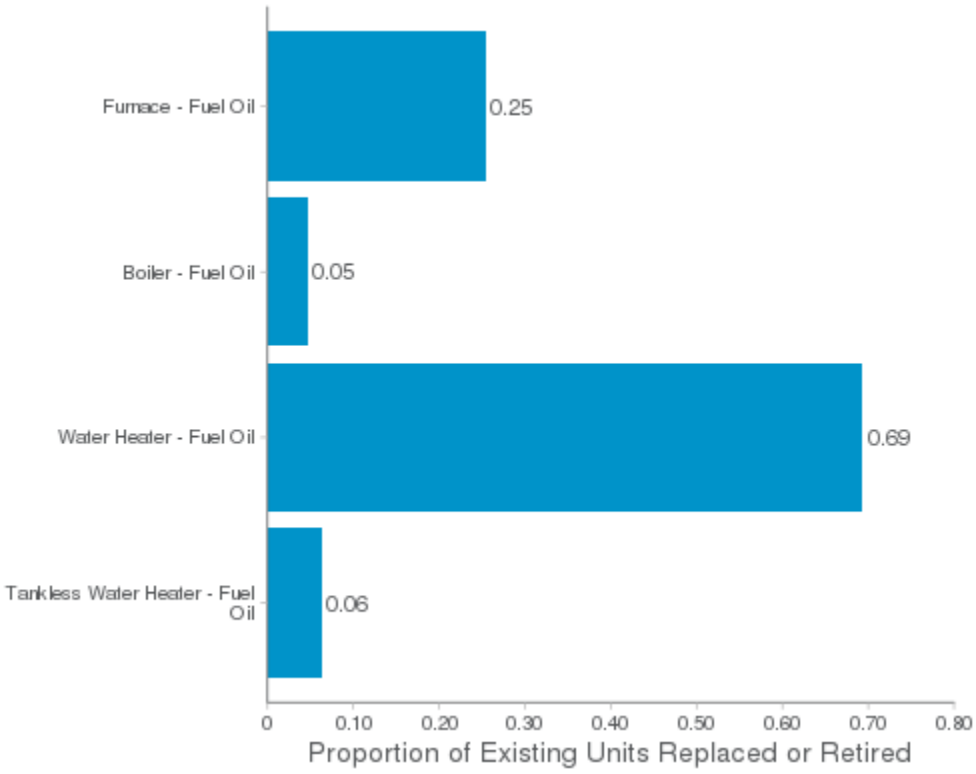
Source: Navigant analysis

Figure 2-8. Proportion of Homes that Purchased Oil End Uses in the Last Year



Source: Navigant analysis

Figure 2-9. Proportion of Oil End Uses Removed in the Last Year



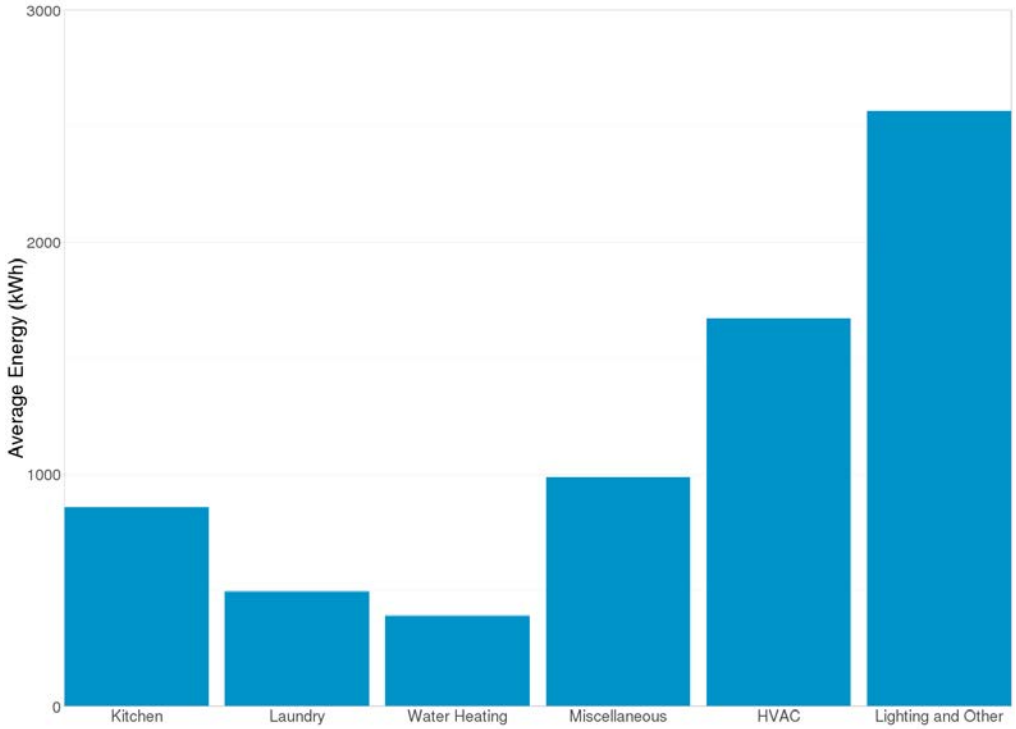
Source: Navigant analysis

Key Finding: *Gas end uses have increased in saturation in the past year, while oil end uses have remained constant.*

2.3 Annual Energy Consumption

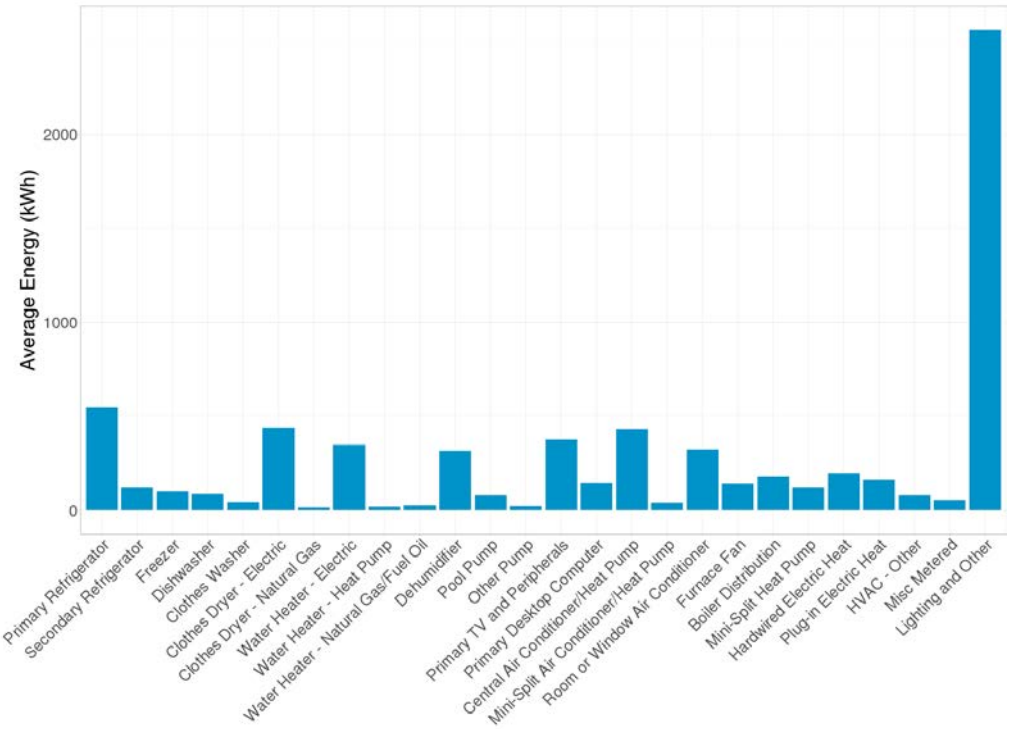
The energy consumption of each end use category is shown in Figure 2-10, and the consumption of each end use individually is shown in Figure 2-11. While seven different ends uses consume at least 300 kWh per household, dehumidifiers have about the same annual consumption as electric water heaters or room ACs, offering larger than expected energy efficiency opportunities.

Figure 2-10. Population Annual Energy Consumption by End Use Category



Source: Navigant analysis

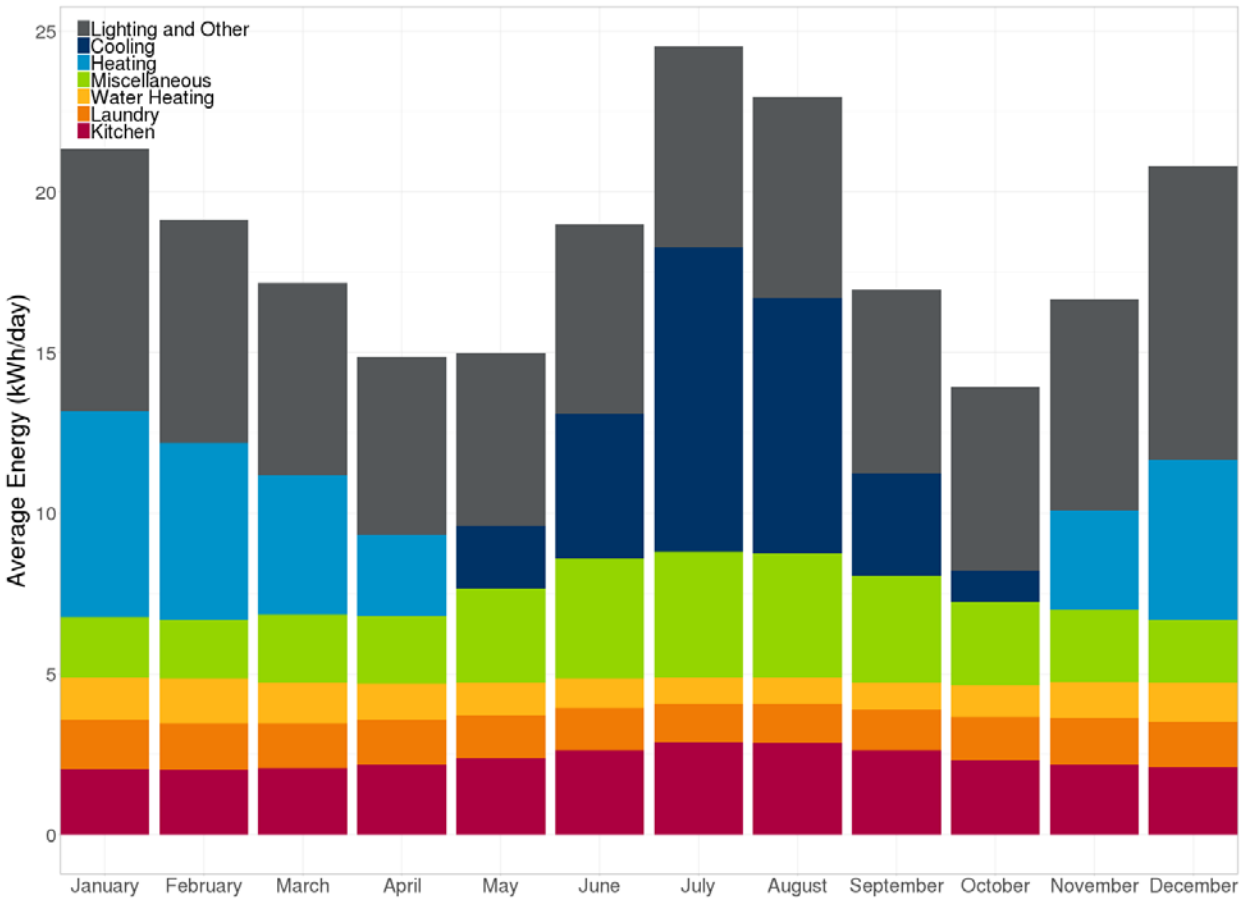
Figure 2-11. Population Annual Energy Consumption by End Use



Source: Navigant analysis

Figure 2-12 shows the monthly average energy consumption for each end use category, demonstrating that all end use categories include end uses with some level of seasonal variability.

Figure 2-12. Population Average Energy Consumption by Month and End Use Category

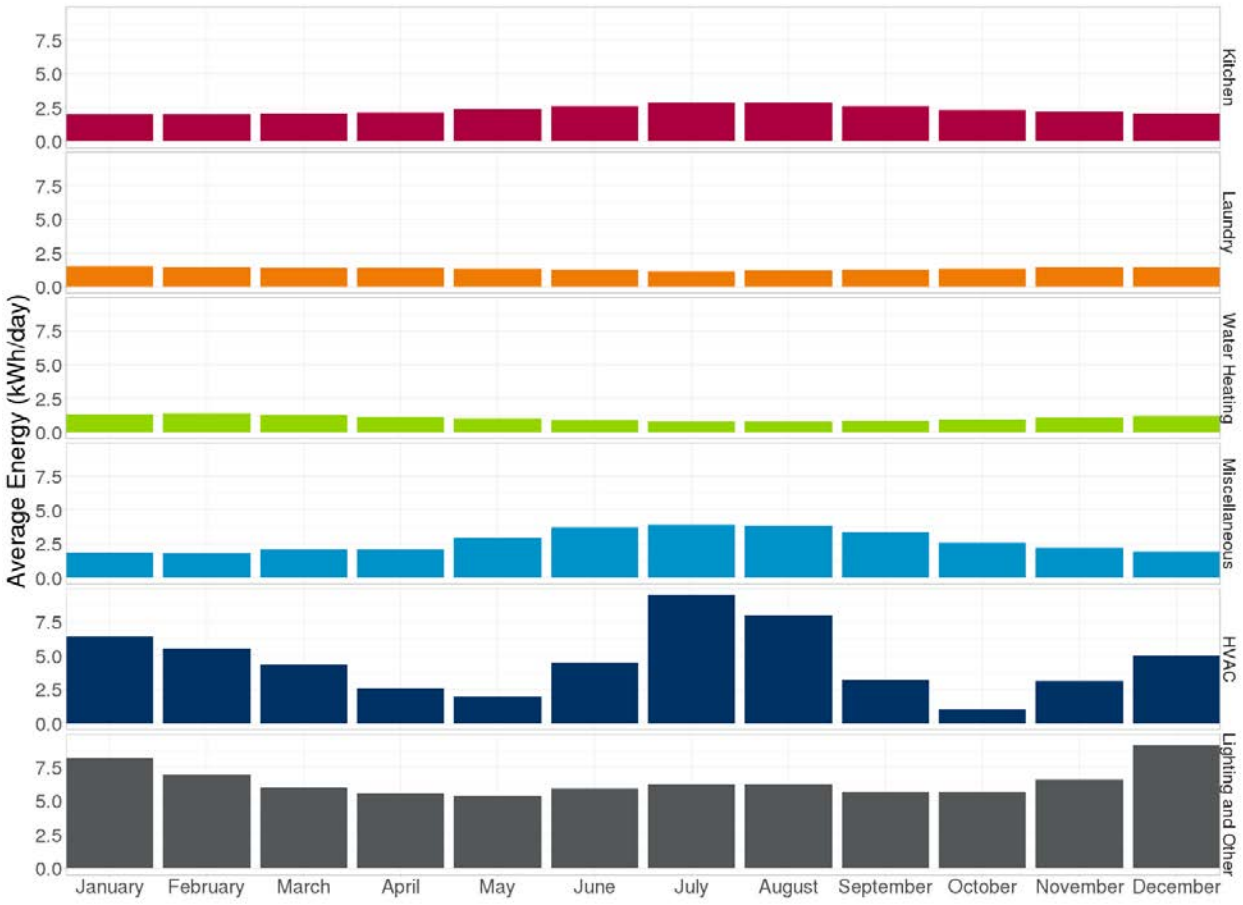


Source: Navigant analysis

Key Finding: *While HVAC is the most seasonally variable end use category, refrigerators, water heaters, dehumidifiers, and pool pumps all contribute seasonal variation.*

Figure 2-13 shows the same information as Figure 2-12 broken out by end use to illustrate the seasonality of each end use category.

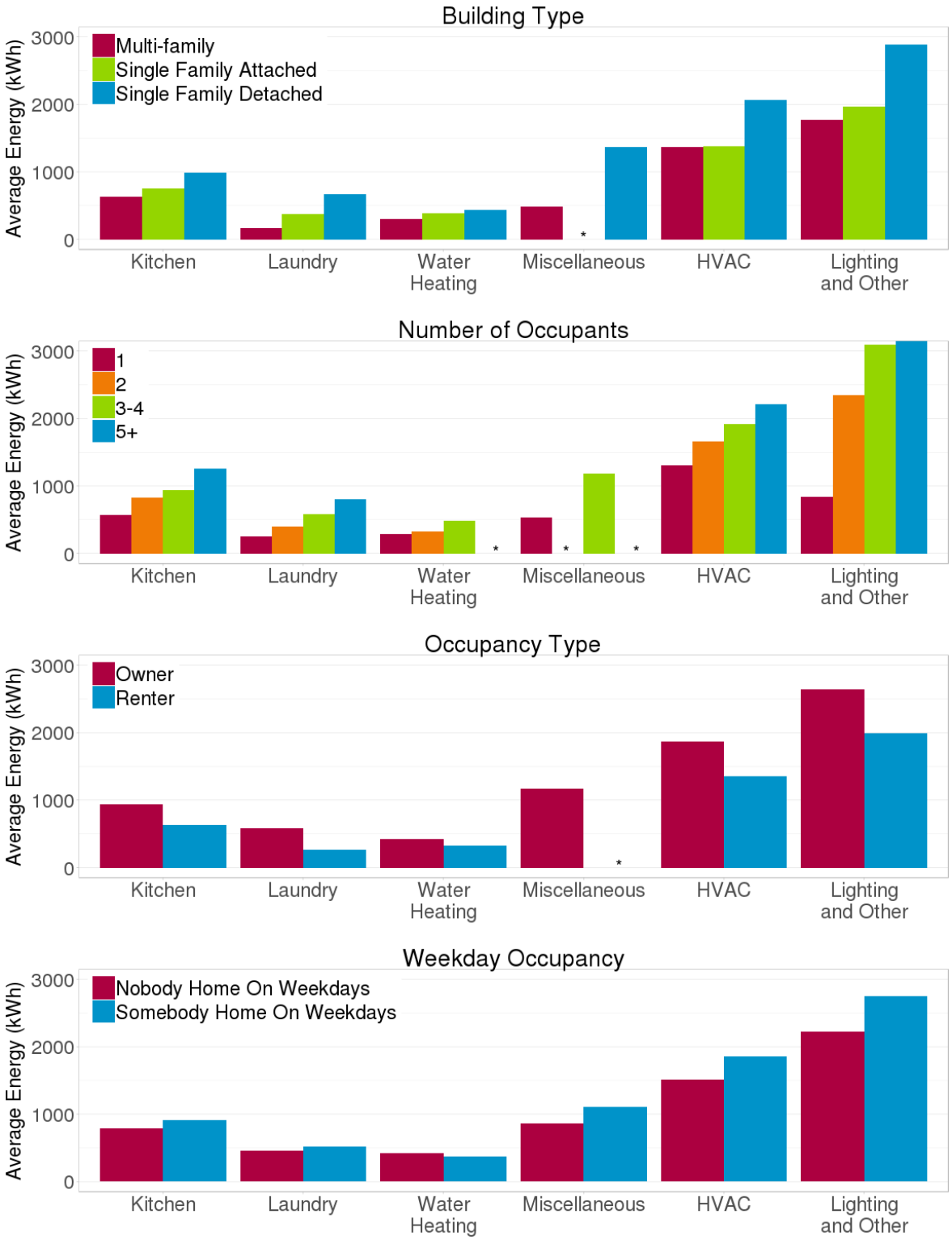
Figure 2-13. Population Average Energy Consumption by Month Split by End Use Category



Source: Navigant analysis

Figure 2-14 shows the breakdown of average energy usage by several key building demographics. As shown in the figure, average energy usage at the end use category level is most highly correlated with the number of occupants and weekday occupancy. Owner-occupied homes and single-family detached homes also tend to have higher energy use. Further breakdowns of energy and demand by demographic and end use categories are available in Appendix C.

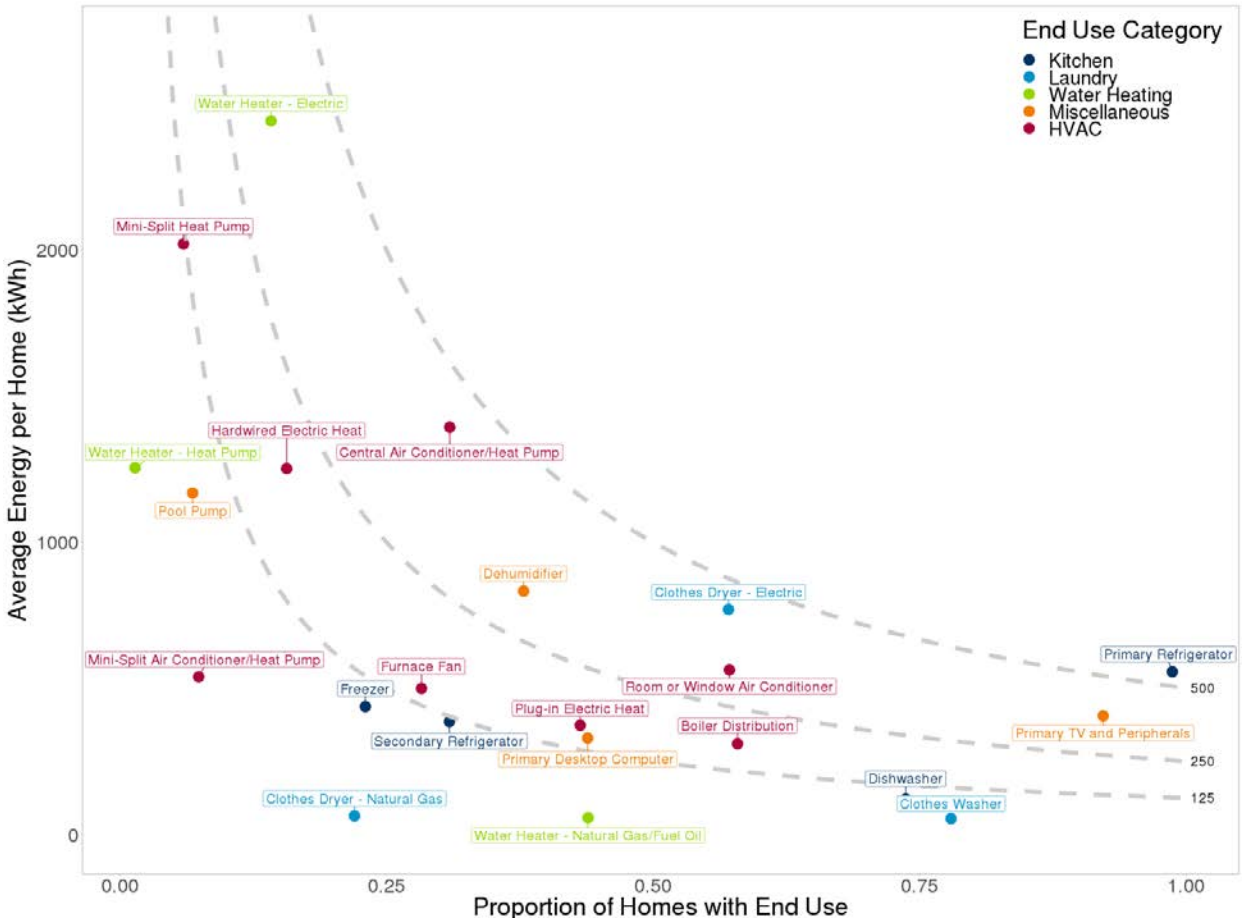
Figure 2-14. Average Annual Energy Consumption by End Use Category and Building/Occupancy Demographics



*Insufficient data to present results
Source: Navigant analysis

Figure 2-15 illustrates the relationship between saturation, energy consumption per home with the end use, and energy consumption for all homes. Saturation is shown on the x-axis; average energy consumption for homes that have a given end use is on the y-axis. The gray lines in Figure 2-15 represent constant statewide energy consumption, which is determined by multiplying the average energy consumption per home by the proportion of homes with the end use.

Figure 2-15. End Use Saturation and Annual Energy Consumption for Homes with End Use



Source: Navigant analysis

Key Finding: *Statewide electricity consumption from certain high consumption, low saturation end uses, like ductless heat pumps and central AC, could increase dramatically with increasing adoption.*

Table 2 shows the energy consumption of individual metered end uses both for homes with the end use and averaged across the entire population of homes in Massachusetts.

Table 2. Annual Energy Consumption by End Use

End Use Category	End Use	Saturation across MA Homes [A]	Annual Energy per Home with End Use (kWh) [B]	Population Annual Energy per Home (kWh) [C = A x B]	Percentage of Annual Energy Load (%) [C/∑C]
HVAC	Central AC/Heat Pump	0.31	1,390	431	6%
	Room or Window AC	0.57	563	322	5%
	Furnace Fan	0.28	500	141	3%
	Boiler Distribution	0.58	311	180	3%
	Hardwired Electric Heat	0.16	1,250	196	2%
	Plug-in Electric Heat	0.43	374	161	2%
	Mini-Split Heat Pump (Heating)	0.06	2020	121	2%
	Mini-Split AC/Heat Pump (Cooling)	0.074	539	40	1%
	HVAC - Other	N/A	N/A	80	1%
	HVAC Total	**N/A**	**N/A**	**1,670**	**24%**
Water Heating	Water Heater - Electric	0.14	2,440	347	5%
	Water Heater - Nat. Gas/Fuel Oil	0.44	57	25	< 0.5%
	Water Heater - Heat Pump	0.014	1,250	18	< 0.5%
	Water Heating Total	**N/A**	**N/A**	**390**	**6%**
Kitchen	Primary Refrigerator	0.99	557	549	8%
	Secondary Refrigerator	0.31	386	119	2%
	Dishwasher	0.23	438	101	1%
	Freezer	0.74	121	89	1%
	Kitchen Total	**N/A**	**N/A**	**859**	**12%**
Laundry	Clothes Dryer - Electric	0.57	769	439	6%
	Clothes Washer	0.78	54	42	1%
	Clothes Dryer - Natural Gas	0.22	63	14	< 0.5%
	Laundry Total	**N/A**	**N/A**	**495**	**7%**
Miscellaneous	Primary TV	0.92	406	375	5%
	Dehumidifier	0.38	832	315	5%
	Primary Computer	0.44	330	145	2%
	Pool Pump	0.068	1,170	80	1%
	Other Pump	N/A	N/A	23	< 0.5%
	Misc. Metered	N/A	N/A	52	1%
	Miscellaneous Total	N/A	N/A	989	14%
Lighting and Other	Lighting and Other	N/A	1,680	2,550	37%
All	**Total**	**N/A**	**N/A**	**7,960**	**100%**

Source: Navigant analysis

2.4 Peak Demand

The average demand for five periods by end use category is shown in Figure 2-16. As laid out in Section 1.4 and shown in Table 3, there are two summer peak periods and two winter peak periods defined—one called on-peak, the other called system peak—with results presented for each throughout the report. Two other peaks were also calculated but only presented in a limited number of cases.

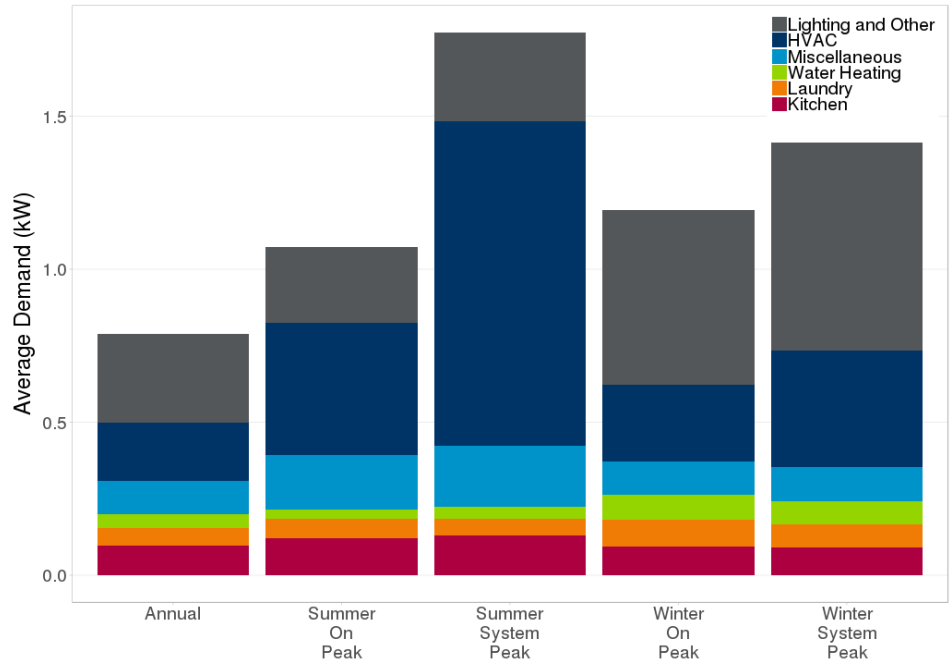
Table 3. Peak Period Definitions

Included Peak Periods	Summer On-Peak	Summer System Peak	Winter On-Peak	Winter System Peak
Days	Non-holiday weekdays in June, July, August		Non-holiday weekdays in December and January	
Times	1 p.m.-5 p.m.	Highest two consecutive hours	5 p.m.-7 p.m.	Highest two consecutive hours

Other Peak Periods	Summer Seasonal Peak	Summer Residential Peak	Winter Seasonal Peak	Winter Residential Peak
Days	Non-holiday weekdays in June, July, August	Single non-holiday weekday in June, July, August with the highest load	Non-holiday weekdays in June, July, August	Single non-holiday weekday in December and January with the highest load
Times	All hours exceeding 90% of the most recent 50/50 forecast	5 p.m. – 7.p.m.	All hours exceeding 90% of the most recent 50/50 forecast	7 p.m. – 9 p.m.

Source: Navigant analysis

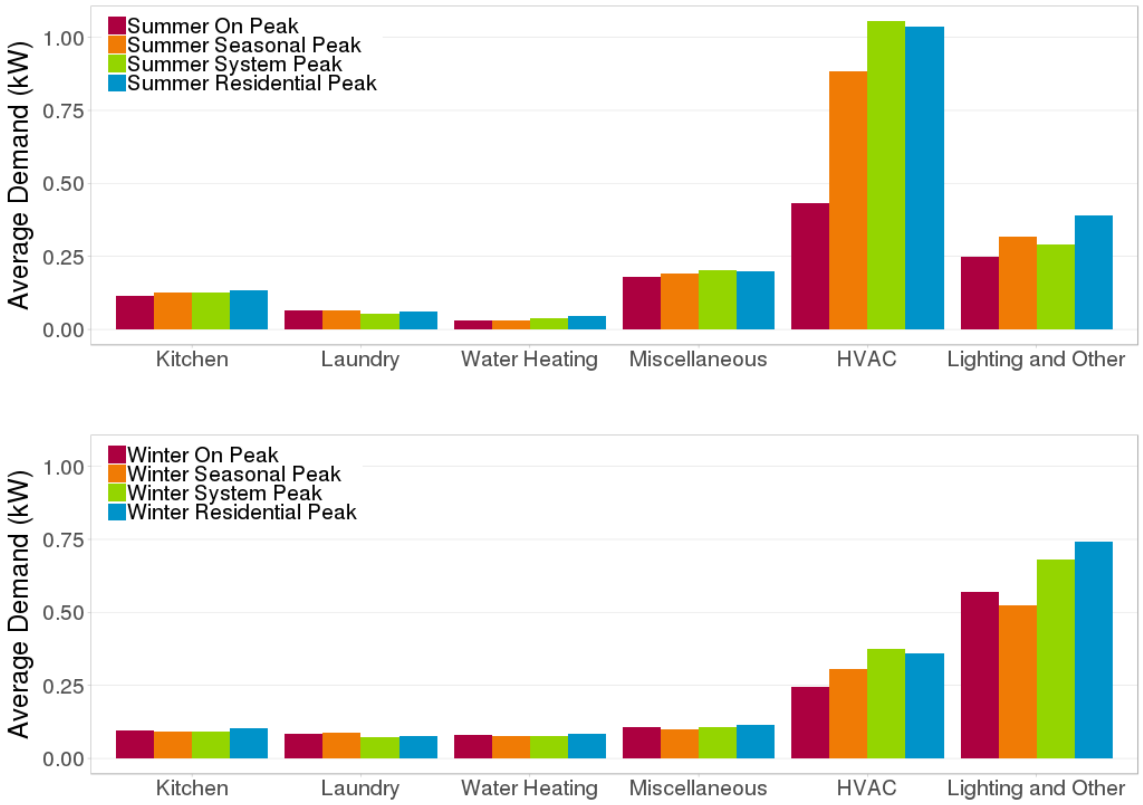
Figure 2-16. Average Weather-Normalized Demand for Five Periods by End Use



Source: Navigant analysis

Figure 2-17 shows a comparison of the four different summer peak demand periods and the four different winter peak demand periods considered for this work, as defined in Table 4. The summer system peak for HVAC end uses is more than twice as high as the on-peak average.[9] For lighting and other, the later in the afternoon/evening the peak occurs, the higher the impact, with the evening-focused residential peaks having the highest impacts. For other end use categories, the choice of peak period does not have much effect on the results.

Figure 2-17. Summer and Winter Weather-Normalized Peak Load by End Use Category



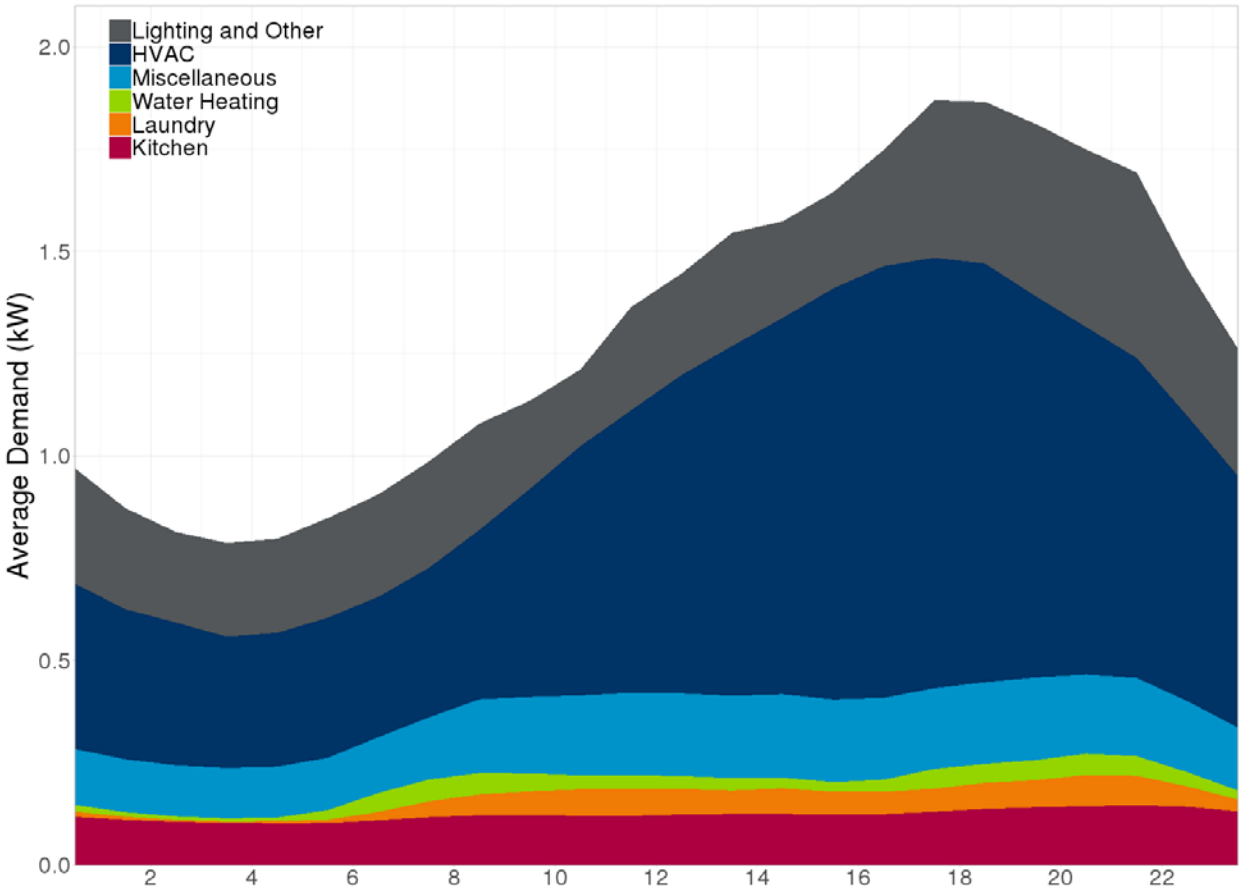
Source: Navigant analysis

2.4.1 Summer Peak Demand

The peak day load shapes by end use category are shown in Figure 2-18. This figure illustrates that summer peak demand is driven primarily by HVAC loads. A more granular breakdown of end use load shapes is shown in Figure 2-19.

[9] The difference in peak definitions has significant implications for determining benefits from HVAC measures, which are discussed further in Section 3, Overall Conclusions and Considerations.

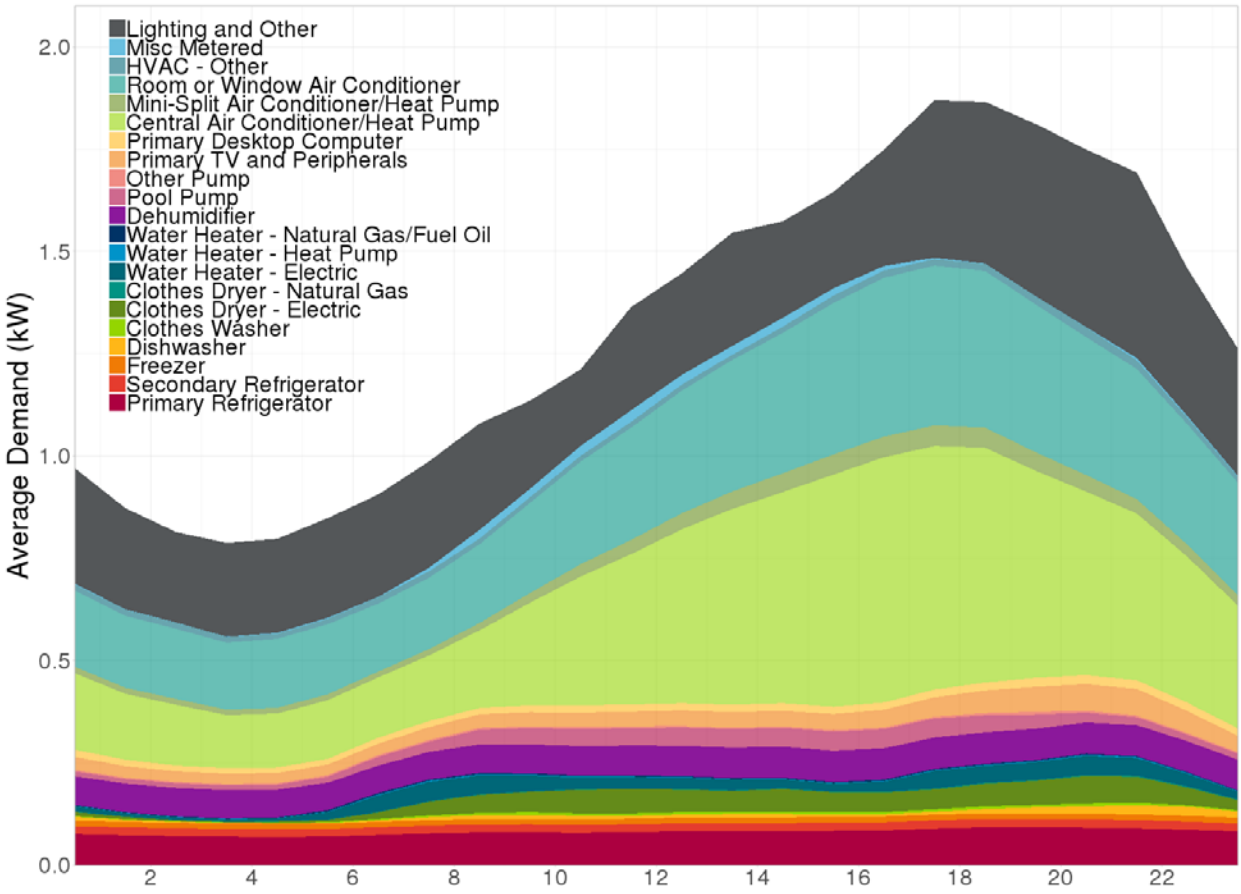
Figure 2-18. Weather-Normalized Summer Peak Day End Use Category Load Shapes



Source: Navigant analysis

Key Finding: *Cooling is responsible for half of summer peak demand.*

Figure 2-19. Weather-Normalized Summer Peak Day End Use Load Shapes



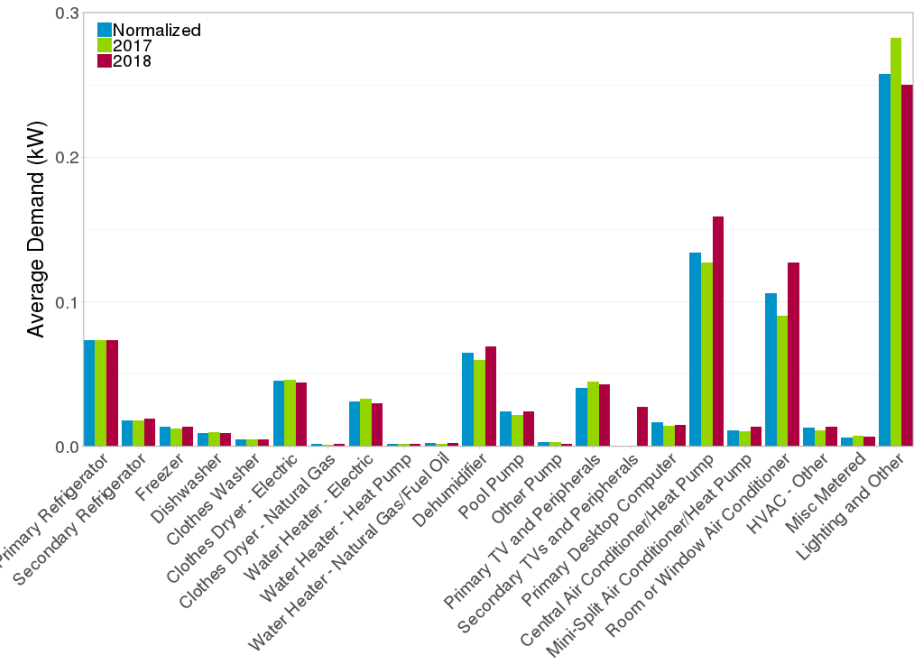
Source: Navigant analysis

Key Finding: *Refrigerators, dehumidifiers, clothes dryers, primary TVs and their peripherals, and pool pumps also contribute to the summer peak demand in Massachusetts.*

Figure 2-20 and Figure 2-21 show a comparison of the whole summer average demand for each end use across the 2017 and 2018 summers and the normalized result for both the entire population of Massachusetts and for each home with the end use, respectively.

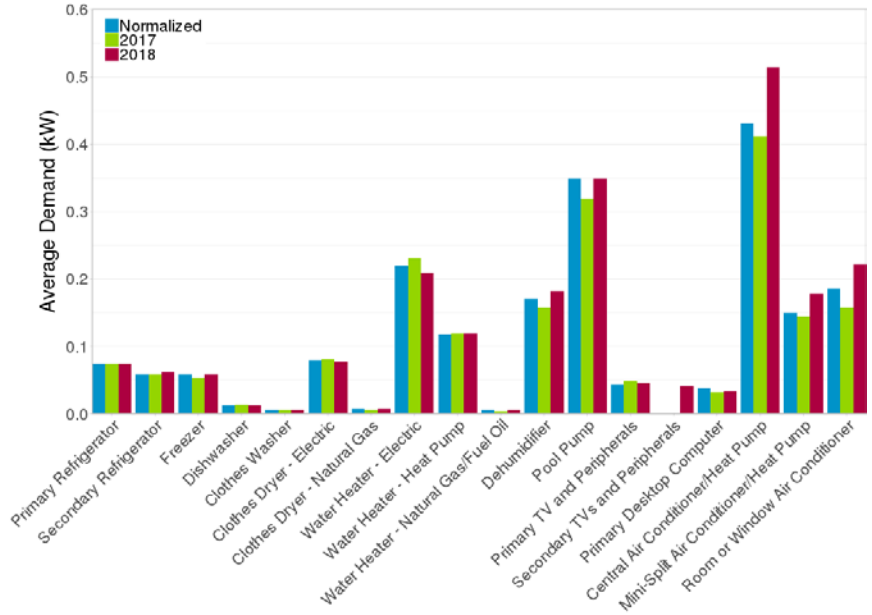
Similarly, Figure 2-22 and Figure 2-23 show the comparison of summer peak average demand for each end use across the 2017 and 2018 summers and the normalized result for both the entire population of Massachusetts and for each home with the end use, respectively.

Figure 2-20. Whole Summer Average Demand Comparison for Population



Source: Navigant analysis

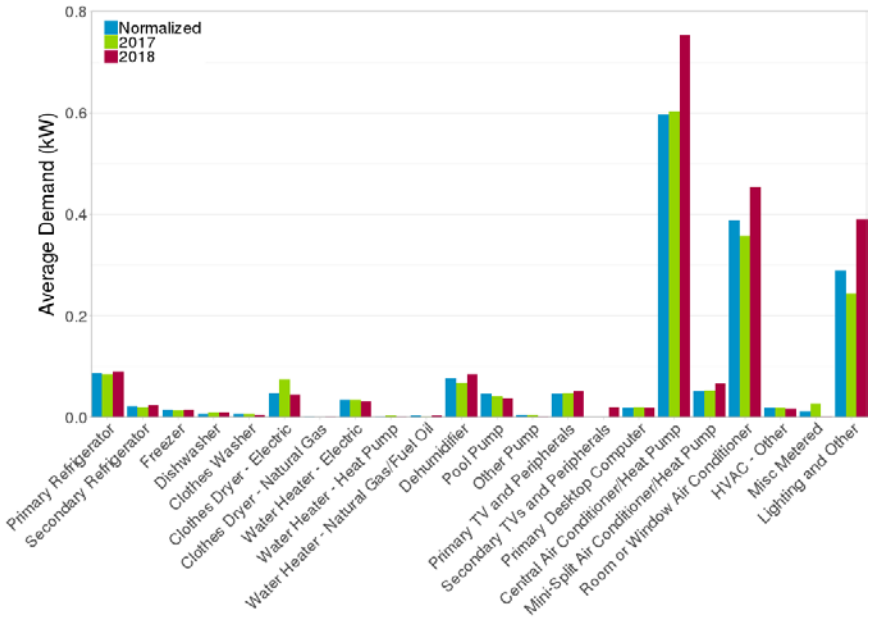
Figure 2-21. Whole Summer Average Demand Comparison per Home with End Use



Source: Navigant analysis

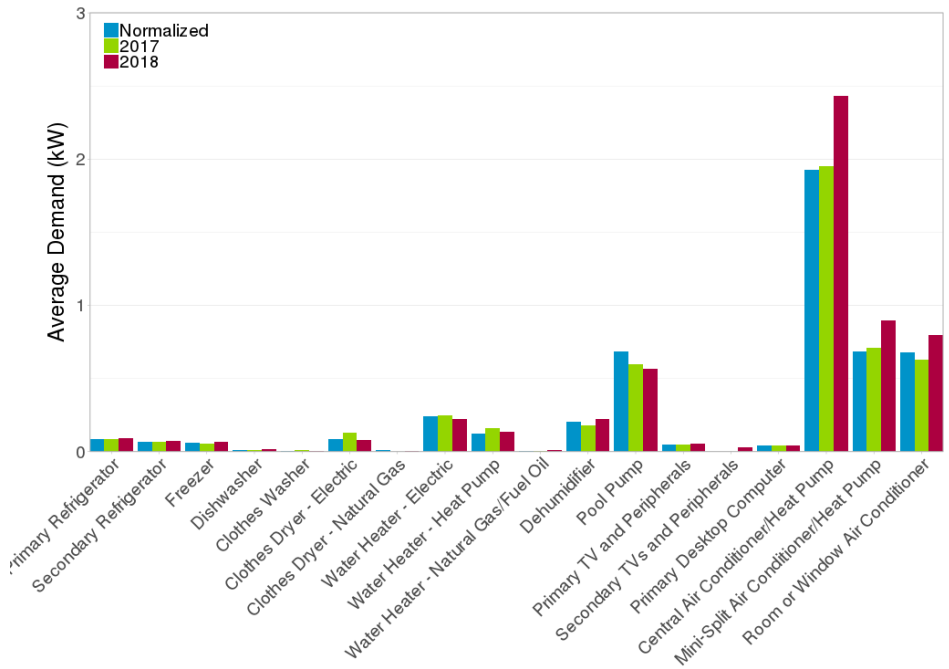
Key Finding: *The higher temperatures in Massachusetts in summer 2018 resulted in higher average consumption for all cooling end uses.*

Figure 2-22. Summer Peak Average Demand Comparison for Population



Source: Navigant analysis

Figure 2-23. Summer Peak Average Demand Comparison per Home with End Use

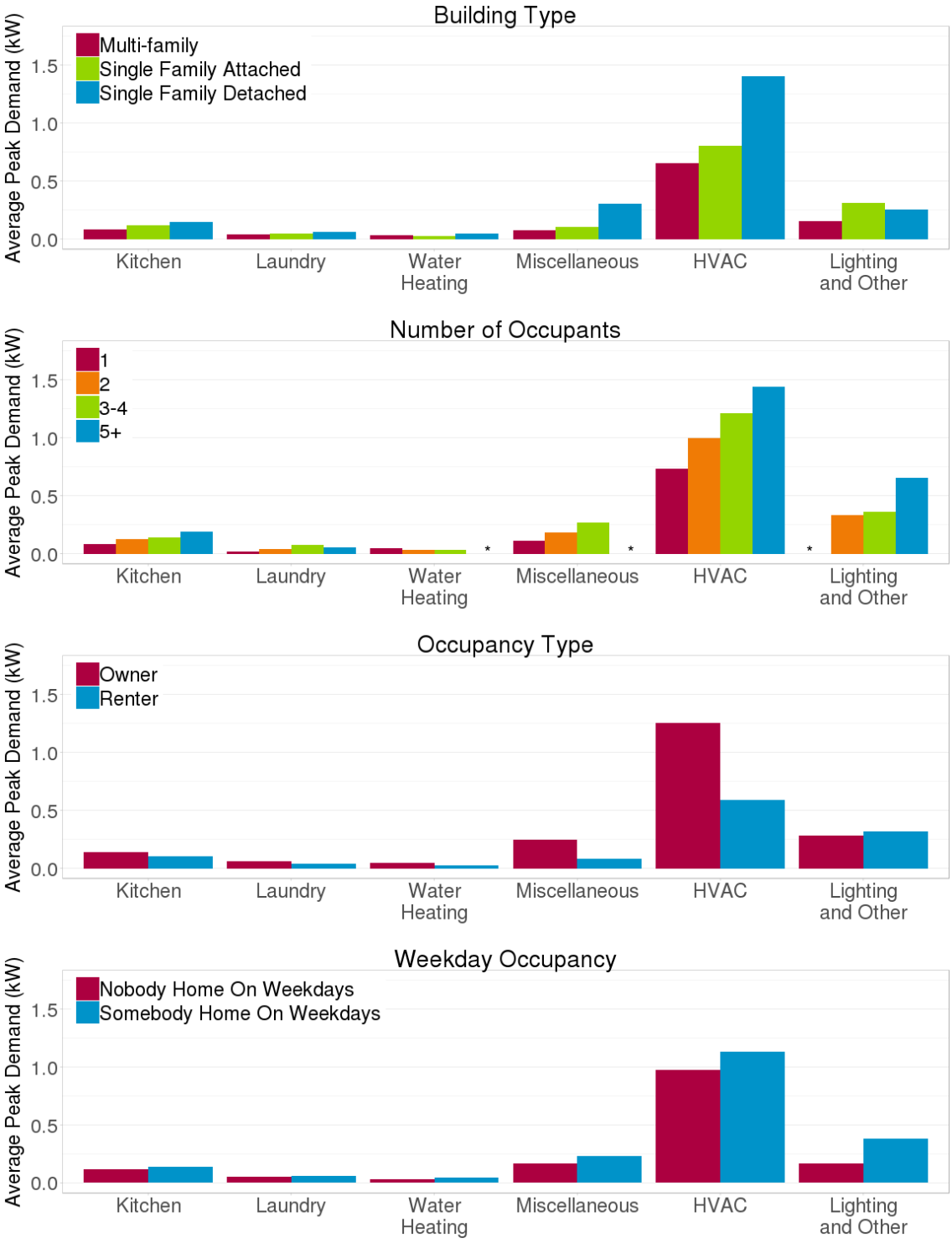


Source: Navigant analysis

Key Finding: *In 2018, HVAC had peak demands about 20% higher than in 2017. Peak demands for water heaters and pool pumps were lower in 2018 than in 2017.*

Figure 2-24 shows summer peak demand by end use category split by key building/occupancy demographics.

Figure 2-24. Weather-Normalized Summer Peak Demand by End Use Category and Building/Occupancy Demographics

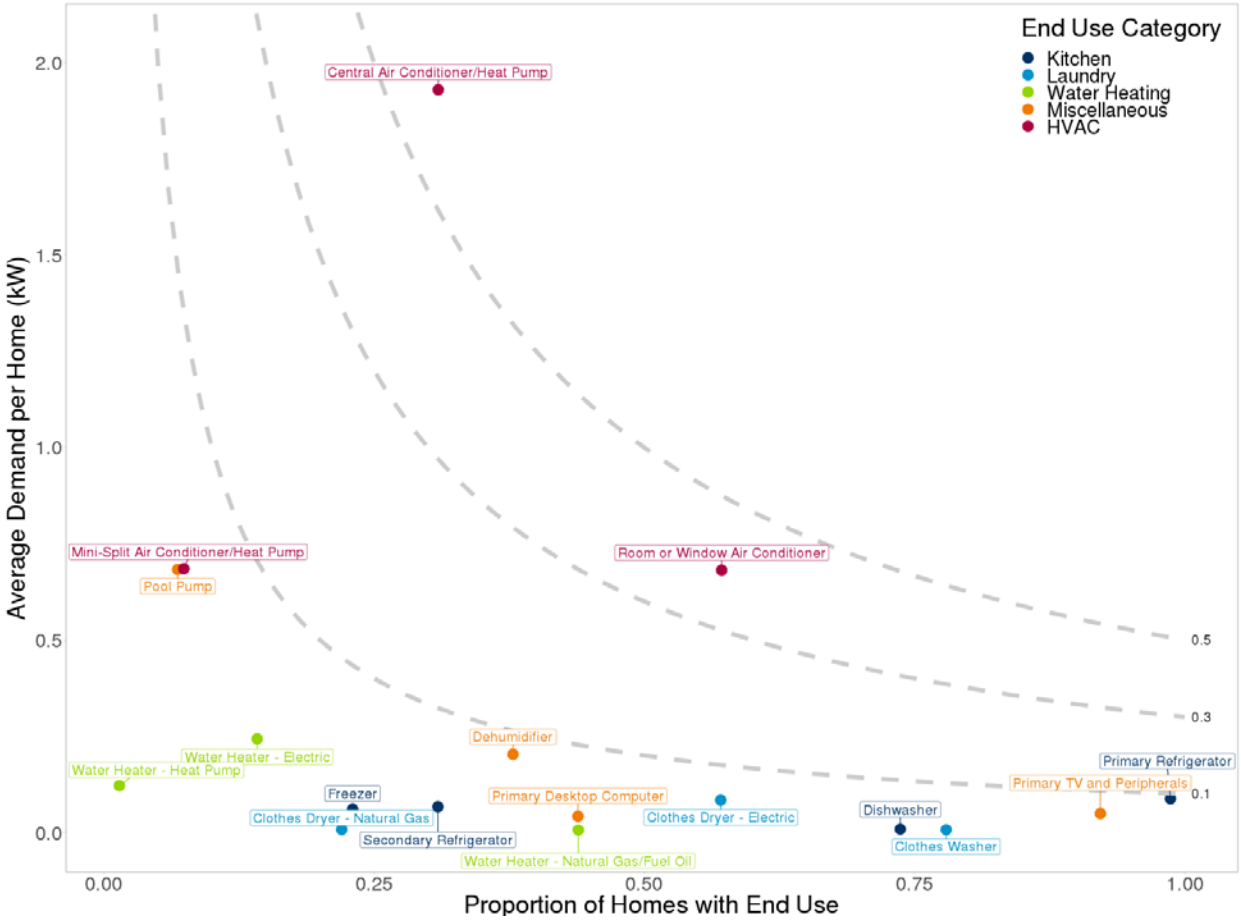


*Insufficient data to present results

Source: Navigant analysis

Figure 2-25 illustrates the relationship between saturation, summer demand per home with the end use, and summer demand for all homes. Saturation is shown on the x-axis; peak demand for homes that have a given end use is on the y-axis. The gray lines represent constant statewide summer demand, which is determined by multiplying the summer demand per home by the proportion of homes with the end use. High saturation but low demand end uses like primary TVs and their peripherals contribute roughly the same demand, on average, as end uses with low saturation and high demand like pool pumps. This is evident in the figure by both end uses being approximately equidistant from the line of constant demand.

Figure 2-25. End Use Saturation and Summer Demand for Homes with End Use

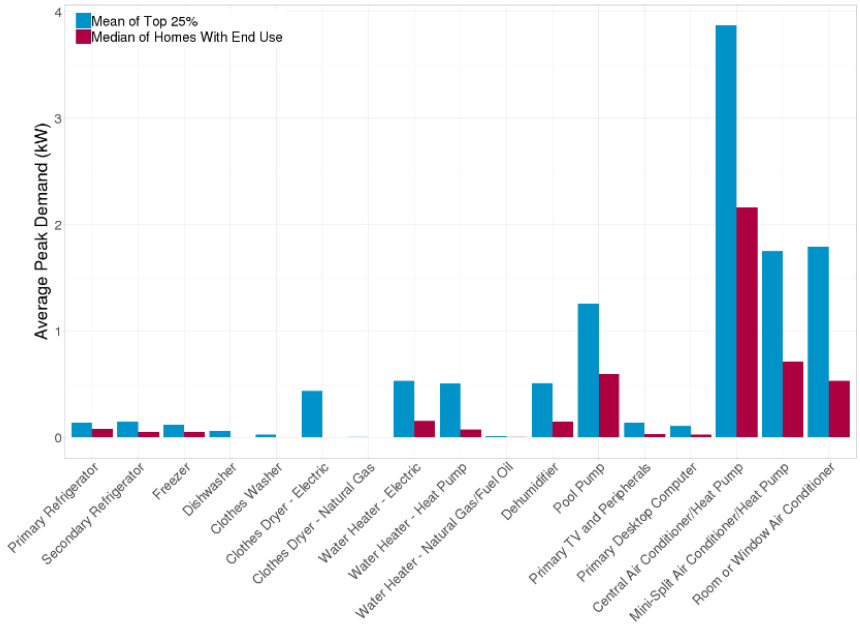


Source: Navigant analysis

Key Finding: *The top contributors to summer peak demand across all homes in Massachusetts are central ACs and room ACs.*

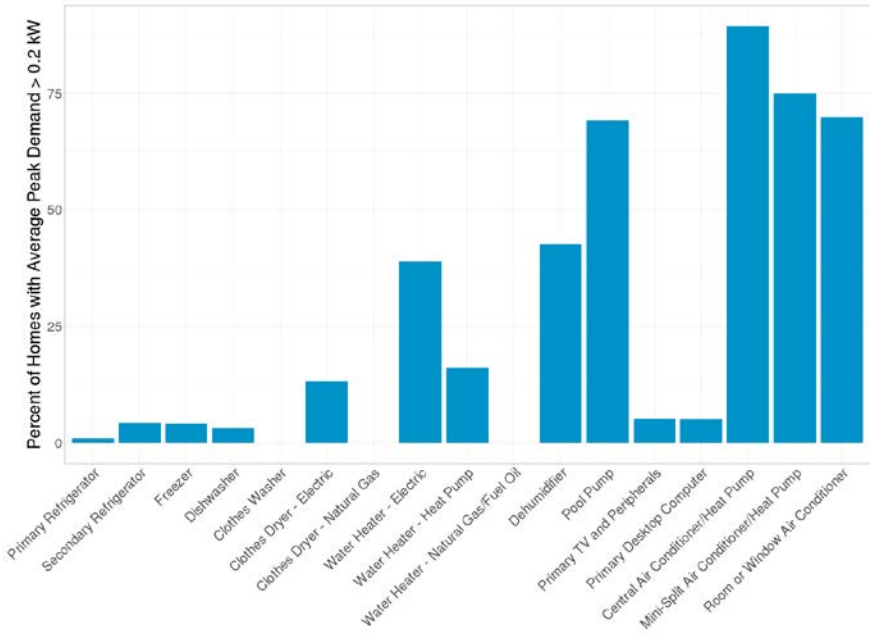
Figure 2-26 shows how the distribution of peak demands across households may influence the savings achievable by targeting high users. End uses with a bigger difference between the mean of the top 25% and the median of all users have peak demand more concentrated in a smaller number of houses, meaning they offer larger opportunities for targeting. Figure 2-27 shows the fraction of homes with an end use that has a peak demand higher than 0.2 kW.

Figure 2-26. Weather-Normalized Summer Peak Demand for Top 25% of Users of Each Metered End Use



Source: Navigant analysis

Figure 2-27. Proportion of Homes with Weather-Normalized Summer Peak Demand Greater than 0.2 kW for Each Measured End Use



Source: Navigant analysis

Average peak demand and saturation values are shown for each end use in Table 4.

Table 4. Weather-Normalized Summer Peak Demand by End Use

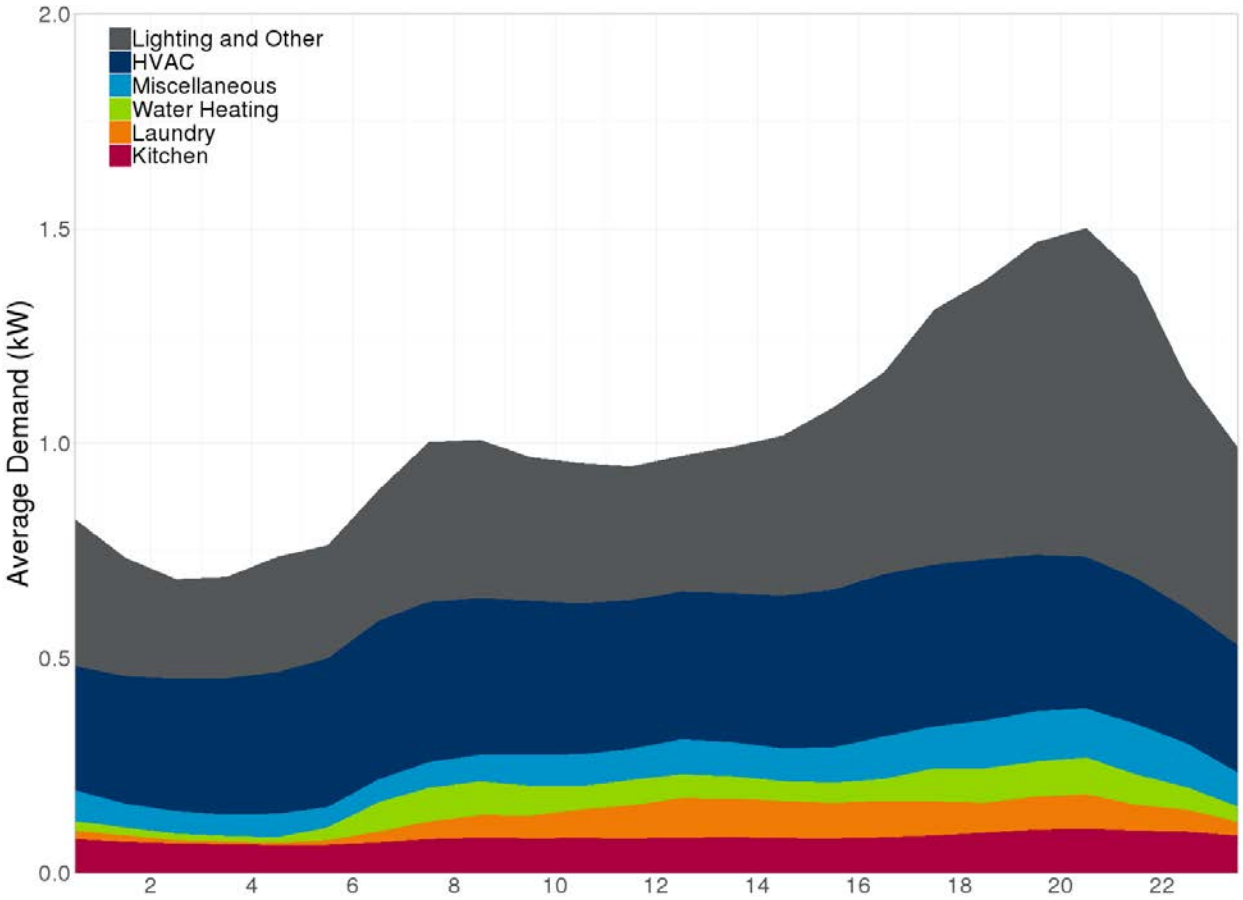
End Use Category	End Use	Saturation in MA	System Peak Demand per Home (kW)	On-Peak Demand per Home (kW)	Population System Peak Demand (kW)	Population On-Peak Demand (kW)	Percent of Population System Peak Load (%)	Percent of Population On-Peak Load (%)
HVAC	Central AC/Heat Pump	0.31	1.93	0.80	0.60	0.25	34%	23%
	Room or Window AC	0.57	0.68	0.27	0.39	0.16	22%	14%
	Mini-Split AC/Heat Pump	0.074	0.69	0.26	0.051	0.019	3%	2%
	HVAC - Other	N/A	N/A	N/A	0.018	0.012	1%	1%
	HVAC Total	**N/A**	**N/A**	**N/A**	**1.06**	**0.43**	**60%**	**40%**
Water Heating	Water Heater - Electric	0.14	0.24	0.18	0.035	0.026	2%	2%
	Water Heater - Nat. Gas/Fuel Oil	0.44	0.0063	0.0056	0.0028	0.0025	< 0.5%	< 0.5%
	Water Heater - Heat Pump	0.014	0.12	0.11	0.0018	0.0016	< 0.5%	< 0.5%
	Water Heating Total	**N/A**	**N/A**	**N/A**	**0.039**	**0.03**	**2%**	**3%**
Kitchen	Primary Refrigerator	0.99	0.088	0.078	0.087	0.077	5%	7%
	Secondary Refrigerator	0.31	0.067	0.06	0.021	0.019	1%	2%
	Freezer	0.23	0.061	0.059	0.014	0.014	1%	1%
	Dishwasher	0.74	0.0086	0.0096	0.0063	0.0071	< 0.5%	1%
	Kitchen Total	**N/A**	**N/A**	**N/A**	**0.13**	**0.12**	**7%**	**11%**
Laundry	Clothes Dryer - Electric	0.57	0.084	0.099	0.048	0.056	3%	5%
	Clothes Washer	0.78	0.0072	0.007	0.0056	0.0054	< 0.5%	1%
	Clothes Dryer - Natural Gas	0.22	0.0075	0.0086	0.0017	0.0019	< 0.5%	< 0.5%
	Laundry Total	**N/A**	**N/A**	**N/A**	**0.055**	**0.064**	**3%**	**6%**
Miscellaneous	Dehumidifier	0.38	0.20	0.18	0.077	0.067	4%	6%
	Primary TV	0.068	0.68	0.62	0.047	0.042	3%	4%
	Pool Pump	0.92	0.049	0.043	0.045	0.04	3%	4%
	Primary Computer	0.44	0.042	0.042	0.018	0.018	1%	2%
	Other Pump	N/A	N/A	N/A	0.0041	0.003	< 0.5%	< 0.5%
	Misc. Metered	N/A	N/A	N/A	0.011	0.011	1%	1%
	Misc. Total	**N/A**	**N/A**	**N/A**	**0.20**	**0.18**	**11%**	**17%**
Lighting and Other	**Lighting and Other**	**N/A**	**N/A**	**N/A**	**0.29**	**0.25**	**16%**	**23%**
All	**Total**	**N/A**	**N/A**	**N/A**	**1.77**	**1.07**		**100%**

Source: Navigant analysis

2.4.2 Winter Peak Demand

The peak day load shapes by end use category are shown in Figure 2-28. This figure demonstrates that winter peak demand values are driven primarily by loads not individually metered in this study, which includes lighting. A more granular breakdown of end use load shapes is shown in Figure 2-29. The end use-specific saturations and average peak demand values for the winter peak are shown in Table 5.

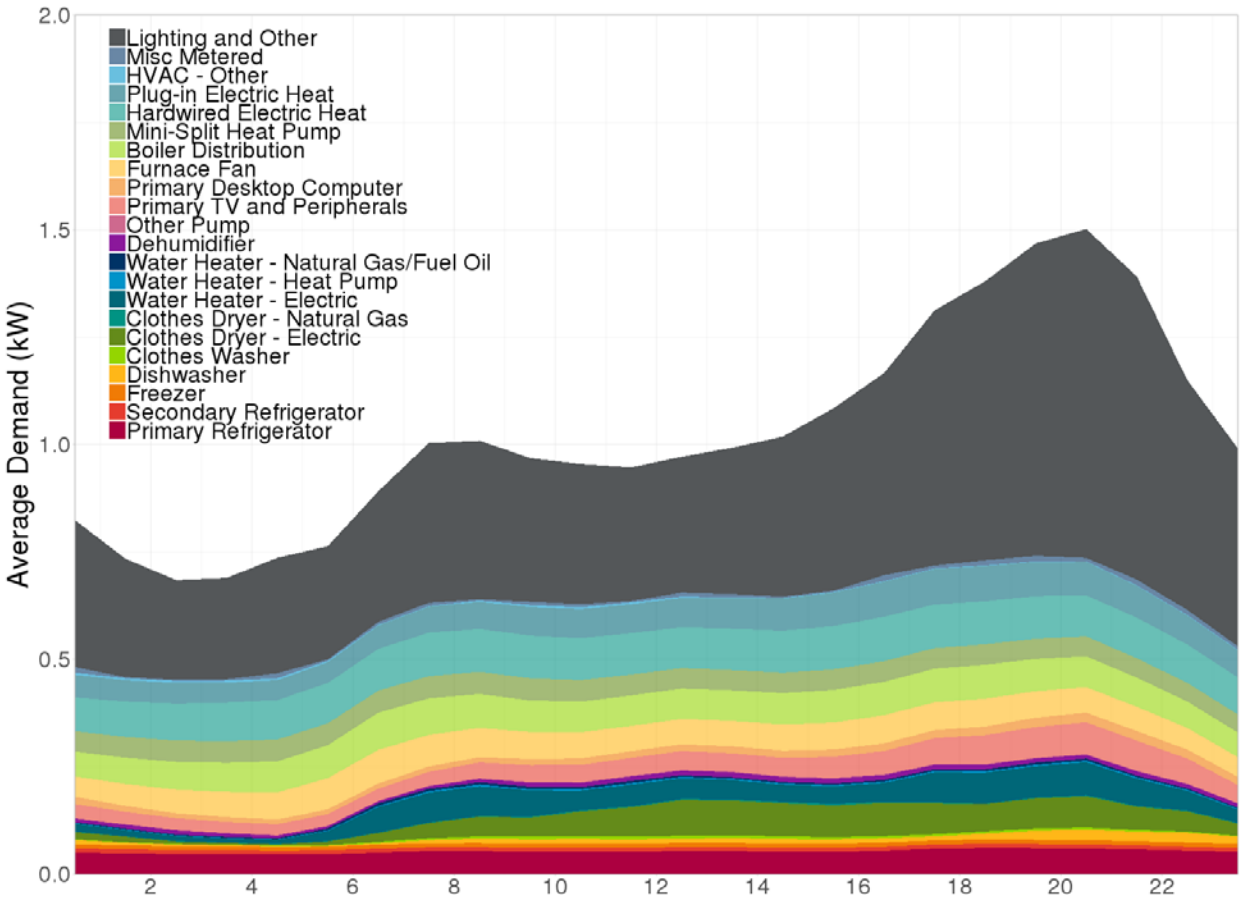
Figure 2-28. Weather-Normalized Winter Peak Day End Use Category Load Shapes



Source: Navigant analysis

Key Finding: *Unmetered loads contributed most to Massachusetts' winter peak demand. These end uses include lighting and various small plug loads. On winter peak days, HVAC loads are large but relatively flat.*

Figure 2-29. Weather-Normalized Winter Peak Day End Use Load Shapes

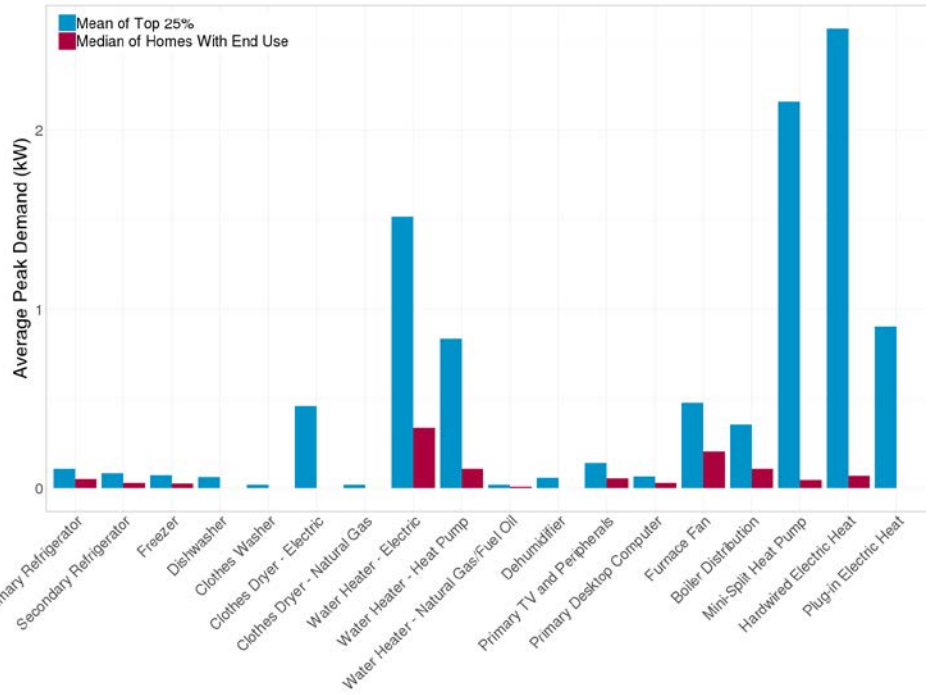


Source: Navigant analysis

Key Finding: *When the major end uses are disaggregated further, no single HVAC end use dominates winter peak demand. However, the aggregate HVAC category presents significant savings opportunities. Savings opportunities may also exist for clothes dryers and water heaters.*

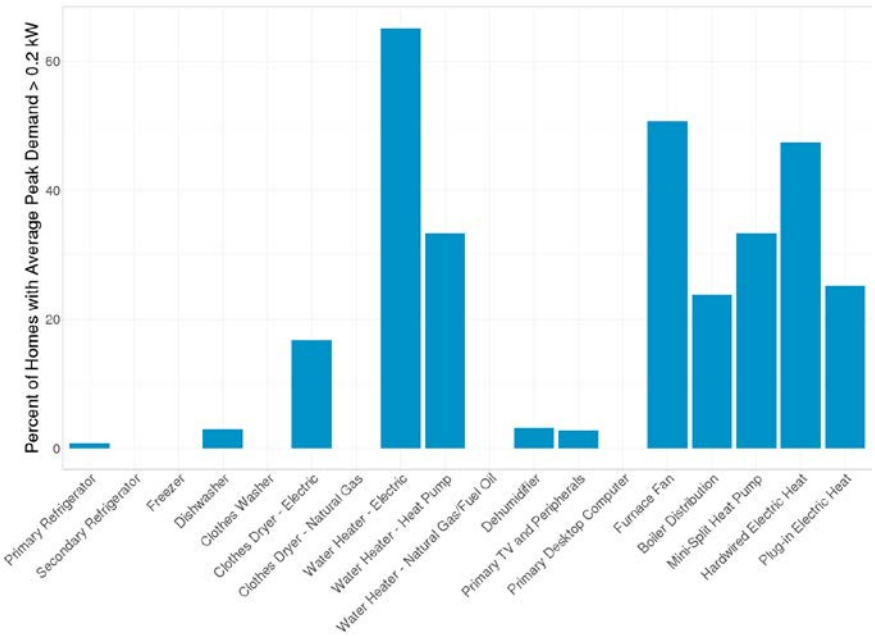
Figure 2-30 shows the peak demand for high users of each end use, which is much higher than the median for many end uses. Figure 2-31 shows the fraction of homes with the end use that consume more than 0.2 kW during peak. These figures illustrate that many households have low usage of HVAC end uses during peak and that winter peak demand is driven by a small number of homes.

Figure 2-30. Weather-Normalized Winter Peak Demand for Top 25% of Users of Each Metered End Use



Source: Navigant analysis

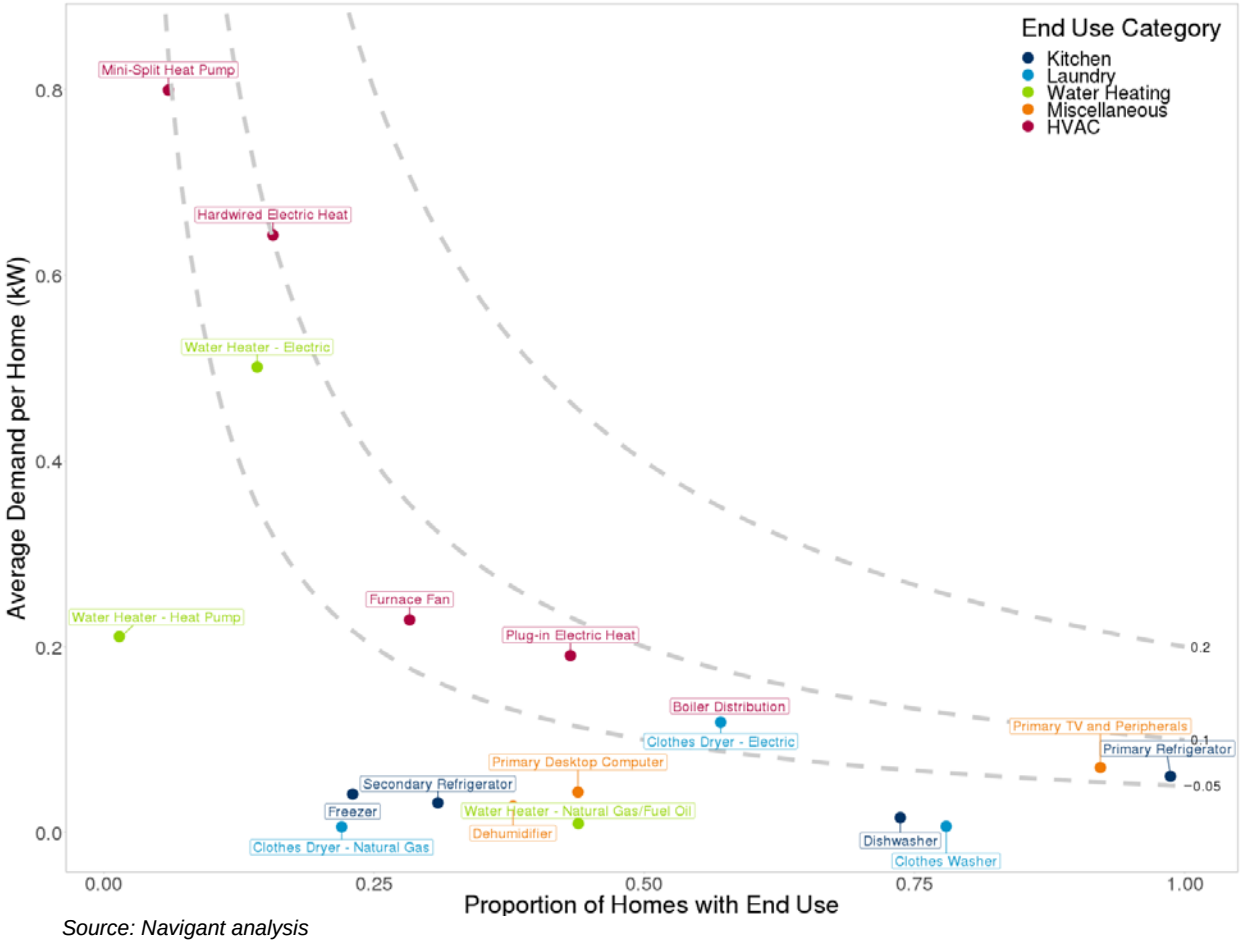
Figure 2-31. Proportion of Homes with Weather-Normalized Winter Peak Demand Greater than 0.2 kW for Each Measured End Use



Source: Navigant analysis

Figure 2-32 illustrates the relationship between saturation, winter demand per home with the end use, and winter demand for all homes. Saturation is shown on the x-axis; winter demand for homes that have a given end use is on the y-axis. The gray lines represent constant statewide winter demand, which is determined by multiplying the average energy consumption per home by the proportion of homes with the end use. High saturation but low demand end uses like primary TVs and their peripherals account for roughly the same winter demand, on average, as end uses with low saturation and high demand like electric water heaters.

Figure 2-32. End Use Saturation and Weather-Normalized Winter Demand for Homes with End Use

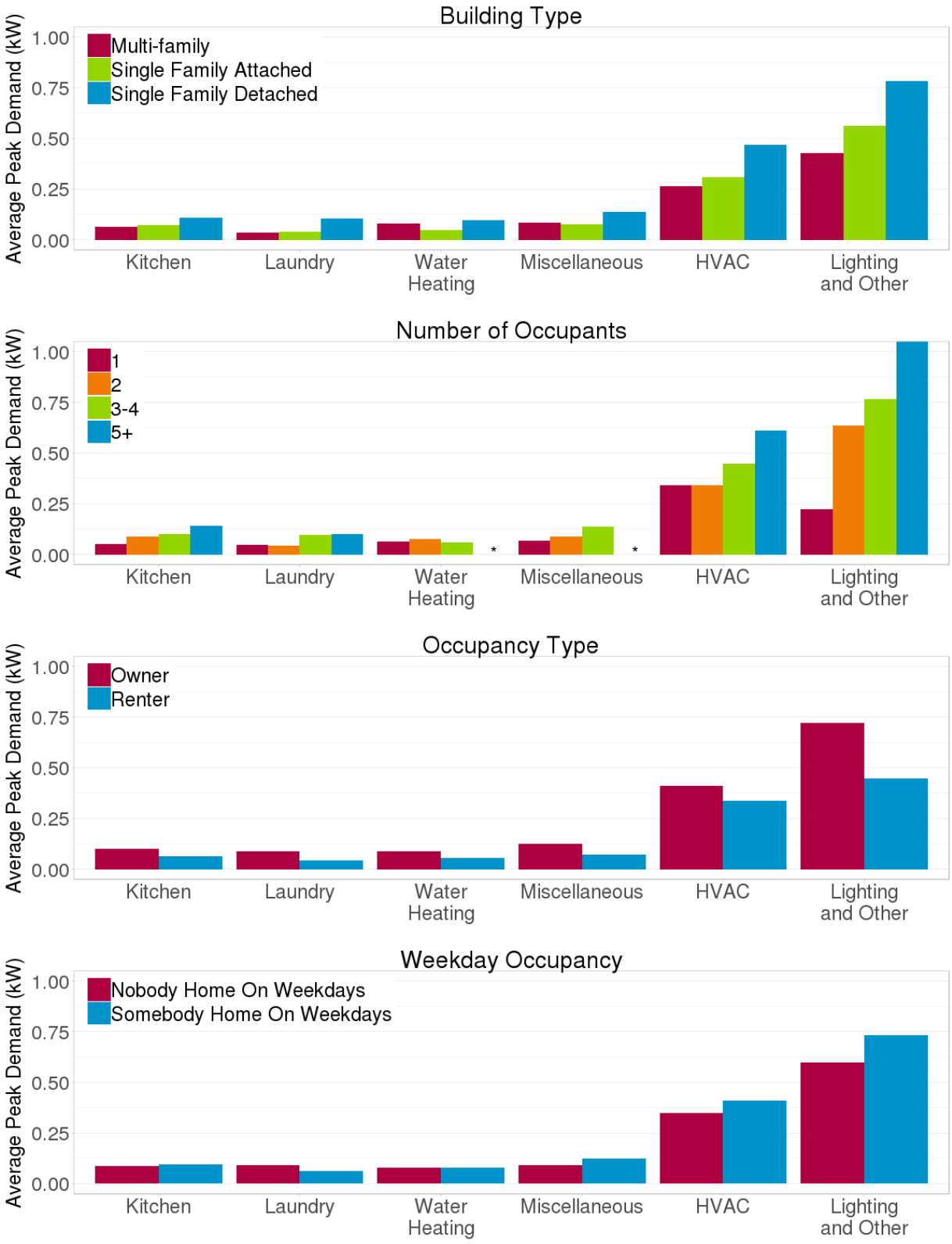


Source: Navigant analysis

Key Finding: *If saturation of ductless heat pumps continues to rise, they could quickly become the single most important driver of winter peak aside from lighting.*

Figure 2-33 shows that the same building and occupancy demographics that drive the summer peak also drive the winter peak. Demand is highest for owner-occupied, single-family homes and is proportional to the number of occupants in the home. Demand is also higher across nearly all end uses when any occupant is home on weekdays. Winter peak demand consumption values by end use are detailed in Table 5.

Figure 2-33. Weather-Normalized Winter Peak Demand by End Use Category and Building/Occupancy Demographics



*Insufficient data to present results

Source: Navigant analysis

Table 5. Weather-Normalized Winter Peak Demand by End Use

End Use Category	End Use	Saturation in MA	System Peak Demand per Home (kW)	On-Peak Demand per Home (kW)	Population System Peak Demand (kW)	Population On-Peak Demand (kW)	Percent of Population System Load (%)	Percent of Population On-Peak Load (%)
HVAC	Furnace Fan	0.28	0.23	0.14	0.065	0.04	7%	5%
	Hardwired Electric Heat	0.16	0.64	0.37	0.10	0.058	6%	5%
	Boiler Distribution	0.58	0.14	0.091	0.079	0.053	6%	4%
	Plug-In Electric Heat	0.43	0.19	0.14	0.082	0.06	5%	3%
	Mini-Split Heat Pump	0.06	0.80	0.55	0.048	0.033	3%	3%
	HVAC - Other	N/A	N/A	N/A	0.0016	0.0016	< 0.5%	< 0.5%
	HVAC Total	**N/A**	**N/A**	**N/A**	**0.38**	**0.25**	**27%**	**21%**
Water Heating	Water Heater - Electric	0.14	0.5	0.53	0.071	0.075	5%	6%
	Water Heater – Nat. Gas/Fuel Oil	0.44	0.0096	0.0084	0.0042	0.0037	< 0.5%	< 0.5%
	Water Heater - Heat Pump	0.014	0.21	0.21	0.003	0.003	< 0.5%	< 0.5%
	Water Heating Total	**N/A**	**N/A**	**N/A**	**0.078**	**0.082**	**6%**	**7%**
Kitchen	Primary Refrigerator	0.99	0.061	0.063	0.060	0.063	4%	5%
	Dishwasher	0.74	0.016	0.016	0.012	0.012	1%	1%
	Secondary Refrigerator	0.31	0.032	0.035	0.0099	0.011	1%	1%
	Freezer	0.23	0.041	0.043	0.0095	0.01	1%	1%
	Kitchen Total	**N/A**	**N/A**	**N/A**	**0.091**	**0.095**	**6%**	**8%**
Laundry	Clothes Dryer - Electric	0.57	0.12	0.13	0.068	0.077	5%	7%
	Clothes Washer	0.78	0.0066	0.0075	0.0052	0.0059	< 0.5%	1%
	Clothes Dryer - Natural Gas	0.22	0.0061	0.01	0.0013	0.0022	< 0.5%	< 0.5%
	Laundry Total	**N/A**	**N/A**	**N/A**	**0.074**	**0.085**	**5%**	**7%**
Miscellaneous	Primary TV and Peripherals	0.92	0.070	0.071	0.064	0.066	5%	6%
	Primary Desktop Computer	0.44	0.044	0.044	0.019	0.019	1%	2%
	Dehumidifier	0.38	0.028	0.028	0.011	0.011	1%	1%
	Other Pump	N/A	N/A	N/A	0.0028	0.0015	< 0.5%	< 0.5%
	Misc. Metered	N/A	N/A	N/A	0.011	0.0086	1%	1%
	Miscellaneous Total	**N/A**	**N/A**	**N/A**	**0.11**	**0.11**	**8%**	**9%**
Ltg and Other	**Lighting and Other**	**N/A**	**N/A**	**N/A**	**0.68**	**0.57**	**49%**	**48%**
All	**Total All End Uses**	**N/A**	**N/A**	**N/A**	**1.41**	**1.18**	**100%**	**100%**

Source: Navigant analysis

3. OVERALL CONCLUSIONS AND CONSIDERATIONS

CONCLUSION 1: Across all homes in Massachusetts, central ACs and room ACs are the largest contributors to peak demand. Collectively, cooling makes up more than half of total residential summer system peak demand. During summer system peak, central AC loads averaged 1.9 kW, and room AC loads averaged 0.7 kW. During summer on-peak, central AC loads averaged 0.8 kW and room AC loads averaged 0.3 kW. Saturation of central cooling (including shared and individual household equipment) increased from 29% of households in 2008 to 39% in 2018, while room AC saturation decreased from 64% in 2008 to 57% in 2018. The central cooling saturation increase is driven primarily by increases in the prevalence of individual household ducted central AC and ductless heat pumps. However, 2018 saw a spike in room AC purchases and a reduction in the number of households reporting they had no cooling.

> **CONSIDERATION: Central AC should be the focus of efforts to reduce peak demands, but ductless heat pumps and room AC are also important to a comprehensive program offering.** Because peak usage is driven as much by Energy Efficiency Ratio (EER) as by Seasonal Energy Efficiency Ratio (SEER), the PAs should consider including EER requirements in addition to SEER requirements to steer customers toward AC and HP offerings with higher peak demand savings. Massachusetts has significant opportunities for early central AC and HP retirement. Over 40% of central systems in Massachusetts have an EER of 9 or lower. This creates opportunities for approximately 0.7 kW of peak demand savings per system replaced with a new code-minimum efficiency system, in addition to significant energy savings. These low efficiency systems will generally be 12-25 years old during the 2019-2021 program period.

CONCLUSION 2: Across the remaining end uses, individual homes have a wide variety of significant end use loads during summer peak times. Electric clothes dryers are common (57% of homes), but they have large variability in usage compared with other end uses. About half of users did not use their dryers at all during peak times, while the top 25% of users have an average of greater than 0.4 kW during peak. Dehumidifiers are relatively common (38% of homes). More than 25% of dehumidifiers were not in use at all during peak times, but the top 25% have a mean peak of greater than 0.5 kW. Electric water heaters are uncommon (14% of homes), but they have a mean of 0.2 kW during summer system peak and the top 25% of users have a mean peak of 0.5 kW. Pool pumps are rare (7% of homes), but they have a mean summer system peak demand of 0.6 kW.

> **CONSIDERATION: PAs should consider targeting homes with dehumidifiers, clothes dryers, and pool pumps for additional peak demand savings with low impacts on occupant comfort.** Dehumidifiers, clothes dryers, and pool pumps all have opportunities for peak savings of at least 0.2 kW without negatively affecting overall equipment performance or comfort.

CONCLUSION 3: Heat pump water heaters use about half as much electricity as domestic water heaters, which corroborates much of the expected energy savings. Electric water heating load will become more important as more people switch from oil or propane heat sources to electricity. Once a home has a heat pump water heater, its water heating summer peak demand is relatively small. However, the increasing saturation of electric water heating in general means that peak demand savings opportunities remain.

> **CONSIDERATION: Energy efficiency program offerings should encourage heat pump water heaters for both energy and demand savings.** Demand response offerings for heat pump water

heaters will not have large effects during the summer or winter, but they may be worth targeting if higher peak users could be identified or influenced through behavior-based messaging.

CONCLUSION 4: Electric resistance heat has a surprisingly flat hourly load shape on peak days and can be highly variable. The top 25% of households with electric resistance heat consume approximately 10 times as much as the median. It may be difficult to generate winter electric HVAC peak demand or energy savings with program interventions because without screening low impacts are likely.

CONSIDERATION: Consider targeting high users to help increase savings. A bill-based electric resistance heating targeting algorithm could be developed and tested using this data. Consider promoting dual fuel heat pumps as part of energy optimization offerings due to their lower peak impact.

CONCLUSION 5: Electric water heaters offer the largest non-HVAC, non-lighting opportunity for winter peak demand savings.

CONSIDERATION: If the PAs are looking for opportunities to reduce winter peak demand, they should consider electric water heater demand response opportunities.

CONCLUSION 6: HVAC end uses have summer system peak impacts that are more than double ISO-NE summer on-peak impacts, which means that using ISO-NE on-peak to account for the system peak benefits of HVAC energy efficiency significantly undervalues these resources. In addition, the 2018 summer system peak occurred during the 4 p.m.-5 p.m. hour, and many of the highest hour loads for the year occurred during the 5 p.m. to 6 p.m. hour. Hours later in the day have much higher coincidence with lighting resources as well.

CONSIDERATION: Consider advocating for ISO-NE to shift back the on-peak definition to 2 p.m.-6 p.m., including June 1 through September 15, and making changes to the seasonal peak definition to better align with system peak. Consider shifting all energy efficiency resources bid into the ISO-NE forward capacity market to ISO-NE seasonal peak resources because almost every measure will be about the same, while lighting and HVAC will get much higher values. Consider changing avoided costs to align better with system peak regardless of how the energy efficiency resource is being bid.

CONCLUSION 7: More than 10% of homes in Massachusetts purchased room ACs in the summer of 2018. This significant increase may contribute to higher cooling consumption in future years. The flow of room ACs into Massachusetts homes increases during summer with extreme high temperatures.

CONSIDERATION: Consider program activities and messaging that could help increase the efficiency of room ACs purchased during heat waves.

CONCLUSION 8: Secondary TVs and their peripherals had summer consumption that was similar to that of primary TVs and peripherals. Additional data is being collected that will confirm if this holds true over a full year.

CONSIDERATION: Consider behavioral messaging and energy efficiency measures focused on reducing consumption from secondary TVs and their peripherals.

APPENDIX A. DETAILED FINDINGS

A.1 End Use-Specific Findings

This section provides plots and key findings by end use category to illustrate how each end use contributes to total energy consumption and peak demand.

A.1.1 HVAC End Uses

Space heating in Massachusetts is transitioning away from oil heat, primarily toward gas, but the saturation of electric heating equipment has stayed constant in the last 9 years, as shown in Table A-1. The table compares this study's results to the 2009 Massachusetts Residential Appliance Saturation Survey (RASS).[10]

Table A-1. RASS Comparison – Heating Systems

End Use	All Homes		Single-Family Detached	
	2009 RASS Saturation	2018 Baseline Study Saturation	2009 RASS Saturation	2018 Baseline Study Saturation
Any Space Heating System	0.99	0.96	0.99	0.98
Natural Gas Heat	0.53	0.56	0.47	0.63
Oil Heat	0.36	0.17	0.44	0.27
Electric Heat	0.08	0.08	0.04	0.04

Sources: Navigant analysis, 2009 RASS

Table A-2 shows that while the saturation of central cooling systems has gone up significantly in the last 8 years, room ACs have seen a decline, resulting in a modest increase for any cooling system across all homes.

Table A-2. RASS Comparison – Cooling Systems

End Use	All Homes		Single-Family Detached	
	2009 RASS Saturation	2018 Baseline Study Saturation	2009 RASS Saturation	2018 Baseline Study Saturation
Any Space Cooling System	0.81	0.88	0.81	0.9
Central Cooling System*	0.29	0.39	0.30	0.44
Room or Window AC	0.64	0.57	0.60	0.55

*Includes central AC/HP and ductless mini-split AC/HP

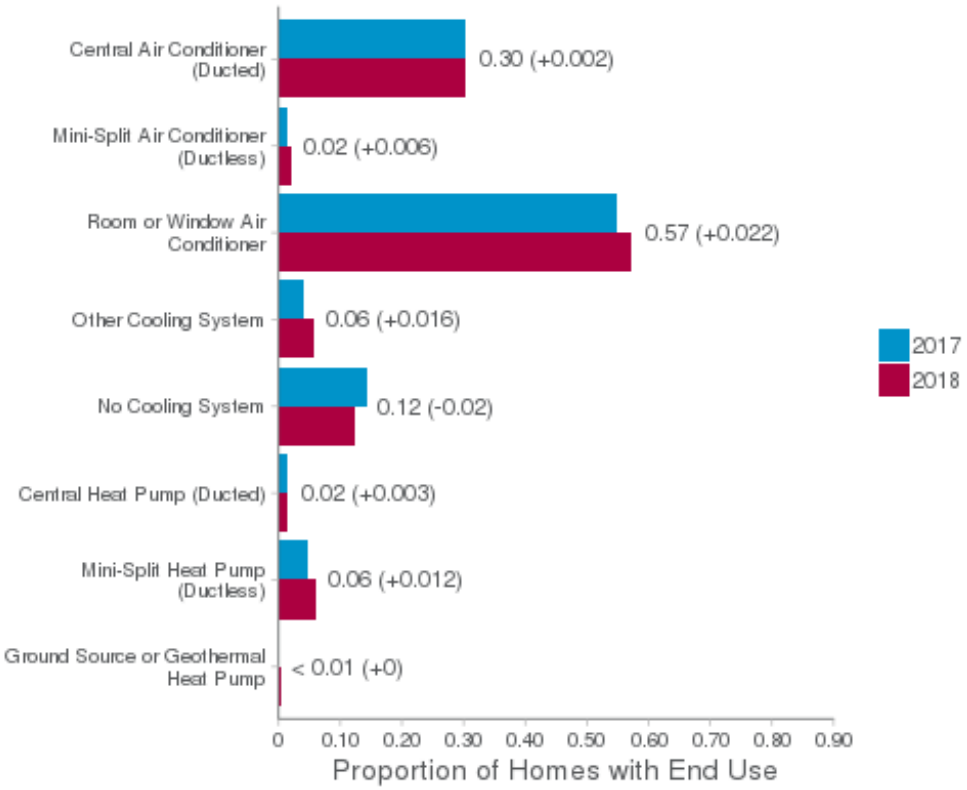
Sources: Navigant analysis, 2009 RASS

[10] The 2009 Residential Appliance Saturation Survey conducted by Opinion Dynamics can be found at http://ma-eeac.org/wordpress/wp-content/uploads/11_MA-Residential-Appliance-Saturation-Survey_Vol_1.pdf

The next several figures relate to the saturation, change in saturation, and characterization of new equipment for HVAC end uses starting with cooling season end uses, followed by heating season end uses, and finally for miscellaneous HVAC end uses.

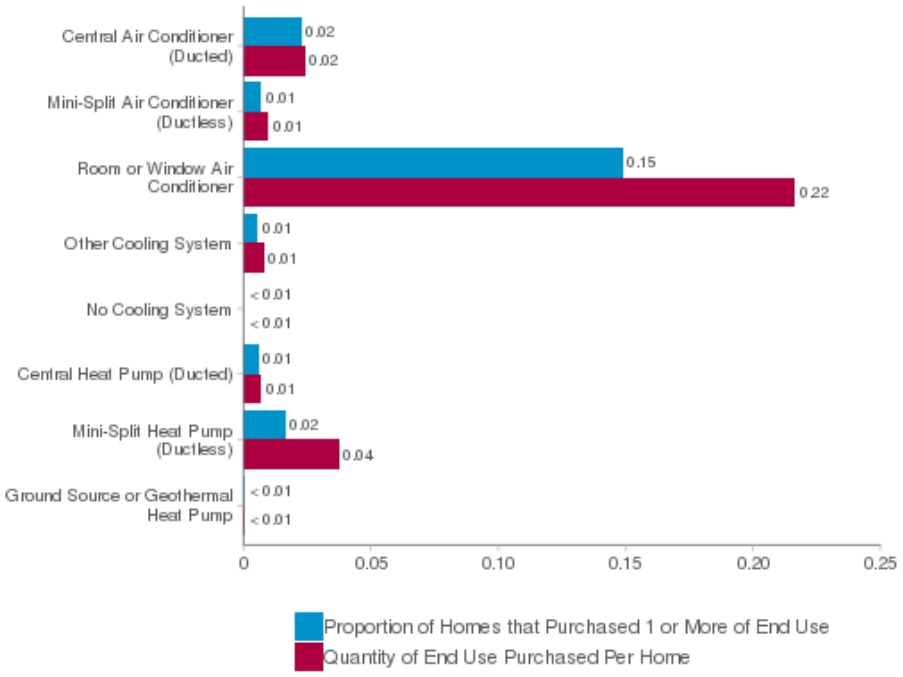
Figure A-1 shows the current saturation of cooling end uses with the red bar and the data label, as well as the change from the previous saturation in parentheses. The previous year's saturation is represented by the blue bar. Figure A-2 and Figure A-3 provide supporting documentation for the current saturations by showing the number of residents that purchased new equipment and the proportion of removed equipment in Massachusetts. Figure A-4, Figure A-5, and Figure A-6 are histograms of the new unit efficiencies for central ACs/HPs, mini-split AC/HPs, and room ACs, respectively. Because room ACs' standard efficiencies are variable, which makes the histogram of absolute efficiencies difficult to interpret, a histogram of new room AC efficiencies as a ratio of the relevant standard efficiency is included in Figure A-7.

Figure A-1. HVAC Cooling Equipment Saturation and Change in Saturation



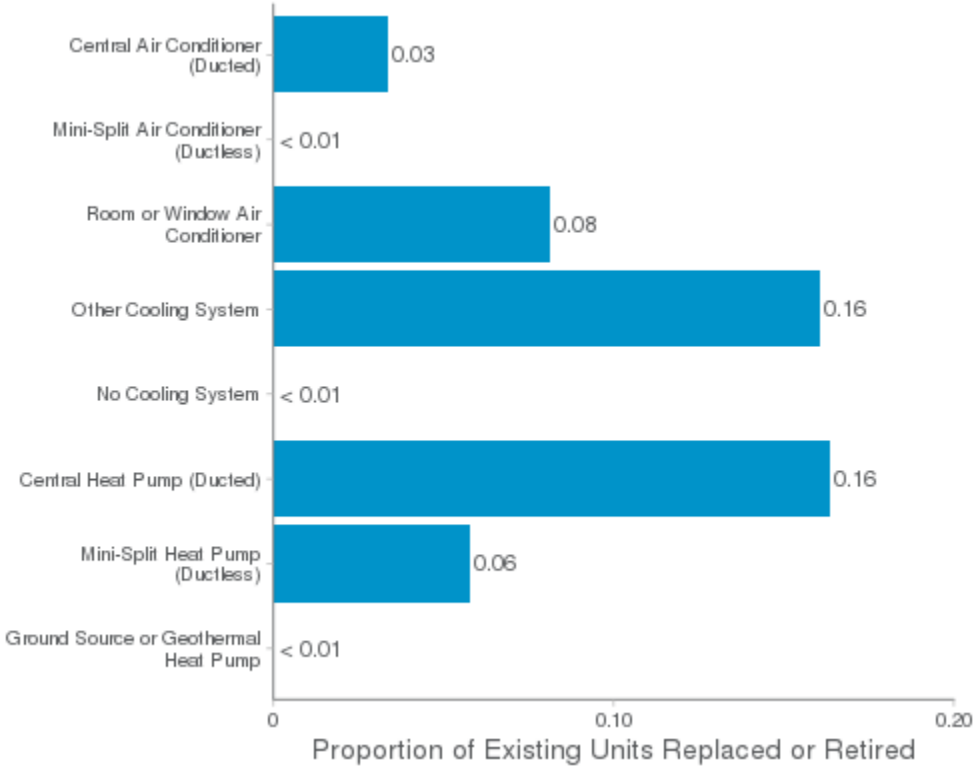
Source: Navigant analysis

Figure A-2. Proportion of Homes that Purchased Cooling Season HVAC End Uses in the Last Year



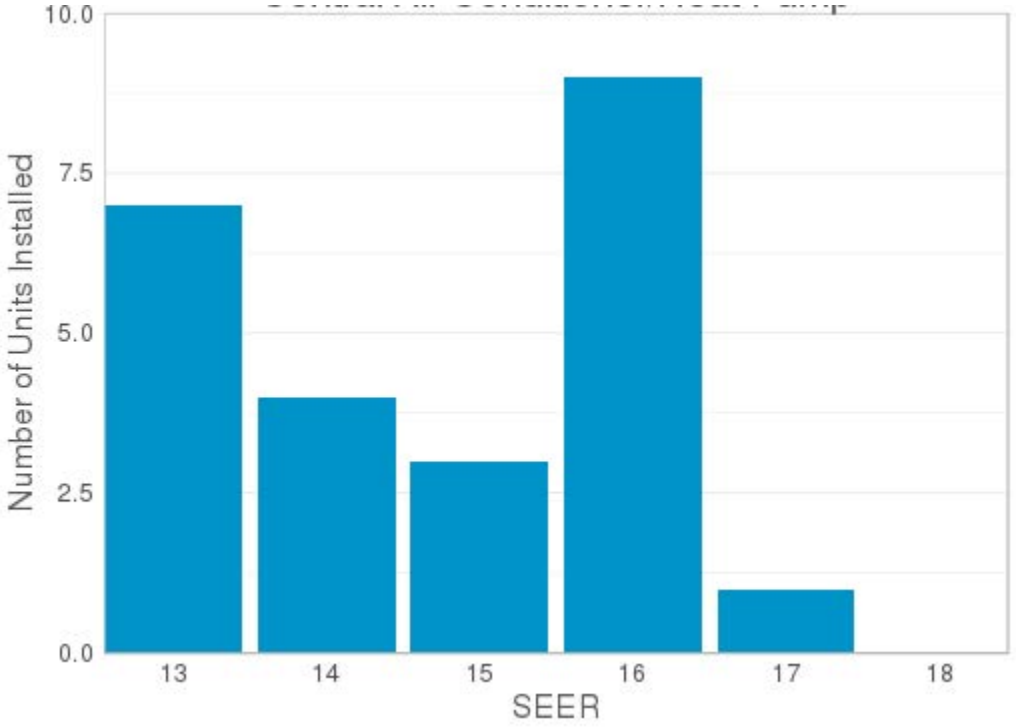
Source: Navigant analysis

Figure A-3. Proportion of Cooling Season HVAC End Uses Removed in the Last Year



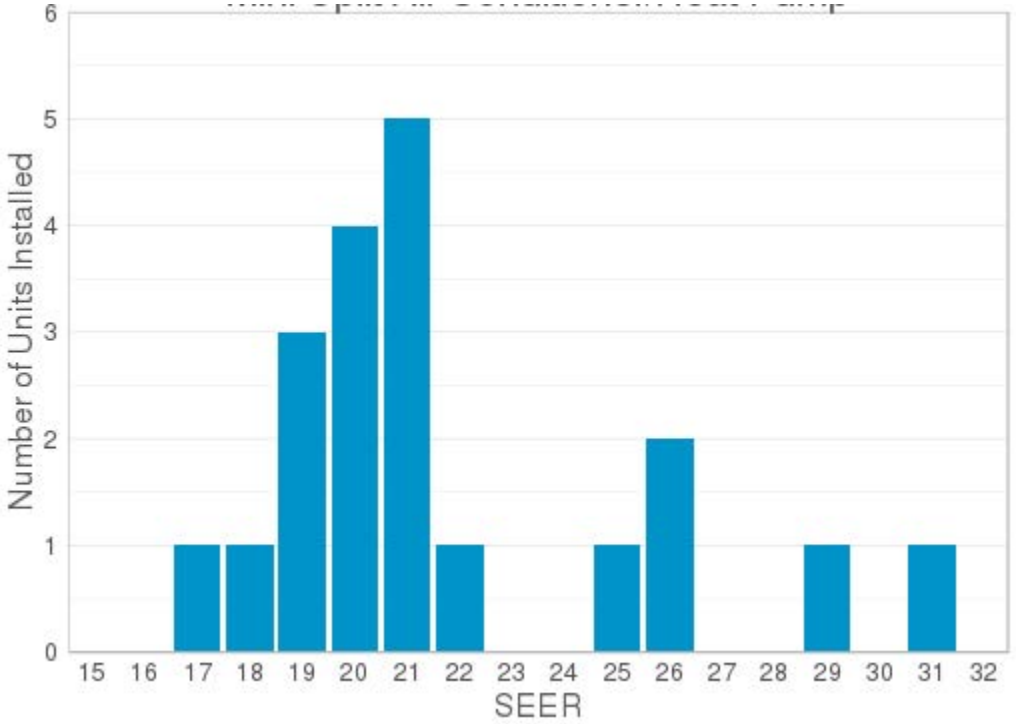
*Mortality rate is inversely proportional to effective useful life (EUL), e.g. EUL ~ 1/mortality rate.
Source: Navigant analysis

Figure A-4. Histogram of New Central Air Conditioner/Heat Pump Efficiencies



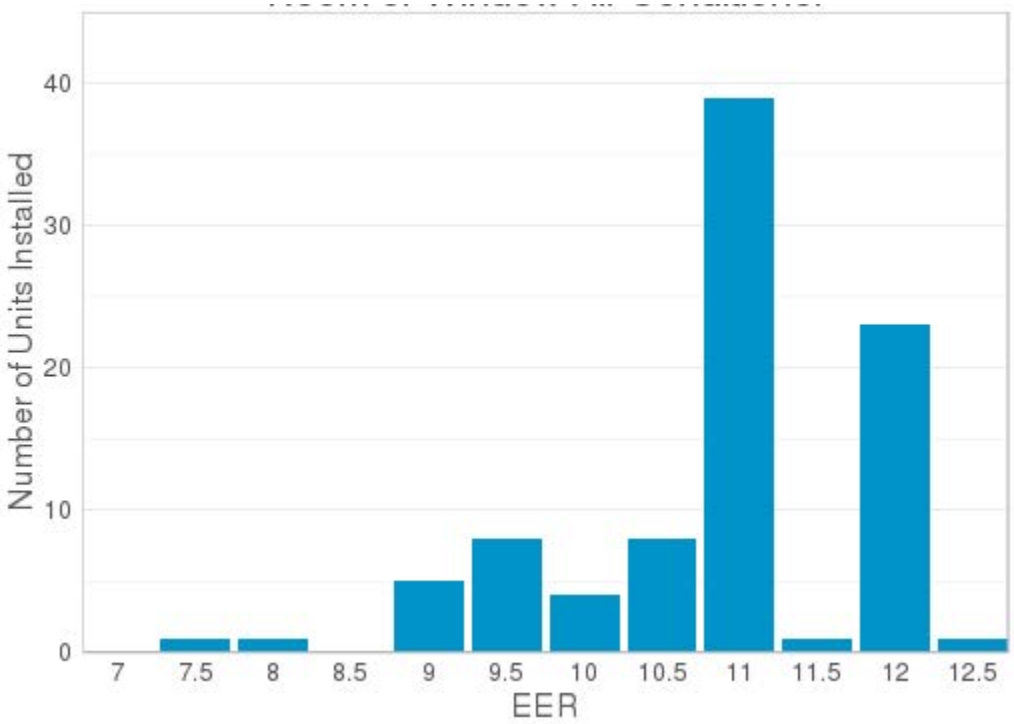
Source: Navigant analysis

Figure A-5. Histogram of Mini-Split Air Conditioner/Heat Pump Efficiencies



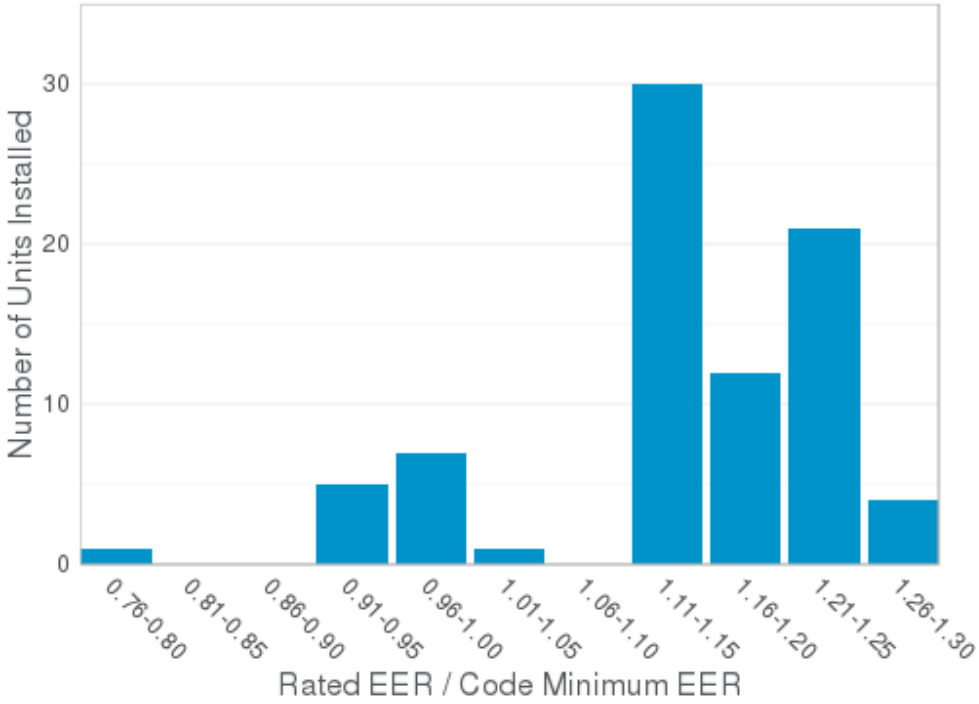
Source: Navigant analysis

Figure A-6. Histogram of New Room/Window Air Conditioner Efficiencies



Source: Navigant analysis

Figure A-7. Histogram of New Room/Window Air Conditioner Efficiencies as a Ratio of Standard Room AC Efficiency



Source: Navigant analysis

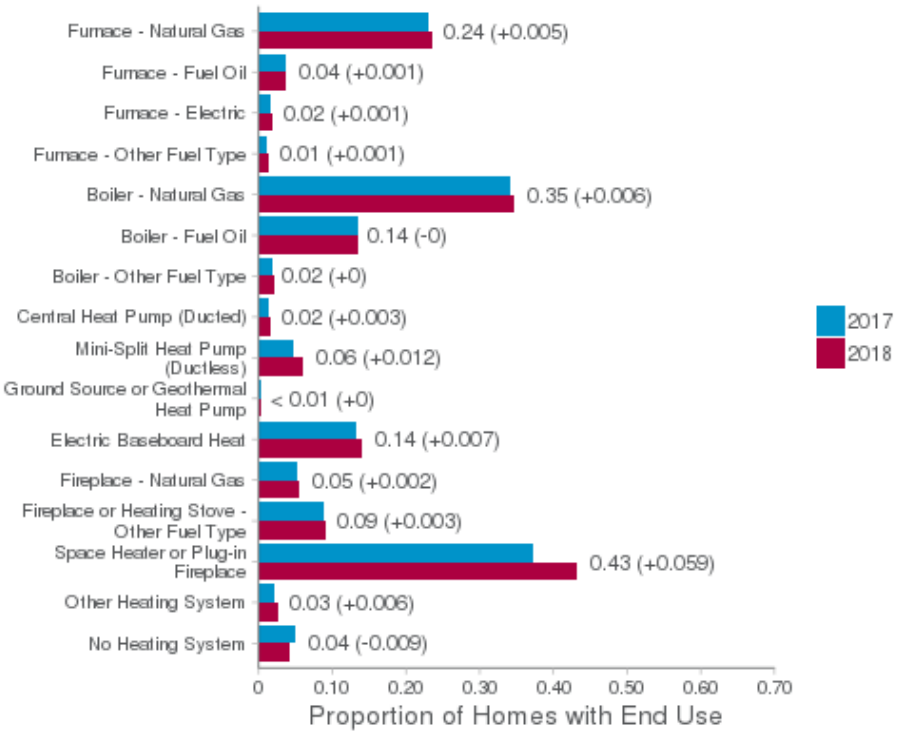
Key Finding: *Most new room ACs, central ACs, and ductless heat pumps are higher than code-minimum efficiency.*

Figure A-8 shows the current saturation of heating end uses with the red bar and the data label, as well as the change from the previous saturation in parentheses. The previous year's saturation is represented by the blue bar. Figure A-9 and Figure A-10 provide supporting documentation for the current saturations by showing the number of residences that purchased new equipment and the proportion of removed equipment in Massachusetts.

Figure A-11 is a histogram of the efficiencies of newly installed gas furnaces. The distribution is heavily skewed towards 95+ AFUE furnaces, which aligns with a general trend of furnace manufacturers focusing their condensing furnace product offerings on 95+ AFUE furnaces. This deserves further research.

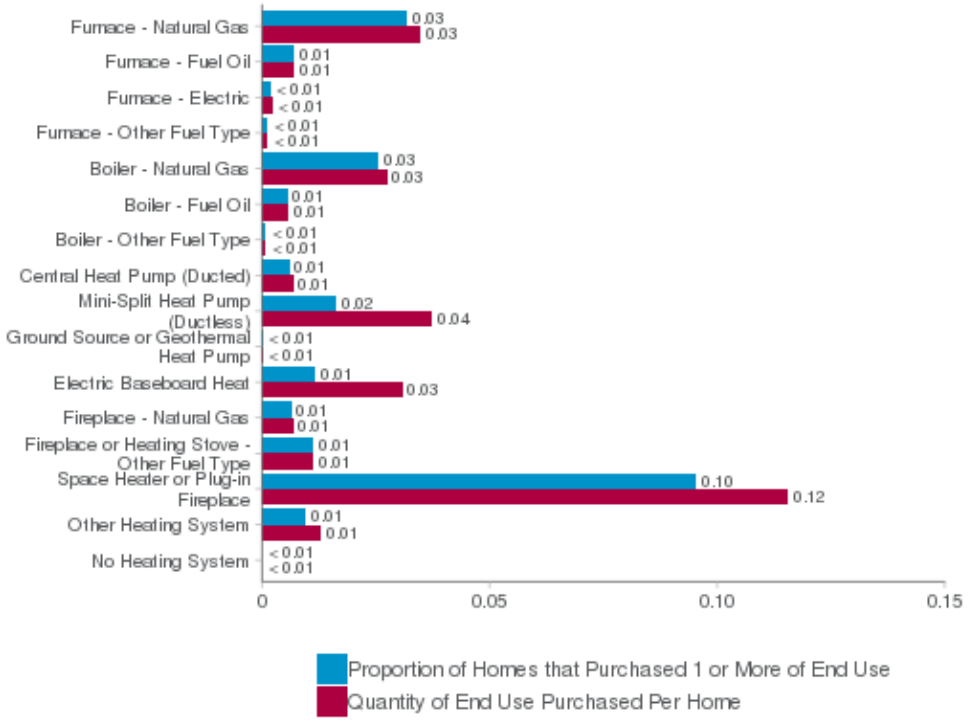
Figure A-13 and Figure A-14 show the number of residences that purchased new equipment and the proportion of removed equipment in the miscellaneous HVAC category.

Figure A-8. HVAC Heating Equipment Saturation and Change in Saturation



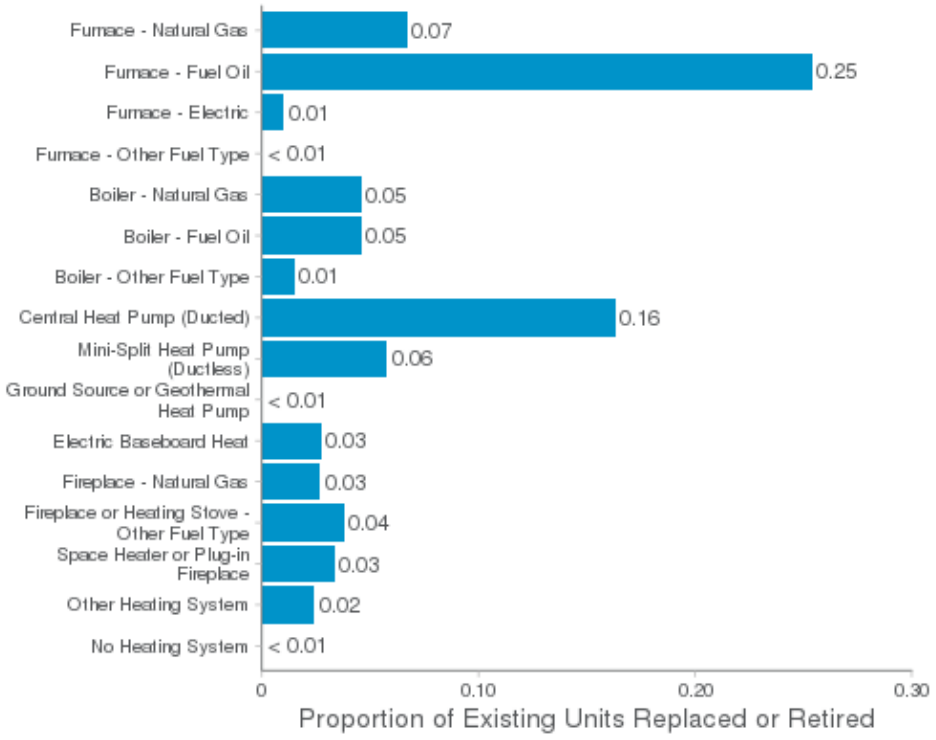
Source: Navigant analysis

Figure A-9. Proportion of Homes that Purchased Heating Season HVAC End Uses in the Last Year



Source: Navigant analysis

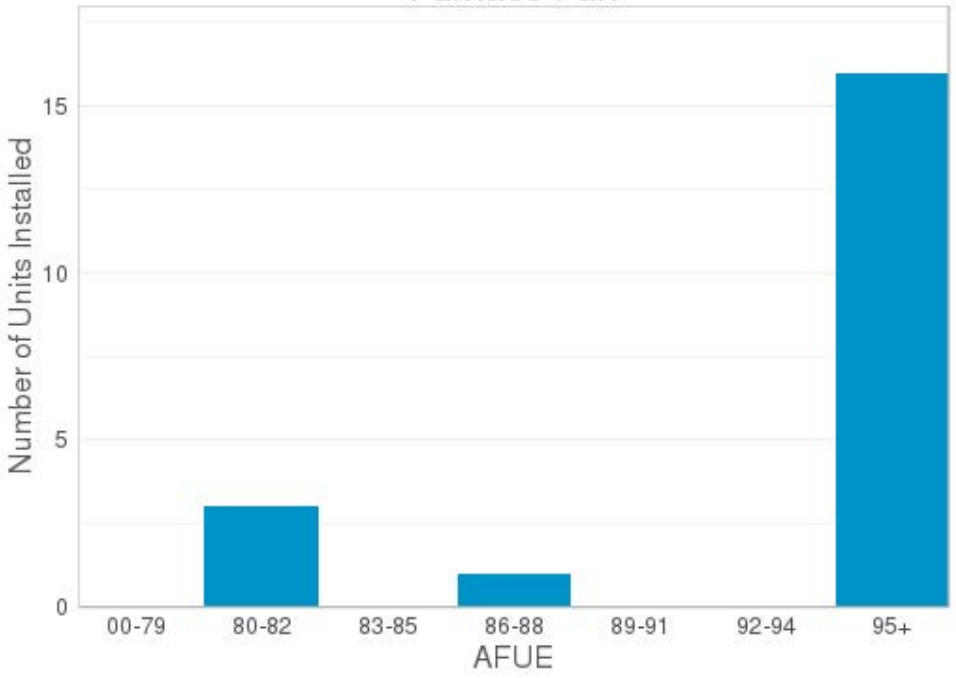
Figure A-10. Proportion of Heating Season HVAC End Uses Removed in the Last Year



*Mortality rate is inversely proportional to effective useful life (EUL), e.g. EUL ~ 1/mortality rate.

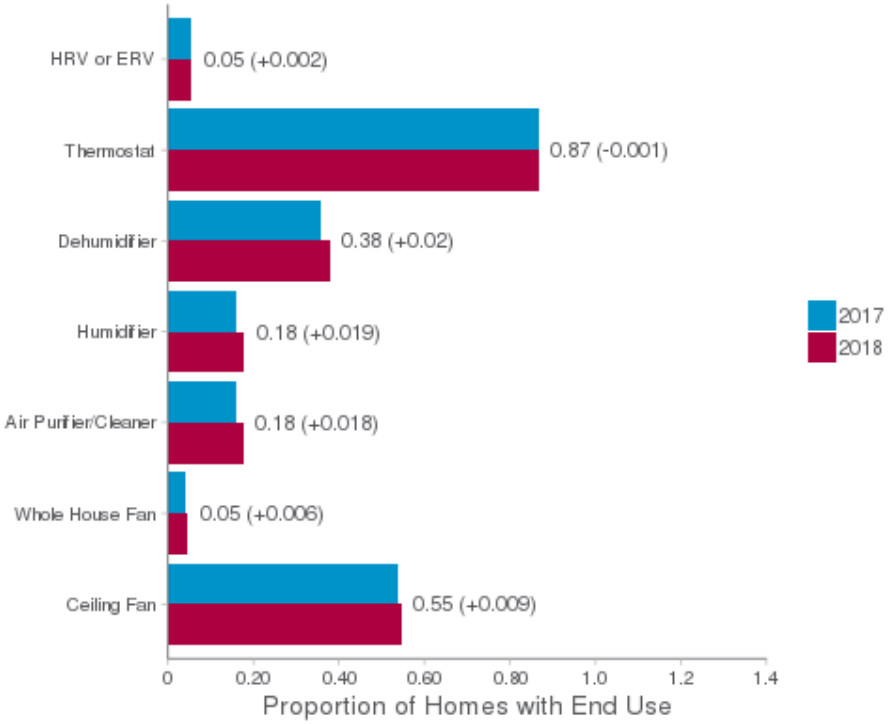
Source: Navigant analysis

Figure A-11. Histogram of New Furnace Efficiencies



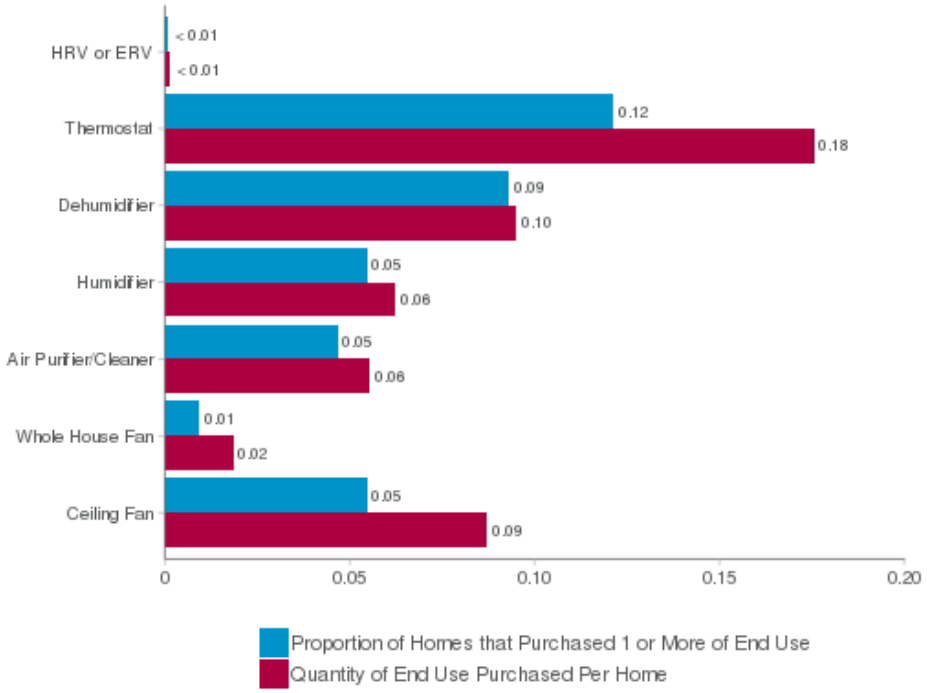
Source: Navigant analysis

Figure A-12. Miscellaneous HVAC Equipment Saturation and Change in Saturation



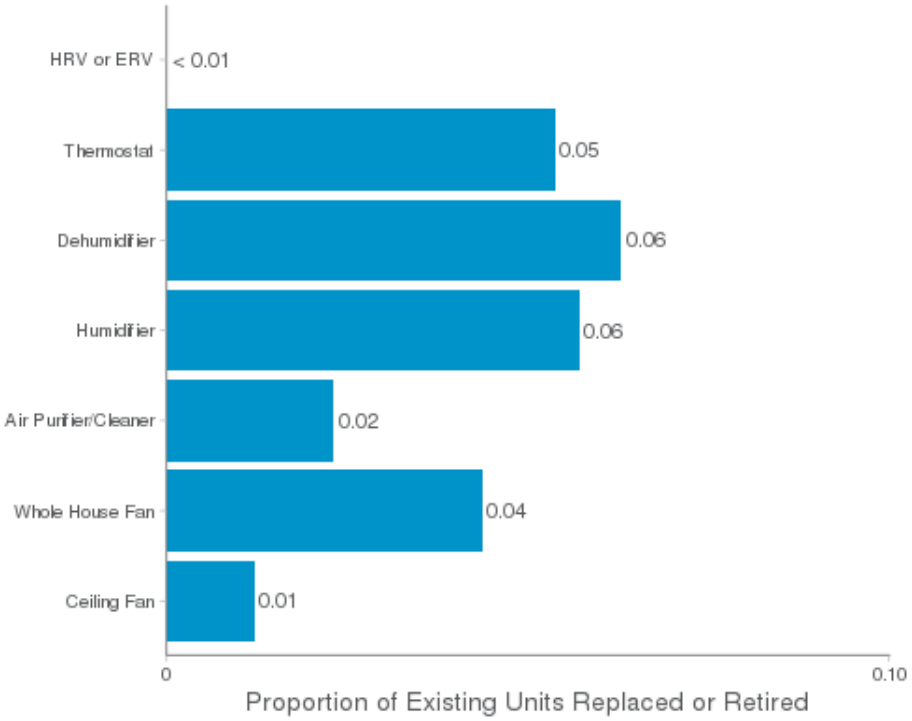
Source: Navigant analysis

Figure A-13. Proportion of Homes that Purchased New Miscellaneous HVAC Equipment in the Last Year



Source: Navigant analysis

Figure A-14. Proportion of Miscellaneous HVAC End Uses Removed in the Last Year

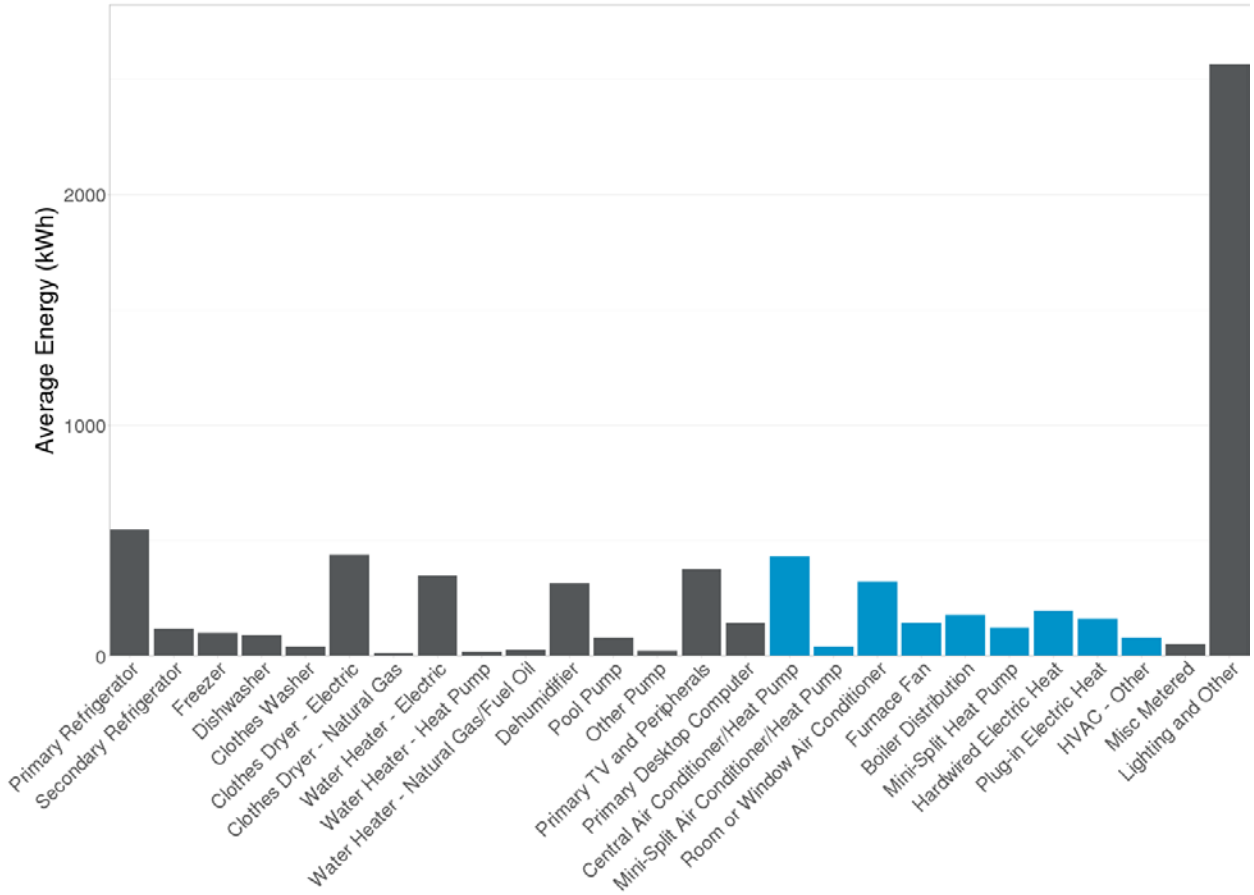


*Mortality rate is inversely proportional to effective useful life (EUL), e.g. EUL ~ 1/mortality rate.

Source: Navigant analysis

Figure A-15 shows the average energy consumption for all end uses; the HVAC end uses are highlighted in blue. As shown in the figure, central AC and room AC are the two largest individual HVAC end uses and are in a similar usage category as primary refrigerators, electric clothes dryers, electric water heaters, dehumidifiers, and primary TVs and their peripherals. Central AC and room AC are each larger than any single heating end use.

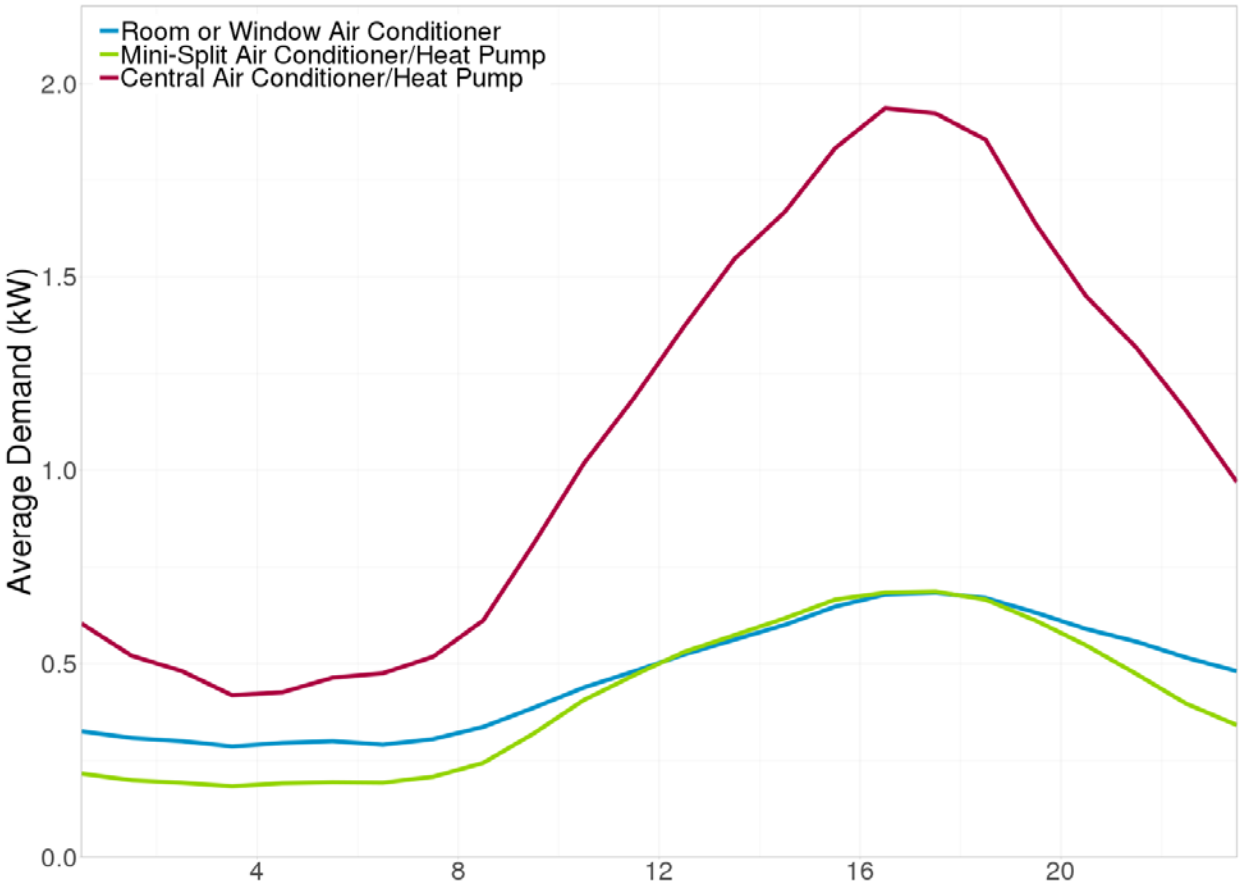
Figure A-15. Population Annual End Use Energy Consumption – HVAC End Uses



Source: Navigant analysis

Cooling season HVAC end uses are the primary driver of summer peak loads. As shown in Figure A-16, central AC demand peaks between 3 p.m. and 7 p.m. on the hottest days. Room AC demand per household is much lower and extends later than central AC load.

Figure A-16. Weather-Normalized Summer Peak Day HVAC End Use Load Shapes for Homes with End Use

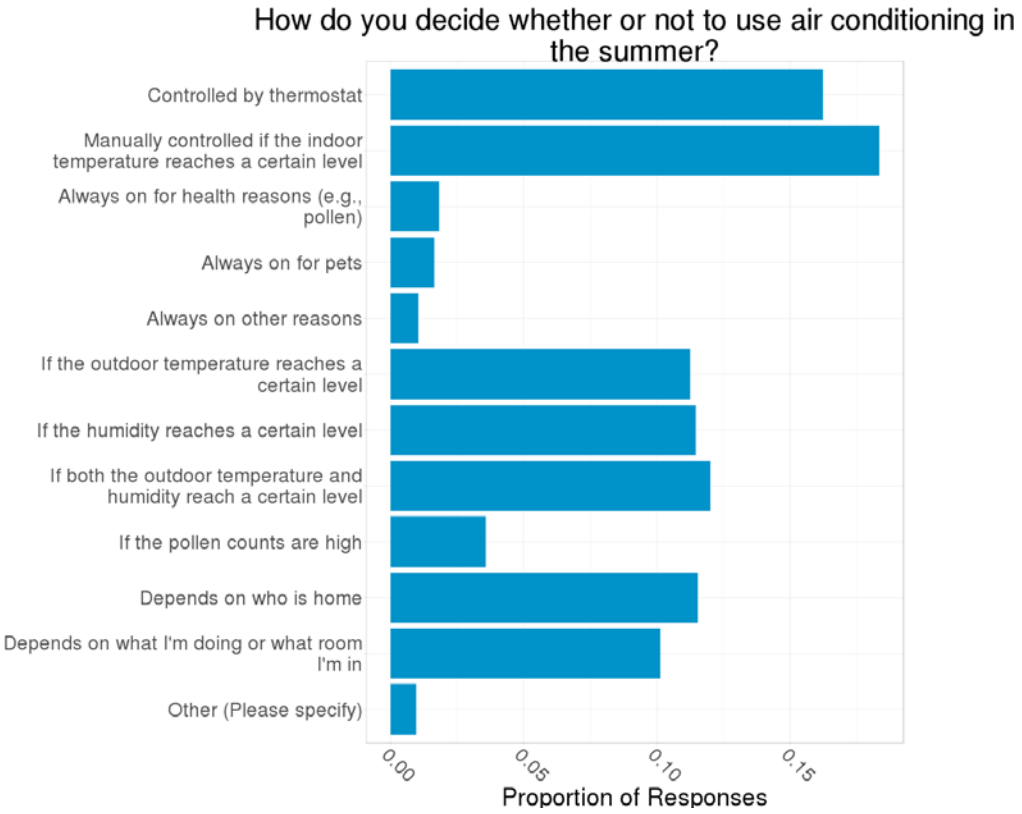


Source: Navigant analysis

Key Finding: *Central ACs are the single most important end use driving summer peak demand. The central AC peak load is greater than the total peak load for households without central AC.*

Figure A-17 demonstrates the wide variety of motivations driving central AC use. This suggests that attempts to change AC behavior on peak days may need to use a variety of tailored messaging to get the desired effect.

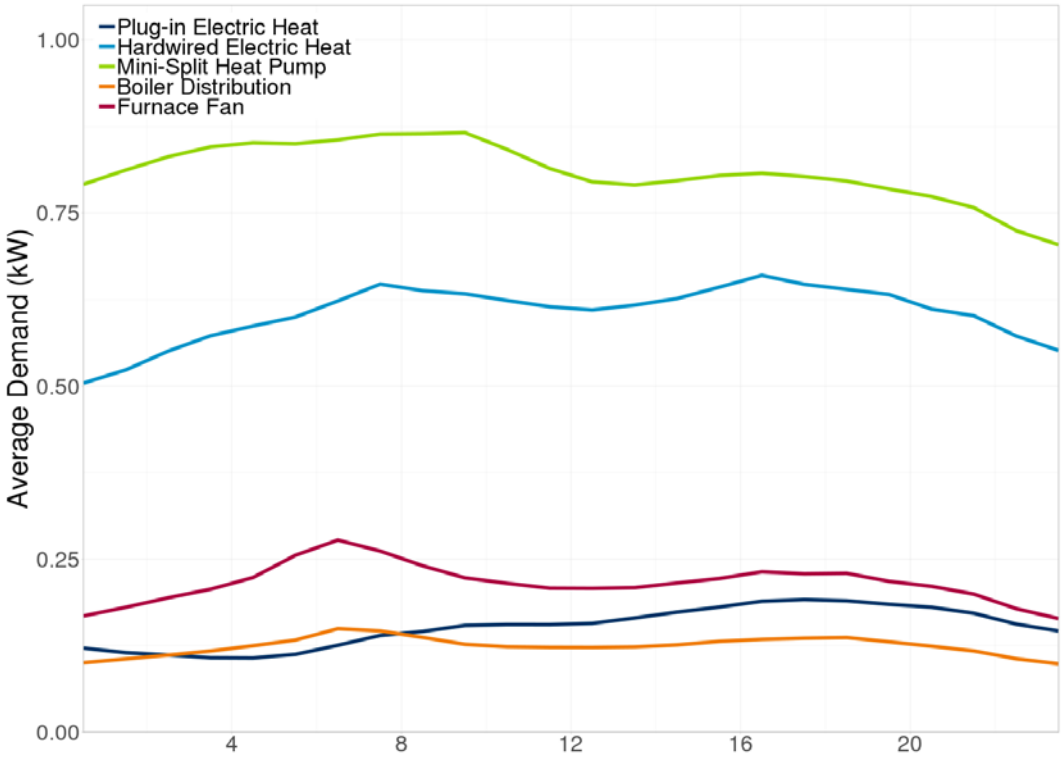
Figure A-17. Cooling System Use Motivation



Source: Navigant analysis

As shown in Figure A-18, during the winter, hardwired electric heat and mini-split HPs are the two end uses with the highest demand in households where they are present. The hardwired electric heat peak day load shape is surprisingly flat compared to existing electric heat load shapes available in the literature, such as those from simulation tools that follow a setback schedule.

Figure A-18. Weather-Normalized Winter Peak Day HVAC End Use Load Shapes for Homes with End Use

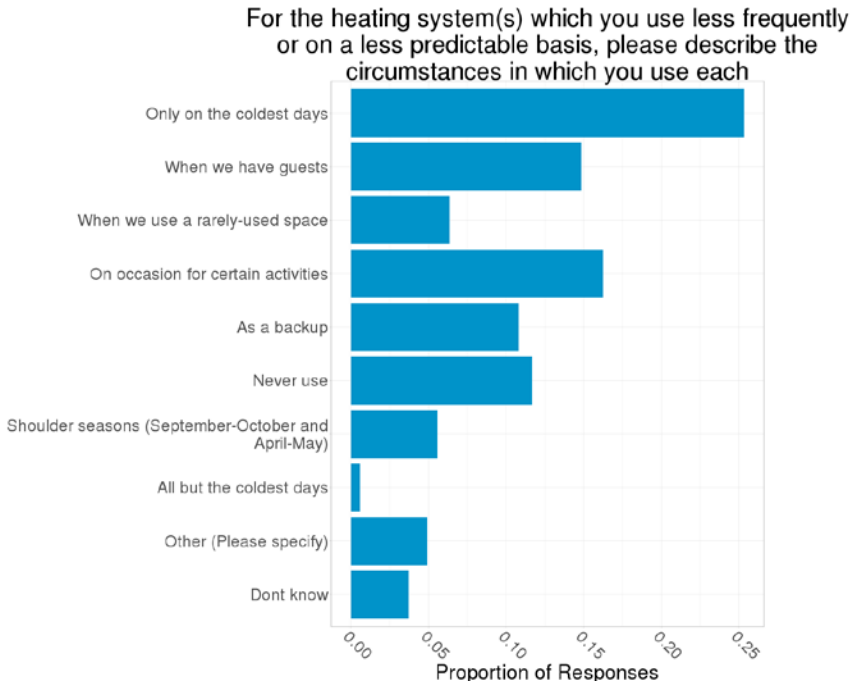


Source: Navigant analysis

Key Finding: *Winter peak day load shapes for heating end uses are flatter than other HVAC load shapes.*

Figure A-19 shows what drives the use of secondary heat, which may be what is driving the flat load shape for electric heat. Over one-third of people report using their secondary heating systems only on the coldest days or for backup heat. This is consistent with the observed trend (the hourly load shape is relatively flat), but usage on the coldest days is much higher than on other days during the winter.

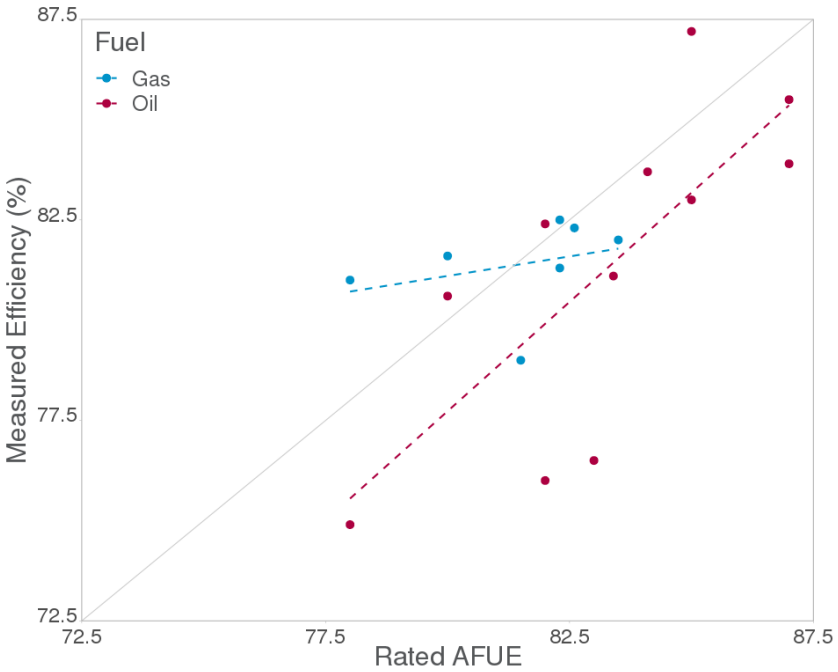
Figure A-19. Secondary Heating Use Motivation



Source: Navigant analysis

Figure A-20 compares measured and rated efficiency for gas and oil boilers. The small sample of equipment measured does not provide statistically significant results; however, the trend in the data indicates that oil-fired boilers operate roughly 2% less efficient than their rating.

Figure A-20. Rated vs. Measured Boiler Efficiency



Source: Navigant analysis

A.1.2 Kitchen End Uses

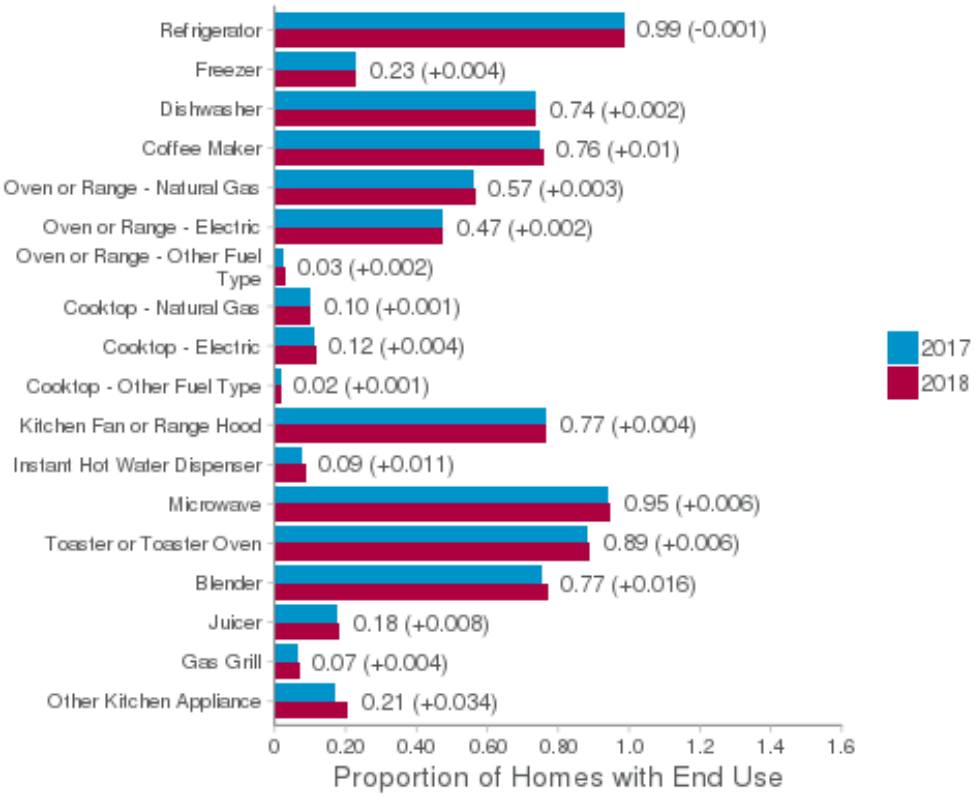
Since the 2009 RASS was conducted, there has been modest increases in freezer and secondary refrigerator saturation, as shown in Table A-3. Figure A-21 shows the updated saturation and change in saturation from 1 year ago for all kitchen end uses.

Table A-3. RASS Comparison – Kitchen Appliances

End Use	All Homes		Single-Family Detached	
	2009 RASS Saturation	2018 Baseline Study Saturation	2009 RASS Saturation	2018 Baseline Study Saturation
Microwave	0.95	0.95	0.97	0.97
Dishwasher	0.71	0.74	0.77	0.84
Primary Refrigerator	1.00	0.99	1.00	0.99
Freezer	0.13	0.23	0.17	0.27
Secondary Refrigerator	0.28	0.30	0.35	0.40

Sources: Navigant analysis, 2009 RASS

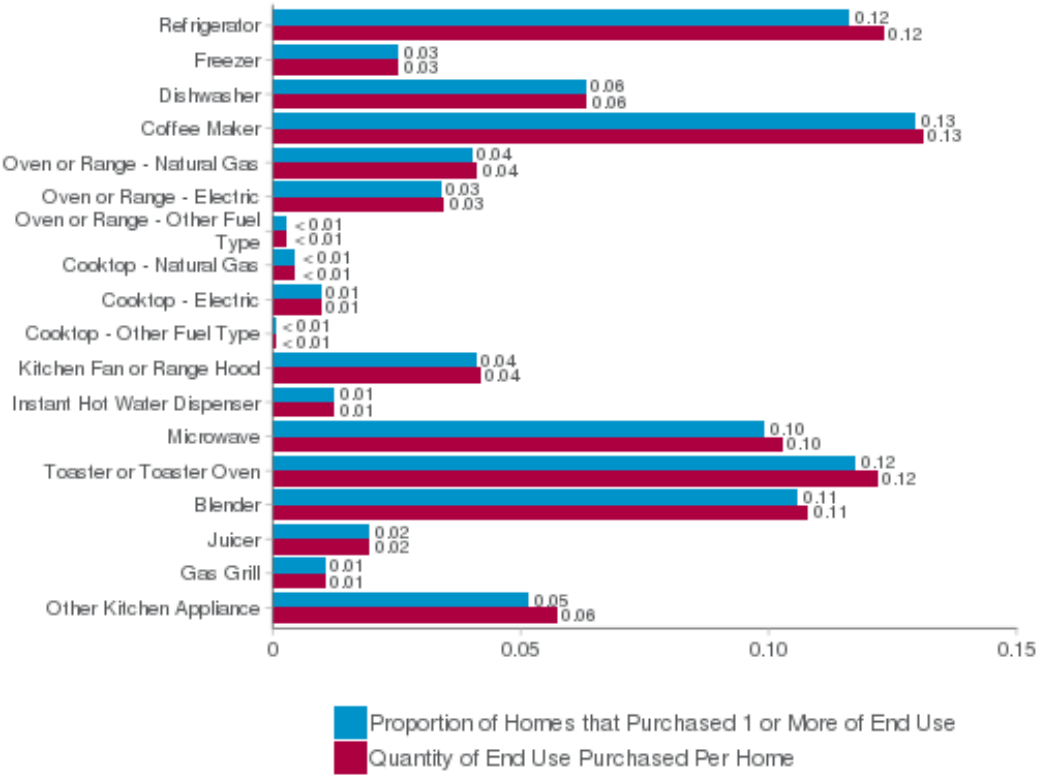
Figure A-21. Kitchen End Use Saturation and Change in Saturation



Source: Navigant analysis

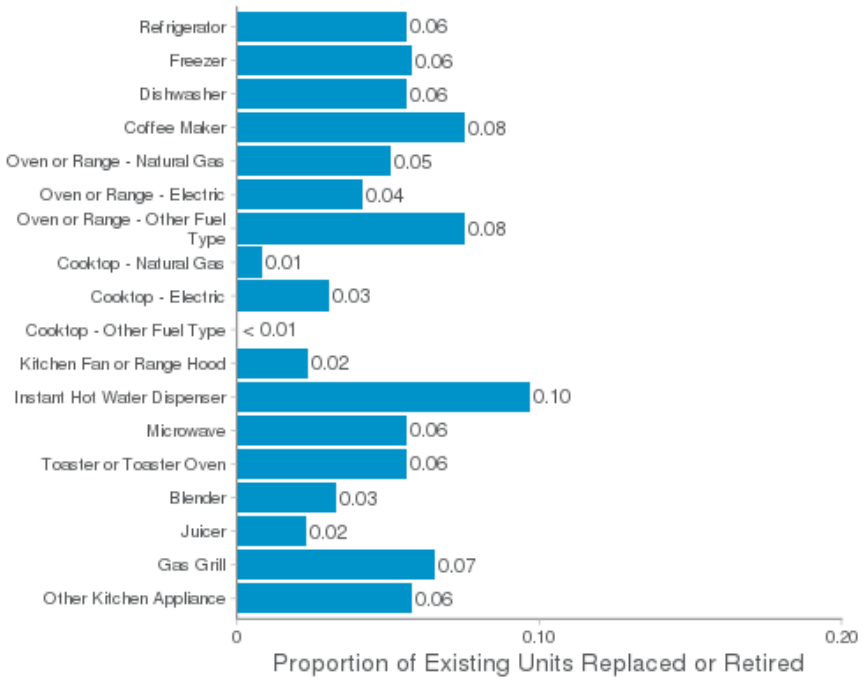
Figure A-22 and Figure A-23 show the proportion of homes that purchased new kitchen equipment in the last year and the proportion of removed kitchen end uses in the last year, respectively. This information supports the change in saturations shown above.

Figure A-22. Proportion of Homes that Purchased New Kitchen End Uses in the Last Year



Source: Navigant analysis

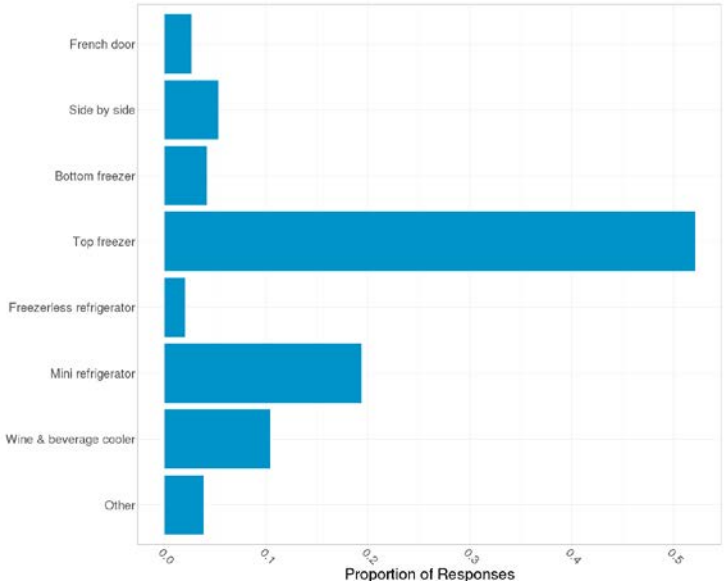
Figure A-23. Proportion of Kitchen End Uses Removed in the Last Year



*Mortality rate is inversely proportional to effective useful life (EUL), e.g. EUL ~ 1/mortality rate.
Source: Navigant analysis

Figure A-24 shows the characterization of secondary refrigerator types according to the initial survey that was administered in 2017.

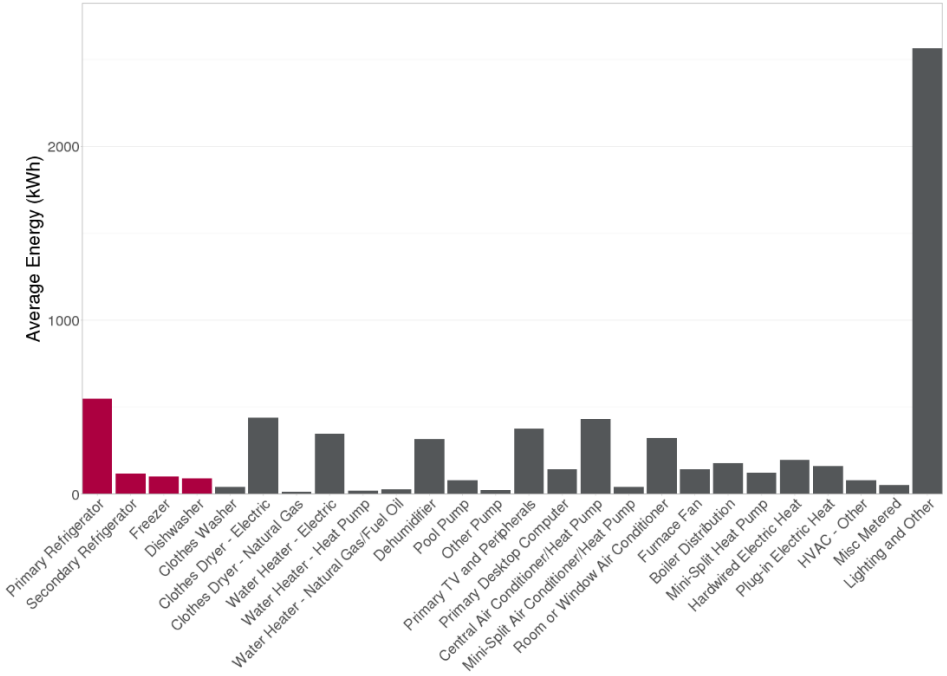
Figure A-24. Secondary Refrigerator Types



Source: Navigant analysis

Because refrigerators are in almost every home and in use constantly, they are the largest non-lighting energy end use when compared with all metered end uses in Figure A-25.

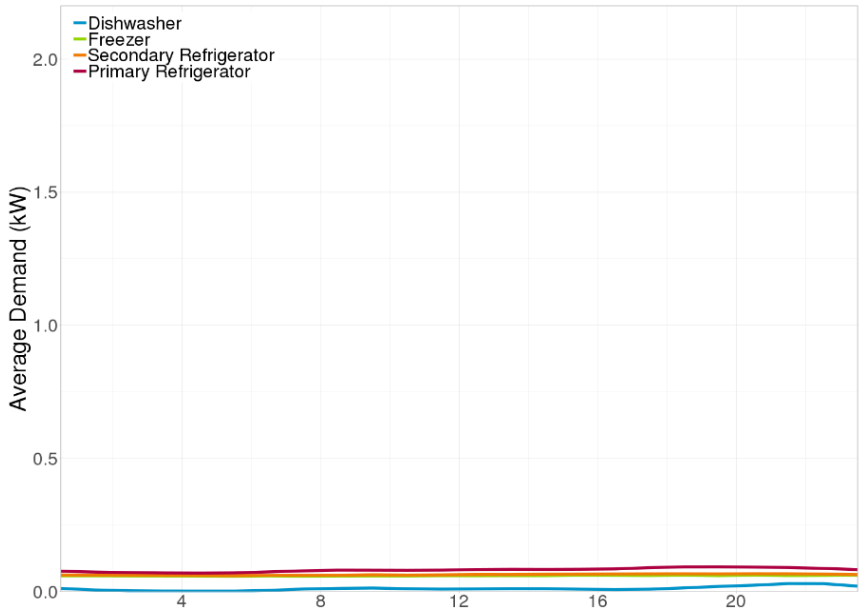
Figure A-25. Population Annual End Use Energy Consumption – Kitchen End Uses



Source: Navigant analysis

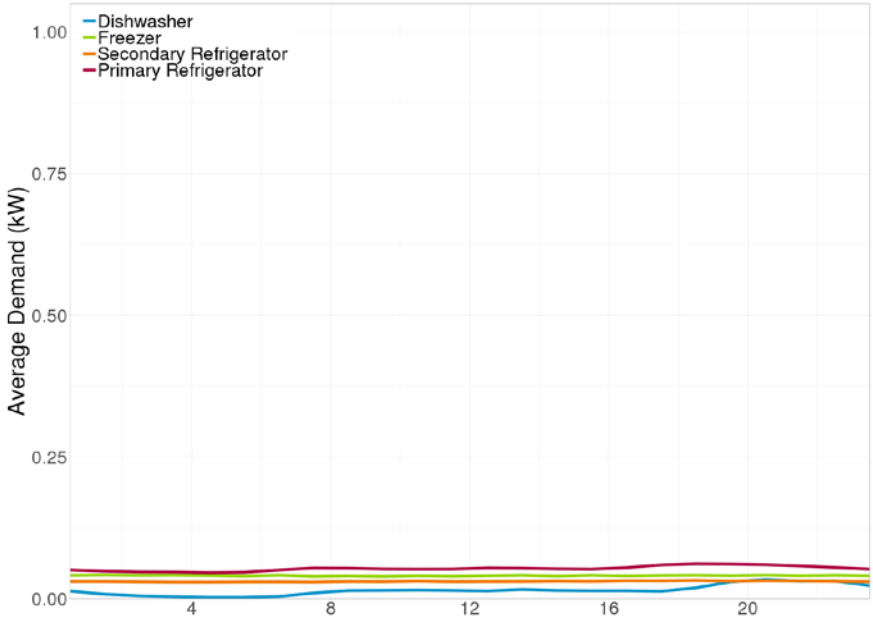
Figure A-26 and Figure A-27 appear to be almost blank because dishwashers, primary refrigerators, secondary refrigerators, and freezers have low peak demands compared with central ACs and other large peak loads. The consumption magnitude for kitchen end uses is nearly the same for summer and winter, showing limited seasonality.

Figure A-26. Weather-Normalized Summer Peak Day Kitchen Load Shapes for Homes with End Use



Source: Navigant analysis

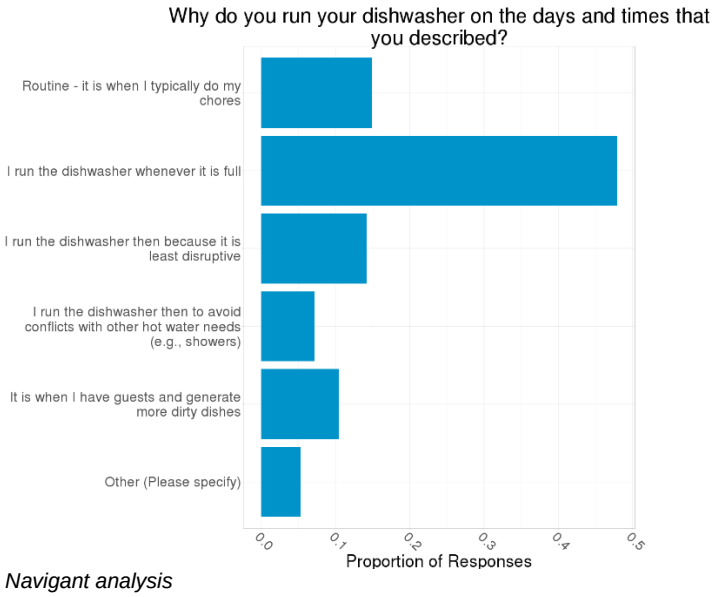
Figure A-27. Weather-Normalized Winter Peak Day Kitchen Load Shapes for Homes with End Use



Source: Navigant analysis

Figure A-28 confirms what the flatness of the load shapes in Figure A-26 and Figure A-27 show—there are not typical schedules for running dishwashers in Massachusetts households.

Figure A-28. Dishwasher Use



Source: Navigant analysis

Key Finding: *Kitchen end uses add no significant summer or winter peak load to the system, but the energy consumption of refrigerators is significant across the entire population because of their high saturation.*

A.1.3 Laundry End Uses

Table A-4 shows that not all single-family detached homes have individual laundry equipment. Differences in question wording and population may explain part of the apparent decline in laundry equipment saturation.

Table A-4. RASS Comparison – Laundry

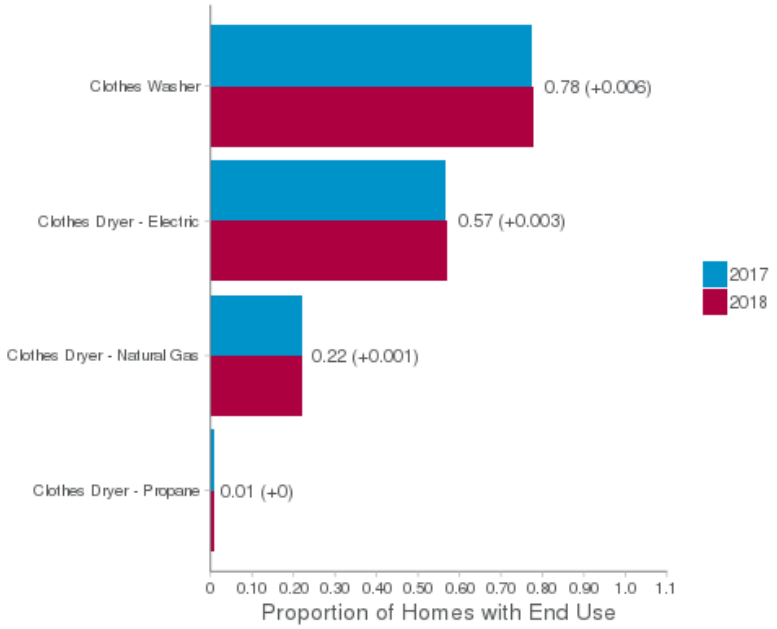
End Use	All Homes		Single-Family Detached	
	2009 RASS Saturation	2018 Baseline Study Saturation	2009 RASS Saturation	2018 Baseline Study Saturation
Clothes Washer (Private Use)	86%	78%	94%	98%
Clothes Dryer (Private Use)*	83%	75%	93%	95%

*Includes electric, natural gas, and propane clothes dryers.

Sources: Navigant analysis, 2009 RASS

Figure A-29 shows the distribution of laundry equipment in Massachusetts homes. Electric dryers are in half of homes and natural gas is the leading dryer fuel in the remaining homes with dryers.

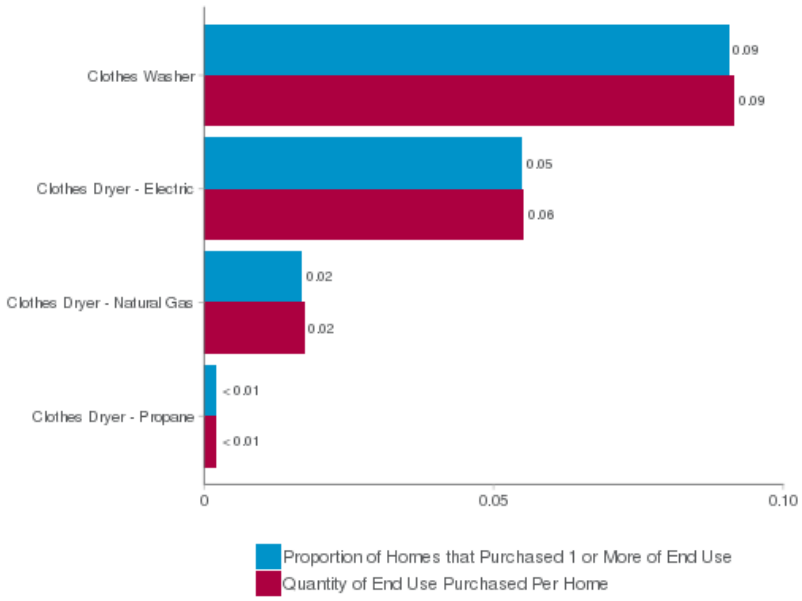
Figure A-29. Laundry End Use Saturation and Change in Saturation



Source: Navigant analysis

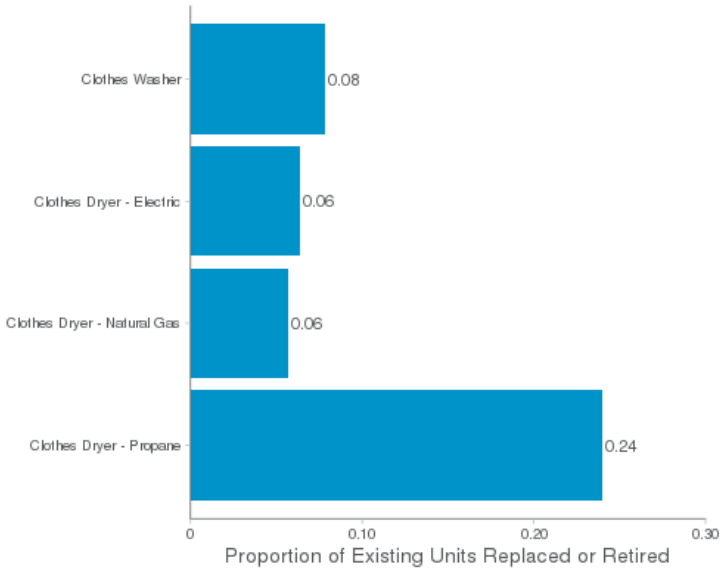
Figure A-30 and Figure A-31 support the change in saturation findings by showing the proportion of homes that purchased new laundry equipment and the proportion of removed laundry equipment in the last year, respectively.

Figure A-30. Proportion of Homes that Purchased New Laundry Equipment in the Last Year



Source: Navigant analysis

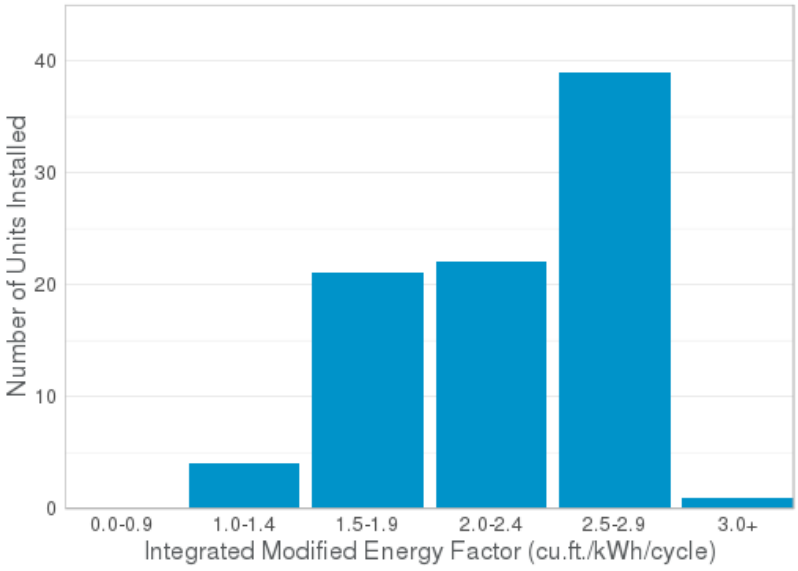
Figure A-31. Proportion of Laundry End Uses Removed in the Last Year



*Mortality rate is inversely proportional to effective useful life (EUL), e.g. EUL ~ 1/mortality rate.
Source: Navigant analysis

Figure A-32 is a histogram of efficiencies for newly installed clothes washers in Massachusetts, which illustrates that most new washers purchased are higher efficiency than the federal standard.

Figure A-32. New Clothes Washer Efficiencies

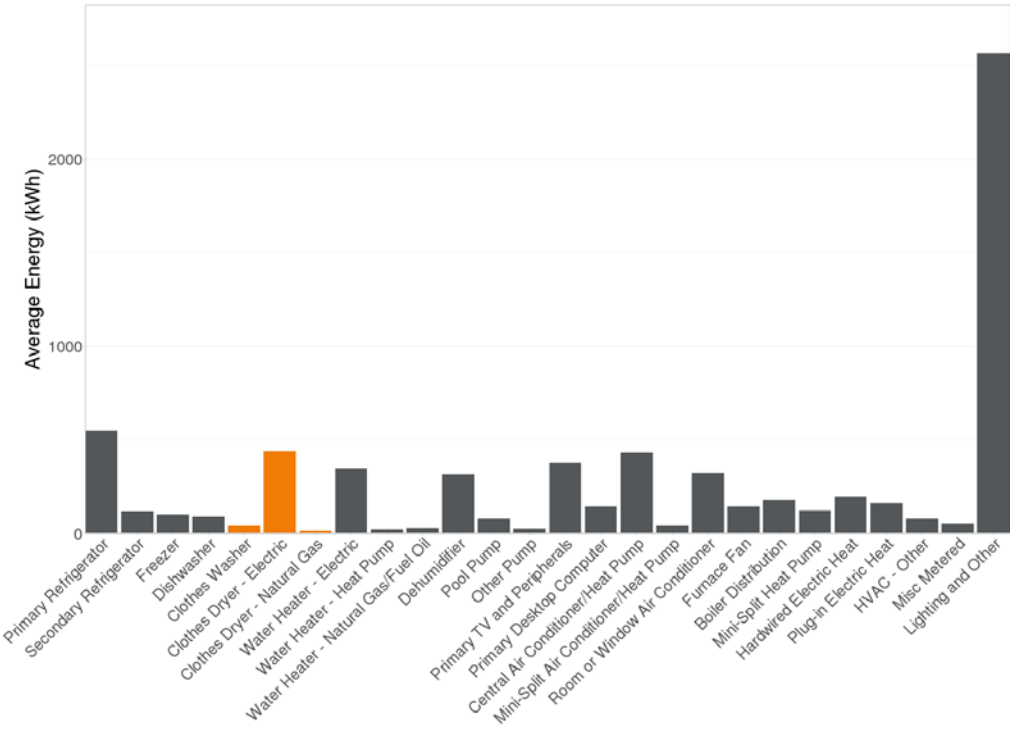


Source: Navigant analysis

***Key Finding:** Most newly purchased clothes washers in Massachusetts are higher than standard efficiency. These savings most likely show up in the clothes dryer load shape.*

Figure A-33 compares laundry end use consumption to energy consumption for all end uses. While clothes dryers have significant energy consumption (fourth largest of all end uses) and clothes washers appear to be low consumers, the energy saved by high efficiency clothes washers shows up primarily as reduced clothes dryer energy consumption and secondarily as reduced water heating consumption. Therefore, the savings potential for clothes dryers should be considered in conjunction with high efficiency clothes washers.

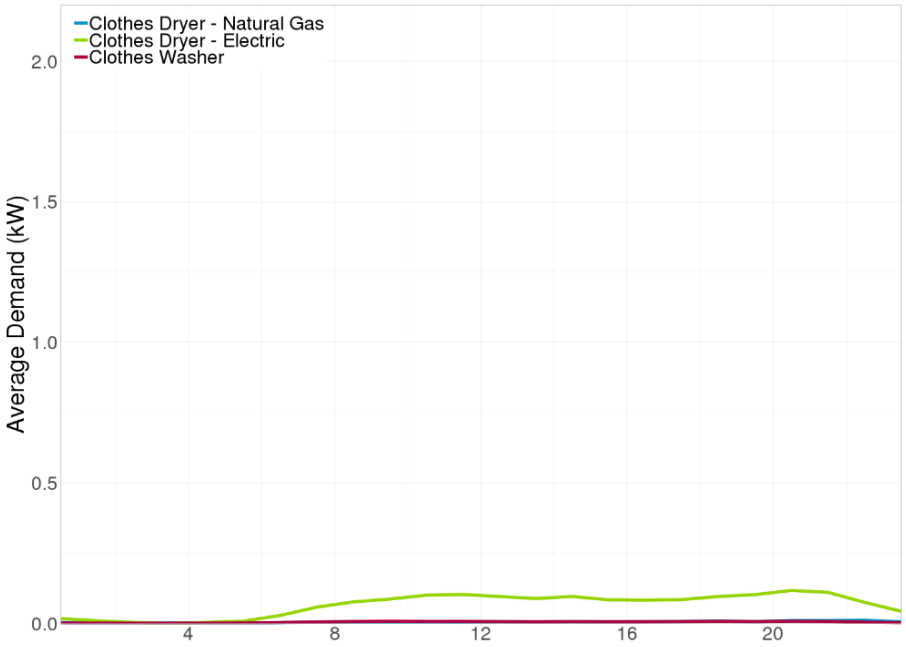
Figure A-33. Population Annual End Use Energy Consumption – Laundry End Uses (kWh)



Source: Navigant analysis

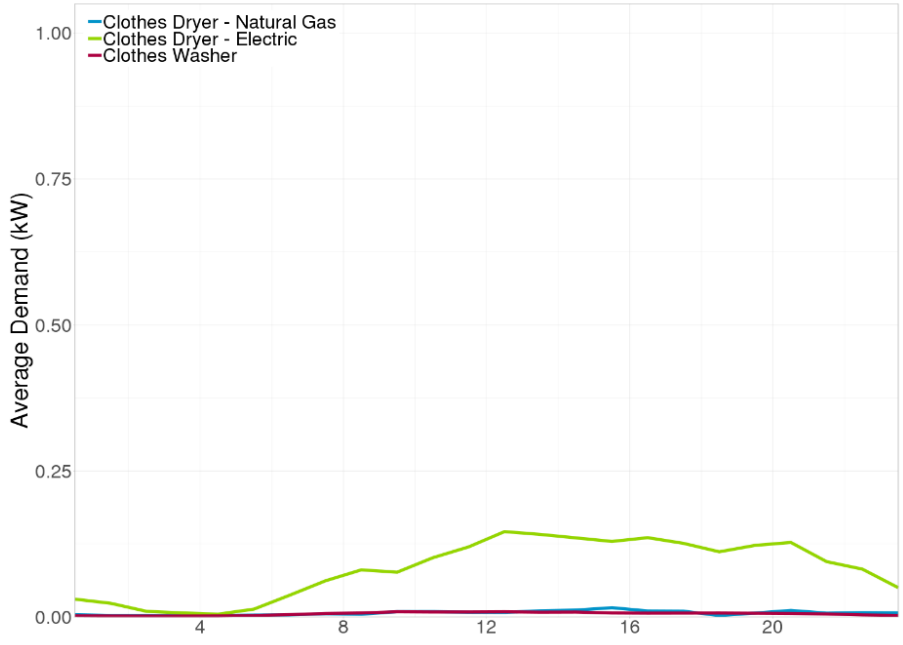
Figure A-34 and Figure A-35 show that while clothes dryer use peaks late in the day on summer peak days, there is some use throughout the day in all seasons. The other laundry end uses have near zero demand. Figure A-36 helps to explain why this is the case—because there is no single time of day that most washers and dryers are running in Massachusetts.

Figure A-34. Weather-Normalized Summer Peak Day Laundry Load Shapes for Homes with End Use



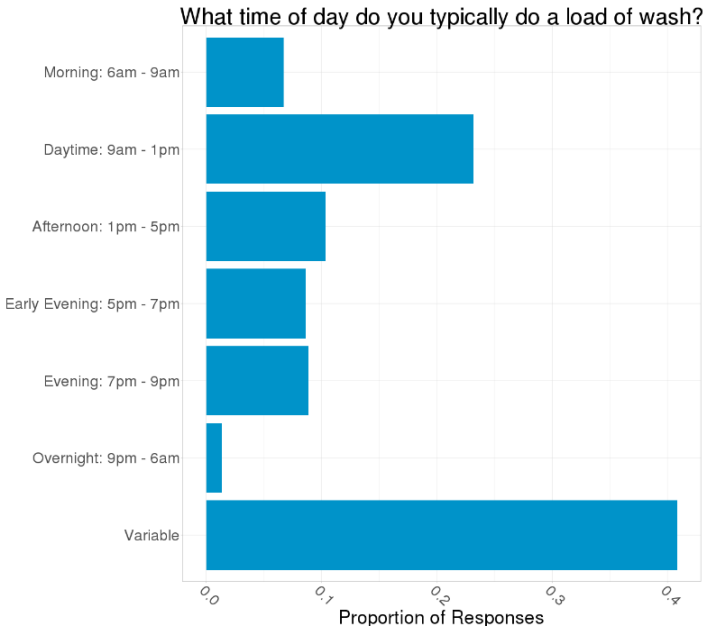
Source: Navigant analysis

Figure A-35. Weather-Normalized Winter Peak Day Laundry Load Shapes for Homes with End Use



Source: Navigant analysis

Figure A-36. Laundry Use Motivation



Source: Navigant analysis

Key Finding: *Some clothes dryers are used throughout the day, including during afternoon and evening peak in summer and winter, but there is no single time that dominates most clothes washer and dryer use.*

A.1.4 Water Heating End Uses

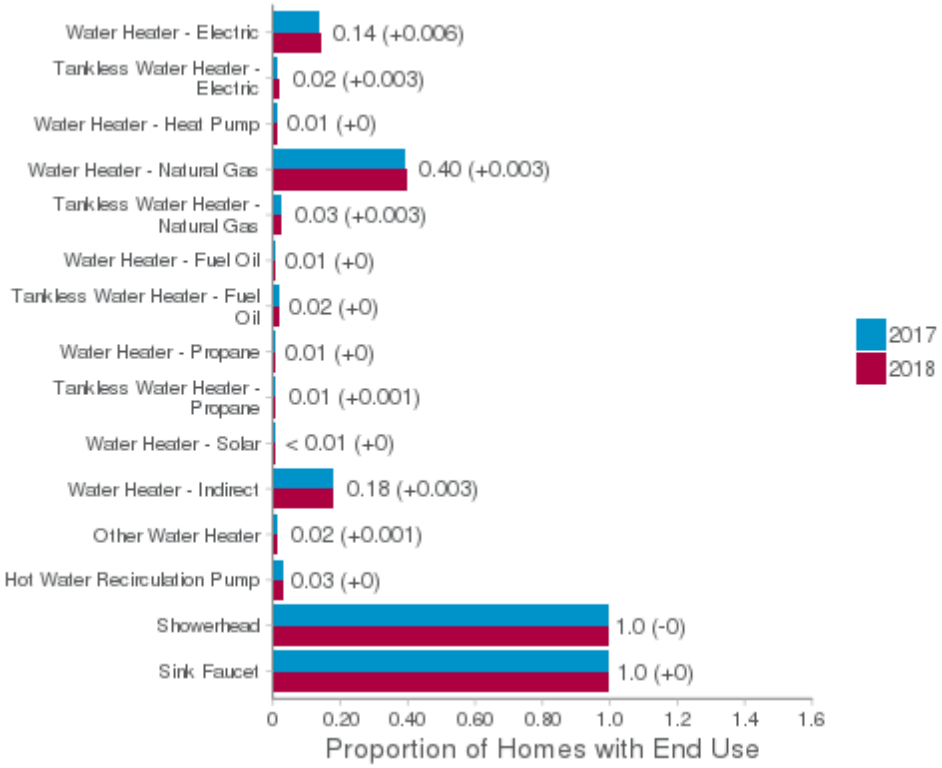
Table A-5 shows the comparison between the 2009 RASS and the 2018 Residential Baseline Study saturation results for water heating end uses. Figure A-37 shows the saturation and change in saturation of water heating end uses. Figure A-38 and Figure A-39 show supporting information for the change in saturations.

Table A-5. RASS Comparison – Water Heating Systems

End Use	All Homes		Single-Family Detached	
	2009 RASS Saturation	2018 Baseline Study Saturation	2009 RASS Saturation	2018 Baseline Study Saturation
Any Water Heating System	0.98	1	0.97	1
Natural Gas Water Heating	0.57	0.43	0.55	0.49
Oil DHW	0.24	0.03	0.30	0.06
Electric DHW	0.16	0.14	0.14	0.14

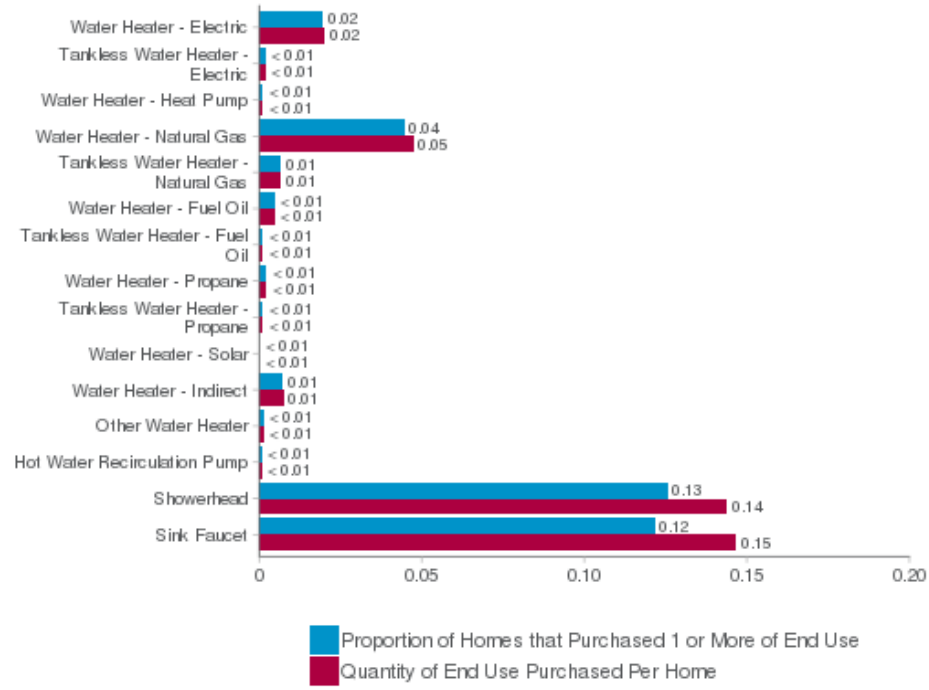
Sources: Navigant analysis, 2009 RASS

Figure A-37. Water Heating End Use Saturation and Change in Saturation



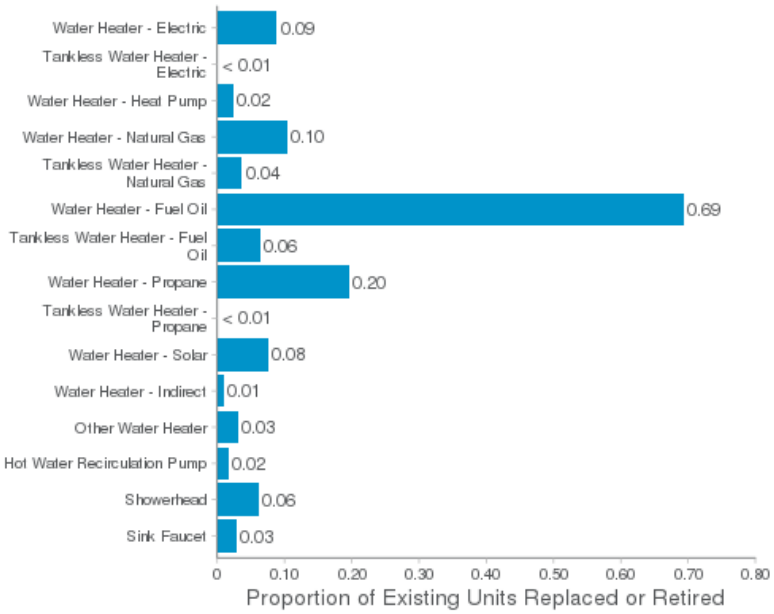
Source: Navigant analysis

Figure A-38. Proportion of Homes that Purchased New Water Heating Equipment in the Last Year



Source: Navigant analysis

Figure A-39. Proportion of Water Heating End Uses Removed in the Last Year



*Mortality rate is inversely proportional to effective useful life (EUL), e.g. EUL ~ 1/mortality rate.
Source: Navigant analysis

Electric water heating is not one of the largest energy consuming end uses in Massachusetts, as shown in Figure A-40. Results from this study corroborate model estimates that show there is significant seasonality to water heating consumption, with higher consumption recorded in the winter and lower consumption in the summer. This is consistent with modeled loads using the mains temperature relationship from Christensen and Burch.[11] Over time, electric water heating may also become more important as Massachusetts residents transition away from using oil boilers to supply space and water heating needs.

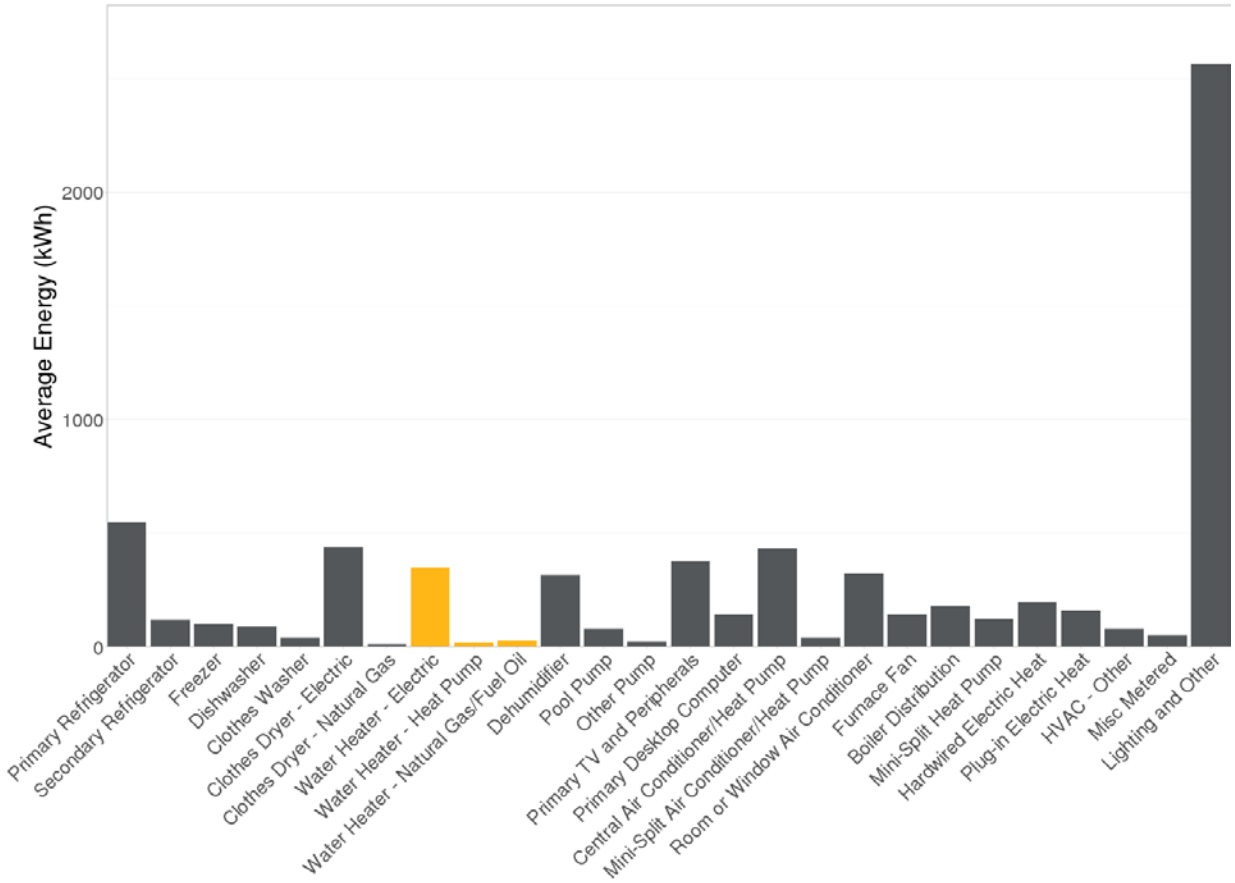
The study included both regular electric water heaters and an oversample of heat pump water heaters. As shown in Figure A-41 and Figure A-42, the summer and winter peak day load shapes for water heating have a modest double peak, with an initial peak in the morning followed by a second peak in the evening.

The load shape for heat pump water heaters is based on a relatively small sample of 30 early adopters of the technology. This is indicative of how people use heat pump water heaters today but may not be representative of long-term adoption. Heat pump water heaters have demands that are about half of regular water heaters. This roughly corroborates the engineering savings estimates, but overall use of electric water heaters is lower than expected (2,540 kWh/year compared to the 3,330 kWh/year value used for Navigant's 2017 Heat Pump Water Heater Impact Study[12] or the 4,622 kWh per year used by

[11] Jay Burch and Craig Christensen, "Towards Development of an Algorithm for Mains Water Temperature." (paper presented at the ASES Annual Conference, Cleveland, Ohio, 2007).
[12] The Navigant Heat Pump Water Heater impact study can be found at http://ma-eeac.org/wordpress/wp-content/uploads/Heat-Pump-Water-Heater-Impact-Study-Volume-1.pdf. This study was based on the 2012 Steven Winter Associates Study, which can be found at: http://ma-eeac.org/wordpress/wp-content/uploads/Heat-Pump-Water-heaters-Evaluation-of-Field-INstalled-Performance.pdf.

ENERGY STAR[13] for the 2015 Massachusetts Technical Reference Manual[14]). This may be because most electric water heaters in Massachusetts are found in multifamily residences with lower occupancy and lower consumption, while standard electric water heater assumptions are based on the hot water consumption of a family of four. However, the summer load shapes for electric water heaters and heat pump water heaters overlap at 4 p.m. during the peak period. Because of the small sample, it may be more appropriate to apply the water heating category load shape to use in calculating peak demand impacts from heat pump water heaters.

Figure A-40. Population End Use Annual Energy Consumption – Water Heating End Uses

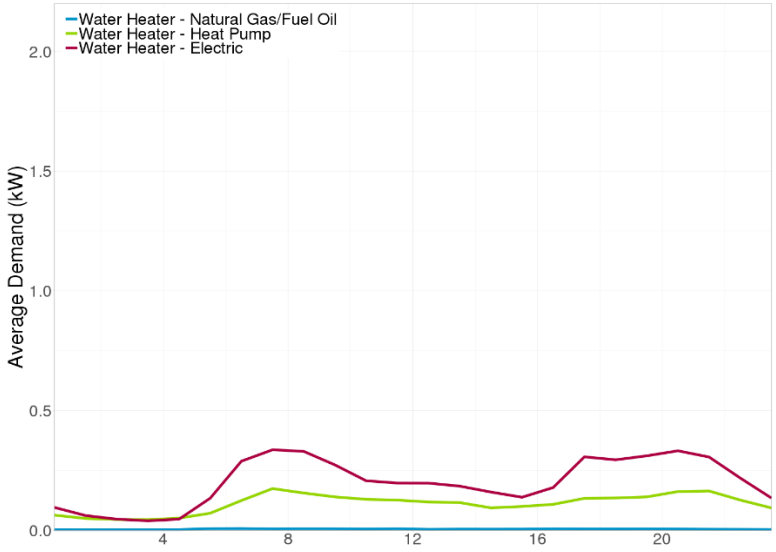


Source: Navigant analysis

[13] ENERGY STAR's water heating consumption analysis is available at https://www.energystar.gov/ia/partners/prod_development/new_specs/downloads/water_heaters/WaterHeaterAnalysis_Final.pdf

[14] The Massachusetts TRM applicable to the 2018 program year can be found at http://ma-eeac.org/wordpress/wp-content/uploads/2016-2018-Plan-1.pdf

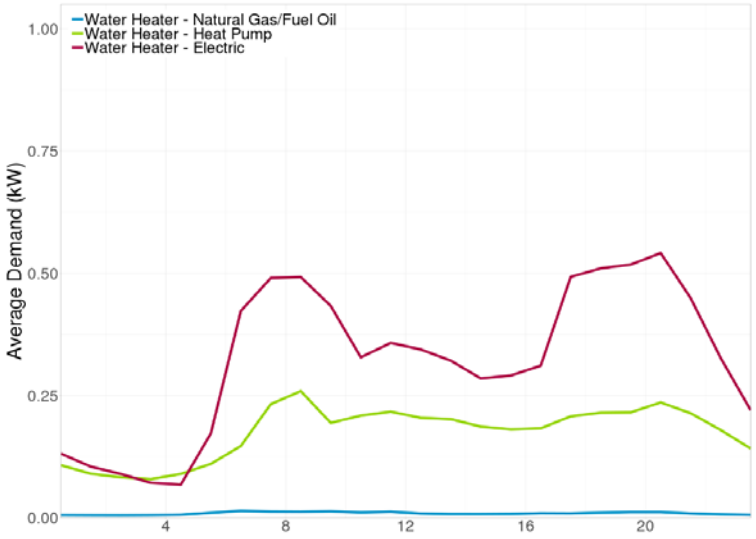
Figure A-41. Weather-Normalized Summer Peak Day Water Heating Load Shapes for Homes with End Use



Source: Navigant analysis

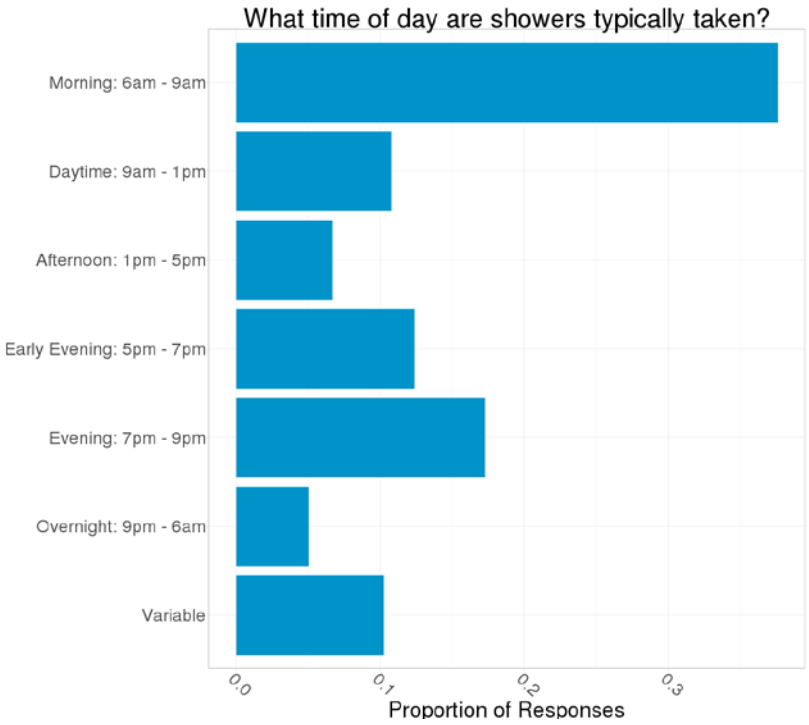
Key Finding: *Heat pump water heaters draw half as much power during peak hours as conventional electric water heaters in summer and winter. More heat pump water heaters replacing electric water heaters in the population could lead to significant reductions in peak demand.*

Figure A-42. Winter-Normalized Winter Peak Day Water Heating Load Shapes for Homes with End Use



Source: Navigant analysis

Figure A-43. Hot Water Use Motivation



Source: Navigant analysis

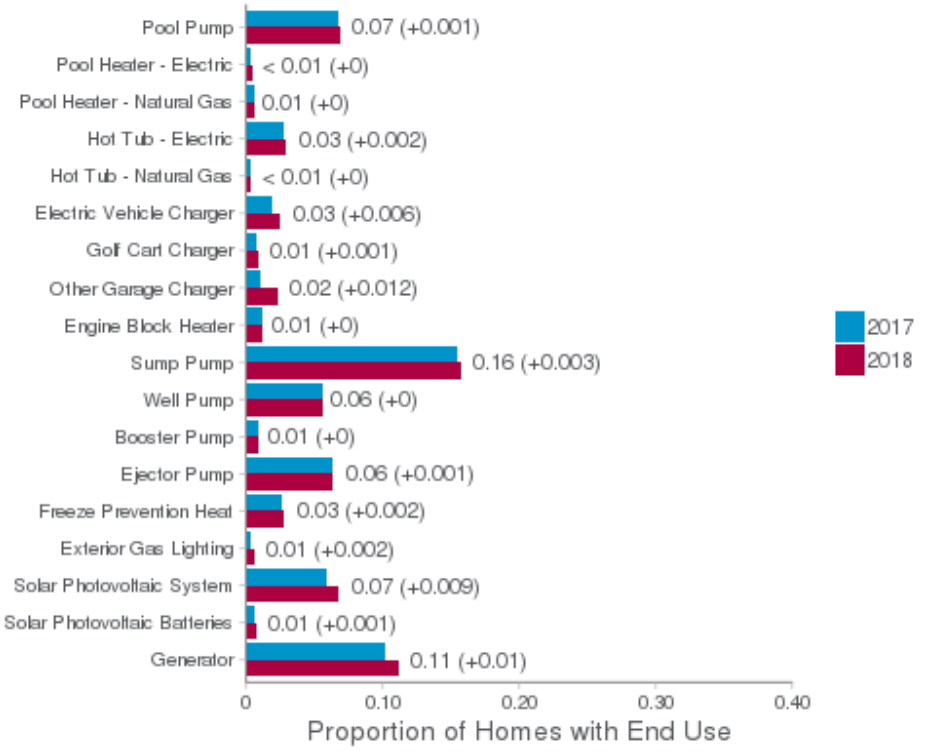
Figure A-43 shows that the morning peak in Figure A-41 and Figure A-42 may be driven primarily by showering, while the evening peak is likely a combination of showering, laundry, and dishwashing.

A.1.5 Miscellaneous End Uses

There were several miscellaneous end uses included in the survey that measured saturation. For easy visualization, the miscellaneous end uses have been split into outdoor end uses and electronic end uses.

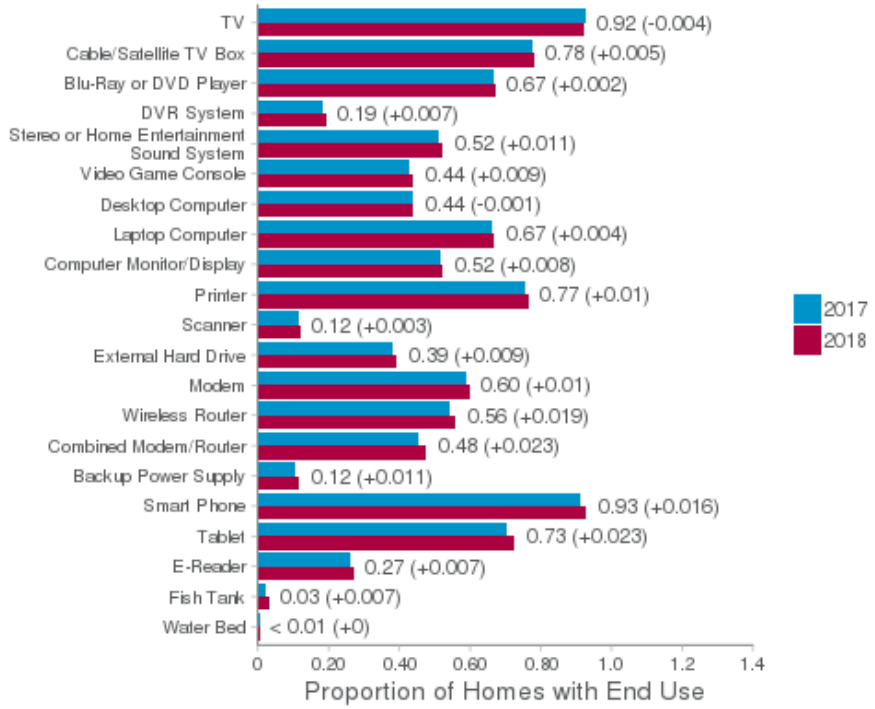
Figure A-44 and Figure A-45 show the saturation and change in saturation for outdoor and electronic miscellaneous end uses, respectively. Figure A-46, Figure A-47, Figure A-48, and Figure A-49 provide supporting information for these values by showing the proportion of homes that purchased miscellaneous end uses and the proportion of removed miscellaneous end uses.

Figure A-44. Miscellaneous End Use Saturation and Change in Saturation – Outdoor



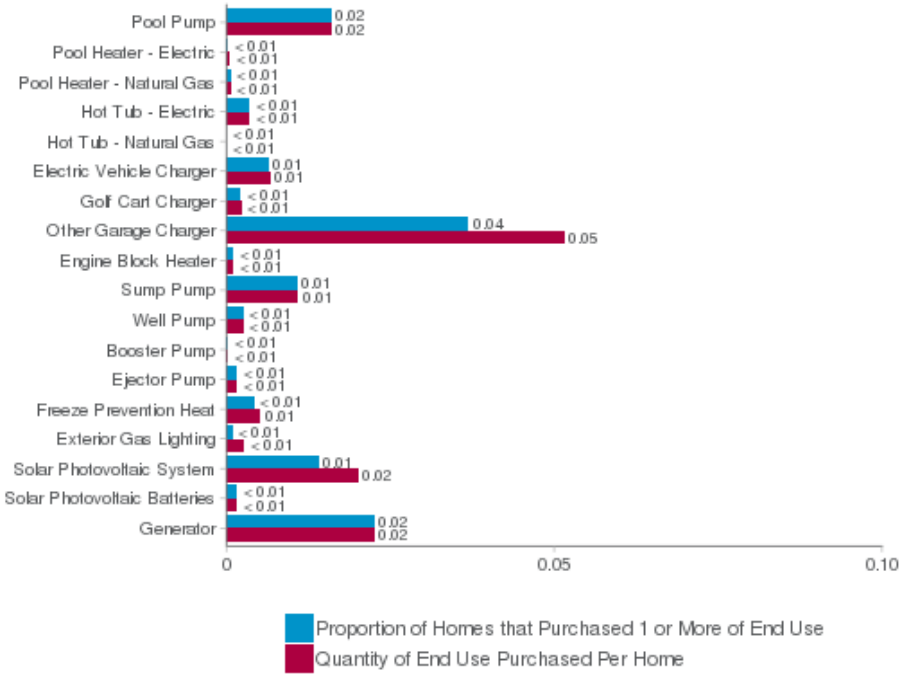
Source: Navigant analysis

Figure A-45. Miscellaneous End Use Saturation and Change in Saturation – Electronics



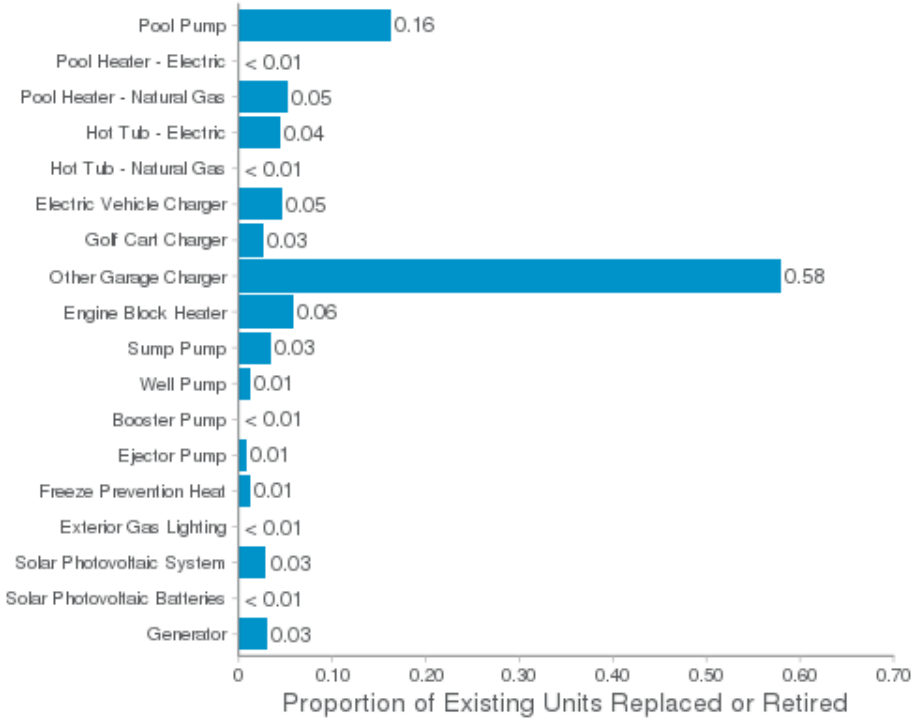
Source: Navigant analysis

Figure A-46. Proportion of Homes that Purchased New Miscellaneous Equipment - Outdoor



Source: Navigant analysis

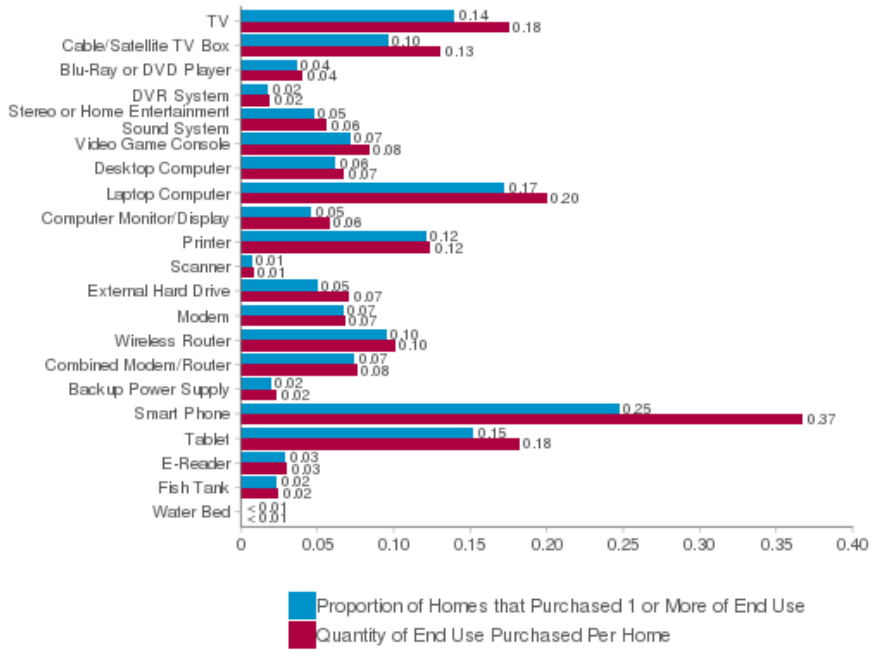
Figure A-47. Proportion of Miscellaneous Outdoor End Uses Removed in the Last Year



*Mortality rate is inversely proportional to effective useful life (EUL), e.g. EUL ~ 1/mortality rate.

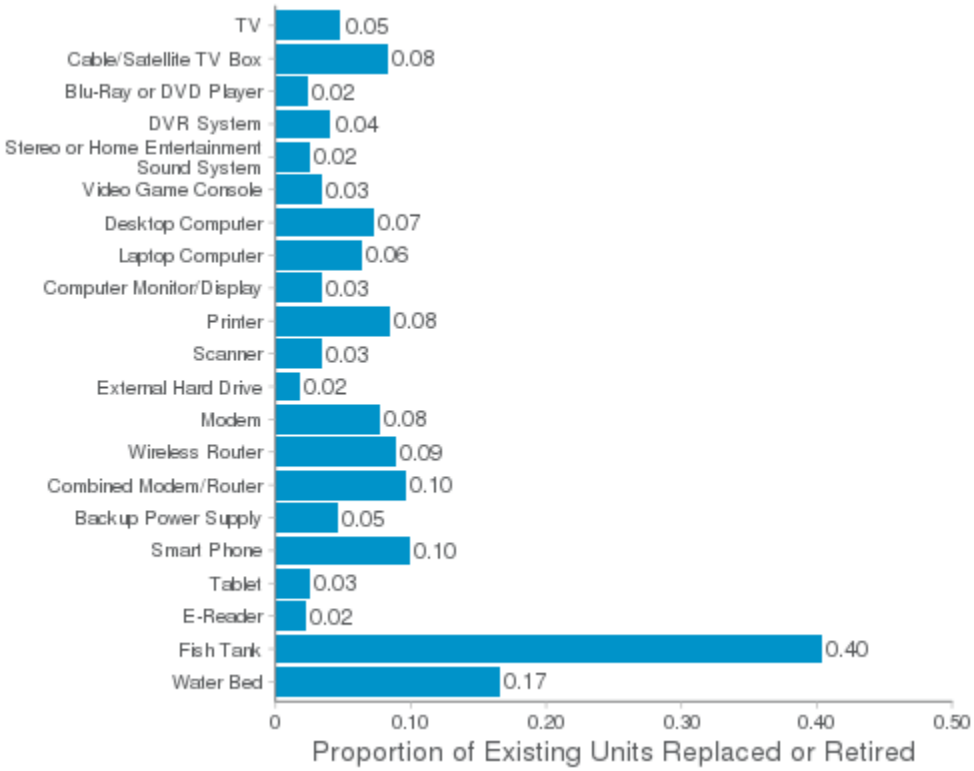
Source: Navigant analysis

Figure A-48. Proportion of Homes that Purchased Miscellaneous Equipment - Electronics



Source: Navigant analysis

Figure A-49. Proportion of Miscellaneous Electronics End Uses Removed in the Last Year

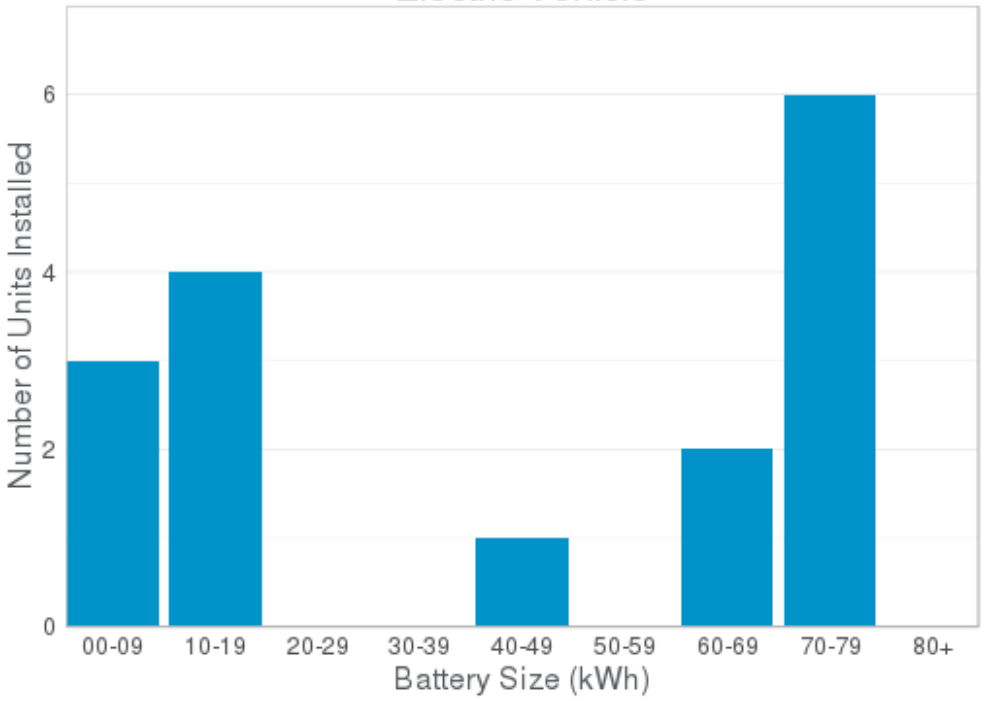


*Mortality rate is inversely proportional to effective useful life (EUL), e.g. EUL ~ 1/mortality rate.

Source: Navigant analysis

Figure A-50 shows the battery size of new EVs that have been purchased in Massachusetts in the last year. Of the 16 electric vehicles purchased, half have batteries above 60 kWh.

Figure A-50. Histogram of New EV Battery Sizes

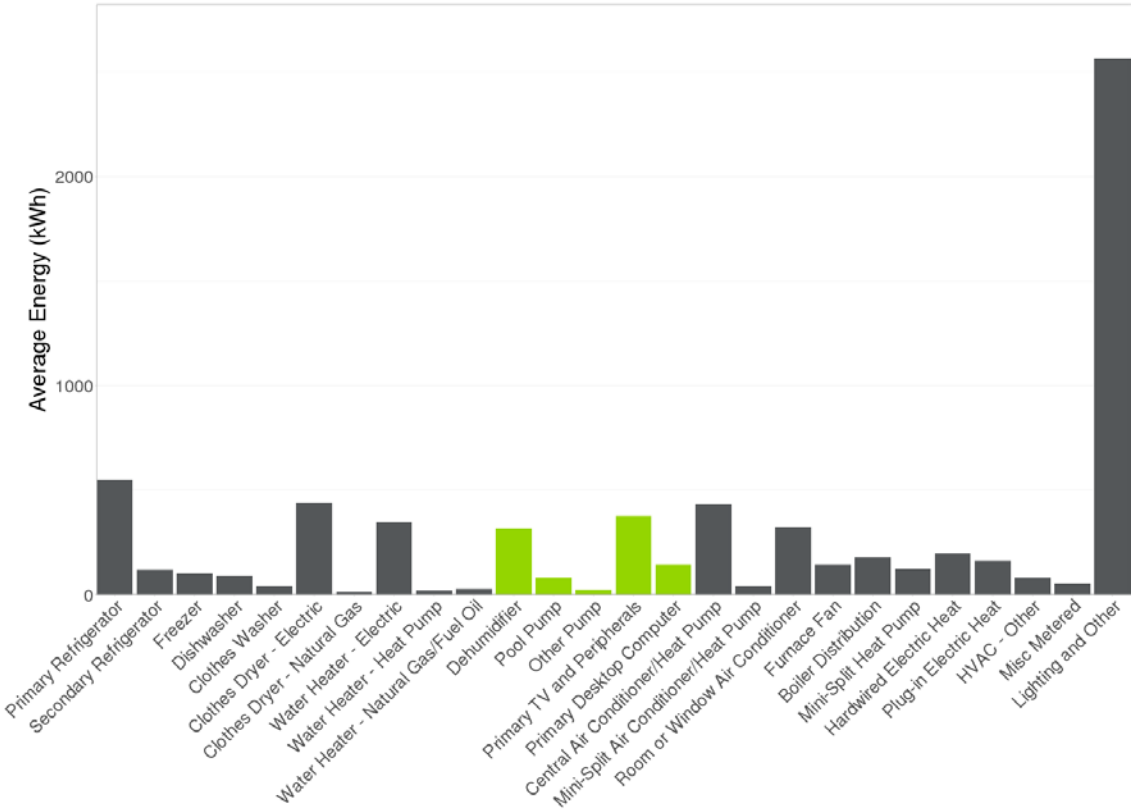


Source: Navigant analysis

The study targeted a few key miscellaneous end uses for metering, including primary TV and their peripherals, primary computer and peripherals, pool pumps, dehumidifiers, and a variety of other pumps. These end uses are compared with the other metered end uses in Figure A-51.

Primary TVs, primary computers, and dehumidifiers all have significant annual energy consumption. Pool pumps contribute to summer energy consumption; however, none of the other pumps (including sump pumps and well pumps) use much energy in Massachusetts.

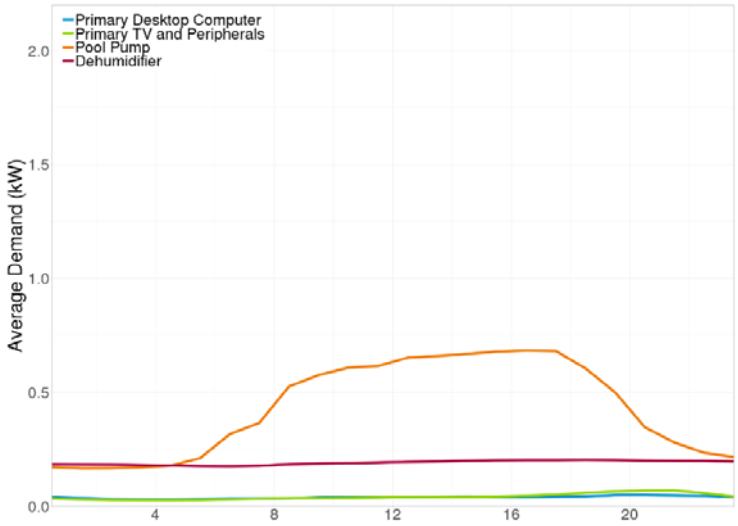
Figure A-51. Population End Use Annual Energy Consumption – Miscellaneous End Uses



Source: Navigant analysis

As shown in Figure A-52, pool pumps are used primarily during the day and have large peak demands in the summer. Dehumidifiers also have significant demands on peak days. None of these end uses contribute significantly to winter peak load, as shown in Figure A-53.

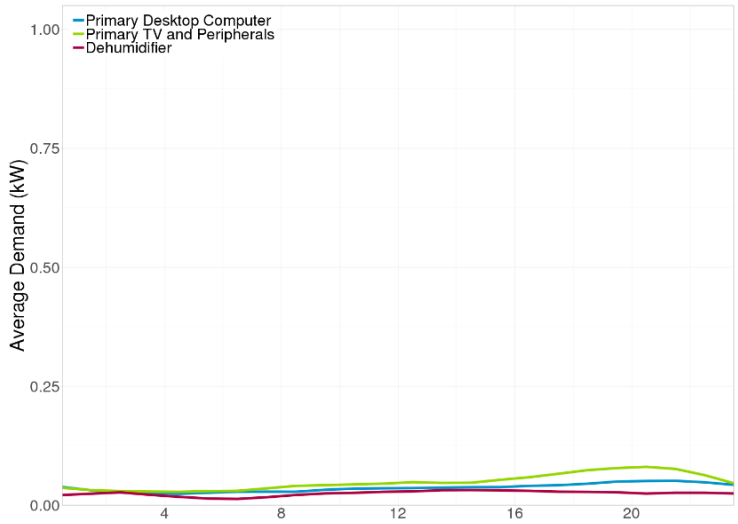
Figure A-52. Weather-Normalized Summer Peak Day Miscellaneous Load Shapes for Homes with End Use



Source: Navigant analysis

Key Finding: *Pool pumps have the largest non-cooling summer peak demand of any metered end use.*

Figure A-53. Weather-Normalized Winter Peak Day Miscellaneous Load Shapes for Homes with End Use



Source: Navigant analysis

Key Finding: *None of the miscellaneous end uses contribute significantly to winter peak demand.*

A.2 Delivered Fuels

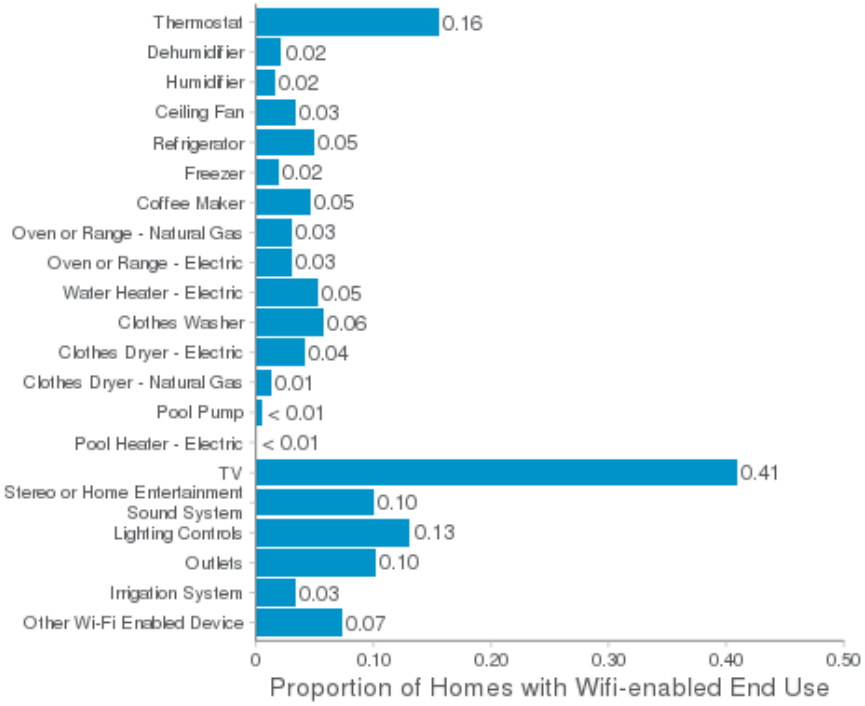
The research team used data from 27 and 28 sites with a complete profile of fuel oil for the 2017-2018 and 2018-2019 winters, respectively. There is some uncertainty inherent in this analysis due to the likelihood that participants do not consistently consume all their fuel by the end of a season (i.e., not all the fuel in an end of season delivery was used during that season). A study participant could fill up their tank at the end of the season with no plans to use that fuel until the next heating season. The opposite scenario is also possible, with a site leaving a tank empty until the following heating season and filling it back up right before the start of the heating season. The team assumed that, on average, these two possibilities will offset each other.

Incorporating this assumption, the non-weather-normalized annual energy for the 2017-2018 heating season was 94 MMBtu (673 gallons of oil)[15] and 88 MMBtu (632 gallons of oil) per site, respectively. Over the two-year collection period, the average non-weather-normalized annual energy usage was 92 MMBtu (653 gallons of oil). While additional data will refine this estimate, the result is similar to previous measurements of natural gas consumption in boilers and furnaces in Massachusetts.

A.3 Internet-Connected End Uses

Figure A-54 shows the saturation of internet-connected end uses according to the surveys administered in 2017 and 2018. As shown in the figure, the most common internet-connected end uses are thermostats, lighting, and home entertainment equipment.

Figure A-54. Saturation of Internet-Connected End Uses

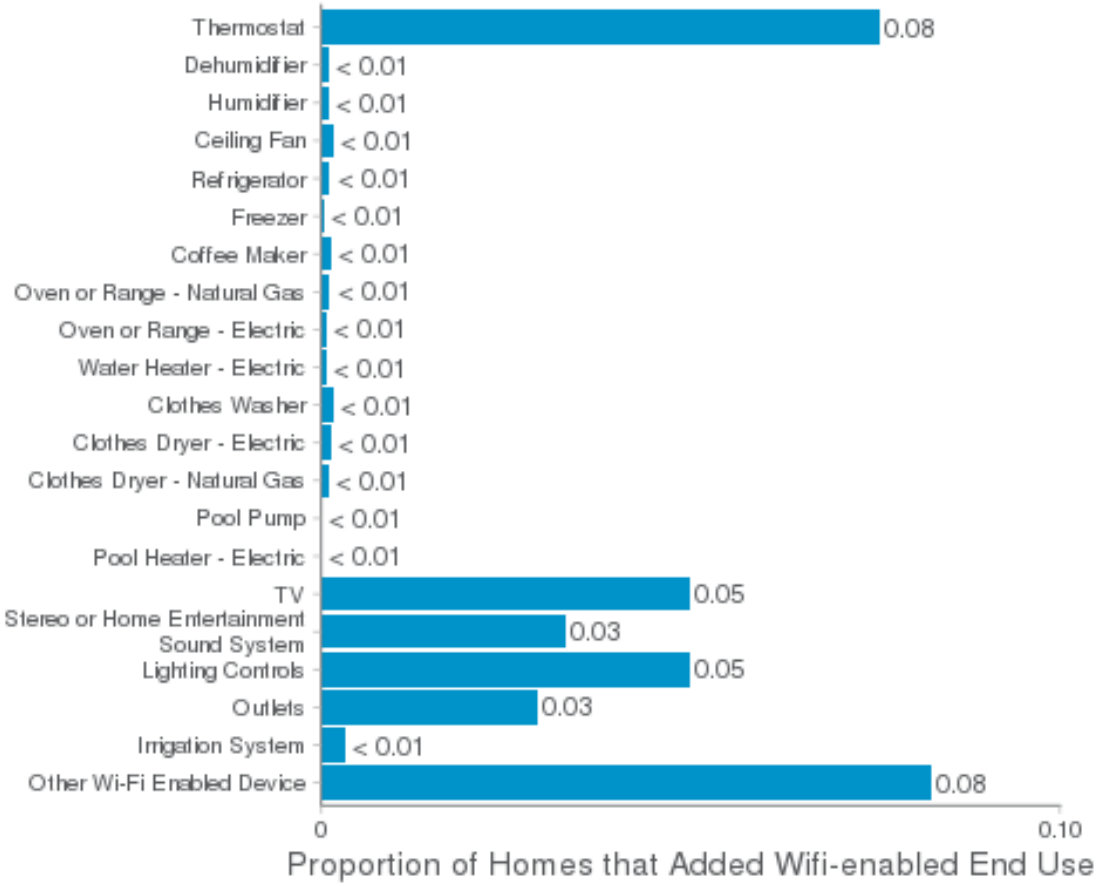


Source: Navigant analysis

[15] 1 gallon of fuel oil #2 = 139,600 Btu

Figure A-55 shows the increase in saturation among internet-connected devices over the last year. This figure illustrates that the same appliances with higher saturation are also the ones with the highest increase in saturation, on a percentage basis, in the last year. This study did not find a high prevalence of internet-connected laundry, kitchen, or water heating appliances.

Figure A-55. Proportion of Homes that Added Internet-Connected Equipment in the Last Year



Source: Navigant analysis

A.4 TRM Inputs

Equivalent full load hours (EFLHs) and coincidence factors (CFs) derived from metered data for selected end uses are presented in Table A-6. The team developed EFLH and CF numbers for metered end uses that include both EFLH and CF in their TRM equations and where appropriate nameplate information was available for metered equipment. The values were calculated using the weather-normalized annual energy and peak demand measured in this study and the relevant nameplate data (size and efficiency) from the measured equipment, as specified in the equations in the Massachusetts TRM.[16] The energy and demand can be used directly for measures using an energy and demand savings factor.

[16] Massachusetts Technical Reference Manual; 2016-2018 Program Years – Plan Version; October 2015 http://ma-eeac.org/wordpress/wp-content/uploads/2016-2018-Plan-1.pdf

Table A-6. EFLH and CF by End Use

End Use	EFLH	System Peak CF	On-Peak CF
Dehumidifier	1,255	0.31	0.27
Pool Pump	872	0.51	0.46
Central Air Conditioner/Heat Pump (Cooling)	379	0.47	0.19
Mini-Split Air Conditioner/Heat Pump (Cooling)	365	0.32	0.12
Room or Window Air Conditioner	338	0.42	0.17

Source: Navigant analysis

APPENDIX B. METHODS

B.1 Online Survey

Both the follow-up survey and the new customer survey were administered online using the Qualtrics survey platform. The follow-up survey used a combination of emails and postcards for recruitment, and the new customer survey relied on postcards only because emails were available for less than one-third of the population, which would have biased the results. The follow-up survey achieved a response rate of 53%, which equates to 3,084 completes. The new customer survey achieved a response rate of 4.7%, which equates to 3,538 completes. Between both surveys, 6,622 residents completed the surveys between September 2018 and January 2019.

B.1.1 Follow-Up Survey

The follow-up survey was sent to 5,795 of the Massachusetts residents that completed the survey in 2017. The team's goal was to achieve as high of a completion rate as possible to maximize the number of residents staying in the panel study. Emails were sent to 5,090 of the 5,795 residents who completed the 2017 survey. An initial postcard was sent to 5,644 residents—all residents except for 151 who received emails only as a test of the response rate from just emails. Reminder postcards were sent to 4,054 of the 5,644 residents who received an initial postcard. The initial and reminder postcards included a link to the online survey and mentioned that a $15 Amazon gift card would be offered to residents who completed the survey and still lived in the same residence as the previous year. The team completed two pilots and rigorous testing prior to the survey's full deployment.

The primary goal of the follow-up survey was to update the saturation numbers collected from the previous year by asking residents how many units they added or removed from their home in the past year for the 106 end uses. For example, residents were asked how many thermostats they added to their home in the past year and how many thermostats they removed from their home in the past year. If the answer was zero, they could leave that question blank. The 106 end uses were grouped by the following categories: heating and cooling, kitchen equipment, domestic hot water equipment, laundry equipment, outdoor/garage equipment, TV/computer equipment, and miscellaneous equipment. There was also a question that asked how many Wi-Fi enabled devices were added to the home in the past year.

The secondary goal of the follow-up survey was to collect characterization data for 42 high priority end uses. If a resident said that they added one of the high priority end uses in the past year, it would trigger the characterization portion of the survey, where they would be eligible to receive an additional $20 gift card if they provided nameplate information for their new equipment. The resident had the option of taking a photo of the nameplate, which included the manufacturer and model information, or manually entering the manufacturer and model number for their unit. The intent of these questions was to gather more specific detail on new equipment being installed in resident homes through Massachusetts, such as size and efficiency of equipment.

Table B-1 provides a summary of the follow-up survey recruitment and results. The difference between the number of saturation survey attempts and the number of saturation survey completes is because 7% of residents were screened out of the survey because they moved during the year. To be eligible for the characterization portion of the survey, the resident had to install one of the 42 high priority end uses in the past year. To complete the characterization portion of the survey, the customer had to agree to take the

survey and either provide nameplate information for the new unit or say that they were unable to access the nameplate information. In total, 53% of residents completed the saturation portion of the follow-up survey and 64% of residents eligible to take the characterization survey completed it. The median time in survey for the saturation survey questions was 5 minutes, and the median time in survey for the characterization questions was 17 minutes.

Table B-1. Follow-Up Survey Recruitment Summary

Wave	Number Contacted	Postcards Sent	Emails Sent	Saturation Survey Attempts		Saturation Survey Completes		Eligible for Characterization Survey		Characterization Survey Completes	
				n	%	n	%	n	%	n	%
Pilot 1	151	0	151	40	26%	37	25%	23	62%	16	70%
Pilot 2	200	200	525	96	48%	82	41%	50	61%	35	70%
General	5,444	9,323	16,195	3,322	61%	2,965	54%	1,806	61%	1,156	64%
Total	**5,795**	**9,523**	**16,871**	**3,458**	**60%**	**3,084**	**53%**	**1,879**	**61%**	**1,207**	**64%**

Source: Navigant analysis

B.1.2 New Customer Survey

The online survey was distributed via postcard to 75,934 Massachusetts residents to achieve 3,538 useable completes. Postcards were mailed to utility account addresses with an invitation to participate in the online survey and a promise of a $20 Amazon gift card for participating. Reminder postcards were used to boost the representativeness of the sample by increasing the response rate of contacted residents. The primary goal of the survey questions was to understand end use saturation and penetration. A secondary goal of the survey was to serve as a population frame for the onsite data collection effort.

The survey was programmed in the Qualtrics survey platform and administered online so that the resident could take it at their convenience. If residents requested to take it over the phone, then that service was provided. The median survey response took 19 minutes, which is 5 minutes faster than in 2017. The 2017 survey was programmed and administered by Bellomy Research. The 2018 survey was programmed by Navigant. The team thoroughly tested the final survey before implementing a pilot to 1,000 residents, followed by two waves of recruitment.

The survey asked questions about the following general areas:

- Premise occupant demographics such as number of occupants, age, work status, income, and homeowner versus renter
- Basic building characteristics such as building type (single or multifamily), age, window type, time since last significant renovation, and recent upgrades
- Presence and basic type of major end uses and appliances, including all those listed in Table 1.
- Detailed building characteristics (subset of homes with specific responses)
- Detailed appliance characteristics (including usage)

A summary of the survey recruitment effort and the response rate is shown in Table B-2. In the end, 3,538 usable completes were obtained, which equated to a response rate of 4.7%. The completion rates

in Table B-2 below are only for residents who said they live at the address on file. The overall response rate, including residents who do not live at the address on file, is 4.9%.

Table B-2. Survey Recruitment Summary

Wave	Residents Contacted	Postcards Sent	Complete Responses	Response Rate Per Resident
Pilot	1,000	1,000	40	4.0%
Wave 1	29,978	59,623	1,306	4.4%
Wave 2	44,956	89,912	2,192	4.9%
Total	**75,934**	**150,535**	**3,538**	**4.7%**

Source: Navigant analysis

Responses from the online survey informed the load shapes in the following ways:

- The online survey respondents formed the population frame from which the metered sites were sampled.
- The saturations calculated from the online survey responses and onsite visits were used to scale the load shapes to the population. More information about this process can be found in Appendix B.4.
- The binning variables used in the load shape calculations were determined through the online survey responses.
- Onsite end use targets were created based on saturations from online survey responses adjusted for onsite findings.

B.2 Onsite Sampling and Precision

The completed responses from the online survey served as the population frame from which the onsite sample was drawn. Having detailed information about each respondent's home and appliances allowed the team to thoughtfully select a sample capturing several different dimensions of the Massachusetts residential population to help meet the objectives of the research.

The team used the following proportional quotas to ensure representativeness was maintained in the onsite sample:

- **Occupant type:** owner-occupied vs. renter-occupied
- **Program interaction:** previous program participation vs. no previous program participation
- **Building type:** single-family detached vs. single-family attached vs. multifamily
- **Heating type:** gas heat only vs. electric heat present vs. other heat
- **Income:** low income vs. non-low income
- **Electric PA**
- **Gas PA**
- **Language spoken at home:** English vs. language other than English

- **Presence of end use**

Navigant's initial goal for load shapes was to achieve results at the 90% confidence level with relative precisions ranging from 10% to 30% depending on the frequency of an end use's occurrence in the population and the interests of stakeholders in achieving various levels of rigor. The team found that data for some housing types and end uses was collected at a high rate in the survey data, while others that may be of interest to the PAs occurred infrequently. Therefore, Navigant implemented oversamples for certain end uses to ensure that sufficient data was collected to produce statistically significant findings at the population level. The oversampled end uses were hardwired electric heat, plug-in space heater/fireplace, electric hot water heaters, heat pump water heaters, and pool pumps.

Table B-3 shows the targeted and achieved precision values at 90% confidence based on the total number of sites in the sample. The data in Table B-3 includes the oversampled sites for the five end uses that have been flagged. Some end uses, including ground source heat pumps, tankless water heaters, aquaria, large battery chargers, well pumps, booster pumps, and EVs, have been flagged as explicitly having no specific precision target due to the expense required to achieve the target. The field technicians metered these end uses when they showed up in the core sample but did not structure the sample to target them. For these end uses, only anecdotal information is likely to be derived from this study, but the team analyzed these results if there were more than five sites with any given end use.

Table B-3. Targeted Sampling Assumptions and Achieved Sample

End Use	Targeted End Use Precision – Energy	Targeted End Use Precision – ISO-NE Peak	Actual End Use Precision – Energy	Actual End Use Precision – On-Peak	Actual End Use Precision – System Peak
Central AC/Heat Pump	10.1%	9.9%	10%	9%	7%
Room AC	15.8%	28.2%	14%	11%	10%
Ground Source Heat Pump	84.3%	93.6%	N/A	N/A	N/A
Other Electric Heat	20.5%	77.2%	31%	24%	23%
Space Heaters/Plug-in Fireplaces	15.0%	36.8%	27%	21%	25%
Boiler Circulator Pump	6.7%	5.8%	14%	12%	11%
Other Fuel Furnace Fan	6.6%	1.7%	13%	12%	11%
Dishwasher	9.0%	30.1%	10%	11%	32%
Freezer	11.2%	10.4%	14%	10%	10%
Refrigerator	3.0%	2.7%	4%	3%	3%
Second Refrigerator	10.7%	9.6%	15%	11%	12%
Hot Water Heater	6.7%	15.0%	12%	11%	20%
Tankless Hot Water Heater	186.1%	415.6%	N/A	N/A	N/A
Heat Pump Water Heater	13.0%	29.1%	25%	28%	45%
Washer	7.0%	25.4%	11%	9%	21%
Electric Dryer	5.4%	17.6%	8%	9%	29%
Dehumidifier	11.2%	10.3%	19%	12%	14%
Aquarium	41.1%	41.1%	N/A	N/A	N/A
Golf Cart/Large Battery Charger	45.5%	45.5%	N/A	N/A	N/A
Well Pump	48.6%	45.6%	N/A	N/A	N/A
Sump Pump	25.3%	25.6%	N/A	N/A	N/A
Booster Pump	36.3%	39.6%	N/A	N/A	N/A
Pool Pump	18.2%	20.2%	24%	22%	21%
EV Charger	N/A	N/A	N/A	N/A	N/A

Source: Navigant analysis

B.3 Onsite Metering

Navigant field technicians installed metering equipment on all applicable energy-consuming equipment to determine end use load consumption and load shape at customer homes. The full list of metered equipment and end uses of interest in this study are listed in Table 1.

Navigant installed two types of meters in customer homes:

1. **eGauge:** An energy monitoring system installed in residential electric panels[17]
2. **Onset UX-120 Plug Load Meters:** A meter installed directly between the end use equipment and the power outlet[18]

The eGauge and Onset meter setups are shown in Figure B-1 and Figure B-2.

Figure B-1. eGauge Energy Metering Setup in Customer Homes

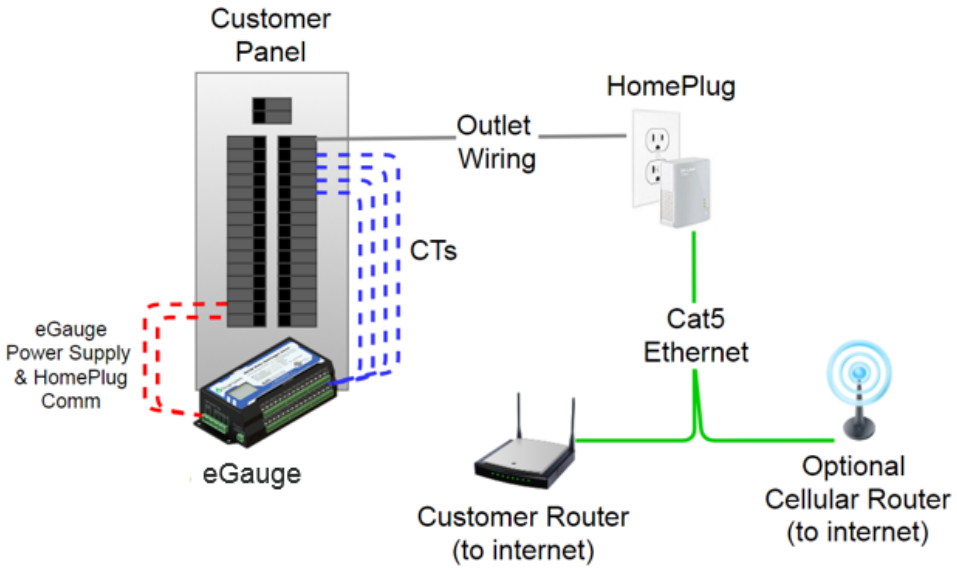


Figure B-2. Onset Plug Load Logger Used in Customer Homes

[17] For more information about eGauge meters, refer to http://www.egauge.net/products/EG3010/.

[18] For more information about Onset plug load meters, refer to http://www.onsetcomp.com/products/data-loggers/ux120-018.

Navigant field technicians programmed both the eGauge and Onset plug load meters to measure the 1-minute power consumption of each piece of metered equipment. The meters were programmed to calculate an average energy consumption value for each minute of recording.

For all metered equipment, Navigant technicians determined the optimal metering device to use based on several factors, including whether the equipment was installed on a dedicated circuit, if the power outlet was accessible, and customer preference. Whenever possible, the Navigant technicians used the eGauge to meter the equipment because it can connect remotely to secure eGauge proxy servers, allowing analysts to access the data in real time for analysis and quality control. To establish communication between the eGauge and the proxy server, Navigant used a Homeplug device, which transmits the eGauge data from the customer's electric panel to a router through powerline communication technology. Navigant used either the customer's personal internet router or a cellular modem/router to securely transmit the metered data to the eGauge servers. Throughout the metering period, Navigant monitored the eGauges remotely daily to ensure they maintained internet connection and high data quality.

The eGauge metering setup is not appropriate for equipment that is mobile or is not on dedicated electrical circuits, such as space heaters, room ACs, and primary televisions. For this equipment, Navigant used the Onset plug load logger, installing it directly between the equipment of interest and the electrical outlet. Navigant technicians secured the meter to the appliance to ensure that it stayed with the appliance of interest, not at the outlet.

Navigant's meter installation period occurred between March and June 2017. Navigant revisited 319 sites in the fall of 2017 to download metered data from the Onset plug load loggers, install meters on newly purchased equipment, and collect characterization data on the equipment, if applicable. The resulting metered period for each logged equipment spanned 3-8 months for this phase of the analysis.

B.4 Delivered Fuels Data Collection

During phase 3 of the Residential Baseline Study, the Navigant evaluation team collected delivered fuel data from participants. The team asked all onsite study participants to provide data for their delivered fuels; 97 sites reported they used a delivered fuel other than natural gas or electricity for heating.[19] The evaluation team collected the dates of delivery, type(s) of fuel delivered, and amount of fuel delivered. Although Navigant collected data on multiple fuel types, only fuel oil was considered in this analysis because of the limited data collected on wood and propane deliveries.

Participant-delivered fuel data was collected from participant bills during the fall 2018 site visits. Sites were offered a $20 incentive for providing their past 2 years of delivery data. Study participants were also informed that they would receive a $20 incentive each time they reported a fuel delivery that took place after the fall 2018 site visit. As of this report's writing, the evaluation team has collected 473 data entries from 69 sites. Additionally, 28 sites that use delivered fuel did not provide their delivery data.[20]

Based on the data collected, Navigant decided there was enough data to report an annual non-weather-normalized average energy usage for both the 2017-2018 and 2018-2019 winter seasons.[21] The evaluation team used a two-step screening process to determine whether a site's dataset was complete

[19] Delivered fuels included fuel oil, propane, wood, and wood pellets.

[20] Some participants were not responsive to the request for the fuel bill; other participants were not interested in participating.

[21] The 2017 winter season was chosen to be September 1, 2017-September 1, 2018. Data collection for the 2018 winter season is ongoing.

and not missing deliveries. First, the team looked through field tech interview notes from the 2018 site visits to determine if the participant mentioned an unusual delivery pattern. Second, the team plotted each site's delivery amounts over time and visually inspected the data for consistency.

B.5 Data Analysis

The saturation and load shape data analysis followed the steps listed in Appendix B.5.1 to B.5.3. The saturation data analysis is included because the saturation results played an important role in scaling the load shape results, as explained in Step 3 in Appendix B.5.2.

B.5.1 Saturation Data Analysis

To derive updated saturation results, Navigant cleaned and summarized data from both rounds of the online saturation survey: customers from the original round (2017) were sent a follow-up survey asking about what had changed in the past year, and a batch of new customers were sent the original saturation survey. The results from the original survey were combined with the results from the new survey to generate saturations for all equipment types in residential homes in Massachusetts. Saturations were adjusted based on onsite verification and post-weighted based on the demographics of the survey respondents and the state of Massachusetts.

Step 1: Clean data

- For values that appeared to be mistakes in the survey responses: For quantities greater than 10 for most end uses or greater than 20 for sink faucets, showers, and gas lighting, values were changed to 1.
- For heating systems, boilers and furnaces were switched based on the distribution type that was indicated. Where radiators were stated, the heating system was changed to boiler and where ducts were indicated, the system was changed to furnace.
- For ductless ACs where responses indicated the unit could also provide heat, AC was changed to heat pump.

Step 2: Adjust raw survey data using onsite findings: Onsite data was used to adjust saturations using the ratio of the number of each type of equipment verified onsite to the number of each type of equipment claimed in the survey for each of the 300 sites visited for metering. Onsite adjustment factors were used for all end uses present in at least 10 sites.

Step 3: Adjust original survey data using the results of the follow-up survey: The data for all customers from the original survey was adjusted by the results of the follow-up survey, in which each customer was asked the quantity of each end use added and removed in the past year. These numbers were then scaled by the number of years since the original survey (generally about 1.5 years for most customers) to account for the incremental changes in the population between what was captured (for the 1-year period that was asked about) and the full time period since the original data was collected.

Step 3: Apply post weights: In conjunction with the survey responses, a set of weights was developed using demographics information from the American Community Survey (ACS). The demographics selected for weighting results were education level (college degree vs. no college degree) and primary language spoken (English vs. non-English). These two demographics were selected because they had

the largest effect on saturation results, they were the two demographics where the survey sample and Massachusetts population differed the most, and they were not highly correlated with each other.

Step 4: Calculate saturations: For each combination of two of the demographic slicing variables and for each individual slicing variable, separate saturations and quantities were computed for the entire Massachusetts population of that demographic. Post weights were normalized for each combination of slicing variables to sum to 1. The weighted proportion of homes with the end use and weighted mean quantity per home were then calculated for each end use. Absolute precision was also computed at the 90% confidence level.

B.5.2 Load Shape Data Analysis

The load shape analysis consisted of five high level steps. First, 1-minute metered data from eGauge and Onset data loggers connected to all manner of equipment was cleaned and aggregated to create a dataset that has hourly data for each end use at each site. Next, the clean hourly data was summarized across sites for multiple time periods of interest to compute the energy consumption and demand for sites that have each end use. Finally, the estimates for homes with each end use were combined with saturations to compute consumption and demand of each end use for the Massachusetts population.

Step 1: Clean data: For the 1-minute data, eGauge and plug load meter data was checked for reasonableness and usability. Systematic checks for incorrect configuration were combined with engineering judgment to determine whether to keep or drop data from each source. Some data was excluded from the analysis, including where eGauges were logging multiple loads on a single register or considerable noise was observed in the data. In some cases, the data from hobo loggers could be subtracted from eGauge registers to isolate an end use. Additionally, for some end uses that were not logged because they are never used, data was filled in with zeros.

Step 2: Aggregate to site, end use, hourly granularity: First, for each logged piece of equipment, 1-minute data was aggregated to hourly data by computing the average kilowatts observed in each hour. Next, hourly unit data was summed into end use totals at each site for each hour.

> **Adjustments:** For hours where not all units of a given end use were logged (e.g., only two out of three room ACs), data was scaled up using the ratio of total units to logged units.

Step 3: Calculate site-level end use load shapes: For each site, end use, time period (individual months, peak days, peak periods), and day type (weekdays, weekends, all days) of interest, the average kilowatts were computed.

> **Exceptions:** Data was removed where a site and end use combination had less than half of the total hours in the period logged. For example, for the month of June, which has 720 total hours, only sites with 360 or more hours of data for a given end use were included in the average.
>
> **Modifications:** Certain end uses were combined to broader categories, and data was summed across end uses to arrive at category (e.g., HVAC)-level average kilowatts per period. Specific combinations are provided in Table B-4.

Table B-4. Combined End Uses for Load Shape Analysis

Category	End Uses Combined
Hardwired Electric Heat	Electric baseboard heat, electric furnace
HVAC – Misc.	Whole house fans, fireplace blowers, heat recovery ventilators, bathroom fan heaters, and ground source heat pumps
DHW – Gas/Oil	DHW – gas, DHW – gas tankless, DHW – oil, DHW – propane
Misc. Metered	Pool heaters, hot tubs, EV chargers, battery chargers, booster pumps, freeze prevention, fish tanks, water beds

Step 4: Calculate load shapes for homes with each end use: For each demographic slicing variable, end use, and time period, the average kilowatts across sites was computed. Statistics (standard error and relative precision) were also computed at this level based on the variation in the site-level results.

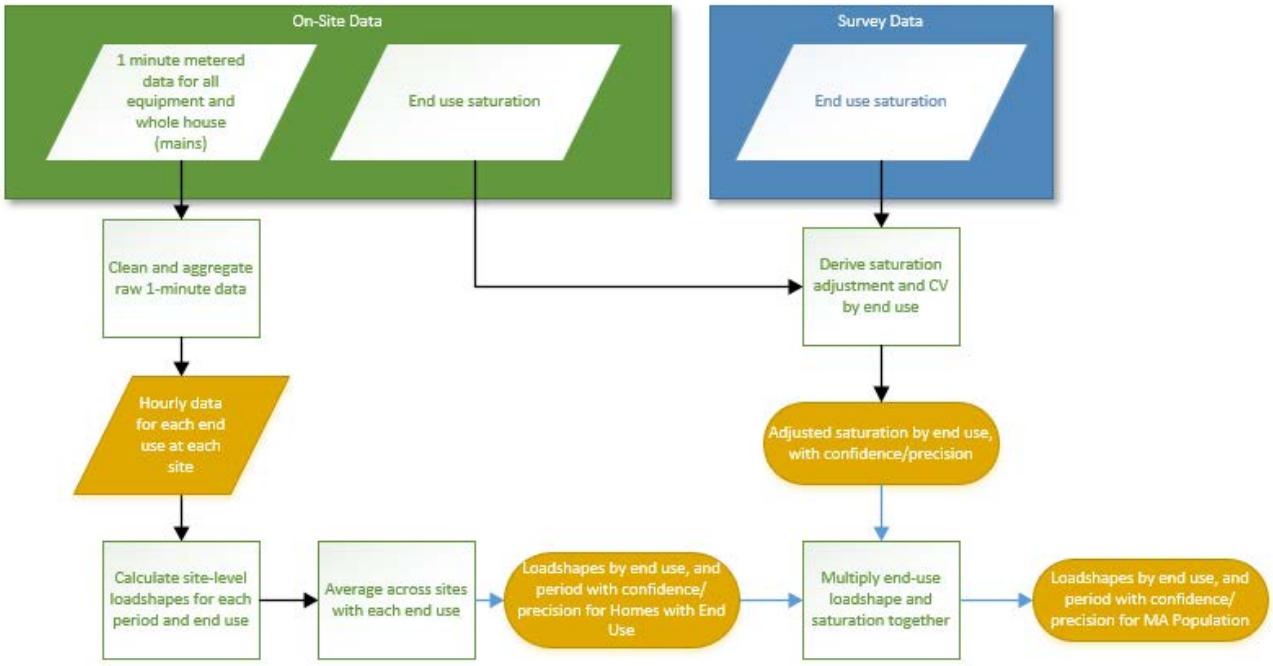
> **Exceptions:** Data was removed for demographic and end use combinations where there was data from less than five sites. For example, for end use XXX and demographic YYY, there were only four sites, so no result was computed for that combination.

Step 5: Calculate load shapes for the Massachusetts population: The average kilowatts per home, end use, category, and time period from the previous step were multiplied by the corresponding statewide saturation (for each end use and demographic) to compute statewide average kilowatts for each end use across all homes.

> **Modifications:** The remaining load values were computed by subtracting all metered end use load shapes from whole home average consumption.

Figure B-3 is a schematic representation of the saturation and load shape analysis.

Figure B-3. Saturation and Load Shape Analysis Map



Source: Navigant analysis

B.5.3 Weather Normalization

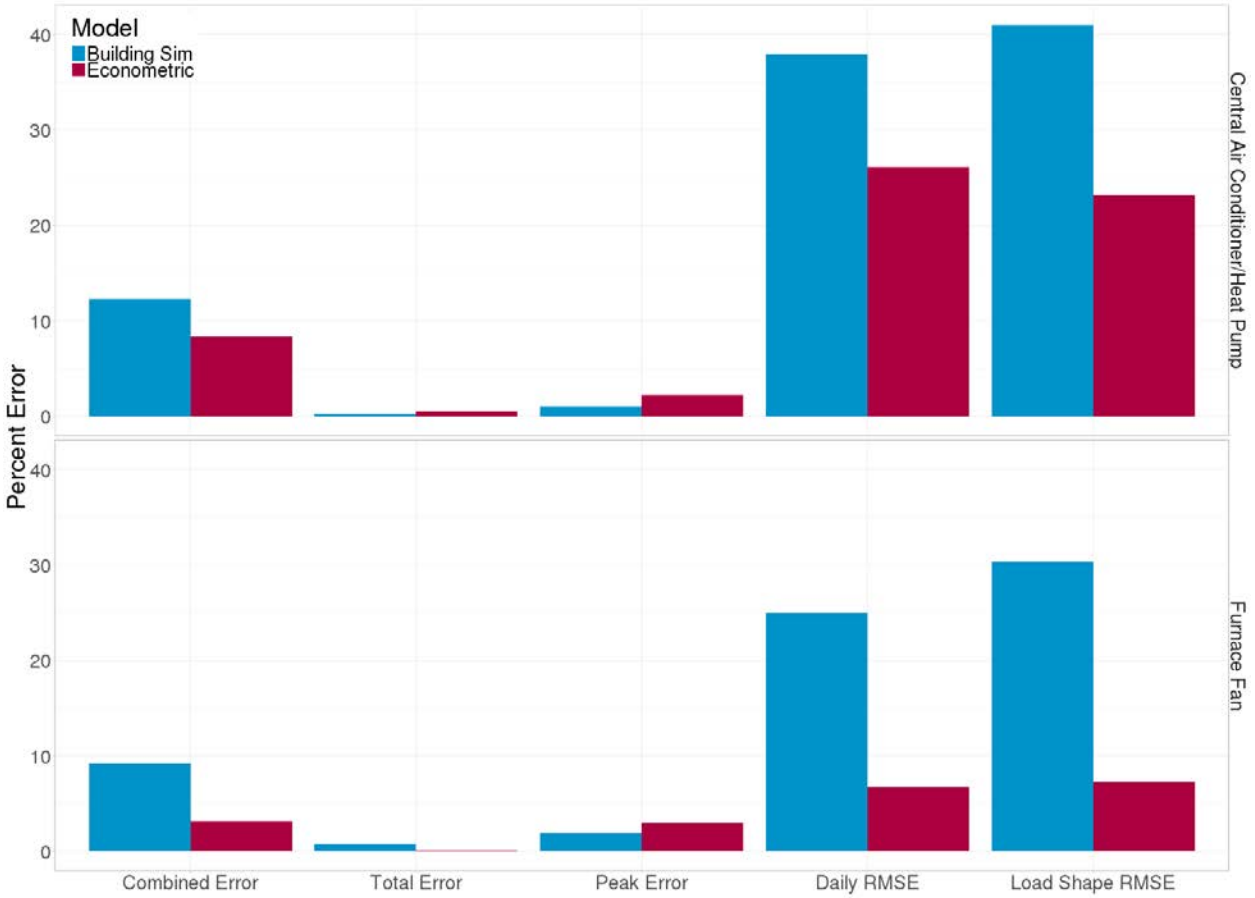
After calculating the end use load shapes for the metered period, the next step was to weather normalize the load shapes to estimate the usage in a typical weather year. The team tested two main methods for performing weather normalization: econometric regression analysis and building simulation modeling.

The evaluation team performed the regression analysis using the R statistical software package and building simulation using EnergyPlus. To test the performance of the two methods, the team divided the hourly metered data into a training set and a test set, split every other day. The evaluation team developed and calibrated models based on the data in the training set and evaluated them based on the test set to prevent over-fitting. The methods were tested on the two end uses that the team expected the building simulation model to perform best on (central AC and furnace fan); they were evaluated based on the following criteria:

1. Each model had to be within 5% of total energy use and peak demand.
2. Of the models that met the first criterion, the best model was selected based on a weighted average error:
    a. 35% error on total energy consumption
    b. 35% error on peak demand
    c. 15% root mean squared error (RMSE) on daily energy consumption
    d. 15% RMSE on average load shape by month, weekday/weekend, and hour of day

The results from the test are shown in Figure B-4.

Figure B-4. Weather Normalization Test Results



Source: Navigant analysis

For both end uses, the regression model performed significantly better than the building simulation model. Based on these results and that this was based on the end uses best suited to building simulation, the evaluation team decided to use the regression method to perform weather normalization for all end uses.

To determine the final regression model formulation for each end use, the team performed model selection using an iterative process based on 5-fold cross-validation to determine the best model while avoiding over-fitting. The method was as follows:

1. Add new predictor variables into the model one at a time based on the expected significance of the term from exploratory data analysis and engineering judgment. For numeric variables, try out polynomial terms up to the fourth degree.
2. Calculate the average error across all five cross-validation folds based on the weighted average error described above.
3. Keep the terms that result in a noticeable reduction in error, on average, across all folds.
4. Repeat steps 1-3 for all relevant variables.
5. Check the residuals plots of the final models to look for nonlinearity, heteroskedasticity, outliers, and correlation over time.

After deciding on the optimal model formulation using cross-validation, the final models for each end use were re-run on the entire dataset. The team performed model selection by category for groups of similar end uses, but all model coefficients were calculated for each end use individually. The final model formulations by category were as follows.

Equation B-1. Cooling Model

$$y_t = \sum_{h=1}^{24} \beta_{1,h} \cdot Hr_{h,t} + \sum_{m=1}^{12} \beta_{2,m} \cdot Month_{m,t} + \sum_{b=1}^{2} \beta_{3,b} \cdot (NHBU_t)^b + \sum_{c=1}^{2} \beta_{4,c} \cdot (MA4_CDH_t)^c + \sum_{d=1}^{3} \beta_{5,d} \cdot (MA24_CDH_t)^c + \beta_6 \cdot Lag_{CDH_t} + \sum_{r=1}^{2} \beta_{7,r} \cdot (RH_t)^r + \sum_{m=1}^{12} \beta_{8,m} \cdot Month_{m,t} \cdot MA4_{CDH_t} + \sum_{h=1}^{24} \sum_{m=1}^{12} \beta_{9,h,m} \cdot Hr_{h,t} \cdot Month_{m,t} + \sum_{s=1}^{n} \beta_{10,s} \cdot NHBU_t \cdot Site_s$$

Equation B-2. Heating Model

$$y_t = \sum_{h=1}^{24} \beta_{1,h} \cdot Hr_{h,t} + \sum_{m=1}^{12} \beta_{2,m} \cdot Month_{m,t} + \sum_{d=1}^{3} \beta_{3,d} \cdot (MA4_HDH_t)^d + \sum_{e=1}^{3} \beta_{4,e} \cdot (MA24_HDH_t)^e + \beta_5 \cdot NHBU_t + \sum_{m=1}^{12} \beta_{6,m} \cdot Month_{m,t} \cdot NHBU_t + \beta_7 \cdot MA6_GHR_t + \sum_{s=1}^{n} \beta_{8,s} \cdot MA4_HDH_t \cdot Site_s$$

Equation B-3. Dehumidifier Model

$$y_t = \sum_{h=1}^{24} \beta_{1,h} \cdot Hr_{h,t} + \sum_{m=1}^{12} \beta_{2,m} \cdot Month_{m,t} + \beta_3 \cdot RH_t + \sum_{b=1}^{3} \beta_{4,b} \cdot (NHBU_t)^b + \beta_5 \cdot CDH_t + \beta_6 \cdot MA4_CDH_t + \sum_{d=1}^{3} \beta_{7,d} \cdot (MA24_CDH_t)^c + \beta_8 \cdot HDH_t + \sum_{m=1}^{12} \beta_{9,m} \cdot Month_{m,t} \cdot NHBU_t + \sum_{m=1}^{12} \beta_{10,m} \cdot Month_{m,t} \cdot HDH_t + \sum_{s=1}^{n} \beta_{11,s} \cdot NHBU_t \cdot Site_s$$

Equation B-4. Pool Pump Model

$$y_t = \sum_{h=1}^{24} \beta_{1,h} \cdot Hr_{h,t} + \sum_{m=1}^{12} \beta_{2,m} \cdot Month_{m,t} + \beta_3 \cdot Day_Type_t + \sum_{b=1}^{3} \beta_{4,b} \cdot (NHBU_t)^b + \sum_{c=1}^{3} \beta_{5,c} \cdot (MA4_CDH_t)^c + \sum_{h=1}^{24} \sum_{m=1}^{12} \beta_{6,h,m} \cdot Hr_{h,t} \cdot Month_{m,t} + \sum_{h=1}^{24} \beta_{7,h} \cdot Hr_{h,t} \cdot Day_Type_t + \sum_{m=1}^{12} \sum_{b=1}^{3} \beta_{8,m,b} \cdot Month_{m,t} \cdot (NHBU_t)^b + \sum_{s=1}^{n} \beta_{9,s} \cdot Site_t$$

Equation B-5. Refrigerator/Freezer Model

$$y_t = \sum_{h=1}^{24} \beta_{1,h} \cdot Hr_{h,t} + \sum_{m=1}^{12} \beta_{2,m} \cdot Month_{m,t} + \beta_3 \cdot Day_{Type_t} + \sum_{b=1}^{2} \beta_{4,b} \cdot (NHBU_t)^b + \sum_{c=1}^{2} \beta_{5,c} \cdot (MA4_{CDH_t})^c + \sum_{h=1}^{24} \sum_{m=1}^{12} \beta_{6,h,m} \cdot Hr_{h,t} \cdot Month_{m,t} + \sum_{h=1}^{24} \beta_{7,h} \cdot Hr_{h,t} \cdot Day_{Type_t} + \sum_{m=1}^{12} \sum_{b=1}^{2} \beta_{8,m,b} \cdot Month_{m,t} \cdot (NHBU_t)^b + \sum_{s=1}^{n} \beta_{9,s} \cdot Site_t$$

Equation B-6. Water Heating Model

$$y_t = \sum_{h=1}^{24} \beta_{1,h} \cdot Hr_{h,t} + \beta_2 \cdot DB_Ave_Month_t + \beta_3 \cdot Day_Type_t + \sum_{b=1}^{2} \beta_{4,b} \cdot (NHBU_t)^b + \sum_{h=1}^{24} \beta_{5,h} \cdot Hr_{h,t} \cdot DB_Ave_Month_t + \sum_{h=1}^{24} \beta_{6,h} \cdot Hr_{h,t} \cdot Day_Type_t + \sum_{s=1}^{n} \beta_{7,s} \cdot Site_t$$

Equation B-7. All Other End Uses Model

$$y_t = \sum_{h=1}^{24} \beta_{1,h} \cdot Hr_{h,t} + \sum_{m=1}^{12} \beta_{2,m} \cdot Month_{m,t} + \beta_3 \cdot Day_Type_t + \sum_{h=1}^{24} \sum_{m=1}^{12} \beta_{4,h,m} \cdot Hr_{h,t} \cdot Month_{m,t} + \sum_{h=1}^{24} \beta_{5,h} \cdot Hr_{h,t} \cdot Day_Type_t + \sum_{s=1}^{n} \beta_{6,s} \cdot Site_t$$

Where:

y_t = Hourly consumption in hour *t*.

$Hr_{h,t}$ = A set of 24 flag variables corresponding to hour ending, where each flag is set to 1 if *h* is equal to the hour ending *t* falls in.

$Month_{m,t}$ = A set of 12 flag variables corresponding to month, where each flag is set to 1 if *m* is equal to the month *t* falls in.

Day_Type_t = A flag variable corresponding to day type, to 1 if *t* falls on a weekday and 0 if it falls on a weekend or federal holiday.

$NHBU_t$ = The normalized heat buildup observed in hour ending *t*. Normalized heat buildup is calculated as follows:

$$NHBU = \frac{\sum_{t=1}^{72} (0.96)^t * (HeatIndex\ t\ hours\ prior)}{1,000}$$

CDH_t = The cooling degree hours observed in hour ending *t*. For this study CDH is defined as the greater of either the temperature in Fahrenheit less 65° or 0. CDH with base temperatures of 70°F and 75°F were also tested, and it was determined that base 65°F produced the best fit.

$MA4_CDH_t$	=	The 4-hour moving average of cooling degree hours (base 65°F) observed in hour ending *t*.
MA_24CDH_t	=	The 24-hour moving average of cooling degree hours (base 65°F) observed in hour ending *t*.
Lag_CDH_t	=	The cooling degree hours (base 65°F) observed in hour ending prior to *t* (lagged by 1 hour).
HDH_t	=	The heating degree hours observed in hour ending *t*. For this study HDH is defined as the greater of either 65°F less the temperature in Fahrenheit or 0.
$MA4_HDH_t$	=	The 4-hour moving average of heating degree hours (base 65°F) observed in hour ending *t*.
MA_24HDH_t	=	The 24-hour moving average of heating degree hours (base 65°F) observed in hour ending *t*.
RH_t	=	The relative humidity in hour ending *t*, expressed as a percentage.
$MA6_GHR_t$	=	The 6-hour moving average of global horizontal radiation.
$DB_Ave_Month_t$	=	The 30-day moving average of outdoor dry bulb temperature observed in hour ending *t*, used as a proxy for the water main temperature (used in the water heating model).
$Site_t$	=	Dummy variables for each individual site.

To produce typical year results, the evaluation team ran the final models on 15 years' worth of actual weather data from Worcester, Massachusetts (chosen as a representative weather station). Results were derived as follows:

1. Calculate average energy consumption for each end use in each month and peak period.
    a. For peak periods, determine the day of the system summer/winter peak for each year based on historical ISO-NE load data[22] and calculate the average consumption in the peak hours (1-5 p.m. in the summer, 5-7 p.m. in the winter) on those days.
2. Sum the modeled population energy consumption (per-home consumption x saturation) across all end uses to get the typical home consumption.
3. For each month and peak period, choose the weather year that resulted in the median typical home consumption across all end uses
4. Sum the data from the chosen months to derive the annual results

The years chosen are shown in Table B-5.

[22] Historical ISO-NE data was pulled from the "Daily Summary of Hourly Data" files found on the ISO-NE website: https://www.iso-ne.com/isoexpress/web/reports/load-and-demand/-/tree/zone-info.

Table B-5. Weather Years Used by Time Period

Time Period	Weather Year
Summer Peak Days	2015
Winter Peak Days	2013
Summer On-Peak	2011
Summer Seasonal Peak	2015
Summer System Peak	2015
Summer Residential Peak	2015
Winter On-Peak	2018
Winter Seasonal Peak	2011
Winter System Peak	2013
Winter Residential Peak	2013
January	2010
February	2004
March	2011
April	2016
May	2004
June	2014
July	2008
August	2015
September	2016
October	2013
November	2010
December	2004

APPENDIX C. SUPPORTING DATA

The supporting data for all end use load shapes is included in the attached spreadsheets. The statistics for each value are also included within the spreadsheets.

Table C-1. Appendix D Supporting Documents File Names and Contents

File Name	File Type	Contents
Appendix D-1 Saturation Results Plots 2018-04-12	PDF	Detailed plots of saturation and quantity of all end uses by end use and demographic
Appendix D-2 Annual Results Plots 2018-07-27	PDF	Detailed plots of annual consumption, summer/winter peak demand, and load shapes by end use and demographic
Appendix D-3 All End Use Whole Period Results 2018-07-27	Excel	Total annual and monthly consumption and peak demand for each end use and time period with statistics
Appendix D-4-1 HVAC Load Shape Results 2018-07-27	Excel	Hourly load shapes by end use, demographics, time period, and day type with statistics
Appendix D-4-2 Water Heating Load Shape Results 2018-07-27	Excel	
Appendix D-4-3 Kitchen Load Shape Results 2018-07-27	Excel	
Appendix D-4-4 Laundry Load Shape Results 2018-07-27	Excel	
Appendix D-4-5 Miscellaneous Load Shape Results 2018-07-27	Excel	
Appendix D-4-6 Lighting Load Shape Results 2018-07-27	Excel	
Appendix D-4-7 Remaining Load Load Shape Results 2018-07-27	Excel	