RES 1 Baseline Load Shape Study

Cooling Season Short Report

Prepared for:

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

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EXECUTIVE SUMMARY

The Navigant team is conducting a residential baseline end use load research study on behalf of the Massachusetts Program Administrators (PAs) and Energy Efficiency Advisory Council (EEAC). This report documents the load shapes, summer peak demand levels and summer energy consumption for all major end uses,[1] metered at approximately 350 homes representative of the Massachusetts statewide population during the summer of 2017. The results are designed to assist the PAs and EEAC in designing and evaluating program offerings targeted to reduce residential peak demands now and in the future.

Study highlights include:

1. **Central air conditioners (AC) and room AC are by far the largest contributors to residential peak demand.** Cooling collectively makes up about half of total residential ISO-NE and residential peak demand, with household ISO-NE peak demands of 1.7 kW and 0.6 kW from central AC/heat pump (HP) and room AC, respectively. The saturation of central cooling (including shared and individual household equipment) increased from 29% in 2008 to 45% of households in 2017, negating all cooling equipment efficiency gains over the same time period.

2. **Across the rest of the metered end uses, individual homes have a variety of significant end use loads during peak times.** Dehumidifiers, clothes dryers, pool pumps, and hot water heaters all have significant load during peak times.

3. **Heat pump water heaters appear to use about half as much electricity as domestic water heaters,** which corroborates much of the expected savings, at least during the summer.

Based on these findings, the evaluation team recommends considering:

1. **Central AC should continue to be the primary focus of program efforts to reduce peak demands, but ductless HP and room AC are also important to a comprehensive AC program offering.** Energy efficiency measures for central AC/HPs should include Energy Efficiency Ratio (EER) requirements to steer customers towards offerings with higher peak demand savings. PAs should explore opportunities for central AC early retirement. Over 40% of central AC systems in Massachusetts have an EER of 9 or lower, which creates large opportunities for peak demand reductions.

2. **PAs should consider targeting high use dehumidifiers, clothes dryers, and pool pumps for additional peak demand savings with low customer impacts while exploring cost-effective control options.** Dehumidifiers (13% of all homes), clothes dryers (10% of homes), and pool pumps (5% of homes) all have opportunities for valuable peak savings of at least 0.2 kW.

3. **Energy efficiency program offerings should push heat pump water heaters for both energy and demand savings.**

[1] Lighting was not metered as part of this study and is therefore not presented.

1. INTRODUCTION

A Navigant research team is currently conducting a large multiyear baseline saturation and load shape study in which data is collected via online survey, onsite validation, and long-term metering. This study 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, and learn more about relevant opportunities for reducing overall consumption and consumption during peak periods. The study began in January 2017 and will continue through at least the spring of 2019.[2]

1.1 Study Goals

The primary goal of this study is to collect saturation, penetration, and usage behavior data for all major electric and gas appliances, mechanical equipment, and electronics in Massachusetts homes. These data will support energy and peak demand savings calculations for program evaluation and design, and provide 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 by providing comprehensive data for the sampled customers. These include energy efficiency potential studies and market effects research, among others.

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?" by presenting key findings from the metered data relevant to the cooling season.[3] The data contained and referred to in this report was collected between March 2017 and October 2017. In future updates to this report, the results and findings may change based on newly available or updated information.

1.2 Summary of Research Activities

To answer the primary research question of "How and when are people using the electric equipment in their homes?", the research team followed the high level step-by-step process outlined in Figure 1.

Figure 1. Study Approach for Determining End Use Load Shapes

[2] The originally scoped study was intended to last until the spring of 2018. However, the program administrators (PAs) and Energy Efficiency Advisory Council (EEAC) have decided to extend the study for at least 1 additional year. The Stage 3 Plan for the additional year of the study is not yet complete.

[3] This study has two primary research questions and three secondary research questions. All research questions can be found in the study's Stage 3 Plan.

Information for each step is provided below, and additional details on the study's methodology is contained in Appendix A.

1. **Conduct online survey** to inventory saturation of several key end uses in Massachusetts residences, which serves as the population frame for the metered sample. The online survey was designed by Navigant and administered by Bellomy. The survey asked questions related to the respondents' demographics, home characteristics, and home appliances. Survey recruitment was completed via mailed postcards; most of the postcards were sent to households sampled randomly from the participating statewide utilities' customer bases. The last 1,600 completes were obtained as part of a targeted recruitment effort based on geographies that had a higher saturation of underrepresented priority characteristics, such as renter, low income, multifamily, and non-English speaking households. The research team received 6,901 total survey completes, including 228 Cape Light Compact (CLC) oversample completes, between February and June 2017.
2. **Draw onsite sample,** including the core sample and oversample, to meet end use confidence and precision targets determined by the research team, PAs, and EEAC during the project's planning phase. The core sample was drawn using a semi-automated script to maintain several representativeness quotas, including quotas by end use. The oversample includes homes with specific under-sampled end uses which ensures that all end uses meet the desired confidence and precision targets.
3. **Install meters** to measure all end uses at core sampled homes and the sampled end use for oversampled homes. Two kinds of meters were installed: meters installed in the panel which communicate remotely via powerline carrier, and non-communicating plug load meters installed at the end use. The 300 core site visits and 56 oversample site visits were completed between March and June 2017. Revisits were conducted during September and October 2017 to download data from plug load meters. The meters will be installed for at least 1 more year.
4. **Analyze metered data** to determine typical year and peak year load shapes by end use. Data from all meters were rigorously checked for quality and completeness before being aggregated to hourly granularity at each site. Site-level data was aggregated to generate per-home average load shapes and peak period consumption for each end use. Saturations from survey data were used in conjunction with site-level metered data to generate aggregate (statewide) average load shapes and peak period results.

Table 1 shows the measured end uses for which Navigant is providing cooling season load shape results in this report. Most end uses on this list were identified during study planning as high priority end uses to measure. The end uses in the table marked with an asterisk (*) were those that the team had enough metered data to report on even though they were not identified as high priority end uses. End uses that proved to be inconsequential to the overall load due to either small sample size or small load are combined as other heating and cooling,[4] other pumps,[5] and other miscellaneous metered loads.[6] Unmetered loads were calculated by subtracting all of the metered loads from the metered whole premise loads. While lighting is not explicitly addressed in this report or the accompanying Appendices, the load attributable to lighting is included in the unmetered loads.

[4] All heating-only end uses (furnace fans, space heaters/plug-in fireplaces, hardwired electric heat, boiler circulator pumps), whole house fans, and ground source heat pumps are combined as other heating and cooling.
[5] 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.
[6] 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 chargers, hot tubs, pool heaters, water beds, large battery chargers, and large fish tanks.

Table 1. Measured End Uses by Category

End Use Category	Measured End Uses	
Heating and Cooling	• Central air conditioner/heat pump • Room air conditioner	• Ductless air conditioner/heat pump* • Other heating and cooling
Kitchen	• Dishwasher • Refrigerator	• Second refrigerator • Freezer
Hot Water	• Electric water heater • Heat pump water heater	• Gas water heater*
Laundry	• Electric clothes dryer • Gas clothes dryer*	• Electric washer
Miscellaneous	• Pool pumps • Other pumps • Primary TVs and peripherals*	• Dehumidifiers • Computers and peripherals* • Other miscellaneous metered loads

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

1.3 Terminology

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

- **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:** To calculate summer-only results, the team has used the metered data from June 1, 2017 to September 30, 2017.
- **Residential Peak:** For the purposes of this report, residential peak is defined as a forward-looking evening peak, set for 5-7 p.m. on the 4 hottest weekdays of the year (June 12, June 13, July 19, July 20).
- **ISO-NE Peak:** For the purposes of this report, ISO-NE peak is approximated as 1-5 p.m. on the 4 days with highest ISO-NE system peak loads in 2017 (June 12, June 13, July 19, July 20).[7]
- **Peak Days:** These results include data only from the 4 days identified as peak days (June 12, June 13, July 19, July 20).
- **Building Type:** Either Single-Family Detached, Single-Family Attached (2-4 units), or Multi-family (5+ units)
- **Number of Occupants:** number of permanent residents (adults and children) living in the home

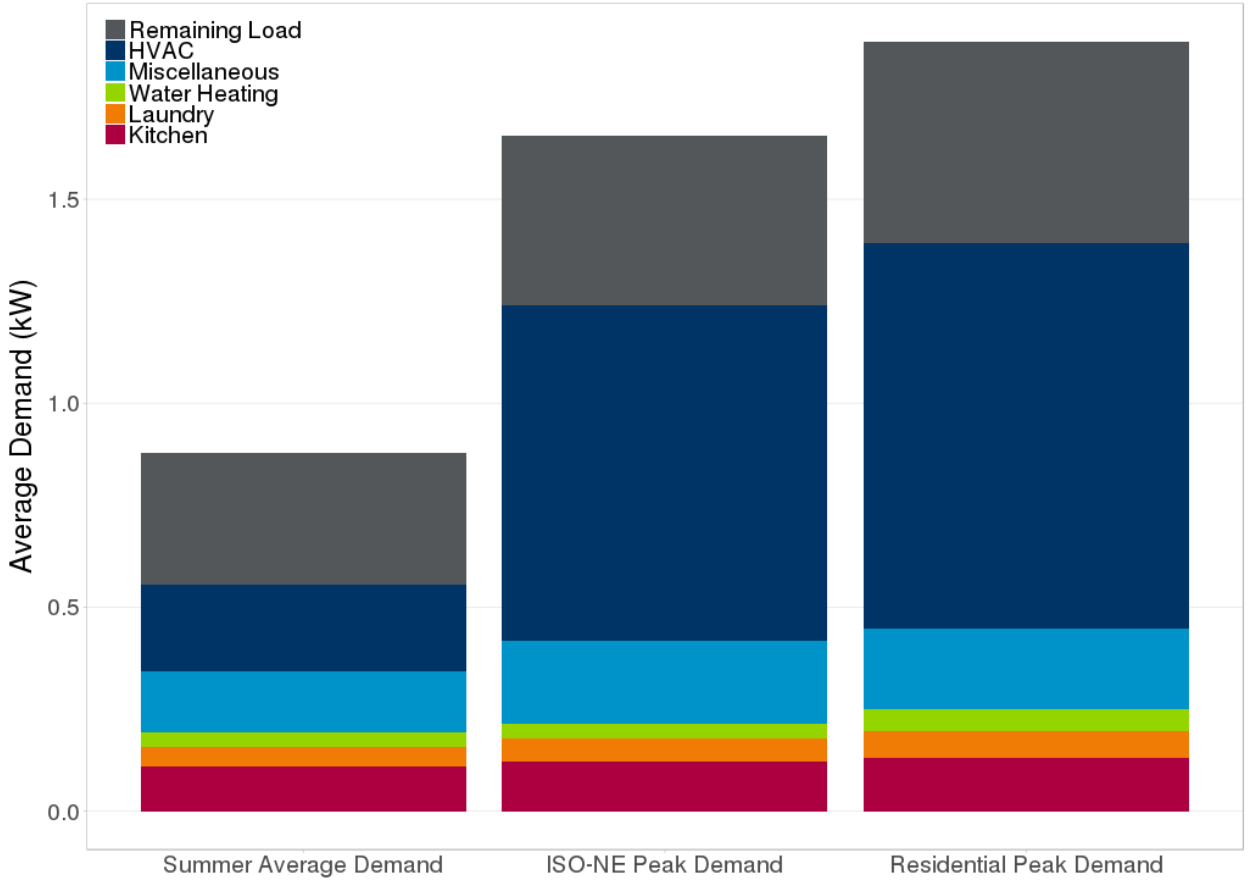
[7] ISO-NE load data for 2017 can be retrieved at https://www.iso-ne.com/isoexpress/web/reports/load-and-demand/-/tree/dmnd-rt-hourly-sys

2. RESULTS AND KEY FINDINGS

This section contains the summer metering period energy consumption (expressed as average power), residential peak demand, and ISO-NE peak demand findings by end use category in the first two subsections and further end use specific results in the third subsection. The full accompanying datasets, including additional charts and graphics, are provided as Appendix C to this report.

These results are not weather normalized and represent the total consumption over the 4-month summer metered period (June 1, 2017 through September 30, 2017).[8] The team performed a preliminary building modeling analysis of a typical single family residential building model with weather data for Worcester, MA from 2005 through 2017 to compare seasonal data over the last several years. The preliminary analysis suggests that the 2017 cooling season was about average based on modeled cooling energy consumption from the past 12 years. Therefore, when the cooling season results are fully weather-normalized, the team expects that the consumption will not change appreciably. However, 2017 did not have as extreme a peak day as previous years, so peak day weather-normalization will likely result in somewhat higher peak demand for cooling end uses.

Figure 2. Average Demand for Three Time Periods by End Use



[8] Weather normalized load shape results will be delivered for the cooling season in January 2018 as an addendum to this report.

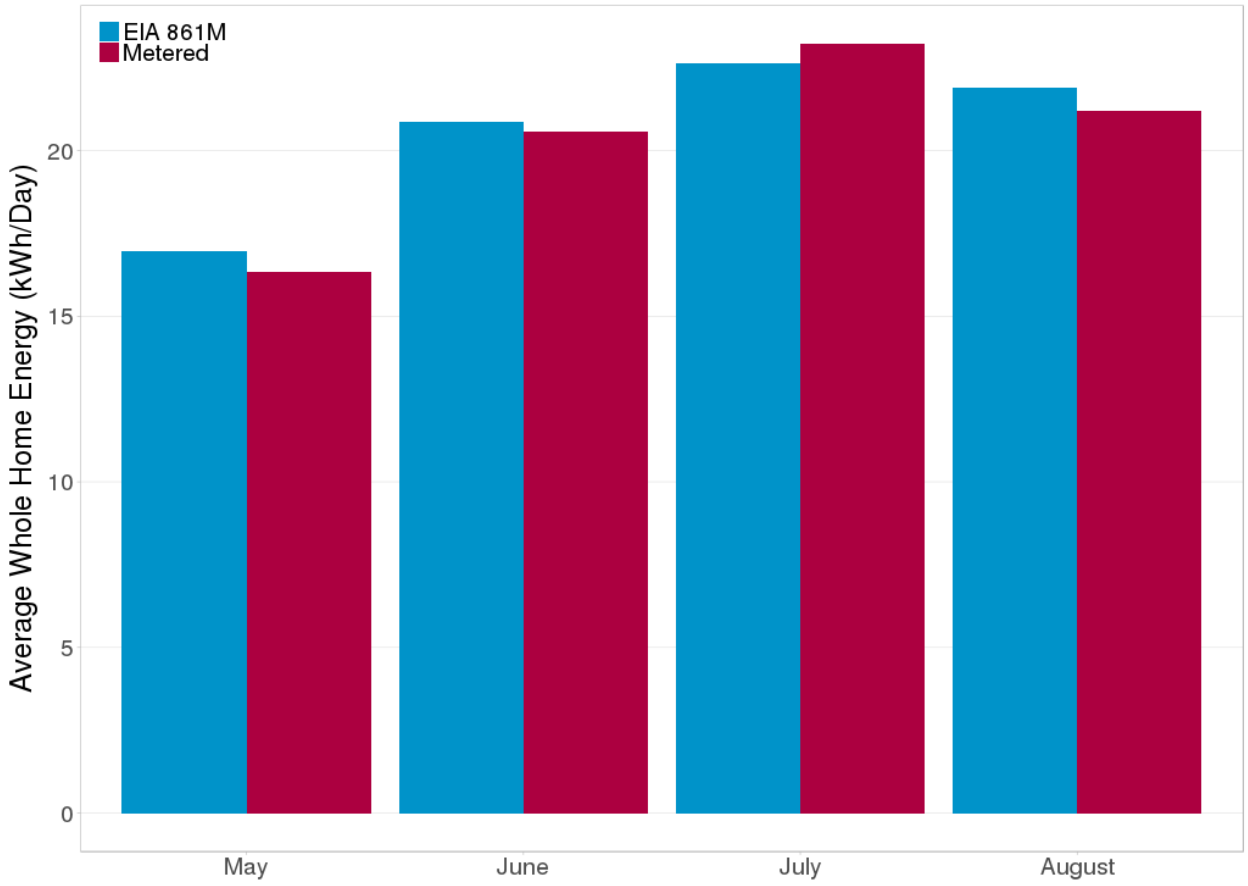
2.1 Energy Consumption

A wide variety of end uses contributes to overall energy consumption. The end use specific energy consumption values for the summer metering period (June 1, 2017 through September 30, 2017) are shown in Table 2. The saturations listed in the first column of the table were collected as part of this study and delivered to the PAs on July 17, 2017.

As a quality control check, Navigant compared the latest EIA-861M-derived consumption per customer, per day for Massachusetts residential customers to the metered consumption per study participant, per day for May through August.[9] The results, shown in Figure 2, illustrate that study participants had monthly consumption for May through August within 2% of the statewide average, verifying that the metered sample is representative of the consumption of the overall population.

[9] EIA-861M (formerly EIA-826) data provides monthly billed energy and number of customers for the state of Massachusetts. Navigant lagged US Energy Information Administration (EIA) data by half a month, based on previous experience working with this data.

Figure 3. Average Monthly EIA-861M and Metered Energy Consumption (kWh/Day)



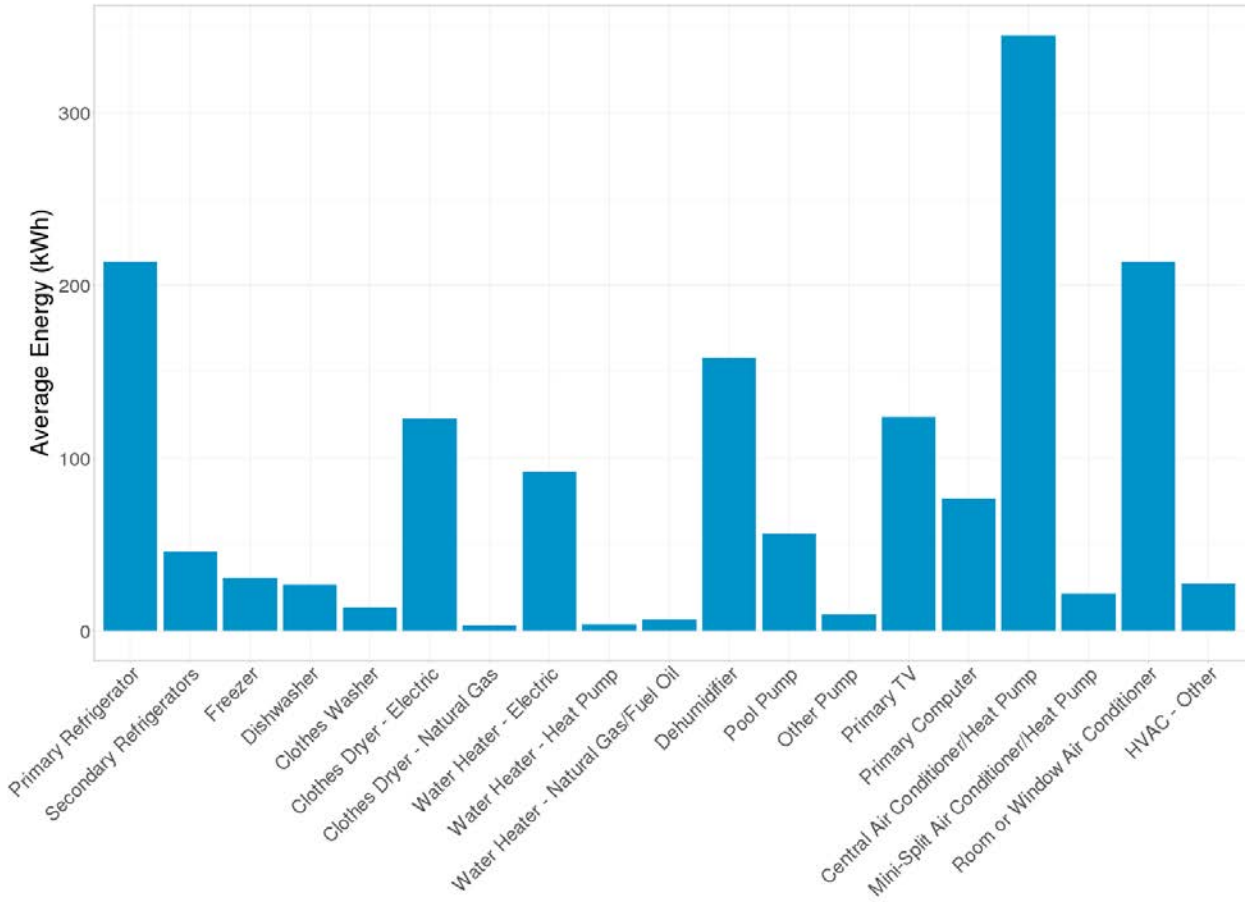
Key Finding: *The average metered consumption across sampled homes aligns well with the Massachusetts average per-home energy consumption.*

Source: Navigant analysis, US Energy Information Administration

The energy consumption of each end use across the population is shown in Figure 4. There are several end uses within various categories that contribute to the overall energy consumption in Massachusetts, including central AC, room AC, primary refrigerators, dehumidifiers, water heating, and clothes dryers.

This report will draw attention to opportunities that the research team has identified in these areas in particular.

Figure 4. End Use Specific Energy Consumption for the Population by End Use (kWh)



Key Finding: *The top contributors to summer season energy consumption across all homes in Massachusetts are central air conditioners, room air conditioners, primary refrigerators, dehumidifiers, primary TVs, and clothes dryers.*

The number of occupants and weekday occupancy are highly correlated with overall energy usage, as shown in Figure 5. Owner-occupied homes and single family detached homes also tended to have higher

energy use. 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.

Figure 5. Average Summer Energy Consumption by End Use Category and Building/Occupancy Demographics

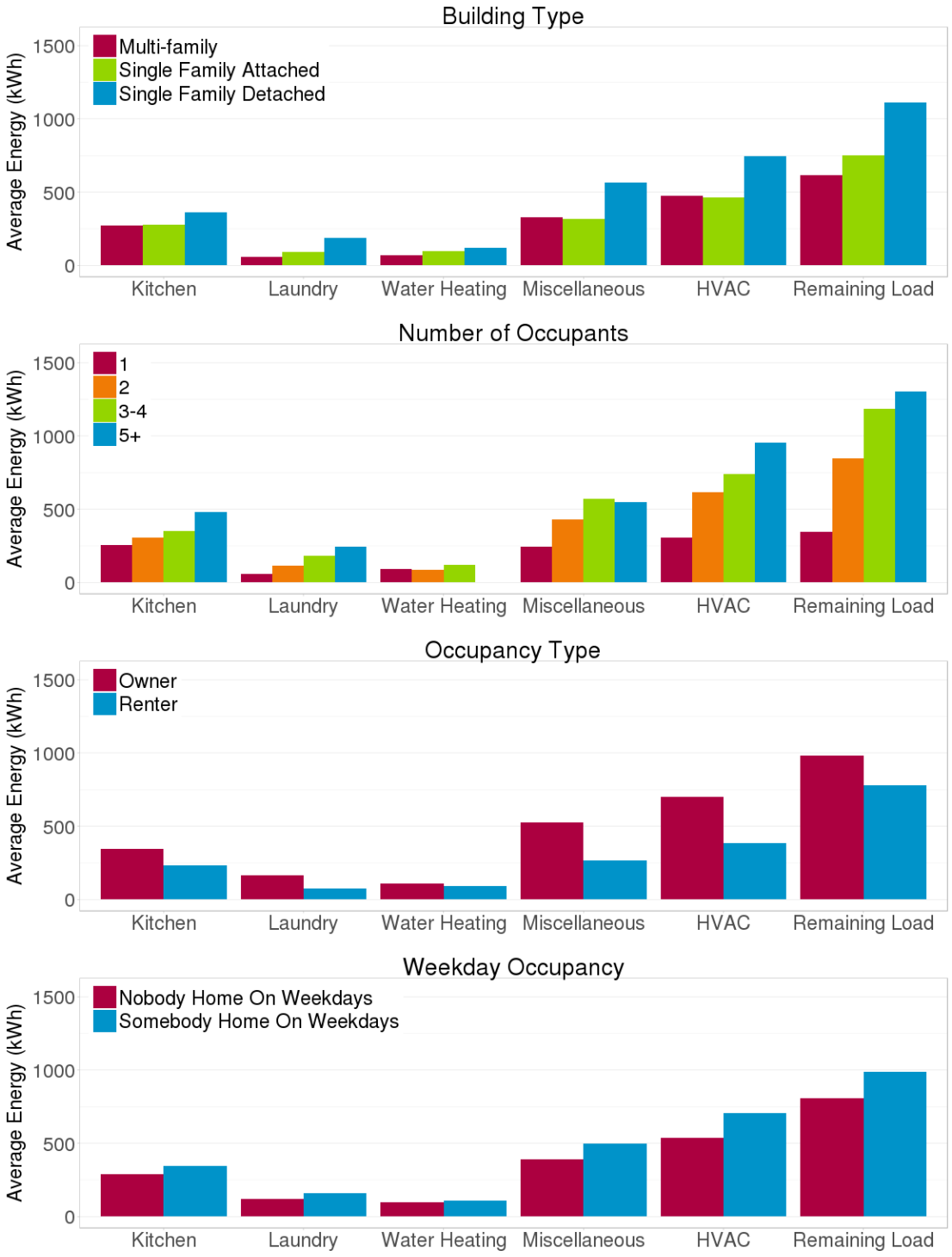


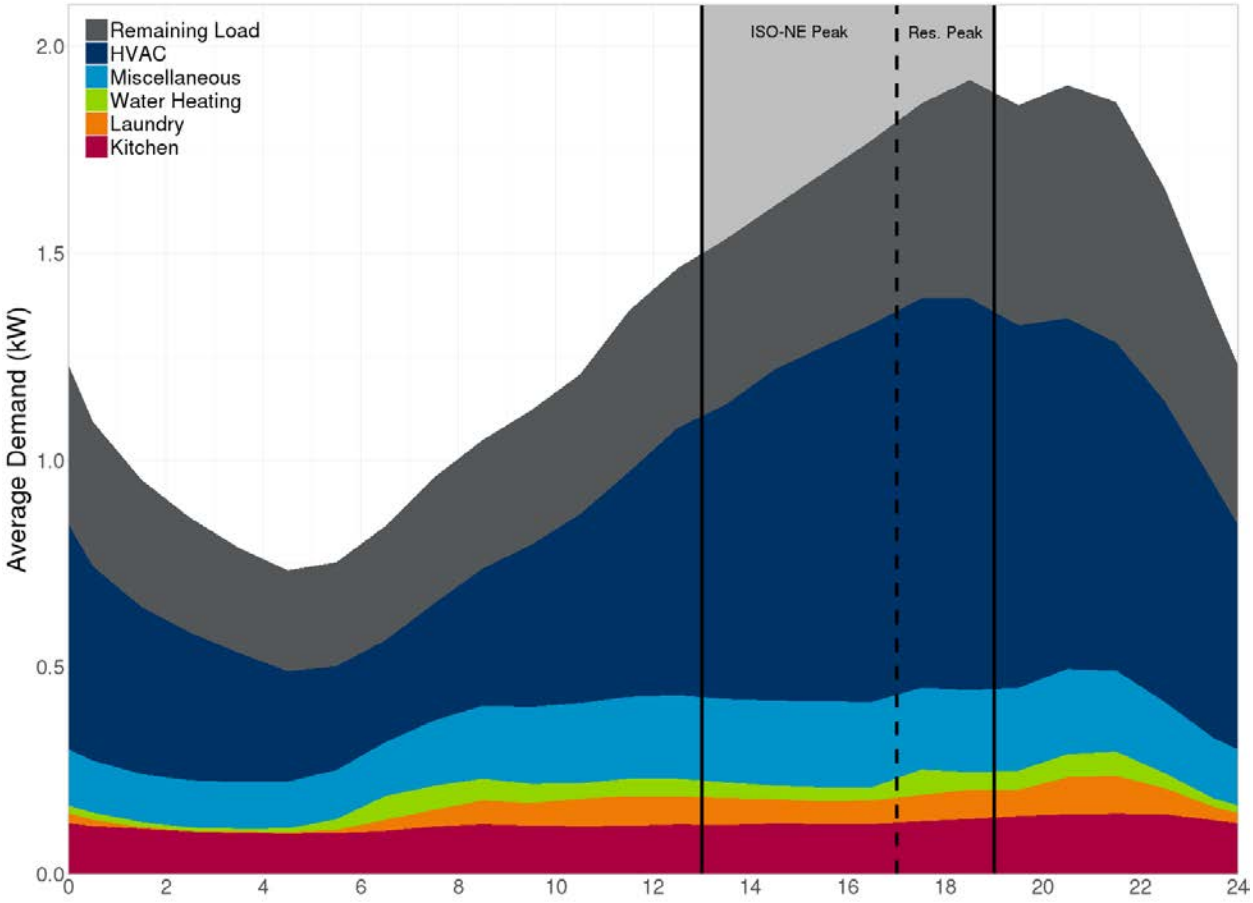
Table 2. Summer (June 1 through September 30, 2017) Energy Consumption by End Use

End Use Category	End Use	Saturation Across MA Homes [A]	Summer Energy Per Home with End Use (kWh) [B]	Population Summer Energy Per Home (kWh) [C = A x B]	Percent of Summer Energy Load (%) [C/∑C]
Heating, Cooling, and Ventilation	Central Air Conditioner/Heat Pump	0.28	1210	344	13%
	Room or Window Air Conditioner	0.48	466	222	9%
	Mini-Split Air Conditioner/Heat Pump	0.051	422	22	1%
	HVAC - Other	N/A	N/A	35	1%
	HVAC Total	**N/A**	**N/A**	**622**	**24%**
Water Heating	Water Heater - Electric	0.14	679	92	4%
	Water Heater - Natural Gas/Fuel Oil	0.4	17	7	< 0.5%
	Water Heater - Heat Pump	0.011	343	4	< 0.5%
	Water Heating Total	**N/A**	**N/A**	**103**	**4%**
Kitchen	Primary Refrigerator	0.99	218	215	8%
	Secondary Refrigerators	0.28	168	46	2%
	Freezer	0.2	150	30	1%
	Dishwasher	0.69	39	27	1%
	Kitchen Total	**N/A**	**N/A**	**319**	**12%**
Laundry	Clothes Dryer - Electric	0.53	234	123	5%
	Clothes Washer	0.73	18	14	1%
	Clothes Dryer - Natural Gas	0.21	17	3	< 0.5%
	Laundry Total	**N/A**	**N/A**	**140**	**6%**
Miscellaneous	Dehumidifier	0.35	431	153	6%
	Primary TV	0.93	133	124	5%
	Primary Computer	0.76	102	78	3%
	Pool Pump	0.06	939	56	2%
	Other Pump	N/A	N/A	9	< 0.5%
	Misc. Metered	N/A	N/A	22	1%
	Miscellaneous Total	**N/A**	**N/A**	**441**	**17%**
Remaining Load	Unknown	N/A	N/A	944	37%
All	**Total All End Uses**	**N/A**	**N/A**	**2,569**	**100%**

2.2 Peak Demand

The end use peak day load shapes by category with both peak periods highlighted are shown in Figure 6, which illustrates that both summer peak demand values are driven primarily by HVAC loads and loads not individually metered in this study. Cooling drives most of the residential and ISO-NE peak demand. The end use specific average peak demand values for the summer metering period (June 1, 2017 – September 30, 2017) are shown in Table 3. The saturations listed in the first column of Table 3 were collected as part of this study and delivered to the PAs on July 17, 2017.

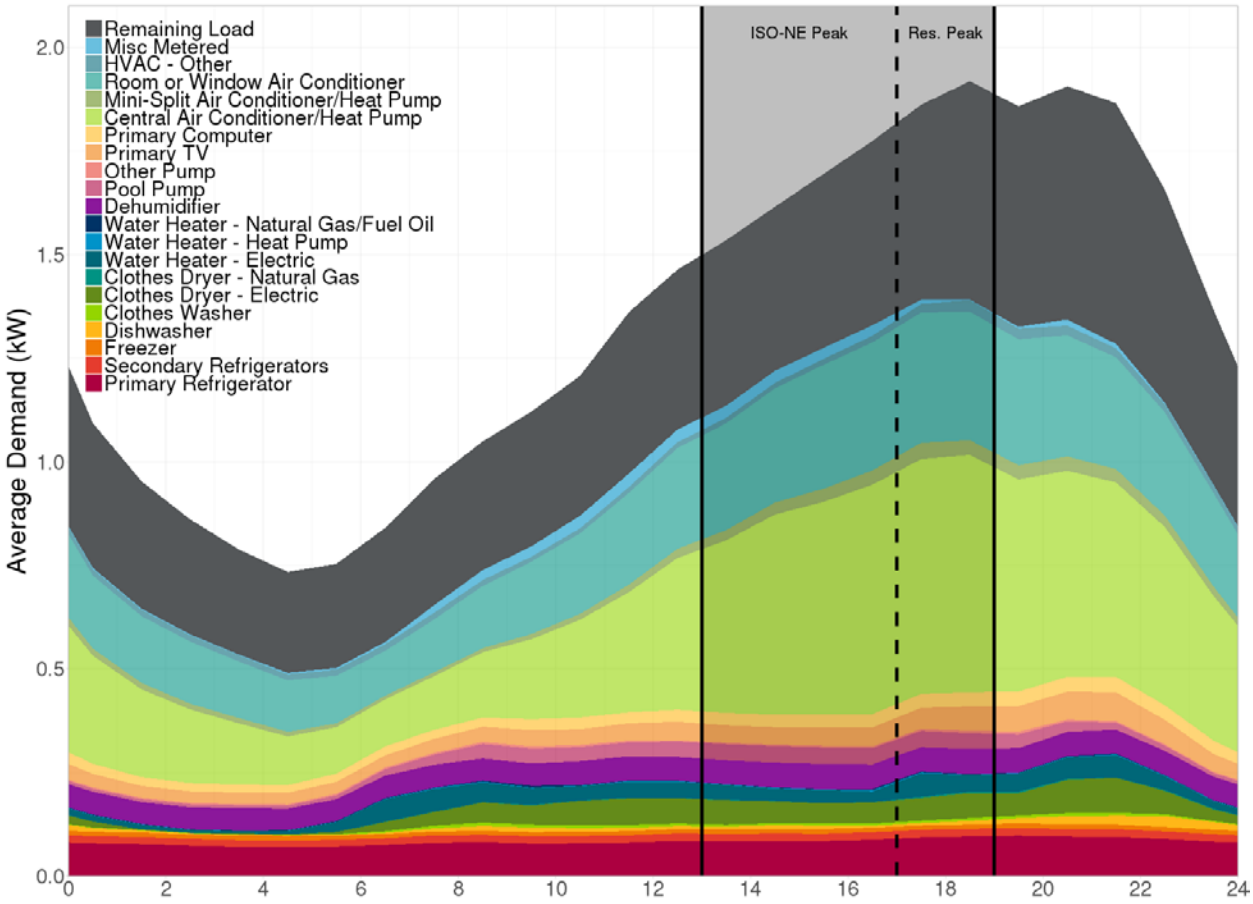
Figure 6. End Use Category Load Shapes with Peak Periods Highlighted



Key Finding: Cooling is responsible for half of peak demand. *The top contributors to summer peak demand across all homes in Massachusetts are central air conditioners and room air conditioners.*

Figure 7 shows the load shapes of all metered end uses.

Figure 7. End Use Load Shapes with Peak Periods Highlighted



Key Finding: *Refrigerators, dehumidifiers, clothes dryers, primary TVs and their peripherals, and pool pumps account for an additional 17% of summer peak in Massachusetts.*

Figures 8 and 9 show the end use ISO-NE summer peak demand for homes with the end use, and averaged across all homes. Figure 10 and 11 show the peak demand for high users of each end use, which is much higher than the average for many end uses, and the fraction of homes with the end use who consume more than a given threshold (0.2 kW) during peak.

Figure 8. ISO-NE Summer Peak Demand for Homes with End Use

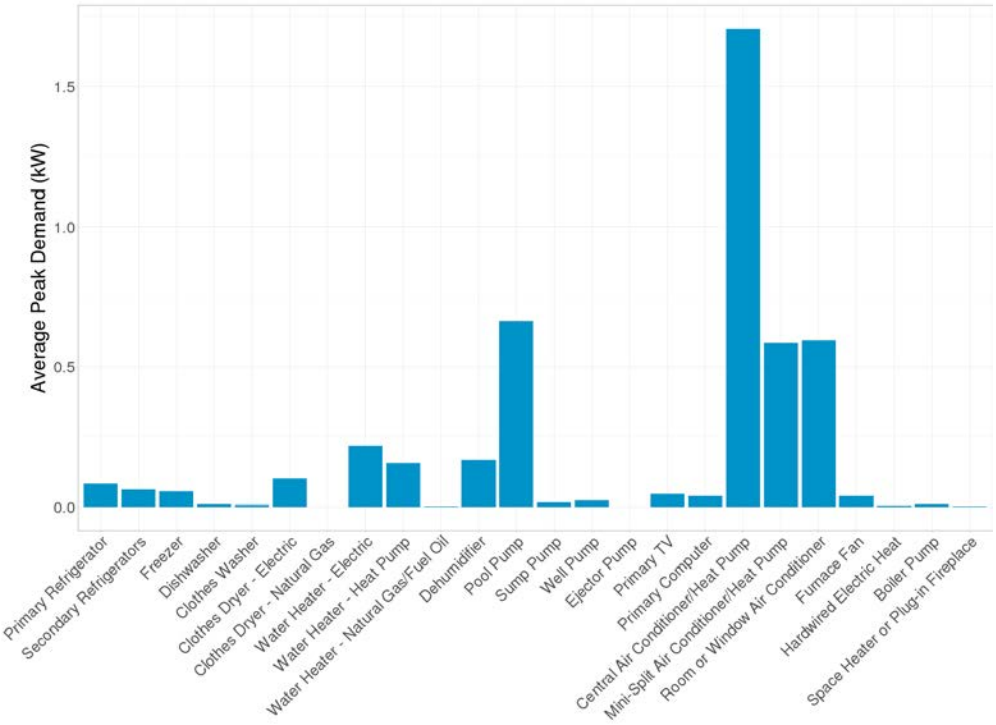


Figure 9. ISO-NE Summer Peak Demand for Population

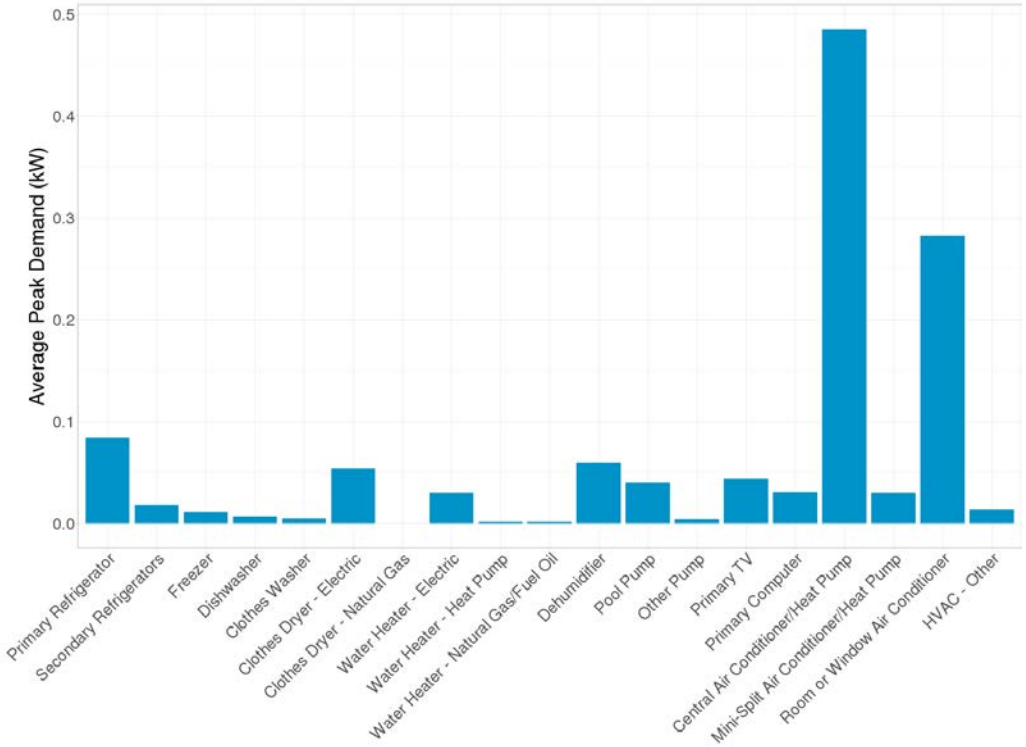


Figure 10. ISO-NE Summer Peak Demand for Top 25% of Users of Each Metered End Use

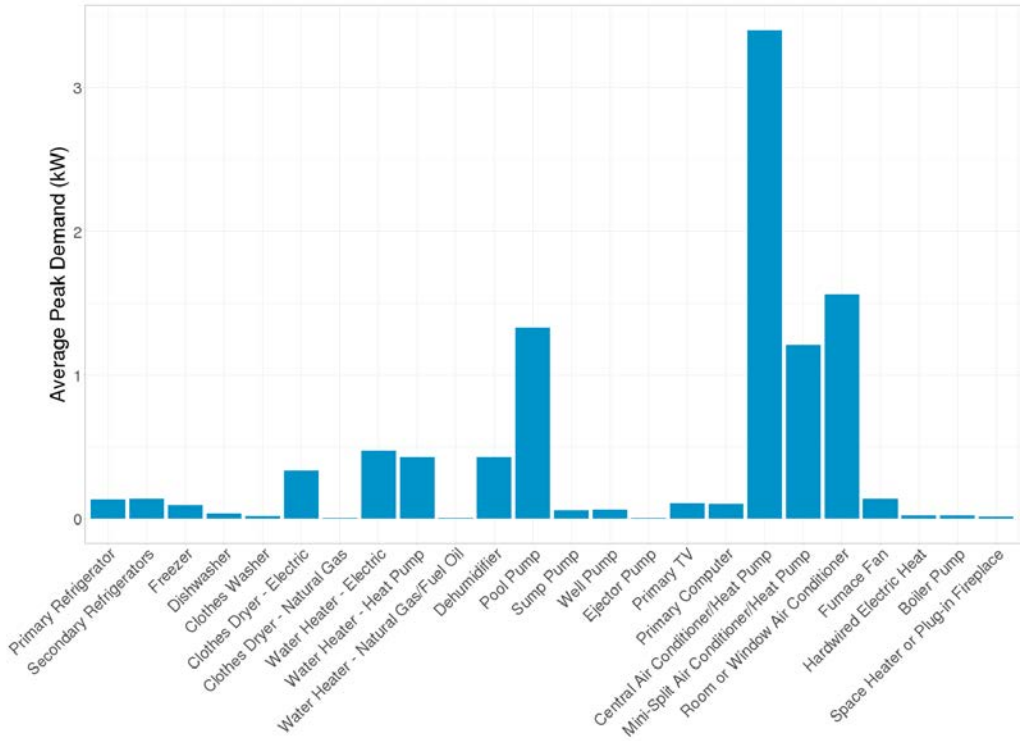


Figure 11. Proportion of Homes with Average ISO-NE Summer Peak Demand Greater than 0.2 kW for Each Measured End Use

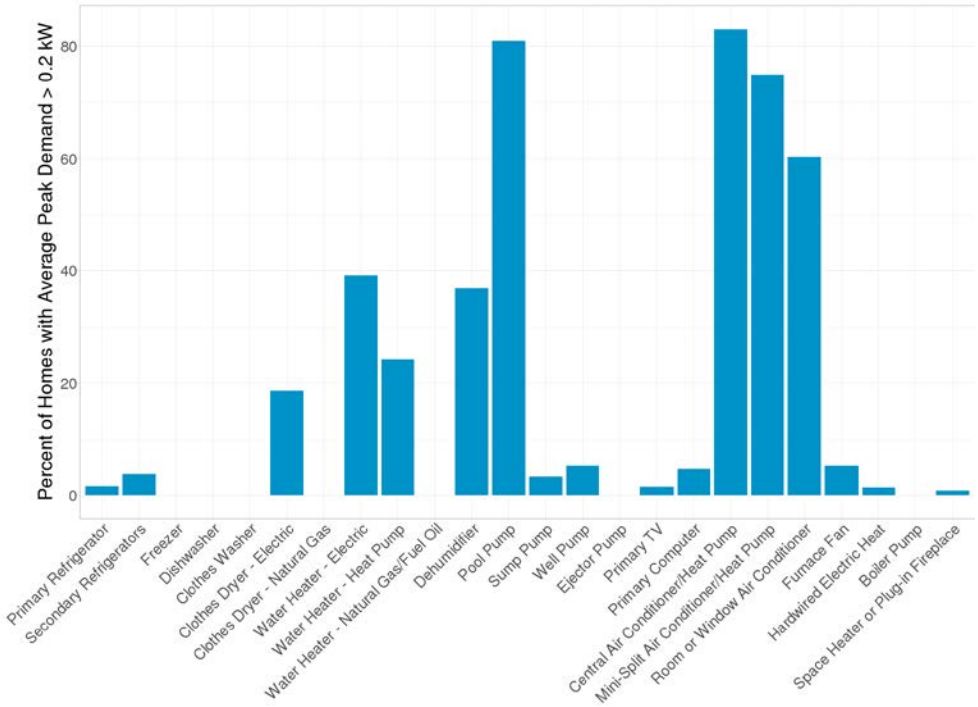


Figure 12 illustrates the average summer peak demand varying by building type, number of occupants, occupancy type, and weekday occupancy. As expected, the greatest opportunity for peak demand savings continues to be HVAC end uses in owned, single family homes with multiple occupants.

Figure 12. Average Summer ISO-NE Peak Demand by End Use Category and Building/Occupancy Demographics

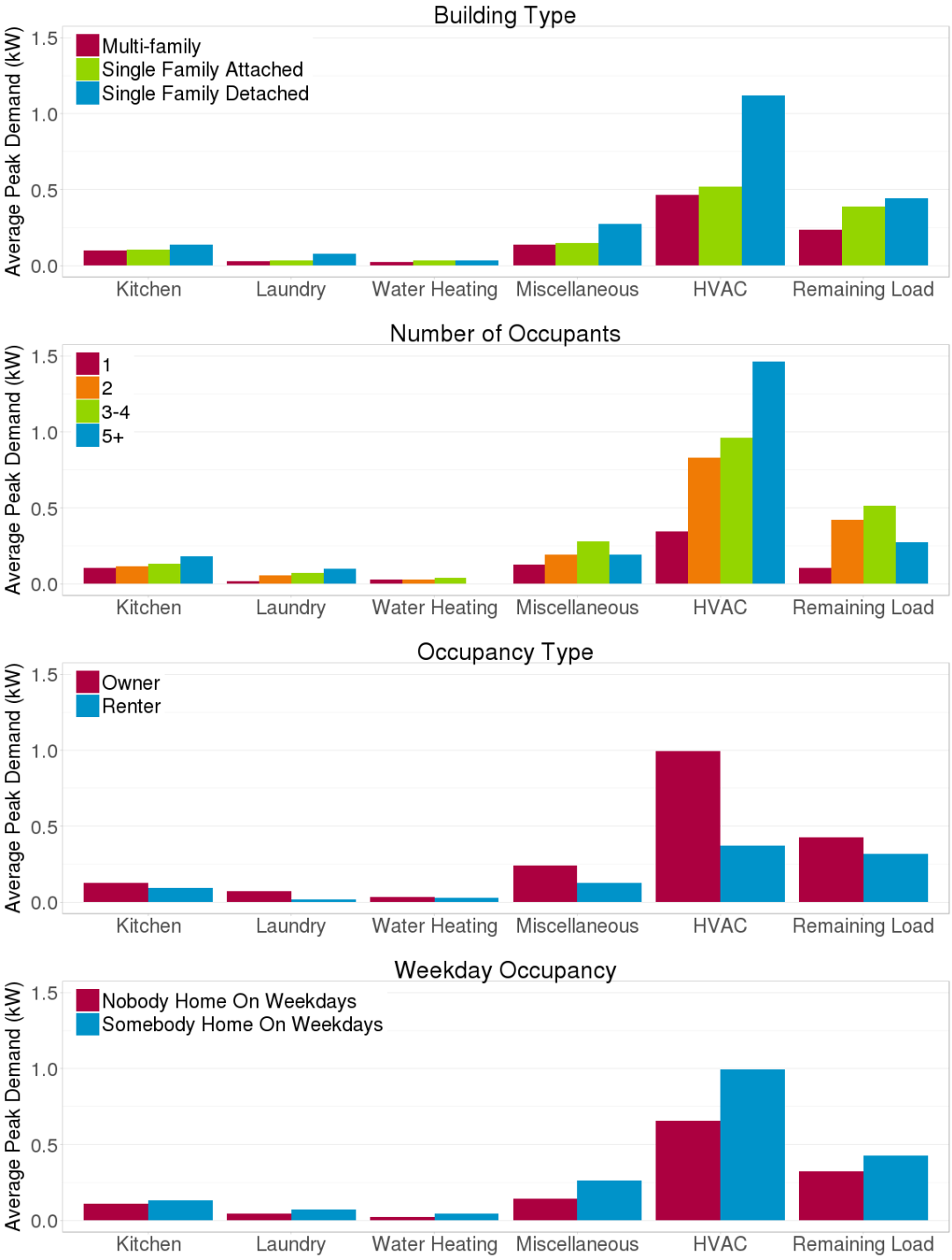


Table 3. Summer Peak Demand by End Use

End Use Category	End Use	Saturation Across MA Homes [A]	ISO-NE Peak Demand for Homes with End Use (kW) [B]	Residential Demand Per Home (kW) [C]	Average Population ISO-NE Peak Demand (kW) [D = A X B]	Average Population Res. Demand (kW) [E = A X C]	Percent of System Average Res. Peak Load (%) [E/∑E]
Heating, Cooling, and Ventilation	Central Air Conditioner/HP	0.28	1.73	2.01	0.49	0.57	30%
	Room or Window AC	0.48	0.60	0.66	0.29	0.31	17%
	Mini-Split AC/HP	0.051	0.58	0.73	0.03	0.038	2%
	HVAC - Other	N/A	N/A	N/A	0.014	0.024	1%
	HVAC Total	**N/A**	**N/A**	**N/A**	**0.82**	**0.94**	**50%**
Water Heating	Water Heater - Electric	0.14	0.23	0.36	0.031	0.049	3%
	Water Heater - Heat Pump	0.011	0.16	0.13	0.0017	0.0015	< 0.5%
	Water Heater – Nat. Gas/ Oil	0.40	0.0032	0.0043	0.0013	0.0017	< 0.5%
	Water Heating Total	**N/A**	**N/A**	**N/A**	**0.034**	**0.052**	**3%**
Kitchen	Primary Refrigerator	0.99	0.086	0.095	0.085	0.094	5%
	Secondary Refrigerators	0.28	0.065	0.069	0.018	0.019	1%
	Freezer	0.20	0.055	0.051	0.011	0.010	1%
	Dishwasher	0.69	0.01	0.011	0.0069	0.0074	< 0.5%
	Kitchen Total	**N/A**	**N/A**	**N/A**	**0.12**	**0.13**	**7%**
Laundry	Clothes Dryer - Electric	0.53	0.10	0.11	0.053	0.057	3%
	Clothes Washer	0.73	0.0069	0.0087	0.0051	0.0064	< 0.5%
	Clothes Dryer - Natural Gas	0.21	0.0015	0.013	0.00030	0.0028	< 0.5%
	Laundry Total	**N/A**	**N/A**	**N/A**	**0.058**	**0.067**	**4%**
Miscellaneous	Dehumidifier	0.35	0.17	0.17	0.059	0.060	3%
	Primary TV	0.93	0.047	0.059	0.044	0.055	3%
	Pool Pump	0.06	0.66	0.65	0.040	0.039	2%
	Primary Computer	0.76	0.041	0.045	0.031	0.034	2%
	Other Pump	N/A	N/A	N/A	0.0037	0.0057	< 0.5%
	Misc. Metered	N/A	N/A	N/A	0.028	0.0058	< 0.5%
	Miscellaneous Total	**N/A**	**N/A**	**N/A**	**0.21**	**0.20**	**11%**
Remaining Load	Unknown	N/A	N/A	N/A	0.42	0.49	26%
All	**Total All End Uses**	**N/A**	**N/A**	**N/A**	**1.65**	**1.89**	**100%**

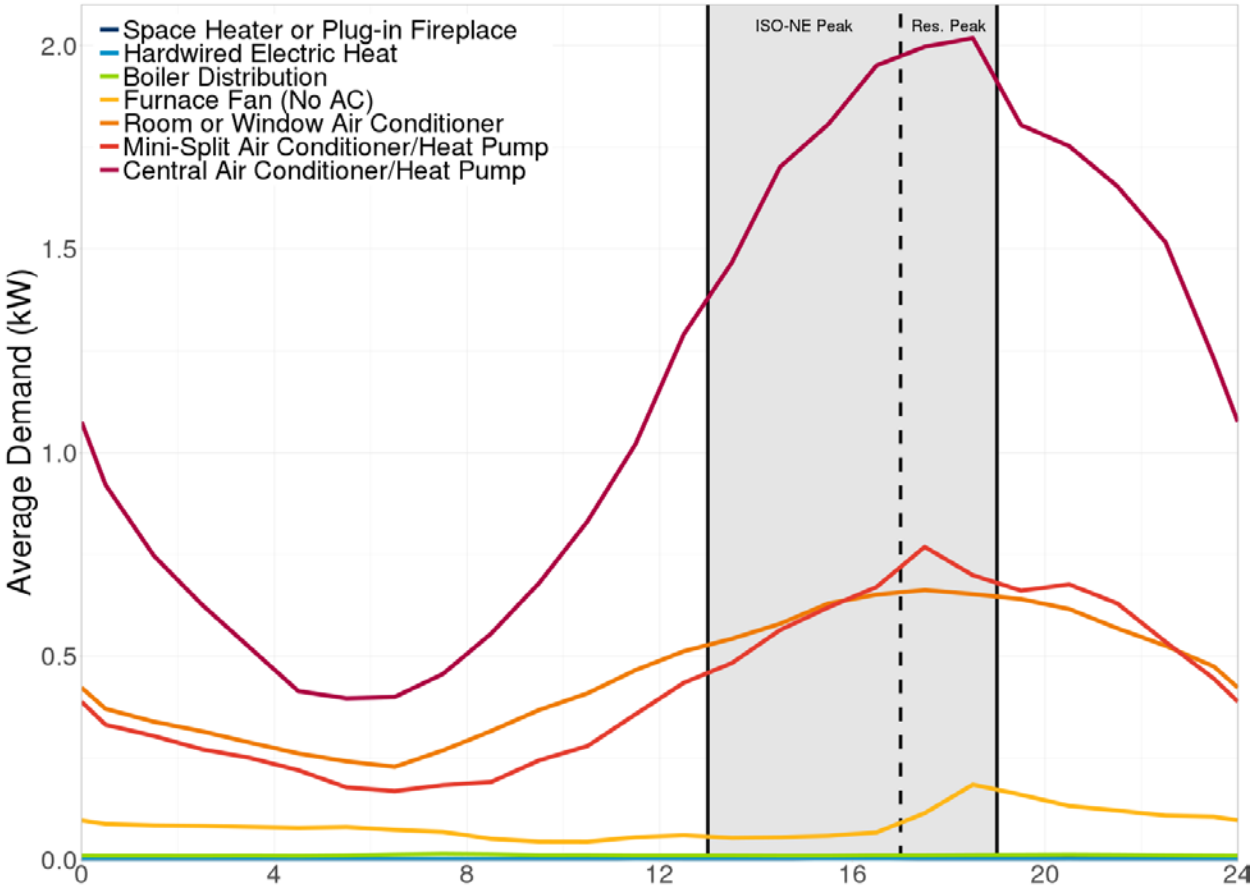
2.3 End Use Specific Findings

This section provides plots and key findings by end use category for a closer look at how each end use contributes to total energy consumption and peak demand.

2.3.1 Heating, Cooling, and Ventilation End Uses

Cooling-season HVAC end uses are the primary driver of the summer peak loads. As shown in Figure 13, 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 a little bit later than the central AC load.

Figure 13. Peak Day HVAC End Use Load Shapes for Homes with End Use

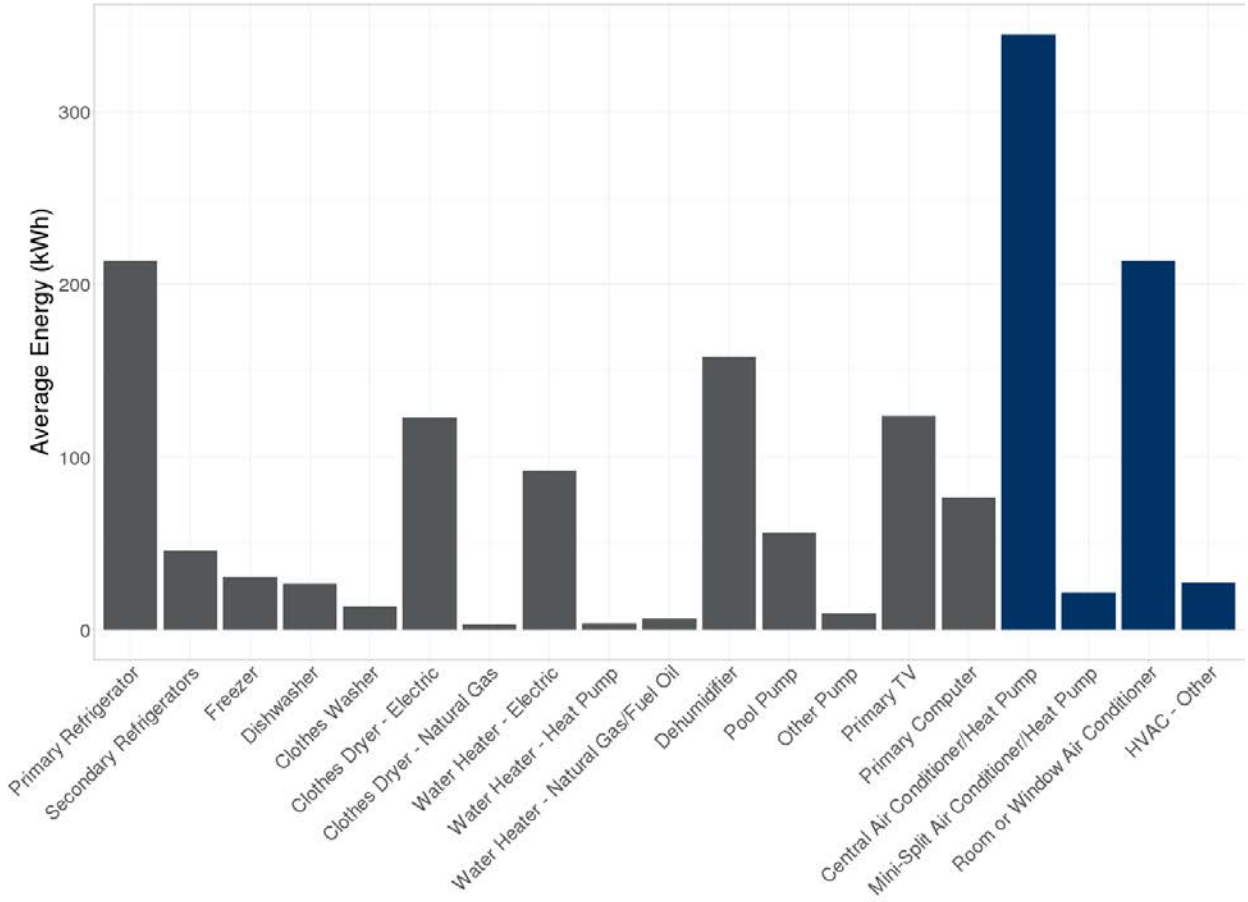


Key Finding: *Central air conditioners are the single most important end use driving both statewide energy consumption and summer peak demand.*

As shown in Figure 14, central air conditioners and room air conditioners are the two largest individual end uses during the summer. It should be noted that some homes have a combination of room AC and

central AC, and that homes cooled entirely with room ACs would have higher room AC demands and energy use than homes partially cooled by room ACs.

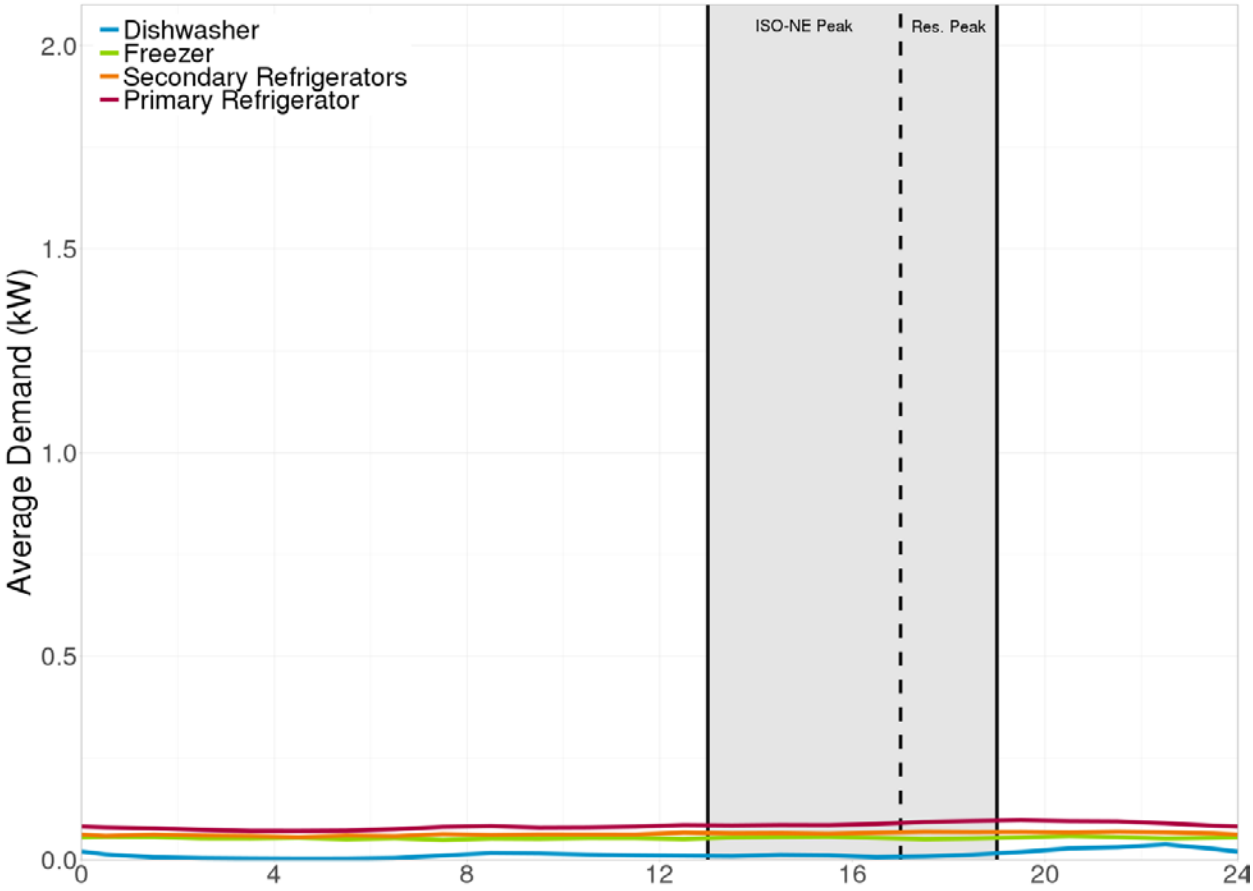
Figure 14. Population Summer End Use Energy Consumption – HVAC End Uses (kWh)



2.3.2 Kitchen End Uses

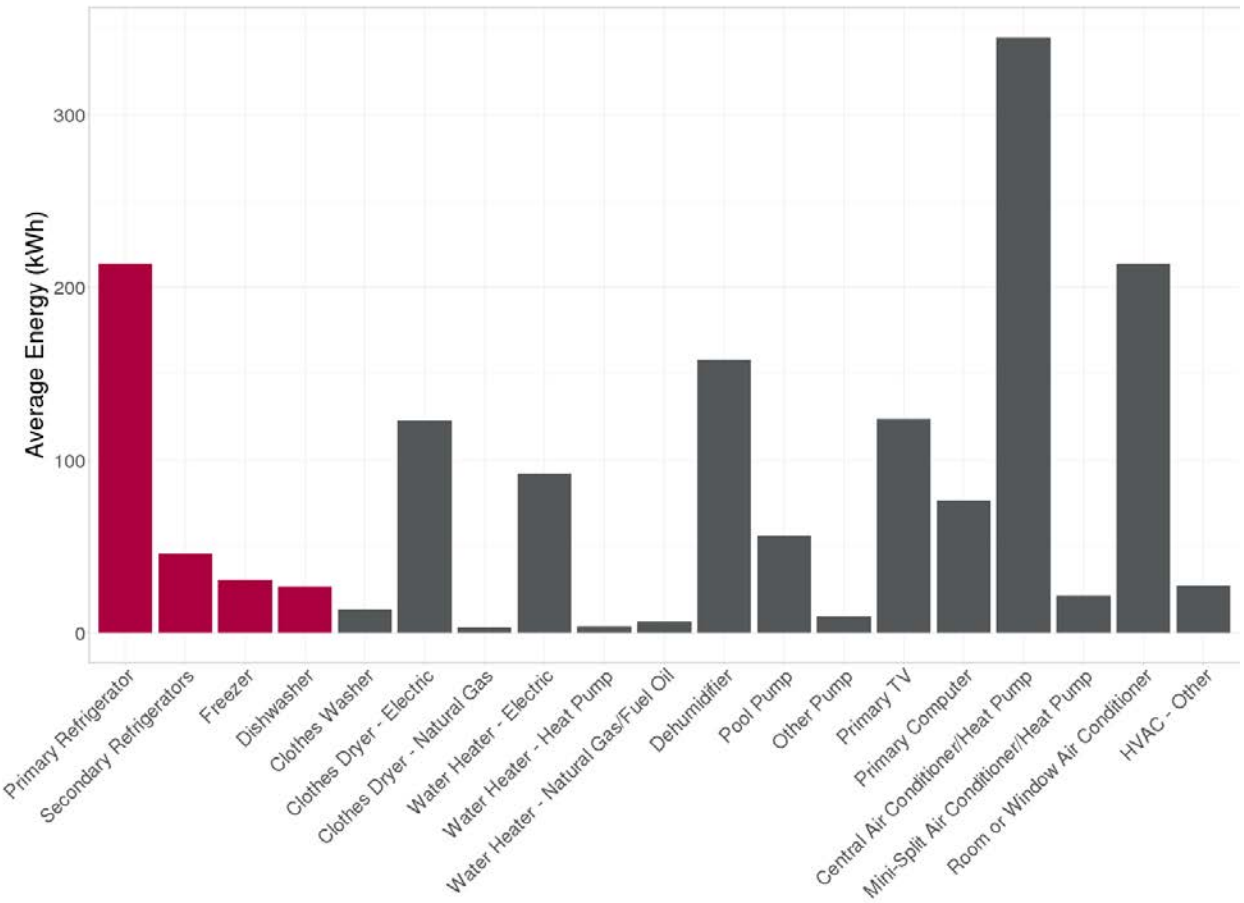
Figure 15 appears to be almost blank, but this is because dishwashers, primary refrigerators, secondary refrigerators, and freezers have low peak demands compared with central AC and other large peak loads.

Figure 15. Peak Day Kitchen Load Shapes for Homes with End Use



Key Finding: *Kitchen end uses add no significant summer peak load to the system, but refrigerators' energy could be considered significant because of their high saturation.*

Figure 16. Population Summer End Use Energy Consumption – Kitchen End Uses (kWh)

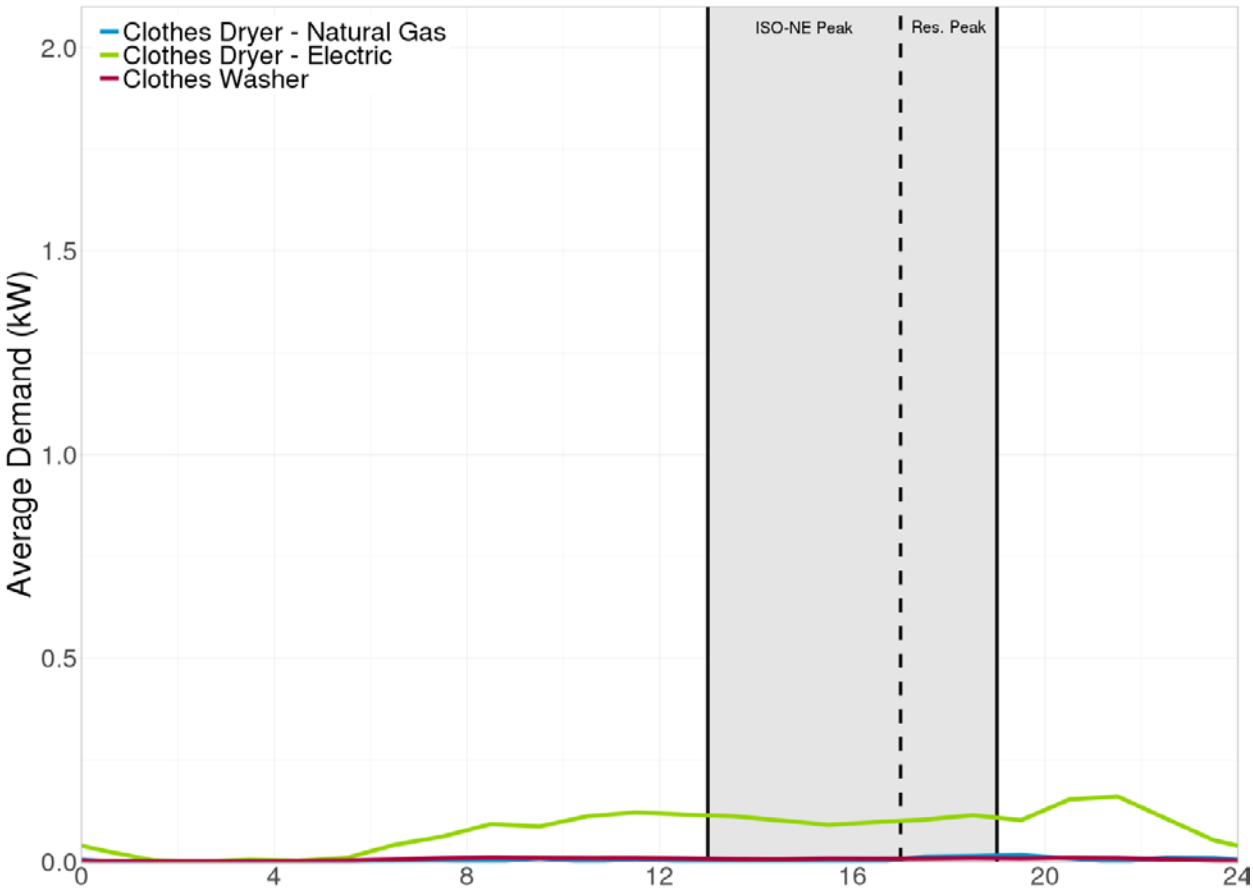


Because refrigerators are in almost all homes and in use 24/7, they show up as one of the largest summer energy consumers in Figure 16. Preliminary findings also show some seasonality to refrigerator and freezer energy consumption, with higher consumption in the middle of summer than in the fall months (See monthly energy consumption plots in Appendix C).

2.3.3 Laundry End Uses

Figure 17 shows that while clothes dryer use peaks late in the day on peak days, there is some use throughout the day. The other laundry end uses have near zero demand.

Figure 17. Summer Peak Day Laundry Load Shapes for Homes with End Use



Key Finding: *Some clothes dryers are used throughout the day, including during afternoon and evening peak.*

Figure 18. Population End Use Summer Energy Consumption – Laundry End Uses (kWh)

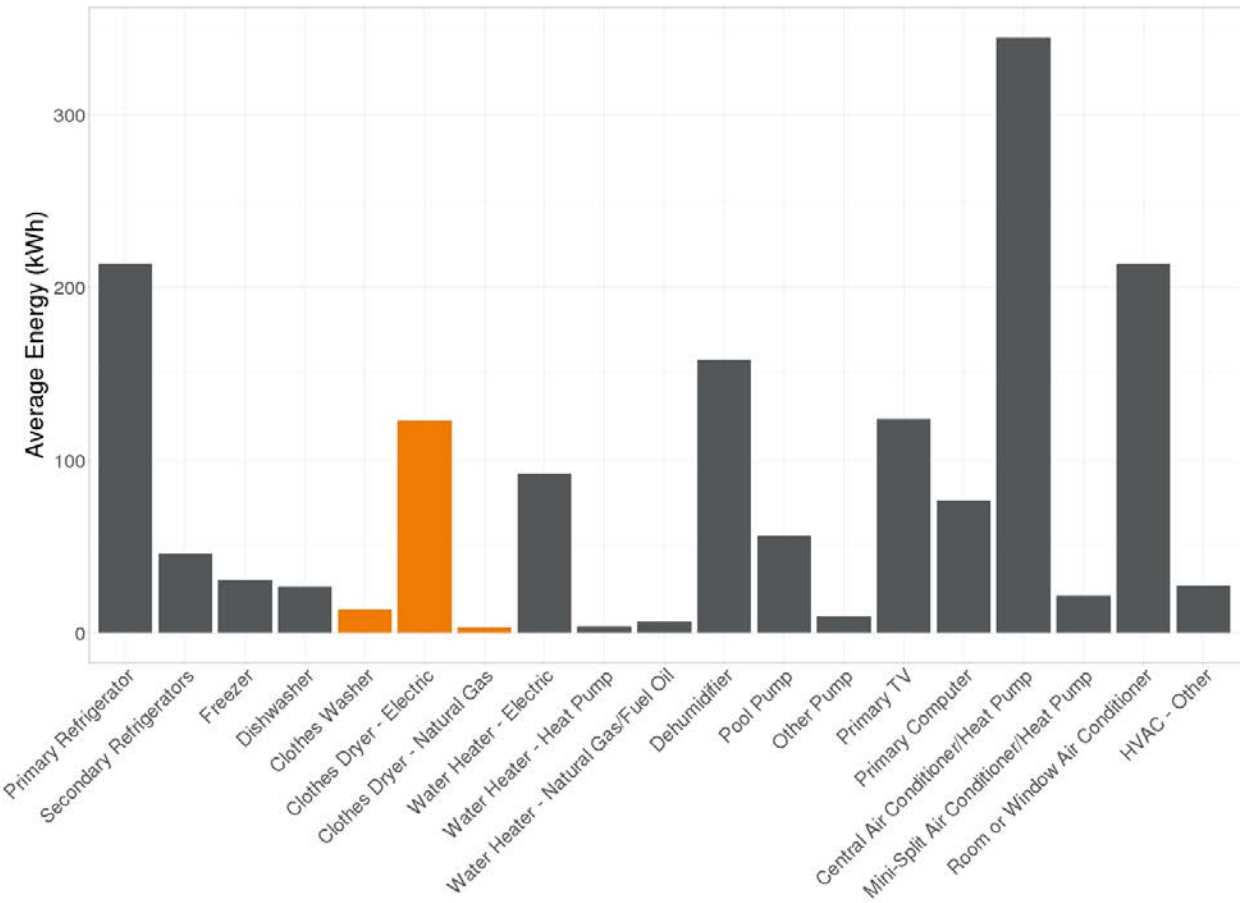
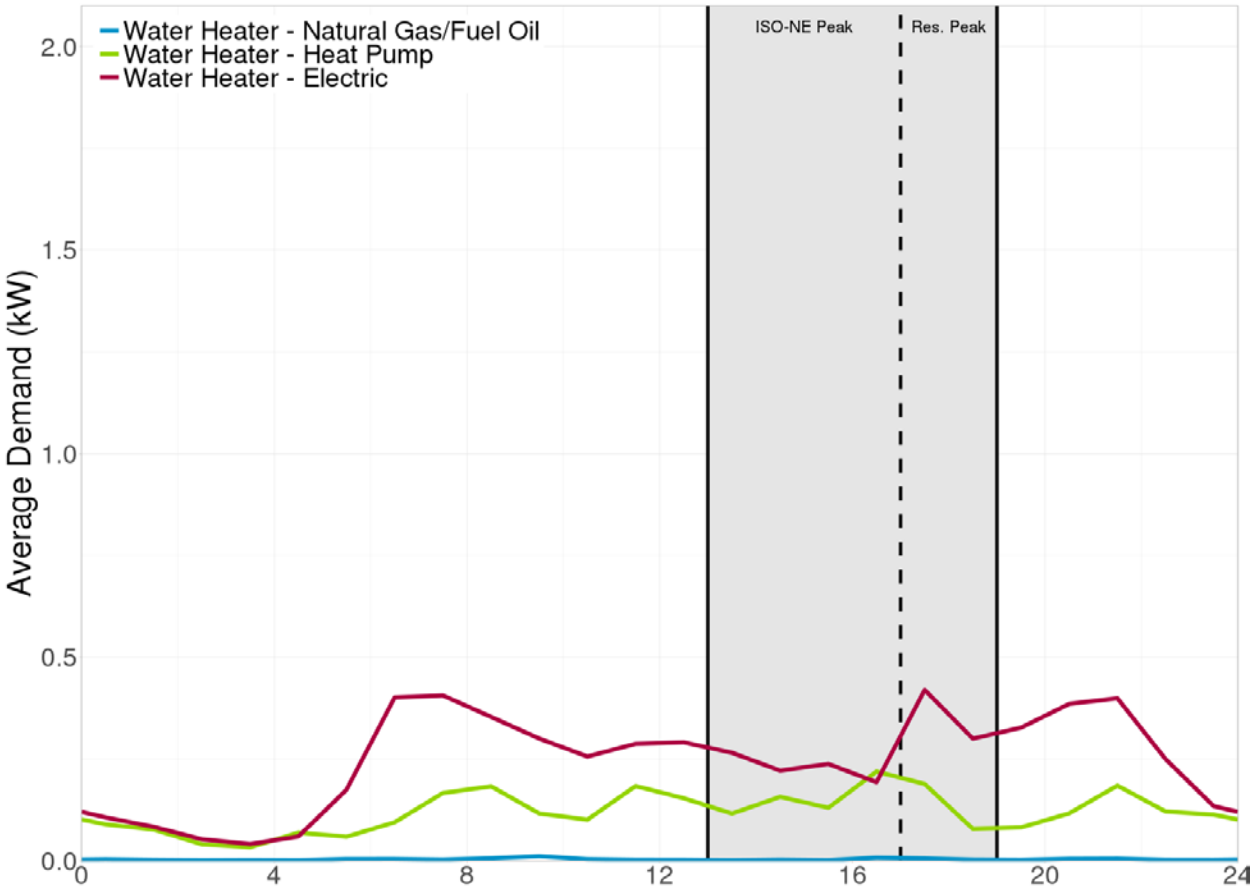


Figure 18 compares laundry end use consumption to energy consumption for other end uses. While clothes dryers have significant summer energy consumption (fifth largest of all end uses), the energy saved by high efficiency clothes washers shows up primarily as reduced clothes dryer energy consumption and secondarily as reduced water heating consumption.

2.3.4 Water Heating End Uses

The study included both regular electric water heaters and an oversample of heat pump water heaters. As shown in Figure 19, the summer peak day load shapes for water heating have a modest double hump, with an initial peak in the morning followed by a second peak in the evening. The shape of heat pump water heaters is based on a relatively small sample of 30 early adopters of the technology, which is indicative of how people use heat pump water heaters today, but may not be representative of long-term adoption. Overall, heat pump water heaters appear to have demands that are about half of regular water heaters, which roughly corroborates the engineering savings estimates. However, the load shapes overlap at 4 p.m. during the peak period. As a result of this anomaly, it may be more appropriate to apply the overall water heating load shape to use in calculating peak demand impacts from heat pump water heaters.

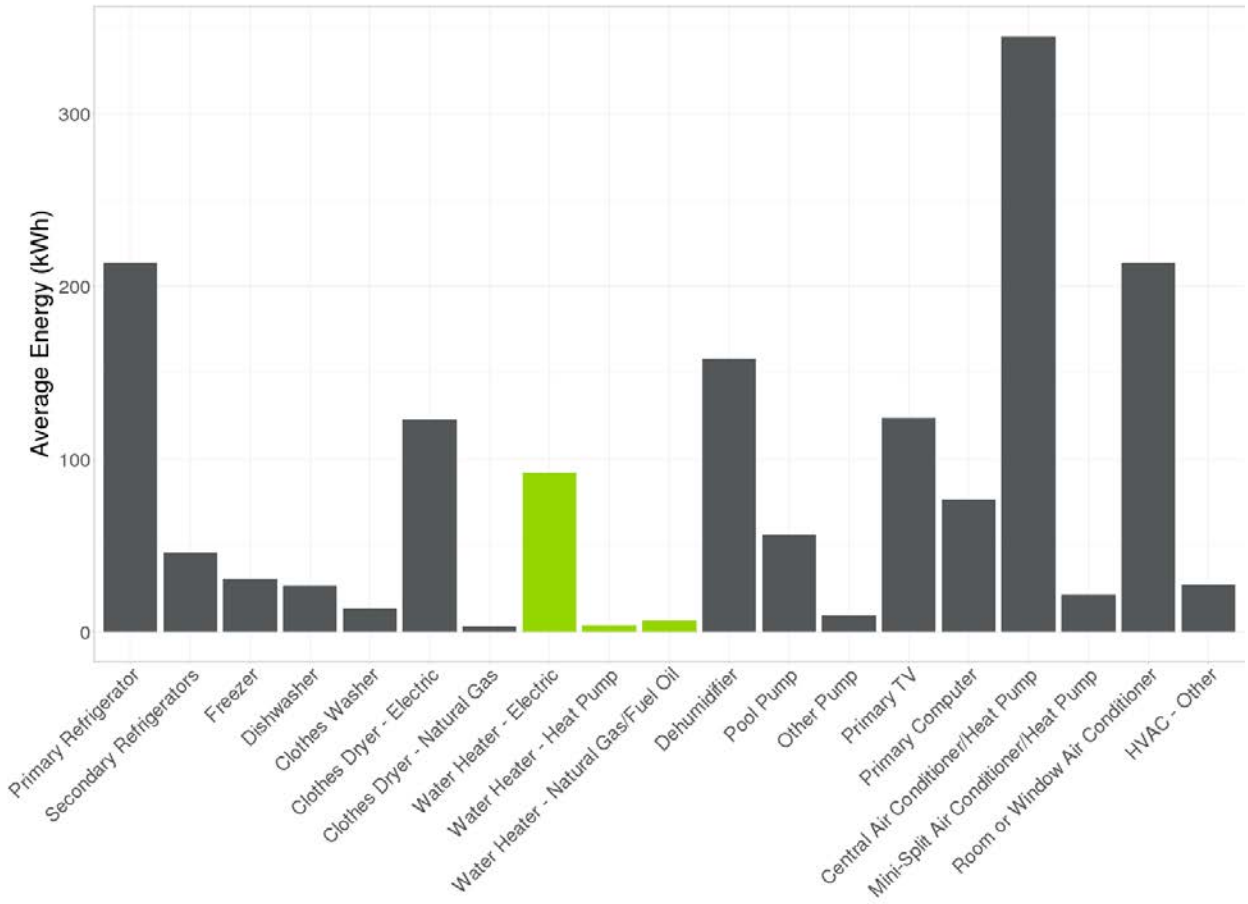
Figure 19. Summer Peak Day Water Heating Load Shapes for Homes with End Use



Key Finding: *Heat pump water heaters have about half of the energy consumption and peak demand of regular electric water heaters, providing potentially significant reductions in peak demand.*

Overall, electric water heating is not a large summer energy consumer in Massachusetts at this time (Figure 20). However, results corroborated model estimates that show there is significant seasonality to water heating consumption, with higher consumption recorded in May and October and lower consumption in August and September. This is consistent with modeled loads using the mains temperature relationship from Christensen and Burch.[10] As a result, electric water heating consumption per day over the whole year is likely to be around 50% higher than metered in the summer. Over time, electric water heating may also become more important as people transition away from using oil boilers to supply space and water heating needs.

Figure 20. Population End Use Summer Energy Consumption – Water Heating End Uses (kWh)



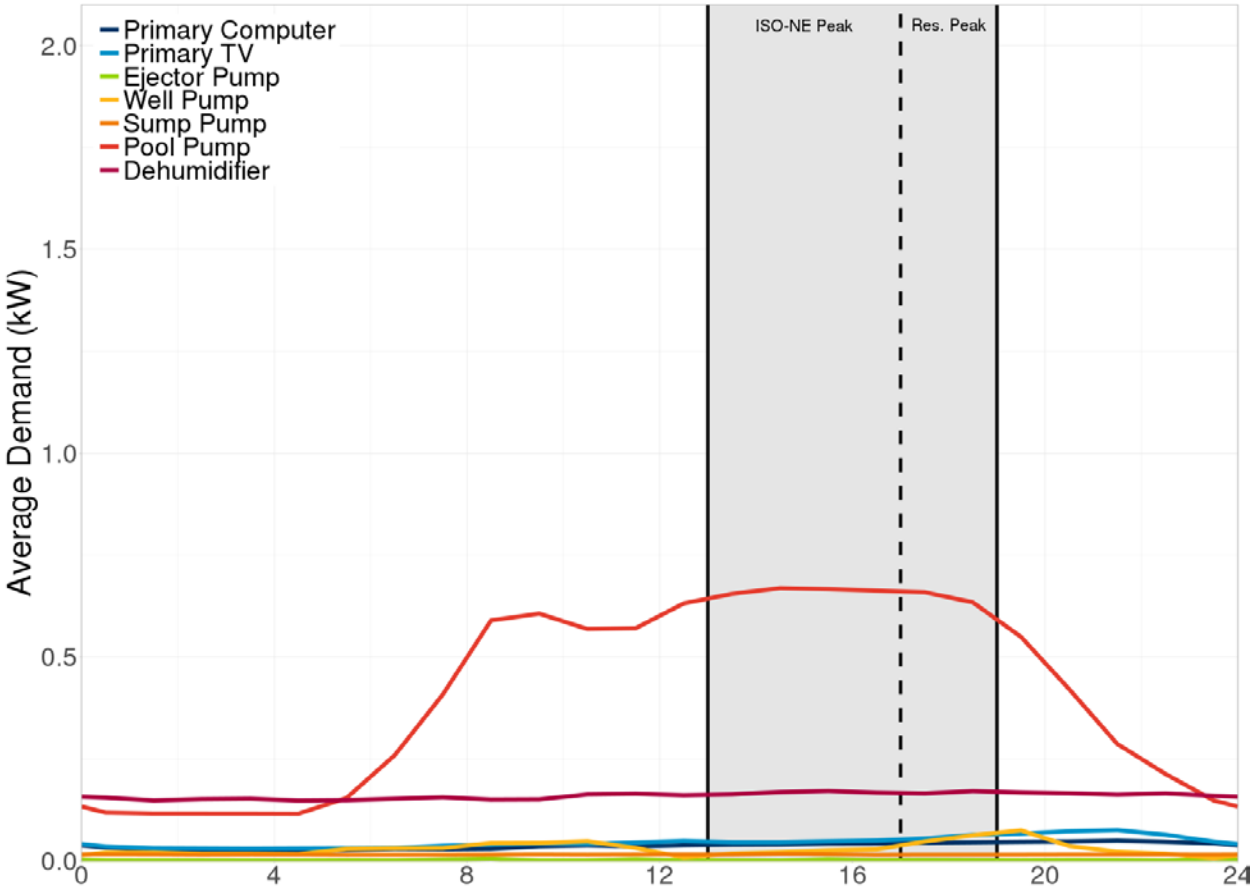
[10] Jay Burch and Craig Christensen, "Towards Development of an Algorithm for Mains Water Temperature." (paper presented at the ASES Annual Conference, Cleveland, Ohio, 2007).

2.3.5 Miscellaneous End Uses

The study targeted a handful of miscellaneous end uses for metering, including primary TV and accessories, primary computer and accessories, pool pumps, dehumidifiers, and a variety of other pumps. As shown in Figure 21, pool pumps are currently used primarily during the day and have large peak demands. Dehumidifiers also have significant demands during peak days.

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

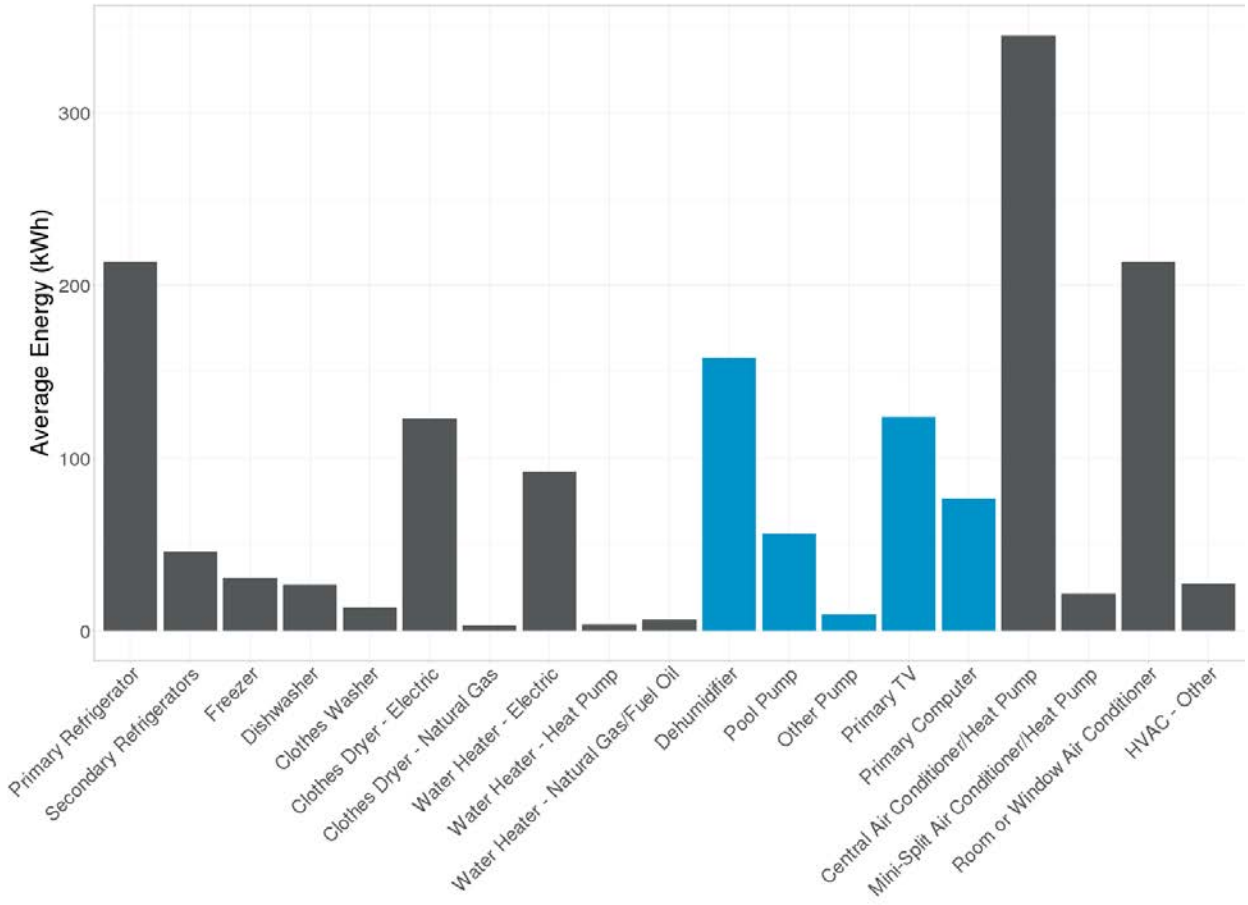
Figure 21. Summer Peak Day Miscellaneous Load Shapes for Homes with End Use



Key Finding: *Dehumidifiers are relatively common and are used 24/7, including during summer peak times.*

Dehumidifiers, primary TVs, primary computers, and pool pumps all have significant summer energy consumption (Figure 22). None of the other pumps (including sump pumps and well pumps) use much energy in Massachusetts.

Figure 22. Population End Use Summer Energy Consumption – Miscellaneous End Uses (kWh)



Key Finding: *Dehumidifiers are the fourth largest summer energy consuming end use.*

3. CONCLUSIONS AND CONSIDERATIONS

Conclusion 1: Across all homes in Massachusetts, central AC and room AC are by far the largest contributors to peak demand. Cooling collectively makes up about half of total residential ISO-NE and residential peak demand.

- Central AC loads averaged 1.7 kW during ISO-peak and room AC loads averaged 0.6 kW.
- Saturation of central cooling (including shared and individual household equipment) increased from 29% in 2008 to 45% of households in 2017, while room AC saturation is dropping (64% in 2008 down to 48% in 2017). The central cooling saturation increase is being driven primarily by increases in the prevalence of individual household ducted central AC and ductless HP.

Consideration 1: Central AC should be the focus of efforts to reduce peak demands, but ductless HP and room AC are also important to a comprehensive program offering.

- Because peak usage is driven as much by EER as by Seasonal Energy Efficiency Ratio (SEER), energy efficiency measures for central AC/HPs should include EER requirements to steer customers towards offerings with higher peak demand savings.
- Massachusetts has significant opportunities for central AC early retirement. Over 40% of central AC systems in Massachusetts have an EER of 9 or lower, which create 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 rest of the end uses, individual homes have a wide variety of significant end use loads during peak times.

- Electric clothes dryers are common (53% of homes), but they had large variability in use compared to other end uses. The bottom half of users did not use their dryers at all during peak times, while the top 25% of users had a mean peak of greater than 0.3 kW.
- Dehumidifiers are relatively common (36% of homes). More than 25% of dehumidifiers were not in use at all during peak times, but the top 25% had a mean peak of greater than 0.4 kW.
- Electric water heaters are uncommon (14% of homes), but they have a mean of 0.2 kW during ISO-peak and the top 25% of users have a mean of 0.5 kW.
- Pool pumps are rare (6% of homes) but they have a mean ISO-peak demand of 0.6 kW.

Consideration 2: PAs should consider targeting high use dehumidifiers, clothes dryers, and pool pumps for additional peak demand savings with low customer impacts while exploring cost-effective control options. Dehumidifiers (13% of all homes), clothes dryers (10% of homes), and pool pumps (5% of homes) all have opportunities for relatively easy peak savings of at least 0.2 kW.

Conclusion 3: Heat pump water heaters appear to use about half as much electricity as domestic water heaters, which corroborates much of the expected savings, at least during the summer.

- Electric water heating load may become more important in the long run if more people switch from oil or propane as heat sources to electricity.
- Once a home has a heat pump water heater, the water heating summer peak demand is relatively small.

Consideration 3: Energy efficiency program offerings should push heat pump water heaters for both energy and demand savings. Demand response offerings for heat pump water heaters will not have large impacts.

APPENDIX A. METHODS

A.1 Online Survey

The online survey was distributed via postcard to 200,300 Massachusetts residents to achieve 6,901 completes. Postcards were mailed to utility account addresses with an invitation to participate in the online survey and a promise of a $10 gift card or check for participating. The invitation postcard also indicated that there would be another opportunity to participate in the metering study to earn $250 more. The primary goal of the survey questions was to understand end use saturation and penetration. The secondary goals of the survey questions were to understand residential customers' motivations for how they use energy and to understand where energy efficiency opportunities exist. Another explicit goal of the survey was to serve as a population frame for the onsite data collection effort.

The online survey was deployed in a modular way so not all survey recipients were asked to respond to all questions, but rather, respondents answered questions about two of the end uses that they have indicated are present in their residence. This allowed the evaluation team to receive an adequate number of detailed survey modules while reducing the burden to the participant. The median survey response took 24 minutes. Bellomy Research programmed and administered the survey and managed the data collection process. The team thoroughly tested the final survey before implementing.

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 4. Reminder postcards were used to boost the representativeness of the sample by increasing the response rate of contacted residents.

Table 4. Survey Recruitment Summary

Wave	Sampling Type	Residents Contacted	Postcards Sent	Complete Responses	Response Rate Per Resident
Pre-test	Random	1,000	1,000	62	6.2%
Wave 1	Random	50,000	150,000	3,364	6.7%
Wave 2	Random	30,000	60,000	978	3.3%
Wave 3	Random	38,000	76,000	1,231	3.2%
Wave 4	Targeted	73,000	73,000	1,038	1.4%
Oversample	Random	8,300	16,600	228	2.7%
Total		**200,300**	**376,600**	**6,901**	**3.4%**

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 A.4, “Data Analysis.”
- 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.

A.2 Onsite Sampling

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 that will 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 occurrence of the end use in the population and the interests of stakeholders in achieving various levels of rigor. Navigant 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 5 shows Navigant’s final sample for each end use of interest, including the targeted values on which the sample was designed. The precision values in the third through fifth columns of the table are the targeted relative precisions at 90% confidence based on the total number of sites in the last column, which 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 electric vehicles have been flagged as explicitly having no specific precision target due to the expense required to achieve the target. The team metered these end uses when they showed up in the core sample, but did not structure the sample to target them. Only anecdotal information from a handful of sites is likely to be derived from this study for these end uses, but the team analyzed these results if there were more than five sites with any given end use.

Table 5. Initial Assumptions for Sample Counts and Resulting Precisions

End Use	Assumed Saturation	Targeted End Use Precision - Energy	Targeted End Use Precision – Residential Peak	Targeted End Use Precision – ISO-NE Peak	Number of Core Sample Sites*	Targeted Number of Oversample Sites	Targeted Total Number of Sites
Central AC/Heat Pump	29%	9.0%	9.5%	6.9%	108	0	108
Room AC	64%	18.4%	23.7%	25.6%	142	0	142
Ground Source Heat Pump	1%	95.2%	100.6%	60.4%	3	0	3
Other Electric Heat	13%	20.1%	22.3%	19.8%	52	26	78
Space Heaters/Plug-in Fireplaces	39%	15.0%	36.8%	28.6%	112	11	123
Boiler Circulator Pump	51%	6.6%	10.2%	4.4%	156	0	156
Other Fuel Furnace Fan	53%	8.1%	2.4%	1.7%	104	0	104
Dishwasher	71%	8.4%	20.5%	22.1%	240	0	240
Freezer	13%	8.5%	6.6%	6.1%	66	0	66
Refrigerator	100%	3.0%	3.1%	2.1%	300	0	300
Second Refrigerator	28%	10.5%	9.7%	7.4%	86	0	86
Hot Water Heater	15%	9.8%	12.0%	11.7%	42	3	45
Tankless Hot Water Heater	0.6%	186.1%	289.8%	202.6%	2	0	2
Heat Pump Water Heater	2%	13.0%	20.3%	22.4%	3	28	31
Washer	86%	7.0%	22.1%	19.6%	262	0	262
Electric Dryer	68%	5.5%	45.1%	14.0%	195	0	195
Dehumidifier	50%	12.7%	12.8%	9.1%	116	0	116
Aquarium	2%	41.1%	41.1%	30.1%	6	0	6
Golf Cart/Large Battery Charger	5%	45.5%	45.5%	34.7%	15	0	15
Well Pump	12%	48.6%	51.8%	35.2%	36	0	36
Sump Pump	30%	36.6%	37.4%	28.7%	44	0	44
Booster Pump	5%	36.3%	2.9%	30.2%	15	0	15
Pool Pump	10%	18.2%	19.1%	15.6%	21	7	28
EV Charger	0.4%	N/A	N/A	N/A	1	0	1
Total					**300**	**178**	**376**

* The sum of core sampled sites is greater than the total because the team will collect data for more than one end use from each site.

A.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 in Table 1.

Navigant installed two types of meters in customer homes:

1. **eGauge:** An energy monitoring system installed in residential electric panels[11]
2. **Onset UX-120 Plug Load Meters:** A meter installed directly between the end use equipment and the power outlet[12]

The eGuage and Onset meter setups are shown in Figure 9 and Figure 10.

Figure 23. eGauge Energy Metering Setup in Customer Homes

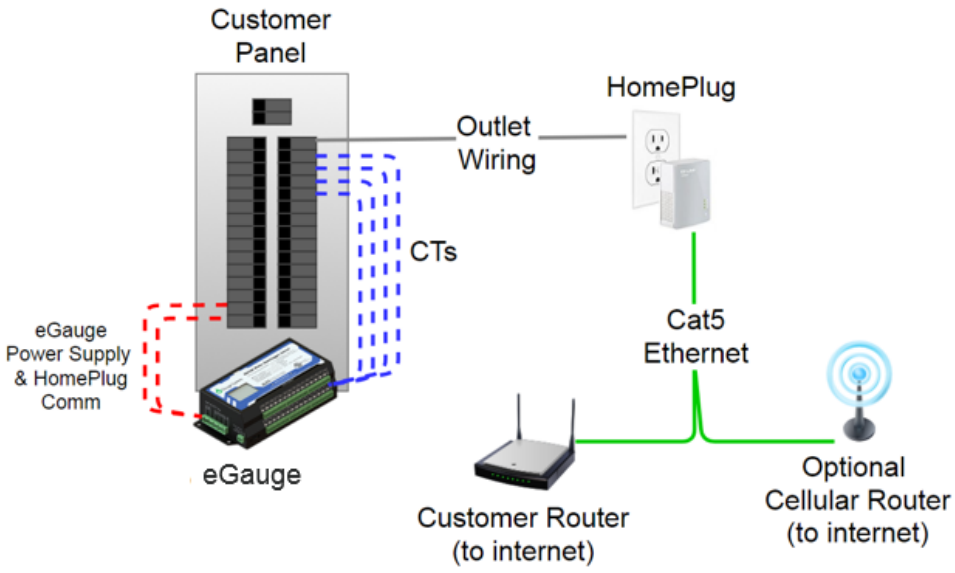


Figure 24. Onset Plug Load Logger Used in Customer Homes

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

[11] For more information about eGauge meters, refer to http://www.egauge.net/products/EG3010/.
[12] For more information about Onset plug load meters, refer to http://www.onsetcomp.com/products/data-loggers/ux120-018.

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, Navigant used the eGauge to meter the equipment as it is able to connect remotely to secure eGauge proxy servers, allowing the analysis team to access the data in real time for analysis and quality control. To establish communication between the eGauge and the proxy server, Navigant utilized 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 on a daily basis to ensure they maintain internet connection and high data quality.

The eGauge metering setup is not appropriate for equipment that are mobile or are not on dedicated electrical circuits, such as space heaters, room air conditioners, and primary televisions. For these equipment, Navigant used the Onset plug load logger, installing it directly between the equipment of interest and the electrical outlet. Navigant 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.

In collaboration with NMR, Navigant installed Tier 1 and Tier 2 smart strips on a sample of logged television and computer equipment in the study.[13] These equipment are logged with plug load meters, which will provide data to support deemed savings assumptions for smart strip equipment installed in customer homes. This pre/post metering study will extend through February 2018, at which point Navigant plans to revisit customer homes to download the plug load meter data. The data collected to date on these end uses is included in the results presented in this report.

[13] Both Tier 1 and Tier 2 smart strips contain controlled outlets that switch on and off using smart sensors for the purpose of reducing power consumption of electronics that are not being used. Tier 1 smart strips use current sensing technology. When the control device (such as TV or PC) is turned on, the controlled equipment plugged into the controlled outlets are also turned off. When the control device is turned off, the accompanying equipment also turn off. Tier 2 smart strips use either a motion and/or remote control infrared activity sensor. In this study, the Tier 2 smart strips are only being used for TV and TV-related peripherals. The strip is programmed to turn the equipment off after a period of inactivity, typically one hour. Both smart strip types have a few "Always On" outlets, used for equipment that must remain on at all times due to customer preference, such as internet routers.

A.4 Data Analysis

The saturation and load shape data analysis followed the steps listed below. 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 of the load shape analysis section below.

Saturation Data Analysis

Data from the online portion for 6,901 respondents was cleaned and summarized to generate saturations for all equipment types in residential homes in MA. Saturations were adjusted based on onsite verification, and post-weighted based on the demographics of the survey respondents and the state of MA.

Step 1: Clean data: For values that appeared to be mistakes in the survey responses: 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 a furnace. For ductless AC units where surveyees indicated the unit could also provide heat, AC was changed HP.

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: 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 impact on saturation results, they were the two demographics where the survey sample and MA population differed the most, and they were not highly correlated with each other.

Step 4: Calculate saturations: For each 1-D and 2-D combination of the demographic "slicing" variables, separate saturations and quantities were computed for the entire MA population of that demographic. Post weights were normalized for each combination of slicing variables to sum to 1, then the weighted proportion of homes with the end use and weighted mean quantity of per home were calculated for each end use. Absolute precision was also computed at the 90% confidence level.

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 which has hourly data for each end use at each site. Second, 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 MA population.

Step 1: Clean data: For the 1-minute data, eGauge and hobo logger 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 analysis 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, and 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 kW 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 2 out of 3 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, and each time period of interest (all days, weekdays, weekends, summer 2017, calendar months, peak days, and peak periods), average kW was computed.

> **Exceptions**: Data was removed where a site and end use combo had less than half of the total hours in the period logged (e.g. for the ISO-NE peak, which covers 16 hours total, only sites with 8 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 kW per period. Specific combinations are provided in the table below. A different set of categories may be appropriate for the winter metering and final results.

Table 6. Combined End Uses for Load Shape Analysis

Category	End Uses Combined
Central AC/HP	Central AC, Central HP
Ductless AC/HP	Ductless AC, Ductless HP
Hardwired Electric Heat	Elec baseboard heat, Elec furnace
HVAC – Misc	Whole house fans, Fireplace blowers, HRVs, 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 kW 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.

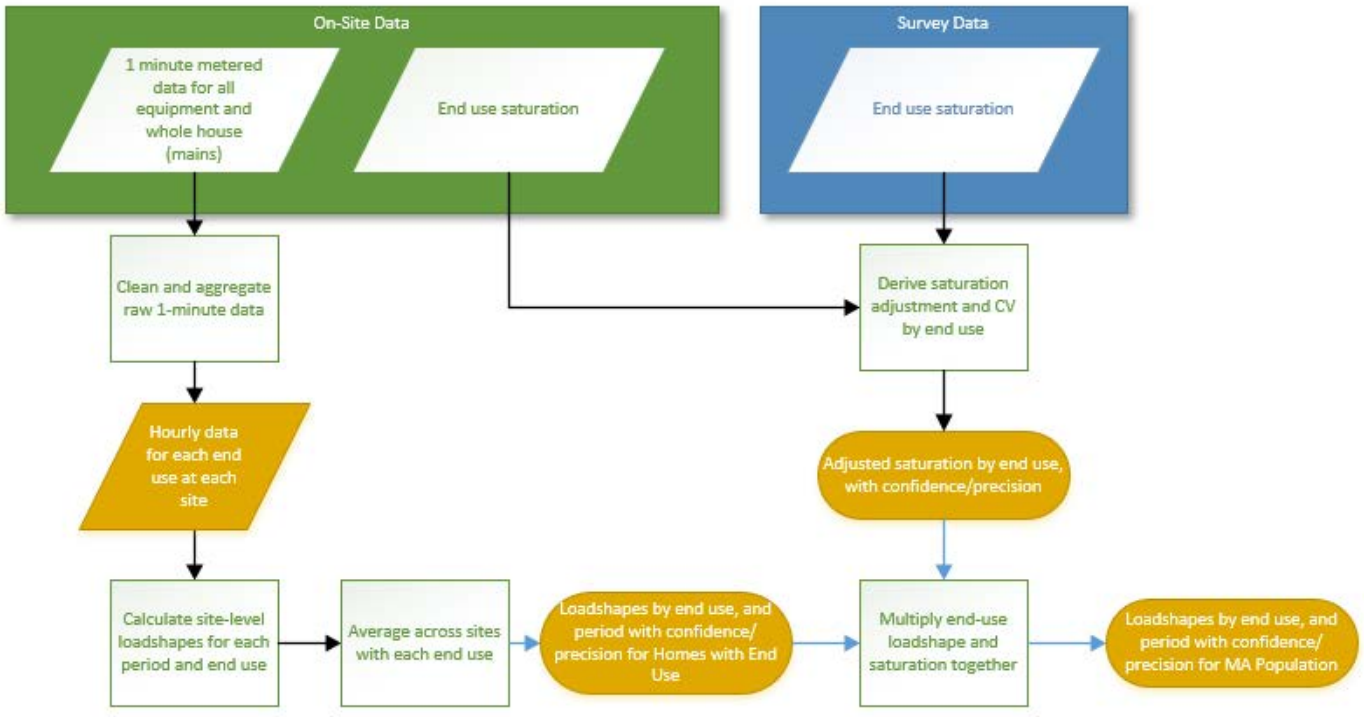
> **Exceptions**: Data was removed for demographic and end use combinations where there was data from less than 5 sites (e.g. for end use XXX and demographic YYY, there were only 4 sites, so no result was computed for that combination).

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

> **Modifications**: Some end uses like Air Handling Units were metered onsite but were not explicitly included in the survey and did not have saturations in the July 17 deliverable, saturations were newly computed for these end uses. The "remaining load" load shape was computed by subtracting all metered end use load shapes from whole home average consumption.

Figure 25 is a schematic representation of the saturation and load shapes analysis.

Figure 25. Saturation and Load Shape Analysis Map



APPENDIX B. STATISTICS

The study attained confidence and precision that was comparable to expected or better for almost all major end uses, as shown in Table 6. The only notable exceptions were pool pumps and heat pump water heaters where the results were not quite as precise as planned due to their usage being more variable than expected. Primary TVs and primary computers were added to the study later and had no original target. The energy and residential peak values are expressed at a 90% confidence level, while the ISO-NE values are expressed at an 80% confidence level.

Table 7. Comparison of Actual Relative Precision to Expected Relative Precision

End Use	Targeted End Use Relative Precision: Energy	Actual Summer Energy	Targeted End Use Relative Precision: Residential Peak	Actual Res. Peak	Targeted End Use Relative Precision: ISO-NE Peak	Actual ISO-NE
Central AC/Heat Pump	10.1%	11%	10.6%	9%	9.9%	9%
Room AC	15.8%	17%	20.3%	15%	28.2%	13%
Ground Source Heat Pump	84.3%	N/A	100.6%	N/A	93.6%	N/A
Hardwired Electric Heat	20.5%	N/A	82.0%	NA	77.2%	N/A
Space Heaters/ Plug-in Fireplaces	15.0%	49%	36.8%	149%	36.8%	88%
Boiler Circulator Pump	6.7%	16%	10.3%	18%	5.8%	15%
Other Fuel Furnace Fan	6.6%	83%	1.9%	140%	1.7%	115%
Dishwasher	9.0%	11%	21.8%	27%	30.1%	21%
Freezer	11.2%	12%	8.7%	12%	10.4%	9%
Refrigerator	3.0%	5%	3.1%	5%	2.7%	4%
Second Refrigerator	10.7%	15%	9.9%	15%	9.6%	12%
Water Heater	6.7%	12%	10.5%	23%	15.0%	16%
Tankless Water Heater	186.1%	N/A	289.8%	N/A	415.6%	N/A
Heat Pump Water Heater	13.0%	24%	20.3%	44%	29.1%	33%
Washer	7.0%	13%	22.3%	28%	25.4%	16%
Electric Dryer	5.4%	8%	44.1%	20%	17.6%	16%
Dehumidifier	11.2%	16%	11.3%	17%	10.3%	14%
Aquarium	41.1%	N/A	41.1%	N/A	41.1%	N/A
Golf Cart/Large Battery Charger	45.5%	N/A	45.5%	N/A	45.5%	N/A
Well Pump	48.6%	46%	51.8%	65%	45.6%	69%
Sump Pump	25.3%	134%	25.9%	148%	25.6%	116%
Booster Pump	36.3%	N/A	2.9%	N/A	39.6%	N/A
Pool Pump	18.2%	25%	19.1%	28%	20.2%	22%
EV Charger	N/A	N/A	N/A	N/A	N/A	N/A
Primary TV		10%		13%		10%
Primary Computer		26%		30%		26%

APPENDIX C. SUPPORTING DATA

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

Table 8. Appendix C Supporting Documents File Names and Contents

File Name	File Type	Contents
Appendix C-1 Draft Cooling Season Results Plots 2017-11-14	PDF	Detailed plots of summer consumption, peak demand, and load shapes by end use and demographic
Appendix C-2 Draft Cooling Season All End Use Metered Whole Period Results 2017-11-14	Excel	Total summer consumption and peak demand for each end use and time period with statistics
Appendix C-3-1 Draft Cooling Season HVAC Metered Load Shape Results 2017-11-14	Excel	Hourly load shapes by end use, demographics, time period, and day type with statistics
Appendix C-3-1 Draft Cooling Season Water Heating Metered Load Shape Results 2017-11-14	Excel	
Appendix C-3-1 Draft Cooling Season Kitchen Metered Load Shape Results 2017-11-14	Excel	
Appendix C-3-1 Draft Cooling Season Laundry Metered Load Shape Results 2017-11-14	Excel	
Appendix C-3-1 Draft Cooling Season Miscellaneous Metered Load Shape Results 2017-11-14	Excel	
Appendix C-3-1 Draft Cooling Season Remaining Load Load Shape Results 2017-11-14	Excel	