Cost-Effectiveness of Electric Demand Response for Residential End-Uses

Final Report

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National Grid

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EXECUTIVE SUMMARY

Study Scope and Approach

To inform the direction of National Grid's residential demand reduction (DR) programs, Navigant estimated the benefits and costs of demand reduction for DR-enabled appliances. For each of the appliance, enabling device, and DR strategy combinations listed in Table 1, this study provides estimates of:

1) Potential savings per unit during the summer peak period;[1]
2) Current and forecasted market saturation data;
3) Approximate incremental costs for summer DR;
4) Benefit-cost ratio.

As shown in Table 1, this report considers a wide range of residential appliances and multiple enablement strategies for each appliance type. This report documents the relative potential and cost-effectiveness of various residential DR programs, providing National Grid a basis for selecting a subset of these programs to pursue in the years ahead.

It is important to note that bundling EE and DR efforts were not included in the scope of this study. Bundling EE and DR may result in more opportunities for demand reduction technologies, while adjusting the cost-effectiveness perspective to consider EE and DR incentives.

This study occurred over two phases:

- **Phase 1:** Research of DR-Enabled Appliances

  In Phase 1, which occurred from August 2017 to October 2017, Navigant conducted a literature review and analysis of Massachusetts Residential Baseline Study (MA Baseline Study) survey data (from 2017) related to appliance saturation to collect information on potential impacts and costs of DR to inform preliminary cost-effectiveness results for the appliances listed in Table 1.

- **Phase 2:** Load Shape Development and Benefit-Cost Analysis

  To estimate potential impacts of DR by appliance type, Navigant constructed average daily load shapes for each appliance type using end-use metering data from the MA Baseline Study for the 2017 and 2018 summer periods (see Appendix A). This phase allowed for refinement of the potential savings per appliance, and incorporation of avoided costs from the 2018 Avoided Energy Supply Cost (AESC) Study to measure cost-effectiveness of each of the options considered in this study.

This final report contains findings from Phase 1 and Phase 2 and includes chapters for each appliance type listed in Table 1.
The benefit-cost ratios (BCRs) included in the report generally reflect potential demand reductions based on end-use metering data associated with weekdays for which the maximum temperature during the peak

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[1] For the purposes of this study, National Grid has defined summer peak periods as non-holiday weekdays from 2 p.m. to 5 p.m. from June 1 through September 30.

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period was above 85°F.[2] For central air conditioners (CACs), because National Grid has already piloted and evaluated a DR program for CACs harnessing Wi-Fi thermostat technology, the demand reduction estimate used for the purposes of this report is the evaluated value from the 2018 program evaluation. Additionally, BCRs for battery storage (option with solar)[3] and EV charging scenarios are based on literature review findings.

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[2] All non-holiday weekdays in the summers of 2017 and 2018 for which Worcester, Massachusetts had a maximum temperature of greater than 85°F during the 2 p.m. to 5 p.m. period. In 2017, there were 4 such days: June 12, June 13, July 19, and August 22. In 2018, there were 12 such days: June 18, July 2, July 3, July 5, July 10, July 16, August 2, August 6, August 7, August 28, August 29, and September 6.

[3] Navigant assumed that the impact associated with the no solar option battery option would be equal to average whole-home load during peak periods for these participants. This is consistent with DPU 17-146-A which prohibits residential battery systems without solar from exporting to the grid.

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Table 1. Combinations of DR-Enabled Appliances

Appliance[4]	Enabling Device[5][6]	DR Strategy[7]
Central Air Conditioner	Wi-Fi thermostat	Temperature setback
Room Air Conditioner	Built-in	Temperature setback
	Simple timer plug	Direct load control (DLC)
	Wi-Fi plug	Temperature setback
Clothes Washer	Built-in	DLC
	Simple timer plug	DLC
	Wi-Fi plug	DLC
Clothes Dryer	Built-in	DLC
Dishwasher	Built-in	DLC
Refrigerator	Built-in	Deferred defrost
	Wi-Fi plug	DLC
Dehumidifier	Built-in	DLC
	Simple timer plug	DLC
	Wi-Fi plug	DLC
Ductless Heat Pump / Air Conditioner	Wi-Fi thermostat	Temperature setback
Heat Pump Water Heater	Built-in	DLC
	Simple timer switch	DLC
	Wi-Fi switch	DLC
Electric Resistance Water Heater	Built-in	DLC
	Simple timer switch	DLC
	Wi-Fi switch	DLC
Pool Pump	Built-in	DLC
	Wi-Fi plug[8]	DLC
	Simple timer switch	DLC
	Wi-Fi switch	DLC
Battery Storage	Built-in No-Solar	DLC (Discharge)
	Built-in Solar	DLC (Discharge)
Electric Vehicles (Home Charging)[9]	Built-in	DLC
	Wi-Fi Electric Vehicle Supply Equipment (EVSE) Controller	DLC
	Onboard Diagnostic (OBD) Dongle	DLC
	EVSE Built-In	DLC

Source: List compiled collaboratively by National Grid and Navigant.

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[4] The DR benefit-cost analysis assumes the customer already owns the appliance/battery.

[5] All switches (Wi-Fi and Simple) refer to in-line switches that must be installed by an electrician.

[6] “Simple” refers to mechanical.

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Summary Results

Table 2 contains a comparison of the estimates of peak period potential unit impacts based on the literature review (Phase 1) and MA Baseline Study metering data (Phase 2) for each appliance/equipment type, enabling technology, and DR strategy combination. Potential impacts based on metering data represent coincident peak average demand across units in the metering sample, with derating factors applied. Potential unit impacts based on metering data are reported both for all summer weekdays (All Days)[10] and the weekdays for which the maximum temperature during the peak period was above 85°F in Worcester, MA (Hottest Days). The "Estimated Unit Impacts (kW)" represents the final impact value assumed for the purposes of the benefit-cost analysis conducted for this study.

Table 2. Potential Unit Impacts[11] Based on Literature Review and End-Use Metering

Appliances	Enabling Device	DR Strategy	Phase 1 – Literature Review[12] (kW)	Phase 2 – Baseline Study All Days (kW)	Phase 2 – Baseline Study Hottest Days (kW)	Estimated Unit Impacts[13] (kW)
Central Air Conditioner	Wi-Fi thermostat	Temperature setback	0.71	0.35	0.85	0.71
Room Air Conditioner	Built-in	Temperature setback	0.08	0.05	0.13	0.13
	Simple timer plug	DLC	0.06	0.05	0.11	0.11
	Wi-Fi plug	Temperature setback	0.06	0.04	0.09	0.09
Clothes Washer	Built-in	DLC	0.02	0.00	0.00	0.00

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[7] In this report, with the exception of battery storage, direct load control (DLC) refers to the strategy of the program automatically shutting off the appliance for the duration of a DR event. For battery storage, DLC refers to the discharge of stored energy over the peak period (with export to the grid in the with solar scenario and local discharge in the no solar scenario). Temperature setback refers to the strategy of increasing the temperature setpoint of a Wi-Fi thermostat to shut off the connected HVAC unit's compressor periodically during peak hours. Temperature setback employed by DR programs typically ranges from 1° to 4°. For the purposes of this study, a 3° temperature setback was assumed for all combinations for which temperature setback is the DR strategy.

[8] Based on MA Baseline Study 2017 Saturation Survey results, Navigant estimates that there are effectively no plug-in pool pumps in National Grid's Massachusetts territory. Therefore, Navigant excludes benefit-cost results for this option in this report.

[9] Due to the complicated nature of tracking charging that occurs through non-home private and public charging stations, the benefit-cost analysis in this report reflects demand reduction associated with control of EV home charging. It does cover the demand reduction potential associated with non-home charging.

[10] All non-holiday weekdays in the summers of 2017 and 2018.

[11] Net of derating factors associated with event participation, Wi-Fi connectivity, DR enablement strategy, and first-year in-service rate.

[12] Sources used for the literature review estimates are detailed in the body of the report. They include state and regional technical reference manuals and program evaluation report.

[13] With a few exceptions, all potential impacts used for calculating BCRs are based on end-use metering for the hottest 2017 and 2018 summer days; i.e., all non-holiday weekdays in the summers of 2017 and 2018 for which Worcester, Massachusetts had a maximum temperature of greater than 85°F during the 2 p.m. to 5 p.m. period. For CACs, because National Grid has already piloted and evaluated a DR program for CACs harnessing Wi-Fi thermostat technology, the final summer peak coincident demand reduction estimate used for the purposes of this report is the evaluated value from the 2018 program evaluation. Additionally, BCRs for battery storage with solar and EV charging scenarios are based on literature review findings.

Appliances	Enabling Device	DR Strategy	Phase 1 – Literature Review[12] (kW)	Phase 2 – Baseline Study All Days (kW)	Phase 2 – Baseline Study Hottest Days (kW)	Estimated Unit Impacts[13] (kW)
	Simple timer plug	DLC	0.02	0.00	0.00	0.00
	Wi-Fi plug	DLC	0.02	0.00	0.00	0.00
Clothes Dryer	Built-in	DLC	0.06	0.04	0.04	0.04
Dishwasher	Built-in	DLC	0.01	0.01	0.01	0.01
Refrigerator	Built-in	Deferred defrost	0.03	0.05	0.05	0.05
	Wi-Fi plug[14]	DLC	0.05	0.05	0.05	0.05
Dehumidifier	Built-in	DLC	0.20	0.13	0.14	0.14
	Simple timer plug	DLC	0.17	0.08	0.10	0.10
	Wi-Fi plug	DLC	0.19	0.09	0.11	0.11
Ductless Heat Pump/Air Conditioner	Wi-Fi thermostat	Temperature setback	0.05	0.10	0.25	0.25
Heat Pump Water Heater	Built-in	DLC	0.13	0.10	0.09	0.09
	Simple timer switch	DLC	0.13	0.10	0.09	0.09
	Wi-Fi switch	DLC	0.13	0.10	0.09	0.09
Electric Resistance Water Heater	Built-in	DLC	0.27	0.17	0.16	0.16
	Simple timer switch	DLC	0.27	0.17	0.16	0.16
	Wi-Fi switch	DLC	0.27	0.17	0.16	0.16
Pool Pump	Built-in	DLC	0.58	0.46	0.61	0.61
	Wi-Fi plug[15]	DLC	N/A	N/A	N/A	N/A
	Simple timer switch	DLC	0.58	0.46	0.61	0.61
	Wi-Fi switch	DLC	0.58	0.46	0.61	0.61
Battery Storage[16]	Built-in No-Solar	DLC	N/A	0.86	1.37	1.37
	Built-in Solar	DLC	4.00	N/A	N/A	4.00
EVs[17]	Built-in EV	DLC	0.09	N/A	N/A	0.09

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[14] Although benefit-cost analysis was conducted for this option, the DR strategy associated with the smart plug option presents health and safety risks. Therefore, final results are excluded from this summary table.

[15] Based on MA Baseline Study Saturation Survey results, Navigant estimates that there are effectively no plug-in pool pumps in National Grid's Massachusetts territory. Therefore, Navigant excludes benefit-cost results for this option in this summary table.

[16] The MA Baseline Study did not include any metering of residential energy storage systems. For battery storage with no-solar, whole-home meter data from the MA Baseline Study was used to estimate potential peak demand reductions for homes with a battery system but no solar.

[17] The MA Baseline Study metered only two EV home charging systems. Due to the small sample size, end-use metering results for EV charging systems are not used in this report.

Appliances	Enabling Device	DR Strategy	Phase 1 – Literature Review[12] (kW)	Phase 2 – Baseline Study All Days (kW)	Phase 2 – Baseline Study Hottest Days (kW)	Estimated Unit Impacts[13] (kW)
(Home Charging)	Wi-Fi EVSE Controller	DLC	0.09	N/A	N/A	0.09
	OBD Dongle	DLC	0.09	N/A	N/A	0.09
	EVSE Built-In	DLC	0.09	N/A	N/A	0.09

Source: Navigant analysis based on multiple data sources, reference footnotes.

For each appliance, enabling technology, and DR strategy combination, Table 3 contains potential unit impact estimates, potential DR program size in 2019 and 2028 (the start year and end year of this study's benefit-cost analysis), and BCRs reflecting the total resource cost (TRC) test over the 2019 to 2028 period (meaning, BCRs reflect the benefits and costs incurred during the 10-year period associated with those who enroll and participate during that period).

Benefits from each DR program option analyzed represent the avoided costs associated with avoided generation capacity and avoided transmission and distribution capacity. Costs included in the benefit-cost analysis are measure-level costs—in other words, costs that depend on the number of enrolled devices. From the analysis, Navigant excludes DR program costs in the benefit-cost analysis—or costs that would be shared with other DR initiatives, such as program setup costs and annual DR management system (DRMS) license fees.

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Table 3. Potential Unit Impacts[18], Program Size, and Benefit-Costs (TRC, 2019-2028)

Appliances	Enabling Device	DR Strategy	Estimated Unit Impacts[19] (kW)	Potential Units Enrolled in MA NGrid area (2019)	Potential Units Enrolled in MA NGrid area (2028)	BCR (TRC, 2019-2028)[20]
Central Air Conditioner	Wi-Fi thermostat	Temperature setback	0.71	12,000	32,000	2.9
Room Air Conditioner	Built-in	Temperature setback	0.13	2,000	79,000	0.6
	Simple timer plug	DLC	0.11	6,000	64,000	0.5
	Wi-Fi plug	Temperature setback	0.09	6,000	64,000	0.2
Clothes Washer	Built-in	DLC	0.00	4,000	90,000	0.0
	Simple timer plug	DLC	0.00	4,000	45,000	0.0
	Wi-Fi plug	DLC	0.00	4,000	45,000	0.0
Clothes Dryer	Built-in	DLC	0.04	4,000	72,000	0.2
Dishwasher	Built-in	DLC	0.01	1,200	84,000	0.0
Refrigerator	Built-in	Deferred defrost	0.05	5,000	172,000	0.2
	Wi-Fi plug[21]	DLC	0.05	N/A	N/A	0.1
Dehumidifier	Built-in	DLC	0.14	1,500	29,000	0.7
	Simple timer plug	DLC	0.10	2,000	23,000	0.5
	Wi-Fi plug	DLC	0.11	2,000	23,000	0.3
Ductless Heat Pump/Air Conditioner	Wi-Fi thermostat	Temperature setback	0.25	225	5,000	1.1
Heat Pump Water Heater	Built-in	DLC	0.09	40	1,300	0.4
	Simple timer switch	DLC	0.09	60	600	0.2

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[18] Net of derating factors associated with event participation, Wi-Fi connectivity, DR enablement strategy, and first-year in-service rate.

[19] With a few exceptions, all potential impacts used for calculating BCRs are based on end-use metering for the hottest 2017 and 2018 summer days; i.e., all non-holiday weekdays in the summers of 2017 and 2018 for which Worcester, Massachusetts had a maximum temperature of greater than 85°F during the 2 p.m. to 5 p.m. period. For CACs, because National Grid has already piloted and evaluated a DR program for CACs harnessing Wi-Fi thermostat technology, the final summer peak coincident demand reduction estimate used for the purposes of this report is the evaluated value from the 2018 program evaluation. Additionally, BCRs for battery storage and EV charging scenarios are based on literature review findings.

[20] Some costs were not included in the BCR calculation such as program administration, setup costs, and software costs. The realized BCR would be lower depending on the scale of the DR programs. See Section 2.4 for more details.

[21] Although benefit-cost analysis was conducted for this option, the DR strategy associated with the smart plug option presents health and safety risks. Therefore, final results are excluded from this summary table.

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Appliances	Enabling Device	DR Strategy	Estimated Unit Impacts[19] (kW)	Potential Units Enrolled in MA NGrid area (2019)	Potential Units Enrolled in MA NGrid area (2028)	BCR (TRC, 2019-2028)[20]
	Wi-Fi switch	DLC	0.09	60	600	0.1
Electric Resistance Water Heater	Built-in	DLC	0.16	600	19,000	0.7
	Simple timer switch	DLC	0.16	900	9,000	0.4
	Wi-Fi switch	DLC	0.16	900	9,000	0.3
Pool Pump	Built-in	DLC	0.61	200	9,000	2.7
	Wi-Fi plug[22]	DLC	N/A	N/A	N/A	N/A
	Simple timer switch	DLC	0.61	400	4,000	1.6
	Wi-Fi switch	DLC	0.61	400	4,000	1.0
Battery Storage	Built-in No-Solar[23]	DLC	1.37	25	3,500	1.6
	Built-in Solar[24]	DLC	4.00	60	8,000	4.7
EVs[25] (Home Charging)	Built-in EV	DLC	0.09	1,200	40,000	0.3
	Wi-Fi EVSE Controller	DLC	0.09	1,200	40,000	0.1
	OBD Dongle	DLC	0.09	1,200	40,000	0.2
	EVSE Built-In	DLC	0.09	35	6,000	0.3

Source: Navigant analysis based on multiple data sources, reference footnotes.

Figure 1 displays the results of the benefit-cost analysis (TRC, 2019 to 2028) for each appliance type and enablement strategy, as well as the associated demand reduction (MW) potential in 2019 and in 2028 program years. It is important to note that BCRs associated with all appliances, including battery storage assume the participant (and not the program) pays the upfront cost associated with the purchase and installation of the battery system.

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[22] Based on MA Baseline Study Saturation Survey results, Navigant estimates that there are effectively no plug-in pool pumps in National Grid's Massachusetts territory. Therefore, Navigant excludes benefit-cost results for this option in this summary table.

[23] The MA Baseline Study did not include any metering of residential energy storage systems. For battery storage with no-solar, whole-home meter data from the MA Baseline Study was used to estimate potential peak demand reductions for homes with a battery system but no solar.

[24] Potential unit impact and BCR for battery storage with solar are based on literature review findings.

[25] The Residential Baseline Study metered only two EV home charging systems. Therefore, potential unit impacts and BCRs for EVs are based on literature review findings.

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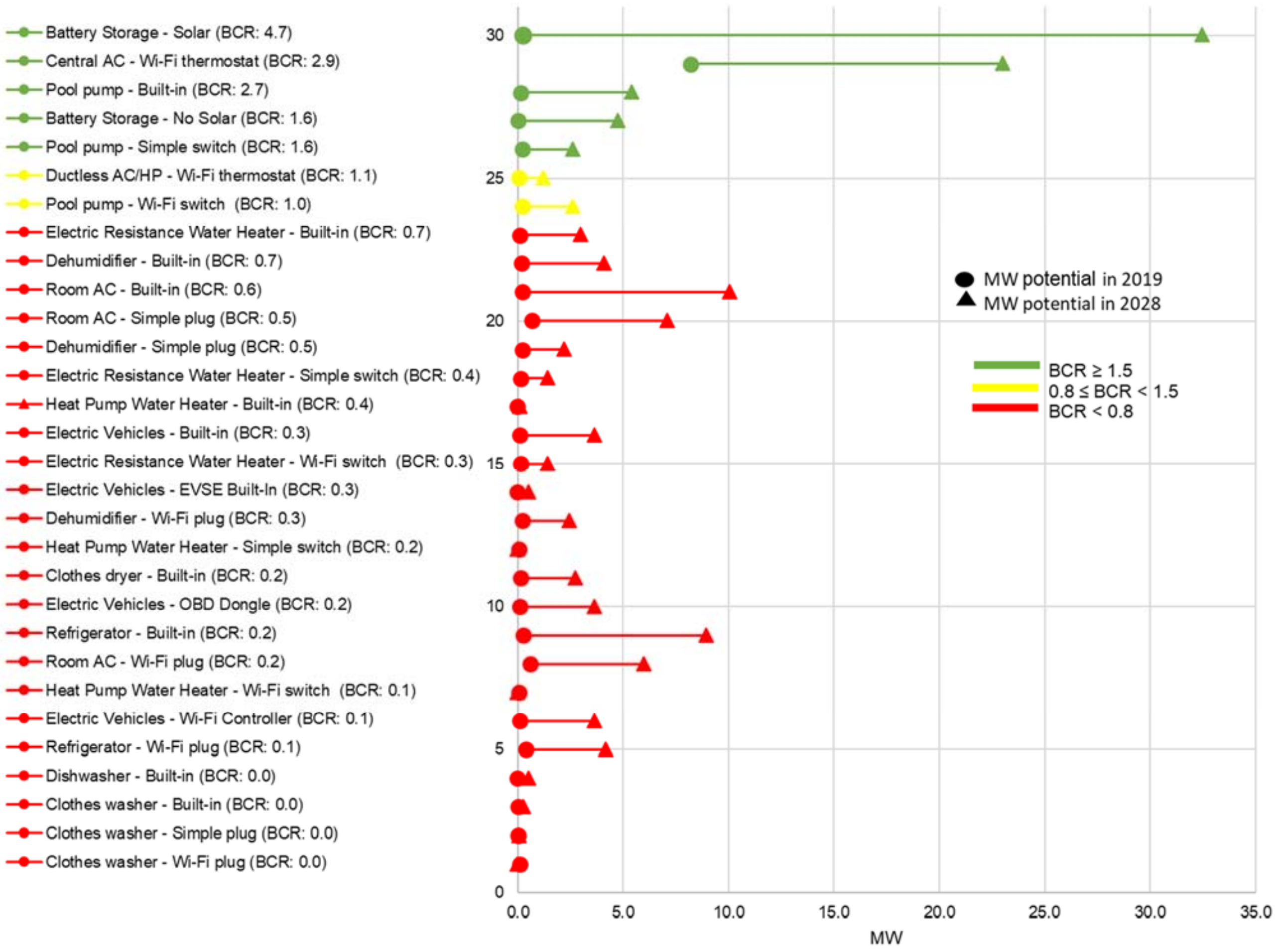
Figure 1. Benefit-Costs (TRC, 2019-2028) and Demand Reduction (MW) Potential



Source: Navigant analysis.

Key Findings

This section provides a summary of findings for each appliance type. Findings reflect benefit-cost analysis for the period of 2019 through 2028 using the TRC test.

- **Central Air Conditioners**: Using the 2018 evaluated impact results for National Grid's ongoing residential Wi-Fi thermostat DR program, central air conditioners have the highest per-unit impact for an appliance (0.71 kW), excluding battery storage. DR for central air conditioners proves to be cost-effective, with a BCR of 2.9. Program potential is estimated to be 8.2 MW in 2019 and 23.0 MW by 2028 due to the increasing penetration of Wi-Fi thermostats.
- **Room Air Conditioners:** Due to lower peak coincident load than central air conditioners, room air conditioners are associated with relatively low BCRs (0.6, 0.5 and 0.2, for built-in, simple plug and Wi-Fi plug enablement strategies, respectively). DR program potential in 2019 is estimated to

be 0.2 MW, 0.7 MW, and 0.6 MW for the built-in, simple plug and Wi-Fi plug options, respectively. By 2028, MW potential is estimated to be 10.0 MW, 7.1 MW and 6.0 MW for the built-in, simple plug and Wi-Fi plug options, respectively. Similar to other end-uses where plugs and smart appliances are DR enablement options, for room air conditioners, plug-based enablement is associated with higher costs, lower per unit potential (due to higher derating factors) and higher near-term MW potential than DR enablement through an already Wi-Fi enabled product (i.e. built-in). However, Navigant estimates that the penetration of room air conditioners with built-in capability will surpass that of traditional room air conditioners by 2028.

- **Clothes Washers:** Estimated peak coincident average demand impact per clothes washer device is just a few watts, implying the smallest overall potential for all the appliances analyzed. Even with the forecasted emergence of smart clothes washers driving potential program enrollment over the next ten years, this low demand impact keeps the BCR close to zero through 2028.
- **Clothes Dryers:** Navigant estimates that smart clothes dryers average 0.04 kW peak demand impact per device. Current market penetration of smart clothes dryers is estimated to be low, associated with total DR program potential of 0.1 MW in 2019. Navigant estimates that growth in smart dryer penetration will make 3.0 MW of total program peak demand reduction achievable in 2028. While smart dryers are associated with higher potential than clothes washers, potential impacts are still not high enough to allow for cost-effectiveness. Navigant estimates a BCR of 0.2 for smart clothes dryers.
- **Dishwashers:** Like clothes dryers, the emergence of smart dishwashers with built-in DR capability over the next 10 years increases the total DR potential of dishwashers. However, with an estimated peak demand impact per device of just 0.01 kW, the total projected peak reduction in 2028 is just 0.52 MW. This leads to one of the lowest BCRs at just 0.03.
- **Refrigerators:** With high market penetration, high coincidence with peak periods, refrigerators seem like a desirable choice for DR programs. However, due to safety concerns the DR strategy for refrigerators cannot include shutting the unit off for any meaningful amount of time during the event. For this reason, the smart plug DR-enablement option (assuming it is used to shut off the refrigerator entirely during events) is not a viable option for refrigerators peak load reduction. However, by utilizing creative DR-strategies such as delaying the defrost cycle and shutting off ice makers, Navigant estimates that smart refrigerators can reduce peak demand by around 0.05 kW per device. This equates to a projected peak reduction of nearly 9 MW by 2028, on par with some of the more promising appliances studied. However, the costs associated with this option still outweigh the possible benefits, with a BCR of around 0.2.
- **Dehumidifiers:** Dehumidifiers can provide an estimated 0.10 to 0.14 kW of peak demand impact per device, associated with a projected peak reduction in 2028 of around 2.4 MW for a Wi-Fi plug, 2.2 MW for a simple timer plug, and 4.1 MW for smart dehumidifiers with built-in DR capability. Navigant finds that potential demand impacts do not outweigh costs associated with DR programs for dehumidifiers, estimating BCRs of 0.3, 0.5, and 0.7 for programs using Wi-Fi plugs, simple plugs and built-in dehumidifiers, respectively.[26]

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[26] As detailed in the RES 1 Comprehensive Report from January 2019, the MA Baseline Study found that there is a high amount of variability across households in usage of dehumidifiers during peak periods. 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. For this reason, the report proposes that the PAs consider targeting certain dehumidifier users for a summer DR program.

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- **Ductless Mini-Splits:** For ductless mini-splits enabled with a Wi-Fi thermostat, Navigant estimates the achievable peak load reduction per device to be 0.25 kW, but the total projected peak reduction from ductless mini-splits is just 1.2 MW in 2028 due to their relatively low market penetration. However, given the relatively high demand reduction, Navigant estimates a BCR of just above 1 (1.1) for ductless mini-splits.
- **Water Heaters:** The cost-effectiveness of water heaters varies greatly depending on the type and the DR-enabling technology. Through this analysis it appears that the only technology combination that could be cost effective in the future is controlling electric water heaters through built-in DR capability. It appears that controlling heat pump water heaters through the same means would not be cost effective due to their lower average load. National Grid offers energy efficiency incentives to customers to encourage them to use the more efficient heat pump water heaters. Offering a demand response incentive only to new electric resistance water heaters could confuse customers, and decrease the adoption of heat pump water heaters, which provide savings year-round, not just for demand response events. Whereas, offering DR incentives to both electric resistance and heat pump water heaters in an effort to remove the conflict of interest may result in a program that is not cost-effective, since the majority of smart water heaters are heat pump water heaters.
- **Pool Pumps**: Pool pumps are found to have the second greatest per-unit impact for an appliance (0.61 kW). As a result, DR will likely be cost-effective for programs featuring smart pool pumps (i.e., pool pumps with Wi-Fi built-in) and simple mechanical switches. Additionally, the BCR for the Wi-Fi switch option was estimated to be 1. One advantage of DR for pool pumps is that it is assumed to be less of an inconvenience to participants – in contrast to some other end-uses – and, therefore, the rate of opt-out is assumed to be low. However, the low penetration of pool pumps in MA shows that the MW benefit 10 years out remains modest at 5.4 MW for built-in and 2.6 MW for smart or simple switch programs. This lower benefit may not be able to support the upfront cost IS/IT, administration, and marketing cost to set up a pool pump program. These upfront costs are not included in the BCR estimates; see Section 2.4 for more details.
- **Battery Storage**: Assuming a “Bring-Your-Own” battery program, residential battery storage systems, both for customers with and without solar, are associated with high benefits to costs because system and installation costs are borne by the customer. With a per-unit impact of 4 kW, Navigant estimates a BCR of 4.7 for both systems when combined when the homeowner also has solar. Systems with no solar are somewhat less cost-effective (with a BCR of 1.6) due to the inability of residential battery systems to export to the grid in Massachusetts. Projected peak reduction in 2028 is dependent on market adoption in Massachusetts over the next ten years. Based on current market adoption forecasts, Navigant estimates that peak reduction associated with a DR program for residential batteries to be 32 MW for customers with solar and 5.0 MW for customers without solar by 2028.
- **Electric Vehicles**: Due to the more complicated nature of tracking charging that occurs through non-home private and public charging stations, the benefit-cost analysis in this report reflects demand reduction associated with control of EV home charging. It does not cover the demand reduction potential associated with non-home charging. DR targeting non-home charging is another area that should be explored further, especially if/when the adoption of wireless EVSEs increases.

  The low potential peak demand impact per electric vehicle (under 0.1 kW, on average during the summer peak period) associated with home charging curtailment has implications on the cost-effectiveness of a DR program targeting home charging of EVs. Given the cost of harnessing the

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more prevalent DR-enabling technologies, the estimated BCR is under 0.3 for all associated electric vehicle DR programs.

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1. STUDY SCOPE

To inform the direction of National Grid's residential demand response (DR) program, Navigant researched benefits and costs of demand reduction for DR-enabled appliances. For each of the appliance, enabling device, and DR strategy combinations listed in Table 1-1, this study provides estimates of:

1) Potential savings per unit during summer peak period;[27]
2) Current and forecasted market saturation data;
3) Approximate incremental costs for summer DR;
4) Benefit-cost ratio.

As shown in Table 1-1, this report considers a wide range of residential appliances and multiple enablement strategies for each appliance type.

Table 1-1. Combinations of DR-Enabled Appliances

Appliances[28]	Enabling Device
Central Air Conditioner	Wi-Fi thermostat
Room Air Conditioner	Built-in
	Simple timer plug
	Wi-Fi plug
Clothes Washer	Built-in
	Simple timer plug
	Wi-Fi plug
Clothes Dryer	Built-in
Dishwasher	Built-in
Refrigerator	Built-in
	Wi-Fi plug
Dehumidifier	Built-in
	Simple timer plug
	Wi-Fi plug
Ductless Heat Pump/Air Conditioner	Wi-Fi thermostat
Heat Pump Water Heater	Built-in
	Simple timer switch
	Wi-Fi switch
Electric Resistance Water Heater	Built-in
	Simple timer switch
	Wi-Fi switch

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[27] For the purposes of this study, National Grid has defined summer peak periods as non-holiday weekdays from 2 p.m. to 5 p.m. from June 1 through September 30.

[28] The DR benefit-cost analysis assumes the customer already owns the appliance.

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Appliances[28]	Enabling Device
Pool Pump	Built-in
	Wi-Fi plug[29]
	Simple timer switch
	Wi-Fi switch
Battery Storage	Built-in No-Solar
	Built-in Solar
EVs	Built-in
	Wi-Fi Electric Vehicle Supply Equipment (EVSE) Controller
	Onboard Diagnostic (OBD) Dongle
	EVSE Built-In

Source: List compiled collaboratively by National Grid and Navigant.

Accordingly, this report is intended to document the relative potential and cost-effectiveness of various residential DR programs, providing National Grid a basis for selecting a subset of these programs to pursue in the years ahead.

It is important to note that bundling EE and DR efforts were not included in the scope of this study. Bundling EE and DR may result in more opportunities for demand reduction technologies, while adjusting the cost-effectiveness perspective to consider EE and DR incentives.

The following sections further describe the study objectives, approach, and schedule for the study of the demand reduction opportunity for DR-enabled appliances.

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[29] Based on MA Baseline Study Saturation Survey results, Navigant estimates that there are effectively no plug-in pool pumps in National Grid's Massachusetts territory. Therefore, Navigant excludes benefit-cost results for this option in this report.

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2. STUDY APPROACH

The study consists of two phases:

- **Phase 1:** Research of DR-enabled appliances

  In Phase 1, which occurred from August 2017 to October 2017, Navigant conducted a literature review and analysis of MA Residential Baseline Study (MA Baseline Study) survey data (from 2017) related to appliance saturation to collect information on potential impacts and costs of DR for the appliances listed in Table 1-1.

- **Phase 2:** Load Shape Development and Analysis

  To estimate potential impacts of DR by appliance type, Navigant constructed average daily load shapes for each appliance type using end-use metering data from the MA Baseline Study for the 2017 and 2018 summer periods. This phase allowed for refinement of the potential savings per appliance, and incorporation of avoided costs from the 2018 Avoided Energy Supply Cost (AESC) Study to measure cost-effectiveness of each of the options considered in this study.

This final report contains findings from Phase 1 and Phase 2 activities and contains chapters for each appliance type listed in Table 1-1 With a few exceptions, all benefit-cost ratios (BCRs) included in the body of the report reflect potential impacts based on end-use metering for the hottest 2017 and 2018 summer days.[30] For central air conditioners (CACs), because National Grid has already piloted and evaluated a DR program for CACs harnessing Wi-Fi thermostat technology, the final summer peak coincident demand reduction estimate used for the purposes of this report is the evaluated value from the 2018 program evaluation. Additionally, BCRs for battery storage and EV charging scenarios are based on literature review findings.

Table 2-1. Combinations of DR-Enabled Appliances

Chapter Subsection	Data Sources
DR Context	Literature Review
Potential Impact Per Device	Literature Review, MA Baseline Study End-Use Metering
Total Achievable Impact	Literature Review, MA Baseline Study Saturation Survey
Benefit-Cost Analysis	All of the above

Source: Navigant.

The following is an outline of the subsections contained in each appliance chapter.

2.1 DR Context

This section provides a discussion of the appliance and options for DR-enablement. This includes a summary of proven and potential second-generation technologies utilized in order to make each appliance type DR-enabled. For a given appliance, peak demand reduction enabling technologies may include a Wi-Fi plug, Wi-Fi inline switch, Wi-Fi thermostat, and/or smart appliance (built-in DR capabilities). For appliances where a Wi-Fi plug or Wi-Fi switch technology was considered, a simple mechanical timer plug or switch was also analyzed. For second-generation DR-enabling technologies,

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[30] All non-holiday weekdays in the summers of 2017 and 2018 for which Worcester, Massachusetts had a maximum temperature of greater than 85°F during the 2 p.m. to 5 p.m. period. In 2017, there were 4 such days: June 12, June 13, July 19, and August 22. In 2018, there were 12 such days: June 18, July 2, July 3, July 5, July 10, July 16, August 2, August 6, August 7, August 28, August 29, September 6.

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major technology manufacturers are reviewed, along with each manufacturers' relevant DR program involvement.

This section also describes possible DR strategies employed to achieve peak load reductions (e.g., 3° temperature setpoint, direct load curtailment, delayed defrost, etc.).[31] Where applicable, this section also summarizes the program designs of relevant utility programs, along with challenges encountered.

2.2 Potential Impact Per Device

In Phase 1 of this study, Navigant conducted a review of selected technical reference manuals (e.g., Massachusetts, Rhode Island, New York, Vermont, Illinois), and potential studies and program evaluations conducted by other utilities and organizations to collect information that informs the typical load that could be reduced for the appliances identified in Figure 1-1. Metrics collected include estimates of average load[32] and summer peak coincidence factors, and evaluated summer peak demand impacts, where available. Other metrics researched include willingness to participate in (i.e., sign up for) a DR program (i.e., discretionary factor), and per event participation rates (i.e., the inverse of opt-out rate), connectivity rates, and, for smart plug-based DR programs, the first year in-service rate[33] (i.e., derating factors).

In Phase 2 of this study, Navigant constructed average daily load shapes for each appliance type using end-use metering data from the MA Residential Baseline Study for the 2017 and 2018 summer periods (see Appendix A). For each appliance type, Navigant reports the average load coincident with the summer peak period of 2 p.m. to 5 p.m. for all 2017 and 2018 summer non-holiday weekdays (All Days), and for the weekdays for which the maximum temperature during the peak period was above 85°F (Hottest Days). With the exception of CACs, the Hottest Days scenario was chosen as the scenario upon which to base the benefit-cost analysis. Since peak demand impacts related to National Grid's Massachusetts Wi-Fi thermostat DR program for CACs have been evaluated, Navigant based the benefit-cost analysis for CACs DR on the evaluated impact value.

2.3 Total Achievable Impact

In this section, Navigant summarizes findings from the MA Baseline Study Saturation Survey related to the installed base (in National Grid's Massachusetts territory) of the appliances considered in this study. This section also contains Navigant's assumptions related to customers' willingness to enroll in a DR program and related to program participation in years following participants' first year of a DR program (i.e., the likelihood that customers will continue to participate in a program after year 1).

2.4 Benefit-Cost Analysis

Combining research on achievable unit impacts and program costs, Navigant performed a benefit-cost analysis, using the MA Total Resource Cost (TRC) Test, for each appliance and DR-enabling device

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[31] For each appliance and DR-enabling device, benefit-cost analysis results will be based on an assumed DR strategy.

[32] Average appliance load for the summer peak period was collected, if available. Otherwise, average load on a summer-wide or annual basis was collected.

[33] Defined for this report as the rate at which smart plugs are self-installed in the first year of participation.

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combination. For these analyses, Navigant calculated the net-present value of annual benefits and costs for the period from 2019 to 2028.

In converting unit kilowatt impacts to monetary benefits, Navigant used avoided cost assumptions from the 2018 Avoided Energy Supply Cost (AESC) Study. Avoided costs related to avoided generation capacity and avoided transmission and distribution (T&D) capacity represent the total avoided costs resulting from DR. Avoided generation capacity costs used in the benefit-cost models for this report range from 81 $/kW-year in 2019 to 111 $/kW-year in 2028[34]. Avoided T&D capacity costs used for this report stay at approximately 182 $/kW-year between 2019 and 2028. These avoided costs are in real dollars and are discounted using the inflation-adjusted discount rate of 0.4%.

Navigant assumes no net-energy savings (for any appliance/DR device combination). This is because energy consumption is assumed to be shifted (not lowered) in response to DR participation. Therefore, avoided costs of energy estimated for this report are assumed to be zero.

Navigant gathered available information on DR program costs from National Grid program managers. For the purposes of this study, costs such as program setup costs and DR management system (DRMS) annual license fees, which are/would be shared with other DR programs (both residential and commercial and industrial [C&I]) are not included as costs in the appliance-specific benefit-cost ratio.

Costs included in the benefit-cost analysis are measure-level costs—in other words, costs that depend on the number of enrolled devices. From the analysis, Navigant excludes DR program costs in the benefit-cost analysis—or costs that would be shared with other DR initiatives, such as program setup costs and annual DRMS license fees.

Measure-level costs include upfront device costs for non-bring-your-own (BYO) programs. The programs for which Navigant included device costs in the total resource cost (TRC) include those featuring smart plugs, simple timer plugs, smart switches, and simple timer switches.[35] The device cost for smart and simple switches includes the cost of installation, since an electrician would be required to install these devices. Devices for which Navigant does not include device cost in the TRC for the associated program include Wi-Fi thermostats, all smart (built-in) appliances, and the battery in the case of battery storage DR program.

Other costs included in the benefit-cost analysis include per device original equipment manufacturer (OEM) and DRMS fees, and costs of program administration and evaluation,[36] and marketing.[37] Additionally, customer incentives are included in the TRC as a cost (to the utility).

For simple timer plug and switch options, no per device OEM and DRMS fee is included. However, a pre-programming fee per device is included.

As with the avoided costs, these costs are discounted using the inflation-adjusted discount rate of 0.4%.

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[34] Avoided generation costs include DRIPE benefits of $71.71/kW in 2019 and $101.17 /kW in 2028.

[35] As well as the OBD dongle in the case of EV charging DR.

[36] Administration and evaluation costs are assumed to be 15% of total program costs every year.

[37] For all program except those featuring smart or simple timer plugs, a fixed annual marketing cost was assumed. For smart/simple plug programs (including OBD dongle for EVs), a per device-per-year marketing cost was assumed. This cost was applied to returning customers in addition to new customers since returning customers will need to be reminded to re-plug their appliances into the smart/simple plug.

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Table 2-2. Total Resource Cost (TRC) Test, Benefits and Costs

Benefits	Costs
Avoided Generation Capacity Avoided T&D Capacity	Device cost (non-BYO only) OEM Fee per device per year (excluding Simple timer plugs/switches) DRMS Fee per device per year (excluding Simple timer plugs/switches) Pre-programming fee (Simple timer plugs/switches only) Program Administration and Evaluation[38] Program Marketing Customer Incentives

Source: Navigant analysis, reference footnote.

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[38] Evaluation of programs involving simple timer plugs/switches would require some metering since no telemetry data would be available. No additional evaluation costs were assumed for programs involving simple timer plugs/switches.

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3. STUDY FINDINGS

Findings related to each appliance type are discussed in the subsections below.

3.1 Central Air Conditioners

A. DR Context

CACs are the most common target of DR programs across the US. One popular option for controlling residential CACs is by a Wi-Fi-enabled thermostat. For some years, utilities have sponsored direct install thermostat programs. More recently, thermostat OEMs have begun marketing smart thermostats directly to consumers, allowing utilities to offer BYO-thermostat (BYOT) programs to residential customers.

The strategies used for reducing the coincident peak load of CACs include cycling and setpoint adjustment. Cycling involves shutting the compressor off for short intervals for a total of anywhere from 25% to 100% of the peak energy event. The setpoint of the thermostat can also be adjusted upwards during an event in order to effectively shut off the AC's compressor for a portion of event. The setpoint may also be adjusted prior to a peak period (precooling a home) so that demand will be reduced during the event, or to minimize negative impacts on customer comfort during the DR event.

One of the major concerns with DR involving residential ACs is customer behavior. Peak energy events in the summer are often the hottest summer days when consumers use AC the most. Thus, some customers may choose to override their thermostat's setpoint adjustment, which lowers the aggregate demand reduction.

There are many smart thermostat OEMs, but Nest, Honeywell, Ecobee, and Building36 are the four primary types of smart thermostats owned by National Grid's Massachusetts customers (Figure 3-1). Nest, Honeywell, and Ecobee all have partnerships with numerous utilities (including National Grid) to offer residential DR programs targeting CACs and other connected home appliances. These three smart thermostat providers were all deemed residential DR market "Contenders" in Navigant Research's recently published report, *Navigant Research Leaderboard: Residential Demand Response*.[39] Historically the highest cost option among smart thermostats, Nest recently introduced the Nest thermostat E model (at $169). Building36, although a seemingly lesser known brand, also has a strong hold in National Grid's Massachusetts territory, and is a local company. Additionally, Building36's Wi-Fi thermostat does not require a common wire. This enables the installation of a Building36 thermostat in some situations where other thermostats could not function without alterations to the home's wiring.

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[39] Contenders are companies that have a solid foundation for growth and long-term success, but which have not attained a superior position in the market. They are well-positioned to become Leaders, but have not yet fully executed their product launches, need to differentiate themselves via unique DR technology or cost breakthroughs, are seeing weaker than expected demand, or have limited market penetration. (Scoring strongest to weakest: Leaders, Contenders, Challengers, Followers)

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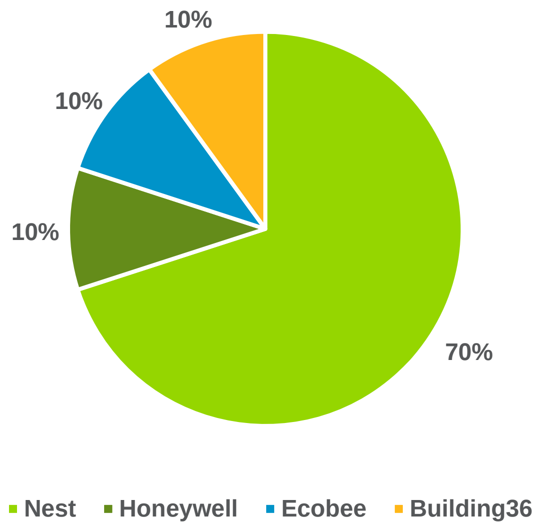
Figure 3-1. Wi-Fi Thermostat OEM Market Share in National Grid Massachusetts Territory



Source: MA Baseline Study Saturation Survey

Table 3-1. DR-Enabling Device Market, Wi-Fi Thermostats

OEMs	Proven in DR Context?	Example Utility Partners
Nest	Yes	Duke, KCP&L, ComEd, PG&E, Reliant, Austin Energy, Con Edison, Hydro One, and more
Ecobee	Yes	SCE, CPS, and others
Honeywell	Yes	Xcel Energy, DTE, Con Edison, Austin Energy, CPS Energy, SCE, and more
Building36	Yes	6% of DR and EE projects in NEEP jurisdiction[40]

Source: Web research

B. Potential Impact Per Device

Due to the fact that National Grid has already piloted and evaluated a DR program for CACs, harnessing Wi-Fi thermostat technology and a 3° F temperature setback strategy, the final summer peak coincident demand reduction estimate used for the purposes of this report is the evaluated 2018 value of 0.71 kW

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[40] According to a 2015 NEEP Program Activity Survey, Nest was listed as the most frequently used hardware brand, with approximately 27% of pilots or programs partnering with Nest. ecobee and Honeywell both came in as serving approximately 16% of DR and EE program Wi-Fi thermostat needs. Source: Northeast Energy Efficiency Partnerships, *Opportunities for Home Energy Management Systems (HEMS) in Advancing Residential Energy Efficiency Programs*, August 2015.

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per device.[41] This value reflects the average treatment effect (ATE) across all event days in the summer of 2018, as detailed in the 2018 evaluation of National Grid's residential DR program impacts.[42]

For comparison purposes, Table 3-2 includes unit impact findings based on a review of the Technical Reference Manuals (TRMs) for Massachusetts, New York, and Illinois. The table also includes average coincident load results from the metering conducted as part of the MA Baseline Study for all summer weekdays (All Days) and weekdays for which the maximum temperature during the peak period was above 85°F (Hottest Days). The size of the metering sample for CACs was 94 units. After applying a derating factor, potential load reduction during the peak period for the All Days and Hottest Days scenarios was 0.35 and 0.85 kW, respectively.

The derating factor listed in Table 3-3 is also based on the 2018 evaluation of National Grid's residential DR program impacts. An overall derating factor of 0.6 was calculated based on ATE demand impacts and average predicted baseline across all 2018 events. This derating factor is applied to coincident load estimates to estimate potential or achievable impact per unit. The ATE value of 0.71 kW from the 2018 impact evaluation of National Grid's DR program already theoretically includes the 0.6 derating factor.

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[41] It is important to note that impacts associated with a larger temperature setback could be even higher. For example, the evaluation of National Grid New York's 2017 coolControl program, found that, on average, each Emerson Sensi Wi-Fi thermostat curtailed an average of 0.93 kW during events; from *National Grid Dynamic Load Management Programs Annual Report for 2017 Capability Period*.

[42] National Grid's 2018 Residential DR Program Evaluation Final Report (not yet public).

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Table 3-2. Unit Impact Metrics

Source	Wi-Fi Thermostat, Temperature Setback				
	Year of Publication	**Average Load**	**Coincidence Factor**	**Derating**	**kW/Appliance During Peak**
MA TRM	2015	2.8[43]	0.25	0.6	0.39
NY TRM	2017	2.8	0.80	0.6	1.25
IL TRM	2017	3.0	0.68	0.6	1.14
2018 National Grid MA DR Evaluation	2018	N/A	N/A	N/A	**0.71**
Source	**Year of Publication**	**Average Coincident Load**		**Derating**	**kW/Appliance During Peak**
MA Baseline Study End-Use Metering – All Days	2018	0.63		0.6	0.35
MA Baseline Study End-Use Metering – Hottest Days	2018	1.52		0.6	0.85
Potential Peak Demand Impact per Device					**0.71**

Source: Navigant analysis based on multiple data sources, reference footnotes.

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[43] While the 2016-2018 Massachusetts TRM does not directly provide this listed value, it provides a formula and values for calculating CAC demand: $kW = (Cooling\ Capacity)/(Energy\ Efficiency\ Ratio)$, with an average cooling capacity of 31.2 kBtu/h and an EER of 11.

Table 3-3. Derating Assumptions, CACs

Derating Factor	Value
Participation Rate per event	0.8[44]
Connectivity	0.9[45]
Additional Derating Associated with Temp Setback	0.8[46]
First Year In-Service	N/A
Final Derating Factor	**0.6[47]**

Source: Navigant analysis based on multiple data sources, reference footnotes.

C. Total Achievable Impact

Table 3-4 contains relevant saturation statistics from the MA Baseline Study Saturation Survey. The results show that there were approximately 40,000 Wi-Fi thermostats installed in National Grid's Massachusetts territory as of 2017. [48] This information serves as a basis for estimating total impacts (benefits) on a program level. Additionally, it provides context for the feasibility of program expansion in coming years. Navigant predicts that the amount of Wi-Fi thermostats installed in homes will more than double by 2028.

Table 3-4. Saturation and Estimated Enrollment in National Grid's Massachusetts Territory

	2019	2028
Average Number of CACs/Customer	0.34[49]	0.34
Approximate Number of CACs[50]	400,000	400,000

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[44] National Grid's 2018 Residential DR Program Evaluation Final Report (not yet public).

[45] The connectivity rate from National Grid's 2018 Residential DR Program Evaluation Final Report is closer to 100%. As a conservative approach, Navigant assumes a 90% connectivity rate, which aligns with rates of Wi-Fi thermostat connectivity for earlier years of National Grid's residential DR program.

[46] Navigant assumed an additional derating factor of 0.8 reflecting the fact that the temperature setback strategy entails a cycling of the air conditioner compressor aimed at maintaining a certain temperature. This additional 0.8 derating factor was back calculated from the evaluated total derating factor (0.6) and the combined participation rate and connectivity rate derating factor (0.7).

[47] Using Navigant's 2018 impact analysis of National Grid's DR program, Navigant calculated a total derating factor of 0.6 by dividing ATE by average predicted kilowatt during events (baseline).

[48] Based on MA Baseline Study Saturation Survey results for National Grid (*National Grid Electric Final Saturation Results 2017-07-16.xls* and *National Grid Electric Draft Final Survey Characterization Results 2017-07-16.xls*).

[49] From MA Baseline Study Saturation Survey results for National Grid (*National Grid Electric Final Saturation Results 2017-07-16.xls*).

[50] Based on MA Baseline Study estimate/forecast of National Grid's Massachusetts population of households (approximately 1.2 million households in 2017 and in 2028).

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	2019	2028
Approximate Number of Wi-Fi Thermostats	55,000[51]	160,000[52]
Estimated Devices Enrolled in DR Program	12,000	32,000

Source: Navigant analysis based on multiple data sources, reference footnotes.

Two other factors impact the total peak demand reduction achievable on a program level: customers' willingness to sign up for a DR program (i.e., discretionary factor) and customers' likelihood of continued program participation following the first year of participation (i.e., persistence factor). Based on a review of available literature, Navigant assumed that up to 20 percent of customers with Wi-Fi thermostats would be willing to enroll in a program in which their thermostat setpoint would be automatically adjusted by National Grid.[53][54] A persistence factor of nearly 100 is the percentage of 2016 Wi-Fi thermostat DR enrollees who re-enrolled or continued to participate in National Grid's 2017 DR program offering.

Based on the assumptions discussed above, Navigant estimates achievable DR program enrollment to be 10,000 devices in 2019 and 27,000 devices by 2028.

D. Benefit-Cost Analysis

Table 3-5 shows the estimated net-present value of total benefits and costs, according to the TRC test, for the 2019 to 2028 timeframe, based on expected program size over this period. This results in a benefit-cost ratio of 1.7, indicating National Grid's Wi-Fi thermostat DR program for CACs is cost-effective.

Table 3-5. TRC Test Benefits and Costs, 2019 to 2028

	Wi-Fi Thermostat, Temperature Setback		
	Total Impact (Benefit) (Millions)	Total Costs (Millions)	Benefit-Cost Ratio
CACs - Wi-Fi Thermostat	$44.2	$15.1	2.9

Source: Navigant analysis.

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[51] Based on the penetration rate of smart, communicating thermostats in North America from the Navigant Research report, *Market Data: IoT for Residential Energy Customers, Global Market Forecasts, 2016-2026,* 2016. Due to the existence of incentives for Wi-Fi thermostats in MA, Navigant assumed double the North American growth rate.

[52] ibid.

[53] Based on discussions with National Grid.

[54] Navigant assumes program adoption would be gradual, not immediate. Thus, the assumed willingness percentage (20% for CACs) is used as an enrollment cap for forecasting of program enrollment over a 10-year period. For CACs, this cap is reached in 2019.

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3.2 Room Air Conditioners

A. DR Context

Room ACs (RACs) can be DR-enabled either indirectly through a smart plug, such as those offered by ThinkEco, or directly if the RAC is Wi-Fi enabled, such as some models offered by Frigidaire, Friedrich, and LG (see Table 3-6). There is also a device currently on the market called the AirPatrol WiFi AC Controller, which can connect to most remote-controlled RACs via an IR controller, and can itself be controlled like a Nest thermostat.

In 2012, Con Edison began the CoolNYC pilot (later called the Residential Smart AC program), a DR program targeting RACs in New York City. Over the years, Con Edison experimented with multiple program channels for DR-enablement (i.e., ThinkEco smart plug and BYOT smart AC), and with how to best facilitate and incentivize self-installation of smart plugs to keep costs down (avoiding having to go to homes to install) and maintain program participation year after year. Participation rates have been a problem for utility pilot programs; in their room AC pilot with ThinkEco, CPS energy found that while 793 of the 820 ThinkEco Wi-Fi plugs installed in 2016 were online (97%), just 35% (287 devices) of the SmartAC kits provided in the previous year were online.[55] Since room AC units are typically uninstalled for the winter, they found that most people did not plug the AC unit back in through the Wi-Fi plug. While built-in DR-enabled room ACs solve this problem, they are generally more expensive and have less penetration in the market. Con Edison’s CoolNYC program found success with its customer self-install option by leveraging a “Try-it” program that changed the eligibility requirements to ensure that customers could install the devices and would only get to keep them if they were installed correctly, and by introducing a points program that rewarded the quick installation of devices. In 2015, its self-install strategy had a setup rate of 74% of gross enrollments and 95% of net enrollments after accounting for devices that were sent back by customers if they decided they no longer wanted to participate.

The main DR strategies used for RACs are cycling and setpoint adjustment. CPS Energy in Texas uses a combination of these strategies for its ThinkEco pilot program, cycling the RAC off for the first 10 minutes and then increasing the setpoint by 3° after that. For the bulk system, the cycle times are randomized to best reduce peak load overall.

One drawback to DR for RACs is that RAC load is associated with relatively low peak coincident load (compared to CACs). The CoolNYC program found that in fact 50% of rebated RACs are installed in a bedroom, and therefore are likely used mostly at night.[56] Relatedly, due to their lower capacities (relative to CACs), RACs are likely used more on an as needed basis to cool a proximal space than to cool on a consistent schedule. Findings from the MA Baseline Study support this. For RACs, the MA Baseline

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[55] Frontier Associates LLC, *Evaluation, Measurement & Verification of CPS Energy’s FY 2016 DSM Programs*, June 2016, https://www.sanantonio.gov/portals/0/files/sustainability/Environment/CPSFY2016.pdf.

[56] Energy & Resources Solutions, *Con Edison EEPS Programs – Impact Evaluation of Residential Room Air Conditioner Program* October 10, 2013.

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Study calculated a System Peak[57] coincidence factor of 0.42 and an On-Peak[58] coincidence factor of 0.17.[59]

Table 3-6. DR-Enabling Device Market

OEMs	DR-Enabled Product	Proven in DR Context?	Example Utility Partners
Smart Plugs			
ThinkEco^	Smart Plug	Yes	National Grid, CPS Energy, United Illuminating, Con Edison
Belkin	Wemo Smart Plug	No	
TP-Link	Smart Plug	No	
iHome	SmartPlug	No	
Built-In			
Frigidaire	Cool Connect	Yes	Con Edison
Freidrich	Kühl	Yes	Con Edison
GE/Haier	Comfort Mobile	No	
LG	SmartThinQ	No	

Source: Navigant Research Leaderboard: Residential Demand Response (2017); Web research
^Ranked as a "Challenger" in the DR space by Navigant Research (Scoring strongest to weakest: Leaders, Contenders, Challengers, Followers)

B. Potential Impact Per Device

Table 3-7, Table 3-8, and Table 3-9 contain the average coincident load results for RACs from the metering conducted as part of the MA Baseline Study for all summer weekdays (All Days) and weekdays for which the maximum temperature during the peak period was above 85°F (Hottest Days) for the smart plug, simple timer plug, and smart RAC (built-in) technologies, respectively. The size of the metering sample for RACs was 147 units.

For each RAC's technology option, Navigant used the Hottest Days' impact as final potential peak demand reduction value for BCR purposes. After applying a derating factor, potential load reduction during the peak period associated with the Hottest Days scenario for the smart plug, simple timer plug and smart RACs options is 0.09 kW, 0.11 kW, and 0.13 kW, respectively.

For comparison purposes, Table 3-7 (Smart Plugs) and Table 3-9 (Smart RAC) also include unit impact findings based on a review of the TRMs for Massachusetts, New York, and Illinois, and evaluated peak demand reduction estimates associated with Con Edison's Residential Smart Appliance (CoolNYC) program. Con Edison's program included both smart plug DR-enablement and BYO smart RAC options.

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[57] The MA Baseline Study defines summer system peak 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.

[58] The MA Baseline Study defines summer On-Peak equivalent to 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.

[59] *Massachusetts Residential Baseline Study – 2018 Comprehensive Report, March 1, 2019.*

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The estimated demand impacts associated with smart RACs and simple timer plugs are slightly higher than that impacts achieved by smart plug participants due to the lower derating factor of the latter. Derating factor assumptions are described below.

Table 3-7. Unit Impact Metrics for RACs with Smart Plug

	Smart Plug, Temperature Setback				
Source	**Year of Publication**	**Average Load**	**Coincidence Factor**	**Derating**	**kW/Appliance During Peak**
MA TRM	2012	1.0[60]	N/A	0.35	0.36
NY TRM	2017	1.0	0.80	0.35	0.28
IL TRM	2017	0.9	0.30	0.35	0.10
Con Edison's Residential Smart Appliance program[61]	2013/2015	N/A	N/A	N/A	0.06
National Grid NY coolControl Pilot[62]	2017	N/A	N/A	N/A	0.05
Source	**Year of Publication**	**Average Coincident Load**		**Derating**	**kW/Appliance During Peak**
MA Baseline Study End-Use Metering – All Days	2018	0.11		0.35	0.04
MA Baseline Study End-Use Metering – Hottest Days	2018	0.27		0.35	**0.09**
Potential Peak Demand Impact per Device					**0.09**

Source: Navigant analysis based on multiple data sources, reference footnotes.

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[60] Average load from the TRM includes summer peak CF..

[61] Consolidated Edison Company of New York, *Cost-Effectiveness of CECONY Demand Response Programs*, November 2013.

[62] In total, there were 313 ThinkEco SmartAC kits participated in the coolControl program by the end of the 2017 capability period. On average each SmartAC kit curtailed 0.050 kW for a total curtailment of 15.7 kW; from *National Grid Dynamic Load Management Programs Annual Report for 2017 Capability Period*.

Table 3-8. Unit Impact Metrics for RACs with Simple Timer Plug

Source	Simple Plug, DLC			
	Year of Publication	Average Coincident Load	Derating	kW/Appliance During Peak
MA Baseline Study End-Use Metering – All Days	2018	0.11	0.42	0.05
MA Baseline Study End-Use Metering – Hottest Days	2018	0.27	0.42	**0.11**
Potential Peak Demand Impact per Device				**0.11**

Source: *Navigant analysis based on MA Baseline Study data.*

Table 3-9. Unit Impact Metrics for RACs with Built-in DR Capability

Source	Smart Appliance, Temperature Setback				
	Year of Publication	Average Load	Coincidence Factor	Derating	kW/Appliance During Peak
MA TRM	2012	0.9[63]	1.0	0.48	0.44
NY TRM	2017	0.9	0.80	0.48	0.35
IL TRM	2017	0.9	0.30	0.48	0.12
Con Edison's Residential Smart Appliance program[64]	2013/2015	N/A	N/A	N/A	0.08
Source	**Year of Publication**	**Average Coincident Load**		**Derating**	**kW/Appliance During Peak**
MA Baseline Study End-Use Metering – All Days	2018	0.11		0.48	0.05
MA Baseline Study End-Use Metering – Hottest Days	2018	0.27		0.48	0.13
Potential Peak Demand Impact per Device					**0.13**

Source: *Navigant analysis based on multiple data sources, reference footnotes.*

The derating factors listed in Table 3-10, Table 3-11 and Table 3-12 are based on information provided in cost-effectiveness reports relating to Con Edison's CoolNYC program (though Navigant assumes a 90%

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[63] Average load from the TRM includes summer peak CF. Therefore, CF is listed as 1 in the above table.

[64] Consolidated Edison Company of New York, *Cost-Effectiveness of CECONY Demand Response Programs*, November 2013.

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connectivity rate based on National Grid's DR program findings). Results for CoolNYC showed an average 30% opt-out rate (i.e., 70% participation rate). Additionally, for the smart plug strategy, Navigant assumed an optimistic first year in-service rate of 70%, consistent with the rate Con Edison was able to achieve by 2015 by adjusting its penalty/incentive structure. Navigant assumed a slightly lower first year in-service rate of 60% for the simple timer plug option due to the fact that the program will not be able to verify installation.

In addition, for the smart plug and smart RACs options, Navigant incorporated the same 80% derating factor as for CACs, associated with a 3° temperature setback strategy.

For each technology option, these derating factor components were combined and applied to coincident load estimates to estimate potential or achievable impact per unit, as reported above.

Table 3-10. Derating Assumptions, Smart Plug

Derating Factor	Value
Participation Rate per event	0.7[65]
Connectivity	0.9[66]
Additional Derating for Temperature Setback Strategy	0.8[67]
First Year In-Service	0.7[68]
Final Derating Factor	**0.35**

Source: Navigant analysis based on multiple data sources, reference footnotes.

Table 3-11. Derating Assumptions, Simple Timer Plug

Derating Factor	Value
Participation Rate per Event	0.7[69]
Connectivity	N/A
Additional Derating for Temperature Setback Strategy	N/A
First Year In-Service	0.6[70]

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[65] Based on CoolNYC program average event participation rate across all events in summer 2015; Consolidated Edison Company of New York, Inc., *Program Performance and Cost Effectiveness of Demand Response Programs*, December 1, 2015, 53.

[66] Assumed the same connectivity rate as for CACs

[67] Assumed to be the same as for CACs.

[68] CoolNYC 2015 installation rate for first-year enrollees based on 2015 incentive structure (up from 40% in 2013); Consolidated Edison Company of New York, Inc., *Program Performance and Cost Effectiveness of Demand Response Programs*, December 1, 2015, 53.

[69] Based on CoolNYC program average event participation rate across all events in summer 2015; Consolidated Edison Company of New York, Inc., *Program Performance and Cost Effectiveness of Demand Response Programs*, December 1, 2015, 53.

[70] Assumed to be slightly lower than smart plug first-year in-service rate due to the fact that installation cannot be verified by program.

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Final Derating Factor	**0.42**

Source: Navigant analysis based on multiple data sources, reference footnotes.

Table 3-12. Derating Assumptions, Smart RAC

Derating Factor	Value
Participation Rate per Event	0.7[71]
Connectivity	0.9[72]
Additional Derating for Temperature Setback Strategy	0.8[73]
First Year In-Service	N/A
Final Derating Factor	**0.48**

Source: Navigant analysis based on multiple data sources, reference footnotes.

C. Total Achievable Impact

Table 3-13 contains relevant saturation statistics from the MA Baseline Study Saturation Survey and Navigant Research reports. The results show that there were approximately 1.2 million RACs in National Grid's Massachusetts territory as of 2017. The number of smart RACs (with built-in DR-enablement) is currently assumed to be small (less than 5% of installed RACs). This information serves as a basis for estimating total impacts (benefits) on a program level. Additionally, it provides context for the feasibility of program expansion in coming years. Navigant predicts that the number of smart RACs will increase to approximately 20% of installed RACs by 2028.[74]

Table 3-13. Saturation and Estimated Enrollment in National Grid's Massachusetts Territory

	2019	2028
Average Number of RACs/Customer	1.05[75]	1.05

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[71] Based on CoolNYC program average event participation rate across all events in summer 2015; Consolidated Edison Company of New York, Inc., *Program Performance and Cost Effectiveness of Demand Response Programs*, December 1, 2015, 53.

[72] Assumed the same connectivity rate as for CACs.

[73] Assumed to be the same as for CACs.

[74] Based on forecasted penetration rate for smart appliances in North America. Navigant Research, *Market Data: IoT for Residential Energy Customers, Global Market Forecasts, 2016-2026*, 2016.

[75] From MA Baseline Study Saturation Survey results for National Grid (*National Grid Electric Final Saturation Results 2017-07-16.xls*).

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	2019	2028
Approximate Number of RACs[76]	1,200,000	1,200,000
Approximate Number of Smart RACs[77]	40,000	250,000
Estimated Devices Enrolled in DR Program with Simple Timer Plug	6,000	60,000
Estimated Devices Enrolled in DR Program with Wi-Fi Plug	6,000	60,000
Estimated Smart RAC Devices Enrolled in DR Program	2,000	80,000

Source: Navigant analysis based on multiple data sources, reference footnotes.

Two other factors impact the total peak demand reduction achievable on a program level: customers' willingness to sign up for a DR program (i.e., discretionary factor) and customers' likelihood of continued program participation following the first year of participation (i.e., persistence factor). Based on a review of available literature, Navigant assumed that 30% of customers with RACs would be willing to enroll in a program in which their AC use would be automatically curtailed or temperature setpoint adjusted by National Grid.[78] A persistence factor of 90% is assumed for smart RAC participant (i.e., slightly lower than the persistence rate associated with National Grid's CAC Wi-Fi Thermostat DR program). However, a persistence factor of 30% is assumed for smart plug and simple timer plug participants, reflecting the fact that a segment of returning participants will forget to reconnect their RAC with the plug provided by the program every season.[79]

Based on the assumptions discussed above, while Navigant estimates achievable DR program enrollment associated with Wi-Fi plugs or simple timer plugs to outnumber smart RAC enrollment 3 to 1 in 2019, Navigant expects enrollment of smart RACs to outpace enrollment in plug-based DR programs by 2028.

D. Benefit-Cost Analysis

Table 3-14 shows the estimated net-present value of total benefits and costs, according to the Total Resources Cost (TRC) test, for the 2019 to 2028 timeframe, based on expected program size over this period. Results for both the smart plug and smart appliance DR-enablement strategies are provided. Results show a benefit-cost ratio of 0.2, 0.5, and 0.6 for the smart plug, simple timer plug, and smart RAC options, respectively. Although the none of these options passes the cost-effectiveness test, it is evident that the plug-based programs are less cost-effective than a RAC DR program targeting RACs with built-in DR capability due to the added device costs associated with the smart plug.[80]

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[76] Based on MA Baseline Study estimate/forecast of National Grid's Massachusetts population of households (approximately 1.2 million households in 2017 and in 2028).

[77] Based on forecasted smart appliance penetration for North America (Table 3.22). Navigant Research, *Market Data: IoT for Residential Energy Customers, Global Market Forecasts, 2016-2026*, 2016.

[78] Consolidated Edison Company of New York, *Report on Program Performance and Cost Effectiveness of Demand Response Programs*, December 1, 2015.

[79] Ibid.

[80] In the future, more customers may have their own smart plugs, and the program's cost-effectiveness would improve.

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Table 3-14. TRC Test Benefits and Costs, 2019-2028

	Smart Plug, Temperature Setback		
	Total Impact (Benefit) (Millions)	Total Costs (Millions)	Benefit-Cost Ratio
RACs - Smart Plug	$10.0	$60.9	0.2

Source: Navigant analysis

	Simple Timer Plug, DLC		
	Total Impact (Benefit) (Millions)	Total Costs (Millions)	Benefit-Cost Ratio
RACs - Simple timer plug	$11.9	$26.3	0.5

Source: Navigant analysis

	Smart Appliance, Temperature Setback		
	Total Impact (Benefit) (Millions)	Total Costs (Millions)	Benefit-Cost Ratio
RACs - Smart Appliance	$15.6	$26.9	0.6

Source: Navigant analysis

3.3 Clothes Washers

A. DR Context

The following section provides background on the integration of clothes washers as a DR resource. It is important to note, however, that this study finds that clothes washers are associated with low coincident peak demand and a relatively low event participation rate. Section 3.3 B describes the basis for these findings.

In the past 5 years, there has been increasing interest in DR for appliances other than ACs, such as clothes washers. Numerous studies have been performed to understand the DR potential, though there have not been large-scale utility pilots focused on direct load control. Instead, pilots have largely utilized dynamic pricing to assess the potential cost savings associated with customers being economically persuaded into using the clothes washer at a nonpeak period. In 2009, GE employees served by Louisville Gas and Electric were provided with dynamic pricing and a suite of connected smart appliances included clothes washers and dryers and dishwashers, and after a year saw a reduction in energy usage of as much as 20%.

With the prevalence of smart meters, some utilities such as Exelon's Commonwealth Edison (ComEd) and San Diego Gas & Electric are now offering credits from $0.75-$1.25 per kWh of energy saved by residential customers during a defined peak period by delaying their appliance load, advertising credits of $1-$3 per event for delaying usage of a clothes washer. In fact, ComEd partnered with Whirlpool in 2013 during its rollout of connected washers and dryers as part of this program.

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ENERGY STAR has defined a DR-enabled clothes washer as having "the capability to receive, interpret, and act upon consumer-authorized signals by automatically adjusting its operation depending on both the signal's contents and settings from consumers." Note that there is no requirement for the mode of communication, though it now occurs most commonly over Wi-Fi. There are numerous clothes washers on the market that meet this connected definition and can be utilized as built-in, smart clothes washers, though there are questions surrounding manufacturers' willingness to work with utilities in developing outright DR capabilities.

Clothes washers are also a good option for connected smart plugs, which can turn the unit off for the duration of the peak energy period. While smart plug manufacturers have largely focused their development on other appliances, many of the major brands on the market would still work for clothes washers. Belkin's line of Wemo smart plugs and ThinkEco's model are all rated at 120V/15A/1800W, which is sufficient for most residential clothes washers that are normally plugged into the wall.

For direct load control, the main DR strategy is to shift the load to a nonpeak period by shutting the device off. There is also limited discussion about modifying the clothes washer settings to lower the temperature of the water.

Table 3-15 provides a summary of smart plug players and manufacturers of smart clothes washers.

Table 3-15. DR-Enabling Device Market

OEMs	DR-Enabled Product	Proven in DR Context?	Example Utility Partners
Smart Plugs			
ThinkEco	Modlet	No	
Belkin	Wemo Smart Plugs	No	
Smart Clothes Washers			
GE	GE Appliances	Yes	SDG&E
Whirlpool	Supreme Care with 6TH SENSE LIVE	Yes	ComEd
Bosch	Home Connect	No	
LG	LG Smart Washer	No	

Source: Navigant Research Leaderboard: Residential Demand Response (2017); Web research

B. Potential Impact Per Device

Table 3-16, Table 3-17, and Table 3-18 contain the average coincident load results for clothes washers from the metering conducted as part of the MA Baseline Study for all summer weekdays (All Days) and weekdays for which the maximum temperature during the peak period was above 85°F (Hottest Days) for the smart plug, simple timer plug, and smart clothes washers (Built-In)[81] technologies, respectively. The size of the metering sample for clothes washers was 218 units.

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[81] The metered sample included only 10 smart washers. Therefore, for the smart clothes washer option, Navigant used the load associated with all metered clothes washers, not just smart washers.

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For each clothes washer technology option, Navigant used the Hottest Days' impact as final potential peak demand reduction value for BCR purposes. After applying a derating factor, potential load reduction during the peak period associated with the Hottest Days scenario is 0.00 kW for all technology options. Low cost-effectiveness of DR for clothes washers is driven by the fact that demand does not correspond with peak periods (pre-derating average peak coincident demand associated with clothes washers is only 0.01).

For comparison purposes, Table 3-16 and Table 3-18 also include unit impact findings based on a review of from several states' TRMs and studies conducted by PNNL, LBNL, and Ecotope.

Table 3-16. Unit Impact Metrics for Clothes Washers with Smart Plug

Source	Smart Plug, DLC				
	Year of Publication	**Average Load**	**Coincidence Factor**	**Derating**	**kW/ Appliance During Peak**
MA TRM	2015	0.1[82]	N/A[83]	0.3	0.04
NY TRM	2017	1.3	0.03	0.3	0.01
VT TRM	2015	1.8	0.03	0.3	0.02
ME TRM	2017	1.6	0.05	0.3	0.02
IL TRM	2017	2.1	0.04	0.3	0.03
PNNL[84]	2010	N/A	N/A	0.3	0.00
Ecotope[85]	2014	N/A	N/A	0.3	0.00
LBNL[86]	2015	N/A	N/A	0.3	0.04
Source	**Year of Publication**	**Average Coincident Load**		**Derating**	**kW/ Appliance During Peak**
MA Baseline Study End-Use Metering – All Days	2018	0.01		0.3	0.00
MA Baseline Study End-Use Metering – Hottest Days	2018	0.01		0.3	0.00
Potential Peak Demand Impact per Device					**0.00**

Source: Navigant analysis based on multiple data sources, reference footnotes.

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[82] While the 2016-2018 MA TRM does not directly provide this listed value, it provides a formula and values for calculating average annual energy usage: $kWh = \left((Capacity * \# \, Cycles)/(Integrated \; Modified \; Energy \; Factor)\right) * (\% \; heating \; by \; electricity)$, with listed capacities of 3.09 to 3.90 ft^3, 283 cycles/year, along with a table of IMEFs and percentages for different model efficiencies.

[83] The coincidence factor provided by the Massachusetts TRM relates their calculated value to summer versus winter peaks; therefore, their value of 1.0 is not meaningful.

[84] PNNL, *Use of Residential Smart Appliances for Peak-Load Shifting and Spinning Reserves (Cost/Benefit Analysis)*, 2010.

[85] Ecotope, *Is Your Refrigerator Running? Energy Use and Load Shapes for Major Household Appliances*, ACEEE Summer Study 2014.

[86] Lawrence Berkley National Laboratory, *Demand Response Automation in Appliances and Equipment*, 2015.

Table 3-17. Unit Impact Metrics for Clothes Washers with Simple Timer Plug

	Simple Timer Plug, DLC			
Source	**Year of Publication**	**Average Coincident Load**	**Derating**	**kW/Appliance During Peak**
MA Baseline Study End-Use Metering – All Days	2018	0.01	0.3	0.00
MA Baseline Study End-Use Metering – Hottest Days	2018	0.01	0.3	0.00
Potential Peak Demand Impact per Device				**0.00**

Source: Navigant analysis based on MA Baseline Study data.

Table 3-18. Unit Impact Metrics for Clothes Washers with Built-in DR Capability

	Smart Appliance, DLC				
Source	**Year of Publication**	**Average Load**	**Coincidence Factor**	**Derating**	**kW/Appliance During Peak**
MA TRM	2015	0.1[87]	N/A[88]	0.5	0.04
NY TRM	2017	1.2	0.03	0.5	0.02
VT TRM	2015	1.3	0.03	0.5	0.02
ME TRM	2017	1.1	0.05	0.5	0.02
IL TRM	2017	1.5	0.04	0.5	0.03
Source	**Year of Publication**	**Average Coincident Load**		**Derating**	**kW/Appliance During Peak**
MA Baseline Study End-Use Metering – All Days	2018	0.01		0.5	0.00
MA Baseline Study End-Use Metering – Hottest Days	2018	0.01		0.5	**0.00**
Potential Peak Demand Impact per Device					**0.00**

Source: Navigant analysis based on multiple data sources, reference footnotes.

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[87] While the 2016-2018 MA TRM does not directly provide this listed value, it provides a formula and values for calculating average annual energy usage: $kWh = ((Capacity * \# Cycles)/(Integrated\ Modified\ Energy\ Factor)) * (\%\ heating\ by\ electricity)$, with listed capacities of 3.09 to 3.90 ft^3, 283 cycles/year, along with a table of IMEFs and percentages for different model efficiencies.

[88] The coincidence factor provided by the Massachusetts TRM relates their calculated value to summer versus winter peaks; therefore, their value of 1.0 is not meaningful.

The derating factors listed in the above tables are based on multiple sources. Table 3-19, Table 3-20, and Table 3-21 list the components of the derating factors assumed for a clothes washer DR program utilizing smart plugs, simple timer plugs, and smart clothes washers, respectively.

Together, these factors make up the derating factor for each option, which is applied to coincident load estimates to estimate potential or achievable impact per unit.

Table 3-19. Derating Assumptions, Smart Plug

Derating Factor	Value
Participation Rate per Event	0.5[89]
Connectivity	0.9[90]
Additional Derating for Temperature Setback Strategy	N/A
First Year In-Service	0.7[91]
Final Derating Factor	**0.3**

Source: Navigant analysis based on multiple data sources, reference footnotes.

Table 3-20. Derating Assumptions, Simple Timer Plug

Derating Factor	Value
Participation Rate per Event	0.5[92]
Connectivity	0.9[93]
Additional Derating for Temperature Setback Strategy	N/A
First Year In-Service	0.6[94]
Final Derating Factor	**0.3**

Source: Navigant analysis based on multiple data sources, reference footnotes.

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[89] Pessimistic scenario for “Fraction of On-Peak Load that Customers Willing to Shift” for clothes washers; from PNNL, *Use of Residential Smart Appliances for Peak-Load Shifting and Spinning Reserves: Cost/Benefit Analysis*, December 2010.

[90] Assumed the same connectivity rate as for CACs.

[91] Assumed to be the same as for RACs.

[92] Pessimistic scenario for “Fraction of On-Peak Load that Customers Willing to Shift” for clothes washers; from PNNL, *Use of Residential Smart Appliances for Peak-Load Shifting and Spinning Reserves: Cost/Benefit Analysis*, December 2010.

[93] Assumed the same connectivity rate as for CACs.

[94] Assumed to be the same as for RACs.

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Table 3-21. Derating Assumptions, Smart Clothes Washer

Derating Factor	Value
Participation Rate per event	0.5[95]
Connectivity	0.9[96]
Additional Derating for Temperature Setback Strategy	N/A
First Year In-Service	N/A
Final Derating Factor	**0.5**

Source: Navigant analysis based on multiple data sources, reference footnotes.

C. Total Achievable Impact

Table 3-22 contains relevant saturation statistics from the MA Baseline Study Saturation Survey. The results show that there were approximately 860,000 clothes washers in National Grid's Massachusetts territory as of 2017. The number of smart clothes washers (with built-in DR-enablement) is found to be approximately 70,000 as of 2017. This information serves as a basis for estimating total impacts (benefits) on a program level. Additionally, it provides context for the feasibility of program expansion in coming years. Based on a Navigant Research report on growth projections of smart appliances, Navigant estimates that the number of smart clothes washers will increase to be approximately 19% of installed base by 2028.[97]

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[95] Pessimistic scenario for "Fraction of On-Peak Load that Customers Willing to Shift" for clothes washers; from PNNL, *Use of Residential Smart Appliances for Peak-Load Shifting and Spinning Reserves: Cost/Benefit Analysis*, December 2010.

[96] Assumed the same connectivity rate as for CACs.

[97] Based on forecasted penetration rate for smart appliances in North America. Navigant Research, *Market Data: IoT for Residential Energy Customers, Global Market Forecasts, 2016-2026*, 2016.

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Table 3-22. Saturation and Estimated Enrollment in National Grid's Massachusetts Territory

	2019	2028
Average Number of Clothes Washers/Customer	0.74[98]	0.74
Approximate Number of Clothes Washers[99]	860,000	900,000
Approximate Number of Smart Clothes Washers[100]	87,000[101]	170,000[102]
Estimated Devices Enrolled in DR Program with a Simple Timer Plug	4,000	45,000
Estimated Devices Enrolled in DR Program with a Wi-Fi Plug	4,000	45,000
Estimated Smart Clothes Washer Devices Enrolled in DR Program	4,000	90,000

Source: Navigant analysis based on multiple data sources, reference footnotes.

Two other factors impact the total peak demand reduction achievable on a program level: customers' willingness to sign up for a DR program (i.e., discretionary factor) and customers' likelihood of continued program participation following the first year of participation (i.e., persistence factor). Based on a review of available literature, Navigant assumed that 70% of customers with clothes washers would be willing to enroll in a program in which their clothes washer use would be automatically delayed by National Grid.[103] A persistence factor of 90% is assumed for all three technology options (i.e. slightly lower than the persistence rate associated with National Grid's CAC Wi-Fi Thermostat DR program). Since clothes washers stay plugged in all year round, it is assumed that the smart plug or simple timer plug will also stay plugged in in years following the initial program year.

Based on the assumptions discussed above, Navigant estimates achievable DR program enrollment in 2019 to be approximately equal across enabling strategies. Navigant predicts enrollment of smart washers would outpace enrollment in plug-based DR programs by 2028.

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[98] From MA Baseline Study Saturation Survey results for National Grid (*National Grid Electric Final Saturation Results 2017-07-16.xls*).

[99] Based on MA Baseline Study estimate/forecast of National Grid's Massachusetts population of households (approximately 1.2 million households in 2017 and in 2028).

[100] The MA Baseline Study Saturation Survey contained questions related to whether customers' appliances (including clothes washers, refrigerators, pool pumps, water heaters, dehumidifiers, dryers) were Wi-Fi-enabled. Given the context of these questions, Navigant believes that these represent appliances with built-in Wi-Fi capabilities (as opposed to retrofits).

[101] Based on MA Baseline Study Saturation Survey results for National Grid (*National Grid Electric Final Saturation Results 2017-07-16.xls* and *National Grid Electric Draft Final Survey Characterization Results 2017-07-16.xls*).

[102] Based on forecasted penetration rate for smart appliances in North America. Navigant Research, *Market Data: IoT for Residential Energy Customers, Global Market Forecasts, 2016-2026*, 2016.

[103] Pessimistic scenario for "Fraction of Customers Willing to Shift On-Peak Load" for clothes washers; from PNNL, *Use of Residential Smart Appliances for Peak-Load Shifting and Spinning Reserves: Cost/Benefit Analysis*, December 2010.

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D. Benefit-Cost Analysis

Table 3-23 shows the estimated net-present value of total benefits and costs, according to the TRC test, for the 2019 to 2028 timeframe, based on expected program size over this period. Results for the smart plug, simple timer plug and smart clothes washer DR-enablement strategies are provided. Results show a benefit-cost ratio of 0.0 for all options considered due most units not being used during peak times.

Table 3-23. TRC Test Benefits and Costs, 2018-2028

	Smart Plug, DLC		
	Total Impact (Benefit) (Millions)	Total Costs (Millions)	Benefit-Cost Ratio
Clothes Washers - Smart Plug	$0.2	$60.9	0.0

Source: Navigant analysis

	Simple timer plug, DLC		
	Total Impact (Benefit) (Millions)	Total Costs (Millions)	Benefit-Cost Ratio
Clothes Washers - Simple timer plug	$0.2	$60.9	0.0

Source: Navigant analysis

	Smart Appliance, DLC		
	Total Impact (Benefit) (Millions)	Total Costs (Millions)	Benefit-Cost Ratio
Clothes Washers - Smart Appliance	$0.4	$27.6	0.0

Source: Navigant analysis

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3.4 Clothes Dryers

A. DR Context

As with clothes washers, it is important to note that this study finds that clothes dryers are associated with a relatively low event participation rate. This finding is discussed further in Section 3.4 B.

Similar to clothes washers, few pilots have tested direct load control for residential clothes dryers, instead favoring dynamic pricing for peak load to encourage shifting of dryer use to off-peak times.

As with clothes washers, there are dryers on the market that meet ENERGY STAR's connected definition and can be utilized as built-in DR-enabled devices. These could be used in a DR program to shift the load to a nonpeak period by shutting the device off. Another possible strategy would be to modify the drying temperature, by, for example, shutting off one of the heating elements for dryer with multiple heating elements. This would likely require cooperation with the manufacturer, which may be difficult to attain if the manufacturer senses that the customer may be dissatisfied with the product.

Table 3-24. DR-Enabling Device Market

OEMs	DR-Enabled Product	Proven in DR Context?	Example Utility Partners
GE	GE Appliances	Yes	SDG&E
Whirlpool	Supreme Care with 6TH SENSE LIVE	Yes	ComEd
Bosch	Home Connect	No	
LG	LG Smart Washer	No	

Source: Web research

B. Potential Impact Per Device

Table 3-25 contains the average coincident load results for clothes dryers from the metering conducted as part of the MA Baseline Study for all summer weekdays (All Days) and weekdays for which the maximum temperature during the peak period was above 85°F (Hottest Days). The size of the metering sample for clothes dryers was 178 units.[104]

Navigant used the Hottest Days' impact as final potential peak demand reduction value for BCR purposes. After applying a derating factor, potential load reduction during the peak period associated with the Hottest Days scenario is 0.04 kW for smart dryers.

For comparison purposes, the figure also includes peak demand reduction estimates derived from NY and VT TRMs and studies conducted by PNNL and Ecotope. From the TRMs, average load values for high efficiency unit were taken, as Navigant assumes that smart clothes dryers will also generally be high efficiency.

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[104] The metered sample included only six smart dryers. Therefore, Navigant used the load associated with all metered electric dryers, not just smart dryers.

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Table 3-25. Unit Impact Metrics

	Smart Appliance, DLC				
Source	**Year of Publication**	**Average Load**	**Coincidence Factor**	**Derating**	**kW/Appliance During Peak**
NY TRM	2017	2.1	0.04	0.5	0.04
VT TRM	2015	2.3	0.03	0.5	0.03
PNNL[105]	2010	N/A	N/A	0.5	0.08
Ecotope[106]	2014	0.17	N/A	0.5	0.08
Source	**Year of Publication**	**Average Coincident Load**		**Derating**	**kW/Appliance During Peak**
MA Baseline Study End-Use Metering – All Days	2018	0.10		0.5	0.04
MA Baseline Study End-Use Metering – Hottest Days	2018	0.10		0.5	**0.04**
Potential Peak Demand Impact per Device					**0.04**

Source: Navigant analysis based on multiple data sources, reference footnotes.

The derating factors listed in the above tables are based on multiple sources. Table 3-26 lists the components of the derating factors assumed for a smart dryer DR program.

Together, these factors make up the derating factor, which is applied to coincident load estimates to estimate potential or achievable impact per unit.

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[105] PNNL, *Use of Residential Smart Appliances for Peak-Load Shifting and Spinning Reserves (Cost/Benefit Analysis)*, 2010.

[106] Ecotope, *Is Your Refrigerator Running? Energy Use and Load Shapes for Major Household Appliances*, ACEEE Summer Study 2014.

Table 3-26. Derating Assumptions

Derating Factor	Value
Participation Rate per event	0.5[107]
Connectivity	0.9[108]
Additional Derating for Temperature Setback Strategy	N/A
First Year In-Service	N/A
Final Derating Factor	**0.5**

Source: Navigant analysis based on multiple data sources, reference footnotes.

C. Total Achievable Impact

Table 3-27 contains relevant saturation statistics from the MA Baseline Study Saturation Survey. The results show that there were approximately 50,000 Smart dryers installed in National Grid's Massachusetts territory as of 2017. This information serves as a basis for estimating total impacts (benefits) on a program level. Additionally, it provides context for the feasibility of program expansion in coming years. Based on a Navigant Research report on growth projections of smart appliances, Navigant estimates that the number of smart dryers will increase to be approximately 19% of installed base by 2028.[109]

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[107] Pessimistic scenario for "Fraction of On-Peak Load that Customers Willing to Shift" for clothes dryers; from PNNL, *Use of Residential Smart Appliances for Peak-Load Shifting and Spinning Reserves: Cost/Benefit Analysis*, December 2010.

[108] Ibid.

[109] Based on forecasted penetration rate for smart appliances in North America. Navigant Research, *Market Data: IoT for Residential Energy Customers, Global Market Forecasts, 2016-2026*, 2016.

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Table 3-27. Saturation and Estimated Enrollment in National Grid's Massachusetts Territory

	2019	2028
Average Number of Dryers/Customer	0.54[110]	0.54
Approximate Number of Dryers[111]	630,000	650,000
Approximate Number of Smart Dryers[112]	60,000[113]	120,000[114]
Estimated Smart Dryer Devices Enrolled in DR Program	4,000	72,000

Source: Navigant analysis based on multiple data sources, reference footnotes.

Two other factors impact the total peak demand reduction achievable on a program level: customers' willingness to sign up for a DR program (i.e., discretionary factor) and customers' likelihood of continued program participation following the first year of participation (i.e., persistence factor). Based on a review of available literature, Navigant assumed that 70% of customers with dryers would be willing to enroll in a program in which their dryer use would be automatically delayed by National Grid.[115] A persistence factor of 90% is assumed for smart dryers participants (i.e., slightly lower than the persistence rate associated with National Grid's CAC Wi-Fi Thermostat DR program).

Based on the assumptions discussed above, Navigant estimates achievable DR program enrollment to be 4,000 devices in 2019 and 72,000 devices by 2028.

D. Benefit-Cost Analysis

Table 3-28 shows the estimated net-present value of total benefits and costs, according to the TRC test for the 2019 to 2028 timeframe based on expected program size over this period. This results in a benefit-cost ratio of 0.2, indicating a DR program for smart dryers may not be cost-effective.

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[110] From MA Baseline Study Saturation Survey results for National Grid (*National Grid Electric Final Saturation Results 2017-07-16.xls*).

[111] Based on MA Baseline Study estimate/forecast of National Grid's Massachusetts population of households (approximately 1.2 million households in 2017 and in 2028).

[112] The MA Baseline Study Saturation Survey contained questions related to whether customers' appliances (including clothes washers, refrigerators, pool pumps, water heaters, dehumidifiers, dryers) were Wi-Fi-enabled. Given the context of these questions, Navigant believes that these represent appliances with built-in Wi-Fi capabilities (as opposed to retrofits).

[113] Based on MA Baseline Study Saturation Survey results for National Grid (*National Grid Electric Final Saturation Results 2017-07-16.xls* and *National Grid Electric Draft Final Survey Characterization Results 2017-07-16.xls*).

[114] Based on forecasted penetration rate for smart appliances in North America. Navigant Research, *Market Data: IoT for Residential Energy Customers, Global Market Forecasts, 2016-2026*, 2016.

[115] Pessimistic scenario for "Fraction of Customers Willing to Shift On-Peak Load" for clothes dryers; from PNNL, *Use of Residential Smart Appliances for Peak-Load Shifting and Spinning Reserves: Cost/Benefit Analysis*, December 2010.

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Table 3-28. TRC Test Benefits and Costs, 2019-2028

	Smart Appliance, DLC		
	Total Impact (Benefit) (Millions)	Total Costs (Millions)	Benefit-Cost Ratio
Dryers - Smart Appliance	$3.9	$22.5	0.2

Source: Navigant analysis

3.5 Dishwashers

A. DR Context

As with clothes washers and dryers, dishwashers are an enticing option for demand response researchers. Studies have been performed in the US and Europe to gauge the potential benefits of DR for dishwashers. Like the other appliances, the DR strategy would be to shift the cycle to an off-peak energy period. This can be done today with a few dishwashers on the market from companies like GE, LG, and Miele, who have all participated to some extent in using their smart appliances to reduce peak loads. Miele was a part of a 2014 pilot in Belgium related to automated demand response to help utilities balance wind power availability. For Miele dishwashers, customers would set a finish time for a cycle, so that the dishwasher could be turned off so long as the cycle would finish by the time the user selected. These flexible hours were used to smooth out potential fluctuations in capacity, finding that they could potentially call upon 2 GW (including contributions from clothes washers and dryers) for up to 30 minutes after extrapolating to all of Belgium’s 4.6 million households.[116]

Table 3-29. DR-Enabling Device Market

OEMs	DR-Enabled Product	Proven in DR Context?	Example Utility Partners
GE	GE Appliances	Yes	SDG&E
Miele		Yes	Belgium
Bosch	Home Connect	No	
LG		No	

Source: Web research

B. Potential Impact Per Device

Table 3-30 contains the average coincident load results for dishwashers from the metering conducted as part of the MA Baseline Study for all summer weekdays (All Days) and weekdays for which the maximum temperature during the peak period was above 85°F (Hottest Days). The size of the metering sample for dishwashers was 208 units.[117]

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[116] R. D’hulst, et. al., *Demand Response Flexibility and Flexibility Potential in Residential Households: Experiences from Large Pilot Test in Belgium,* May 2016.

[117] The metered sample did not include any smart dishwashers. Therefore, Navigant used the load associated with all metered dishwashers.

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Navigant used the Hottest Days’ impact as final potential peak demand reduction value for BCR purposes. After applying a derating factor, potential load reduction during the peak period associated with the Hottest Days scenario is 0.01 kW for smart dishwasher.

For comparison purposes, the figure also includes unit impacts derived from NY, ME, and IL TRMs and studies conducted by PNNL and Ecotope. From the TRMs, average load values for high efficiency unit were taken, as Navigant assumes that smart dishwashers will also generally be high efficiency.

Table 3-30. Unit Impact Metrics

	Smart Appliance, DLC				
Source	**Year of Publication**	**Average Load**	**Coincidence Factor**	**Derating**	**kW/Appliance During Peak***
NY TRM	2017	0.02[118]	N/A	0.6	0.01
ME TRM	2017	1.4	0.02	0.6	0.02
IL TRM	2017	1.1	0.03	0.6	0.02
PNNL[119]	2010	N/A	N/A	0.6	0.01
Ecotope[120]	2014	N/A	N/A	0.6	0.02
Source	**Year of Publication**	**Average Coincident Load**		**Derating**	**kW/Appliance During Peak**
MA Baseline Study End-Use Metering – All Days	2018	0.01		0.6	0.01
MA Baseline Study End-Use Metering – Hottest Days	2018	0.01		0.6	0.01
Potential Peak Demand Impact per Device					**0.01**

Source: Navigant analysis based on multiple data sources, reference footnotes.

The derating factors listed in the above tables are based on multiple sources. Table 3-31 lists the components of the derating factors assumed for a smart dishwasher DR program.

Together, these factors make up the derating factor, which is applied to coincident load estimates in order to estimate potential or achievable impact per unit.

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[118] Average load from the TRM includes summer peak CF.

[119] PNNL, *Use of Residential Smart Appliances for Peak-Load Shifting and Spinning Reserves (Cost/Benefit Analysis)*, 2010.

[120] Ecotope, *Is Your Refrigerator Running? Energy Use and Load Shapes for Major Household Appliances*, ACEEE Summer Study 2014.

Table 3-31. Derating Assumptions

Derating Factor	Value
Participation Rate per Event	0.7[121]
Connectivity	0.9[122]
Additional Derating for Temperature Setback Strategy	N/A
First Year In-Service	N/A
Final Derating Factor	**0.6**

Source: Navigant analysis based on multiple data sources, reference footnotes.

C. Total Achievable Impact

Table 3-32 contains relevant saturation statistics from the MA Baseline Study Saturation Survey and Navigant Research reports. The results show that there were approximately 8,000 smart dishwashers installed in National Grid's Massachusetts territory as of 2017. This information serves as a basis for estimating total impacts (benefits) on a program level. Additionally, it provides context for the feasibility of program expansion in coming years. Based on a Navigant Research report on growth projections of smart appliances, Navigant estimates that the number of smart dishwashers will increase to be approximately 20% of installed base by 2028.[123]

Table 3-32. Saturation and Estimated Enrollment in National Grid's Massachusetts Territory

	2019	2028
Average Number of Dish Washers/Customer	0.66[124]	0.66
Approximate Number of Dish Washers [125]	770,000	800,000
Approximate Number of Smart Dish Washers[126]	25,000	160,000
Estimated Smart Dishwasher Devices Enrolled in DR Program	1,200	84,000

Source: Navigant analysis based on multiple data sources, reference footnotes.

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[121] Pessimistic scenario for "Fraction of On-Peak Load that Customers Willing to Shift" for dishwashers; from PNNL, *Use of Residential Smart Appliances for Peak-Load Shifting and Spinning Reserves: Cost/Benefit Analysis*, December 2010.

[122] Same as for CACs.

[123] Based on forecasted penetration rate for smart appliances in North America. Navigant Research, *Market Data: IoT for Residential Energy Customers, Global Market Forecasts, 2016-2026*, 2016.

[124] From MA Baseline Study Saturation Survey results for National Grid (*National Grid Electric Final Saturation Results 2017-07-16.xls*).

[125] Based on MA Baseline Study estimate/forecast of National Grid's Massachusetts population of households (approximately 1.2 million households in 2017 and in 2028).

[126] Based on forecasted smart appliance penetration for North America (Table 3.22). Navigant Research, *Market Data: IoT for Residential Energy Customers, Global Market Forecasts, 2016-2026*, 2016.

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Two other factors impact the total peak demand reduction achievable on a program level: customers' willingness to sign up for a DR program (i.e., discretionary factor) and customers' likelihood of continued program participation following the first year of participation (i.e., persistence factor). Based on a review of available literature, Navigant assumed that 70% of customers with dishwashers would be willing to enroll in a program in which their dishwashing use would be automatically delayed by National Grid.[127] A persistence factor of 90% is assumed for Smart dishwasher participant (i.e., slightly lower than the persistence rate associated with National Grid's CAC Wi-Fi Thermostat DR program).

Based on the assumptions discussed above, Navigant estimates achievable DR program enrollment to be 1,200 devices in 2019 and 84,000 devices by 2028.

D. Benefit-Cost Analysis

Table 3-33 shows the estimated net-present value of total benefits and costs, according to the TRC test, for the 2019 to 2028 timeframe, based on expected program size over this period. This results in a benefit-cost ratio of 0.0 (0.03), indicating a DR program for smart dishwashers may not be cost-effective.

Table 3-33. TRC Test Benefits and Costs, 2018-2028

	Smart Appliance, DLC		
	Total Impact (Benefit) (Millions)	Total Costs (Millions)	Benefit-Cost Ratio
Dishwashers - Smart Appliance	$0.6	$22.5	0.0

Source: Navigant analysis

3.6 Refrigerators

A. DR Context

With high market penetration, relatively high load, and a coincidence factor of essentially 100%, refrigerators seem like a desirable choice for DR programs. However, due to safety concerns the DR strategy for refrigerators cannot include shutting the unit off for any meaningful amount of time during the event. Although, for the purposes of this report, a benefit-cost analysis was conducted related to refrigerator DR using smart plugs, this DR-enablement strategy is not a viable option for refrigerators peak load reduction.

The remaining available DR strategies are to increase the setpoint of the freezer, delay the defrost cycle, and shut off ice making, which have shown to be difficult strategies to implement. Still, there are many refrigerators on the market that have built-in capability for DR; according to ENERGY STAR, as of September 2017, 48 refrigerator models on the market are connected and could be accessed by a utility, far more than any other appliance tracked by ENERGY STAR. Dacor and LG in particular have the most certified connected refrigerator models according to ENERGY STAR, with Dacor's connected refrigerators

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[127] Pessimistic scenario for "Fraction of Customers Willing to Shift On-Peak Load" for dishwashers; from PNNL, *Use of Residential Smart Appliances for Peak-Load Shifting and Spinning Reserves: Cost/Benefit Analysis*, December 2010.

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able to control the ice maker and enter an energy saver mode designed for when the refrigerator is not in daily use. These connected refrigerators are also generally the more advanced models, which are also more energy efficient.

Navigant conducted limited web research and interviewed members of National Grid's DR team to further understand and obtain data related to the current and future market for each appliance and enabling device. Table 3-34 provides a summary of available information:

Table 3-34. DR-Enabling Device Market

OEMs	DR-Enabled Product	Proven in DR Context?
Dacor	Wi-Fi Connected	No
LG	SmartThinQ	No
Samsung	Family Hub	No
GE	GE Appliances	No
Bosch	Home Connect	No
Whirlpool	Supreme NoFrost Refrigerator with 6TH SENSE LIVE	No

Source: Web research

B. Potential Impact Per Device

Table 3-35 and Table 3-36 contain the average coincident load results for refrigerators from the metering conducted as part of the MA Baseline Study for all summer weekdays (All Days) and weekdays for which the maximum temperature during the peak period was above 85°F (Hottest Days). The size of the metering sample for refrigerators included 249 primary refrigerators and 81 secondary refrigerators.[128]

Navigant used the Hottest Days' impact as final potential peak demand reduction value for BCR purposes. After applying a derating factor, potential load reduction during the peak period associated with the Hottest Days scenario is 0.04 kW for Smart Plugs and 0.03 kW for Smart refrigerators.

For comparison purposes, the table also includes unit impact estimates derived from several states' TRMs and studies conducted by PNNL, LBNL, and Ecotope.

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[128] The metered sample included only six smart refrigerators. Therefore, Navigant used the load associated with all metered primary and secondary refrigerators for both the plug and built-in refrigerator scenarios.

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Table 3-35. Unit Impact Metrics for Baseline Refrigerators with Smart Plug

Source	Smart Plug, DLC				
	Year of Publication	Average Load	Coincidence Factor	Derating	kW/ Appliance During Peak
MA TRM	2015	0.06[129]	1.0	0.6	0.03
NY TRM	2017	0.08	1.0	0.6	0.05
VT TRM	2015	0.07	1.0	0.6	0.04
ME TRM	2017	0.06	1.0	0.6	0.03
IL TRM	2017	0.08	1.0	0.6	0.05
PNNL[130]	2010	N/A	N/A	0.6	0.11
Ecotope[131]	2014	N/A	N/A	0.6	0.04
LBNL[132]	2015	N/A	N/A	0.6	0.01
Source	**Year of Publication**	**Average Coincident Load**		**Derating**	**kW/ Appliance During Peak**
MA Baseline Study End-Use Metering – All Days	2018	0.08		0.6	0.05
MA Baseline Study End-Use Metering – Hottest Days	2018	0.08		0.6	**0.05**
Potential Peak Demand Impact per Device					**0.05**

Source: Navigant analysis based on multiple data sources, reference footnotes.

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[129] The 2016-2018 MA TRM dictates that average demand of refrigerators be taken from published EPA data (MA TRM, pg. 23)

[130] PNNL, *Use of Residential Smart Appliances for Peak-Load Shifting and Spinning Reserves (Cost/Benefit Analysis)*, 2010.

[131] Ecotope, *Is Your Refrigerator Running? Energy Use and Load Shapes for Major Household Appliances*, ACEEE Summer Study 2014.

[132] Lawrence Berkley National Laboratory, *Demand Response Automation in Appliances and Equipment*, 2015.

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Table 3-36. Unit Impact Metrics for Efficient Refrigerators with Built-in DR Capability

	Smart Appliance, Delayed Defrost				
Source	**Year of Publication**	**Average Load**	**Coincidence Factor**	**Derating**	**kW/Appliance During Peak**
MA TRM	2015	0.04	1.0	0.6	0.03
NY TRM	2017	0.06	1.0	0.6	0.04
VT TRM	2015	0.06	1.0	0.6	0.03
ME TRM	2017	0.05	1.0	0.6	0.03
IL TRM	2017	0.07	1.0	0.6	0.04
Source	**Year of Publication**	**Average Coincident Load**		**Derating**	**kW/Appliance During Peak**
MA Baseline Study End-Use Metering – All Days	2018	0.08		0.6	0.05
MA Baseline Study End-Use Metering – Hottest Days	2018	0.08		0.6	**0.05**
Potential Peak Demand Impact per Device					**0.05**

Source: Navigant analysis based on multiple data sources, reference footnotes.

The derating factors listed in the above tables are based on multiple sources. Table 3-37 and Table 3-38 list the components of the derating factors assumed for a refrigerator DR program utilizing smart plugs and a program utilizing smart refrigerators, respectively. Together, these factors make up the derating factor, which is applied to coincident load estimates to estimate potential or achievable impact per unit.

Table 3-37. Derating Assumptions, Smart Plug

Derating Factor	Value
Participation Rate per event	0.9[133]
Connectivity	0.9[134]
Additional Derating for Temperature Setback Strategy	N/A
First Year In-Service	0.7
Final Derating Factor	**0.6**

Source: Navigant analysis based on multiple data sources, reference footnotes.

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[133] Pessimistic scenario for "Fraction of On-Peak Load that Customers Willing to Shift" for refrigerators; from PNNL, *Use of Residential Smart Appliances for Peak-Load Shifting and Spinning Reserves: Cost/Benefit Analysis*, December 2010.

[134] Assumed the same connectivity rate as for CACs.

Table 3-38. Derating Assumptions, Smart Refrigerator

Derating Factor	Value
Participation Rate per event	0.9[135]
Connectivity	0.9[136]
Additional Derating for Temperature Setback (Delayed Defrost) Strategy	0.8[137]
First Year In-Service	N/A
Final Derating Factor	**0.6**

Source: Navigant analysis based on multiple data sources, reference footnotes.

C. Total Achievable Impact

Table 3-39 contains relevant saturation statistics from the MA Baseline Study Saturation Survey. The results show that there were approximately 1.6 million refrigerators in National Grid's Massachusetts territory as of 2017, 5% of which were smart refrigerators. This information serves as a basis for estimating total impacts (benefits) on a program level. Additionally, it provides context for the feasibility of program expansion in coming years. Based on a Navigant Research report on growth projections of smart appliances, Navigant estimates that the number of smart refrigerators will be approximately 300,000 by 2028.[138]

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[135] Pessimistic scenario for "Fraction of On-Peak Load that Customers Willing to Shift" for refrigerators; from PNNL, *Use of Residential Smart Appliances for Peak-Load Shifting and Spinning Reserves: Cost/Benefit Analysis*, December 2010.

[136] Assumed the same connectivity rate as for CACs.

[137] Assumed to be the same as for CACs.

[138] Based on forecasted penetration rate for smart appliances in North America. Navigant Research, *Market Data: IoT for Residential Energy Customers, Global Market Forecasts, 2016-2026*, 2016.

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Table 3-39. Saturation and Estimated Enrollment in National Grid's Massachusetts Territory

	2019	2028
Average Number of Refrigerators/Customer	1.36[139]	1.36
Approximate Number of Refrigerators[140]	1,600,000	1,650,000
Approximate Number of Smart Refrigerators[141]	100,000[142]	300,000[143]
Estimated Devices Enrolled in DR Program with a Wi-Fi Plug	8,000	83,000
Estimated Smart Refrigerators with Deferred Defrost Enrolled in DR Program	5,000	170,000

Source: Navigant analysis based on multiple data sources, reference footnotes.

Two other factors impact the total peak demand reduction achievable on a program level: customers' willingness to sign up for a DR program (i.e., discretionary factor) and customers' likelihood of continued program participation following the first year of participation (i.e., persistence factor). Based on a review of available literature, Navigant assumed that 70% of customers with refrigerators would be willing to enroll in a program in which their refrigerator defrost cycle and ice making would be automatically delayed by National Grid.[144] A persistence factor of 90% is assumed for smart plugs and smart refrigerator participants (i.e., slightly lower than the persistence rate associated with National Grid's CAC Wi-Fi Thermostat DR program).

Based on the assumptions discussed above, Navigant estimates achievable DR program enrollment in 2019 to be 8,000 and 5,000 for a plug-based program and a smart appliance program, respectively. Navigant predicts enrollment of smart refrigerators would outpace enrollment in a plug-based DR program by 2028.

D. Benefit-Cost Analysis

Table 3-40 shows the estimated net-present value of total benefits and costs according to the TRC test, for the 2019 to 2028 timeframe based on expected program size over this period. This results in benefit-

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[139] From MA Baseline Study Saturation Survey results for National Grid (*National Grid Electric Final Saturation Results 2017-07-16.xls*).

[140] Based on MA Baseline Study estimate/forecast of National Grid's Massachusetts population of households (approximately 1.2 million households in 2017 and in 2028).

[141] The MA Baseline Study Saturation Survey contained questions related to whether customers' appliances (including Clothes Washers, Refrigerators, Pool Pumps, Water Heaters, Dehumidifiers, Dryers) were Wi-Fi-enabled. Given the context of these questions, Navigant believes that these represent appliances with built-in Wi-Fi capabilities (as opposed to retrofits).

[142] Based on MA Baseline Study Saturation Survey results for National Grid (*National Grid Electric Final Saturation Results 2017-07-16.xls* and *National Grid Electric Draft Final Survey Characterization Results 2017-07-16.xls*).

[143] Based on forecasted penetration rate for smart appliances in North America. Navigant Research, *Market Data: IoT for Residential Energy Customers, Global Market Forecasts, 2016-2026*, 2016.

[144] PNNL, *Use of Residential Smart Appliances for Peak-Load Shifting and Spinning Reserves: Cost/Benefit Analysis*, December 2010.

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cost ratios of 0.1 to 0.2 for both the smart plug (again, this option is not viable due to health concerns) and built-in smart refrigerator options, indicating a DR program for refrigerators may not be cost-effective.

Table 3-40. TRC Test Benefits and Costs, 2019-2028

	Smart Plug, DLC		
	Total Impact (Benefit) (Millions)	**Total Costs (Millions)**	**Benefit-Cost Ratio**
Refrigerators - Smart Plug	$7.0	$51.1	0.1

Source: Navigant analysis

	Smart Appliance, Delayed Defrost		
	Total Impact (Benefit) (Millions)	**Total Costs (Millions)**	**Benefit-Cost Ratio**
Refrigerators - Smart Appliance	$11.4	$48.6	0.2

Source: Navigant analysis

3.7 Dehumidifiers

A. DR Context

In a 2009 report on the potential for DR programs in the US, EPRI predicted DR program implementation rates for dehumidifiers of just 2% to 5% from 2015 to 2030, far below that of any other residential end-use that they studied.[145] However, numerous utilities are exploring demand response with dehumidifiers. United Illuminating has expanded its Smart AC program this year to include smart plugs for dehumidifiers, and Eversource (CT) is hoping to begin a pilot for residential dehumidifiers using a smart plug. According to a 2015 white paper written by Cadmus and Eversource, dehumidifiers represented some of the highest potential for demand response savings.[146] Other utilities have mainly tried to capture this with whole home behavioral programs, such as those by ComEd and San Diego Gas & Electric (SDG&E) (discussed in the clothes washer section), and that of the Town of Danvers in Massachusetts, which offers a Peak Savings Program to residential customers who turn off devices in their home during peak energy events. Customers are alerted the day before about a 4-hour window (usually between 12 p.m. and 7 p.m.) eligible for the program. If customers turn off their dehumidifier for this whole period, they are entered into a raffle with a 1 in 50 chance at a $50 credit on their electric bill. In 2015, 756 customers enrolled in the program, which also incentivizes curtailment of clothes washer and dryers, dishwashers, pool pumps, and CACs. The program has helped Danvers reduce its peak load from 74 MW to 72.1 MW.[147]

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[145] *Assessment of Achievable Potential from Energy Efficiency and Demand Response Programs in the U.S. (2010–2030)*. EPRI, January 2009. http://www.edisonfoundation.net/iee/Documents/EPRI_SummaryAssessmentAchievableEEPotential0109.pdf

[146] R. Lamoureux, et. al., *Home Energy Management Systems (HEMS) Paths to Savings: On-Ramps and Dead Ends*, 2016, http://aceee.org/files/proceedings/2016/data/papers/12_630.pdf.

[147] Daniel DeMaina. *Danvers Incentive Program Reduces Peak Electricity Use and Costs*, February 10, 2016, https://www.mma.org/danvers-incentive-program-reduces-peak-electricity-use-and-costs-0.

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There are currently no built-in DR-enabled residential dehumidifiers on the market. Connectivity would require a smart plug. As part of its Smart AC program today, United Illuminating is offering smartAC kits from ThinkEco that can be used for either RACs or dehumidifiers. With this setup, the DR strategy would be to shut off the device during peak periods. With more collaboration with manufacturers, there is also potential to cycle the compressor and/or fan in a dehumidifier.

Research indicates that DR-enabled dehumidifiers will be commercially available in the near to medium term. Therefore, Navigant includes dehumidifiers with built-in DR capability in the BCR analysis, in addition to a smart plug and simple timer plug option.

Navigant conducted limited web research and interviewed members of National Grid's DR team to further understand and obtain data related to the current and future market for each appliance and enabling device. Table 3-41 provides a summary of available information.

Table 3-41. DR-Enabling Device Market

OEMs	DR-Enabled Product	Proven in DR Context?	Example Utility Partners
Smart Plugs			
ThinkEco^	Modlet, smartAC kit	Yes	United Illuminating, National Grid NY
Belkin	Wemo Smart Plug	No	

Source: Navigant Research Leaderboard: Residential Demand Response (2017); Web research
^Ranked as a "Challenger" in the DR space by Navigant Research (Scoring strongest to weakest: Leaders, Contenders, Challengers, Followers)

B. Potential Impact Per Device

Table 3-42, Table 3-43, and Table 3-44 contain the average coincident load results for dehumidifiers from the metering conducted as part of the MA Baseline Study for all summer weekdays (All Days) and weekdays for which the maximum temperature during the peak period was above 85°F (Hottest Days) for the smart plug, simple timer plug, and smart dehumidifier (Built-In) technologies, respectively. The size of the metering sample for dehumidifiers was 102 units.[148]

For each dehumidifier technology option, Navigant used the Hottest Days' impact as final potential peak demand reduction value for BCR purposes. After applying a derating factor, potential load reduction during the peak period associated with the Hottest Days scenario is 0.11 kW, 0.10 kW, and 0.14 kW for the smart plug, simple timer plug, and smart dehumidifier options, respectively.

For comparison purposes, Table 3-42 and Table 3-44 also include unit impact findings derived from several states' TRMs and studies sponsored by the Massachusetts Energy Efficiency Advisory Council (MA EEAC), Focus on Energy, and Eversource.

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[148] The metered sample did not include any smart dehumidifiers. Therefore, Navigant used the load associated with all metered dehumidifiers.

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Table 3-42. Unit Impact Metrics for Dehumidifiers with Smart Plug

Source	Smart Plug, DLC				
	Year of Publication	**Average Load**	**Coincidence Factor**	**Derating**	**kW/ Appliance During Peak**
MA TRM	2015	0.5[149]	0.85	0.6	0.25
NY TRM	2017	0.5	1.00	0.6	0.31
VT TRM	2015	0.6	0.35	0.6	0.14
ME TRM	2017	0.5	0.37	0.6	0.12
IL TRM	2017	0.6	0.37	0.6	0.14
MA EEAC[150]	2012	N/A	N/A	0.6	0.28
Focus on Energy[151]	2009	N/A	0.24	N/A	N/A
Eversource[152]	2016	N/A	N/A	0.6	0.09
Source	**Year of Publication**	**Average Coincident Load**		**Derating**	**kW/ Appliance During Peak**
MA Baseline Study End-Use Metering – All Days	2018	0.16		0.6	0.09
MA Baseline Study End-Use Metering – Hottest Days	2018	0.18		0.6	**0.11**
Potential Peak Demand Impact per Device					**0.11**

Source: Navigant analysis based on multiple data sources, reference footnotes.

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[149] The 2016-2018 MA TRM provides a formula and values for energy demand from a dehumidifier: $kW = (Capacity)/(Efficiency)$, where the average capacity is 35 pints/day and the average efficiency is 1.35 L/kWh.

[150] MA EEAC and Cadmus, *Dehumidifiers: A Major Consumer of Residential Electricity*, ACEEE Summer Study, 2012.

[151] PA Consulting, *Dehumidifiers Deemed Savings Review for Targeted Home Performance with ENERGY STAR*, Focus on Energy, 2009.

[152] Cadmus and Eversource, *Home Energy Management Systems (HEMS) Paths to Savings: On-Ramps and Dead Ends*, 2016.

Table 3-43. Unit Impact Metrics for Dehumidifiers with Simple timer plug

Source	Simple Timer Plug, DLC			
	Year of Publication	Average Coincident Load	Derating	kW/Appliance During Peak
MA Baseline Study End-Use Metering – All Days	2018	0.16	0.5	0.08
MA Baseline Study End-Use Metering – Hottest Days	2018	0.18	0.5	**0.10**
Potential Peak Demand Impact per Device				**0.10**

Source: Navigant analysis based on MA Baseline Study data.

Table 3-44. Unit Impact Metrics for Efficient Dehumidifiers with Built-in DR Capability

Source	Smart Appliance, DLC				
	Year of Publication	Average Load	Coincidence Factor	Derating	kW/Appliance During Peak
MA TRM	2015	0.4	0.85	0.8	0.26
NY TRM	2017	0.4	1.00	0.8	0.30
VT TRM	2015	0.5	0.35	0.8	0.16
ME TRM	2017	0.4	0.37	0.8	0.13
IL TRM	2017	0.5	0.37	0.8	0.16
Source	**Year of Publication**	**Average Coincident Load**		**Derating**	**kW/Appliance During Peak**
MA Baseline Study End-Use Metering – All Days	2018	0.16		0.8	0.13
MA Baseline Study End-Use Metering – Hottest Days	2018	0.18		0.8	**0.14**
Potential Peak Demand Impact per Device					**0.14**

Source: Navigant analysis based on multiple data sources, reference footnotes.

The derating factors listed in the above tables are based on multiple sources. Table 3-45, Table 3-46, and Table 3-47 list the components of the derating factors assumed for a dehumidifier DR program utilizing smart plugs, simple time plugs and smart dehumidifiers, respectively.

Together, these factors make up the derating factor, which is applied to coincident load estimates in order to estimate potential or achievable impact per unit.

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Table 3-45. Derating Assumptions, Smart Plug

Derating Factor	Value
Participation Rate per Event	0.9[153]
Connectivity	0.9[154]
Additional Derating for Temperature Setback Strategy	N/A
First Year In-Service	0.7[155]
Final Derating Factor	**0.6**

Source: Navigant analysis based on multiple data sources, reference footnotes.

Table 3-46. Derating Assumptions, Simple Timer Plug

Derating Factor	Value
Participation Rate per Event	0.9[156]
Connectivity	N/A
Additional Derating for Temperature Setback Strategy	N/A
First Year In-Service	0.6[157]
Final Derating Factor	**0.5**

Source: Navigant analysis based on multiple data sources, reference footnotes.

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[153] Navigant assumes that dehumidifiers would be associated with fewer event opt outs than room air conditioners. Therefore, Navigant assumed a participation rate of 90% for dehumidifiers, somewhat higher than that assumed for room air conditioners (70%).

[154] Assumed the same connectivity rate as for CACs.

[155] Assume the same first year in-service rate as for RACs smart plug option.

[156] Navigant assumes that dehumidifiers would be associated with fewer event opt outs than room air conditioners. Therefore, Navigant assumed a participation rate of 90% for dehumidifiers, somewhat higher than that assumed for room air conditioners (70%).

[157] Assumed to be slightly lower than smart plug first-year in-service rate (than for smart plug) because the installation cannot be verified by program.

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Table 3-47. Derating Assumptions: Smart Dehumidifier

Derating Factor	Value
Participation Rate per Event	0.9[158]
Connectivity	0.9[159]
Additional Derating for Temperature Setback Strategy	N/A
First Year In-Service	N/A
Final Derating Factor	**0.8**

Source: Navigant analysis based on multiple data sources, reference footnotes.

C. Total Achievable Impact

Table 3-48 contains relevant saturation statistics from the MA Baseline Study Saturation Survey. The results show that there were approximately 450 thousand dehumidifiers in National Grid's Massachusetts territory as of 2017, 5% of which are smart dehumidifiers. This information serves as a basis for estimating total impacts (benefits) on a program level. Additionally, it provides context for the feasibility of program expansion in coming years. Based on a Navigant Research report on growth projections of smart appliances, Navigant estimates that the number of smart dehumidifiers will be approximately 90,000 by 2028.[160]

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[158] Navigant assumes that dehumidifiers would be associated with fewer event opt outs than room air conditioners. Therefore, Navigant assumed a participation rate of 90% for dehumidifiers, somewhat higher than that assumed for room air conditioners (70%).

[159] Assumed the same connectivity rate as for CACs.

[160] Based on forecasted penetration rate for smart appliances in North America. Navigant Research, *Market Data: IoT for Residential Energy Customers, Global Market Forecasts, 2016-2026*, 2016.

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Table 3-48. Saturation and Estimated Enrollment in National Grid's Massachusetts Territory

	2019	2028
Average Number of Dehumidifiers/Customer	0.38[161]	0.38
Approximate Number of Dehumidifiers[162]	450,000	450,000
Approximate Number of Smart Dehumidifiers[163]	30,000[164]	90,000[165]
Estimated Devices Enrolled in DR Program with a Simple Timer Plug	2,000	23,000
Estimated Devices Enrolled in DR Program with a Wi-Fi Plug	2,000	23,000
Estimated Smart Dehumidifier Devices Enrolled in DR Program	1,500	29,000

Source: Navigant analysis based on multiple data sources, reference footnotes.

Two other factors impact the total peak demand reduction achievable on a program level: customers' willingness to sign up for a DR program (i.e., discretionary factor) and customers' likelihood of continued program participation following the first year of participation (i.e., persistence factor). Based on a review of available literature, Navigant assumed that 30% of customers with dehumidifiers (same percentage assumed as for RACs) would be willing to enroll in a program in which their dehumidifiers use would be automatically delayed by National Grid.[166] For smart dehumidifiers, a persistence factor of 90% is assumed (i.e., same as for smart RACs and slightly lower than the persistence rate associated with National Grid's CAC Wi-Fi Thermostat DR program). A persistence factor of 75% is assumed for the smart plug and simple timer plug options, an estimate in between the persistence rates used for CACs (99%) and plug options for RACs (30%). Navigant assumes that many dehumidifiers in the northeast will remain plugged in all year round.

Based on the assumptions discussed above, while Navigant estimates achievable DR program enrollment associated with Wi-Fi plugs or simple timer plugs to outnumber smart dehumidifier enrollment in 2019, Navigant expects enrollment of smart dehumidifiers to slightly outpace enrollment in plug-based DR programs by 2028.

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[161] From MA Baseline Study Saturation Survey results for National Grid (*National Grid Electric Final Saturation Results 2017-07-16.xls*).

[162] Based on MA Baseline Study estimate/forecast of National Grid's Massachusetts population of households (approximately 1.2 million households in 2017 and in 2028).

[163] The MA Baseline Study Saturation Survey contained questions related to whether customers' appliances (including clothes washers, refrigerators, pool pumps, water heaters, dehumidifiers, dryers) were Wi-Fi-enabled. Given the context of these questions, Navigant believes that these represent appliances with built-in Wi-Fi capabilities (as opposed to retrofits).

[164] Based on MA Baseline Study Saturation Survey results for National Grid (*National Grid Electric Final Saturation Results 2017-07-16.xls* and *National Grid Electric Draft Final Survey Characterization Results 2017-07-16.xls*).

[165] Based on forecasted penetration rate for smart appliances in North America. Navigant Research, *Market Data: IoT for Residential Energy Customers, Global Market Forecasts, 2016-2026*, 2016.

[166] Assumed the same as for RACs; from PNNL, *Use of Residential Smart Appliances for Peak-Load Shifting and Spinning Reserves: Cost/Benefit Analysis*, December 2010.

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D. Benefit-Cost Analysis

Table 3-49 shows the estimated net-present value of total benefits and costs, according to the TRC test, for the 2019 to 2028 timeframe, based on expected program size over this period. This results in benefit-cost ratios of 0.1, 0.3, and 0.4 for the smart plug, simple timer plug and built-in smart dehumidifier options, respectively.

Table 3-49. TRC Test Benefits and Costs, 2019-2028

	Smart Plug, DLC		
	Total Impact (Benefit) (Millions)	**Total Costs (Millions)**	**Benefit-Cost Ratio**
Dehumidifiers - Smart Plug	$4.1	$16.2	0.3

Source: Navigant analysis

	Simple timer plug, DLC		
	Total Impact (Benefit) (Millions)	**Total Costs (Millions)**	**Benefit-Cost Ratio**
Dehumidifiers – Simple timer plug	$3.7	$7.7	0.5

Source: Navigant analysis

	Smart Appliance, DLC		
	Total Impact (Benefit) (Millions)	**Total Costs (Millions)**	**Benefit-Cost Ratio**
Dehumidifiers - Smart Appliance	$6.8	$10.4	0.7

Source: Navigant analysis

3.8 Ductless Mini-Splits

A. DR Context

Ductless mini-splits have become another viable demand response option in the AC space. Like other AC units, for participation in DR these devices can either be adjusted to a higher setpoint or cycled on and off.

Cape Light Compact explicitly offers incentives for ductless mini-split systems for the purposes of peak load management, including a $25 enrollment bonus and a free Sensibo Wi-Fi control device (worth $99). Sensibo is a third-party device that connects to the internet and to any remote controlled mini-split, allowing for connectivity regardless of the unit’s manufacturer.

Some manufacturers like Samsung are currently selling DR-enabled Wi-Fi connected mini-split systems, while others like Fujitsu and Mitsubishi promote mini-splits that require some external device that allows for connectivity. Usually these external devices can communicate with the system through IR remote control signals, though there are also wired systems, such as that offered by Fujitsu. Regardless of the mode of connectivity, many of these mini-splits can also be controlled by connected thermostats like Nest and Honeywell, or devices such as Sensibo. National Grid currently has some participants with Mitsubishi mini-split units enrolled in its Wi-Fi thermostat DR program.

Navigant bases the estimate of cost-effectiveness in Section 3.8 D. on a BYO Wi-Fi thermostat model.

Table 3-50. DR-Enabling Device Market

OEMs	DR-Enabled Product	Proven in DR Context?	Example Utility Partners
Wi-Fi Controller			
Sensibo	Sensibo	Yes	Cape Light Compact
Built-In			
Mitsubishi	Wi-Fi Thermostat Interface/Kumo Cloud	Yes	
LG	LG Smart AC	Yes	
Samsung	Whisper Mini-Split with Wi-Fi	Yes	
Fujitsu	Halcyon	Yes	

Source: Navigant analysis based on web research

B. Potential Impact Per Device

Table 3-51 contains the average coincident load results for ductless mini-splits from the metering conducted as part of the MA Baseline Study for all summer weekdays (All Days) and weekdays for which the maximum temperature during the peak period was above 85°F (Hottest Days). The size of the metering sample for ductless mini-splits was 19 units.

Navigant used the Hottest Days' impact as final potential peak demand reduction value for BCR purposes. After applying a derating factor, potential load reduction during the peak period associated with the Hottest Days scenario is 0.25 kW for ductless mini-splits enabled via Wi-Fi thermostats.

For comparison purposes, the figure also includes potential unit impacts based on the 2016 ductless HP impact evaluation conducted for the Massachusetts PAs and EEAC, several states' TRMs, and studies sponsored by NEEP and Emera Maine.

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Table 3-51. Unit Impact Metrics

Source	Wi-Fi Thermostat, Temperature Setback				
	Year of Publication	**Average Load**	**Coincidence Factor**	**Derating**	**kW/ Appliance During Peak**
MA TRM	2015	1.6[167]	0.07	0.6	0.06
IL TRM	2017	1.5	0.37	0.6	0.32
MA EM&V Study[168]	2016	N/A	N/A	0.6	0.06
Emera Maine[169]	2014	N/A	N/A	0.6	0.56
NEEP[170]	2014	N/A	0.15	0.6	N/A
NEEP[171]		N/A	N/A	0.6	0.08
Fujitsu[172]	2016	1.2	N/A	0.6	N/A
Source	**Year of Publication**	**Average Coincident Load**		**Derating**	**kW/ Appliance During Peak**
MA Baseline Study End-Use Metering – All Days	2018	0.18		0.6	0.10
MA Baseline Study End-Use Metering – Hottest Days	2018	0.45		0.6	**0.25**
Potential Peak Demand Impact per Device					**0.25**

Source: Navigant analysis based on multiple data sources, reference footnotes.

The derating factors listed in the above tables are based on multiple sources. Table 3-52 lists the components of the derating factors assumed for a ductless mini-splits DR program utilizing Wi-Fi thermostats.

Together, these factors make up the derating factor, which is applied to coincident load estimates to estimate potential or “achievable” impact per unit.

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[167] As with the CACs, the 2016-2018 MA TRM provides a formula and values for calculating ductless mini-split demand: $kW = (Cooling\ Capacity)/(Energy\ Efficiency\ Ratio)$, with an average cooling capacity of 16.3 kBtu/h and an EER of 10.

[168] Cadmus, *Ductless Mini-Split HP Impact Evaluation (2016)*, for the MA EEAC.

[169] EMI Consulting, *Emera Maine Ductless Heat Pump Pilot Program Evaluation,* 2014.

[170] NEEP, *EM&V Forum: Primary Research – Ductless Heat Pumps*, April 2014.

[171] NEEP, *Ductless Heat Pump Meta Study*, November 13, 2014.

[172] 2016 Product brochure. Table number in the Average Load column is rated capacity for 12RLS2 HP

Table 3-52. Derating Assumptions

Derating Factor	Value
Participation Rate per event	0.8[173]
Connectivity	0.9[174]
Additional Derating for Temperature Setback Strategy	0.8[175]
First Year In-Service	N/A
Final Derating Factor	**0.6**

Source: Navigant analysis based on multiple data sources, reference footnotes.

C. Total Achievable Impact

Table 3-53 contains saturation statistics from the MA Baseline Study Saturation Survey. The results show that there were approximately 50,000 ductless mini-splits in National Grid's Massachusetts territory as of 2017, 4,000 of which are controlled by thermostats. Navigant assumed that all 4,000 of these thermostats are Wi-Fi enabled. This information serves as a basis for estimating total impacts (benefits) on a program level. Additionally, it provides context for the feasibility of program expansion in coming years. Navigant estimates that the number of ductless ACs with Wi-Fi thermostat integration will be approximately 9,000 by 2028.

Table 3-53. Saturation and Estimated Enrollment in National Grid's Massachusetts Territory

	2019	2028
Average Number of Ductless ACs/Customer	0.04[176]	0.04
Approximate Number of Ductless ACs[177]	50,000	50,000
Approximate Number of Ductless ACs controlled by Wi-Fi Thermostats	5,000[178]	9,000[179]
Estimated Devices Enrolled in DR Program	225	5,000

Source: Navigant analysis based on multiple data sources, reference footnotes.

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[173] Assumed the same participation rate as for CACs.

[174] Assumed the same connectivity rate as for CACs.

[175] Assumed to be the same as for CACs.

[176] From MA Baseline Study Saturation Survey results for National Grid (*National Grid Electric Final Saturation Results 2017-07-16.xls*).

[177] Based on MA Baseline Study estimate/forecast of National Grid's Massachusetts population of households (approximately 1.2 million households in 2017 and in 2028).

[178] Assumed an annual growth rate of 1%.

[179] Assumed an annual growth rate of 1%.

Two other factors impact the total peak demand reduction achievable on a program level: customers' willingness to sign up for a DR program (i.e., discretionary factor) and customers' likelihood of continued program participation following the first year of participation (i.e., persistence factor). Based on a review of available literature, Navigant assumed that 75% of customers with ductless ACs would be willing to enroll in a program in which their thermostat setpoint would be automatically adjusted by National Grid. This assumption is based on the idea that ductless mini-splits are likely a secondary cooling source for some homeowners (which is reflected in the coincident load cited above). A persistence factor of 90% is assumed (i.e., same as for smart RACs and slightly lower than the persistence rate associated with National Grid's CAC Wi-Fi Thermostat DR program).

Based on the assumptions discussed above, Navigant estimates achievable DR program enrollment to be 225 devices in 2019 and 5,000 devices by 2028.

D. Benefit-Cost Analysis

Table 3-54 shows the estimated net-present value of total benefits and costs according to the TRC test for the 2019 to 2028 timeframe based on expected program size over this period. This results in a benefit-cost ratio of 1.1, indicating a DR program targeting ductless ACs via Wi-Fi thermostats may be cost-effective.

Table 3-54. TRC Test Benefits and Costs, 2019-2028

	Wi-Fi Thermostat, Temperature Setback		
	Total Impact (Benefit) (Millions)	**Total Costs (Millions)**	**Benefit-Cost Ratio**
Ductless AC - Wi-Fi Thermostat	$1.7	$1.5	1.1

Source: Navigant analysis

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3.9 Water Heaters

A. DR Context

Along with thermostat-controlled AC systems, water heaters have been the most widely adopted appliance for DR programs. In the US, direct load control pilots for water heaters have been going on since the 1990s, with numerous active programs currently in place around the country. The main DR strategy for water heaters is to turn off the water heater entirely for the duration of the event. Utilities like Duke, Hawaiian Electric (HECO), Baltimore Gas & Electric, Florida Power and Light (FPL), and Eversource Connecticut currently have and have had demand response pilots or programs of this type, with some like Duke finding that both electric resistance and heat pump water heaters are cost-effective.[180]

Programs mainly utilize DR-enabled switches to control water heaters, which requires for the most part that utilities bear the cost of switch installation. Aquanta is emerging as a leading manufacturer in this space, offering a new generation smart controller, compatible with Nest thermostats, that allows for Nest-like control of water heater settings.

Some water heater manufacturers currently offer add-on Wi-Fi enabling devices, with Rheem selling heat pump water heaters (HPWHs) with an optional $49 external device that connects the water heater to Wi-Fi. In 2018, Rheem also plans to unveil water heaters with built-in connectivity. Connected water heaters would provide utilities with more nuanced control of water heater functionality, although it will remain to be seen how consumers adopt these new smart water heaters.

Through this analysis it appears that the only technology combination that could be cost effective is controlling electric water heaters through built-in DR capability. It appears that controlling heat pump water heaters through the same means would not be cost effective due to their lower average load. National Grid offers energy efficiency incentives to customers to encourage them to use the more efficient heat pump water heaters. Offering a demand response incentive only to electric resistance water heaters could confuse customers, and decrease the adoption of heat pump water heaters, which provide savings year-round, not just for demand response events. Whereas, offering DR incentives to both electric resistance and heat pump water heaters in an effort to remove the conflict of interest may result in a not cost-effective program, especially since the majority of smart water heaters are heat pump water heaters.

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[180] George Gurlaskie, *Heat Pump Water Heaters for Demand Response*, February 2016. http://aceee.org/sites/default/files/pdf/conferences/hwf/2017/Gurlaskie_Session7A_HWF17_2.28.17.pdf

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Table 3-55. DR-Enabling Device Market

OEMs	DR-Enabled Product	Proven in DR Context?	Example Utility Partners
External Controller			
Aquanta^	Smart Controller	Piloted	Green Mountain Power
Emerson	CTA-2045 Load Switch	Yes	Duke Florida
Built-In			
Rheem	Performance Platinum	No	

Source: Navigant Research Leaderboard: Residential Demand Response (2017); Web research
^Ranked as a "Challenger" in the DR space by Navigant Research (Scoring strongest to weakest: Leaders, Contenders, Challengers, Followers)

B. Potential Impact Per Device

Table 3-56 and Table 3-57 contain the average coincident load results for water heaters from the metering conducted as part of the MA Baseline Study for all summer weekdays (All Days) and weekdays for which the maximum temperature during the peak period was above 85°F (Hottest Days). The size of the metering sample for HPWHs and electric resistance water heaters (ERWHs) was 28 and 42 units, respectively.

Navigant used the Hottest Days' impact as final potential peak demand reduction value for BCR purposes. After applying a derating factor, potential load reduction during the peak period associated with the Hottest Days scenario is 0.09 kW and 0.16 kW for HPWHs and ERWHs, respectively, regardless of the enabling technology (since all options are assumed to have the same derating factor).

For comparison purposes, Table 3-56 also includes unit impacts derived from several states' TRMs and studies conducted by PNNL, Duke, and United Illuminating. Similarly, Table 3-57 includes unit impacts based on KEMA's 2011 evaluation of HECO's EnergyScout program, and those derived from several states' TRMs and other studies.

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Table 3-56. Unit Impact Metrics for HPWHs

	Smart Switch/Simple Timer Switch/Smart Appliance, DLC				
Source	**Year of Publication**	**Average Load**	**Coincidence Factor**	**Derating**	**kW/ Appliance During Peak**
MA TRM	2015	0.17[181]	N/A	0.9	0.15[182]
NY TRM	2017	N/A[183]	N/A	0.9	0.24
VT TRM	2015	0.4	0.20	0.9	0.08
IL TRM	2017	0.6	0.12	0.9	0.07
PNNL[184]	2013	0.4	N/A	N/A	N/A
PNNL[185]	2015	N/A	N/A	N/A	0.16
Duke[186]	2017	N/A	N/A	0.9	0.07
LBNL[187]	2015	0.3	N/A	N/A	N/A
United Illuminating[188]	2010	N/A	N/A	0.9	0.17
Source	**Year of Publication**	**Average Coincident Load**		**Derating**	**kW/ Appliance During Peak**
MA Baseline Study End-Use Metering – All Days	2018	0.11		0.9	0.10
MA Baseline Study End-Use Metering – Hottest Days	2018	0.10		0.9	**0.09**
Potential Peak Demand Impact per Device					**0.09**

Source: Navigant analysis based on multiple data sources, reference footnotes.

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[181] Average load from the TRM includes summer peak CF. Therefore, average load and CF are not reported separately in the above table.

[182] Annual average kW is based on an update to the 2016-2018 TRM conducted by Navigant between June 2016 and March 2017 (HPWH Impact Study: Volume 1), with space-conditioning impacts excluded: $kW = HPWH_{consumption} * (EF_{old} / EF_{new}) * (1 / 8760)$, where annual HPWH energy consumption is 1643, EF_{old} is 2.35 and EF_{new} is 2.625.

[183] Average load from the TRM includes summer peak CF. Therefore, average load and CF are not reported separately in the above table.

[184] PNNL, *DR Performance of GE Hybrid Heat Pump Water Heater*, 2013.

[185] PNNL, *Evaluation of DR Performance of Large Capacity HPWHs*, 2015.

[186] Duke Energy, *Heat Pump Water Heaters for Demand Response*, 2017.

[187] Lawrence Berkley National Laboratory, *Field Testing of Telemetry for Demand Response Control of Small Loads*, 2015.

[188] United Illuminating, *United Illuminating HPWH Pilot: Impact and Customer Acceptance Study*, 2010.

Table 3-57. Unit Impact Metrics for ERWHs

Source	Smart Switch/Simple Timer Switch/Smart Appliance, DLC				
	Year of Publication	**Average Load**	**Coincidence Factor**	**Derating**	**kW/ Appliance During Peak**
MA TRM	2015	0.37[189]	N/A	0.90	0.33[190]
NY TRM	2017	N/A[191]	N/A	0.90	0.59
VT TRM	2015	1.1	0.20	0.90	0.20
IL TRM	2017	1.2	0.12	0.90	0.13
PNNL[192]	2013	0.9	N/A	0.90	N/A
HECO[193]	2011	0.3	N/A	0.90	0.27
Duke[194]	2017	N/A	N/A	0.90	0.12
EPRI[195]	2009	N/A	N/A	0.90	0.28
BGE[196]	2002	N/A	N/A	0.90	0.24
United Illuminating[197]	2010	N/A	N/A	0.90	0.29
International Journal of Applied Engineering Research	2016	0.8	N/A	N/A	N/A
Source	**Year of Publication**	**Average Coincident Load**		**Derating**	**kW/ Appliance During Peak**
MA Baseline Study End-Use Metering – All Days	2018	0.19		0.9	0.17
MA Baseline Study End-Use Metering – Hottest Days	2018	0.18		0.9	**0.16**
Potential Peak Demand Impact per Device					**0.16**

Source: Navigant analysis based on multiple data sources, reference footnotes.

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[189] Average load from the TRM includes summer peak CF. Therefore, average load and CF are not reported separately in the above table.

[190] Annual average kW is based on an update to the 2016-2018 TRM conducted by Navigant between June 2016 and March 2017 (HPWH Impact Study: Volume 1: $kW = ERWH_{consumption} * (EF_{old} / EF_{new}) * (1 / 8760)$, where annual ERWH energy consumption is 3330, EF_{old} is 0.91 and EF_{new} is 0.945.

[191] Average load from the TRM includes summer peak CF. Therefore, average load and CF are not reported separately in the above table.

[192] PNNL, *DR Performance of GE Hybrid Heat Pump Water Heater*, 2013.

[193] Kema, *2011 EnergyScout Impact Evaluation*, HECO.

[194] Duke Energy, *Heat Pump Water Heaters for Demand Response*, 2017.

[195] EPRI, *Assessment of Achievable Potential from EE and DR Programs in the US*, 2009.

[196] BGE, *Evaluation of the Load Impacts of the Electric Water Heater Load Control Program*, 2002.

[197] United Illuminating, *United Illuminating HPWH Pilot: Impact and Customer Acceptance Study*, 2010.

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The derating factors listed in the above tables are based on the 2011 impact evaluation of HECO's EnergyScout program. Table 3-58 lists the components of the derating factors assumed for water heater DR programs. The derating factor is assumed to be the same regardless of whether the appliance is a HPWH or ERWH and regardless of the DR-enablement scenario (smart switch, simple timer switch, built-in).

The final derating factor is applied to coincident load estimates in order to estimate potential or achievable impact per unit.

Table 3-58. Derating Assumptions, Water Heaters

Derating Factor	Value
Participation Rate per Event and Connectivity	0.9[198]
Additional Derating for Temperature Setback Strategy	N/A
First Year In-Service	N/A
Final Derating Factor	**0.9**

Source: Navigant analysis based on multiple data sources, reference footnotes.

C. Total Achievable Impact

The following tables contain relevant saturation statistics from the MA Baseline Study Saturation Survey for HPWHs and ERWHs. The results show that there were approximately 12,000 HPWHs in National Grid's Massachusetts territory as of 2017, 600 of which were Wi-Fi enabled (the assumption is that these have the add-on device offered by the water heater OEM that makes the unit Wi-Fi enabled). For ERWHs, the results show that there were approximately 175,000 ERWHs in National Grid's Massachusetts territory as of 2017, 10,000 of which were Wi-Fi enabled (with the same assumption as HPWHs, that these are units with an add-on device). Estimates of the growth rate for smart water heaters are based on Navigant Research findings.[199]

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[198] Hawaiian Electric, 2011.

[199] Based on forecasted penetration rate for smart appliances in North America. Navigant Research, *Market Data: IoT for Residential Energy Customers, Global Market Forecasts, 2016-2026*, 2016.

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Table 3-59. Saturation and Estimated Enrollment in National Grid's Massachusetts Territory, HPWHs

	2019	2028
Average Number of HPWHs/ Customer	0.01[200]	0.01
Approximate Number of HPWHs[201]	12,000	12,000
Approximate Number of Smart HPWHs[202]	800[203]	2,400[204]
Estimated Devices Enrolled in DR Program with a Simple Timer Switch	60	600
Estimated Devices Enrolled in DR Program with a Wi-Fi Switch	60	600
Estimated Smart Devices Enrolled in DR Program	40	1,300

Source: Navigant analysis based on multiple data sources, reference footnotes.

Table 3-60. Saturation and Estimated Enrollment in National Grid's Massachusetts Territory, ERWHs

	2019	2028
Average Number of ERWHs/ Customer	0.15[205]	0.15
Approximate Number of ERWHs[206]	175,000	180,000

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[200] From MA Baseline Study Saturation Survey results for National Grid (*National Grid Electric Final Saturation Results 2017-07-16.xls*).

[201] Based on MA Baseline Study estimate/forecast of National Grid's Massachusetts population of households (approximately 1.2 million households in 2017 and in 2028).

[202] The MA Baseline Study Saturation Survey contained questions related to whether customers' appliances (including clothes washers, refrigerators, pool pumps, water heaters, dehumidifiers, dryers) were Wi-Fi-enabled. Given the context of these questions, Navigant believes that these represent appliances with built-in Wi-Fi capabilities (as opposed to retrofits).

[203] Based on forecasted penetration rate for smart appliances in North America. Navigant Research, *Market Data: IoT for Residential Energy Customers, Global Market Forecasts, 2016-2026*, 2016.

[204] Based on forecasted penetration rate for smart appliances in North America. Navigant Research, *Market Data: IoT for Residential Energy Customers, Global Market Forecasts, 2016-2026*, 2016.

[205] From MA Baseline Study Saturation Survey results for National Grid (*National Grid Electric Final Saturation Results 2017-07-16.xls*).

[206] Based on MA Baseline Study estimate/forecast of National Grid's Massachusetts population of households (approximately 1.2 million households in 2017 and in 2028).

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	2019	2028
Approximate Number of Smart ERWHs[207]	12,000[208]	36,000[209]
Estimated Devices Enrolled in DR Program with a Simple Timer Switch	900	9,000
Estimated Devices Enrolled in DR Program with a Wi-Fi Switch	900	9,000
Estimated Smart Devices Enrolled in DR Program	600	19,000

Source: Navigant analysis based on multiple data sources, reference footnotes.

Two other factors impact the total peak demand reduction achievable on a program level: customers' willingness to sign up for a DR program (i.e., discretionary factor) and customers' likelihood of continued program participation following the first year of participation (i.e., persistence factor). Based on a review of available literature, Navigant assumed that 80% of customers with water heaters would be willing to enroll in a program in which their water heater's heating resistance elements are controlled by National Grid.[210] A persistence factor of 90% is assumed (i.e., slightly lower than the persistence rate associated with National Grid's CAC Wi-Fi Thermostat DR program).

Based on the assumptions discussed above, for both heat pump water heaters and electric resistance water heaters, while Navigant estimates achievable DR program enrollment associated with Wi-Fi switches or simple timer switches to outnumber smart water heater enrollment in 2019, Navigant expects enrollment of smart water heaters to be double that of plug-based DR programs by 2028.

D. Benefit-Cost Analysis

Table 3-61 shows the estimated net-present value of total benefits and costs, according to the TRC test, for the 2019 to 2028 timeframe, based on expected program size over this period. For HPWHs and ERWHs, results for both the retrofit (smart switch and simple timer switch) and smart appliance DR-enablement strategies are provided. Results show benefit-cost ratios ranging from 0.1 to 0.4 for HPWH DR programs, and from 0.3 to 0.7 for ERWHs demand response programs. Benefit-cost ratios associated with HPWHs are lower due to the lower average coincident demand (due to HPWHs being more efficient) than ERWHs. Additionally, the retrofit (inline switch/controller) options are less cost-effective for both HPWHs and ERWHs due to the per unit costs of the switch and installation (regardless of whether Wi-Fi or simple mechanical timer).

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[207] The MA Baseline Study Saturation Survey contained questions related to whether customers' appliances (including RACs, Refrigerators, Pool Pumps, Water Heaters, Dehumidifiers, Dryers) were Wi-Fi-enabled. Given the context of these questions, Navigant believes that these represent appliances with built-in Wi-Fi capabilities (as opposed to retrofits).

[208] Based on forecasted penetration rate for smart appliances in North America. Navigant Research, *Market Data: IoT for Residential Energy Customers, Global Market Forecasts, 2016-2026*, 2016.

[209] Based on forecasted penetration rate for smart appliances in North America. Navigant Research, *Market Data: IoT for Residential Energy Customers, Global Market Forecasts, 2016-2026*, 2016.

[210] Lappeenranta University of Technology, *Households Willingness to Engage in Demand Response Programs in the Finnish Electricity Market*, 2015.

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Table 3-61. TRC Test Benefits and Costs, 2019 to 2028

	Smart Switch, DLC		
	Total Impact (Benefit) (Millions)	Total Costs (Millions)	Benefit-Cost Ratio
HPWHs – Smart Switch	$0.1	$0.7	0.1

Source: Navigant analysis

	Simple Timer Switch, DLC		
	Total Impact (Benefit) (Millions)	Total Costs (Millions)	Benefit-Cost Ratio
HPWHs – Simple Timer Switch	$0.1	$0.4	0.2

Source: Navigant analysis

	Smart Appliance, DLC		
	Total Impact (Benefit) (Millions)	Total Costs (Millions)	Benefit-Cost Ratio
HPWHs – Smart Appliance	$0.1	$0.4	0.4

Source: Navigant analysis

	Smart Switch, DLC		
	Total Impact (Benefit) (Millions)	Total Costs (Millions)	Benefit-Cost Ratio
ERWHs – Smart Switch	$2.4	$9.4	0.3

Source: Navigant analysis

	Simple Timer Switch, DLC		
	Total Impact (Benefit) (Millions)	Total Costs (Millions)	Benefit-Cost Ratio
ERWHs – Simple Timer Switch	$2.4	$5.6	0.4

Source: Navigant analysis

	Smart Appliance, DLC		
	Total Impact (Benefit) (Millions)	Total Costs (Millions)	Benefit-Cost Ratio
ERWHs -Smart Appliance	$3.8	$5.4	0.7

Source: Navigant analysis

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3.10 Pool Pumps

A. DR Context

Pool pumps have long been a target of residential DR programs. Largely, these programs have focused on solutions for a suite of home products. In Florida, Duke Energy's Energy Wise and FPL's FPL On Call programs require that a device be installed in the home that controls numerous appliances, including pool pumps. Customers are then rewarded with bill credits in exchange for the utility turning off these appliances during peak energy events. FPL pays $3 per month for full control over connected pool pumps, Duke Energy pays $2.50 per participating month, and LG&E pays $2 per month.

Pool pumps can either have built-in connectivity or can be controlled with plugs or inline switches. Inline switches are the most common control mechanism, with utilities like Eversource Connecticut and LG&E paying for switch installation themselves (note that Eversource is no longer accepting new customers for their pilot). This study assumes that switches used for a DR program would be compatible (in terms of size) with pool pumps in National Grid's territory. Some additional research may be required to determine the saturation of pool pumps of different sizes. Alternatively, the program may have to offer a range of switches.

Smart plugs can also work for pool pumps that are plugged into a traditional outlet, as has been shown with iDevices' Outdoor Switch, although many popular smart plugs like Belkin's Wemo line explicitly are not designed for outdoor use. Though ENERGY STAR does not have any pool pump models that it certifies as connected, there are pumps within custom pool operating systems that work over the home's internet connection. Problems arise, however, in the locational market penetration of pools and these different possible modes of connectivity.

The MA Residential Baseline Study found that there are no plug-in pool pumps in National Grid's Massachusetts jurisdiction. Therefore, Navigant excludes a plug-based option from the BCR analysis. Additionally, the MA Baseline Study Saturation Survey revealed that, for the respondents with smart pool pumps (built-in Wi-Fi capability), the majority were single-speed pool pumps (as opposed to multi-speed). Therefore, Navigant uses the same impact assumptions for all DR-enablement strategies considered in the following sections (i.e., smart switch, simple timer switch, built-in).

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Table 3-62. DR-Enabling Device Market

OEMs	DR-Enabled Product	Proven in DR Context?	Example Utility Partners
Smart Plug			
iDevices	Outdoor Switch	No	
Smart Switch			
Aclara	LCT	Yes	FPL
	[pictured]	Yes	Duke
Built-In			
Zodiac	Aqualink	No	
Pentair	EasyTouch, IntelliTouch	No	
Hayward	AquaConnect	No	

Source: Navigant analysis based on web research

B. Potential Impact Per Device

Table 3-63 contains the average coincident load results for pool pumps from the metering conducted as part of the MA Baseline Study for all summer weekdays (All Days) and weekdays for which the maximum temperature during the peak period was above 85°F (Hottest Days). The size of the metering sample for pool pumps was 25 units.[211]

Navigant used the Hottest Days' impact as the final potential peak demand reduction value for BCR purposes. After applying a derating factor, potential load reduction during the peak period associated with the Hottest Days scenario is 0.61 kW, regardless of the enabling technology (since all options are assumed to have the same derating factor).

For comparison purposes, Table 3-63 also includes unit impacts derived from the MA TRM and from studies conducted by SCE, SDG&E, Pacific Gas and Electric (PG&E), and Eversource (MA and CT).

Table 3-63. Unit Impact Metrics for Pool Pumps

Source	Smart Switch/Simple Timer Switch/Smart Appliance, DLC				
	Year of Publication	Average Load	Coincidence Factor	Derating	kW/ Appliance During Peak

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[211] The metering sample only included one smart pool pump. However, the Baseline Study Saturation Survey results suggest that the majority of smart pool pumps are single speed. Therefore, Navigant assumed the same unit impacts for switch versus smart pool pump options.

MA TRM	2015	0.65[212]	N/A	0.9	0.58[213]
VT TRM	2015	1.9	0.83	0.9	1.39
IL TRM	2017	1.8	0.83	0.9	1.38
SCE[214]	2008	1.2	N/A	0.9	0.43
CA Utilities[215]	2001	1.5	N/A	0.9	0.34
Eversource[216]	2016	N/A	N/A	0.9	0.99

Source	Year of Publication	Average Coincident Load	Derating	kW/ Appliance During Peak
MA Baseline Study End-Use Metering – All Days	2018	0.51	0.9	0.46
MA Baseline Study End-Use Metering – Hottest Days	2018	0.68	0.9	**0.61**
Potential Peak Demand Impact per Device				**0.61**

Source: Navigant analysis based on multiple data sources, reference footnotes.

Navigant assumed that event participation for pool pump owners would be close to 100%. Navigant assumed the connectivity rate to be the same as that for CACs' DR.[217]

Together, these factors make up the derating factor, which is applied to coincident load estimates in order to estimate potential or achievable impact per unit.

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[212] Average load from the TRM includes summer peak CF. Therefore, average load and CF are not reported separately in the above table.

[213] The 2016-2018 MA TRM provides a formula and average values for calculating the maximum daily demand from a pool pump: $kW = ((Flow\ Rate)/(Energy\ Factor)) * (\%\ run\ time\ of\ 24\ hours)$, with average flow rates around 65 gal/min and EFs between 2.1 and 8.8 depending on the efficiency and speed of the pool pump.

[214] SCE, *Pool Pump DR Potential Report*, 2008.

[215] Ibid. 2001 results cited in SCE 2008 report.

[216] Cadmus and Eversource, *Home Energy Management Systems (HEMS) Paths to Savings: On-Ramps and Dead Ends*, 2016.

[217] 2017 Mid-Season Participation Assessment for National Grid's Residential DR evaluation.

Table 3-64. Derating Assumptions, Pool Pumps

Derating Factor	Value
Participation Rate per event	1
Connectivity	0.9[218]
Additional Derating for Temperature Setback Strategy	N/A
First Year In-Service	N/A
Final Derating Factor	**0.9**

Source: Navigant analysis based on multiple data sources, reference footnotes.

C. *Total Achievable Impact*

The figure below contains relevant saturation statistics on pool pump saturation from the MA Baseline Study Saturation Survey. The results show that there were approximately 80,000 pool pumps in National Grid's Massachusetts territory as of 2017, and 3,000 were Wi-Fi enabled. For the purposes of this report, Navigant assumed that these 3,000 pool pumps are smart pool pumps (with built-in capability) rather than retrofitted units (this may or may not be the case). Estimates of the growth rate for smart pool pumps are based on Navigant Research forecasts.[219]

Table 3-65. Saturation and Estimated Enrollment in National Grid's Massachusetts Territory, Pool Pumps

	2019	2028
Average Number of Pool Pumps (PPs)/Customer	0.07[220]	0.07
Approximate Number of PPs[221]	82,000	85,000
Approximate Number of Smart PPs[222]	3,000[223]	11,000[224]
Estimated Devices Enrolled in DR Program with a Simple Timer Switch	400	4,000
Estimated Devices Enrolled in DR Program with a Wi-Fi Switch	400	4,000

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[218] Assumed the same connectivity rate as for CACs.

[219] Based on forecasted penetration rate for smart appliances in North America. Navigant Research, *Market Data: IoT for Residential Energy Customers, Global Market Forecasts, 2016-2026*, 2016.

[220] From MA Baseline Study Saturation Survey results for National Grid (*National Grid Electric Final Saturation Results 2017-07-16.xls*).

[221] Based on MA Baseline Study estimate/forecast of National Grid's Massachusetts population of households (approximately 1.2 million households in 2017 and in 2028).

[222] The MA Baseline Study Saturation Survey contained questions related to whether customers' appliances (including clothes washers, refrigerators, pool pumps, water heaters, dehumidifiers, dryers) were Wi-Fi-enabled. Given the context of these questions, Navigant believes that these represent appliances with built-in Wi-Fi capabilities (as opposed to retrofits).

[223] Based on forecasted penetration rate for smart appliances in North America. Navigant Research, *Market Data: IoT for Residential Energy Customers, Global Market Forecasts, 2016-2026*, 2016.

[224] Based on forecasted penetration rate for smart appliances in North America. Navigant Research, *Market Data: IoT for Residential Energy Customers, Global Market Forecasts, 2016-2026*, 2016.

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	2019	2028
Estimated Devices Enrolled in DR Program with a Wi-Fi Plug	N/A	N/A
Estimated Smart Pool Pump Devices Enrolled in DR Program	200	9,000

Source: Navigant analysis based on multiple data sources, reference footnotes.

Two other factors impact the total peak demand reduction achievable on a program level: customers' willingness to sign up for a DR program (i.e., discretionary factor) and customers' likelihood of continued program participation following the first year of participation (i.e., persistence factor). Since pool pump operation does not impact customer comfort or convenience, Navigant assumed that 90% of customers with pool pumps would be willing to enroll in a program in which their pool pumps are controlled by National Grid. A persistence factor of 90% is assumed.

Based on the assumptions discussed above, while Navigant estimates achievable DR program enrollment associated with Wi-Fi switches or simple timer switches to outnumber smart pool pump enrollment almost 2 to 1 in 2019, Navigant expects enrollment of smart pool pumps to significantly outpace enrollment in switch-based DR programs by 2028. Additionally, based on MA Baseline Study, it is assumed that there are relatively few plug-in pool pumps (the study sample had none). Therefore, Navigant did not analyze plug strategies for pool pumps in the benefit-cost analysis for this study (and therefore did not forecast program enrollment for a plug-based DR program).

D. Benefit-Cost Analysis

Table 3-66 shows the estimated net-present value of total benefits and costs according to the TRC test for the 2019 to 2028 timeframe based on expected program size over this period. Results for the smart switch, simple timer switch, and smart appliance DR-enablement strategies are provided. Results show a benefit-cost ratio of 1.1, 1.7, and 2.7 for the smart switch, simple timer switch, and smart appliance options, respectively. These ratios indicate that a pool pump DR program, in any form, may be worth pursuing. However, the low penetration of pool pumps in Massachusetts shows that the megawatt benefit 10 years out remains relatively modest, at 6.0 MW for built-in and 2.9 MW for smart or simple switch programs. This modest benefit may not be able to support the upfront cost IS/IT, administration, and marketing cost necessary to set up a pool pump program. These upfront costs are not included in the BCR in Table 3-66. See Section 2.4 for more details.

Table 3-66. TRC Test Benefits and Costs, 2019-2028

	Smart Switch, DLC		
	Total Impact (Benefit) (Millions)	Total Costs (Millions)	Benefit-Cost Ratio
Pool Pumps - Smart Switch	$4.4	$4.4	1.0

Source: Navigant Analysis

	Simple Switch, DLC		
	Total Impact (Benefit) (Millions)	Total Costs (Millions)	Benefit-Cost Ratio

Pool Pumps - Simple timer switch	$4.4	$2.8	1.6

Source: Navigant Analysis

	Smart Appliance, DLC		
	Total Impact (Benefit) (Millions)	Total Costs (Millions)	Benefit-Cost Ratio
Pool Pumps - Smart Appliance	$6.8	$2.5	2.7

Source: Navigant Analysis

3.11 Battery Storage

A. DR Context

Energy storage represents many of the same goals as DR in that it provides a more levelized load structure and more energy stability. For that reason, it has been linked with DR as a valuable potential resource. Con Edison, SDG&E, and Green Mountain Power (GMP) are developing business models for harnessing the load stabilizing potential of residential energy storage (RES).

Con Edison's program will include both solar PV and RES systems. The integrated systems will be used to smooth integration of distributed PV onto the grid through both firming the variable output and shifting production to align with peak demand. The aim is to make PV plus RES a single, dispatchable resource that can help reduce load in constrained areas and defer or avoid T&D infrastructure investments. For this demonstration, Con Edison will own all energy storage assets. Following the pilot phase, Con Edison may set up mechanisms to transfer ownership and control of the RES systems to customers.[225]

SDG&E is following a BYO-battery (BYOB) model. The utility will allow any qualifying RES system (including those owned by third-party providers) in its territory to participate in its new RES rate program. SDG&E will offer cash incentives for customers in certain locations where RES systems can provide high value. Program participants will accept a new dynamic rate that will allow SDG&E to directly control the systems charge and discharge functions during a limited number of high load hours annually. Rates will likely reflect forecasted system and circuit conditions and—through hourly price signals—incent both charging and discharging activity. SDG&E may sponsor another pilot project, which is similar to Con Edison's project and would involve deploying utility-owned batteries for direct control.[226]

In May 2016, GMP partnered with Tesla to offer its 7 kWh Powerwall battery to customers, most of whom (but not all) have solar PV on their homes. For participation, customers can either purchase the Powerwall directly from GMP with no utility control, purchase the Powerwall from GMP and allow utility control at certain times in exchange for a bill credit, or customers can lease the RES from GMP with no upfront cost and pay an additional monthly fee to the utility.

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[225] Navigant Research, *Residential Energy Storage Systems*, 2016.

[226] Ibid.

One barrier to large-scale adoption of RES systems is upfront cost. Tesla's Powerwall, including supporting hardware and installation, runs approximately $8,000. However, according to IHS, average lithium ion battery prices decreased in cost over 50% between 2012 and 2015, and are expected to decrease over 50% again before 2019.[227] For BYOB RES DR programs to be feasible, adequate incentives would need to be in place to encourage adoption of RES systems.

Navigant does include costs associated with interconnection in the benefit-cost assessment for battery systems with or without solar. Since homes with solar PV are already net metered, there are no incremental interconnection costs associated with interconnection of a battery storage system. Homes without solar are not currently permitted to export to the grid in Massachusetts,[228] making dispatch-based DR program infeasible for this option (in this case, DR for residential energy storage systems not coupled with solar would entail a reduction of peak demand via local discharge of battery systems to serve the needs of homes during peak times).

Navigant does not believe that battery storage DR will present an issue at secondary transformers since houses are rated for 10 kW, and a residential use battery, like the Powerwall, can only push back 7 kW.

The benefit-cost analysis conducted for this study focused on the Tesla Powerwall. **Importantly, it also assumed BYOB program model.**

Table 3-67. DR-Enabling Device Market

OEMs	DR-Enabled Product	Proven in DR Context?	Example Utility Partners
Tesla	Powerwall	Not yet	Green Mountain Power
Sunverge	Sunverge One	Not yet	Con Edison, SMUD

Source: Navigant analysis based on web research

B. Potential Impact Per Device

For Powerwall, which has a continuous storage capacity of 5 kW, Navigant applied a derating factor of 80% to account for connectivity and participation factors, resulting in a peak demand impact of 4 kW for batteries where solar is also present. For batteries without solar, Navigant applied the same derating factor of 80% to average peak coincident whole-home load in order to derive potential impact.

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[227] Massachusetts Department of Energy Resources, *State-Of-Charge Report*, 2016.

[228] Massachusetts Department of Public Utilities, D.P.U. 17-146-A.

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Table 3-68. Unit Impact Metrics – Battery System With Solar

Source	Tesla Powerwall, DLC			
	Year of Publication	Continuous Storage Capacity (kW)	Coincidence Factor/Derating	kW/Appliance During Peak
Tesla	Powerwall	5.0	0.80	4.0
Tesla	Powerwall 2.0	5.0	0.80	4.0
Potential Peak Demand Impact per Device				**4.0**

Source: Discussions with National Grid

Table 3-69. Unit Impact Metrics – Battery System No-Solar

	Tesla Powerwall, DLC			
Source	Year of Publication	Average Coincident Load	Derating	kW/ Appliance During Peak
MA Baseline Study End-Use Metering – All Days	2018	1.08	0.8	0.86
MA Baseline Study End-Use Metering – Hottest Days	2018	1.71	0.8	**1.37**
Potential Peak Demand Impact per Device				**1.37**

Source: MA Baseline Study

C. Total Achievable Impact

For this study, Navigant considered two types of RES for DR: RES DR for customers with solar PVs and RES DR for customers with no solar.

The current population of RES systems in National Grid's territory, both standalone and combined with solar PV, is unknown. Navigant assumed penetration in both segments was negligible as of 2017 and applied a growth rate based on a Navigant Research report on RES systems.[229] Following this approach, Navigant estimates there will be approximately 17,500 standalone RES systems and 41,000 solar plus RES systems in National Grid's Massachusetts territory by 2028. Note, these numbers are for all RES systems, not just Powerwall. For the purposes of the benefit-cost ratio analysis, Powerwall is assumed to be 100% of the RES market.

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[229] Navigant Research, *Residential Energy Storage: Advanced Lead-Acid, Flow, and Li-Ion Batteries for Residential Applications: Global Capacity and Revenue Forecasts* 1Q 2019.

Based on these assumptions, Navigant estimates achievable DR program enrollment to be 60 batteries in 2019 and 8,000 batteries by 2028 for a DR program targeting customers with solar plus storage. For a DR program targeting customers with storage only, Navigant estimates achievable DR program enrollment to be 30 batteries in 2018 and 3,500 batteries by 2028.

Table 3-70. Saturation and Estimated Enrollment in National Grid's Massachusetts Territory, Residential Energy Storage Systems[230]

	2019	2028
Approximate Number of solar + RES	350	6,000
Approximate Number of Standalone RES	150	3,000
Estimated Devices Enrolled in DR Program with Solar	60	8,000
Estimated Devices Enrolled in DR Program without Solar	30	3,500

Source: Navigant analysis based on multiple data sources, reference footnotes.

D. Benefit-Cost Analysis

The following tables show the estimated net-present value of total benefits and costs according to the TRC test for the 2019 to 2028 timeframe based on expected program size over this period. Navigant estimates healthy benefit-cost ratios of 1.6 and 4.7, associated with DR for standalone RES systems and DR for solar PV plus RES systems, respectively.

Table 3-71. TRC Test Benefits and Costs, 2019-2028

	Powerwall, DLC, No Solar		
	Total Impact (Benefit) (Millions)	Total Costs (Millions)	Benefit-Cost Ratio
Powerwall - No Solar	$5.3	$3.3	1.6

Source: Navigant analysis

	Powerwall, DLC, Solar		
	Total Impact (Benefit) (Millions)	Total Costs (Millions)	Benefit-Cost Ratio
Powerwall - Solar	$36.1	$7.7	4.7

Source: Navigant analysis

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[230] Ibid.

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3.12 EVs

A. DR Context

Vehicle-to-grid integration (VGI) technologies fall into two categories: vehicle-to-grid communications for charge management (V1G) and vehicle-to-grid power transfer (V2G). V1G is the method by which a conventional plug-in EV (PEV) allows a grid operator to modulate the rate its battery is charged for participation in DR programs or regulation services. V2G refers to the ability of a PEV to be supplied with power from the grid and to supply power back to the grid. [231] This report considers only DR programs which harness V1G capabilities, meaning it focuses on vehicle charging load control. V2G would provide additional DR resources (in the form of stored capacity) and should be considered in the future for DR.

Due to the more complicated nature of tracking charging that occurs through non-home private and public charging stations, the benefit-cost analysis in this report reflects demand reduction associated with control of EV home charging. It does cover the demand reduction potential associated with non-home charging. DR targeting non-home charging is another area that should be explored further, especially if/when the adoption of wireless EVSEs increases.

EVs can participate in DR programs in two ways: dynamic pricing programs such as time-of-use (TOU) and/or DR event response. Several EV automakers and EV supply equipment (EVSE) software and hardware OEMs enable their devices to automatically respond to TOU programs to charge EVs at the lowest possible points given EV owner driving requirements. In the US, 22 utilities have adopted or are testing TOU-specific rates for EVs. The EV-specific rates have typically required either the installation of a submeter in the EVSE unit or the installation of an additional meter in the household.[232]

The other way consumers can participate in DR programs is by responding to utility signals to decrease load at scheduled times. EVs are slowly being incorporated into such programs through a number of pilots in the US and Europe that are testing the ability of EVs to respond, EV owner interest in participation, and actual value to the utility. Since light duty (LD) EVs most frequently charge batteries at 7 kW or less in North America, they would need to be aggregated by the hundreds to reach the megawatt volumes necessary to create a separate DR resource. EV manufacturers are exploring options for individual EV owners to participate in DR programs run through the EV manufacturer, whereby the EV manufacturer acts as an energy aggregator managing DR assets in a given DR program.[233]

One of the first demonstration projects of this kind to roll out was the PG&E and BMW iChargeForward pilot. The first phase of iChargeForward occurred from July 2015 to December 2016, during which PG&E sent signals to BMW requesting a load reduction on the grid of up to 100 kW. In response to these DR signals, BMW selected vehicles for delayed charging—up to 1 hour delay per day—based on drivers' needs.[234] BMW is able to manage the charging process of the participating EVs by leveraging cellular (GSM-based) telemetry services.[235] Participants could choose to opt-out of participation as desired if they

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[231] Navigant Research, *Vehicle Grid Integration: VGI Applications for Demand Response, Frequency Regulation, Microgrids, Virtual Power Plants, and Renewable Energy Integration*, 2015.

[232] Ibid.

[233] Ibid.

[234] In the BMW i ChargeForward group about 60% of the participants are on a Time-of-Use (TOU) rate that provides an economic incentive to charge off-peak between the hours of 11:00 PM and 7:00 AM.

[235] PG&E, *BMW i ChargeForward: PG&E's Electric Vehicle Smart Charging Pilot*, 2016.

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needed to begin charging their BMW i3 immediately. The majority of events were called from 8 p.m. to 9 p.m. Average event impact was approximately 0.2 kW, with an average participation rate of 7% (see Section B). As part of this pilot, customers received an upfront incentive of $1,000 and an ongoing incentive for each day they do not opt-out (whether an event was called or not), up to $540 that is distributed after the pilot has ended.

As part of this iChargeForward pilot, customer research was conducted to learn more about EV driver charging habits. The vast majority of participants surveyed said they charge their vehicle at night, while 63% indicated they charge more than once per day. Less than half of survey respondents (41%) have access to charging at their workplace.

Con Edison is testing another way to enable personal use EVs to participate in behavioral DR through its SmartCharge Rewards program. As part of the program, Con Edison provides participants with a C2 by FleetCarma which plugs into the EV's onboard diagnostic (OBD) or Tesla diagnostic connector, in addition to $50 for enrolling, and $5 in rewards in each month that they charge in the Con Edison service territory. EV owners also earn $0.05/kWh of charging during off-peak hours, from midnight to 8 a.m. Although the program is intended to help reduce peak load on the grid, the real goal is for the utility to collect data on how EVs will impact its electric-delivery system.[236]

Wi-Fi EVSEs present another opportunity for utility-controlled charging, although the very low penetration[237] of Wi-Fi-enabled home charging stations makes this an unattractive option in the near-term. Additionally, a Wi-Fi-enabled switch or smart control device could be installed at the charging station in order to enable charging load curtailment.

Navigant conducted web research and interview members of National Grid's DR team to further understand and obtain data related to the current and future market for each appliance and enabling device. Table 3-71 provides a summary of available information:

Table 3-72. DR-Enabling Device Market

OEMs	DR-Enabled Product	Proven in DR Context?	Example Utility Partners	Market Notes
EVSE OEMs with Utility Control Capabilities				
ChargePoint	CT4000 and CPF25, Express 250 and Express Plus DCFC		KCP&L, SCE	Wi-Fi, Cellular, CDMA
Aerovironment	EVSE-RS Version 1.0		SCE	Wi-Fi, Ethernet, Cellular
Emotorworks	JuiceBox Pro			Wi-Fi, Ethernet, Cellular
Itron & Clippercreek	Smart Charging Station		Eversource, TVA, SCE, PEPCO	Wi-Fi, RF Mesh, Cellular, ZigBee
Semaconnect	ChargePro			Cellular

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[236] UtilityDive, *New Con Ed EV program to reward customers for off-peak charging*, April 18, 2017.

[237] Navigant Research, *Vehicle Grid Integration: VGI Applications for Demand Response, Frequency Regulation, Microgrids, Virtual Power Plants, and Renewable Energy Integration*, 2015.

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OEMs	DR-Enabled Product	Proven in DR Context?	Example Utility Partners	Market Notes
Siemens	VersiCharge SG (Level 2)		Duke	Wi-Fi
EVSEE LLC	ChargeWorks 3703		SCE	Ethernet, Cellular, radio, Wi-Fi
EVSE Switch/Controller				
DiUS	Smart control device, attachable to EVSE	Piloted	Victoria, Australia	
OBD Dongle				
FleetCarma	C2 (cellular-enabled device)	Piloted	Con Edison, Toronto Hydro, New Brunswick Power, BC Hydro, PG&E, SDG&E	
EVs with “Built-In” DR Capability				
BMW	iChargeForward program	Piloted	PG&E	Autogrid is also looking to partner with Nissan and Telsa
Honda		Test	PG&E	
GM	OnStar			

Source: Navigant analysis based on web research

B. Potential Impact Per Device

As seen in Table 3-72, the estimated demand impact associated with EVs is based on an average hourly EV home charging load profile provided in a Portland General Electric study from 2016. This value was chosen over the 0.2 average peak demand impact as evaluated by PG&E for its iChargeForward program because most of the events called as part of PG&E’s program were at night, when more charging occurs (than during the summer peak period of 2 p.m. to 5 p.m.). The MA Baseline Study metered two home EV charging stations (in 2017). During the summer peak period, the average load associated with these two units was 0.02 kW to 0.04 kW. The metering data indicates that the majority of home charging occurs between the hours of 8 p.m. and 4 a.m. The maximum average load during this time period was in the 0.5 kW to 0.6 kW range.

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Table 3-73. Unit Impact Metrics for EVs

	OBD Dongle/EV Built-in/Smart Switch/EVSE Built-in, DLC			
Source	**Year of Publication**	**Average Load**	**Coincidence/ Derating Factor**	**kW/Appliance During Peak**
Portland General Electric[238]	2016	N/A	N/A	0.09
PG&E[239]	2016	4.4	0.05	0.2
Potential Peak Demand Impact per Device				**0.09**

Source: Navigant analysis based on multiple data sources, reference footnotes.

C. Total Achievable Impact

Based on research conducted by Navigant Research, the team assumes that there were approximately 9,500 EVs in National Grid's territory as of 2017. [240] Installed base of EVs in National Grid's territory in 2028 is estimated to be approximately 200,000, based on growth rates cited by Navigant Research.[241] The current and forecasted penetration of DR-enabled home charging stations was unknown but assumed to be small in 2017. Public charging and non-single-family home private charging stations are assumed to account for the majority of wireless EVSEs at present and going forward.[242]

Table 3-74. Saturation and Estimated Enrollment in National Grid's Massachusetts Territory, EVs and Smart EVSEs

	2019	2028
Approximate Number of EVs[243]	24,000	200,000
Approximate Number of (Home) Wi-Fi EVSEs[244]	700	30,000
Estimated Built-in EV Devices Enrolled in DR Program	1,200	40,000
Estimated (Home) Wi-Fi EVSE Controller Devices Enrolled in DR Program	1,200	40,000

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[238] The Brattle Group, *Demand Response Market Research: Portland General Electric, 2016 to 2035*, January 2016.

[239] PG&E, *BMW i ChargeForward: PG&E's Electric Vehicle Smart Charging Pilot*, 2016.

[240] LD BEV Population and LD PHEV Population for Massachusetts; from Navigant Research, *Market Data: EV Geographic Forecasts*, 2017.

[241] ibid.

[242] Navigant Research, *Market Data: EV Charging Equipment,* 2017.

[243] LD BEV Population and LD PHEV Population for Massachusetts; from Navigant Research, *Market Data: EV Geographic Forecasts*, 2017.

[244] Navigant Research, *Market Data: EV Charging Equipment*, 2017.

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	2019	2028
Estimated OBD Dongle Devices Enrolled in DR Program	1,200	40,000
Estimated (Home) EVSE Built-in Devices Enrolled in DR Program	35	6,000

Source: Navigant analysis based on multiple data sources, reference footnotes.

Two other factors affect the total peak demand reduction achievable on a program level: customers' willingness to sign up for a DR program that will involve delaying or shifting their EV charging behavior (i.e., discretionary factor) and customers' likelihood of continued program participation following the first year of participation (i.e., persistence factor). Based on the PG&E and BMW iChargeForward pilot, Navigant assumed that 20% of customers with EVs would be willing to enroll in a DR program related to EV charging.[245] A persistence factor of 93 is the percentage of iChargeForward participants who indicated they would be willing to participate in a similar program in the future (of note, incentives for the iChargeForward program were substantial, as noted in Section A).

Based on these assumptions, Navigant estimates achievable DR program enrollment to be 1,200 in 2018 for programs targeting EVs with built-in DR capability and programs leveraging OBD dongles or Wi-Fi controllers (for EVSEs). Achievable enrollment for such programs is estimated to reach 40,000 by 2028.

Due to the current and forecasted saturation of smart home EVSEs, Navigant estimates much lower enrollment in 2019 and 2028 for a DR program targeting smart home EVSEs.

D. Benefit-Cost Analysis

Table 3-74 shows the estimated net-present value of total benefits and costs according to theTRC test for the 2019 to 2028 timeframe based on expected program size over this period. For the built-in EV option, Wi-Fi charger switch option, and OBD dongle options, expected program size is based on the expected overall penetration of EVs, while the smart EVSE is based on expected penetration of DR-enabled charging stations (a much lower penetration than total EVs). As expected, the options that do not require additional devices have more appealing benefit-cost ratios. As with battery storage, the feasibility of DR programs to limit EV charging during peak periods will be dependent on the penetration of EVs and DR-enabled charging stations going forward.

Table 3-75. TRC Test Benefits and Costs, 2019-2028

	EV Built-In, DLC		
	Total Impact (Benefit) (Millions)	Total Costs (Millions)	Benefit-Cost Ratio
EVs - Built-In	$5.4	$17.5	0.3

Source: Navigant Analysis

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[245] PG&E, *BMW iChargeForward: PG&E's Electric Vehicle Smart Charging Pilot*, 2016.

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	Charger Switch, DLC		
	Total Impact (Benefit) (Millions)	Total Costs (Millions)	Benefit-Cost Ratio
EVs - EVSE Smart Switch	$5.4	$41.0	0.1

Source: Navigant Analysis

	OBD Dongle, DLC		
	Total Impact (Benefit) (Millions)	Total Costs (Millions)	Benefit-Cost Ratio
EVs - OBD Dongle	$5.4	$31.2	0.2

Source: Navigant Analysis

	Smart EVSE, DLC		
	Total Impact (Benefit) (Millions)	Total Costs (Millions)	Benefit-Cost Ratio
EVs - Smart EVSE	$0.7	$2.2	0.3

Source: Navigant Analysis

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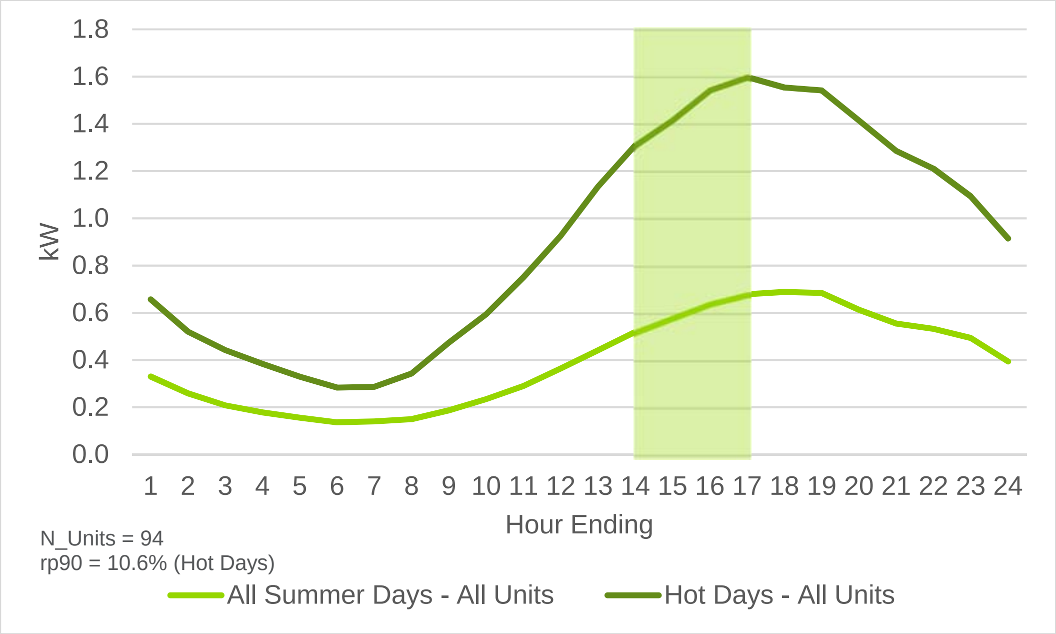
APPENDIX A. MA BASELINE STUDY END-USE METERING LOAD SHAPES

Below are end-use load shapes derived from the MA Baseline Study end-use metering over the summers of 2017 and 2018. These load shapes reflect load per unit, not per household.[246] These load shapes do not incorporate derating factors. For each end-use, two load shapes are shown: 1) All Days, average load over all non-holiday weekdays in the summers of 2017 and 2018; 2) Hot days, average load over weekdays for which the maximum temperature during the peak period was above 85°F. The load shapes for both scenarios include all metered units. Depending on the appliance, a small subset of the metered sample may be smart appliances. The shaded segment on the figure represents the summer peak period of 2 p.m. to 5 p.m., during which DR events would be called. Reported on all charts is the number of units metered and the average of the relative precision (for a 90% confidence level) associated with average load estimates for the peak period. The lower the relative precision value, the more precise the load estimate. Lower relative precisions are associated with appliances with less variability in usage patterns among those sampled.

Figure A-1. Central Air Conditioners



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[246] In contrast to the *RES 1 Baseline Load Shape Study Cooling Season Results* report, which shows household-level load shapes for different appliances.

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Figure A-2. Room Air Conditioners

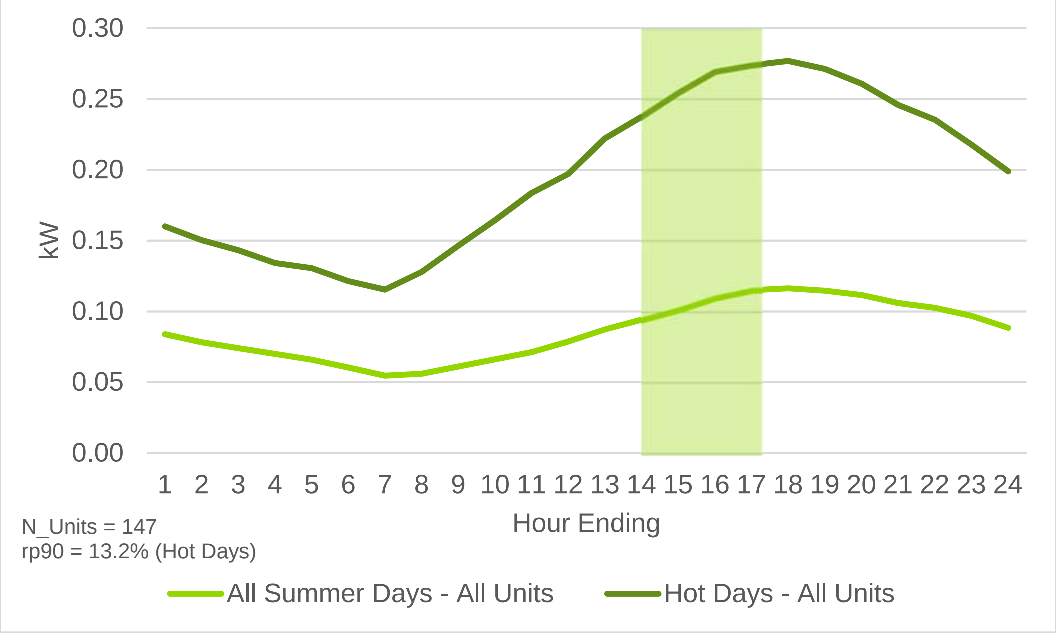

Figure A-3. Clothes Washers

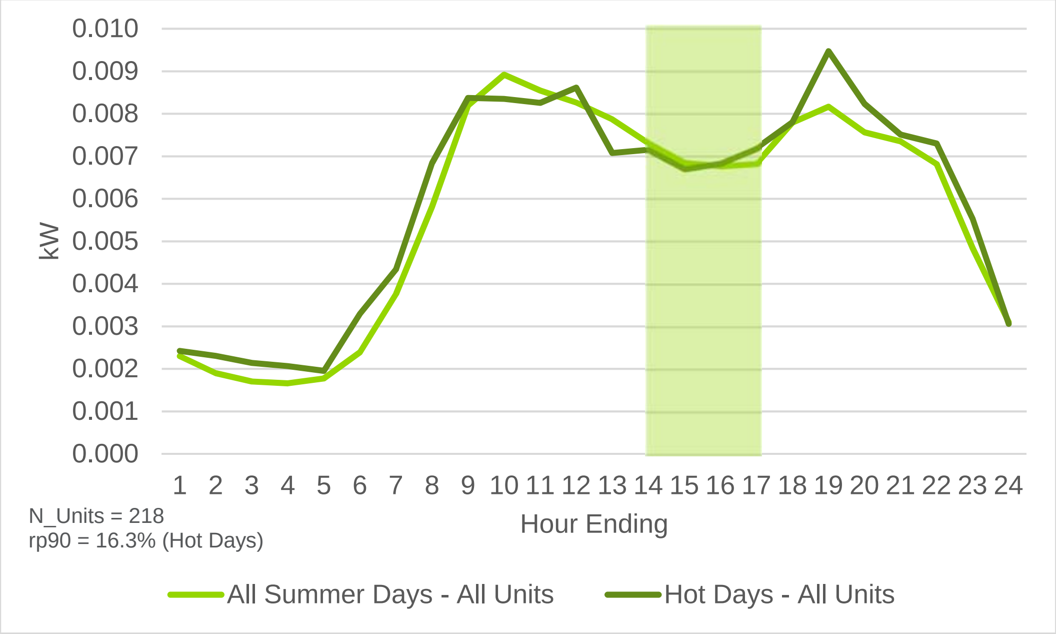

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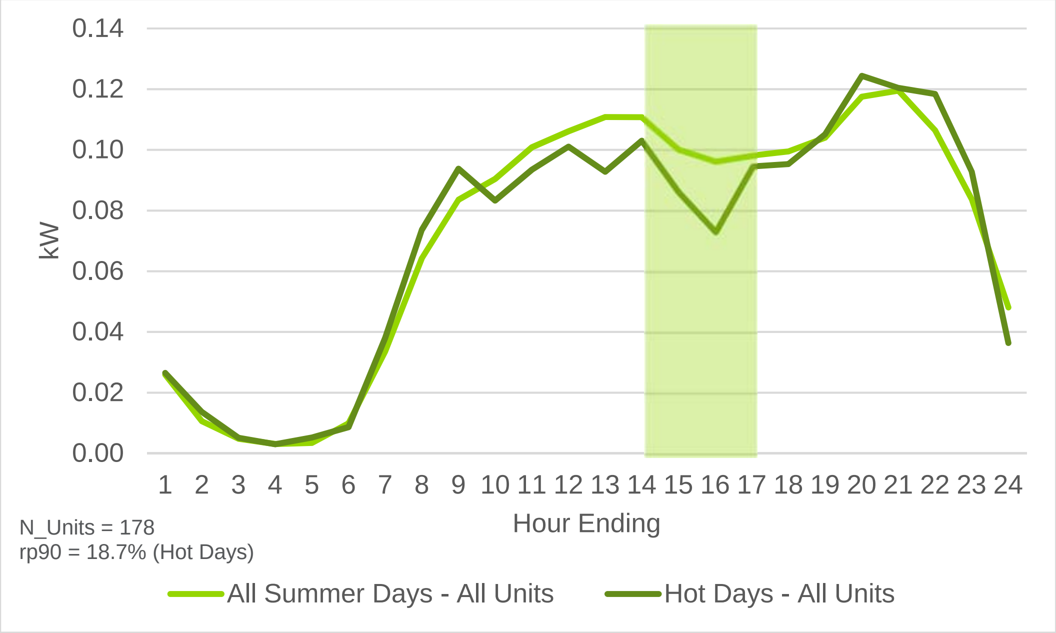
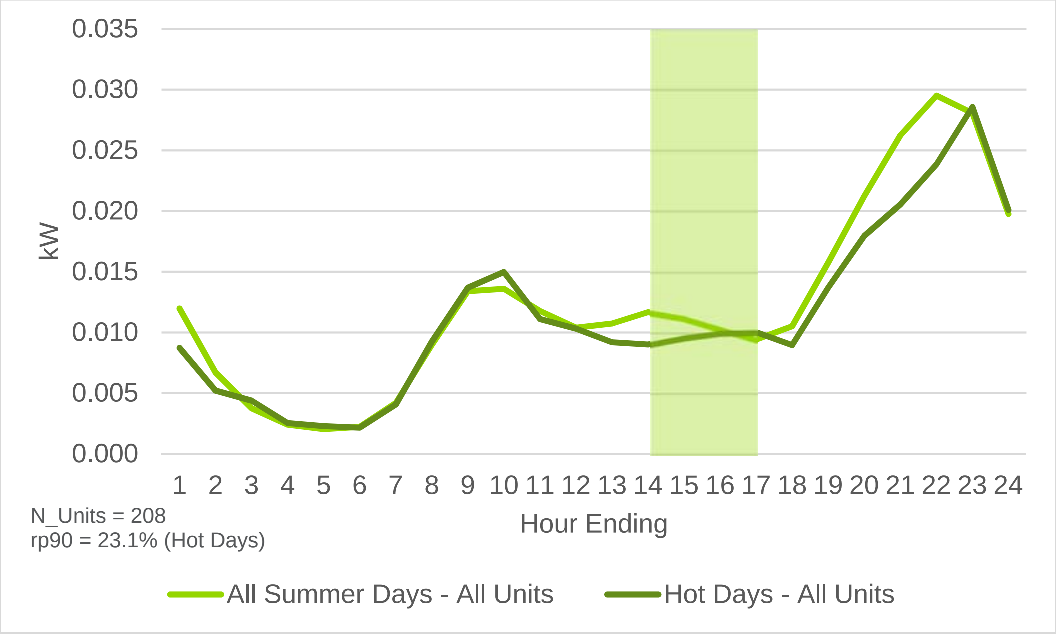
Figure A-4. Clothes Dryers



N_Units = 178
rp90 = 18.7% (Hot Days)

Figure A-5. Dishwashers



N_Units = 208
rp90 = 23.1% (Hot Days)

Figure A-6. Primary Refrigerator

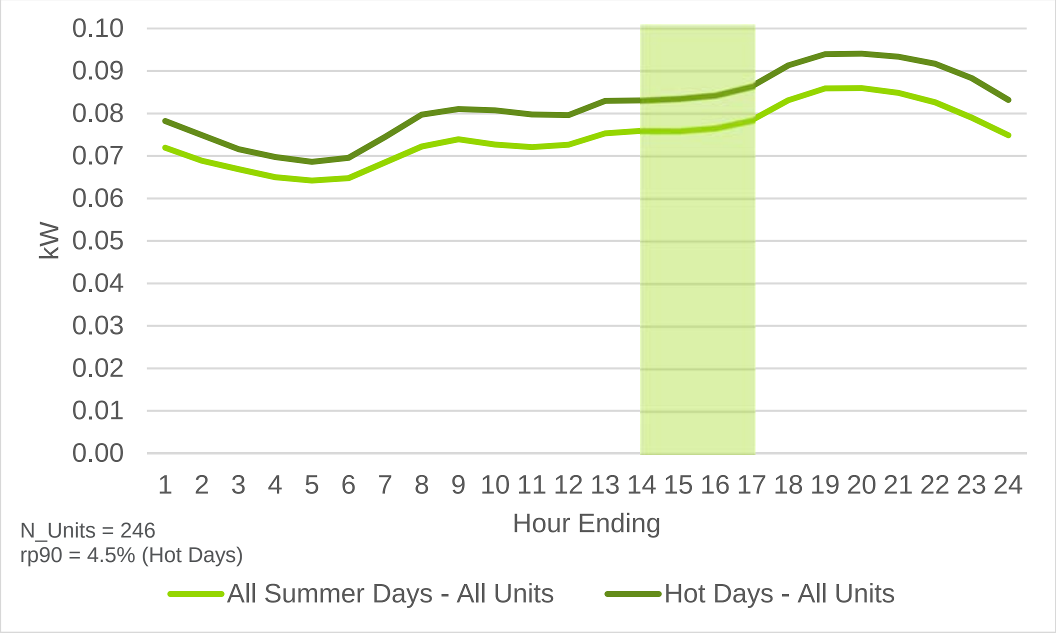


Figure A-7. Secondary Refrigerator

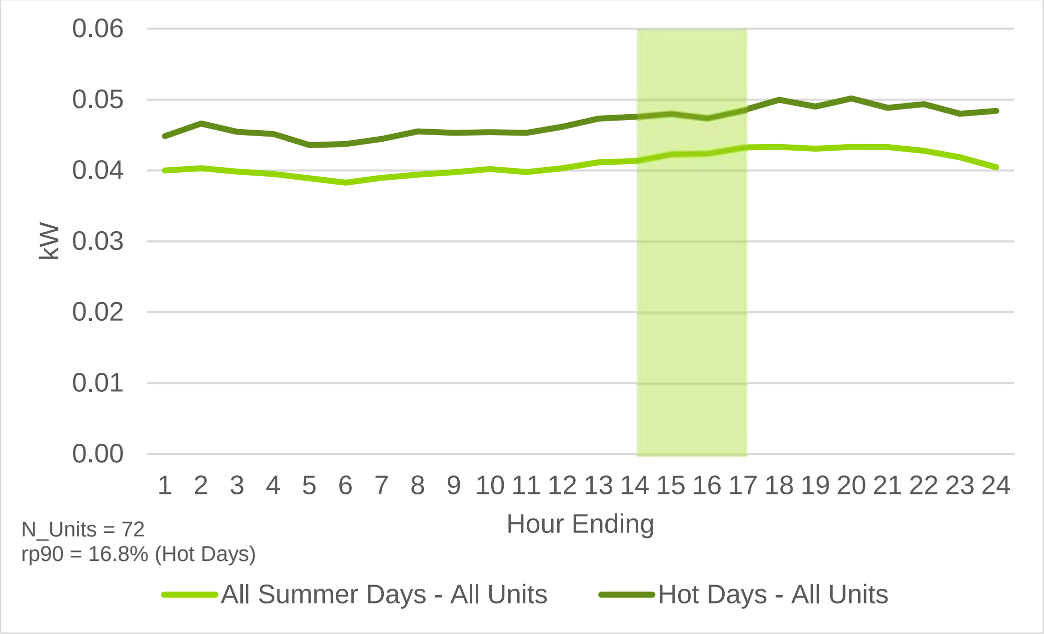


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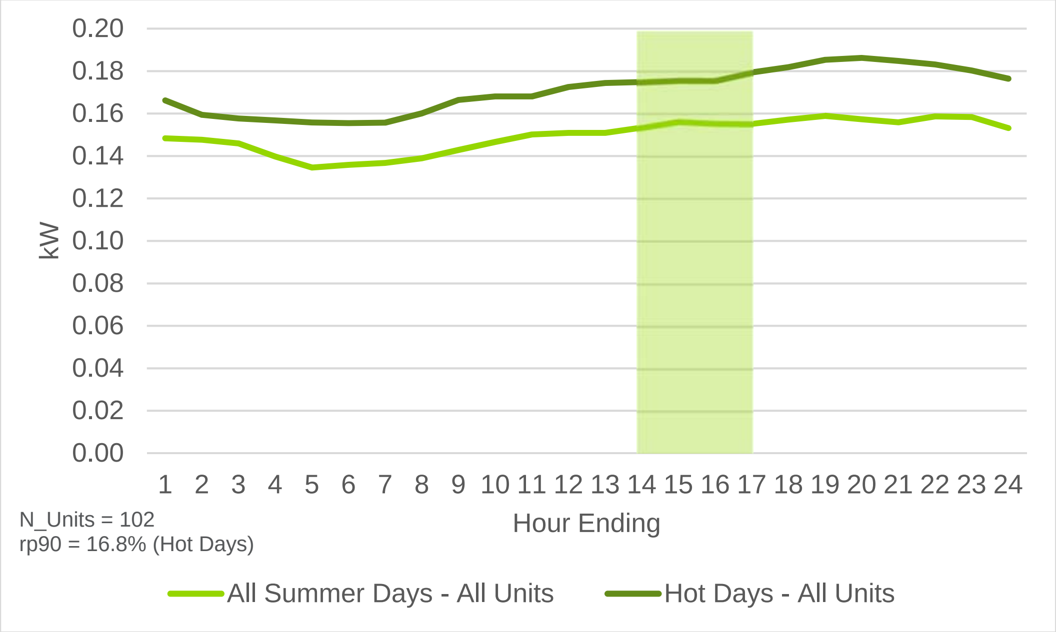
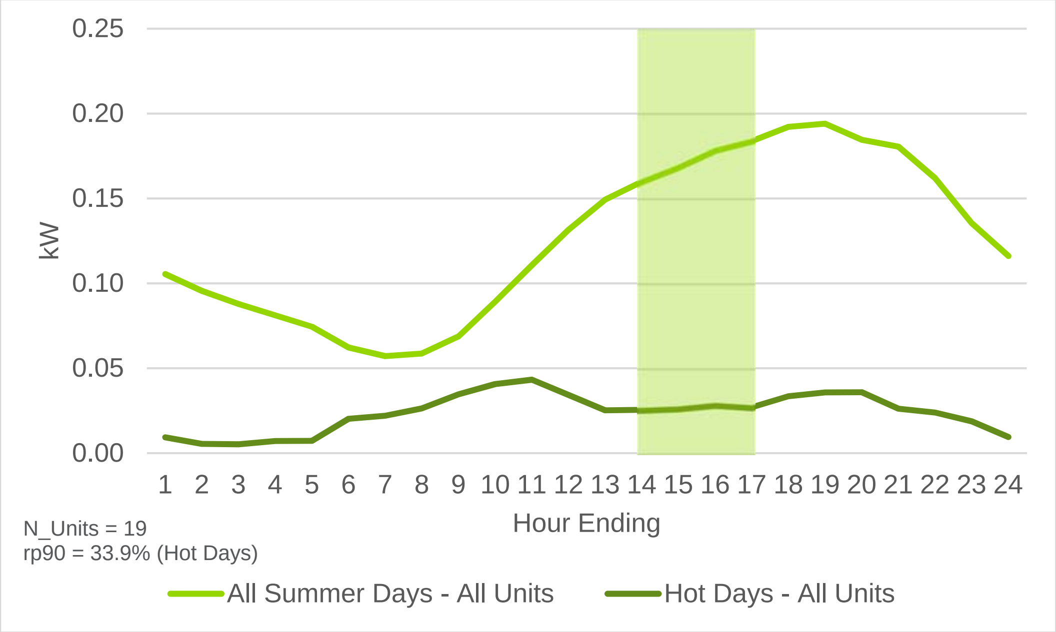
Figure A-8. Dehumidifier



N_Units = 102
rp90 = 16.8% (Hot Days)

Figure A-9. Ductless Mini-Split



N_Units = 19
rp90 = 33.9% (Hot Days)

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Figure A-10. Heat Pump Water Heaters

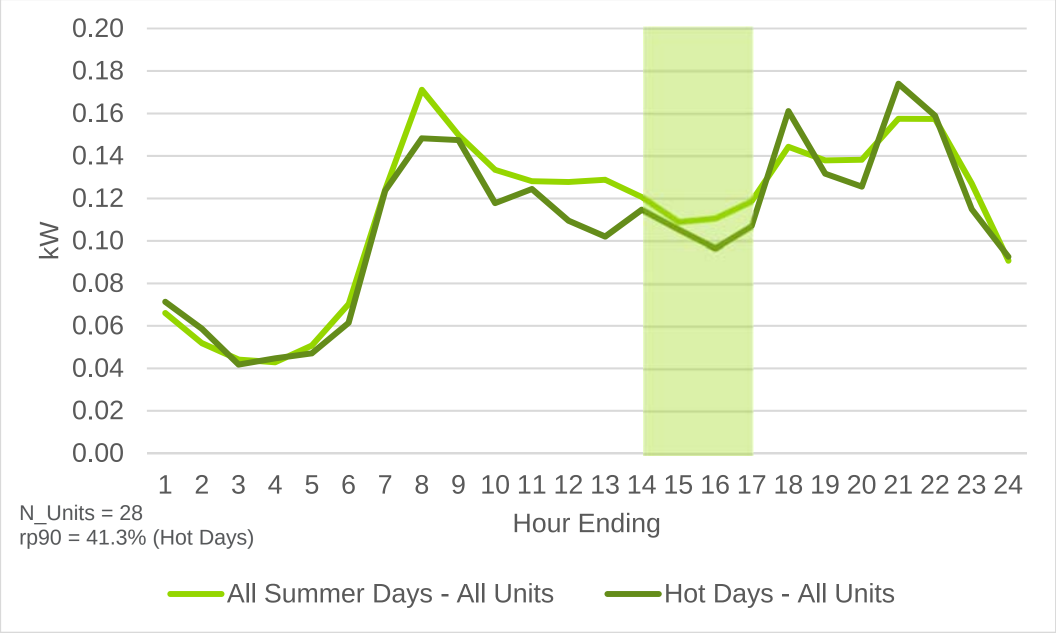

Figure A-11. Electric Resistance Water Heaters

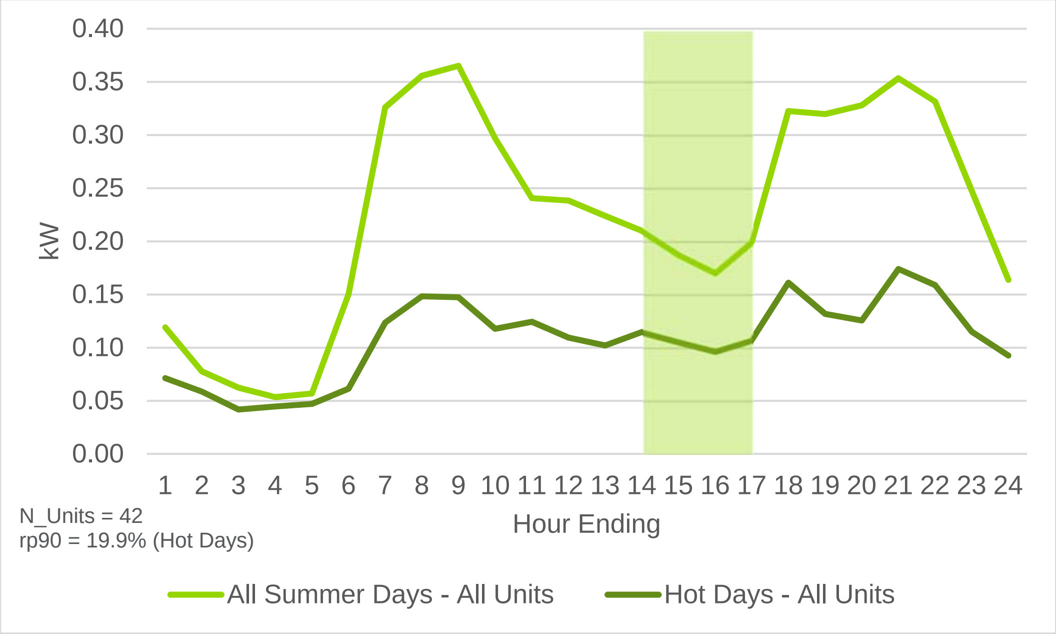

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Figure A-12. Pool Pumps

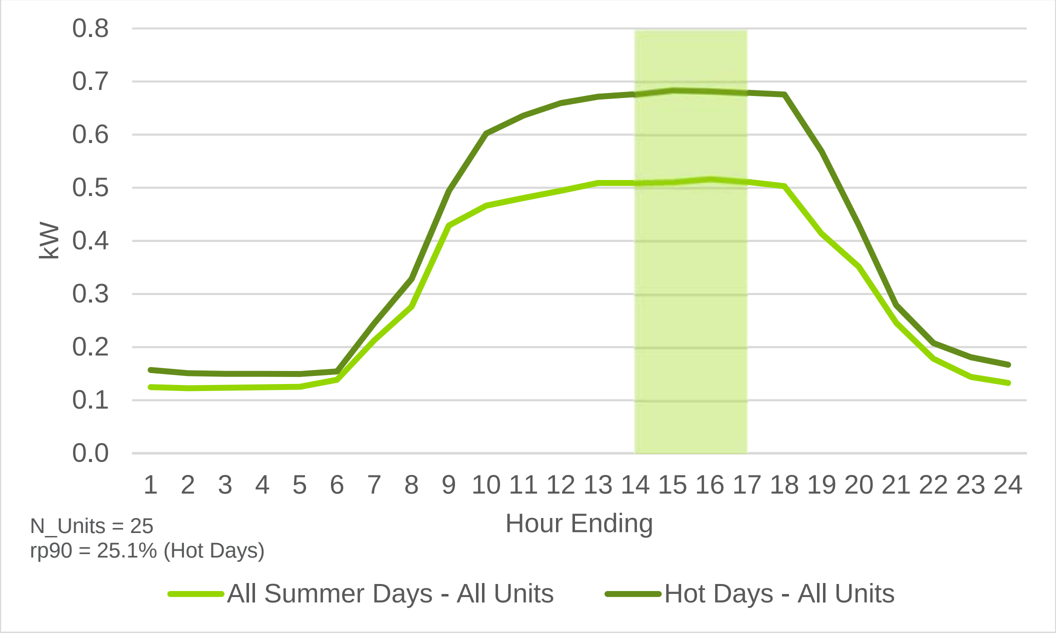
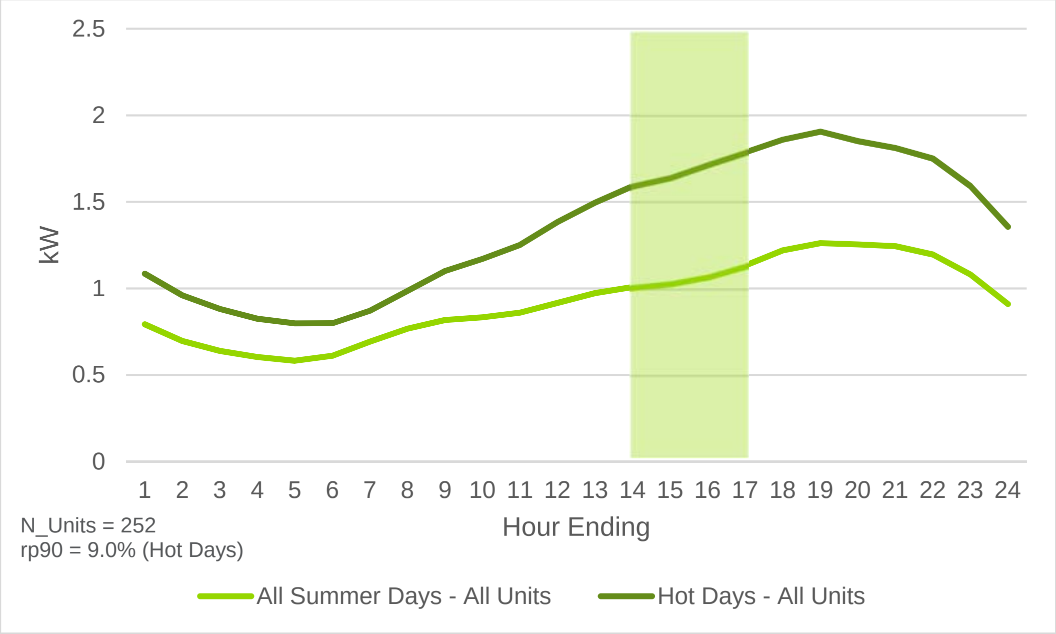


Figure A-13. Whole Home (for Battery System – No-solar)



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