Broadening Grid Flexibility through Customer-Centric Machine Learning: Measured Impacts from a Pilot of 200,000 Smart Thermostat Participants Across the US and Canada

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Abstract

As a ten-year old technology, smart thermostats are becoming a more adopted device. For customers, the drivers for adoption are energy savings, comfort, and ease of control, especially as the market moves from early adopters to the early majority. For utilities, smart thermostats are a resource that offers grid flexibility and meets targets for energy efficiency, load shifting and demand response. But it's here (in serving the drivers of both customers and utilities) where the full potential of smart thermostats has not yet been realized. For example, demand response programs face barriers to customer acceptance when the utility directly controls loads.

And, as more jurisdictions look for solutions to address capacity constraints, including dynamic rate structures and other load flexibility options, it's critical to bring this duality together. The question is then, how can smart thermostats simultaneously be optimized to balance the needs of the grid, while maintaining customer expectations for comfort, lifestyle preferences, and savings?

This paper examines an innovative, machine-learning opt-in feature suite delivered in the form of a free software upgrade to ecobee smart thermostats that enhances their ability to serve as a grid resource without sacrificing comfort or convenience. By redesigning the underpinning technology to be customer-centric and focus on personalized energy savings opportunities, more customers are willing to "give back" to the grid. This paper provides measured results from a large-scale randomized experiment that included over 200,000 smart thermostat users throughout every climate region across the US and Canada. Key Findings across North America include an average of 6% additional HVAC cooling energy savings, additional cooling bill savings for customers on time-of-use rates ranging from 8-19% and an average enrollment rate of 33% in unincentivized demand response events with an average impact of 0.91 kW of peak demand reduction per thermostat. These impacts are measured from a baseline of existing ecobee devices without the feature suite.

Introduction

As a ten-year old technology, smart thermostats are becoming a more widely adopted device in the home. In 2018, 8.6 million smart thermostats were shipped worldwide, with this figure expected to grow to 38.8 million units by 2025 (Cekani, 2019). Utility incentive programs have been a key driver to smart thermostat adoption with research showing $100 rebates more than doubling customer purchase intentions for this technology (Parks Associates, 2017). Such incentives and the overall level of adoption should come as no surprise when considering the benefits offered both to customers and utilities as compared with manual and programmable thermostats.

For customers, smart thermostats offer an improved sense of control and comfort, lower energy bills, and a way to contribute to a sustainable future. With intuitive user interfaces, it's easier for customers to schedule temperature setpoints that match their lives. Setpoints can be controlled on the device remotely via their smart phones wherever they might be. They can also automatically adapt to occupancy levels detected through a network of occupancy sensors.

These features help ensure comfort is not sacrificed when the home is occupied, and that energy is saved when it is not.

For utilities, smart thermostats provide grid flexibility. In addition to energy efficiency features, smart thermostats have also been adapted for load shifting and demand response applications that can be centrally managed over the Internet. By controlling a fleet of smart thermostats at critical times of the year, utilities can materially reduce peak demands that might otherwise necessitate the construction of costly peaker plants. Thus, incentivizing smart thermostats has been a rational demand-side alternative.

Despite these key features, however, the full potential of smart thermostats – in serving both customers and utilities – has not yet been realized. As noted by Abreau et al. (2018) "[Demand Response Programs] face barriers to customer acceptance when the utility directly controls loads." Chief among these barriers are the lack of trust and perceived control. Enrollment processes are also cumbersome and multi-pronged. Meanwhile, more utilities are looking for solutions to address capacity constraints, including time-varying rate structures, peak time rebates and other load flexibility options. The question is then, how can smart thermostats simultaneously be optimized to balance the needs of the grid, while maintaining customer expectations for comfort, lifestyle preferences, and savings?

Delivering Grid Flexibility While Meeting Customer Expectations

In 2019 ecobee launched an optimization suite called eco+ (www.ecobee.com/eco-plus). Through machine learning, eco+ helps improve customer comfort, while reducing energy use and costs. eco+ also enables customers to have a positive impact on their environment by responding to grid-scale capacity constraints. Figure 1 shows the first set of customer-facing enrollment screens highlighting this value proposition.

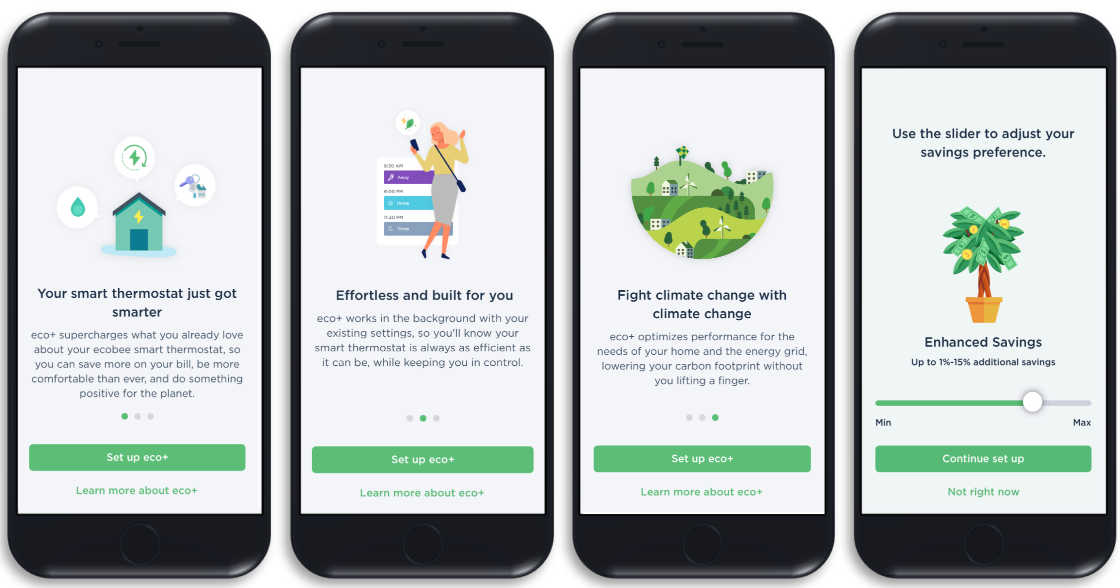

Figure 1 - First set of enrollment screens for eco+

With a single 5-point savings slider (see Figure 1, screen 4) – the fifth setting producing the most savings – customers have control over five algorithms, which, for discussion and analysis, we organize into three optimization categories:

- Energy Efficiency (EE) Optimization:
  - Feels Like (FL) – adapts to fluctuations in indoor humidity to help ensure customers' homes feel like the temperature they have set on their thermostat. This keeps their home energy efficient and comfortable even in periods of unusually high or low humidity.
  - Schedule Assistant (SchA) – recommends personalized updates to customers' thermostat schedules to best match their changing life schedules. Customers maintain control over which recommendations are adopted or ignored.
  - Enhanced Smart Away (ESA) – builds on the existing Smart Away feature by adjusting for vacancy faster and complements Schedule Assistant by adjusting temperature setpoints for occupancy levels on days when customers deviate from their usual schedules.
- Time-of-Use (TOU) Optimization – shifts energy use from high-priced peak hours to low-priced off-peak hours for customers whose retail electricity rate vary by the hour of the day and day of the week. Comfort is maintained through personalized amounts of pre-cooling prior to increases in electricity prices.
- Community Energy Savings (CES) Optimization – is a demand response feature that shifts loads away from peak hours when the electricity grid is most constrained through temporary temperature setbacks. As with TOU optimization, comfort is maintained through personalized amounts of pre-cooling prior to peak periods.

When taken together, these features (collectively eco+) offer customers powerful automation delivering comfort and savings around the clock and around the year by being context-aware and adaptive to changing indoor, outdoor, and grid conditions.

To demonstrate its impact in the field, the balance of this paper describes a large-scale measurement and verification (M&V) study for eco+ with interim impact analyses provided by Demand Side Analytics (2019), who were contracted by ecobee. Additionally, this paper presents key results from a survey that was conducted by ecobee to assess customer satisfaction and comfort.

Measurement & Verification Study Design

During summer 2019, a version of eco+ was deployed across North America to a large pilot group of ecobee thermostats using a Randomized Encouragement Design (RED)[1]. Devices were stratified by climate zone then randomly assigned to either an experimental group or a control group. The experimental group was invited (encouraged) to participate in the eco+ pilot and the control group was not.

The RED provides a robust experimental design against which to measure the impacts of the eco+ platform because the control group experiences all of the same weather and other external factors as the experimental group. Comparing the HVAC runtime characteristics of the experimental group to the control group after the rollout of eco+ produces estimates of the impact of the eco+ offer. Some users in the experimental group accept the offer and some do not, so this set of results is referred to as the Intention to Treat (ITT) impacts. The ITT impacts can then be divided by the percentage of devices in the experimental group that accepted the eco+

[1] The M&V study will continue through September 2020 to demonstrate persistence of reported impacts and customer satisfaction.

offer to determine the Local Average Treatment Effect (LATE). The LATE impacts are the estimated per-device impacts for users who take advantage of eco+.

Recruitment Rates

To be eligible for the pilot, customers had to have an ecobee3 thermostat or newer[2] and their devices needed to have been registered with ecobee for at least a month prior to the pilot in order to have their firmware updated with eco+. Having at least a month's worth of pre-enrollment data is not a requirement for eco+ generally but was useful for pre-post analyses in this pilot. Of thermostats that met this initial screening criteria, 248,186 devices were sampled in total across six climate regions across North America – five according to the US Climate Zone map (see Figure 2) and an additional region for all of Canada. Per climate region, half the thermostats were then randomly assigned to a control group and not offered the eco+ platform to serve as the counterfactual, or baseline, against which energy and demand impacts in the experimental group are measured. The experiment also included a control group buffer in case ecobee owners in the control group learned of eco+ and asked to be included in the offering.

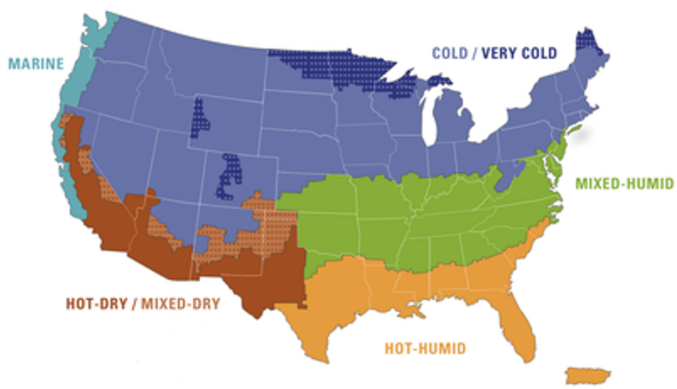

Figure 2 - US DOE Climate Zones Map

Table 1 shows the count of thermostats across the 11 regions and three experimental cells. Region 1 is Canada. Regions 2 through 6 correspond to five US Department of Energy Building America Climate Zones overlaid on a map in 1. Regions 7 through 11 are specific electric utility service territories with high prevalence of time-varying pricing. These utility service territories were intentionally over-sampled in an effort to bolster the sample size for the eco+ TOU optimization algorithm analysis.

Table 1. Eligible and Active Thermostat Count by Region and Experimental Cell.

Region	Experimental	Control	Buffer	Total
01 Canada	10,062	10,026	1,001	21,089
02 Cold/Very Cold	30,001	30,000	3,000	63,001
03 Hot-Dry/Mixed-Dry	5,579	5,570	557	11,706
04 Hot Humid	15,000	15,000	1,500	31,500
05 Mixed Humid	30,000	30,000	3,000	63,000
06 Marine	5,069	5,085	510	10,664

[2] Over 90% of ecobee customers have an ecobee3 or newer.

07 Canada TOU (Hydro One)	1,927	1,932	195	4,054
08 Cold TOU (Fort Collins)	140	139	13	292
09 Dry TOU (PG&E)	8,156	8,150	815	17,121
10 Dry TOU (SMUD)	2,800	2,800	280	5,880
11 Marine TOU (PG&E)	9,473	9,461	945	19,879
Total	118,207	118,163	11,816	248,186

As with many thermostat programs, the pilot began with an identified group of experimental thermostats and tracked the number of remaining devices at each stage in the recruitment process through to enrollment. However, prior to deployment, approximately 9% of the selected thermostats across all experimental cells were deemed inactive as they were offline for over a month prior to the pilot start. This can happen for example when customers upgrade their thermostats, or if they decide to operate them offline. In the Experimental group, out of 118,207 thermostats, 108,898 thermostats were deemed active. From here, the results for each stage of the recruitment funnel are summarized in Table 2 and broken down into four stages described as follows.

A. Eligible and active customers – These customers have an ecobee3 thermostat or newer and their devices were active for at least a month prior to the start of the pilot.
B. Invited customers – 95.6% of customers received the invite and thermostat firmware update. Others were temporarily offline or had some other technical issue when the invitation was issued.
C. Discovered customers – Only customers that engaged with the invitation and went through the enrollment process were considered to have discovered the invite – approximately 78.1% of invited customers.
D. Enrolled customers –77.2% of discovered customers accepted the eco+ terms and conditions and have an acceptance date.

Table 2. eco+ Recruitment Funnel.

Stage	Stage / Rate Description	Device Count	Retention Rate by Stage	Percentage of Eligible & Active
A	Eligible & Active Customers	108,898		100.0%
	Invitation Rate		95.6%	
B	Invited Customers	104,080		95.6%
	Discoverability Rate		78.1%	
C	Discovered Customers	81,303		74.7%
	Acceptance Rate		77.2%	
D	Enrolled Customers	62,748		57.6%

Overall, the pilot had an enrollment rate of 57.6% from the eligible and active customers (i.e., stage A to D). It's worth noting that pilot participants were only sent invitations once and were not retargeted.

Figure 3 shows the distribution of average daily settings of the eco+ 5-point savings slider amongst the enrolled eco+ customers in the pilot. Level 4 is the recommended, default setting and was by far the most popular selection.

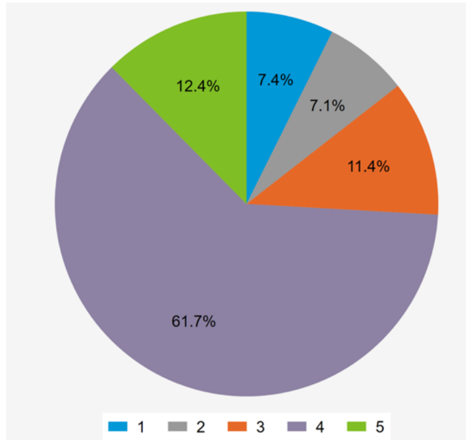

Figure 3 - Distribution of comfort settings

Energy Efficiency Optimization Results

The energy efficiency components of eco+ include Feels Like Temperatures, Schedule Assistant and Enhanced Smart Away. During the measurement period, Enhanced Smart Away was not yet deployed and Schedule Assistant had limitations since recommendations were sent via email instead of within the ecobee app. Therefore, the savings presented are mostly attributable to Feels Like.

Figure 4 shows the difference in average indoor temperature between the experimental group and control groups of the Mixed Humid climate on a daily basis. During the pre-deployment period the two groups show only small variations indoor temperatures, which upon further inspection did not translate to significant differences in runtime. When the eco+ offer was deployed on July 29th, more significant differences begin to appear, and become especially apparent from August 11th onwards when Feels Like was fully enabled. The differences are subtle, with the experimental group only approximately 0.2 degrees (F) higher on average, but the effect of the features is apparent.

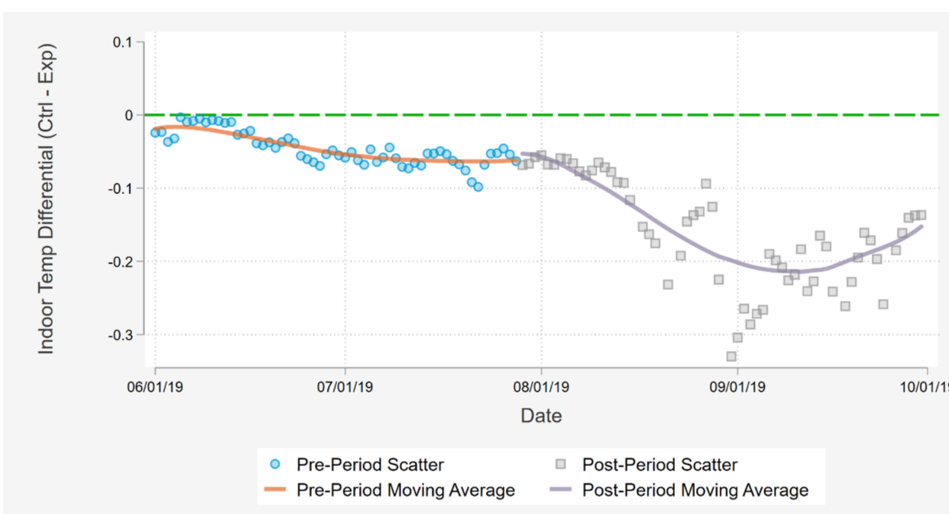

Figure 4 - Difference in Average Daily Indoor Temperature (F) – 05 Mixed Humid Zone

Cooling runtime impacts were modelled with a difference-in-difference regression techniques using thermostat level fixed effects and cluster robust standard errors, as detailed by Demand Side Analytics (2019). Figure 5 shows the modelled hourly LATE KW Impacts, which leverages connected load assumptions[3] to convert runtime to KW. The vertical lines mark a typical peak period from 2-6 pm. Table 3 shows both the connected load assumptions and average LATE kW impact during the 2-6 pm window for each of the six climate zones.

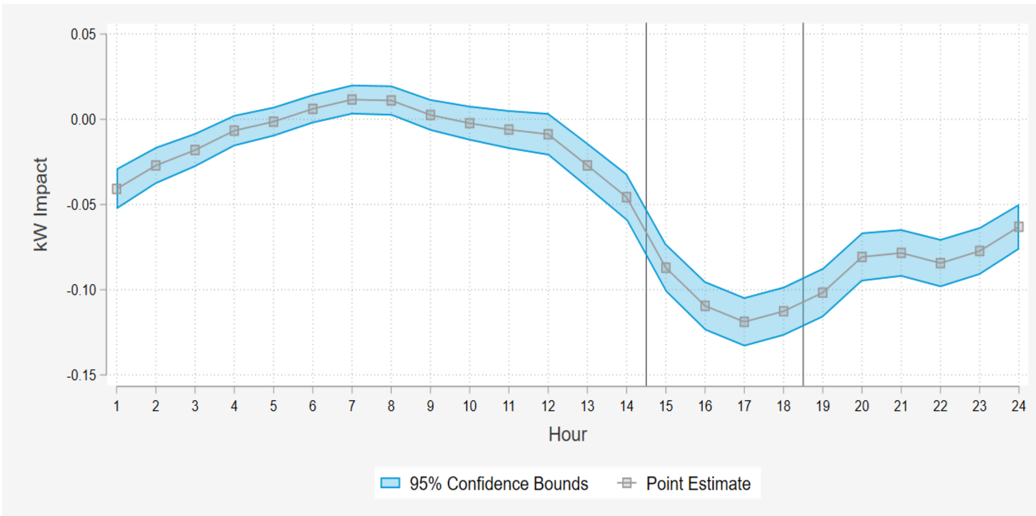

Figure 5 - Hourly LATE kW Impacts – Mixed Humid Region

The peak demand impacts shown in Table 3 demonstrate that the eco+ EE features produce capacity benefits as well as energy savings. This "everyday" reduction in demand is an important consideration in the development of states' technical reference manuals which often attribute zero demand savings to smart thermostats that are part of energy efficiency programs. This highlights a need for more integrated planning and measurement and verification practices.

Table 3: Connected Load Assumptions & Average LATE kW Impact by Climate Zone

Region	Tons	SEER	kW per Device	2-6 pm Average Impact (kW)
01 Canada	2.15	10.5	2.45	-0.08
02 Cold	2.75	10.5	3.10	-0.07
03 Dry	3.25	10.5	3.48	-0.02
04 Hot Humid	3.25	10.5	3.60	-0.08
05 Mixed Humid	2.75	10.5	3.04	-0.11
06 Marine	2.60	10.5	2.93	-0.06

Table 4 shows the average percent energy savings per opt-in thermostat by region and month. The weighted average energy savings per opt-in thermostat was approximately 6% over the two-month period. Table 5 shows the LATE energy efficiency results, by region and month, along with the margin of error at the 95% confidence level. The variation in savings percentages is due largely to the impact of the Feels Like algorithm. In terms of energy usage, Feels Like had most impact in the Hot Humid and Mixed Humid regions, which have some of the highest usage

[3] Connected Load Assumptions are included in an Appendix of the full report by Demand Side Analytics (2019) and based on Technical Reference Manuals, evaluation reports, and other third-party research.

baselines amongst all regions. In contrast, Feels Like appeared to offer the lowest percent savings in the Hot-Dry/Mixed-Dry region. This is due to homes here having lower and less variable indoor humidity levels throughout the study period. Nonetheless, energy efficiency savings were statistically significant for each of the six climate regions analyzed when August and September are pooled. The feature delivered the highest percent savings in the Marine climate zone which has more variable indoor humidity levels.

Table 4. LATE Percent Energy Savings by Region and Month

Region	August Percent Savings	September Percent Savings
01 Canada	7.1%	5.4%
02 Cold/Very Cold	5.0%	6.5%
03 Hot-Dry/Mixed-Dry	2.1%	2.1%
04 Hot Humid	5.3%	6.5%
05 Mixed Humid	5.3%	6.5%
06 Marine	11.6%	16.4%

Table 5. Summer 2019 LATE Energy Savings with Margin of Error at 95% Confidence Level

Region	August Per-Device kWh	September Per-Device kWh	Total kWh
01 Canada	19.0 ± 10.5	5.0 ± 11.8	23.9 ± 15.8
02 Cold/Very Cold	22.2 ± 7.3	16.8 ± 6.5	38.9 ± 9.8
03 Hot-Dry/Mixed-Dry	17.5 ± 16.2	10.9 ± 17.3	28.5 ± 23.7
04 Hot Humid	56.3 ± 13.7	59.5 ± 11.6	115.9 ± 18.0
05 Mixed Humid	33.9 ± 7.1	33.3 ± 6.7	67.2 ± 9.8
06 Marine	26.6 ± 14.6	15.0 ± 10.4	41.6 ± 17.9

Time-of-Use Optimization Results

The Time of Use algorithm simplifies time-varying rates for customers by providing a hassle-free way for customers to automatically respond to price signals through customized pre-cooling and temperature setbacks. The TOU eco+ analysis faced complications due to attrition from those randomized into the experimental group to those receiving treatment. The attrition is likely the result of a number of factors, including low enrollment in time-varying rates in target regions and rate education barriers in regions with default time-of-use rates such as parts of California and Ontario. Surveys conducted in conjunction with California's transition to default time-of-use rates found that approximately half of customers do not know the rate their household is currently on. This is comparable to the eco+ pilot results showing that approximately 59% of those sampled in the SMUD default TOU region (See Table 1, Region 10) did not select a rate. Following from Figure 1, Figure 6 shows the last set of screens in the eco+ enrollment flow, which pertain to TOU and CS optimizations.

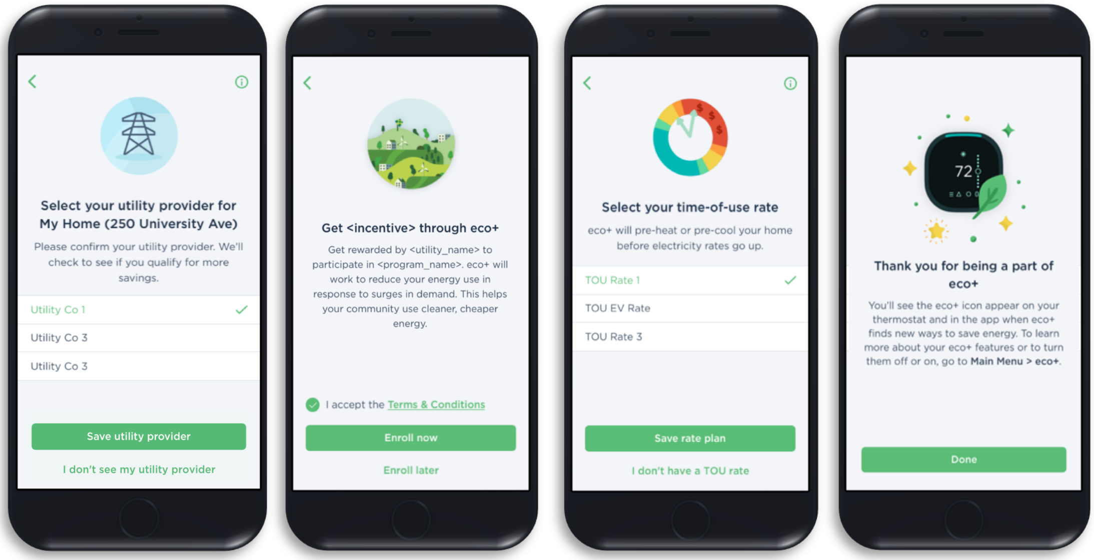

Figure 6 - Last set of enrollment screens for eco+

As a result of TOU enrollment issues, the RED was modified and TOU participants across all experimental cells were included in the analysis. For the months of August and September, four separate rates from five climate zones were analyzed using a matched control group (matched on hour-by-hour runtime for the month of July) to serve as the counterfactual for the difference in differences regression. Results for August and September 2019 are shown in Table 6.

Table 6. TOU High Level Results

Rate	Price Ratio (Peak: Off-Peak)	Climate Region	Average kW Savings During Peak Period	Peak Duration (hours)	Average On-Peak Percent Savings (kWh)	Average Total Energy Savings (kWh)	Percent Savings On Cooling Energy ($)
Hydro One Res TOU	2.0	Canada	0.18	6	36%	3.4%	8%
FPL RTR-1	5.8	Hot Humid	0.22	9	13%	5.0%	10%
SMUD Res TOD	2.4	Hot Dry	0.25	3	23%	3.5%	8%
PG&E EV-A	3.7	Mixed Dry	0.18	6	28%	8.8%	19%
PG&E EV-A	3.7	Marine	0.10	6	20%	4.0%	11%

In general, bill savings associated with the eco+ TOU treatment are larger when participants have higher baseline runtimes to reduce, bigger connected HVAC loads, and more expensive peak electricity prices. Even though the percentage of on-peak savings is highest in Canada, the magnitude of savings is low compared to the other regions due to the cheaper energy prices and limited air conditioning usage. The largest energy expenditure savings were found for the PG&E rate in part because this rate had TOU pricing on weekends. The PG&E rate was also substantially higher than in other rates. In fact, the PG&E off-peak rate is higher than the Hydro One on-peak rate if the Canadian-to-U.S. dollar exchange rate is considered.

With the Hydro One Res TOU rate (See Figure 7.) on an average weekday the impacts are greatest during the 11am-5pm peak period when significant setback occurs and during the hour immediately following the peak period when cooling use increased at the mid-peak rate. Figure 8 displays the average post period weekday runtimes for thermostats at each savings setting for this rate and the control group for reference. As expected, the eco+ TOU algorithm shows a more aggressive setback strategy for higher savings settings.

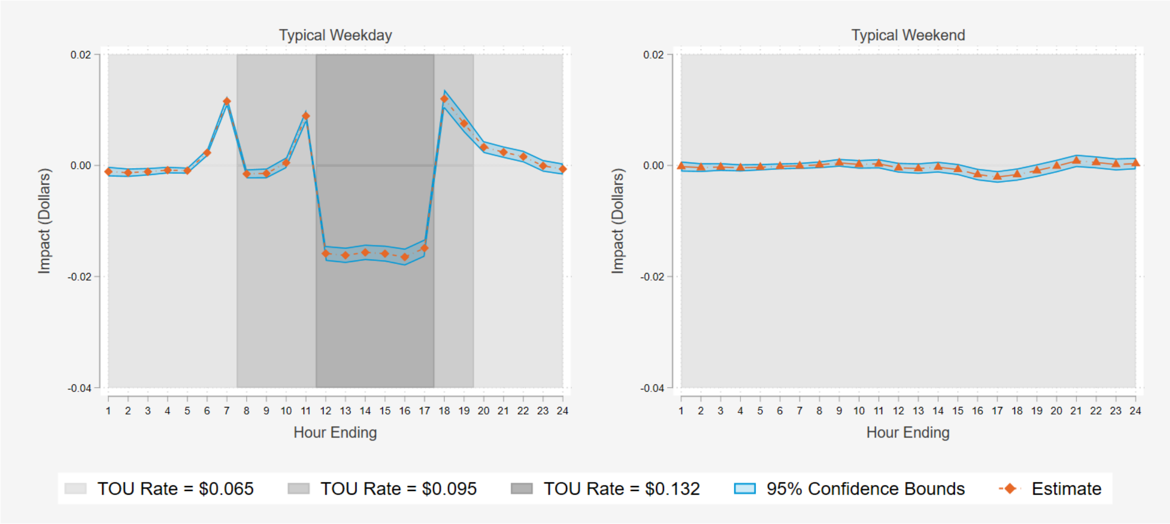

Figure 7 - Hourly bill impacts for Hydro One Res TOU rate

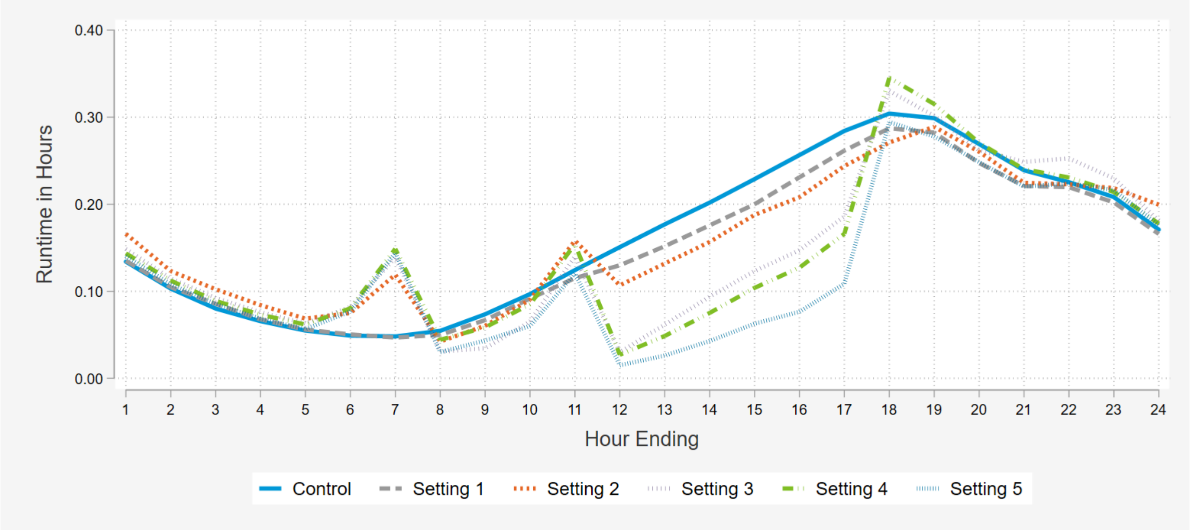

Figure 8 - Hydro One runtime by savings setting

Results indicate that the eco+ TOU algorithm achieves bill savings through shifting load away from high priced periods, and TOU customers also see savings through a decrease in overall cooling energy use. This is not surprising giving the integrated nature of the eco+ offer with many TOU recipients also enabling energy efficiency optimization. Most TOU recipients in the pilot also enabled the eco+ energy efficiency features and the percent savings values in the "average total energy savings" column of Table 6 are comparable to the energy efficiency savings discussed for Energy Efficiency results above. There are some useful insights gained from this pilot that might inform utilities around time-of-use rate design:

- With respect to the duration of the peak, shorter peak pricing hours yielded larger average demand impacts (kW) but less overall energy savings (kWh).
- With respect to the ratio of peak to off-peak prices, higher ratios yielded larger average demand impacts (kW) but less overall energy savings (kWh).
- Having a mid-peak price theoretically smooths the ramp up and down from peak prices. Care should be taken to balance the ratios between rates to ensure desired load shape.

Community Energy Savings Optimization Results

Enabling CES optimization takes place along with the eco+ enrollment process. As shown in Figure 6 (first and second screens), customers simply identify their utility from an eligible list based on their location and agree to terms and conditions. This is a streamlined process compared to traditional program flows. For example, in California the 2016 DRAM program (Pollock & Fogel, 2019) required customers provide their utility service account number, which typically is not readily available. Then customers would complete a CISR-DRP form on paper or through a third-party site, which was a cumbersome and fatiguing process. As a result of these friction points, enrollment rates were just 3% of eligible DRAM customers. In contrast, across all 55 CES DR events there was an average enrollment rate of 33% from the entire experimental cell. Furthermore, CES enrollment rate peaked at 48% for an August 20th event in the central time zone of the Hot-Dry/Mixed-Dry region, with a daily high of 96°F.

Using a newly developed platform for utility users[4], CES events were called on varying days and times for each region and time zone to mimic the way utilities would do so for typical DR. The selected days were chosen based on market research of existing thermostat DR programs. This research provided insight on the outdoor temperatures at which events are usually called, as well as the typical time of day and duration of events (from 2-4 hours). For the six EE/DR regions, altogether 55 demand response events were analyzed.

For logistical reasons, events were only rolled out to a subset of the available pilot group – those who enrolled in eco+ within the first 30 days of the offer. In subsequent events for each region, customers who opted out of prior events were also removed. This was to maintain positive customer sentiment and filter out customers who would not normally participate. Typically, in DR programs, customers are incented through bill rebates or free devices, which were not offered in this pilot.

To illustrate a typical CES event, Figure 9 shows average runtime and the variation in DR impacts by comfort setting for the Hot Humid Eastern region-time zone on August 21st. The control group is shown in blue and experimental thermostats that did not discover the eco+ invite (i.e., those who dropped off from Stage B to C in Table 2) are shown in orange. The gray lines show the performance of experimental group thermostats under different comfort settings[5].

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[4] Details of this platform developed by ecobee will be revealed at a later date.

[5] For the 2020 cooling season, a temperature setback has been added during CES events for those with Comfort Setting 1.

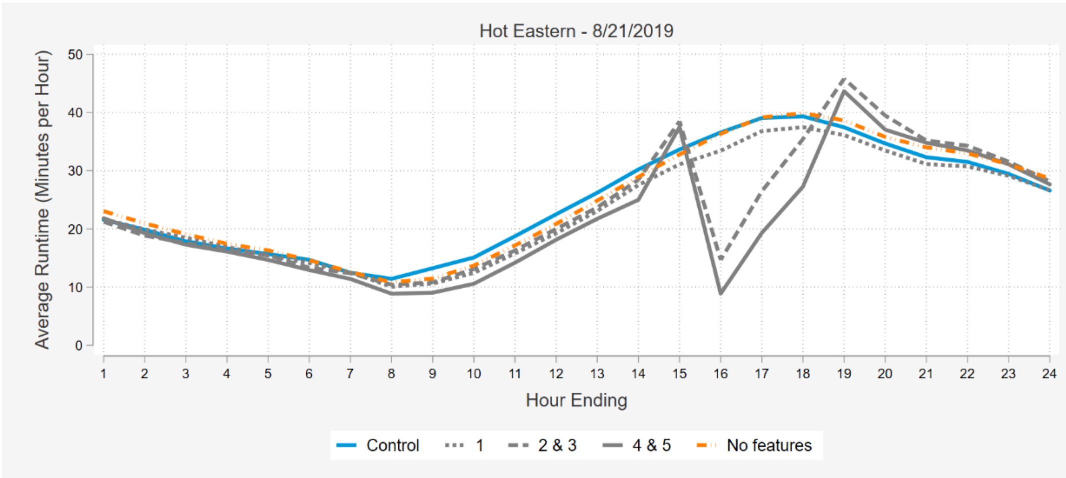

Figure 9 - Example Impacts by Comfort Setting

As with the EE evaluation, runtime impacts here were modeled using a difference-in-differences regression analysis. Pre-treatment data was captured from the period prior to enrolling in eco+ to produce a clean DR model without any EE impact. Results are scaled by the percent treated to estimate LATE impacts, or the average impact among devices who received the Community Energy Savings algorithm. Approximately 45% of the experimental group received the algorithm on this event day, so the LATE impacts are roughly 2.2 times the ITT impacts. Figure 10 shows the modeled impacts on the example event day on both an ITT and LATE basis.

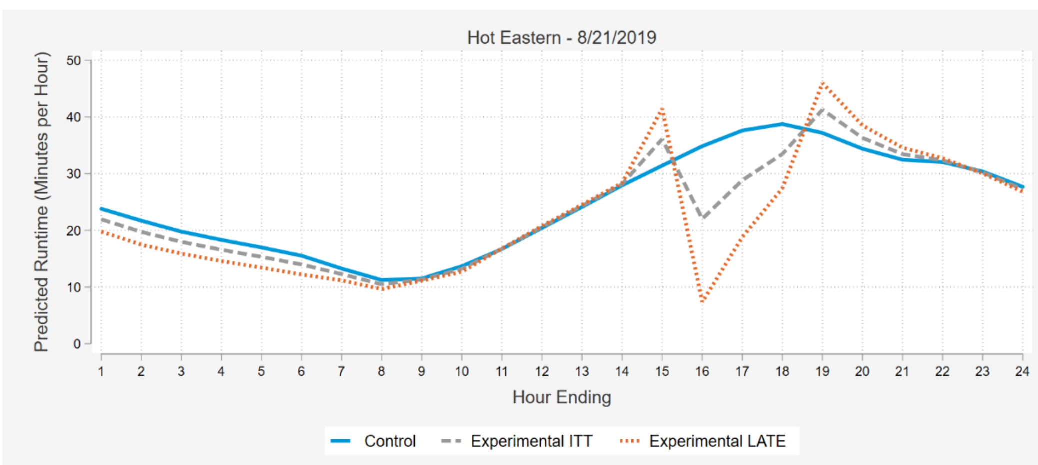

Figure 10 - Modeled Runtime Impacts

Impacts vary by region, time zone, date, and event hour. In order to provide one single value for per thermostat savings, a series of weighted averages were applied to take into account the participation rates, connected load assumptions, and number of events with different durations (Demand Side Analytics, 2019). Ultimately, the average DR savings is estimated to be 0.91 kW per opt-in thermostat across all event hours.

Figure 11 shows the average impacts by event hour and region and the participation rate over the course of events. All summer 2019 events have an Hour 1 and Hour 2, so average impacts from these hours are weighted more heavily in the average hourly demand savings of

0.91 kW. Fewer events are three or four hours long, leading to less weight in the overall savings estimate. In aggregate, summer 2019 impacts were largest during the first event hour and diminished in subsequent hours. More granular inspection shows that this trend is less pronounced in regions with lower average cooling usage. This downward trend is typical of thermostat DR programs that use a setback strategy unless setbacks are increased over the course of the event to hold the kW impact steady[6].

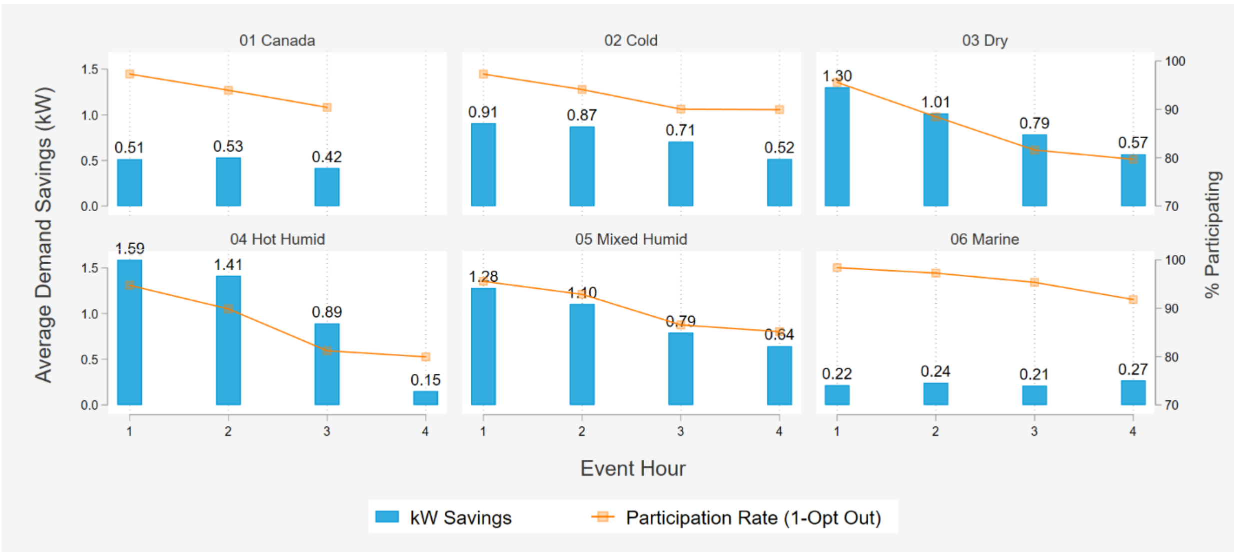

Figure 11 - Demand Savings and Participation Rates by Region and Event Hour

Opt-out rates for the pilot are comparable to those found in typical Bring Your Own Thermostat (BYOT) programs. This is interesting for a couple reasons when the context of Community Energy Savings events is considered. First, it highlights the willingness of customers to participate and persist in Community Energy Savings events despite not being externally incented with rebates. Second, given the high enrollment rates into eco+ and Community Energy Savings, it provides further validation of savings achievable with a broader population. It is also worth noting that opt-outs are not unique to DR event days as users override their thermostat schedule at other times to increase their comfort, and it is worth noting that the opt-out rates presented are inclusive of this generic behavior.

Customer Comfort and Satisfaction

In December 2019, ecobee conducted an interim survey among its eco+ users across North America to complement the quantitative findings to date with insights into customer satisfaction and comfort. Out of 1963 sampled eco+ customers, 168 responsed. Figure 12 shows that being energy efficient was the top factor for customers deciding to enable eco+.

[6] There was only one four-hour event in the Hot Humid region. It was called in the Central time zone on a day when thunderstorms moved across east Texas and lowered outdoor temperatures by approximately 20 degrees (F). The drop in kW impact observed in hour 4 of the Hot Humid region is a function of a single, somewhat atypical, event hour.

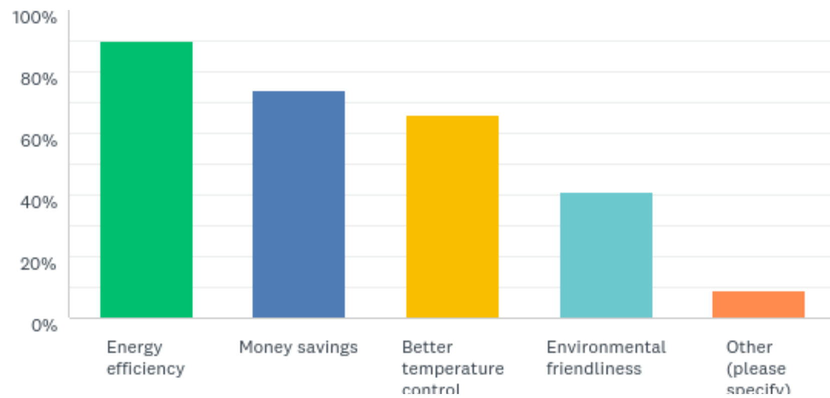

Figure 12 - Survey question:
Which of the following factors influenced your decision to enable eco+? (Select all that apply)

The primary purpose of the survey was to validate customer sentiment. Figure 13 shows 90% of customers being neutral or satisfied with the new features. Furthermore, Figure 14 shows that over 90% of customers indicated their comfort remained the same or improved since enabling eco+ on their ecobee. The most common comments received for both questions were along the lines of not noticing much difference with eco+. This speaks to the value of providing more salient feedback on the savings to reinforce the value of abstract and opaque optimizations delivered by features like eco+. Follow up surveys will be sent to track performance across a full calendar year.

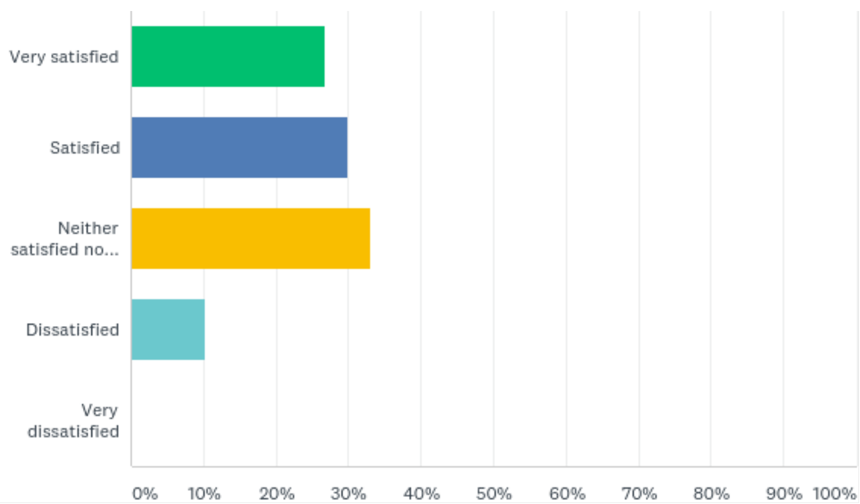

Figure 13 - Survey question: Overall, how satisfied or dissatisfied are you with eco+?

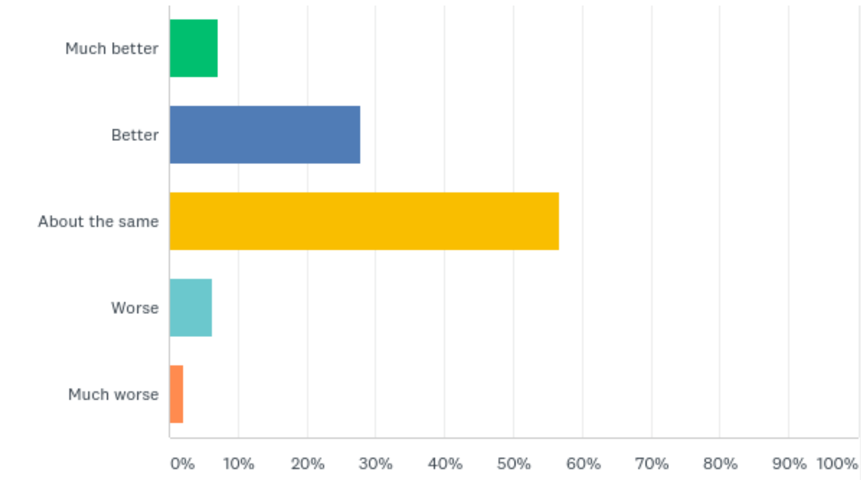

Figure 14 – Survey Question: Since having eco+ enabled, how would you describe the comfort level of your home?

Discussion and Conclusions

ecobee's eco+ feature suite provides an example of how smart thermostats can simultaneously be optimized to balance the needs of the grid, while maintaining customer expectations for comfort, lifestyle preferences, and savings. eco+ demonstrates that integrated demand side management is available today to the masses.

The eco+ results show that by reframing the enrollment process for DR in a customer-centric, streamlined way, it is possible to significantly increase participation in DR events. eco+ achieved enrollment rates of up to 48% in CES events without offering customers incentives to participate. This is especially important when extreme weather conditions and natural disasters lead to severe grid conditions that require high participation quickly. With eco+ along with a newly developed utility-facing DR platform[4], utilities can have a large resource at their disposal during these situations in territories with a large footprint of ecobee thermostats as any thermostat that has the CES feature enabled in the mobile app could be used as a resource to balance the needs to the grid. Additionally, depending on the conditions, customers could be cycled into and out of the events to maintain their desired comfort levels. In the past, these situations have led to statewide calls to action from Governors, police departments and utilities to adjust thermostat levels through the news and text messages (e.g., (Siacon, 2019)). However, this could happen seamlessly through innovations like eco+. Therefore, by achieving high rates of participation in CES, eco+ could be used as an important tool for utility grid resilience planning.

Additionally, utilities are trending towards using rate structures to provide a new version of demand response in today's age of growing renewable energy targets to provide greater demand flexibility. eco+ demonstrates that by offering customers a tool to set-it-and-forget-it by optimally automating response to price signals through personalized precooling strategies, the impacts are considerably higher than a price only response. With peak demand impacts from time-of-use optimization alone providing an additional .25 kW, eco+ becomes an important resource for this new wave of DR 2.0 through offering micro DR events, continuous optimization and enhanced grid flexibility. This helps encourage the shifting of energy use to times when renewable energy is abundant meeting both customer preferences for clean energy while balancing the grid during the important transition to growing levels of carbon free intermittent generation.

Lastly, eco+ offers a user-friendly approach to enhanced energy savings for all participants and is not limited to regions where energy efficiency optimization programs may exist. Customers are able to control machine learning algorithms like Feels Like, Schedule Assistant and Enhanced Smart Away, that work on their behalf, automatically adapting to changes to their lifestyles and to the seasons. Participants saved on average an additional 6% principally through Feels Like and as the deployment of Enhanced Smart Away and improvements to Schedule Assistant are rolled out, this figure is likely to increase. These additional measures help meet customer desires[7] while also helping utilities improve the net impact of their programs to cost-effectively meet energy efficiency targets.

At the outset of this paper we asked: How can smart thermostats simultaneously be optimized to balance the needs of the grid, while maintaining customer expectations for comfort, lifestyle preferences, and savings? The results presented in this paper demonstrate that free connected thermostat optimization offerings like eco+ are a compelling answer.

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[7] See Figure 12. The biggest driver for customers to enroll in eco+ was enhanced energy efficiency.