WHITE PAPER

Rush Hour Rewards

Results from summer 2013

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1. Introduction

Electric grids are sized to accommodate peaks in energy use, which often occur on hot afternoons when everyone turns air conditioning on at the same time. These peaks represent fewer than 100 hours per year (about 1% of the year). As demand increases, energy companies have two options:

1. Build more power plants and distribution infrastructure.
2. Take steps to encourage customers to conserve during the peak periods.

This second option, traditionally called “demand response,” is cost-effective and environmentally friendly, yet just 6% of households with broadband are currently participating in a demand response program, according to Parks Associates. The reason that demand response has yet to reach mass-market adoption is simple: existing “demand response” strategies are one-size-fits-all and prioritize load reduction over user comfort.

Demand response can only be successful if you personalize the experience and balance comfort with energy savings. To further encourage enrollment and appeal, the marketing and positioning of these programs should be consumer-friendly. Finally, customers need to feel comfortable and in control of the temperature at all times, and receive a meaningful incentive in exchange for participation.

Nest has created a unique, personalized solution marketed as Rush Hour Rewards (RHR). RHR is a proprietary Nest service that helps demand response feel welcoming and manageable to customers while meeting the needs of energy providers. The program takes into account when people are home or away, their preferred temperatures, the “profile” of the home (large/small, how quickly it loses cooling), and only deploys to homes that can help reduce A/C use during peak times. And most importantly, Nest RHR customers are always in control of the temperature to ensure their comfort.

In the summer of 2013, Nest conducted Rush Hour Rewards events with three energy partners. Austin Energy (AE) ran 12 RHR events. Reliant ran four RHR events. Southern California Edison (SCE) ran three RHR events. The AE and Reliant events were two hours long, while SCE events were four hours long. In all cases, these events significantly reduced the electrical load while keeping customers comfortable.

Highlights of Nest's summer 2013 Rush Hour Rewards programs include:

- Each event reduced a significant amount of electricity. Load was reduced an average of 55.1% for an average of 1.18 kW per device.
- Results showed that only 14.5% of participants changed the temperature of their thermostat during events. These users still shifted an average of 0.61 kW overall, only reducing the overall load reduction by 8.6%
- Rush Hour Rewards successfully reduced load while preserving customer comfort. When responding to a survey about comfort during an energy rush hour compared to other hot days, 84% of customers reported minimal to no impact on comfort.
- The marketing was appealing to customers and led to rapid enrollment upon launch of the Rush Hour Rewards programs. In the first few weeks after the Rush Hour Rewards programs went live, Nest quickly enrolled the first 1,000 Austin Energy and 1,000 Southern California Edison customers.
- Support costs for Rush Hour Rewards programs are negligible. Across all Austin Energy, Southern California Edison, and Reliant customers participating in Rush Hour Rewards, just 0.7% of the enrolled customers contacted Nest Support about Rush Hour Rewards, and those calls were about how to enroll in the programs.
- When compared to four-hour events, two-hour events had lower temperature increases, fewer temperature change events, and higher-load shift rates.

2. Methodology

To date, Demand Response providers use a few different strategies for reducing demand during energy rush hours: fixed setbacks, pre-cooling and duty cycle modulation. Rush Hour Rewards uses elements of all three strategies. Rather than pre-cooling by 2 ˚F before the rush hour and raising the target temperature by 2 ˚F during the event, Rush Hour Rewards adjusts the target temperature specifically for the home. RHR adjusts based on the indoor temperature, the outside temperature history and forecast, the home's thermal behavior (i.e. the quality of insulation and the size of the air conditioner, as calculated from data collected

during normal Nest Thermostat operation), user preferences, and occupancy patterns. By modeling the expected air conditioning use with and without Rush Hour Rewards and re-optimizing the strategy throughout the rush hour, both load reduction and user comfort can be maximized. In contrast to many other demand response solutions, customers maintain control of their thermostat during RHR events. Customers can change the thermostat to any temperature of their choice. Nest will hold the temperature until their next schedule set point.

Importantly, RHR optimizes for both customer and energy company needs over the long term. Nest believes that paying attention to the customer experience is important to maintain participation. RHR customers with high trust and satisfaction are likely to encourage others to participate. By establishing a large customer base that trusts Rush Hour Rewards, the potential for long-term load reduction is substantial. The following section presents details on how Nest analyzed the data from RHR this summer.

3. Results

Qualification and Connectivity

Over summer 2013, Nest ran RHR events with three energy partners on thousands of devices. Tables 1-3 summarize the results for the thermostats that participated in each event. Note that AE and Reliant events are two hours long while SCE events are four hours long. The outdoor temperature listed in this table is the maximum outdoor temperature during the event, averaged across all customers who ran the event.

These tables show that 92.9% of devices ran the events. Across all events, an average of 94.8% of devices received events. The remaining devices did not receive the event when it was sent, most likely because they were not connected to Wi-Fi at the time. An average of 1.8% of devices did not qualify for events. A device does not qualify for an event if it is in heating mode or if it switches modes between the presentation time and start time of the event. SCE devices qualified out at a higher rate than the Reliant and Austin Energy devices because some SCE customers were running heat the night before the event days.

Table 1: RHR events run by Austin Energy

Date	Outdoor Temp (˚F)	% Devices Started Event	% Devices Did Not Receive	% Devices Did Not Qualify
6/27/2013	102	96.0%	3.2%	0.8%
6/28/2013	106	96.3%	3.0%	0.7%
7/11/2013	102	95.9%	3.3%	0.9%
7/12/2013	102	95.8%	3.5%	0.7%
7/24/2013	97	95.2%	4.0%	0.8%
7/25/2013	100	96.1%	3.4%	0.5%
7/31/2013	102	96.1%	3.6%	0.4%
8/1/2013	102	95.9%	3.6%	0.5%
8/2/2013	102	95.1%	4.2%	0.8%
8/7/2013	106	96.3%	3.2%	0.5%
9/3/2013	104	95.6%	3.8%	0.6%
9/4/2013	102	95.4%	3.9%	0.7%
Average	102	95.8%	3.6%	0.7%

Table 2: RHR events run by Reliant

Date	Outdoor Temp (˚F)	% Devices Started Event	% Devices Did Not Receive	% Devices Did Not Qualify
9/6/2013	97	93.5%	5.3%	1.2%
9/12/2013	96	94.3%	4.6%	1.1%
10/3/2013	90	92.3%	6.7%	1.0%
10/4/2013	91	93.8%	5.4%	0.8%
Average	93	93.5%	5.5%	1.0%

Table 3: RHR events run by Southern California Edison

Date	Outdoor Temp (˚F)	% Devices Started Event	% Devices Did Not Receive	% Devices Did Not Qualify
7/2/2013	89	89.8%	2.6%	7.6%
8/28/2013	95	63.6%	29.3%	7.0%
8/30/2013	96	88.6%	2.7%	8.8%
Average	93	80.7%	11.6%	7.8%

4. Load Reduction

Rush Hour Rewards events are characterized by up to an hour of pre-cooling followed by a period of load reduction. Length varies by utility. Figure 1 shows a typical example of the AC load during an RHR event.

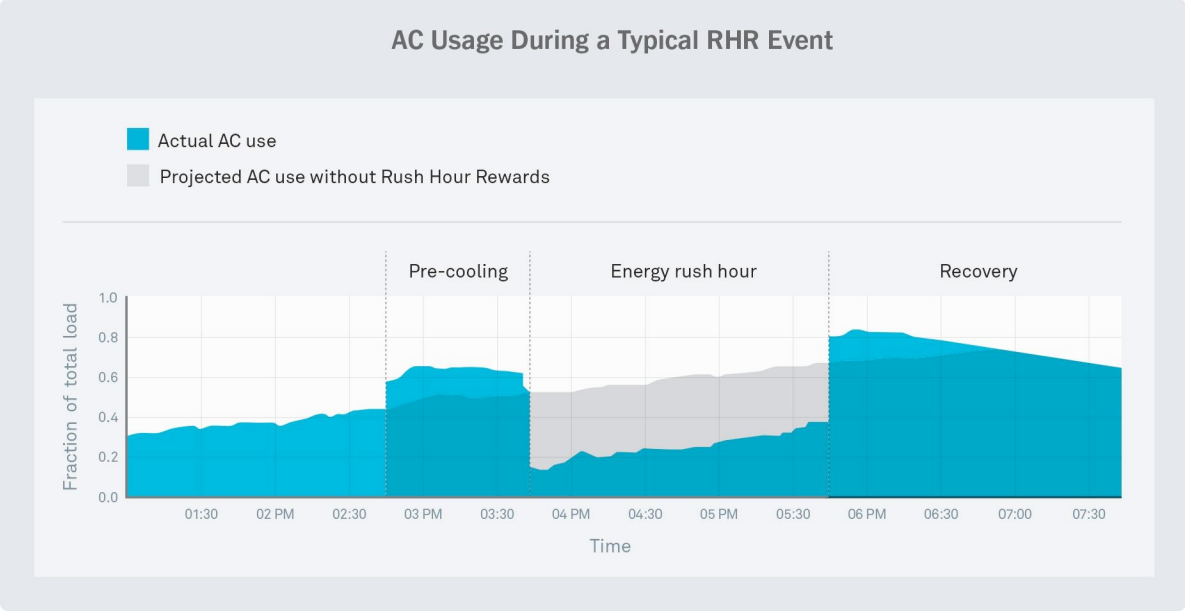

Figure 1: Percentage of air conditioners running over time during a Rush Hour Rewards event. Blue indicates the actual AC usage while gray predicts the AC that would have been used if an energy rush hour was not scheduled.

To calculate the load reduced by the RHR event, we compare the actual AC usage with an estimate of the baseline load if there was not an event. We estimate the baseline load using a thermal model to predict the AC usage of each home given their normal set point temperatures. We evaluated the accuracy of the model on nine days without RHR events. Across these days, the baseline model had an average absolute error of 2.6% AC runtime, which results in an average error of 0.06 kW / device.

Since the baseline AC load is highly variable across devices (from no usage to 100% usage), we present the load reduction in three ways: percentage of AC baseline load reduced, minutes of AC runtime reduced, and estimated power reduction. Tables 4-6 show the load reduction in minutes and percentage averaged over all devices that started the event. Based on the load reduction minutes, we can calculate the estimated kW saved per device if we know the AC capacity for each device. We assume an average AC capacity of 3.9 kW based on a survey made in Austin [Rhodes et al, 2010] and comparing meter data with Nest Thermostat AC runtime data for SCE. These tables show that events reduce a large amount of load: each event reduced an average of 55.1% for an average of 1.18 kW per device.

Table 4: Load reduction of RHR events run by Austin Energy

Date	Outdoor Temp (˚F)	Load Reduction (Percentage)	Load Reduction (Minutes / Device)	Estimated Power Reduction (kW / Device)
6/27/2013	102	57.4%	40.7	1.32
6/28/2013	106	51.1%	39.7	1.29
7/11/2013	102	57.4%	41.6	1.35
7/12/2013	102	55.4%	42.2	1.37
7/24/2013	97	62.8%	37.6	1.22
7/25/2013	100	60.2%	42.3	1.38
7/31/2013	102	58.0%	40.3	1.31

8/1/2013	102	53.8%	38.7	1.26
8/2/2013	102	56.6%	40.8	1.33
8/7/2013	106	54.8%	41.5	1.35
9/3/2013	104	54.0%	39.8	1.29
9/4/2013	102	51.2%	34.0	1.11
Average	102	56.0%	39.9	1.30

Table 5: Load reduction of RHR events run by Reliant

Date	Outdoor Temp (˚F)	Load Reduction (Percentage)	Load Reduction (Minutes / Device)	Estimated Power Reduction (kW / Device)
9/6/2013	97	58.1%	37.4	1.22
9/12/2013	96	62.7%	41.0	1.33
10/3/2013	90	67.0%	32.5	1.06
10/4/2013	91	63.8%	37.2	1.21
Average	93	62.9%	37.0	1.20

Table 6: Load reduction of RHR events run by Southern California Edison

Date	Outdoor Temp (˚F)	Load Reduction (Percentage)	Load Reduction (Minutes / Device)	Estimated Power Reduction (kW / Device)
7/2/2013	89	43.4%	32.9	0.53
8/28/2013	95	47.7%	59.8	0.97
8/30/2013	96	31.1%	35.2	0.57
Average	93	40.8%	42.6	0.69

5. Analysis

Event length

One major difference between these events is that the AE and Reliant events are two hours while SCE events are four hours long. While a similar number of total AC minutes is reduced with both types of events, the shorter events produce a much higher load reduction percentage and load reduction per hour. For a longer event, the effects of pre-cooling do not last as long and the AC must run more to keep customers from deviating too far from their scheduled temperature. In addition, shorter events provide a better customer experience due to a smaller average temperature increase. During the first two hours of the SCE event, the average load reduction is 52.2% and 0.88 kW, while over the entire four hour event, the load reduction is only 40.8% and 0.69 kW. Two hour events appear preferable to four hour events because of both lower temperature deviations and higher load shift rates.

Comparison with other methods

We compared the Rush Hour Rewards algorithm to four other Demand Response approaches.

1) Always run 50% of air conditioners, even if they normally would have been

2) Restrict devices to be off at least 30 minutes of every hour

3) 2˚F setback during the event

4) 2˚F pre-cooling an hour before the event, 2˚F setback during the event

Figure 2 shows the simulated load reduction for each approach during each of the RHR events we ran this summer. The results show that the Nest approach reduces more load than any of these approaches. In addition, while Rush Hour Rewards reduces more load, the average indoor temperature deviation is only 0.2 ˚F more than with a two degree setback with pre-cooling or turning half of the air conditioners off.

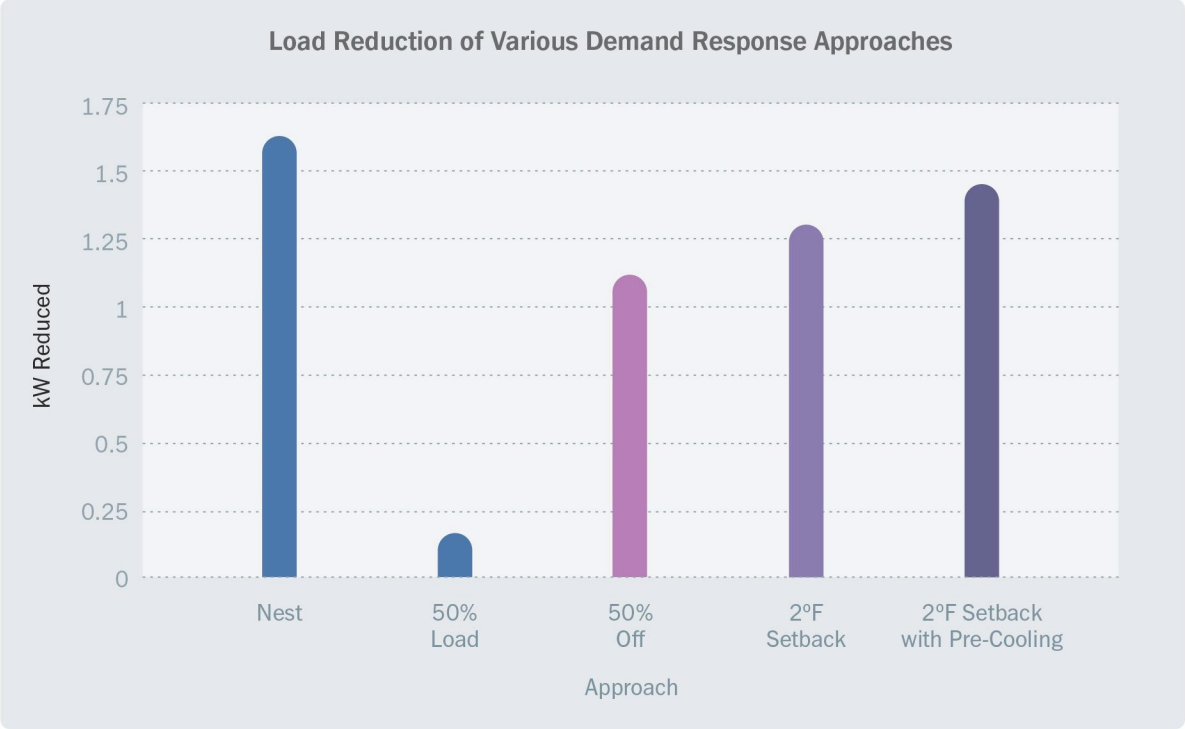

Figure 2: Load Reduction for Various Demand Response Approaches

Impact of User Temperature Adjustments

Rush Hour Rewards is designed to work while still enabling customers to take manual control at any time. Results show that very few customers take manual control of their devices, and those that do still reduce load overall.

In general, very few customers choose to take manual control of their devices and exit the event. Those who do still reduce a significant amount load. Table 7 shows that many users never took manual control during any of the events. In contrast, a small number of customers consistently made manual changes and accounted for a large portion of the manual control events.

Table 7: Manual Control Rates across Events

Utility	% of devices that never took manual control during any event	% of manual control events accounted for by top 15% of devices
Austin Energy	49.6%	58.7%
Reliant	73.0%	66.9%
Southern California Edison	54.1%	51.4%

On average, and across all events, providing customers with the ability to change their temperature only increased AC demand by 0.11 kW or 8.1%. Customers exit energy rush hour events at a steady rate over the entire course of the event, therefore, many have already reduced load before changing their temperature. Figure 3 shows the AC load during the event for all customers as well as just the customers who completed the event. For this event, the difference between the kW reduced for all devices and the kW reduced for only those who completed the event is only 0.27 kW or 10.9%. This shows that enabling customers to take manual control during events does not greatly reduce the overall load reduction.

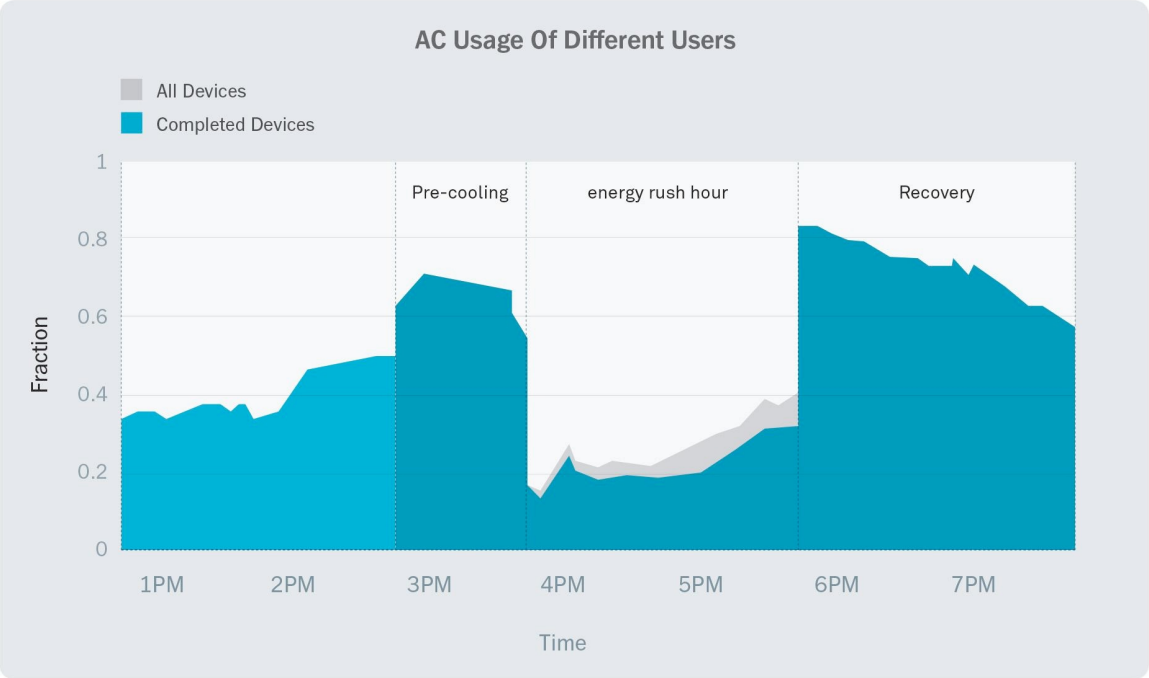

Figure 3: AC load for devices during the AE RHR event on 9/4/2013

Table 8 shows the load reduction for users who completed the event versus those who took manual control of their devices. Across all events, 85.5% of customers completed the event without taking manual control of their devices. Many of the customers who took control of their devices kept efficient temperatures or even made their temperature more efficient. The events still shifted a large amount of load even while users were allowed to take manual control of their devices.

Table 8: Effects of taking Manual Control during an event

Group	% of Overall Customers	Load Reduction
All Users	100.0%	1.28 kW
Completed Event	85.5%	1.40 kW
Took Manual Control	14.5%	0.61 kW

Using Meter Data to Validate Findings

In addition to Nest air conditioning runtime data, we also received customer meter data from SCE, with customer approval, to verify actual kWh saved per device. While we showed that the Rush Hour Rewards algorithms reduce AC runtime during energy rush hours, meter data enables us to show the number of kWh actually reduced and to verify our estimates of kWh reduced, which are based on an assumed capacity of 3.9 kW per AC.

With customer approval, we received meter data from SCE for all customers who ran events. Figure 6 shows the average kWh usage from meters over the course of the day for an event on August 28. Pre-cooling for the event occurred from 1:00 to 2:00 PM and then the event ran from 2:00 to 6:00 PM. The reduction in electricity usage from the RHR event is clear to see. We fit a 7th order polynomial model to the usage before 1:00 PM and after 8:00 PM to estimate the baseline usage from the data outside of the event. A 7th order polynomial was chosen because it gave the least error. Compared to this baseline,

customers used an average of 0.61 kWh extra during pre-cooling, reduced usage by 3.70 kWh during the four hour event, and then used 0.43 kWh extra during the hour after the event.

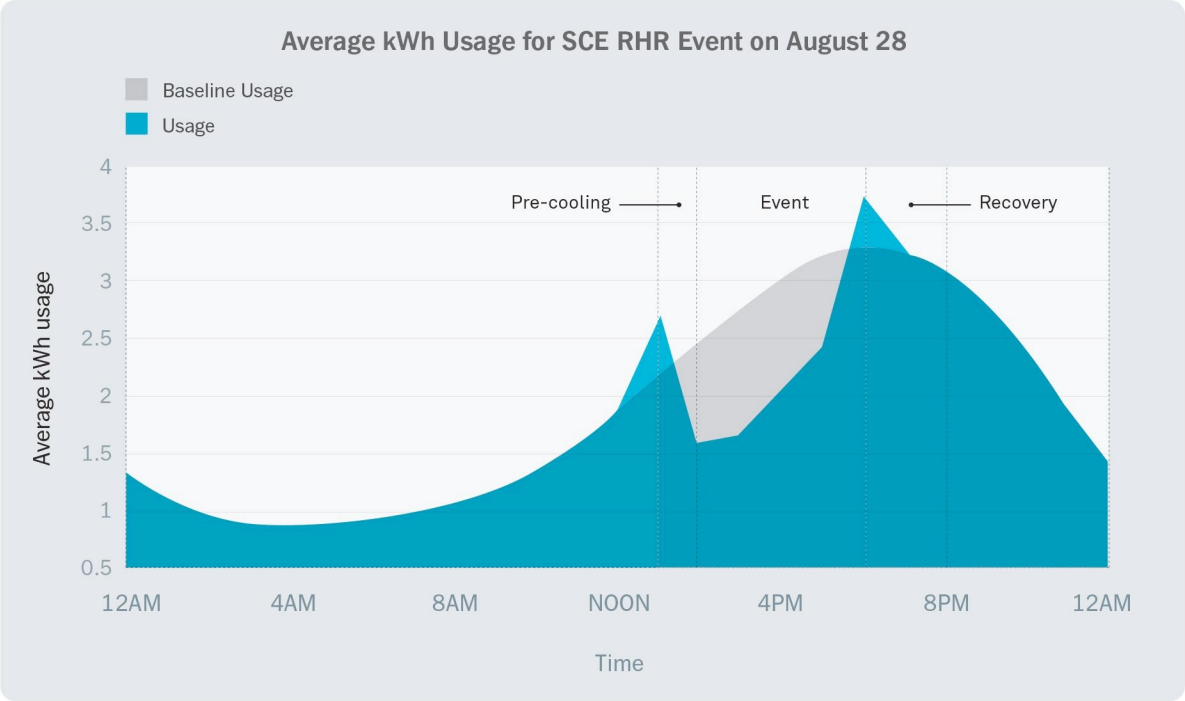

Figure 6: Average kWh usage of meters during an SCE RHR event on August 28

We received SCE meter data for all three RHR events. Table 10 shows the load reduction as calculated from the meter data, compared to the reduction estimated from the Nest data on reduction in AC minutes. The table shows load reduction per home, accounting for homes with multiple devices, and only includes devices that started the RHR event. Similarly, Figure 7 shows a plot of the load reduction calculated both ways for the SCE RHR event on August 28. This table shows that SCE customers generally reduced even more load than what was estimated from AC runtime only. This result could indicate that customers are turning other devices off during the Rush Hour Rewards events or that their AC's are actually larger than 3.9 kW.

Table 10: Comparison of load reduction from meter and AC data per home for users who started RHR event.

Date	kWh Reduction Estimate Using Meter Data	kWh Reduction Estimate Using Nest Data
7/2/2013	2.93	2.14
8/28/2013	3.08	3.88
8/30/2013	3.01	2.29
Average	3.01	2.60

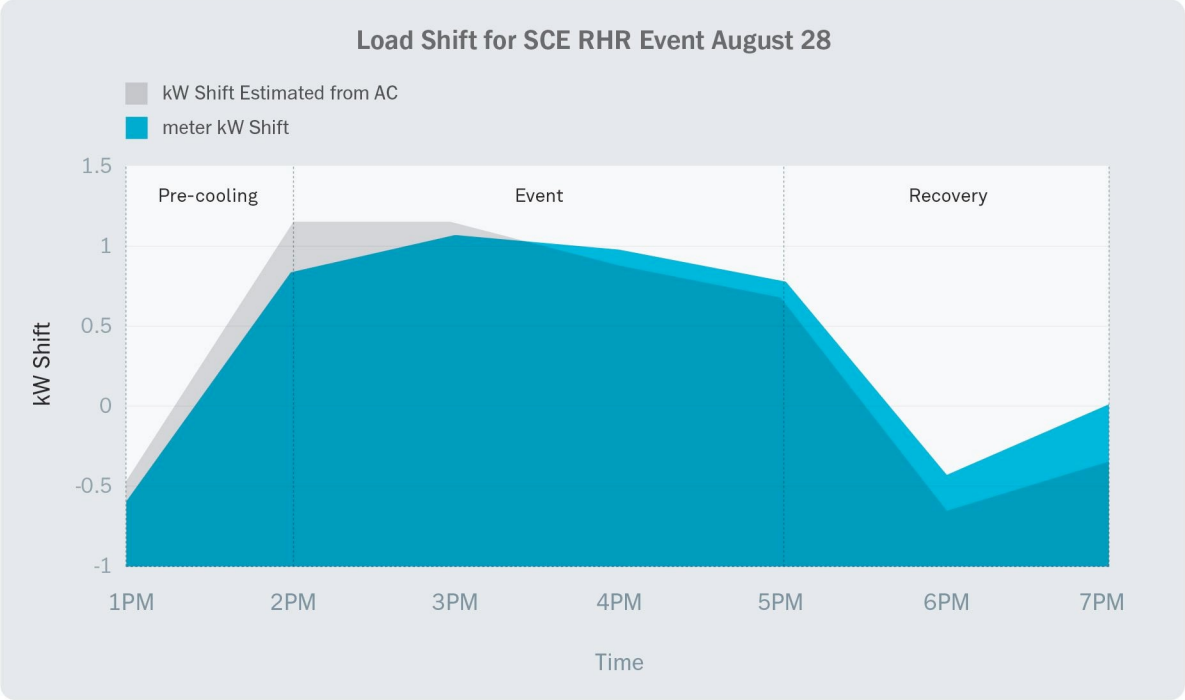

Figure 7: Comparison of load reduction from meter data and load reduction from AC data for the SCE RHR event on August 28.

6. Summary

The comparison of load reduction estimates from meter data and from our AC load data show that Nest can predict load reduction even without meter data. It also shows that during the SCE events, customers reduce even more load than the Nest estimated reduction from just the air conditioner. Perhaps indicating the customers are turning other devices off during the Rush Hour Rewards events or that their AC's are actually larger than 3.9 kW.

Impact of Incentive Structure on Load Reduction

Reliant and SCE paid customers on a per-event basis with credits on their monthly bills. Table 11 shows the average user payment for each of the three events. These figures only include customers who started the events. Customers received an average of $12.00 over the entire summer (note that some were only signed up for the last two events). The difference in payments from event to event can largely be attributed to the baseline calculation used by SCE. SCE calculates their payments based on the difference in energy usage on the day of the RHR event the preceding days. The temperatures for the second two RHR event days were much warmer than those of preceding days, resulting in lower payments to customers. Conversely, the SCE RHR event on 7/2 was the coolest of the three RHR event days, yet delivered the highest estimated baseline usage because of the warmer preceding days.

Table 11: Average user payment for each SCE Event

Event	Average User Payment
July 2	$7.98
August 28	$3.96
August 30	$3.90

Two different incentive structures were used for Rush Hour Rewards. While SCE and Reliant paid customers per event, AE paid customers an incentive up front for enrolling in RHR for the summer. The findings show that neither up-front or per-event payment

increased the percentage of customers completing an event. The 14.5% of users who took manual control of their devices also did not vary significantly between utility payment programs. These results indicate that customers who are paid up front do not exit events any more frequently than those paid for per-event performance. It is also worth noting the significant increase in enrollment rates seen when up-front payments were offered to customers (see next section).

Impact of Up-Front Incentive on Marketing and Enrollments

Nest utilized a low-lift, inexpensive recruiting and enrollment web pages, emails, and social media to enlist costumers. We succeeded in enrolling a significant portion of the Nest customer population in Austin and southern California over one summer. Nest succeeded in enrolling the first 1,000 Austin Energy and 1,000 Southern California Edison customers within just a few weeks after the Rush Hour Rewards program launched. We used only one invitation email to existing Nest Thermostat owners, some social media, and word of mouth. Rush Hour Rewards enrollments are also completed as a fully "self-serve" platform for customers who do not require a home visit by a contractor. Therefore, within weeks of launching a Rush Hour Rewards program, a utility can begin to see returns from its program.

There was a meaningful difference in enrollment rates based on the method of customer payments. In AE, where the first two years of incentives were paid up front upon enrollment, 39% of Nest's customers enrolled in Rush Hour Rewards. In contrast, only 19% of Southern California Edison's Nest customers enrolled in RHR. Incentives for SCE's program were paid in bill credits on a monthly basis.

Customer Satisfaction

As with any Demand Response program, utilities and vendors are concerned with customer response. Nest Thermostat customers reported having very positive experiences with Rush Hour Rewards..

Of the customers participating in Austin Energy, Southern California Edison, and Reliant Rush Hour Rewards programs, only 0.7% contacted Nest Support about Rush Hour Rewards. Figure 8 shows how customer support calls are broken into categories. Just 11% of calls pertained to to un-enrollment from RHR, resulting in a 0.4% reduction of participating customers over the course of the entire summer.

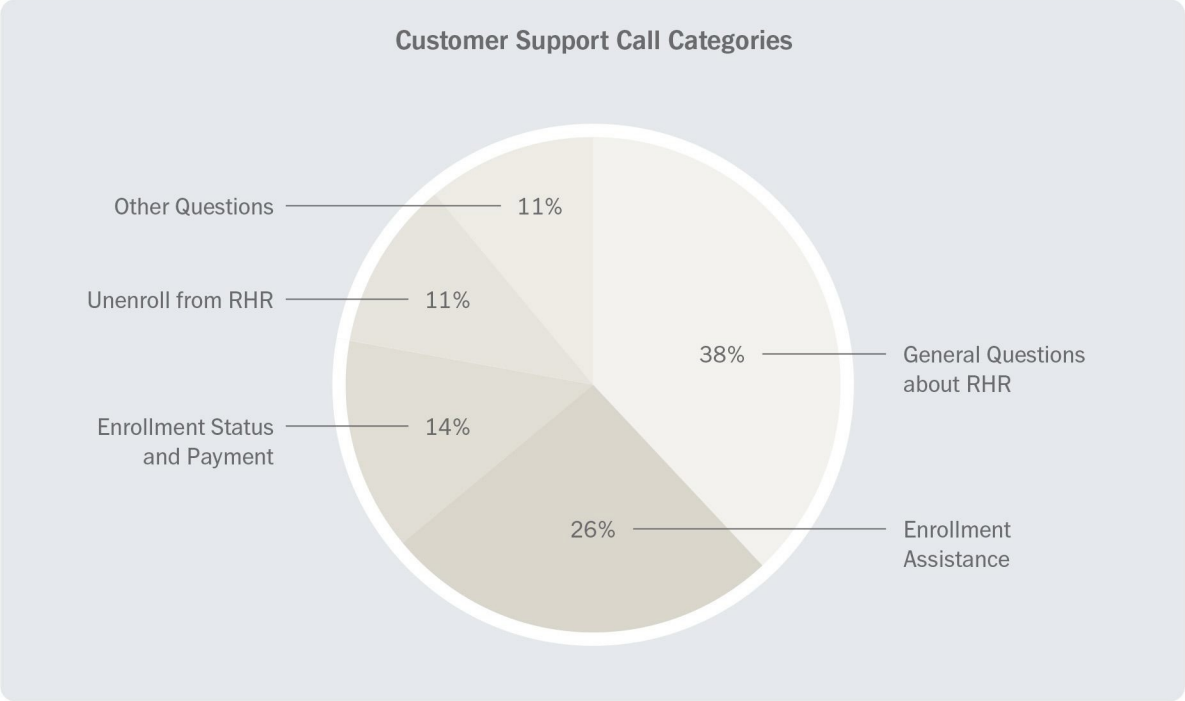

Figure 8: Customer Support Call Categories

Customers participating in Rush Hour Rewards were also presented with a survey at the end of the summer. The survey showed that customers remained comfortable during energy rush hours and enjoyed participating in the program. On the question of how satisfied customers were with the enrollment process, 80.8% of customers rated their experience an 8 or higher on a scale from 1 to 10.

When customers were surveyed about their level of comfort during an energy rush hour compared to any non-event hot day, 84% rated their experience a 3 or higher on a scale of 1 to 5. In addition to the Nest Thermostat helping reduce electricity use, 38% of customers indicated that they also turned off other electricity consuming devices in their home during the event. Overall, the vast majority of customer feedback was positive. As with all Nest products, Nest will continue to strive to create the best possible customer experience.

7. Conclusion

Rush Hour Rewards reduces a significant amount of AC load while maintaining a comfortable user experience. Across all events, the RHR program reduced AC load an average of 55.1%, or 1.18 kW per, with 84% of customers reporting minimal to no impact on comfort..

If they experience discomfort, customers maintain the ability to adjust their temperature. However, these instances were quite rare. Manual temperature changes during an event resulted in a modest 0.12 kW increase in consumption from projected savings. Lastly, Nest has shown the ability to deliver thousands of customer enrollments within weeks of the launch of a Rush Hour Rewards program through a combination of Nest marketing web pages, emails, and social activity.

Nest is always looking to make improvements. The Rush Hour Rewards platform is no exception. For future programs, Nest will continue to optimize the number of devices receiving and qualifying for events. Work to reduce load. And, assure the overall customer experience.

Results show that Rush Hour Rewards is a comprehensive, end-to-end product that significantly reduces AC use during energy rush hours while keeping customers comfortable and in control of their thermostat.

References

J.D. Rhodes, B. Stephens, M.E. Webber, “Using energy audits to investigate the impacts of common air-conditioning design and installation issues on peak power demand and energy consumption in Austin, Texas”, Energy and Buildings, 2010.