Voice Assistants for Customer Engagement and Customer Programs

ET19SDG1011 and DR19SDG0001 Report

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EXECUTIVE SUMMARY

Voice Assistants have found very rapid market adoption increasing to nearly five-fold in market penetration in the U.S. between 2017 and 2021[1]. All three major voice assistant platforms provide an ecosystem for developing applications. Amazon has termed applications that are built to leverage Alexa's natural language processing capabilities as *Alexa Skills* and has provided a variety of tutorials and supporting materials to allow 3rd party developers to develop Alexa skills. Concurrent with the trend of market adoption of voice assistants, smart home devices which provide connectivity and compatibility with voice assistants have seen a significant growth doubling in annual consumer spending from 2015 thru 2021 and expecting to triple by 2023[2]. Given these dual trends, the potential for the smart home devices to provide energy management capability and enhanced customer experience using voice assistants integration is alluring.

This project investigates four research questions with the aim of understanding the potential for voice assistants to provide a channel for better customer engagement:

1. Do voice assistants integrated with custom-built Alexa skill provide better customer engagement regarding Time of Use (TOU) rates?

2. Does improved customer engagement enabled through voice assistant translate to better energy performance?

3. Does voice assistant technology enhance demand side management strategies for automated energy management during peak TOU rate periods?

4. What are the best practices for developing customer demand side management and demand flexibility programs using voice assistant technologies?

To investigate these research questions, the project recruited and provided seven customers in San Diego with Amazon Echo devices enabled with Amazon Alexa voice assistants. These seven customers were recruited from a pool of SDG&E customers who are on a TOU rate plan. In addition to providing Amazon Echo devices, a few customers were also provided Ecobee smart thermostats and Rheem Heat Pump Water Heaters and data monitoring via Rainforest Eagle Advanced Metering Infrastructure gateways. The project equipped the participants with a custom-built Alexa skill that provided a spectrum of services aimed at improving customer engagement related to TOU rates.

The crux of the custom-built Alexa skill involved a phase approach to providing customers information about TOU rate change events. In Phase 1, the skill provides proactive notification about TOU rate change events. Phase 2 focused on providing additional information such as ways to reduce their energy use in addition to the notifications and TOU rate information. In Phase 3, customers were provided feedback on how much energy they used in the previous day or week to motivate them towards energy conservation behaviors.

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[1] https://9to5mac.com/2021/08/04/homepod-market-share-us-still-lags/

[22] https://www.businesswire.com/news/home/20210706005692/en/Strategy-Analytics-Global-Smart-Home-Market-Roaring-Back-in-2021

Finally, in Phase 4, for those customers (3 out of 7) who were provided a smart thermostat, the study also investigated the potential to reduce customer's cognitive burden for energy management during TOU peak hours by automatically adjusting the thermostat setpoints. Customers were given the option to opt-out of automatic control if they chose to do so.

For each of the phases, customers' engagement with Alexa was measured along with the associated energy use during periods of high and low engagement. And for those customers with smart thermostats, the HVAC usage profiles including HVAC runtime characterization – how much do they use HVAC relative to outdoor temperature, and HVAC hourly profile – when and how much is the HVAC used on an hourly basis, was studied for control and treatment periods. It was useful to study the HVAC usage profiles and the energy management to discern if limiting HVAC usage during high TOU rate periods led to reduced overall electricity use.

The analyses of customer engagement, energy performance, and correlated HVAC performance led to a set of results on the efficacy of voice assistants both for customer engagement as well as energy performance improvement. Key lessons learned during project execution provided insights on scaled implementations via demand side management and demand flexibility programs.

- *Customers are interested in using Alexa to stay informed about TOU rate events*. The first three phases of the project which was applicable to the full set of participants showed levels of engagement that was consistent with sending notifications and the engagement increased significantly when the skill was able to provide recommendations for reducing energy use and feedback on energy use the previous day or week.

- *Customer's improved energy performance is correlated to higher customer engagement*. Using Phase 1 results as baseline, higher engagement in Phase 2 & Phase 3 could be correlated to reduced daily energy use on a weather normalized basis. On average, the improvement was of the order of about 5 kWh per day during periods of high engagement in Phase 2 and Phase 3.

- *The use of automated smart thermostat control led to reduced thermostat runtimes during high TOU rate periods*. While this is consistent with expectations, it indicated that customers did not opt-out much. The project team employed a novel learning algorithm for establishing each customer's range of indoor temperatures for comfort and changing thermostat setpoints to stay within this range during high TOU periods to reduce HVAC usage. However, the reduced HVAC did not consistently translate to reduced electricity use during high TOU rate periods potentially indicating that HVAC was not a significant contributor to electricity use for the treatment periods.

- *Design of specific customer interactions is critical to improved engagement*. Given the conversational nature of the interaction between Alexa and the customer employing natural spoken language communications, design considerations that impact the customer experience like length of the messages, depth of information provided, ensuring conversational tone in the message, etc. become crucial to success.

- Use of non-standard vendor provided methods for direct end-use control, e.g., smart thermostat control, enabled via vendor provided Application Programming Interfaces (API), poses a challenge. Cost-effectively achieving persistent results in demand side management programs requires the ability to achieve economies of scale through reduced incremental cost for every new customer acquired. However, as vendor provided APIs are updated and overhauled, the need to maintain and update the end-use device control platforms diminishes the ability to achieve these economies or forces tradeoff of platform costs for potential customer attrition. With vendors like Ecobee and Rheem potentially moving towards platforms that provide higher service guarantees with lower 3rd party control capabilities, utilities may need to update their business calculations for developing pilot programs and/or smart-home type demand side management programs.

ABBREVIATIONS AND ACRONYMS

API	Application Programming Interface
AMI	Advanced Metering Infrastructure
CDD	Cooling Degree Days
DR	Demand Response
DSRIP	Demand Side Resource Integration Platform
EV	Electric Vehicles
HPWH	Heat Pump Water Heater
HSPF	Heating Seasonal Performance Factor
HVAC	Heating, Ventilation, and Air Conditioning
IOU	Investor-Owned Utilities
openADR	Open Automated Demand Response
SDG&E	San Diego Gas & Electric
SEER	Seasonal Energy Efficiency Ratio
TOU	Time of Use
UI/UX	User Interface/User Experience
VA	Voice Assistant
Wi-Fi	Wireless Fidelity

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INTRODUCTION

Voice Assistants have found very rapid market adoption increasing to nearly 5-fold in market penetration in the U.S. between 2017 and 2021 (see Figure 1). This is an incredible rate compared to hubs for energy management that have been tried and tested over the last decade and a half. Given that the voice assistants have now become a gateway for many consumer products, it is critical to understand how they can be used to advance utility customer engagement and drive energy benefits acting as the point of engagement for residential customers (and potentially small commercial customers as well). EPRI research from 2017 and 2018 indicated the potential for voice assistants to enable growth in customer engagement from basic messaging to personalizing customer experiences, with varying degrees of engagement in between. From a customer programs perspective, it is important to understand how voice assistants could play a role in allowing new programs or increasing adoption of existing programs.

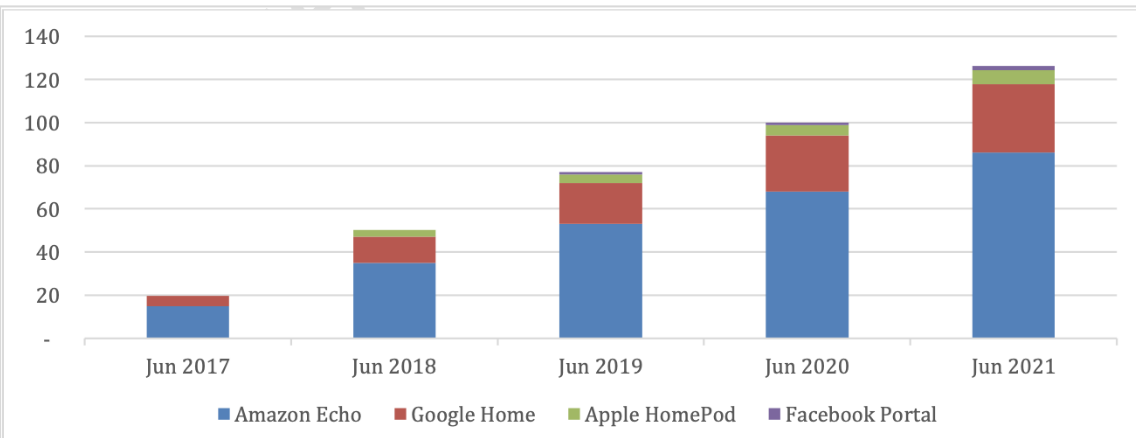

FIGURE 1 – MARKET SHARE OF MAJOR SMART SPEAKERS WITH VOICE ASSISTANTS IN THE US FROM 2017 THRU 2021[3]

To test the potential for Voice Assistants to be used as a customer engagement platform for utilities, the platform with the highest market penetration and ease of developing custom applications was adopted, namely, Amazon Echo with Amazon Alexa. A total of seven homes were selected within the SDG&E territory to pilot the Amazon Echo equipped with Amazon Alexa and a custom-built "Alexa Skill". Only five homes were required for the pilot, but due to increased interest and availability, seven total sites were included. This helped to mitigate potential attrition of homes throughout the testing.

Note: Each of the smart speaker/voice assistant platforms include a mechanism by which custom applications that leverage the natural language processing and integration capabilities of the voice assistant platform can be developed. Amazon Alexa uses the term "Skills" to refer to these applications.

If successful and deemed scalable, the pilot skills can be expanded to other Voice Assistant platforms. To facilitate customer engagement and simplify data acquisition from customer's

[3] https://9to5mac.com/2021/08/04/homepod-market-share-us-still-lags/

smart meters, each home received an Amazon Echo and a Rainforest Eagle[4] AMI metering device. The Rainforest Eagle AMI metering gateway comprises of a Zigbee enabled data acquisition system that gets interval energy data from smart meters through Zigbee protocol and pushes the acquired data to cloud storage where it can be retrieved for calculating baseline energy use and comparing real-time use to appropriate baselines. In addition to the Amazon Echo and Rainforest AMI gateway, an Ecobee smart thermostat and/or a Rheem heat pump water heater, depending on applicability at each home are also provided. Testing began in July 2020 and ran through December 2020 to capture the summer and winter Time of Use (TOU) rates. Testing ran in four phases:

- Customers received a notification on their Alexa, notifying them of a high rate period that day and received recommendations to reduce their energy consumption during the high rate period.
- Customers can ask Alexa various questions regarding their energy consumption and energy bills to better inform themselves of their energy consumption.
- Controllable loads within each home were programmed to automatically respond to high rate periods by reducing and shifting demand by changing thermostat setpoints.

Throughout the testing, data was collected from the Advanced Metering Infrastructure (AMI) meter, smart thermostats, and Amazon Echo to evaluate the following research questions, among others:

- How often do the customers engage with the Amazon Echo regarding their energy consumption or TOU rates?
- Do customers respond to Alexa notifications of high rate periods in ways that reduce their energy consumption?
- Which method of engagement receives the highest volume of interaction? Does this correspond to reduction in energy consumption?
- As notifications increase, does customer attrition occur?
- How often do customers choose to opt out of the automatic load control of Phase 4?

[4] https://www.rainforestautomation.com/rfa-z114-eagle-200-2/

Site Summary and Technology Selection

Site Requirements

To be considered for this pilot test, homes with high energy consumption and high energy bills were targeted. A mixture of homes, both with high and moderate consumption were ultimately recruited. Each site had to meet the following requirements:

- Must be on an SDG&E TOU rate
- Must have a reliable Wi-Fi network
- Must have a Zigbee compatible smart meter

The following additional considerations were preferred but not required:

- Has a central air conditioning system

Among the most important consideration was a willingness to engage with the Amazon Alexa and an openness to testing.

Final Site Selection and Equipment Installation

Seven homes in San Diego Gas & Electric territory were retrofitted with a variety of connected technologies including Amazon Echo smart speakers, smart thermostats, heat pump water heaters, and AMI metering devices. The Table 1 details the technologies installed within each home as well as which TOU rate each home pays.

Table 1 – Technologies installed in homes for the Alexa project

	Amazon Echo with Alexa	Rainforest AMI Meter	Rheem Heat Pump Water Heater	Smart Thermostat	TOU Rate
Home 1	x	x	x		TOU DR1
Home 2	x	x		Ecobee	TOU DR1
Home 3	x	x		Ecobee	DR SES
Home 4	x	x		Ecobee	TOU DR1
Home 5	x	x			TOU DR1
Home 6	x	x		Ecobee	TOU DR1
Home 7	x	x		Nest (no access)	TOU DR1

Home 1 Configuration

As a part of the project, at least one controllable heat pump water heater was hoped to be connected and tested. As all of the homes in the study had gas water heaters, Home 1 was selected to receive a 50-gallon heat pump water heater due to their high bills and upcoming need for a new water heater. To install the electric heat pump unit, a dedicated 30 amp circuit was run to the existing water heater. Home 1 also received the Amazon Echo and Rainforest Eagle AMI meter as required.

FIGURE 2 – IMAGE OF EXISTING GAS WATER HEATER IN HOME 1

With the heat pump water heater installed in Home 1, the potential for inclusion of the water heater as a controllable load in the study existed. At the time of conducting the study (July 2020 thru Dec 2020), Rheem had moved their Demand Response (DR) Application Programming Interface (API) to a different server and in the process, the project team lost its connectivity to the water heater. Subsequent attempts to get the water heater added to the data and control flows were unsuccessful. Consequently, the water heater was not included in any of the automated control studies. However, Home 1 was able to participate in the other parts of the project.

HOME 2 CONFIGURATION

Due to initial concerns revolving around not having enough homes with central air conditioning to be used for the test, a central heat pump HVAC unit was installed at Home 2. A 16 SEER, 9.5 HSPF Carrier heat pump unit with an Ecobee smart thermostat was chosen to provide both efficiency and controllability. Home 2 also received the Amazon Echo and Rainforest Eagle AMI meter as required.

FIGURE 3 – IMAGE OF 16 SEER CARRIER HEAT PUMP AND A CONTROLLABLE ECOBEE THERMOSTAT INSTALLED IN HOME 2

With the controllable thermostat, Home 2 was able to participate in all phases of testing.

HOME 3 CONFIGURATION

Home 3 had an existing central air conditioning system and a first generation Ecobee thermostat. The existing Ecobee was replaced with a newer Ecobee 4 unit to provide the required control for the pilot. Home 3 was also the only home to have a pre-existing photovoltaic system and therefore was the only test site on a different rate (DR SES instead of TOU DR1). Home 3 also received the Amazon Echo and Rainforest Eagle AMI meter as required.

FIGURE 4 – IMAGE OF ECOBEE THERMOSTAT INSTALLED IN HOME 3

HOME 4 CONFIGURATION

Home 4 had an existing central air conditioning system with the newer Ecobee 4 unit already installed. Although an existing Ecobee was installed, it could not be added to the EPRI utility portal for remote control as it was already enrolled in another DR program. Home 4 also received the Amazon Echo and Rainforest Eagle AMI meter as required.

Since the Ecobee could not be enrolled in the EPRI utility account, Home 4 only underwent the first three phases of testing, opting out of automatic control.

HOME 5 CONFIGURATION

Home 5 did not have an existing central air conditioning system and was therefore limited to only the Echo and Rainforest Eagle devices. The home does have multiple window air conditioning units, which were targeted by Phases 1, 2 & 3 (notifications and recommendations/feedback for energy reduction during peak hours), but the automatic control of Phase 4 is unavailable.

HOME 6 CONFIGURATION

Home 6 had an existing central air conditioning system with the newer Ecobee 4 unit already installed. During the commissioning of the Echo and Rainforest Eagle, the Ecobee was added to the EPRI utility portal, allowing for testing the automatic control in Phase 4, as well as all other phases.

HOME 7 CONFIGURATION

Home 7 had an existing central air conditioning system but had a Nest smart thermostat instead of the Ecobee. The project team did not have API access to the Nest devices so automatic control in Phase 4 could not be tested at home 7.

FIGURE 5 – IMAGE OF NEST THERMOSTAT INSTALLED IN HOME 7

Home 7 received the Amazon Echo and Rainforest Eagle AMI meter and participated in Phases 1 through 3.

TECHNOLOGY SELECTION PROCESS

At the beginning of the project, four types of controllable technologies were considered for retrofitting at the selected sites. These technologies were:

- Smart thermostats
- Home batteries
- Smart water heaters
- Smart, controllable blinds

These four technologies have controllable capabilities that allow them to be used in the Phase 4 "Automatic Control" of this project. After further considerations and identification of sites, the list was narrowed down to just smart thermostats. This selection details the limitations of the technologies that were discarded, as well as the capabilities of the technologies installed.

HOME BATTERIES

Although originally considered to be placed in one or two homes, the cost and complexity of a battery installation for this pilot outweighed the benefit, especially as other EPRI projects and CEC funded grants have already explored the use of batteries to manipulate TOU rates. Additionally, batteries are not a "behavioral" load. They will function as programmed and can already manipulate charging and discharging around rates. They could also potentially provide a disincentive for customers to reduce consumption during peak hours. If their battery is already covering excess consumption during peak hours and they are not pulling electricity from the grid, there is less benefit to other demand flexibility measures like changing thermostat setpoint or deferring the use of larger appliances outside TOU peak hours.

Smart Blinds

Smart blinds were also considered as a controllable technology to be integrated into Phase 4 testing. Their capability to respond to rates and control signals was proven in the previous Whole Home DR project with SDG&E, however, the potential ability to reduce energy consumption was not proven. With controllable blinds, customers are likely to control the blinds prior to waiting for an "event" to occur. For instance, in the previous project, the blinds were programmed by the customer to lower at 1:00pm, three hours prior to the peak rate period. At 4:00pm, when the peak rate hits, the blinds would already be down, so no remote action was taken to reduce consumption. The blinds acted as a valuable energy efficiency measure but were less likely to provide value from a controllability standpoint.

In addition, there is a significant cost premium for controllable blinds that can integrate with third party voice assistants. Even for those that can integrate, the integration is not simple. The cost and complexity to provide smart blinds to any of the customers outweighed the potential benefit and were therefore not offered as an option. The seven homes also all already had pre-existing blinds or shades on their south-facing windows or had porch overhangs that shaded the windows, further reducing the value that controllable blinds could bring to manage energy use during TOU peak rates.

Smart Thermostats

Smart thermostats were identified as the highest priority for Phase 4 both due to the ease of installation as well as the opportunity for significant energy reduction. Ecobee smart thermostats were the smart thermostat of choice due to EPRI's past experience working with and controlling the Ecobee smart thermostats based on the available 3rd party data and control API. The availability of the Ecobee API and its online utility portal allows EPRI to control the thermostats in response to peak rates. In addition, three of the homes already had an existing Ecobee, allowing for easy implementation. One of the homes has an existing Nest smart thermostat. While this thermostat was incompatible for the Phase 4 automated control test, it can be utilized by the customer to reduce consumption when notified of their high-rate periods.

Heat Pump Water Heater

Heat pump water heaters were identified as the other high priority technology for Phase 4 control due to their substantial load (300-400W) and the existing control infrastructure that EPRI has developed with the Rheem heat pump water heater. Due to the complexity of installation, only one heat pump water heater was installed. Since the customer had to switch from gas to electric water heating, a 30A circuit had to be installed prior to replacement.

Adoption of heat pump water heaters continues to grow; however, this project showcased the potential distribution and trade barriers to installing heat pump water heaters at scale. Of the 10 plumbers that were contacted to install the heat pump water heater, only two were familiar with the technology and were willing to do the install. Once the 30A service was installed and the plumber was ready to proceed, they were met with 4-6 week lead times on the heat pump water heaters. No local distributors had the Rheem product in stock. Those that carried the product had little visibility into when they would receive their next shipment. A distributor was eventually identified and a water heater installed, but significant delays in identifying the plumber, running the 30A electrical, and finding an available water heater are concerning if heat pump water heaters are attempting to gain market share.

CUSTOMER ENGAGEMENT MODEL

The project employed a classic customer engagement model that uses an Awareness, Action, Feedback paradigm.

FIGURE 6 – CUSTOMER ENGAGEMENT MODEL EMPLOYED IN THE PROJECT

The awareness stage addresses the need for customers to be aware of a market condition, e.g., availability of a product/service, price of a product/service, etc. In the case of the Alexa pilot, the awareness stage involved timely and precise information about rate change events. In particular, the information pertaining to high-rate events and to what extent the rate is different from the base (or off peak) rate.

The action stage addresses the need for customers to act based on the awareness created in the awareness stage, e.g., buying a product/service, upgrading a software, etc. In the case of the Alexa pilot, the action stage involved providing actionable information on how customers could save energy during high rate periods so that they may reduce their energy use.

The feedback stage addresses the need for customers to get information on how good their action was, e.g., providing information on how many other customers have bought the product/service. In the case of the Alexa pilot, the feedback stage involved providing information on what resulted from the customer action (or lack thereof), i.e., how much energy did the household consume the previous day or previous week, and how did it compare to a two-week moving average baseline.

In addition to the above three stages, the project followed up the classic model with another key stage, namely, Automation. Given that energy management is not a task that most customers perform on a regular basis, the need for reducing cognitive burden on the customer exists. To reduce the cognitive burden, automation was selectively used. The automation stage involved the ability to "intelligently" control customer-sited smart home devices with the intention of reducing energy use during high-rate periods. The need for "intelligent" control arises from the fact that actions that inhibit a customer's use of their devices may result in customer frustration that can be detrimental to reducing energy use. This calls for being able to understand the customer's pattern of use of their smart home device(s) and applying controls in a manner that helps them save energy without excessively compromising their comfort/convenience.

TESTING AND DATA COLLECTION

This section provides details on the overall project in terms of various phases of testing and data collection.

TEST PLAN

The test plan for this site is divided into the following 4 phases:

- Phase 1: High-Rate Notification
    - This phase provides the customer with a notification of a high-rate period via a light change from blue to orange atop the Amazon Echo device. The customer must engage with the device once the notification has been received to listen to the message. The message indicates that the customer's electricity rate will increase to X cents per kWh during the specific TOU peak rate period.
- Phase 2: High-Rate Notification + Recommended Actions
    - This phase adds to Phase 1 by recommending actions that the customer can take based on the installed technologies within their homes. Customers can ask for these recommendations at any time and the system attempts to not repeat the same suggestions twice in a row. Also, it provides 2 recommendations on two different classes of end-uses, e.g., HVAC and Water Heating, HVAC and Appliances, etc. For instance, Alexa may suggest the following:
        - Avoid running the dishwasher or doing laundry during the peak hours.
        - Increase the thermostat setpoints to reduce the energy used by the A/C.
        - Turn off excess lighting to reduce energy usage during peak hours.
- Phase 3: Bill and Energy Consumption Calculations and Understanding
    - This phase adds a means for proactive engagement with the Alexa platform. Users can engage with Alexa by asking questions regarding their daily and weekly energy use (and estimated energy bill). Backend data collection through the AMI meter and analytics provides real-time calculations of energy usage for specified lengths of time and estimates energy bills.
- Phase 4: Automatic Load Control
    - This phase adds the ability for the customer to opt-out/opt-in to automatic control of their smart devices (smart thermostats) to reduce energy consumption during peak hours. For instance, during peak hours, the temperature heating setpoint on the thermostat may be lowered, and cooling setpoint may be increase to reduce usage. The customer can opt out of the mode during the peak hours if their comfort is impacted.

For each phase of implementation, Alexa provided analytics are used to measure customer interaction and engagement. The AMI data collected will be compared during periods of low and higher engagement to understand indicators of efficacy of the feedback mechanism. Finally, during Phase 4, AMI and thermostat operating data are collected to understand energy impacts when automation is active vs. when automation is not active and allows attribution of energy impact to thermostat control.

Figure 7 illustrates the design of the Alexa voice assistant engagement, with the back-end data and analytics informing the signals sent to the device as well as calculating the responses to specific user prompts.

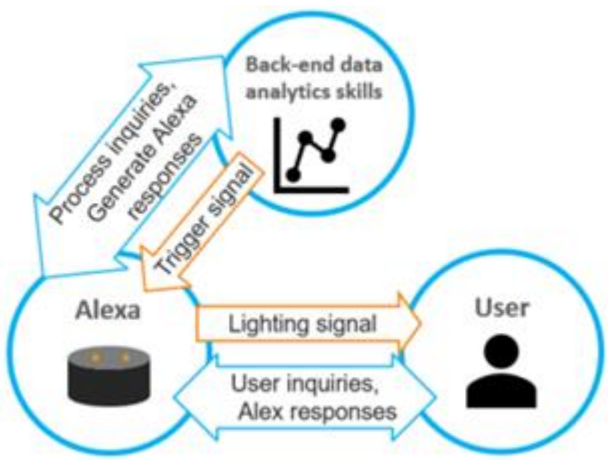

FIGURE 7 – INFORMATION FLOW BETWEEN USER, AMAZON ALEXA, AND BACKEND SERVER

Phases 1, 2, 3 and 4 will follow a pre-designed schedule that accounts for the following rationales:

- Electricity price follows TOU rate structure in which the customers are enrolled.
- The experiment trial will be divided into treatment weeks and non-treatment weeks to allow distinguishing the impact of the treatment to energy use.
- During the treatment week, Alexa will send notifications for high TOU rates along with thermostat DR messages. During the non-treatment weeks, no DR signal will be sent.
- To distinguish the effect of engagement signals from the seasonal consumption, at least one treatment week and one non-treatment week should be scheduled in the same summer or winter season.

The impact of the engagement signal to end user behavior is measured by the metrics defined in Table 2, including energy use, HVAC runtimes, and setpoint shifts.

TABLE 2 – COMPUTED PARAMETERS THAT HELP TO PROVIDE FEEDBACK TO CUSTOMERS

METRIC	DEVICE	TIMESCALE
Baseline Energy Use	AMI	Fortnightly window (last 14 days)
On-going Energy Use	AMI	Daily, Weekly
HVAC Runtime	Thermostat	Daily

TESTING SCHEDULE

PHASE 1

Phase 1 testing which involves notification will be conducted twice a week at two different times (for example, at 8am and at 3pm). The idea of sending the TOU message during the 3pm timeframe is to enable a more timely notification, which could lead to action. Phase 1 testing was conducted in July 2020.

PHASE 2

Phase 2 testing involves notifications following Phase 1 schedule but with additional prompting the user to ask for recommendations to reduce energy use. When the customer asks for recommendations, two recommendations are provided from a configured library of energy saving tips which include tips from 3 different category of end-uses, namely, HVAC, Water Heating, and Appliances. To keep the recommendations fresh and non-repetitive, the skills are randomized to prevent repetitions twice in a row. Phase 2 testing was conducted in August 2020.

PHASE 3

Phase 3 testing involves providing feedback on energy use and estimated energy bills. Notifications are augmented with information on how the user could check on their energy use. Users can check their energy use for the day, previous day, the current week, or the previous week. The user will receive a response that indicates how their energy is used compared to a two-week moving window based hourly baseline. Phase 3 was introduced mid-August (Aug 10, 2020 onwards).

PHASE 4

Phase 4 testing involves adding an automation backend that integrates the Alexa skill with Ecobee's API and DR signaling capability. DR signals are issued on a daily basis during peak TOU rate periods. DR signals are customized to each customer based on a learning model that determines the customer's "comfort band" and does thermostat offsets based on the comfort band. Phase 4 was conducted from Nov 1, 2020 thru Dec 24, 2020.

VOICE INTERACTION FLOWS

The voice interaction flows outline the specific types of voice prompts that the Alexa skill was programmed to understand and provide responses. While these interactions were added with each subsequent phase adding on top of existing interaction provided in the previous phase, there is no necessity for a customer to go through the interactions sequentially. The actual prompts used in the interactions are documented in the Appendix.

Phase 1

The major interactions in Phase 1 are driven by proactive notifications sent to the customer regarding TOU rate change events. Additionally, Phase 1 also involves standalone interactions where users can enquire about their current rate and upcoming rate change events (see Figure 8).

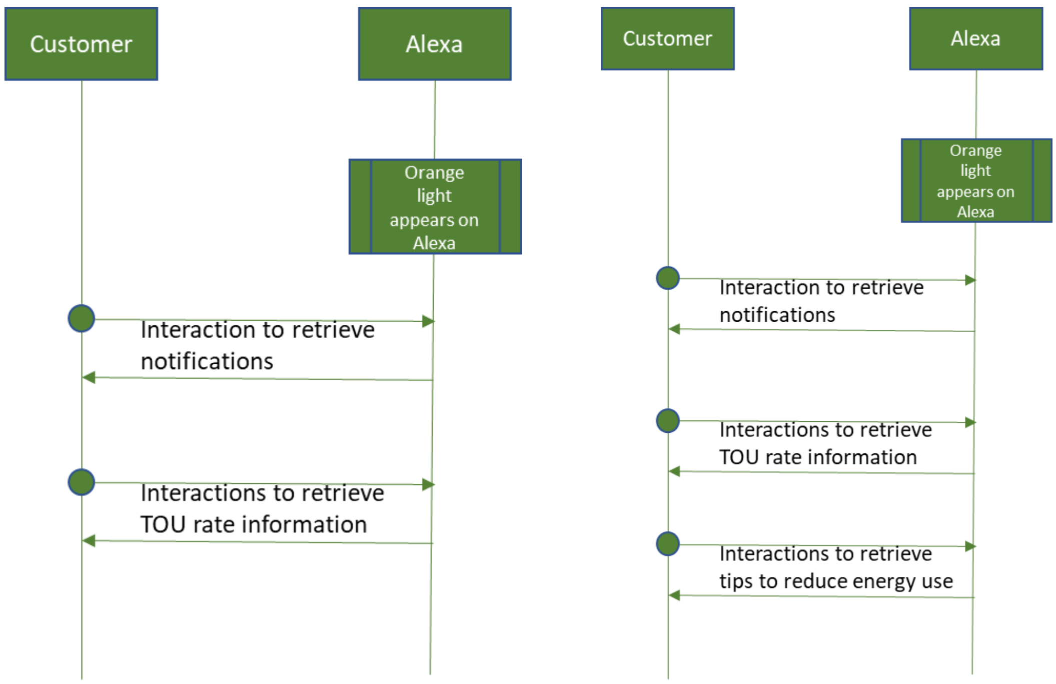

Figure 8 – Interaction model for Phase 1 (left) and Phase 2 (right)

Phase 2

Phase 2 interactions include the ability for the customer to request tips for saving energy during high TOU rate periods. This is done in addition to the Phase 1 interactions (see Figure 8).

Phase 3

Phase 3 interactions take advantage of the availability of the Rainforest AMI data on a real-time basis, to provide feedback to the customer on the cost of electricity use. This cost is estimated based on the interval AMI data and the TOU rates. In addition to the estimated cost of energy used, the interaction also provides a baseline cost of energy used based on the previous fortnight (14-day rolling window). This is done to adjust for seasonal variations in energy use (see Figure 9).

Phase 4

Phase 4 interactions are pertinent to only those households that had an Ecobee thermostat that could be added to a utility DR program via Ecobee's Utility Portal. Of the four homes with Ecobee thermostats, one of them was part of an existing SDG&E DR program so it could not be added to the study. The resulting three households could use Phase 4 interactions which allow users to opt-out (and opt-in) to automated control of their thermostats for energy management during peak TOU periods (see Figure 9).

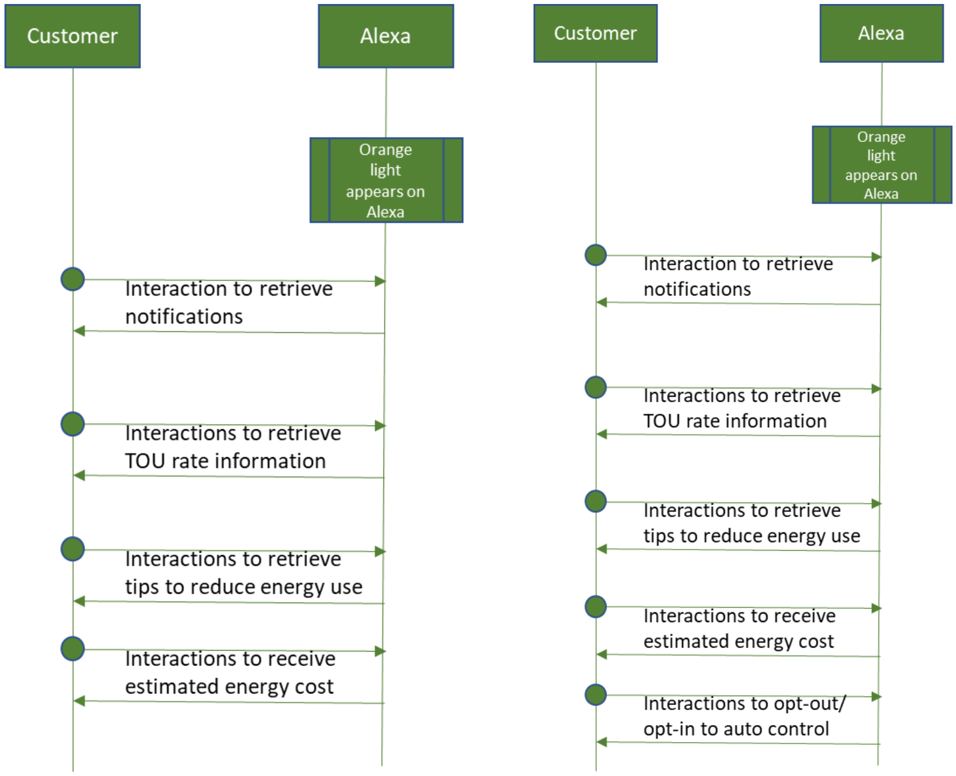

FIGURE 9 – INTERACTION FLOWS FOR PHASE 3 (LEFT) AND PHASE 4 (RIGHT)

DATA COLLECTION AND PROCESSING

DATA ARCHITECTURE

The architecture for data acquisition and control using Amazon Echo in conjunction with Ecobee thermostats and Zigbee enabled smart-meter and Rainforest Eagle is shown in Figure 10. The diagram depicts how data flow between the Amazon Echo (which is at the customer's premise) and the custom Alexa Skills backend server. The Alexa Skills server gets SDG&E TOU rates from Demand Side Resource Integration Platform (DSRIP) which, has a repository of all three CA IOU TOU and EV rates. The Alexa Skills server also performs the computations necessary to obtain each customer's comfort band to determine the DR settings during peak TOU rate periods.

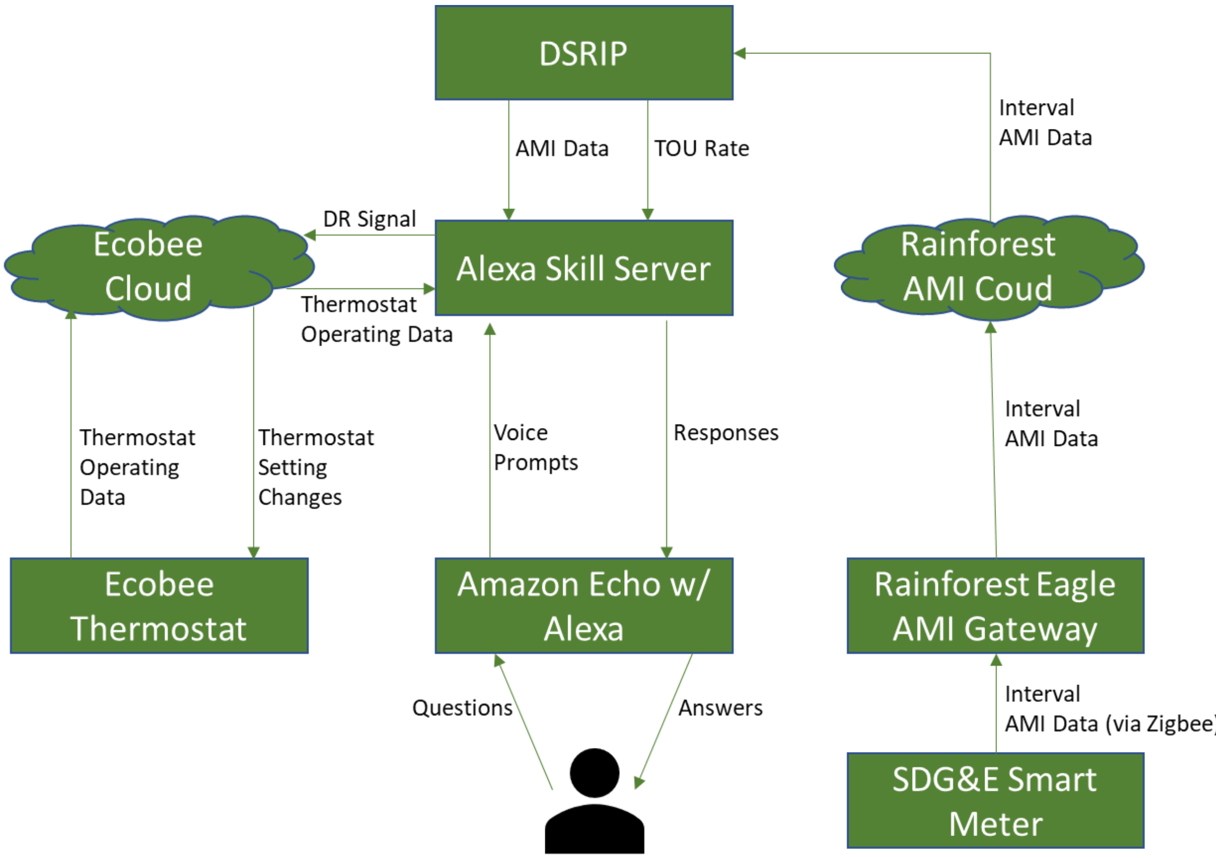

FIGURE 10 - DATA ARCHITECTURE FOR THE PROJECT

RESULTS OF PILOT STUDY AND DISCUSSION

This chapter discusses the results of the pilot study. The overall set of results are categorized into three subcategories:

- Customer Engagement: Results on how customers engaged with the custom Alexa Skill to get information pertaining to rates, recommendations for reducing energy use, quantitative feedback on energy use, and opting-out/opting-in to automated controls.
- Thermostat Data Analysis: Results which indicate customer's comfort preferences and before and after HVAC runtimes from running DR events during TOU peak rate periods.
- Energy Performance Analysis: Results which indicate the energy performance as it relates to different phases of the Pilot study including Phase 4.

CUSTOMER ENGAGEMENT DURING DIFFERENT PHASES

Customer engagement is measured using Amazon Alexa analytics which provides the average number of sessions per user which is defined as:

$$Average\ Session\ Count = \frac{Total\ Number\ of\ User\ Sessions}{Total\ Number\ of\ Active\ Users}$$

PHASE 1

Figure 11 shows the Average Session Count for Phase 1 as of Jul 21, 2020. This period from Jul 1 thru Jul 20, 2020 will be used as the treatment period in Energy Performance analysis as well to correlate the observed usage of the Phase 1 voice interactions to the energy performance. Each session report includes a breakdown of interactions including the identification of successful and failed voice interactions, and interactions that had other anomalous behaviors such as taking too long to respond causing the user to terminate (labeled "In Process/Expired") and not receiving required information from user (labeled "User Did Not Respond"). As may be observed, the simplicity of the interaction models in Phase 1 resulted in successful interactions without any anomalies.

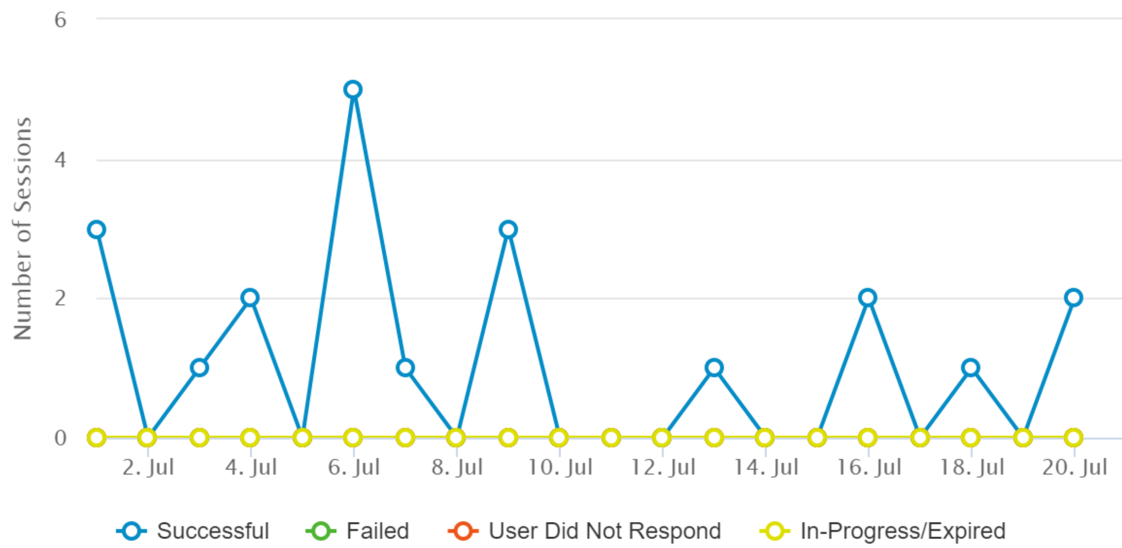

FIGURE 11 – AVERAGE NUMBER OF SESSIONS PER USER IN PHASE 1

With the exception of the first few days where customers may have wanted to check more often, the average number of sessions per user is down to a few and only occurs on days when the notifications are sent. This establishes a baseline for usage.

PHASE 2 & 3

Figure 12 shows the average number of sessions per user corresponding to Phase 2 and 3. This covers the period from Aug 1 thru Aug 31, 2020. The feedback feature was added on Aug 10, 2020 and the number of sessions tapers off after Aug 26, 2020. While the results indicate high customer engagement (and significantly higher compared to Phase 1), the overall period from Aug 1 thru Aug 31 can be split into 2 blocks: 1) Aug 1 thru Aug 9 and Aug 26 thru Aug 31 as a "low-engagement" block, and 2) Aug 10 thru Aug 25 as the "high engagement" block, allowing a study of the energy impacts of these two periods separately.

While the engagement levels are higher in Phase 2 & 3 compared to Phase 1, there were a few instances especially around Aug 9, 2020 where several interactions failed (labeled "Failed") and on occasion a few transactions were too long for the customer who cut off the interaction (labeled "In-Progress/Expired"). Overall, the levels of successful engagement were higher.

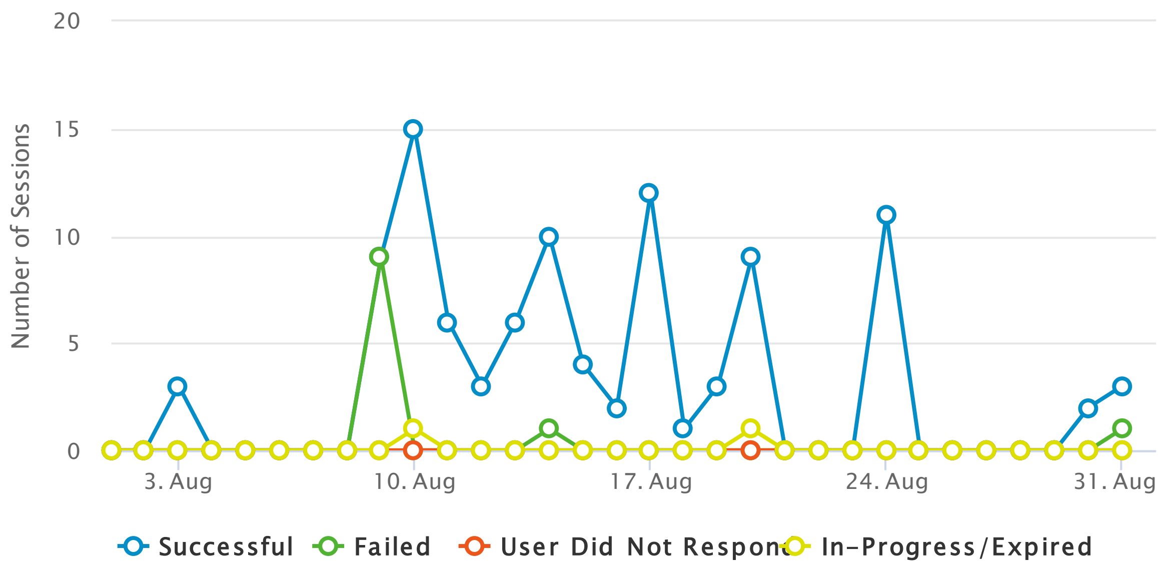

FIGURE 12 – AVERAGE NUMBER OF SESSIONS PER USER IN PHASE 2 AND 3

PHASE 4

Given that Phase 4 was open to only a smaller subset of the total homes in the study, there was no appreciable user engagement activity pertaining to opt-outs/opt-ins in Phase 4.

THERMOSTAT DATA ANALYSIS

The next set of analyses use data collected from the three Ecobee thermostats that were enabled for participation in DR programs.

This analysis formulates a baseline for the Phase 4 (Automated TOU Rate Management) part of the project.

Three types of analyses were performed with the data:

1. Runtime characterization – develop an understanding of the HVAC usage (measured via thermostat run times) on a monthly basis and focus on the usage specifically for the high TOU rate (4pm-9pm) period.
2. HVAC hourly profile – develop a HVAC usage shape (as a proxy) for the HVAC load shape. This analysis informs when HVAC is being used, focus on customers who may/may not be aware of TOU rates and behaviorally regulate their HVAC usage during high TOU rate periods.
3. Comfort model – develop an understanding of the range of room temperatures in which the customer's HVAC is not running (and when the thermostat is not in

vacation[5] mode). Focusing on high TOU rate hours, this helps to understand what temperature ranges the customer may be able to tolerate without having to manually override/opt-out of automated control.

High Level Results – Phase 1 thru 3

HVAC Runtime Characterization: There is an (as expected) positive correlation between HVAC runtimes and max outdoor temperature. The max outdoor temperature has similar influence on the HVAC runtimes during the high TOU rate periods (4pm-9pm). The runtime characterization plots shown in Figure 13 for Home 3 indicates this trend which is further supported by visualizing the correlation of HVAC runtimes to outdoor temp (See Figure 14). The vertical bars are the runtimes, and the line plot represents maximum outdoor temperature. The visual indicator for taller bars (more HVAC runtime) coincident with peaks in the outdoor temp line plot is indicative of positive correlation. The same trends may be observed in the runtime plots for the 4-9pm timeframe as well. The correlations plotted out in Figure 14 show very similar trendlines with almost the same R^2 (goodness-of-fit) measure (0.42 vs. 0.44).

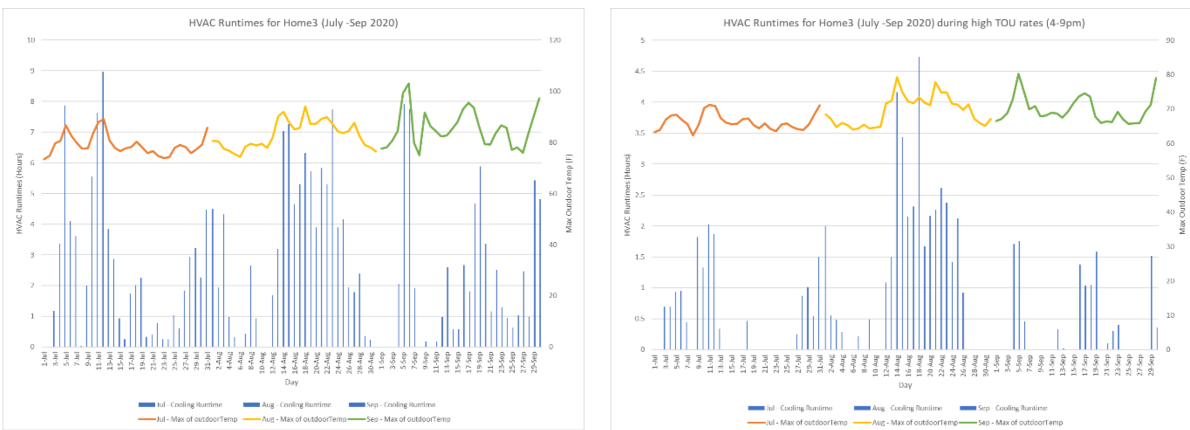

Figure 13 – HVAC Runtime visualization for July thru Sep 2020

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5 Vacation mode refers to a specific state of the thermostat where the occupants are away from home (the home is unoccupied) for a long period of time and scheduled HVAC operations can be temporarily turned off.

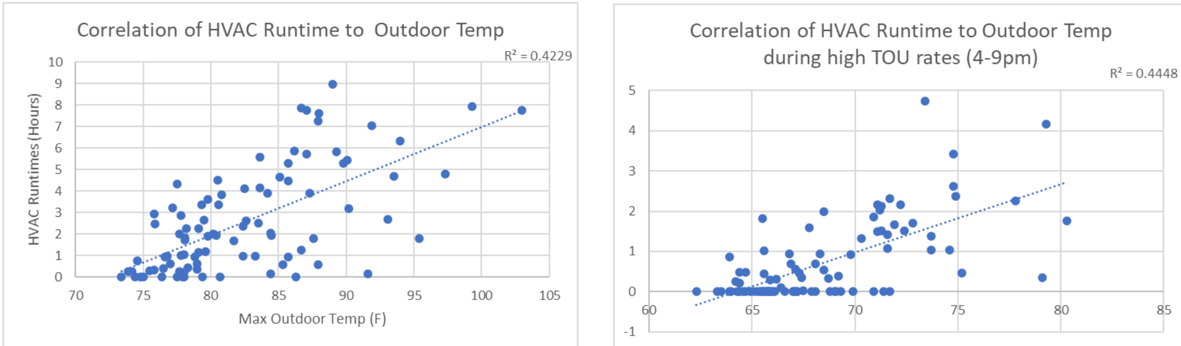


FIGURE 14 – CORRELATION OF HVAC RUNTIMES TO MAX OUTDOOR TEMP SHOWING SIMILAR OVERALL TREND

HVAC Hourly Profile: The purpose of this analysis and visualization is to understand when customers are using their HVAC system. This will help identify which of the homes is likely to benefit from active interventions for energy management during high TOU rates. The hourly profiles indicates that some homes, e.g., Home 3 has high HVAC usage during high TOU rate hours whereas Home 6 has minimal HVAC usage during the same time periods potentially indicating better awareness of TOU rates and energy use impact during TOU hours.

FIGURE 15 – HOURLY HVAC PROFILES FOR HOME 3 (LEFT) AND HOME 6 (RIGHT) SHOWING DIFFERENCES

Comfort Band: The comfort band for a customer is calculated using a technique that establishes the bounds of a distribution of indoor temperatures where the customer is comfortable, i.e., HVAC is not running. The comfort band for each enrolled thermostat showed values that varied month-over-month. The range of temperatures are dependent upon the ambient temperature with Nov and Dec showing much wider comfort bands compared to July, Aug, and Sep. The histogram for Home 3 and Home 6 for July are shown in Figure 16. Given the need for a sample size that is sufficient for establishing the distribution while also accommodating for seasonal changes in occupant preferences, a 30-day (monthly) window was adopted for determining comfort bands to use in TOU energy management.

TABLE 3 – COMFORT BAND TEMPERATURE RANGES BY MONTH FOR DIFFERENT THERMOSTATS

MONTH	HOME 2	HOME 3	HOME 6
July	75.5 – 78.5	72 – 77	71 – 76
Aug	76.5 – 81.5	74 – 78	71 – 78
Sep	75.5 – 81.5	75 – 79	72 – 77
Nov	70 – 81	67 – 83	69 – 80
Dec	67 – 78	67 – 81	69.5 – 81

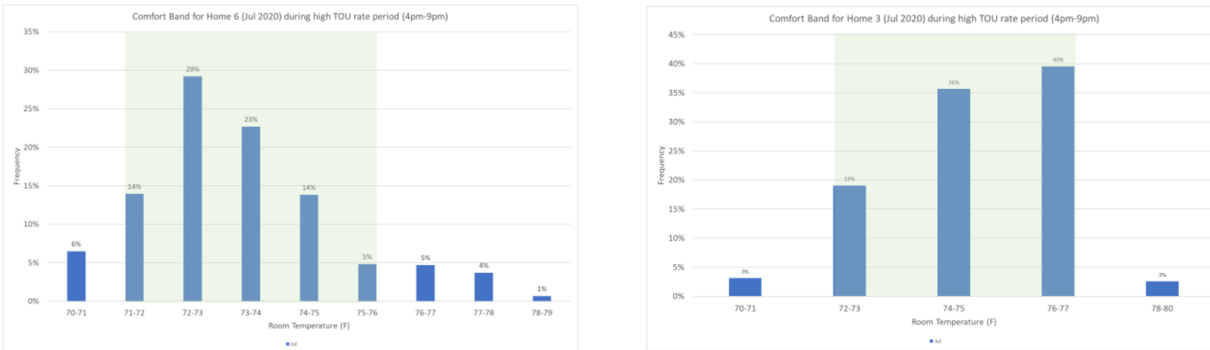


FIGURE 16 – COMFORT BAND FOR HOME 6 (LEFT) AND HOME 3 (RIGHT) SHOWING

HIGH LEVEL RESULTS – PHASE 4

In Phase 4 a comparison of the HVAC hourly profile during non-treatment periods and treatment periods is performed. Table 4 shows the treatment and non-treatment periods for Nov and Dec 2020.

TABLE 4 – PHASE 4 NON-TREATMENT AND TREATMENT PERIODS

MONTH	NON-TREATMENT PERIOD	TREATMENT PERIOD
November 2020	Nov 1 – Nov 9, 2020	Nov 10 – Nov 18, 2020
December 2020	Dec 1 – Dec 12, 2020	Dec 13 – Dec 24, 2020

HVAC Hourly Profiles: In Phase 4, the HVAC hourly profiles were actively managed especially during the 4-9pm timeframe (high TOU rate hours) by automatic control of thermostats using Ecobee's DR signaling API. The results for Home 3 and Home 6 are shown in Figure 17 and Figure 19 respectively for Nov and Figure 18 and Figure 20 respectively for Dec. The broad observation is that the DR signaling was effective in reducing (and in some cases eliminating) HVAC usage during the 4-9pm timeframe. However, as may be observed there were some opt-outs that resulted in minor amounts of use in Home 3 by observing that non-zero HVAC activity during the 4-9pm timeframe.

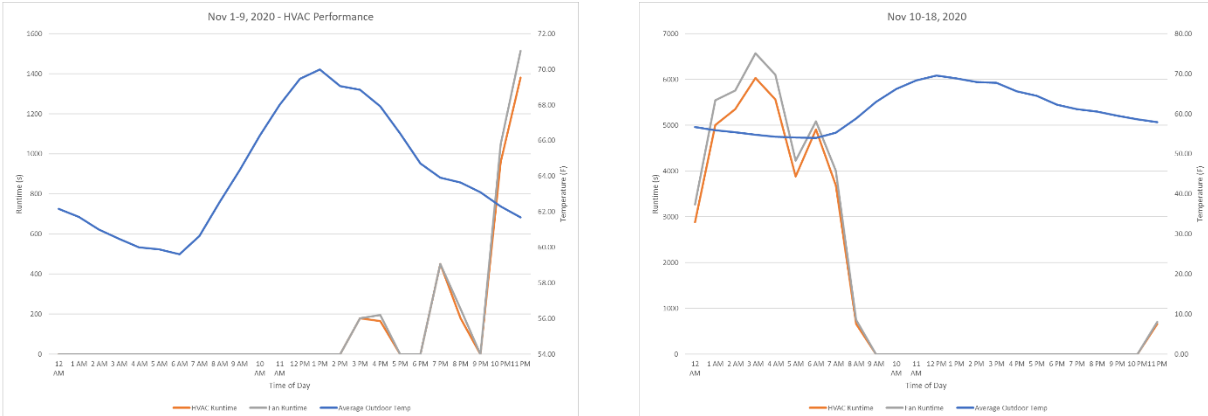


FIGURE 17 – HVAC HOURLY PROFILE FOR NON-TREATMENT (LEFT) AND TREATMENT (RIGHT) PERIODS FOR HOME 3 IN NOV

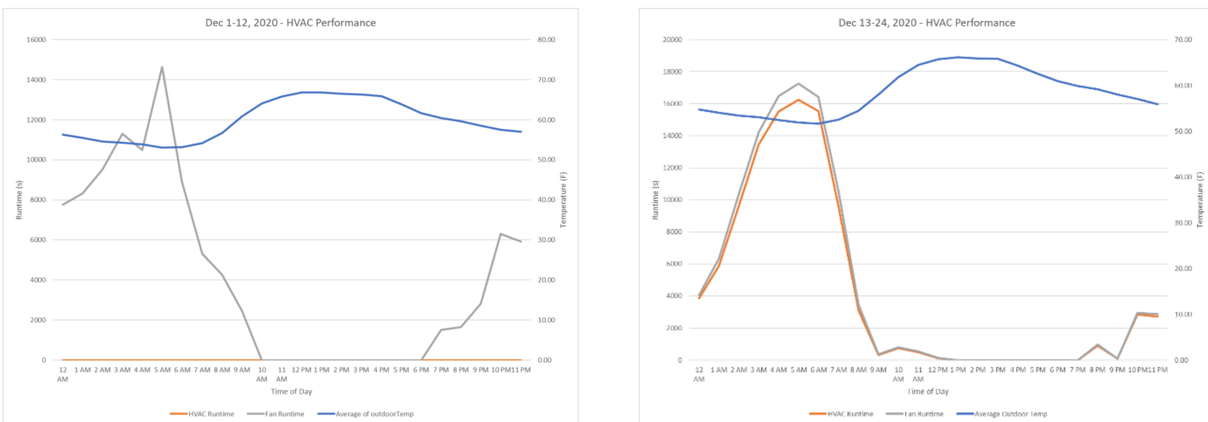


FIGURE 18 – HVAC HOURLY PROFILE FOR NON-TREATMENT (LEFT) AND TREATMENT (RIGHT) PERIODS FOR HOME 3 IN DEC

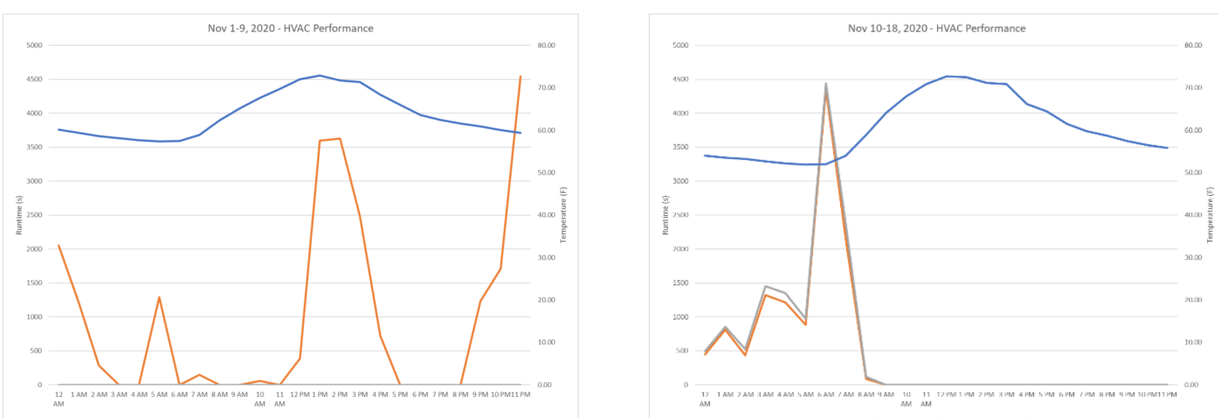


FIGURE 19 – HVAC HOURLY PROFILE FOR NON-TREATMENT (LEFT) AND TREATMENT (RIGHT) PERIODS FOR HOME 6 IN NOV

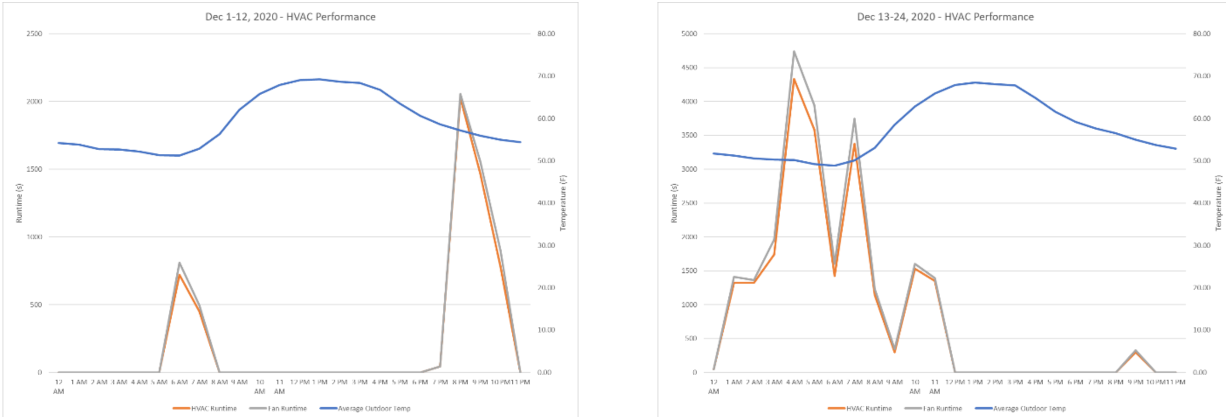


FIGURE 20 – HVAC HOURLY PROFILE FOR NON-TREATMENT (LEFT) AND TREATMENT (RIGHT) PERIODS FOR HOME 6 IN DEC

ENERGY PERFORMANCE ANALYSIS

The energy performance analysis identifies energy performance for one home (as a sample) for July and Aug 2020 corresponding to Phase 1 and Phase 2. For Phase 4, the energy performance analysis is performed for all three homes with Ecobee thermostats.

PRE-PHASE 4 ENERGY PERFORMANCE

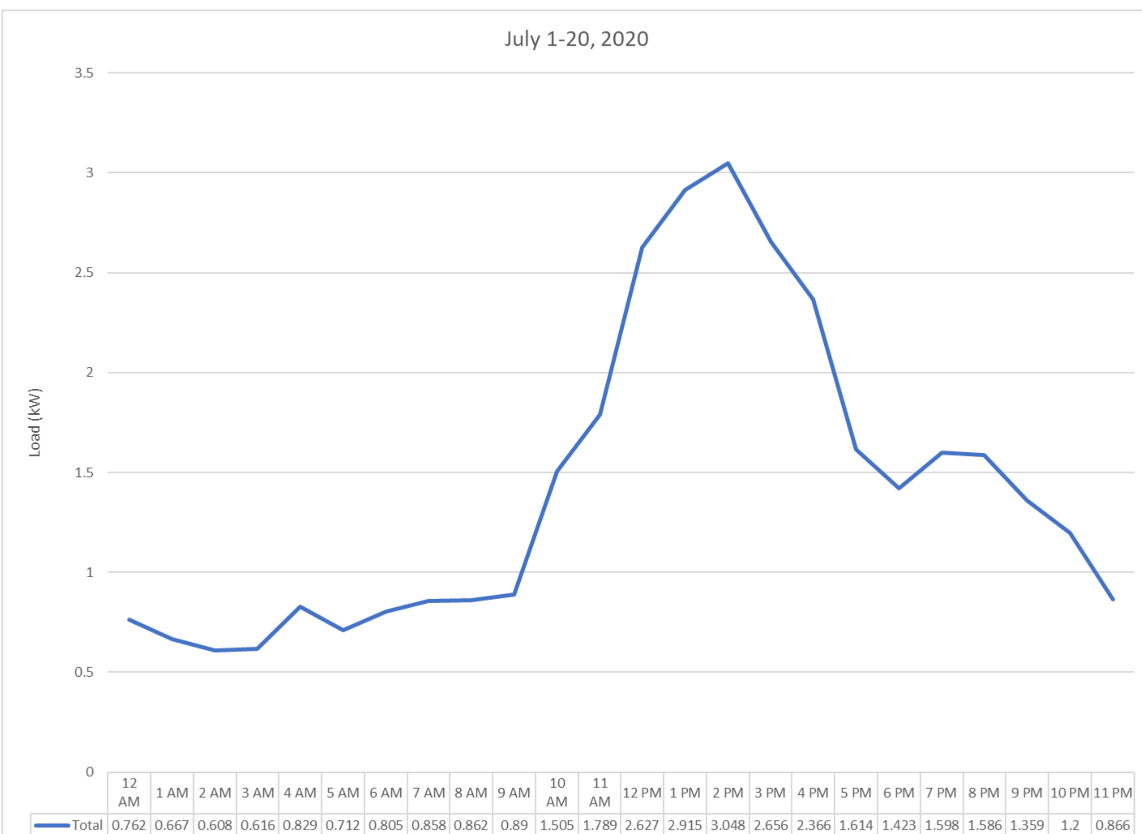
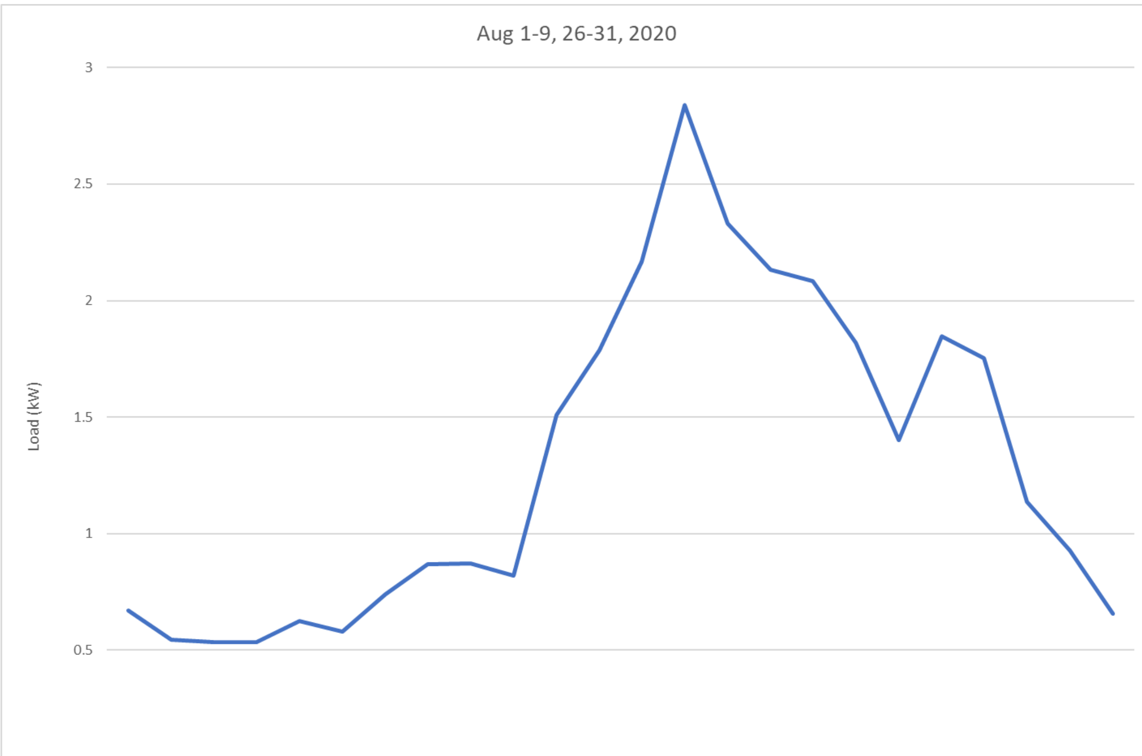


FIGURE 21 – LOAD PROFILE FOR HOME 4 DURING THE PERIOD OF PHASE 1 (NOTIFICATION)

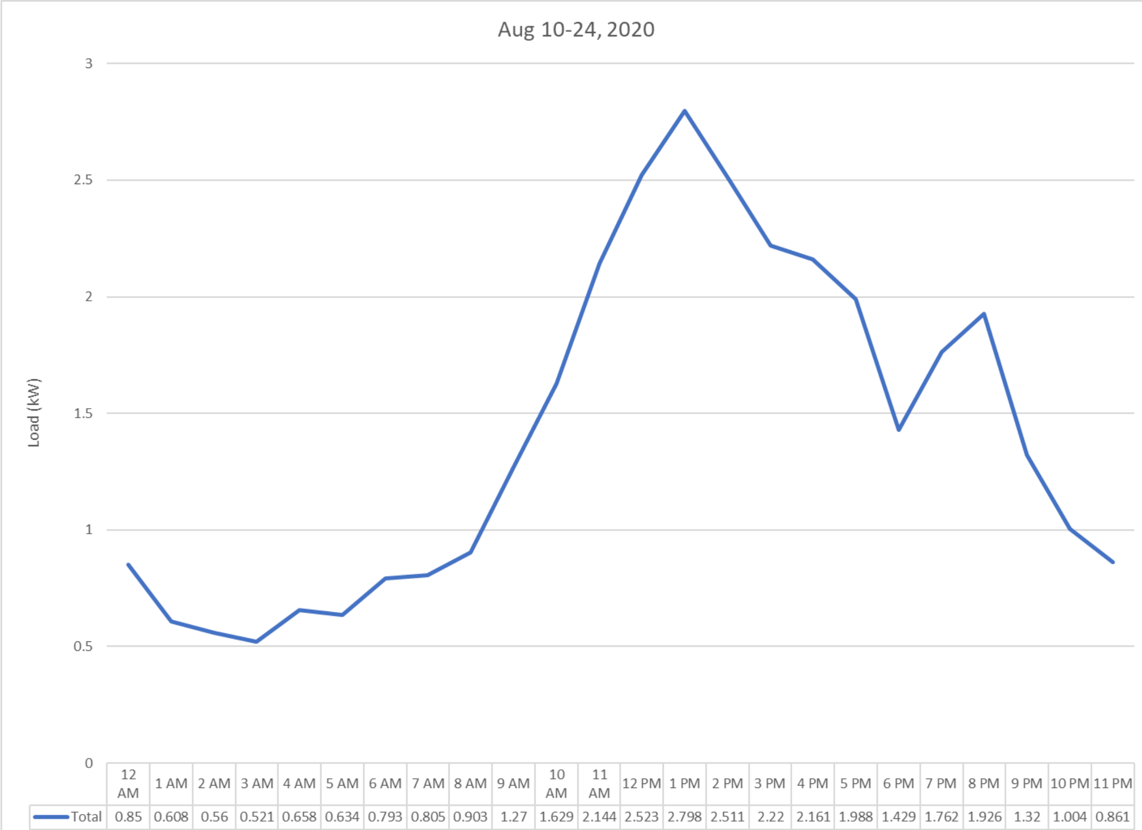
Figure 21 shows the energy performance for Home 4 during the treatment period in July 2020 (Jul 1 – Jul 20). July 2020 saw a high number of cooling degree days (115.8) based on a 65F baseline. Cooling degree days (CDD) correlate strongly with HVAC usage. This establishes a baseline to study the significance of Phase 2 & 3 (Recommendations and Feedback) on the energy performance in pre-Phase 4 period.

Figure 22 and Figure 23 shows the energy performance during Phase 2 & 3. The hourly load profile peaks around 1pm at 2.84 kW for Home 4 during the period of low-engagement (Aug 1-9, 26-31). Comparing this to the peak energy use during high engagement period (Aug 10-25) which peaks around 1pm at 2.79 kW.



	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
Total	0.671	0.544	0.534	0.536	0.626	0.578	0.741	0.868	0.872	0.82	1.508	1.787	2.166	2.838	2.332	2.133	2.084	1.82	1.402	1.846	1.754	1.136	0.928	0.656

FIGURE 22 – LOAD PROFILE FOR HOME4 DURING PERIODS OF LOW ENGAGEMENT IN AUG 2020



	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
Total	0.85	0.608	0.56	0.521	0.658	0.634	0.793	0.805	0.903	1.27	1.629	2.144	2.523	2.798	2.511	2.22	2.161	1.988	1.429	1.762	1.926	1.32	1.004	0.861

FIGURE 23 – LOAD PROFILE FOR HOME4 DURING HIGH-ENGAGEMENT PERIOD IN AUG 2020

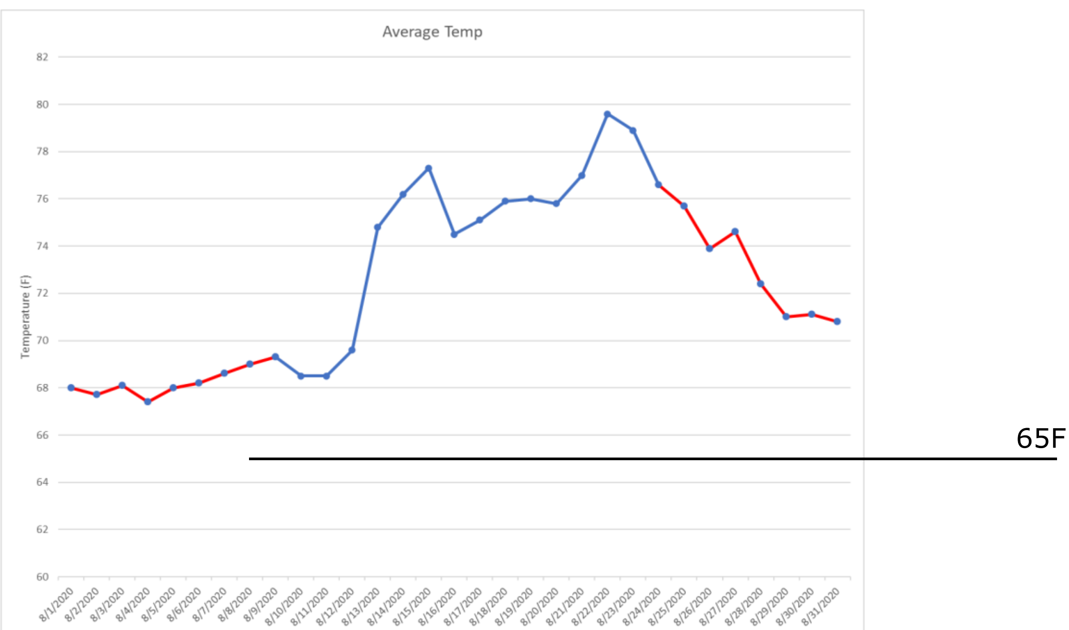


FIGURE 24 – TEMPERATURE PROFILE FOR AUG 2020 SHOWING COOLING DEGREE DAYS

As is evident from the temperature profile (Figure 24), the number of cooling degree days are significantly higher (160 CDD) during days of high engagement compared to days of low engagement (73.1 total). However, the peak load during the period of high engagement is 2.79 kW at 1pm compared to 2.84 kW at 1pm during the period of low engagement. To better quantify the amount of energy consumed during the high engagement period relative to the treatment period July (July 1-20), we further analyzed the CDD dependency of the July and August energy use profiles.

To establish a baseline with July 2020 data, the correlation between daily energy consumption in July 2020 as a function of CDD was drawn. Figure 25 shows the correlation of daily energy consumption to CDD for July 2020.

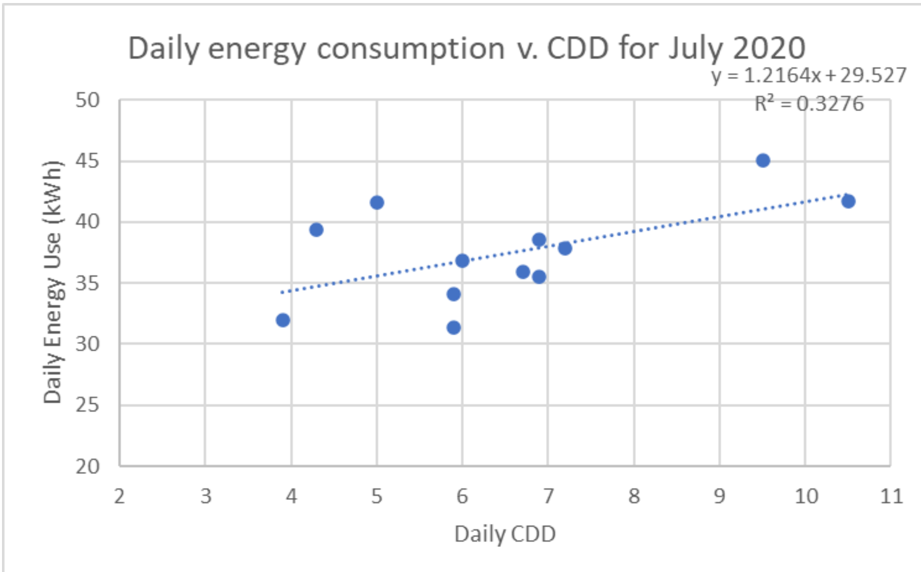


FIGURE 25 – DAILY ENERGY CONSUMPTION AS A FUNCTION OF CDD IN JULY 2020

Using the baseline of July 2020, an expected consumption for August 2020 for the high engagement period is calculated using the linear regression shown in Figure 25 and compared to the actual usage in August 2020. This comparison is shown in Figure 26[6]. This shows a consistent reduction in energy use compared to "expected" use based on CDD.

[6] The data collection on Aug 25th was not sufficient (large period of loss of connectivity) and consequently Aug 25 was excluded from the expected vs. actual calculation.

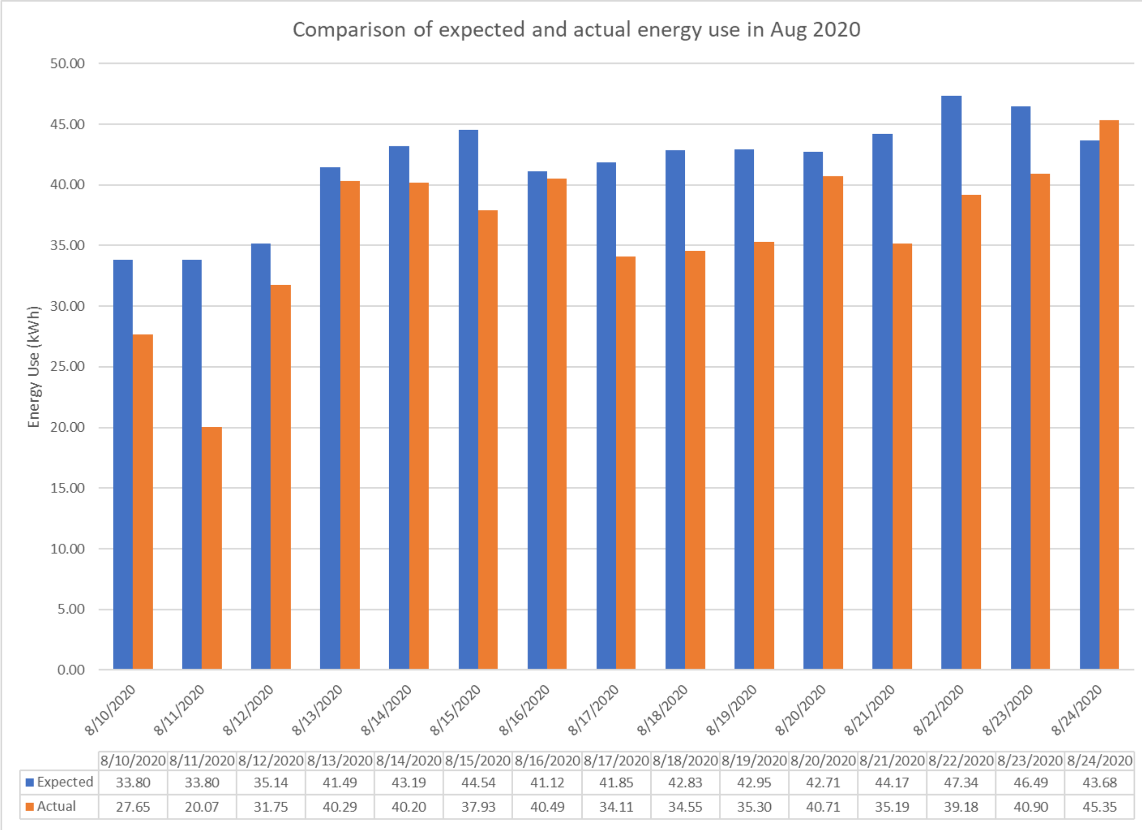


FIGURE 26 – COMPARISON OF EXPECTED AND ACTUAL ENERGY CONSUMPTION DURING HIGH ENGAGEMENT PERIOD IN AUG

Overall, the reduction of energy use and peak energy use suggests that the use of recommendations and feedback has had an impact. This when compared to the peak of 2.92 kW in July 2020 where the total CDD was lower (115.8) also suggests that providing recommendations and feedback helps over and above notifications.

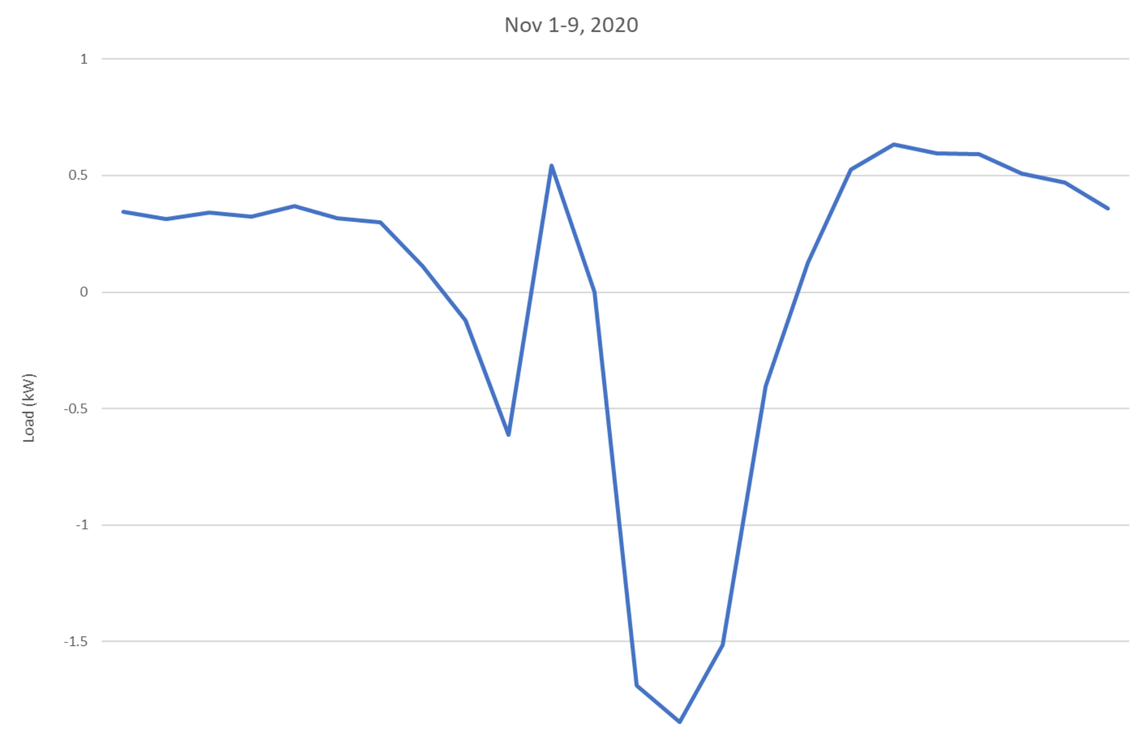
Given that the notifications and recommendations are related to the 4-9pm TOU peak hours, performing similar calculations specifically for the 4-9pm hours yields the results in Table 5. The results of energy consumption during the 4-9pm is slightly higher in Aug 2020 during high engagement period compared to Aug low-engagement period and July 2020. However, from Figure 26, we can observe that the actual energy use in Aug high-engagement period is lower than what is expected based on weather normalized Jul 2020 energy use pattern. The average difference is roughly 5 kWh per day. This suggests that higher engagement can lead to improved energy conservation.

TABLE 5 – ENERGY CONSUMED DURING 4-9PM FOR PHASE 1 AND PHASE 2 & 3 PERIODS

JULY 2020	AUG 2020 LOW ENGAGEMENT	AUG 2020 HIGH ENGAGEMENT
8.57 kWh	8.9 kWh	9.27 kWh

Phase 4 Energy Performance

Figure 27 shows the energy performance for Home 3 for the non-treatment period of Nov 2020. Home 3 has a rooftop solar which allows the load to tip close to ~ -2kW in the middle of the day. Comparing that to the treatment period (Figure 28), the difference is not significant. In Dec 2020, the comparison of non-treatment (Figure 29) to treatment (Figure 30) indicates a shift in the peak to the 9pm hour (post TOU peak hours). The ensuing shift in the peak causes a relative flattening of the load shape in the 4-9pm timeframe (see Figure 30)



	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
Total	0.346	0.313	0.34	0.322	0.368	0.316	0.3	0.112	-0.12	-0.61	0.542	-0	-1.69	-1.84	-1.51	-0.4	0.124	0.527	0.634	0.597	0.593	0.508	0.471	0.359

Figure 27 – Load profile for Home 3 during non-treatment period in Nov 2020

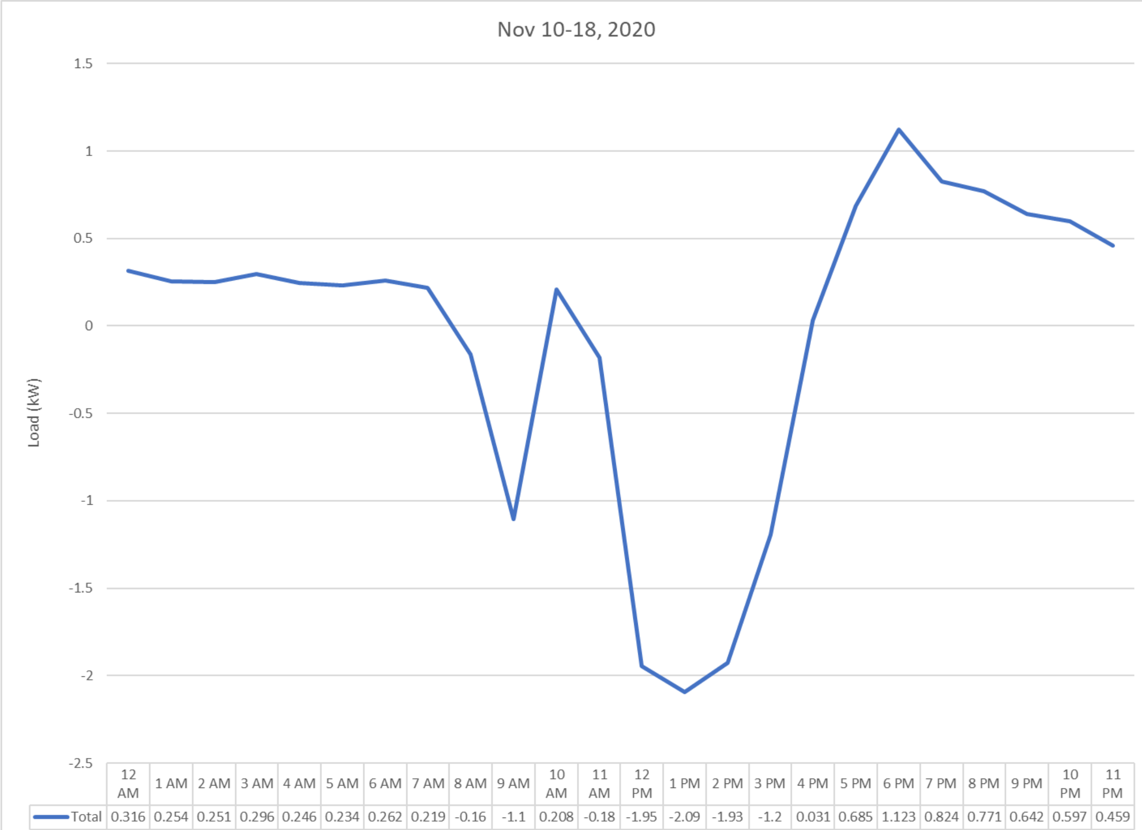


FIGURE 28 – LOAD PROFILE FOR HOME 3 DURING TREATMENT PERIOD IN NOV 2020

	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
Total	0.459	0.291	0.307	0.292	0.293	0.294	0.282	0.238	0.072	-0.33	1.191	0.601	-1.2	-1.26	-1.22	-0.57	0.384	0.69	0.89	1.207	1.31	0.991	0.707	0.449

FIGURE 29 – LOAD PROFILE FOR HOME 3 DURING NON-TREATMENT PERIOD IN DEC 2020

FIGURE 30 – LOAD PROFILE FOR HOME 3 DURING TREATMENT PERIOD IN DEC 2020

Home 3 energy performance results are summarized in Table 6 below. Even though Home3 HVAC hourly profile indicated reduced HVAC use in Nov 2020 and Dec 2020 (see Figure 20), the only improvement in treatment vs. non-treatment is in the energy use during 4-9pm in Dec 2020. This strongly suggests that HVAC may not a significant load contributor in this household during Nov and Dec.

TABLE 6 – HOME 3 ENERGY PERFORMANCE SUMMARY

METRIC	NON-TREATMENT PERIOD	TREATMENT PERIOD
Peak Load – Nov 2020	0.63 kW at 6pm	1.12 kW at 6pm
Energy Use during 4-9pm Nov 2020	2.475 kWh	3.43 kWh
Peak Load – Dec 2020	1.3kW at 8pm	1.60 at 9pm
Energy Use during 4-9pm Dec 2020	4.48 kWh	3.78 kWh

Figure 31 and Figure 32 shows the load profiles for Home 2 during the non-treatment and treatment periods of Nov 2020. The load shapes are quite different with the major 3 kW peak at 1pm has been reduced and the smaller peaks in the 4-9pm timeframe have also been reduced.

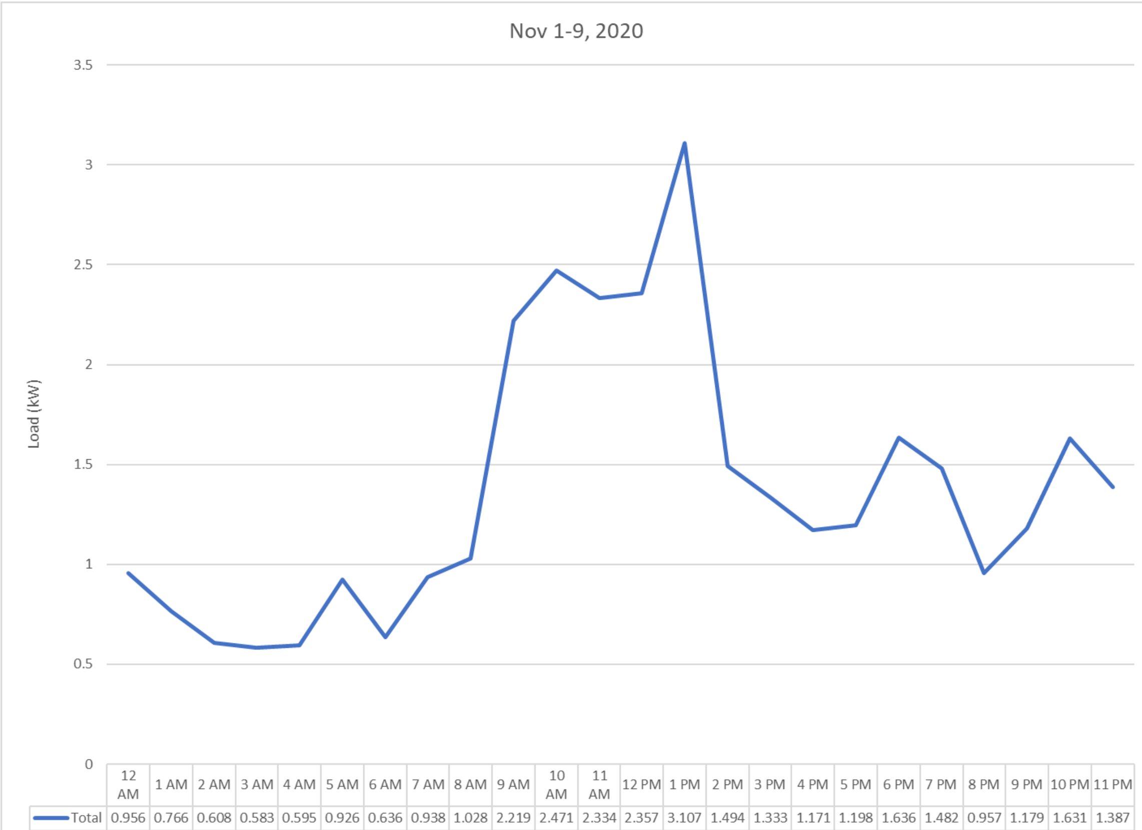


Figure 31 – Load profile for Home 2 during non-treatment period in Nov 2020

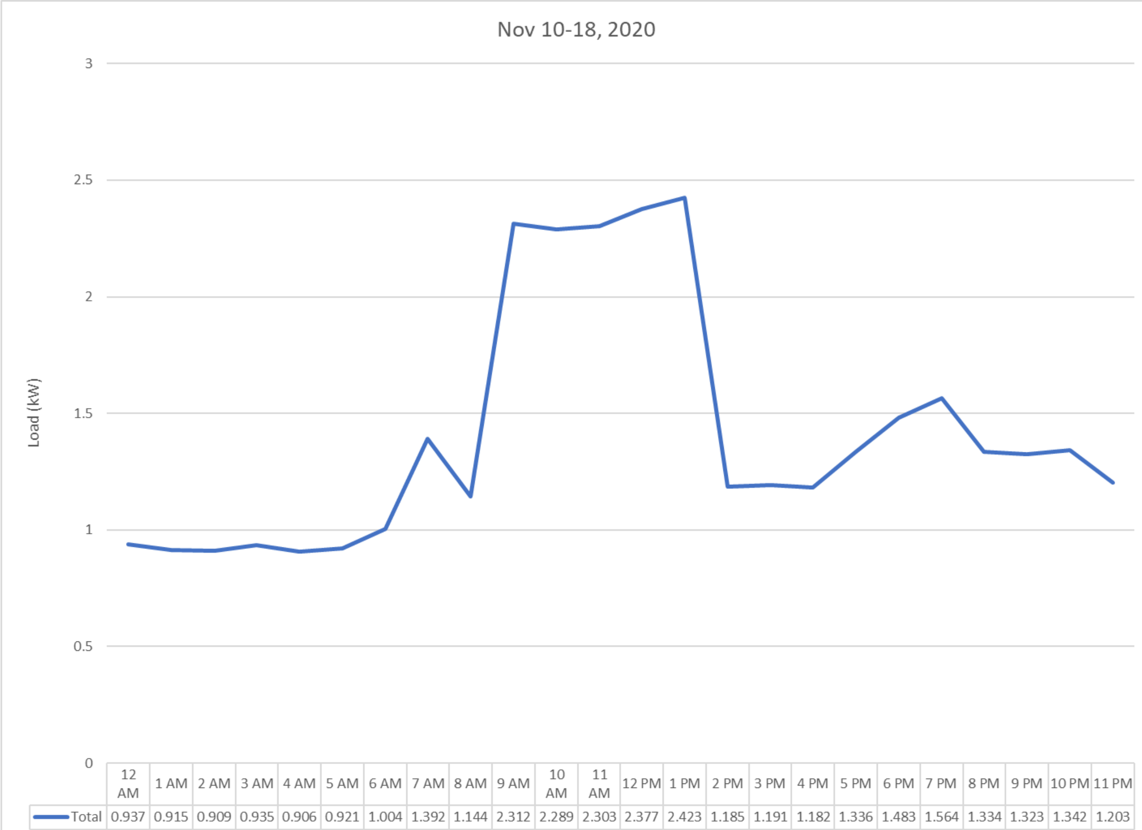


FIGURE 32 – LOAD PROFILE FOR HOME 2 DURING TREATMENT PERIOD IN NOV 2020

Home 2's results are summarized in Table 7[7]. The results indicate a positive impact of the use of Phase 4 automation in reducing overall peak demand but is not consistent with the HVAC hourly profile for non-treatment and treatment as related to energy use during 4-9pm timeframe which manifests as higher energy use during 4-9pm timeframe.

TABLE 7 – HOME 2 ENERGY PERFORMANCE RESULTS SUMMARY

METRIC	NON-TREATMENT PERIOD	TREATMENT PERIOD
Peak Load – Nov 2020	3.11kW at 1pm	2.42kW at 1pm
Energy Use during 4-9pm Nov 2020	6.44 kWh	6.89 kWh

Figure 33 and Figure 34 shows the non-treatment and treatment periods for Home 6 for Nov 2020. Even though the profiles are visually different, quantitative characteristics including peak loads are relatively similar. This pattern holds for Dec 2020 as well (Figure 35 and Figure 36).

[7] Home 2's AMI data feed was interrupted on Nov 30, 2020 and did not recover until April 2021. This meant that only results for Nov 2020 could be provided.

	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
Total	0.709	0.661	0.669	0.661	0.656	0.532	0.644	0.827	1.201	1.031	1.015	0.998	1.113	1.146	1.326	1.282	1.259	1.636	1.08	0.904	0.776	0.724	0.737	0.751

Figure 33 – Load profile for Home 6 during non-treatment period in Nov 2020

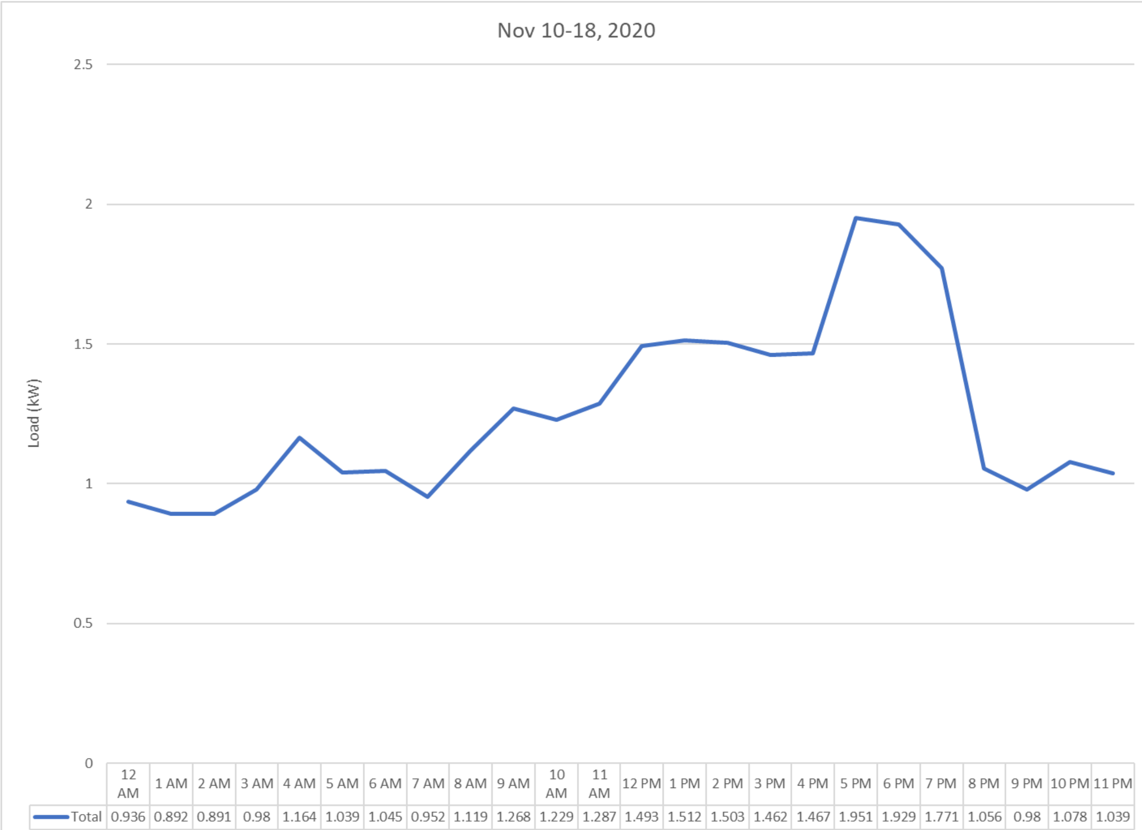


FIGURE 34 – LOAD PROFILE FOR HOME 6 DURING TREATMENT PERIOD IN NOV 2020

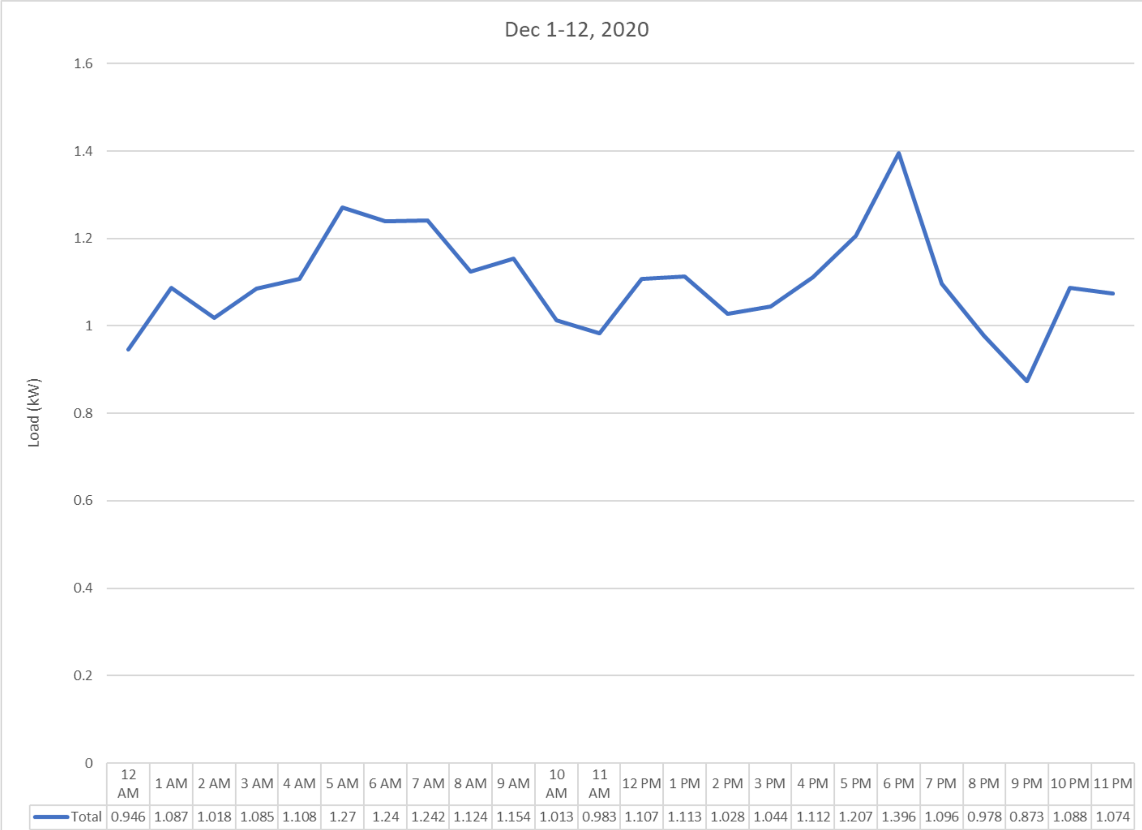


FIGURE 35 – LOAD PROFILE FOR HOME 6 DURING NON-TREATMENT PERIOD IN DEC 2020

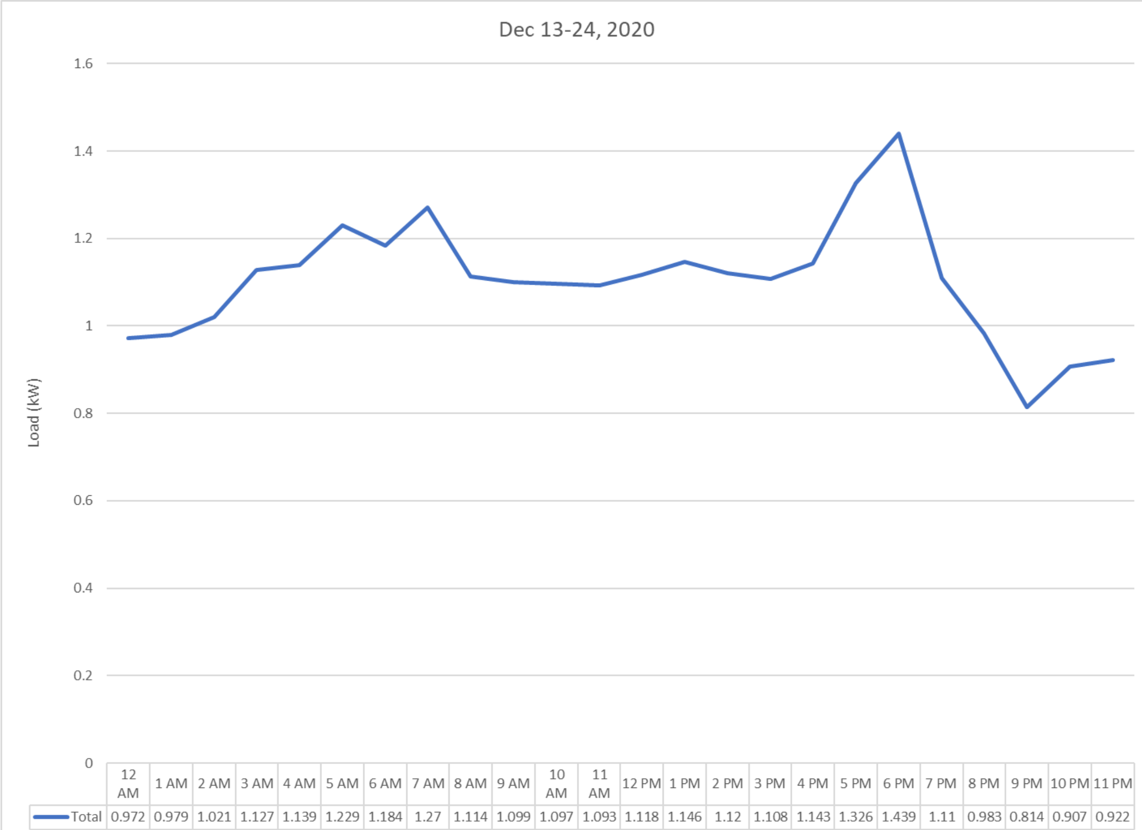


FIGURE 36 – LOAD PROFILE FOR HOME 6 DURING TREATMENT PERIOD IN DEC 2020

Home 6's results are summarized in Table 8. As with the other homes, the results on energy performance are not consistent with the reduced HVAC usage that is observed with the HVAC hourly profiles (Figure 20). As with the other homes, this could be related to HVAC not being a major contributor of load during the winter months.

TABLE 8 – HOME 6 ENERGY PERFORMANCE SUMMARY

METRIC	NON-TREATMENT PERIOD	TREATMENT PERIOD
Peak Load – Nov 2020	1.64kW at 5pm	1.95kW at 5pm
Energy Use during 4-9pm Nov 2020	5.67 kWh	8.17 kWh
Peak Load – Dec 2020	1.39 kW at 6pm	1.44 kW at 6pm
Energy Use during 4-9pm Nov 2020	5.79 kWh	6.00 kWh

DESIGN CONSIDERATIONS FOR CUSTOMER PROGRAMS

One of the key expected outcomes of this project is an understanding of how the results of this pilot study could be extended towards developing innovative customer programs that use Voice Assistants to engage with customers and induce energy conservation behaviors, especially during high TOU periods.

In taking the results and the lessons learned in this project, three main considerations are provided:

- **Design of user interactions**: Thoughtfully crafting the user interaction is crucial to getting better engagement and in-turn getting better energy conservation outcomes.
- **Using Alexa-Certified Skills**: One of the points of investigation is to understand the limitations of using a "private" or In-Development skill which can only support beta-testers for a period of three months. To overcome these limitations, processes need to be added to make sure that the Alexa Skill gets certified.
- **Availability of open APIs**: A key challenge is the availability of control APIs for end-use loads such as Ecobee thermostats and Rheem water heaters. With many of these APIs moving away from open APIs to closed APIs, the need to develop strategic automations has to be made part of the customer interaction.

DESIGN OF USER INTERACTIONS

One of the key outcomes of the pilot was the establishment of the need for careful design of user interactions. Amazon development toolkit provides excellent support for developing high quality user interactions and following a set of "rules of thumb" to make sure that the information that is presented is clear and concise. A couple of key considerations are listed:

- **Information provided in small chunks**: Amazon advises the use of the "One-breath rule" wherein information that cannot be conveyed in a single breath should be broken up to allow for a more natural conversation style. In the pilot, feedback messages on electricity use were typically long-winded and would not be considered "high quality" interactions even though the information presented is highly useful for the user. A suggestion for improving the user interaction is to engage a user-experience expert as part of the Alexa Skill design working as part of the Skill development team and to drive the overall system engineering based on the user experience that is defined with high quality interactions in mind.
- **Limiting the number of "Calls to actions"**: Another key aspect of user experience design is to reduce the number of call to actions in a single interaction. In the pilot study, recommendations were provided on two different end uses at a time. While this is useful, to make these recommendations highly impactful, it may be better to make them more customized to the user's context. For example, do not provide advice on reducing HVAC usage to cool in a house which does not have any air-conditioning loads.
- **Understand notification fatigue**: Repeatedly notifying customers about the same information is likely to lead to annoyance and may completely turn customers away

from using the skill. The pilot overcame this by designing notifications to be delivered twice a week at different times.

ALEXA CERTIFICATION PROCESS

Amazon uses a well-documented process for certifying Alexa Skills. There are two main steps involved in the certification process in addition to development and functional and beta testing.

- Skills need to satisfy Amazon's security and privacy requirements
- Skills hosted as web services on non-AWS servers (like those used in this pilot) must use a valid, trusted certificate for authentication and authorization of server-to-server communications. The server employed in the pilot uses Let's Encrypt which is a free Certificate Authority supported by Mozilla.
- Skills must comply with privacy requirements:
    - Skills should not collect personally identifiable information without sufficient privacy notice.
    - Skills should not collect sensitive information such as Social Security Number, Passport number, etc.
    - Skills should not provide information to the user without identifying the source of the information.
- Skills need to get published after certification
    - Conduct extensive functional testing
    - Skills are required to perform all the necessary functional testing.
    - Make sure to cover all necessary built-in commands like "repeat that", "start over", "stop", etc.
- Conduct extensive UX testing
    - Skills are required to ensure that combinations of utterances and keywords (slots) are fully tested for errors.
    - Responses should meet Amazon's requirements for clarity, brevity, information content in consumable chunks, do not include technical or legal jargon, are easy to understand and "written for the ear, not the eye".

AVAILABILITY OF APIS AND IMPACT ON PROGRAM ROLLOUT

One of the key demonstrations in the pilot was the integration of Alexa Skill to allow customers opt-out/opt-in for automated control of end-use loads. The automation was designed to reduce the cognitive burden on the customer. The recommendation is to use pre-existing Alexa integrations from the end-use vendors as opposed to developing custom 3rd party integrations. If pre-existing integrations are not available, approaches such as providing customers with prompts to make changes may help. The recommendation to reduce development of custom 3rd party integrations is consistent with the decreasing availability of open APIs and a move by a few key vendors in the smart home space towards "closed" API model.

Table 9 provides the existing Alexa integrations for major smart thermostat brands.

TABLE 9 – MAJOR SMART THERMOSTATS AND ALEXA INTEGRATION AVAILABILITY

MANUFACTURER	MODEL	ALEXA COMPATIBILITY	API FOR DR SIGNALING
Ecobee	Ecobee 3, Ecobee 3 Lite, Ecobee 4	Yes	Available through the Zeus API Paradigm
Nest	Nest Learning Thermostat	Yes	No. Requires custom development.
Honeywell	Lyric, RTH9580WF	Yes	No. Requires custom development.
Emerson	Sensi	Yes	No. Open-source code available for custom development and extensions.
Venstar	T7900 Colortouch	Yes	No. Local API available and requires presence of a controller that is collocated with the thermostat.
iDevices	iDevices	Yes	No. No published API available.
Carrier	Infinity, Cor	Yes	No. API for custom development available.
Lennox	iComfort	Yes	No. no published API available.
Aprilaire	Aprilaire	Yes	No. No published API available.
Johnson Controls	GLAS	Yes	No. No published API available.
Bosch	BCC50 WiFi Thermostat	Yes	No. No published API available.
Kono	KN-S-AMZ-004 WiFi Thermostat	Yes	No. No published API available.
Hive	Hive Smart Home Thermostat	Yes (Requires Hive Hub)	No. No published API available.

Given the high number of Alexa compatible (which typically means Alexa voice enabled controls), an alternative to custom development approach is to use more prescriptive user directives. As an example, rather than developing custom integrations, the skill could instruct the customer to adjust the thermostat setpoint e.g., "Set you thermostat's cooling setpoint to 76 degrees at 3:55pm".

LESSONS LEARNED AND RECOMMENDATIONS

The project has conducted a study into the use of voice assistant technology for improving utility customer engagement and for energy management and for customer programs. The lessons learned from this project are summarized below.

DESIGN THE PROJECT WITH THE VOICE-ASSISTANT AS THE CENTERING ELEMENT

Voice assistants provide a great mechanism for presence-driven communication. Given the ubiquity of voice assistants in devices beyond smart speakers it is worthwhile using the voice assistant for end-to-end customer engagement. For example, if a utility is interested in rolling out an end-use electrification or direct-install type program, then choosing products that work with voice assistants may help with customer adoption. Direct install programs that support voice assistant compatible products can use the voice assistant as a convenience feature while also taking advantage of the voice assistant’s ability to send notifications, providing feedback on energy use and explore such options for customer engagement.

DESIGN THE INTERACTION MODEL FOR MAXIMIZING CUSTOMER VALUE

The crux of the voice assistant is a well-designed interaction model. Interaction models that support an exchange of information through a dialog between the user and the voice assistant helps improves the overall customer experience. Wherever possible, voice assistant prompts may also help nudge the customer towards specific actions that the utility may want the customer to do. However, improved customer experience arises from improving customer value with helpful information or helpful automations wherever appropriate. For example, when designing a voice assistant application that provides information and energy management for peak rate periods in a TOU rate regime, interaction model that provides information on the peak vs. off-peak price differential, information on how much energy is used during peak and off-peak periods, etc. could be valuable information for the customer. One of the lessons learned is to keep customer informed of interaction updates that provides additional value-adds, e.g., useful automations on top of notifications. Given the interactive nature of the voice assistant application, voice prompts could be used provide helpful information on new features on an incremental basis.

LEVERAGE READILY AVAILABLE AUTOMATIONS

Given the large number of devices and automations that are already in place, it may be worthwhile designing voice-assistant applications that leverage these pre-existing integrations using paradigms such as Skills or Routines. Many newer devices and skills are now being built with abilities to add external routines and so this is a feature that may be leveraged depending upon the voice assistant platform.

BETA-TEST BEFORE PUBLICATION

Most voice assistant application development platforms provide a beta test period where select users may be added to the distribution list to test the skill. The beta test period is typically valid for 90 days and may be extended. To best leverage this, it is necessary to enter the beta test with full feature set that is introduced in stages through interactions, i.e., do not develop the feature while you are beta testing it. Given the short beta test period, it is best to develop the application in full and then introduce the features sequentially over the 3-month beta-test period.

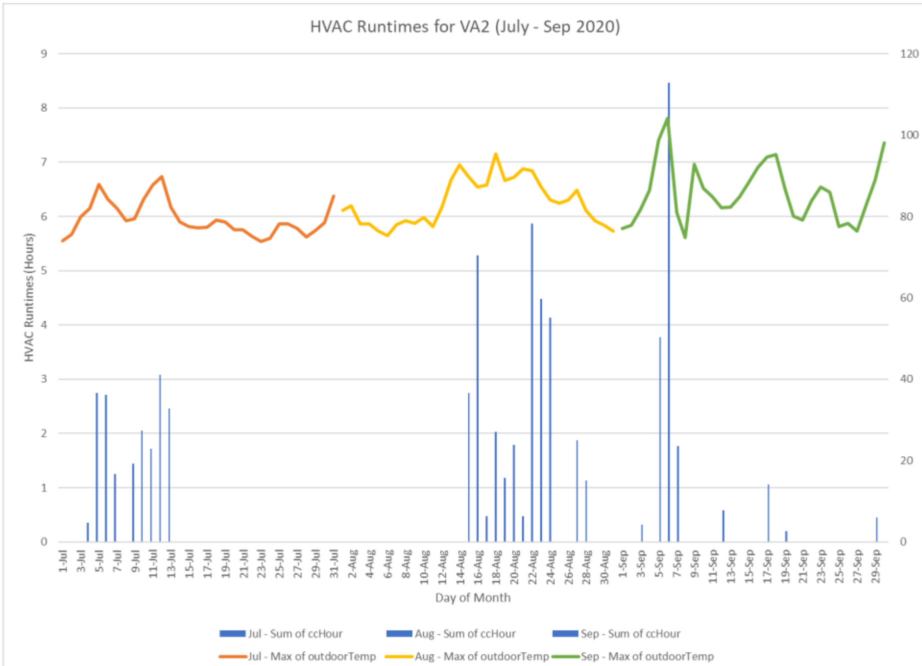
PLAN FOR FUTURE TECHNOLOGY UPDATES

Given the API issue encountered with Ecobee, customer programs may benefit from approaches that strictly depend upon industry standards like openADR. The challenge with this is that the market availability and maturity of openADR compatible smart thermostats is very limited which restricts the reach of the customer programs. Alternately, platforms such as Alexa become de-facto standards through their market share and integration capabilities so utilities may want to start working with Amazon, Google and Apple to allow for energy management features to be pre-integrated into the end-use devices. The pace of innovation in smart home technologies enabled by platforms such as Alexa could provide utilities the level of flexibility it needs to plan for future technology updates.

APPENDICES

DETAILED RESULTS

HVAC RUNTIME CHARACTERIZATION[8]



[8] The figures identify the homes as VA2, VA5, and VA7 instead of Home 2, 3, and 6 – VA# is the internal database identifier and was identified as such by the data analysis programs.

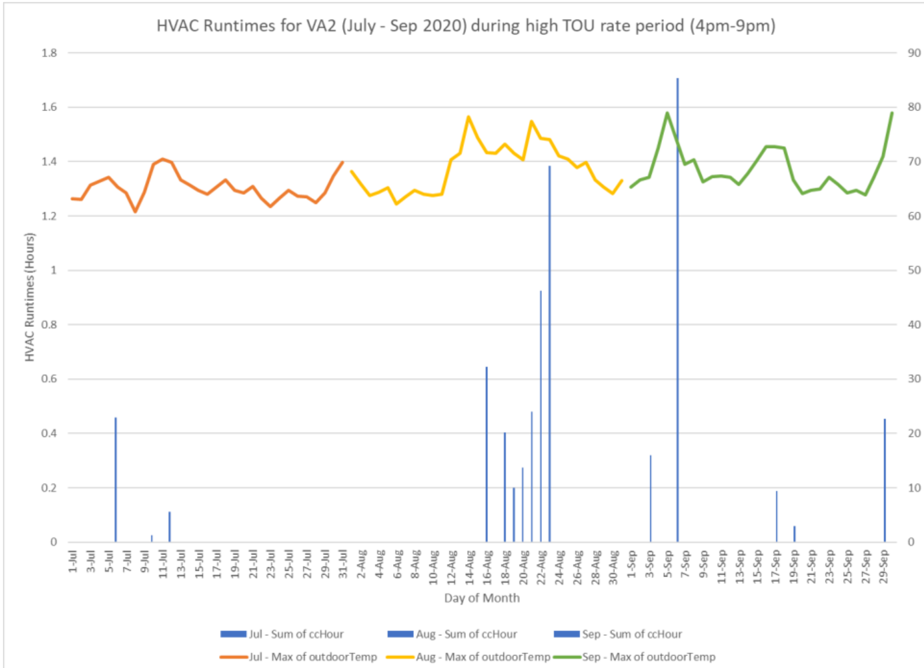


FIGURE 37 – HVAC RUNTIMES FOR HOME 2 (TOP); HVAC RUNTIMES DURING 4PM-9PM (BOTTOM)

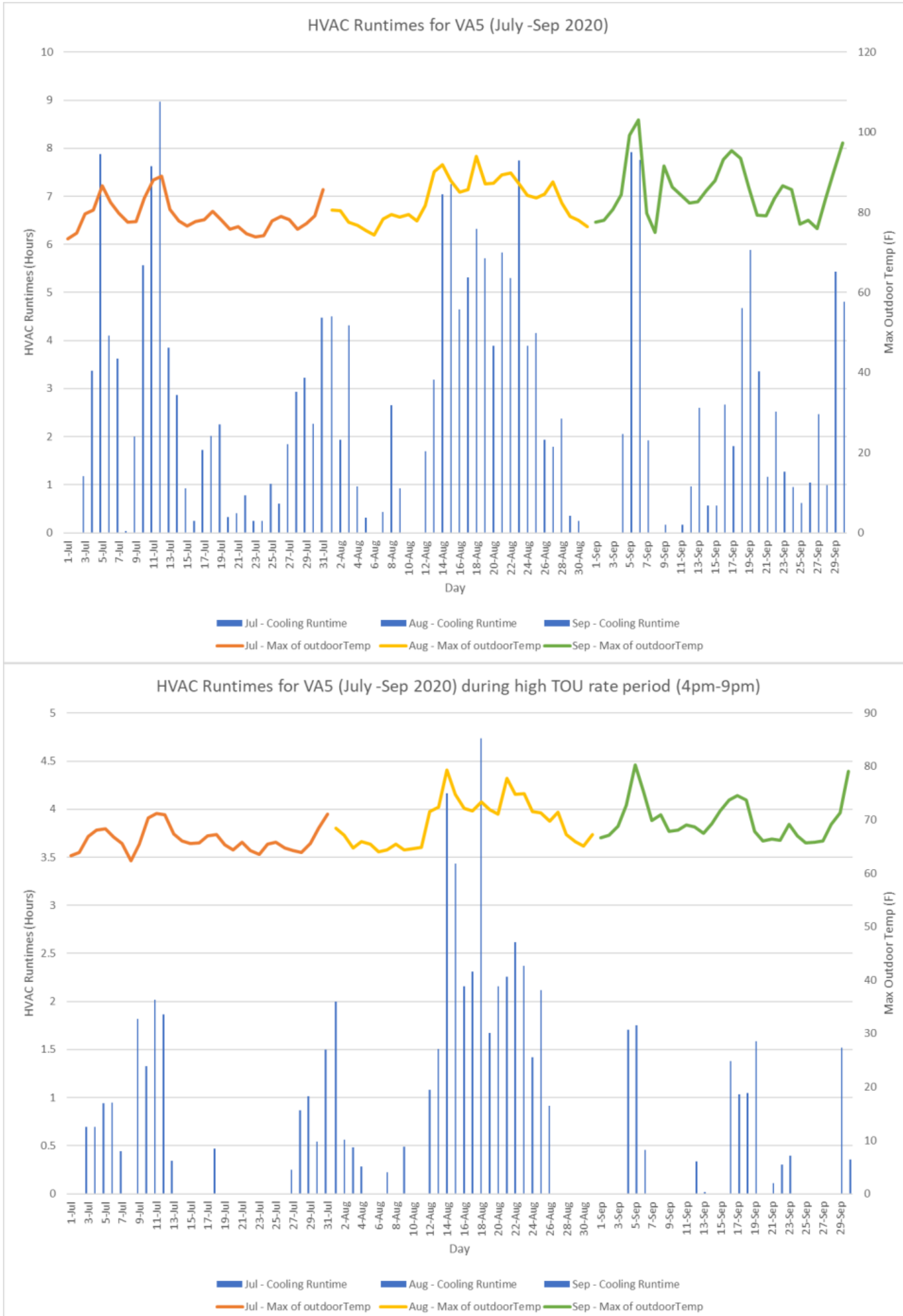


FIGURE 38 – HVAC RUNTIMES FOR HOME 3 (TOP); HVAC RUNTIMES DURING 4PM-9PM (BOTTOM)

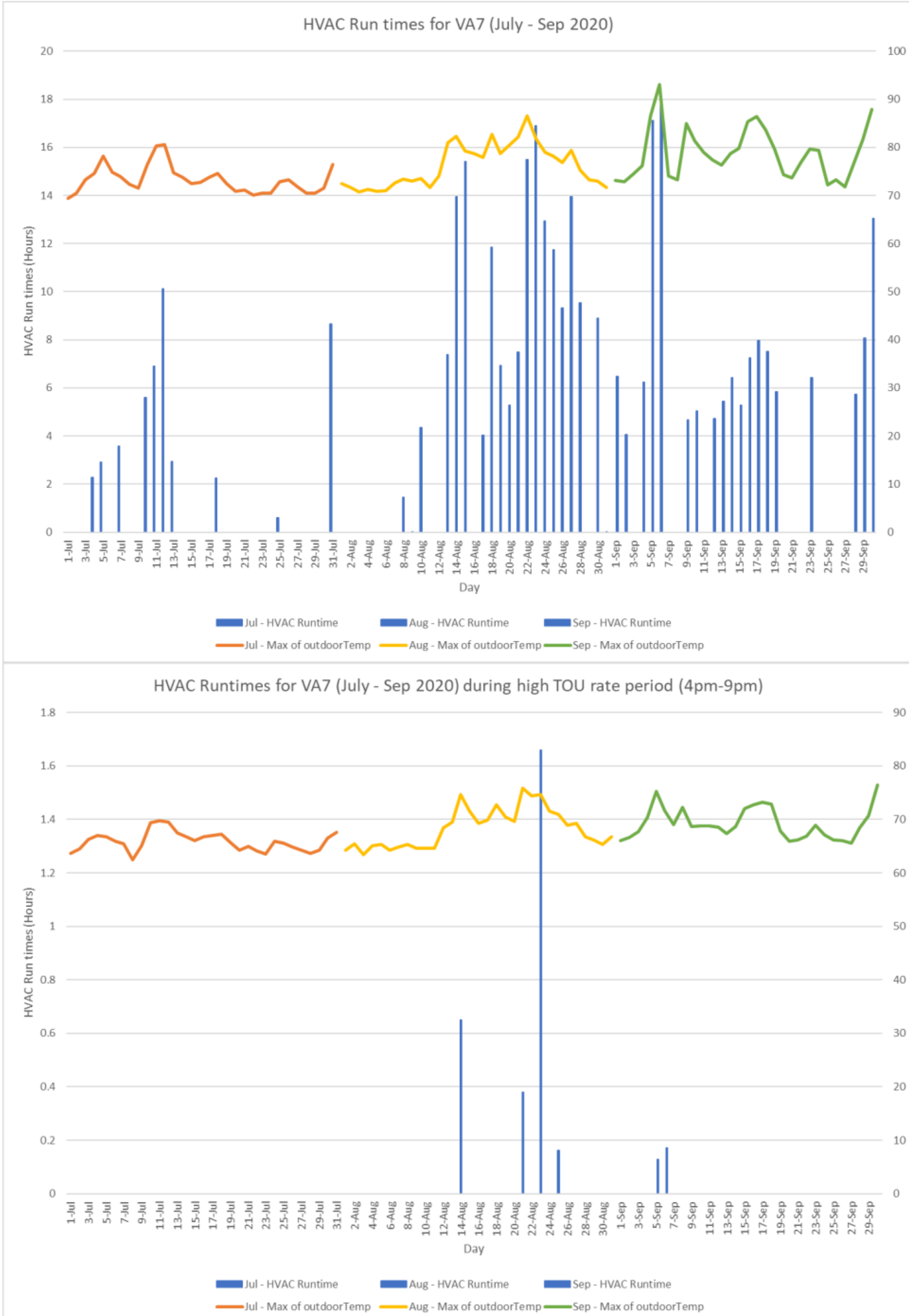


FIGURE 39 – HVAC RUNTIMES FOR HOME 6 (TOP); HVAC RUNTIMES DURING 4PM-9PM (BOTTOM)

Customer Comfort Band Analysis

Using an approach guided by prior research work[9] on the development of smart thermostats, a customer's comfort band is defined as the range of indoor temperatures when the HVAC is not operational, i.e., HVAC does not run. The comfort band varies by person and is typically a function of factors such as outdoor temperature, indoor humidity, etc. However, by modeling the comfort band at fairly frequent intervals (e.g., updated every 15 days), the effects of other factors may be eliminated to produce a reduced order model. The comfort band is defined as the 10th to 90th percentile of the range of indoor temperatures where the HVAC is not running, subject to doing this analysis at a fairly frequent interval to eliminate the effects of other potential factors.

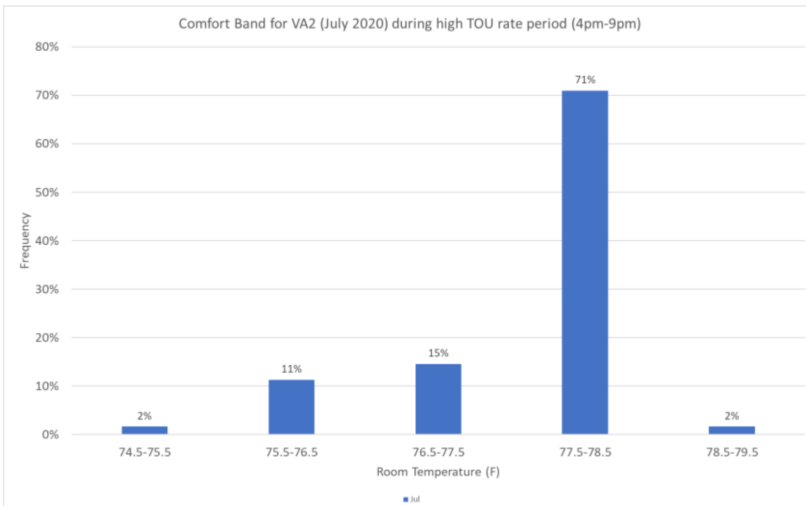


Figure 40 – Comfort band for Home 2 for July 2020

[9] EPRI, "Intelligent HVAC Controls for Low Income Households", 3002021229, Palo Alto, CA.

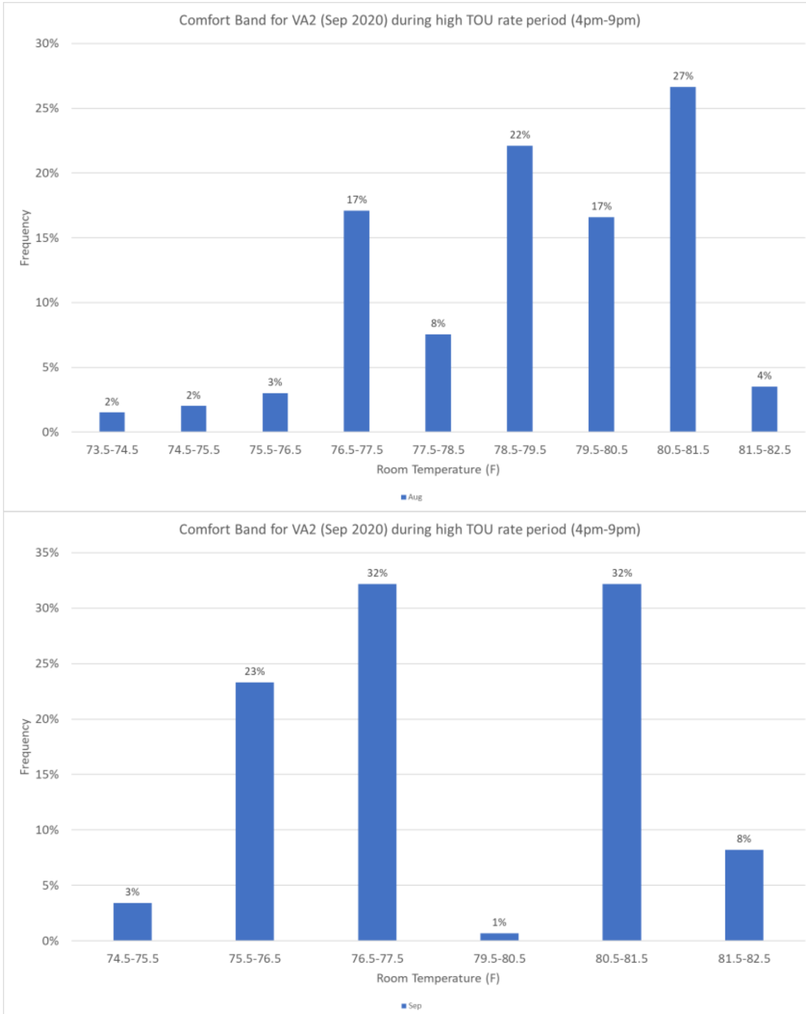


FIGURE 41 – COMFORT BAND FOR HOME 2 FOR AUG AND SEP 2020 (TOP, BOTTOM)

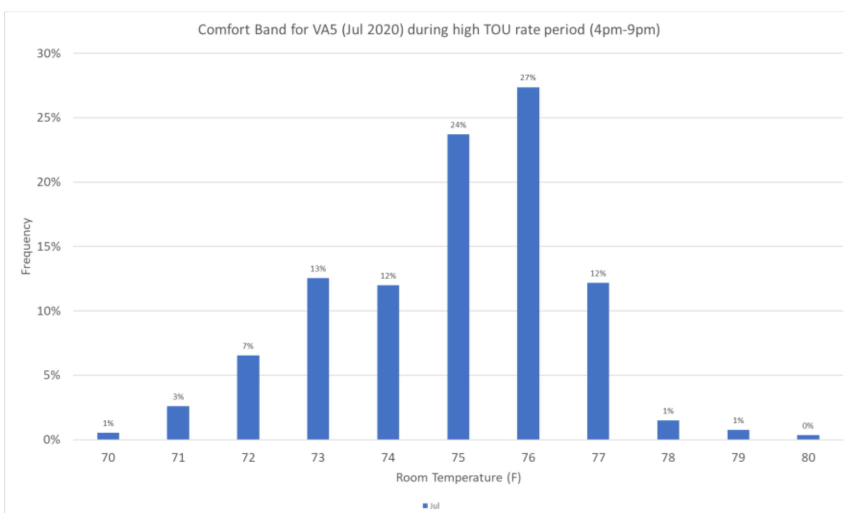


FIGURE 42 – COMFORT BAND FOR HOME 3 FOR JULY 2020

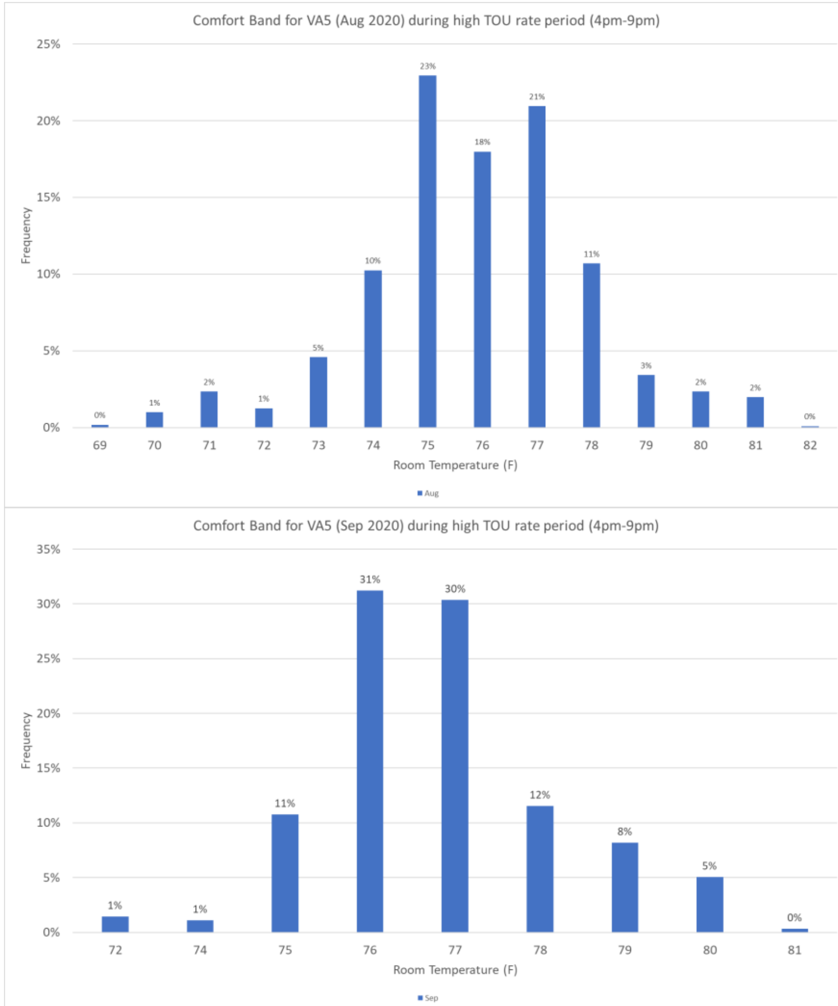


Figure 43 – Comfort Band for Home 3 for Aug and Sep 2020 (top, bottom)

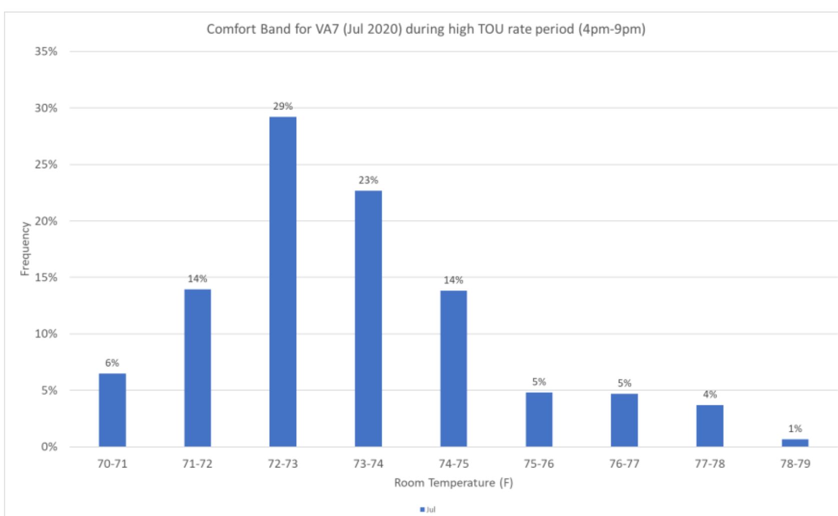


Figure 44 – Comfort band for Home 6 for July 2020

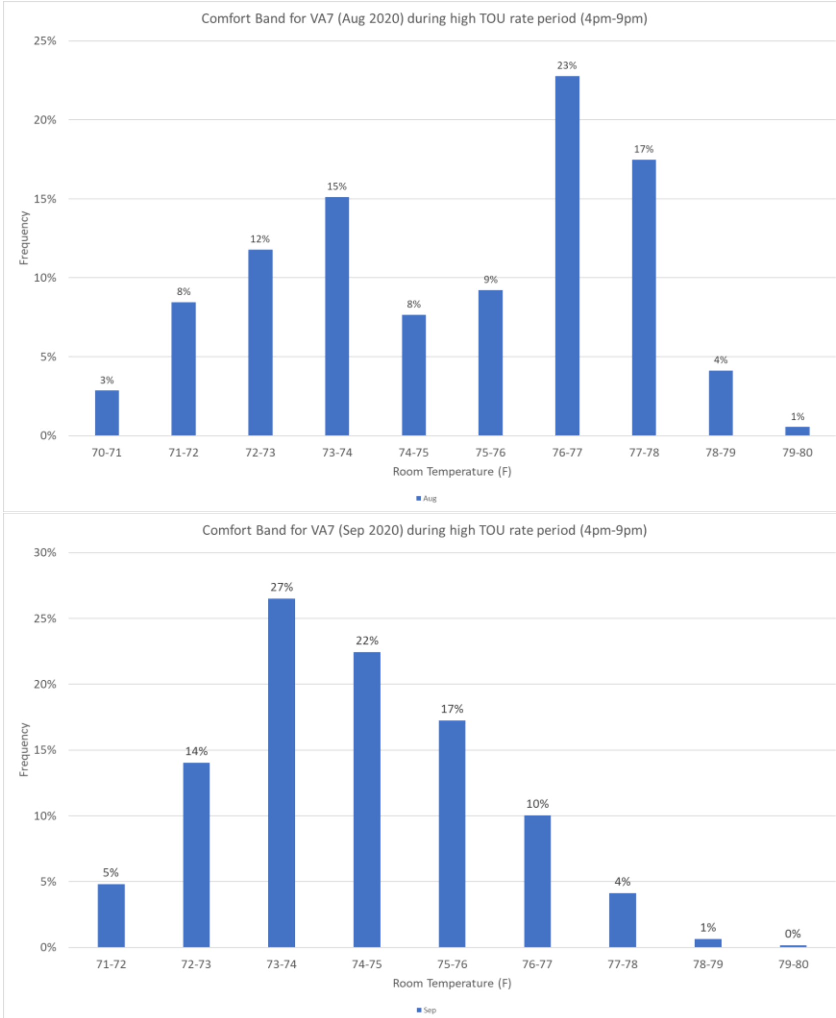


FIGURE 45 – COMFORT BAND FOR HOME 6 FOR AUG AND SEP 2020 (TOP, BOTTOM)

HVAC Hourly Profile

Pre-Phase 4 hourly profiles

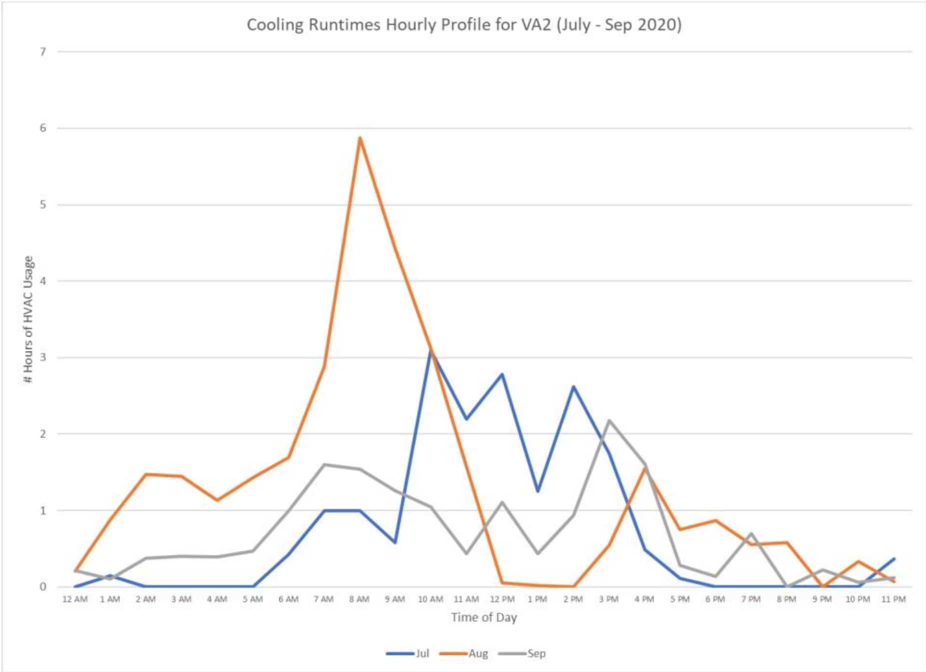


Figure 46 – HVAC Runtime Hourly Profile for Home 2

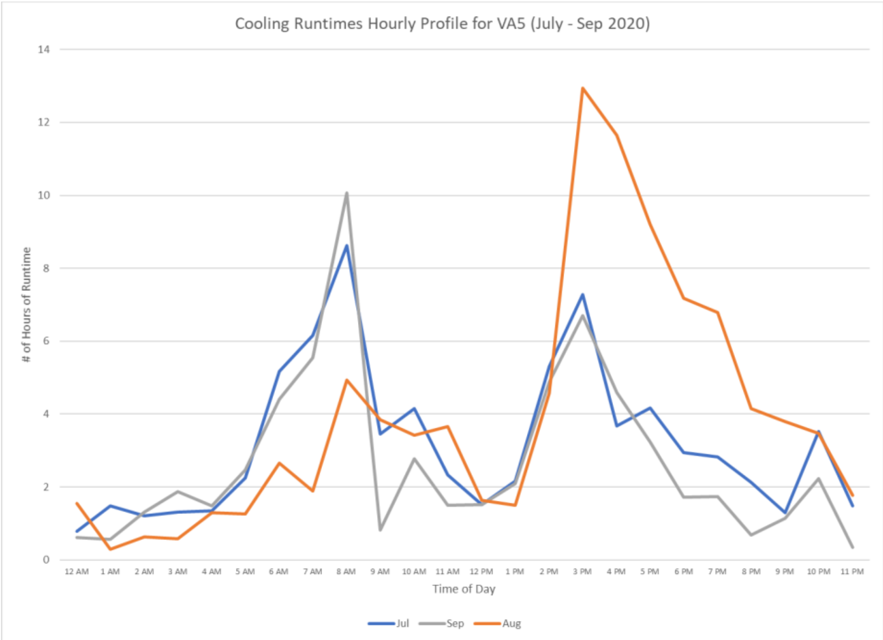


Figure 47 – HVAC Runtime Hourly Profile for Home 3

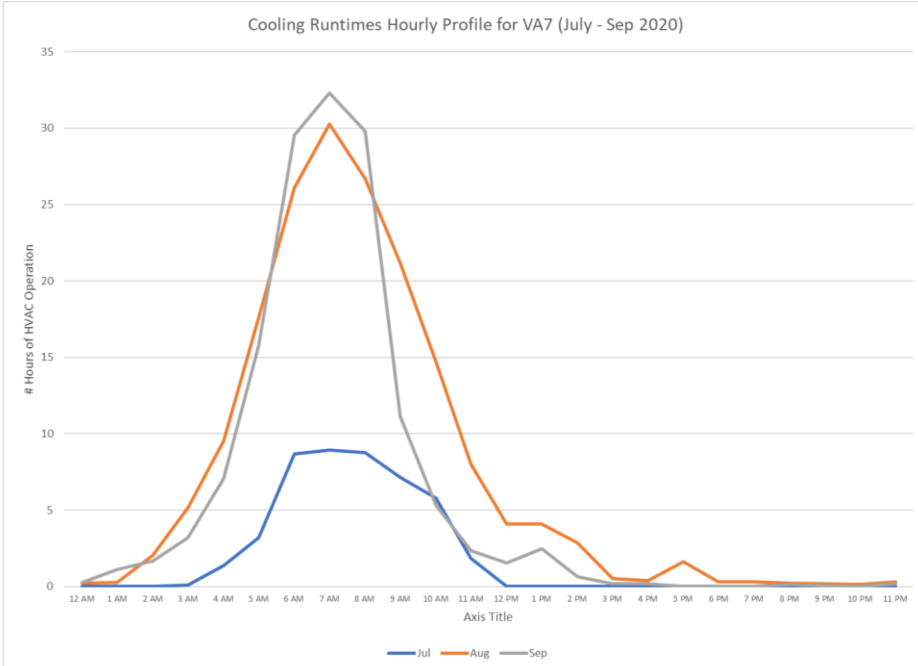


FIGURE 48 – HVAC RUNTIME PROFILE FOR HOME 6

PHASE 4 HOURLY PROFILE

FIGURE 49 – HVAC RUNTIME PROFILE NON-TREATMENT PERIOD IN NOV 2020 FOR HOME 2

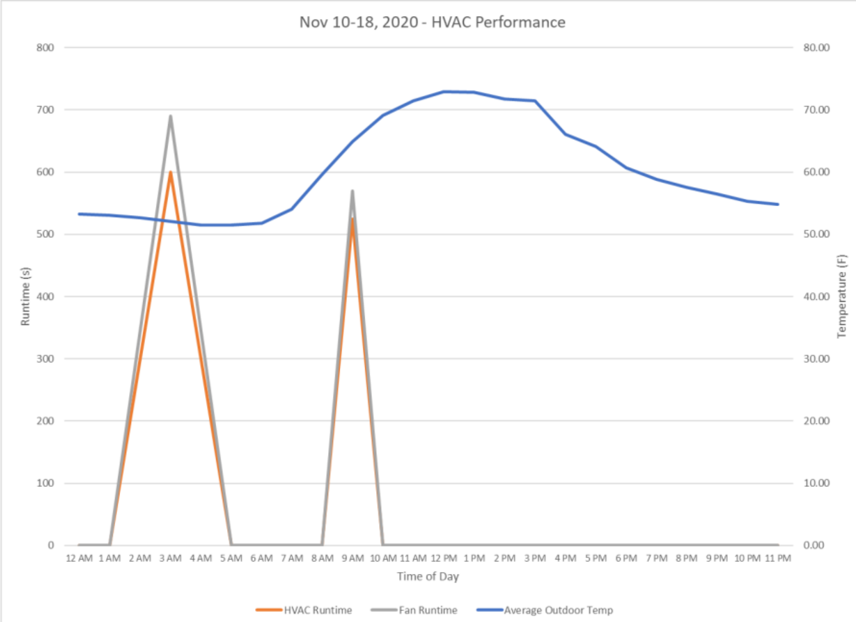


Figure 50 – HVAC runtime profile during treatment in Nov 2020 for Home 2

Figure 51 – HVAC runtime profile during non-treatment period in Dec 2020 for Home 2

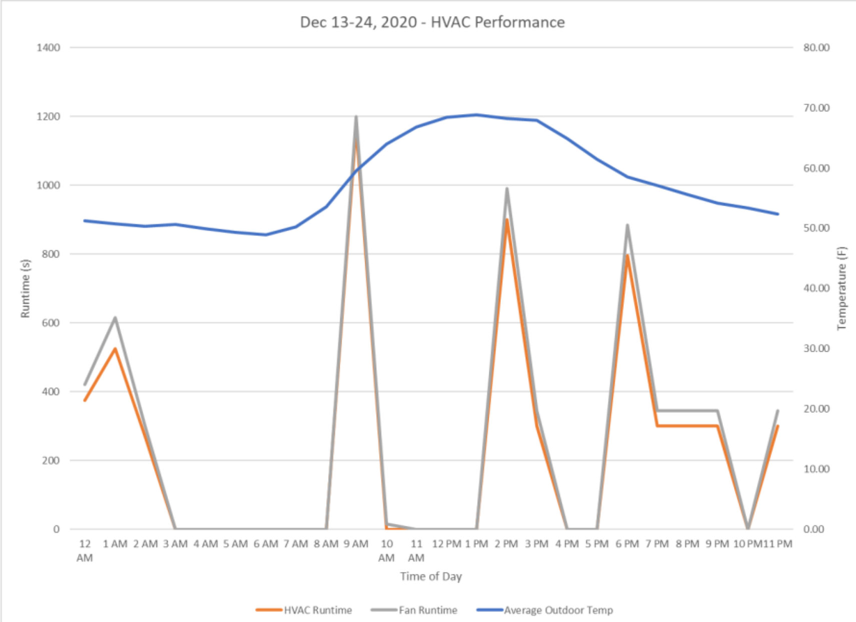


FIGURE 52 – HVAC RUNTIME PROFILE DURING TREATMENT PERIOD IN DEC 2020 FOR HOME 2

Home 2 has mixed results as far as treatment is concerned. While in November 2020, there is no HVAC operation during the 4-9pm window during treatment period compared to the non-treatment period, in Dec 2020 there are many "implicit opt-outs" that effectively eliminate the effect of the DR signaling.

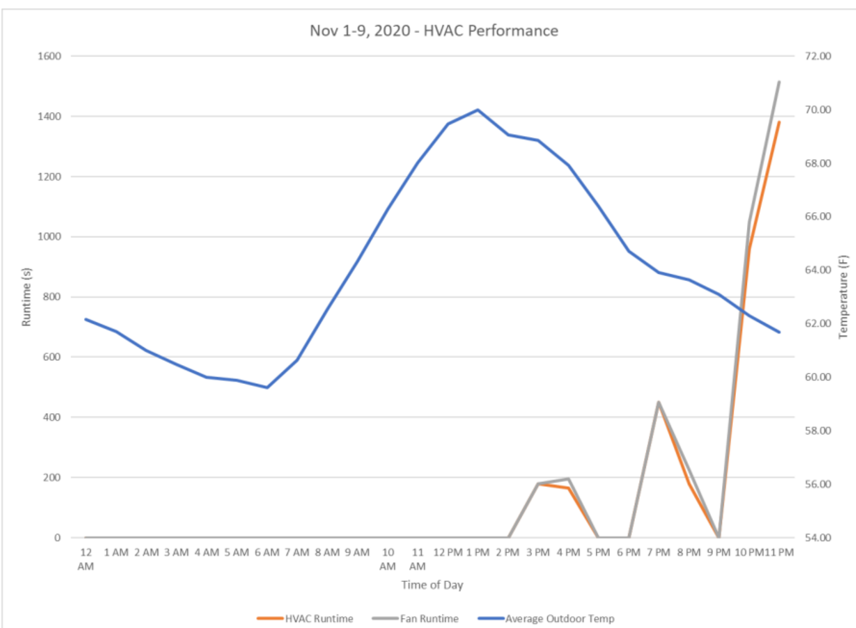


FIGURE 53 – HVAC RUNTIME PROFILE DURING NON-TREATMENT PERIOD IN NOV 2020 FOR HOME 3

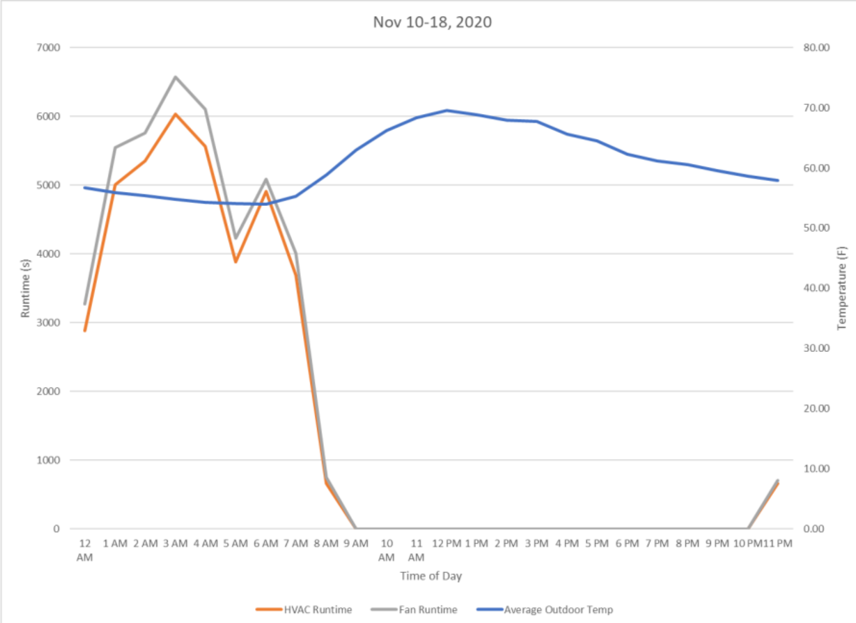


FIGURE 54 – HVAC RUNTIME PROFILE DURING TREATMENT PERIOD IN NOV 2020 FOR HOME 3

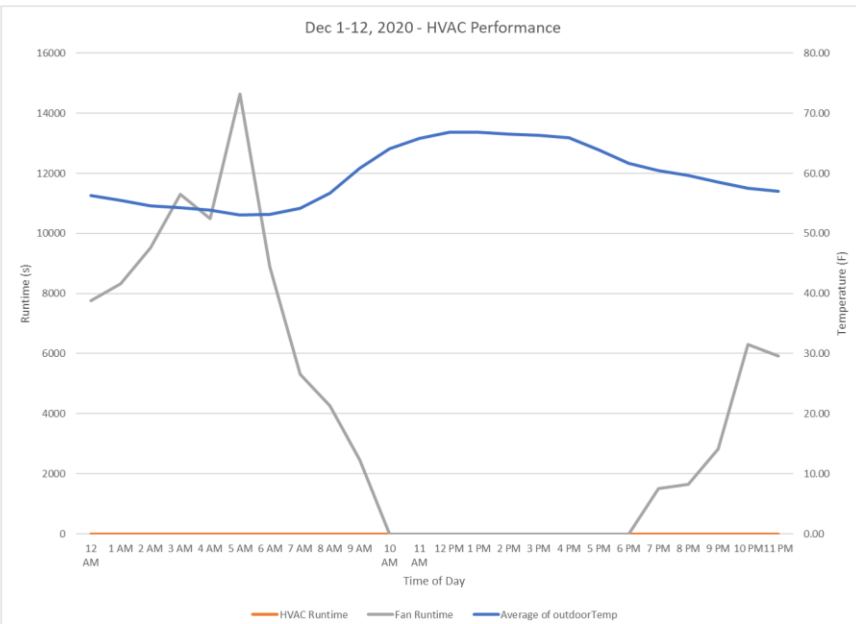


FIGURE 55 – HVAC RUNTIME PROFILE FOR NON-TREATMENT IN DEC 2020 FOR HOME 3

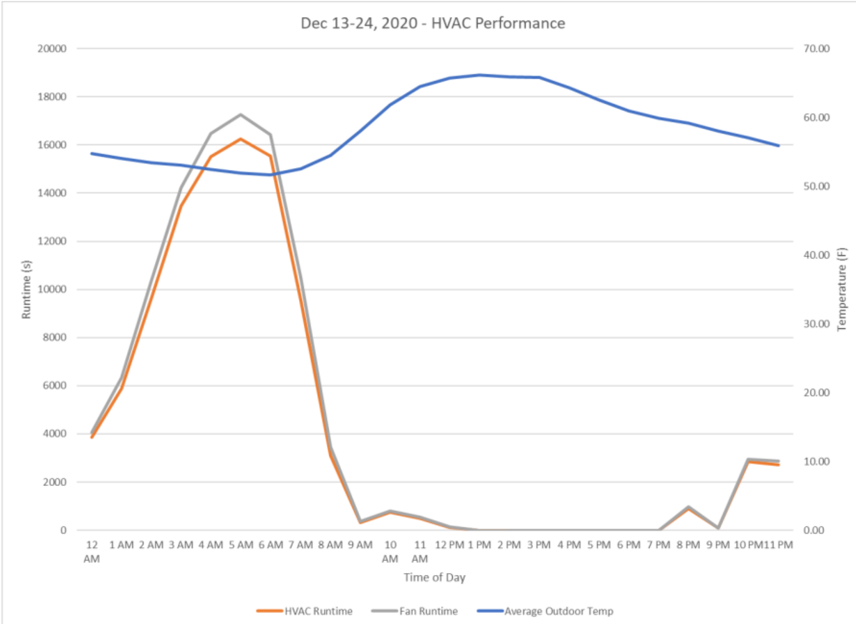


FIGURE 56 – HVAC RUNTIME PROFILE DURING TREATMENT PERIOD IN DEC 2020 FOR HOME 3

Home 3 is similar to Home 2 in terms of November 2020 being different from December 2020 in non-treatment and treatment HVAC runtime profiles. The similarity is that in Nov 2020, the treatment period no little HVAC activity during the 4-9pm timeslot whereas in Dec 2020, there are some opt-outs causing HVAC activity but in the later hours.

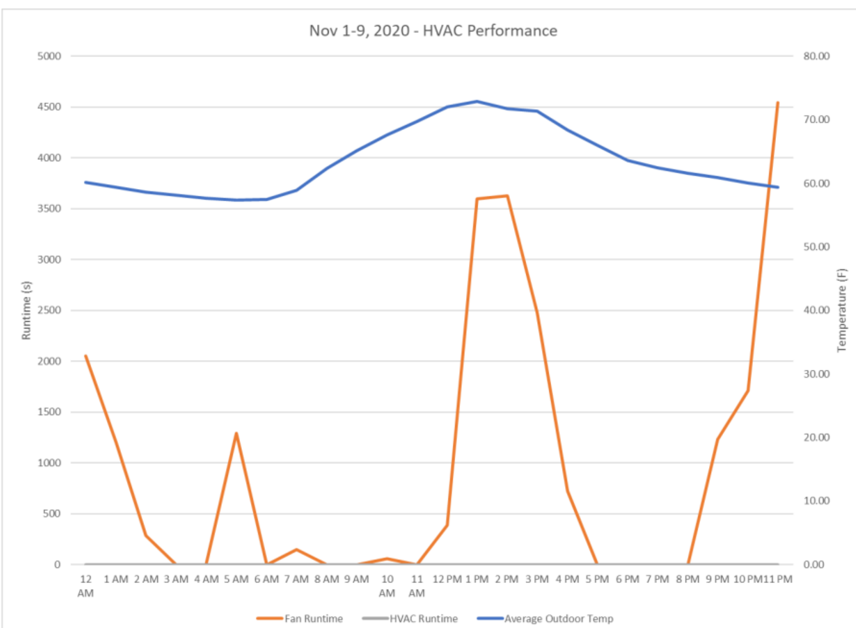


FIGURE 57 – HVAC RUNTIME PROFILE DURING NON-TREATMENT PERIOD FOR NOV 2020 IN HOME 6

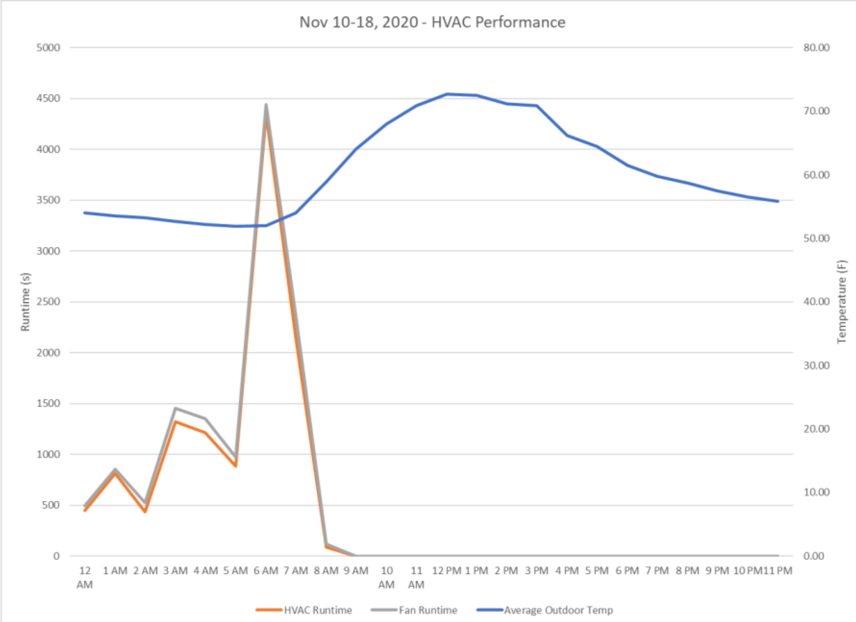


FIGURE 58 – HVAC RUNTIME PROFILE DURING TREATMENT IN NOV 2020 FOR HOME 6

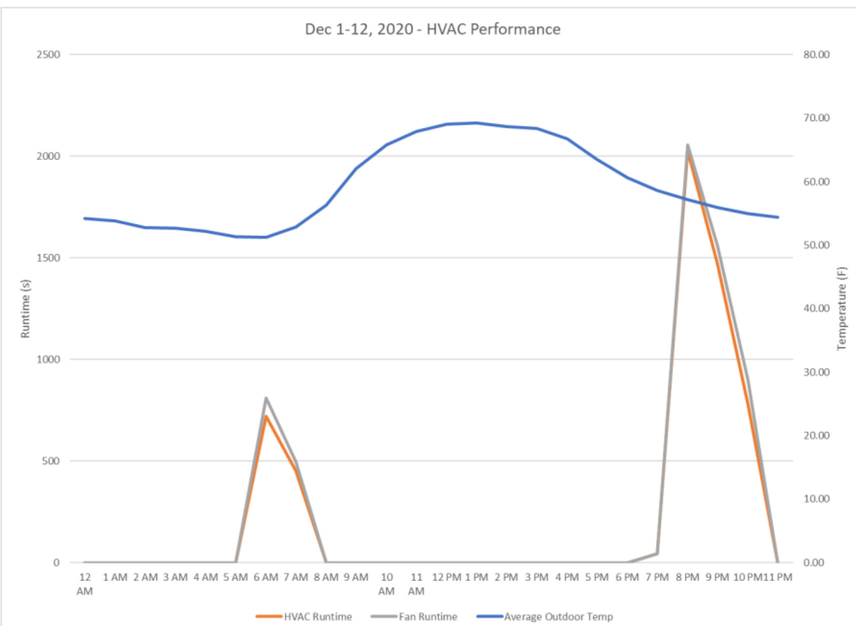


FIGURE 59 – HVAC RUNTIME PROFILE DURING NON-TREATMENT PERIOD IN DEC 2020 FOR HOME 6

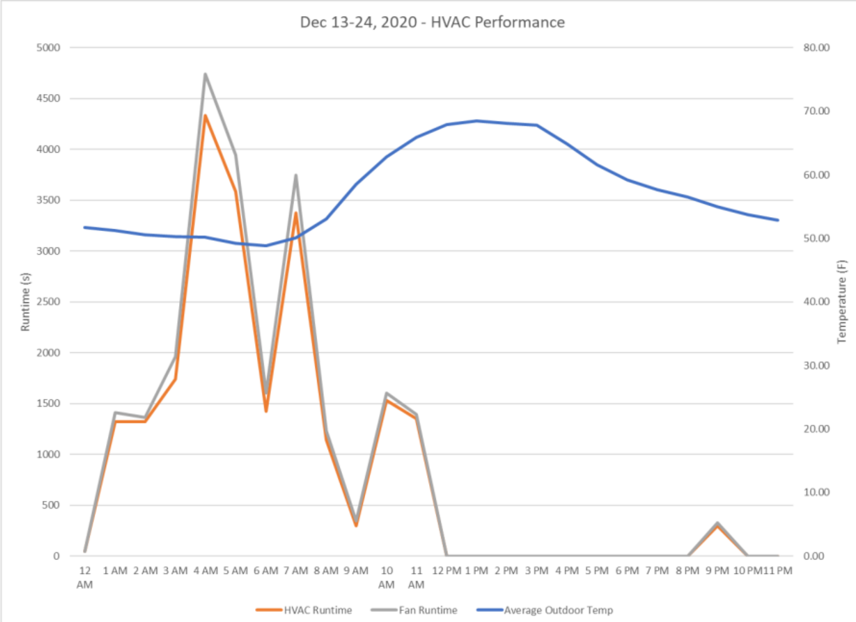


Figure 60 – HVAC runtime profile during treatment period in Dec 2020 for Home 6

Home 6 has consistent treatment performance between Nov and Dec 2020 where treatment (except for one occasion of an implicit opt-out) provides no HVAC usage during the 4-9 pm timeslot.

Detailed Alexa Prompts for each Phase

Phase 1: Peak Pricing Notification – July

Alexa: *Orange light will appear on the Echo device(s)*.

Homeowner: “Alexa, what are my notifications?”

Alexa: “You have one unread message from your energy provider. To get your message, say, “Alexa, ask Energy Facts to read my message.”

Homeowner: “Alexa, ask Energy Facts to read my message.”

Alexa: “Your current electricity rate is X cents per kilowatt hour compared to a super off-peak rate of Y cents per kilowatt hour. Your peak electricity rate is Z cents per kilowatt hour between 4pm and 9pm today.”

END

Phase 2: Peak Pricing Notification with Recommended Energy Savings Actions – August

Alexa: Orange light will appear on the Echo device(s).

Homeowner: “Alexa, what are my notifications?”

Alexa: “You have one unread message from your energy provider. To get your message, say, “Alexa, ask Energy Facts to read my message.”

Homeowner: “Alexa, ask Energy Facts to read my message.”

Alexa: “Your current electricity rate is X cents per kilowatt hour compared to a super off-peak rate of Y cents per kilowatt hour. Your peak electricity rate is Z cents per kilowatt hour between 4pm and 9pm today. You can say ‘Alexa, ask Energy Facts for recommendations to reduce energy use.’”

Homeowner: “Alexa, ask Energy Facts for recommendations to reduce energy use.”

Alexa: Will provide recommendations based on two end-use categories, e.g., HVAC and Appliances.

END

PHASE 3 – NOTIFICATIONS + RECOMMENDATIONS + ENERGY PERFORMANCE FEEDBACK – AUGUST

Alexa: Orange light will appear on the Echo device(s).

Homeowner: “Alexa, what are my notifications?”

Alexa: “You have one unread message from your energy provider. To get your message, say, “Alexa, ask Energy Facts to read my message.”

Homeowner: “Alexa, ask Energy Facts to read my message.”

Alexa: “Your current electricity rate is X cents per kilowatt hour compared to a super off-peak rate of Y cents per kilowatt hour. Your peak electricity rate is Z cents per kilowatt hour between 4pm and 9pm today. You can say ‘Alexa, ask Energy Facts for recommendations to reduce energy use.’. You can also say “Alexa, ask Energy Facts how much electricity I used yesterday’.”

Homeowner: “Alexa, ask Energy Facts how much electricity I used yesterday.”

Alexa: You estimated electricity use yesterday was $X. Of this $Y was consumed during peak hours. Your baseline daily usage is $Z. Great job on doing better than the baseline. .

END

PHASE 4

Alexa: Orange light will appear on the Echo device(s).

Homeowner: “Alexa, what are my notifications?”

Alexa: “You have one unread message from your energy provider. To get your message, say, “Alexa, ask Energy Facts to read my message.”

Homeowner: “Alexa, ask Energy Facts to read my message.”

Alexa: “Your current electricity rate is X cents per kilowatt hour compared to a super off-peak rate of Y cents per kilowatt hour. Your peak electricity rate is Z cents per kilowatt hour between

4pm and 9pm today. You can say 'Alexa, ask Energy Facts for recommendations to reduce energy use.' You have been opted-in to automated control of your thermostat to reduce energy use during peak rate hours. You can opt-out by saying 'Alexa, ask Energy Facts to opt out of automated control.'"

Homeowner: "Alexa, ask Energy Facts to Opt-Out of automated control".

Alexa: "You have opted-out of automated control. You can opt in by saying 'Alexa, ask Energy Facts to opt in to automated control'".

{This customer will not have DR signaling sent to their Ecobee thermostat until they opt in.}

END