Design & Engineering Services

Whole Home Demand Response Pilot

DR15SDGE0007 Report

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Prepared by:

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EXECUTIVE SUMMARY

KEY RESEARCH QUESTIONS

The following key research questions are addressed in this report:

- How do commercially available connected device ecosystems enable premise-level or whole home control? How do they perform in real-world application?
- What amount of energy reduction can be realized by each end use and through whole home DR?
- What impact does whole home DR have on customer comfort and satisfaction?
- What barriers and challenges remain to further implement whole home DR at larger scale?
- Can voice assistants have a role in engaging customers for DR?
- What is the cost effectiveness of whole home DR for a scaled utility DR program?

RESEARCH METHODOLOGY

Expanding on prior laboratory research and testing of whole home connected ecosystems, three different ecosystems were deployed in three homes in the San Diego Gas & Electric territory. Of the three ecosystems, two were commercially available with the third being developed by the project team. Each ecosystem connected various end-uses within the home and provided a central point of communication to respond to a variety of DR signals. During the peak cooling season of 2018, a combination of DR events was called at each home to analyze the technical feasibility and robustness of whole home ecosystems, the quantitative ability of such ecosystems to reduce energy consumption on demand, and the homeowner response to, and interaction with, the various ecosystems. Although small scale, the deployments provided insight into the possibilities and potential issues for larger, program-scale deployments.

TARGET AUDIENCES

The main target audience for this report is utility programs searching for feasible, cost-effective solutions for residential DR that are, or could be made, commercially available and widely deployed. Program implementers searching for lessons learned and issues found through actual implementation may find this report useful as there are ample lessons from both a technology implementation and occupant behavior perspective.

KEY FINDINGS

Learnings from ecosystem commissioning and device lab testing as well as analysis of the collected data from the three field deployments identified the following key findings:

- The whole home ecosystem is technically feasible, and multiple ecosystems currently exist that can provide premise-level control, however, the robustness of such systems and the consistency in response must be further evaluated prior to confident, scaled deployment.

- Recruitment of engaged and willing homeowners is critical to the success of whole home DR. Otherwise, events will be ignored, ecosystem issues may be left unresolved, and homeowners may be left unsatisfied, all ultimately leading to low, inconsistent energy reduction during peak hours. Due to the ability to opt out of events, unwilling occupants can occasionally cause increased energy consumption over the course of the event due to high kickback caused by lower-than-usual set-points.
- Integration of voice assistants into demand response programs may be an effective way to engage the homeowner, and its function has been proven feasible, however, major market players should be the entities to drive further device integration and design due to their ability for scaled recruitment of, and access to, connected device manufacturers.
- As peak residential energy consumption shifts to longer, later hours, whole home DR improves the opportunity to incorporate energy savings from multiple devices. Recruitment of homes should include an understanding of when each home experiences consumption from different devices in order to avoid unutilized capital expenditures. This demonstration saw low to no usage of the spa and pool pump during peak hours, with energy consumption from the water heater only occasionally occurring during event hours. Analysis of a home's usage and end use load profile, if available, can determine if a home is best suited for whole home DR or if only specific appliances should be targeted.
- Technical feasibility of device integration does not warrant market ready deployment. Implementation of outlet and blinds control as well as lab testing of demand response capable LED dimming show technical feasibility, but in-practice energy reduction will be limited and is dependent on each premises' application. Large scale deployment is needed to understand and establish customer acceptance, cost effectiveness, and available energy reduction from smaller scale connected devices.

PROJECT RECOMMENDATIONS

The results of this project serve to recommend further research into three main whole home DR technologies: HVAC, electric water heating, and pool pumps. Although technically capable, control of plug loads, lighting, and blinds, see significantly less available reduction while potentially having a negative impact on homeowner comfort.

This project also recommends additional research into the smart voice assistant platform as a means of communication and engagement with the homeowner to develop a more informed and willing participant base.

ABBREVIATIONS AND ACRONYMS

API	Application Program Interface
CAISO	California Independent System Operator
DLC	Direct Load Controller
DR	Demand Response
EPRI	Electric Power Research Institute
IFTTT	If This Then That
IoT	Internet of Things
HPWH	Heat Pump Water Heater
HVAC	Heating Ventilation and Air Conditioning
kW	Kilowatt
kWh	Kilowatt hour
NPV	Net Present Value
PAC	Program Administrator Cost
PCT	Participant Test
RIM	Ratepayer Impact Measure
TRC	Total Resource Cost
VTN	Virtual Top Node

CONTENTS

FIGURES

TABLES

EQUATIONS

INTRODUCTION

The objective of this project was to evaluate the possibilities for Demand Response (DR) using connected ecosystems currently available in the market. Current residential demand response programs focus on the control of single communicating devices such as Direct Load Control (DLC) switch connected to residential systems such as HVAC and water heater or communicating devices such as connected and/or smart thermostats. Recent market interest in the ability to control residential connected and communicating devices have led to the proliferation of ecosystems that, if leveraged, can be used to providing premise level or whole home level DR. For this report, whole home DR can be defined as demand response where multiple residential end-use systems and devices can be triggered by a single DR signal by the utility, or a third party acting on behalf of the utility, to provide some form of beneficial DR load management.

Possible advantage of whole-home DR includes:

- A whole home DR program can leverage a single customer acquisition cost and extend kW reduction significantly beyond the load reduction from a single device.
- In the future, it is expected that short term DR needs (2 hours or less) could increase. Whole home DR can enable other loads that can provide fast response, such as appliances and plug loads that are not economically feasible to participate by themselves. Whole Home DR programs can then allow blending of resources to provide response to multiple programs (peak demand and ramping, for example) with the same infrastructure.
- Cost effectiveness could be greater both due to greater kW shed per home, as well as by leveraging the same cost for multiple programs
- Whole Home DR programs can also enable utility programs to adapt to policy changes such as Rule 24, by providing integrated platforms that can bid into both ISO market as well as traditional DR programs

The project established feasibility of how whole home demand response is enabled by demonstrating two (2) commercially available ecosystems identified via secondary research[1]. Targeted research questions included:

1. How is home demand response enabled in commercially available and deployed systems?
2. What types of devices can each commercially available system control?
3. What type of device (and overall ecosystem) level controls can each device enable?
4. What type of data or signal does each ecosystem provide to validate that intended DR signals were enabled?
5. How can residential devices and systems outside of communicating thermostats and pool pumps be enabled to provide load reduction in a whole home DR environment?
6. How can increased control enable grid flexibility without sacrificing customer comfort and preference?

In addition, a third ecosystem was developed by the project team. It is important to note that this third ecosystem is not a commercially available ecosystem. As the connected device space is ever evolving and the various value propositions result in business

[1] *Laboratory Tests of Control Upgrades for Integration of Residential and Small Commercial Buildings into Integrated Demand-Side Management Programs.* EPRI, Palo Alto, CA: 2016. 3002008229.

partnerships between product and service providers make it difficult to decouple technical interdependencies between product offerings. The intent of the third ecosystem will be used as a benchmarking tool of sorts in order to best understand how to aggregate various residential end-use devices and systems – what product providers make available to utilities and third parties and how they make this information available. The ecosystem will also help to understand what data is collected and made available by connected device providers as well as what and how controls are made available.

SITE SELECTION

In order to assess the research questions associated with this project, three sites in San Diego Gas & Electric territory were recruited. The sites were screened for the following criteria.

- **Reliable Wi-Fi Connectivity:** Connectivity of these connected devices tied to particular ecosystems typically rely on consumer or community-provided Wi-Fi connectivity.
- **Working Central Air-Conditioning:** Currently, space conditioning is the main load in residential applications. Although there are communicating window A/C units or smart plugs used to provide DR capabilities to window A/Cs, there were not any readily available as part of an overall connected ecosystem to enable whole-home DR capabilities.
- **Controllable Loads Outside of Pool Pumps and Thermostats:** Current SDG&E DR programs delineate tiers of controllable loads. Communicating thermostats and pool pumps are considered tier 1 and load control is incentivized at $0.75/kW load reduction. As one of the main goals of this effort is to extend DR capabilities, each ecosystem site must be willing to control devices outside of thermostats and pool pumps.
- **Customer Willingness to Control and Collect Data from Wi-Fi Devices:** As part of project participation, the homeowner must be willing to let SDG&E and the project team control the connected devices as well as collect data associated with the project. Each homeowner was required to sign a field demonstration agreement as well as customer data access agreements to ensure this is completed during the period of performance of the project.

Throughout the report, the sites are referred to as “Home 1”, “Home 2”, and “Home 3”. A description of the systems installed at each site are detailed in the following section.

TECHNICAL APPROACH

Each home consists of a central controls aggregator, either physical or cloud-based, which accepts the DR signal and then translates and transfers the signal to the end use devices. In doing so, multiple devices within the home are able to respond to a singular DR signal sent by the utility. The specific configurations are detailed below.

HOME 1: CTA 2045

Home 1 employs a standards-based approach for two different products. The smart thermostat and heat pump water heater for Home 1 are referred to as “ST1” and “WH1” throughout the report. The ST1 and the WH1 heat pump water heater both use a CTA 2045 module, a prototype gateway designed to communicate via ZigBee with other ZigBee enabled devices. Once devices are connected, the CTA 2045 portal can send an event for all connected devices in a group (in this case, ‘Home 1’) to respond to. While event details are called through the portal, control commands (i.e. on/off control, dimming or set points reset) are performed through the CTA modules themselves. A PV system is also installed and connected to the circuit level monitoring unit-1 (CLM1) to provide real time measurements of PV generation. A layout of the devices in Home 1 is provided in Figure 1.

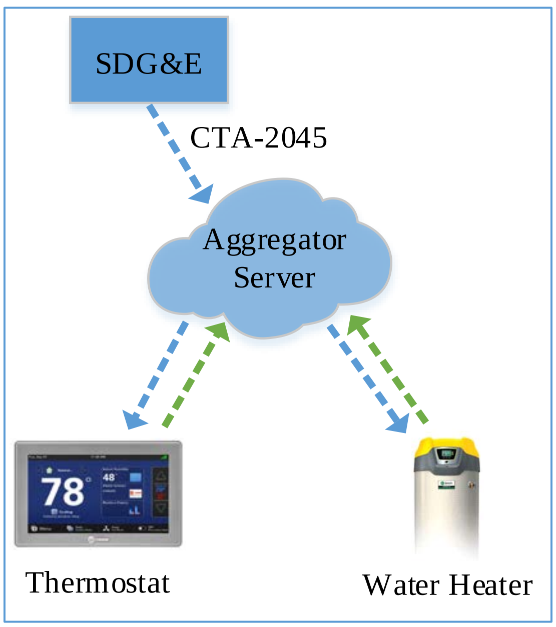

FIGURE 1: CTA 2045 MODULAR CONNECTION CONFIGURATION

CTA 2045 MODULES

To meet the CTA 2045 standard, manufacturers must include a standardized socket interface on which to attach the CTA 2045 communicating device. In this case, the WH1 manufacturer provided a separate module to be attached to the heat pump which is then attached to the CTA 2045 AC module. Figure 2 shows the WH1 module and the CTA 2045 module (circled in red) attached to WH1.

FIGURE 2: (LEFT) WH1 HPWH PORT ADAPTOR; (RIGHT) CTA 2045 MODULE

Figure 3 shows the CTA 2045 module connected to the ST1 CTA 2045 compatible thermostat, designed to be field tested with EPRI as a part of this project.

FIGURE 3: ST1 THERMOSTAT CTA 2045 MODULE

EXPECTED SYSTEM RESPONSE

According to CTA 2045 documentation, Table 1 details the demand response commands available to the two communicating devices. Both the thermostat and water heater can respond to load shed, critical peak, and grid emergency events, however, only the water heater is able to respond to load up events.

TABLE 1: PRODUCT RESPONSE TO DR EVENTS

	Load Shed	Critical Peak Event	Grid Emergency	Load Up
ST1 Thermostat	X	X	X	
WH1 HPWH	X	X	X	X

It is important to note that the CTA 2045 module is only responsible for receiving the event and pushing it to the end product. Each product is pre-programmed to then translate the event signal into specific actions as detailed in Table 2, summarized from CTA 2045 documentation.

Table 2: Pre-programmed manufacturer responses to event signals (Home 1)

	ST1 Thermostat	WH1 HPWH
Load Shed	4-degree offset	Turns off, but will turn on if needed to prevent cold water delivered
Critical Peak	8-degree offset	Turns off, but will turn on if needed to prevent cold water delivered
Grid Emergency	10-degree offset	Turns off, will **not** turn on if needed to prevent cold water delivered
Load Up	N/A	Turns on until water is fully heated

Home 2: Open ADR Gateway

Home 2 contains an Open ADR Gateway controlled by EPRI's OpenADR Virtual Top Node (VTN). The gateway communicates through ZigBee protocol to a smart programmable thermostat (referred to as ST2), a smart outlet (referred to as SO1), and a Direct Load Control (DLC) switch connected to the spa pump. Alongside confirmation of a successful event by the EPRI VTN, the analysis of hourly consumption data will verify that events have been successfully called. The circuit level monitoring unit system for Home 2 (CLM2) can provide immediate confirmation that the event has been called and correctly executed. A layout of the devices in Home 2 is provided in Figure 4.

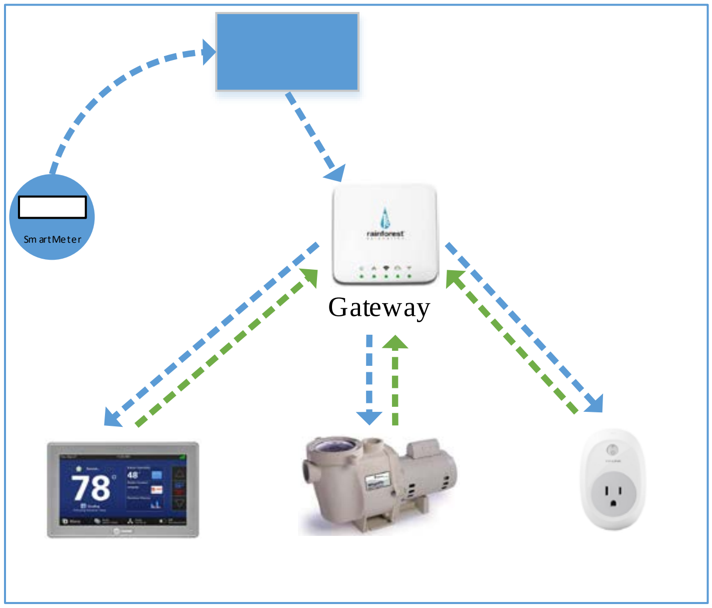

FIGURE 4: AMI METER CONNECTED NETWORK

CONNECTED DEVICES

For Home 2, three connected devices were originally proposed to respond to DR events, a smart thermostat, a controllable outlet, and a DLC to control a spa pump. The thermostat and outlet (Figure 5) were successfully installed and controlled, however, the installation of the direct load controller (Figure 6) was avoided due to added complexity and lack of scalability.

FIGURE 5: (LEFT) ST2 SMART THERMOSTAT; (RIGHT) SO1 CONTROLLABLE OUTLET

Since the DLC was rated for only 30A (the maximum rating for the Open ADR Gateway compatible load controllers), less than the rated current of the spa pump, a workaround relay system installed by a licensed electrician would have been needed to successfully control the spa pump in response to a DR event. Although possible, the added complexity of the installation proved to be cost prohibitive and would defeat the purpose of finding more "off-the-shelf", easy to implement, scalable solutions, resulting in cancelling the installation of the DLC. Even if the DLC was installed as a part of a new construction project instead of a retrofit, the high amperage of the spa pump would still require a similar relay workaround as before, remaining cost prohibitive. The search for a different "off-the-shelf" technology to meet the needs of 30A and compatible with the chosen Open ADR Gateway uncovered no results during the installation timeline.

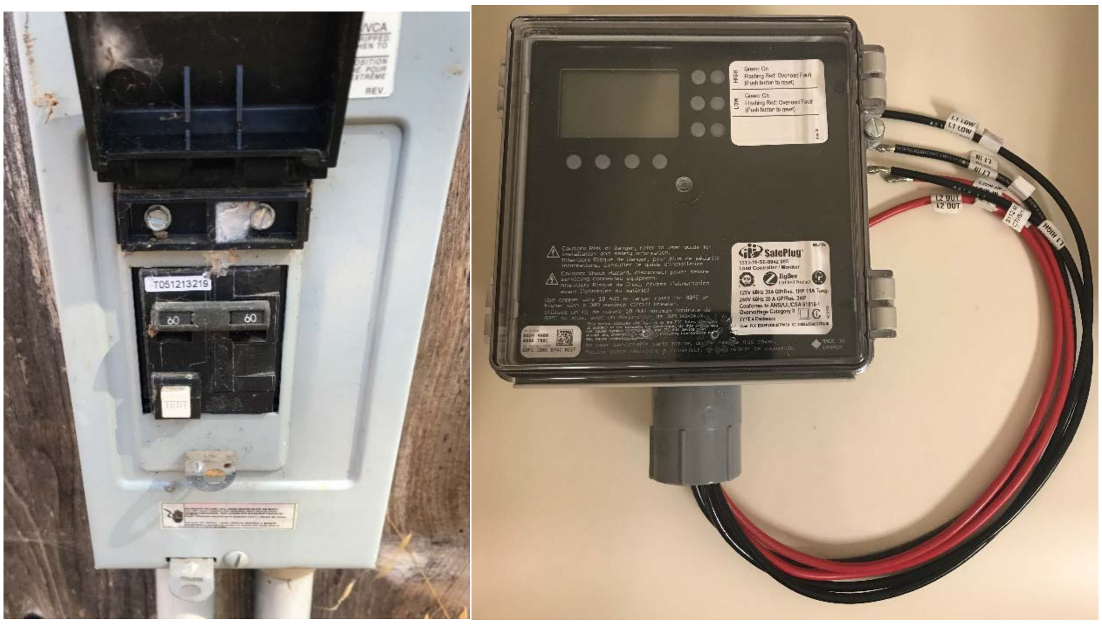

FIGURE 6: (LEFT) BREAKER FOR SPA PUMP AT HOME 2; (RIGHT) HOME 2 DIRECT LOAD CONTROLLER

EXPECTED SYSTEM RESPONSE

The expected system responses for the ST2 thermostat and the SO1 outlet are outlined in Table 3. Once each individual device receives the signal from the Open ADR Gateway device, it translates the signal into the corresponding action.

TABLE 3: PRE-PROGRAMMED MANUFACTURER RESPONSES TO EVENT SIGNALS (HOME 2)

	ST2 THERMOSTAT	SO1 OUTLET
Load Shed	4-degree offset	Turns Off all devices without Data Tags
Critical Peak	8-degree offset	Turns Off all devices without Data Tags
Grid Emergency	10-degree offset	Turns Off all devices without Data Tags
Load Up	N/A	Devices remain On

HOME 3: VA1 VOICE ASSISTANT

Home 3 applies an application program interface (API) based platform to control multiple smart home connected end-use devices, with a VA1 voice assistant "skill" enabled to provide the homeowner a means of communication with their devices and with the DR event. Individually available APIs for the smart thermostat and controllable light switches, as well as the controllable pool pump and controllable blinds were to be used as the means of communication to each device. EPRI's aggregator server was built to communicate to a range of APIs, allowing for a single DR call to translate to multiple devices via each separate API. A layout of the devices in Home 3 is provided in Figure 7.

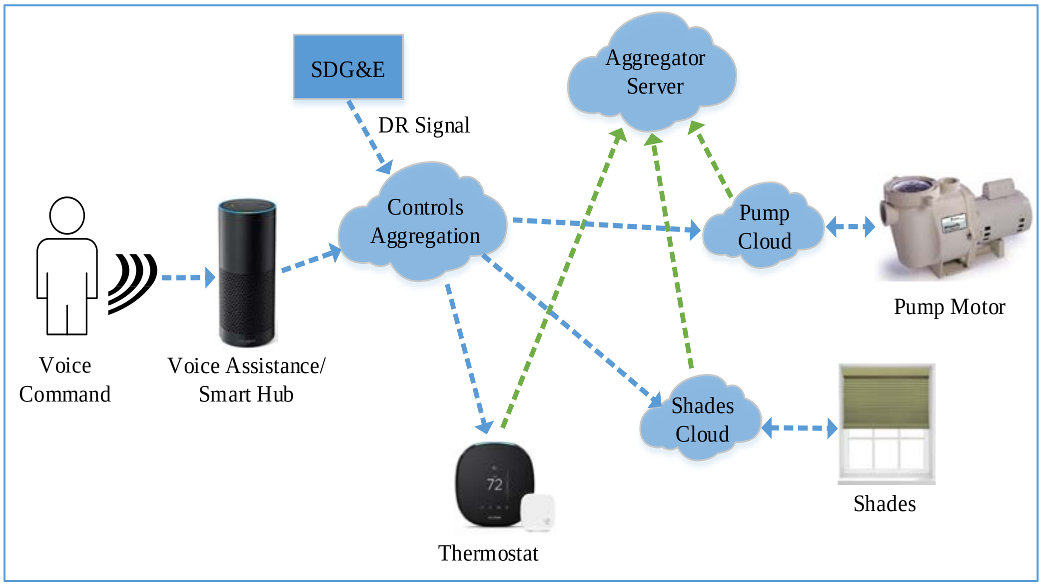

FIGURE 7: IOT API INTEGRATED CONFIGURATION

CONNECTED DEVICES

Initially within Home 3, four devices were to be connected to the DR scheduler and the voice assistant: a smart thermostat (ST3), controllable shades (CB1), smart light switches (SL3), and a controllable pool pump (PP1). Due to delays in the API integration as well as the inability to gain access to the PP1 API, the only two devices to be installed and commissioned were the ST3 thermostat and the CB1 controllable shades/blinds (Figure 8). Work on the SL3 light switches remained in lab testing to ensure proper response. No integration was completed on the pool pump due to the lack of the API.

FIGURE 8: (LEFT) ST3 SMART THERMOSTAT; (RIGHT) CB1 CONTROLLABLE SHADES

Through the secondary research to find a suitable shades system with an open API, it was established that the few controllable shades with an open API (in this case CB1) used an additional hub with proprietary communication protocols between the hub and the shades, unfortunately adding another piece of hardware when only one central hub was desired. This additional piece cannot be avoided unless controllable shades are taken out of the equation. The hardware is shown in Figure 9. The CB1 hub must be connected via Ethernet to the customer's internet router. The smart speaker (SS1) is connected via Wi-Fi.

FIGURE 9: CB1 HUB AND SS1 SMART SPEAKER

EXPECTED SYSTEM RESPONSE

The expected system responses of the ST3 thermostat and CB1 shades are displayed in Table 4. With open access to the API, the ST3 thermostat can be programmed to respond to different DR events as desired. In this case, it is programmed to respond following the same guidelines as the ST1 and ST2 thermostats in Homes 1 and 2. For any event, the CB1 shades will close or remain closed depending on their status at the time of the event.

TABLE 4: RESPONSES TO EVENT SIGNALS (HOME 3)

	ST3 THERMOSTAT	CB1 SHADES
Load Shed	4-degree offset	Closed
Critical Peak	8-degree offset	Closed
Grid Emergency	10-degree offset	Closed
Load Up	4-degree decrease	Closed

DR EVENT SCHEDULING METHODOLOGY

HOME 1

Events for Home 1 were called through the CTA 2045 online portal. Choosing the date from a calendar pane, the user can detail the start and end time, the type of event and the devices that will be impacted. For example, in Figure 10, a load up event is called on all devices from 2-3pm on October 11th 2017.

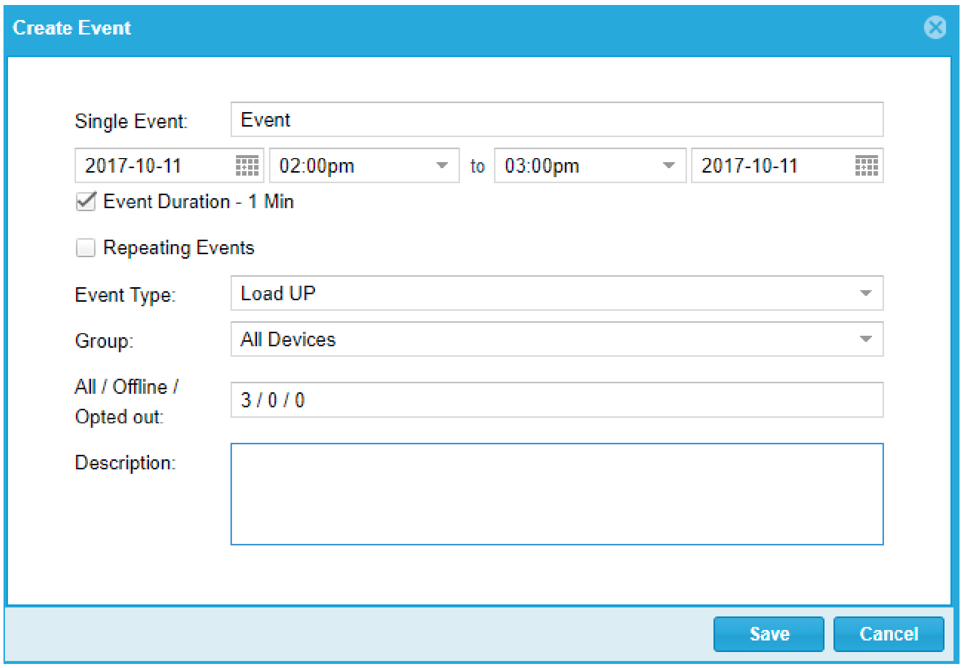

FIGURE 10: CTA 2045 "CREATE EVENT" VIEW

EVENT VERIFICATION

Verification of a successfully called event for Home 1 can be seen through the load plots on the CTA 2045 portal in Figure 11. Here, the pink bar indicates that the HVAC unit is running 'Idle Curtailed', indicating that the thermostat received the shed event.

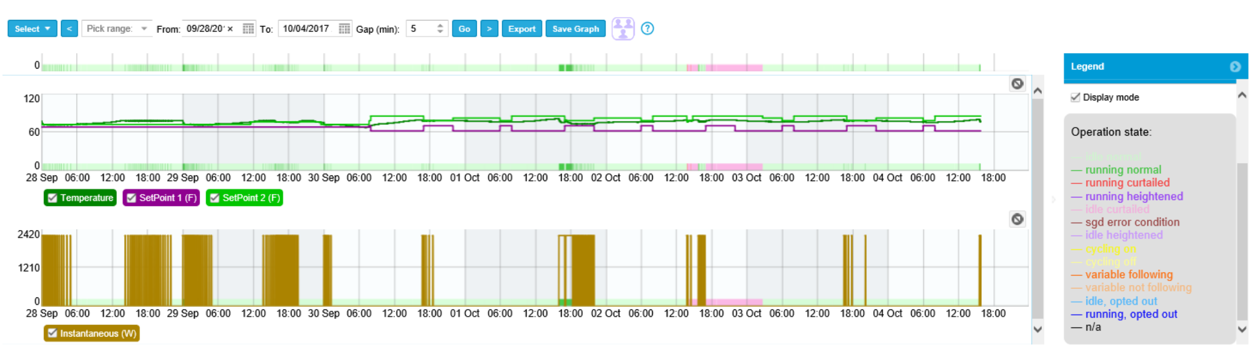

FIGURE 11: CTA 2045 HVAC SETPOINT AND LOAD PROFILE

HOME 2

For Home 2, events were called through the EPRI Open ADR VTN as shown in Figure 12. After adding the start time, duration and signal type, the user adds specific “Targets” which refer to individual Open ADR Gateway devices.

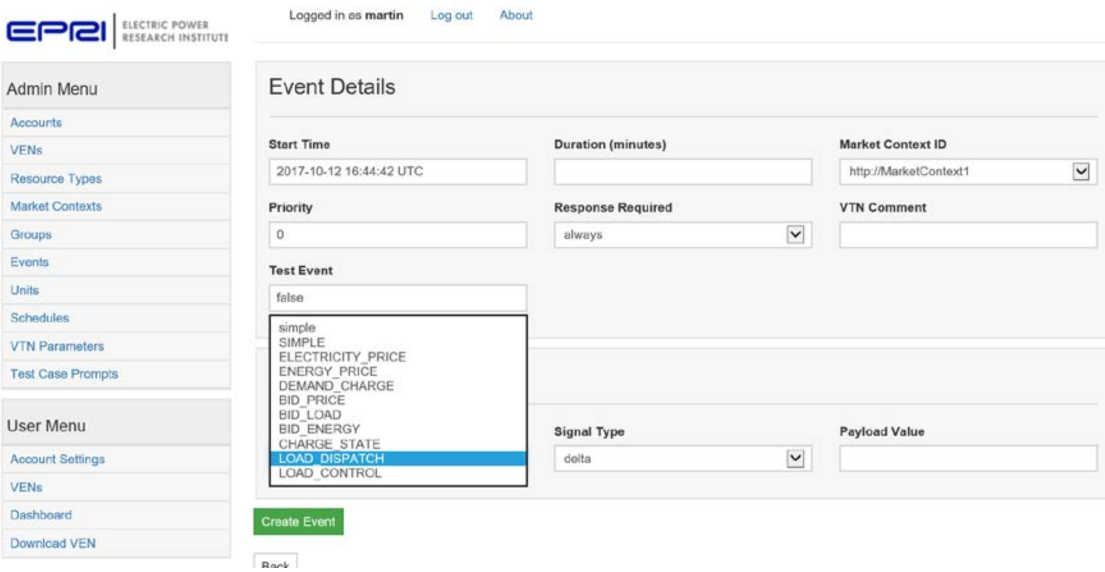

FIGURE 12: EPRI-OPEN ADR GATEWAY VTN

EVENT VERIFICATION

Verification of a successfully called event for Home 2 is seen through the Open ADR Gateway VTN. Upon completion of an event, the VTN will show a “completed” status as circled in red in Figure 13. During an event, the VTN will show an “active” status in place of the “completed”.

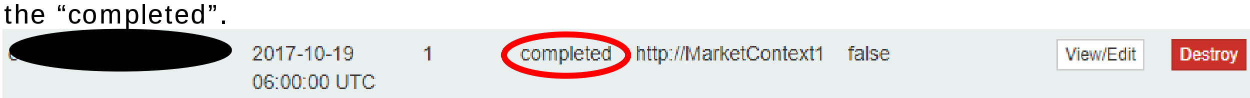

FIGURE 13: EPRI-OPEN ADR GATEWAY VTN EVENT VERIFICATION

HOME 3

Events at Home 3 were scheduled using an event scheduler on the EPRI server that communicates via If This Then That (IFTTT) communication to the API of the CB1 controllable blinds and via direct API calls to the ST3 thermostat. Once the event is scheduled, the customer interacts with the VA1 voice assistant according to the flow chart shown in Figure 14. As programmed, the customer must interact with the voice assistant to “Opt in” to the event rather than defaulting into the DR event. Although a barrier to customer participation if deployed at scale, due to its nature as a proof of concept, the necessity to “Opt in” forces interaction with the voice assistant, proving the technical feasibility of voice assistants as the point of interaction for DR events. If expanded to a larger testbed, the logic should be replaced to default into the event, ensuring higher participation. The voice assistant would then be used as the point of communication to "Opt out" of an event.

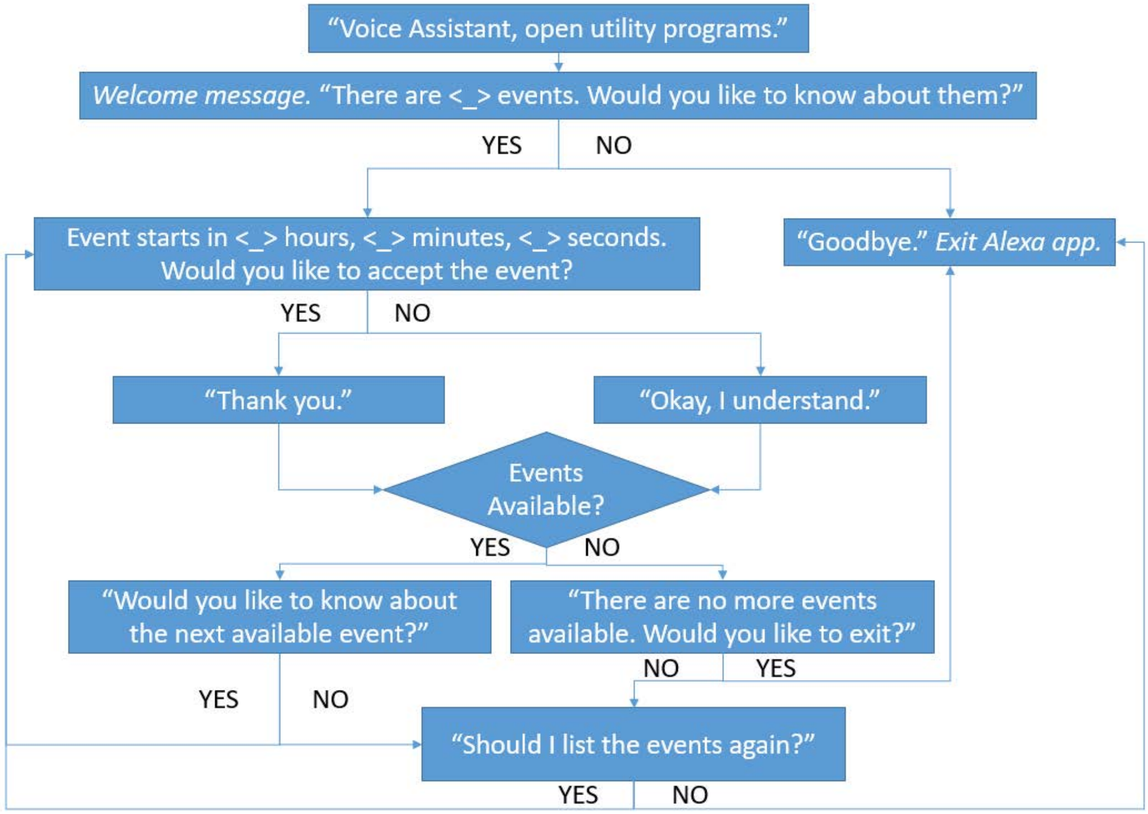

FIGURE 14: VA1 VOICE ASSISTANT DR EVENT FLOW CHART

EVENT VERIFICATION

For Home 3, verification of an event can be obtained by the customer using a "get" status command via the voice assistant in order to see if an event is in progress and if they are opted in or out. That being said, no direct verification through an online portal is available. Instead, along with the get status from VA1, unofficial verification can be completed through analysis of the circuit level monitoring real-time data. By monitoring the consumption of large individual loads prior to an event through minutes after the demand response call, a clear response to an event can be identified.

BASELINING

In the past, SDG&E's residential demand response calls utilized a 3-in-5 baselining technique to determine kWh reduction and to pay out customer incentives and bill credits. Load Research also uses a regression analysis on all of the residential participants to determine a total kW load drop for the group. The 3-in-5 baseline is calculated by averaging the hourly consumption over the 3 most similar days within the last 5-day time frame (not including weekends, holidays or event days). A "Day of" adjustment can be added to adjust the baseline to more accurately reflect what the actual load would be during the event, but is not included in this project.

In order to determine the three most similar days, an equally weighted (0.5 each), two-pronged approach is used to ensure accurate identification of the three most similar days within the last five days. The two components are as follows:

1) Comparison of total kWh consumption of each of the 5 days prior to each other

    - This step calculates the difference in total energy consumed between sets of eligible days before the event. For example, days 1 and 2 are compared, then days 1 and 3, 1 and 4, etc. until all possible sets are compared.

$$\Delta E = 1 - \left| \frac{\sum Day\ x\ consumption - \sum Typical\ day}{\sum Typical\ day} \right|$$

2) r^2 correlation between each of the 5 days prior to the event

    - Similar to the first component, the r^2 correlation is calculated for all possible pairs of days (1-2,1-3,1-4,1-5,2-3, etc.) in order to show which days have a higher correlation. The r^2 correlation value will always lie in between 0 and 1 and is an accurate representation of how close in shape the two load shapes are.

The r^2 correlation component was introduced to avoid the pitfalls of the first calculation, namely the opportunity for the total energy consumed throughout the day to be similar while having very different load shapes.

Once the 3 most similar days have been decided, the average energy consumption of those three days during the event hours act as the baseline energy consumption to which the event day consumption is compared.

SYSTEM RESPONSES

Although the expected responses across ecosystems and technologies were similar, the actual responses were not always as expected. This section details how each technology responded to DR events in the field and how unexpected responses reduced overall energy reduction.

HOME 1

ST1 THERMOSTAT - LOAD SHED

Response to CTA 2045 DR events varies per manufacturer as found through interaction with the ST1 thermostat connected via the CTA 2045 module. Early on, it was noticed that the homeowner would opt out of events almost immediately following event start times. The CTA 2045 web portal would show an event with an opt out. Further discussion with the CTA 2045 module manufacturer uncovered that the ST1 thermostat would automatically opt out of events if a set-point “Hold” had been applied earlier in the day. When the thermostat resumes the scheduled operation (set-points were typically scheduled to change at 6pm) the thermostat then opts IN to the event, shedding load for the second half of the DR event. If a “Hold” had not been applied, the ST1 would properly respond at 4:00pm. Figure 15 shows a flow chart of the logic behind DR events for the ST1 thermostat:

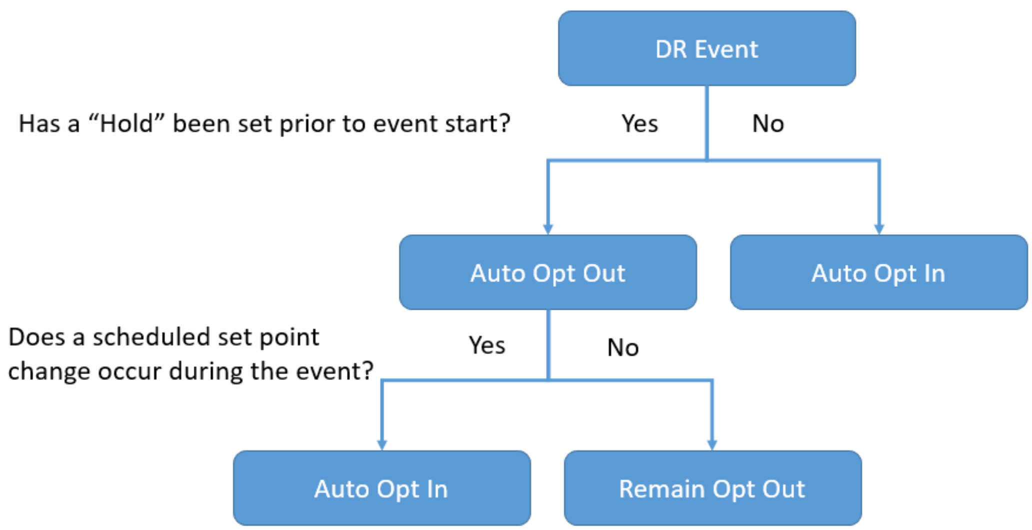

FIGURE 15: ST1 THERMOSTAT DR LOGIC

An example response from the CTA 2045 web portal is shown in Figure 16. The top graph displays the heating and cooling temperature set-points (the purple and light green lines, respectively) as well as the measured temperature (the dark green line). The bottom graph displays the consumption pattern of the HVAC with the brown line representing the instantaneous wattage, the dark green bars representing when the HVAC was ON, the light green representing when the HVAC was idle during normal operation, and the light pink representing when the HVAC was idle as a result of an event.

FIGURE 16: 8/31/2018 SHED EVENT

The following timeline details what occurred during the 8/31 Load Shed event:

- 3:30pm: A "Hold" of 78 degrees is placed on the thermostat by the occupant since the internal temperature had reached over 80 degrees. In response, the A/C turns on and the internal temperature begins to drop.
- 4:00pm: A "Load Shed" event is called, but does not register since the "Hold" setting automatically "opts out" of any event.
- ~6:00pm: The thermostat resumes scheduled operation, releasing the "Hold" and opting into the DR event. The A/C remains off for the next 40 minutes even as the temperature within the home exceeds the scheduled set-point of 78 degrees.
- 6:35pm: An occupant "opts out" of the event and applies another "Hold" setting to the thermostat, this time of 75 degrees. In response, the A/C turns on for 30 minutes to lower the temperature to 75 degrees, creating an increase in consumption during the final 1.5 hours of the event, negating the savings that had occurred prior to the "opt out".

The 8/31 event is representative of the majority of events that were called at Home 1. The typical assumed schedule for Home 1, based on inspection of all successful events, is outlined below:

1) When unoccupied, the thermostat has a programmed set-point range of 62 – 85 degrees.
2) At around 3:30pm each day, one or more of the occupants come home to a house with internal temperatures of above 80 degrees. In response to the high internal temperature, the occupants set the thermostat between 75-78 degrees.
3) At 4:00pm, when the "Load Shed" event begins, the thermostat sees the "Hold" and automatically "opts out" of the event.
4) Near 6:00pm, when the pre-programmed schedule resumes and the set-point changes to 78 degrees, the event finally registers with the device and "opts in" to the event.
5) Within 15-45 minutes, the internal temperature has breached 80 degrees and, for the sake of comfort, the occupants "opt out" of the event, setting a new "Hold" on the thermostat.

Not all of the events followed this schedule, but the majority of successful events saw a similar pattern, with only 15-45 minutes of the total event time actually seeing reduction, and the rest remaining "opted out". This pattern of events has a very clear negative impact on the event load shed with a more detailed analysis in the DR Summary "Results" section of this report.

ST1 THERMOSTAT - LOAD UP

At the time of deployment, the thermostat used with the CTA 2045 module did not have "Load Up" capability. Although multiple "Load Up" events were called and received by the CTA 2045 module, no setpoint response was detected as expected.

WH1 HEAT PUMP WATER HEATER – LOAD SHED

Similar to the ST1 thermostat, the WH1 water heater did not respond to load shed events as expected, with the expected response being to shut-off the water heater during the entirety of the event (unless necessary to prevent a cold water event). Instead, two scenarios would play out:

1) If the event was called during a period of time in which the water heater was already **OFF**, the shed event would restrict the water heater from turning on until event end. This was the expected response.
2) If the event was called during a period of time in which the water heater was **ON**, the water heater would remain on until the available heating capacity (based on the current set-point) reached zero. Only then would the water heater remain off until the end of the event.

Figure 17 is a screenshot of the CTA 2045 portal which displays an event on 8/17/2018 which represents both of the above scenarios. The following timeline explains each step:

- 3:30pm: The water heater turns on (as shown by the light brown line) to account for the increased available heating capacity.
- 3:45pm: The water heater enters resistive mode (as shown by the peak in the light brown line).
- 4:00pm: The "Load Shed" event is called and registers with the device as shown by the red bar beginning at 16:00.
    - Prior to the event call, the water heater had returned to heat pump mode.
    - Since the water heater was already on during the event call, it remained on until the available capacity (the dark green line) reaches 0.
- 6:15pm: The available heating capacity reaches zero.
    - Immediately after, the available capacity increases quickly (indicating hot water draw), but the water heater remains off, showing proper response to the load shed event.
- 8:00pm: The water heater remains off until 8:00pm, at which point the event ends and the water heater resumes normal operation.

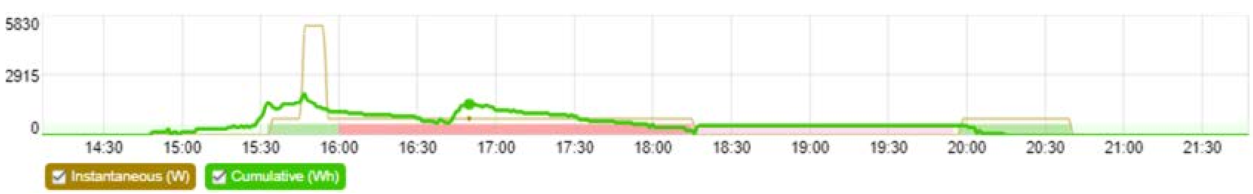

FIGURE 17: CTA 2045 "LOAD SHED" EVENT ON 8/17/2018

Throughout the testing period, the response of the WH1 heat pump water heater controlled by the CTA 2045 module was inconsistent. The majority of the events saw little value in the water heater response due to a lost connection, improper response or the unavailability of capacity within the water heater to require turning on.

An analysis of the afternoon and evening hours from May to September 2018 show the trends in energy consumption due to water heating at Home 3. Although only a single home, which will not represent scaled trends, the hot water consumption of Home 3 points to possible residential energy consumption patterns that are not well suited for demand response events. As Table 5 shows, the water heater was only ON between 11 – 15% of the time during the event hours of 4-8pm. When only looking at non-holiday weekdays, those numbers drop to 9 – 14%. The final hour of 8-9pm sees a substantial jump to nearly 50%. More telling is the energy consumption during those times.

All days included, the average consumption during the event hours run around 115 Watt-hours (Wh) of consumption per hour, adding up to 460 Wh of possible reduction. Only looking at non-holiday weekdays, the average drops to around 75Wh per hour, with a possible reduction of 300Wh during a four-hour event period. These averages were calculated using only the hours that saw energy consumption from the water heater, excluding hours that would contain a 0Wh which would artificially drop the average consumption.

When scaled, the ~300Wh reduction during the four-hour event period could be substantial, however, when applying the ON-rate of only 10-15% during event hours, 7 to 10 homes would have to be aggregated in order to reliably see a ~300Wh reduction from water heating.

TABLE 5: AVERAGE ENERGY CONSUMPTION DURING AFTERNOON AND EVENING HOURS

		2-3pm	3-4pm	4-5pm	5-6pm	6-7pm	7-8pm	8-9pm	9-10pm	10-11pm	11-12pm
With weekends / holidays / event days	% of Days with Consumption	10%	14%	11%	13%	14%	15%	47%	49%	48%	33%
	Average Consumption	150.7	134.4	112.6	121.4	114.1	118.8	110.2	267.4	151.9	137.4
Non-event/holiday Weekdays	% of Days with Consumption	6%	8%	9%	11%	12%	14%	51%	56%	55%	36%
	Average Consumption	54.5	81.4	71.8	72.1	79.4	72.9	86.8	227.6	124.8	114.7

As residential peaks continue to shift to later hours, the potential for energy reduction from water heating improves. As shown in Table 5, the percentage of time that the water heater is on between the hours of 8-11pm increases to ~50% for all measured days and ~55% for possible event days, with average consumption being highest during the 9-10pm timeframe at over 225Wh. Although 9-10pm may be too late for load shed events, the 8-9pm timeframe is included in peak hours, and at an ON-rate of 51% during the hour, the near 90Wh reduction could reliably scale.

WH1 WATER HEATER - LOAD UP

Although few load up events were scheduled during this testing period, the results from Table 5 show that increasing consumption prior to a load shed event will likely have little impact on the energy reduction during an event due to the low probability that the water heater turns. A load up event, while at minimum having no impact on energy reduction during the preceding load shed event, may in fact waste energy by causing the water heater to run at a lower efficiency than it otherwise would have after the end of the event. Further heating water already at a higher temperature requires more energy, decreasing the efficiency of the heat pump.

Figure 18 shows an example case in which a load up event was called and the proper response was triggered. As shown, the water heater remains off during the event, eventually turning on around 9pm (not shown). It is possible that the additional heating that was applied at 3:00pm did reduce the need to turn on during the event, however, the low probability that the water heater would turn on in the first place renders the scenario unlikely. The more likely scenario follows that the load up event heated the water heater to a higher set-point while running at a lower efficiency, only for some of that added energy to then be lost as standby losses. Access to water heater data would help prove either scenario, however, water heater data was not collected.

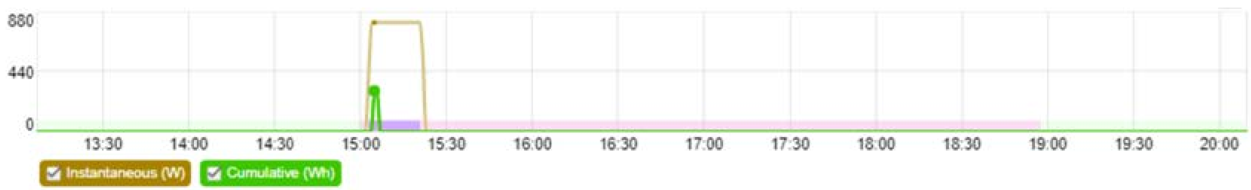

FIGURE 18: HOME 3 WATER HEATER RESPONSE TO A "LOAD UP" EVENT

HOME 2

The drawback of the EPRI VTN used with the Open ADR Gateway device was the lack of transparency in how devices responded to events. Unlike the CTA 2045 portal where the user can identify whether or not and how individual devices are responding to events, the EPRI VTN provides only three statuses: scheduled, in progress, or completed, without providing context as to what has responded. Using the CLM2 circuit level monitoring data as a visualization allows the user to determine whether an event has properly ben recorded on the HVAC, but the data is not well suited to determine whether a single outlet has responded.

ST2 THERMOSTAT

The ST2 thermostat responded as expected as shown in Figure 19. Although no new temperature setpoint is displayed, the "Active Utility Event" signals to the customer that an event is in progress and that the setpoints have been changed. When opting out, the customer encounters the "Event Participation" message, urging them to remain opted in to the event.

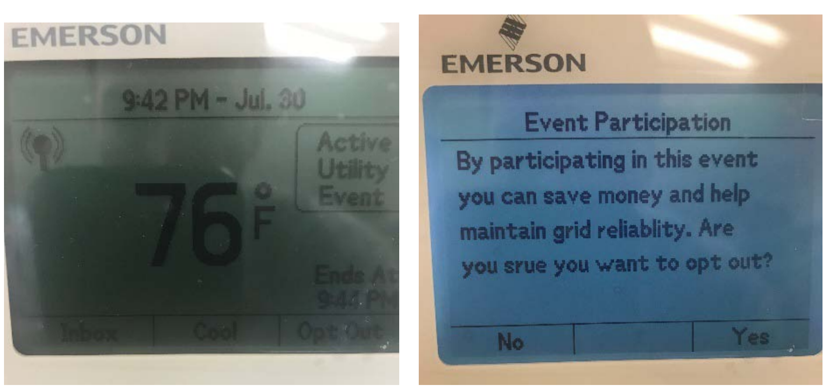

FIGURE 19: (LEFT) ST2 THERMOSTAT IN ACTIVE UTILITY EVENT; (RIGHT) ST2 OPT OUT MESSAGE

SO1 OUTLET

The SO1 outlet is programmed to respond to load shed events by cutting off power to plugs connected to the outlet. Although technically feasible, the high variability in possible loads connected to the outlet, as well as the lower consumption of such loads, leads to inconsistencies in the amount of available reduced consumption. For this project, a family room TV was plugged into the outlet.

HOME 3

ST3 THERMOSTAT

By project end, the DR scheduler could successfully schedule set-point changes through EPRI's server and push the event to the in-home VA1 voice assistant. The set-point changes would register, and allow for the customer to opt out through the ST3 itself or through the VA1. While successful, the eventual response of the ST3 was misrepresented due to the available smart modes on the thermostat itself.

The "Smart Home" and "Smart Recovery" modes on the ST3 thermostat, while useful in other scenarios, proved a barrier to prolonged deployment (the complete 4 hours) of a DR event. The "Smart Home" mode identifies when there is occupancy and adjusts the thermostat accordingly. During a DR event, the setpoint would change to 81 degrees, but as the ST3 detected occupancy, the setpoint would drop down to a typical comfortable temperature (~78 degrees). The "Smart Recovery" mode uses collected data to predict how long it will take for the temperature to reach the next scheduled setpoint, then turns the thermostat on prior to the scheduled setpoint change so as to have the house cooled by the time the setpoint changes. Both modes are meant to ensure occupant comfort, however, they interrupted the majority of the demand response events. Through the scheduler, it is not possible to exit or disable the smart modes, proving a challenge to successful scaled implementation. Other smart thermostats have the same functionality and would likely encounter the same problem if being integrated through a DR scheduler with voice assistance interaction.

When looking solely at energy consumption data, it seems as though an occupant consistently opts out of load shed events within 45 minutes of the event start. Looking closely at the ST3 data reveals that the "opt out" calls were indeed caused by the smart home mode. Comments from the occupant revealed that they would attempt to override the smart home mode when they noticed that they had unknowingly opted out of the event. However, much of the time, the opt out would go unnoticed, leaving up to over 3 hours of potential load reduction off the table. Figure 20 shows an example of the issue at hand.

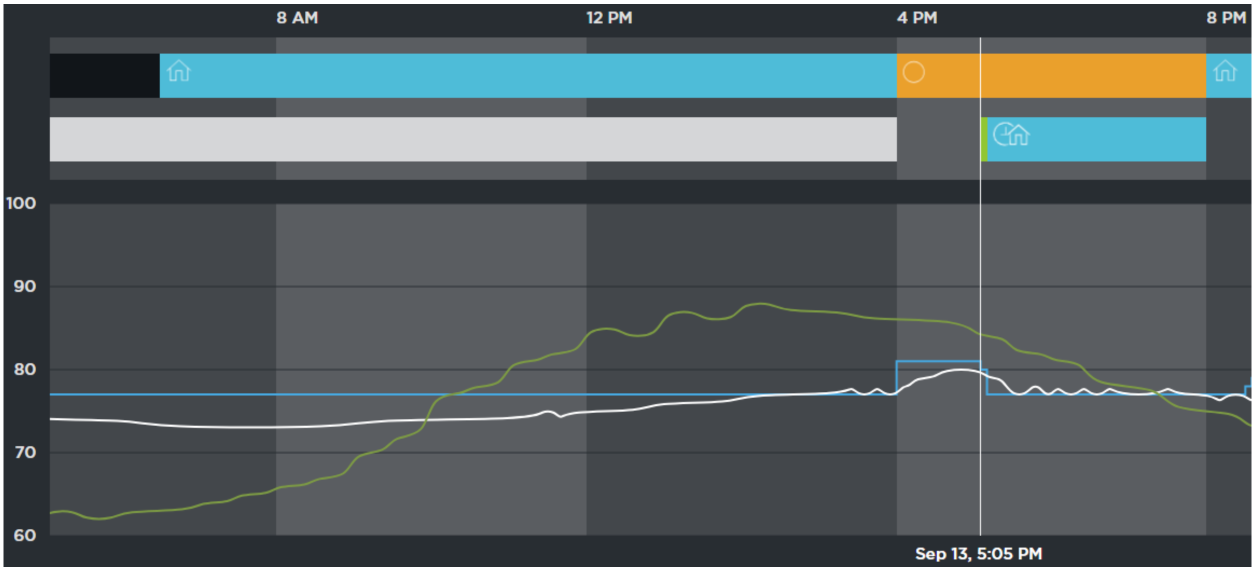

FIGURE 20: EXAMPLE OF ST3 SMART MODES

A timeline of events from Figure 20 is detailed below to showcase the issue:

- 4:00pm: The “Load Shed” event begins (as indicated by the top orange bar). Temperature set point increases from 78 degrees to 81 degrees.
- 5:05pm: The ST3 enters “Smart Recovery” mode (as indicated by the middle green bar), cooling the home in preparation for the “Smart Home” set-point.
- 5:10pm: The ST3 enters “Smart Home” mode (as indicated by the middle blue bar with the clock and home figures), lowering the set-point back to 78 degrees, “opting out” of the event.
- 8:00pm: The “Load Shed” event ends.

The 4 hour “Load Shed” event was reduced to a 1-hour event as a result of the “Smart Recovery” and “Smart Home” modes. Table 6 displays the number of successfully called events that were impacted by at least one or both of the smart home modes. Over 80% of the events entered either “Smart Recovery” mode or “Smart Home” mode, with 55% of the events entering into both. Less than 20% of the events did not enter into either of the modes.

TABLE 6: PERCENTAGE OF EVENTS IMPACTED BY SMART THERMOSTAT MODES

	SMART RECOVERY ONLY	SMART HOME ONLY	BOTH MODES	NEITHER
Number of events affected	1	2	6	2
% of events affected	9%	18%	55%	18%

A simple solution would be to disable the smart modes, however, that capability is not built into the scheduler, nor is it ideal for the customer who uses those modes during non-event hours to save energy and improve comfort. It should be noted that ST3 thermostats do integrate with, and have been proven effective with, other demand response managements systems. Collaboration with the ST3 manufacturer could help to resolve this issue and allow for smart modes to be disabled during event hours.

CB1 Shades/Blinds

The response of the CB1 controllable blinds is limited to two modes: “Open” or “Closed”. Although able to set the blinds at any point between fully open or closed, the blinds should be fully shut to ensure maximum energy reduction during a load shed event. The DR scheduler sends a “close” signal to the blinds when an event begins. If the blinds are up, the event will lower the blinds. If already closed, nothing occurs, and the blinds remain closed until the end of the event.

For a load up event, the blinds are set to remain in their current position, however, this response could be adjusted if it is determined that blinds should close in response to load up events to help store the cool air within the home.

DR EVENT SUMMARY

Over the course of the summer, 16 DR events were called to varying degrees of success across the three homes. The events were primarily called during the months of July and August to account for the hottest weeks of the year and were scheduled on weekdays which had seen high temperatures in the days leading up to the event in order to more adequately represent when DR events would typically be called.

HOME 1

Home 1 experienced a number of issues early on which reduced the total number of successful events. In mid-May, the two devices had been tested to ensure proper response, however, as events began to be called at the end of June and beginning of July, no response was being recorded by the CTA 2045 module. The EPRI team worked with CTA 2045 to remotely troubleshoot the issue, but eventual homeowner outreach was needed in order to record the status and the serial numbers of the two devices and to re-provision the devices onto the CTA 2045 portal. By the beginning of August, the HVAC was working successfully and the water heater followed suit. A detailed summary of events can be found in Table 7.

TABLE 7: EVENT SUMMARY FOR HOME 1

Home 1	Event Type	Load	Status	Opt Out Time	Notes
6/26/2018	Shed	HVAC	Unsuccessful	--	No response from CTA 2045, could schedule event, but did not register
		HPWH	Unsuccessful	--	
7/3/2018	Shed	HVAC	Success - Loss of Data	--	Successful call, but lost all stored data on 7/12
		HPWH	Unsuccessful	--	No response from CTA 2045, could schedule event, but did not register
7/10/2018	Shed	HVAC	Success - Loss of Data	--	Successful call, but lost all stored data on 7/12
		HPWH	Unsuccessful	--	No response from CTA 2045, could schedule event, but did not register
7/12/2018	Shed	HVAC	Unsuccessful	--	CTA modules disappeared from utility portal - troubleshooting with CTA 2045 and customer
		HPWH	Unsuccessful	--	
7/18/2018	Shed	HVAC	Unsuccessful	--	CTA modules disappeared from utility portal - troubleshooting with CTA 2045 and customer
		HPWH	Unsuccessful	--	
7/24/2018	Shed	HVAC	Unsuccessful	--	CTA modules disappeared from utility portal - troubleshooting with CTA 2045 and customer
		HPWH	Unsuccessful	--	
7/26/2018	Shed	HVAC	Unsuccessful	--	CTA modules disappeared from utility portal - troubleshooting with CTA 2045 and customer
		HPWH	Unsuccessful	--	
7/31/2018	Shed	HVAC	Unsuccessful	--	CTA modules back on line but not responding to events
		HPWH	Unsuccessful	--	
8/2/2018	Shed	HVAC	Success	6:05pm	Successful shed for 10 minutes, opt out at 75 degrees
		HPWH	Unsuccessful	--	Needed MAC address from customer to troubleshoot, AO Smith troubleshooting port adaptor
8/7/2018	Shed	HVAC	Success	6:10pm	Successful shed for 15 minutes, opt out at 81 degrees

		HPWH	Unsuccessful	--	Needed MAC address from customer to troubleshoot, AO Smith troubleshooting port adaptor
8/8/2018	Shed	HVAC	Success	6:14pm	Successful shed for 20 minutes, opt out at 80 degrees
		HPWH	Unsuccessful	--	Needed MAC address from customer to troubleshoot, AO Smith troubleshooting port adaptor
8/15/2018	Load Up/Shed	HVAC	Success	6:35pm	No load up capability. Successful shed for 40 minutes, opt out at 81 degrees. Minimal impact from load up.
		HPWH	Success	--	No hot water draw during event
8/17/2018	Shed	HVAC	Success	--	Successful shed for 2 hours till event end. Likely that homeowners were not home as temperature reached 82 degrees w/o opt out
		HPWH	Success	--	Opted in at 6:15pm. Successful event through 8:00pm. See "System Response" section for explanation of opting in at 6:15pm.
8/28/2018	Load Up/Shed	HVAC	Success	6:55pm	No load up capability. 3 hour load shed from 4-6:55pm. Ran curtailed to keep the setpoint of 82 degrees met
		HPWH	Success	--	Loaded up for 20 minutes. Reduced available heat capacity to 0kWh. No load draw until 9:00pm.
8/31/2018	Shed	HVAC	Success	6:35pm	Successful shed for 40 minutes, opt out at 80 degrees
		HPWH	Success	--	No hot water draw during event

Although all issues were eventually resolved, the sudden loss of connection and visibility to the CTA 2045 devices raised concerns over the durability of these types of devices for DR. When successfully called, the devices did respond in a consistent pattern.

HOME 2

Home 2 experienced a number of early issues as well, reducing the total number of successful events in half. During the first two weeks of DR calls, the connection to the Open ADR Gateway hub had been lost due a software update not having been pushed to the device. Those weeks were followed by another two weeks in which a member of the household had unplugged the Ethernet from the Gateway. Remote troubleshooting was unsuccessful and eventually the homeowner was contacted to help determine the issue. As the final issue, once back up online and available to respond, the utility VTN was under maintenance and undergoing a security update during the 7/26 event, rendering the event unavailable for Home 2. The 7/31 event finally saw a successful call.

TABLE 8: EVENT SUMMARY FOR HOME 2

Home 2	Event Type	Status	Opt Out Time	Notes
6/26/2018	Shed	Unsuccessful	--	Connection to Open ADR Gateway lost
7/3/2018	Shed	Unsuccessful	--	Connection to Open ADR Gateway lost
7/10/2018	Shed	Unsuccessful	--	Connection to Open ADR Gateway lost, had to push update
7/12/2018	Shed	Unsuccessful	--	Open ADR Gateway unplugged
7/18/2018	Shed	Unsuccessful	--	Open ADR Gateway unplugged

7/24/2018	Shed	Unsuccessful	--	Open ADR Gateway unplugged
7/26/2018	Shed	Unsuccessful	--	Open ADR Gateway VTN in maintenance, security upgrade
7/31/2018	Shed	Success	--	
8/2/2018	Shed	Success	--	
8/7/2018	Shed	Success	--	
8/8/2018	Shed	Success	--	
8/15/2018	Load Up/Shed	Success	--	No load up functionality
8/17/2018	Shed	Success	--	
8/28/2018	Load Up/Shed	Success	--	No load up functionality
8/31/2018	Shed	Success	--	

After the first successful call, all subsequent calls ran successfully. That being said, the initial lost Open ADR Gateway connection leads to the concern of how often remote software updates are missed by devices and whether that may impact reliability of devices, especially at scale.

HOME 3

Overall, Home 3 saw the greatest percentage of successfully called events, which, unexpectedly, does not correlate with the most amount of energy reduced. Due to complications with the voice assistant technology, initial events at Home 3 were called manually through the ST3 portal. Once fixed and installed, the homeowner could use the VA1 voice assistant as the communicating platform for opting in and out of an event.

TABLE 9: EVENT SUMMARY FOR HOME 3

Home 3	**Event Type**	**Status**	**Opt Out Time**	**Notes**
6/26/2018	Shed	Success	5:30pm	Thermostat turned off at 7pm
7/3/2018	Shed	Success	--	
7/10/2018	Shed	Success	5:15pm	
7/12/2018	Shed	Success	5:45pm	
7/18/2018	Shed	Success	5:00pm	
7/24/2018	Shed	Unsuccessful	--	Mediator error
7/26/2018	Shed	Vacation (Thermostat off)	--	
7/31/2018	Shed	Vacation (Thermostat off)	--	
8/2/2018	Shed	Vacation (Thermostat off)	--	
8/7/2018	Shed	Success	4:50pm	
8/8/2018	Shed	Success	5:05pm	
8/15/2018	Load Up/Shed	Success	4:40pm	Load Up - Temp drops to 75 degrees F
8/17/2018	Shed	Success	4:40pm	
8/28/2018	Load Up/Shed	Success	4:15pm	Unsuccessful load up
8/31/2018	Shed	Unsuccessful	--	Call did not register

RESULTS

This section details the reduction seen during successful events at each home, showing varying, inconsistent results overall, heavily impacted by the communicating ecosystem as well as occupant behavior.

HOME 1

Much of the inconsistency in results in Home 1 can be attributed to the amount of variability in the homeowner's response to the DR event. Although events were being successfully received, the homeowner was typically quick to "Opt out".

For Home 1, the results are split into two main tables (Table 10 and Table 11). The first table compares the 4-hour baseline load to the 4-hour event load, calculating the total and percent reduction from the baseline. The second table splits the analysis into two 2-hour sections, comparing the total and percent reduction of each 2-hour period to the corresponding 2-hour baseline. This split is used to display a more accurate representation of the response found in Home 1. Although a 4-hour event, the scheduling placed on the ST1 thermostat, and the propensity of the customer to put a "Hold" on the thermostat, opting out prior to the event, caused most events to register on the thermostat at 6:00pm (a scheduled setpoint) rather than at 4:00pm. Splitting the table into two distinct timeframes distinguishes between when the hours when the thermostat typically responded and when it typically did not. The 4-hour reduction can still be used to look at the overall reduction with the water heater and thermostat.

TABLE 10: 4-HOUR EVENT REDUCTION FOR HOME 1

Home 1	4 Hr Baseline Load	4 Hr Event Load	4 Hr Event Reduction	% Reduction
8/2	12956	13524	-568	-4%
8/7	12034	17260	-5226	-43%
8/8	12034	15160	-3126	-26%
8/15	11536	9041	2495	22%
8/17	10688	6820	3868	36%
8/28	10191	7043	3148	31%
8/31	9978	12233	-2255	-23%
Average	11345	11583	-238	-2%

That being said, the results from Home 1 are far from what was expected. When looking at the 4-hour reduction, on average, the total load *increased* by 2% during load shed events, contrary to any sort of reduction that would be expected. Three of the events did see high reduction (between 22-36%), but the confidence to consistently receive even a fraction of that much load shed is minimal as the other four fully successful events saw load increases anywhere from 4-43%.

TABLE 11: 2-HOUR EVENT REDUCTION FOR HOME 1

Home 1	2 Hr Baseline Load		2 Hr Event Load		2 Hr Event Reduction			
	4-6pm	6-8pm	4-6pm	6-8pm	4-6pm	6-8pm	4-6pm	6-8pm
8/2	7762		6510		1252		16%	
		5194		7014		-1820		-35%
8/7	7385		8429		-1044		-14%	
		4649		8831		-4182		-90%
8/8	7385		6404		981		13%	
		4649		8756		-4107		-88%
8/15	5036		4105		931		18%	
		6500		4936		1564		24%
8/17	4579		5011		-432		-9%	
		6109		1809		4300		70%
8/28	5079		1192		3887		77%	
		5113		5851		-738		-14%
8/31	5595		5378		217		4%	
		4383		6855		-2472		-56%
Average	6117	5228	5290	6293	827	-1065	14%	-20%

Looking at the 2-hour table shows that during the 4-6pm time period, when the thermostat typically did **not** respond to events, the home saw an average reduction of 14%, a number that has little correlation to the event, and can be considered coincidental. Interestingly, the second 2-hour timeslot saw the average load *increase* by 20% during load shed events, the opposite of what was expected. Looking at the CTA 2045 portal to understand how the setpoints change points us to an explanation of these results.

Tables 12, 13, and 14, help show how the homeowner or other members of the household responded to DR load shed events. To set the baseline case, Table 12 details the typical August weekday response to the internal temperature of the home. The “Time of Change” column shows at what point the homeowner changed the thermostat setpoint after the programmed setpoint change to 78ºF at 6:00pm. The “Temp Threshold” column shows at what temperature the homeowner felt uncomfortable enough to lower the setpoint. Typically, the customer would have already set a hold earlier in the day (near 76 ºF) prior to the scheduled change to 78 ºF, meaning that the scheduled setpoint change would *increase* the temperature setpoint (~76 to 78). In response, the homeowner sometimes moves the setpoint back down.

That being said, the majority of the time (69%), the homeowner leaves the setpoint at 78 ºF. The other 31% of the time, when the homeowner does change the setpoint between 6-8pm, the average setpoint drops to 75.6 ºF (Table 13). Factoring both when they do and do not change the setpoint, the average setpoint on non-event weekdays for the month of August is calculated at 77.25 ºF, only 0.75 ºF below the programmed setpoint of 78 ºF.

TABLE 12: HOME 1 SETPOINT RESPONSE DURING NON-EVENT WEEKDAYS.

Non-Event Weekdays	Time of Change	Temp Threshold	New Setpoint
8/1/2018	6:16 PM	78	75
8/3/2018	--	78	78
8/6/2018	6:15 PM	78	76
8/9/2018	7:00 PM	78	76
8/10/2018	--	78	78
8/13/2018	6:55 PM	78	76
8/14/2018	--	78	78
8/16/2018	--	78	78
8/20/2018	6:20 PM	78	75
8/21/2018	--	78	78
8/22/2018	--	78	78
8/23/2018	--	78	78
8/24/2018	--	78	78
8/27/2018	--	78	78
8/29/2018	--	78	78
8/30/2018	--	78	78
Average	6:33 PM	78	77.25
Temperature Difference		0.75	
% of Days with Adjusted Setpoints		31%	

TABLE 13: HOME 1 SETPOINT RESPONSE ON ADJUSTED NON-EVENT WEEKDAYS

Date	Time of Change	Temp Threshold	New Setpoint
8/1/2018	6:16 PM	78	75
8/6/2018	6:15 PM	78	76
8/9/2018	7:00 PM	78	76
8/13/2018	6:55 PM	78	76
8/20/2018	6:20 PM	78	75
Average	6:33 PM	78	75.6
Difference		2.4	

In comparison, event days see a much different pattern of behavior. To begin, during the event hours of 6-8pm, the homeowner lowers the setpoint ("opts out") 86% of the time, much more often than the 31% of the time that they adjust the setpoint during non-event days. When they do adjust the setpoint, they, on average, adjust down to 74.8ºF, 0.8ºF lower than the average 75.6ºF that they set when they adjust during non-event days. The homeowner also responds to the temperature changes more quickly, responding, on average 25 minutes after the event setpoint changes to 82ºF, compared to the average 33 minutes after the scheduled setpoint changes to 78ºF at 6:00pm on non-event days. Keep in mind that the 33 minutes does not reflect all non-event weekdays, rather just the weekdays that saw setpoint adjustments during the 6-8pm timeframe. In reality, the average 33-

minute response should be much higher as most non-event days never saw a setpoint adjustment.

TABLE 14: HOME 1 SETPOINT RESPONSE ON EVENT DAYS

Opt out Event Days	Time of Change	Temp Threshold	New Setpoint
8/2/2018	6:05	75	74
8/7/2018	6:10	80	74
8/8/2018	6:13	80	72
8/15/2018	6:35	81	77
8/28/2018	6:56	82	78
8/31/2018	6:34	80	74
Average	6:25	79.7	74.8
Temperature Difference		4.8	
Opt Out Percentage		86%	

These results exhibit how this particular homeowner responded to DR events. On non-event weekdays, they would rarely adjust the temperature below its 78ºF scheduled setpoint during the set hours of 6-8pm, keeping consumption predictable and lower. When they would adjust the setpoint, they would on average only adjust it by 2.4 degrees. However, on load shed event days, the higher temperature setpoint (82ºF), followed quickly by increasing inside temperatures, triggered more drastic homeowner response. Not only would they near-always quickly adjust the setpoint, they would adjust it even lower than if it had been a regular day, adjusting on average by 4.8 degrees from the current measured temperature, to the new setpoint. In doing so, they ended up running the HVAC for a longer period of time in order to hit the lower setpoint, nullifying any energy savings that had occurred during the first ~25 minutes of the event and actually increasing overall energy consumption by an average of 20% when compared to the baseline. For reference, Figure 1 shows an example of the kickback, with the pink bar showing the load shed event quickly followed by an opt out and large HVAC consumption (the brown rectangular plot).

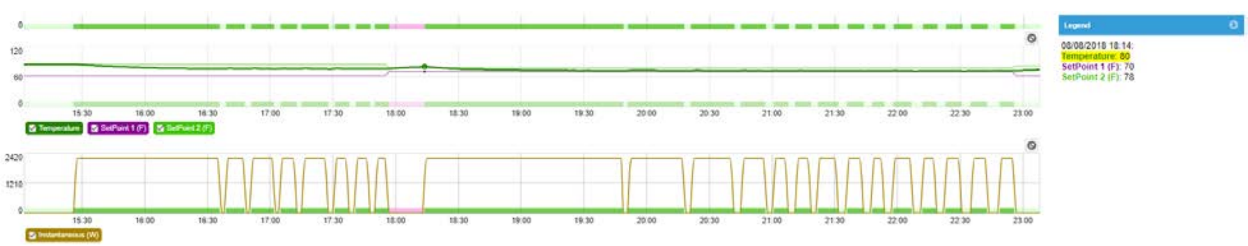

FIGURE 21: EXAMPLE OF KICKBACK EFFECT SEEN IN HOME 1

HOME 2

The results from the second home are more promising than Home 1, but consistency in response remains an issue. Shown in Table 15, of the 8 successfully called events, load shed was observed 50% of the time, seeing reduction of anywhere from 46-75% from the baseline load. Although significant reduction when reduced, the other 50% of events saw an increase in consumption during event hours, twice seeing increases of over 250%. That being said, both of the increases over 250% occurred at the end of July or the very beginning of August. The consumption patterns of home 2 indicate that throughout the June and July months, HVAC usage was sporadic and inconsistent, occasionally remaining off for a week or so, even when occupied (as confirmed by the homeowner). This inconsistent usage led to much reduced baseline calculations, which, when followed by opt out responses by the homeowner, caused high percentage increases in consumption, which do not reflect typical expected reduction.

TABLE 15: HOME 2 LOAD SHED RESPONSE

Home 2	4 Hr Baseline Load	4 Hr Event Load	4 Hr Event Reduction	% Reduction
7/31/2018	2853	11243	-8390	-294%
8/2/2018	3033	10685	-7652	-252%
8/7/2018	12034	6507	5527	46%
8/8/2018	10891	11535	-644	-6%
8/15/2018	12518	3133	9385	75%
8/17/2018	10632	2762	7870	74%
8/28/2018	4163	1797	2366	57%
8/31/2018	4032	5100	-1068	-26%
Average	8186	5931	2255	28%

As August began, however, a noticeable increase in consistency of HVAC consumption was observed. The homeowner began to use the HVAC nearly every day, increasing the baseline calculations for early and middle August as shown in Table 15. Now, when the homeowner would decide to opt out, the percent increase was much less drastic (only 6% increase when opting out on 8/8/2018). Factoring in the reduction for all of the events, Home 2 saw an average reduction of 28% during the 8 events. If the first two events were removed due to their low baseline calculation due to inconsistent HVAC use, Home 2 would have seen an average reduction of 43% during load shed events. Although promising, the inconsistency in HVAC usage as well as low percentage of events that were not opted out (50%), leads to little confidence that this homeowner will consistently reduce load during load shed events.

It should be noted that although the DR capable plug load controller was connected and responding, its usage during DR events was even more sporadic than that of the HVAC and its typical consumption of ~50 to 100 watts was negligible compared to the HVAC, calling into question the value of DR capable plug load controllers. In addition, had the direct load controller been installed for the spa pump, absolutely zero reduction would have been observed due to the lack of usage by the spa pump as indicated in Figure 22. Although difficult to see, the figure shows consumption by the spa pump only during the months of March through May, with no consumption during peak load months. While spa pumps do have a large capacity for load shed (this one in particular running over 4,000W when in use), in this case, there is no confidence that the spa pump can be used as a load shed resource due to the likelihood that it will already be turned off. There would be little value for load up events since it is very unpredictable when the spa pump will be in use after an event ends.

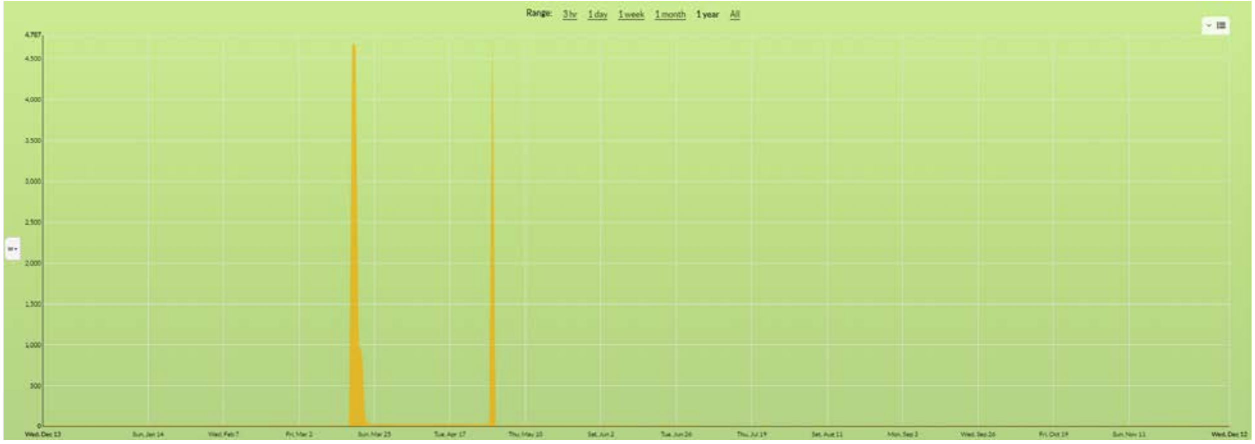

FIGURE 22: SPA PUMP CONSUMPTION FOR HOME 2

HOME 3

Much like Home 1, the technology within Home 3 restricted the homeowner from seeing reduction during load shed events, on average seeing loads *increase* by 16% during event hours. As mentioned in the "System Responses" section, the Smart Recovery and Smart Home modes would automatically opt the homeowner out of the event when the temperature within the home would reach temperatures that the smart thermostat would not typically expect (usually above 80 ºF). Due to the placement of large southwest facing windows, the inside temperature would reach over 80 degrees very quickly, typically within 30 to 45 minutes. In response, the ST3 thermostat would adjust the setpoint back between 76 and 78ºF, increasing overall HVAC consumption.

TABLE 16: HOME 3 LOAD SHED RESPONSE

Home 3	4 Hr Baseline Load	4 Hr Event Load	4 Hr Event Reduction	% Reduction
6/26/2018	2043	5035	-2992	-146%
7/3/2018	1021	3415	-2394	-234%
7/10/2018	6413	6529	-116	-2%
7/12/2018	5914	9102	-3188	-54%
7/18/2018	9280	10131	-851	-9%
8/15/2018	7563	8784	-1221	-16%
8/17/2018	7563	11901	-4338	-57%
8/28/2018	10148	10603	-455	-4%
8/31/2018	12494	7126	5368	43%
Average	6938	8070	-1132	-16%

Additionally, the CB1 controllable blinds had little impact on overall energy consumption due to customer behavior. In order to take full advantage of the blinds, the homeowner pre-programmed the blinds to lower on all days at 1pm, when the sun would typically begin shining through. In doing so, the baseline calculations factored in the already lower energy consumption, so any reduction during the DR event was already reflected in the baseline, resulting in ~0 reduction due to the blinds. Although able to increase the amount of time before the customer opts out, controllable blinds seem to be more effective as an overall energy efficiency technique rather than one suitable for DR programs.

CUSTOMER SEGMENTATION

A key finding during this project is the establishment of different types of demand response customers. Although a small sample size, the amount of variation between behavior and energy consumption provides an intriguing case study on how customers react to demand response events. The three homeowners were recruited by SDG&E as a part of the pilot and were fully aware of how the demand response events would impact their energy consumption and how they may impact their comfort.

As a result of the pilot, three customer profiles emerged:

1) Home 1: The comfort-oriented homeowner
2) Home 2: The inconsistent and uninterested homeowner
3) Home 3: The engaged homeowner

It should be noted that the main homeowner incentive to opting in to demand response calls was energy reduction and not bill savings, possibly skewing the results as homeowners may care less about energy savings and more about bill savings. Although minor bill savings could be seen due to the overall reduced consumption, there were no direct financial incentives (rate increases during DR events or opt in incentives) to encourage the homeowner to remain opted in during load shed events, decreasing the overall energy reduction during DR events.

COMFORT ORIENTED

The responses by the homeowner in Home 1 revolved around their own comfort, opting out as soon as their levels of comfort were breached (~80ºF internal temperature). This response could be attributed to the occupancy in home 1 which was greater than that of the other two homes. The larger family size likely had an impact on consumption as there was an increased chance that someone would become uncomfortable and opt out of the event. The parents may have wanted to ensure comfort for their children as well, opting out in order to provide them that comfort.

Whatever the case, the comfort oriented home always chose comfort over completion of the event. During actual DR events, the incentives to opt-in, and remain opted in, have to be large enough to see consistent energy reduction from this homeowner. This is likely a common customer personification and will not make the best use case for scaled DR. DR programs should be targeted towards more willing participants.

UNINTERESTED

The homeowner in Home 2 can be characterized by being uninterested and inconsistent. They too were comfort oriented in that they would opt out when uncomfortable, but their patterns of opting out were more inconsistent. To them, it seems like the DR events were more of a nuisance that they had to deal with, rather than something in which they saw value. Again, this may have changed had a large enough financial incentive been a part of the pilot, but it remains that this homeowner profile is not an ideal home to be recruited for DR. The homeowner also voiced displeasure with their new thermostat which had replaced an existing programmable thermostat that they had enjoyed using, likely impacting their willingness to stay opted in to the events.

Although inconsistent, the smaller number of occupants (~2) may have impacted how often events were opted out. The reduced number of individuals concerned about comfort means fewer people to adjust the setpoint during an event.

ENGAGED

Assuming the DR system works appropriately, the homeowner in Home 3 is an ideal target for DR programs. The homeowner was thoroughly engaged with the program and brought up concerns when the thermostat automatically opted out of events. When noticed, the homeowner would opt back into the event in order to ensure energy reduction. Although still comfort concerned, the homeowner was willing to negotiate on internal temperature during load shed events for the sake of the program.

Similar to Home 2, the smaller family size may have had an impact on engagement as well, allowing the primary homeowner to prioritize load reduction while impacting the comfort of fewer individuals.

LESSONS LEARNED

Throughout the design and implementation of the demonstration, many lessons were learned at the program and technical levels for each system. Although each eventually successful, the process to reach success for each system was arduous and, although each worked well in a laboratory environment, field deployments experienced additional complexities and barriers to entry.

RECRUITMENT

For the project, recruitment of appropriate sites was integral to the success of the ecosystem deployments. As expected, not all homes are made ready for connected devices DR and there is high cost associated with replacing or integrating large loads with communicable devices. Bring Your Own Devices (BYOD) programs can be effective to reduce upfront costs to the utility, but expanding past thermostats for whole home demand response introduces new integration challenges, such as device commissioning at each site, that may require intervention from the utility.

As mentioned earlier, the appropriate technology within the home does not ensure consistent load reduction. Programs should target homeowners who have consistent usage during peak months and who may be more willing to remain opted in to every event. Homes with higher occupancy, although having a larger potential for reduction, may have increased opt-out rates.

MAINTENANCE

Based on the project demonstrations, for whole home DR, device connection and maintenance may prove a barrier to scale. Although by the end of the DR tests, devices were responding consistently and appropriately, initial event calls proved troubling, with multiple dropped connections at multiple sites, each time eventually requiring interaction with the customer. For three homes, this is not a problem. For 1000 homes, this becomes an issue. It is not cost effective to have the utility troubleshoot issues on a per site basis. Having an acceptable threshold of dropped homes (say only needing 80% connected at all times) will reduce these added maintenance costs, but either way, the robustness of device connection must be emphasized.

Key to maintenance or troubleshooting issues is the availability and willingness of a homeowner to engage with the utility to pinpoint issues or to allow access to the home. Throughout this demonstration, technical support was met with an unwillingness and unresponsiveness from multiple homeowners, indicative of a larger population who may resist or have a negative reaction towards utility intervention, furthering the need for robust and proven whole home ecosystems as well as targeted recruitment of willing participants.

HOME 1 ECOSYSTEM

The CTA 2045 modules were inconsistent in their responses and connectivity. Although eventually consistently working by the end of the project, the initial events saw unexplained dropped connectivity from the CTA 2045 portal and inconsistent response, at times not responding to an event at all even when connected. CTA 2045 has successfully deployed systems at scale with fewer connection issues, improving the confidence of the CTA modules as a whole home DR system, however, the inconsistency and issues with Home 1 call to mind no matter how proven, unforeseen issues can still arise and may need utility or 3rd party intervention to have them corrected.

ST1 Thermostat

As mentioned in the "System Response" section, the ST1 thermostat would "opt out" of events prior to the event start if a set point "Hold" had been called earlier in the day. This response, although decreasing the ultimate value of the peak load shed, called to mind the number of pieces that must be coordinated for Whole Home DR. First, the central point of control must be capable of repeatedly and reliably accepting, translating and communicating the DR signal to each end device. Second, even if an event is properly called, has each manufacturer built the end use technology to respond as the utility would expect? If the utility is expecting reduction over a 2-5 hour period, but receives reduction for less than 1 hour, what are the implications? Will it take 2-4 homes to attain the same level of reduction as expected from 1?

Using the CTA 2045 or Open ADR standards in lab or field testing, it is critical to vet the DR responses of the increasing list of products available on the market to understand the nuances of each response. The majority may respond as expected, but identifying those with unexpected behavior can instill added confidence in reliable whole home load reduction.

WH1 HPWH

Although electric water heaters can have large energy draws, inconsistent timing of usage (at least for Home 1), and variability in type of water heater are concerns for consistent energy reduction. Electric resistance water heaters have a larger potential for energy reduction than heat pump water heaters due to their less efficient operation and high power draw, however, residential energy efficiency experts now often advocate for heat pump water heaters with less power draw and more efficient operation. Although reducing the peak draw from thousands of watts to hundreds of watts, heat pump water heaters can still see demand response load reduction of ~1-2kWh, assuming they would be on during the full event otherwise. More realistically, heat pump water heaters will see less than 1kWh reduction over a 5-hour event.

When scaled, less than 1kWh reduction from each water heater could be significant, but that assumes operation during the peak period. As mentioned earlier, during the event hours for this demonstration, the water heater was on only between 10-15% of the time, providing little confidence in consistent reduction. This changes per site, but better understanding each sites' usage prior to integrating water heaters into the whole home DR program can determine whether water heater DR is financially feasible.

Home 2 Ecosystem

The Open ADR Gateway, although effective in relaying the DR events to the thermostat and outlet, ran into a number of connection issues, dropping connection with the Open ADR Gateway VTN whenever updates were created but not pushed to the device itself. Once the Open ADR Gateway support team was notified, the update was easily pushed to the device and the connection would be re-established. However, updates should automatically apply to all deployed units to avoid this error. That being said, it is possible that since the version of the Open ADR Gateway used was a single test product for this project, it was not automatically included in software updates. At scale, it would be expected that all devices that maintain an internet connection would consistently receive updates without interference to successful DR events.

The Open ADR Gateway also experienced physical disconnection from power when one of the occupants moved out of the house, showcasing the ever-present possibility that devices become unplugged. With an engaged participant, this is less likely to be an issue as they will discover the disconnection quickly. With a less engaged participant, however, a physical disconnection could go undiscovered and might require utility intervention.

ST2 Thermostat

Although the thermostat was effective in responding to DR events, the homeowner had a negative reaction to the new thermostat. The homeowner had become accustomed to the original thermostat and enjoyed the ability to access the thermostat via the mobile app. Unable to do this on the new thermostat, the homeowner voiced displeasure with the device, likely impacting how the homeowner felt about the event and how they responded to events.

For future programs, replacing thermostats that the customers enjoy with thermostats that have lesser capabilities should be avoided.

SO1 Outlet

The use of smart outlets or smart plug strips for DR leaves much room for variation of amount of load reduction available as well as consistency of usage during peak hours. In this case, the TV which was plugged into the smart outlet was rarely used during peak hours. Not to mention, a load shed event will negatively impact the homeowner's perception of DR (TV turning off in the middle of a program) and the low power draw reduces the value of load shed.

Although technically feasible, the preferred type of controllable plug loads as well as the value of controlling outlets for DR needs to be further investigated.

Home 3 Ecosystem

As the ability to use a voice assistant as a central point of communication for demand response events evolved, the importance of understanding the end use responses to the scheduled events as well as the scenario in which each was placed grew. While scheduling the event was a technical challenge, ensuring that load shed would actually occur became another.

The hope of the voice assistant platform was to prove the capability using the VA1 voice assistant as a way to opt in and out of DR events. Although successful, integrating multiple devices to respond to the VA1 voice commands as well as incorporating a DR scheduler to send events to each device, is complex and at this point, not easily scalable to a wide range of products. Although the connections can be made using the individual API's of each product, research is limited to the API's to which EPRI is able to gain access. If major market players, were to create a DR skill or action, they would be able to incorporate many more technologies due to their power in the market, increasing the reach that the skill or action could have. At this point, the process has been proven technically feasible but to scale requires movement from the major market players.

ST3 Thermostat

Two main lessons arise from working with the ST3 thermostat to connect to the VA1 voice assistant:

1) It is not an easy, straightforward integration and, at this point, requires commissioning by an EPRI representative in the home, infeasible at scale.
2) As detailed in the *System Responses* section of this report, the “Smart Recovery” and “Smart Home” modes on the ST3 thermostat consistently interrupted the DR events, “opting out” at times to ensure occupant comfort. For other DR programs, this functionality is successfully disabled during an event, however, due to the limited functionality that EPRI’s scheduler provides via the API integration of the ST3 with VA1 voice assistant, these modes could not be disabled, a barrier against scaled deployment.

CB1 Controllable Blinds

Similar to the ST3 thermostat, when tested, the CB1 blinds would appropriately respond to the scheduled event by closing at the start of the “Load Shed” event and opening at the end of the event. However, since the blinds were installed on four South facing bay windows, sunlight and heat would begin entering the home prior to the event. To combat this, outside of the DR scheduler, the homeowners scheduled the blinds to close at 1:00pm, resulting in no response to the “Load Shed” events that began at 4:00pm.
Two preliminary conclusions can be made from this installation:

1) Adjusting connected blinds in response to a demand response event may prove fruitless since the ease of scheduling Up/Down times encourages the homeowner to set a daily schedule, which will likely overlap with the DR event. As a result, the 3 in 5 baseline would calculate **no change** from the baseline to the event day.

   Installation of controllable blinds can result in overall energy savings, but the value of blinds for active DR could be found negligible. That being said, the passive energy reduction due to reduced heat gain from the windows will reduce overall consumption during peak hours, but cannot be deployed on demand.

2) The technical feasibility of DR for blinds exists, but scaled replicability lacks an attractive cost to benefit ratio:

   - First, only a few higher-end blinds have the technical capability to eventually be connected to a utility program. Even then, the communication through IFTTT is complex and had to be setup by EPRI representatives within the home. The technology is not yet at a point where a simple VA1 “Skill” can be set up by the customer and used to control the blinds from a utility program.
   - Second, cost will continue to be a barrier for scaled deployment. Even if the technology improves to increase the ease of adding blinds to a DR program, the uptake rate will be low. For scaled deployment, less expensive blinds would need to be able to connect. Further still, the value proposition of blinds for energy efficiency and DR needs to be solidified.

Controllable blinds may begin to make more sense in different scenarios (i.e. where the sun starts peeking through nearer to peak load times), however, each scenario will be site specific. Including the fact that the blinds will likely already be utilized to reduce heat gain and direct sunlight penetration into the home during event hours, the peak load reduction that can be offered is minimal. Although based only on one experience, the conclusions lend concern to the value of controlling blinds in response to a DR event. Further scaled research needs to be conducted to investigate financial feasibility, but the high upfront costs are not promising.

PP1 Controllable Pool Pump

As mentioned earlier, the PP1 controllable pool pump was unable to be connected to the utility event scheduler through VA1 voice assistant due to limited access to the API, however, circuit level consumption data was analyzed to determine the potential impact that pool pump demand response could have on total load shed Home 3. In this particular example, the PP1 pool pump ran continuously everyday between the hours of 9:00am – 4:00pm, with an average of around 500Wh consumed each hour. Due to this scheduling, even connectivity with the VA1 voice assistant would have rendered "Load Shed" or "Load Up" events useless since there would be no available consumption to reduce starting at 4:00pm.

That being said, DR events utilizing pool pumps have already been proven, indicating that this demonstration may not be representative of a larger sample of pool pumps. Research into pool pump schedules does show high variability in schedules from residence to residence. While Home 3 runs continuously from 9:00am – 4:00pm, others may run in different increments throughout the day such as from 5:00am – 10:00am and then 3:00pm – 6:00pm. Still, others may run continuously through the night to save on energy bills. Typical suggestions include:

- Running the pool pump throughout the day since the sunlight promotes algae growth if the water is stagnant.
- Running the pool pump from 6 – 12 hours each day, enough to cycle the full volume of the pool.

These suggestions indicate that there are likely many instances for which pool pump "Load Shed" is well suited. Assuming 500Wh of possible reduction during each event hour, pool pump DR could potentially reduce consumption by 2.5kWh during a single 5-hour event. If access to the PP1 API is granted, further research could work to connect the pool pump to the DR scheduler through the VA1 voice assistant.

ST3 Controllable Light Switches

Although the ST3 thermostat was the predominant product to be tested for home 3, connected light switches by the same manufacturer were also included. However, testing to connect the light switches to respond to the scheduler through VA1 voice assistant is ongoing and the light switches were never installed in the home.

Looking briefly at the circuit level monitoring of home 3, lighting and plug loads combined offer between 150-200Wh of possible reduction during each event hour at Home 3. Since plug loads and lighting were grouped together, it is unclear how much of the 150-200Wh can be attributed to lighting loads. Generously assuming 100-125W of possible reduction in lighting, one home could be responsible for up to 500Wh of reduction during a 5-hour event due to shutting off the lights. A lighting DR event will not completely shut off the lights, however, since doing so would negatively impact occupant comfort. A more reasonable response of dimming to 30-50% could account for 250-350Wh of reduction. Based on too many assumptions, further research is needed to determine the possible impact of aggregated lighting DR and the various implementation challenges of shutting off or dimming residential lights, many of which are already energy-efficient LEDs or CFLs. The technical feasibility of integrating dimming light switches into whole home DR with voice assistants exists, but has yet to be field tested and the high costs of such integration may prove scaled deployment as unfeasible.

COST ANALYSIS

The purpose of the project was to look at off-the-shelf ecosystems that could enable DR using technologies already installed within the home, therefore, it assumes only the cost of the additional hardware and replacement of low-cost products. For instance, it assumes the additional cost for replacing thermostats and light switches, but only assumes the cost of the AC CTA 2045 module itself (WH1 water heater – Home 1) and not the cost of replacing the entire water heater. It assumes high cost, communicating items (water heater, HVAC, blinds, pool pump, etc.) already exist as part of the home. The additional infrastructure that must be added as the control hub (Open ADR Gateway, CTA 2045 modules, VA1) as well as low cost communicating items (thermostats, light switches, etc.) are included in the cost analysis as those products are more financially feasible to provide or replace for DR needs.

DEMAND RESPONSE TEST RESULTS

The Total Resource Cost (TRC), Program Administrator Cost (PAC), Ratepayer Impact Measure (RIM), and Participant (PCT) tests were all investigated in this economic analysis. Each of them offering a unique perspective on the cost effectiveness and scalability of the DR program. The table below, Table 17, highlights the different summary metrics that are available. A more comprehensive explanation of the benefits and costs follows later.

TABLE 17: COST BENEFIT ANALYSIS OF A BASE CASE WHOLE HOME DR PROGRAM

2019 DOLLARS	BENEFITS	COSTS	NET BENEFITS	NET $/KW-YR.	RATIO
TRC	$2,623,676	$3,747,375	($1,123,699)	($66)	0.7
PAC		$4,015,000	($1,391,324)	($82)	0.7
RIM		$4,178,929	($1,555,253)	($91)	0.6
PCT	$663,929	$232,375	$431,554	$25	2.9

1. Net Present Value (NPV) Net Benefits ($):
    a. This value is the levelized costs subtracted from the levelized benefits, where parenthesized values are negative.
2. Net $/kW-Year: The net benefit divided by the levelized total demand reduction(kW):
    a. It is essentially the net benefit divided by the total demand reduction due to the NPV assumptions.
    b. It is three years of net benefits divided by three years of kW saved which yields the dollar value benefit per kW per year.
3. Ratio: The benefit to cost ratio is compared for each of these tests. It is a simplified measure for understanding the cost effectiveness of a utility incentive program.
    a. This metric does not factor in the energy saved or demand reduction. This metric gives insight on the estimated rate of return from the differing perspectives.

DR TEST ASSUMPTIONS

- The program scale estimate is 1000 homes in 2020, 5000 homes in 2021, and 10000 homes in 2022. The analysis assumes 9 demand response events per year, each of which lasts 4 hours long, meaning 36 total hours of demand response per year.
- The discounting factor used in the tests is 1, so it is incorrect to say the values are the NPV. The timeline on the program scale is only 3 years, so the variance between NPV and the calculated values is insignificant.
- Amortization period of the equipment is five years.
- The estimated price of electricity follows a constant 3% increase in price each year.
- The equipment cost will fall under the cost burden of the utility. The amortized equipment cost estimate is roughly $425 per home.

BENEFITS

TRC, PAC, AND RIM

The benefits of TRC, PAC, and RIM tests are the same because these tests capture the avoided supply costs. The total benefit is the summation of the following equations:

EQUATION 1: AVOIDED ENERGY VALUE

$$Avoided\ Energy\ Value = (avoided\ energy\ cost) * (estimated\ energy\ savings)$$

EQUATION 2: SOCIAL NON-ENERGY BENEFITS GUARANTEED

$$Social\ non\ energy\ benefits\ generated = \left(GHG\ Value\ \left(\frac{\$}{unit\ of\ energy}\right)\right) * (estimated\ energy\ savings)$$

EQUATION 3: GENERATION CAPACITY VALUE

$$Generation\ Capacity\ Value = (load\ impact) * \left(adjusted\ generation\ capacity\ value\ (\frac{\$}{kW})\right)$$

EQUATION 4: CAISO MARKET BID VALUE

$$CAISO\ Market\ Bid\ Value = (MWh\ bids) * (average\ market\ price)$$

PCT

The PCT test is from the perspective of the program participants, so the benefits in this test are the incentive quantity and the net electricity bill reduction, scaled over the program size. Mathematically:

EQUATION 5: PCT BENEFITS

$$PCT\ Benefits = (program\ wide\ incentive\ cost) * (net\ bill\ savings)$$

$$Net\ bill\ savings = (program\ wide\ energy\ savings) * (assumed\ price\ of\ electricity)$$

COSTS

The variance in TRC, PAC, and RIM come from the differences in the costs associated with these tests. All tests include the administration cost involved in creating an incentive program. The cost breakdown for each test will be divided into sections for each test.

TRC:

The Total Resource Cost test encompasses the total cost whether the cost is associated with the utility or the participant. The TRC cost is the summation of the administration cost involved in setting up an incentive program, the amortized equipment cost, and the participant annual expense. The TRC does not include total incentive cost or net bill reduction because those are viewed as a transfer payment. Both the utility and participant costs are included in this test, and incentive payments or bill reductions are just transfer between utility and participants. If the ratio is greater than 1 it can be assumed that the program is beneficial for the utility and ratepayers.

PAC

The PAC test factors in the total administrative costs of the program. The PAC cost is similar to the TRC in that it includes the administration cost and the amortized equipment cost, but the PAC does not include the participant annual expense. Instead, it includes the total incentive cost as well. The total incentive cost is also included because the incentive paid out is seen as an administrative cost of running the program.

RIM

The RIM test factors in the total cost of the program from the utility perspective. The RIM cost is a slight variation on the PAC cost. The RIM includes the same values as the PAC, except the net bill reduction is also included. This value is included because net bill reduction is seen as a loss of revenue from the utility perspective.

PCT

The Participants test is a quantifiable metric to describe the total benefit and cost from a participant's perspective. The primary criticism of this metric is that there are many unquantifiable variables that influence a customer's decision to implement an incentivized technology. In this analysis the only costs contributing to the PCT test are the participant annual expenses.

ANALYSIS

TRC

The TRC net benefit suggests that the cost will cost $1,123,699 more than the value it will create. Not all of this cost burden comes from the utility, but because the utility is paying for the equipment cost and administration cost, ~94% of the total cost is covered by the utility. The benefit to cost ratio of 0.7 highlights that the rate of return is negative to the utility and the ratepayers on a total resource basis.

The Net $/kW-Yr value of ($66) shows the cost per kW of peak demand reduction per year. The events occur over a four-hour window where kW reduction is an averaged power reduction over the four-hour period. In reality, the kW reduction will be less temporally consistent.

TABLE 18: TRC COST BENEFIT

2019 DOLLARS	BENEFITS	COSTS	NET BENEFITS	NET $/KW-YR.	RATIO
TRC	$2,623,676	$3,747,375	($1,123,699)	($66)	0.7

PAC

The PAC net benefit suggests that the program will have a net cost of $1,391,324 from an administrative cost perspective. The ratio of 0.7 mirrors the TRC ratio with rounding error because ultimately the change in costs between the tests is relatively small. The program cost can be levelized by its demand response impact with a cost of $82 per kW per year.

TABLE 19: PAC COST BENEFIT

2019 DOLLARS	BENEFITS	COSTS	NET BENEFITS	NET $/KW-YR.	RATIO
PAC	$2,623,676	$4,015,000	($1,391,324)	($82)	0.7

RIM

The RIM test yielded an even greater net cost, net $/kW-Yr, and a lower benefit to cost ratio. The RIM test encompasses the total ratepayer impact, which can give insight into how a program can shift the rates and bills of customers. The RIM test values shown all suggest an increase in rates and bills due to the low benefit to cost ratio, and high $/kW-Yr cost.

TABLE 20: RIM COST BENEFIT

2019 DOLLARS	BENEFITS	COSTS	NET BENEFITS	NET $/KW-YR.	RATIO
RIM	$2,623,676	$4,178,929	($1,555,253)	($91)	0.6

PCT

The Participant Cost Test is the only test that yields net benefits. The PCT values need to suggest a net benefit for the participants in order to expect program adoption. Across all metrics, the participants see net benefits to their investments which highlights the adoption effectiveness and scalability for implementation.

TABLE 21: PCT COST BENEFIT

2019 DOLLARS	BENEFITS	COSTS	NET BENEFITS	NET $/KW-YR.	RATIO
PCT	$663,929	$232,375	$431,554	$25	2.9

COST – BENEFIT SUMMARY

The DR cost tests highlight the cost burden that will be directed to the utility in this program. The primary takeaway from these cost tests is the low return on investment from a utility or total resource perspective. The participants are the only stakeholders that will see a positive return on investment, making the program worthwhile. The actual performance of this program would be highly variable and dependent on realized energy savings and product and installation costs. Additionally, the realized energy savings must assume a level of reliability within the IoT devices. When weighing the results of all tests within the scope of the assumptions, the program can be seen as an inefficient investment for the utility.

CONCLUSION

The technical potential for whole home demand response exists, however, the business case has yet to be solidified. By project end, the communication platforms had all successfully been deployed and could control devices, however, multiple devices within the home including the ST1, ST2 and ST3 thermostats did not respond to “load shed” signals as expected. Nuances in device response should be established prior to field test in order to allow for more seamless deployment. Assuming proper response from each end use device, including thermostats, water heaters, pool pumps, plug loads, and blinds, the potential load reduction and energy savings could be greater than controlling individual devices. However, during successful events, the thermostat held significantly more value (thousands of watts vs. hundreds or less) and had a much higher ON rate than the other devices, calling into question whether the increased cost of whole home DR can be justified, or whether HVAC DR should remain the primary focus area for “load shed” events. For “load up” events, the case for controllable HPWHs improves.

The potential for a significant improvement in load reduction discussed above was not realized in application of DR within the three test homes due largely to customer response, unexpected device response, and low or no consumption of devices during peak hours, as was the case for pool pump, spa pump, and HPWH. Once any technical barriers are overcome (unexpected response, dropped connectivity, etc.), the next key to a successful scaled deployment will be targeted deployment. Without an engaged, understanding set of participants, the reliability of consistent reduction can be called into question. Of the three homes, the participants in home 3 would be the ideal participant for scaled deployment.

With an ideal participant and reliable connection with and response from the technology, the cost-benefit ratios in each case would improve, however, the costs of program deployment of whole home DR may still see a cost-benefit ratio below 1. Further technology refinement and targeted deployment is needed to establish how the cost effectiveness is impacted at scale.

RECOMMENDATIONS

The assessment of the whole home DR technologies using off-the-shelf, available customer devices does not provide enough reliable reduction at the time to warrant adoption into the EE program. Prior to adoption into the program, further field pilots should be conducted to aggregate thermostats, water heaters, and pool pumps at a single location to identify the potential for high reduction. Based on the project results, blinds, plug loads, and light switches, at this time, do not provide enough reduction, or have significant barriers to adoption (customer perception and response), to warrant scaled deployment. To improve understanding of how and if lighting and plug loads can be incorporated better into whole home DR, customer research should be conducted to evaluate the appetite of homeowners for utility control of smaller end use loads.

As mentioned before, a primary barrier to adoption is the ability to recruit engaged, willing participants who have the appropriate technologies already within their home. Having a voice assistant device or a smart thermostat does not automatically signify that the homeowner is interested in energy savings and in participating. Future research will observe how further engaging homeowners through a smart voice assistant platform can help to develop a more informed and potentially more involved base of participants.

APPENDIX

Average hourly load reduction per home.

Field Test - Actual		4-5pm	5-6pm	6-7pm	7-8pm	8-9pm
Actual Performance	Home 1	152	197	-5	-454	NA
	Home 2	609	65	512	-365	NA
	Home 3	1094	-133	-276	-71	NA
Average (Wh)		**619**	**43**	**77**	**-297**	NA
Program Scale (kWh)		6186.67	**430.25**	**774.30**	**-2966.39**	NA
Field Test - Best		4-5pm	5-6pm	6-7pm	7-8pm	8-9pm
Best Performance	Home 1	2270	1976	1856	1997	2094
	Home 2	983	1565	1398	325	266
	Home 3	2246	871	423	248	282
Average		**1833**	**1470**	**1226**	**857**	**881**
Program Scale (kWh)		**18330.73**	**14704.46**	**12255.81**	**8569.59**	**8807.09**

Field Test + Opt Out		4-5pm	5-6pm	6-7pm	7-8pm	8-9pm
Realistic Performance	Home 1	2270	1976	1856	1997	2094
	Home 2	983	1565	1398	325	266
	Home 3	2246	871	423	248	282
Average		**1833**	**1470**	**1226**	**857**	**881**
Cumulative Opt Out Rate		**10%**	**15%**	**20%**	**20%**	**20%**
Program Scale (kWh)		**16497.65**	**12498.79**	**9804.65**	**6855.68**	**7045.67**

Field Test + Assumptions		4-5pm	5-6pm	6-7pm	7-8pm	8-9pm
Added Performance	Home 1	2270	1976	1856	1997	2094
	Home 2	983	1565	1398	325	266
	Home 3	*2946*	*1571*	*1123*	*948*	*982*
Average		**2066**	**1704**	**1459**	**1090**	**1114**
Program Scale (kWh)		**20664.06**	**17037.79**	**14589.15**	**10902.93**	**11140.43**