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Smart Enegy Technologies – An Application Using Residential Battery Storage

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ABSTRACT

This paper present's DNV GL's energy and demand impact evaluation of the Glasgow (Kentucky, USA) Smart Energy Technology (GSET) Pilot from mid-June 2016 through mid-June 2017. The GSET program was a first-of-its-kind project using a large-scale deployment of non-PV supported residential batteries using only the grid to recharge after displacement. The batteries proved to be a very effective means of managing a customer's load with invaluable experience gained by the project team. While the current cost of the technology makes its widespread use not economically feasible, when it becomes cost-effective the technology will be an excellent tool to include in the utility's tool box to manage customer loads with little or no inconvenience to the customer.

Introduction

The GSET Pilot is one of the Tennessee Valley Authority's (TVA) Smart Communities program offerings for existing single-family homes and small businesses in the Glasgow Electric Plant Board (GEPB) service area. Participation in the program was differentiated by the types of advanced technologies installed, with each tier adding additional smart energy features. The **Basic** group (n=165) included Wi-Fi enabled thermostats and controllable heat pump water heaters (HPWH). The **Advanced** group (n=115) added an advanced battery system (see below), with the **Ultra-Advanced** group (n=50) adding advanced weatherization.

The major innovation was the use of a smart battery system applied to the Advanced and Ultra-Advanced group. The battery system charges during off-peak hours until a discharge command is issued to partially or fully carry the site's load on demand-response event days. The battery system also serves as an uninterruptible power supply that provides power to the home within milliseconds of a power outage. The battery system consists of a Lithium Manganese Cobalt Oxide (NMC) secondary battery unit rated at 48 V and 6 kW.

All participants were controlled using Virtual Peaker enhanced software that integrates with the AMI/SCADA system to control the various devices with information provided back to the customer through a secure portal. The paper will review and contrast the energy and demand savings achieved by the various residential groups of pilot customers.

Growth in residential battery storage installations is driven primarily by residential solar energy generation. Even though this pilot focused on grid battery charging, the lessons learned can be easily extrapolated to other residential battery impact analyses with mixed or off-grid charging.

Battery storage in all customer sectors is increasing rapidly and experiencing a corresponding price drop. A publicly available summary of proprietary research by Greentech Media suggests that the cost of residential energy storage in the U.S. will drop approximately 40% in the next 5 years (from 2018 to 2023).

In Europe, storage capacity more than doubled from 2015 (300 MWh) to 2017 (700 MWh), with Italy, Germany, and the UK leading the way. Residential storage, closely tied to PV installations, accounted for 40% to

45% of the new capacity, second only to utility-scale storage. A combination of lower battery prices, lower feed-in tariffs, and increases in electricity rates are making storage attractive in the residential market[1].

Glasgow Service Territory

Glasgow Electric Plant Board (GEPB) is a relatively small municipal utility located in south central Kentucky (See Figure 1) with just over 7,300 electric customers. Over the years, GEPB management team has implemented several very innovative customer initiatives including a grid enabled appliance project (2013), a residential coincident demand rate called "Infotricity" (2016), and the GSET Pilot discussed in this paper, Glasgow's most recent smart energy technology program offering.

Figure 1 – Glasgow Service Territory

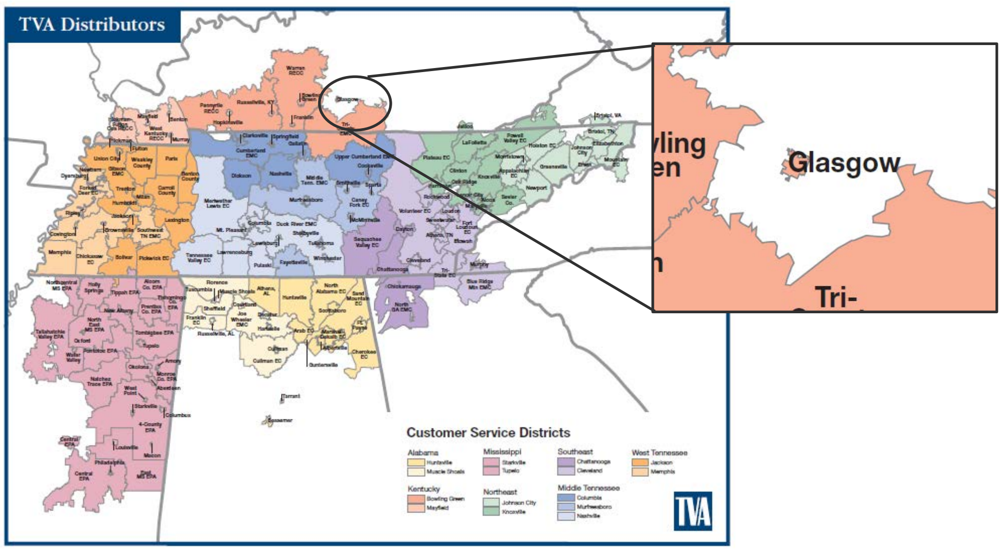


Figure 2 highlights the cornerstones of the GSET program bundle including ECOBEE Smart-SI[2] Wi-Fi enabled thermostats, a large on-site battery storage system comprised of a Sunverge SIS6848s battery system[3], a GE Geospring heat pump water heater[4] and advanced Virtual Peaker software[5] to integrate the connected operation of the devices.

[1] Grintals, Valts. From followers to leaders: The changing face of Europe's energy storage market. January, 2018. https://www.energy-storage.news/blogs/from-followers-to-leaders-the-changing-face-of-europes-energy-storage-marke

[2] https://www.ecobee.com/

[3] http://www.sunverge.com/sunverge-announces-next-generation-energy-storage-system/

[4] http://www.geappliances.com/ge/heat-pump-hot-water-heater/

[5] http://www.virtualpeaker.io/

Figure 2 – Smart Energy Technologies

Participation Groups

Figure 3 summarizes the three GSET program participation groups that were differentiated by the types of advanced technologies installed. The **Basic** group included Wi-Fi enabled thermostats and controllable heat pump water heaters (HPWH). The **Advanced** group included the features of the Basic group, and added an advanced battery system. The **Ultra-Advanced** group included the features of the Advanced group, and added advanced weatherization. All participants were controlled using the Virtual Peaker enhanced software. The software integrates with Glasgow's AMI/SCADA system to control the various devices with information provided back to the customer through a secure portal.

Figure 3 – GSET Project Participation

Home Type	Smart Thermostat	Water Heater	Storage Battery	Advanced Weatherization	No. Homes
Basic	✓	✓			165 homes
Advanced	✓	✓	✓		115 homes
Ultra Advanced	✓	✓	✓	✓	50 homes

Most measures were installed by mid-June, 2016. The analysis period for this paper runs from June 2016 through July 2017.

Events

The impact analysis examined pilot program performance by group for the period beginning mid-June 2016 through mid-June 2017. Numerous events were dispatched, i.e., customer control was initiated, during the study window. Our analysis examines the performance on each of the events to determine the impacts of the technology. The Virtual Peaker software team indicated that better performance could be expected as more experience was gained with the operation of the battery. The Virtual Peaker team indicated that they could isolate and treat each participating customer individually helping to customize and improve the pilot performance. Detailed event logs were maintained by the project team and reviewed by DNV GL staff to help isolate events for analysis. Three types of events were examined in the project:

- **Notification Events** – for Basic, Advanced and Ultra-Advanced participants, these were periods of time where Glasgow sent out notices to inform the general public about likely high system load conditions;
- **Dispatch Events** – for Basic, Advanced and Ultra-Advance participants, these were periods of time when the project team controlled the customer's load and were identified by the analysis team by examining the event logs and the corresponding participant load response; and
- **Charging Events** – for Advanced and Ultra-Advanced participants these were periods of time when the battery was re-charged.

For this paper, we focus on the performance during the numerous dispatch events. Table 1 presents the number of dispatch events and total number of event hours observed. The table shows the number of events that began before noon and after noon. There were substantially more dispatch events run for the Advanced and Ultra-Advanced groups.

Table 1: Dispatch Events

Group	Morning Events (Start before Noon)	Afternoon Events (Start Noon or Later)	Total Number of Unique Events	Total Event Hours	Average Event Length (Hours)
Basic	12	35	47	194	4.1
Advanced	15	49	64	285	4.5
Ultra-Advanced	17	51	68	326	4.8

Analysis Approach and Control Group Selection

The analysis approach examines the load on the various dispatch event days for the participant group compared to a matched comparison group. The comparison group participants were selected based on several aspects of the participant consumption parameters to find the best match including:

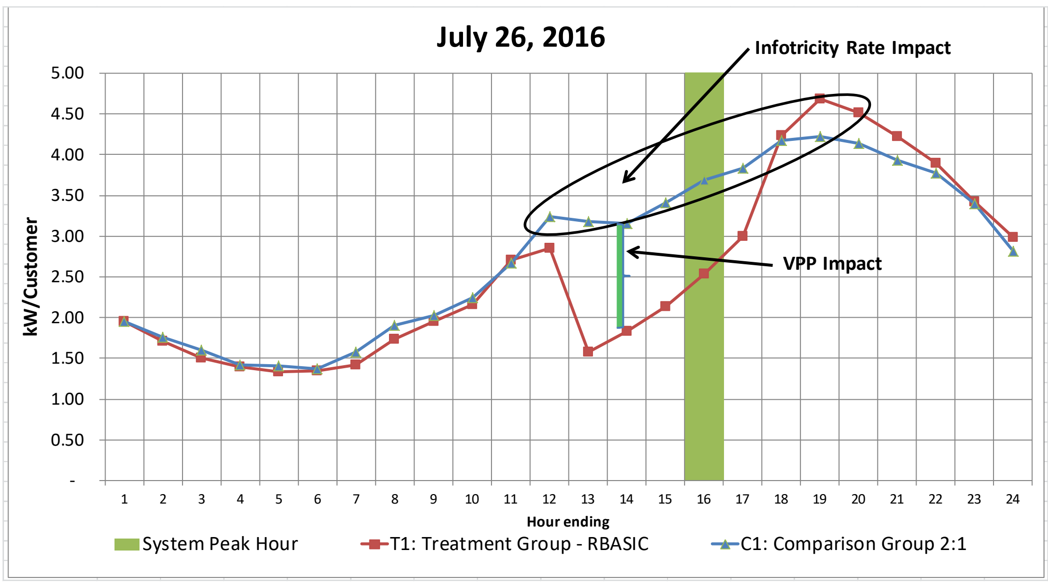
- Daily usage
- Daily Maximum demand
- Daily On-peak Energy
- Daily On-peak maximum demands
- Daily usage patterns
- Daily on-peak usage patterns
- Daily maximum demand patterns
- Daily maximum on-peak demands
- Load shape

The following figures present selected analyses for each of the participant groups. The sample event was the 2017 Glasgow summer system peak day. All events were analyzed in a similar fashion.

Event Performance on System Peak Day

The following figures display the participant versus the comparison group analysis for Tuesday, July 26, 2016, the system peak day. The temperature on this day ranged from 72° to 91° F. Figure 4 presents an example of the event day performance for the Residential Basic group.

Figure 4 – Residential Basic Example



In the figure, we highlight the system peak hour in the solid green column. In addition, we bring attention to the comparison group that shows a noticeable reduction during the event window (black circled area). This is a direct result of the Infotricity Rate notification issued by GEPB staff to warn customers of a likely peak day. All GEPB customers (including the comparison group) were on the Infotricity Rate at this time, and received the notification. DNV GL completed a separate analysis of the impacts of the Infotricity rate impacts using all customers, with data from before and after the start of the rate, to isolate the additional reduction resulting from the rate itself and the notification provided by GEPB.

The virtual peak power plant (VPP) impact which results from a combination of water heating and HVAC control is calculated as the difference between the comparison group line (blue line labeled C1: Comparison Group 2:1 and the red line labeled T1: Treatment Group – RBASIC) and the participant line. This method excludes the additional impact being achieved by the current rate design. For this system peak day, the load reduction exceeded 1.0 kW per participant. There is a slight return to service (i.e., payback) immediately following control. The graph clearly shows the energy displacement during the event exceeds the return to service payback load. A similar analysis was conducted for every dispatch and notification event day.

Figure 5 presents the same peak day for the Residential Advanced group. Please note, there was an event day called the previous day and the early morning period shows the impact of the battery charging that takes place throughout the late evening/early morning hours. The Residential Advanced group shows a much larger impact than the RBASIC group (greater than 2.5 kW per participant) during the event window. In our discussions with the VPP team, there was some indication that sufficient experience has now been gained with the software to effectively remove the customer's entire load during the event call. In this figure, we see the diversified load of the group is reduced to below 0.5 kW per household. There appears to be some degradation of performance during the course of the long event window. In the very late evening, you can see the battery charging starting up again.

Figure 5 – Residential Advance Example

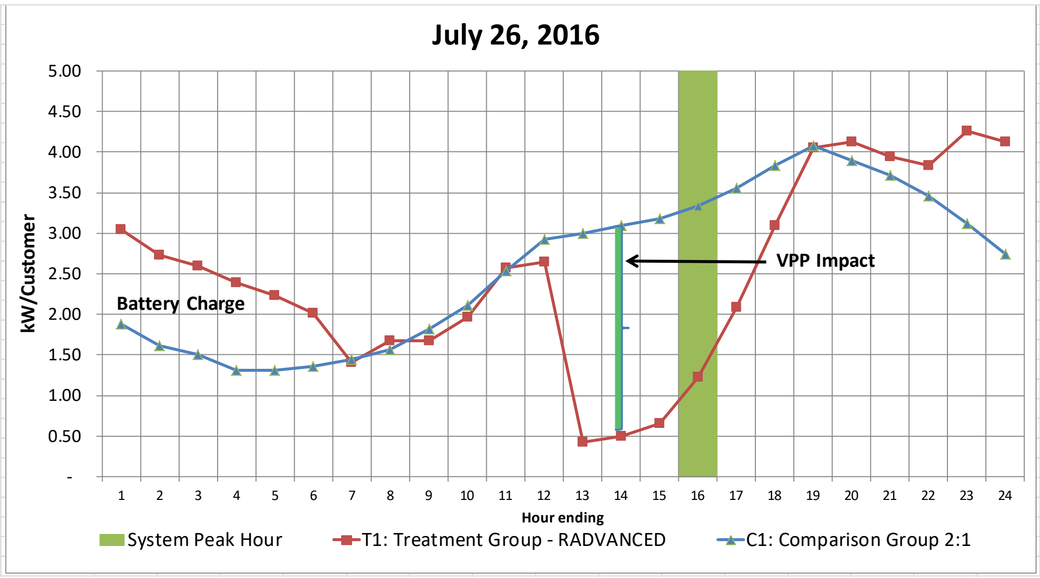
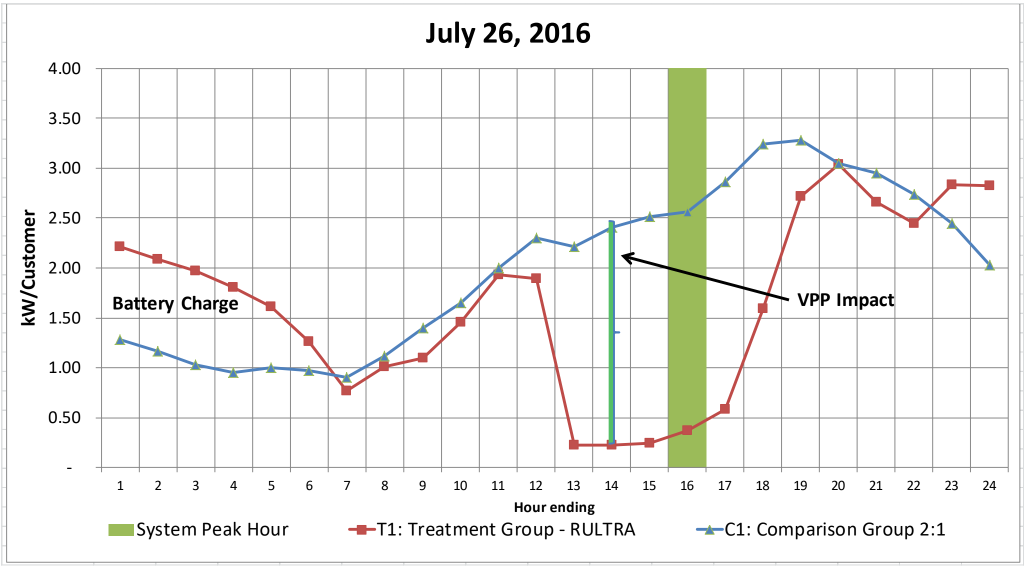


Figure 6 presents the same event day for the Residential Ultra-Advanced. This group is similar to the Residential Advanced with the exception that additional energy efficiency measures have been installed at each household. A similar pattern is seen with the early morning battery charging, the deep cut during the event window, and the late evening battery recharging. Here again, the diversified base load is reduced to below 0.5 kW per household. There are two very interesting aspects of this figure. First, the sustained trough shows less degradation displayed than that experienced by the Residential Advanced group. The second is that the comparison group load profile is notably lower (approximately 0.75 kW lower at peak when compared to the Advanced comparison group. The project team speculates that there are simply no good comparison customers to account for the advanced energy efficiency measure component for this Ultra-Advanced group and we may be underestimating the actual load reduction being experienced by this group.

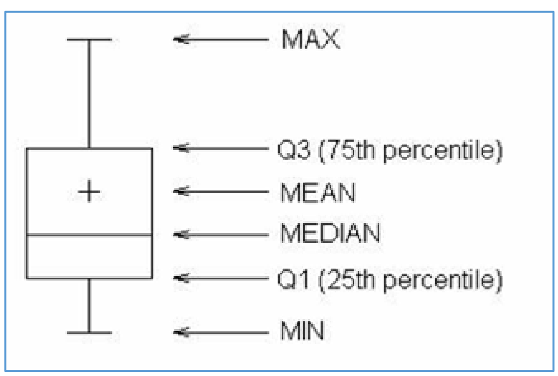
Figure 6 – Residential Ultra-Advanced Example



Performance Across Events

Since we analyzed multiple events, the project team needed a way to communicate the impacts observed across multiple days. The project team elected to use a Box-Whiskers graph for this purpose. Figure 7 shows the various statistical attributes that are indicated on the Box-Whiskers graph. These include the minimum value, 25th percentile, median, mean, 75th percentile and maximum value. The mean is the arithmetic average of the selected variables. The median defines the point where 50% of the observations are above and below the stated value. The 25th percentile defines the point where 75% of all observations are at or above the stated value.

Figure 7 – Box-Whiskers Description



The information summarized in the Box-Whiskers diagrams provide policy makers and planners a summary of the types of demand reductions and energy displacement that is likely to occur with the varying technology combinations.

Residential Basic Group

Figure 8 summarizes the "average" and "maximum" observed demand reduction for the full complement of 46 dispatch events called during the year. The average dispatch event was slightly more than four hours. There is a small difference between the average reduction across the event period and the maximum reduction observed in the event period. The mean "average" event savings was estimated to be 0.85 kW with a maximum observed "average" reduction of 1.53 kW. Please note, the event periods ranged between 2 and 7 hours in length. Seventy-five percent of all observed average reductions were above 0.59 kW (the 25th Percentile). The mean "maximum" event savings was estimated to be 1.05 kW with a maximum of 1.71 kW observed. The maximum reduction was above 0.78 75% of the time.

Figure 8 – Residential Basic Dispatch Event Summary: Demand Reduction

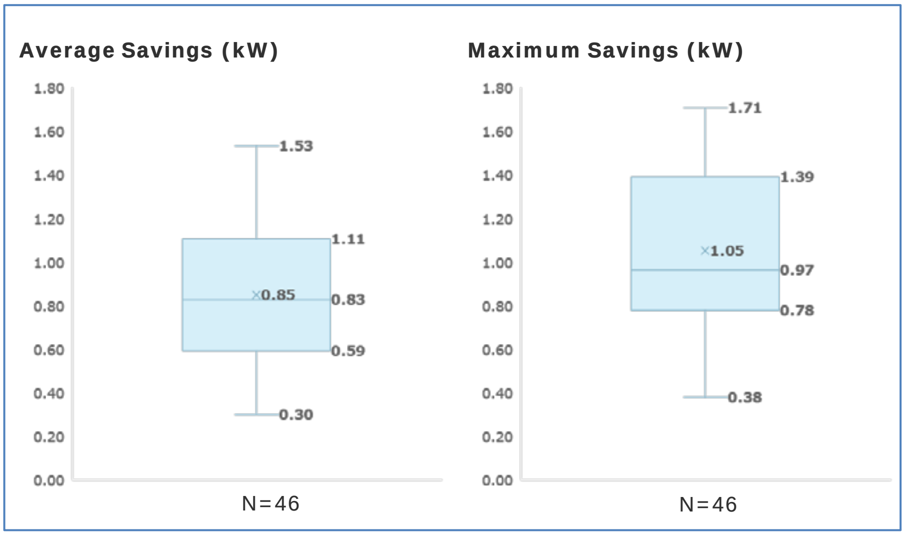
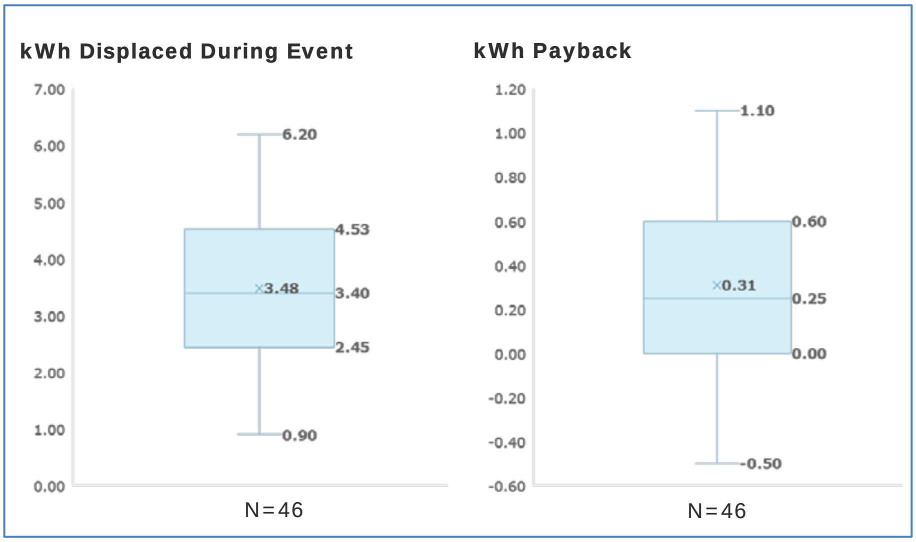


Figure 9 summarizes the displaced energy and the payback associated with return to service load. The energy savings were calculated across the event period whereas the payback was calculated based on the difference observed in the three hours following control. Three hours was selected as the approximate number of hours required until the treatment load aligned with the comparison baseline. The "average" energy displaced during the event was calculated to be 3.48 kWh. The maximum energy displacement was observed to be 6.2 kWh. Seventy-five percent of all events saved more than 2.45 kWh. In contrast, the average energy payback, i.e., the amount of energy consumed where the treatment load was above the comparison load, was calculated to be a modest 0.31 kWh.

Figure 9 – Residential Basic Dispatch Event Summary: Energy Displacement



Residential Advanced

Figure 10 summarizes the average and maximum demand savings observed across and within the dispatched event period. The average dispatch event was 4.5 hours in length. The figure summarizes the information for the full complement of 63 events. The average reduction was estimated to be 1.42 kW with a maximum “average” of 2.60 kW. Seventy-five percent of all observed average reductions were above 1.02 kW (the 25th percentile). The maximum observed reduction in the event period was much larger averaging 1.87 kW. The 25th percentile is 1.41 kW meaning 75% of all events had at least one hour greater than this value. The bigger difference between the average and maximum savings for this group is due to the degradation of savings later in the event.

Figure 10 – Residential Advanced Dispatch Event Summary: Demand Reduction

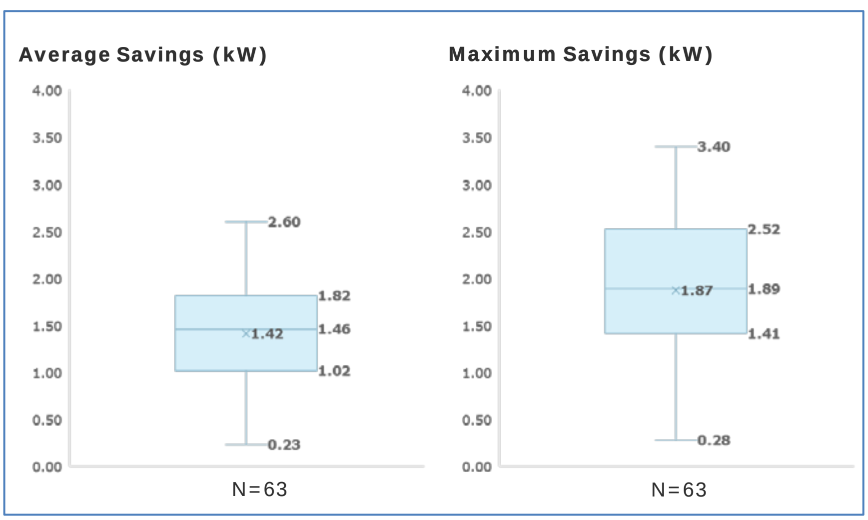
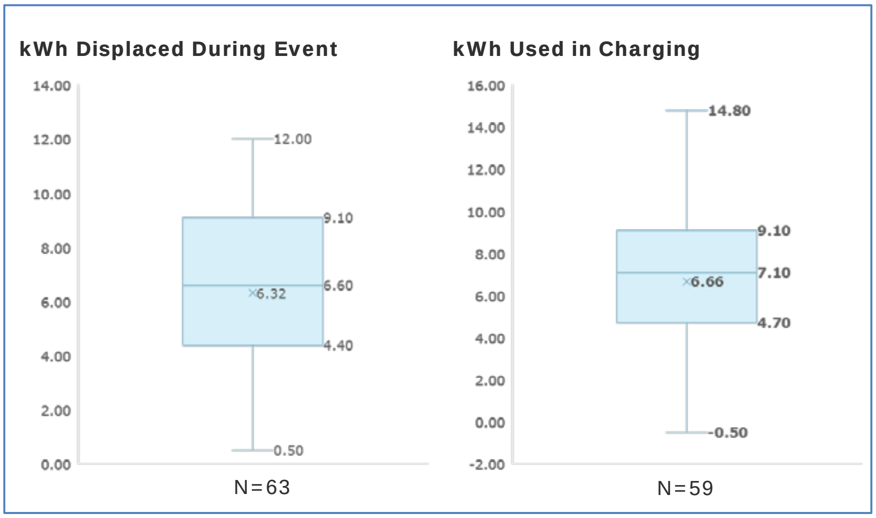


Figure 11 summarizes the energy displaced during the event period and the additional energy used during the charging period. The energy displaced during the dispatch events averaged 6.32 kWh with a median reduction of 6.6 kWh. A similar increase was observed during the charging period. The average increase in energy during the charging period was calculated to be 6.66 kWh with a median increase of 7.1 kWh.

Figure 11 – Residential Advanced Dispatch Event Summary: Energy Displacement



Residential Ultra-Advanced

Figure 12 summarizes the demand savings associated with the 67 dispatch events. The average dispatch event was 4.8 hours in length. The mean average demand reduction was 1.48 kW. This compares to an average maximum demand reduction of 1.91 kW. The 25th percentile for the average demand reduction was calculated to be an impressive 0.94 kW. The “maximum” savings values were somewhat higher than the average savings value.

Figure 12 – Residential Ultra-Advanced Dispatch Event Summary: Demand Reduction

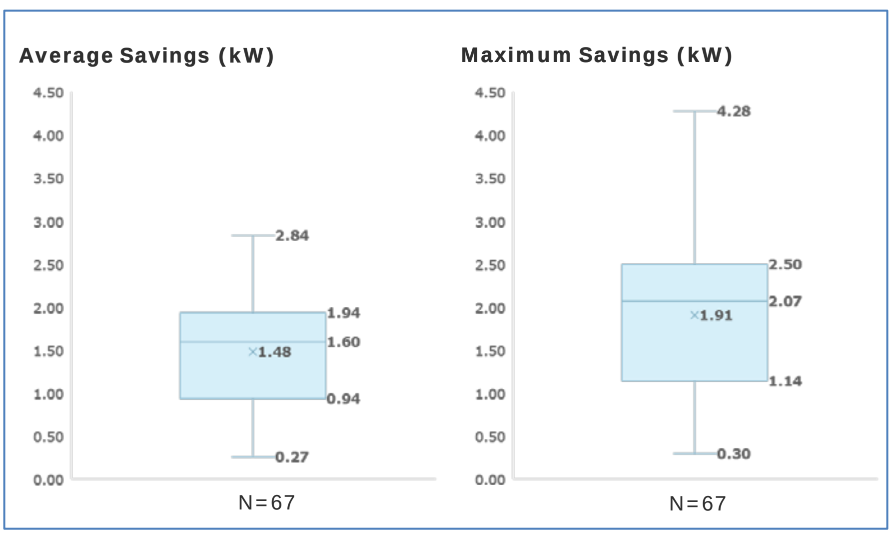
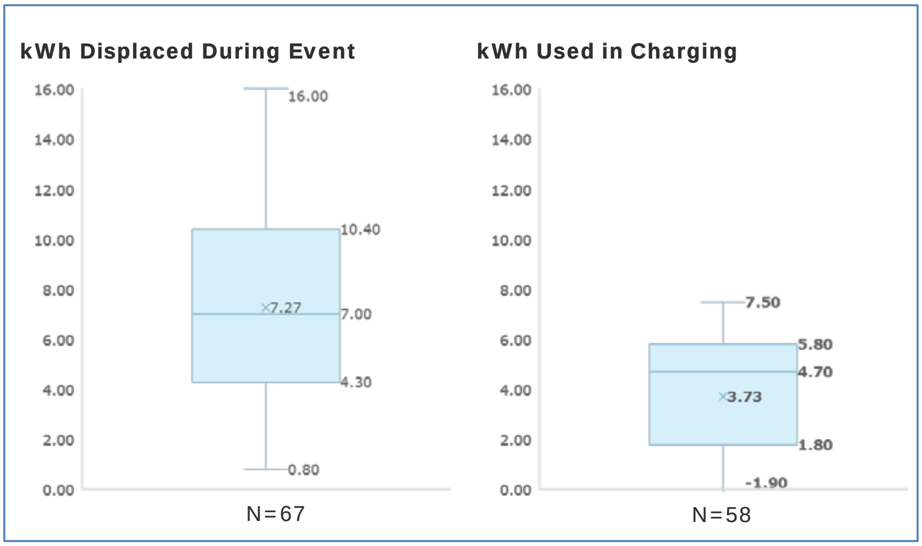


Figure 13 summarizes the average energy displaced during the events. The average energy displaced during the dispatched event period was 7.27 kWh with an observed maximum of 16 kWh. The 25th percentile is 4.3 kWh. During the charging events, the average increase in energy use was approximately half of the savings measured at 3.73 kWh. One of the challenges discussed earlier was that the Ultra-Advanced comparison group was not a particularly good reference set particularly for the determination of energy displacement and energy charging.

Figure 13 – Residential Ultra-Advanced Dispatch Event Summary: Energy Displacement



Battery Cold Weather Charging

During the analysis, we noticed that the participant group on certain days had a one hour spike in their load pattern (see Figure 14). After discussions with the VPP team, we learned that the battery is charged during cold periods to ensure proper operations. Upon examining the load data, a total of 80 cold weather charging events were identified. The cold weather charging requirements adds additional load to the system and increases the customer's usage slightly.

Figure 14 – Cold Weather Charging

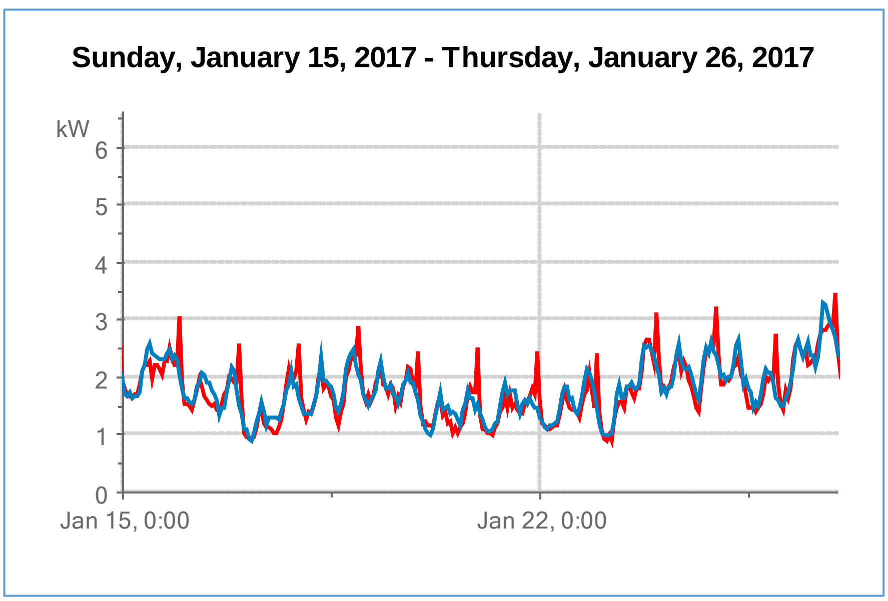
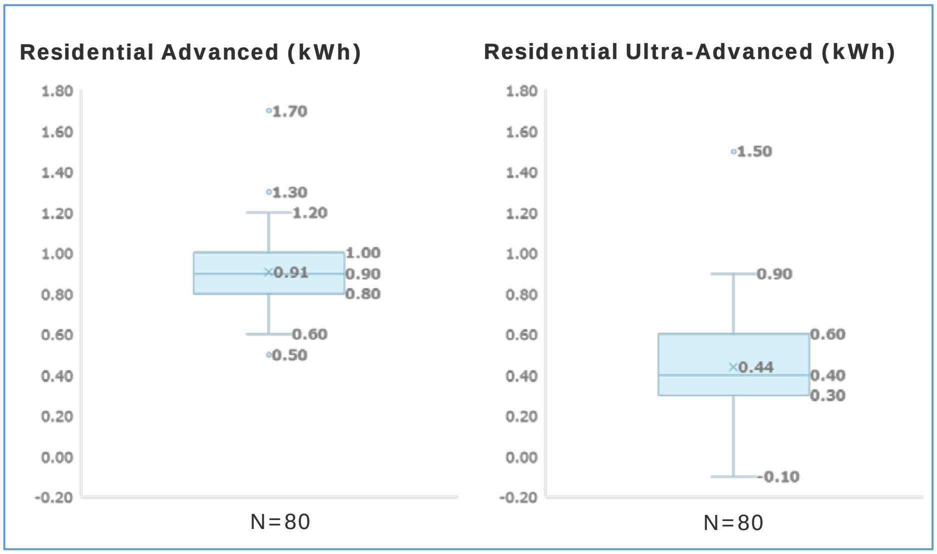


Figure 15 displays a summary of the 80 cold weather charging events for the Residential Advanced and Residential Ultra-Advanced groups. The mean average increase in usage was calculated to be 0.91 kWh for the Residential Advanced group and 0.44 kWh for the Residential Ultra-Advanced group. This equates to just under 73 kWh for the 80 observed events for the Residential Advanced group and approximately 36 kWh for the Residential Ultra-Advanced group.

Figure 15 – Cold Weather Charging for Residential



Summary and Conclusions

Table 2 presents a summary of the observed demand reductions associated with each group. The table includes the number of events called, the total number of hours for the events, and then summary statistics for the "average demand reduction" observed across the events and the "maximum demand reduction" observed within the event. For each variable of interest, we present the 25th percentile, the mean, and the median The 25th percentile represents the demand value where 75% of all observed values are at or above the stated value, the mean is the simple arithmetic average and the median is the point where 50% of all estimates are above the stated value. The Residential Basic group has a mean average demand reduction of 0.83 kW with a median reduction of 0.85 kW. The Residential Advanced and Ultra groups have similar levels of mean reduction estimated at 1.42 kW and 1.48 kW, respectively.

Table 1: Dispatch Event Performance Summary

Statistics	Residential		
	Basic	Advanced	Ultra Advanced
Number of Events	46	64	68
Hours of Event Called	194	285	326
Average Demand Reduction (kW) Across the Event Period			
25th Percentile	0.59	1.02	0.94
Mean	0.83	1.42	1.48
Median	0.85	1.46	1.60
Maximum Demand Reduction (kW) Within the Event Period			
25th Percentile	0.78	1.41	1.14
Mean	1.05	1.87	1.91
Median	0.97	1.89	2.07

The GSET program was a first-of-its-kind project using a large-scale deployment of non-PV supported residential batteries using just the grid to recharge after displacement. The batteries proved to be a very effective means of managing a customer's load with invaluable experience gained by the VPP team. While the current cost of the technology makes its wide spread use not economically feasible, when it becomes cost effective the technology will be an excellent tool to include in the utility's tool box to manage customer loads with little or no inconvenience to the customer.

References

Greentech Media, Compared U.S. Annual Energy Storage Deployment Forecast and the U.S. Annual Energy Storage Market Size graphs published in https://www.greentechmedia.com/research/report/us-energy-storage-monitor-2017-year-in-review#gs.IhyiH7U