Research & Development 2019 Year-End, Interim Report for PowerShift

EFFICIENCY VERMONT WHITE PAPER OR REPORT

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Introduction

Changing energy systems—from the fuels that generate electricity and the ways in which utilities interact with customers, to the role of increasingly mature energy efficiency programs—require all energy industry players to think differently about customer service offerings. Since 2000, when the statewide energy efficiency utility Efficiency Vermont began offering demand-side management (DSM) services, the primary objective of most energy efficiency programs has been to provide *least*-cost electric energy supply for Vermonters.

This objective has historically been met by focusing on traditional energy efficiency measures, which are passive in nature (not controlled) and have the goal of annual energy savings (kWh). Demand response (DR) is another demand-side management strategy that has not been delivered by EEUs, and DR has historically focused on reducing demand during specific peak periods, for which success is quantified in kW.

Building on lessons from the 2018 Assessment of Demand Response Capability and Effectiveness[1] research and development project where Efficiency Vermont investigated where existing efficiency program activities might complement existing distribution utility-led DR services, Efficiency Vermont and Washington Electric Co-op (WEC) are partnering on a two-year (2019-2020) project named PowerShift, which seeks to demonstrate the potential for water heaters to function as "virtual batteries" within the territory of this low density, residentially-focused Vermont utility. Conceptually, this project goes beyond traditional energy efficiency or demand response and considers how DSM can be leveraged by WEC to shape member loads optimizing utility and member benefits. In Vermont, "flexible load management" has recently been adopted as the definition for this this burgeoning DSM activity.[2]

PowerShift was made possible through a Vermont Low Income Trust for Electricity (VLITE) grant to Washington Electric Co-op (WEC) and the Development and Support Services Research & Development budget of Efficiency Vermont. A final assessment of this demonstration project, due at the conclusion of the project duration in early 2021, will review the costs and benefits of the work at hand, and pending preliminary results, will consider how these concepts might be applied to different technologies and be accessible for more WEC members and Efficiency Vermont customers.

[1] https://www.efficiencyvermont.com/news-blog/whitepapers/assessment-of-demand-response-capability-and-effectiveness

[2] Case No. 19-2956-INV; See definitions on page 5 of Department of Public Service second set of comments regarding proceeding; October 18, 2019.

Background and Significance

As more renewables with very low marginal operating costs come online and as winter peaks constrain the supply of natural gas regionally, the timing of energy use is becoming more important. Utility costs associated with "peak times" have been rising in recent years, which is causing upward pressure on utility rates. WEC, for example, has over $4 million dollars in peak-related expenses. By pre-loading storage devices and deploying other demand response controls, power draw during peak events can be reduced, resulting in lower costs while ensuring grid performance and member satisfaction.

Electro-chemical batteries are gaining in popularity as storage to provide power during peak demand periods, but the price tag of either a grid-scale or an individual-home-scale electric battery can be cost-prohibitive. Most homes in Vermont have a "battery" in the basement already: a thermal battery in the form of an electric water heater storage tank. By safely raising the temperature of hot water in advance of members' needs (e.g. pre-loading), a well-insulated water heater tank can store hot water until the member needs it—without having to draw power from the grid during expensive peak times.

To determine the potential for reducing peak demands in Vermont through residential water heater controls, Efficiency Vermont and WEC are collaborating on Powershift, a two-year demonstration pilot. PowerShift adds advanced controls to existing water heaters to create a "virtual battery" that can help WEC save costs during peak times. The controls allow WEC to manage when members' water heaters draw power from the grid and when the water heaters "coast" on stored hot water.

Specific Aims

PowerShift aims to utilize WiFi-enabled sequencing controls to demonstrate that shifting energy demand for up to 200 units of two types of residential water heaters can be accomplished remotely such that energy use is shifted away from peak times to times that are less costly for WEC, while ensuring members' hot water supply is not disrupted.

Efficiency Vermont brings program and technological experience to support WEC in these PowerShift goals:

- Prove the concept of using advanced controls to remotely optimize the time at which water heaters use energy.
- Quantify the value of flexible energy use in reducing WEC's peak-related capacity and transmission costs, and consider the costs and benefits associated with scaling up the demonstration.
- Bring new value to WEC's members by making existing water heaters grid-interactive and enabling members to access new information from the member's water heater.

Efficiency Vermont's learning objectives for PowerShift are to:

- Understand potential areas for collaboration in flexible load management activities with distribution utilities.
- Understand three WiFi-enabled options for controlling connected water heaters

- Gain experience with controls protocols, generally.
- Gain experience with data transfer options (cellular (lower frequency) vs. WiFi (LAN/radio)).
- Understand the role of an aggregator and the value proposition the aggregator brings to flexible load management programs.
- Gain experience with projection algorithms and how loads respond to time-shift events.
- Gain experience behind-the-meter with a connected home product that could have greater potential impact on the home as a system.
- Identify barriers that constrain scaling up of the FLM model.

Research Questions

PowerShift is testing the following hypotheses:

- Efficiency Vermont and Washington Electric Co-op can collaborate effectively on flexible load management projects for WEC's members.
- Connected water heaters can be successfully utilized to reduce utility cost of service for water heaters with no negative member impact.
- The total benefits associated with flexible load management of water heaters are greater than the costs.
- Efficiency Vermont's measurement and verification capabilities are valuable to WEC in proving out the net value of flexible load management.
- PowerShift lessons are valuable to other Efficiency Vermont program designs and to other Vermont distribution utility programs.

Methods

The following sections describe PowerShift activities during planning, design, deployment and evaluation. Efficiency Vermont worked with WEC to create a PowerShift project plan that incorporated elements for each activity.

Planning

For the first year of PowerShift, WEC focused on shifting demand from residential water heaters during peak events, with a goal of enrolling 100 electric resistance water heaters (ERWH) and 100 heat pump water heaters (HPWH). To conduct preliminary project scoping, Efficiency Vermont used estimates from a 2018 residential loadshape study completed by the Massachusetts Energy Efficiency Advisory Council (EEAC) to estimate the potential impact of shifting individual water heater loads.[3] The average load of an ERWH from the MEEA study is shown in Figure 1. The orange line represents the estimated average kW (0.40 kW) that could be avoided during WEC's typical 5:00-9:00 p.m. peak period.

[3] Report can be found here: http://ma-eeac.org/wordpress/wp-content/uploads/RES-1-FINAL-Comprehensive-Report-2018-07-27.pdf

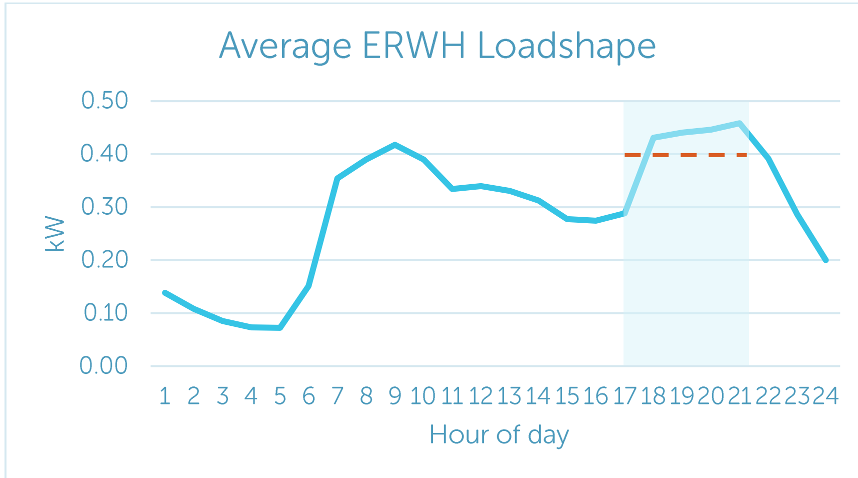

Figure 1: Average ERWH electric consumption loadshape

The average usage of an HPWH, shown in Figure 22, was used to estimate the potential impact of shifting the load of the HPWHs used in the study. The orange line represents the estimated average kW of a HPWH (0.18 kW) that could be avoided during WEC's typical 5:00-9:00 p.m. peak period.

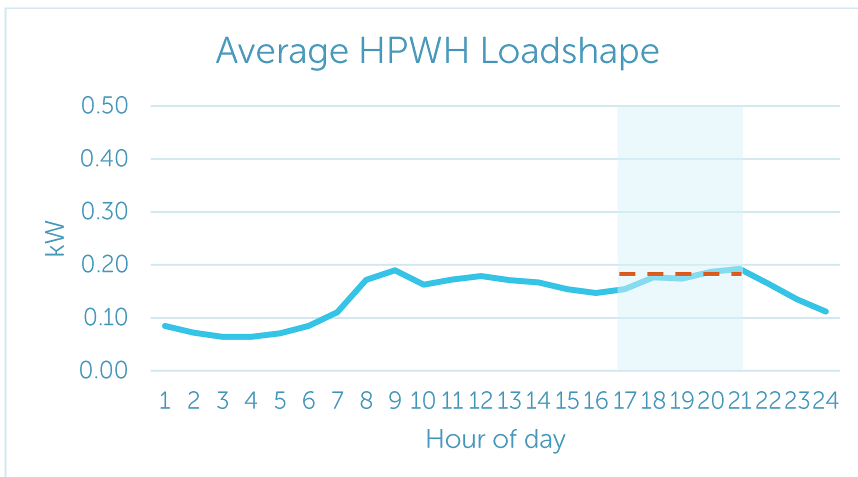

Figure 2: Average HPWH electric consumption loadshape

WEC estimates the financial value of avoiding demand during the 13 hours of the year that comprise peak energy times will result in cost reductions of approximately $253 per kW[4]. These peak hours were assumed to take place in the 5:00-9:00 p.m. timeframe (as indicated by the blue shaded areas in Figure

[4] This value is a summation of the following: 2019 RNS charges of $117/kW-year; 2019 FCM charges of $7.03/kW-month (or $84/kW-year); 2019 other local transmission charges of approximately $52/kW-year.

1 and Figure 2). Average water heater load during this timeframe was used to estimate the kilowatts that could be avoided for both ERWH and HPWH, as shown in Figure 3.

	Measure Controlled		
	ERWH	HPWH	Annual total
kW / unit	0.40	0.17	n/a
number of units	100	100	n/a
total kW	40	17	58
total annual value @ $253/kW savings	$10,120	$4,301	$14,674
annual $ peak value / unit	$101	$43	n/a

Figure 3: Estimated annual savings from peak demand load shifting for WEC residential water heaters

Prior to Efficiency Vermont joining the project, WEC had conversations with two software companies that provided water heaters controls. Efficiency Vermont played a support role in understanding the nuances of the separate contracts so that PowerShift could be created to optimize program costs and member benefits. WEC ultimately purchased access to two separate software platforms as follows:

- Vermont-based Packetized Energy Technologies (PET) Mello™ controls for ERWH with the Nimble™ dashboard software to manage the load.
- Virtual Peaker (VP) for HPWH with a distributed energy platform to remotely control the HPWHs.

Program design

Efficiency Vermont and WEC coordinated on all aspects of program design, including:

- program requirements
- member engagement and outreach
- gaining access to data from software companies
- onboarding and scheduling contractors, where necessary
- calling and scheduling peak events
- member support
- measurement and evaluation of the program impacts

Program deployment

WEC and Efficiency Vermont conducted outreach to enroll members in PowerShift, using marketing materials inserted into WEC member utility bills, articles in WEC's *Co-op Currents* periodical, notices on Front Porch Forum, and direct mail and email to WEC members. The following two sections describe member enrollment and controls sequencing for peak events, as determined during program design.

Member enrollment

Member requirements for pre-qualification were as follows.

The member must:

- own the home (to simplify participation agreements)
- live in the home year-round (to ensure savings will accrue)
- have a smart phone or tablet (to enable connection to water heater)
- have WiFi 24/7 (to enable connection of device)
- have at least 2 bars of WiFi strength at water heater (to ensure adequate communication)
- have a mixing valve[5] if HPWH (to allow for shifting / storing energy safely)[6]

Forecasting and controls sequencing for events

The peak-related costs that PowerShift intended to avoid include ISO-New England (NE) Forward Capacity Market (FCM) costs[7], Regional Network Service (RNS) costs[8], and local transmission costs. The water heater controls strategy focused on the ability for water heaters to avoid using energy during the forecasted peak times—without disrupting the hot water service for members. To avoid using energy at peak times, WEC and Efficiency Vermont utilized peaking forecasting models supplied by Utopus Insights to "call" peak events 1-5 times per month.[9]

For electric resistance water heaters, peaks were avoided by using PET's "Peak Crusher" algorithm to reduce kW used during events. For heat pump water heaters, peaks were avoided by preheating tanks to 140°F starting 3 hours before a forecasted peak, and during events, HPWH temperatures were turned down to 120°F. The peak event windows were 2 hours long for both types of water heaters.

Evaluation

To verify program impacts for both WEC and individual members, access to device-level data was a critical element of the program. Efficiency Vermont's Data and Technical Services team worked with WEC and the software providers during the early phases of the project in order to ensure access to device-level data to allow for evaluation of the project impact on a monthly basis and for verification at the end of the project.

Evaluation of the PowerShift program focused on WEC's peak impact and participant members' energy and bill impacts. To calculate these impacts, Efficiency Vermont sought to quantify the load reduction from the devices under the control and monitoring of both VP and PET for WEC during peak hours, as well as total energy consumption for participant members. The evaluation determined how the devices impacted members' electricity bills to ensure that pre-heating the water prior to events did not increase

[5] Mixing valves are required to be installed on all water heaters per Vermont building codes

[6] The specific controls approach that PET uses for ERWHs does not require a mixing valve

[7] FCA rates: https://www.iso-ne.com/static-assets/documents/2018/05/fca-results-report.pdf

[8] RNS rates: https://www.iso-ne.com/static-assets/documents/2018/08/a2.0_2018_08_07_08_rc_tc_ptoac_rates.pptx

[9] This forecasting tool is no longer available as of Q1 2020, which will directly impact the program in the second year

total energy costs for the members. The next two sections review the methodology used for the evaluation.

Utility Peak Impact

Efficiency Vermont's goal was to create an accurate and scalable baseline that measured the water heater load over time without the effects of the controllable devices. Using the baseline, Efficiency Vermont measured the change in load during the monitored flexible load event. To understand the typical impact on load due to these devices, Efficiency Vermont averaged the load for all participating water heaters in each cohort. A cohort is a group of devices based on the water heater type: HPWH or ERWH.[10] Aggregation across cohorts helped the team understand the average impact for a typical household device, as well as the total impact for a peak hour with the entire population of participating devices. In this study, the water heaters showed some hour-of-day and hour-of-week patterns for when hot water was used, but there was also a lot of variability related to human behavior in the home that was very difficult to predict. Device level models are very inaccurate for homes with irregular schedules. Aggregating the devices by cohort allowed the team to capture the average water heater usage pattern which is more predictable.[11] After aggregating the data, Efficiency Vermont evaluated two models to create a baseline for the event period of interest - a model used by ISO New England (ISO-NE)[12], and a time series model based on literature[13].

Efficiency Vermont used ISO-NE's unadjusted baseline model from the Price-Responsive Demand programs as a preliminary baseline model. The unadjusted ISO-NE baseline uses a 10-day average from the past 30 non-holiday weekdays to predict a weekday baseline. It is extended for weekends or holidays by taking a 5-day average of Saturday, Sunday, or holidays. The maximum lookback is 42 days.

Additionally, Efficiency Vermont implemented a time series modeling approach, called an Auto-Regressive Integrated Moving Average (ARIMA) model. The ARIMA model uses a linear combination of lagged historical data, outdoor air temperature, time of use variables, and other variables to explain periodic trends in the data to predict the baseline. Variables for hour-of-week seasonality and hour-of-day seasonality were included. This methodology is commonly used for modeling aggregate hot water consumption.[14] For further details on the implementation of the ARIMA model see Appendix A: Technical Supplement.

Both the ISO-NE model and the ARIMA model have assumptions built-in. First, the models assume that there is recent (in the last 30 days) historical data that has not been biased by the flexible load behavior.

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[10] Efficiency Vermont separated water heaters by type due to the differences in how the water heaters perform. Heat pumps have been shown to be far more efficient than electric resistance water heaters.
[11] As more devices enroll in the pilot in the future, the results will be more representative of the behavior of the WEC population and baseline error will decrease.
[12] ISO-NE model https://www.iso-ne.com/static-assets/documents/2017/11/20171107-webinar-prd-overview.pdf.
[13] Time-series model https://www.mdpi.com/1996-1073/8/11/12336/htm.
[14] Linas, et al. "Forecasting Hot Water Consumption in Residential Houses." *MDPI*, Multidisciplinary Digital Publishing Institute, 11 Nov. 2015, www.mdpi.com/1996-1073/8/11/12336/htm.

Second, if a member is participating in a flexible load management event every day or almost every day, there is not enough evidence to build a model of the counterfactual. Finally, these models predict the expected or on-average behavior of the cohort. They are unable to predict unusual or one-off changes in the load, such as the electric resistance mode coming on in a heat pump water heater if there is no prior evidence that the electric resistance element turns on during that time.

Peak Impact Model Evaluation

To evaluate the accuracy of the baseline models, Efficiency Vermont predicted 15 randomly selected non-event days per month and evaluated the accuracy of the models during the hours 3:00 to 9:00 p.m. These hours are the most likely hours for RNS and FCM peaks to occur. Efficiency Vermont measured the coefficient of variation of root mean squared error (CV(RMSE)) when the members were not following flexible load events. The goal was to have a lower CV(RMSE). CalTrack recommends a CV(RMSE) threshold of 100% as a default for portfolio-level (cohort-level) model performance.[15]

Figure 1 shows the mean CV(RMSE) for each month for the ISO-NE model and the ARIMA model. The average number of devices enrolled during each month is referenced under the month label. As expected, the error tended to drop as more devices were enrolled. The ISO-NE and the ARIMA models performed with similar accuracy on electric resistance data. With the heat pump results the error between the two models was similar, although in November and December, when the sample size increases, there was a larger improvement with the ARIMA model. Overall, the accuracy of the models was similar. Efficiency Vermont expects the model accuracy to continue to improve as the sample size increases.

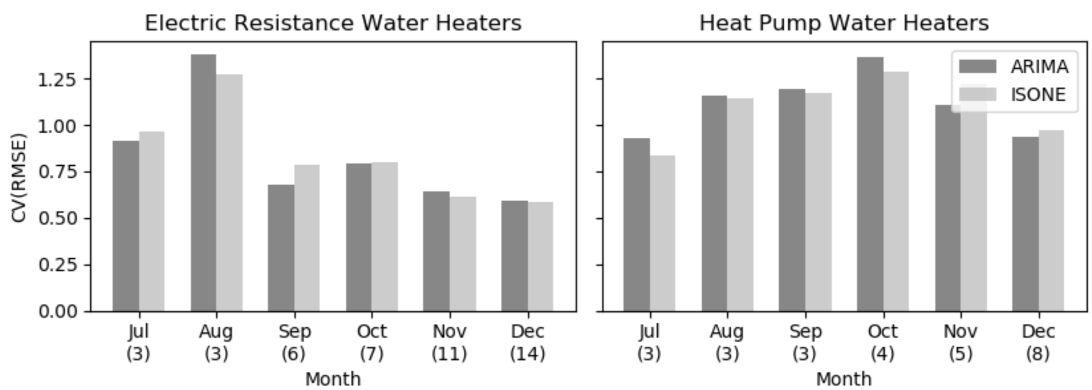


Figure 1: Model error by month

[15] "CalTRACK Methods." CalTRACK Methods - CalTRACK Technical Documentation 2.0 Documentation, docs.caltrack.org/en/latest/methods.html.

Based on the data collected so far, the ARIMA model showed equivalently accurate predictions and will continue to improve throughout the pilot as water heaters are added. PowerShift results related to peak impact were calculated from the ARIMA baseline.

Participant Member Impact

To estimate the impact of called peak events on member energy bills, Efficiency Vermont modeled the daily energy usage for all days within the month of interest. To isolate the effects of the event days on total energy usage, Efficiency Vermont built a mixed effects model controlling for differences between devices, time of week and temperature. The model yielded an estimate of the average effect of an event day on the energy per day controlling for time of week and temperature. Modeling the daily energy usage was a simpler model than the hourly ARIMA model. The granularity of an hourly model was not needed to evaluate the impact on energy bills. The mixed model enabled an estimate of the effect of events on daily energy while controlling for each device's schedule. More details on model parameters, and evaluation are in the Appendix A: Technical Supplement.

Limitations of Water Heater Modeling

The Utility Peak Impact section explains why aggregating to the cohort-level was important to understand the typical impact of these devices. Additionally, heat pump and electric resistance water heaters have very different load patterns. Figure 2 shows an example of 5-minute interval load shapes of these two types of water heaters. Without aggregation, accuracy hinges on the time the water heater turns on which can be very difficult to predict. Efficiency Vermont also aggregated to the average kW draw over the hour instead of 5-minute intervals to improve accuracy. Heat pumps can go into electric resistance mode which is difficult to predict unless the water heater enters that mode regularly due to consistent user behavior.

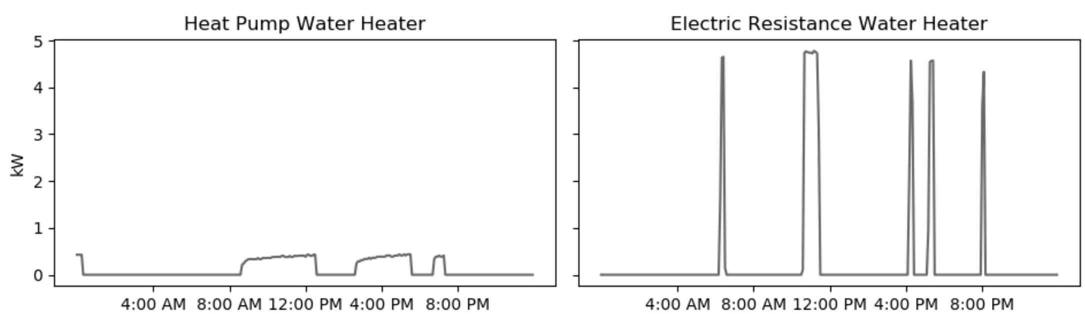


Figure 2: Example load shapes for HPWH and ERWH

Results & Findings

PowerShift results to date are preliminary due to the small number of enrolled devices. As more water heaters are enrolled, a more accurate estimate can be derived for the impacts for both HPWH and ERWH. Results to-date are categorized as follows: program deployment, utility impact, participant member impacts, program costs and benefits, and project roles and measures of success.

Program deployment

The program deployment results are categorized by member enrollment, forecasting and controls, and technology performance.

Member enrollment

PowerShift enrollment aims to enroll 100 electric resistance water heaters and 100 heat pump water heaters within the 24-month pilot. Program planning and design took longer than anticipated, and 6 months passed before the pilot was deployed and outreach was initiated. From July thru December 2019, 138 WEC members interacted with Efficiency Vermont's Customer Support Team about PowerShift. Of those total inquiries, 78 (57%) WEC members did not qualify for the program and were referred to other energy savings programs offered by Efficiency Vermont and WEC. The reasons those 78 members did not qualify for the PowerShift pilot are noted in Table 1. While the factors below impacted some WEC member's abilities to participate and thereby prevented the project team from having a representative sample across WEC's membership, the expectation of this limited scale demonstration was never to have a representative sample.

Table 1: WEC member reasons for non-participation

WEC Member Reasons for Non-Participation	Count	% of total
No response / Opted out	19	32%
Disqualified water heater types (e.g. gas, oil, storage only)	12	20%
HPWH without a mixing valve	11	19%
HPWH model not WiFi enabled	10	17%
Technology limitations (e.g. no internet, no smartphone, no WiFi, "too complicated")	7	12%
WiFi signal too weak	5	8%
Technical issues with existing water heater	4	7%
Seasonal property	3	5%
Other	7	12%
Total unqualified participants	78	100%

By the end of the first 12 months of the pilot, 15 HPWH and 18 ERWH were fully enrolled in PowerShift, and 27 additional members were in various stages of the prequalification or enrollment process.

Member education was an important element of the PowerShift program. The concept of "energy efficiency" is fairly well known by WEC members, but most members were new to the idea of "flexible load management." A video on the PowerShift website[16] was a key component of helping members understand the purpose of the demonstration project. A few members were concerned about the data sharing aspects of the program.

The ease with which WiFi controllers were installed varied widely by site. The most challenging examples included rerouting plumbing (not recommended by the program) in order to make space for the controller on top of an ERWH before a second trip was made by an installer to wire in a controller. The easiest examples of enrollment were when the built-in WiFi controls of an existing HPWH were already utilized by the member, and a simple hyperlink was sent via email to make the connection to the WEC dashboard to complete enrollment.

Forecasting

Forecasting the monthly Vermont grid peaks and the annual ISO-NE peak requires skills in peak load forecasting, and this task is becoming increasingly difficult as more variable renewable resources are added behind the meter (e.g. net-metered PV) and as more flexible load devices are controlled by various distribution utilities in Vermont. From July through December 2019, 1 FCM peak and 6 RNS peaks took place. The project team correctly scheduled water heater control responses for 4 of the 7 peak events. Given the low number of peak events when the water heater controls were deployed at the correct time, regardless of how many devices were enrolled or how well the devices performed, the peak cost to WEC could not have been avoided during the times and days when the peaks were missed entirely. This forecasting challenge is not unique to the PowerShift program or to WEC, and the Recommendations section below proposes strategies to mitigate the uncertainty related to peak forecasting for future FLM efforts.

Technology performance

To complicate the forecasting challenges noted above, a series of technology challenges were encountered. For ERWHs, the PET Mello WiFi controller could be retrofitted onto nearly any existing electric resistance water heater and controlled using PET's Nimble software dashboard. The team experienced challenges during the first few months of the program with mode settings and the continuity of data flow, and therefore, results were not valid until after October 2019 for ERWHs. The issues were resolved for events in November 2019 and for the rest of the events going forward. Additionally, a few installs were not conducted properly, which resulted in temporary disruptions to members' hot water service. These issues were fully resolved, and the project team is making program changes to ensure these issues to not reoccur in the future.

For HPWHs, the two WiFi controllers that were used to connect to the VP software were EcoNet by Rheem and ConnectPlus by GE. Both Rheem and GE support the hardware and the back-end application programming interfaces required to connect to the devices remotely. At the time of the pilot, these two HPWH manufacturers were the only manufacturers supporting commercially available hardware and software for FLM. The software that was used to control the water heaters was VP's

[16] www.EfficiencyVermont.com/PowerShift

dashboard. Understanding the manufacturer settings that govern the controls was challenging in the early months of the program, but those issues have since been resolved. For a few devices, the continuity of power data was an issue, making evaluation impossible for those devices.

Evaluation

The following sections describe the results of the evaluation undertaken to understand the impacts for WEC and for participant members.

Utility Impacts

Peak event tracking started in July 2019 and PowerShift will continue tracking these events through December 2020. Tables 2 and 3 show the change in kW demand (impact) during the RNS or FCM peak hours on water heater consumption and the associated avoided cost for WEC for ERWH and HPWH respectively. The RNS and other local transmission peak costs were based on $14.33/kW for WEC during peak hours. For the FCM peak in July, the rate was $84.36/kW. Positive impact indicates a reduction in the load used during the peak hour compared to the baseline. Similarly, positive avoided cost indicates less peak demand charges for WEC relative to the baseline.

Due to data quality issues and peak forecasting inaccuracies, the ERWH results were valid for only 1 of the 7 peak events in 2019.[17] Moreover, the PowerShift team does not expect to see significant change in demand (impact) in the PET devices until the sample size is around 50 devices because, at small numbers, and given the quality of service guarantee, one or two large usage events may trigger power consumption that would outweigh the impact of any energy saved.

Table 2: July - December 2019 ERWH demand impacts and avoided costs.

	Electric Resistance Water Heaters (Packetized Energy)				
	Number of devices	Impact per device (kW)	Avoided cost per device ($)	Total impact (kW)	Total avoided cost ($)
RNS					
July*	3	n/a	n/a	n/a	n/a
August*	3	n/a	n/a	n/a	n/a
September*	6	n/a	n/a	n/a	n/a
October**	6	n/a	n/a	n/a	n/a
November	12	-0.07	-0.94	-0.72	-11.33
December**	15	n/a	n/a	n/a	n/a

[17] Preliminary results for January and February are promising and ERWH performance appears to be more in line with the hypotheses.

Total	-	-	-	-0.72	-11.33
FCM*	3	n/a	n/a	n/a	n/a

* Results are not valid due to errors in device modes. ** No event called on this RNS peak.

The team drew some insight about HPWH performance using VP software, although sample sizes were small.

Table 3: July - December 2019 HPWH demand impacts and avoided costs.

Heat Pump Water Heaters (Virtual Peaker)

	Number of devices	Impact per device (kW)	Avoided cost per device ($)	Total impact (kW)	Total avoided cost ($)
RNS					
July	3	0.10	1.45	0.30	4.34
August	3	0.05	0.67	0.14	2.01
September	4	0.05	0.69	0.19	2.77
October*	4	n/a	n/a	n/a	n/a
November	5	0.20	2.89	1.01	14.44
December*	9	n/a	n/a	n/a	n/a
Total	-	-	-	1.64	23.56
FCM	3	0.03	2.41	0.09	7.26

* No event called on this RNS peak.

As a point of comparison, a similar project undertaken in the Pacific Northwest demonstrated that ERWHs could shift approximately 0.32-0.33 kW and HPWHs could shift 0.09-0.20 kW, with results varying by season and with different controls strategies.[18] Preliminary results from the first PowerShift events called in early 2020 are showing per device impacts that are closer in magnitude to the results of other studies.

[18] *Load Shifting Using Storage Water Heaters in the Pacific Northwest*. Results can be found in Appendix E of this report: https://www.bpa.gov/EE/Technology/demand-response/Documents/20181118_CTA-2045_Final_Report.pdf

As noted in a previous section, peak forecasting accuracy is important in order to control the water heaters to avoid peak demand costs and to create value for WEC.

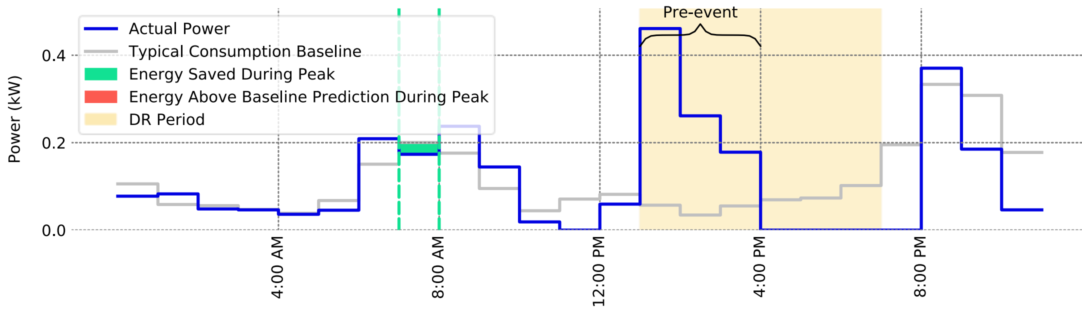


Figure 3 illustrates an event that was called for HPWHs on December 19th. The pre-event period was 1:00-4:00 p.m., and the blue line indicates an increase in power during this time. The period of 5:00-7:00 p.m. was the forecasted peak, and no power was drawn from the water heaters during this time, which indicates a successful load-shifting event. However, after the month ended, the peak was determined to have occurred during 7:00-8:00 a.m. on this day. Therefore, the successful shift in energy in the afternoon had no impact on WEC's peak costs, which occurred in the morning, on that month.

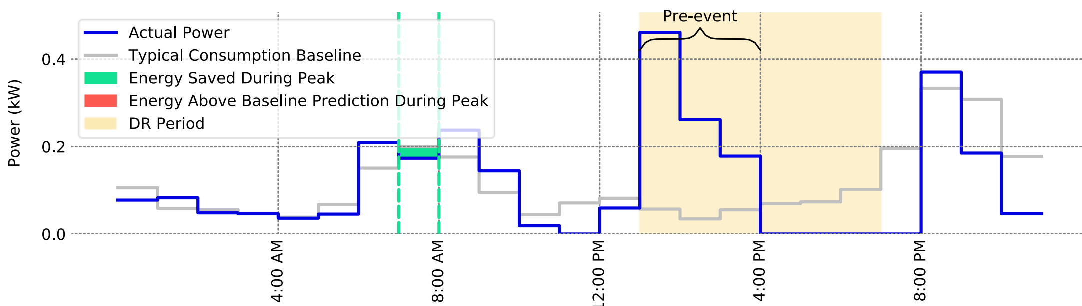


Figure 3: HPWH (VP) aggregated cohort load shape for December 19 RNS event

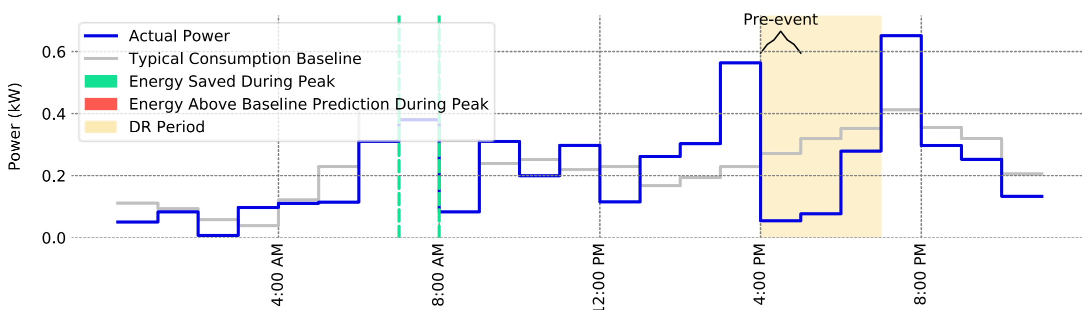


Figure 4 illustrates an event that was called for ERWH on December 19th. The pre-event period was 4:00-5:00 p.m., and the blue line indicates an increase in power leading up the forecasted peak period of 5:00-7:00 p.m. During this forecasted peak period, a lesser amount of power was drawn from the water heaters, which again indicates a successful load-shifting event. However, because the peak occurred during the morning on this day, the movement of energy during the afternoon provided no peak cost reduction value for WEC.

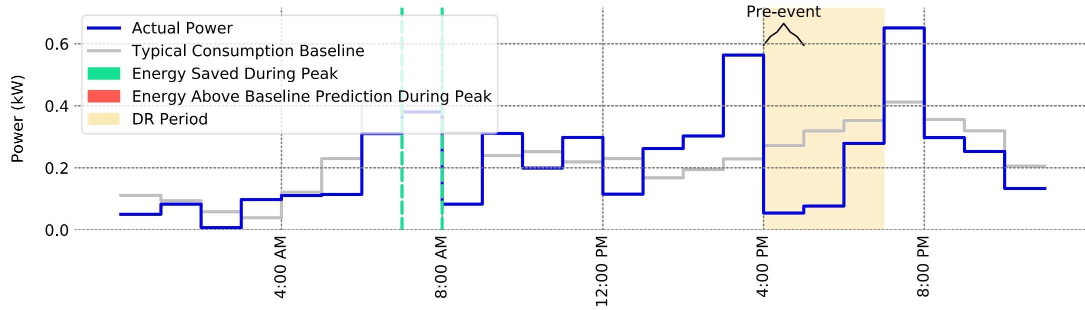


Figure 4: ERWH (PET) aggregate load shape for December 19 RNS event

Participant member impacts

The team found that event days did not have a significant effect on the member's energy consumed per day. Table 4 and Table 5 show the average effect of the event day on the total energy per day based on the mixed model. The change in bill calculation assumed a residential rate of $0.23/kWh.

Positive changes in bill amount per event day indicate that the event days increased the total energy consumed, while negative bill amounts per event day indicate that the event says decreased total energy consumed. The net member impact was based on the effects of the called events plus a monthly credit of $5.00 for participating members. If the net member impact per month was positive, on average, the monthly credit did not cover the cost of the event day behaviors. Thus far, the team has not seen significant effects from event days on water heater energy usage. The monthly credit was shown to be enough to cover any variability in energy usage.

Table 4: ERWH (PET) member impacts

	Electric Resistance Water Heater			
	Number of events	Change in usage per event day (kWh)	Change in bill per event day ($)	Net member impact per month ($)
July*	3	N/A	N/A	-5.00
August*	4	N/A	N/A	-5.00
September*	8	N/A	N/A	-5.00
October*	2	N/A	N/A	-5.00
November	1	-2.51	-0.58	-5.58

December	1	-0.23	-0.05	-5.05
Average	-	-	-	-5.11

* Results not valid due to errors in device modes.

Table 5: HPWH (VP) member impacts

	Heat Pump Water Heater			
	Number of events	Change in usage per event day (kWh)	Change in bill per event day ($)	Net member impact per month ($)
July	4	0.17	0.04	-4.84
August	5	-0.01	0.00	-5.01
September	6	-0.49	-0.11	-5.68
October	2	-0.44	-0.10	-5.20
November	2	-0.45	-0.10	-5.21
December	1	0.33	0.08	-4.92
Average	-	-	-	-5.14

Program costs and benefits

The PowerShift program costs are provided in the Table 6.

Table 6: PowerShift Program Costs 2019

PowerShift	**2019**
Program administration	
Project Management	$5,000
Data Analytics	$37,800
Customer Support	$4,500
Marketing	$6,300
Software	$18,650
Subtotal	$72,530
Variable costs, HPWH	
Hardware	$1,666
Contractor	$0
Member incentives	$140
Subtotal	$1,806
Variable costs, ERWH	
Hardware	$5,467
Contractor	$2,213
Member incentives	$140
Subtotal	$7,820
Total	$81,876

While the lessons learned in this demonstration project were invaluable, the quantifiable program benefits were insignificant in the first year of the PowerShift demonstration project. As noted in the Technology Performance section above, the software controls for the electric resistance water heaters were not operational until November, and in December, the peak hour and day was missed. Therefore, the total avoided costs realized for electric resistance water heaters was approximately $0 in 2019. For heat pump water heaters, a maximum of 9 water heaters were performing during a monthly peak hour in 2019. The total impact for WEC from July thru December 2019 for heat pump water heaters was estimated to result in peak cost savings of approximately $25. By the end of the demonstration project in December 2020, it is expected that a more significant number of connected units will be installed, increasing impact and improving the assessment of the impact. Achieving scale will be important for the pilot and for any future FLM-related endeavors.

Project Roles and Measures of Success

The partnership for PowerShift was established through a memorandum of understanding (MOU) between WEC and Efficiency Vermont, and this project has allowed both organizations to learn about FLM in collaboration. Early planning between WEC and Efficiency Vermont was a critical and necessary step to ensure each party was able to focus on the project aspects that matched the partner's skillsets, expertise, and capacity. The project design phase was led by Efficiency Vermont's experience in customer-facing programs. The project design incorporated Efficiency Vermont data analysts' experience in evaluation and WEC's goals to create one succinct voice for discussions with software providers. Deployment responsibilities were shared with Efficiency Vermont's marketing team supporting WEC's member outreach in monthly utility bills, newsletters, and existing media channels. For event days, WEC provided access to forecasting services while Efficiency Vermont worked to optimize the control schedules to meet those forecasts. Efficiency Vermont provided the lead on project intake and evaluation, while WEC provided participant lead generation through existing member engagement channels.

Efficiency Vermont identified several metrics that would indicate a successful project. Table 7 provides the status of the success metrics.

Table 7: PowerShift success metrics status at end of first pilot year

Success Metric		Status as of 12/31/2019
1.	Explore Efficiency Vermont's role in supporting distribution utilities (DU) with FLM—within the bounds of the Order of Appointment and existing Quality Performance Indicators	Achieved
2.	Strong partnership with DUs to explore FLM programming	Achieved
3.	Demonstration of FLM without adversely impacting the member	Achieved
4.	Quantification of the value of FLM	Work in progress
5.	Understand any potential paths forward for Efficiency Vermont to support future FLM programs	Work in progress

The first and second measures of success were achieved by building upon an existing relationship between WEC and Efficiency Vermont. The member survey results in Appendix B and the preliminary results noted in the Member Impacts section of the results are indications that the third success metric was achieved. An assessment of the fourth success metric will only be possible after more devices are in the field. The fifth success metric is being contemplated in ongoing regulatory proceedings as of the writing of this paper.

Recommendations

Electric vehicle supply equipment (e.g. electric vehicle chargers) will be added to the demonstration project in 2020. These measures will be folded under the PowerShift program in order to leverage the existing program infrastructure already in place.

If the pilot findings support WEC continuing FLM as a formal tariff member offering at the end of pilot period, a plan needs to be developed for WEC to address the peak forecasting and controls scheduling challenges posed by elusive monthly peak events. One solution could be to schedule load-shifting events more regularly, or even daily, to have a better chance that the load shifting matches the peak time. Because the team has not seen negative member impacts related to calling peak events, a daily load shift for water heaters should be a serious consideration starting in 2020.

Beyond the term of this pilot, WEC might consider how additional avoided costs may be realized beyond RNS and FCM peaks. Energy arbitrage is an additional value stream that may be relatively easy to monetize. Another potential value stream for load shifting relates to emissions. While WEC is 100% renewable on an annual basis, the carbon intensity of the ISO-NE grid varies by the hour, day and season.

Clearly defining roles and building strong partnerships, as outlined in the first and second metrics of the Project Roles and Measures of Success, should be a focal point as FLM programs evolve in Vermont. Efficiency Vermont and WEC were able to collaborate successfully on program planning, program design, and implementation, and this was only possible with a deep level of trust and mutual respect between organizations in order to serve WEC's members well. The lessons learned from PowerShift should inform the regulatory proceedings related to the Efficiency Vermont Demand Resource Plan for the 2021-2023 performance period.

Appendix A: Technical Supplement

Evaluation Interval

Flexible load performance was evaluated from July 2019 until December 2019. The performance was evaluated during the hour of each monthly RNS and hours of the yearly FCM peak. Power reduction was calculated based on the mean 5-minute reading within the peak hour compared to the forecast for that hour.

Calculation Methodology and Analysis Procedure

The sections below describe the calculation methodology and the analysis procedure.

WEC Peak Impact

To model the baseline Efficiency Vermont implemented an auto-regressive integrated moving average model (ARIMA). The model is trained on the 30 days prior to the peak event and forecasts from 3 hours prior to the peak event through the end of the peak event. Any peak events that occurred in the prior 30 days are removed from the training data. Efficiency Vermont only included devices into the aggregation that had at least 30 days of historical data. This model assumes that there are enough days in the training data that there are not demand response (DR) event days so that the model has evidence to learn the typical power consumption behavior of each site. The model predicts the average behavior and cannot predict one-off or uncommon load changes. This makes predicting changes in household schedules nearly impossible without other variables to predict schedule.

Dependent variables: y_t = *load* at time t where the timeseries frequency is hourly

Independent variables: Time series configuration ARIMA (2,1,1) with exogenous variables

Model parameters: Model is trained before each evaluation period, and parameter values are stored in a database.

$$\hat{y}_t = y_{t-1} + \phi_1(y_{t-1} - y_{t-2}) + \phi_2(y_{t-2} - y_{t-3}) + \delta_1 y_{t-24} + \delta_2 y_{t-48} - \theta_1 \epsilon_1 + \beta_w x_{w_t} + \beta_T x_{T_t} + \sum_{n=1}^{40} \left(a_n \cos \frac{n\pi h_t}{168} + b_n \sin \frac{n\pi h_t}{168} \right)$$

$\boldsymbol{y_t}$	**Load at time** $\boldsymbol{t}$
$\boldsymbol{\phi_i}$	Parameter for the i^{th} lag term, i = 1, 2
$\boldsymbol{\delta_i}$	Parameter for 24-hour seasonal lag terms, i = 1, 2
$\boldsymbol{\theta_i}$	Parameter for the i^{th} moving average term, i = 1
$\boldsymbol{\epsilon_i}$	The i^{th} moving average term (lagged forecast error), i = 1
$\boldsymbol{\beta_w}$	Parameter for the indicator of weekend or holiday

x_{w_t}	Indicator variable for weekend or holiday at time t
β_T	Parameter for temperature
x_{T_t}	Temperature in degrees F at time t
a_n, b_n	Parameters for Fourier series for 168-hour of week seasonality
h_t	Indicator of hour of week (ranges from 0, ..., 167)

Member Impact

Efficiency Vermont modeled the effect of event days on total kWh using a mixed effects model. For each month, Efficiency Vermont re-fit the model on the data for that month. Efficiency Vermont included a random intercept for each device to account for the variability in hot water consumption among households. Efficiency Vermont also included random slopes for the effect of weekends vs. weekdays on daily kWh. This means that each device can have a different effect for the type of day. A fixed effect for temperature was also included. The model was selected based on lowest Akaike information criterion (AIC)value and best CV(RMSE). Due to the small sample sizes Efficiency Vermont was not able to include many variables or fit very complicated model to account for confounding variables.

Expected Accuracy

To assess model error, Efficiency Vermont trained the model on 15 random non-event days, and then measured the Coefficient of Variation of the Root Mean Squared Error (CV(RMSE)) of the predicted values compared to the actual values. The CV(RMSE) values are on the higher side since PowerShift is trying to predict schedule of hot water use which can be very difficult without other data.

ISO-NE Unadjusted and Adjusted Baseline

Efficiency Vermont used ISO-NE's unadjusted baseline from the Price-Responsive Demand programs as a reference for modeling. The unadjusted ISO-NE baseline uses a 10-day average from the past 30 non-holiday weekdays to predict a weekday baseline. The baseline is extended for weekends or holidays by taking a 5-day average of Saturday, Sunday, or holidays. The maximum lookback is 42 days. This adjustment procedure is not designed for device level data and is mostly for large or aggregated assets. Therefor this adjustment was not effective in this pilot. Figure 5 shows the ISO-NE procedure for adjustment.

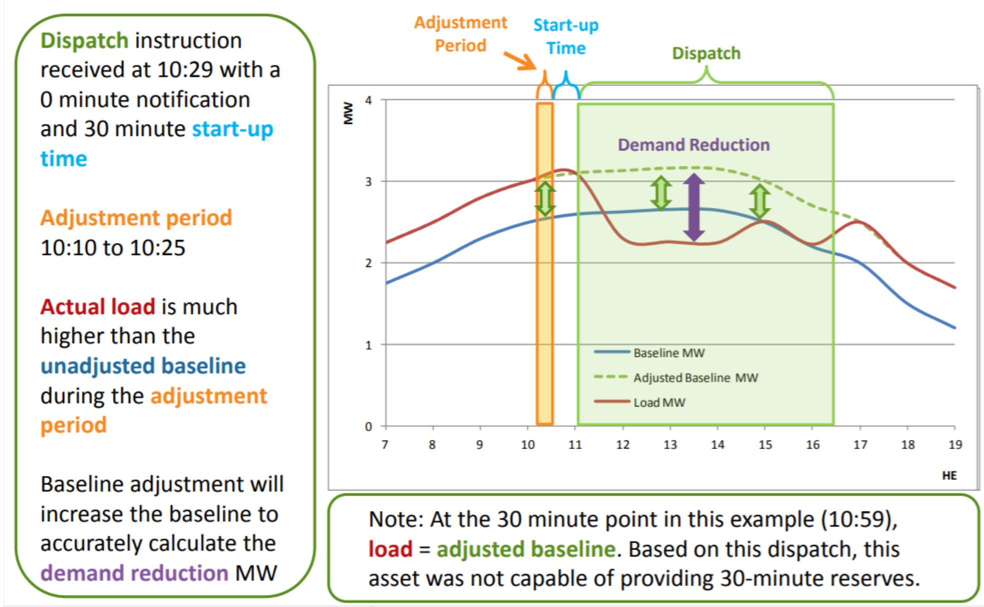


Figure 5: ISO-NE Adjustment Procedure

Methodology Improvements

One possibility for improving aggregate baselines is to implement a more complex black box model such as a neural network to capture the complexity of the time when water heaters turn on and off. This could improve the aggregate modeling and may also allow modeling of device level impact.

Figure 6 shows the distribution of the hour that a member's heat pump water heater turns on by day of week. Looking at the hours between 17 and 22 during weekdays there is a lot of variability on when the water kicks on. Without variables to explain that variability, the device level is difficult to predict. These hours are typically when peaks occur.

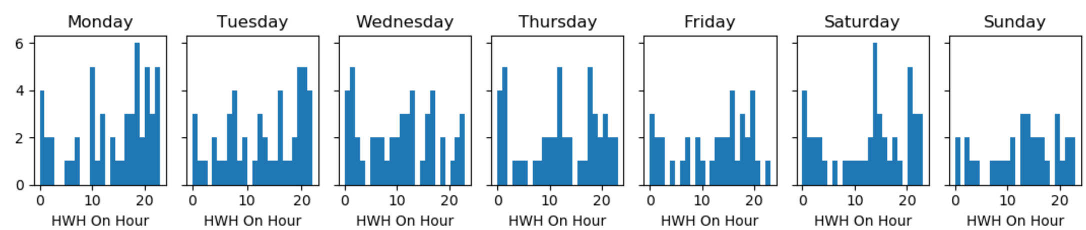
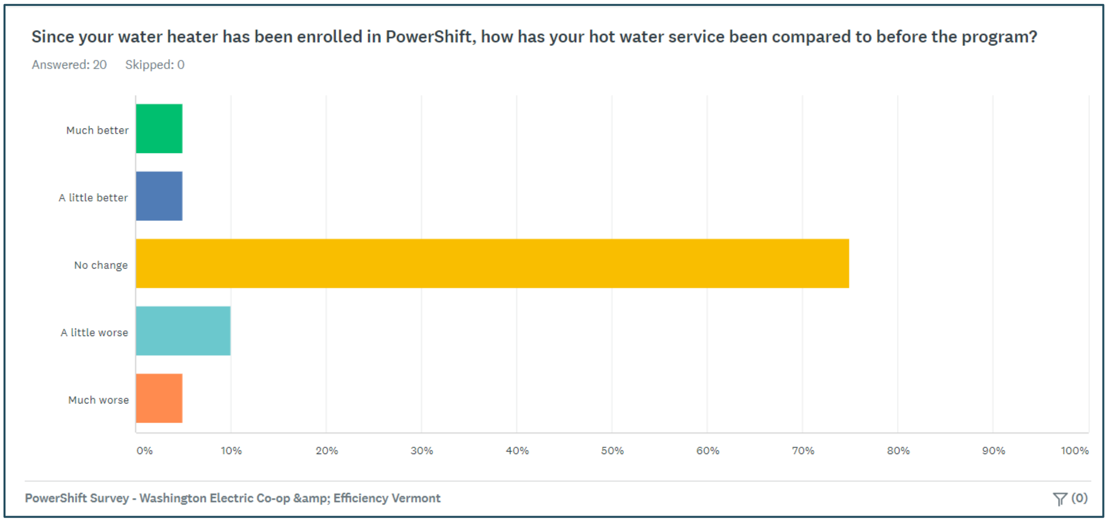


Figure 6: Heat pump water heater distribution of the hour it turns on by day of week.

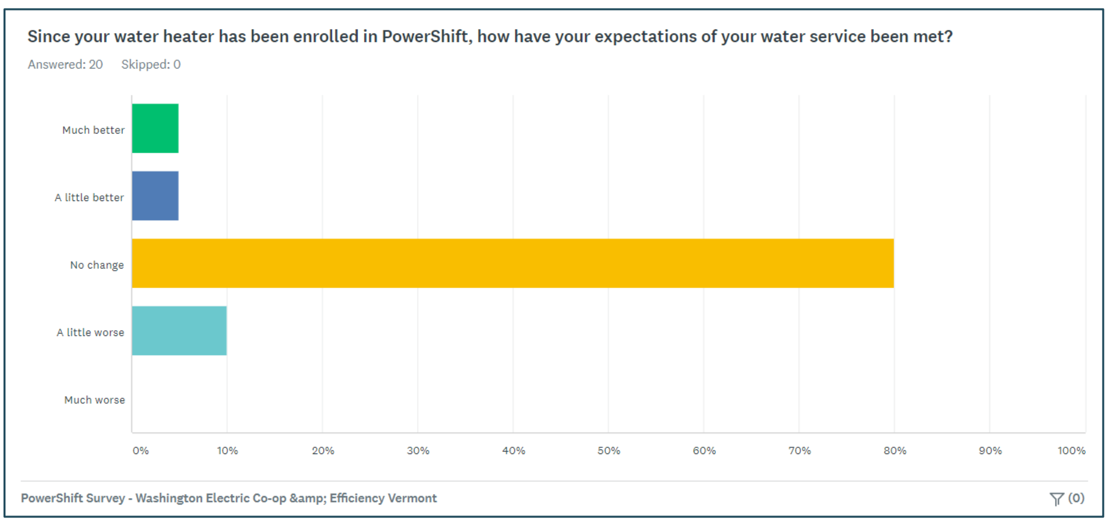
Appendix B: Member Survey Results

The following survey questions were given to PowerShift participants six weeks after enrollment. Thus far, 20 participants have responded to the survey as of the writing of this paper.

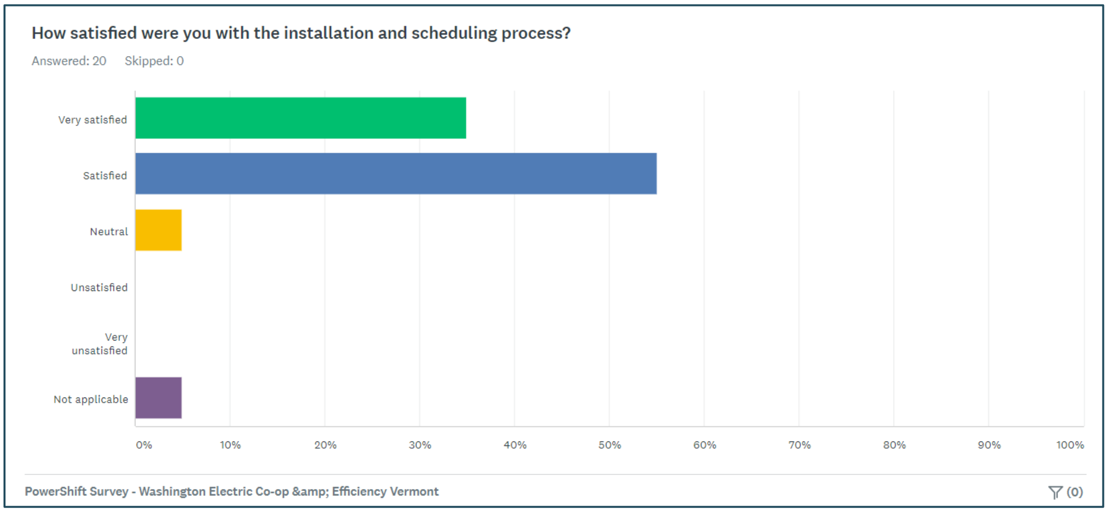
Question 1:



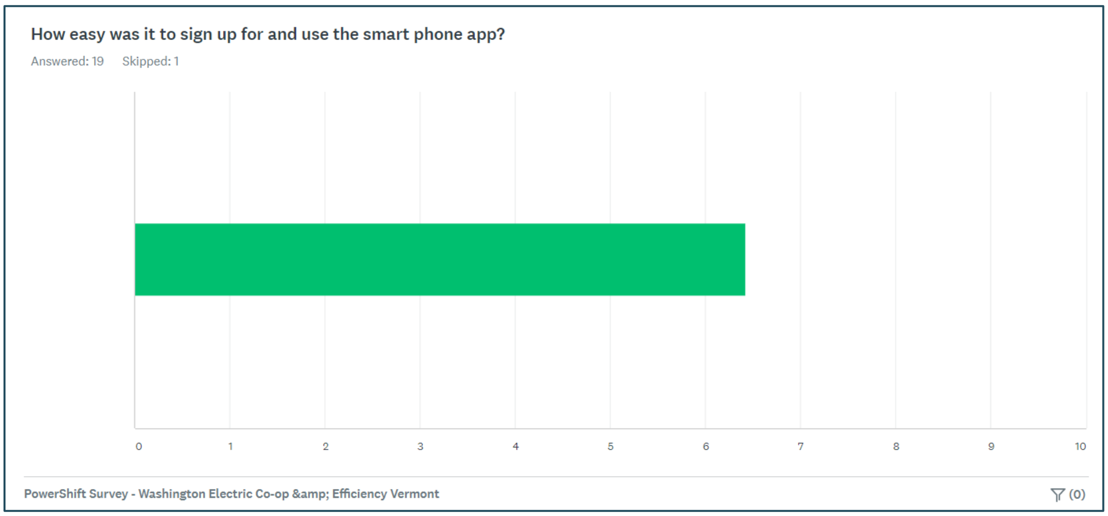
Question 2:



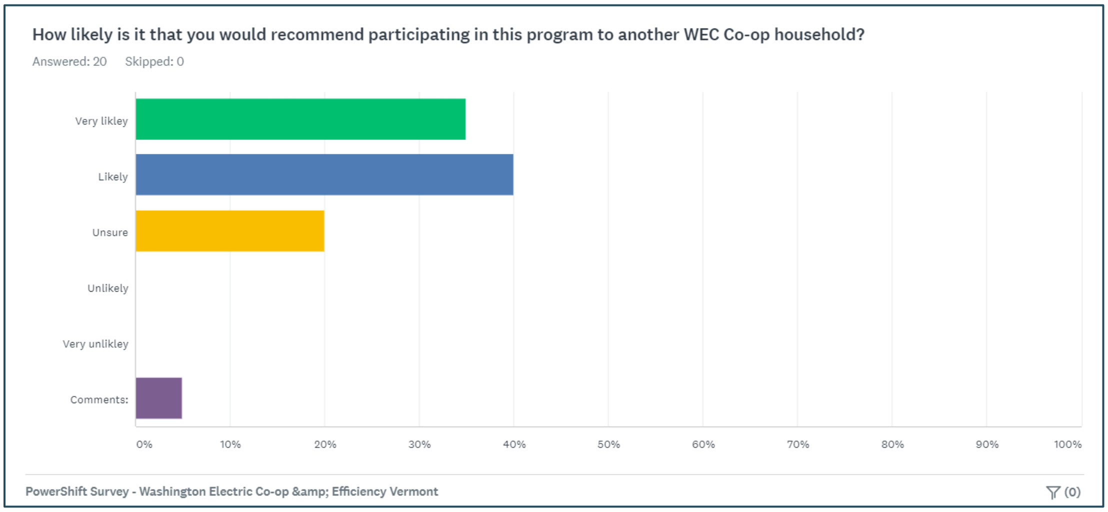
Question 3:



Question 4: (scale of 0-10 with 0 being difficult and 10 being easy)



Question 5:



Question 6: