Pacific Gas and Electric Company

Evaluation of the Automated Emissions Reduction Dispatch Signal DRET Assessment
(San Ramon, CA)

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EXECUTIVE SUMMARY

The purpose of this Demand Response Emerging Technology (DRET) Assessment is to confirm that, in a laboratory setting, end-use energy consumption by certain appliances can be automatically controlled by a combination of: 1.) a frequently changing (every 5 minutes) GHG intensity signal based on near-real-time data from power grid operators; 2.) an end-use specific control algorithm that utilizes the GHG intensity signal, energy consumption data, and customer inputs (simulated in the lab) to produce and communicate a dispatch order to a smart controller and 3.) a smart controller that can reliably act on the dispatch order created by the control algorithm to shift energy consumed by the appliance into periods of relatively low GHG intensity.

For this DRET assessment both the high-frequency GHG intensity signal and the control algorithm were provided by WattTime[1]. The smart controllers and associated end-uses tested are shown in Table 1.

Table 1 – Smart Controller and End-Uses Tested

Smart Controller	**Manufacturer**	**End-Use Controlled**	**Proxy End-Use Tested at Lab**
Programable Communicating Thermostat	Honeywell	Air Conditioning Unit	Computer Simulation
Programable Communicating Thermostat	Ecobee	Air Conditioning Unit	Computer Simulation
Smart Plug	TP-Link	Refrigerator	Empty Refrigerator installed at the lab
Water Heater Load Controller	Smartenit	50 – 100 Gallon Water Heater	10 Gallon Water Heater installed at the lab without regular hot water consumption
Electric Vehicle Service Equipment (EVSE)	Smartenit	Electric Vehicle	Electric Vehicle Load Simulator

The smart plug was the only device where the intended end use was tested directly because of the ease of acquiring and setting up a refrigerator. The thermostats were not tested with a real AC unit because of the complexity in setting up a lab test with the appropriate AC size and thermal load. If an AC unit was tested without an appropriate thermal load, it would not be possible to extract a realistic understanding of the reduction in carbon emissions. Also, because WattTime was changing the setpoint on the thermostat and not directly controlling the AC unit it was possible to run a computer simulation with the setpoint changes. A 10-gallon water heater was used instead of a full-sized water heater because of limitations with respect to the required secondary water containment system in the lab. While the thermal response characteristics of the 10-gallon water heater is faster than a full sized one, information can still be gained

[1] WattTime is a nonprofit subsidiary of the Rocky Mountain Institute founded in 2014 by UC Berkeley researchers to give energy customers the freedom to choose the power they consume. WattTime seeks to give individuals and organizations the information they need to make smart energy decisions. Their goal is to offers technology solutions that make it easy for anyone to achieve emissions reductions without compromising cost, comfort, and function.

on how the WattTime GHG intensity signal and algorithms operate and are acted on by the water heater load controller. An electric vehicle load simulator was used instead of an actual electric vehicle so tests could be run day after day without having to discharge the vehicle battery. The load simulator also allowed repeatability in the duration of charge.

The DRET Assessment confirmed that, in a laboratory setting, WattTime was reliably able to control devices using a high-frequency GHG intensity signal and control algorithm combined with end-use energy consumption data and simulated customer preference settings to minimize the GHG content of the energy consumed by the end-use. Additionally, the assessment concluded that the devices under WattTime control maintained satisfactory performance and functioned in adherence to user-defined constraints. While the DRET Assessment did confirm that the signal, algorithms, and smart devices do reliably work in combination to minimize the GHG content of the end-use electricity consumed, the assessment also showed that the amount of emissions reductions achieved is dependent upon the operating characteristics of the end-use being controlled and the emissions variability of the electricity grid producing the energy being consumed. As part of this assessment a method for baselining GHG content of electric consumption was developed and used to quantify emission reductions.

Based on the data available from lab testing the following conclusions can be drawn.

- The smart plug paired with a refrigerator delivered an average reduction in carbon emissions of 1.3% on average per day. WattTime turns the refrigerator off during times higher GHG emissions but does not keep it off so long as to impact the average temperature inside the refrigerator. With a few exceptions due to communication outages affecting the smart plug, the smart plug reliably received the control signal from WattTime. One limitation of the smart plug is that it turns off power to the entire refrigerator which means the light and water/ice dispenser will not work while WattTime is avoiding high GHG times.
- WattTime was able to control the thermostat setpoint from two vendors, while allowing the customer to easily override WattTime control when they choose. The cooling setpoint is adjusted up during times of high GHG intensity. Software simulations of a representative house and HVAC system showed emissions reductions between 7.5% and 13.2% per year using a 2 ºF to 4 ºF setpoint offset. The simulation showed reduction in emission was due to less energy used per the higher setpoint, and not time shifting when the energy is used. AC usage is often coincident with higher GHG intensity on the California electric grid. Due to limitations of the software simulation, emissions benefits related to load shifting strategies such as pre-cooling and thermostat hysteresis were not tested.
- The water heater load controller with temperature monitor performed well in controlling the water heater temperature within the defined parameters. During periods of low GHG intensity, WattTime’s algorithm brings the water temperature up to the maximum specified value. During periods of high GHG intensity WattTime’s algorithm allows the water temperature to fall while remaining the minimum specified value. Days with high variability in GHG intensity could see emissions reduced by as much as 20% per day for the energy used to maintain water temperature. Little benefit is seen in days with low GHG variability because of relatively few instances when energy is required to maintain water temperature. Water usage behavior was not tested in this assessment.
- WattTime’s algorithm was able to effectively shift the daytime charging of an electric vehicle to achieve a 13% per day average reduction in GHG emissions. Low GHG intensity variability overnight in California’s grid limited potential emissions reduction for overnight charging.

In short, the DRET Assessment concluded that WattTime was able to reliably control these devices using a high frequency GHG signal and control algorithm in order to reduce the carbon emissions associated with operating those devices.

The results of this DRET assessment suggest that the control signal, algorithms, smart controllers and end use appliance and the interactions between these various elements are sufficiently robust and coordinated that the technologies are ready to move from the lab environment to field testing. Field testing would allow a number of additional questions to be addressed including:

- How human interaction with the technologies impacts results
- Customer acceptance of end-use appliance control strategies
- How aggregations of resources perform
- Cost-effectiveness of various program/incentive designs and end-use control strategies utilizing these technologies based on amount of GHG reduction
- Customer engagement with device control for emissions reductions

PG&E is hopeful that this DRET assessment will provide useful information to industry participants regarding this innovative technological approach to reduce GHG emissions resulting from the end-use appliances tested. PG&E may consider working with industry participants to extend the testing to field experiments in the future.

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INTRODUCTION

The purpose of this Demand Response Emerging Technology (DRET) Assessment is to confirm that smart devices can be automatically controlled by a continuous/high frequency dispatch Demand Response (DR) signal based on a combination of near-real-time data from power grid operators and a continuous optimization algorithm in a lab environment.[2] The DRET Assessment tested fast and frequent DR signals, the success of algorithms that convert signals to device control, and the potential impacts on both the electric grid and the devices themselves when operated under the command of the signal and algorithms. This study also estimates the potential reduction in carbon emissions that result from the electricity consumption of the devices controlled by WattTime.

WattTime, a non-profit organization, was created to provide consumers the ability to support a cleaner electric grid. To enable this, WattTime has developed a real-time Marginal Operating Emissions Rate (MOER) signal which indicates the carbon intensity of the grid and can be used to control smart devices with the aim of reducing emissions from electricity generation by shifting or reducing load to lower emission periods. Emissions reductions are achieved in the connected devices by shifting or reducing load through a control algorithm which schedules devices to use less electricity if the carbon intensity of the grid is predicted to go up and use more electricity if carbon intensity is predicted to go down.

This project specifically tested the responsiveness of programmable controllable thermostats (PCTs), smart plugs connected to refrigerators, electric hot water heaters, and EVSEs to WattTime's automated control signal focused on reducing the emissions associated with electricity consumption. As part of this test, WattTime designed and dispatched a custom control signal to a set of thermostats, electric hot water heater, load control switches, and electric vehicle chargers in order to shift or reduce load and reduce emissions.

METHODOLOGY

Overview

Testing WattTime's ability to control devices and reduce emissions through load shifting required two distinct phases. First, WattTime's ability to connect to and communicate with devices was confirmed in the Communications Lab at PG&E's San Ramon Facility. Once WattTime's communication with the devices had been established, the devices were relocated to the Modular Generation Test Facility where they were connected to loads to determine the load shifting, load reductions, and emissions performance.

The initial communication verification was performed in the Communications Lab. The second phase of testing was performed with electrical loads attached to the devices in the Modular Generation Test Facility. WattTime can control devices by connecting to the various vendor's clouds and using the vendor APIs to retrieve data and send control signals. Verification of communications was performed before the devices were electrically connected to loads.

[2] This concept of load shifting for emission reductions is also known as the WattTime Automated Emissions Reduction signal.

Communications Testing

Programmable Communicating Thermostats

Device Connection to Vendor Cloud

<u>Honeywell Thermostat</u>

The Honeywell RTH6580WF Thermostat is shipped with bilingual installation instructions. There is an instruction sheet and a more detailed instruction booklet in English and Spanish. On the box there is a sticker that states “C wire accessory included” but none was found. Only a short jumper was found. To simulate installation in a house, the thermostat was powered by using a 24 AC doorbell transformer. The transformer was wired to the “C” terminal and the “R” terminal. The “R” and “Rc” terminals were jumpered when the device was received from the manufacturer.

Figure 1 – Honeywell Mounting Plate

Connecting the device to the vendor cloud was possible using a laptop computer. Before the included instructions could be followed, the clock on the thermostat had to be set. After that, the laptop was connected to the thermostat by joining the WiFi network the thermostat was broadcasting, named "NewThermostat_15EAED". Per the instructions, the next step was to go to the web browser on the laptop and enter “http://192.168.1.1”. The first time this was attempted, the thermostat had been powered on for over an hour. When that happened, the following message was received.

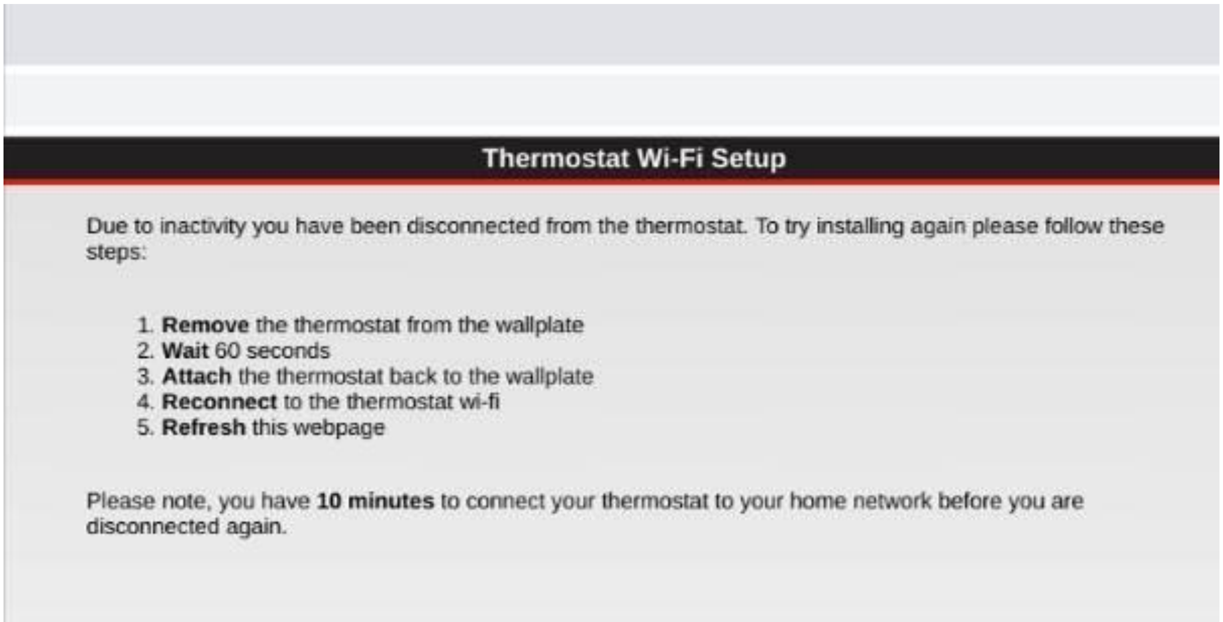

Figure 2 – Honeywell Timeout Error

Thermostat needs to be set up within 10 minutes of powering up. This is a good security measure to prevent someone else from accidentally or intentionally registering the thermostat. The next step is to select the lab's WiFi network and enter the password. After about 2 minutes, the thermostat indicates that it is connected to WiFi and prompts registration with Honeywell's web platform Total Connect. At this point the WiFi access point that the thermostat was broadcasting is shut down and the laptop reverts to the lab WiFi connection. The thermostat is registered at "mytotalconnectcomfort.com". User name and password are required to create an account that the thermostat is registered under. The end of registration requires setting the thermostat to 76 degrees heat. The thermostat indicates setup is complete in less than a minute. It is now possible to log into "mytotalconnectcomfort.com" and see the thermostat's status.

<u>Ecobee Thermostat</u>

Internal packaging of the Ecobee 3 Lite has the feel of a consumer product and the instruction booklet is well organized and easy to follow. The ratio or words to pictures makes the instructing feel less intimidating. A C-wire adaptor is included.

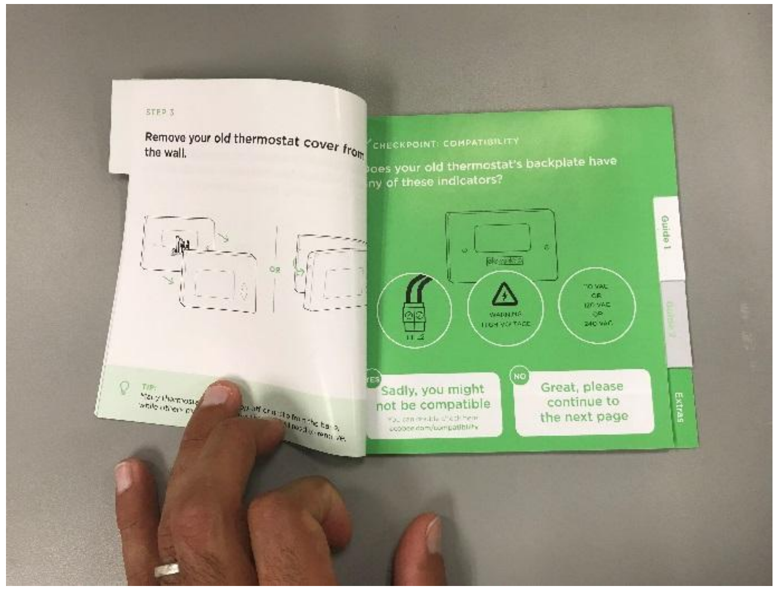

Figure 3 – (Left) Ecobee Package Contents
Figure 4 – (Right) Ecobee Instruction Booklet

Thermostat is powered from C and Rc.

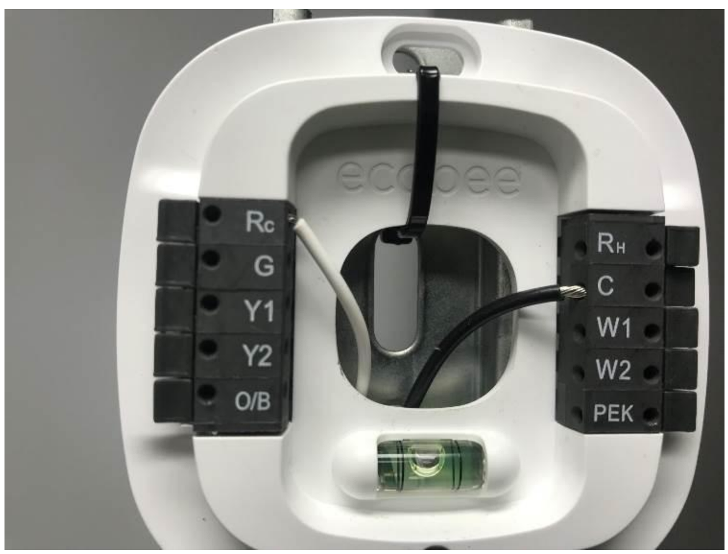

Figure 5 – Ecobee Mounting Plate

The thermostat has a touch screen and the on-screen instructions are followed for setup. The lab WiFi SSID and password are entered on the touch screen. There is an option to use an iOS app but that was not tested. The thermostat notifies that it is connected to the ecobee.com server and continues to ask a few more questions about ideal temperature and location. The thermostat then shows a registration code, which is "NEH8" in this case. At this point a computer is used to go to “www.ecobee.com” to register the thermostat. The website first asks for the type of thermostat, then registration code, and then the user account is created. After registration is complete, the thermostat status is viewable on Ecobee’s website.

WattTime Communication and Control of Device

Honeywell Thermostat

Connecting WattTime to the device starts by going to device.watttime.org. A new account is created by supplying a username and password. Under “Manage devices” there is a list of supported device manufacturers that are supported. Honeywell is selected and then there is the option to add a new device. When that is selected, the user is taken away from the WattTime site and to a Honeywell site which prompts a username and password. This site is telling Honeywell that the user gives WattTime permission to communicate with and control the thermostat.

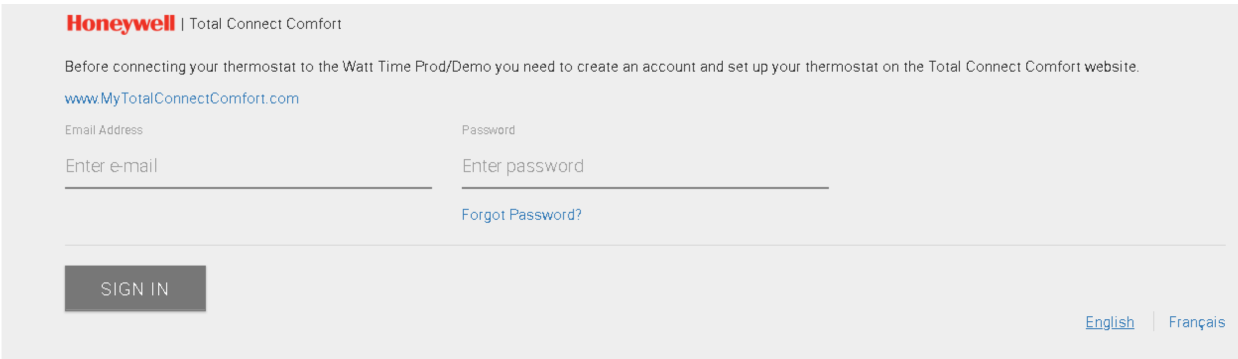

Figure 6 – Honeywell Authentication Screen

After this is done the user goes back to the Honeywell option under “Manage devices” and the thermostat previously registered with Honeywell is now available for WattTime control. When testing was originally done, the balancing authority[3] would need to be entered but now a city and state can be entered, and the appropriate balancing authority is automatically found.

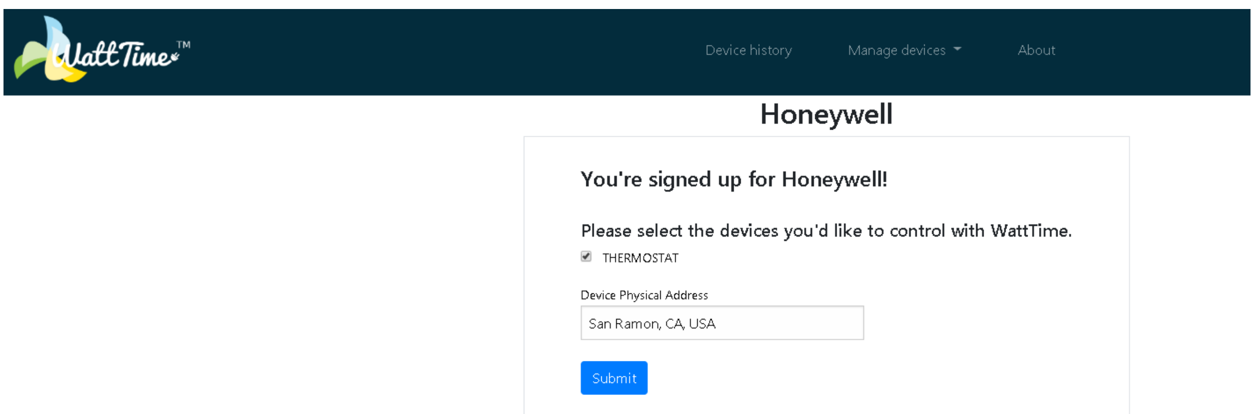

Figure 7 – WattTime Screen to Manage Honeywell Thermostat

After refreshing the “Device history” screen, the temperature data populates on the WattTime display which can be seen in Figure 8.

[3] The electric grid in the United States is comprised of different regions where each region is regulated by a ‘balancing authority.’ The balancing authority manages electricity within each region and between neighboring regions to maintain a balanced supply and demand.

Honeywell

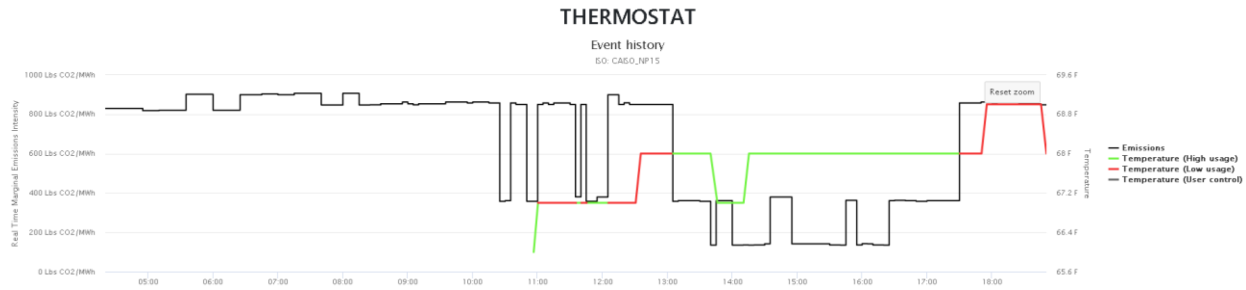

Figure 8 – Real-time WattTime Thermostat Display

When WattTime controls for high energy usage, the thermostat setpoint will change by 3 degrees in the positive direction for heating and the negative direction for cooling. The opposite is true for low energy usage. Table 2 gives an example.

Table 2 – Honeywell Thermostat Setpoints with WattTime Control

Mode	**User Setpoint**	**High Usage Setpoint**	**Low Usage Setpoint**
Heating	68	71	65
Cooling	78	75	81

WattTime will control the thermostat if it is set to a permanent hold or on a schedule. If the thermostat is set to a temporary hold, the setpoint will stay at the user's setting. This behavior was verified using the setpoint above and observing the setpoints change over time as WattTime switched between high and low usage. The thermostat was then put on a temporary hold and it was observed to keep the user entered setpoint. The thermostat was then switched to schedule mode and it held the scheduled setpoint for a few minutes but then switched the WattTime adjusted setpoint. WattTime does not change the scheduled setpoints. WattTime utilizes a high or low usage setpoint with a temporary hold which is set to expire when the current scheduled interval is complete. This is an effective way of exerting control without changing the base schedule, which gives the user the option to turn off WattTime control without having to re-program their base schedule.

Ecobee Thermostat

Connecting the Ecobee thermostat to WattTime is done the same way as the Honeywell. The only difference is that the re-direct takes you to an Ecobee website for credentials instead of a Honeywell website.

WattTime exerts the same control over the Ecobee thermostat as the Honeywell with one additional feature. The Ecobee thermostat can be set to auto heat or cool. When in auto mode, there are 2 setpoints to adjust. WattTime will change both setpoints together while maintaining a minimum of 6 degrees of separation between the two. Table 3 gives an example.

Table 3 – Ecobee Thermostat Setpoints with WattTime Control

Mode	**User Heat**	**User Cool**	**H.U. Heat**	**H.U. Cool**	**L.U. Head**	**L.U. Cool**
Heat	68	---	71	---	65	---
Cool	---	78	---	75	---	81
Auto	68	78	70	76	65	81
Auto	67	79	70	76	64	82

The WattTime control behavior was verified by using these settings and monitoring throughout the day.

Smart Plug & Refrigerator

Device Connection to Vendor Cloud

<u>TP-Link Smart Plug</u>

The HS1 smart plug from TP-Link does not provide any instructions for connecting the device. It simply says to download the Kasa app which will provide further instructions.

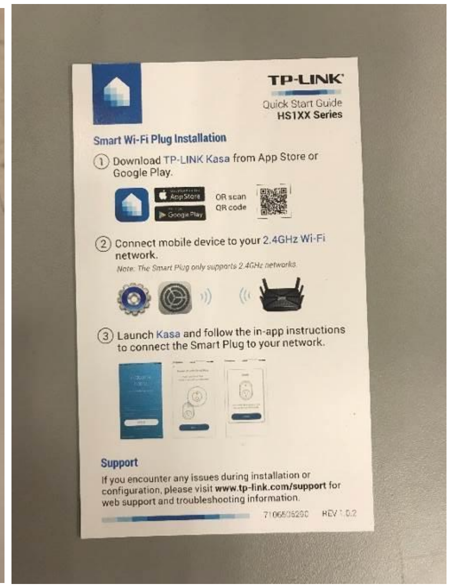

Figure 9 – (Left) Smart Plug in Package
Figure 10 – (Right) Smart Plug Instruction Page

Because a phone was not initially available, the app was installed on an Acer Chromebook 14 CB3-431 in Beta Channel which can install Android apps. The smart plug broadcasts a WiFi network that can be joined to initiate communication. Unfortunately, the Chromebook was unable to join the smart plugs WiFi network. A member of the WattTime team was able to join the smart plugs WiFi network using an Android phone, so it is suspected that the problem is with the Chromebook and not the Android app. Because it is not possible to install the Kasa app on a PG&E iPhone, a personal iPhone was used to continue testing. On the iPhone, the app was installed, and a TP-Link account was created. The phone was then able to connect to the smart plugs WiFi network. The problem with the Chromebook is not considered significant because it is extremely unlikely that a user would be using anything other than a smart phone to set up the device. The lab’s WiFi SSID and password are entered into the smart plug and the phone is switched to the lab’s WiFi. From the app, the smart plug status is visible and controllable. The plug can be turned on and off from the app. Additionally, when the plug’s button is used to turn the plug on and off, the status is reflected in the app.

WattTime Communication and Control of Device

TP-Link Smart Plug

To connect WattTime to the user's TP-Link account, the credentials are entered in WattTime's site. There are 2 smart plugs registered to the TP-Link account. Both are available for WattTime control and there are multiple control options. The refrigerator option is selected.

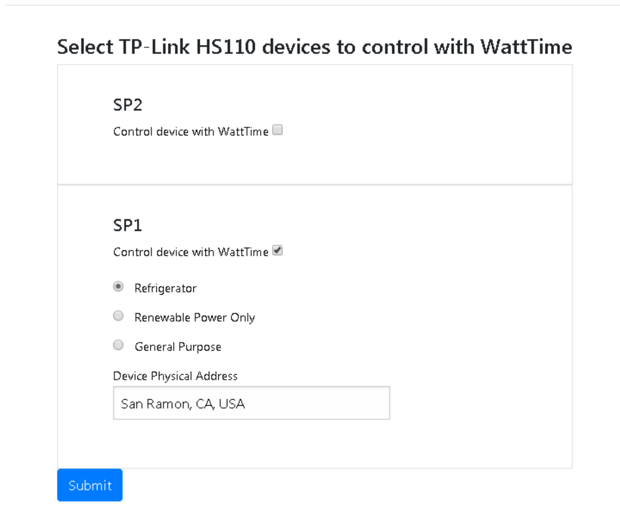

Figure 11 - WattTime Screen to Manage TP-Link Smart Plug

A mini refrigerator in the communication lab was used to test the smart plug. The power usage of the refrigerator could be seen in the WattTime website. WattTime will send no commands for the first 24 hours in order to learn the refrigerators cooling cycle. After 24 hours, WattTime will start to control the refrigerator, which was observed. WattTime controls the refrigerator by turning the smart plug off when there is an anticipated increase in carbon intensity. This will defer the refrigerator operation to a future time when the carbon intensity is lower. Because of the learning period, it is best to have the refrigerator in a cool state before plugging in the smart plug. Unless the refrigerator has not been in use prior to attaching the smart plug, this will not be an issue for any real-world deployment. However, it would still be prudent to notify any potential user that the refrigerator should be in operation 24 hours prior to installing the smart plug.

Hot Water Heater Retrofit

Device Connection to Vendor Cloud

Smartenit Load Controller

The Smartenit Metering Load Controller 4040C was shipped in a brown cardboard box with the device and a 2-page instruction sheet. The instructions came with wiring instructions but no WiFi communication instructions, only Zigbee communication instructions. The vendor provided the WiFi connectivity instructions over e-mail.

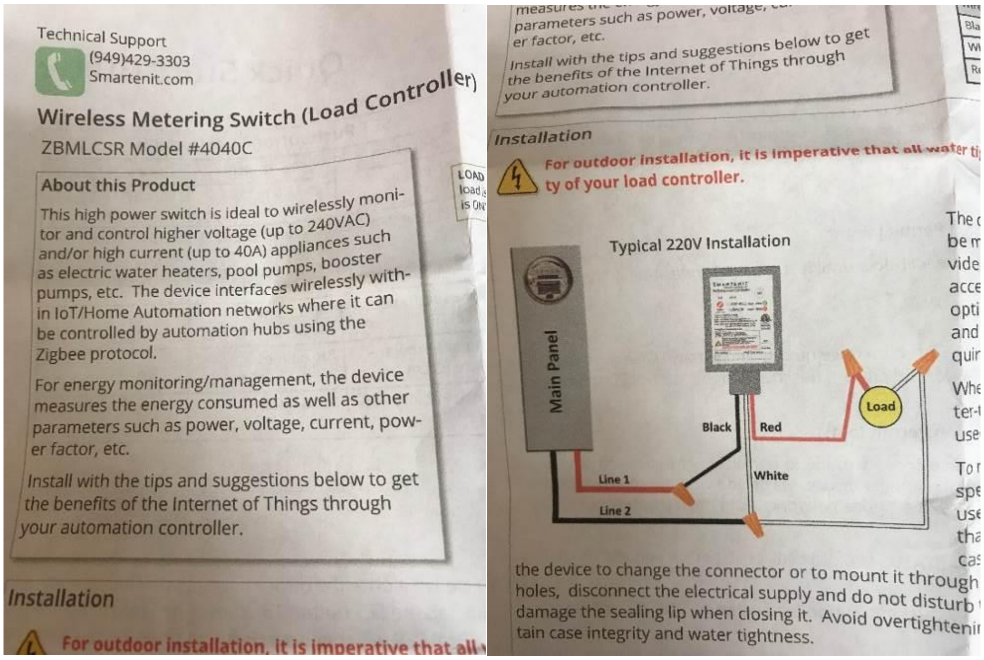

Figure 12 – Smartenit Load Controller Instructions

The color coding on the wiring diagram is inconsistent. It suggests a line-to-line source and a line-to-neutral load. The current rating on the instructions is 40 A but the current rating on the device is 30 A. It is recommended that the in-box instructions be reviewed again as part of any future testing.

For communication testing, the black and white wires were connected to a 110 VAC source and the red wire was capped.

Figure 13 – Smartenit Load Controller Powered On

To connect the load controller to the vendor cloud, a laptop is required. When the device is powered up, it broadcasts a WiFi access point. The laptop joins that network and “http://192.168.4.1:54443” is entered in the web browser. From here all available WiFi networks are scanned and the lab network is selected using the lab’s password. The Smartenit app is required to communicate with the device over the vendor cloud. The app was not available on the Chromebook. A member of the WattTime team was able to find and install the Smartenit app on their Android phone, so this issue is not considered significant, much like the Kasa app. The Smartenit app was installed on a personal iPhone and a username and password was created though the app. The iPhone was connected to the lab network. From there the app was able to find the load controller on the same network and it was added to the user account. When the circuit is opened and closed on device, the change is reflected in the phone and vice versa.

WattTime Communication and Control of Device

<u>Smartenit Load Controller</u>

The load controller was the first of the two Smartenit devices to be connected to WattTime. Like Honeywell and Ecobee, the user is re-directed to a Smartenit login page when adding the device. After entering the credentials, WattTime still asked to sign in to Smartenit. When that was tried again, it prompted an error that said, "provided redirect uri is invalid". WattTime was contacted and the issue was that the specific load controller had not been tested by WattTime before and was not in their system. When WattTime tried to collect the devices available for control, none were found despite the Load Controller being registered with the Smartenit account. The load controller sent was a different model than what was previously tested by WattTime. After informing WattTime that the Load Controller was not found they promptly it to their system and the device was then available for WattTime control.

After adding the device, the realtime power and temperature can be seen in WattTime’s webpage. The load controller is used to control a water heater. The temperature probe is put on the water tank so WattTime can control based off the tank temperature. The user needs to specify a minimum and maximum temperature and WattTime will keep the temperature in that range by turning on and off the heating element. The thermostat on the water heater should be set to a temperature that is above the WattTime maximum but still safe. In this arrangement, the water heater thermostat is always keeping the heating element on and WattTime has full control. If the load controller gets stuck in the on position, the water heater’s thermostat will turn off the heating element at its setpoint which will keep the water at a safe temperature. With full control of the heating element, WattTime can maintain the specified temperature range while attempting to avoid turning on the heating element when the carbon intensity of the grid is higher. WattTime control testing requires a water heater so that was not tested in the communication lab.

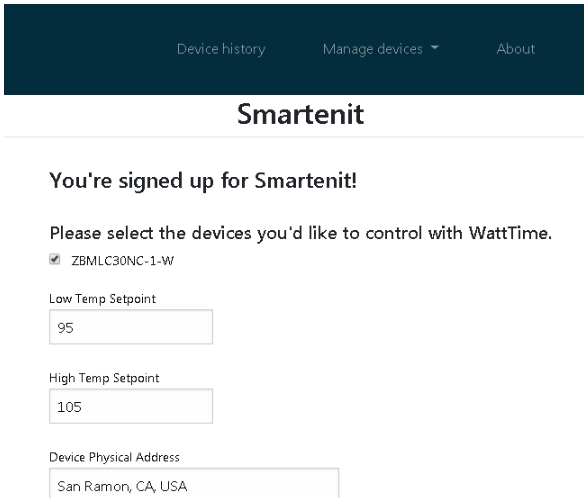

Figure 14 - WattTime Screen to Manage Smartenit Load Controller

Electric Vehicle Service Equipment

Device Connection to Vendor Cloud

<u>Smartenit EV Charging Station</u>

The Smartenit EV Charging Station 4040D was shipped in a brown cardboard box with no instructions. Like the load controller, the vendor provided the WiFi connectivity instructions over e-mail. It is recommended that the in-box instructions be reviewed as part of any future testing.

Figure 15 – Smartenit EVSE Powered On

The same procedure that is used for the load controller is used to connect the EVSE to the vendor cloud. One issue did arise. When the EVSE was first powered, the blue communication light was on, but the device was not broadcasting a WiFi network. The control button was pressed exactly 13 times to reset the device. After that, the device broadcasted it's WiFi network and the setup proceeded the same as the load controller.

After adding the device to the user account on the Smartenit app, it was not possible to toggle the switch. This is because there is no EV plugged in. The EVSE will not energize the plug unless it detects that it is connected to an EV.

WattTime Communication and Control of Device

Smartenit EV Charging Station

After the EVSE was added to the Smartenit account, it was available for control by WattTime because the connection was already made while setting up the load controller.

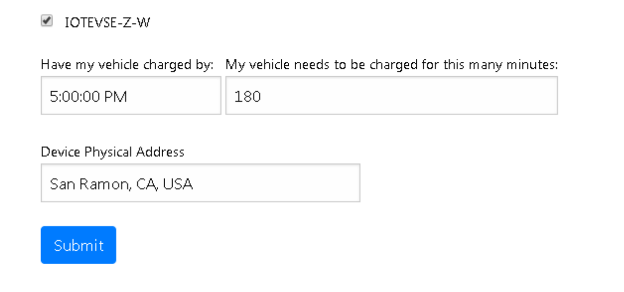

Figure 16 - WattTime Screen to Manage Smartenit EVSE

WattTime control of the EVSE works by setting a time the EV needs to complete its charge and how much charging time is required. WattTime will attempt to charge when the carbon intensity of the grid is lower but if the amount of time left is equivalent to the remaining time required to meet the user's charge time, WattTime will charge the car regardless of carbon intensity. If the requested amount of charge time is reached before the required time, WattTime will continue to apply power during lower carbon intensity periods.

Because there was no EV plugged in there was no data available for WattTime to plot in realtime. The communication link was verified by calling WattTime and they checked that the device was communicating on the back end of their system.

Electrical Load Testing

Programmable Communicating Thermostats

Overview

The thermostats were not tested with an electrical load. Constructing a lab setup with a realistic load was prohibitive because the load would be an AC system and it would need a space to cool. The space would have to be big enough to somewhat resemble a residence and no space that large was available for the test. The space available was far too small and the AC available was far too large so the loading profile was not suitable to draw any conclusions on the efficacy of WattTime control. Because the communications and control has been verified to operate as expected, the efficacy of WattTime control is evaluated by running a home energy simulation.

Simulation Setup

Energy use simulations were performed using *EnergyPlus* (v.9.0.1)—the US DOE's state-of-the-art, open-source whole-building energy simulation engine.[4] A prototype model originally developed by US DOE's Pacific Northwest National Laboratory (PNNL) for energy savings analysis[5] was modified to reflect building characteristics and site energy uses for a typical single-family residential building of 1980s vintage in Central California. Detailed documentation of the original prototype model specifications[6] is available from US DOE[7], while modifications to the original model and default EnergyPlus assumptions are summarized as follows:

- Infiltration modified to reflect NREL ResStock[8] estimates of 8-15 ACH50 for infiltration rates in 1980s-vintage homes in California from default effective air leakage areas (56 sq.in. for living space and 57 sq.in. for unconditioned attic) to 132 sq.in. each for the conditioned and unconditioned zones.
- Default thermostat setpoints (72°F for cooling and 75°F for heating) were modified as follows:
    - Cooling:
        - 76°F occupied period
            - Weekdays 5PM-9AM and weekends (all day)
        - 82°F unoccupied period
            - Weekdays 9AM-5PM
    - Heating:
        - 71°F occupied period
            - Weekdays 6AM-9AM and 5PM-11PM, and weekends 6AM-11PM
        - 65°F unoccupied period
            - Rest of the time

[4] URL: https://www.energy.gov/eere/buildings/downloads/energyplus-0 (Last accessed: 7/15/19)

[5] URL: https://www.energycodes.gov/development/residential/iecc_models (Last accessed: 7/15/19)

[6] URL: https://www.energycodes.gov/development/residential/methodology (Last accessed: 7/15/19)

[7] The original, starting model was a US DOE single-family residential home of IECC-2012 code vintage, with slab foundation construction and gas furnace heating for the closest applicable location in California ("SF_California_Sacramento.Metro.AP.724839_gasfurnace_slab_IECC_2012.idf").

[8] URL: https://resstock.nrel.gov/dataviewer/efs_v2_base#building-characteristics (Last accessed: 4/17/19)

Default weather file was replaced with actual weather year data for Fresno.[9] Hourly weather data for Calendar Year 2018 were used.

The selected prototype model, subsequent modifications, and its outputs were validated using previously published simulation results by US DOE, benchmark data from NREL's ResStock,[10] and engineering judgment. The originally selected model was found to result in energy use outputs nearly identical to previously reported US DOE results, while the modified model resulted in annual site energy use values reasonably within the range of values for similar homes in the ResStock dataset (1980s CA homes with slab foundation and gas heating). The annual- and seasonal-average duty cycle for the HVAC systems were also checked using the original prototype and found to be reasonable for the Fresno climate (i.e., approx. 0.333).

All EnergyPlus simulations for this project were performed with a 1-minute timestep. Thermostat setpoints were specified at 5-minute intervals. Input weather data were specified at hourly intervals. For simplicity, no daylight savings or other special days or holidays were specified. All key output parameters were also reported in 1-minute intervals. Time-series data with flags indicating when WattTime was engaged were provided by WattTime using the historical 2018 MOER signal. The following cases were then simulated for analysis of WattTime's potential impacts:

(1) Base case: Used modified thermostat setpoints above.
(2) Proposed case #1: Applied setpoint offset (set-back/set-up) of 2°F when WattTime engaged
(3) Proposed case #2: Applied setpoint offset (set-back/set-up) of 3°F when WattTime engaged
(4) Proposed case #3: Applied setpoint offset (set-back/set-up) of 4°F when WattTime engaged

WattTime is engaged when the algorithm specifies it is an appropriate time to reduce energy usage. The cooling setpoint for the thermostat is increase and the heating setpoint is decreased. In the lab testing WattTime would command a setpoint shift in the opposite direction during times when energy reduction is not being targeted. This was not done in the simulation because it is not likely that the bi-directional setpoint changes would be used in a field trial.

Additional detail regarding EnergyPlus simulation/runtime assumptions are available from the input-output reference and engineering reference.[11]

Simulation Results

The simulation outputs the electric energy used by the HVAC system. This energy includes the AC system and the fans for air movement. Because of the electricity required to fun the fans there is a small amount of energy used when the gas furnace is running. The carbon emissions associated with the energy use is calculated by multiplying every minute's energy by the MOER value for that minute and summing over the year. Because the MOER value is reported every 5 minutes the 1-minute value is interpolated. Details on how the interpolation is done can be seen in the *Smart Plug & Refrigerator* section. The results from the simulations are seen in Table 4.

[9] Actual weather data for Fresno, CA, was obtained from internal PG&E sources and used for simulations. This data was provided for CY2018 and post-processed into EnergyPlus format ("AMY2018_Fresno.epw") using the open-source *Elements* tool from Big Ladder Software.

[10] URL: https://resstock.nrel.gov/dataviewer/efs_v2_base (Last accessed: 7/15/19)

[11] URL: https://energyplus.net/documentation (Last accessed: 7/15/19)

Table 4 – Energy and Emissions from Thermostat Simulations

WattTime Setpoint Delta (F)	HVAC Energy (kWh)	Energy Carbon (lbs)
0	3103.0	2727.2
2	2869.5	2521.5
3	2775.6	2439.0
4	2693.0	2366.3

The difference in energy and emissions resulting from WattTime operation are determined by dividing the proposed thermostat setpoint offset to the base case where there is no setpoint offset. The difference from WattTime operation can be seen in Table 5.

Table 5 – Difference in Energy and Emissions from WattTime Operation of Thermostat

WattTime Setpoint Delta (F)	HVAC Energy	Energy Carbon
2	-7.52%	-7.54%
3	-10.55%	-10.57%
4	-13.21%	-13.23%

The reduction in carbon emissions in nearly identical to the reduction in energy used by the HVAC system. The reduction in energy and carbon is significant with a 2-degree setpoint adjustment making a 7.5% (206 lbs of carbon) difference over the year but the reduction in carbon emissions is resulting from using less energy and not shifting when the energy is used. AC usage is generally coincident with higher GHG content on the California grid. Load shifting (pre-cooling) strategies may also be possible using some combination of GHG intensity signals and control algorithms but these strategies were not tested as there is a dependency on existing leakage from building envelope. An important limitation of the simulation is it does not simulate the thermostat discreetly turning the HVAC system on and off. The simulation is calculating the energy required by the HVAC system without considering the duty cycle. This method is appropriate for estimating the impacts of load shedding strategies but may not be accurate for strategies that involve high frequency load shifting. High frequency load shifting, pre-cooling and other long-range load shifting strategies could be tested in the field in a subsequent stage.

Smart Plug & Refrigerator

A Whirlpool 36-inch Wide Side-by-Side Refrigerator - 24 cu. ft. (Model # WRS325SDHZ01) is plugged into a TP-Link SmartPlug (Model # HS110). Temperature probes are put in the refrigerator, in the freezer, and right outside the door.

Figure 17 – Refrigerator with Temperature Probes

Every day at midnight, WattTime provides measurement data from the devices for the previous day. From that data the power profile of the refrigerator can be seen.

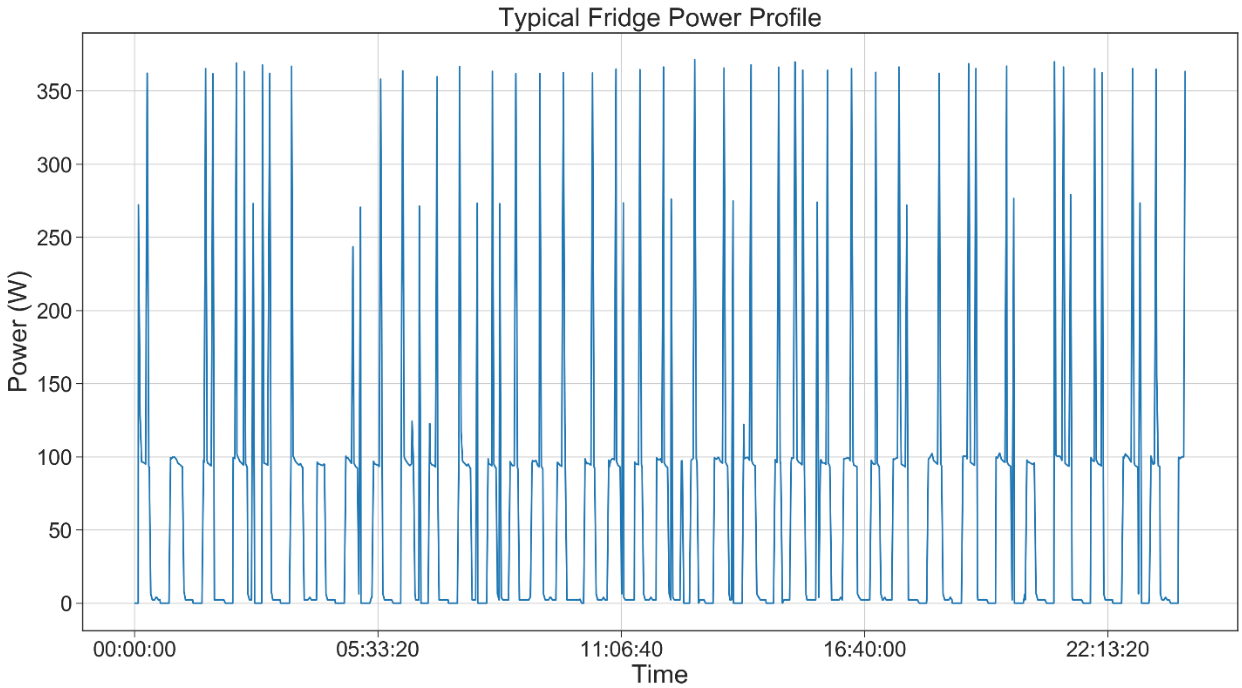

Figure 18 – Typical Power Profile for Refrigerator

Most power measurements from the refrigerator are below 600 W. There are occasionally (once every 2-3 days) a measurement above 1000 W. This is believed to be a timing issue where the inrush current is being measured. Because energy will be calculated from the power measurement, a measurement taken during an inrush period can result in an erroneously high energy value. All power measurements above 600 W are removed to prevent these values from impacting the energy calculation. Energy is calculated for adjacent measurement that pass the filer by multiplying the average power over the time interval. The calculation is as follows:

$$E_x = \frac{P_x + P_{x-1}}{2} * (t_x - t_{x-1})$$

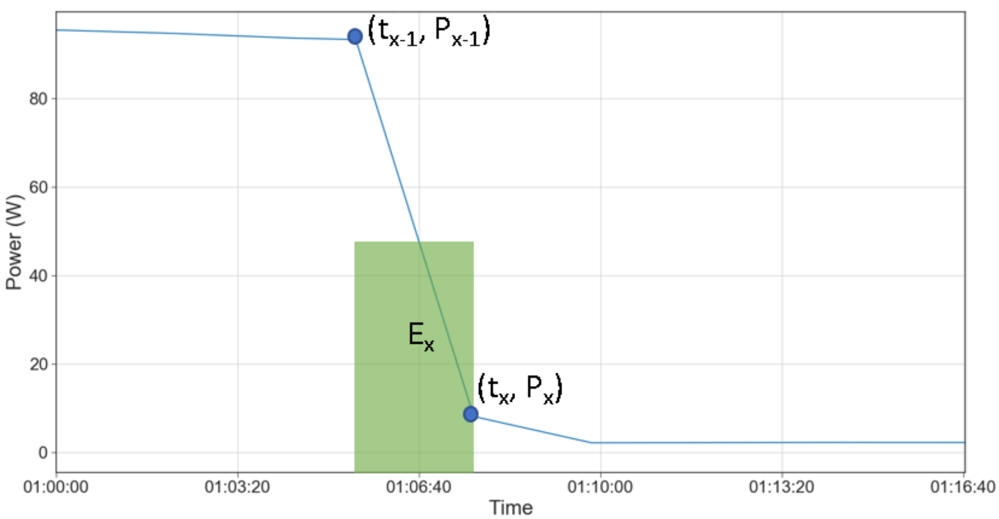

Figure 19 – Energy Calculation from Power Measurements

When WattTime is not controlling the refrigerator, there is a power measurement every ~300 seconds. When WattTime is controlling the refrigerator, there is a power measurement every ~60-120 seconds. A time delta between measurements greater than 300 seconds could be from a loss of communication. The longer the time period an energy measurement is calculated over, the less accurate it is because the two power measurements that energy is calculated from cannot represent the entire time interval. So all-time intervals above 400 seconds are removed.

Marginal emissions Intensity is reported on a 5-minute scale. Power measurements are not reported evenly and are reported with 1-second precision. To align reported marginal emissions with power the marginal emissions is interpolated to a 1-second time scale. The average marginal emission intensity can then be calculated over any time interval with the same second precision that the power measurements are recorded with. This allows the calculated energy to be multiplied against the average emissions on a common time scale.

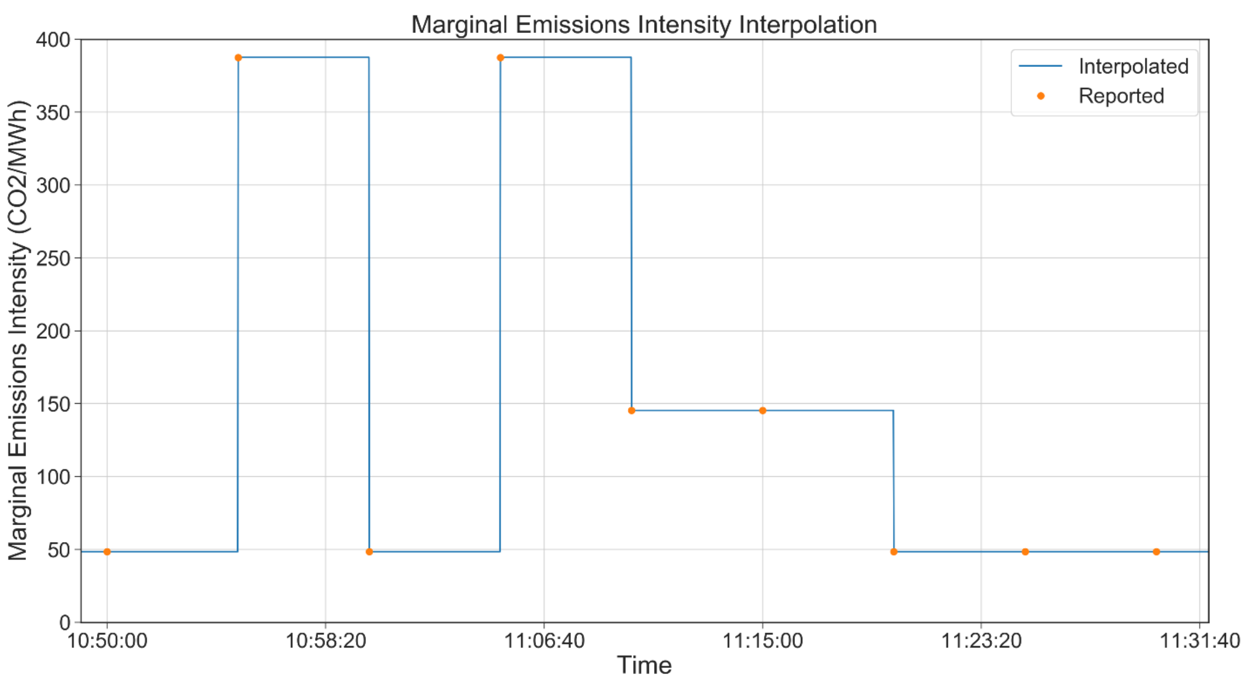

Figure 20 – MOER Interpolation Method

The refrigerator was run from 1-3-2019 to 1-30-2019. The MOER signal used for this time period is a test signal which repeats the day 3-27-2018. The day was chosen for its high variability.

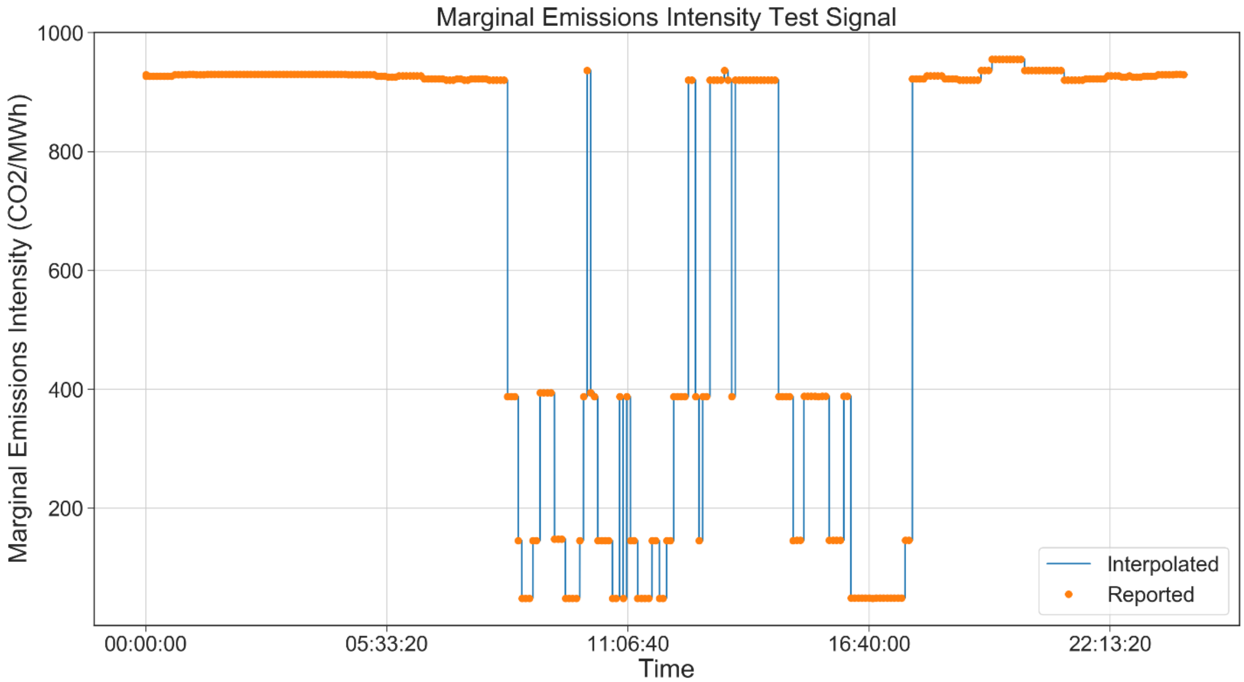

Figure 21 – High Variability MOER Test Signal

After examining this data, it was determined that the use of the test signal was not appropriate. The original intent was to see the repeatability of WattTime operation, but the refrigerator operation is dependent on ambient temperature which was not controlled during this time. Additionally, the live MOER signal has a weather dependency because of solar and wind energy. One very useful piece of information gathered during this test run was the impact of WattTime control on the operating temperature of the refrigerator. The refrigerator (blue) and freezer (black) temperatures can be seen in Figure 22 and Figure 23 when WattTime is operating and a baseline when WattTime is not operating.

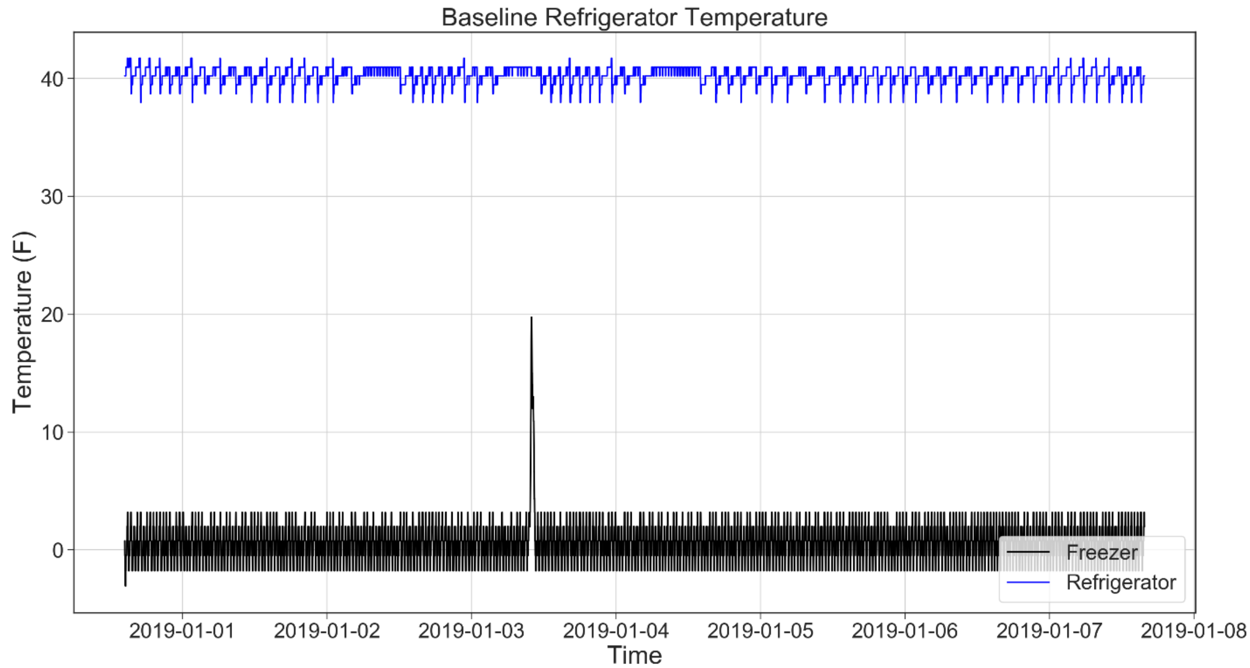

Figure 22 – Baseline Refrigerator Temperature

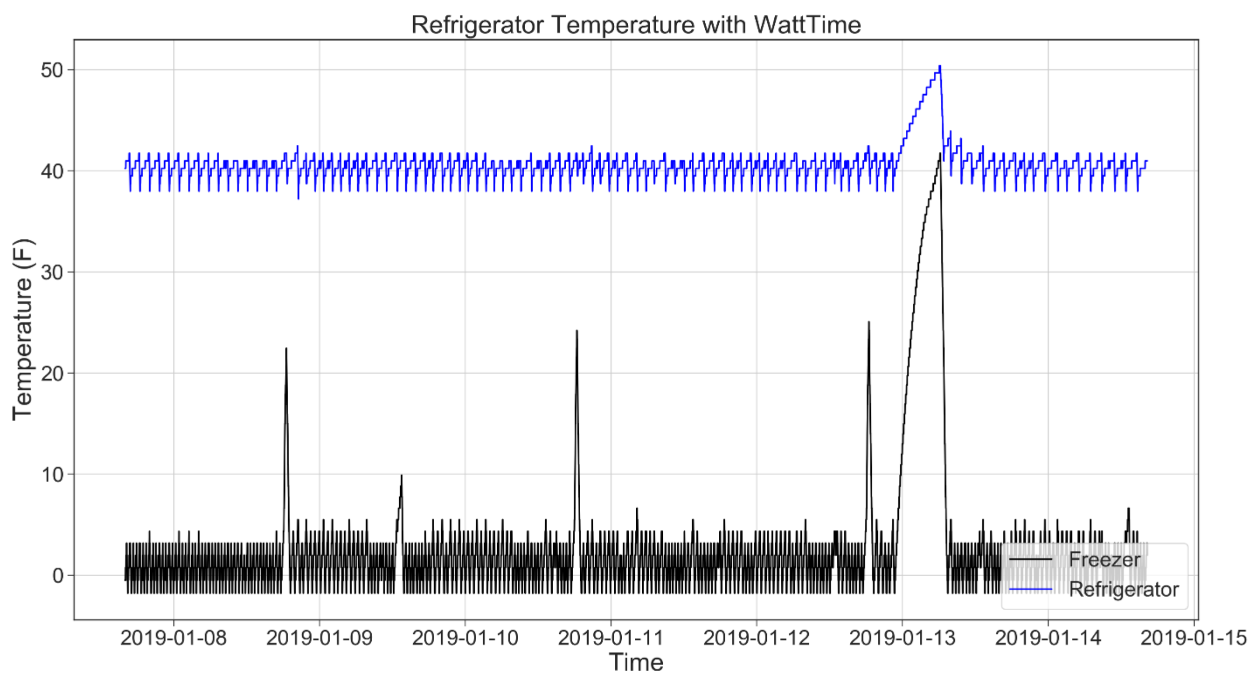

Figure 23 – Refrigerator Temperature with WattTime Control

There is no significant change in operating temperature in the refrigerator or freezer except for a period of time around 1-13-2019. There was a communication outage at this time which will be discussed further in a later section of the report.

The carbon associated with the energy used is compared against a baseline which is the average carbon intensity for the day multiplied by the day's energy usage. A negative difference means that there was a reduction in carbon. The percentage of time that WattTime is turning power off to the refrigerator is also calculated. This is important because when WattTime turns off the smart plug, the refrigerator light will not work because the refrigerator has no power. If the refrigerator has an ice and water dispenser, those will also not work. The time that the refrigerator is off can be viewed as the cost to the user.

Testing was done again 2-5-2019 to 3-9-2019. Throughout this test period, measurements were taken every 1 to 2 minutes with or without WattTime control. The MOER signal was set to the live CAISO_NP15 signal. Also because of the minimal impact to refrigerator temperature seen in the previous round, WattTime used a more aggressive control algorithm which would allow the refrigerator to be off for longer continuous periods of time. There were 13 days without WattTime control whose results are in Table 6.

Table 6 – Refrigerator Emissions Reduction with Live MOER Signal and without WattTime

Date	WattTime Control	Carbon Signal	Energy Used (kWh)	Energy Carbon (lbs)	Baseline Carbon (lbs)	Difference	Time Off (%)
2/5/2019	No	CAISO_NP15	1.59572	1.70976	1.71378	-0.23%	0%
2/6/2019	No	CAISO_NP15	1.69756	1.81318	1.81980	-0.36%	0%
2/7/2019	No	CAISO_NP15	1.73132	1.84235	1.85313	-0.58%	0%
2/8/2019	No	CAISO_NP15	1.59379	1.69885	1.69572	0.18%	0%
2/9/2019	No	CAISO_NP15	1.64367	1.74810	1.74275	0.31%	0%
2/10/2019	No	CAISO_NP15	1.74782	1.84780	1.85465	-0.37%	0%
2/11/2019	No	CAISO_NP15	1.55712	1.64246	1.64166	0.05%	0%
2/12/2019	No	CAISO_NP15	1.54102	1.62390	1.62481	-0.06%	0%
2/13/2019	No	CAISO_NP15	1.65475	1.78919	1.78680	0.13%	0%
2/14/2019	No	CAISO_NP15	1.93957	2.13323	2.13298	0.01%	0%
2/15/2019	No	CAISO_NP15	1.66009	1.69648	1.70226	-0.34%	0%
2/16/2019	No	CAISO_NP15	1.59178	1.52010	1.52747	-0.48%	0%
2/17/2019	No	CAISO_NP15	1.60380	1.65060	1.65395	-0.20%	0%

The difference between the carbon associated with the energy usage and the baseline carbon calculation is now less than a percent in all days with a mean of -0.15% per day. This is good validation of the baseline comparison methodology which will be used to determine carbon reduction with WattTime control. There were 18 days with WattTime control whose results are shown in Table 7.

Table 7 – Refrigerator Emissions Reduction with Live MOER Signal and with WattTime

Date	WattTime Control	Carbon Signal	Energy Used (kWh)	Energy Carbon (lbs)	Baseline Carbon (lbs)	Difference	Time Off (%)
2/19/2019	Yes	CAISO_NP15	1.46715	1.42176	1.48441	-4.2%	25%
2/21/2019	Yes	CAISO_NP15	1.48570	1.27987	1.29022	-0.8%	13%
2/22/2019	Yes	CAISO_NP15	1.67990	1.23800	1.32297	-6.4%	11%
2/23/2019	Yes	CAISO_NP15	1.77251	1.47394	1.47500	-0.1%	9%
2/24/2019	Yes	CAISO_NP15	1.87482	1.39134	1.45000	-4.0%	3%
2/25/2019	Yes	CAISO_NP15	1.55170	1.32479	1.33020	-0.4%	21%
2/26/2019	Yes	CAISO_NP15	1.57723	1.35896	1.35855	0.0%	26%
2/27/2019	Yes	CAISO_NP15	1.67383	1.44417	1.45122	-0.5%	29%
2/28/2019	Yes	CAISO_NP15	1.59297	1.37416	1.37608	-0.1%	27%
3/1/2019	Yes	CAISO_NP15	1.64455	1.41579	1.42153	-0.4%	31%
3/2/2019	Yes	CAISO_NP15	1.81314	1.49986	1.51880	-1.2%	19%
3/3/2019	Yes	CAISO_NP15	1.76063	1.35085	1.37282	-1.6%	17%
3/4/2019	Yes	CAISO_NP15	1.73256	1.45957	1.46836	-0.6%	29%
3/5/2019	Yes	CAISO_NP15	1.69375	1.46628	1.46990	-0.2%	30%
3/6/2019	Yes	CAISO_NP15	1.72045	1.48607	1.49513	-0.6%	23%
3/7/2019	Yes	CAISO_NP15	1.81889	1.54957	1.55955	-0.6%	20%
3/8/2019	Yes	CAISO_NP15	1.43954	1.13306	1.15323	-1.7%	39%
3/9/2019	Yes	CAISO_NP15	1.59665	1.32696	1.33636	-0.7%	26%

The mean amount of carbon reduction is 1.35% (0.019 lbs of carbon) per day and the mean time the refrigerator is off is 22%. The range of results is large, so it is instructive to take a closer look at a few examples. Figure 24 is from 2-22-2019 where there was a 6.4% (0.085 lbs) reduction in carbon emissions. The day had some large changes in emissions which WattTime was able to take advantage of.

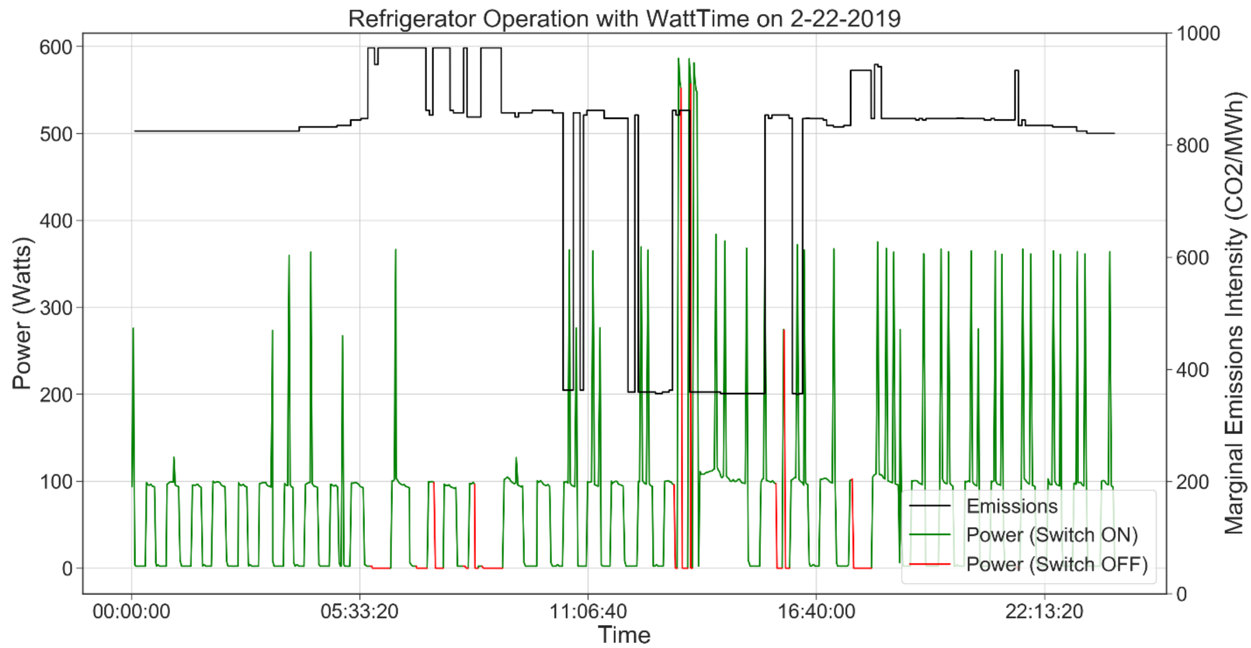

Figure 24 – Refrigerator Operation with High MOER Variability

Figure 25 a plot from 2-23-2019 where there was only a 0.1% (0.001 lbs) reduction is carbon. There was very little variability in the MOER signal that day so there was not much opportunity for WattTime to reduce carbon emissions. There was an opportunity at 8 in the morning, but it was missed.

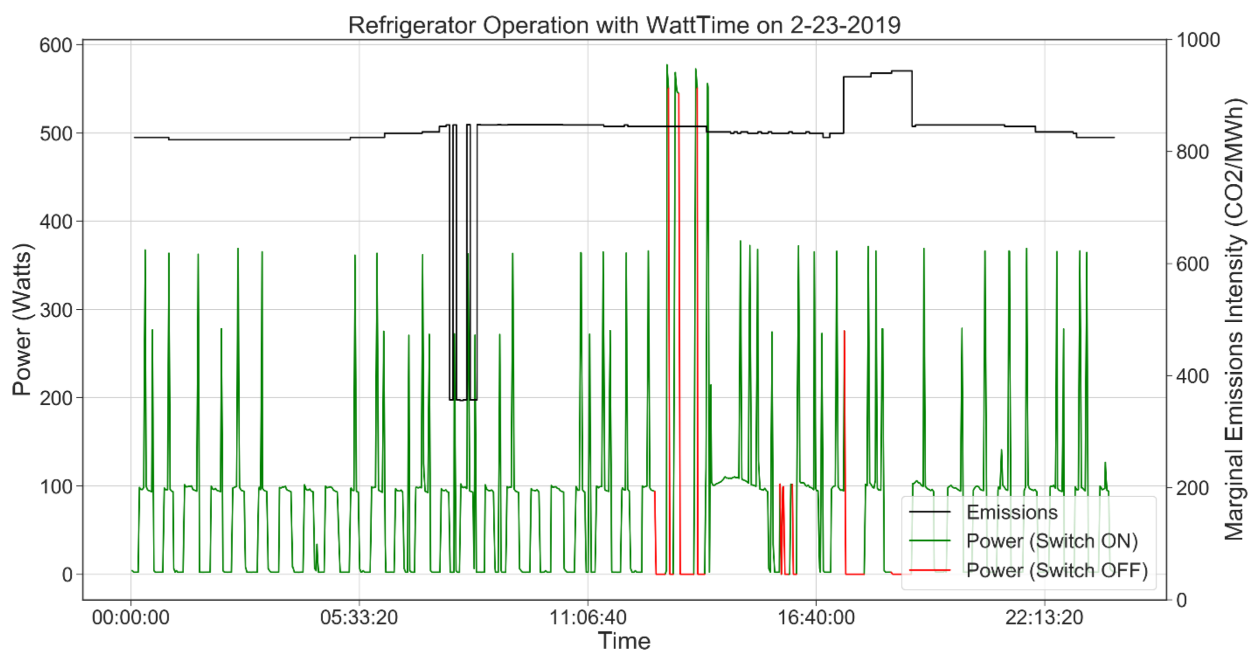

Figure 25 – Refrigerator Operation with Low MOER Variability

This final example shows WattTime operating at peak efficiency. On 2-24-2019 there was a 4% (0.059 lbs) reduction in carbon with the refrigerator being off only 3 percent of the time. The commands WattTime sent were very well placed to take advantage of the MOER variability.

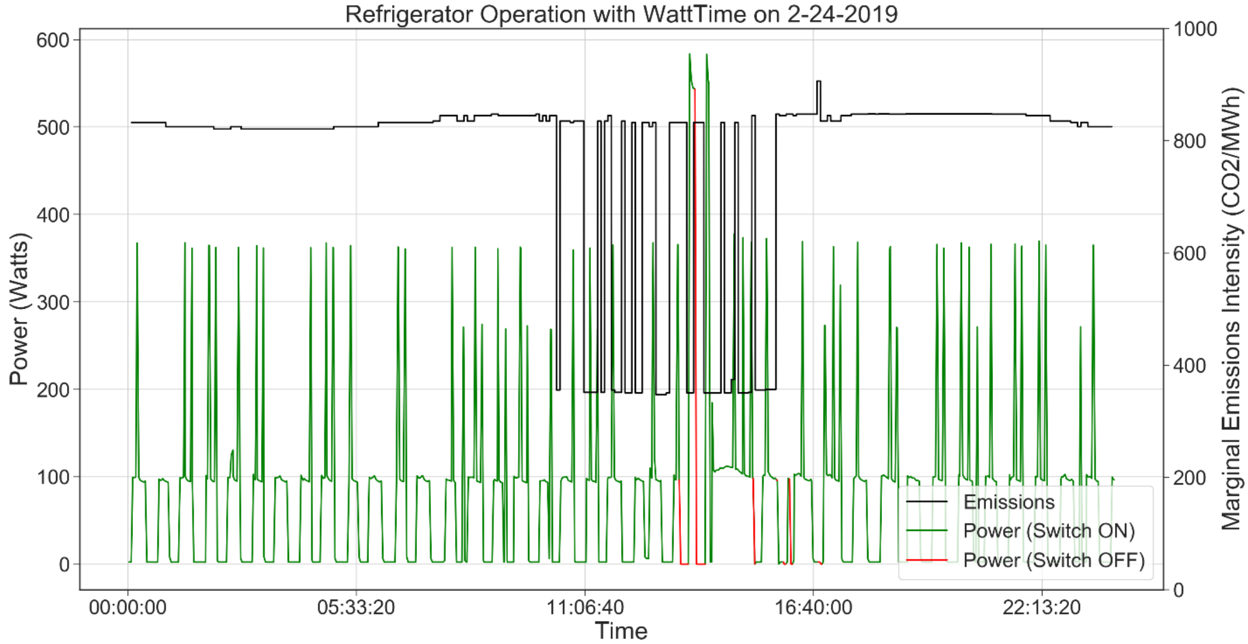

Figure 26 – Refrigerator Operation with High WattTime Efficiency

For this second round of testing, WattTime used a more aggressive control algorithm which will increase the temperature the refrigerator will reach. Figure 27 shows the ambient (green), refrigerator (blue), and freezer (black) temperature. The freezer temperature does get higher than the last round of testing, but it is important to note that the freezer was empty during the test so the change in temperature is a worst-case scenario. Even though the temperature is higher, it is deemed to be acceptable.

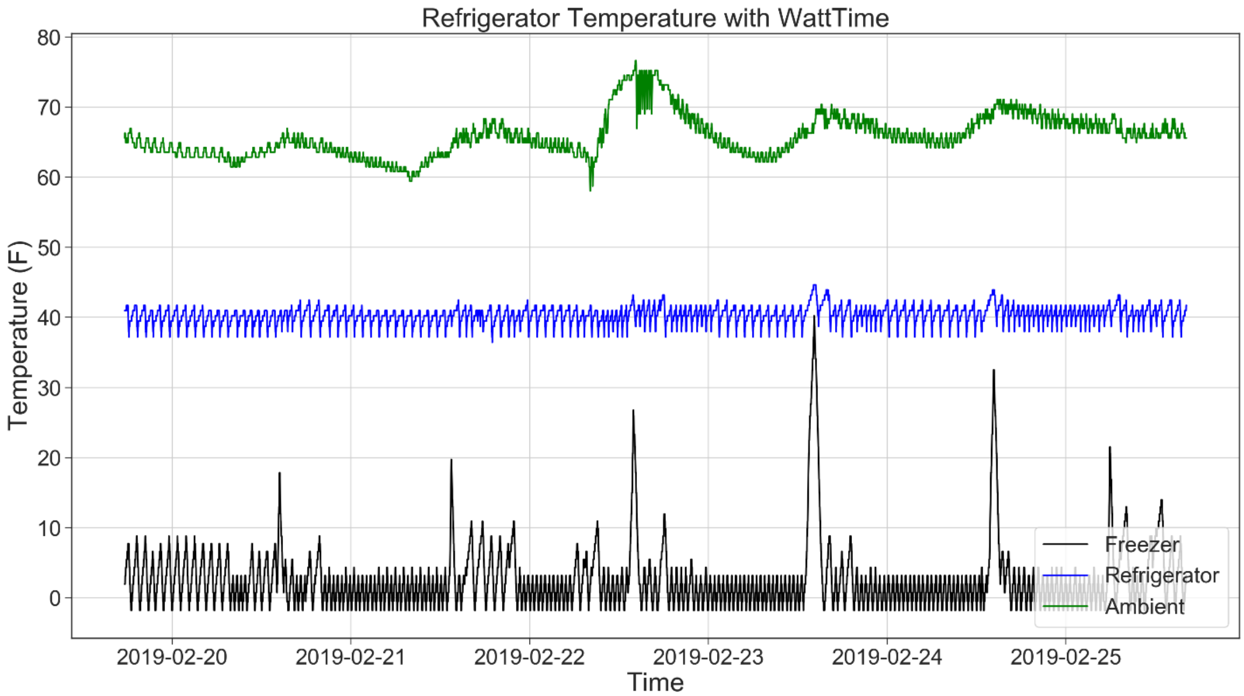

Figure 27 – Refrigerator Operation with Aggressive WattTime Control

Hot Water Heater Retrofit

A 10-gallon water heater is used to test the load controller. The temperature probe from the load controller is attached to the top of the tank by removing the lid and taping the probe under the insulation.

Figure 28 – Temperature Probe Install on Water Heater

Figure 29 – Water Heater Setup in Lab

The inlet to the water heater is fed by city water and the outlet has a valve which can be opened to represent water usage. The switch in the load controller is in series with one of the phases of the 240 VAC supply to the water heater.

Temperature measured by the load switch is observed for a day. The highest temperature recorded is 110 ºF. The control range put in WattTime is a maximum temperature of 105 ºF and a minimum of 95 ºF. This gives WattTime a 10-degree control range that is always below the water heater's thermostat setpoint, eliminating potential conflict between the controllers.

The test signal with high variability was used with the load controller for 14 days. There was no water discharged from the water heater during this time, so the temperature would gradually drop due to convective losses. Carbon reduction is calculated the same way as with the refrigerator, but without the high-power filter because the resistive heater will not have an inrush current. The WattTime measurement period for the load controller is 1 – 2 minutes, like the smart plug. Table 8 shows the results from this first round of testing.

Table 8 – Water Heater Emissions Reduction with Test Signal

Date	**Energy Used (kWh)**	**Carbon Generated (lbs)**	**Baseline Carbon (lbs)**	**Difference**
2/6/2019	0.332682036	0.179893544	0.232280479	-23%
2/7/2019	0.300748281	0.155228488	0.20998415	-26%
2/8/2019	0.370144781	0.232922146	0.258437179	-10%
2/9/2019	0.30244014	0.131130349	0.211165416	-38%
2/10/2019	0.301676235	0.168084557	0.210632053	-20%
2/11/2019	0.294863126	0.161399492	0.205875102	-22%
2/12/2019	0.297832517	0.157307954	0.207948347	-24%
2/13/2019	0.34212665	0.208682749	0.238874761	-13%
2/14/2019	0.253462619	0.125066184	0.176969034	-29%
2/15/2019	0.320148507	0.197538742	0.223529498	-12%
2/16/2019	0.278258013	0.152336639	0.194281318	-22%
2/17/2019	0.406558964	0.278348393	0.283861767	-2%
2/18/2019	0.225395321	0.103460015	0.157372287	-34%
2/19/2019	0.320151197	0.18458701	0.223531376	-17%

Figure 30 shows when WattTime commanded the heating element to turn on for the first 5 days for the test.

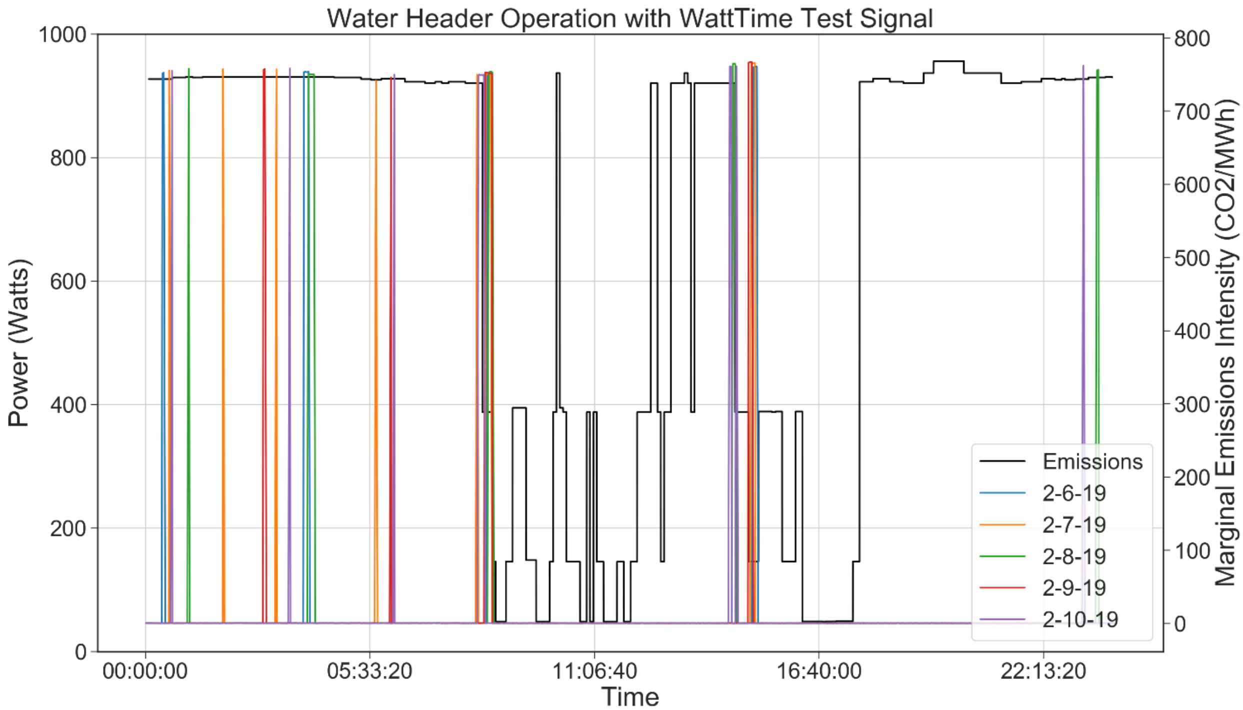

Figure 30 – Repeated Water Heater Operation with Test Signal

There is a clear pattern where WattTime turns on the heater for an extended period when the carbon intensity falls and lets the temperature drop from there until the next big drop in carbon intensity. One particularly interesting day from the test is 2-17-2019. There was only a 2% reduction in carbon on that day and from the plot below, it's clear that it is because of an extended heating period near the end of the day.

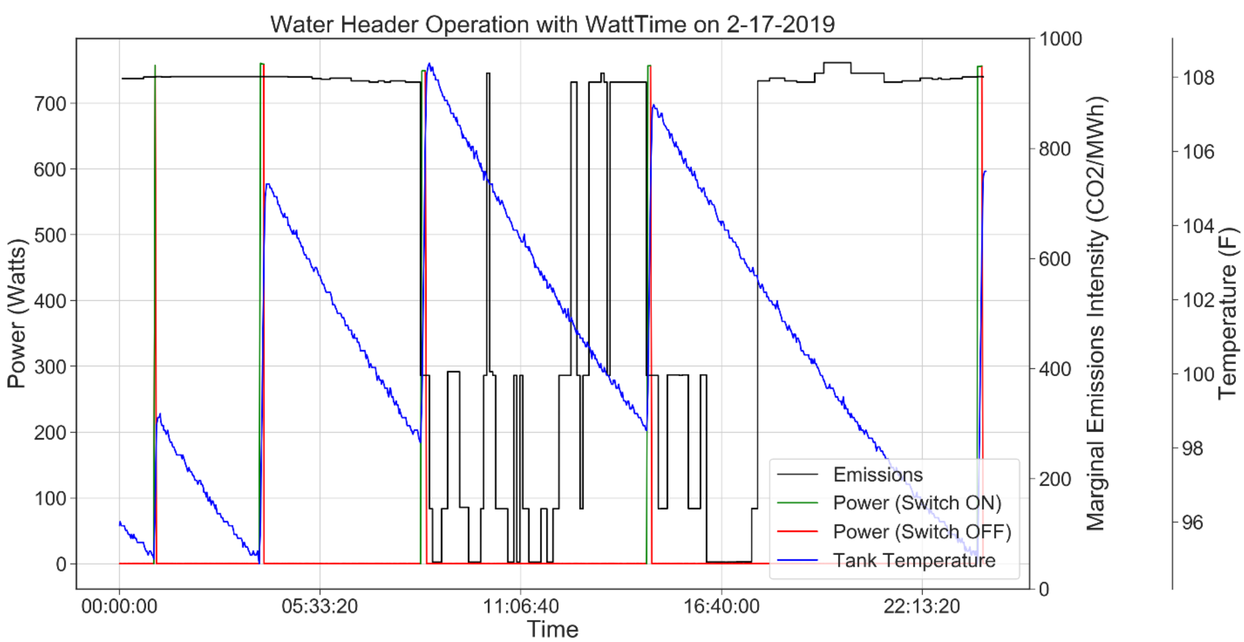

Figure 31 – Water Heater Operation with Test Signal on 2-17-2019

The day after the carbon reduction was above average at 34%. This is because the water heater was already sitting at a high temperature at the beginning of the day.

On 2-26-2019, the carbon signal was switched to the live CAISO_NP15 and on 2-27-2019, water was discharged for 20 minutes.

Table 9 – Water Heater Emissions Reduction with Live MOER Signal

Date	Energy Used (kWh)	Carbon Generated (lbs)	Baseline Carbon (lbs)	Difference
2/26/2019	0.284172	0.241482	0.244773	-1%
2/27/2019	0.602474	0.531134	0.518944	2%

Figure 32 shows the temperature, power, and carbon intensity from 2-26-2019. The variability in carbon intensity is low so there is not much opportunity for carbon reduction.

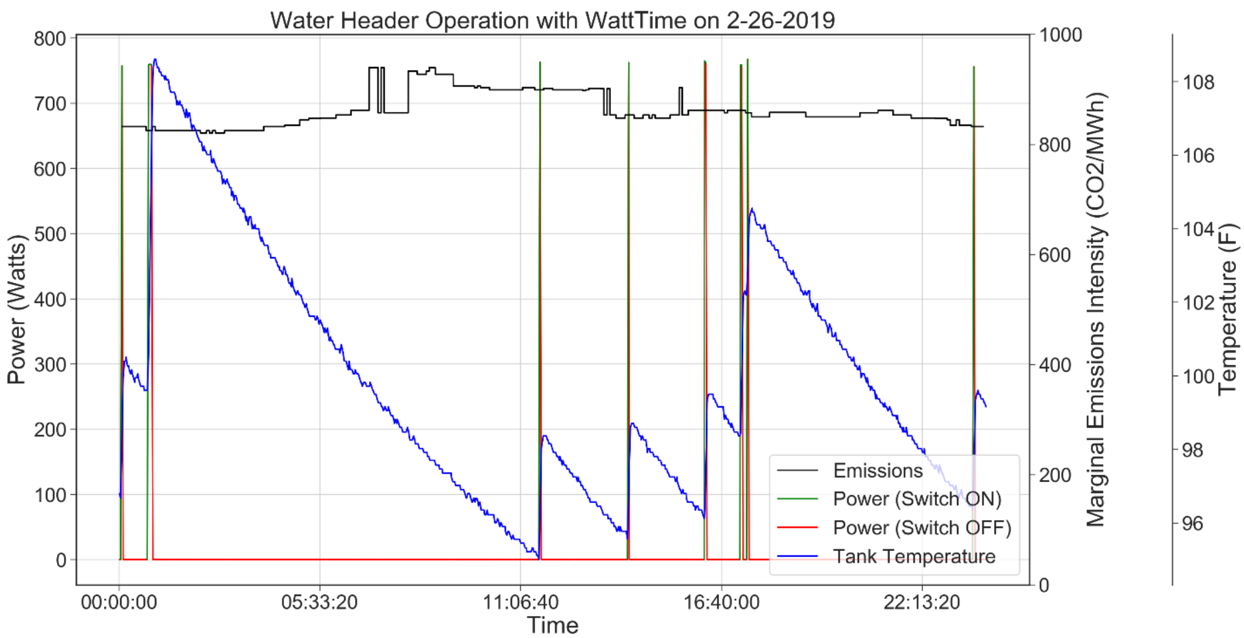

Figure 32 – Water Heater Operation with Low Variability MOER

On 2-27-2019, there is a 2% increase in carbon calculated. This is a surprising result. Water was discharged from the water heater between 11:55am and 12:15pm. This can be seen by the dip in temperature in Figure 33.

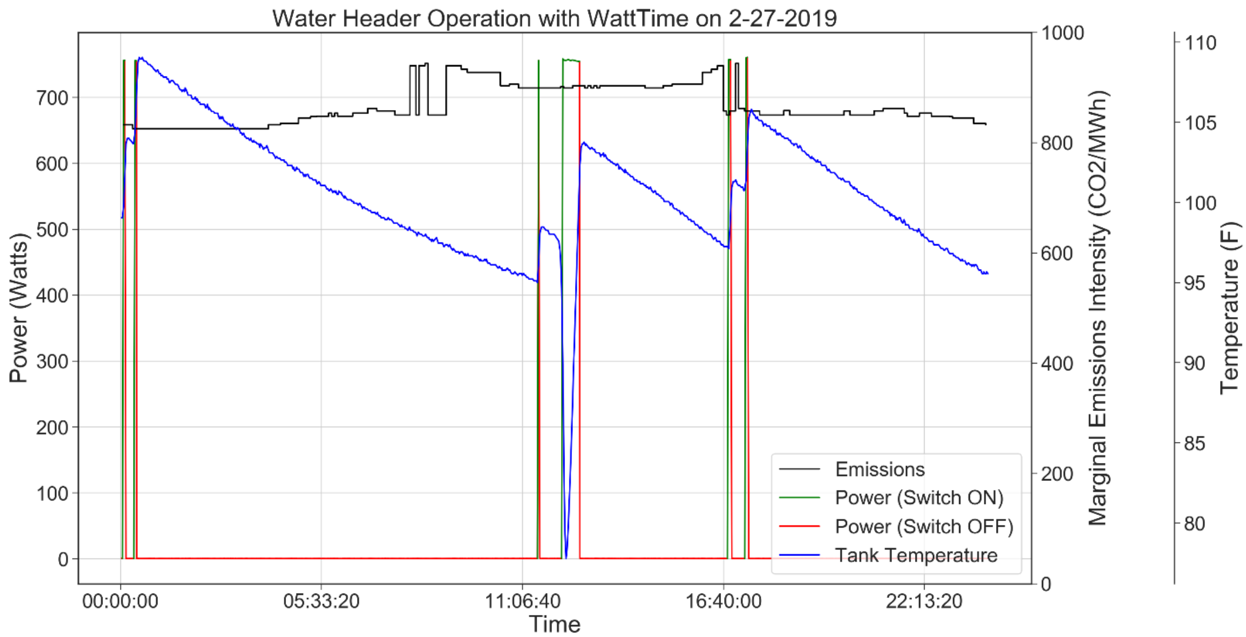

Figure 33 – Water Heater Operation with User Interaction

WattTime is forced to turn on the heater because of the human interaction with the system and that happens to be at a relatively high carbon intensity for the day. To capture the effect of WattTime control on carbon emissions, it is required to remove the period of time where the user interaction forced the system. This is done by removing the time period that starts when the rate of change in temperature exceeds the natural rate of change and ends when the temperature goes above the temperature at the beginning of the time interval. After removing this time period, there is a carbon reduction of 1.7% for the day.

Table 10 is a list of events that were executed.

Table 10 – Water Heater User Events

Date	Time	Event
2/27/2019	1155	Open Water Valve
2/27/2019	1215	Close Water Valve
3/7/2019	1130	Open Water Valve
3/7/2019	1150	Close Water Valve
3/7/2019	1457	Open Water Valve
3/7/2019	1517	Close Water Valve
3/8/2019	1112	Open Water Valve
3/8/2019	1132	Close Water Valve

Date	Time	Event
3/8/2019	1427	Open Water Valve
3/8/2019	1447	Close Water Valve
3/8/2019	1643	Open Water Valve
3/8/2019	1703	Close Water Valve
3/15/2019	844	Open Water Valve
3/15/2019	904	Close Water Valve
3/15/2019	1335	Open Water Valve
3/15/2019	1355	Close Water Valve
3/18/2019	1007	Open Water Valve
3/18/2019	1027	Close Water Valve
3/18/2019	1304	Open Water Valve
3/18/2019	1324	Close Water Valve
3/20/2019	1423	Open Water Valve
3/20/2019	1445	Close Water Valve

The carbon reduction calculation without removing the user events is in Table 11.

Table 11 – Water Heater Emissions Reduction without Removing User Events

Date	Energy Used (kWh)	Carbon Generated (lbs)	Baseline Carbon (lbs)	Difference
2/27/2019	0.602474	0.531	0.522	1.6%
3/7/2019	0.967601	0.859	0.830	3.5%
3/8/2019	1.450331	1.072	1.162	-7.7%
3/15/2019	1.043823	0.815	0.833	-2.1%
3/18/2019	0.899293	0.739	0.763	-3.1%
3/20/2019	0.557244	0.488	0.470	3.8%

And the carbon reduction with removing the user events is in Table 12.

Table 12 – Water Heater Emissions Reduction with Removing User Events

Date	Energy Used (kWh)	Carbon Generated (lbs)	Baseline Carbon (lbs)	Difference
2/27/2019	0.241119	0.205	0.209	-1.7%
3/7/2019	0.160706	0.135	0.138	-2.0%
3/8/2019	0.227248	0.147	0.182	-19.1%
3/15/2019	0.328781	0.205	0.262	-21.7%
3/18/2019	0.245575	0.166	0.208	-20.3%
3/20/2019	0.247026	0.208	0.208	-0.3%

After removing the user events there is a visible pattern in the carbon emission reduction. On the days of 2-17-2019, 3-7-2019 and 3-20-2019 there was a low level of MOER variability and the reduction is 2% or less (0.004 lbs of carbon or less). The rest of the days the reduction is around 20% (0.045 lbs of carbon) which is what was seen with the high variability test day.

Electric Vehicle Service Equipment

the load side of the EVSE is connected to an electronic load. The electronic load is programmed so that a charging rate and capacity can be specified. When the capacity is reached, the load will turn off until the program is started again. In that way the electronic load is being used to simulate an EV.

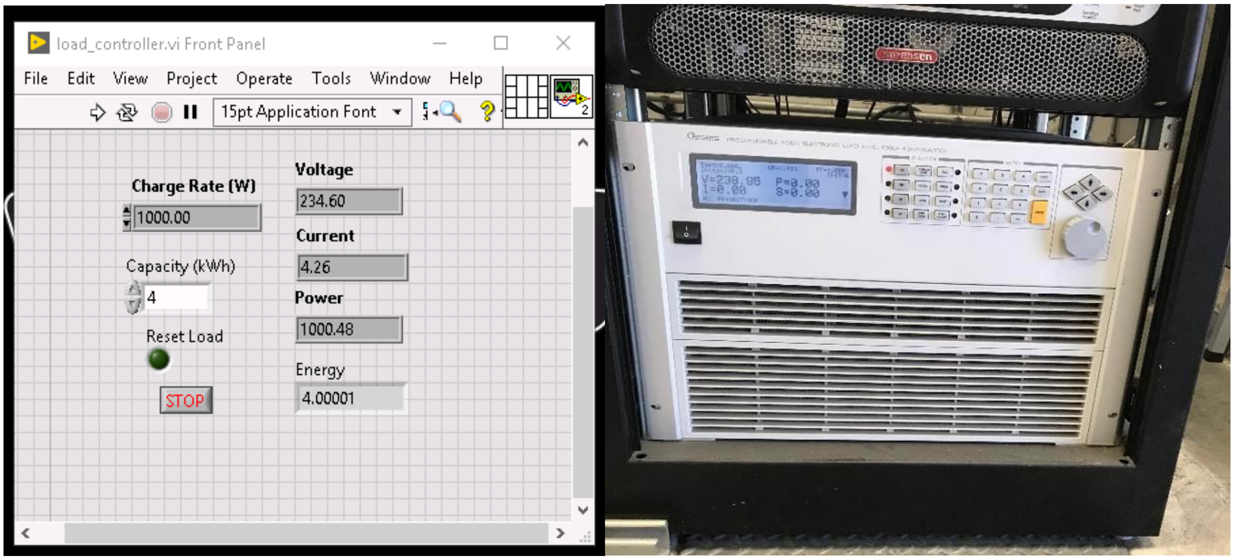

Figure 34 – Electric Vehicle Load Simulator

The load is connected to a J1772 port that the EVSE can connect to. The J1772 port has switches to break the control and proximity pilots. There is a ~900 Ohm resistor between the control pilot and ground to indicate that the simulated EV is ready to charge. To simulate the EVSE being plugged into the EV and the beginning of the charge time, there is a relay in series with the proximity pilot. The relay is controlled by a 5 VDC power supply connected to a programmable timer.

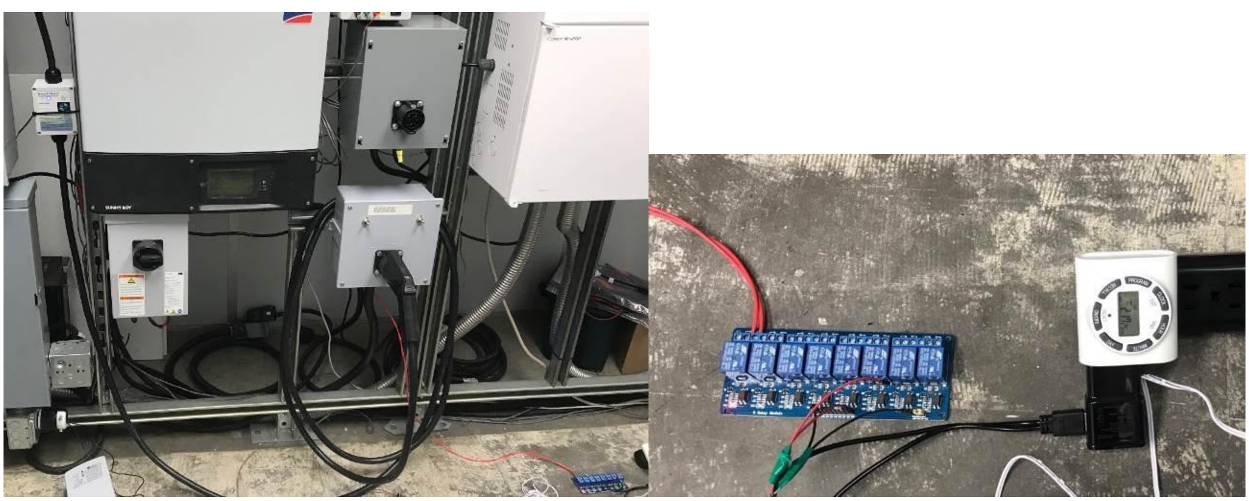

Figure 35 – EVSE Plug Setup

Three different charging windows were used. The windows were selected based on time of use rates and anticipated use patterns. This included a workday charging window aligned with typical office hours where the allowable charge window starts and 9:00AM and ends at 5:00PM. Two cases representing residential charging were also selected, reflecting the new time-of-use and electric vehicle rates. The allowable charge window for the TOU rate started at 9:00PM when the lowest rate begins and ends at 7:00AM. For the electric vehicle rate, the super off peak period starts at 12:00AM and ends at 7:00AM.

In all cases, the charging rate was set at 1 kW and the charging capacity was set at 3 kWh. The timer controlling the proximity pilot was set to the beginning of the charging window, and the end of the window was entered in the WattTime website. A minimum charging duration of 180 minutes was also entered in the WattTime website.

The carbon attributed to the energy usage is calculated in the same way as the refrigerator and water heater, but the baseline carbon is calculated differently. Instead of multiplying the total energy by the average MOER for the day, the average MOER for the first three hours of the charging window is used. The results are in Table 13.

Table 13 – EVSE Emissions Reduction

Date	Charge Time	Carbon (lbs)	3 Hour Carbon Baseline (lbs)	Difference
2/6/2019	9pm - 7am	3.559	3.559	0.0%
2/7/2019	9pm - 7am	3.558	3.558	0.0%
2/8/2019	9pm - 7am	3.487	3.556	-1.9%
2/9/2019	9pm - 7am	3.553	3.554	0.0%
2/10/2019	9pm - 7am	3.548	3.563	-0.4%
2/12/2019	12am - 7am	3.666	3.666	0.0%
2/13/2019	12am - 7am	2.777	2.807	-1.1%
2/14/2019	12am - 7am	3.511	3.511	0.0%
2/16/2019	9am - 5pm	2.458	2.456	0.1%
2/18/2019	9am - 5pm	3.116	3.109	0.2%
2/19/2019	9am - 5pm	2.967	3.151	-5.8%
2/22/2019	9am - 5pm	2.171	2.711	-19.9%
2/23/2019	9am - 5pm	2.782	2.795	-0.5%
2/24/2019	9am - 5pm	2.288	2.457	-6.9%
2/26/2019	9am - 5pm	2.88	3.026	-4.8%
2/27/2019	9am - 5pm	3.058	3.098	-1.3%
3/1/2019	9am - 5pm	2.98	3.066	-2.8%
3/5/2019	9am - 5pm	3	3.119	-3.8%
3/7/2019	9am - 5pm	3.018	3.044	-0.9%
3/8/2019	9am - 5pm	1.908	2.839	-32.8%
3/9/2019	9am - 5pm	2.784	2.819	-1.2%
3/12/2019	9am - 5pm	1.186	2.402	-50.6%
3/14/2019	9am - 5pm	1.266	2.814	-55.0%

Date	Charge Time	Carbon (lbs)	3 Hour Carbon Baseline (lbs)	Difference
3/15/2019	9am - 5pm	1.776	2.374	-25.2%
3/18/2019	9am - 5pm	2.145	2.171	-1.2%
3/19/2019	9am - 5pm	2.942	2.839	3.6%
3/20/2019	9am - 5pm	3.833	3.838	-0.1%

The overnight charging windows show little or no carbon reduction. This is because there is very little variability in the carbon intensity during those times, although variability may increase as more renewables like wind are integrated into the grid. This can be seen in the Figure 36.

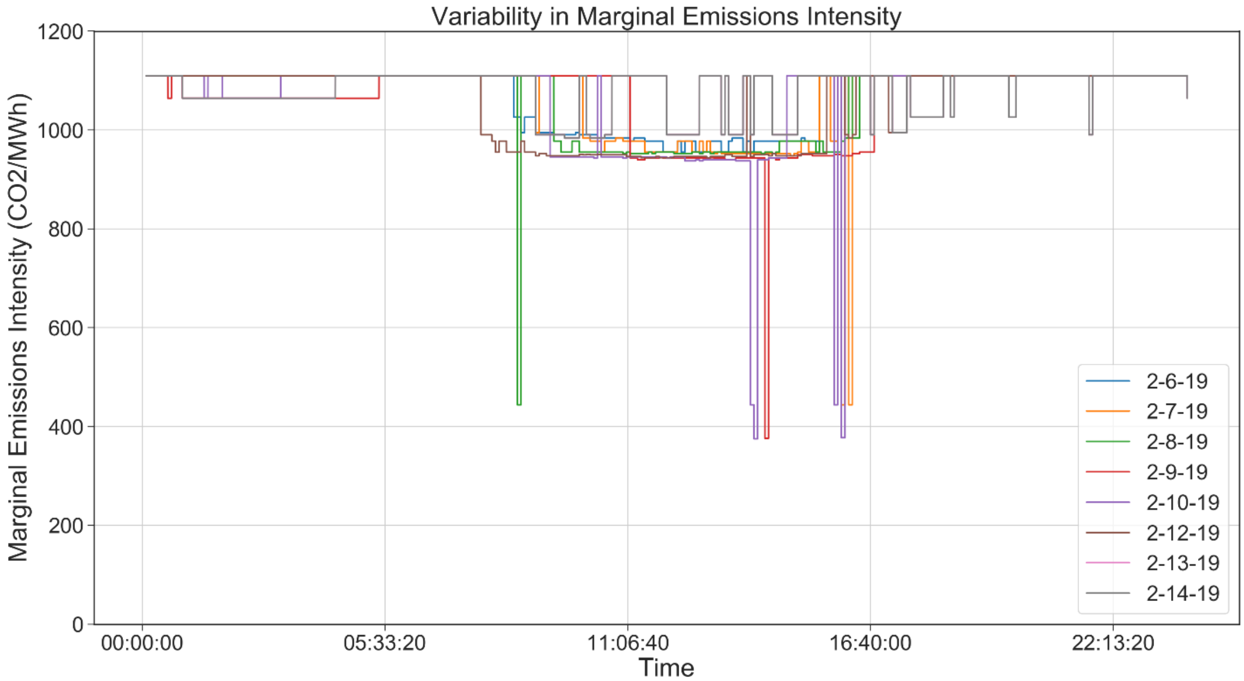

Figure 36 – Low Overnight MOER Variability

The 9am to 5pm time frame is more interesting. Figure 37 shows how WattTime controlled the EVSE on 2-22-2019.

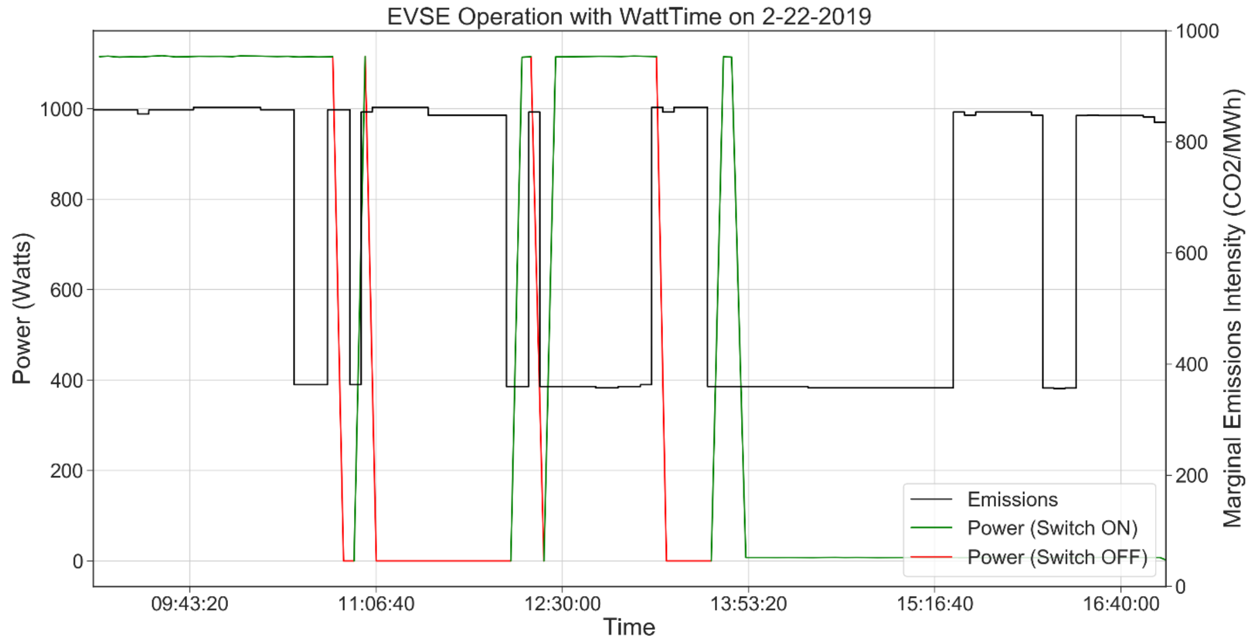

Figure 37 – EVSE Operation with High Variable MOER

On this day there was a 19.9% (0.540 lbs) reduction in carbon. WattTime did a good job avoiding charging between 11am and 12pm when the carbon intensity was high and resuming charging after 12:30pm when the carbon intensity dropped. There was a potential for even greater carbon saving. There was a prolonged low carbon intensity period between 2pm and 3:30pm that could not be taken advantage of because the EV simulator had already hit its 3 kWh.

On 2-23-2019 there was only a 0.5% (0.013 lbs) carbon reduction. Figure 38 shows that this is because there was little variability in carbon intensity between 9pm and 5pm.

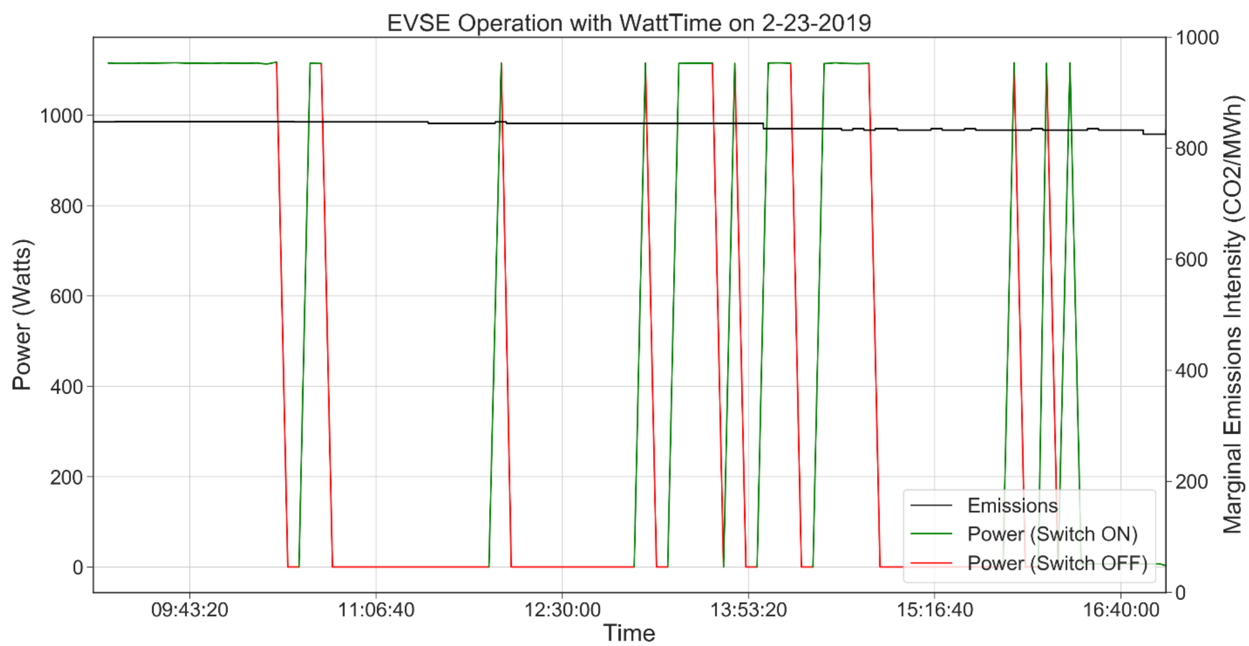

Figure 38 – EVSE Operation with Low Variable MOER

On 2-24-19 WattTime achieved a 6.9% (0.169 lbs) reduction in carbon. Figure 39 shows frequent control changes to react to the changing carbon intensity. The carbon reduction could have been higher if there wasn't the propensity to charge at the beginning of the charge window.

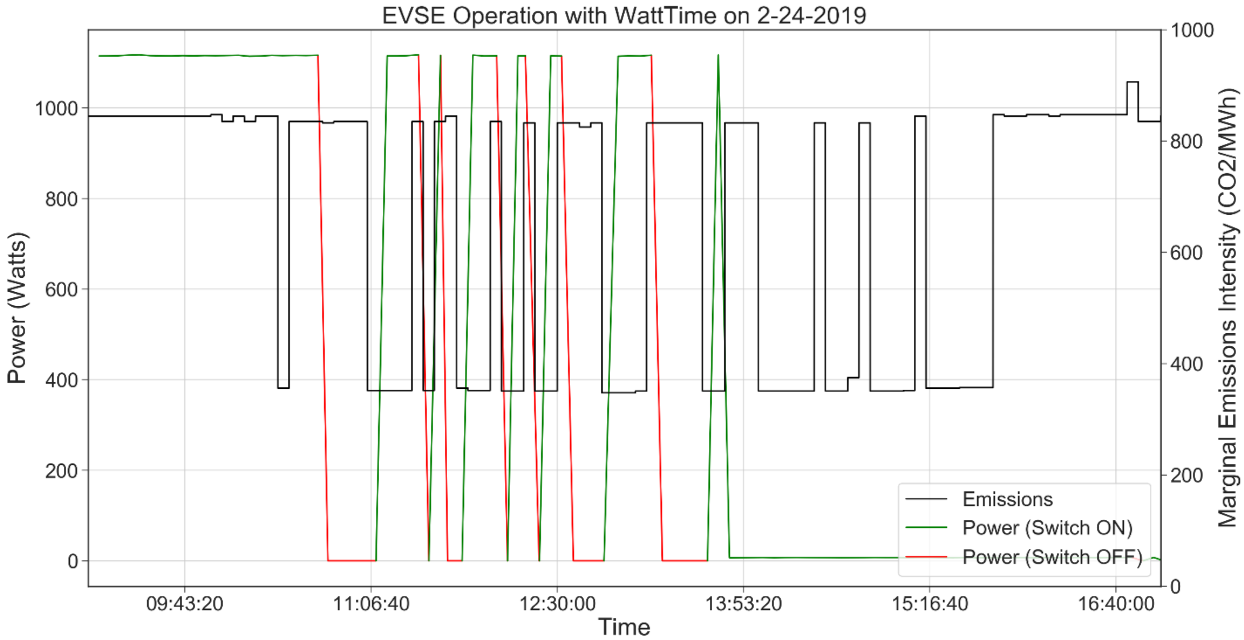

Figure 39 – EVSE Charging at Beginning of Interval

On 2-27-2019 the EVSE stopped charging at the beginning of the charge window. This enabled greater flexibility in when charging could occur before topping of the simulated battery. On 3-12-2019 and 3-14-2019 the carbon reduction was greater than 50% (1.216 lbs of carbon).

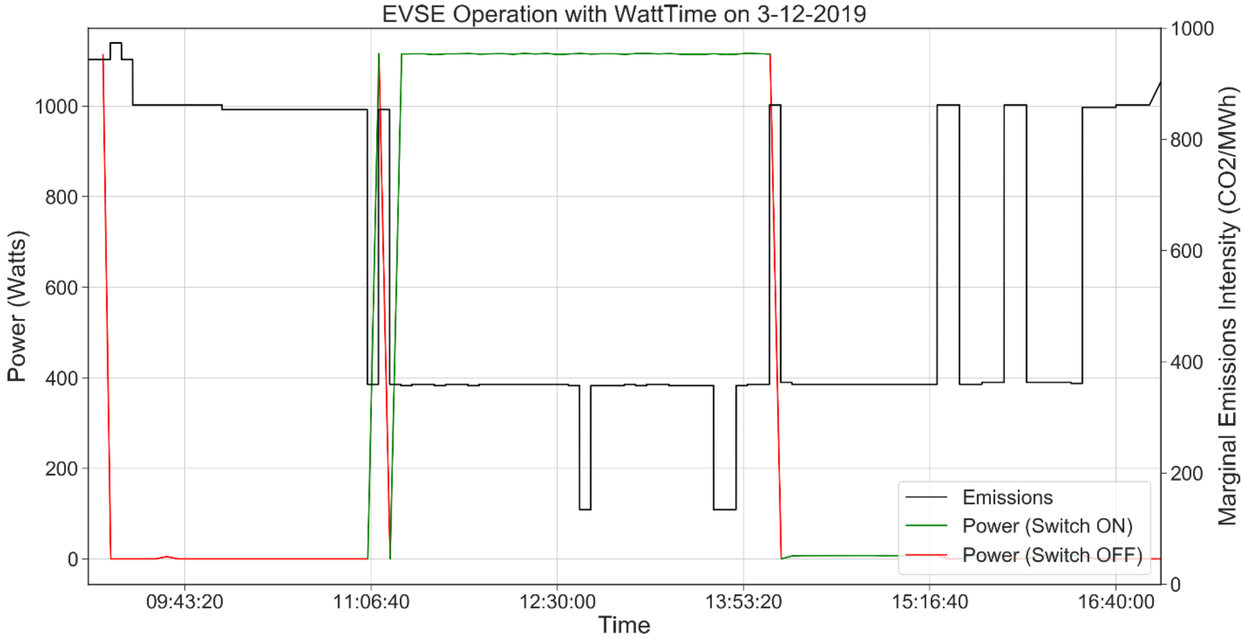

Figure 40 – EVSE Operation on 3-12-2019 with 50% Emissions Reduction

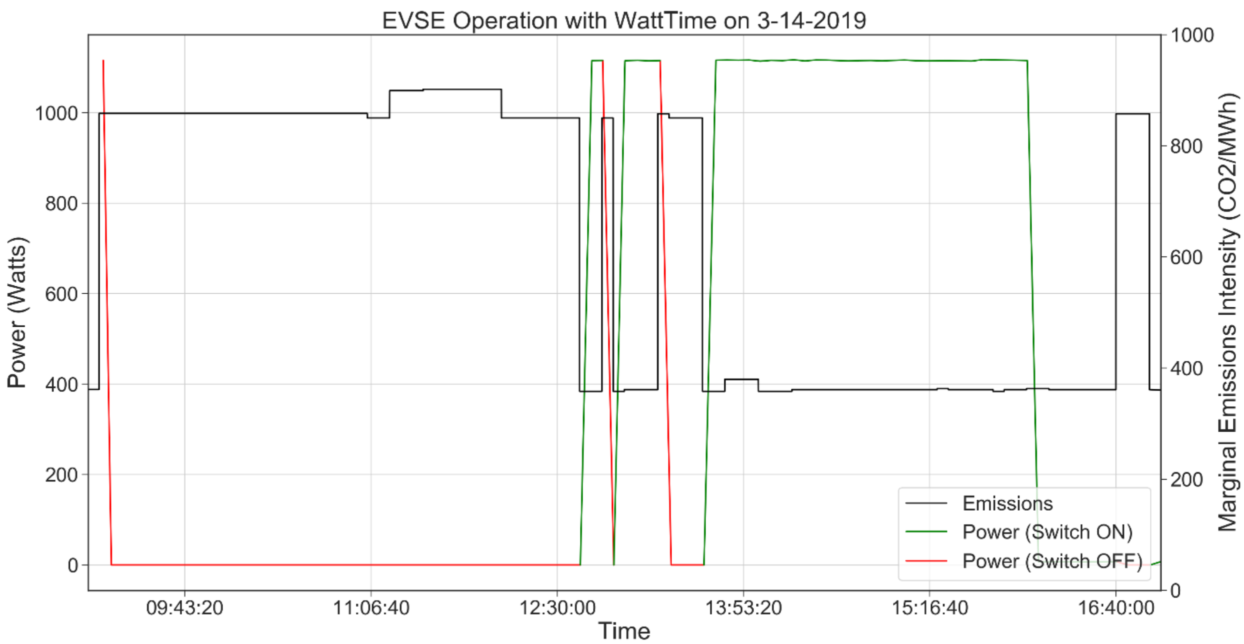

Figure 41 – EVSE Operation on 3-14-2019 with 55% Emissions Reduction

WattTime succeeded in providing power to the EVSE for the full 3-hour duration required on all days except for two days. This was 3-15-2019 and 3-18-2019 when it charged 2.5 and 2.25 hours respectively. The finish by 5pm time was entered into the WattTime website before the daylight savings shift, and the time was stored as 5pm PST which is the equivalent of 6pm PDT, so WattTime was planning on having another hour to charge. The issue was brought up to WattTime on 3-19-2019 and a fix was implemented to prevent the same issue from happening in the future.

The EVSE is the most straightforward device to control for carbon reduction because it does not involve buffering energy in a thermal system. WattTime was successful in reducing carbon when possible and improvement in the algorithm was seen during the testing period.

RESULTS

Programmable Communicating Thermostats

WattTime was able to successfully communicate with and control the PCTs included in the test. Because of limitations of a lab testing environment, it was not possible to attach the thermostats to actual AC compressors. Once the communication and control had been established, in order to estimate the potential emissions savings from real-time control, a simulation in EnergyPlus was conducted.

As modeled, the simulation showed that controlling an air conditioning system with the WattTime signal is able to reduce emissions, by 7.5% when allowing a 2 ^{0}F thermostat setpoint change and 13.2% when allowing a 4 ^{0}F change. Based on the simulation, continuous control of thermostats for emissions reductions, especially in regions with high air conditioning penetration, is an effective strategy for emissions reduction, but the simulation indicates that the reduction in emissions is due to the total reduction in energy use and not shifting when the energy is used. Load shifting (pre-cooling) strategies were not tested in this assessment due to dependencies on building envelope leakage which are difficult to model in a lab environment. Pre-cooling and thermostat hysteresis strategies that were not captured in the simulation could be tested in subsequent field based trials. Further testing in the field under real world conditions should show how the compressor reacts to changes in setpoint.

Smart Plug & Refrigerator

WattTime was able to control the smart plug in order to reduce emissions by adjusting the timing of a refrigerator's compressor operation. Before further smart plugs are deployed connected to refrigerators, the plugs will need to be adjusted to ensure that the plug always defaults to on in the case of communication failure to ensure cooling is always provided.

While the emissions savings from smart plugs combined with refrigerators are comparatively low at 1.3% based on data available from lab test, the ubiquity of refrigerators in households makes them an effective end use to control for emissions reductions.

Hot Water Heater Retrofit

WattTime effectively communicated with and controlled the hot water heater through the retrofit system.

Data available from lab test showed WattTime's control of the hot water heater resulted in a 20% reduction of emissions compared to typical operation when there is high variability in the emissions rate. When the variability is low the reduction of emissions is less than 2%. It is important to note that this reduction is emissions is only for the energy associated with maintaining the water temperature when the water heater is not in use. Understanding the relationship between habitant water usage behavior and potential GHG reductions related to GHG intensity signals combined with control algorithms could be tested in subsequent field based trials.

Electric Vehicle Service Equipment

WattTime controlled the EV charger in real-time to reduce emission from charging electricity. Data available from lab test showed on average, day charging with WattTime control was able to reduce emissions from charging by more than 12%. High variability in emissions rates between different days means emissions reductions reached as high as 55% in the lab. While night charging is not as effective as daytime charging due to reduced variability in emissions rates during the night, charging at night still achieves emission reductions of 1% on average. WattTime control of the EV charger achieved significant emissions reductions.

CONCLUSIONS

This study shows that is it possible both to communicate with and control smart devices in real-time to achieve emissions reductions through load reduction and load shifting. As the electric grid incorporates more renewable generators, the variability of grid emissions should continue to rise, increasing the potential of load shifting to reduce emissions.

WattTime has demonstrated their ability to robustly communicate with their supported endpoint devices. Majority of communication issues were reported by WattTime before they were noticed by PG&E. Issue resolution was quick and as the testing period went on, communication issues became less frequent.

WattTime has also demonstrated the effectiveness of their algorithm and load reduction and shifting through devices for reducing the carbon emissions associated with energy use. The degree to which WattTime can reduce carbon is largely dependent on the variability of the carbon intensity of the grid, which have seasonal and daily trends, and the device type. The effectiveness and appropriateness of the different device types for real time emissions reductions varies depending on impact and use.

Pairing the refrigerator with the smart plug is compelling because, while the carbon reduction is small, every house has at least one refrigerator and many homes have two refrigerators. In addition, refrigerators represent a relatively large component of daily energy consumption and cycle continuously throughout the day, season and year. It will need to be seen if the inability to use the refrigerator light, water, and ice for about 5% to 20% of the day is too large of an inconvenience for customers. With the proper incentive, that inconvenience may be seen as a worthwhile tradeoff. Additionally, second fridges would be a good application for smart plug deployment as they are used less. Furthermore, as more smart appliances become available, the load shifting functionality can be built directly into the device.

Controlling a thermostat with WattTime will lead to a reduction in carbon emissions by virtue of the fact that the WattTime algorithm increases the cooling setpoint which conserves energy. Reducing carbon emission though load shifting was not seen but the implementation method makes it very easy for the customer to override WattTime control so it could still be a customer friendly way to achieve energy and carbon savings. A field test may show emissions reductions potential from load shifting when attached to an actual HVAC unit.

The EV use case is very straight forward and there is almost no inconvenience to the user. Daytime charging is the better application given the higher amount of variability in carbon intensity during daytime hours in California, but there are merits to nighttime charging too. Because there is no inconvenience to the user, even a small amount of carbon reduction from WattTime control provides benefit.

The water heater use case was shown to work in the lab, but real water usage patterns may have a significant impact on the results. Given that the water temperature will stay in the user defined range, load shift for emissions reductions would not be an inconvenience to users.

The recommendation from the PG&E DRET team is that the Automated Emissions Reduction signal developed by WattTime, associated control algorithms, and control devices as tested in the PG&E ATS labs for this assessment are sufficiently robust to move to limited field testing.

APPENDIX A – ENERGATE LOAD CONTROLLER

WattTime's ability to control an Energate load controller was also tested. In previous work by PG&E, a version of the load controller that can communicate though the Home Area Network connection on a Smart Meter has been tested in the lab and used in the field to control air conditioning units for demand response pilots. The load controller tested in this project uses an Energate gateway called ZIP Connect (Figure 42) to facilitate internet communication. The ZIP Connect communicates wirelessly with the load controller and makes a wired connection to a home router to communicate to the internet.

Figure 42 – Energate ZIP Connect Gateway

The load controller is an Energate LC2200 (Figure 43). The load controller is powered from 240 VAC which would be a typical power source near and air conditioning unit.

Figure 43 – Energate LC2200 Load Controller

The setup of the load controller is done by the utility, not by the end user. In this project WattTime registered as a utility with Energate and they set up the load controller. In the lab the gateway was connected to the WiFi router on TICnet and the load controller was powered by a 240 VAC source. The load control relay was connected to a 24 VAC source and a resistor. The 24 VAC source and the resistor simulates the furnace controller sending an on signal to an AC unit. The load controller will open a relay to stop the 24 VAC signal from reaching the AC unit. To simulate the cycling of the AC control signal, the 24 VAC source was put on a timer (Figure 44) which would cycle being off for 1 hour and on for 3 hours.

Figure 44 – Timer and 24 VAC Source to Simulate AC Cycling

WattTime control of the load controller was observed and an example can be seen in Figure 45.

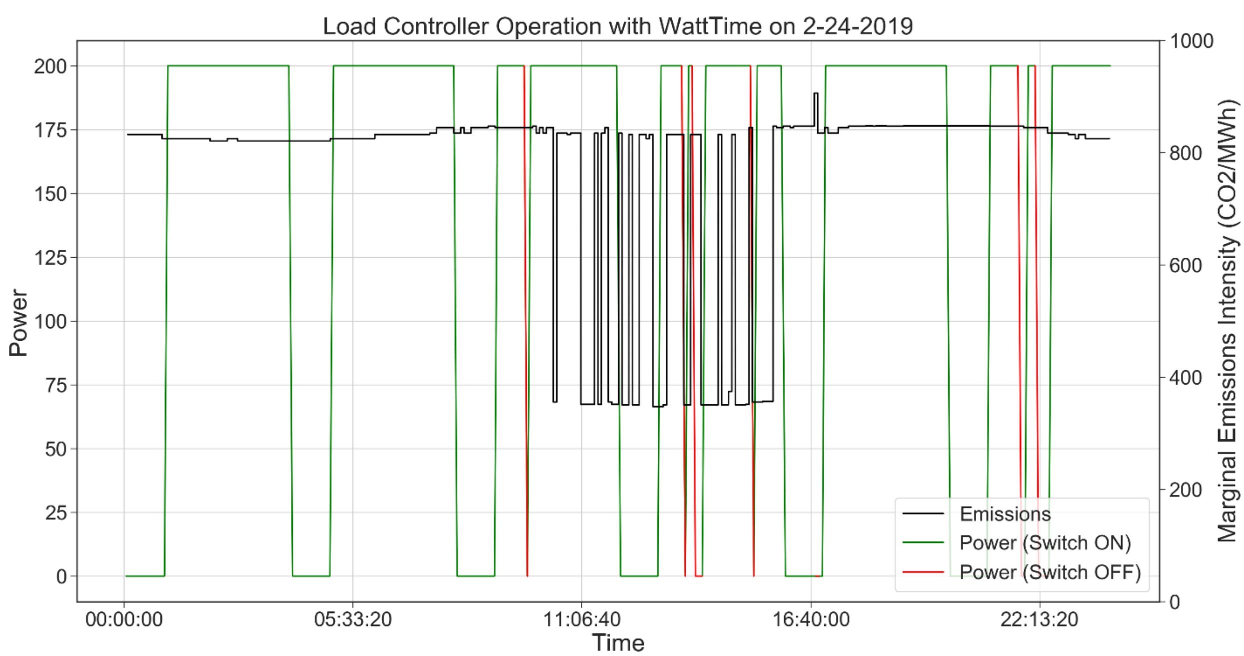

Figure 45 – Example of WattTime Controlling Energate Load Controller