Testing of a Whole Home Energy Management System

Cooperative Research and Development Final Report

CRADA Number: CRD-23-24313

NREL Technical Contacts: Bethany Sparn, Prateek Shrestha, and Noah Sandoval

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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5500-91652
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NOTICE

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Cooperative Research and Development Final Report

Report Date: October 18, 2024

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the CRADA final report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: B&B Technology Solutions Inc.

CRADA Number: CRD-23-24313

CRADA Title: Testing of a Whole Home Energy Management System

Responsible Technical Contact at Alliance/National Renewable Energy Laboratory (NREL):

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Sponsoring DOE Program Office(s):

Office of Energy Efficiency and Renewable Energy (EERE), Buildings Technology Office

Joint Work Statement Funding Table showing DOE commitment:

Table 1 outlines the estimated costs for each year of the CRADA.

Table 1: Joint Work Statement Funding

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
Year 1	$75,000.00
Year 2, Modification #1	$0.00
Year 3, Modification #2	$0.00
Year 4, Modification #3	$0.00
TOTALS	$75,000.00

Executive Summary of CRADA Work:

NREL and B&B Technology Solutions Inc. will perform verification testing to demonstrate the effectiveness of our whole home energy management system. This energy management system will allow the electrification of various styles of homes reducing the emissions of CO2 by replacing existing fossil fuel-based home systems.

CRADA benefit to DOE, Participant, and US Taxpayer:

- Assists laboratory in achieving programmatic scope, and/or
- Uses the laboratory's core competencies, and/or
- Enhances U.S. competitiveness by utilizing DOE developed intellectual property and/or capabilities.

Summary of Research Results:

Task 1: Technical Briefing

B&B team provided a technical briefing to the NREL technical team on their whole home energy management system. We discussed the goals that B&B had for their lab demonstration and the physical equipment available in the lab. B&B shared some high-level schematics for their solution and a timeline for when it would be available (Figure 1). The technical briefing occurred over Teams on 2/2/24.

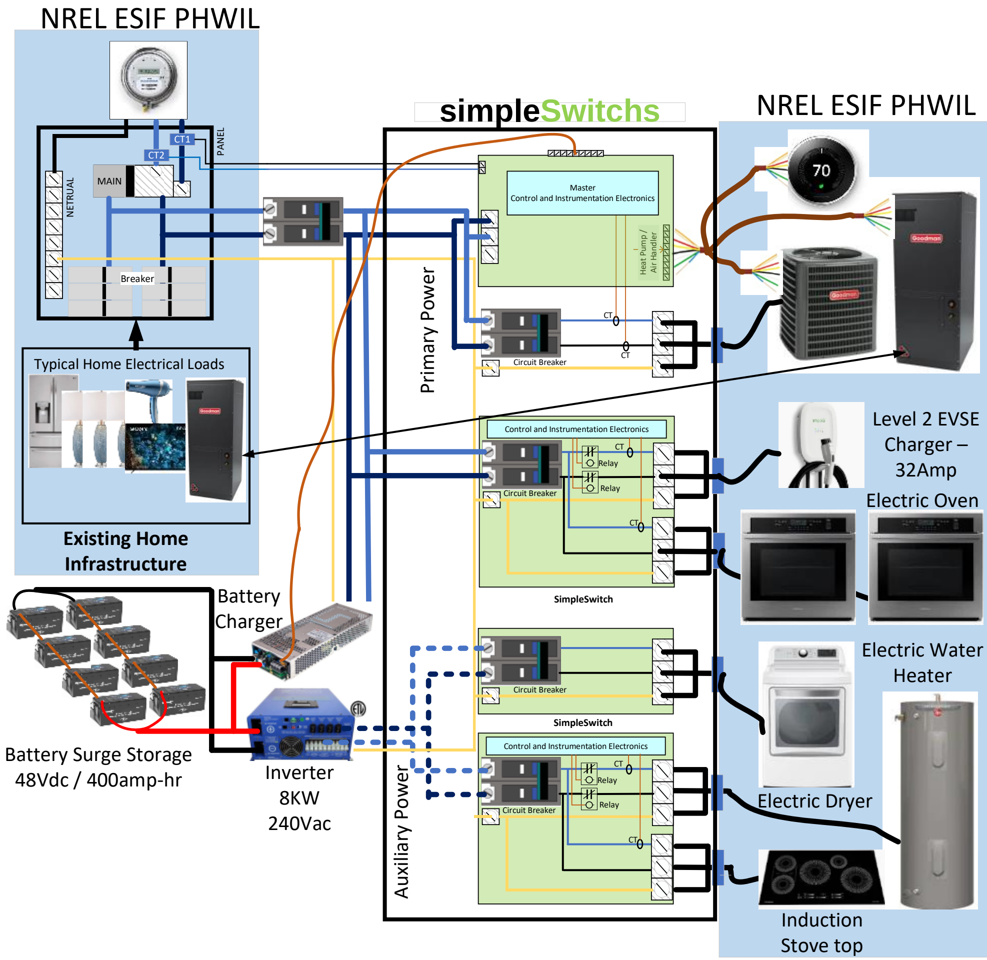

Figure 1. Initial schematic of laboratory demonstration for B&B Technology

Task 2: Develop Test Plan

Based on the requirements for the EAS-E Prize and the solution developed by B&B, we developed a test plan that included two different summer days. Each day was run twice: (1) a baseline case without any special controls or configurations and (2) an experiment with the B&B skid and controls applied. The cases could be compared for peak power draw, total energy use, comfort and more. The test plan is shown in Table 2.

Table 2. Experimental cases developed for B&B Technologies.

Scenario	Location	Weather File Date	HVAC Set Point	Water Heater Draw Volume	Oven Schedule	Washer/ Dryer Schedule	EV Charging Schedule
1.0: Mild Summer Baseline	San Francisco	8/27/21	72F	45.7 gallons	Stovetop 6:30 pm - 7:00pm	7:00 pm / 8:00 pm	6:00 pm – 8:30 pm
1.1: Mild Summer Experiment	San Francisco	8/27/21	72F	45.7 gallons	Stovetop 6:30 pm- 7:00pm	7:00 pm / 8:00 pm	6:00 pm – 8:30 pm
2.0: Hot Summer Baseline	Cleveland	7/26/21	70F	74.1 gallons	Stovetop 5:30pm – 6:00pm	7:00 pm / 8:00 pm	6:00 pm – 8:00 pm
2.1: Hot Summer Experiment	Cleveland	7/26/21	70F	74.1 gallons	Stovetop 5:30 pm - 6:00pm	7:00 pm / 8:00 pm	6:00 pm – 8:00 pm

Task 2: Home Energy Management System

The B&B team shipped the whole home energy management system, including batteries, inverter, SimpleSwitches and subpanels, to NREL for testing (Figure 2 and Figure 3). The skid arrived the day before the B&B Technology team was set to arrive at NREL for the lab demonstration. B&B's electrician unpacked the skid and prepared the equipment for electrical inspection. After the inspection was complete, all the wiring was connected and it was inspected a second time. Then we were able to plug it in and turn the appliances on.

Figure 2. B&B Technology Solutions' skid from front

Figure 3. B&B Technology Solutions' skid from the back

Task 3: Testing and Technical Support

To conduct the testing and data collection necessary to execute the Test Plan outlined in Table 2, the NREL technical team:

- Installed loaned equipment and make necessary adjustments to lab setup for testing.
- Modified a building energy model file based on a typical northern California single-family detached home (Table 3) to run in the Simulink program as a part of SPL's hardware-in-the-loop testing platform.
- Selected existing hot water draw profiles appropriate for the locations chosen for testing.
- We selected two actual meterological year (AMY) weather files for the year 2021, for San Francisco and Cleveland, and in each weather file we selected a typical summer day to use for testing.

Table 3. Household characteristics of the building energy model

Household Characteristic	Building Energy Model Characteristics
Building Type	Owner-occupied, single-family home
Vintage	1970s
Size	1 story, 1,499 ft2 , 5 bedrooms
Foundation	Slab on grade foundation
Wall Construction	Wood frame, uninsulated, double-pane metal windows
Attic Construction	Vented attic, R-13 insulation
Air Tightness	15 ACH50

The Test log (Table 4) includes the list of tests, the start day and time, and notes describing any issues, observations, or lessons learned.

Table 4. Test log for B&B Technology Experiments

Test	Date	Start Time	Notes
San Francisco Summer Baseline	3/5/24	3:00 PM	Changed weather day to 8/27. No dishwasher. EV is ready.
Cleveland Summer Baseline	3/18/24	4:00 PM	Initially started ~3:45pm, but then stopped and restarted again at 4pm.
San Francisco Summer Experiment	4/17/24	2:00 PM	Set EV charging schedule to 6pm - 10 pm simulation time to allow charging to resume after Oven is on.
Cleveland Summer Experiment	4/18/24	2:10 PM	Using Denver_1D profile, but edited to add another big draw in the evening. Richard wanted to add second washer/dryer cycle right after the first set. So we will do that. Will amend baseline data to shift large loads to same start time as experiment case. *EV did not resume charging after oven was turned off. Not sure why as everything looked normal. Unplugged and re-plugged back in and charging resumed but ~30 minute delay
Cleveland Summer Experiment	4/19/24	3:00 PM	Re-running same water draw as Cleveland Summer case with WH in ER mode
San Francisco Summer Experiment	4/21/24	12:00 PM	Re-running same water draw as San Fran Summer case with WH in ER mode (Eaton_H1_Aug25) Reverted to Heat pump soon after test started.
San Francisco Summer Experiment	4/29/24	10:40 AM	Started Eaton_H1_Aug25 draw profile with HPWH in ER mode

Task 4: Report and Test Measurement Data

What follows is a summary of the baseline and experimental test run by the NREL team with results shown in Figure 4 through Figure 11, followed by the description of the findings from these tests.

Baseline Testing:

Figure 4 shows the current draw from the San Francisco Summer Baseline test.

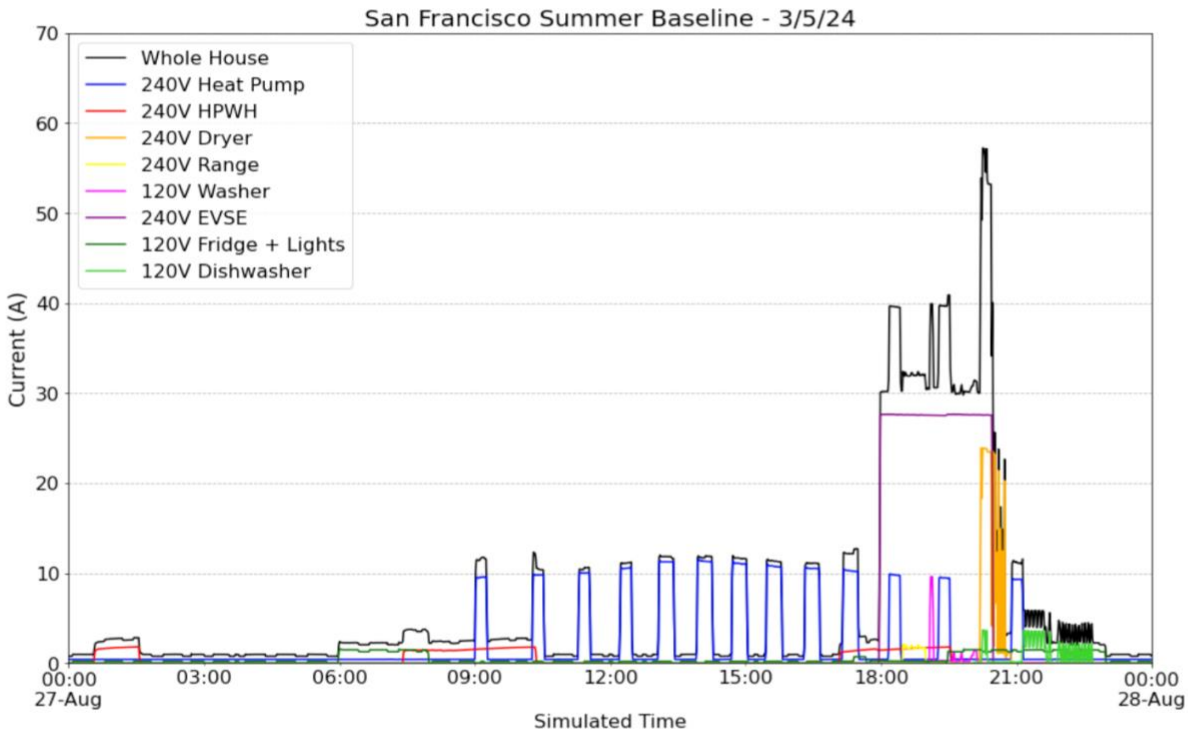

Figure 4. Appliance-level and whole home current draw for San Francisco summer baseline test

Figure 5 shows the current draw from the Cleveland Summer Baseline test.

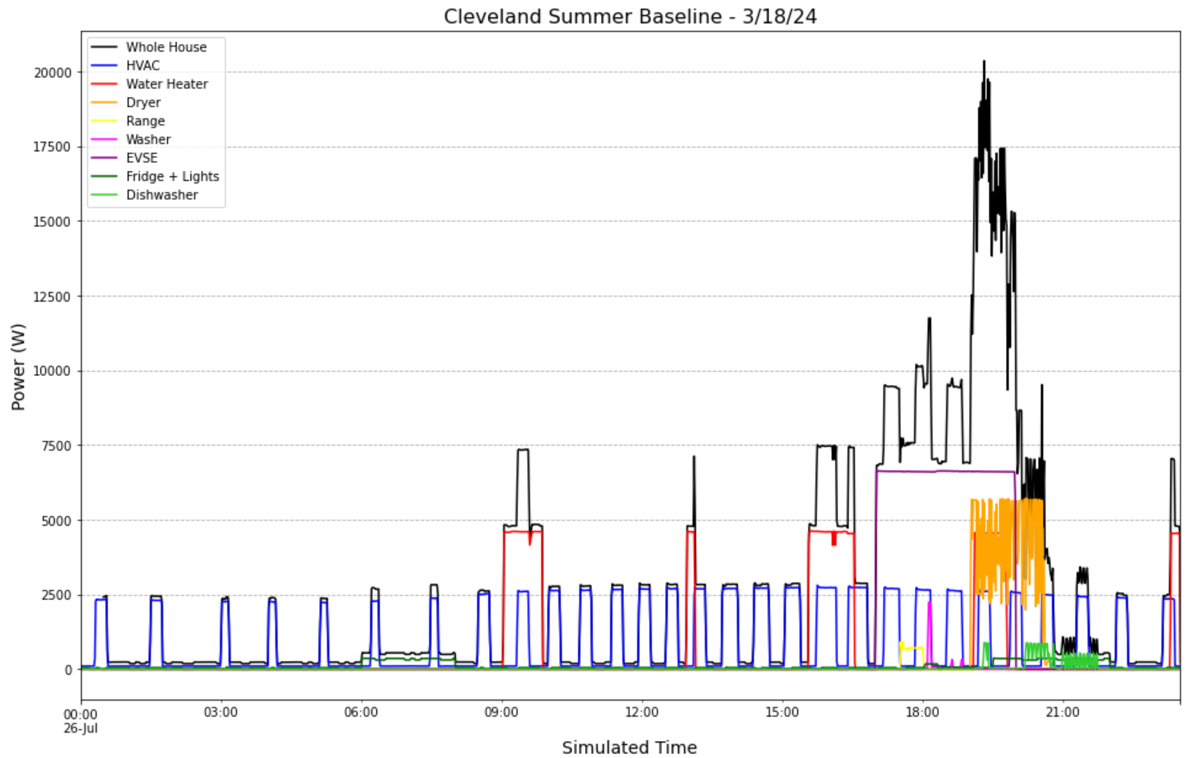

Figure 5. Appliance-level and whole home current draw for Cleveland summer baseline test

Experimental Testing:

San Francisco Summer Experiment

The-day-in-the-life power profile is depicted in Figure 6. Power data from the San Fransisco summer experiment day. This profile illustrates the power drawn from the panel (Black), as well as from the hot water heater (Yellow) and the electric clothes dryer (Blue). The power drawn from these appliances is provided by the inverter and, therefore, does not reflect in any additional instantaneous loads from the home power panel. Specifically, when the water heater is on (Yellow), the home power drawn from the panel (Black) does not reflect the equivalent power increase. Similarly, the power usage of the electric clothes dryer (Blue) is not reflected in the home power from the panel (Black) indicating no corresponding increase in power demand.

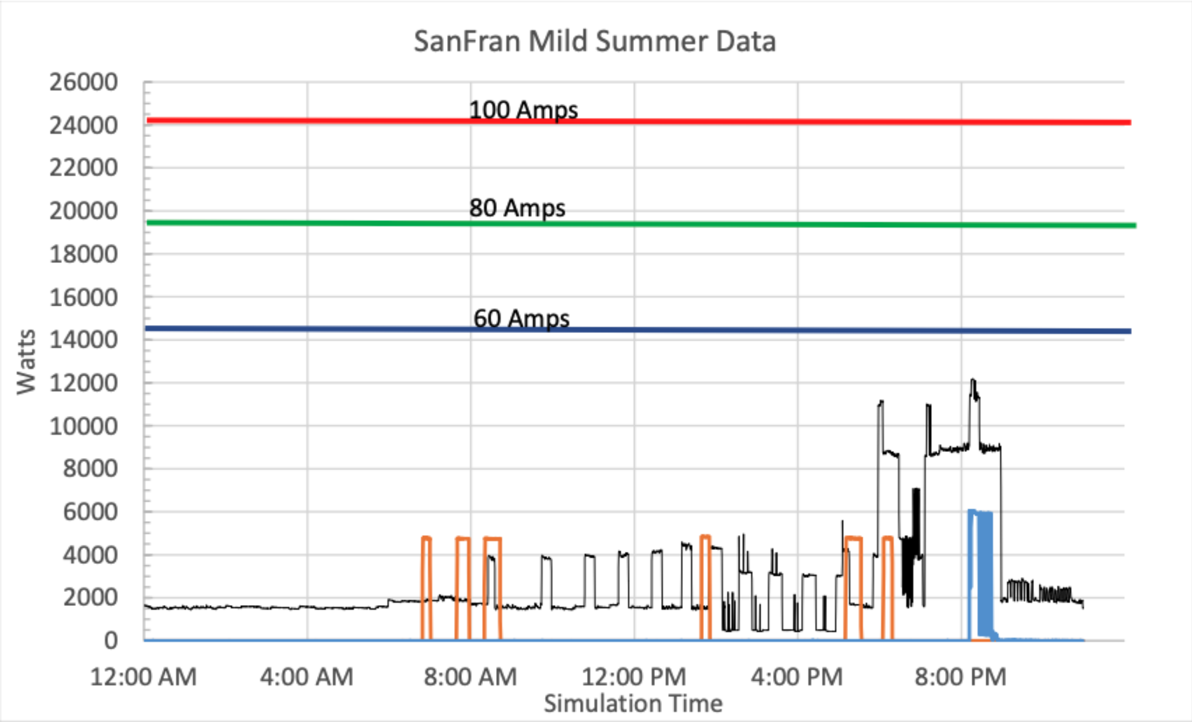

Figure 6. Power data from the San Fransisco summer experiment day.

Referencing Figure 6. Power data from the San Fransisco summer experiment day., it is notable that the total home power drawn from the panel measurement (Black) peaks at 12,000 Watts or 50 Amps. This level is significant as it stands at 50% below the example home(s) outlined in the EAS-E challenge rules.

Referencing Figure 7, the battery capacity (Red) begins at full charge and drops to 92% capacity. Additionally, Figure 7 illustrates the power draws of the electric dryer and electric water heater power. As per the solutions document, these two appliances are connected to the SimpleSwitch 240, which shares the power with the appliances in a manner that permits only one appliance to operate at a time. Therefore, the electric dryer drawing 6,000 Watts remains below 90% of the capability of the 8000-Watt inverter.

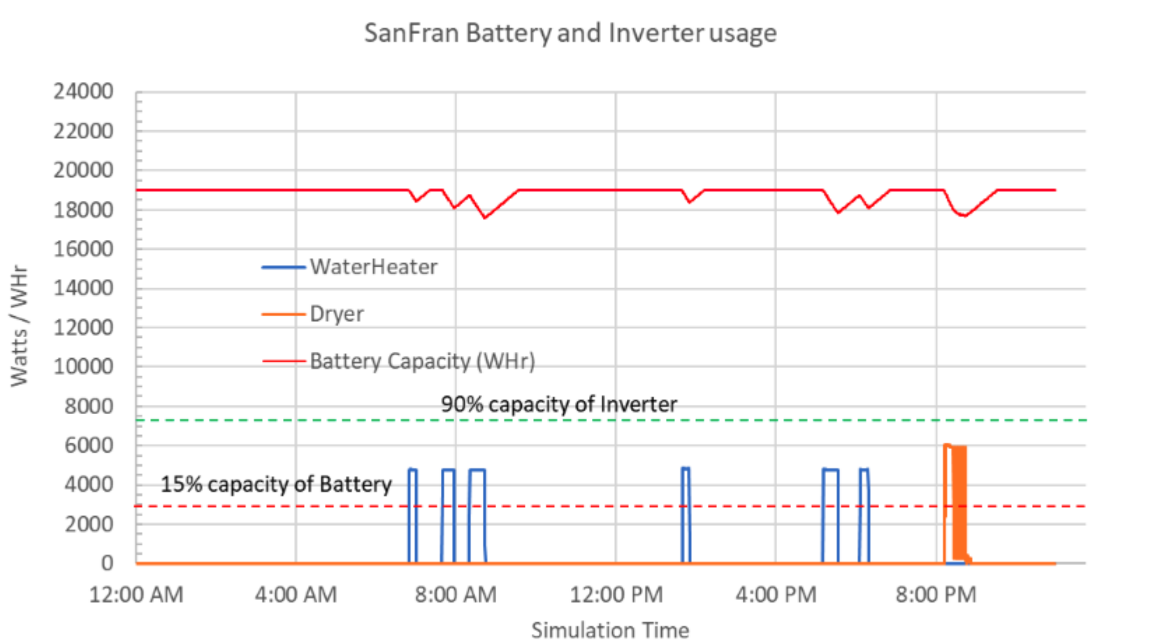

Figure 7: Battery and inverter usage from a San Francisco mild summer

Referring to Figure 8, both the hot water temperature outlet (Orange), and the average hot water temperature (Blue) inside the tank consistently remain above 110°F, even during hot water usage. Although the graph may pose challenges in interpretation due to fluctuating measurement locations, it’s evident that the outlet temperature consistently exceeds the tank temperature, suggesting that the placement of the sensor is influenced by incoming cold water while the outlet remains consistently hot. Upon analysis, it's apparent that the hot water temperature remains unaffected by the power management system.

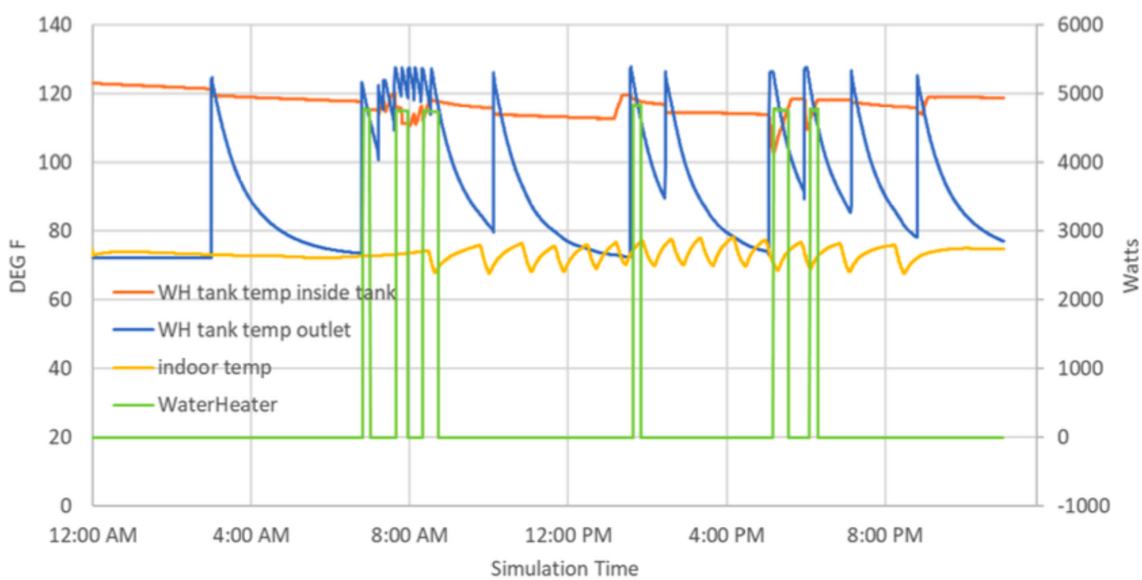

Figure 8: Hot water and home inside temperatures from San Francisco mild summer

Cleveland Summer Experiment

The hot summer day simulation included additional occupants that contributed to increased hot water usage and greater utilization of the clothes dryer. The day-in-the-life power profile, illustrated in Figure 9, delineates the power drawn from the panel (Black), as well as from the water heater (Yellow), and the electric clothes dryer (Blue). Importantly, the power drawn from these appliances is provided by the inverter and, therefore, does not reflect in any additional instantaneous loads from the home power panel. Specifically, when the water heater is in use (Yellow), the power drawn from the panel (Black) does not reflect the equivalent power increase. Similarly, the power consumption of the electric clothes dryer (Blue), is not reflected in the overall home power draw from the panel (Black), demonstrating no concurrent increase in power demand.

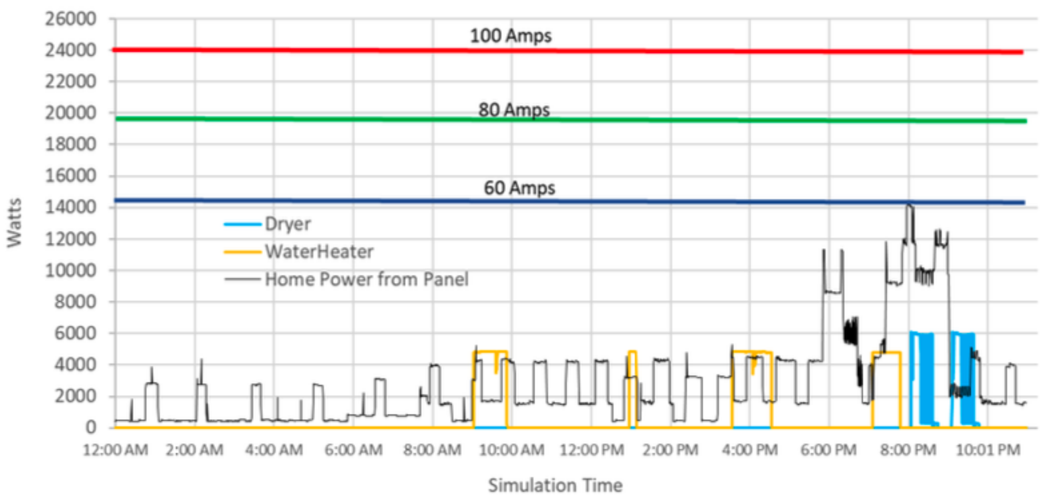

Figure 9: Power Usage from Cleveland hot summer

Referencing Figure 9, the total home power from the panel measurement (Black) peaks at a total draw of 14,000 Watts or 58 Amps. This level is noteworthy as it is 58% below the assumed power capacity of example homes outlined in the EAS-E challenge rules, which assume 100-amp panels.

Referencing Figure 10, the battery capacity (Red) indicates that a full charge carried over from the previous day and subsequently decreased to 77% capacity. Furthermore, Figure 10 displays the power draws of the electric dryer and electric water heater. These appliances operate within the power management system's parameters, contributing to the system's overall efficacy in load management.

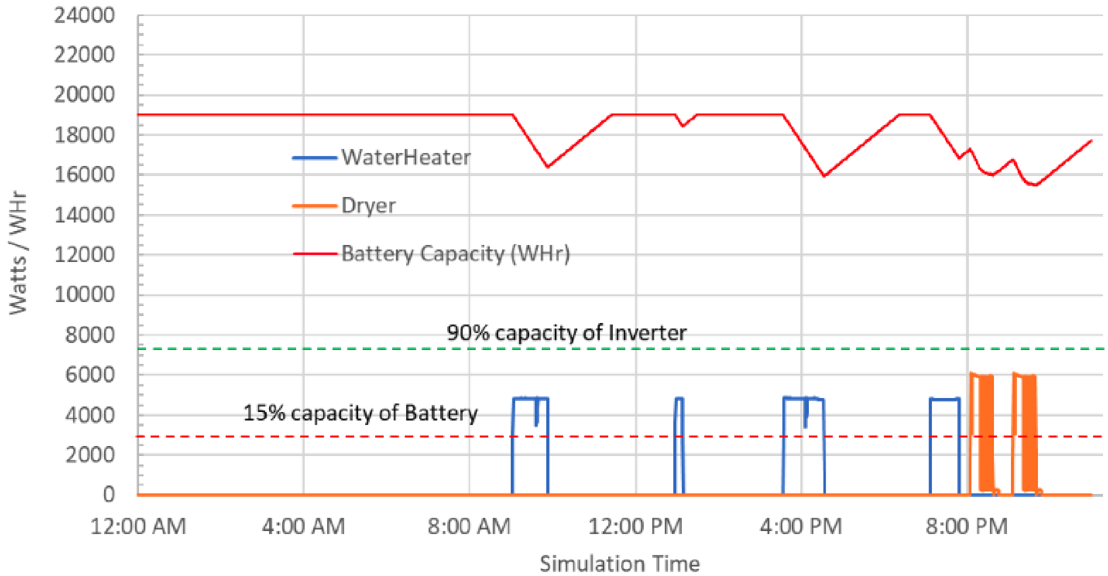

Figure 10: Battery and inverter usage from Cleveland hot summer

Referencing Figure 11, it is observed that both the hot water temperature outlet (light orange), and the average hot water temperature (Blue) within the tank consistently remain above 110°F even during hot water usage. It's evident that the outlet temperature remains relatively stable during use but drops once the usage ceases, indicating a return to normal conditions. Additionally, it's noteworthy that the outlet temperature consistently exceeds the tank temperature, suggesting that the placement of the tank temperature sensor is influenced by incoming cold water while the outlet remains consistently hot. Furthermore, referencing Figure 11 again, it's noted that the indoor temperature (orange) consistently stays within 10 degrees of the thermostat setting.

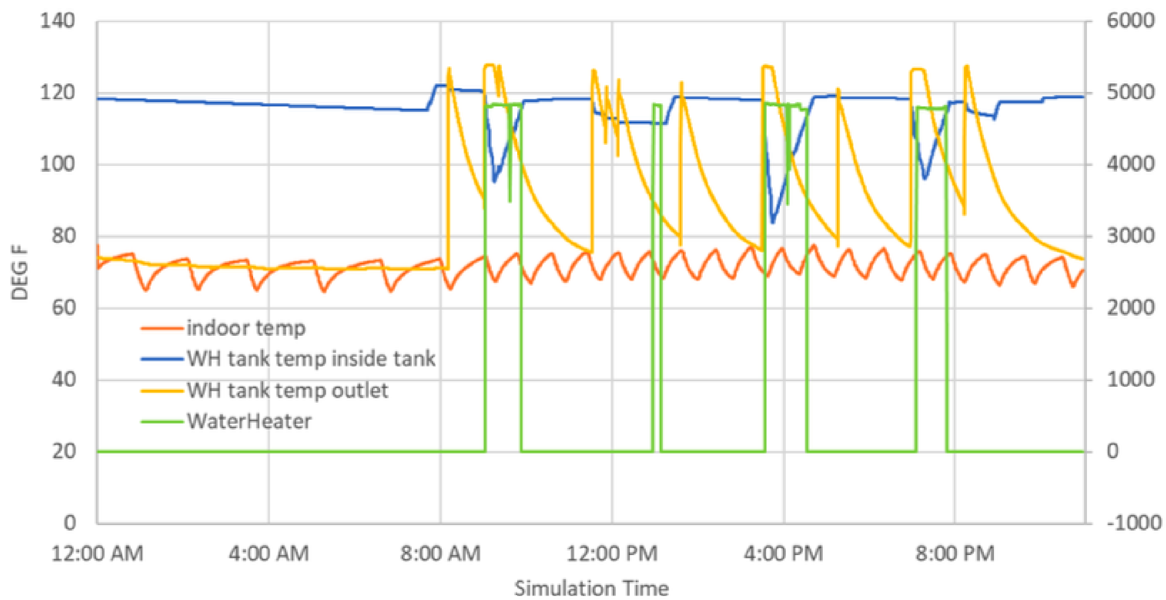

Figure 11: Hot water and inside home temperature from Cleveland hot summer

Task 5: Additional Tasks

Contractor will perform other work at the direction of the Participant, consistent with the scope and subject to the availability of funding.

No additional Tasks were competed.

Task 6: CRADA final report

This report serves to meet the requirement for the CRADA Final Report with preparation and submission in accordance with the agreement's Annex A – Statement of Work.

References: None

Subject Inventions Listing: None

ROI#: None