FSEC Energy Research Center

UNIVERSITY OF CENTRAL FLORIDA

Connected Water Heater Load Shifting and Energy Efficiency Evaluation for the Southeast: Winter Laboratory Assessment, Final Report

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Executive Summary

The University of Central Florida's FSEC Energy Research Center (FSEC) and Pacific Northwest National Laboratory (PNNL) are conducting laboratory electrical load shifting experiments using the CTA-2045-A standard to demonstrate the viability of grid-connected heat pump water heaters (HPWH), compared to electric resistance water heaters (ERWH), in providing load shifting in the Southeastern United States (U.S.). The investigation applied different CTA-2045 shed and critical peak (CP) control command designs under two different water draw profiles. The highly-controlled laboratory experiments were conducted on four HPWHs and one ERWH from December 2020 through February 2021.

The research aimed to evaluate the load shifting potential of grid-connected HPWHs in a high-impact region. A secondary objective was to evaluate energy efficiency implications of HPWHs compared with ERWHs that comprise greater than 73% of water heaters in the Southeastern U.S. (DOE/EIA, 2015)[1].

Two hot water draw profiles were implemented in the FSEC Hot Water Systems Laboratory (HWS) in Cocoa, Florida. Using electronically controlled solenoids, all of the tested systems were simultaneously subjected to the same draws with flows and temperatures carefully measured as well as electrical power demand, room temperature, and outdoor temperature. Data were collected at a one-minute interval, which were then aggregated into 15-minute bins, commonly used for utility load evaluations across the U.S.

Two draw profiles were used, an evening-weighted 47-gallon draw profile (most typical of year round consumption) and a Northwest Energy Efficiency Alliance (NEEA) 4-occupant profile (57 gallons) morning weighted draw profile to represent higher hot water use households. A three-hour morning curtailment (6 – 9 AM) and four-hour evening curtailment (4 – 8 PM) were defined as the shed or critical peak periods to reflect periods of maximum utility coincident load when system-wide electric demand reductions are of high value.

Tests were performed under baseline conditions (i.e., no load shifting commands) and then four different load shifting schemes: one-hour load up followed by a shed period, two-hour load up followed by a shed period, one-hour load up followed by a CP period, and two-hour load up followed by a CP period. The load up command calls on the water heater to raise the tank temperature up to its set point ahead of the shed or CP period. A longer load up period is intended to fully charge hot water storage. This longer length is likely more important to HPWH compressors with a limited capacity compared to larger resistance elements in ERWHs.

Tests were conducted under varying weather conditions with temperatures for tests grouped into "mild" and "cool" as reflecting winter conditions in Central Florida. These clusters did not include the coldest of days, as we desired to find clusters with a baseline as well as all grid-connected schemes tested. Separately there is one colder winter day presented (February 3rd, 2021) which in Florida consisted of low temperatures below 40°F. This day is of particular interest as it most closely represents a day when Florida utilities experience their maximum annual electric demand from many customers

[1] This includes the South Atlantic division, comprised of Delaware, the District of Columbia, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, and West Virginia, and the East South Central division comprised of Alabama, Kentucky, Mississippi, and Tennessee.

engaging electric-resistance space heating as well as increased hot water energy consumption.

Figure E-1 shows the 57-gallon draw profile for cool conditions with the various water heater models plotted over the 24 hour cycle. The CP signal is sent to all units to avoid the morning and evening peak. A one-hour "load up" signal is sent to the water heaters prior to the peak. The ERWHs exhibit a much larger magnitude of power use as reflected in the ~5 kW heating elements in use in these tanks. For comparison, modern HPWH compressors draw only ~0.4 kW—less electric demand than ERWHs by more than an order of magnitude.

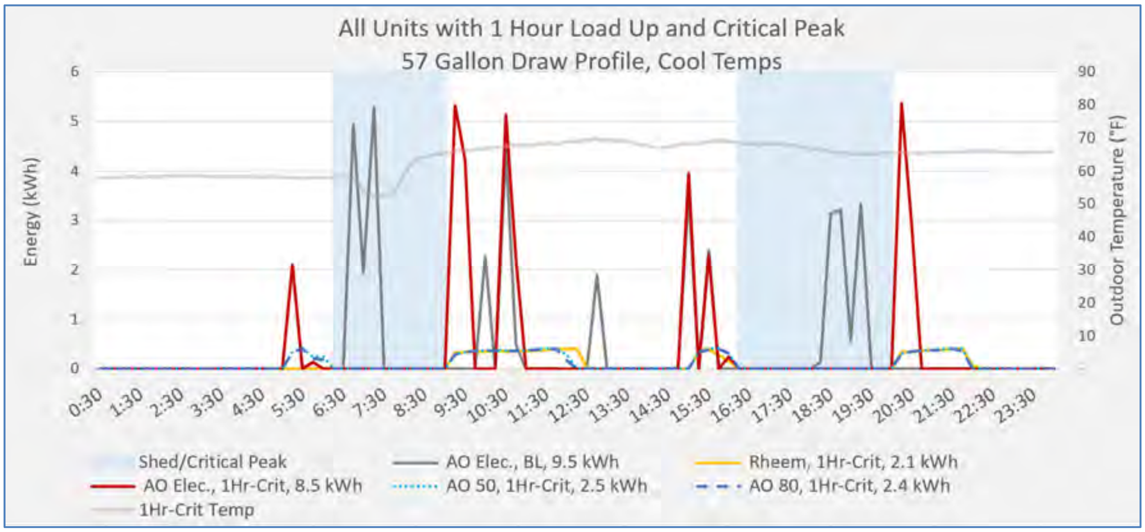

Figure E-1: Evaluation of all WH systems with Critical Peak signal & cool weather conditions. Gray is ER baseline -- unconnected; red is grid-connected.

The unconnected ERWHs had a maximum 15-minute demand of 5.28 kW across the morning peak period, and 3.34 kW during the evening peak period. In contrast, all of the HPWH systems (A.O. Smith 50- and 80-gallon models as well as the Rheem 50-gallon model) were able to avoid electrical demand entirely during the peak periods in response to the CP signal. However, some differences were seen by tank size and manufacturer. As shown within the report, the CP signal appeared more effective at eliminating peak across all tank types than the Shed command.

Figure E-2 shows the load reduction on the coldest day where outdoor temperatures dropped to 37ºF, (but with no baseline on a day with those temperatures). It is confined to only the HPWH systems for increased resolution. This can be considered the most extreme case in terms of load and outdoor temperatures, which impacts a water heater's ability to shift load. In this case, all but the smaller A.O. Smith 50-gallon HPWH were able to avoid electrical demand during peak.

For the coldest day, the maximum demand during the morning peak period on a 15-minute basis was 0.00 kW for the Rheem 50-gallon unit, 0.36 kW for the A.O. Smith 50-gallon unit, and 0.01 kW for the A.O. Smith 80-gallon unit. The ERWH, which also implemented the shed command, showed 1.46 kW for comparison. The average kW demand across this three-hour period for the three water heaters was 0.00 kW (50-gallon Rheem) 0.21 kW (50-gallon A. O. Smith), 0.00 kW (80-gallon A.O. Smith), and 0.31 kW for the ERWH. An important conclusion from this test is that not only do the grid-connected HPWHs provide large reductions on peak against unconnected ERWHs,

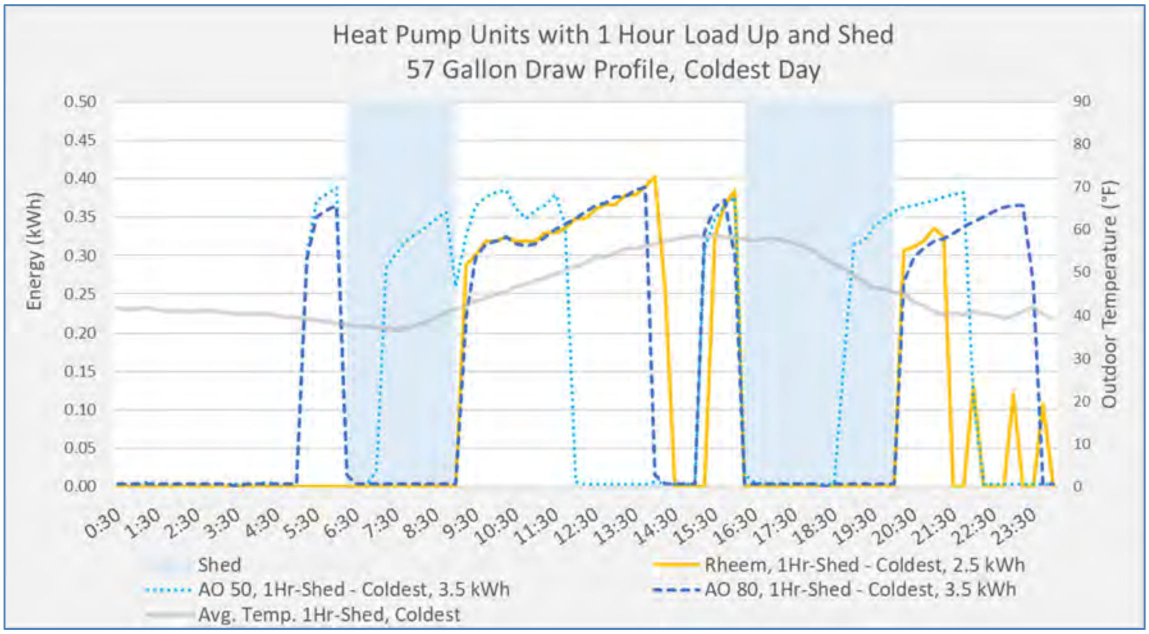

Figure E-2: Evaluation of grid-connected HPWH systems with Shed signal sent under coldest weather conditions.

they also provide sizable reductions against grid-connected ERWHs. Also, among the HPWHs, the 80-gallon A.O. Smith model shifted considerably more load on the coldest day than that manufacturer's 50-gallon unit.

In the report, tested influences are shown in detail. Below we highlight findings:

- All of the load shifting schemes were able to provide meaningful avoidance of peak periods, although the CP signal used with the ERWH results in a large "payback" of over 5 kW in the hour after release of control. On the cool baseline day (a bit milder than the coldest day), the average kW across the morning peak period of the unconnected ERWH was 1.02 kW under the 57-gallon draw profile with a maximum 15-minute demand of 5.28 kW.
- The grid-connected HPWHs typically used only about 25% of daily electricity for water heating used by ERWHs. The unconnected ERWH used about 8-9 kWh per day against about 2 kWh per day used for controlled HPWHs. Notably, HPWH daily energy use is only about the magnitude of refrigerator consumption in measured households.
- Average water heater inlet temperatures during draws averaged 68.5°F over the period and ranged from 63.5ºF to 74.3ºF. The relatively high inlet water temperature in Central Florida substantially reduces water heating load relative to colder climates such as the Pacific Northwest, while the higher ambient temperatures (> 45°F) result in HPWHs infrequently using electric-resistance back-up. Average daily minimum temperatures during the "cool temperature" cluster ranged from 45.5°F to 62.3 °F.

- Grid-connected HPWHs have similar daily electricity consumption compared with unconnected HPWHs (~2.0 kWh/day for daily 47-gallon draws and ~2.4 kWh/day for the 57-gallon draws).
- Manufacturer control algorithms for the water heater response to a CP command successfully avoided on-peak power for all tested models, although the Rheem HPWH delivered lower hot water outlet temperatures.
- Cooler weather conditions impacted the ability of A.O. Smith 50-gallon HPWH to completely shift load under the shed command, while the Rheem 50-gallon HPWH consistently shifted load. The Rheem HPWH's minimum delivered water temperature was about 4°F lower than the A.O. Smith units, but at 117°F, not problematic for hot water use purposes.
- The two-hour load up versus one-hour load up showed improvement in load shed for the smaller capacity 50-gallon A.O. Smith HPWH during the longer evening peak period.
- The 80-gallon A.O. Smith HPWH was able to more successfully avoid on-peak demand than the 50-gallon A.O. Smith HPWH for the cooler temperatures with the 57-gallon draw profile. The Rheem HPWH avoided on-peak demand in all tested configurations although with slightly lower delivered hot water temperatures.
- Evaluation of the outlet hot water temperatures during on peak draws for all tested tanks and configurations showed that the lowest outlet hot water temperature was ~117°F—well above the 110°F level where problems with useful hot water service temperatures emerge.
- Examination of the one-minute resolution data showed no incidence of HPWH back-up electric resistance element operation during the chosen days for the analysis. The higher ambient temperatures surrounding the water heaters in Florida's climate increases compressor COP and avoids the temperatures where electric resistance heating typically activates, often around 35°F-37°F[2].

The fundamental conclusion from the FSEC laboratory study is that grid connected HPWHs can provide large and dependable electric demand reduction from CTA-2045 load shed and critical peak commands relative to ERWHs in Southeastern U.S. climate—up to ~1 kW from laboratory results. In addition, the grid-connected HPWHs were able to reduce peak demand by as much as 0.4 kW, depending on unit, time of day, control scheme, draw profile, and temperature cluster, over the non-controlled HPWH. Factors observed within the study should inform the optimization of field performance by consideration of influences. Results may also be useful to manufacturers implementing the CTA-2045-A, or the newer CTA-2045-B protocol.

[2] https://www.geappliances.com/ge/heat-pump-hot-water-heater/water-heater-faq.htm, https://www.home-water-heater.com/rheem-heat-pumps.html, https://www.geappliances.com/ge/heat-pump-hot-water-heater/water-heater-faq.htm

Table of Contents

Executive Summary 2

Introduction 9

Test Facility 11

Experiments 14

Evaluation Method 16

Results 17

Caveats 29

Conclusions 30

References 33

Appendix A: Weighted Average and Minimum Outlet Temperatures 34

Appendix B: Peak Demand at 8:00AM and 5:00PM and Average during Peak Morning and Evening Hours 36

Appendix C-1: All Units Compared per Command Structure – 47 Gallon, Cool Temperatures 38

Appendix C-2: All Units Compared per Command Structure – 47 Gallon, Mild Temperatures 40

Appendix C-3: All Units Compared per Command Structure – 57 Gallon, Coldest Day and Cool Temperatures 43

Appendix C-4: All Units Compared per Command Structure – 57 Gallon, Cool Temperatures 46

Appendix D-2: All Command Structures Compared per Unit – 47 Gallon, Mild Temperatures 51

Appendix D-3: All Command Structures Compared per Unit – 57 Gallon, Cool Temperatures 53

Appendix D-4: All Command Structures Compared per Unit – 57 Gallon, Mild Temperatures 55

Appendix E: Total Daily and Peak Hours Water Heater Energy 57

Table of Figures

Figure 1. E-Radio P2D 2045 Unitary Control Module. 11
Figure 2. FSEC's hot water research test facility. 12
Figure 3.Five-year (2009–2013) compilation of inlet water temperatures (°F) at the HWS laboratory from 2009 through 2013. 13
Figure 4. FSEC Infomointors site for CWH test facility metrics monitoring. 13
Figure 5. FSEC hot water test facility draw profiles for connected water heater experiment. 15
Figure 6. Comparison of electric resistance controlled and unconnected vs. grid-connected HPWH under mild conditions. 19
Figure 7. A.O. Smith 50-gallon HPWH load shifted using the one-hour load up and shed during cold versus mild weather. 20
Figure 8. A.O. Smith and Rheem 50-Gallon HPWHs demonstrating no change in load reduction using the one-hour load up and shed between mild and cooler weather. 20
Figure 9. Heat pump units under two-hour load up and shed during cooler weather – The A.O. Smith unable to shed for duration; Rheem unit avoids load during peak periods. 21
Figure 10. Little difference seen among different manufacturers and tank volumes for 1-hour load up and critical peak control scheme under mild weather. 22
Figure 11. Difference between manufacturer and unit: Little difference seen for Critical Peak; However, differences seen with the Shed command. 22
Figure 12. One hour load up and shed loses control with 50 gallon A.O. Smith unit and compressor is activated. 23
Figure 13. Critical peak strategy shows no demand from any of the tanks during the two peak periods. 23
Figure 14. The A.O. Smith 80 gallon unit much more successful at avoiding electrical demand during morning and evening peak periods with one-hour load up. 24
Figure 15. The Rheem 50-gallon HPWH successfully avoids running during peak hours under all command strategies. 25
Figure 16. When responding to a shed command, the two-hour load up improves the A.O. Smith 50 gallon HPWHs ability to avoided some peak hour run time. 25
Figure 17. The A.O. Smith 80 gallon HPWH successfully avoids running during peak hours under all command strategies. 26
Figure 18. When responding to a shed command, A.O. Smith 50 gallon electric resistance unit is unable to compete avoid peak hour run time. 27
Figure 19. AO Smith 50 gallon HPWH does not completely avoid run time during one-hour load up and shed under the 57 gallon draw profile. 28
Figure 20. 50 gallon AO Smith HPWH does not completely avoid run time during one-hour load up and shed under the 47 gallon draw profile. 28
Figure 21. Average monthly water heating demand profiles from 186 sub-metered electric water heaters (Masiello and Parker, 2000). 30

Table of Tables

Table 1. Percentage of Electric Water Heaters in Southeastern U.S. by Housing Type .. 10
Table 2. FSEC Test Facility Water Heater Model Numbers, Capacity and UEF............. 12
Table 3. Draw Profiles 14
Table 4. Grid-connected Command Schedules.. 15
Table 5. Evaluation Days for Each Grid-connected Command Schedule, by Draw Schedule and Temperature Cluster 17
Table 6. Daily Weighted Average and Minimum Outlet Temperatures During the 57 Gallon Draw Profile Under Mild Temperatures 17
Table 7. Peak Demand at 8:00AM and 5:00PM and Average during Peak Morning and Evening Hours 18
Table 8. Delivered Water Temperatures Under Shed vs. Critical Peak Grid-connected Commands 24
Table 9. Daily and Peak Hours Water Heater Energy Under Baseline and All Command Structures 29

Introduction

Scope and objectives

The University of Central Florida's FSEC Energy Research Center (FSEC), in coordination with the Pacific Northwest National Laboratory (PNNL), is conducting load shifting experiments using the ANSI CTA-2045-A protocol to demonstrate the viability of heat pump water heaters (HPWH) to provide load shifting, relative to electric-resistance water heaters (ERWH) in the Southeast United States (U.S.). The study entails applying different CTA-2045 load up, shed, and critical peak control commands designs under varying hot water draw profiles.

The volume of hot water used per day in households varies due to various influences, including the number of occupants, hot water fixtures, and occupant behavior. Parker, Fairey, and Lutz studied hot water demand in 105 North American households and found an average gallons-per-day (GPD) of 51, but with a standard deviation of 25 gallons (Parker et al., 2015). They also found that volumetric consumption varied with weather conditions (i.e., outdoor ambient temperature, relative humidity) such that hot water demand is higher under cold conditions, primarily due to occupant behavior. This means higher water volumes will be used on the coldest days since the mains water temperatures vary with outdoor temperature (Burch and Christiansen, 2007). Additionally, water heater performance, and specifically that of HPWHs, is influenced by weather in the following ways:

1. A heat pump's coefficient of performance (COP) is sensitive to ambient air temperatures around the compressor. The colder the air temperature surrounding the compressor the weaker the HPWH's ability to meet load because there is less heat available to extract from the air.
2. The colder the air temperature surrounding the tank the greater the standby losses due to thermal transfer.
3. The colder the inlet water temperatures the greater the load on the water heater because a greater change in water temperature change is required to delivered the desired temperature.
4. The colder the average tank temperature (which is colder with colder inlet water after draws), the higher the HPWH's COP.

Winter peak water heating loads are likely to be higher and the inlet water temperatures low, resulting in more rapid stored water mixing. Elevated hot water energy consumption on the coldest days has been observed in a monitored earlier load control program of approximately 153 ERWHs in Florida (Bouchelle et al., 2000). The combination of hot water consumption behavior and weather-influences make it important to research grid-connected HPWH operation in the field.

A secondary objective of this research was to evaluate energy efficiency implications of HPWHs compared with ERWHs which comprise greater than 73% of water heaters in the Southeastern U.S. (DOE/EIA, 2015)[3]. The percentage of electric water heaters broken down by occupancy type is provided in Table 1.

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[3] This includes the South Atlantic division, comprised of Delaware, the District of Columbia, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, and West Virginia, and the East South Central division comprised of Alabama, Kentucky, Mississippi, and Tennessee.

Table 1. Percentage of Electric Water Heaters in Southeastern U.S. by Housing Type

Housing Type	Percent of Sample	Percent of Water Heaters that are Electric
Manufactured Homes	8.6%	97.6%
Single Family Detached	65.9%	67.9%
Single Family Attached	9.9%	69.7%
Apartments, 2-4 units	4.9%	77.1%
Apartments, >4 units	10.6%	81.6%

Data compiled from DOE/EIA 2015 Residential Energy Consumption Survey.

This report focuses on the tests of three HPWHs and one ERWH. Results from these tests span December 2020 through February 2021. We established the following research questions to guide our evaluation:

Research questions

1) What is the indicated magnitude of the controlled HPWH load reduction (and electric resistance back-up) versus unconnected units during peak periods, and compared to ERWHs?
2) What is the success of load reduction during peak periods for HPWH by test under cooler weather conditions?
3) What is the success of load reduction during peak periods by unit manufacturer and unit?
4) What is the success of load reduction during peak periods by control strategy?
5) Can differences be seen in the success of load reduction during peak period by the gallons of storage tank volume?
6) How does the success of load reduction during peak periods vary depending on load up strategy?
7) How is the success of load reduction during peak periods seen by the specific draw profile?
8) What is the impact on energy use when peak load reduction is achieved?

Background

Current HPWHs and some ERWHs available for purchase are compatible with CTA-2045-A protocol (ANSI/CTA, 2018). This protocol has demonstrated demand flexibility in the Northwest, to provide a utility the ability to control when an appliance draws power from the grid (Metzger et al 2018).

The CTA-2045 protocol standardizes both the hardware interface between a communications module and 'smart' appliance, as well as the language for communication. Unitary Control Modules (UCM) can be attached to conforming appliances, enabling dedicated, digital control of the appliance using the CTA-2045 protocol, and allowing electricity providers to communicate with end uses over the standard interface. PNNL chose E-Radio, developer of control services such as appliance owner apps and utility provider interfaces, for the communications integration on this project. E-Radio's UCM for AC communication is pictured in Figure 1.

Figure 1. E-Radio P2D 2045 Unitary Control Module.

The communications standard specifies messages, called commands, that each CTA-2045 enabled device must support. The current CTA-2045-A communications commands for water heaters include:

- Load up: operate now and attempt to raise the water temperature to its set point
- Shed load: avoid operation to allow the present stored energy level of the tank to decrease
- End shed: return to normal operations
- Critical peak: avoid operation and more aggressively allow the present stored energy level of the tank to decrease
- Emergency Shutdown: avoid operation until emergency ends
- Operate at specific duty cycle

Water heater manufacturers determine how different water heaters respond to the control commands and thus differences in implementation exist. To date, the commands executed in the experiments conducted at the FSEC hot water research test facility include shed load, end shed, critical peak, and load up. See the Experiments section for more detail.

Test Facility

FSEC's hot water systems (HWS) test facility (Figure 2) located in central Florida is a 10 foot by 16 foot structure, with uninsulated vinyl siding walls and a white metal roof. The facility was established for comparing the overall performance of a large number of residential hot water systems side-by-side and has been operating since 2009. The small 160 square foot building houses five water heaters with a tight side-by side layout configuration. The HWS has been instrumented for measurements of a water heater's energy use, inlet flow rates, inlet and outlet water temperature, as well as the laboratory's indoor and outdoor temperatures. Hot water draws are measured with positive displacement flow meters, which are also used as feedback control mechanisms. The test facility is designed for computerized solenoid activated draw patterns.

Figure 2. FSEC's hot water research test facility.

Equipment

The five water heaters evaluated in the FSEC test facility, characterized in Table 2, were installed in December 2020. Due to testing delays, the GE unit was not evaluated for this time. For the experiments, the water heaters were all set to deliver temperatures of 125°F which is essentially identical to the audited hot water. Bouchelle et al (2000) found average tank set points of 127.4°F in a sample of 138 Florida homes.

Table 2. FSEC Test Facility Water Heater Model Numbers, Capacity and UEF

Manufacturer	Model	Technology	Capacity	Uniform Energy Factor
Rheem	XE50T10H45UO	HPWH	50	3.75
A.O. Smith	EG12-50H	ERWH	50	0.93
A.O. Smith	HPTU-50N	HPWH	50	3.45
A.O. Smith	HPTU-80N	HPWH	80	3.45
GE/Haier	Prototype	HPWH	50	N/A

Instrumentation and Monitoring

The HWS laboratory automated instrumentation and controls are programmed into a Campbell Scientific CR10X which executes measurements every 12 seconds. Scanned data are then averaged (e.g., temperature) or totaled (e.g., watt-hour pulses) into 1-minute intervals, stored, and time-stamped into final memory. A custom program takes into consideration the hot water draw events that occur during the day. Inlet water temperatures are physically measured using ungrounded immersion well (stainless steel) type T thermocouples of special limit error (SLE +/-0.5ºC) positioned upstream of the flow meter at floor level to avoid convective temperature migration from the tank. Hot water outlet temperatures are also measured with immersion thermocouples at the system positioned less than 6 inches from the outlet port. The immersed thermocouple sensors are positioned to measure in a counter-flow direction. Additional processing routines were written to handle inlet and outlet temperatures to be averaged only during hot water draw events. The data are automatically uploaded twice per day via facilities network and archived under FSEC's Web Get database capabilities.

The annual weighted average inlet water temperatures experienced in the HWS are provided in Figure 3 to illustrate month-by-month inlet water temperature variability in Central Florida.

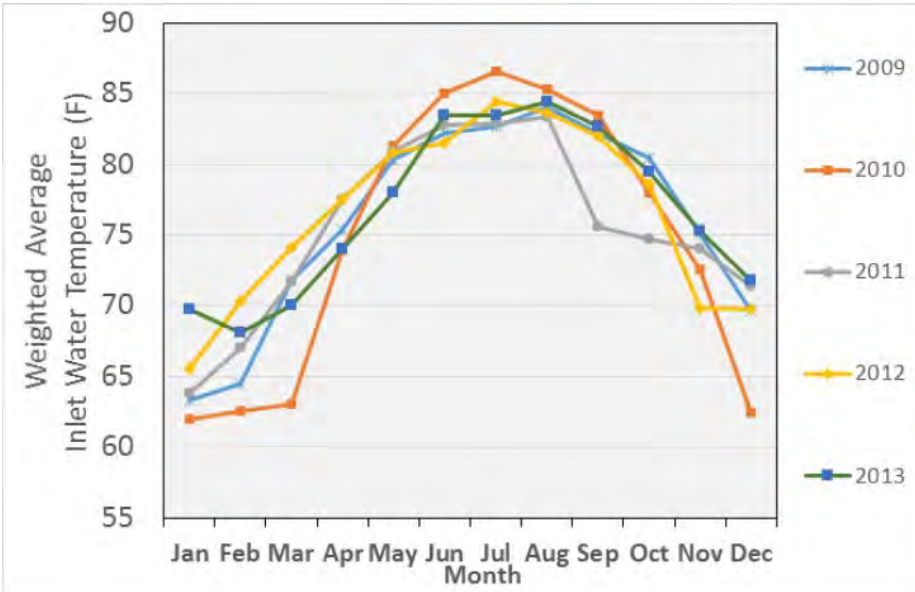

Figure 3.Five-year (2009–2013) compilation of inlet water temperatures (°F) at the HWS laboratory from 2009 through 2013.

Each unit is monitored daily for coefficient of performance (COP), and weighted average inlet and outlet temperature. An automated summary site was developed to provide quick snapshots of unit performance.: http://www.infomonitors.com/cwh/. An sample summary is provided in Figure 4.

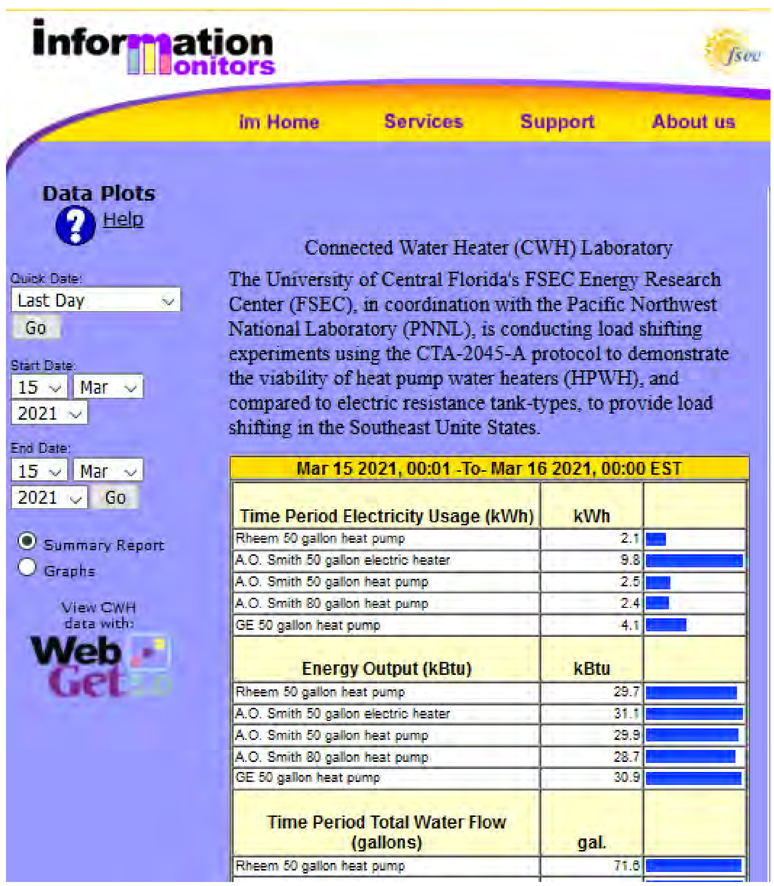

Figure 4. FSEC Infomointors site for CWH test facility metrics monitoring.

Experiments

Draw Profile and Grid-Connected Command Schedules

For the test facility evaluation, different water heater models were compared in their responses to combinations of the three draw profiles and four grid-connected command schedules, as designed by PNNL and FSEC. Each distinct test, as well as a baseline with no commands under each draw schedule, was run for one week at a time, with an attempt to do the same draw and command combination under varying weather conditions. Mild central Florida winters limit the number of tests that can be conducted during cooler weather – there are limited opportunities to conduct tests when the daily average temperature is below 60°F.

The two draw profiles tested and reviewed in this report are named the "PNNL – Medium" 47 gallons per day (GPD), and the "NEEA – 4 Occupant" 57 GPD, detailed in Table 3, and plotted in comparison in Figure 5. The shape of the two draw profiles differ in an important way. The PNNL profile is evening weighted with the implicit assumption of higher evening hot water use. The NEEA profile, on the other hand, aligns with common draw profiles with morning weighted draws, consistent with measured hot water energy demand and associated hot water consumption profiles seen in studies stretching back to the 1980s (Bouchelle et al., 2000; Fairey and Parker, 2004). The differing shape of the draw profiles is captured in Figure 5 in the cumulative gallons over time for the vertical draw events shown.

Table 3. Draw Profiles

47 Gallons/day (PNNL, Medium)			57 Gallons/day (NEEA, 4 Occupant)	
Time	Gallons		Time	Gallons
6:30	3		6:30	8
6:50	2		6:53	12
7:12	3		9:50	2
7:27	3		10:05	8
8:01	5		10:26	2
10:52	7		14:59	6
17:22	4		15:22	3
17:45	14		18:12	5
18:27	3		18:32	5
18:58	3		18:53	2
			21:25	4

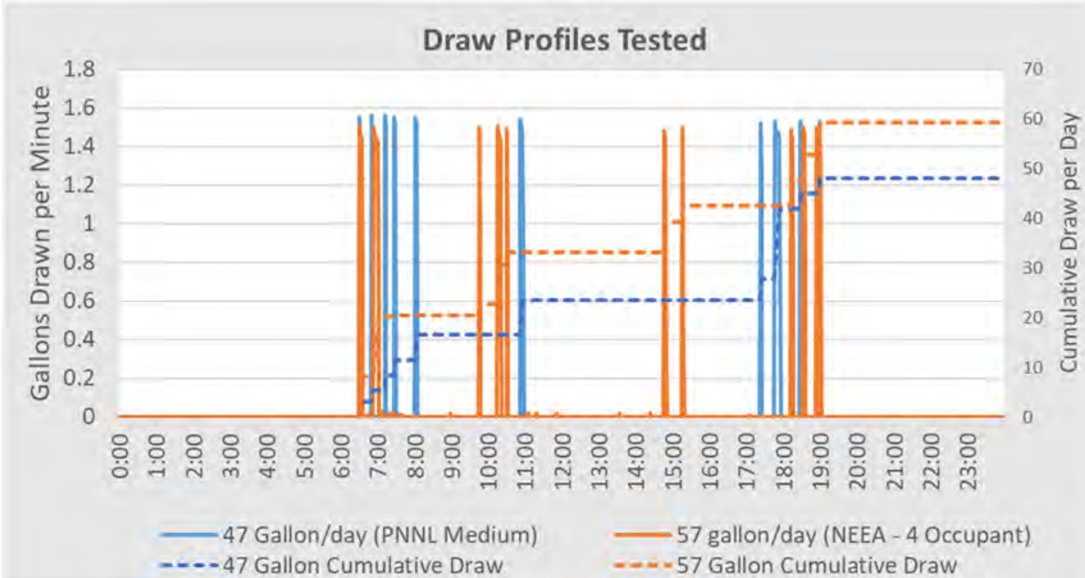

Figure 5. FSEC hot water test facility draw profiles for connected water heater experiment.

The four grid-connected command strategies issued to the test facility units for these experiments are a combination of a one- or two-hour load up and followed by a three-hour shed or critical peak period in the morning, and a one- or two-hour load up followed by a four-hour shed or critical peak period in the evening. A longer load up period was tested to see if it is needed to fully charge hot water storage. This longer load up is likely more important to HPWH compressors with a limited capacity compared to larger resistance elements in ERWHs. The evening peak curtailment length is slightly longer in the morning, each length to reflect periods of maximum utility coincident load when system-wide electric demand reductions are of high value. To help guide the signal timing, we referred to the Peak Demand hours reported by the Orlando Public Utilities via conversation, which, over four years preceding the COVID pandemic were 8:00 and 17:00 or 18:00, for morning and evening peak, respectively. The timing of these schedules are laid out in Table 4.

Table 4. Grid-connected Command Schedules

Time	Shed Schedules		Critical Peak Schedules	
	Schedule 1	**Schedule 2**	**Schedule 3**	**Schedule 4**
4:00-5:00		Load Up		Load Up
5:00-6:00	Load Up	Load Up	Load Up	Load Up
6:00-9:00	Shed	Shed	Critical Peak	Critical Peak
14:00-15:00		Load up		Load up
15:00-16:00	Load up	Load up	Load up	Load up
16:00-20:00	Shed	Shed	Critical Peak	Critical Peak

Unit Capabilities and Limitations

The GE 50-gallon HPWH is a prototype, not yet commercially available in the U.S. It is unique among the units tested in that it has the enhanced capability of heating the tank water 15°F above the tank set point, or ‘advanced load up’, a new command integrated into the CTA-2045-B protocol. The tank has two set points – a user set point and a tank set point. The advanced capability creates the need for an internal, integrated mixing valve as a safeguard against delivering scalding temperatures to occupants. The 'advanced load up' feature is triggered by sending the regular load up command for extended durations. The special capabilities of the GE prototype created some challenges for the laboratory testing:

- Outlet Temperature – The unit was delivered with a tank set point too high. GE provided researchers with an app with a real-time view, and ability to adjust the tank and user set points. Working with GE, we tested different user and tank points to eventually arrive at a 130°F tank set point to approximately deliver the targeted 125°F outlet temperature set for the other units being tested.
- Load Up vs. Advanced Load Up – For this experiment, the mechanism for triggering advanced load up with the load up command meant that conducting an ordinary load up, such as being sent to the other units, is not possible. As a compromise, the load up command is issued for an abbreviated length of time – long enough for the signal to be received, but not so long to trigger aggressive tank heating. Timing of the signal length, determined by trial and error.

Ultimately, data were lost for the GE HPWH through early February as we worked to resolve these issues. Thus, the evaluation for the GE unit will be conducted once more data are collected and will be reported upon in the final report. A final note on limitations, the GE prototype does not currently have the capability of accepting the Critical Peak command.

The Rheem unit experienced communications errors on a few occasions. When e-Radio sends a request for operational state, sometimes the Rheem unit did not receive or act upon the request, and thus no data was returned. This communication issue led to lost synchronization between e-Radio and the Rheem HPWH, resulting in errors in which 1-2 minutes of data were lost per day. To resolve the issue, e-Radio spaced out the timing of message transmissions to prevent the communications from falling out of sync. The modification involved changing the e-Radio module to use a more simplistic algorithm that is more tolerant of changes in timing on water heaters and adapters. This appears to have solved the problem. This error caused data loss for two days used in our evaluation: 1/3/21 and 1/22/21.

The 80-gallon A.O. Smith unit experienced improper water draws on 12/22/20. Also, this unit also had an intermittent temperature sensor error for many of the earlier days; this was corrected on 1/27/21.

Evaluation Method

Preliminary evaluations for the *PNNL - Medium* 47-gallon and *NEEA - 4 Occupant* 57-gallon draw profiles were conducted for this report. Data accessed for the evaluation herein were collected between December 20, 2020 through February 24, 2021. A cluster around a baseline day with cooler temperatures, and one with a more mild temperatures were identified for each draw profile, with temperature groupings determined by both the average daily and minimum daily outdoor temperatures. Within each draw profile and each temperature bin, we identified the best day for each command schedule comparison. In some cases not all command schedules existed within a temperature cluster and were excluded. Days chosen for evaluation for each command structure are identified by draw profile and temperature cluster in Table 5.

Table 5. Evaluation Days for Each Grid-connected Command Schedule, by Draw Schedule and Temperature Cluster

Command Schedule	47 Gallon, Cool	47 Gallon, Mild	57 Gallon, Cool	57 Gallon, Mild
Baseline	12/22/2020	12/20/2020	1/31/2021	1/27/2021
1 Hr. Load up, Shed	n/a	12/29/2020	2/6/2021	2/7/2021
2 Hr. Load up, Shed	1/6/2021	1/3/2021	n/a	2/11/2021
1 Hr. Load up, Critical Peak	1/14/2021	1/12/2021	2/21/2021	2/16/2021
2 Hr. Load up, Critical Peak	1/18/2021	1/22/2021	2/24/2021	2/27/2021

Using 15-minute data, energy use profiles were compared among baseline and command schedule days within each temperature cluster and draw profile. Daily energy use, peak hours energy use, peak demand, average outlet water temperature, and minimum outlet water temperature for all test days are summarized.

Results

The 57 GPD draw profile under mild temperatures is highlighted most often, for both its completeness in grid-connected command strategies, because it is more representative of a morning weight draw profile which appears to dominate residential households. It is also the more demanding of the two draw profiles evaluated and more applicable to utilities with winter morning peaks, which is common in Florida.

The pool of days used for this evaluation consisted of days in which the 15-minute outdoor temperature samples ranged from 62.3°F to 80.6°F. For all draw profiles and temperature clusters, the weighted average outlet temperatures and the minimum draw temperatures varied very little from the 125°F user set point; reasonable temperatures are consistently delivered.

The outlet temperatures for the different command schedules are provided in Table 6. A similar table for all draw profiles and temperature clusters is provided in Appendix A.

Table 6. Daily Weighted Average and Minimum Outlet Temperatures During the 57 Gallon Draw Profile Under Mild Temperatures

Weighted Average and Minimum Outlet Temperatures: 57 Gallon Draw Profile, Mild Temperatures											
		Outdoor		AO Smith 50 Elec.		Rheem 50 HP		AO Smith 50 HP		AO Smith 80 HP	
Date	Schedule	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)
1/27/2021	Baseline	71.4	55.4	126.5	124.1	127.6	126.8	122.7	120.2	n/a	n/a
2/7/2021	1 Hr. Load Up, Shed	69.1	62.3	126.0	122.9	124.6	119.9	124.2	121.8	123.1	122.1
2/11/2021	2 Hr. Load Up, Shed	72.0	60.9	125.2	122.9	124.4	119.3	124.2	120.6	122.9	121.9
2/16/2021	1 Hr. Load Up, Critical Peak	70.2	57.7	124.7	123.4	124.8	121.5	124.1	121.8	122.6	122.4
2/27/2021	2 Hr. Load Up, Critical Peak	74.3	54.7	126.8	123.4	125.5	122.1	124.1	121.3	123.7	122.9

The morning and evening peak demand are provided for the 57 GPD draw profile tested under mild temperatures for all grid-connected command strategies relative to baseline, for all tested water heaters in Table 7. All water heaters effectively avoided almost all peak demand (8:00 AM and 5:00 PM) under all grid-connected schemes. A similar table for all draw profile and temperature clusters is provided in Appendix B.

Table 7. Peak Demand at 8:00AM and 5:00PM and Average during Peak Morning and Evening Hours

Peak Demand and Peak Hours Energy use: 57 Gallon Draw Profile, Mild Temperatures										
Morning: 6:00 Am - 9:00 AM										
		Temperature	AO Smith 50 Elec.		Rheem 50 HP		AO Smith 50 HP		AO Smith 80 HP	
Date	Schedule	Average Outdoor (°F)	Peak 15-Min (kW)	Avg. Peak Hours (kW)	Peak 15-Min (kW)	Avg. Peak Hours (kW)	Peak 15-Min (kW)	Avg. Peak Hours (kW)	Peak 15-Min (kW)	Avg. Peak Hours (kW)
1/27/2021	Baseline	71.4	5.21	0.98	0.38	0.24	0.41	0.25	0.40	0.24
2/7/2021	1 Hr. Load Up, Shed	69.1	1.98	0.19	0.00	0.00	0.16	0.02	0.00	0.00
2/11/2021	2 Hr. Load Up, Shed	72.0	1.67	0.18	0.00	0.00	0.14	0.02	0.00	0.00
2/16/2021	1 Hr. Load Up, Critical Peak	70.2	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
2/27/2021	2 Hr. Load Up, Critical Peak	74.3	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Evening: 4:00 PM - 8:00 PM										
1/27/2021	Baseline	71.4	3.21	0.62	0.40	0.17	0.40	0.15	0.43	0.19
2/7/2021	1 Hr. Load Up, Shed	69.1	1.46	0.18	0.00	0.00	0.37	0.07	0.01	0.00
2/11/2021	2 Hr. Load Up, Shed	72.0	1.73	0.11	0.00	0.00	0.01	0.00	0.00	0.00
2/16/2021	1 Hr. Load Up, Critical Peak	70.2	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00
2/27/2021	2 Hr. Load Up, Critical Peak	74.3	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00

We now apply our findings to address our previously stated research questions.

1. *What is the indicated magnitude of the controlled HPWH load reduction (and electric resistance) versus unconnected units during peak periods, and compared to ERWHs?*

As seen in Table 7, under the 57 GPD draw schedule and mild conditions, the grid-connected HPWHs were able to reduce peak demand by as much as 0.4 kW, depending on unit, time of day, and control scheme, over the unconnected HPWH. For example, regardless of load shifting strategy during this draw profile and temperature cluster, the Rheem achieved a 0.38 kW reduction during the morning peak and 0.40 during the evening peak, relative to its unconnected baseline day.

Figure 6 provides the daily energy profile for all units under the one-hour load up and critical peak grid-connected command structure. Similar plots are provided for every combination of temperature bin, water draw profile, and command schedule in Appendix C-1 through C-4.

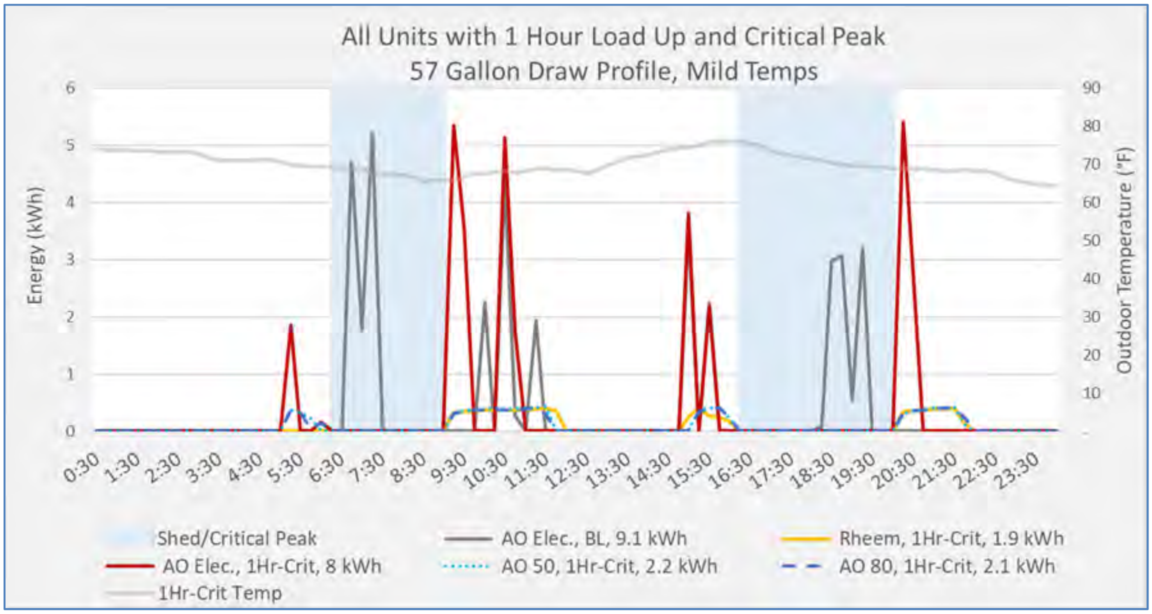

Figure 6. Comparison of electric resistance controlled and unconnected vs. grid-connected HPWH under mild conditions.

The ERWH was demonstrated as creating large peaks in electrical demand (typically 1-5 kW when activated) that are avoided through commanding shifts of the electric resistance elements. Under the load shifting strategy, the HPWHs completely avoid operation during peak periods. The average hourly demand of the unconnected ERWH across the morning peak demand period was 0.98 kW (with a maximum 15-minute demand of 5.21 kW) compared to 0.00 kW for the load-controlled HPWH. The average demand of the unconnected ERWH across the evening peak period was 0.62 kW (with a maximum 15-minute demand of 3.21 kW) compared to 0.00 kW for the grid connected HPWH.

In addition, all HPWHs across all load shifting scenarios had total daily electricity demand that was 25% less compared to the load-controlled ERWH. In Florida, with the 57 gallon/day draw profile and mild temperatures, consumption in all the grid-connected HPWH cases averaged ~2.1 kWh/day, nearly always performing at least slightly better than the baseline period with consumption of 2.4 kWh/day. However, these results vary under the different draw profiles and temperature, as detailed in Appendix E. Regardless, the daily HPWH consumption is quite modest and similar to what is used for household refrigeration (Fenaughty et al., 2017).

2. *What is the load reduction benefit for HPWHs tested during peak periods under cooler weather conditions?*

The control schemes provided extensive load reduction during the cooler weather conditions during the 57-gallon draw profile testing. Figure 7 compares results of the one-hour load up and shed command structure for the 50-gallon HPWHs under warmer and cooler weather conditions. For analyzing the one-hour load up and shed during the cold period, we pull in data from the coldest day experienced under the 57 GPD tests; however, this fell outside the 'cool profile' cluster of days, as there is no baseline nor other grid-connected tests compare in temperatures experienced. We find the Rheem is able to eliminate loads during the peak periods regardless of temperature, while the AO

Smith was not able to, especially during the morning peak period on the coldest day, as seen in Table 7. Figure 8 depicts similar plot, but for the one-hour load up and critical peak control strategy, and the temperature difference between days compared is much more subtle than shown in Figure 7. Given the critical peak command structure, the AO Smith 50-gallon unit had no trouble voiding runtime during the peak periods during the milder cooler temperatures, though the cooler day is milder in Figure 8 than in Figure 7.

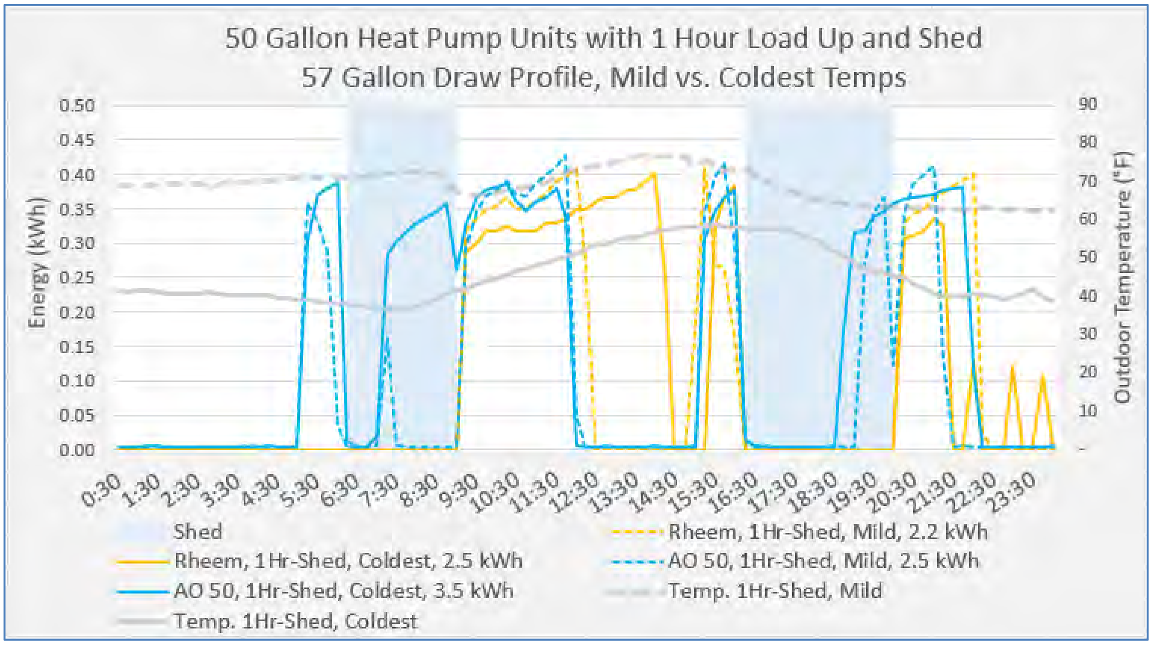

Figure 7. A.O. Smith 50-gallon HPWH load shifted using the one-hour load up and shed during cold versus mild weather.

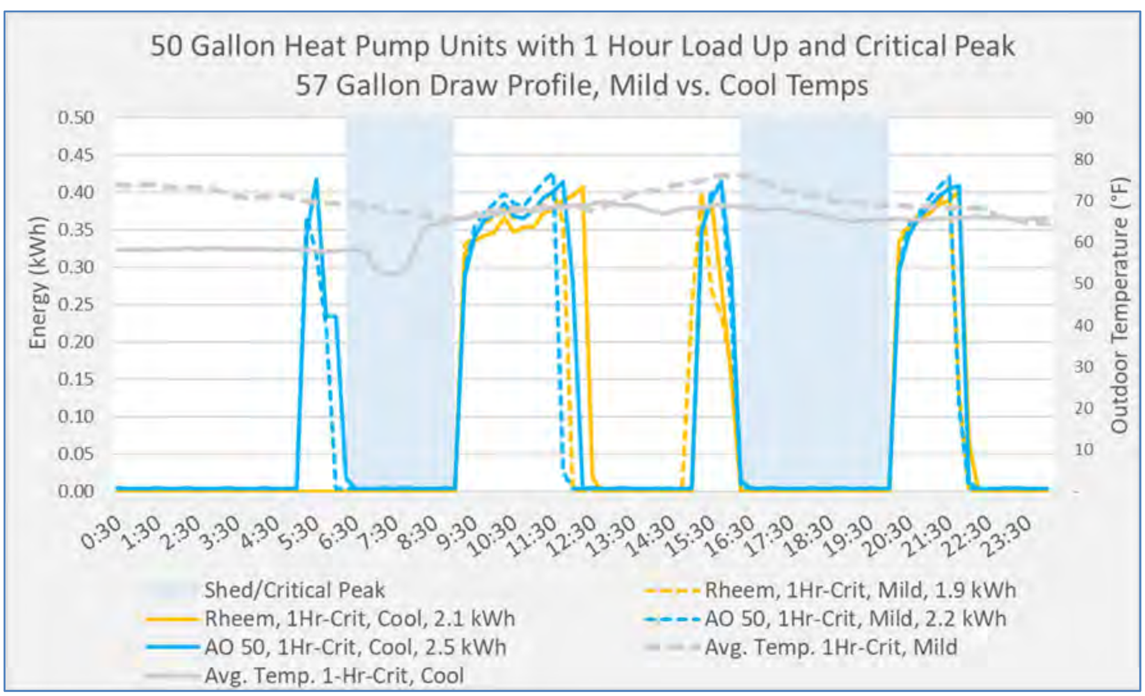

Figure 8. A.O. Smith and Rheem 50-Gallon HPWHs demonstrating no change in load reduction using the one-hour load up and shed between mild and cooler weather.

A difference was also observed between the mild and cooler weather for the 47-gallon hot water draw profile using a two-hour load up and shed strategy. As shown in Figure 9, the A.O. Smith 50-gallon HPWH consumed more power during the cooler weather with the larger evening-weighted draw. However, the two-hour load up was not fully utilized and did not prevent the unit from engaging during the evening peak period, regardless of temperature.

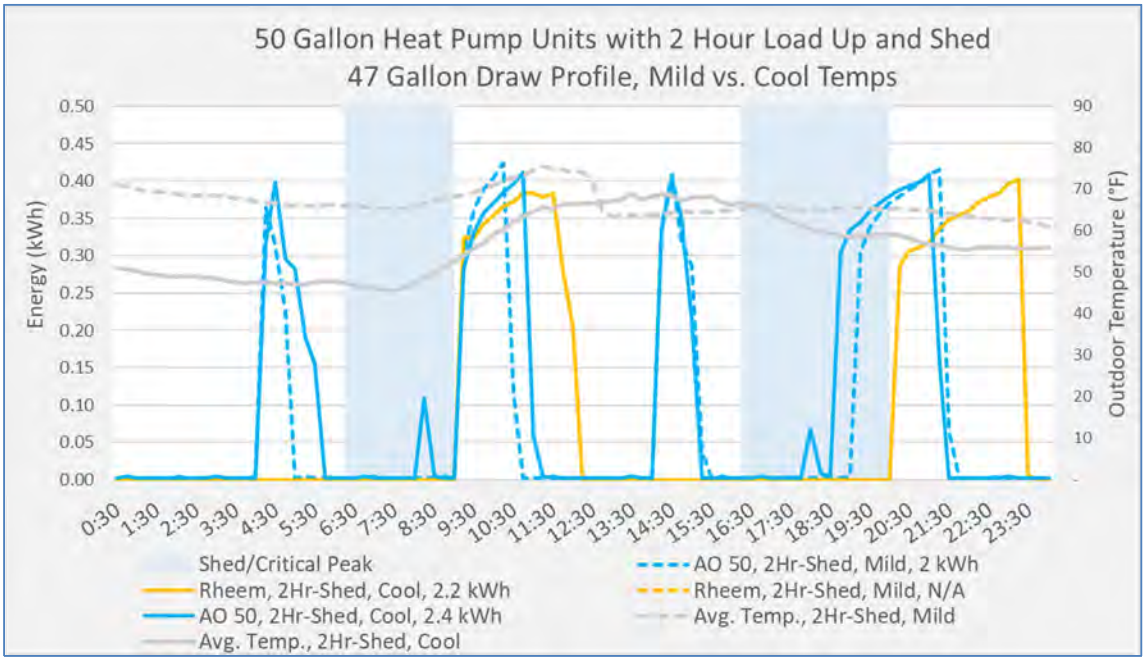

Figure 9. Heat pump units under two-hour load up and shed during cooler weather – The A.O. Smith unable to shed for duration; Rheem unit avoids load during peak periods.

3. *What is the success of the different load reduction schemes during peak periods by unit manufacturer and unit?*

The A.O. Smith 50-gallon HPWH was unable to shift load entirely out of the morning and evening peak period using the *shed* command. However, there was little difference in the performance of each of the three grid-conneted HPWHs, (in profile demand or daily energy) under the *critical peak* command. All of the units provide perfect grid-connected during the morning and evening peak periods and similar consumption in daily energy use under the one-hour load up with critical peak (Figure 10). However, differences were observed during the shed strategy (Figure 11). In observing the recorded hot water outlet temperatures during draws at the coolest temperatures, the Rheem 50-gallon HPWH allowed water delivery temperatures that were approximately ~2 °F lower than those provided by the two A.O. Smith HPWHs. This likely has a large part to do with the greater ability of the Rheem unit to remain off during the period periods with the shed command.

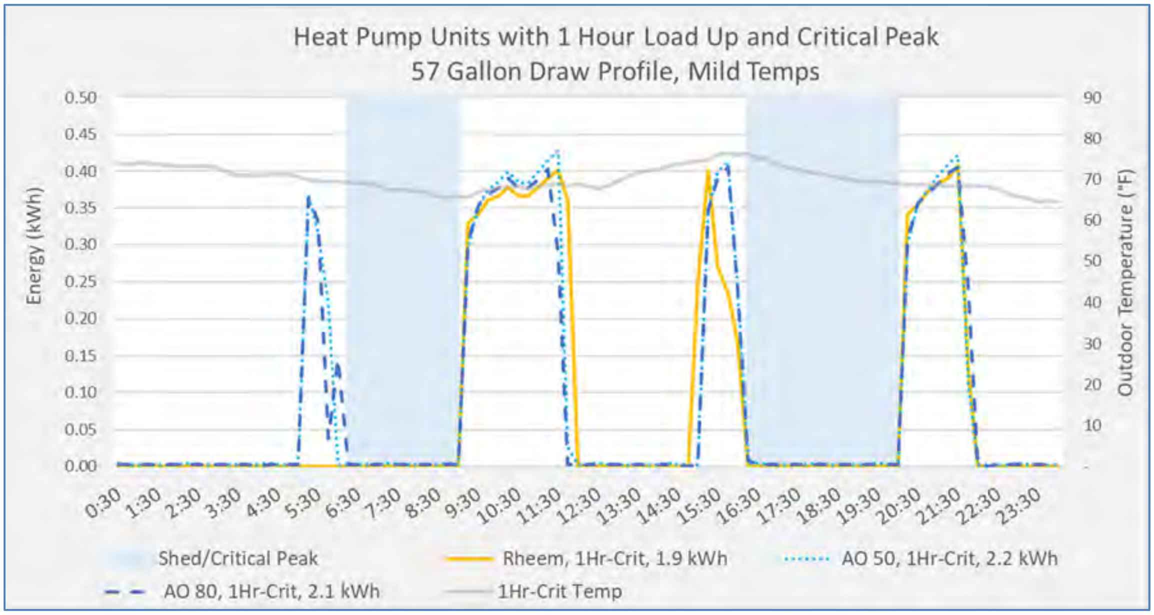

Figure 10. Little difference seen among different manufacturers and tank volumes for 1-hour load up and critical peak control scheme under mild weather.

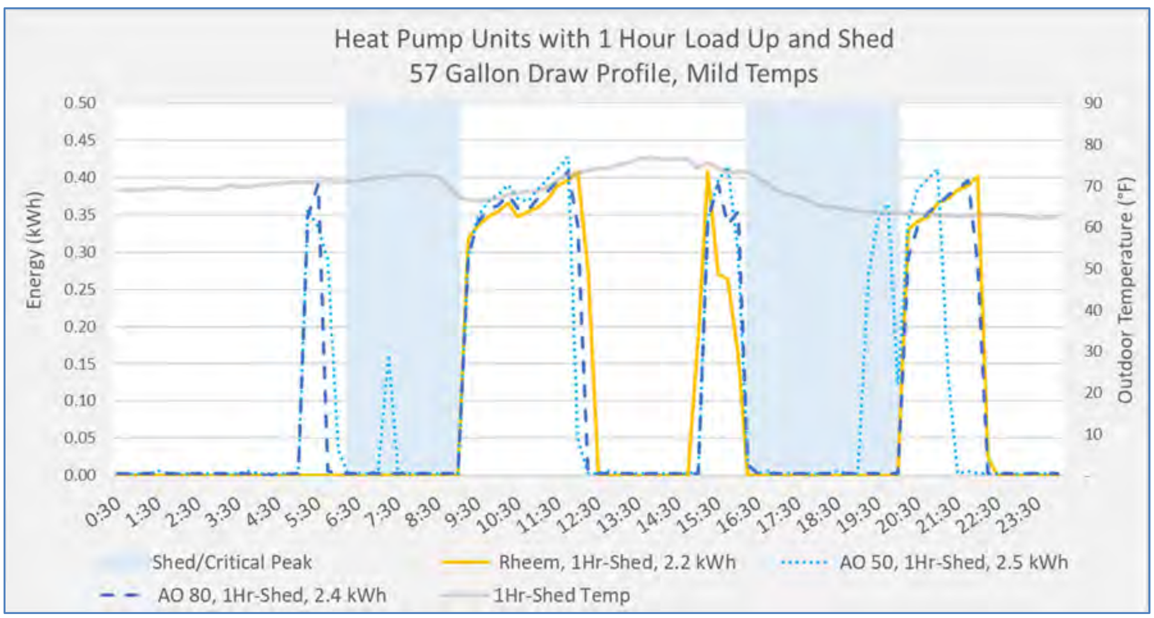

Figure 11. Difference between manufacturer and unit: Little difference seen for Critical Peak; However, differences seen with the Shed command.

The data for one-hour load up and shed showed that the 50-gallon A.O. Smith HPWH provided less load shed, although the Rheem 50-gallon HPWH and 80-gallon A.O. Smith completely shifted load from peak periods. In addition, the Rheem unit does not take advantage of the morning load up under these conditions, which may indicate that tank standby losses are lower.

4. *What is the success of load reduction during peak periods by control strategy?*

Comparing Figure 12 to Figure 13, the CP strategy appears to result in real changes to potential peak load shed for the 50-gallon A.O. Smith HPWH. Thus, the CP strategy as implemented, provides real changes in the likelihood that HPWH electric demand will occur in the peak periods. As seen in Table 8, it appears some reduction occurred in the minimum delivered water temperature between the shed and CP commands.

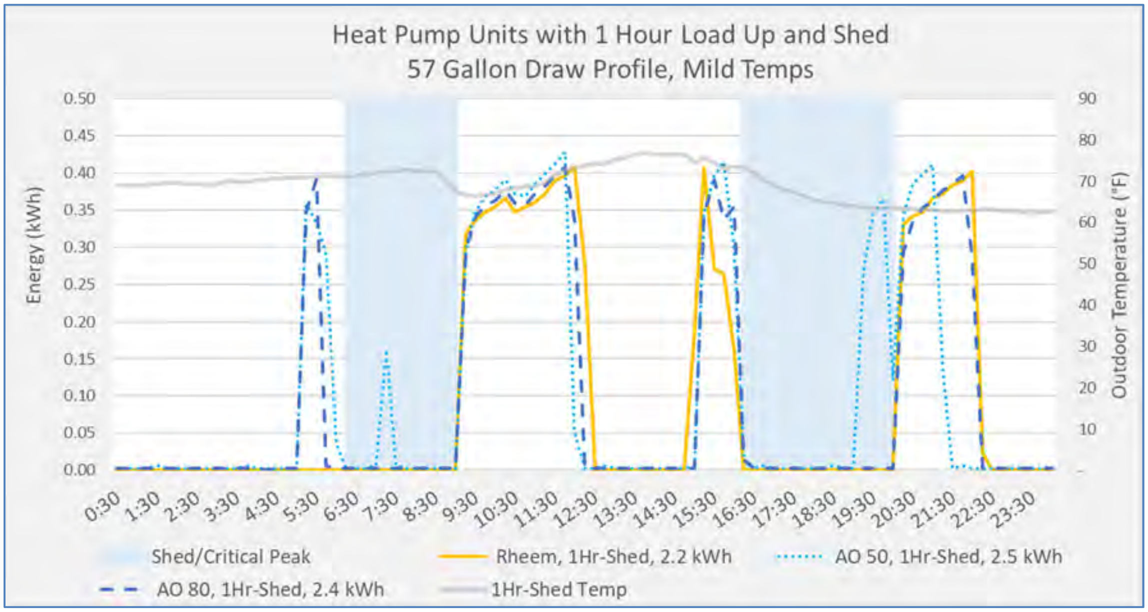

Figure 12. One hour load up and shed loses control with 50 gallon A.O. Smith unit and compressor is activated.

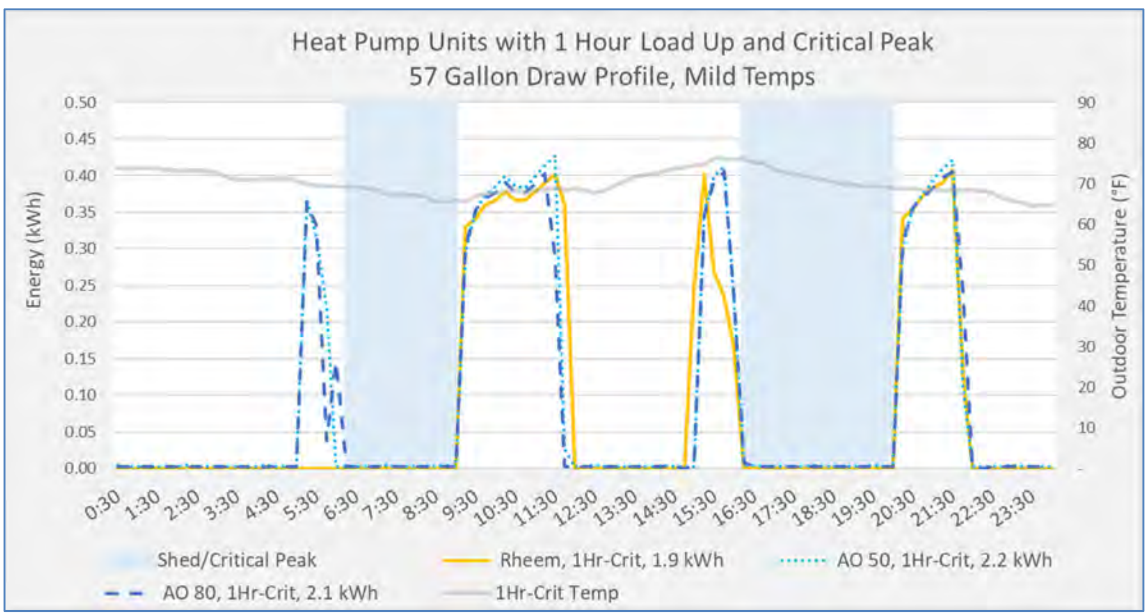

Figure 13. Critical peak strategy shows no demand from any of the tanks during the two peak periods.

Table 8. Delivered Water Temperatures Under Shed vs. Critical Peak Grid-connected Commands

Weighted Average and Minimum Outlet Temperatures: 57 Gallon Draw Profile, Mild Temperatures									
		Outdoor Temperature		Rheem 50 HP		AO Smith 50 HP		AO Smith 80 HP	
Date	Schedule	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)
2/7/2021	1 Hr. Load Up, Shed	69.1	62.3	124.6	119.9	124.2	121.8	123.1	122.1
2/16/2021	1 Hr. Load Up, Critical Peak	70.2	57.7	124.8	121.5	124.1	121.8	122.6	122.4

5. *Can differences be seen in the success of load reduction during peak period by the gallons of storage tank volume?*

In Figure 14, the A.O. Smith 50- and 80-gallon HPWHs are compared. The simple one-hour load up and shed shifts greater load for the 80-gallon model. This suggests the 80-gallon HPWH is likely more assured of completely shifting load under demanding conditions.

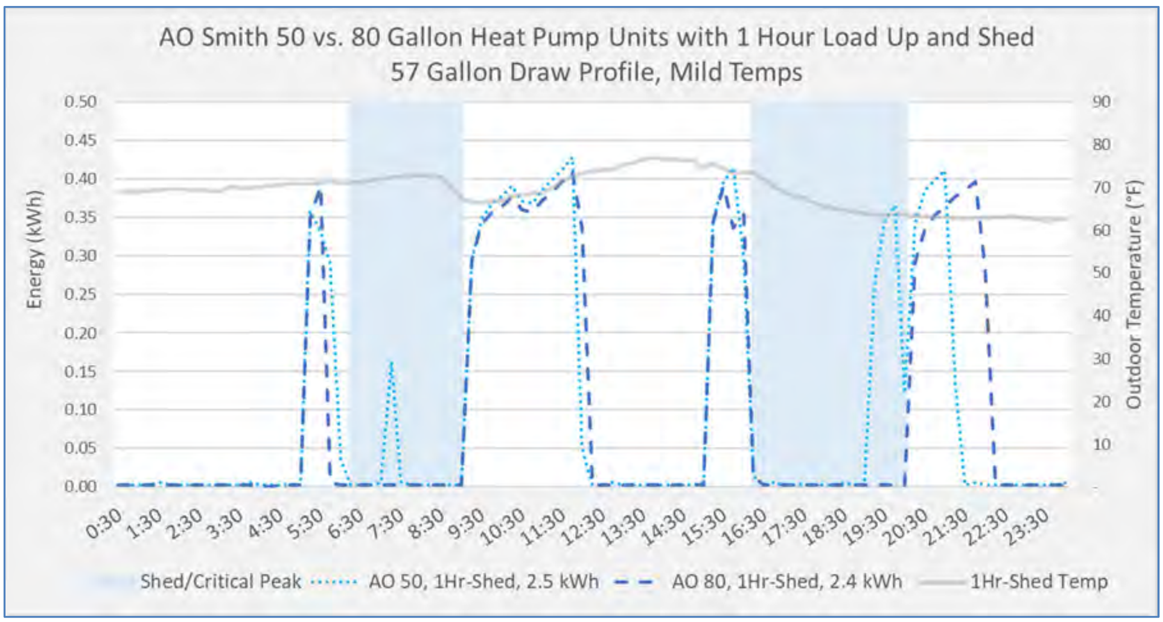

Figure 14. The A.O. Smith 80 gallon unit much more successful at avoiding electrical demand during morning and evening peak periods with one-hour load up.

6. *How does the success of load reduction during peak periods vary depending on load up strategy?*

The Rheem 50-gallon HPWH successfully avoided running during peak hours during all load shifting strategies, although with some minor reductions in delivered hot water temperatures, shown in Table 6. This was the case for all temperature clusters and both water draw schedules. Figure 15 compares how each of the four load shifting strategies performed relative to the baseline day. A comparison for all units, temperature bins, and draw profiles is provided in Appendix D-1 through D-4.

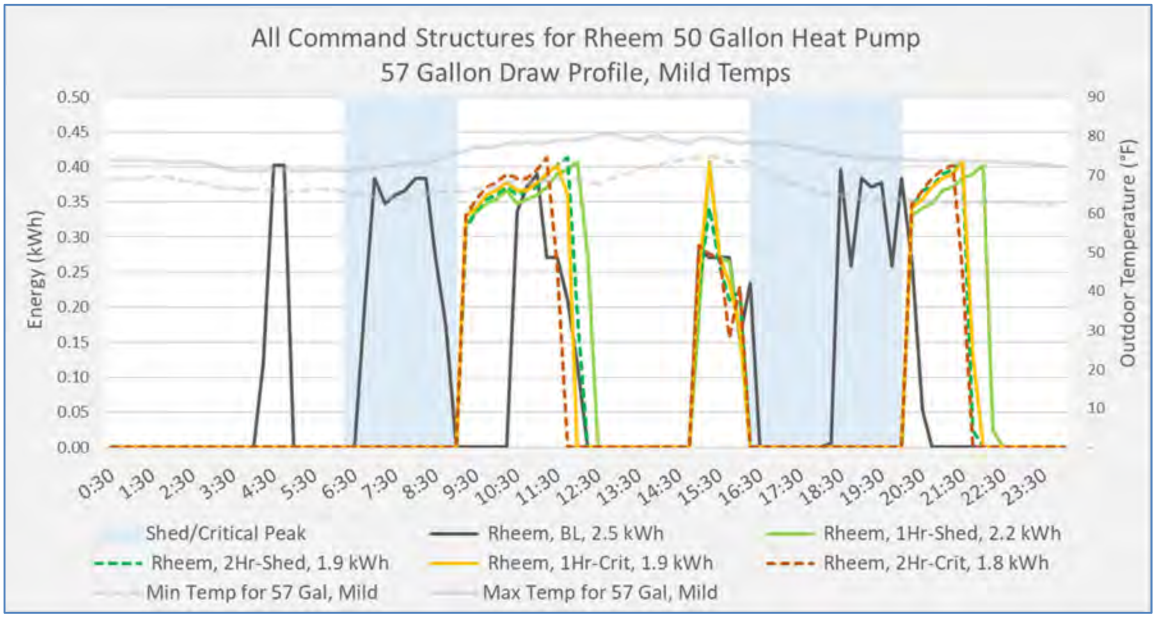

Figure 15. The Rheem 50-gallon HPWH successfully avoids running during peak hours under all command strategies.

As demonstrated previously, the A.O. Smith 50-gallon HPWH was unable to completely avoid runtime during peak hours under the shed load shifting strategies, regardless of the length of load up or outdoor temperature. Still, all strategies demonstrated significant load shifting away from peak hours compared to baseline. Figure 16 compares how the A.O. Smith 50-gallon HPWH performed under all four load shifting strategies. The two-hour load up strategy enabled this model to completely reduce load during the both peak demand periods, for both CP and shed commands.

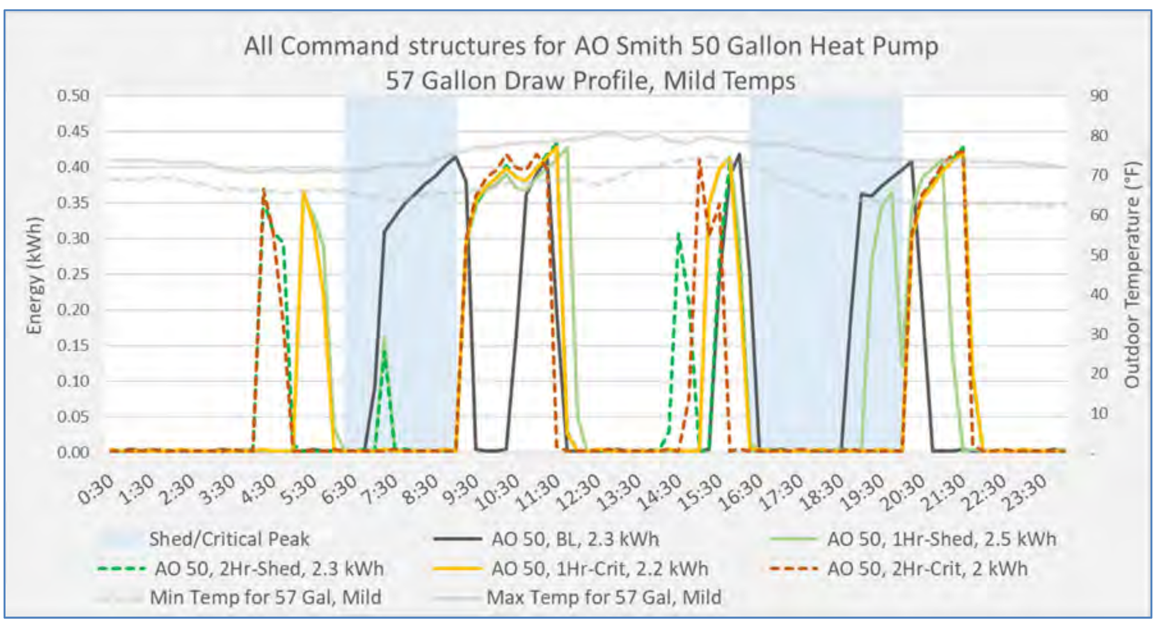

Figure 16. When responding to a shed command, the two-hour load up improves the A.O. Smith 50 gallon HPWHs ability to avoided some peak hour run time.

The 80-gallon A.O. Smith HPWH successfully avoided running during peak hours across all load shifting strategies, as seen in Figure 17. The baseline load profile, indicated by dark gray, shows the a complete shift of load achieved by the load shifting strategy.

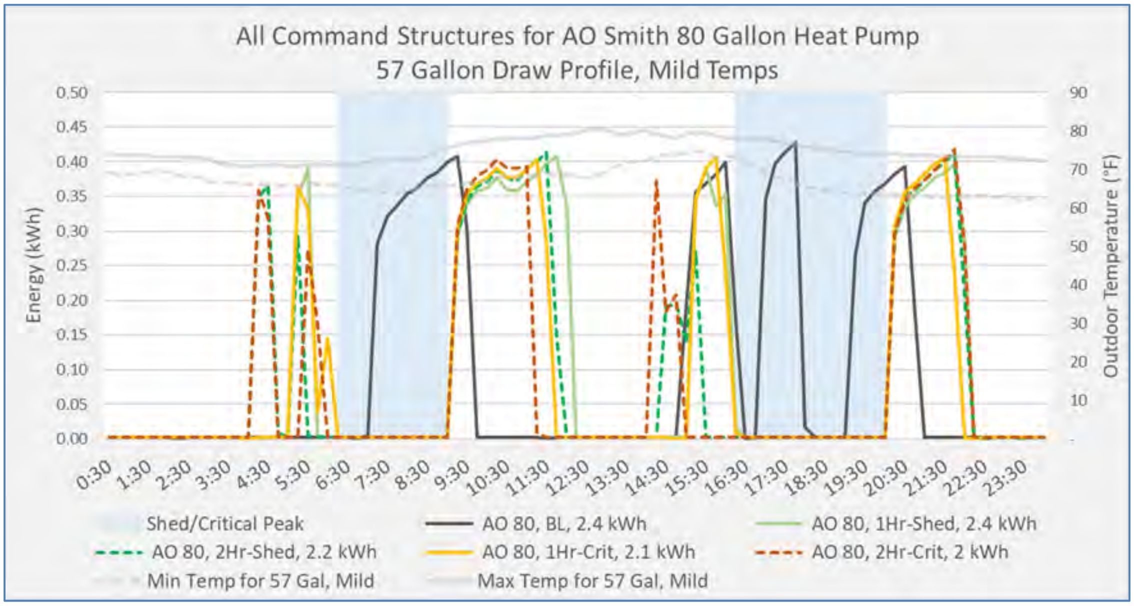

Figure 17. The A.O. Smith 80 gallon HPWH successfully avoids running during peak hours under all command strategies.

As with A.O. Smith's 50-gallon HPWH, the A.O. Smith 50-gallon ERWH is unable to completely avoid peak hour run time during the shed command structures (shown in Figure 18). The length of the load up does not appear to improve control, which is not surprising as the ERWHs add heat to stored hot water at a very fast rate using 4.5-5.5 kW resistance elements. However, it's worth noting that load-shifting ERWHs still provide a large reduction in kW, even if load is not completely shifted during the peak demand period.

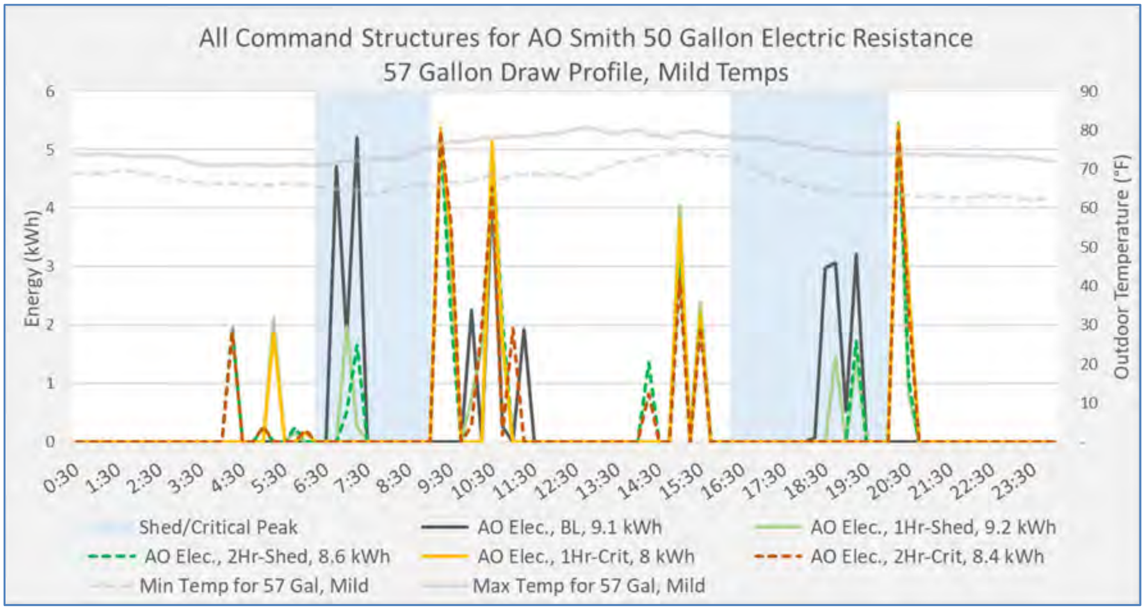

Figure 18. When responding to a shed command, A.O. Smith 50 gallon electric resistance unit is unable to compete avoid peak hour run time.

7. *How does the success of load reduction during peak periods vary by the specific draw profile?*

The draw profiles—although with very different shapes over the daily cycle-- did not appear to impact peak load reduction of a given load shifting strategy for the lab tests. The A.O. Smith 50-gallon HPWH was the only unit to add load during peak periods under load shifting strategies, and only under the shed command, and especially under one-hour of load up. The smaller 47 GPD draw profile did not appear to alter this observation. Comparing Figure 19 to Figure 20, the A.O. Smith 50-gallon HPWH is unable to reduce load during peak periods with the one-hour load up and shed command structure, whether under the under the 57 GPD or 47 GPD schedules.[4]

[4] Both the 47 and 57 GPD draw profile tests were conducted under similar weather profiles.

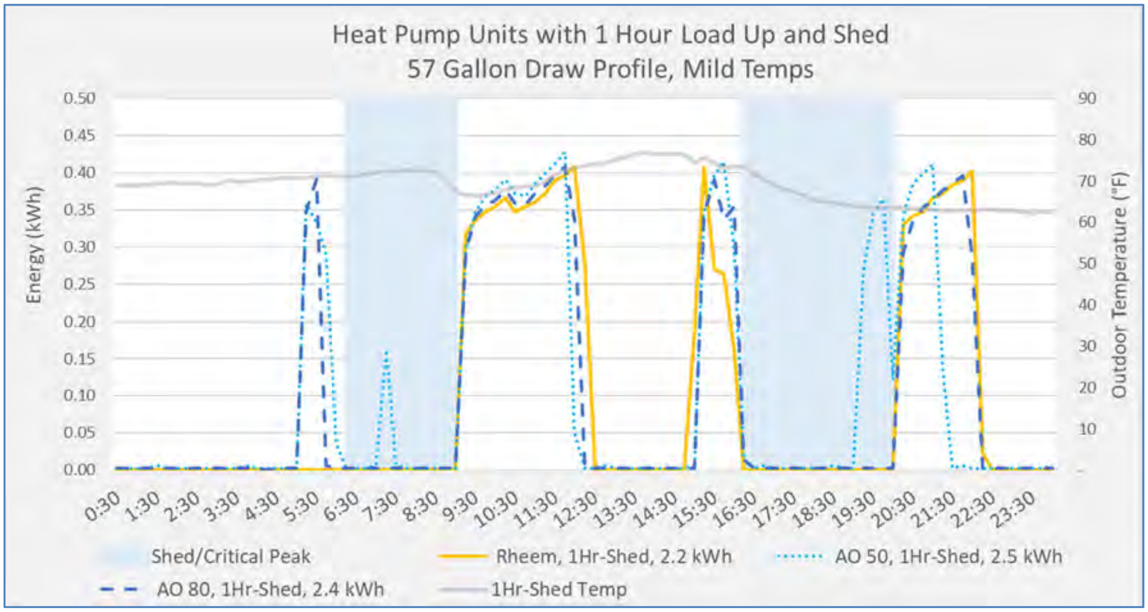

Figure 19. AO Smith 50 gallon HPWH does not completely avoid run time during one-hour load up and shed under the 57 gallon draw profile.

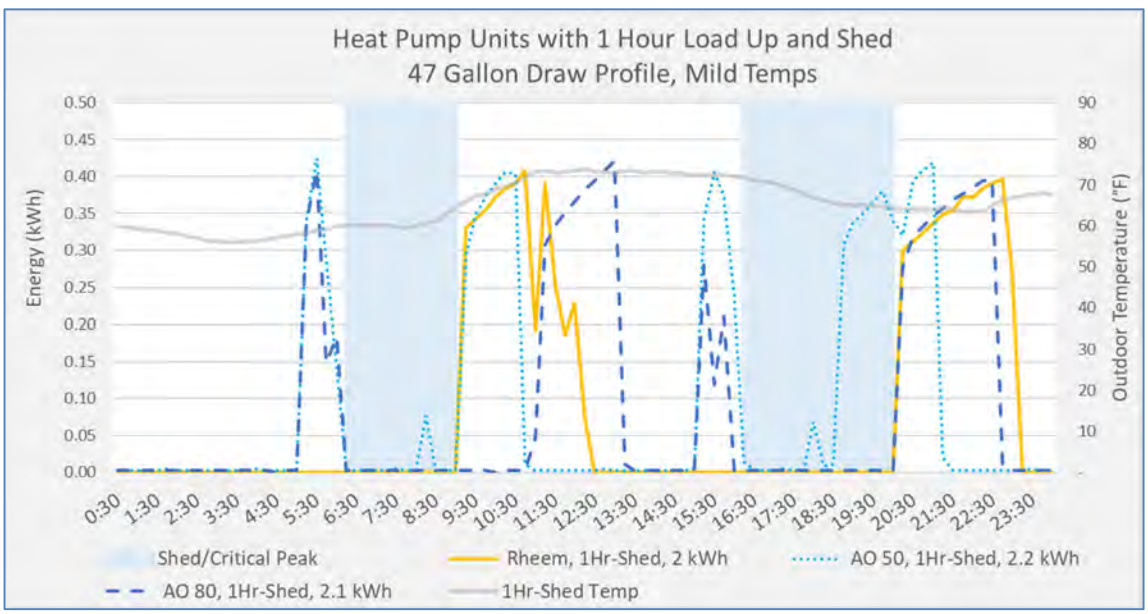

Figure 20. 50 gallon AO Smith HPWH does not completely avoid run time during one-hour load up and shed under the 47 gallon draw profile.

8. *What is the impact on energy use when peak load reduction is achieved?*

For almost all units, and under almost all load shifting strategies under the 57 GPD draw and mild weather conditions, the daily energy use was equivalent or slightly reduced over baseline. As shown in Table 9, the exception is that the 50 gallon A.O. Smith HPWH consumed slightly more energy than did the baseline day during one-hour load up and shed, 2.3 kWh vs. 2.5 kWh, an increase of 7%. However, the one-hour load up and shed was the coldest day of the temperature cluster among load shifting strategies. During colder days, the load shifting strategies tended to come with energy penalties; whereas during more mild days, the load shifting strategies generally provided both energy savings and demand reduction. In general, the HPWH had daily energy use that was about 23-27% of the daily energy consumed by ERWH. Appendix E provides the daily and peak water heater energy use for all test days evaluated.

Table 9. Daily and Peak Hours Water Heater Energy Under Baseline and All Command Structures

Total Daily and Peak Hours Water Heater Energy: 57 Gallon Draw Profile, Mild Temperatures										
		Temperature	AO Smith 50 Elec.		Rheem 50 HP		AO Smith 50 HP		AO Smith 80 HP	
Date	Schedule	Average Outdoor (°F)	Daily (kWh)	Peak Hours (kWh)	Daily (kWh)	Peak Hours (kWh)	Daily (kWh)	Peak Hours (kWh)	Daily (kWh)	Peak Hours (kWh)
1/27/2021	Baseline	71.4	9.10	5.41	2.50	1.39	2.29	1.35	2.37	1.49
2/7/2021	1 Hr. Load Up, Shed	69.1	9.22	1.29	2.22	0.00	2.46	0.34	2.38	0.02
2/11/2021	2 Hr. Load Up, Shed	72.0	8.59	0.99	1.95	0.00	2.26	0.06	2.17	0.02
2/16/2021	1 Hr. Load Up, Critical Peak	70.2	8.01	0.02	1.94	0.00	2.19	0.02	2.14	0.02
2/27/2021	2 Hr. Load Up, Critical Peak	74.3	8.41	0.02	1.76	0.00	2.01	0.02	2.00	0.02

Caveats

Lab testing the load shifting potential of water heaters had certain limitations, and pointing out these limitations may be useful in interpreting results to enhance field studies. First, water heaters were tested in Central Florida where tap water and tank inlet water temperatures tend to be higher than in many other regions of the U.S. and even in regions in the Southeast such as Atlanta, GA or Raleigh, NC. Air temperatures around the water heaters, impacting heat pump compressor COP, would also be lower in many other U.S. locations. This suggests coldest day performance is more applicable to warmer climates from the results.

Second, the results are from two draw profiles— one weighted to high evening draws (PNNL) and the other with morning weighted draws (NEEA-4) — the latter of which many studies from the last 35 years indicate is more typical in a U.S. household.

Third, the draw profiles are very specific while real draws in occupied homes vary in complex ways over time. Across households, the draws are even more complicated and vary stochastically with time in such a way that the peak-ness of electrical demand is smoothed. This is one reason that distributed hot water draw event models have been created for analysis purposes (Hendron et al., 2010). Concurrent field research is ongoing as part of this larger study.

Last, the water inlet temperatures vary over the course of the year, leading to the 15-minute electrical demand profile changing monthly, as seen in a previous FSEC monitoring project of 186 electric water heaters (Masiello and Parker, 2000) (Figure 21). This means that summer contributions to peak load will be smaller than winter contributions.

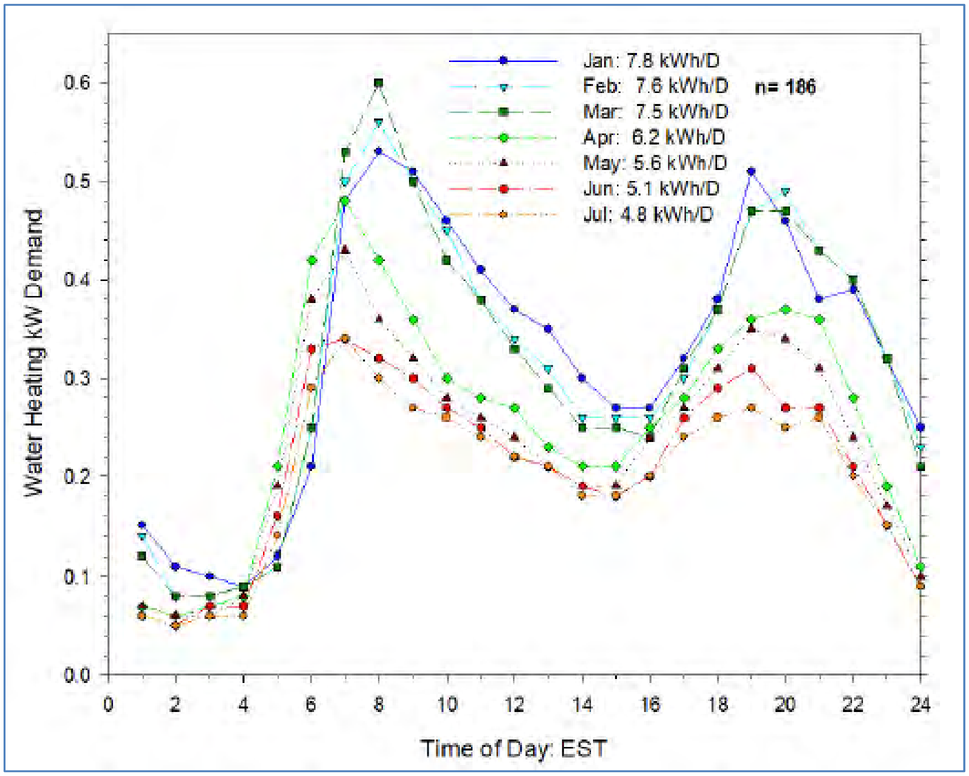

Figure 21. Average monthly water heating demand profiles from 186 sub-metered electric water heaters (Masiello and Parker, 2000)

Conclusions

FSEC conducted load shifting experiments using the ANSI CTA-2045-A protocol to demonstrate the viability of heat pump water heaters (HPWH), compared to electric resistance water heaters (ERWH), to provide load shifting in the Southeast United States. The investigation entailed applying different shed and critical peak control command designs to three HPWHs and one ERWH in a laboratory setting, under two different hot water draw profiles. Preliminary results from these tests span December 2020 through February 2021.

The fundamental conclusion from the FSEC laboratory study is that grid-connected HPWHs can provide large and dependable electric demand load reduction from load shed and critical peak signals relative to ERWHs in Southeastern U.S. climate. Compared to unconnected HPWH, the grid-connected HPWHs were able to reduce peak demand by as much as 0.4 kW. The specific reductions depended on unit/model, time of day, control scheme, draw profile, and temperature cluster. Other findings include:

- All of the load shifting strategies were able to provide meaningful avoidance of peak period energy use, although the CP command used with the ERWH results in a large “payback” (i.e., recovery) spike of over 5 kW in hour after release of control. The average kW across the morning peak period of the unconnected ERWH was 1.02 kW under the 57 GPD profile with a maximum 15-minute demand of 5.28 kW.
- The grid-connected HPWHs typically used only about 25% of the daily electricity for water heating used by ERWHs. The unconnected ERWH system used about 8-9 kWh per day against about 2 kWh per day used for grid-connected HPWH. The

HPWH daily energy use is approximately the magnitude of refrigerator consumption in measured households (Fenaughty et al 2017).

- Average inlet water temperatures during hot water draws averaged 68.5°F over the period and ranged from 63.5ºF to 74.3ºF. The relatively high inlet water temperature in Central Florida substantially reduces water heating load relative to colder climates, while the higher ambient temperatures (> 45°F) make activation of electric-resistance back-up heat very infrequent for HPWHs. Average daily minimum air temperatures during the "cool temperature" cluster ranged from 45.5°F to 62.3 °F.
- Grid-connected HPWHs have similar daily electricity consumption compared with unconnected HPWHs (~2.0 kWh/day for 47 GPD profile and ~2.4 kWh/day for the 57 GPD profile). No systematic increase or decrease was seen.
- Manufacturer implemented algorithms for Critical Peak (CP) successfully avoided on-peak power for all tested water heaters, although the Rheem HPWH allowed lower hot water outlet temperatures.
- Cooler weather conditions impacted how well the A.O. Smith 50-gallon HPWH was able to shed load, while the Rheem 50-gallon HPWH eliminated demand under colder conditions. The Rheem HPWH's minimum hot water delivery temperature was about 4°F lower than the A.O. Smith 50-gallon HPWH, but at 117°F, would not likely be problematic to users.
- The two-hour load up versus the one-hour load up showed improvement in load shed for the smaller capacity 50-gallon A.O. Smith HPWH during the longer, four-hour evening peak demand period.
- The 80-gallon A.O. Smith HPWH avoided on-peak demand more regularly than the A.O. Smith 50-gallon HPWH during cooler air temperatures under the 57 GPD profile. The Rheem 50-gallon HPWH was able to avoid on-peak demand in all tested configurations although with slightly lower delivered hot water temperatures.
- Evaluation of the outlet hot water temperatures during on-peak draws for all tested water heaters and configurations showed that the lowest outlet hot water temperature was ~117ºF—well above the 110ºF level in which problems with useful hot water service temperatures emerge. One of the concerns may be managing bacterial growth (e.g. Legionnaires) tank. Typically, this is done by manufacturers by an automated "kill cycle", raising the set point above the high end of the optimal legionella growth temperature of 122 ^{0}F.[5] Since the temperature in the tank tends to reach the setpoint at least once a day in the controlled schemes, this serves as a kill cycle.
- Examination of the one-minute data indicated the A.O. Smith 50- and 80-gallon HPWHs activated electric resistance back-up heat, during both baseline days and days of load shifting while the equipment was commissioned in December.[6]

[5] https://thermaco.com/blog/legionnaires-disease/

[6] For the A.O. Smith water heaters, the back-up electric resistance elements are 2.5 kW for the bottom element and 4.5 kW for the top element. The compressor cuts out to back-up electric resistance heating

During the cluster days analyzed for comparison between load shifting strategies and baseline, no electric resistance back-up heating was activated. The higher ambient temperatures surrounding the water heaters, typical of Florida's climate, increases compressor COP and avoids the temperatures below 35°F -37°F, below which electric resistance heating typically takes over from the compressor.

The preceding report narrative highlights the primary permeations of different load shifting strategies, outdoor temperature clusters, and draw profiles tested. Observations for all tests cases analyzed are provided in the tables and plots in Appendices A – E. Results should allow optimization of field study research, based on observed influences. Manufacturers may also see findings useful for better implementing the CTA-2045-A, as well as the new CTA-2045-B protocol. The U.S. Department of Energy's Residential Energy Consumption Survey data (DOE/EIA, 2015) suggest that ERWHs comprise greater than 73% of water heaters in the Southeastern U.S. These data also indicate that to reach the largest portion of the water heating market that one must make compact (and quiet) HPWHs since electric water heating dominates multi-family occupancy and manufactured homes which do not typically have garages and basements in which to locate water heaters.

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when the ambient temperature around the tanks falls below 45ºF. Such weather events happen infrequently in Florida in semi-conditioned spaces such as garages.

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Appendix A: Weighted Average and Minimum Outlet Temperatures

Weighted Average and Minimum Outlet Temperatures: 47 Gallon Draw Profile, Cool Temperatures

		Outdoor		AO Smith 50 Elec.		Rheem 50 HP		AO Smith 50 HP		AO Smith 80 HP	
Date	Schedule	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)
12/22/2020	Baseline	56.1	46.9	128.6	125.1	127.3	126.2	121.4	118.8	n/a	n/a
n/a	1 Hr. Load Up, Shed										
1/6/2021	2 Hr. Load Up, Shed	56.7	45.8	124.5	123.0	124.9	123.5	124.6	124.1	n/a	n/a
1/14/2021	1 Hr. Load Up, Critical Peak	54.7	45.6	124.3	122.9	124.9	124.0	124.8	124.4	122.4	121.9
1/18/2021	2 Hr. Load Up, Critical Peak	55.8	45.5	127.9	125.8	124.9	124.1	124.8	124.3	n/a	n/a

Weighted Average and Minimum Outlet Temperatures: 47 Gallon Draw Profile, Mild Temperatures

		Outdoor		AO Smith 50 Elec.		Rheem 50 HP		AO Smith 50 HP		AO Smith 80 HP	
Date	Schedule	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)
12/20/2020	Baseline	67.2	46.9	127.9	125.4	127.8	126.5	121.4	119.2	n/a	n/a
12/29/2020	1 Hr. Load Up, Shed	65.1	62.3	124.7	122.8	125.6	123.6	124.8	124.5	n/a	n/a
1/3/2021	2 Hr. Load Up, Shed	66.7	45.8	124.5	122.7	125.4	123.8	124.4	123.9	n/a	n/a
1/12/2021	1 Hr. Load Up, Critical Peak	62.1	45.6	126.3	124.8	125.2	123.8	124.6	124.2	n/a	n/a
1/22/2021	2 Hr. Load Up, Critical Peak	65.7	45.5	126.9	124.4	126.2	123.7	124.6	124.3	n/a	n/a

Weighted Average and Minimum Outlet Temperatures: 57 Gallon Draw Profile, Cool Temperatures

		Outdoor		AO Smith 50 Elec.		Rheem 50 HP		AO Smith 50 HP		AO Smith 80 HP	
Date	Schedule	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)
1/31/2021	Baseline	66.8	46.9	126.9	123.8	127.7	126.9	122.7	119.7	122.2	120.4
2/6/2021	1 Hr. Load Up, Shed	65.0	62.3	125.8	122.4	124.1	118.2	124.0	121.2	123.2	122.4
n/a	2 Hr. Load Up, Shed										
2/21/2021	1 Hr. Load Up, Critical Peak	63.8	45.6	124.8	122.6	124.7	119.9	124.2	121.3	123.4	122.5
2/24/2021	2 Hr. Load Up, Critical Peak	66.1	45.5	125.0	122.9	124.5	120.0	124.3	121.1	122.9	122.1

Weighted Average and Minimum Outlet Temperatures: 57 Gallon Draw Profile, Mild Temperatures

		Outdoor		AO Smith 50 Elec.		Rheem 50 HP		AO Smith 50 HP		AO Smith 80 HP	
Date	Schedule	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)
1/27/2021	Baseline	71.4	55.4	126.5	124.1	127.6	126.8	122.7	120.2	n/a	n/a
2/7/2021	1 Hr. Load Up, Shed	69.1	62.3	126.0	122.9	124.6	119.9	124.2	121.8	123.1	122.1
2/11/2021	2 Hr. Load Up, Shed	72.0	60.9	125.2	122.9	124.4	119.3	124.2	120.6	122.9	121.9
2/16/2021	1 Hr. Load Up, Critical Peak	70.2	57.7	124.7	123.4	124.8	121.5	124.1	121.8	122.6	122.4
2/27/2021	2 Hr. Load Up, Critical Peak	74.3	54.7	126.8	123.4	125.5	122.1	124.1	121.3	123.7	122.9

Weighted Average and Minimum Outlet Temperatures: 57 Gallon Draw Profile, Mild Temperatures									
		Outdoor		Rheem 50 HP		AO Smith 50 HP		AO Smith 80 HP	
Date	Schedule	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)	Average (°F)	Minimum (°F)
2/7/2021	Shed	69.1	62.3	124.6	119.9	124.2	121.8	123.1	122.1
2/16/2021	1 Hr. Load Up, Critical Peak	70.2	57.7	124.8	121.5	124.1	121.8	122.6	122.4

Appendix B: Peak Demand at 8:00AM and 5:00PM and Average during Peak Morning and Evening Hours

Peak Demand and Peak Hours Energy use: 47 Gallon Draw Profile, Cool Temperatures										
Morning: 6:00 Am - 9:00 AM										
		Temperature	AO Smith 50 Elec.		Rheem 50 HP		AO Smith 50 HP		AO Smith 80 HP	
Date	Schedule	Average Outdoor (°F)	Peak 15-Min (kW)	Avg. Peak Hours (kW)	Peak 15-Min (kW)	Avg. Peak Hours (kW)	Peak 15-Min (kW)	Avg. Peak Hours (kW)	Peak 15-Min (kW)	Avg. Peak Hours (kW)
12/22/2020	Baseline	56.1	3.22	1.07	0.39	0.30	0.39	0.21	0.34	0.09
n/a	1 Hr. Load Up, Shed									
1/6/2021	2 Hr. Load Up, Shed	56.7	1.63	0.22	0.00	0.00	0.11	0.01	0.00	0.00
1/14/2021	1 Hr. Load Up, Critical Peak	54.7	0.07	0.01	0.00	0.00	0.06	0.01	0.00	0.00
1/18/2021	2 Hr. Load Up, Critical Peak	55.8	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Evening: 4:00 PM - 8:00 PM										
12/22/2020	Baseline	56.1	5.45	0.95	0.38	0.24	0.38	0.23	n/a	n/a
n/a	1 Hr. Load Up, Shed									
1/6/2021	2 Hr. Load Up, Shed	56.7	2.03	0.23	0.00	0.00	0.38	0.14	0.00	0.00
1/14/2021	1 Hr. Load Up, Critical Peak	54.7	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00
1/18/2021	2 Hr. Load Up, Critical Peak	55.8	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00

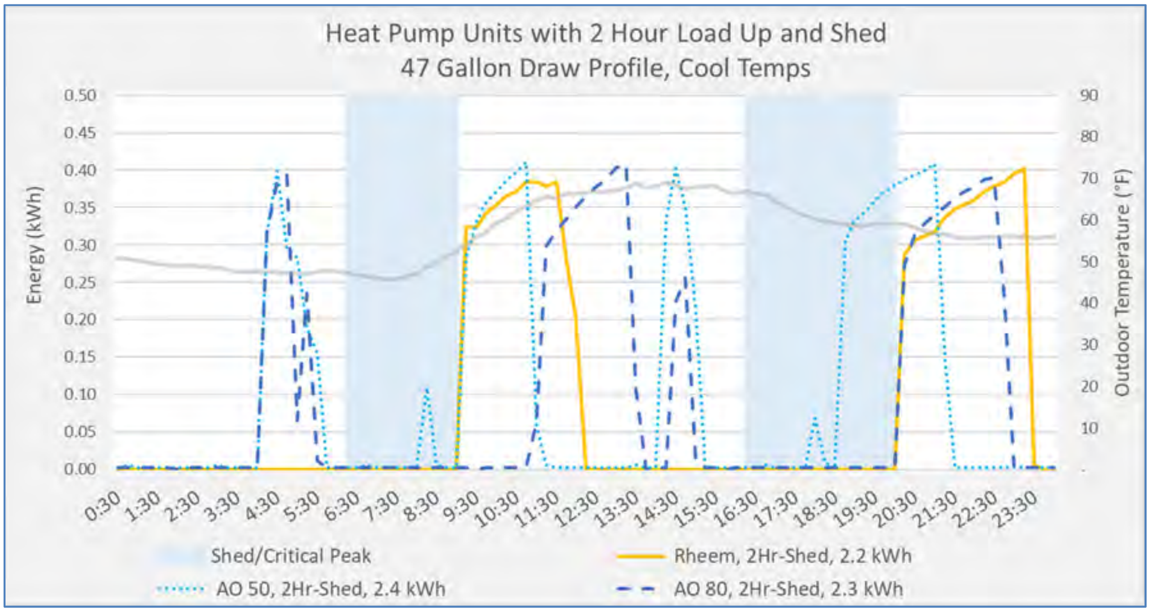
Peak Demand and Peak Hours Energy use: 47 Gallon Draw Profile, Mild Temperatures										
Morning: 6:00 Am - 9:00 AM										
		Temperature	AO Smith 50 Elec.		Rheem 50 HP		AO Smith 50 HP		AO Smith 80 HP	
Date	Schedule	Average Outdoor (°F)	Peak 15-Min (kW)	Avg. Peak Hours (kW)	Peak 15-Min (kW)	Avg. Peak Hours (kW)	Peak 15-Min (kW)	Avg. Peak Hours (kW)	Peak 15-Min (kW)	Avg. Peak Hours (kW)
12/20/2020	Baseline	67.2	3.25	0.99	0.38	0.20	0.40	0.19	0.36	0.10
12/29/2020	1 Hr. Load Up, Shed	65.1	1.66	0.23	0.00	0.00	0.08	0.01	0.00	0.00
1/3/2021	2 Hr. Load Up, Shed	66.7	1.52	0.13	n/a	n/a	0.01	0.00	0.00	0.00
1/12/2021	1 Hr. Load Up, Critical Peak	62.1	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
1/22/2021	2 Hr. Load Up, Critical Peak	65.7	0.00	0.00	n/a	n/a	0.01	0.00	0.00	0.00
Evening: 4:00 PM - 8:00 PM										
12/20/2020	Baseline	67.2	4.38	0.93	0.40	0.22	0.42	0.24	0.39	0.19
12/29/2020	1 Hr. Load Up, Shed	65.1	2.20	0.24	0.00	0.00	0.38	0.14	0.00	0.00
1/3/2021	2 Hr. Load Up, Shed	66.7	1.77	0.19	n/a	n/a	0.37	0.09	0.00	0.00
1/12/2021	1 Hr. Load Up, Critical Peak	62.1	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.00
1/22/2021	2 Hr. Load Up, Critical Peak	65.7	0.00	0.00	n/a	n/a	0.01	0.00	0.00	0.00

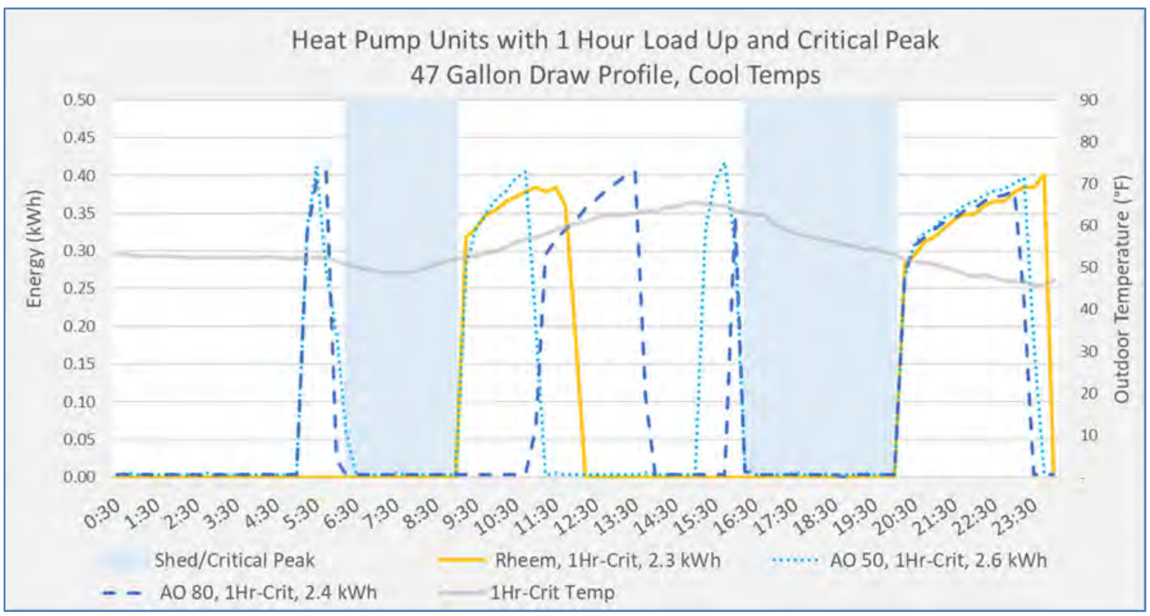
Peak Demand and Peak Hours Energy use: 57 Gallon Draw Profile, Cool Temperatures										
Morning: 6:00 Am - 9:00 AM										
		Temperature	AO Smith 50 Elec.		Rheem 50 HP		AO Smith 50 HP		AO Smith 80 HP	
Date	Schedule	Average Outdoor (°F)	Peak 15-Min (kW)	Avg. Peak Hours (kW)	Peak 15-Min (kW)	Avg. Peak Hours (kW)	Peak 15-Min (kW)	Avg. Peak Hours (kW)	Peak 15-Min (kW)	Avg. Peak Hours (kW)
1/31/2021	Baseline	66.8	5.28	1.02	0.39	0.26	0.41	0.25	0.39	0.23
2/6/2021	1 Hr. Load Up, Shed	65.0	1.62	0.30	0.00	0.00	0.21	0.03	0.00	0.00
n/a	2 Hr. Load Up, Shed									
2/21/2021	1 Hr. Load Up, Critical Peak	63.8	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0.00
2/24/2021	2 Hr. Load Up, Critical Peak	66.1	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Evening: 4:00 PM - 8:00 PM										
1/31/2021	Baseline	66.80	3.34	0.65	0.39	0.16	0.42	0.16	0.41	0.16
2/6/2021	1 Hr. Load Up, Shed	65.04	1.59	0.20	0.00	0.00	0.38	0.07	0.01	0.00
n/a	2 Hr. Load Up, Shed									
2/21/2021	1 Hr. Load Up, Critical Peak	63.85	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
2/24/2021	2 Hr. Load Up, Critical Peak	66.09	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00

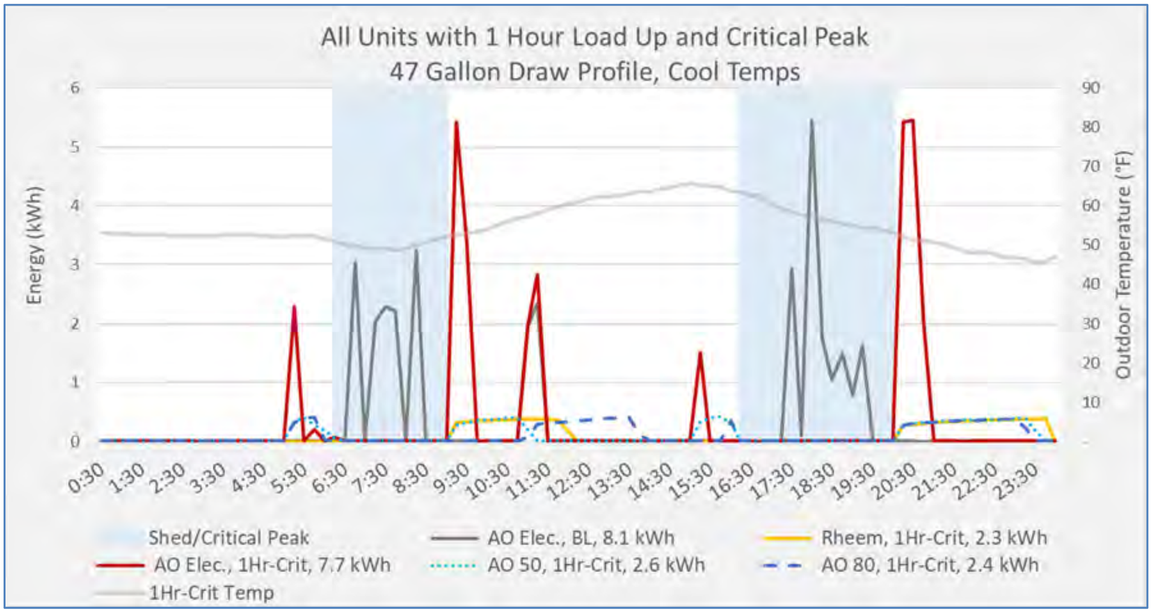
Peak Demand and Peak Hours Energy use: 57 Gallon Draw Profile, Mild Temperatures										
Morning: 6:00 Am - 9:00 AM										
		Temperature	AO Smith 50 Elec.		Rheem 50 HP		AO Smith 50 HP		AO Smith 80 HP	
Date	Schedule	Average Outdoor (°F)	Peak 15-Min (kW)	Avg. Peak Hours (kW)	Peak 15-Min (kW)	Avg. Peak Hours (kW)	Peak 15-Min (kW)	Avg. Peak Hours (kW)	Peak 15-Min (kW)	Avg. Peak Hours (kW)
1/27/2021	Baseline	71.4	5.21	0.98	0.38	0.24	0.41	0.25	0.40	0.24
2/7/2021	1 Hr. Load Up, Shed	69.1	1.98	0.19	0.00	0.00	0.16	0.02	0.00	0.00
2/11/2021	2 Hr. Load Up, Shed	72.0	1.67	0.18	0.00	0.00	0.14	0.02	0.00	0.00
2/16/2021	1 Hr. Load Up, Critical Peak	70.2	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
2/27/2021	2 Hr. Load Up, Critical Peak	74.3	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Evening: 4:00 PM - 8:00 PM										
1/27/2021	Baseline	71.4	3.21	0.62	0.40	0.17	0.40	0.15	0.43	0.19
2/7/2021	1 Hr. Load Up, Shed	69.1	1.46	0.18	0.00	0.00	0.37	0.07	0.01	0.00
2/11/2021	2 Hr. Load Up, Shed	72.0	1.73	0.11	0.00	0.00	0.01	0.00	0.00	0.00
2/16/2021	1 Hr. Load Up, Critical Peak	70.2	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00
2/27/2021	2 Hr. Load Up, Critical Peak	74.3	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00

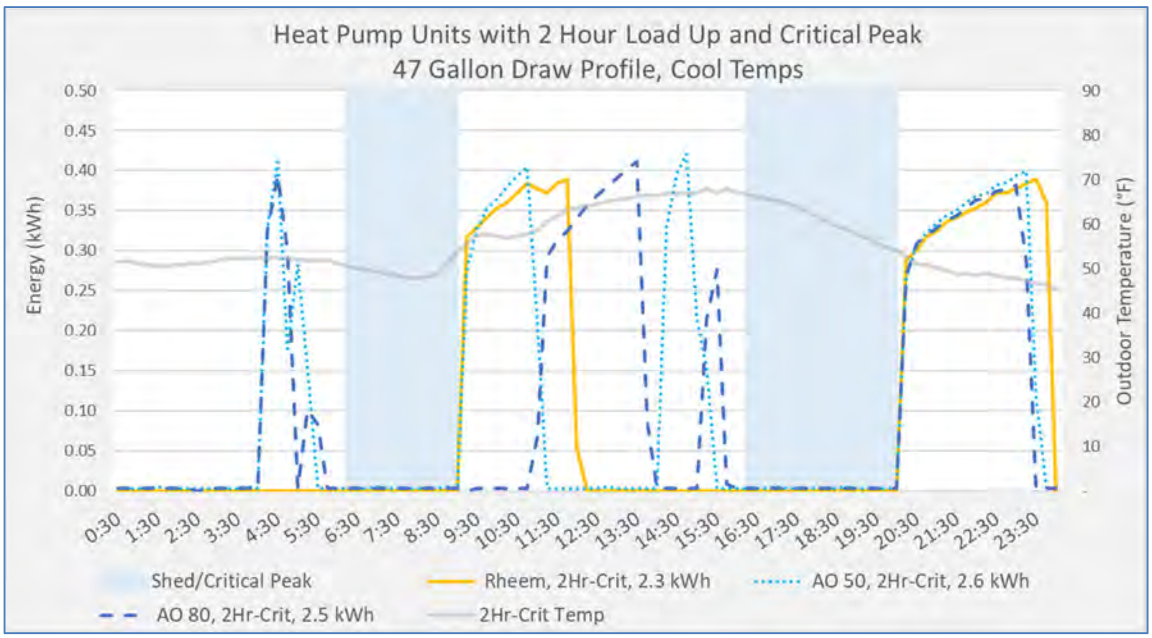
Appendix C-1: All Units Compared per Command Structure – 47 Gallon, Cool Temperatures

1 hour load up and shed is not available for comparison in this temperature/draw profile.

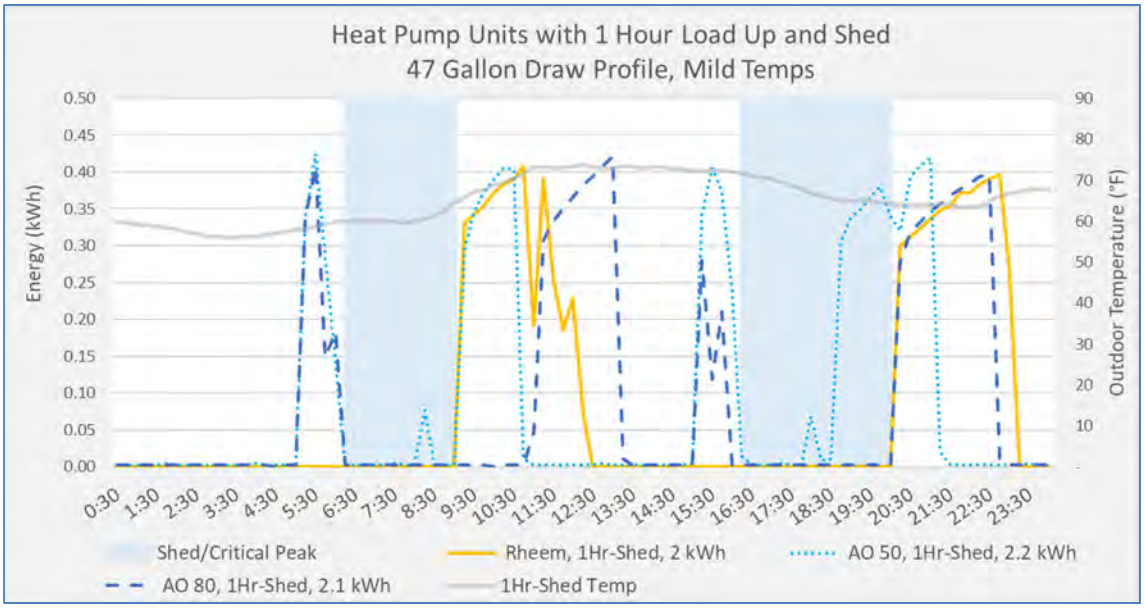


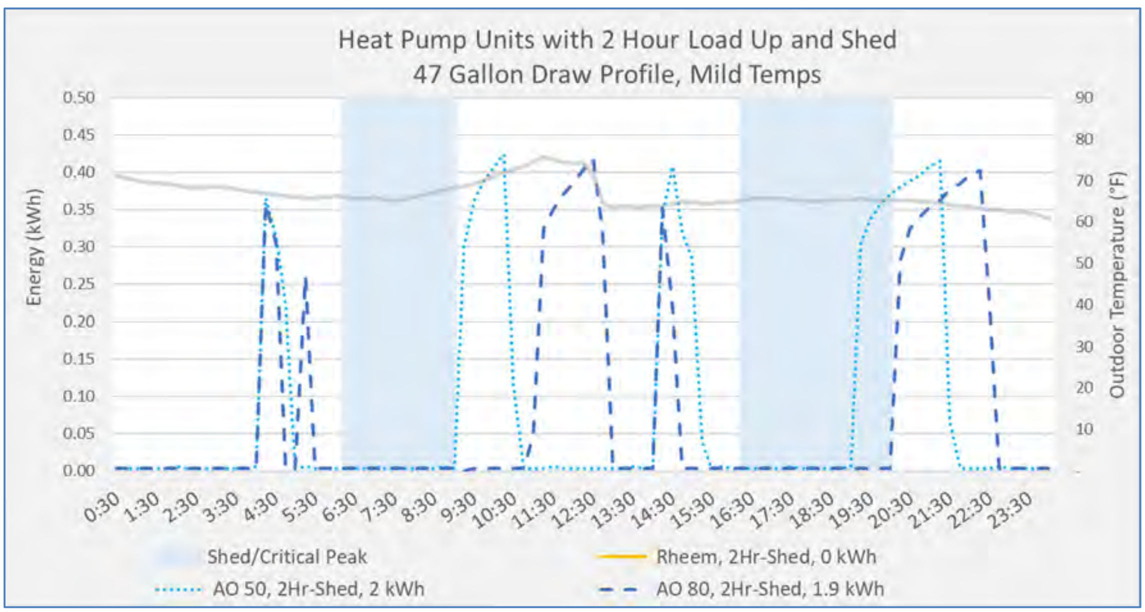


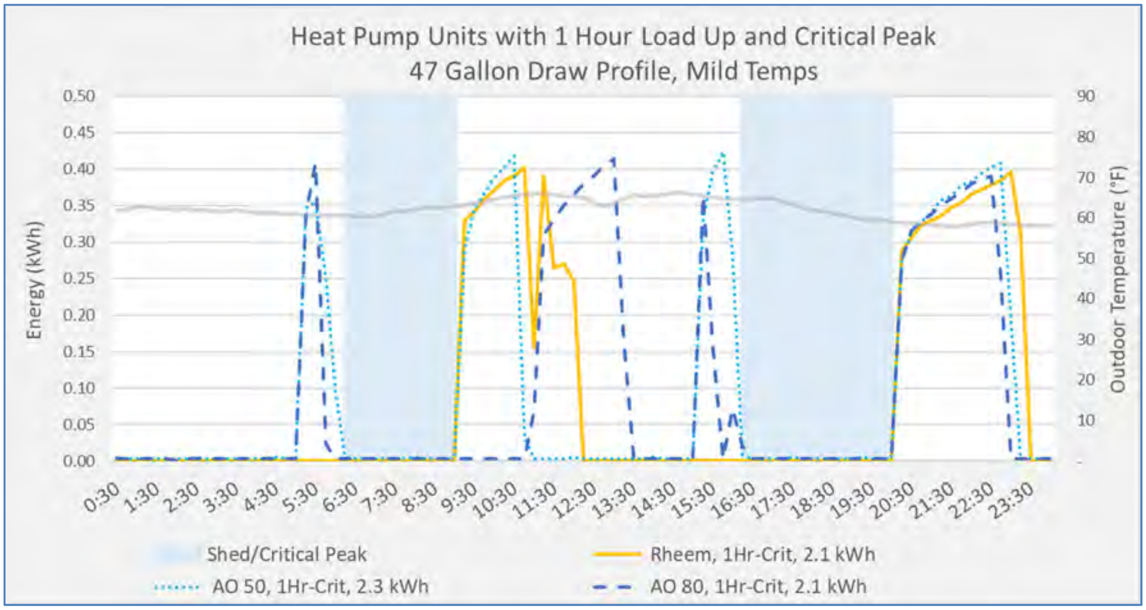

All Units with 1 Hour Load Up and Critical Peak
47 Gallon Draw Profile, Cool Temps
Energy (kWh)
Outdoor Temperature (°F)
Shed/Critical Peak
AO Elec., BL, 8.1 kWh
Rheem, 1Hr-Crit, 2.3 kWh
AO Elec., 1Hr-Crit, 7.7 kWh
AO 50, 1Hr-Crit, 2.6 kWh
AO 80, 1Hr-Crit, 2.4 kWh
1Hr-Crit Temp

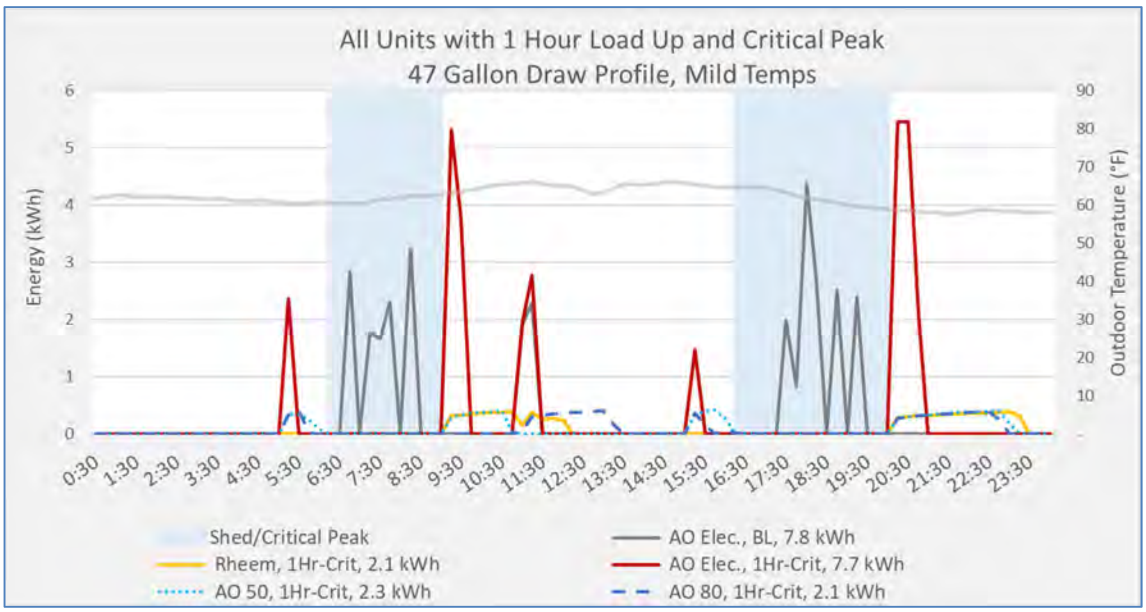

Heat Pump Units with 2 Hour Load Up and Critical Peak
47 Gallon Draw Profile, Cool Temps
Energy (kWh)
Outdoor Temperature (°F)
Shed/Critical Peak
Rheem, 2Hr-Crit, 2.3 kWh
AO 50, 2Hr-Crit, 2.6 kWh
AO 80, 2Hr-Crit, 2.5 kWh
2Hr-Crit Temp

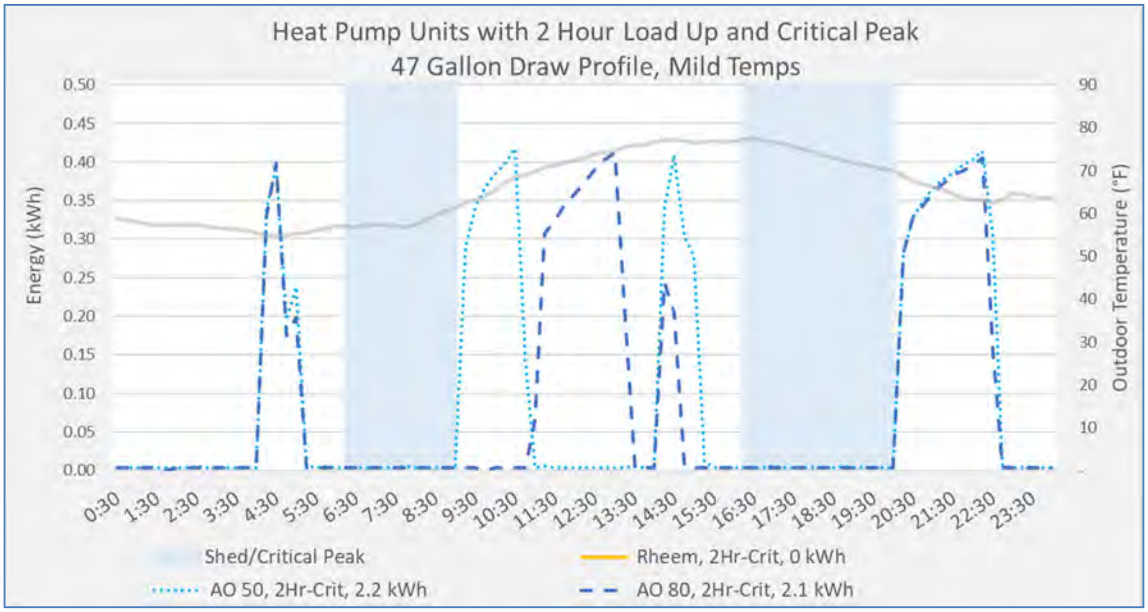
Appendix C-2: All Units Compared per Command Structure – 47 Gallon, Mild Temperatures





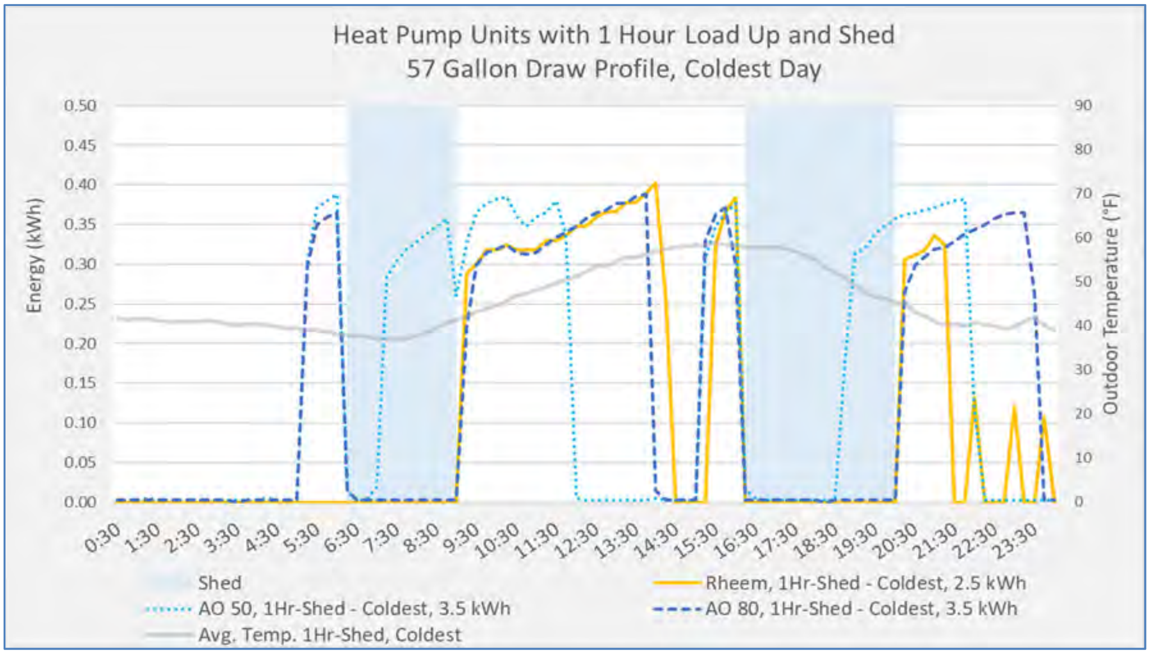

Heat Pump Units with 1 Hour Load Up and Critical Peak
47 Gallon Draw Profile, Mild Temps
Energy (kWh)
Outdoor Temperature (°F)
Shed/Critical Peak
Rheem, 1Hr-Crit, 2.1 kWh
AO 50, 1Hr-Crit, 2.3 kWh
AO 80, 1Hr-Crit, 2.1 kWh

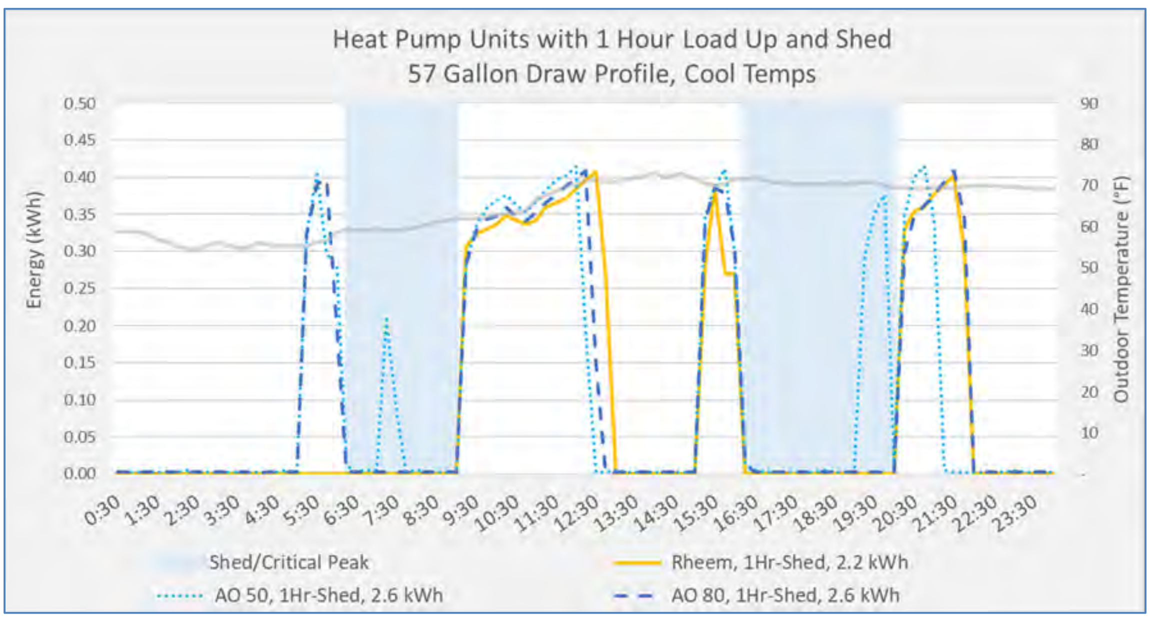

All Units with 1 Hour Load Up and Critical Peak
47 Gallon Draw Profile, Mild Temps
Energy (kWh)
Outdoor Temperature (°F)
Shed/Critical Peak
AO Elec., BL, 7.8 kWh
Rheem, 1Hr-Crit, 2.1 kWh
AO Elec., 1Hr-Crit, 7.7 kWh
AO 50, 1Hr-Crit, 2.3 kWh
AO 80, 1Hr-Crit, 2.1 kWh



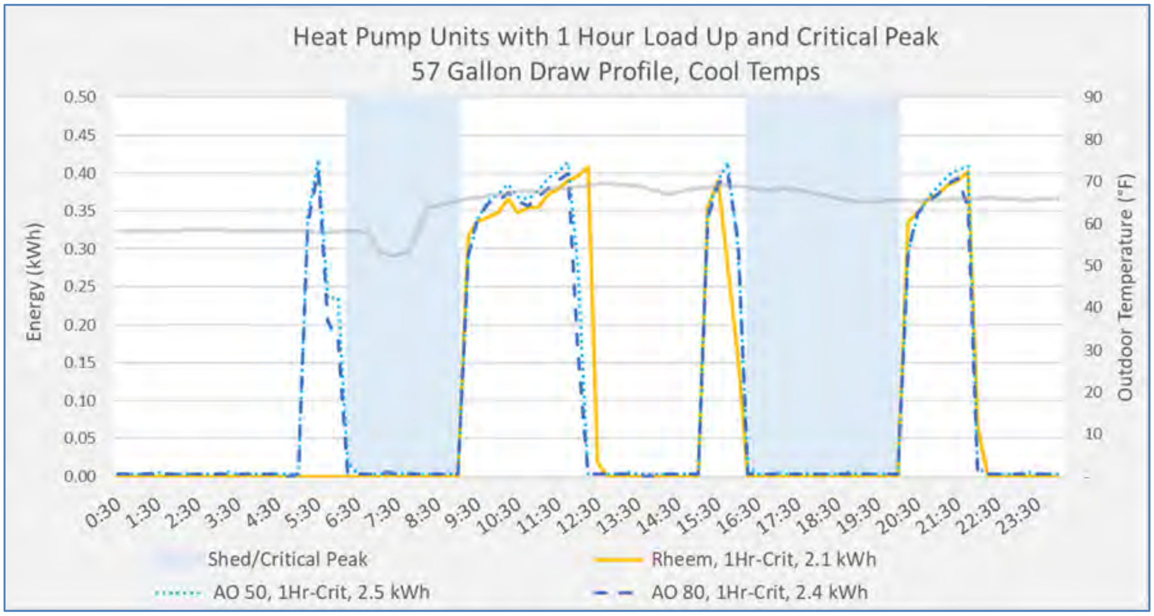
Heat Pump Units with 2 Hour Load Up and Critical Peak
47 Gallon Draw Profile, Mild Temps
Energy (kWh)
Outdoor Temperature (°F)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
90
80
70
60
50
40
30
20
10
0:30 1:30 2:30 3:30 4:30 5:30 6:30 7:30 8:30 9:30 10:30 11:30 12:30 13:30 14:30 15:30 16:30 17:30 18:30 19:30 20:30 21:30 22:30 23:30
Shed/Critical Peak
Rheem, 2Hr-Crit, 0 kWh
AO 50, 2Hr-Crit, 2.2 kWh
AO 80, 2Hr-Crit, 2.1 kWh

Appendix C-3: All Units Compared per Command Structure – 57 Gallon, Coldest Day and Cool Temperatures

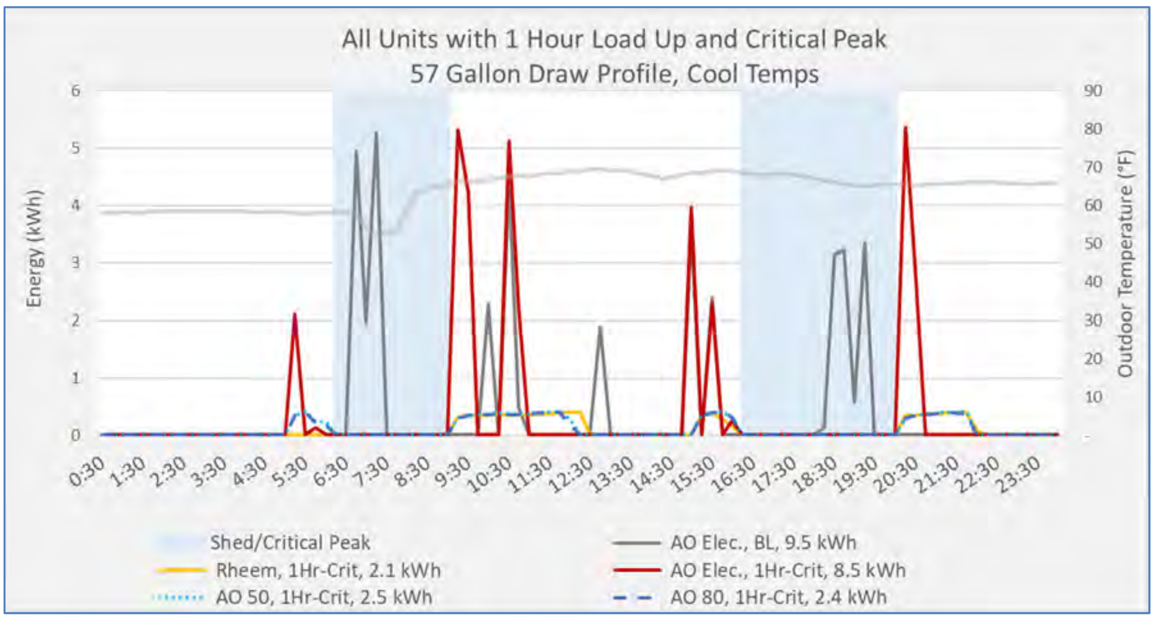




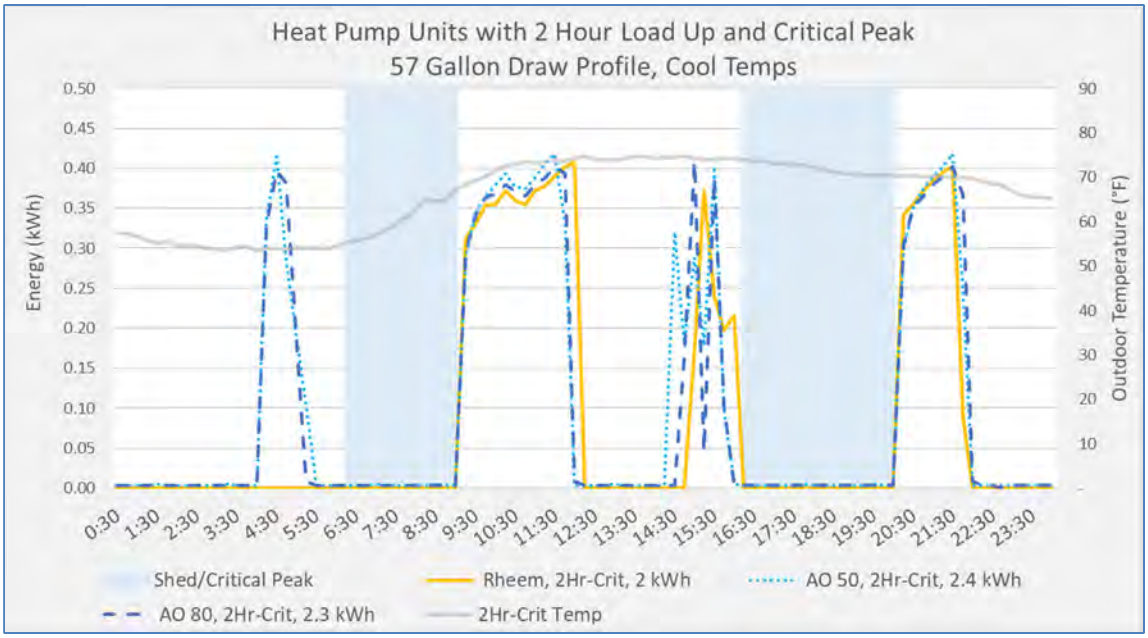
2 hour load up and shed is not available for comparison in this temperature/draw profile.



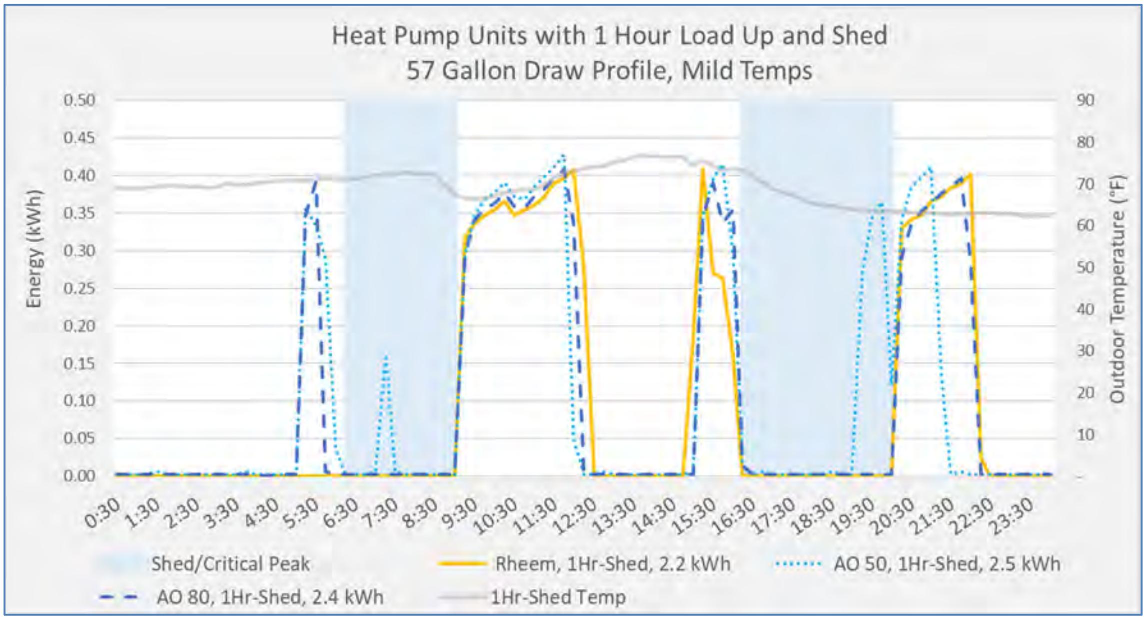
Heat Pump Units with 1 Hour Load Up and Critical Peak
57 Gallon Draw Profile, Cool Temps
Energy (kWh)
Outdoor Temperature (°F)
Shed/Critical Peak
Rheem, 1Hr-Crit, 2.1 kWh
AO 50, 1Hr-Crit, 2.5 kWh
AO 80, 1Hr-Crit, 2.4 kWh

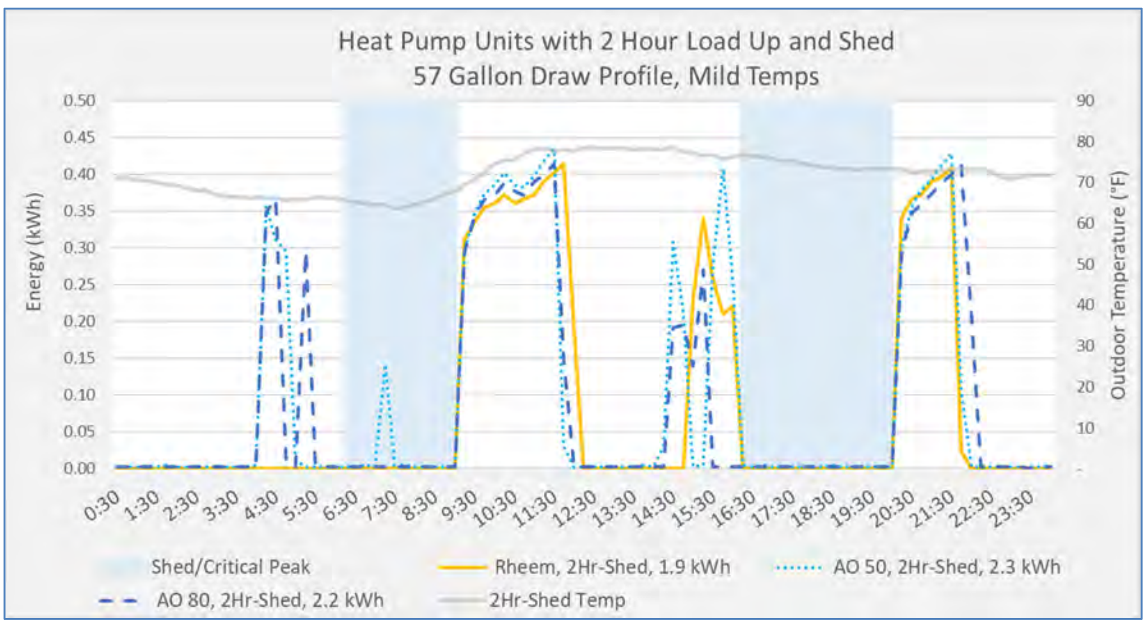


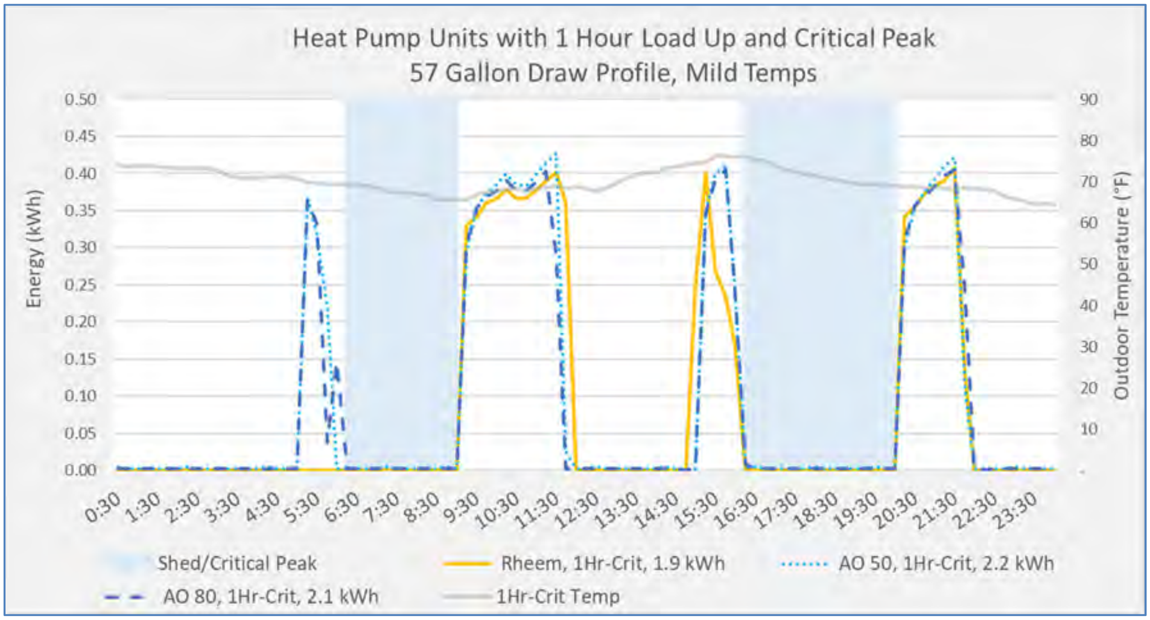
All Units with 1 Hour Load Up and Critical Peak
57 Gallon Draw Profile, Cool Temps
Energy (kWh)
Outdoor Temperature (°F)
Shed/Critical Peak
AO Elec., BL, 9.5 kWh
Rheem, 1Hr-Crit, 2.1 kWh
AO Elec., 1Hr-Crit, 8.5 kWh
AO 50, 1Hr-Crit, 2.5 kWh
AO 80, 1Hr-Crit, 2.4 kWh

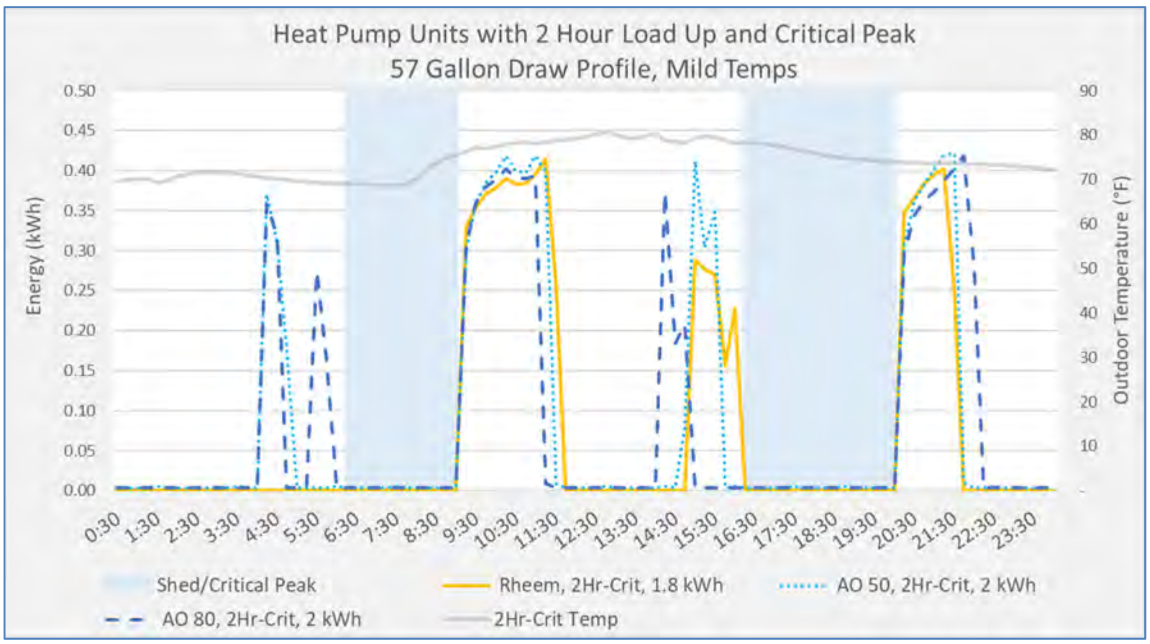

Heat Pump Units with 2 Hour Load Up and Critical Peak
57 Gallon Draw Profile, Cool Temps
Energy (kWh)
Outdoor Temperature (°F)
Shed/Critical Peak
Rheem, 2Hr-Crit, 2 kWh
AO 50, 2Hr-Crit, 2.4 kWh
AO 80, 2Hr-Crit, 2.3 kWh
2Hr-Crit Temp

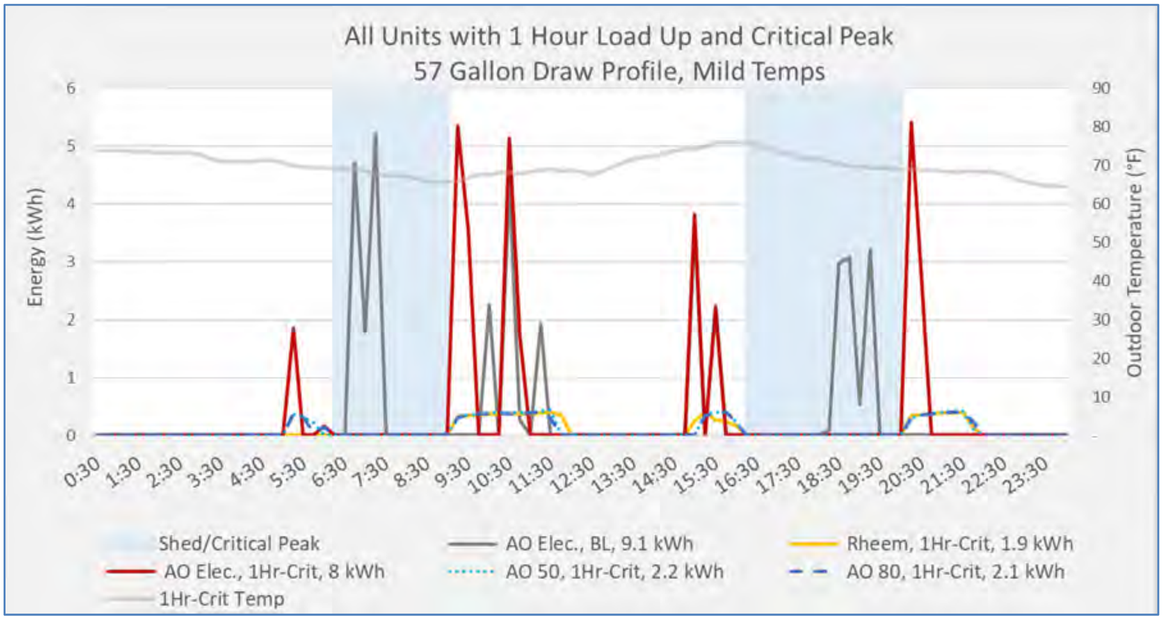
Appendix C-4: All Units Compared per Command Structure – 57 Gallon, Cool Temperatures



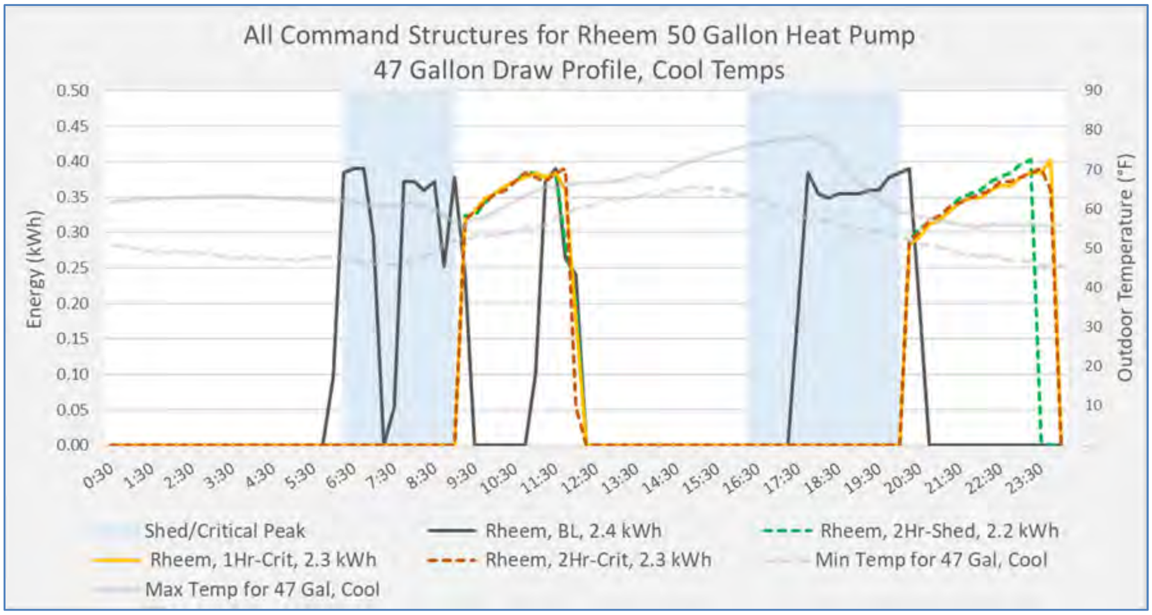


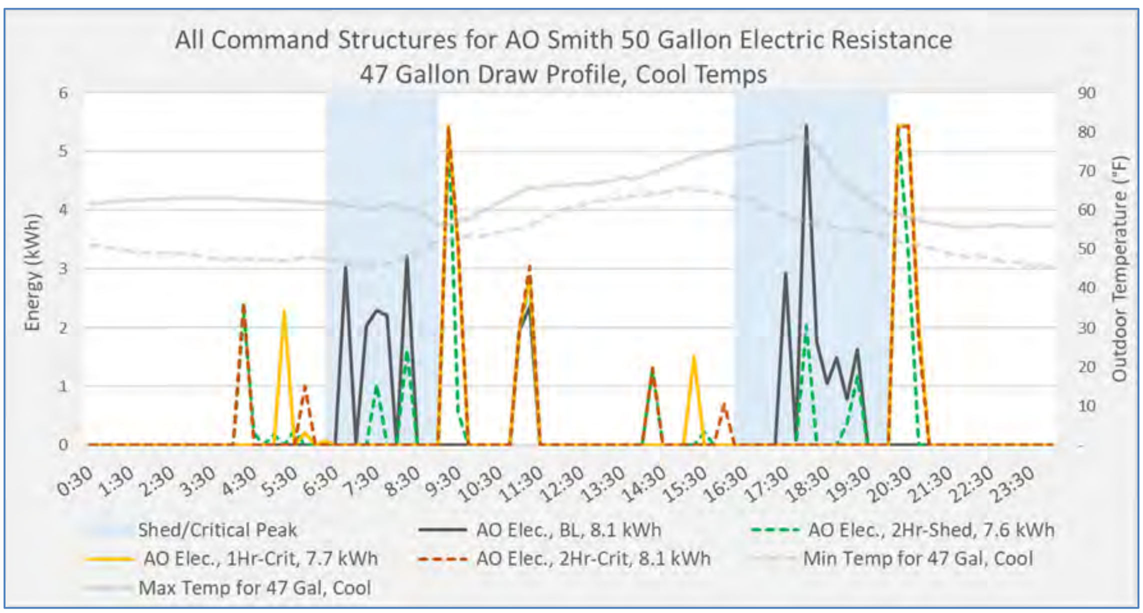

Heat Pump Units with 1 Hour Load Up and Critical Peak
57 Gallon Draw Profile, Mild Temps
Energy (kWh)
Outdoor Temperature (°F)
Shed/Critical Peak
Rheem, 1Hr-Crit, 1.9 kWh
AO 50, 1Hr-Crit, 2.2 kWh
AO 80, 1Hr-Crit, 2.1 kWh
1Hr-Crit Temp

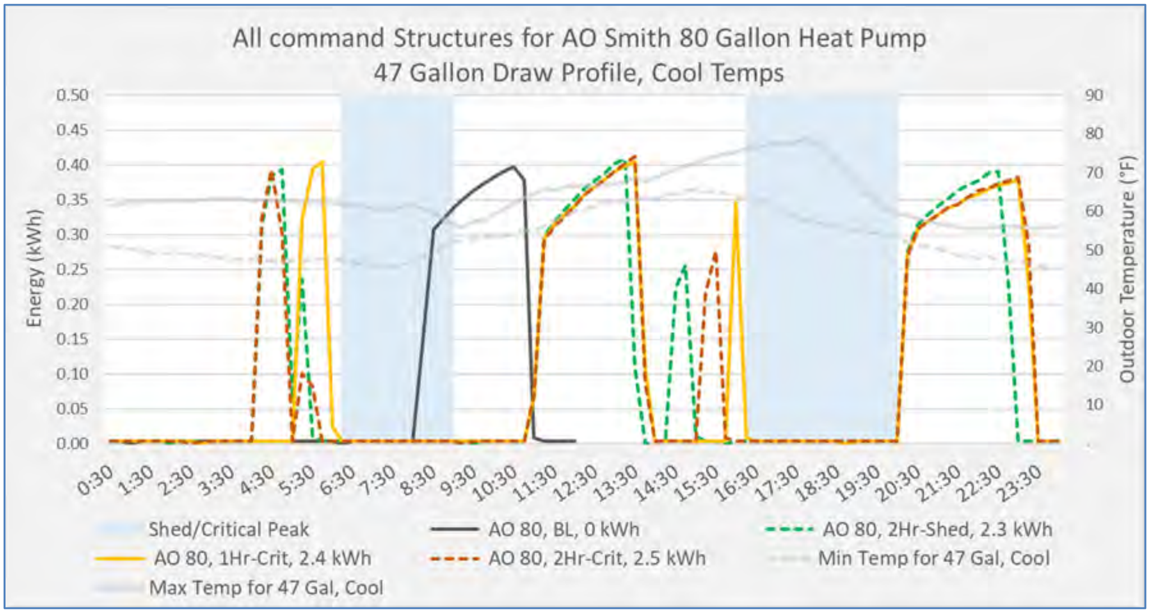

Heat Pump Units with 2 Hour Load Up and Critical Peak
57 Gallon Draw Profile, Mild Temps
Energy (kWh)
Outdoor Temperature (°F)
Shed/Critical Peak
Rheem, 2Hr-Crit, 1.8 kWh
AO 50, 2Hr-Crit, 2 kWh
AO 80, 2Hr-Crit, 2 kWh
2Hr-Crit Temp

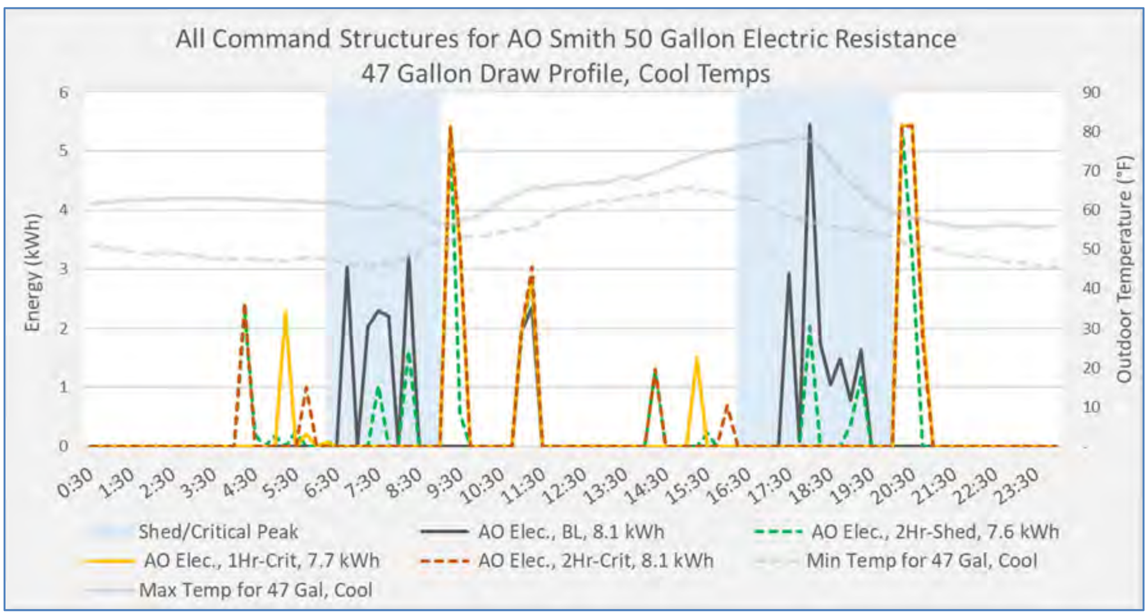

All Units with 1 Hour Load Up and Critical Peak
57 Gallon Draw Profile, Mild Temps
Energy (kWh)
Outdoor Temperature (°F)
Shed/Critical Peak
AO Elec., BL, 9.1 kWh
Rheem, 1Hr-Crit, 1.9 kWh
AO Elec., 1Hr-Crit, 8 kWh
AO 50, 1Hr-Crit, 2.2 kWh
AO 80, 1Hr-Crit, 2.1 kWh
1Hr-Crit Temp

Appendix D-1: All Command Structures Compared per Unit – 47 Gallon, Cool Temperatures

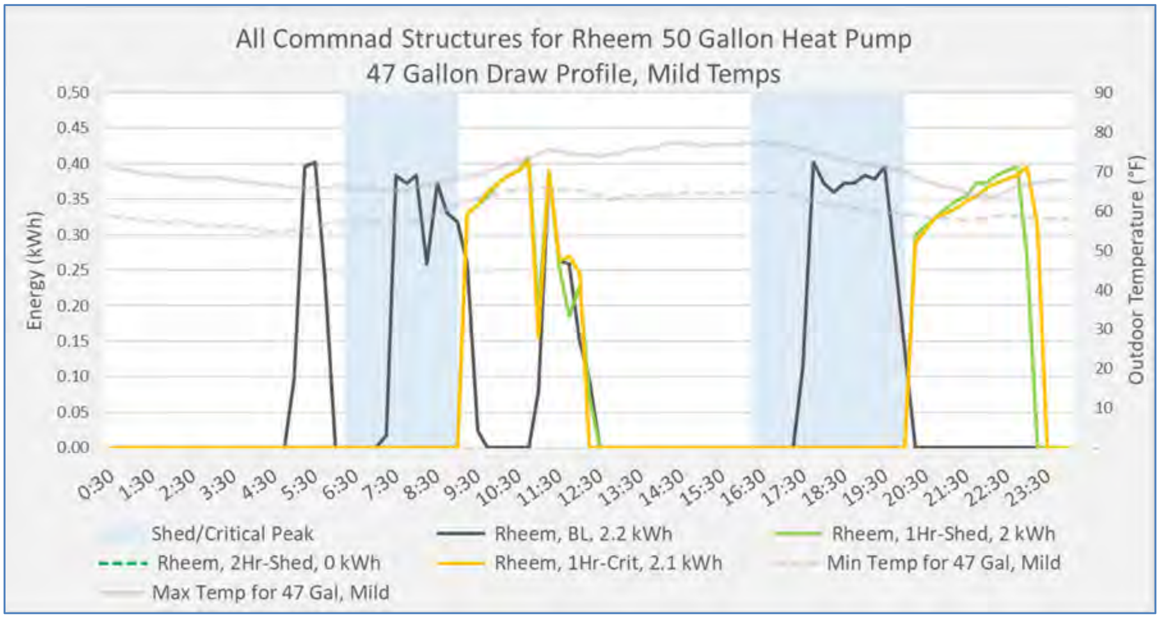


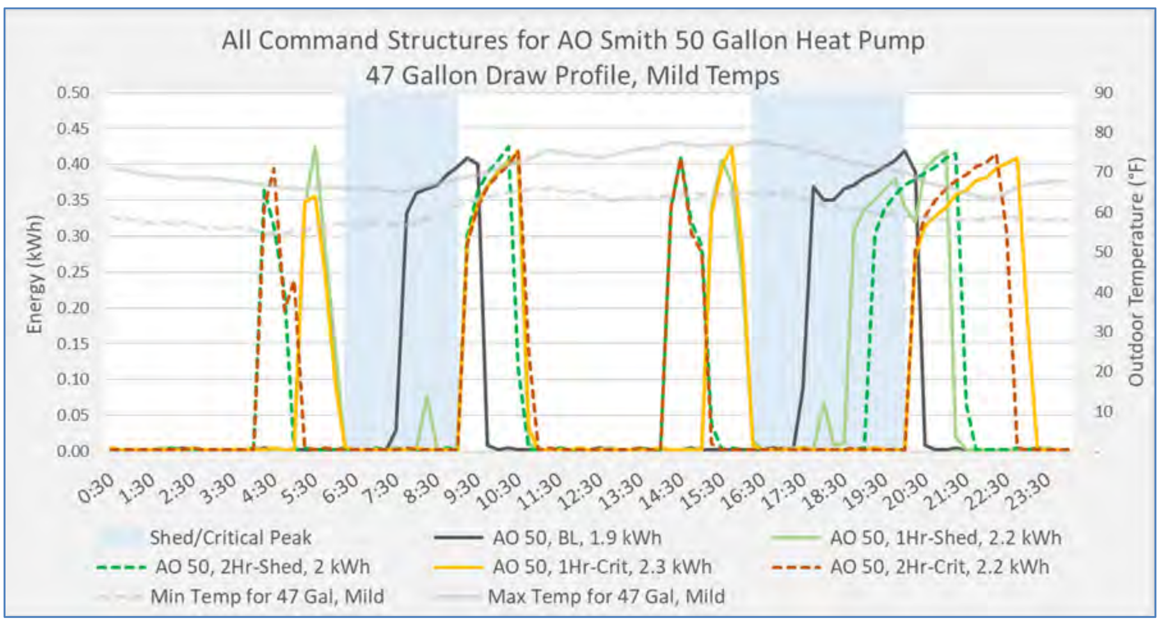


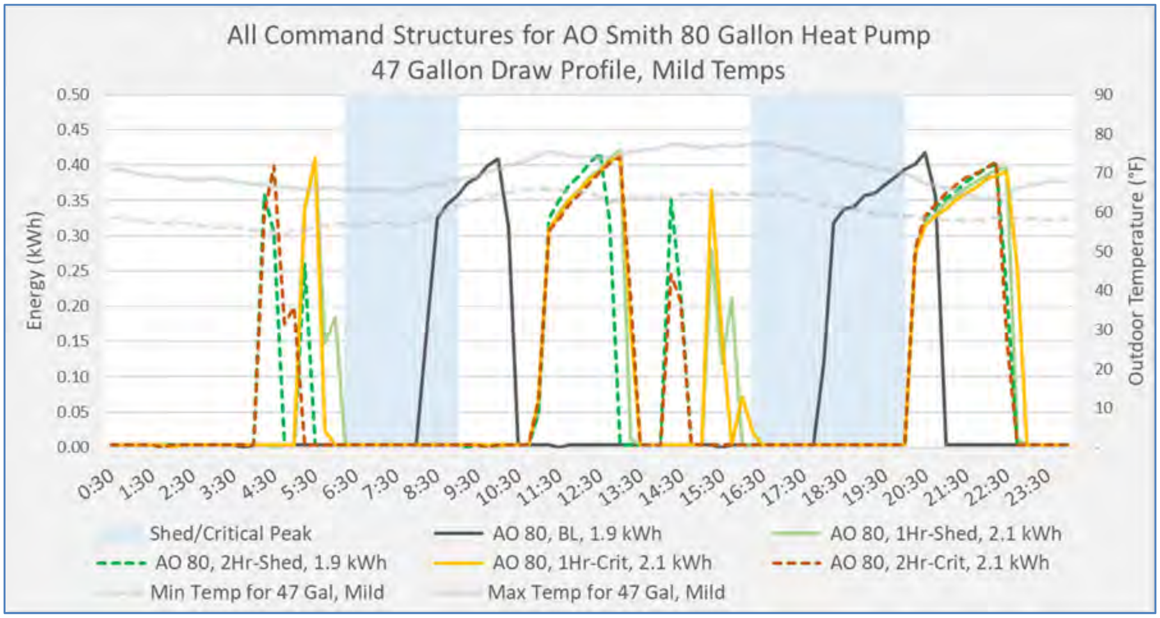

All command Structures for AO Smith 80 Gallon Heat Pump
47 Gallon Draw Profile, Cool Temps
Energy (kWh)
Outdoor Temperature (°F)
Shed/Critical Peak
AO 80, BL, 0 kWh
AO 80, 2Hr-Shed, 2.3 kWh
AO 80, 1Hr-Crit, 2.4 kWh
AO 80, 2Hr-Crit, 2.5 kWh
Min Temp for 47 Gal, Cool
Max Temp for 47 Gal, Cool

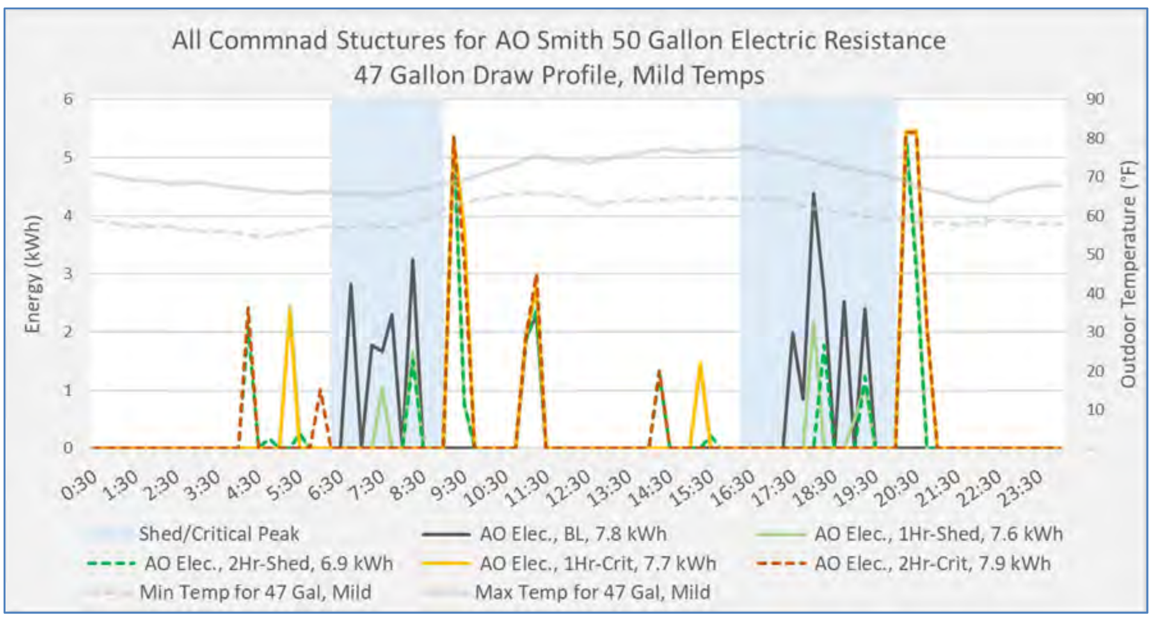

All Command Structures for AO Smith 50 Gallon Electric Resistance
47 Gallon Draw Profile, Cool Temps
Energy (kWh)
Outdoor Temperature (°F)
Shed/Critical Peak
AO Elec., BL, 8.1 kWh
AO Elec., 2Hr-Shed, 7.6 kWh
AO Elec., 1Hr-Crit, 7.7 kWh
AO Elec., 2Hr-Crit, 8.1 kWh
Min Temp for 47 Gal, Cool
Max Temp for 47 Gal, Cool

Appendix D-2: All Command Structures Compared per Unit – 47 Gallon, Mild Temperatures

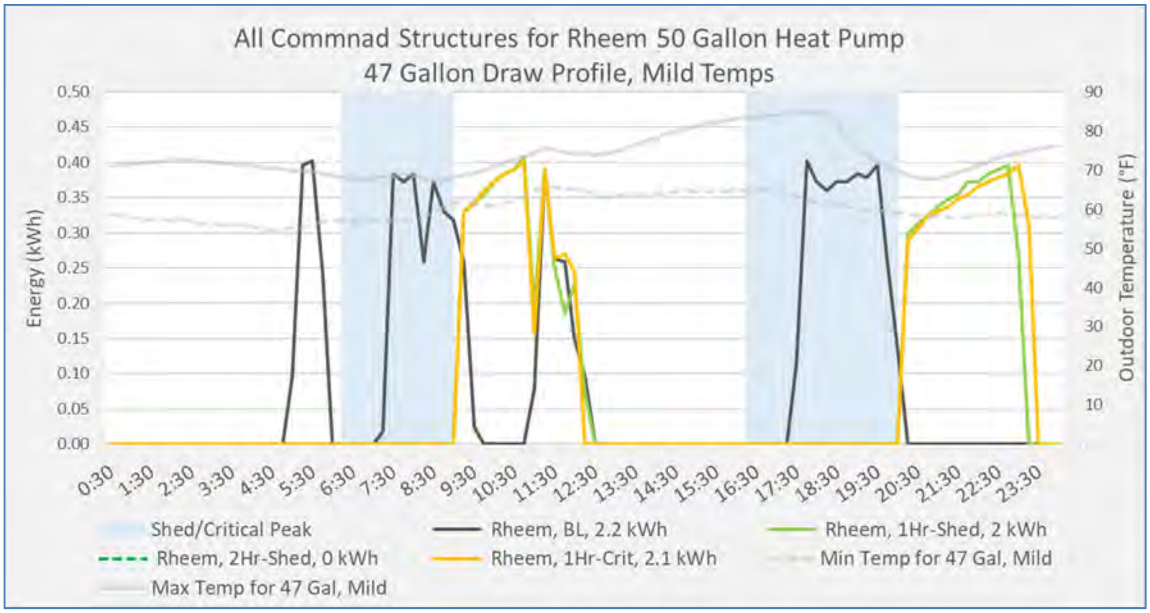


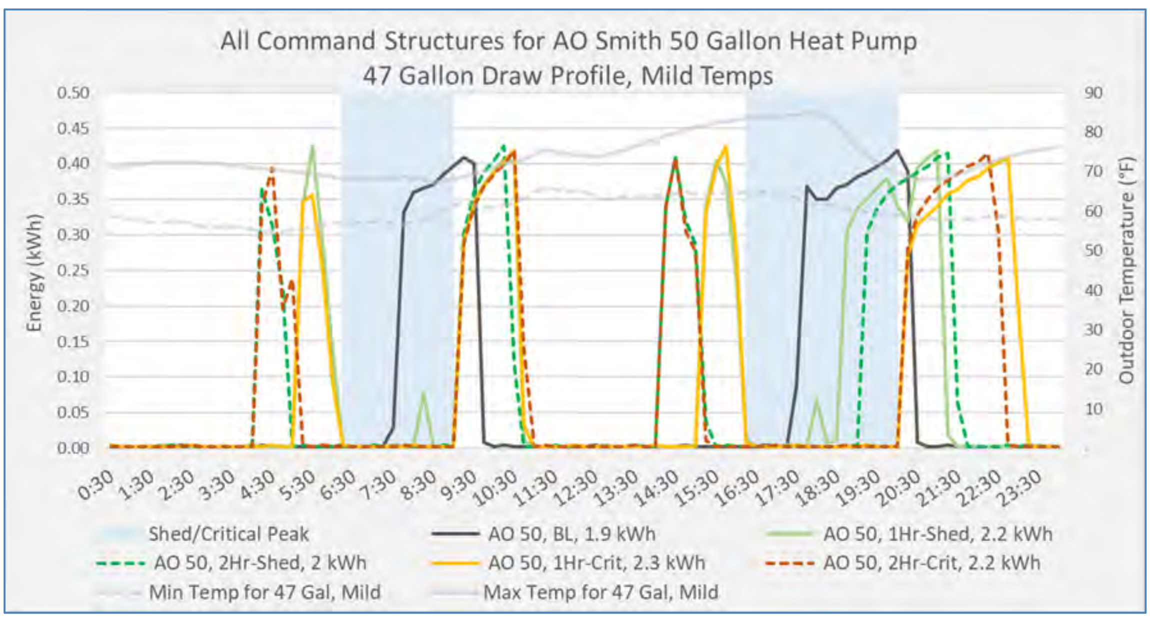


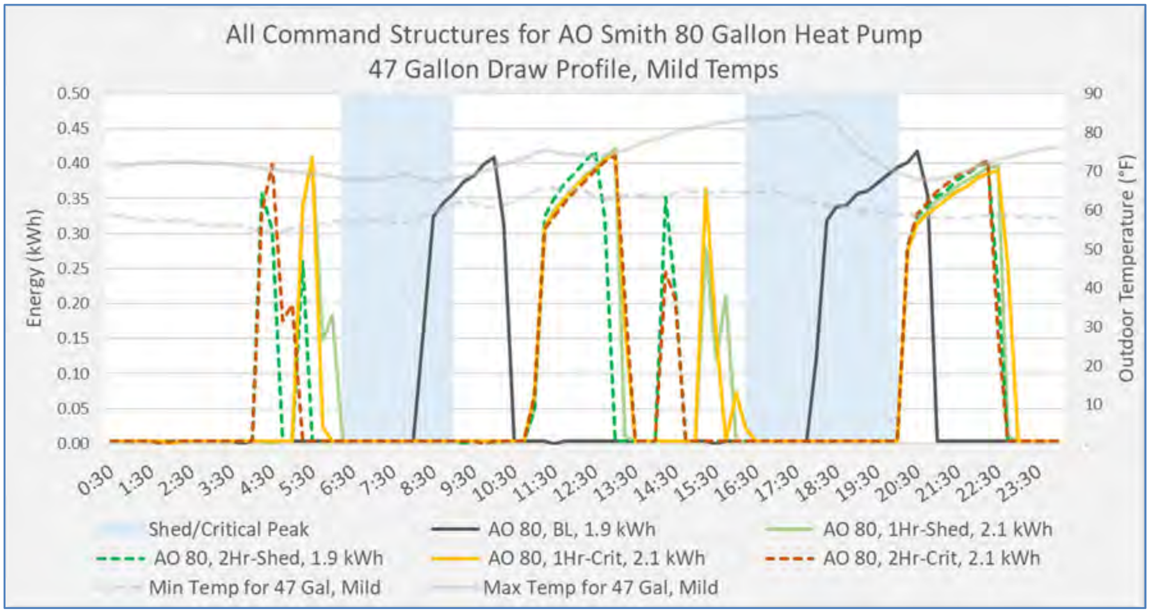

All Command Structures for AO Smith 80 Gallon Heat Pump
47 Gallon Draw Profile, Mild Temps
Energy (kWh)
Outdoor Temperature (°F)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
10
20
30
40
50
60
70
80
90
0:30 1:30 2:30 3:30 4:30 5:30 6:30 7:30 8:30 9:30 10:30 11:30 12:30 13:30 14:30 15:30 16:30 17:30 18:30 19:30 20:30 21:30 22:30 23:30
Shed/Critical Peak
AO 80, BL, 1.9 kWh
AO 80, 1Hr-Shed, 2.1 kWh
AO 80, 2Hr-Shed, 1.9 kWh
AO 80, 1Hr-Crit, 2.1 kWh
AO 80, 2Hr-Crit, 2.1 kWh
Min Temp for 47 Gal, Mild
Max Temp for 47 Gal, Mild

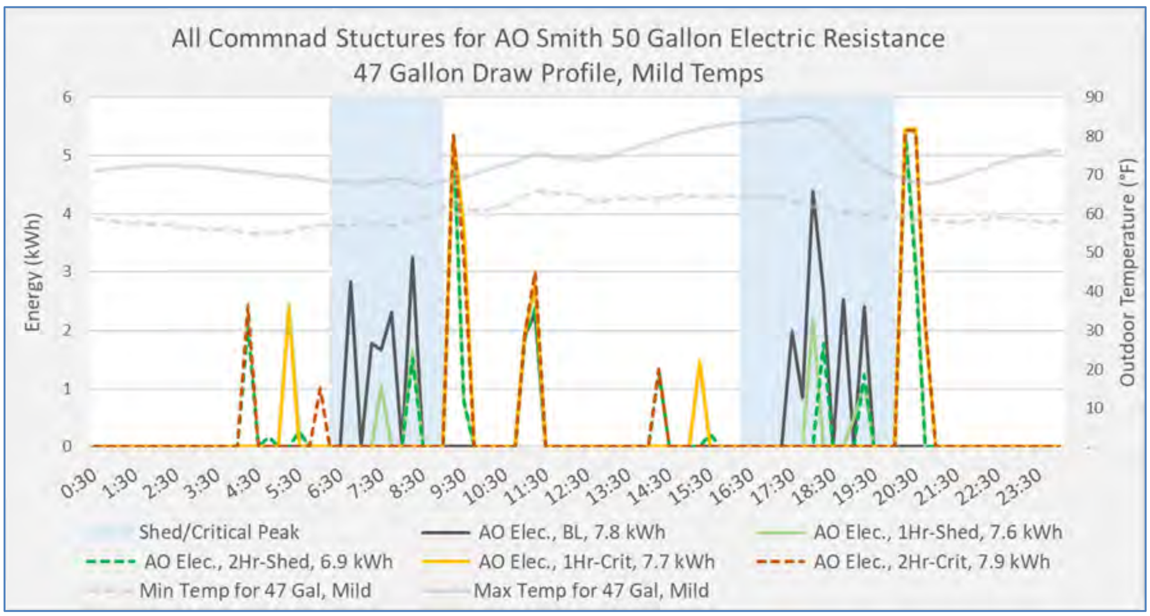

All Commnad Stuctures for AO Smith 50 Gallon Electric Resistance
47 Gallon Draw Profile, Mild Temps
Energy (kWh)
Outdoor Temperature (°F)
0
1
2
3
4
5
6
10
20
30
40
50
60
70
80
90
0:30 1:30 2:30 3:30 4:30 5:30 6:30 7:30 8:30 9:30 10:30 11:30 12:30 13:30 14:30 15:30 16:30 17:30 18:30 19:30 20:30 21:30 22:30 23:30
Shed/Critical Peak
AO Elec., BL, 7.8 kWh
AO Elec., 1Hr-Shed, 7.6 kWh
AO Elec., 2Hr-Shed, 6.9 kWh
AO Elec., 1Hr-Crit, 7.7 kWh
AO Elec., 2Hr-Crit, 7.9 kWh
Min Temp for 47 Gal, Mild
Max Temp for 47 Gal, Mild

Appendix D-3: All Command Structures Compared per Unit – 57 Gallon, Cool Temperatures

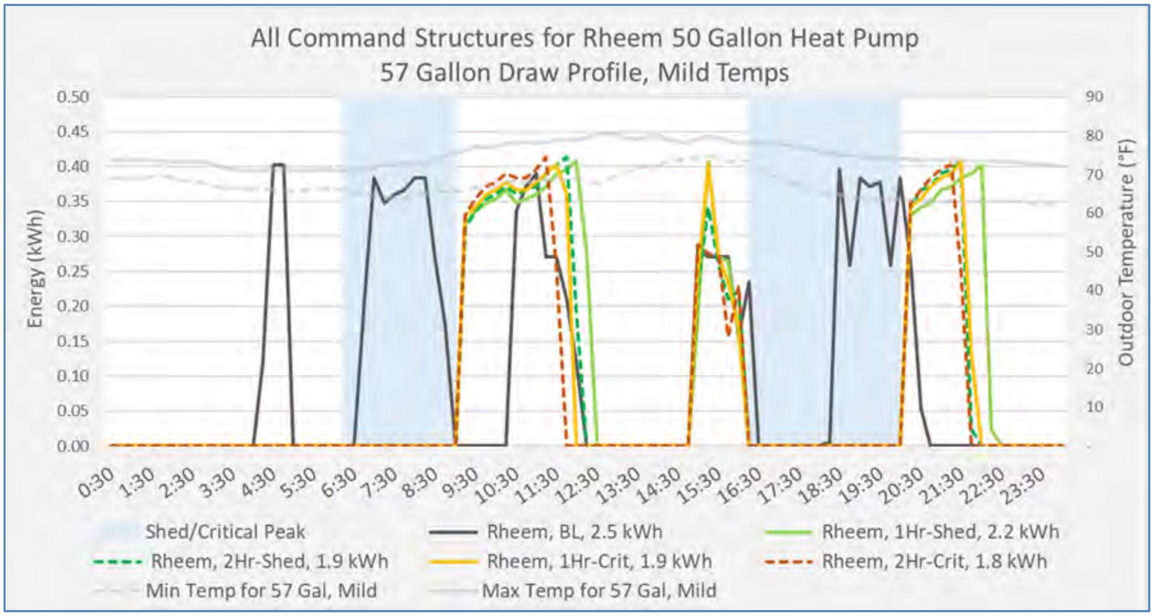


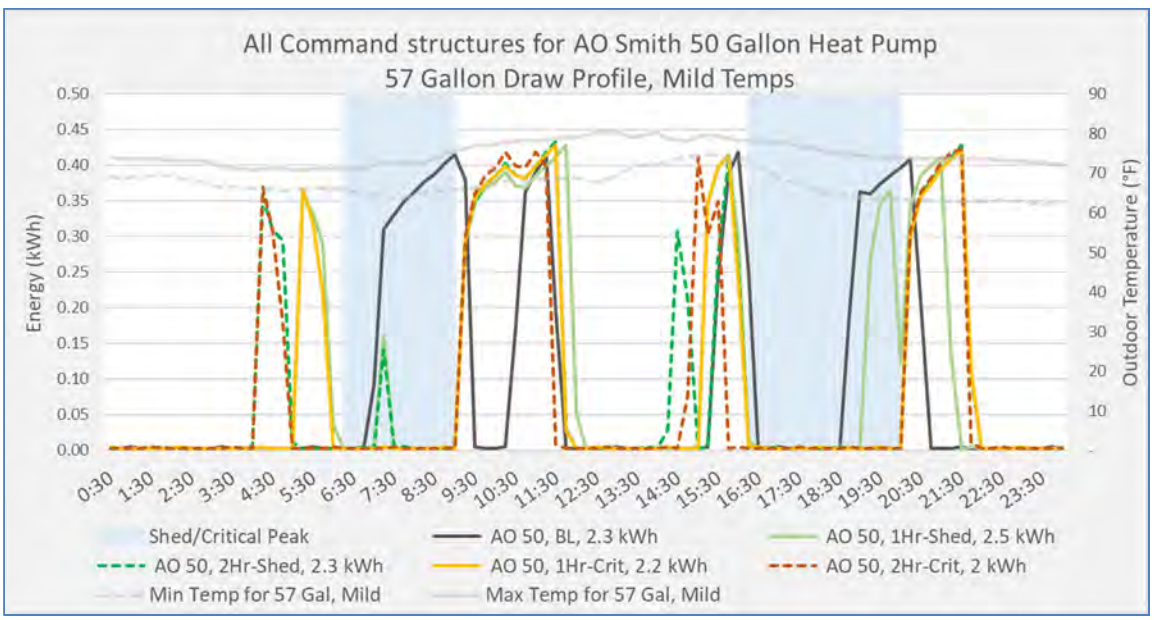


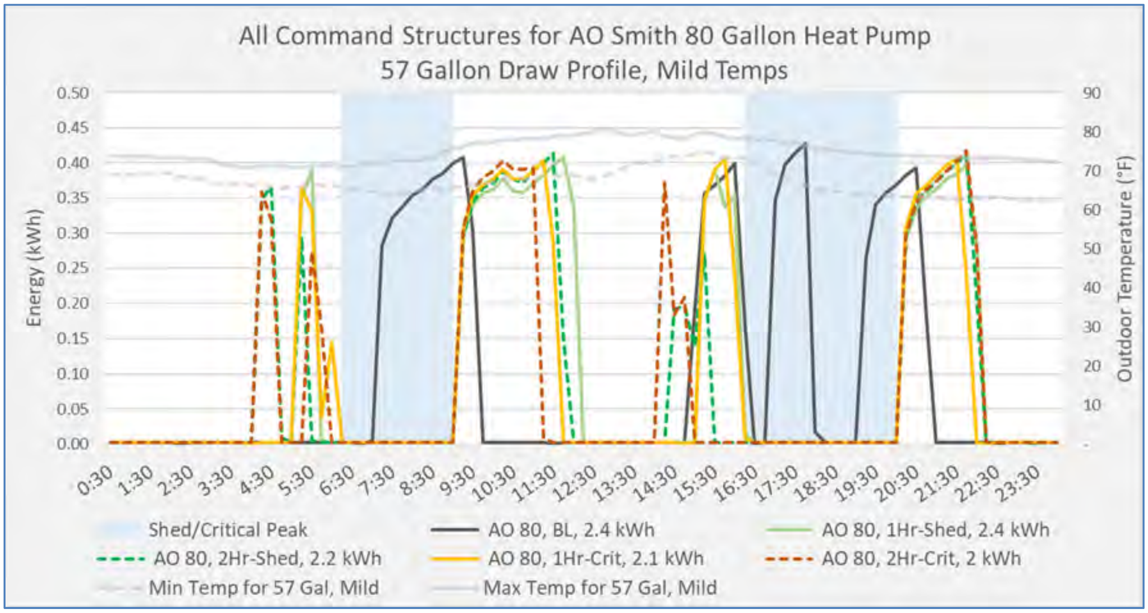

All Command Structures for AO Smith 80 Gallon Heat Pump
47 Gallon Draw Profile, Mild Temps
Energy (kWh)
Outdoor Temperature (°F)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
90
80
70
60
50
40
30
20
10
0:30 1:30 2:30 3:30 4:30 5:30 6:30 7:30 8:30 9:30 10:30 11:30 12:30 13:30 14:30 15:30 16:30 17:30 18:30 19:30 20:30 21:30 22:30 23:30
Shed/Critical Peak
AO 80, BL, 1.9 kWh
AO 80, 1Hr-Shed, 2.1 kWh
AO 80, 2Hr-Shed, 1.9 kWh
AO 80, 1Hr-Crit, 2.1 kWh
AO 80, 2Hr-Crit, 2.1 kWh
Min Temp for 47 Gal, Mild
Max Temp for 47 Gal, Mild


All Commnad Stuctures for AO Smith 50 Gallon Electric Resistance
47 Gallon Draw Profile, Mild Temps
Energy (kWh)
Outdoor Temperature (°F)
6
5
4
3
2
1
0
90
80
70
60
50
40
30
20
10
0:30 1:30 2:30 3:30 4:30 5:30 6:30 7:30 8:30 9:30 10:30 11:30 12:30 13:30 14:30 15:30 16:30 17:30 18:30 19:30 20:30 21:30 22:30 23:30
Shed/Critical Peak
AO Elec., BL, 7.8 kWh
AO Elec., 1Hr-Shed, 7.6 kWh
AO Elec., 2Hr-Shed, 6.9 kWh
AO Elec., 1Hr-Crit, 7.7 kWh
AO Elec., 2Hr-Crit, 7.9 kWh
Min Temp for 47 Gal, Mild
Max Temp for 47 Gal, Mild

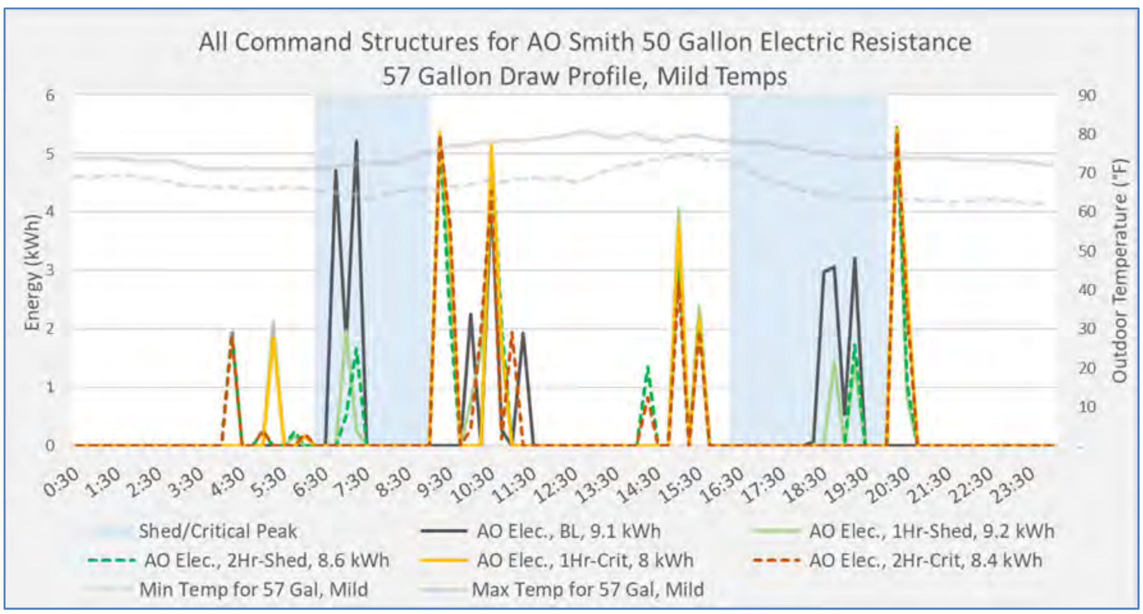
Appendix D-4: All Command Structures Compared per Unit – 57 Gallon, Mild Temperatures







All Command Structures for AO Smith 80 Gallon Heat Pump
57 Gallon Draw Profile, Mild Temps
Energy (kWh)
Outdoor Temperature (°F)
Shed/Critical Peak
AO 80, BL, 2.4 kWh
AO 80, 1Hr-Shed, 2.4 kWh
AO 80, 2Hr-Shed, 2.2 kWh
AO 80, 1Hr-Crit, 2.1 kWh
AO 80, 2Hr-Crit, 2 kWh
Min Temp for 57 Gal, Mild
Max Temp for 57 Gal, Mild



All Command Structures for AO Smith 50 Gallon Electric Resistance
57 Gallon Draw Profile, Mild Temps
Energy (kWh)
Outdoor Temperature (°F)
Shed/Critical Peak
AO Elec., BL, 9.1 kWh
AO Elec., 1Hr-Shed, 9.2 kWh
AO Elec., 2Hr-Shed, 8.6 kWh
AO Elec., 1Hr-Crit, 8 kWh
AO Elec., 2Hr-Crit, 8.4 kWh
Min Temp for 57 Gal, Mild
Max Temp for 57 Gal, Mild

Appendix E: Total Daily and Peak Hours Water Heater Energy

Total Daily and Peak Hours Water Heater Energy: 47 Gallon Draw Profile, Cool Temperatures										
		Temperature	AO Smith 50 Elec.		Rheem 50 HP		AO Smith 50 HP		AO Smith 80 HP	
Date	Schedule	Average Outdoor (°F)	Daily (kWh)	Peak Hours (kWh)	Daily (kWh)	Peak Hours (kWh)	Daily (kWh)	Peak Hours (kWh)	Daily (kWh)	Peak Hours (kWh)
12/22/2020	Baseline	56.12	8.12	6.99	2.43	1.86	2.29	1.56	n/a	n/a
n/a	1 Hr. Load Up, Shed									
1/6/2021	2 Hr. Load Up, Shed	56.74	7.56	1.57	2.16	0.00	2.44	0.59	2.31	0.02
1/14/2021	1 Hr. Load Up, Critical Peak	54.66	7.71	0.04	2.34	0.00	2.60	0.04	2.44	0.02
1/18/2021	2 Hr. Load Up, Critical Peak	55.81	8.05	0.02	2.32	0.00	2.62	0.02	2.51	0.02

Total Daily and Peak Hours Water Heater Energy: 47 Gallon Draw Profile, Mild Temperatures										
		Temperature	AO Smith 50 Elec.		Rheem 50 HP		AO Smith 50 HP		AO Smith 80 HP	
Date	Schedule	Average Outdoor (°F)	Daily (kWh)	Peak Hours (kWh)	Daily (kWh)	Peak Hours (kWh)	Daily (kWh)	Peak Hours (kWh)	Daily (kWh)	Peak Hours (kWh)
12/20/2020	Baseline	67.24	7.77	6.68	2.16	1.50	1.89	1.54	1.86	1.05
12/29/2020	1 Hr. Load Up, Shed	65.12	7.57	1.64	2.01	0.00	2.20	0.58	2.12	0.02
1/3/2021	2 Hr. Load Up, Shed	66.74	6.89	1.15	n/a	n/a	1.99	0.36	1.94	0.02
1/12/2021	1 Hr. Load Up, Critical Peak	62.07	7.74	0.02	2.10	0.00	2.27	0.02	2.13	0.03
1/22/2021	2 Hr. Load Up, Critical Peak	65.71	7.89	0.02	n/a	n/a	2.17	0.02	2.09	0.02

Total Daily and Peak Hours Water Heater Energy: 57 Gallon Draw Profile, Cool Temperatures										
		Temperature	AO Smith 50 Elec.		Rheem 50 HP		AO Smith 50 HP		AO Smith 80 HP	
Date	Schedule	Average Outdoor (°F)	Daily (kWh)	Peak Hours (kWh)	Daily (kWh)	Peak Hours (kWh)	Daily (kWh)	Peak Hours (kWh)	Daily (kWh)	Peak Hours (kWh)
1/31/2021	Baseline	66.8	9.45	5.65	2.64	1.43	2.38	1.40	2.22	1.32
2/6/2021	1 Hr. Load Up, Shed	65.0	9.63	1.67	2.24	0.00	2.60	0.36	2.56	0.02
n/a	2 Hr. Load Up, Shed									
2/21/2021	1 Hr. Load Up, Critical Peak	63.8	8.54	0.02	2.14	0.00	2.47	0.03	2.36	0.02
2/24/2021	2 Hr. Load Up, Critical Peak	66.1	8.46	0.02	1.98	0.00	2.39	0.02	2.31	0.02

Total Daily and Peak Hours Water Heater Energy: 57 Gallon Draw Profile, Mild Temperatures										
		Temperature	AO Smith 50 Elec.		Rheem 50 HP		AO Smith 50 HP		AO Smith 80 HP	
Date	Schedule	Average Outdoor (°F)	Daily (kWh)	Peak Hours (kWh)	Daily (kWh)	Peak Hours (kWh)	Daily (kWh)	Peak Hours (kWh)	Daily (kWh)	Peak Hours (kWh)
1/27/2021	Baseline	71.4	9.10	5.41	2.50	1.39	2.29	1.35	2.37	1.49
2/7/2021	1 Hr. Load Up, Shed	69.1	9.22	1.29	2.22	0.00	2.46	0.34	2.38	0.02
2/11/2021	2 Hr. Load Up, Shed	72.0	8.59	0.99	1.95	0.00	2.26	0.06	2.17	0.02
2/16/2021	1 Hr. Load Up, Critical Peak	70.2	8.01	0.02	1.94	0.00	2.19	0.02	2.14	0.02
2/27/2021	2 Hr. Load Up, Critical Peak	74.3	8.41	0.02	1.76	0.00	2.01	0.02	2.00	0.02