December 9, 2015

Laboratory Assessment of A. O. Smith HPTU Series Heat Pump Water Heaters

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Executive Summary

The Northwest Energy Efficiency Alliance (NEEA) contracted with Ecotope, Inc. and Cascade Engineering Services, Inc. to conduct a laboratory assessment of the A. O. Smith HPTU Series heat pump water heaters (HPWHs) for northern climate installations. Cascade Engineering evaluated the HPTU Series using a testing plan developed by Ecotope to assess HPWH performance.

The goal of the work is to evaluate the products using the Northern Climate Heat Pump Water Heater Specification. The test matrix, specified fully in Appendix A, includes the standard US Department of Energy (DOE) 24- and 1-hour tests for both the previous DOE test procedure and the new one released in 2014, as well as low-ambient-temperature tests and noise output level measurements.

Overall, the results suggest that the A. O. Smith HPTU Series water heaters are highly efficient. Specific findings include the following:

- Measured Northern Climate Specification Metrics:[1]
  - Northern Climate Energy Factor: 2.43, 2.56, 2.70
  - Percent of tank drained before resistance elements engage in 1-hour test: 74%, 72%, 79%
  - Compressor low-ambient temperature operating cutoff: 42°F, 42°F, 42°F
  - Number of consecutive, sixteen-gallon, efficient showers: 2.5, 3, 4
  - Sound level: 51.7, 54.2, 53.6 dBA

- Individual Test Results:
  - Energy Factor from 24-hour test at 67°F: 3.37, 3.62, 3.21
  - Energy Factor from 24-hour test at 50°F: 2.00, 2.06, 2.70
  - Uniform Energy Factor from 24-hour test at 67°F: 3.54, 3.8, 3.58
  - Uniform Energy Factor from 24-hour test at 50°F: 2.87, 3.07, 2.77
  - 1-hour test: 72.6, 78.6, 91 gallons
  - 2014 1-hour test: 72.6, 70, 85.6 gallons

- The HPTU Series of HPWHs offers a versatile range of tank sizes that will serve most residential needs. The compressor performs admirably in each unit, resulting in high overall test efficiencies when the resistance element does not engage and modest efficiencies for tests in which it does. The 490-watt compressor is an average size for integrated HPWHs such as this, and delivers a reasonable heating capacity.

- The first hour rating is particularly high for the 50-gallon unit, partially due to generous use of the resistance elements. A slight delay in engaging the resistance elements for the 66-gallon model mean the first hour rating is proportionally less high, though still adequate. The 80-gallon has a high first hour rating commensurate with its tank size. Notably, after heating the top of the tank with resistance, all of the units remain in resistance heating mode and continue to heat with the lower element.

[1] Values for each metric and test result are presented in order of tank size: 50, 66, and 80 gallons

1. Introduction

The Northwest Energy Efficiency Alliance (NEEA) contracted with Ecotope, Inc. and Cascade Engineering Services, Inc. to conduct a laboratory assessment of the A. O. Smith HPTU Series heat pump water heaters (HPWHs) for northern climate installations. Cascade Engineering evaluated the HPTU Series using a testing plan developed by Ecotope to assess HPWH performance.

The tests included measurement of basic characteristics and performance including first hour rating and Department of Energy (DOE) Energy Factor (EF); description of operating modes; measuring heat pump efficiency at lower ambient temperatures; and conducting a number-of-showers test at 50°F ambient. Appendix A contains a table describing all tests performed for this report.

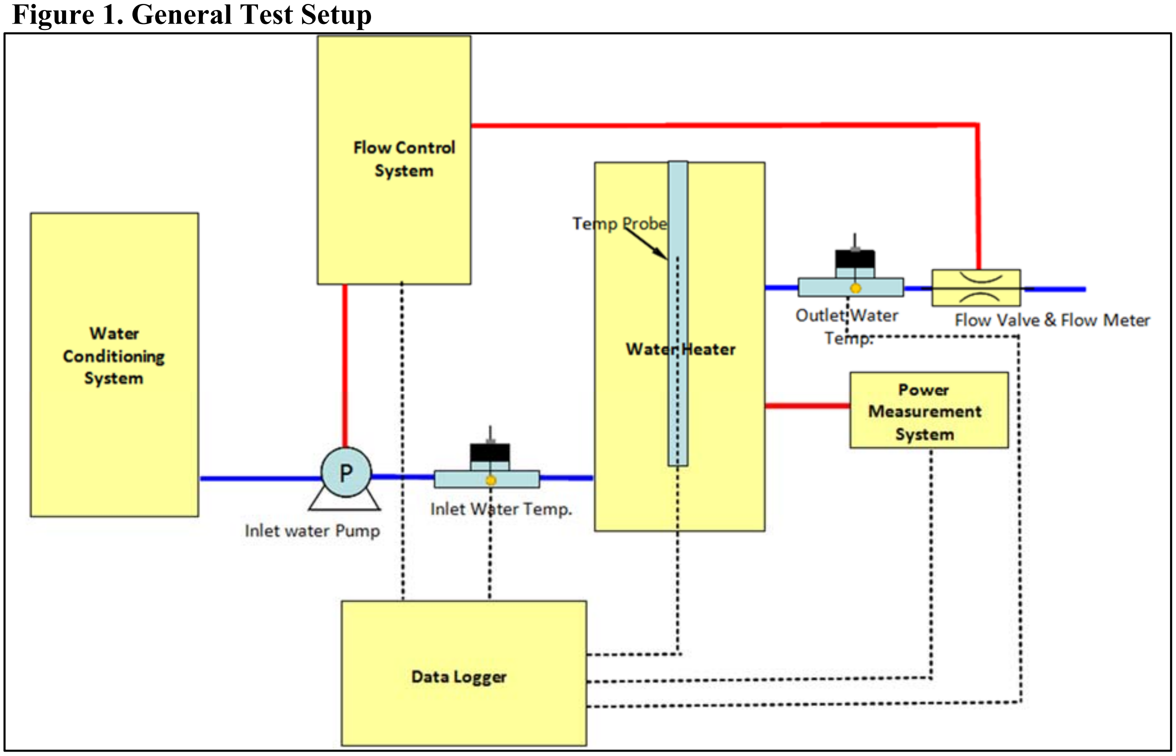
2. Methodology

Cascade Engineering collaborated with Ecotope and NEEA to devise methods and protocols suitable for carrying out the testing plan. Cascade Engineering incorporated the following documents into its procedures:

- The heat pump water heater measurement and verification protocol developed by Ecotope (Ecotope 2010)
- Northern Climate Specification for Heat Pump Water Heaters (NEEA 2013)
- Department of Energy testing standards from Appendix E to Subpart B of 10 CFR 430 (DOE 2014, DOE 1998)
- American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 118.2-2006 for the Method of Testing for Rating Residential Water Heaters (ASHRAE 2006)

Figure 1 shows a schematic representation of the test setup. Appendix B provides specifications of the measurement instruments used in the tests.

Figure 1. General Test Setup

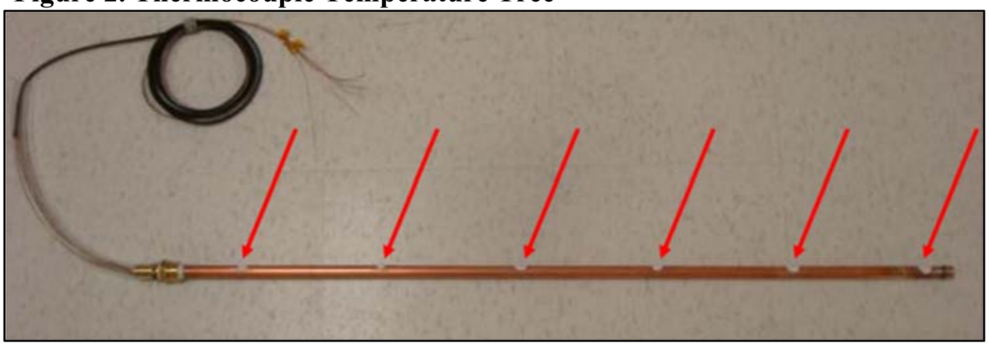


Ambient temperature control is provided by an ESPEC Model # EWSX499-30CA walk-in thermal chamber. The chamber is capable of regulating both temperature and humidity over a wide range, and independently monitors and records temperature and humidity conditions at one-minute intervals.

Conditioned water is stored in a large tank to be supplied to the water heater at the desired inlet temperature. A pump and a series of flow control valves in the inlet and outlet water piping control the water flow rate and maintain water pressure. A flow meter measures and reports the actual water flow.

Cascade Engineering installed an instrumentation package to measure the required points specified by the DOE test standard as well as additional points to gain further insight into HPWH operation. A tree of six thermocouples positioned at equal water volume segments measured tank water temperature (Figure 2 – arrows indicate measurement points). Cascade Engineering measured inlet and outlet water temperatures with thermocouples immersed in the supply and outlet lines. Three thermocouples mounted to the surface of the evaporator coil at the refrigerant inlet, outlet and midpoint monitored the coil temperature to indicate the potential for frosting conditions.

Figure 2. Thermocouple Temperature Tree



A data acquisition (DAQ) system collected all the measurements at three-second intervals and logged them to a file. In a post processing step, Ecotope merged the temperature log of the thermal chamber with the DAQ log file to create a complete dataset for analysis.

3. Findings: Equipment Characteristics

3.1. Basic Equipment Characteristics

The HPTU Series is a set of three HPWHs with similar characteristics. The main aspect that varies is the tank size; the series includes 50-, 66-, and 80-gallon (nominal) models. The compressor and heat exchanger are essentially the same for each model, so similar performance is expected. Individual test results will vary among models, due to the differing levels of stratification and tank utilization that occur with different sizes. These units are similar to other integrated HPWHs currently available on the market, and possess no unusual features. Figure 3 shows all three units in the series in a staging area at the lab. Table 1 describes the properties of the HPTU Series units, most of which are identical among models.

Figure 3. The HPTU Series HPWHs

Table 1. Properties of the A. O. Smith HPTU Series

	Laboratory Measurement
Tank Volume (gallons)	50, 66, 80 nominal, 45.1, 64.6, 79.1 measured
Refrigerant	R-134a
Airflow Path	Top to Side
Upper Element (W)	4,500
Lower Element (W)	4,500
Compressor (W)	490
Standby (W)	1.5
Fan (W)	30.8 nominal
Low-Temperature Cutoff (°F)	42
Tank Heat Loss Rate (Btu/hr °F)	3.6, 4, 4.7

3.2. Operating Modes

Efficiency Mode: Only the heat pump is allowed to operate. It provides the highest level of efficiency and heats only with the refrigeration cycle. If the ambient temperature drops below that specified in Table 1 as the "Low-Temperature Cutoff," the compressor will not operate. The researchers did not investigate efficiency mode as it is not the default mode. They expect operation to be similar to compressor operation in hybrid mode.

Electric Mode: In electric mode, the heat pump does not run and the equipment operates as a conventional resistance tank. Ecotope did not investigate this mode in detail as it provides no efficiency improvements over a conventional system.

Hybrid Mode: The default mode from the factory, hybrid mode, will engage both the compressor and the resistance elements according to its internal logic. Testing indicates that the upper resistance element will engage when the average tank temperature falls to 80°F. The unit will continue to heat with the upper resistance element until the top third of the tank is within 10°F of the setpoint, at which point it switches to the lower element to finish heating the tank. In cases where the average tank temperature is greater than approximately 100°F when the upper resistance element is finished, the compressor will come on instead of the lower resistance element. The compressor engages when the average tank temperature has dropped 20°F below setpoint. Within experimental error, all three models in the HPTU Series behave in the same manner.

4. Findings: Testing Results

4.1. First Hour Rating and Energy Factor Tests

As described in the Methodology section, Cascade Engineering carried out tests using both the older (pre-2014) and new (2014) DOE test procedures. Per the 2014 DOE test procedure, the first hour rating sets which draw pattern to use in the Uniform Energy Factor (UEF) test. Accordingly, Cascade Engineering used the Medium Usage Pattern for the 50- and 66-gallon tanks and the High Usage Pattern for the 80-gallon tank.

The EF and UEF tests on the 66-gallon unit both returned substantially higher values than expected based on the values from the other tank sizes and from the manufacturer's submittals. Ecotope conducted a thorough investigation to understand the reasons for the differences but found no conclusive explanation. There were no known instrumentation or measurement errors. Moreover, the compressor output capacity was consistently high in every test conducted (EF67, EF50, UEF67 and UEF50). It appears that the particular unit tested performs anomalously well. Given the manufacture's submittals, it is likely this unit is a performance outlier and that typical performance may be closer to the submitted values. Only further testing of additional units can answer the question and that is beyond the scope of this study.

The remainder of this section shows graphs of all the test results, depicting the water heaters' responses to various draw patterns. The graphs show the results for both the previous and the current DOE test procedures. The notation of "EF" for Energy Factor, or no specific modifiers, indicates a test under the previous procedure. The notation of "UEF," for Uniform Energy Factor, or a specific mention of "2014" indicates a test under the current (published in 2014) test procedure.

4.1.1. 1-Hour Test

Figure 4 through Figure 9 illustrate the results of the 1-hour tests.

Figure 4. DOE 1-Hour Test – HPTU-50

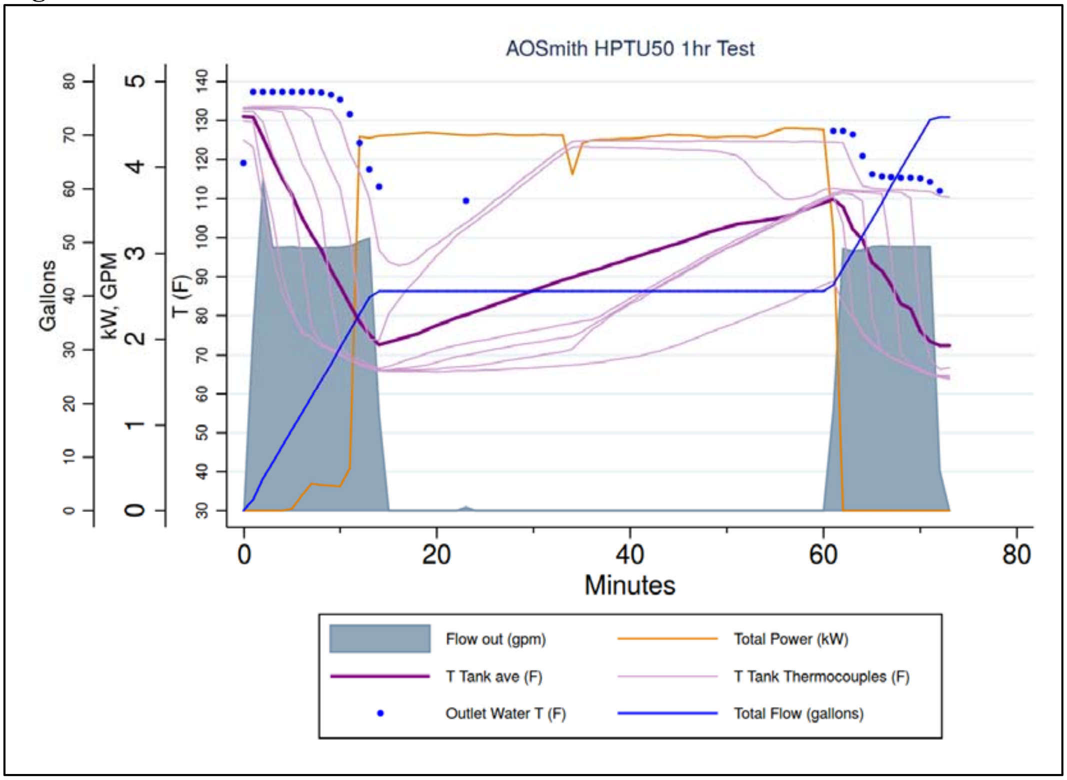


Figure 5. DOE 1-Hour Test – HPTU-66

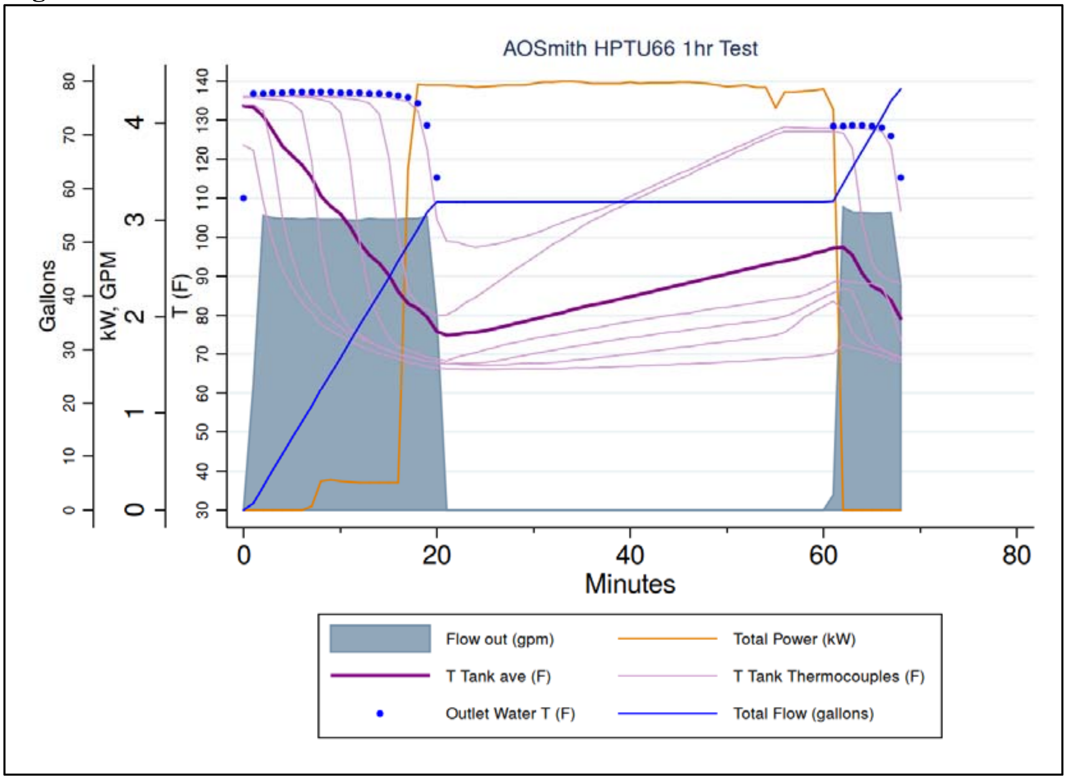


Figure 6. DOE 1-Hour Test – HPTU-80

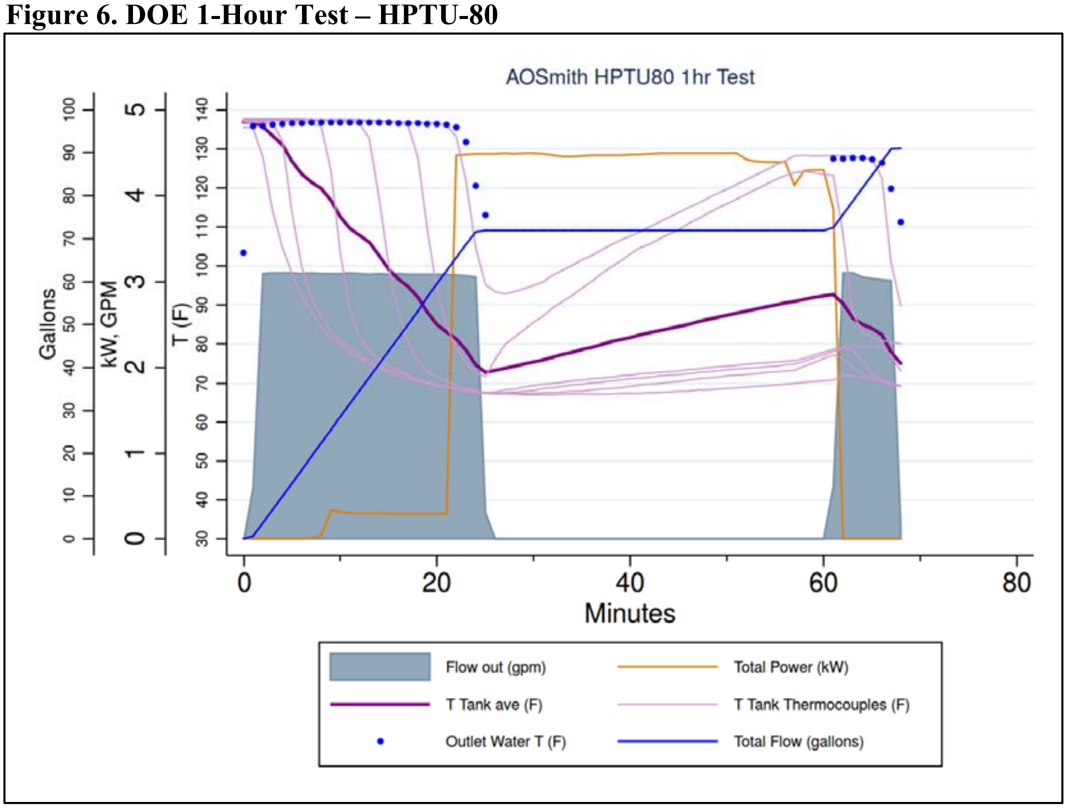


Figure 7. DOE 2014 1-Hour Test – HPTU-50

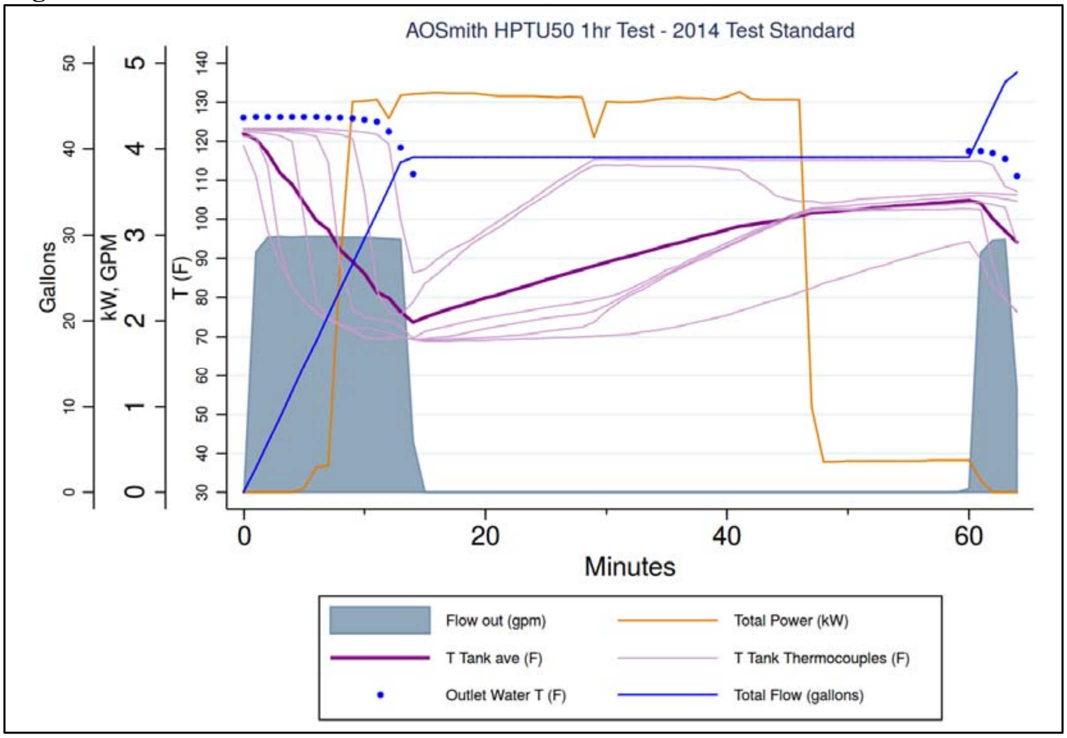


Figure 8. DOE 2014 1-Hour Test – HPTU-66

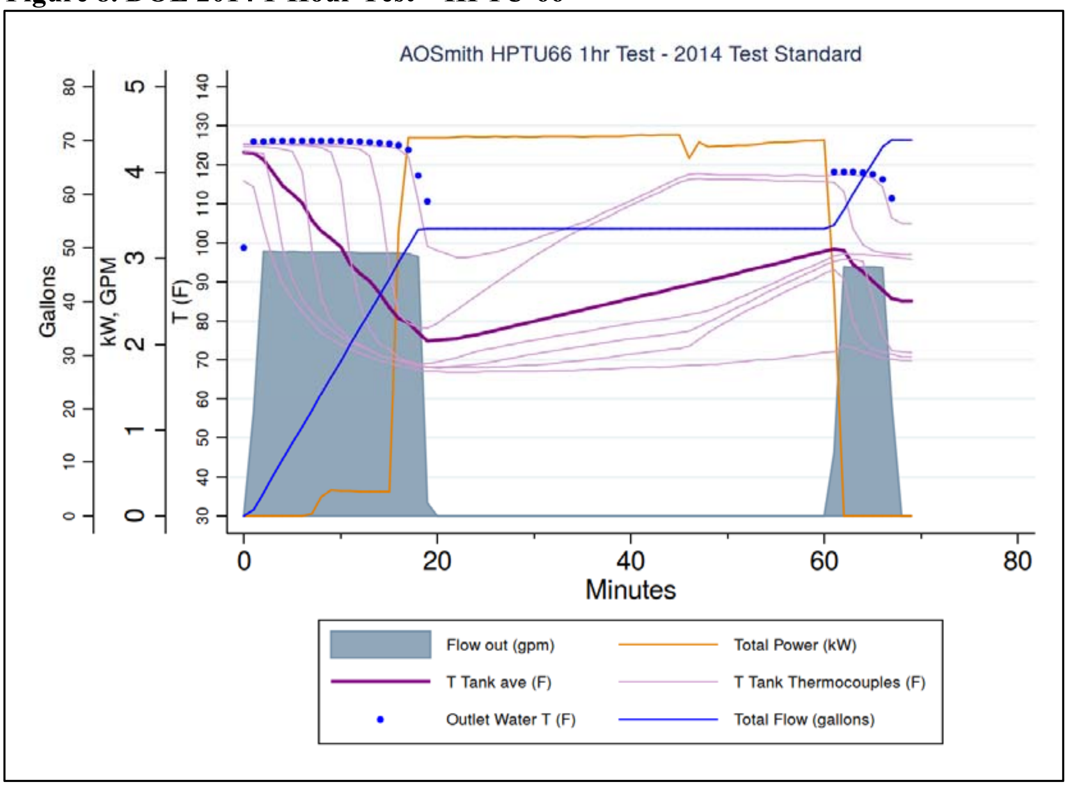
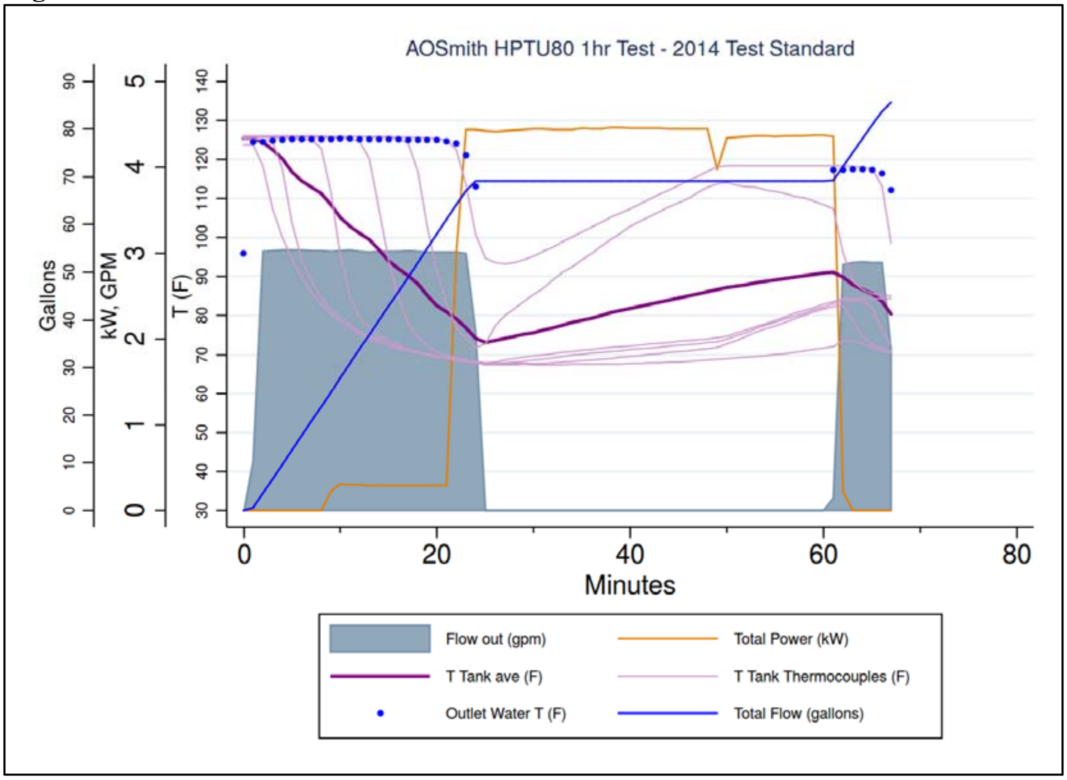


Figure 9. DOE 2014 1-Hour Test – HPTU-80



4.1.2. Energy Factor Tests

Figure 10 through Figure 27 illustrate the results of the energy factor tests.

Figure 10. DOE 24-Hour EF Test, First 8 Hours – HPTU-50

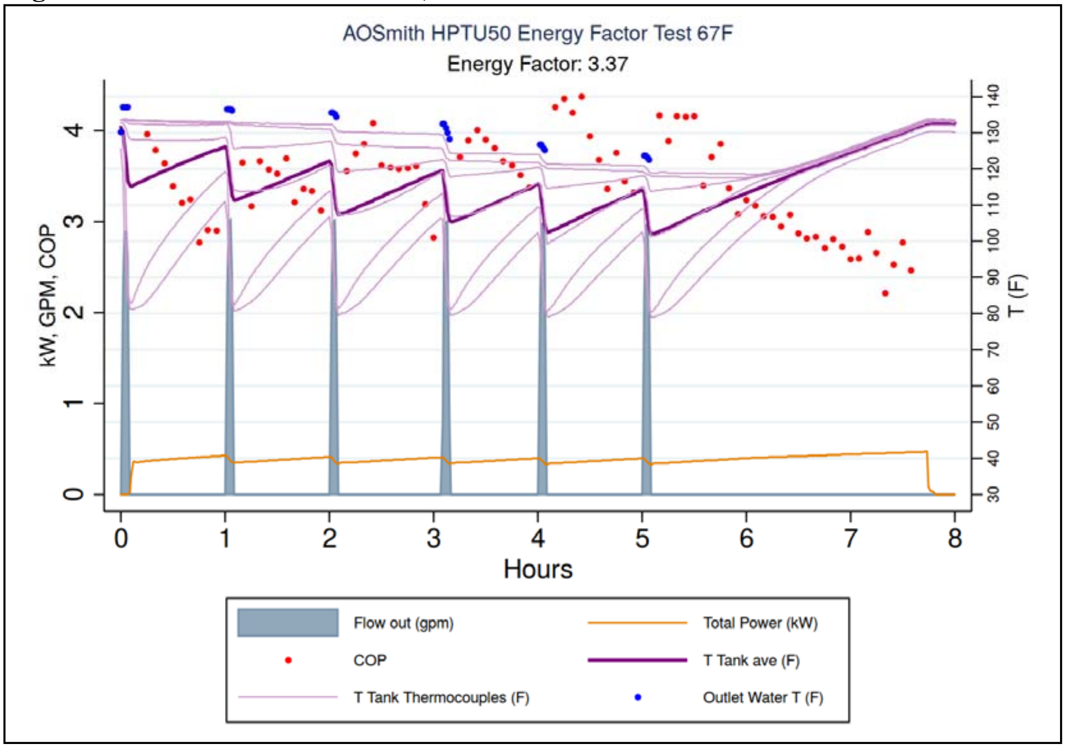


Figure 11. DOE 24-Hour EF Test, Full 24 Hours – HPTU-50

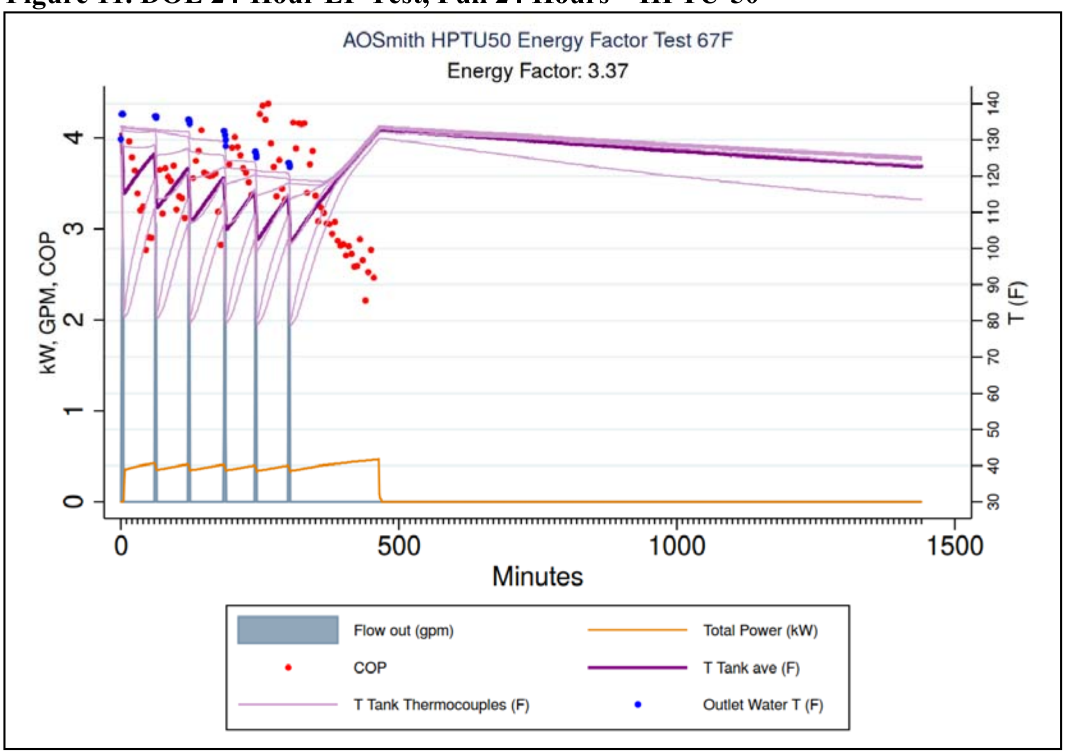


Figure 12. DOE 24-Hour EF Test, First 9 Hours – HPTU-50

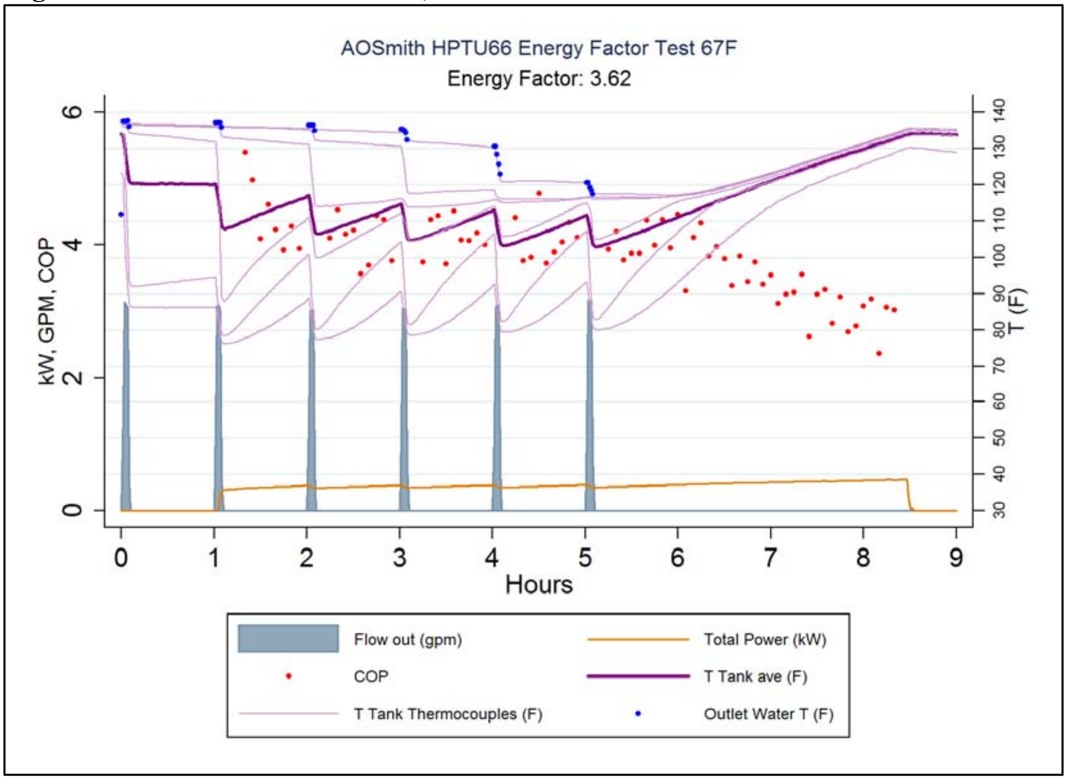


Figure 13. DOE 24-Hour EF Test, Full 24 Hours – HPTU-66

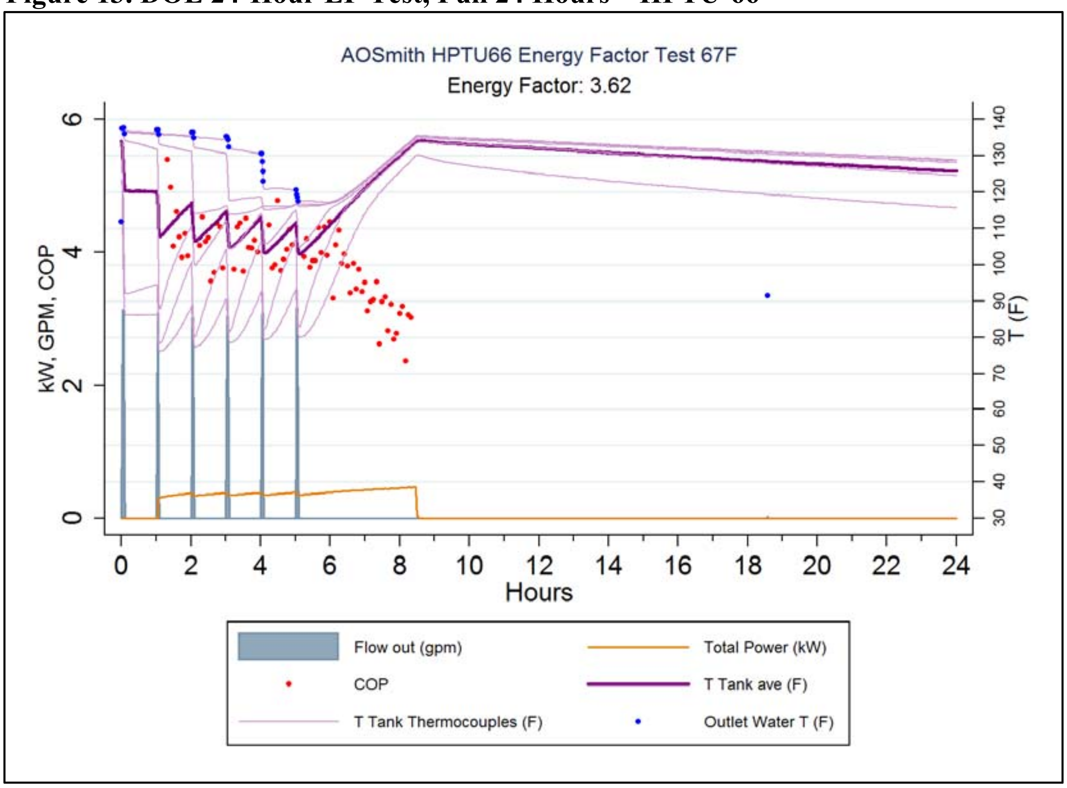


Figure 14. DOE 24-Hour EF Test, First 8 Hours – HPTU-80

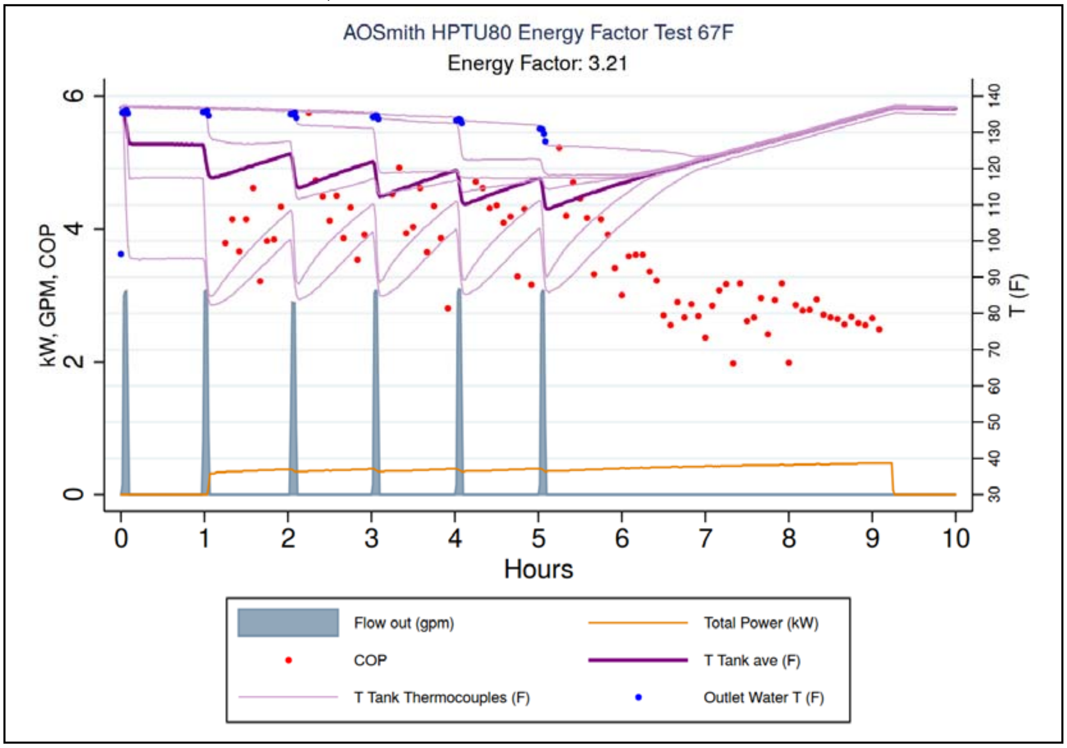


Figure 15. DOE 24-Hour EF Test, Full 24 Hours – HPTU-80

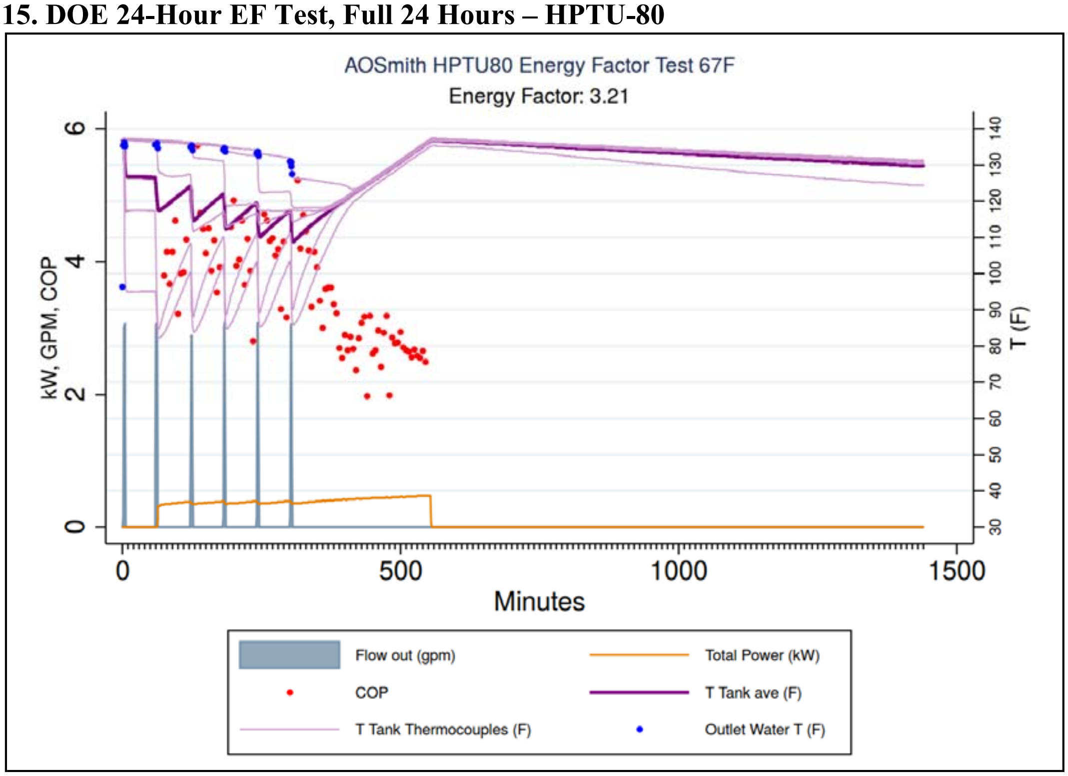


Figure 16. DOE 24-Hour, 50°F Ambient Air 50°F Inlet Water, First 9 Hours – HPTU-50

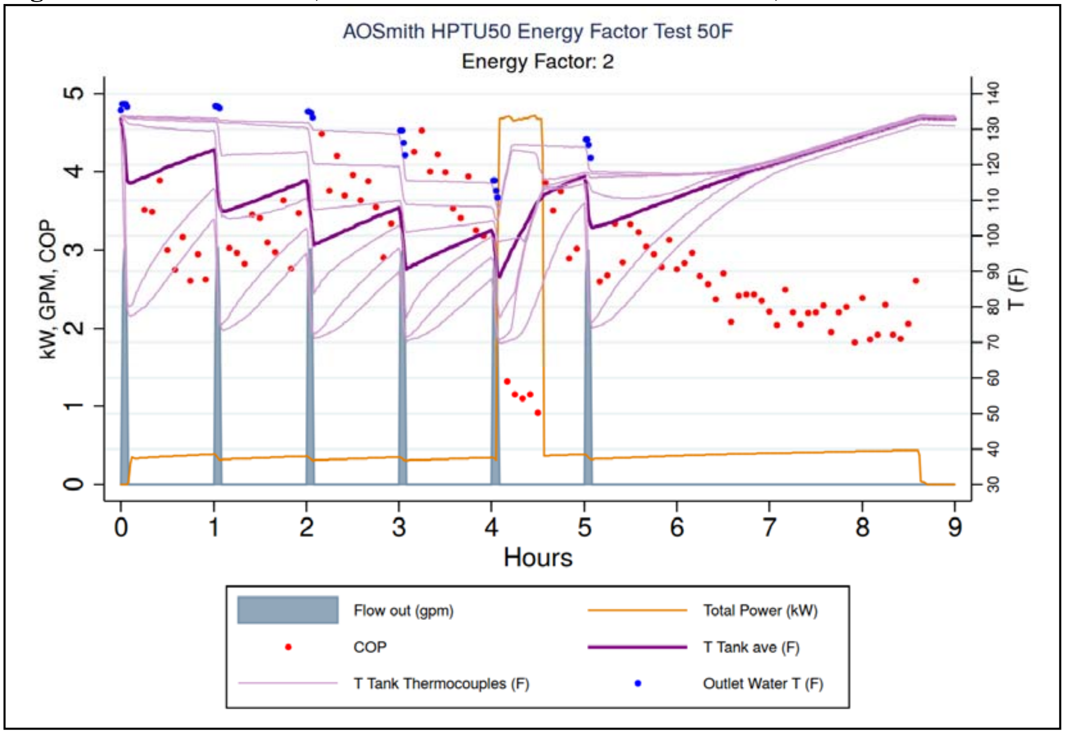


Figure 17. DOE 24-Hour, 50°F Ambient Air 50°F Inlet Water, Full 24 Hours – HPTU-50

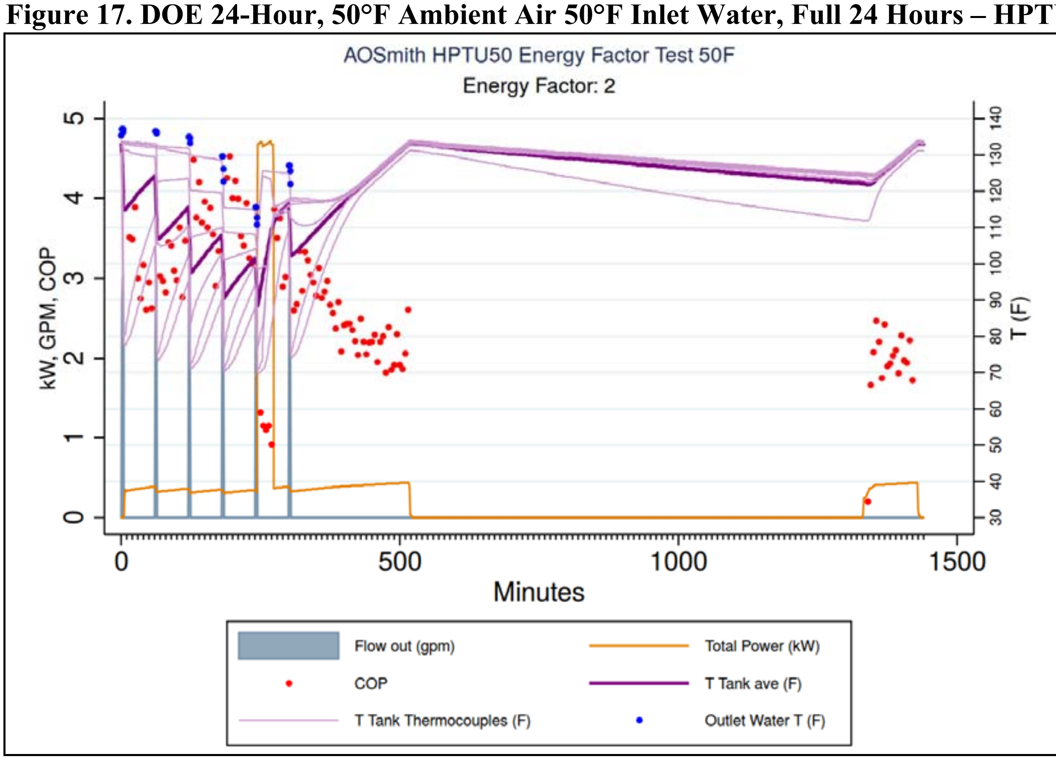


Figure 18. DOE 24-Hour, 50°F Ambient Air 50°F Inlet Water, First 10 Hours – HPTU-66

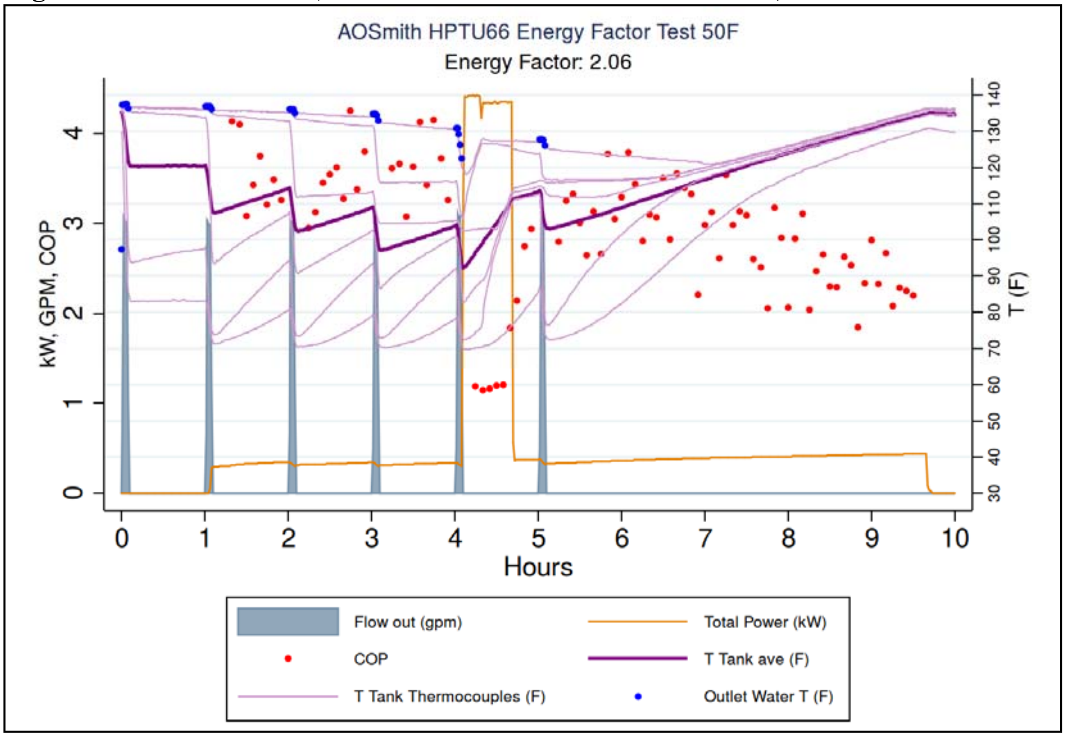


Figure 19. DOE 24-Hour, 50°F Ambient Air 50°F Inlet Water, Full 24 Hours – HPTU-66

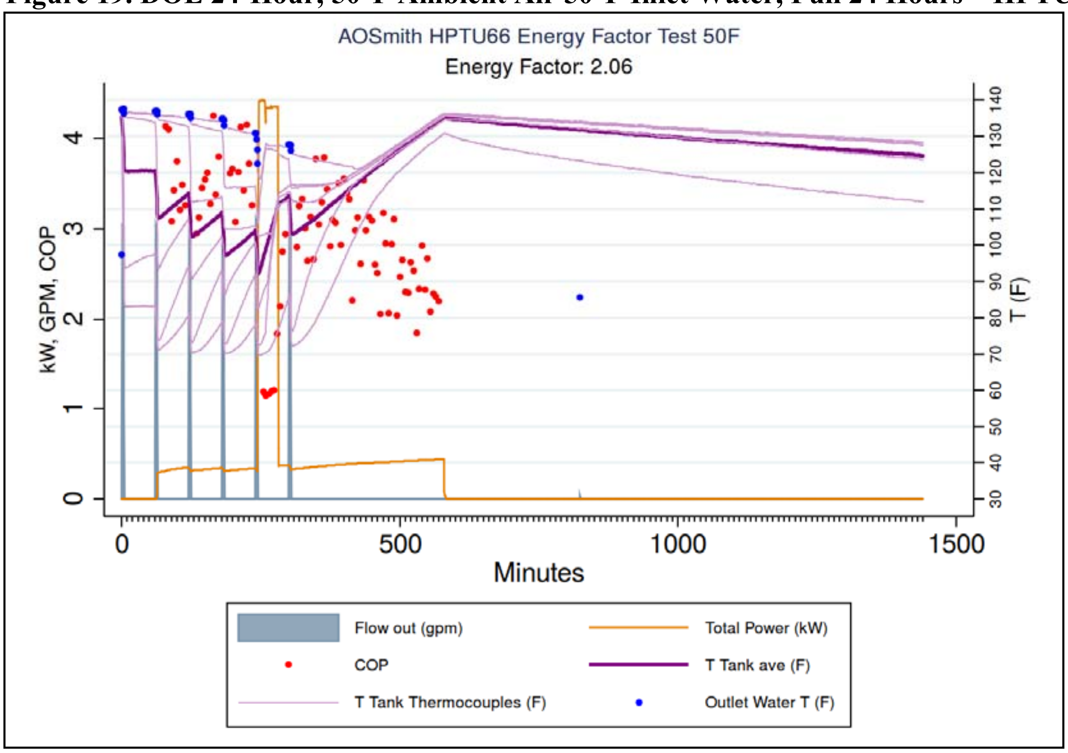


Figure 20. DOE 24-Hour, 50°F Ambient Air 50°F Inlet Water, First 13 Hours – HPTU-80

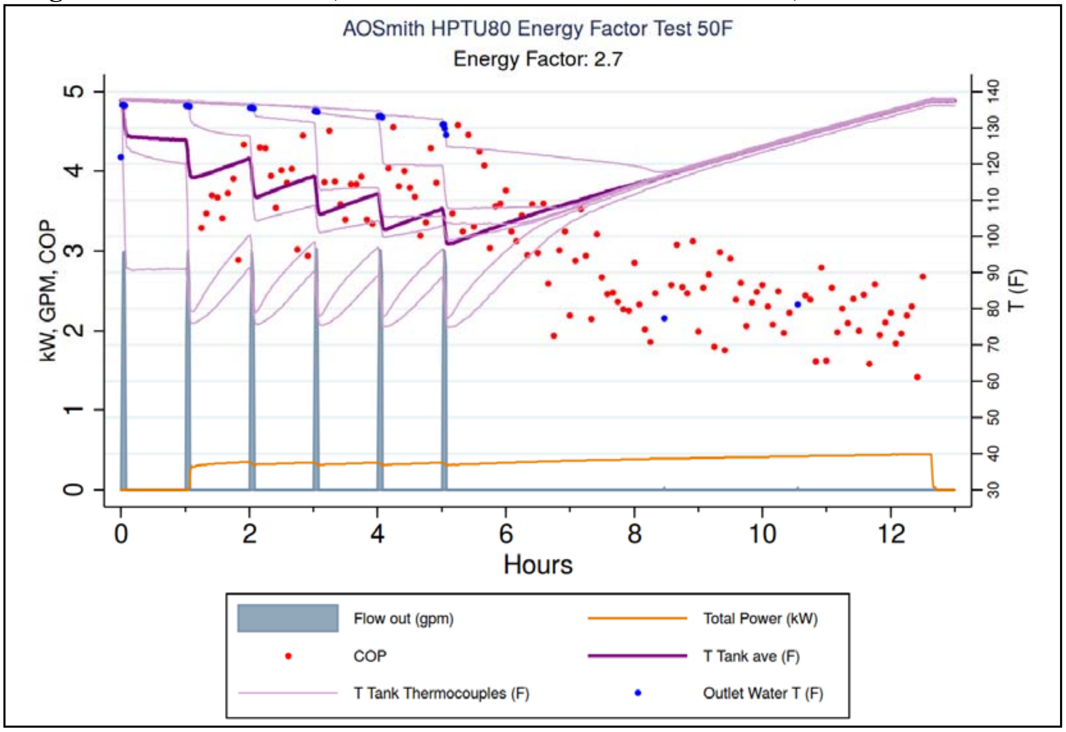


Figure 21. DOE 24-Hour, 50°F Ambient Air 50°F Inlet Water, Full 24 Hours – HPTU-80

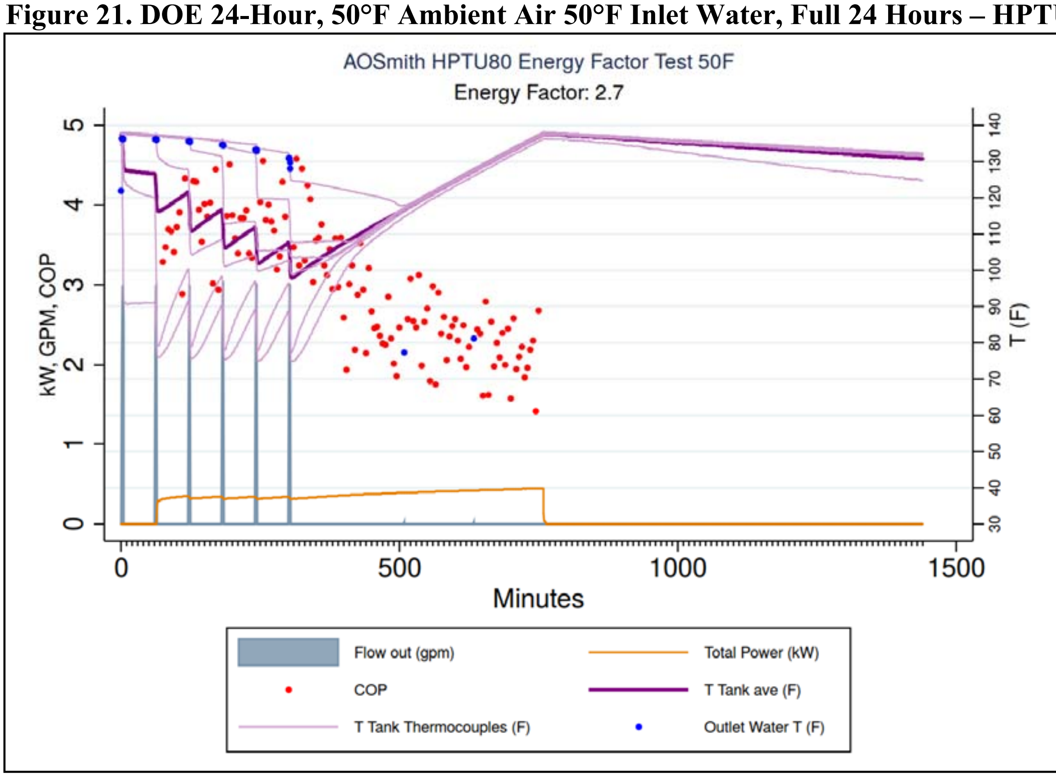


Figure 22. DOE 24-Hour UEF Test 67°F – HPTU-50

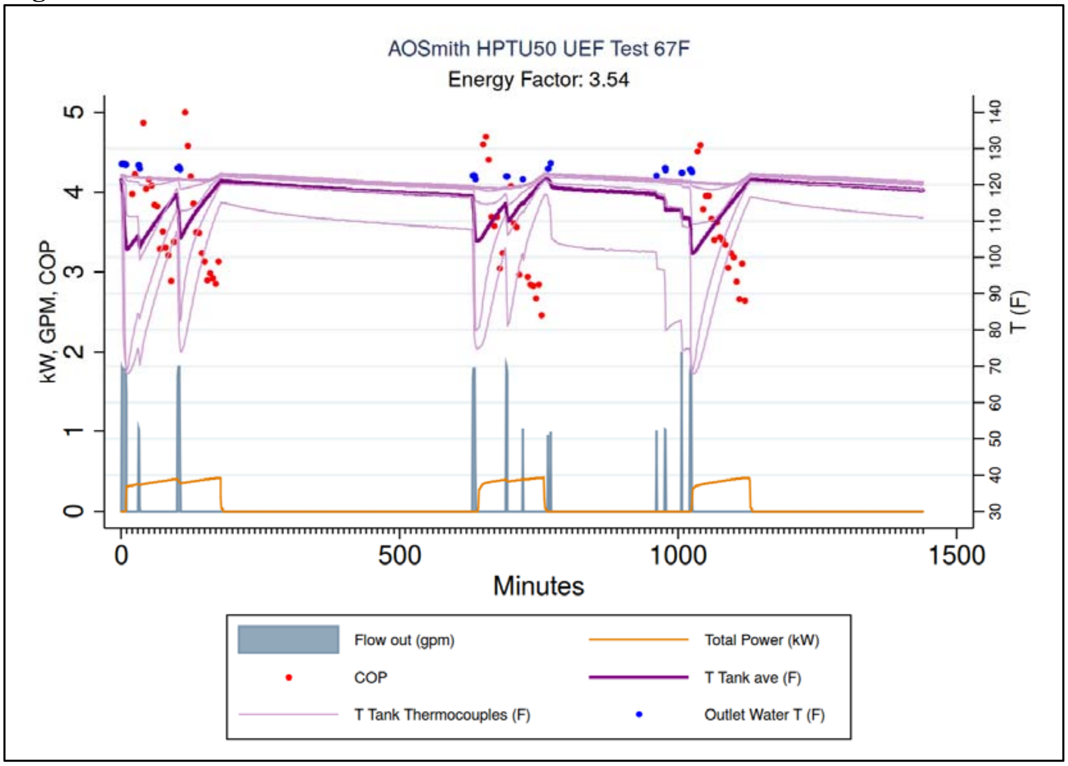


Figure 23. DOE 24-Hour UEF Test 67°F – HPTU-66

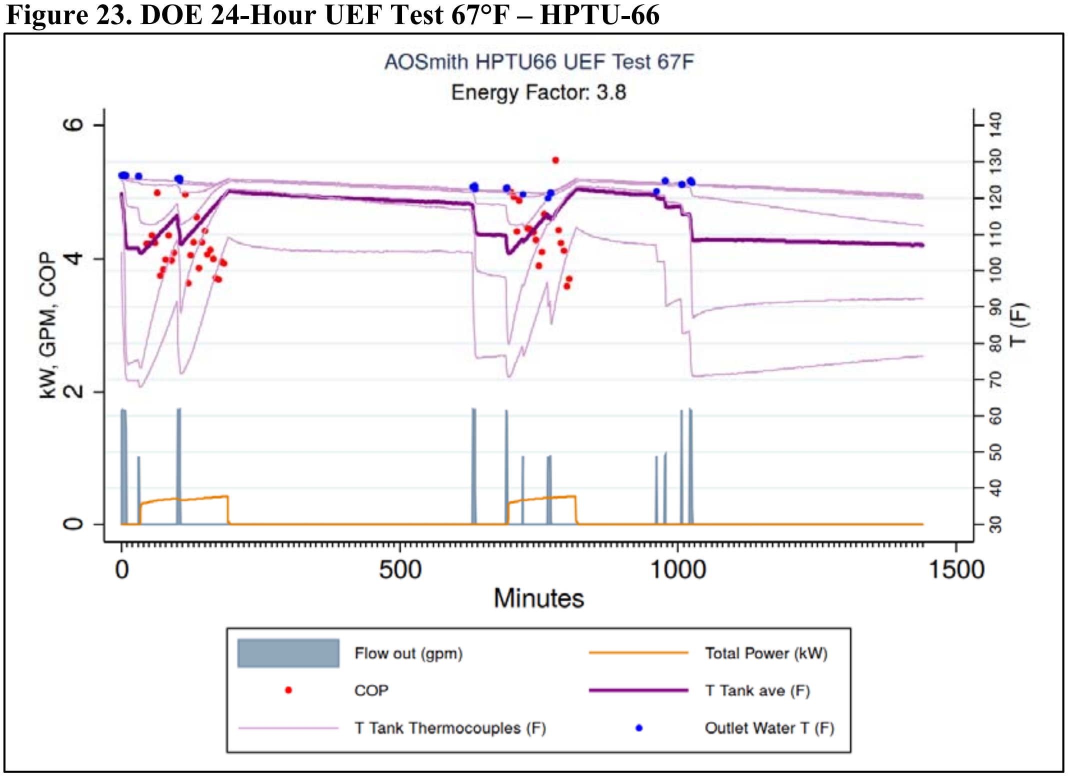


Figure 24. DOE 24-Hour UEF Test 67°F – HPTU-80

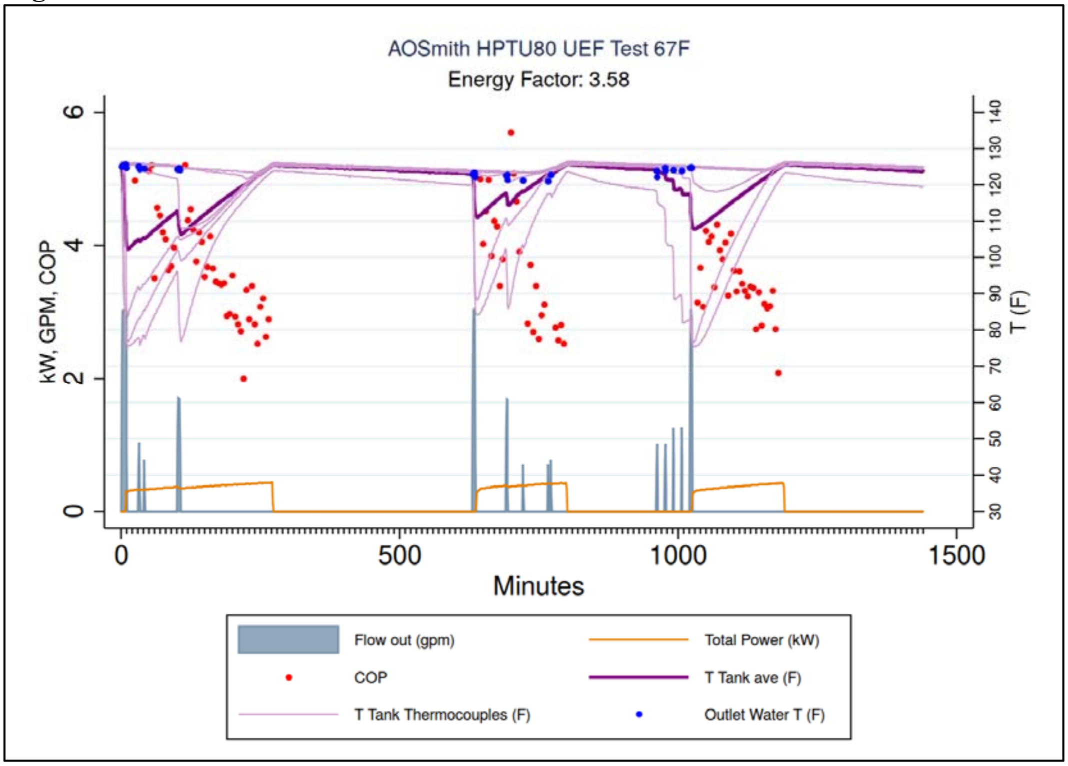


Figure 25. DOE 24-Hour UEF Test 50°F – HPTU-50

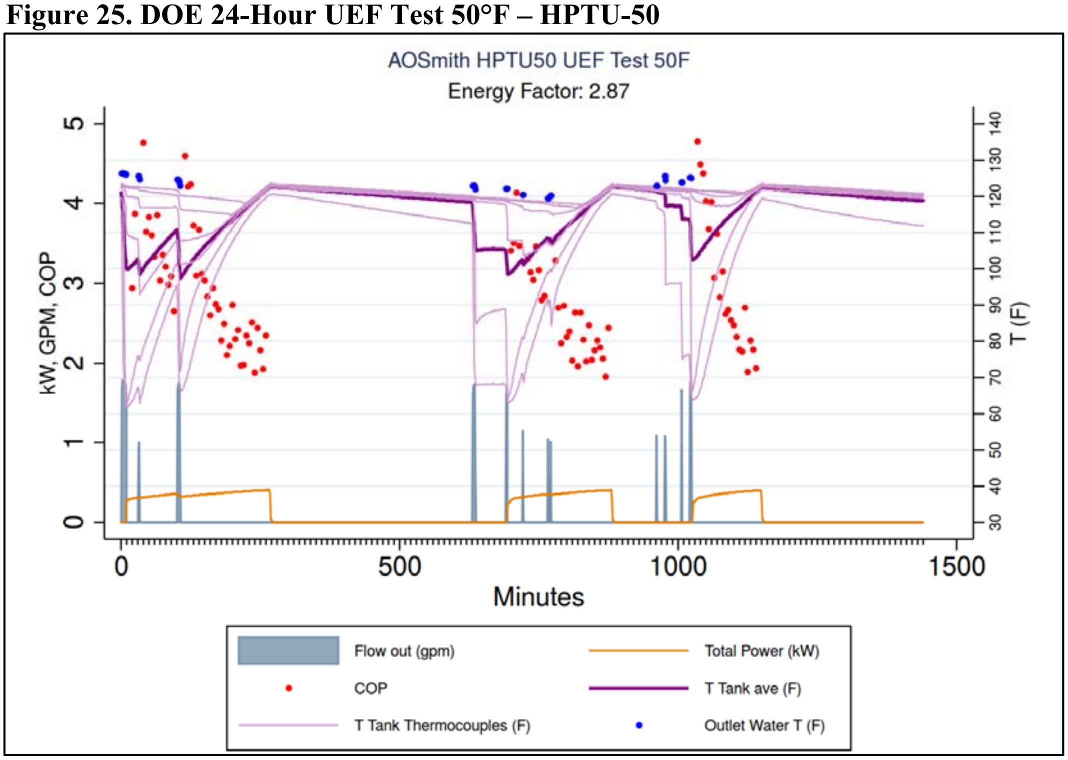


Figure 26. DOE 24-Hour UEF Test 50°F – HPTU-66

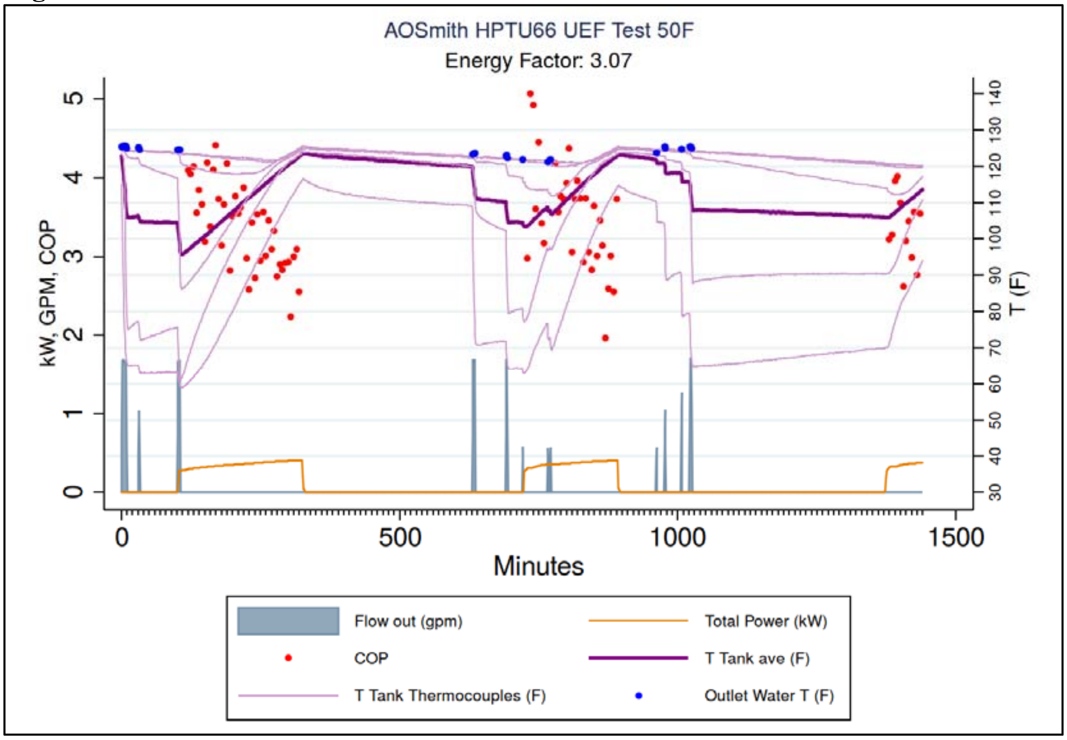
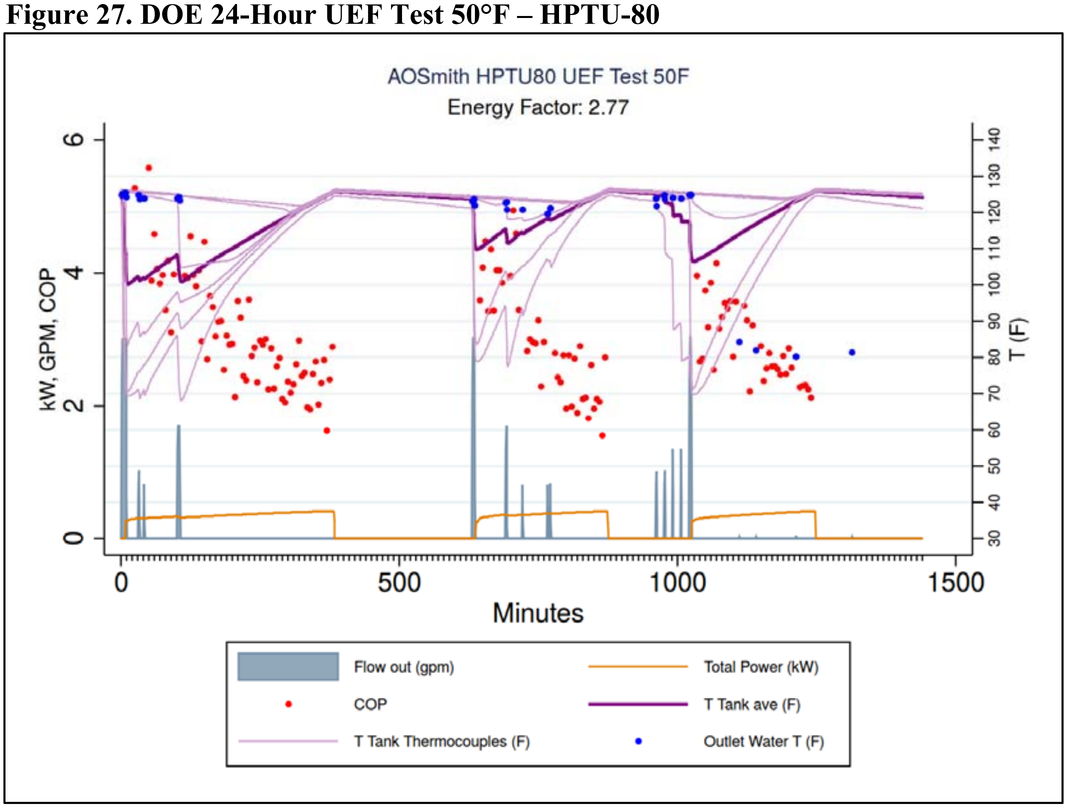


Figure 27. DOE 24-Hour UEF Test 50°F – HPTU-80



4.2. Efficient Showers Test

Figure 28, Figure 29, and Figure 30 illustrate the results of the efficient showers test.

Figure 28. Shower Test Supplemental Draw Profile – HPTU-50

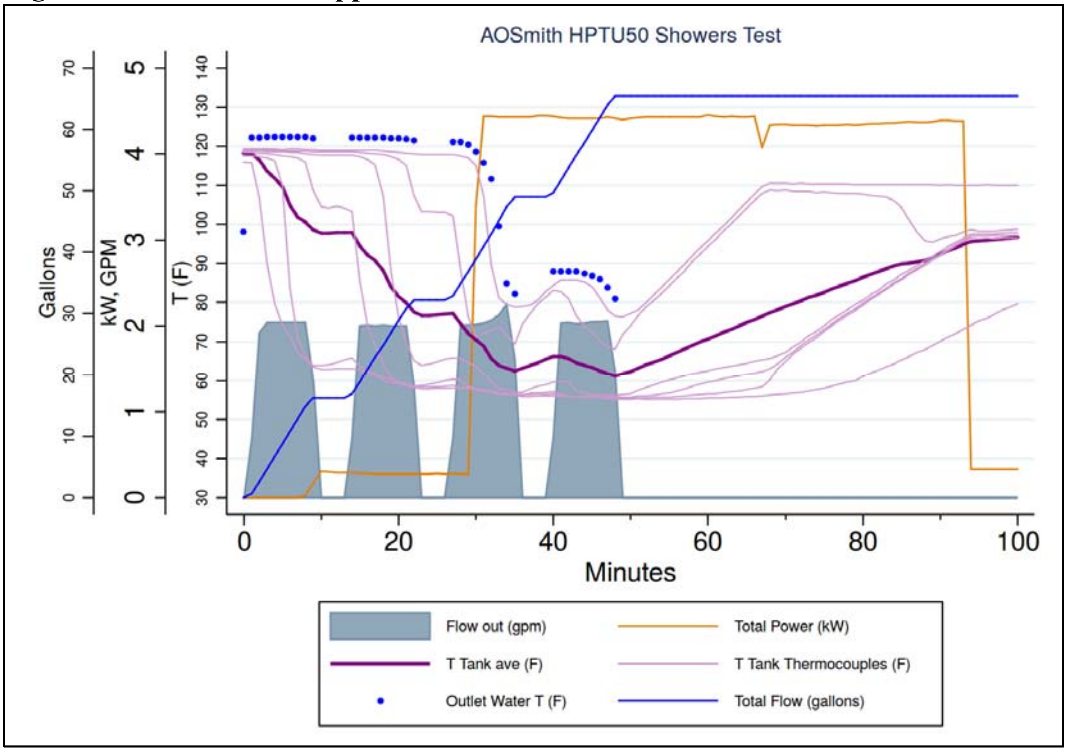


Figure 29. Shower Test Supplemental Draw Profile – HPTU-66

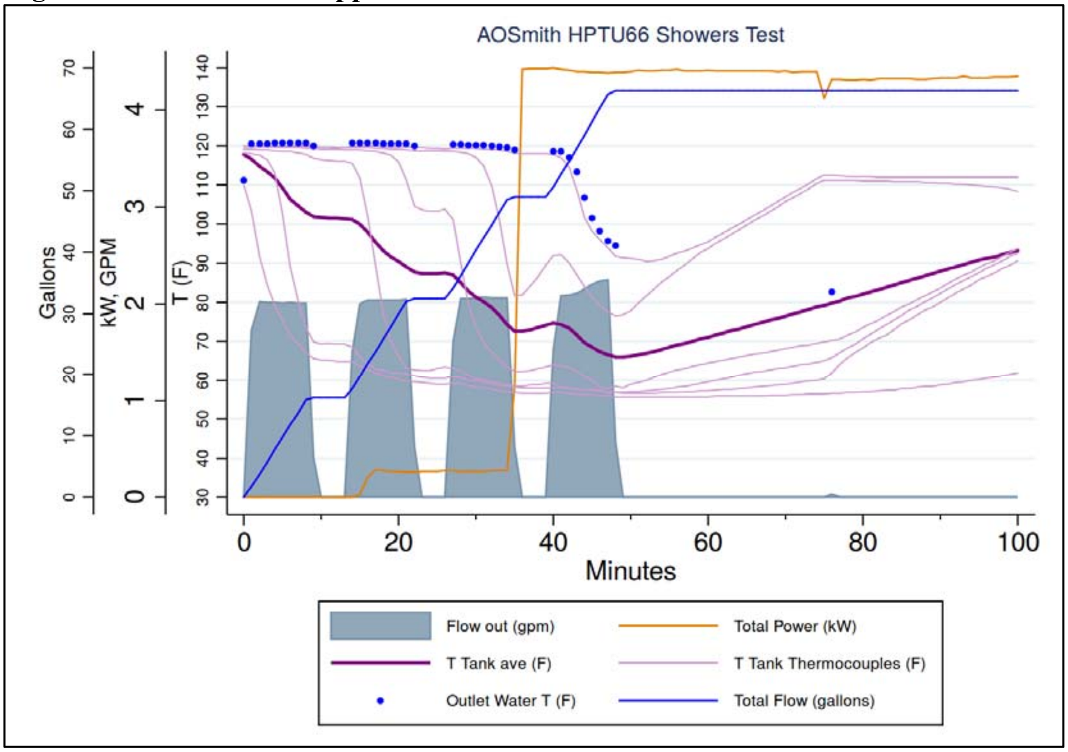
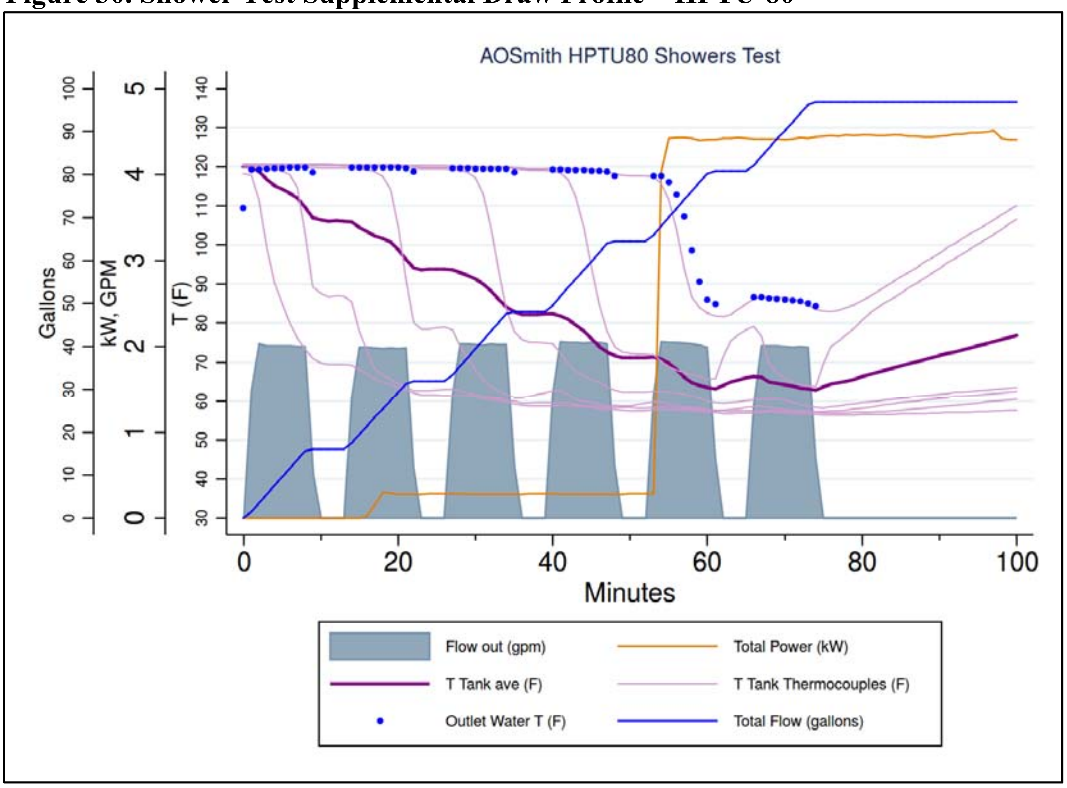


Figure 30. Shower Test Supplemental Draw Profile – HPTU-80



4.3. Low Temperature Limit

None of the units in the series will operate the compressor at an ambient temperature below 42°F. Resistance elements are used exclusively below this temperature.

4.4. Noise Measurements and Additional Observations

The lab also measured the sound level of the equipment. Researchers placed the units in a room near a wall and then measured the sound level at five different points on a circumference three feet distant and five feet high. The ambient temperature for the test was ~72°F. The decibel levels when the units are running are 51.7, 54.2, 53.6 dBA for the 50-, 66-, and 80-gallon units respectively.

5. Conclusions

Overall, the results suggest that the A. O. Smith HPTU Series water heaters are highly efficient. Specific findings include the following:

- Measured Northern Climate Specification Metrics:[2]
  - Northern Climate Energy Factor: 2.43, 2.56, 2.70
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References

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Appendix A – Testing Matrix

DOE Standard Rating Point Tests

Test Name	Ambient Air Conditions					Inlet Water		Tank Set Point		Airflow	Operating Mode	Notes
	Dry-Bulb		Wet-Bulb							inch. static pressure		
	F	C	F	C	RH	F	C	F	C			
DOE-1-hour_old	67.5	20	57	14	50%	58	14	149	65	0.0"	Hybrid	Follow test sequence in Federal Register 10 CFR Part 430 Section **5.1.4, using old test standard**
DOE-24-hour_old	67.5	20	57	14	50%	58	14	149	65	0.0"	Hybrid	Follow test sequence in Federal Register 10 CFR Part 430 Section **5.1.5, using old test standard**
DOE-24-hour-50_old	50	10	44	7	58%	50	10	149	65	0.0"	Hybrid	Follow test sequence in Federal Register 10 CFR Part 430 Section **5.1.5, using old test standard,** but replace ambient conditions with those given in this table.
DOE-1-hour	67.5	20	57	14	50%	58	14	125	52	0.0"	Hybrid	Follow test sequence in Federal Register 10 CFR Part 430 Section **5.1.4**
DOE-24-hour	67.5	20	57	14	50%	58	14	125	52	0.0"	Hybrid	Follow test sequence in Federal Register 10 CFR Part 430 Section **5.1.5**
DOE-24-hour-50	50	10	44	7	58%	50	10	125	52	0.0"	Hybrid	Follow test sequence in Federal Register 10 CFR Part 430 Section **5.1.5,** but replace ambient conditions with those given in this table.

Draw Profiles

DP-SHW-50	50	10	44	7	58%	50	10	125	52	0.0"	Hybrid	Draw Profile: DP-SHW. Conduct identical, repeated draws until ending conditions observed.

Additional Observations

AO-VOL	Measure tank water volume											
AO-PWR	One-time measurements of component power										Hybrid	Make measurement of fan, pump, & circuit board power draw if possible.

Noise Measurement

NOI	Measure combined fan and compressor noise									0.0"	Hybrid	Install equipment in relatively quiet room. Measure sound at 1 meter away, 1.8 meters high at several points around circumference of tank using a hand-held meter.

Appendix B – Measurement Instrumentation Specifications

Equipment	Make and Model	Function	Accuracy
Walk-in Chamber	Make : ESPEC, Model No.: EWSX499-30CA	Test environment temperature and relative humidity control	±1°C
Data Acquisition System	Make : Agilent Technologies, Model No : Agilent 34970A	Log temperature, power and flow rate data	Voltage: 0.005% of reading + 0.004% of range Temperature: (Type T):1.5°C
Thermocouple	OMEGA, T type	Temperature measurement	0.8°C Note 1
Power Meter	Yokogawa WT500 Power Analyzer	Continuous power measurement (system and heat pump)	Main Unit: Current range: *0.5 to 40A* Voltage range: *15 to 1000V* Basic Power Accuracy: *0.1%* frequency range: *DC 0.5 Hz to 100 kHz*
Power Source	Fluke 5520	Power meter comparison/calibration	AC Current ±0.15%
Current Transformer (25:5)	Make: Midwest Model: 3CT625SP	Use with Yokogawa power meter for total UUT power measurement	0.4% at 5VA
Flow Meter	Make: Seametrics Model: SPX-050 and FT420 Indicator	Water flow measurement	±1 % of full scale
Flow Controller	Make: Watlow Model: F4P	Control timing of flow pattern	Note 2
Hand-Held Temperature and Humidity Meter	Omega RH820W	Lab environment temperature and humidity measurement	± 0.5°C
Electronic Scale	Dogain Model: TS300K Range 300 Kg	Measurement of water mass	300 x 0.05Kg 660 x 0.1 lb

1. Thermocouples are calibrated using Omega CL1500 system
2. Flow control is checked by actual collected water weight measurement at required GPM