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NEEA Report: Laboratory Assessment of AO Smith Voltex Hybrid Heat Pump Water Heater for Northern Climate Installations

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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 AO Smith Voltex hybrid heat pump water heater (HPWH) for northern climate installations. Using a testing plan developed by Ecotope to assess heat pump water heater performance, Cascade Engineering Services evaluated the AO Smith Voltex. The project examined both tank model sizes: 60 gallons and 80 gallons.

The testing plan, developed in support of the Northern Climate Heat Pump Water Heater Specification, included characterizing the fan airflow with a ducting kit; observing heat pump efficiency at lower ambient temperatures; and conducting a number-of-showers test at 50°F ambient. Overall, the results demonstrated that both the 60- and 80-gallon tank capacities are sized large enough to adequately exploit heat pump efficiency. Further, the testing process revealed the AO Smith-provided ducting kit was a well-designed way to attach ducts to the inlet, outlet, or both air paths. Specific findings include:

- The 24-hour Energy Factor (EF) tests on the 60-gallon tank at 67°F and 50°F demonstrated the equipment design preserves performance over its low-end operating range with only a 7% decrease in EF between the two tests.

- The 60-gallon tank provides three consecutive 16-gallon showers before switching to resistance heat, while the 80-gallon tank provides four consecutive 18-gallon showers.

- The heating component controls are designed in a way to be both efficient and to meet high demand periods. In Hybrid mode, approximately 72% and 84% of the stored hot water for 60- and 80-gallon tanks respectively needs to leave the tank before the resistance elements engage.

- The presence of the ducting kit significantly reduces airflow across the evaporator coil but does not dramatically reduce performance. The duct kit brings the flow down to ~250cfm from 475cfm in open air. Earlier work performed for the Bonneville Power Administration (BPA) showed minimal change in efficiency when stepping down to ~285cfm from 475cfm. The Draw Profile 4 (DP-4) tests showed, for a simulated draw pattern, a reduction in efficiency of ~5% at 67°F with the duct kit attached, as compared to no ducting.

1. Introduction

The Northwest Energy Efficiency Alliance (NEEA) contracted with Ecotope, Inc. and Cascade Engineering Services Inc., to conduct a laboratory assessment of the AO Smith Voltex hybrid heat pump water heater (HPWH) for northern climate installations. Using a testing plan developed by Ecotope to assess heat pump water heater performance, Cascade Engineering Services, of Redmond, WA, evaluated the AO Smith Voltex. This model has two tank sizes available: 60 gallons and 80 gallons. Cascade Engineering tested both sizes, examining the 80-gallon size first in May-June 2011 and the 60-gallon size second in November 2011.

The tests build on previous work conducted by Ecotope for the Bonneville Power Administration (BPA) and carried out by the National Renewable Energy Laboratory (NREL).[1] Ecotope devised a testing plan to support the development of the Northern Climate Heat Pump Water Heater Specification and to complement the BPA/NREL project. The test plan focused on the performance effects due to variations in airflow and lower ambient temperature conditions. The tests specific to this project include characterizing fan performance and airflow with a new ducting kit, measuring heat pump efficiency at lower ambient temperatures, and conducting a number-of-showers test at 50°F ambient. A table describing all tests performed for this report is included in Appendix A.

As our understanding of HPWHs evolved, so did the testing list. Consequently, the test suite is different between the two tank sizes. Through examination of the equipment and discussions with AO Smith, Ecotope has determined that the component selection of the tanks is similar, with the tank size as the only exception. Therefore, many of the findings are applicable across tank sizes. This report makes distinctions between the sizes and points out similarities where they apply.

[1] The report is available here:
http://www.bpa.gov/energy/n/emerging_technology/pdf/AOSmith_Prelim_HPWH_report_rev1a.pdf

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 http://www.bpa.gov/energy/n/emerging_technology/pdf/HPWH_MV_Plan_Final_012610.pdf
- Northern Climate Specification for Heat Pump Water Heaters http://neea.org/northernclimatespec/Northern%20Climate%20Specification.pdf
- Department of Energy testing standards from Appendix E to Subpart B of 10 CFR 430
- American Society of Heating, Refrigeration, and Air Conditioning Engineers Standard 118.2-2006 for the Method of Testing for Rating Residential Water Heaters

The general approach and methodological overview is provided here.

In alignment with the type of test conducted, Cascade Engineering carried out the testing at three different locations within its facility:

- Inside an ESPEC Model # EWSX499-30CA walk-in, thermal chamber;
- In a large lab space which was not thermally controlled but was kept at room temperature conditions; and
- In a room with low ambient noise.

The Department of Energy (DOE), coefficient of performance (COP), and Draw Profile type tests require tight controls on the ambient air conditions, so those tests were all conducted in the thermal chamber. The chamber is capable of regulating both temperature and humidity over wide ranges. For this testing, the chamber created environmental temperatures from 30°F to 95°F. The chamber independently monitors and records temperature and humidity conditions at one-minute intervals. Cascade Engineering conducted the airflow measurements and any one-time measurements of system component power levels under conditions found within the large lab space (typically 55°F-70°F). Lastly, Cascade Engineering moved the HPWH to a room with ambient noise levels below 35dBA to measure the noise emanating from the operating equipment.

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. Thermocouples immersed in the supply and outlet lines measured inlet and outlet water temperatures. 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. Cascade Engineering independently monitored the power for the equipment for the entire unit, the compressor and the resistance elements. It also made a series of one-time power measurements for other loads including the control board and the fan. Appendix B provides a complete list of sensors, which includes more than those mentioned here, plus their rated accuracies.

Cascade Engineering conditioned tempered water and stored it 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 controlled the water flow rate. A flow meter measured and reported the actual water flow.

The lab measured the airflow through the evaporator coil fan using a flow station in line with the exhaust duct. The flow station provided a physical average pressure of four points facing into the airstream and four points facing away from the airstream. The lab calibrated the stations to known airflows so that the differential pressure between the up and down stream measurements determined the airflow. The lab conducted the airflow measurements once to establish an equipment fan curve; therefore, by measuring only the power in other situations, the airflow could be determined without continuous flow monitoring.

A data acquisition (DAQ) system collected all the measurements at five-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.

Cascade Engineering conducted all tests to align with the DOE specifications, with exceptions described as follows:

- The tests placed the unit on top of a plywood and foam insulated test pad instead of the prescribed ¾" plywood and three 2x4 platform.
- The pump for conditioned water maintained the supply pressure near 20psi instead of the 40+psi of the spec.
- Water inlet and outlet supply piping was of the cross-linked polyethylene (PEX) variety instead of copper.
- The lab took inlet and outlet water temperature measurements ~15 feet from the tank for the 80-gallon tank (Ecotope subsequently corrected for the actual temperatures in the post-processing phase to remove time lags caused by added distance) but took measurements 2 feet from the tank for the 60-gallon tank.

In all, the deviations from the standard protocol are expected to produce minimal differences in testing outcomes. If anything, the difference in platform and piping could be expected to slightly reduce the heat loss rate of the tank.

3. Findings

3.1. Airflow Effects

AO Smith is exploring equipping the Voltex with a ducting kit to route either intake air, exhaust air, or both, and provided to Ecotope a sample kit for evaluation. In conversations with AO Smith[2], Ecotope learned the duct kit is designed to support a total of 10 feet of supply and exhaust ducting. The lab specifically examined the configuration of ducting the exhaust air outside of the conditioned envelope of a house. Cascade Engineering performed the measurements on the 80-gallon tank; the fan on the 60-gallon tank is similar, so the results are expected to be applicable across both sizes. Figure 1 shows the upper portion of the water heater with the standard exhaust grill configuration. The axial fan is visible behind the grill. Figure 2 shows the unit with the duct adaptor attached. The adaptor is sized for 8-inch diameter round ducts. This is a substantial reduction in cross-sectional area from the nearly 12-inch fan diameter.

Figure 1. Standard Exhaust Configuration

Figure 2. Exhaust Ducting Kit Attached

Adding both the duct adaptor and ducts increases the static pressure and decreases the airflow, which in turn affects performance. The change in airflow due to the presence of the ducts is displayed in Table 1. The BPA/NREL round of testing measured the airflow for the standard exhaust configuration without ducts. Ecotope and Cascade Engineering used a flow station /

[2] Phone call with Bill Hewa November 22, 2011

flow measurement grid in line with four feet of eight-inch diameter duct to measure airflow for the ducted configurations. Figure 3 depicts the ducting attached for airflow measurement. The lab installed a damper at the outlet of the duct to simulate higher static pressure situations.

Table 1. Fan Power and Flow

Configuration	Static Pressure (in W.G.)	Power (W)	Airflow (CFM)
Standard – No duct kit	0	89	475
Duct Kit w/ 4ft duct (no restriction to flow besides duct and air measurement grid)	not measured	95	250
Duct Kit w/ 4ft duct (outlet damper slightly closed to create static pressure)	0.05	97	155
Duct Kit w/ 4ft duct (outlet damper closed more than previous case to create even more static pressure)	0.14	102	105

In addition to the open system airflow measurement, the BPA/NREL tests investigated the degradation of capacity and efficiency brought on by reduced airflow. The ducting kit was not available at the time of those tests so the lab took a different approach to reducing flow by blocking 1/3 and 2/3 of the filter rack area. Those tests showed reductions in airflow to 372 CFM and 284 CFM respectively. The tests further monitored system capacity and efficiency and remarkably observed little significant change with either of the reduced airflows. This may be because the unrestricted airflow of 475 cfm provides more than adequate heat transfer.

Table 1 shows that installing a duct substantially reduces airflow. The airflow is reduced significantly even before the outlet damper is adjusted to increase the static pressure in the duct system. The major reduction in flow appears to be attributable to the presence of the duct kit itself, which presents a much smaller cross-sectional area to the fan than would be encountered in a free-air discharge installation. Adding further restrictions to flow in the duct system such as elbows or long duct runs would reduce the airflow even more.

The airflow in the case of the four-foot duct and no additional flow restrictions – 250 cfm – matches closely to the reduced airflow caused by a 2/3 filter blockage from the BPA/NREL round of testing. In light of these and the previous results, it appears as though ducting the exhaust air could slightly reduce performance, but likely not significantly so, as long as the ducting is free of flow restrictions. It follows that when the airflow is reduced to 155 or 105 cfm, capacity and efficiency will likely drop correspondingly. Finally, the data suggest using short duct runs with minimal obstructions to flow, per the installation guidelines, to maintain performance.

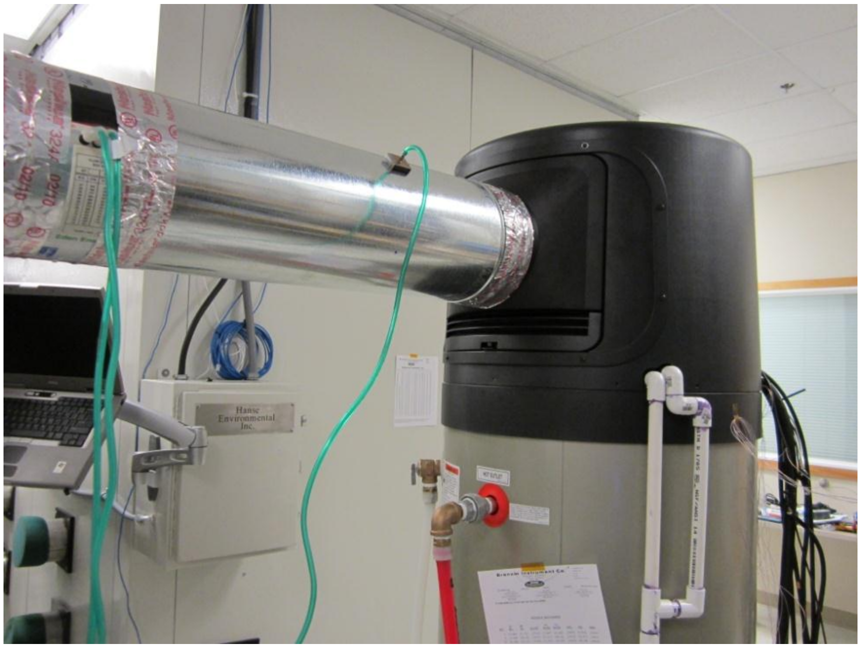

Figure 3. 8-inch Diameter Duct Connected to Exhaust Side for Airflow Measurement

3.2. First Hour Rating and Energy Factor

The Department of Energy has established two tests to rank the comparative performance of heat pump water heaters. The first test produces a first hour rating that determines how much useable hot water the heater makes in one hour. The second, a 24-hour simulated use test, produces an energy factor (EF) that identifies how much input energy is needed to generate the 64.3 gallons of hot water used in the simulated 24-hour period. For tank-type water heaters, the first hour rating depends largely on tank volume and heating output capacity, while the EF depends on the heating system efficiency and the heat loss rate of the tank. The normative performance characteristics of the equipment are shown in Table 2 and are discussed in the rest of this section. Although the lab carried out the tests to align with the DOE specifications, the outputs here should be considered advisory only – any official ratings are those reported by the manufacturer.

The lab conducted the tests with the Voltex in Hybrid mode – the default setting on the equipment when shipped by AO Smith. In addition to performing the tests at the standard rating conditions for both tank sizes, Cascade Engineering conducted another EF-type test for the 60-gallon tank. The second EF-type test used the same methods and draw patterns but different environmental conditions of 50°F ambient air / 50°F inlet water.

Table 2. Performance Characteristics for Voltex 60- & 80-Gallon Tanks

	60 Gallon		80 Gallon	
	Laboratory Measurement	Specification Sheet	Laboratory Measurement	Specification Sheet
First Hr Rating (gal)	68	68	87[3]	84
Energy Factor (std conditions)	2.35	2.33	2.07 / 2.26[4]	2.33
Energy Factor @ 50°F Ambient	2.18	-	2.1[5]	-
Northern Climate Energy Factor	1.98	-	1.9[6]	-
Tank Heat Loss Rate (Btu/hr°F)	3.9	-	5.3 / 3.9[7]	-

3.2.1. 1-hour Test

The data from the 1-hour test for the 60-gallon tank are plotted in Figure 4. The test begins with a 3gpm draw. Approximately 5 minutes into the first draw, the heat pump activates (green line showing 0.7kW). As the draw continues past 14 minutes, the water temperature falls enough to

[3] For the 80-gallon tank 1-hour test, see the BPA report.

[4] The EF is calculated using two different tank heat loss rates. The lower EF corresponds to a higher heat loss rate which was measured for the 80-gallon tank at Cascade Engineering. The higher EF corresponds to an adjusted calculation using the lower heat loss rate measured at NREL, which may be more typical of the 80-gallon tank.

[5] Not measured - modeled estimate based on compressor COP performance map: 2.1±0.1.

[6] Estimated using modeled EF at 50°F and measured EF at 67°F: 1.9±0.1.

[7] Measurements from the Cascade Engineering round of tests show a tank heat loss rate of 5.3 Btu/hr-F (10.1 kJ/hr-C) while the NREL tests show 3.9 Btu/hr-F (7.5 kJ/hr-C). The difference appears small but leads to an additional heat loss of ~2000 kJ over the course of the test. In turn, the heat pump needs to use ~800 kJ to make up the difference, which amounts to about a 5% greater energy input requirement.

engage the upper heating element, and at 18 minutes the outlet temperature has fallen enough that the draw is terminated. At 50 minutes, the upper portion of the tank has recovered to setpoint, so the equipment switches to the compressor. Per the DOE test method, this triggers another draw since the water at the top of the tank is now hot. During the second draw the resistance element reactivates. At minute 58 the draw is terminated and the unit is in recovery for the remainder of the 60-minute test.

The 1-hour test data also show how many gallons of hot water are withdrawn in the first draw before the resistance element turns on.

- For the 60-gallon tank, it is 72% of the tank volume.
- For the 80-gallon tank, it is 84% of the tank volume.

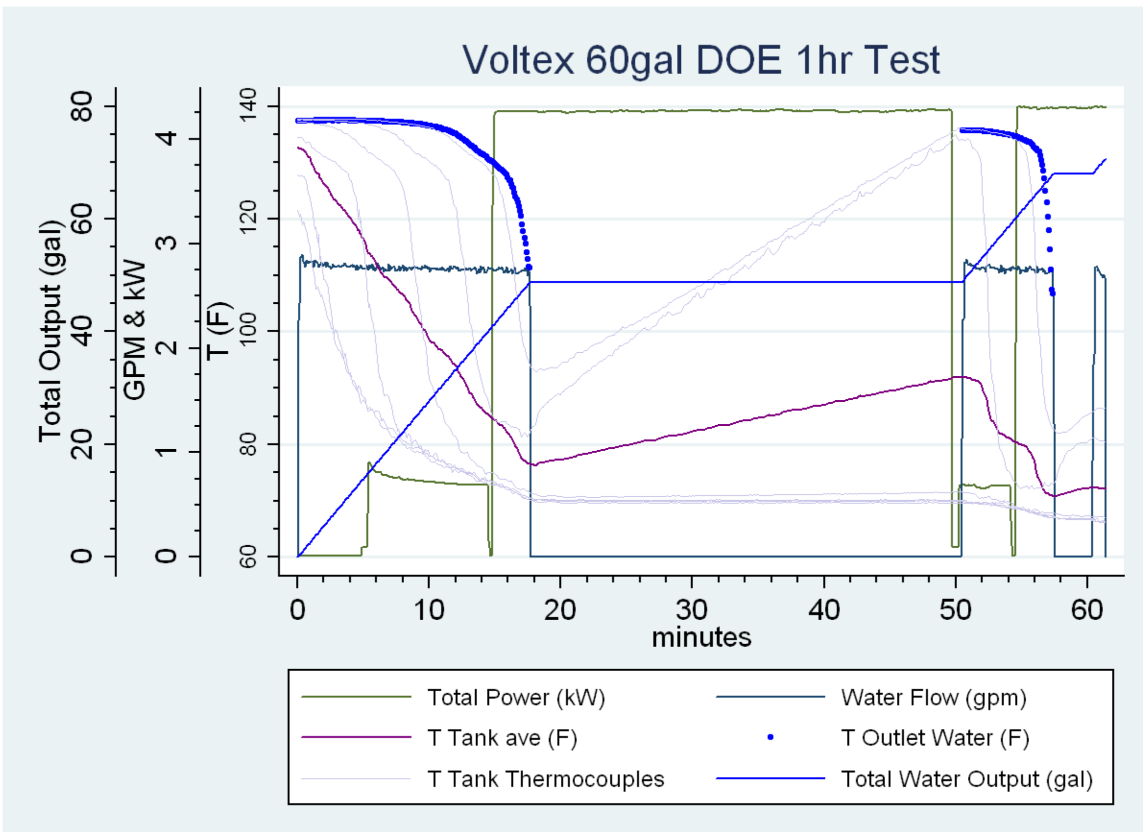

Figure 4. 60-Gallon Tank DOE 1-Hour Test

3.2.2. Energy Factor

The 24-hour simulated use test consists of six 10.7 gallon draws equally spaced over six hours, followed by 18 hours of standby. The standard test conditions are 67.5°F, 50% RH ambient air, 135°F tank set point and 58°F incoming water temperature. As with the first hour rating, the equipment used the Hybrid operating mode. The lab tested both tank sizes at standard conditions. For the 60-gallon size, the lab also performed the 24-hour simulated use test at colder ambient conditions of 50°F ambient air and 50°F inlet water. As part of the Northern Climate Heat Pump Water Heater Specification, the tests demonstrate the variation in performance with varied ambient conditions.

The EFs for all the tests are displayed in Table 2. They are calculated with the DOE method but with different ambient conditions where relevant for the 50°F ambient test. The Northern Climate HPWH spec provides a calculation method for determining the Northern Climate Energy Factor (EF_{NC}); it is a weighted combination of the EF at 67°F and 50°F using a temperature bin profile. The procedure also uses the lowest ambient temperature at which the compressor no longer operates. These temperature bins use the performance of resistance heating. The higher the compressor cutoff temperature, the lower the overall EF_{NC} will be (for details, see the Northern Climate HPWH spec). In the calculations, Ecotope used a 45°F temperature cutoff as found in the AO Smith Installation Instructions[8] and verified by Cascade Engineering.

Figure 5 through Figure 10 plot the behavior of the heat pump in three 24-hour tests. Figure 5 and Figure 6 are for the 80-gallon tank at standard testing conditions. Likewise, Figure 7 and Figure 8 are for the 60-gallon tank at standard conditions. Figure 9 and Figure 10 show testing for the 60-gallon tank at 50°F ambient air and 50°F inlet water conditions, but for the same draw profile as the others. All the figures show that the Voltex exclusively uses the compressor throughout the tests. For the 24-hour simulated use test, the tank capacity and efficient compressor operation more than sufficiently meet the hot water demand so no resistance heat is needed. In fact, Figure 5 shows that the tank volume and control logic are such that the first draw does not trigger any heating at all. The compressor activates at the second draw and remains on until just before the sixth draw when the tank has recovered.

[8] www.hotwater.com/Resources/Literature/Instruction-Manuals/Residential-Electric/Voltex-Hybrid-Electric-Manual-318257/

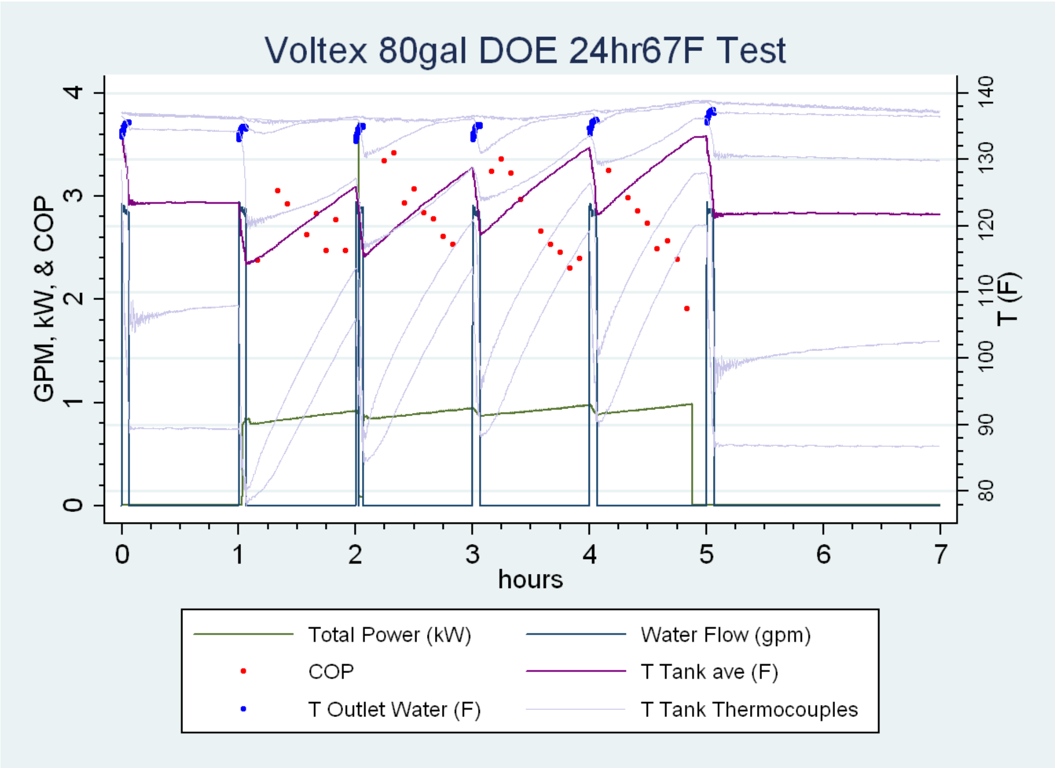

Figure 5. 80-Gallon Tank DOE 24-Hour Test. First 7 hours.

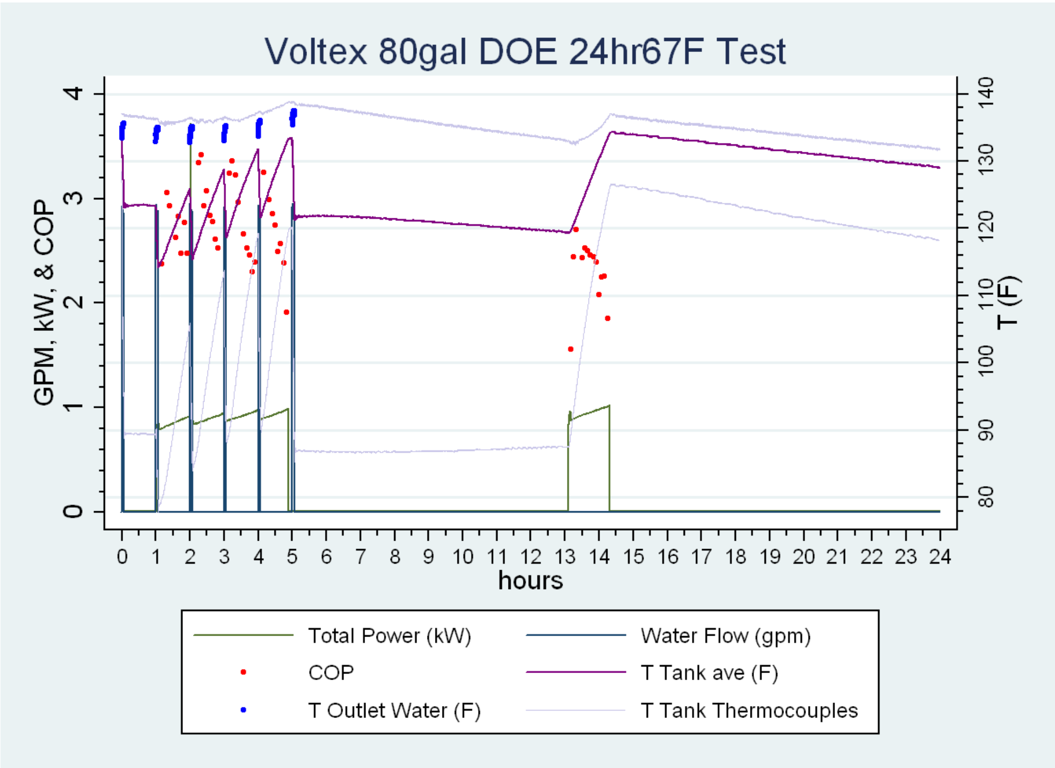

Figure 6. 80-Gallon Tank DOE 24-Hour Test. Full 24 hours.

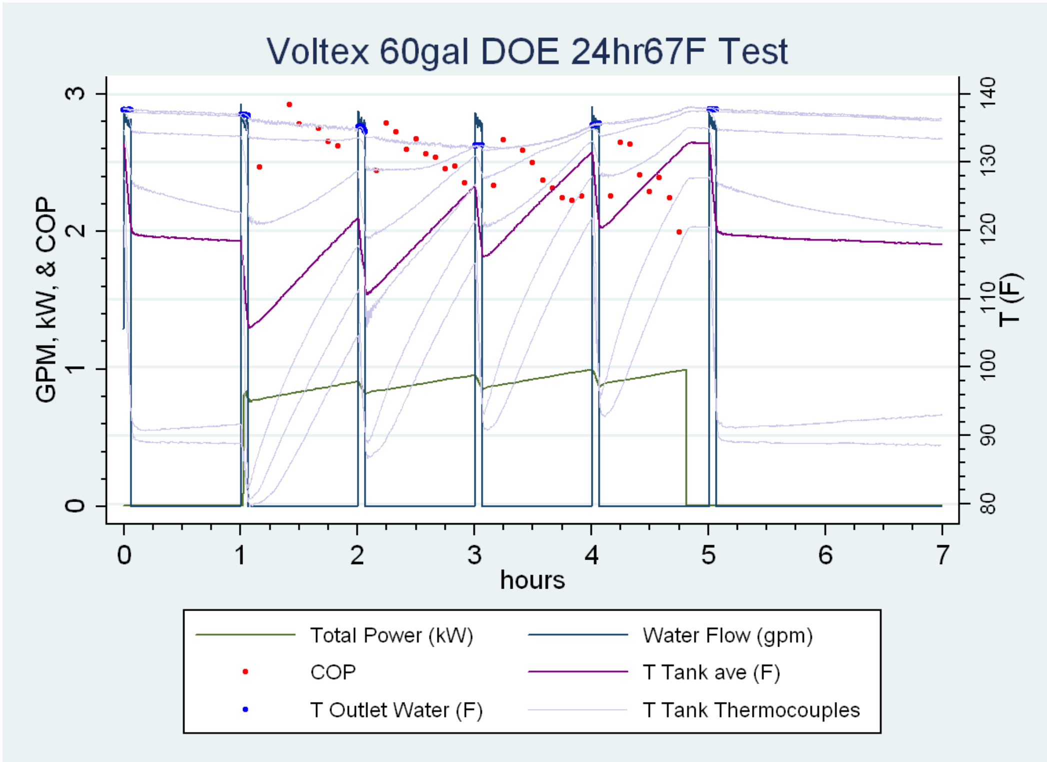

Figure 7. 60-Gallon Tank DOE 24-Hour Test. First 7 hours.

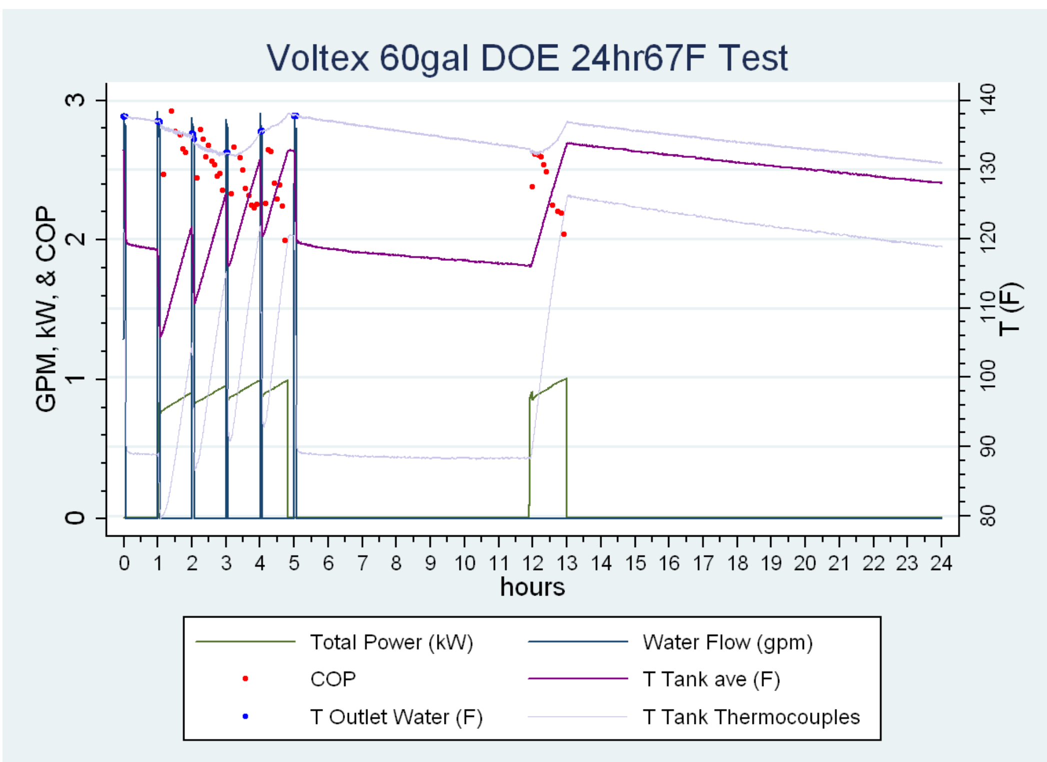

Figure 8. 60-Gallon Tank DOE 24-Hour Test. Full 24 hours.

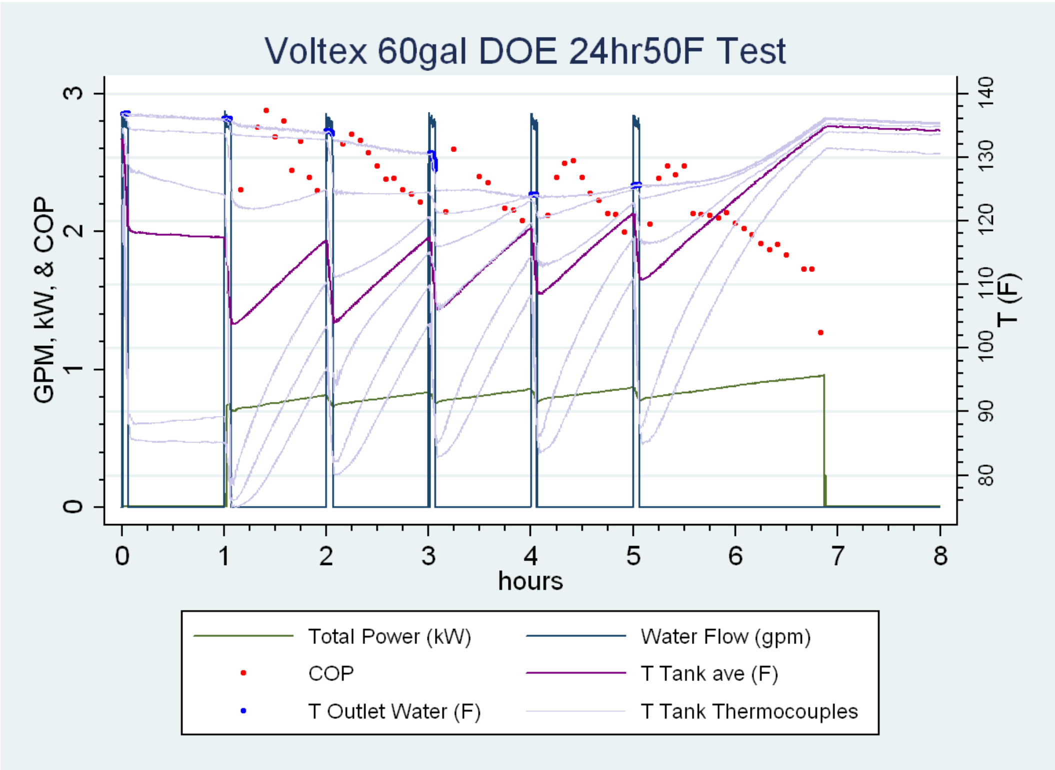

Figure 9. DOE 24-hour, 50°F Ambient Air 50°F Inlet Water. First 8 hours.

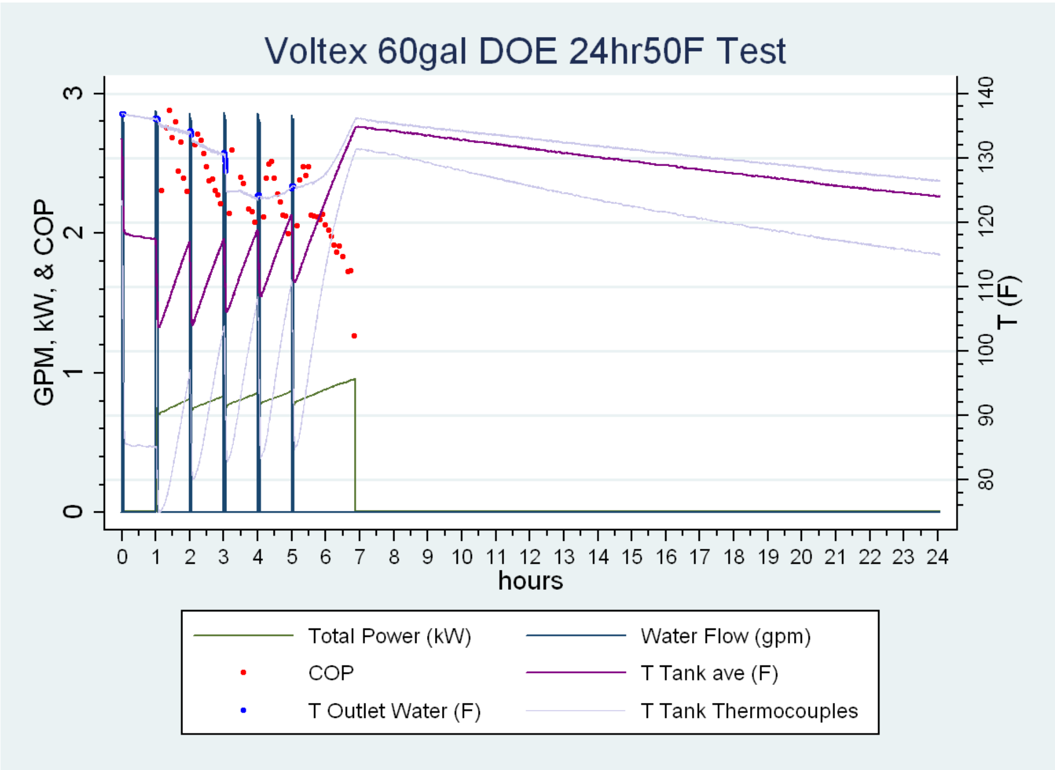

Figure 10. DOE 24-hour, 50°F Ambient Air 50°F Inlet Water. Full 24 hours.

3.3. Supplemental Tests

In addition to measuring airflow, recreating the standard DOE and low temperature tests, Cascade Engineering conducted several supplemental draw profiles to better understand performance.

The first is a simulated-use "Shower Test." This test describes the number of efficient, hot showers the HPWH is capable of providing. The test is performed at 50°F ambient air and the tank starts at setpoint of 120°F. To mimic a series of morning showers, 9-minute (for the 80-gallon tank) and 8-minute (for the 60-gallon tank) draws at two gallons per minute are conducted repeatedly.[9] The draws are separated by a 15-minute lag time and continued until either the resistance element activates or the outlet temperature falls below 105°F. When one of these events occurs, the current draw is allowed to finish and the tank is allowed to recover, concluding the test. The useful rating that comes out of this is a single number: how many consecutive, efficient showers are available. The results of the test are displayed in Figure 11 and Figure 12 for the 80- and 60-gallon tank sizes respectively. The 80-gallon tank provides four consecutive efficient showers before the resistance element activates, while the 60-gallon tank provides three.

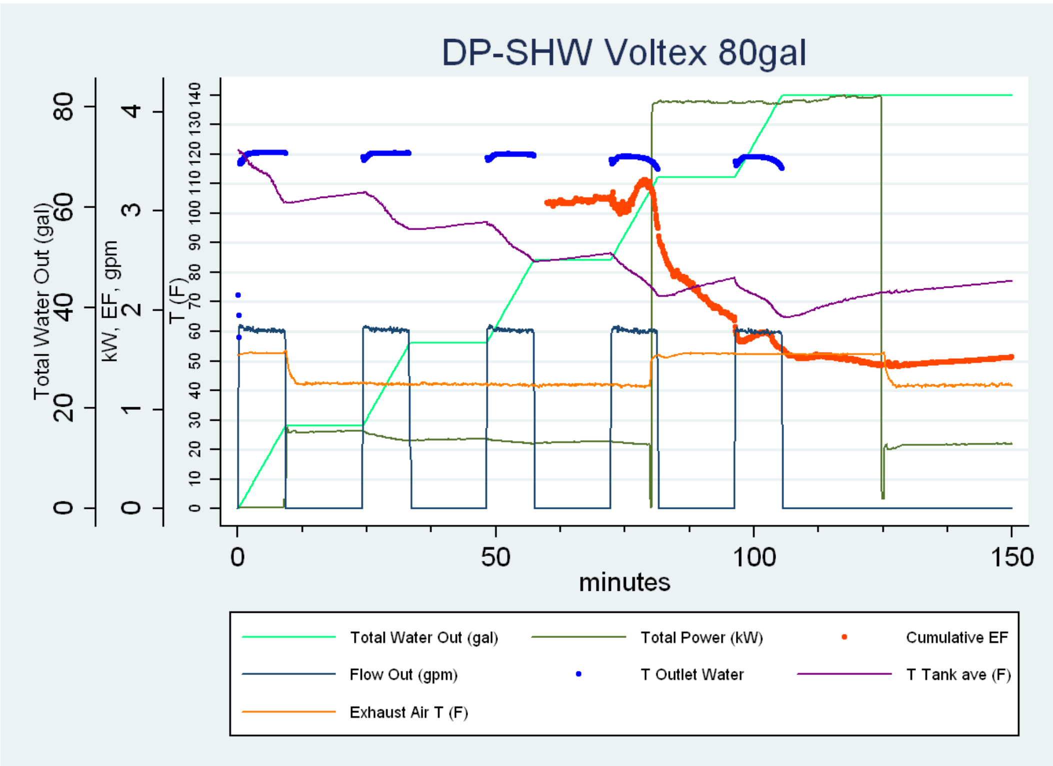

Figure 11. Shower Test Supplemental Draw Profile 80 Gallon Tank.

[9] NEEA and Ecotope revised the testing protocol between examinations of the two water heaters, which is why the duration of the draw differs slightly.

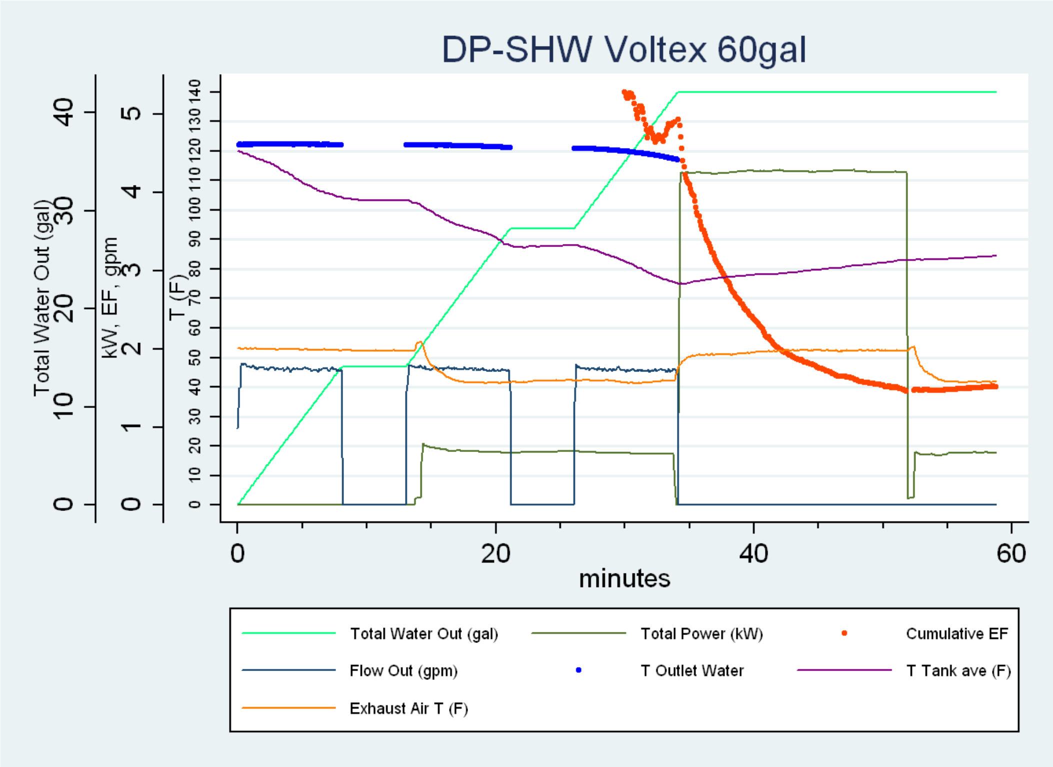

Figure 12. Shower Test Supplemental Draw Profile 60 Gallon Tank.

The second supplemental test is referred to as DP-4 (Draw Profile 4), its name a relic of previously-used, and discarded, draw profiles from earlier rounds of testing. DP-4 is a light use draw profile totaling 29 gallons. The illustrative utility of this test comes from repeating it at different evaporator fan flows. DP-4 was conducted at 67°F with full evaporator flow, and also at 67°F, with the duct kit in place reducing the airflow. This is analogous to demonstrating how the HPWH would respond to the draw profile a) inside conditioned space, and b) inside conditioned space with exhaust air ducted outside the envelope.

At 67°F the compressor ran for 94 minutes and the overall energy factor was 2.35; at 67°F with the ducting kit installed (with 4 feet of exhaust duct), the compressor ran for 111 minutes and the overall energy factor was 2.22. The airflow reduction caused by installing a duct slightly reduced capacity and efficiency.

The results of all the tests are depicted below in Figure and Figure . Note the differing runtimes and COP measurements. The draw profile itself is also represented through the "Flow Out (gpm)" line and the "Total Draw (gal)" line.

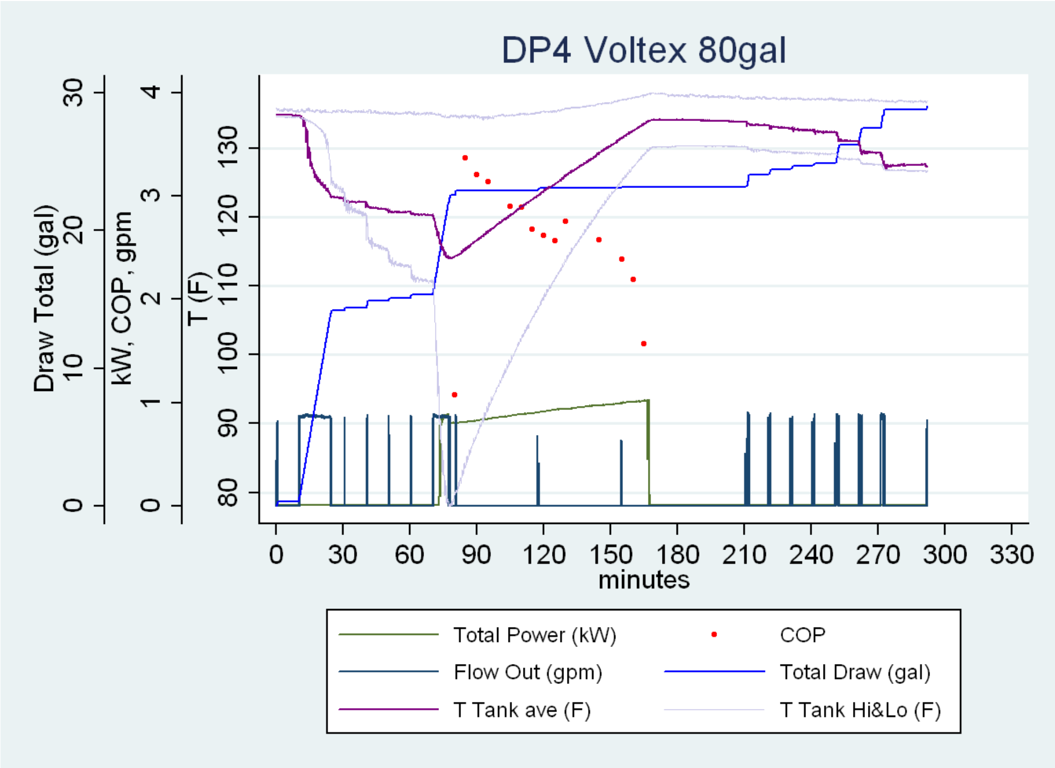

Figure 13. DP-4 Test at 67°F. 80-Gallon Tank.

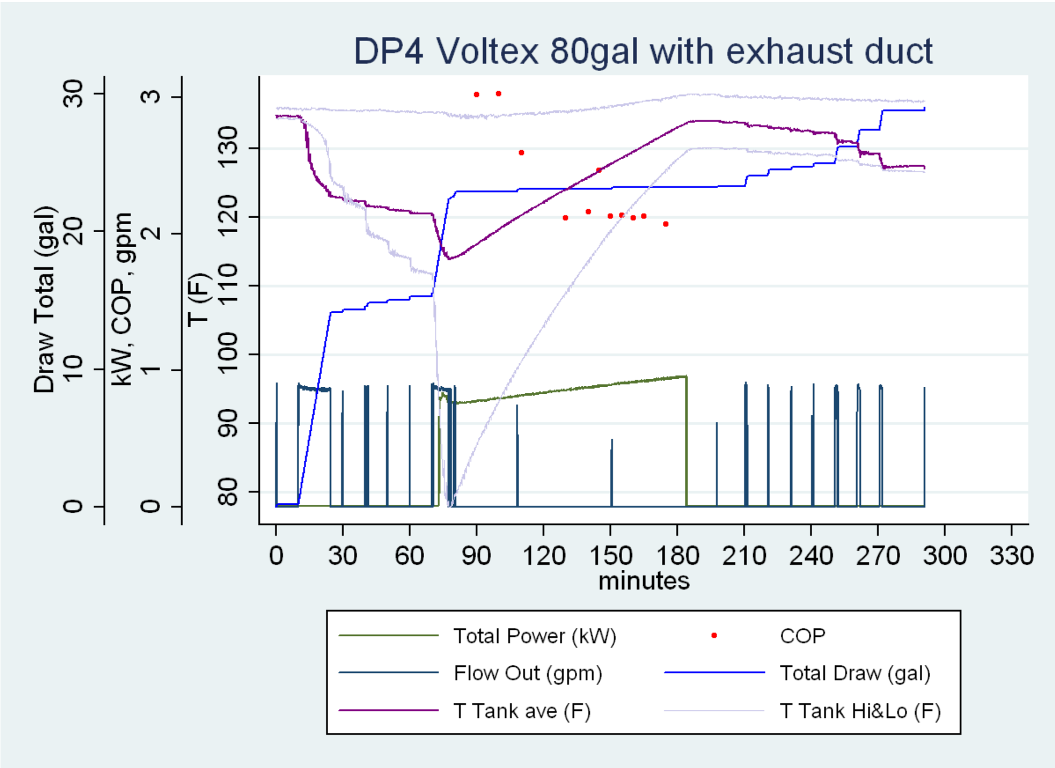

Figure 14. DP-4 Test at 67°F with Exhaust Duct. 80-Gallon Tank.

3.4. Freeze Protection Test, Additional Testing Observations and Noise Measurements

To test the ability of the water heater to withstand extreme cold temperature events, the 80-gallon Voltex was subjected to 24 hours at 30°F temperatures. The test began with the tank at setpoint and then all power to the unit was disabled for the test period. At the end of 24 hours, the lab inspected the unit for any obvious leaks, cracks or ice formation. None were found, so the unit was powered on and observed to be fully functional, thus passing the freeze protection test.

Additionally, the lab observed the condensate collection pan and drainage path throughout the testing process. The pan would collect and drain condensate as expected. The lab observed no blockage, overflows or adverse outcomes.

Using the Northern Climate Spec protocol, the lab also measured the sound level of the 80-gallon Voltex. With the unit placed against one wall of a room (ambient dBA of 31.8), lab staff made five measurements around the circumference of the water heater. In one case, an 18-inch length of 6-inch diameter duct was connected to the air exhaust port to see if the duct would dampen any sound. The averages of the five measurements were:

- 63.2 dBA, with no ducting attached
- 62.4 dBA, with short ducting attached

4. Conclusions

The last section in this report discusses observations, in no particular order, on the equipment design, test outputs, and their implications for operation and performance.

- Both the 60- and 80-gallon tank capacities are sized large enough to adequately exploit heat pump efficiency. The 60-gallon tank provides three consecutive 16-gallon showers before switching to resistance heat, while the 80-gallon tank provides four consecutive 18-gallon showers.

- The heating component controls are designed in a way to be both efficient and to meet high demand periods. In Hybrid mode, approximately 72% and 84% of the stored hot water for 60- and 80-gallon tanks respectively needs to leave the tank before the resistance elements engage. Delaying the onset of resistance heating in such a way is desirable from an efficiency perspective.

- The EF tests on the 60-gallon tank at 67°F and 50°F demonstrated the air temperature dependence of the performance. The EF decreased 7% between the two tests, which shows that the equipment design preserves performance over its lower-end operational temperature range.

- The ducting kit AO Smith provided created an integrated way to add ducts to the inlet, outlet, or both air paths. The kit design is clearly well-executed, and from a homeowner's or installer's perspective would likely appear as an attractive, viable addition to the equipment.

- Draw Profile 4 (DP-4), which was conducted in two different scenarios, provided useful insight into installation configurations. The tests showed the most efficient operation for the HPWH in isolation (neglecting interactions with the house) was for non-ducted operation at 67°F. Adding the ducts, but still using the 67°F air, lowered efficiency somewhat.

- The presence of the ducting kit significantly reduces airflow across the evaporator coil but does not dramatically reduce performance. The duct kit brings the flow down to ~250cfm from 475cfm in open air. The BPA/NREL tests showed minimal change in efficiency when stepping down to ~285cfm from 475cfm. The DP-4 tests showed, for a simulated draw pattern, a reduction in efficiency of ~5% at 67°F with the duct kit attached, as compared to no ducting. If the exhaust duct kit is installed, the best performance will be achieved for short duct runs.

Appendix A: Testing Matrix

Tank Size Tested		Test Name	Ambient Air Conditions					Inlet Water		Outlet Water		Airflow	Operating Mode
60	80		Dry-Bulb		Wet-Bulb							inch. static pressure	
			F	C	F	C	RH	F	C	F	C		
DOE Standard Rating Point Tests													
X	X	DOE-24hr	67.5	20	57	14	50%	58	14	135	57	0.0"	Factory Default
X		DOE-24hr-50	50	10	44	7	58%	50	10	135	57	0.0"	Factory Default
X		DOE-1hr	67.5	20	57	14	50%	58	14	135	57	0.0"	Factory Default
Airflow Measurement													
	X	AM	Temperature and humidity need not be tightly controlled - room conditions. Connect ducting kit and outlet damper to measure flow in various static pressure regimes.									0.0" to 0.25"	Factory Default
Draw Profiles													
	X	DP-4-67-duct	67.5	20	57	14	50%	58	14	135	57	With Duct Kit	Factory Default
	X	DP-4-67	67.5	20	57	14	50%	58	14	135	57	0.0" - No Duct Kit	Factory Default
X	X	DP-SHW-50	50	10	44	7	58%	45	7	120	49	0.0" - No Duct Kit	Factory Default
Noise Measurement													
	X	NOI	Measure combined fan and compressor noise									0.0"	Heat Pump running
Additional Observations													
X	X	AO-ICE	Monitor evaporator coil for frosting										
X	X	AO-CND	Observe condensate drainage and note effectiveness										
Freeze Protection Test													
	X	FRZ	30	-1	28	-2	80%	55	13	130	54	0.0" - No Duct Kit	Factory Default

Appendix B: Measurement Instrumentation List

Equipment	Make and Model	Function	Accuracy
Walk-in Thermal Chamber	Make: ESPEC, Model No.: EWSX499-30CA	Control temperature and relative humidity in test environment	
Data Acquisition System	Agilent Technologies Model No.: 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	1.0°C
Power Meter	Acuvim II - Multifunction Power Meter with AXM-I02 I/O Module	Power measurement, PF measurement of system, resistance heater, and heat pump	Main Unit: 0.2% full scale for voltage and current. AXM-I02 Analog Output: 0.5% full scale + 1% resistor tolerance
Current Transformer (25:5)	Midwest CT model 3CT625SP	Use with Acuvim Power Meter for total UUT power and heater power measurement	0.4% at 5VA
Current Transformer (5:5)	Midwest CT model 3CT205SP	Use with Acuvim Power Meter for total UUT power and heater power measurement	0.6% at 2VA
Flow Control System	Systems Interface Inc.	Water draw rate and volume control	
Flow meter	Signet 2537 paddlewheel Flow Meter	Use with Flow Control System	+/- 1% linearity +/- 0% repeatability
Inlet Water Conditioning System	Pro Refrigeration	Conditioning of UUT inlet water temperature	
Water pressure gauge	Noshok 25.100-100	Inlet water pressure measurement	+/- 2.5% full scale
Hand-held temperature and humidity meter	Omega RH820W	Lab environment temperature and humidity measurement	
Electronic Scale	OXO "Good Grips" Scale	Measurement of water mass	5.0 Kg full scale with 1g increment
Electronic Scale	Pelouze Model: 4040	Measurement of water mass	