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NEEA Report: Laboratory Assessment of AirGenerate ATI80 Heat Pump Water Heater

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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 AirGenerate AirTap™ model #ATI80 hybrid heat pump water heater (HPWH) for northern climate installations. Cascade Engineering evaluated the ATI80 using a testing plan developed by Ecotope to assess heat pump water heater performance.

The goal of the work: to evaluate the product using the Northern Climate Heat Pump Water Heater Specification (Northwest Energy Efficiency Alliance, 2012. *Northern Climate Heat Pump Water Heater Specification*. Retrieved from http://neea.org/northernclimatespec/). The testing plan included characterizing the equipment operating modes; observing heat pump efficiency at lower ambient temperatures; conducting the standard 24-hour and first hour rating tests; measuring noise output levels; and quantifying the number of efficient showers delivered at 50°F ambient. Overall, the results suggest the ATI80 is an efficient heat pump water heater for use in both small and extremely large hot water load applications. In addition, it is appropriate for all applications in the Pacific Northwest. Specific findings include:

- Measured Northern Climate Specification Metrics:
  - Northern Climate Energy Factor: 2.01
  - Percent of tank drained before resistance elements engage in 1-hour test: 82%
  - Number of consecutive, 16-gallon, efficient showers: 4
  - Sound level: 58 A-weighted decibels (dBA) (high fan speed) / 54 dBA (low fan speed)

- The heating component controls are designed in a simple and elegant way to both be efficient and to meet high demand periods. The 80-gallon tank provides four consecutive 16-gallon showers before switching to resistance heat. Further, in the "Auto" operating mode, the 1-hour tests showed approximately 82% of the stored hot water needs to leave the tank before the resistance element engages.

- The water heater is similar to the ATI66 model in most ways. The compressor and heat exchanger components are the same. Aside from the larger tank volume, a key difference is a new two-speed fan rather than the previous single-speed fan. The fan has two airflow settings, both of which are lower than those of the previous fan. Tests show that the decreased airflow did not reduce performance. Additionally, the tests measured lower sound levels for the lower fan speed. Lastly, the fan can maintain air flow across any reasonable duct scenario, giving the installer the flexibility to duct cooler exhaust air outside the house.

- Like the ATI66 model, this one has active defrost and a wide ambient temperature operating range, which makes the unit well-suited for Pacific Northwest buffer space installation. Notably, the compressor operates until 32°F under default settings.

1 Introduction

The Northwest Energy Efficiency Alliance (NEEA) contracted with Ecotope, Inc. and Cascade Engineering Services Inc. to conduct a laboratory assessment of the AirGenerate ATI80 heat pump water heater (HPWH) for northern climate installations. Cascade Engineering Services, of Redmond, WA, evaluated the AirTap™ model #ATI80 using a testing plan developed by Ecotope to assess heat pump water heater performance. The test plan follows that of the Northern Climate Heat Pump Water Heater Specification with several added investigations (Northwest Energy Efficiency Alliance, 2012. *Northern Climate Heat Pump Water Heater Specification*. Retrieved from http://neea.org/northernclimatespec/). It consists of a series of tests to assess equipment performance under a wide range of operating conditions with a specific focus on low ambient air temperatures.

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

Ecotope previously evaluated the slightly smaller ATI66 model under contract with NEEA. (Larson and Logsdon 2012. Retrieved from https://conduitnw.org/_layouts/conduit/ViewFileRedirector.ashx?fileName=389-ATI66_HPWH_Report_final.pdf). Both models use the same refrigerant heat exchangers, compressors, and controls. They differ in tank volume, size, and fan type. The ATI80 has a larger tank capable of storing more hot water, which can be useful in meeting high-demand periods. The larger volume also requires the unit be larger overall. It has the same diameter, 25.5 inches, as the ATI66 but is 4 inches taller at 73.75 inches. The ATI80 also has a new two-speed fan. The airflow path is the same as on the ATI66, but the installer may now select a high- or low-speed fan setting. The fan does not change speeds during operation. The speed setting is designed to allow the installer to control the amount of air being ducted away from the water heater.

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
- 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. All figures and schematics in this section are courtesy of Cascade Engineering.

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 not thermally controlled but kept at room-temperature conditions; and
- In a room with low ambient noise.

The DOE and Draw Profile type tests require tight controls on the ambient air conditions, so Cascade Engineering conducted all of those tests in the thermal chamber. The chamber is capable of regulating both temperature and humidity over a wide range. The chamber independently monitors and records temperature and humidity conditions at one-minute intervals. Figure 1 shows the HPWH installed inside the thermal chamber. The test plan did not require tightly-controlled conditions to conduct airflow measurements and any one-time measurements of system component power levels, so Cascade Engineering conducted those tests in the large lab space at the conditions encountered at the time (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.

Figure 1. HPWH Test Unit Installed Inside Thermal Chamber

Figure 2 is a schematic of the general test setup. 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 3 – 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. Power for the equipment received independent monitoring for the entire unit, the compressor, and the resistance elements (Figure 4 and Figure 5). Cascade Engineering 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.

Figure 2. General Test Setup

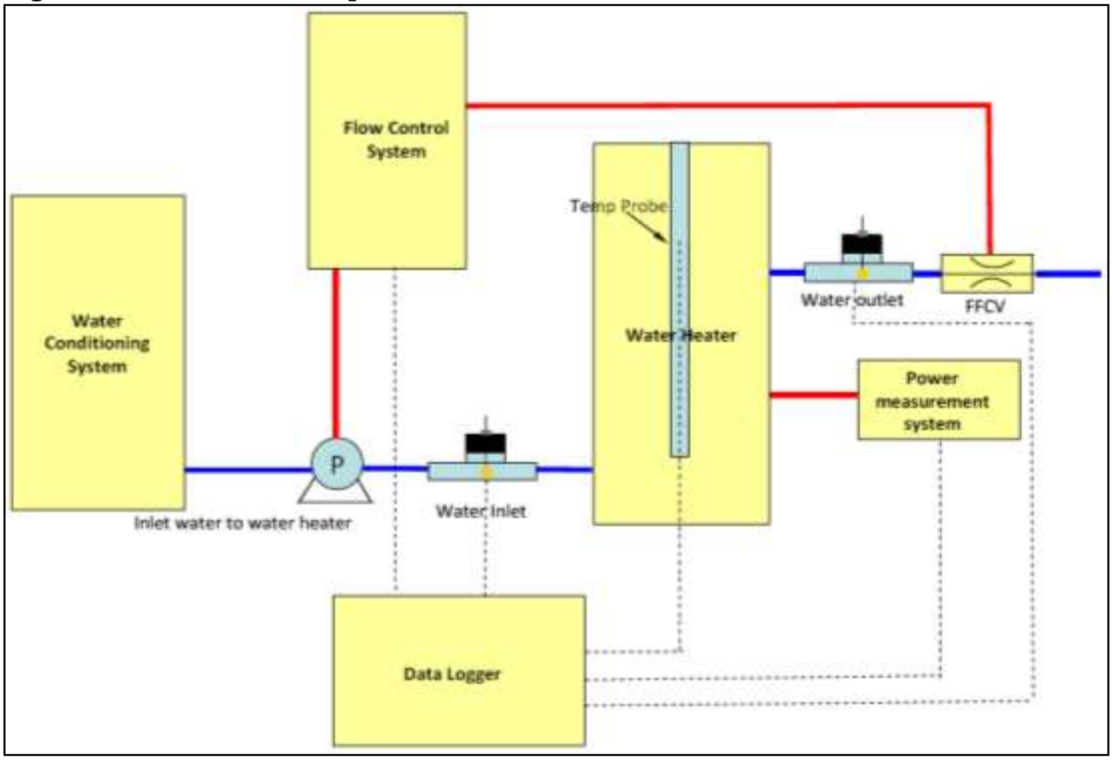


Figure 3. Thermocouple Temperature Tree

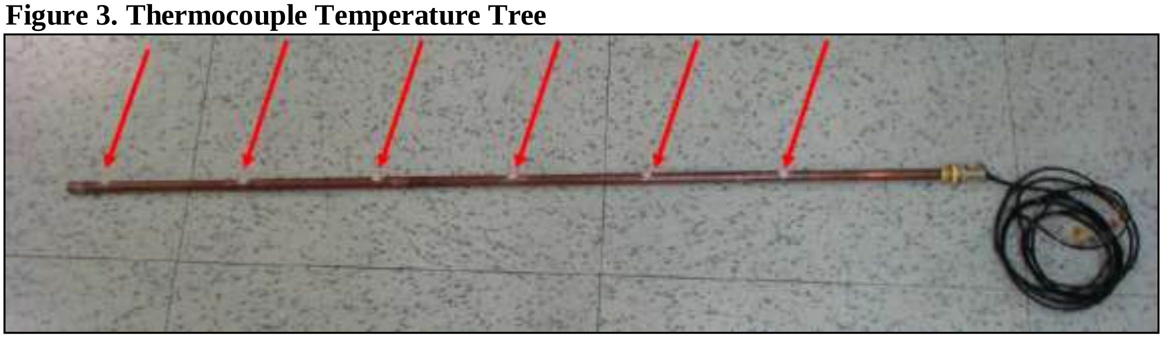


Figure 4. Power Measurement Current Transducers

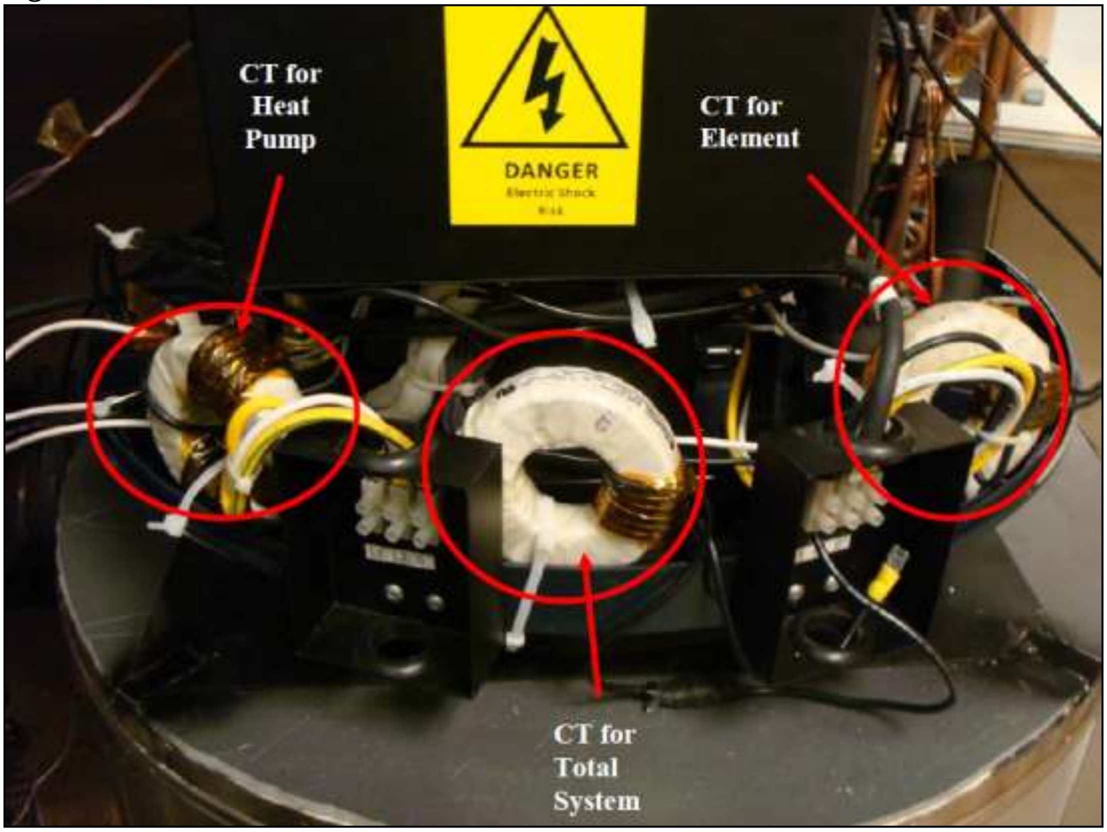
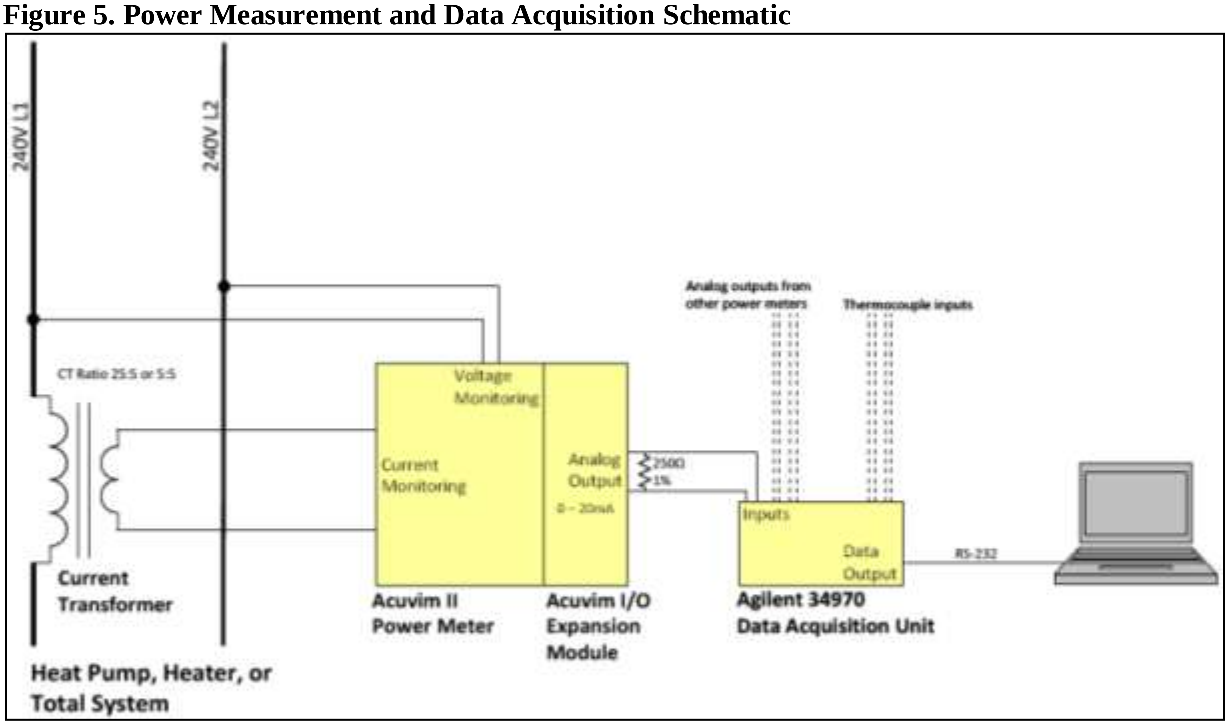


Figure 5. Power Measurement and Data Acquisition Schematic



Cascade Engineering conditioned and stored tempered water 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. A flow meter measures and reports the actual water flow.

A data acquisition (DAQ) system collects all the measurements at five-second intervals and logs 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 rather than the 40+psi of the spec.
- Water inlet and outlet supply piping consisted of the cross-linked polyethylene (PEX) variety instead of copper.
- The lab took inlet and outlet water temperature measurements two feet from the 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, thereby improving performance.

3 Findings: Equipment Characteristics

3.1 Basic Equipment Characteristics

The ATI80 HPWH is an all-electric water heater consisting of a heat pump integrated with a hot water tank. The equipment has two methods of heating water:

(1) Using a heat pump to extract energy from the ambient air and transfer it to the water, and
(2) Using resistance heating elements immersed within the tank.

The heat pump compressor and evaporator are located on top of the tank. A two-speed centrifugal fan draws ambient air from the right side of the unit, pulls it through the filter and across the evaporator coils, and exhausts colder air out the top. The unit is designed to easily duct the exhaust air through a six-inch round duct. The refrigerant condenser, which transfers heat to the water, is submerged inside the tank at the bottom.

The lab conducted a series of measurements comprising a basic descriptive characterization of the equipment. These are shown in Table 1 and are discussed in the rest of this section. For reference purposes, the table also shows the values given by AirGenerate's equipment specifications.

As with traditional electric tank water heaters, the ATI80 contains two electric resistance heating elements. Unlike most traditional tanks with one element at the top and one element at the bottom of the water column, the ATI has one element at the top and a backup element in the middle. The backup element does not activate during normal operating modes and is designed to be activated only in the event the heat pump system stops functioning. Each resistance element draws 4kW of power when active. The primary resistance element may operate either by itself or in conjunction with the compressor.

The controls for the ATI80 are configured to operate the compressor by itself; the upper element by itself; or both concurrently. Measurements show that the compressor draws 600W to 1,000W depending on both tank water and ambient air conditions, resulting in a maximum power draw of 5.0 kW. For the heat pump, lower temperatures for both water and air result in lower power draws, while higher temperatures result in larger power draws. Obviously, resistance element power draw is constant. Two other components of the equipment also consume power: the fan, which moves either 220CFM or 170CFM (depending on setting) of air with no obstructions to flow, drawing 85W and 73W respectively; and the control circuits, which use a constant 2.5W.

The ATI80 has a nominal 80-gallon capacity, but measurements showed the unit in the lab held 72.5 gallons. National guidelines on the sizing of equipment allow a 10 percent variation in nominal versus actual size; this water heater falls within those guidelines, albeit at the lower end. The difference in nominal size versus actual size is not unique to HPWHs and occurs with traditional electric resistance tanks as well.

The ATI80 uses R-410a refrigerant. R-410a has lower condensing temperatures than R-134a, which is used by some other HPWH manufacturers. This can lead R-410a systems to experience difficulties in heating water to high setpoints. The ATI80 testing, however, showed that the heat pump successfully heated water to 135°F. Cascade Engineering did not test higher setpoints;

they may or may not be attainable through heat pump operation. Regardless, 135°F is sufficiently hot for most conceivable applications.

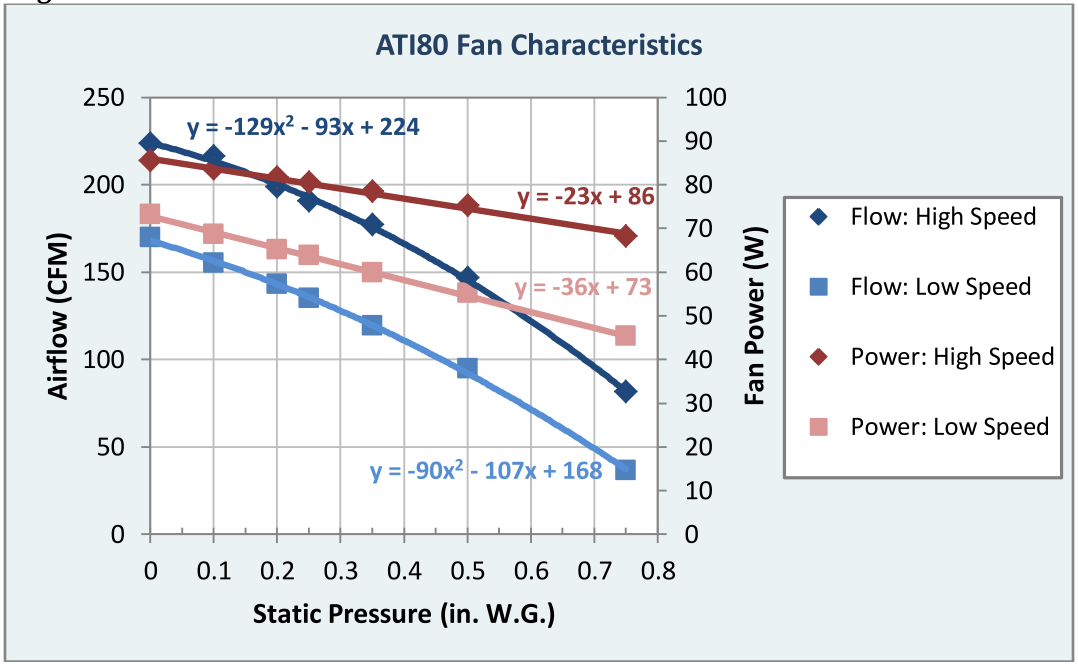
Table 1. Basic Characteristics for AirGenerate ATI80

	Laboratory Measurement	Manufacturer's Specification
Upper Element (W)	4,000	4,000
Lower Element (W)	4,000	4,000
Compressor* (W)	600-1,000	790-1,000
Standby (W)	2.5	2.5-3.5
Fan† (W)	73-85	78-90
Airflow Path	Inlet on right side. Exhaust out top.	Inlet on right side. Exhaust out top.
Airflow Unobstructed (CFM)	220 / 170	--
Airflow at 0.25in static (CFM)		--
Refrigerant	R-410a	R-410a

Notes: *range depends on water T and ambient T. Power increases with each. Observations cover a water temperature range from 50°F to 135°F and an ambient air temperature range from 50°F to 68°F.
†Fan has high and low speeds. Increases to external static pressure, due to ducting, reduce the power consumption.

To characterize the fan airflow and power, Cascade Engineering measured those values over a range of static pressures. Given that the fan has two speeds, two sets of curves exist with flow and power for each speed setting. Figure 6 shows the fan characteristics. The figure also displays the functional curve fits for flow and power in terms of static pressure. Those relationships can be used to predict the airflow for any given set of duct configurations.

Figure 6. Fan Characteristics



3.2 Operating Modes and Sequence of Heating Firing

The HPWH has an integrated circuit control board that may be programmed in a number of ways to control when the heating components turn on and off. AirGenerate has developed several control strategies, referred to as operating modes, to determine equipment operation. The ATI80 HPWH has three basic modes of operation, shown below in order of most efficient to least efficient:

- "Econ" – compressor only during user-defined time intervals
- "Auto" – combination of compressor and resistance elements
- "Heater" – primary resistance heat element only

AirGenerate provides detailed information for the operating modes in their installation and service manuals (AirGenerate 2012a & 2012b). The modes are determined by two temperature sensors: an upper sensor to control resistance element operation and a lower sensor to control compressor operation. Observations of the equipment during the course of testing showed the behavior matched the operating mode information provided by AirGenerate. Summaries of behaviors in all modes are described below. Again, the controls are identical to those of the ATI66.

The equipment operating logic for all modes is governed by the following set of parameters:

F11: Water setpoint temperature. Factory default is 130°F
F12: Temperature difference from setpoint for heating activation. Factory default is 20°F
T1: Water temperature measured by upper temperature sensor (adjacent to resistance element)
T2: Water temperature measured by lower temperature sensor (adjacent to heat pump coil)

<u>Econ Mode:</u> The heat pump activates when the lower temperature sensor T2 falls below F11-F12. Under factory default settings, this means that the heat pump activates when the surrounding water temperature falls below 110°F. The heat pump runs until the water around it as measured by sensor T2 meets setpoint. The resistance element does not operate in this mode. Additionally, the heat pump is only operational during user-defined time intervals. No default setting exists for these time intervals, so switching to Econ mode without defining the operating time settings will result in the heat pump remaining off.

<u>Auto Mode:</u> The heat pump activates when the lower temperature sensor T2 falls below F11-F12 and the resistance element activates when the upper temperature sensor T1 falls below F11-F12. Under factory default settings, this means that the heat pump activates when the surrounding water temperature falls below 110°F and the resistance element activates when the surrounding water temperature falls below 110°F. Both heating types are allowed to run concurrently. The heat pump and resistance element shut off when their respective temperature sensors read that the water has re-attained setpoint.

<u>Heater Mode:</u> The resistance element activates when the upper temperature sensor T1 falls below F11-F12. Under factory default settings, this means that the resistance element activates when the surrounding water temperature falls below 110°F. The heat pump does not operate in this mode. The resistance element shuts off upon re-attaining setpoint at its temperature sensor.

4 Findings: Testing Results

4.1 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 ATI80 in Auto mode – the default setting on the equipment when shipped by AirGenerate. The results are shown in Table 2. In addition to performing the tests at the standard rating conditions, Cascade Engineering conducted several other, similar tests. 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, which are the conditions used to determine the Northern Climate Energy Factor.

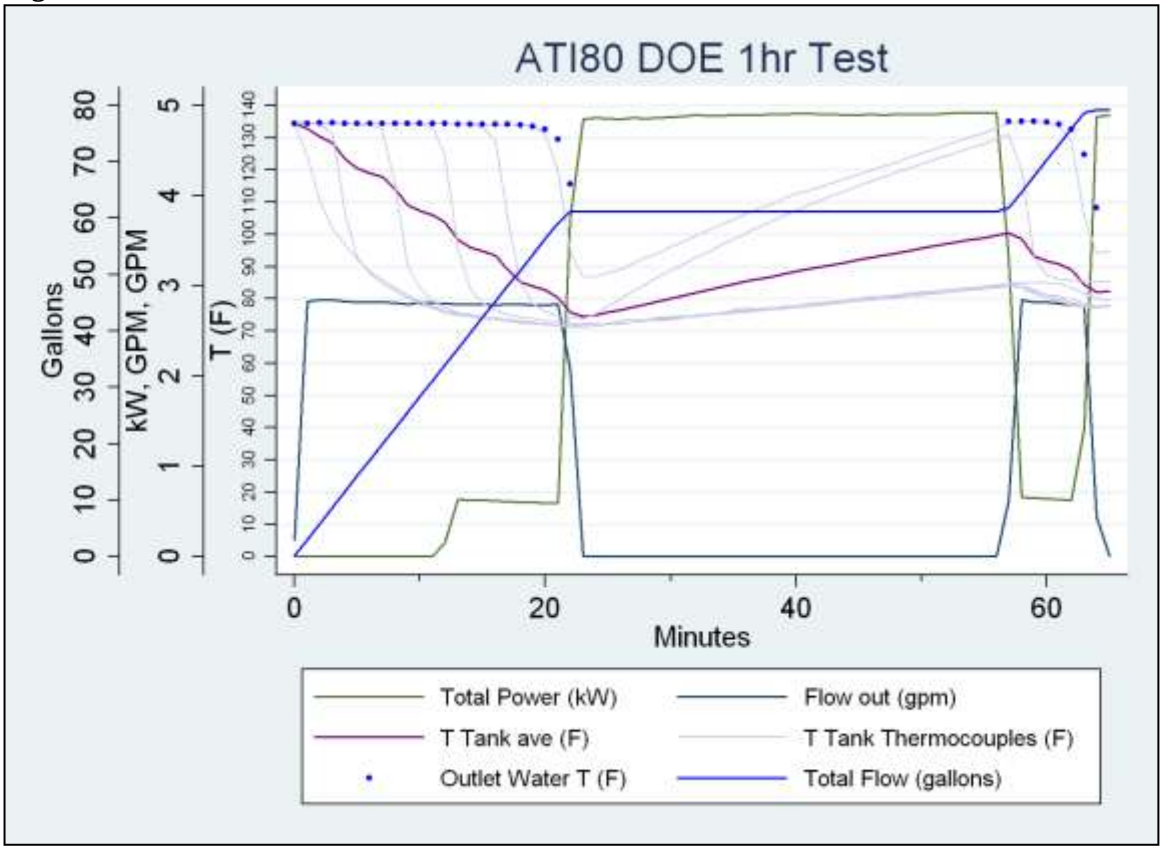
Table 2. Performance Characteristics for ATI80

	Laboratory Measurement	Specification Sheet
First Hour Rating (gal)	79	80
Energy Factor (std conditions)	2.26	2.2
Energy Factor @ 50°F Ambient	1.91	-
Northern Climate Energy Factor	2.01	-
Tank Heat Loss Rate (Btu/hr°F)	4.0	-

4.1.1 1-hour Test

The data from the 1-hour test are plotted in Figure 7. The test begins with a 3gpm draw. Approximately 12 minutes into the first draw, the heat pump activates (green line showing 0.6kW). As the draw continues past 21 minutes, the water temperature at the upper sensor falls 20°F below the setpoint, which triggers the resistance element. Both heating components continue to run until minute 57. At that time, the upper portion of the tank has recovered to setpoint, switching off the element. Per the DOE test method, this triggers another draw since the water at the top of the tank is now hot. That draw is terminated near minute 63, concluding the test.

Figure 7. DOE 1-Hour Test



The bright blue line shows the cumulative water drawn during the test. The green line plots the total equipment power consumption. The thick purple line displays the average tank temperature while the thin lavender lines show the temperatures reported from the six thermocouples placed at different heights (corresponding to equal volume segments) within the tank (in effect a temperature profile of the tank at any point in the test). Lastly, the blue dots plot the outlet water temperature.

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 ATI80, the test data show 59.5 gallons, equivalent to 82% of the measured tank volume.

4.1.2 Energy Factor Tests

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% relative humidity (RH) ambient air, 135°F tank setpoint and 58°F incoming water temperature. As with the first hour rating, the equipment used the auto operating mode. 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 Heat Pump Water Heater Specification 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 and electric resistance heating is used exclusively. The higher the compressor cutoff temperature, the lower the overall EF_{NC} will be (for details, see the Northern Climate Heat Pump Water Heater Specification). In the calculations, Ecotope used a 32°F temperature cutoff as found in the ATI80 Service Manual (AirGenerate 2012b).

Figure 8 shows the first eight hours of the test so the draw events and recovery can be examined in more detail. Figure 9 shows the full 24 hours, which also demonstrates the tank heat loss rate. The figures plot the same type of data as shown in Figure 7. One distinction for this test is the exclusive use of the compressor for heating, unlike the 1-hour test which shows both compressor heat and resistance element heat to meet the high demands of the test.

Figure 8 also plots the instantaneous coefficient of performance (COP), a measure of how much heat is added to the hot water in a given time interval divided by the energy used to create or deliver that heat in that interval (in this case five minutes). For electric resistance heat, the COP is generally assumed to be 1. In contrast, the COP for heat pumps can vary greatly depending largely on the ambient air conditions (heat source) and the tank temperature (heat sink). The downward trend of the COP in Figure 9 with each recovery cycle reflects the warming tank temperature. The scatter in the COP plots is due to tank mixing and uneven, short-term fluctuations in the tank temperature measurements, but the general trend is clear. The COP varies between 1.7 and 3.5 throughout each recovery period, decreasing as the tank temperature warms (the heat pump is less efficient when working against a larger temperature difference).

Figure 8. DOE 24-Hour Simulated Use Test, First Eight Hours

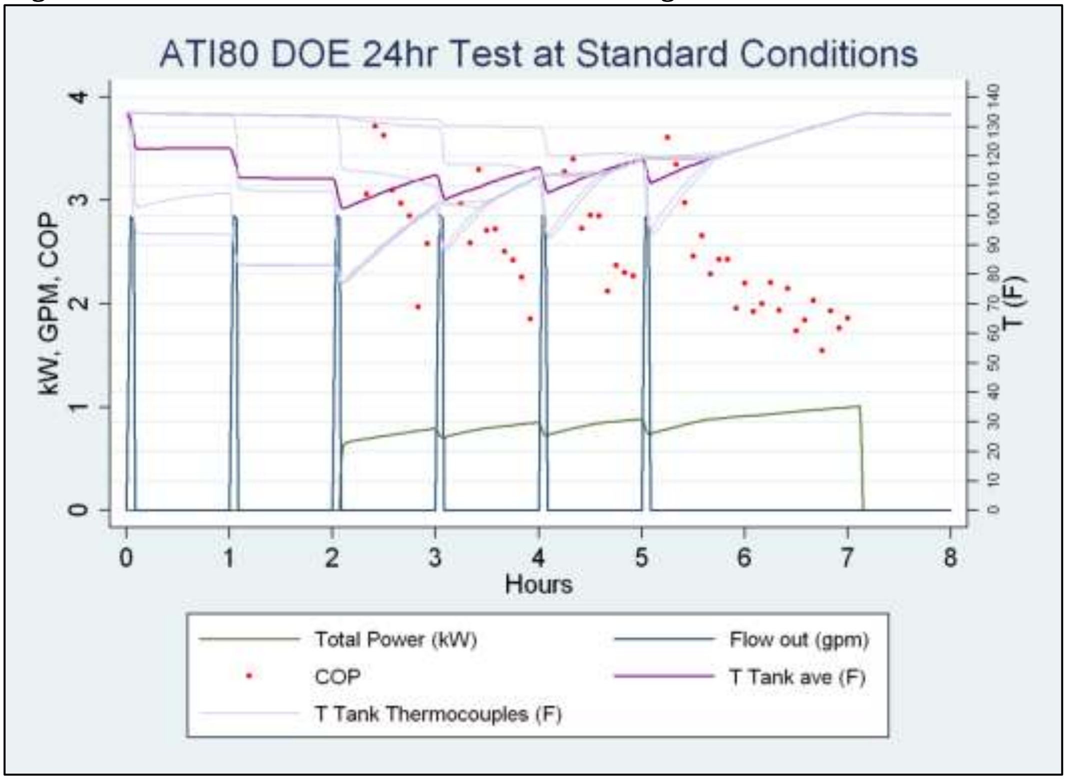


Figure 9. DOE 24-hour Simulated Use Test. Full 24 hours.

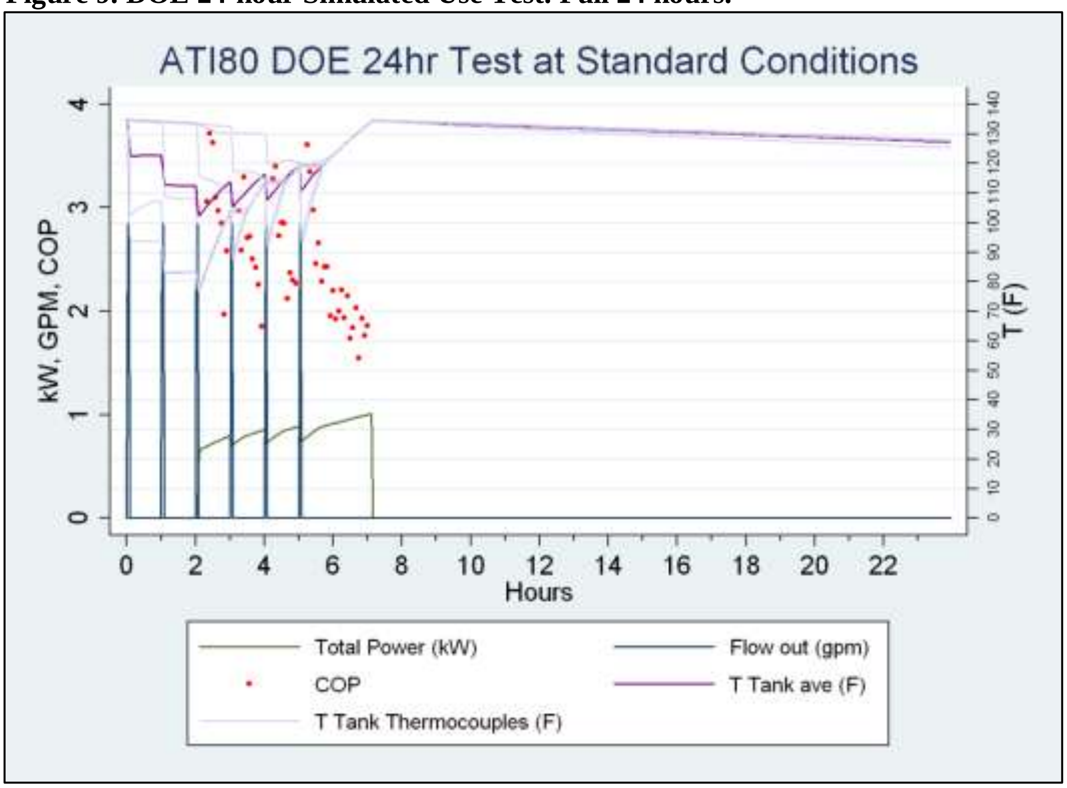


Figure 10 and Figure 11 plot the heat pump behavior for the 50°F ambient air and 50°F inlet water 24-hour testing conditions. In contrast to the test at 67°F ambient air, the unit takes until hour 9, 1.75 hours longer, to recover the tank – to be expected, given the difference in air temperature. Accordingly, the compressor COPs also show up lower at 50°F ambient. The outlet water temperature difference for the last two draws is also notable. Due to the lower ambient air temperature, the compressor is unable to reheat the tank as quickly, causing lower outlet water temperature as the test progresses. Water temperatures during the last draw approach 108°F. A final note on the 50°F test is that the increased heat loss through the tank is observable through the slightly lower average tank temperature at the end of the test.

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

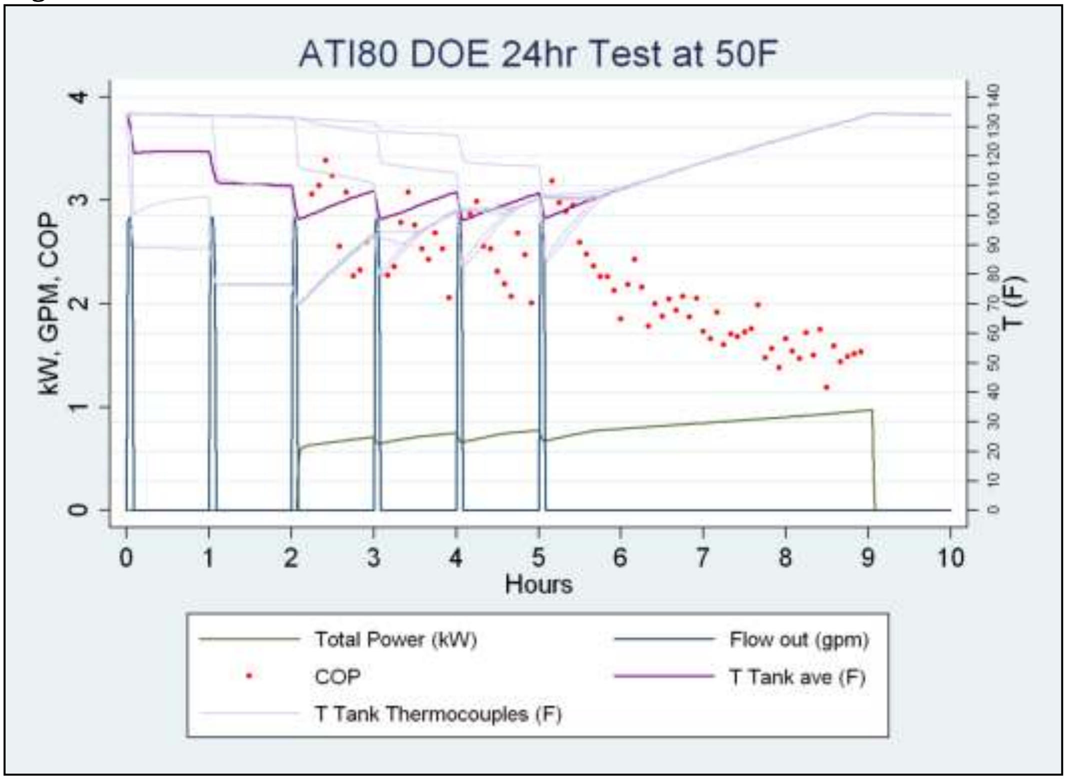
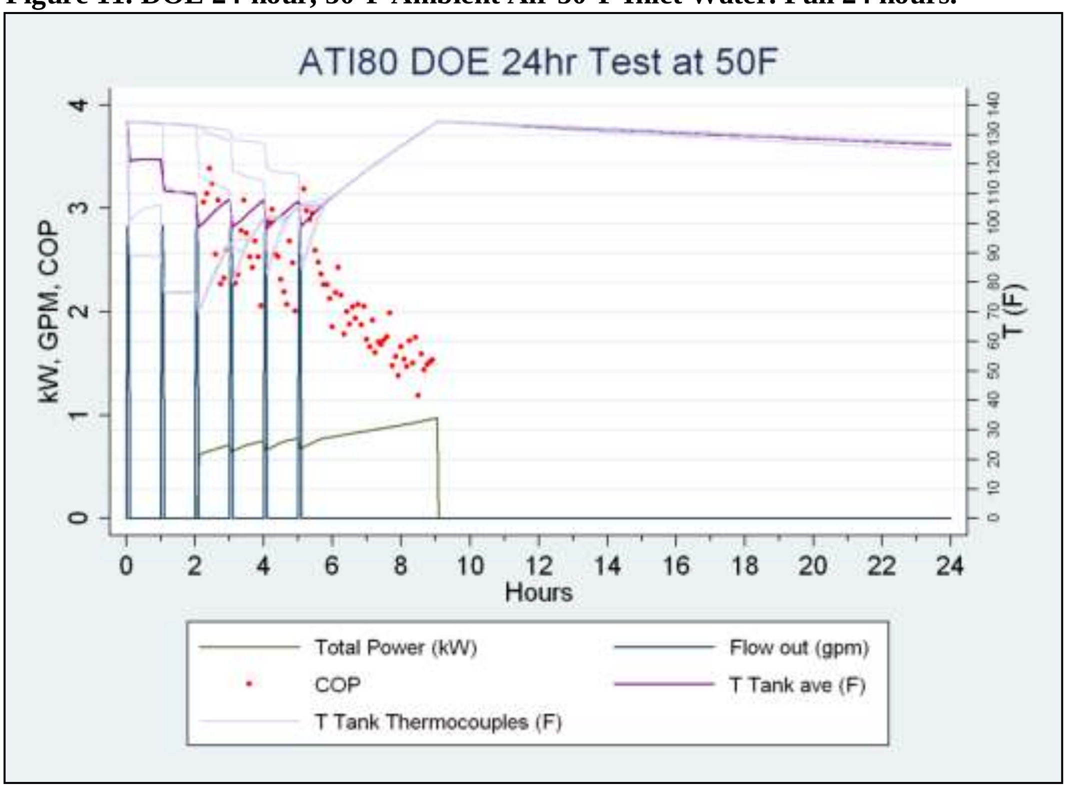


Figure 11. DOE 24-hour, 50°F Ambient Air 50°F Inlet Water. Full 24 hours.



4.2 Supplemental Tests

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

4.2.1 Efficient Showers

The first supplemental draw profile, which is part of the Northern Climate Heat Pump Water Heater Specification, is a simulated-use “Shower Test,” which 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 a setpoint of 120°F. To mimic a series of morning showers, the lab conducted repeated eight-minute draws at two gallons per minute. The draws are separated by a five-minute lag time and continue 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, the tank to recover, and the test concludes. The test yields a useful rating: the number of consecutive efficient showers available. The ATI80 water heater provides four consecutive efficient showers. The results of the test are displayed in Figure 12.

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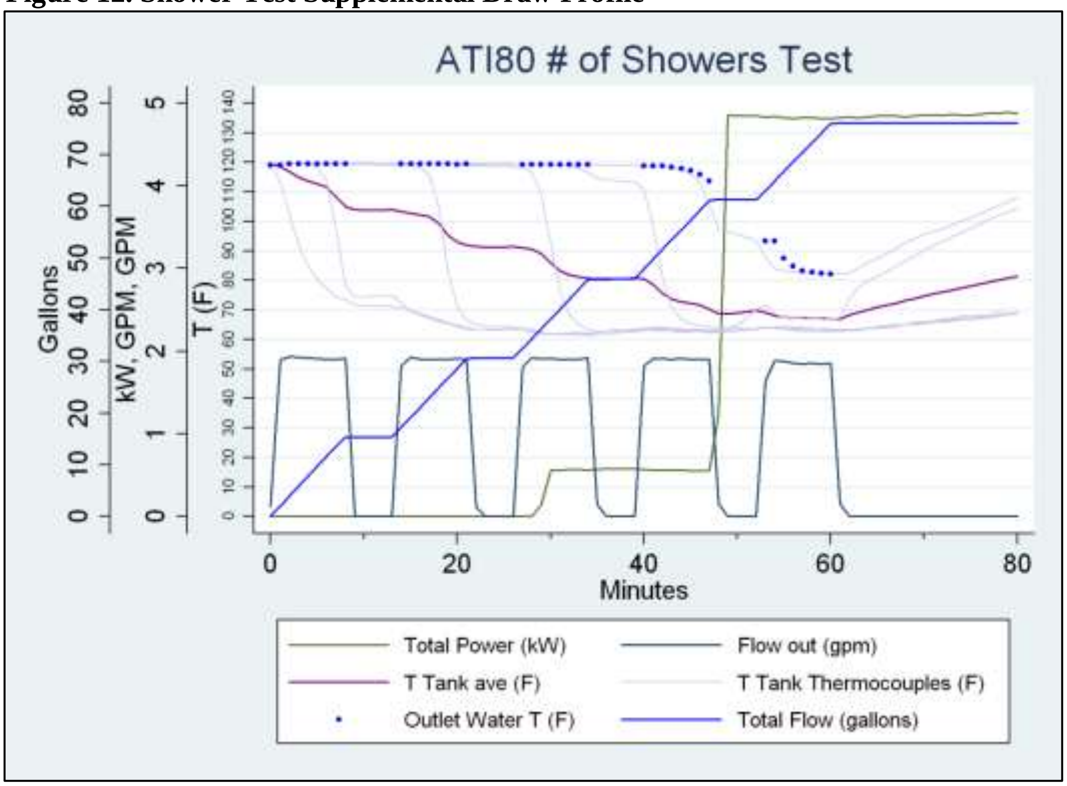
Figure 12. Shower Test Supplemental Draw Profile



Both the DOE 1-hour and DP-SHW tests function as a delivery rating. The Uniform Plumbing Code (UPC) (Uniform Plumbing Code 2009) uses the 1-hour test output (the first hour rating) for tank sizing requirements. Crucially, neither the UPC nor the DOE 1-hour test is concerned with the efficiency with which that first hour rating is obtained. Indeed, the delivery rating efficiency of older water heating technologies, including electric resistance and gas-fired tanks, turned out to be largely irrelevant. For those tanks with only one means with which to heat water, two outputs from the DOE 24-hour test – the recovery efficiency and energy factor – could be used to reliably describe the operational efficiency during the 1-hour tests. In contrast, HPWHs have two distinct heating efficiencies, depending on which of the two heating methods the control strategies use. Consequently, the DP-SHW test provides additional insight into how much hot water the tank can *efficiently* deliver.

The UPC requires a minimum capacity (first hour rating) for a water heater based on number of bathrooms and bedrooms. Both are proxies, respectively, for water demand and for number of people in a house.[1] The UPC requires a minimum first hour rating of 67 gallons for three bedrooms and two to 3.5 baths. The next-lower rating of 54 gallons covers three bedrooms with up to 1.5 bathrooms, or two bedrooms with up to 2.5 baths. The next-higher rating of 80 gallons covers four or more bedrooms with three or more bathrooms. The first hour rating of 79 gallons shows the ATI80 can satisfy nearly all of the sizing scenarios in the UPC.

The DP-SHW test shows that in satisfying the sizing requirements of the UPC, the tank can do so relying largely on the heat pump. The tank can handily provide four consecutive morning showers without using the resistance elements, demonstrating its suitability for large households and those with high demand periods. By not resorting to the resistance element, the tank stays in higher efficiency mode, delivering energy savings over a standard all resistance heat water heater.

4.3 Compressor Efficiency Tests

As previously mentioned, the ATI80 differs from earlier model ATI66 and ATI50 tanks in that it has a two-speed fan. Both fan speeds are lower than the single speed fan used on the earlier tanks. For reference, previous revisions of the ATI (66 and 50) had a fan moving 370cfm with no ducts attached. To better understand the HPWH performance and what might happen with the exhaust connected to a duct system, the testing plan called for mapping equipment COP as a function of fan airflow. In all, the lab measured the COP at a constant 67.5˚F / 50% RH ambient air condition[2] across four airflow regimes:

- 220cfm – Full flow, high fan speed setting
- 170cfm – Full flow, low fan speed setting
- 155cfm – Restricted flow, low fan speed setting
- 125cfm – Further restricted flow, low fan speed setting.

The two restricted flow scenarios examine how the flow and performance would change when the equipment is connected to a duct system. Lab measurements showed that the 155cfm

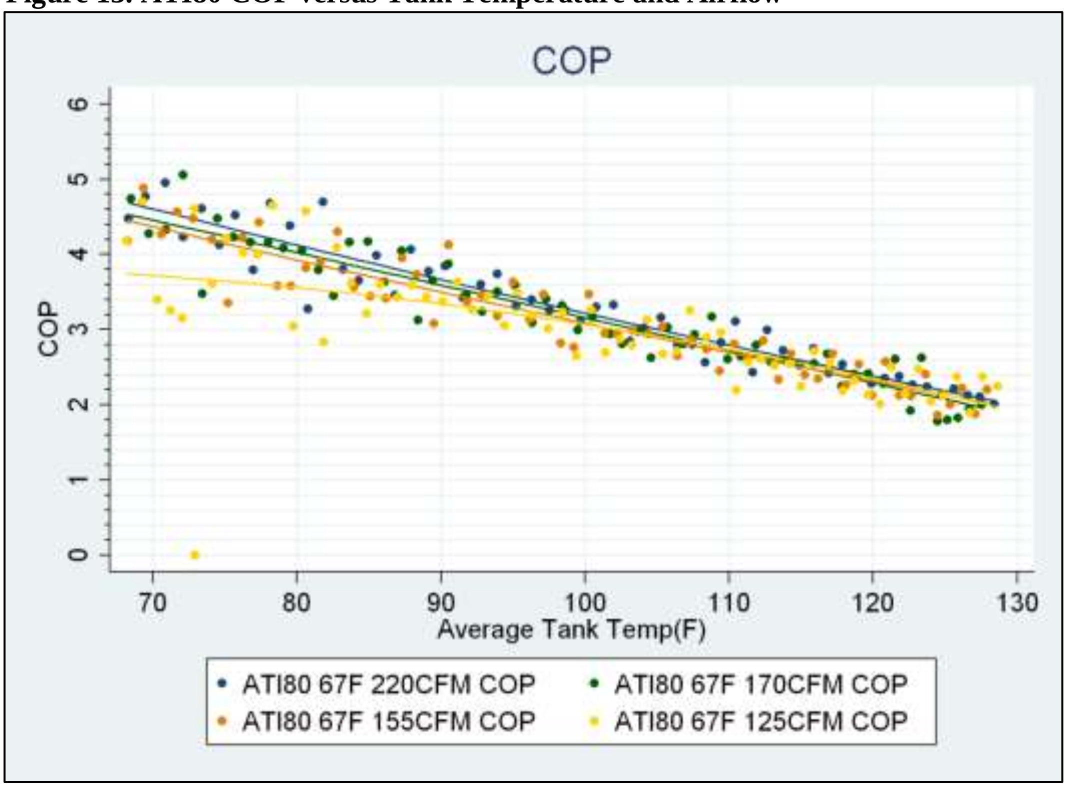
[1] The number of people in a house is often taken to be number of bedrooms plus one. For an example, see ASHRAE Std 62.2.
[2] Selected because 67.5°F / 50% RH approximates house interior air conditions

condition is equivalent to connecting 25 feet of 6-inch smooth, round duct with three elbows to the exhaust side of the fan on low speed. Such a duct run is quite long and elaborate and is likely more than most installations will ever encounter. A more typical run of 10 feet with one elbow results in an airflow of 215cfm on the high fan speed and 170cfm on the low fan speed. The 125cfm scenario simulates what may occur with a blocked filter.

The COP test begins with the tank full of 60-70°F water. The heat pump is then turned on and the tank heats up to 125°F. During the test, data loggers record the change in tank temperature (equivalent to output energy) and the equipment input energy. The quotient of the two is the COP. To achieve the reduced flows, the lab connected an outlet duct with an adjustable damper to restrict flow. The flow was left constant throughout each test.

Figure 13 shows the results of the four tests. For each test, the figure shows the five-minute average COP and a line fitted to those points to demonstrate the trend. The measurements showed no discernible difference in performance among any of the airflows for tank water (specifically the heat pump condenser) temperatures above 95°F. For tank temperatures 95°F and below, the results suggested a slight drop in COP of 5% between the 220cfm and 155cfm cases. The 170cfm case was roughly in between. For the lowest flow case at 125cfm, the COP started to drop more quickly relative to the others below 95°F tank temperature. At 95°F it was about even but by 70°F water temperature, its COP was approximately 20% less than the 220cfm case. Nevertheless, this may not dramatically influence real-world performance because the COP was still above 3.4 for all these cases and the amount of time the water tank spends heating at the colder temperatures is limited.

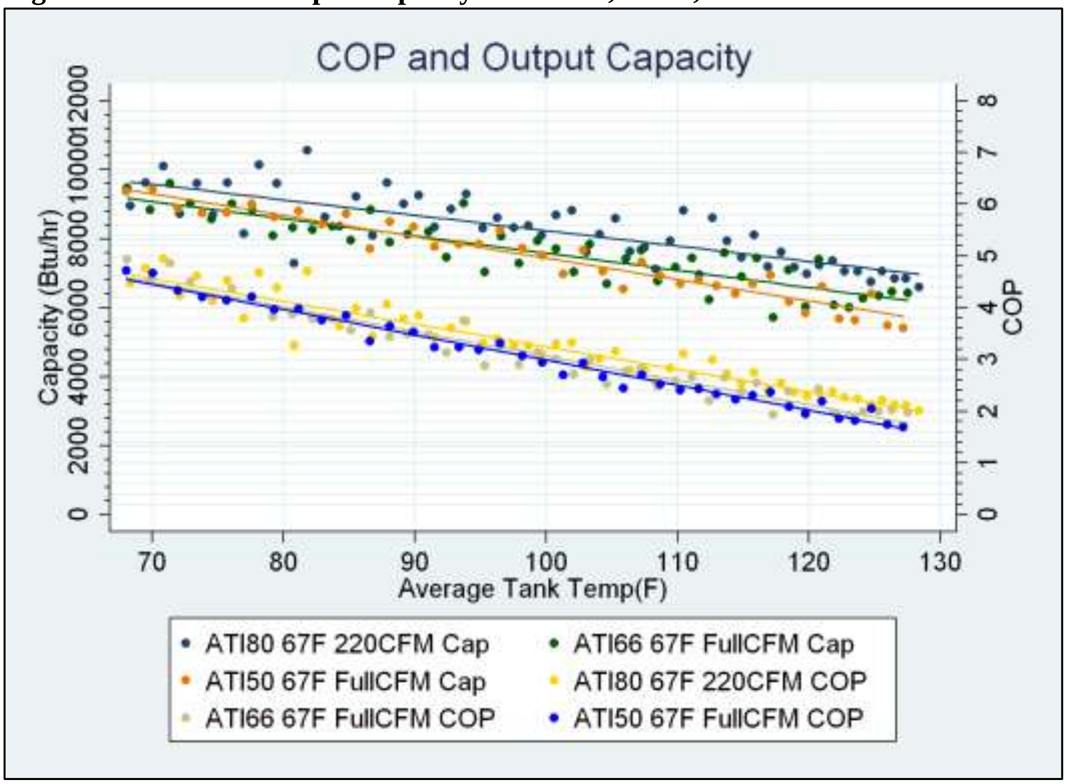
Figure 13. ATI80 COP versus Tank Temperature and Airflow



Appendix C shows the results from the COP tests in more detail with a single graph for each test.

Similar measurements of COP were made on the ATI50 and ATI66 tanks with the fan at the full flow level, or 370cfm. Figure 14 compares the COP and output capacity across all the tank models at the maximum flow possible for each tank. The ambient air conditions were identical, at 67.5°F / 50% RH, for all tests. Notably, the ATI80, with a lower fan speed, shows a slightly greater output capacity and COP. Part of the marginal efficiency improvement comes from the fan's reduced power draw. The fan for the ATI66, at full flow, used 100W. By comparison, the ATI80 fan, at full flow, draws ~85W. The difference is expected given the lower flow rate, and it contributes to a slightly more efficient unit.

Figure 14. COP and Output Capacity for ATI80, AT66, and ATI50



4.4 Noise Measurements and Additional Observations

The lab measured the sound level of the equipment using the Northern Climate Heat Pump Water Heater Specification. It made five measurements around the circumference of the water heater with the unit placed against one wall of a room (ambient 32.9 dBA, 54.9 dBC). Table 3 shows the averages of the five measurements for the two fan speeds.

Table 3. Sound Level Measurements for ATI80

	High Fan Speed	Low Fan Speed
dBA	58.3	53.7
dBC	62.0	59.8

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

5 Conclusions

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

- The compressor and tank sizes are large enough to adequately exploit heat pump efficiency. At 72.5 gallons (nominally 80) the unit is able to meet higher peak loads than 50- and 60-gallon tanks. Moreover, because of the large storage capacity, the unit can spend more recovery time using the compressor only while still satisfying hot water demand. Likewise, the compressor has enough output capacity to recover the tank in a reasonable period of time following peak draws.

- The heating component controls are designed in a simple and elegant way to both be efficient and to meet high demand periods. In Auto mode, the independent controls of the resistance element and compressor allow one or both to run. For most draws, the lower temperature sensor triggers the compressor on for efficient heating, while for deep draws, the upper element activates the resistance element to heat the upper portion of the tank as quickly as possible. Allowing simultaneous operation of the heat pump and resistance element increases the overall COP during periods of high demand. The controls also succeed in delaying the time when the resistance element engages. During the first draw of the 1-hour test, ~82% of the tank volume was withdrawn before the element activated.

- The user can change many equipment operating parameters, including settings for the defrost cycle—a nice feature to optimize performance, but most homeowners would be unlikely to actually adjust these settings.

- The Econ mode timer may dissuade users from using the most efficient setting, as an operating schedule must be programmed in or the HPWH will not heat any water at all.

- With a wide ambient temperature operating range, and active defrost, the unit is well-suited for Pacific Northwest buffer space installations. The fan in the unit makes the equipment suitable for connecting to an exhaust duct system, which gives the installer the flexibility of ducting the cooler exhaust air outside the house envelope. Further, this model has a two-speed fan, which allows the installer to tune that exhaust airflow directly at the HPWH.

- Accessing the air filter is now far easier than on early ATI heat pumps. The washable filter now simply slides out a slot in the top of the unit.

- Using R-410a refrigerant can cause problems when heating the water to higher setpoint temperatures, although Ecotope observed the ATI80 heating to 135°F with no difficulties.

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Appendix A: Testing Matrices

Testing Matrix: AirGenerate ATI80

DOE Standard Rating Point Tests

Test Name	Ambient Air Conditions					Inlet Water		Outlet Water		Airflow	Operating Mode	Notes
	Dry-Bulb		Wet-Bulb		RH					inch. static pressure		
	F	C	F	C		F	C	F	C			
DOE-1hr	67.5	20	57	14	50%	58	14	135	57	0.0"	Factory Default. Use default fan speed setting	Follow test sequence in Federal Register 10 CFR Part 430 Section **5.1.4**
DOE-24hr	67.5	20	57	14	50%	58	14	135	57	0.0"		Follow test sequence in Federal Register 10 CFR Part 430 Section **5.1.5**
DOE-24hr-50	50	10	44	7	58%	50	10	135	57	0.0"		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	120	49	0.0"	Factory Default.	Draw Profile: DP-SHW. Conduct identical, repeated draws until ending conditions observed.

Airflow Measurement

AM	UUT has two fan speeds. Perform tests at both fan speeds. Temperature and humidity need not be tightly controlled. They can be room conditions which might approximate DOE standard conditions.	0.0" to 0.75"	N/A	Map fan power and airflow with ducting connected to exhaust air port. Create variation in static pressure with damper at outlet. Measure at static pressures: 0.0, 0.1, 0.2, 0.25, 0.35, 0.5, 0.75

Noise Measurement

NOI	Measure combined fan and compressor noise. Measure with fan in both high and low speed.	0.0"	Heat Pump running	Install equipment in relatively quiet room. Measure sound at 1 meter away, 1.8 meters high at several points around circumference of tank.

COP Curve Development - Performance Mapping

Test Name	F	C	F	C	RH	F	C	F	C	CFM	Operating Mode	Notes
COP-67-AF220	67.5	20	57	14	50%	55	13	130	54	220	Compressor only	Run with fan on high speed. No outlet restrictions.
COP-67-AF170	67.5	20	57	14	50%	55	13	130	54	170	Compressor only	Run with fan on low speed. No outlet restrictions.
COP-67-AF155	67.5	20	57	14	50%	55	13	130	54	155	Compressor only	Run with fan on low speed with outlet duct and damper attached to regulate flow.
COP-67-AF125	67.5	20	57	14	50%	55	13	130	54	125	Compressor only	

Additional Observations

AO-VOL	Measure tank water volume			

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	

Appendix C: Additional Graphs

Figure 15. COP, Output Capacity, and Input Power at 220cfm.

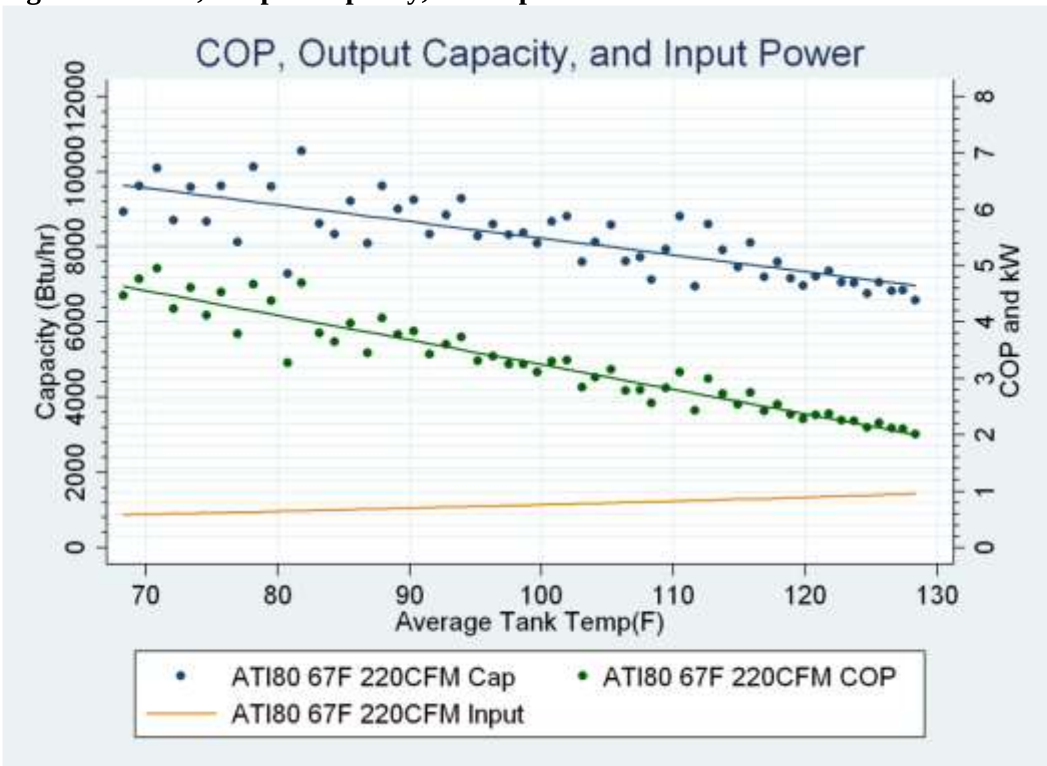

Figure 16. COP, Output Capacity, and Input Power at 170cfm.

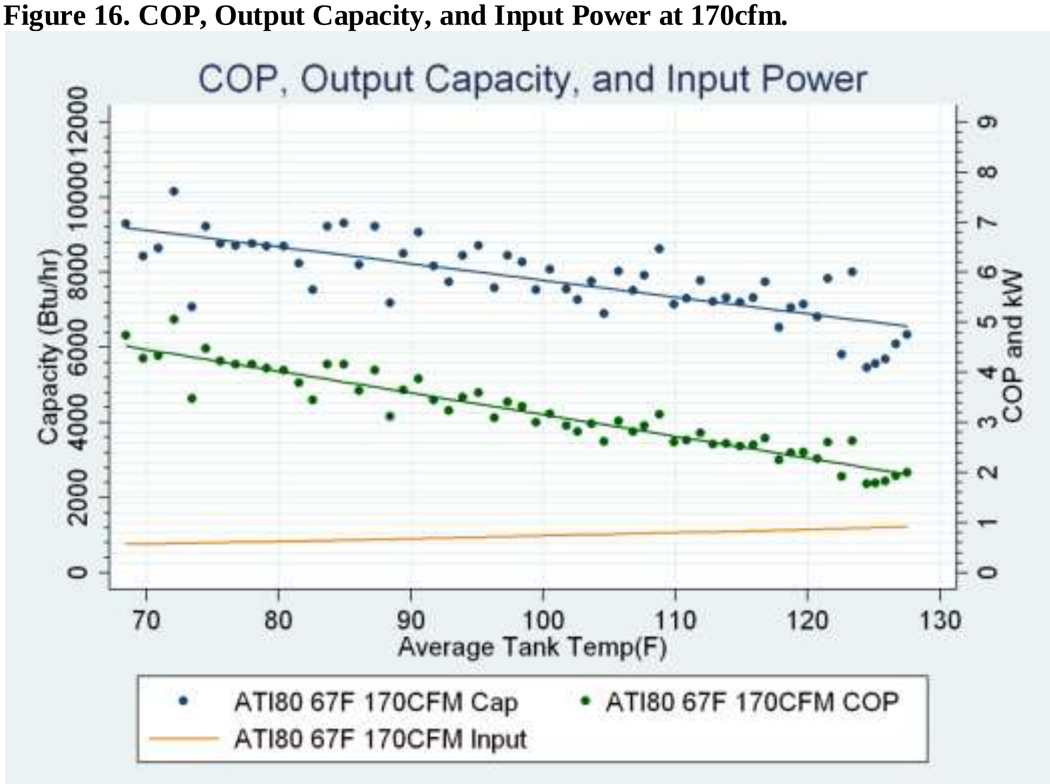

Figure 17. COP, Output Capacity, and Input Power at 155cfm.

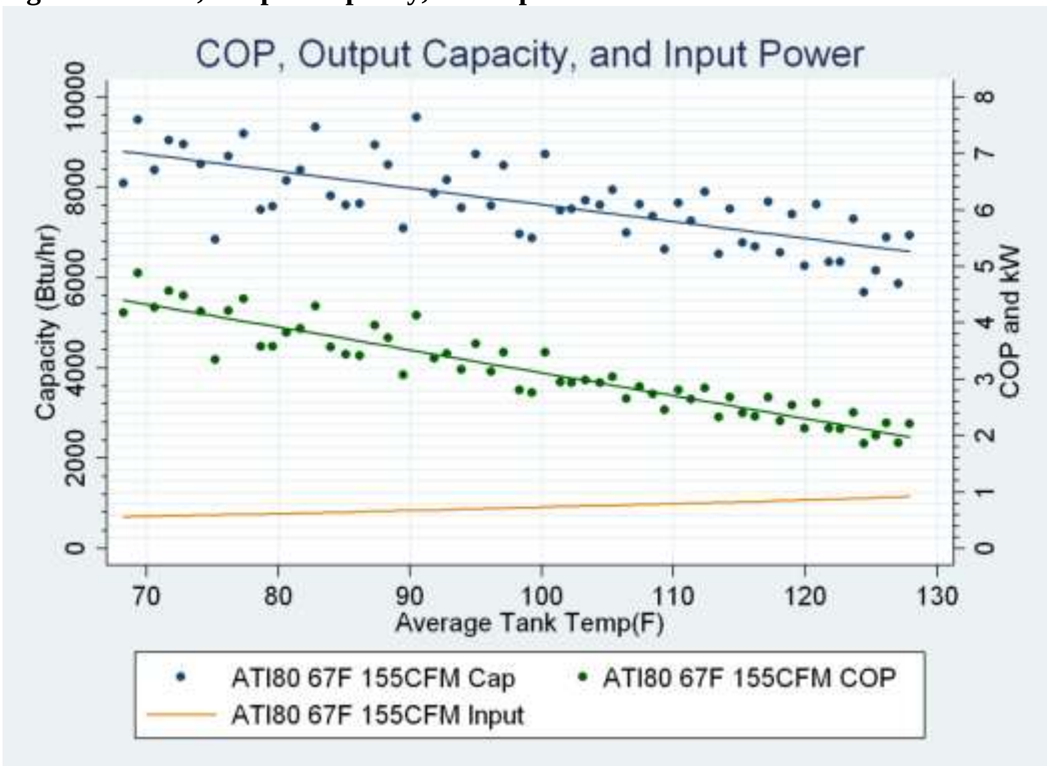

Figure 18. COP, Output Capacity, and Input Power at 125cfm.