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REPORT E15-013

Laboratory Assessment of GE GEH50DFEJSRA 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 GE model #GEH50DFEJSRA heat pump water heater (HPWH) for northern climate installations. Cascade Engineering evaluated the GEH50DFEJSRA using a testing plan developed by Ecotope to assess HPWH performance.

The goal of the work: to evaluate the product using the Northern Climate Heat Pump Water Heater Specification (NEEA 2013). The testing plan included characterizing the equipment operating modes; observing heat pump efficiency at lower ambient temperatures; conducting the standard 24-hour and 1-hour rating tests; measuring noise output levels; and quantifying the number of efficient showers delivered at 50°F ambient. Ecotope also included in the testing the new US Department of Energy (DOE) standard written in 2014, and conducted all tests in both Cold Climate Efficiency (CCE) mode and Hybrid mode.

Overall, the results suggest that the GEH50DFEJSRA is an efficient heat pump water heater for use under small to medium hot water loads and is appropriate for some, but not all, applications in the Pacific Northwest. Specific findings include:

- Measured Northern Climate Specification Metrics:
    - Northern Climate Energy Factor: CCE mode 2.66, Hybrid mode 2.13
    - Percent of tank drained before resistance elements engage in 1-hour test: 85%
    - Number of consecutive, sixteen-gallon, efficient showers: 2.5
    - Sound level: 55 dBA

- The GEH50DFEJSRA offers a significant redesign, if not a totally new design, compared to previous offerings from GE. It endeavors to meet all criteria for the Northern Climate Tier 3 Qualification, including a substantial increase in the efficiency of the compressor system

- Ecotope and Cascade Engineering observed the heat pump ambient temperature operating range to be as low as 37°F, and the unit has an optional intake and exhaust ducting kit.

- Overall, the GEH50DFEJSRA is the highest-performing integrated HPWH from GE to date. The best savings occur when the unit is in Cold Climate Efficiency mode, which is not the default. The fifty-gallon tank size means it would not be efficient for households with large draws where a larger tank is more appropriate.

- The Cold Climate Efficiency mode setting offers a significant improvement in hybrid HPWH control strategies. The mode limits use of resistance elements only for times when the tank is close to running out of hot water. Then, it engages the upper element but only long enough to heat the upper tank to a usable temperature of 120°F. Once the top is hot, the rest of the tank reheats with the heat pump. In this mode, for most users, the tank will likely deliver the performance promised by a heat pump.

- As with some other fifty-gallon HPWHs, testing indicates a key distinction in operating performance depending on draw pattern and water demand. The number of showers test, in particular, shows the small storage volume and compressor output capacity will tend to reduce operating efficiencies for households with more than 2-2.5 morning showers (or other similar peak demands) unless placed in Cold Climate Efficiency mode.

1. Introduction

The Northwest Energy Efficiency Alliance (NEEA) contracted with Ecotope, Inc. and Cascade Engineering Services, Inc. to conduct a laboratory investigation of the General Electric (GE) model #GEH50DFEJSRA heat pump water heater (HPWH) for northern climate installations. Cascade Engineering Services of Redmond, WA evaluated the GEH50DFEJSRA using a testing plan developed by Ecotope to assess HPWH performance. The test plan follows that of the Northern Climate Heat Pump Water Heater Specification with several added investigations (NEEA 2013). 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); description of operating modes; 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.

The GEH50DFEJSRA is one of four product models recently released by GE. It released an eighty-gallon tank size, as well, which is not directly evaluated here. The eighty-gallon model has identical heat pump components to the fifty-gallon model sitting atop a larger tank. Each of the tank sizes has a retail version and a contractor/plumber version, yielding four models in all. This series of products is the third generation in GE's GeoSpring line of integrated, hybrid HPWHs. This series has new heat pump system components compared to the second generation. It also offers a new operating mode: "Heat Pump Mode / Cold Climate Efficiency," which relies less on resistance heat than did the previously-available Hybrid modes. Further, it has an optional ducting kit to attach to either the intake or exhaust air.

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 (DOE) testing standards from Appendix E to Subpart B of 10 CFR 430 (DOE 2014)
- American Society of Heating, Refrigerating and Air-Conditioning Engineers Standard 118.2-2006 for the Method of Testing for Rating Residential Water Heaters

This section describes the general approach and methodological overview for this test. 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.

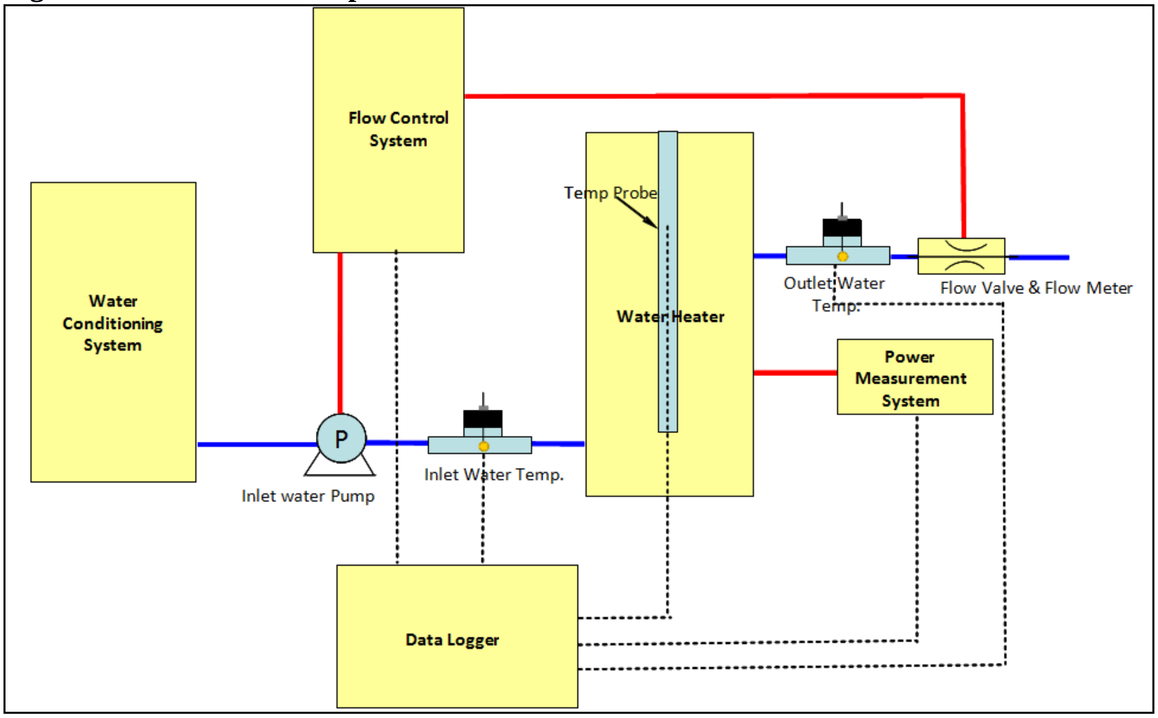
Because the DOE, draw profile type, and low temperature cutoff tests require tight controls on the ambient air conditions, Cascade Engineering conducted all of those tests in the thermal chamber. The chamber is capable of regulating both temperature and humidity over a wide range, and independently monitors 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 any one-time measurements of system component power levels or airflows, so Cascade Engineering conducted those tests in the large lab space at the conditions encountered at the time (typically between 55° F and 70°F). Lastly, Cascade Engineering moved the HPWH to a room with ambient noise levels below 35 dBA to measure the noise emanating from the operating equipment.

Figure 1. HPWH Test Unit Installed Inside Thermal Chamber

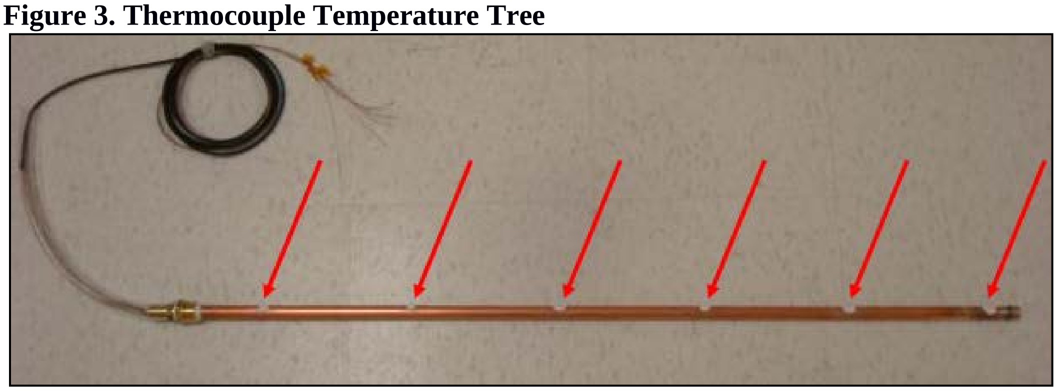
Figure 2 is a schematic of the general test setup. Cascade Engineering installed an instrumentation package to measure the required points specified by the DOE test standard as well as additional points to gain further insight into HPWH operation.

Figure 2. General Test Setup



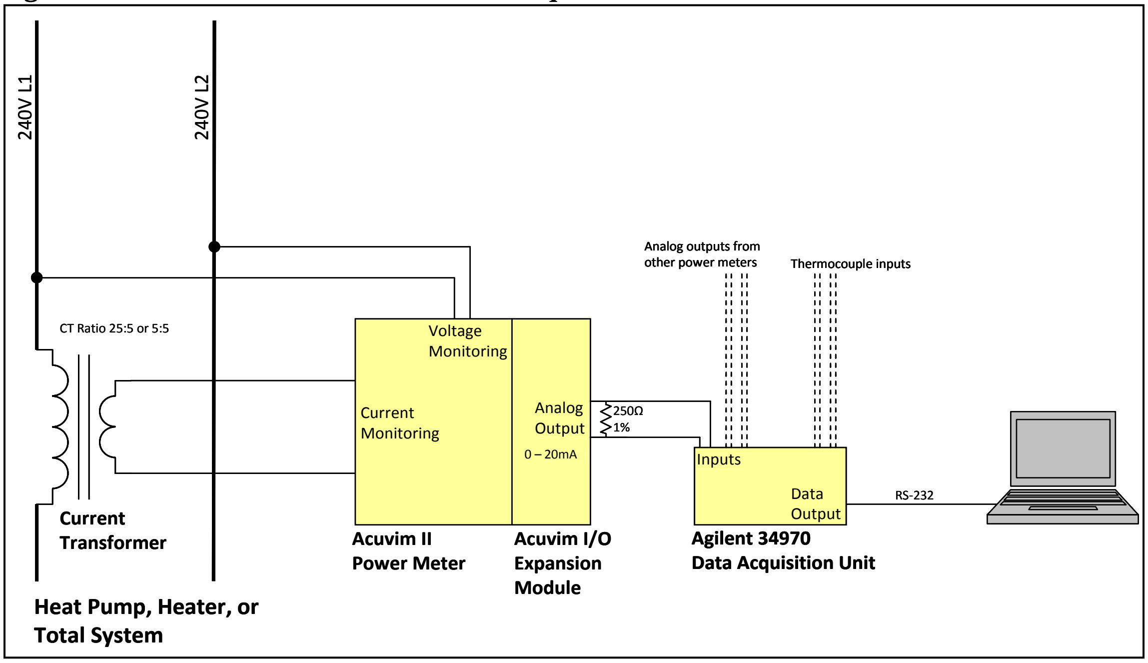
A tree of six thermocouples positioned at equal water volume segments measured tank water temperature (Figure 3). Cascade Engineering measured inlet and outlet water temperatures with thermocouples immersed in the supply and outlet lines. Three thermocouples mounted to the surface of the evaporator coil 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). 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 3. Thermocouple Temperature Tree



Note: Arrows indicate measurement points

Figure 4. 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 found in the 1998 and 2014 Test Procedures (TP) (DOE 2014; DOE 1998). In 2014, DOE revised the test procedure to rate performance of water heaters; the previous method had been in effect since 1998. The numerous changes in the new procedure include more stringent and specific instrumentation tolerances and changes to hot water draw patterns and setpoints. Throughout this project, all instrumentation and measurements are configured per the 2014 TP. The draw profiles, test conditions, and specific calculation procedures conform to either TP depending on whether the test being run was based on an old or new version.

3. Findings: Equipment Characteristics

3.1. Basic Equipment Characteristics

The GE GEH50DFEJSRA is an all-electric water heater consisting of a heat pump integrated with a hot water storage 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
2. Using resistance heating elements immersed within the tank

The heat pump compressor and evaporator are located on top of the tank. A fan draws ambient air from the top of the unit, pulls it through the filter and across the evaporator coils, and exhausts colder air out the side. The condenser coil, which transfers heat to the water, is wrapped around the outside, lower portion of the tank underneath the insulation.

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.

As with traditional electric tank water heaters, the GEH50DFEJSRA contains two electric resistance heating elements. The element located in the upper portion of the tank draws 4.5kW, while the element in the lower portion draws 4kW. The third heating component for the tank is the heat pump compressor. Measurements show the compressor draws 250W[1] to 470W[2] depending on both tank water and ambient air conditions.

For the heat pump, lower temperatures for both water and air result in lower power draws, while higher temperatures result in larger power draws. Resistance element power draw is constant. Two other components of the equipment also consume power: a one-time measurement showed the fan draws ~30W, and the control circuits use a constant ~1W.

The GEH50DFEJSRA has a nominal fifty-gallon capacity, but measurements showed the unit in the lab held forty-five gallons. National guidelines on the sizing of equipment allow a ten percent variation in nominal versus actual size; this water heater falls within those guidelines. The difference between nominal size and actual size is not unique to HPWHs and occurs with traditional electric resistance and gas tanks as well.

[1] Observed during the number of showers test with water temperature near the condensers of 65°F and ambient temperature of 50°F

[2] Observed during a standby recovery of DOE 24-hour test. Water temperature near condenser was ~135°F and ambient temperature was 68°F

Table 1. Basic Characteristics for GE GEH50DFEJSRA

	Laboratory Measurement
Upper Element (W)	4,500
Lower Element (W)	4,000
Compressor* (W)	250-470
Standby (W)	1
Fan (W)	30
Airflow Path	Inlet on top. Exhaust out the side.
Refrigerant	R-134a

Notes: *Range depends on water T and ambient T. Power increases with each. Observations cover a water temperature range from 65°F to 135°F and ambient air temperature range from 50°F to 68°F.

3.2. Operating Modes and Sequence of Heating Firing

The HPWH has an integrated circuit control board which may be programmed in a number of ways to control when the heating components turn on and off. GE has developed several control strategies, referred to as operating modes, to determine equipment operation. The GEH50DFEJSRA has five basic modes of operation, shown below in order of most efficient to least efficient:

- Heat Pump Mode – compressor-only operation unless outside of ambient temperature operating parameters
- “Cold Climate Efficiency” – combination of compressor and resistance elements; designed to minimize resistance element runtime
- “Hybrid” – combination of compressor and resistance elements; the default mode when shipped from the factory
- “High Demand/Boost” – combination of compressor and resistance elements in which the elements engage more readily than in Hybrid mode
- “Electric” – no compressor usage – upper and lower elements only

A sixth operating mode – “Vacation” – exists, but is basically a tank temperature setback option (to 50°F) for use while the occupants are not in the house for extended periods (3-199 days).

Earlier studies provided both loose and specific quantifications of the operating modes of the previous generations of GE HPWHs (Larson, Logsdon 2012; Fitzpatrick, Murray 2011; Larson, Logsdon 2011; Sparn 2011; Pacific Gas and Electric 2010). Ecotope and Cascade Engineering conducted an especially-detailed investigation of the second generation HPWH operating modes (Larson, Logsdon 2012).

3.3. Operating Mode Findings

For this project, Ecotope and Cascade Engineering focused on exploring the Cold Climate Efficiency mode and generally observed little change in the other operating modes. The findings are as follows:

Heat Pump Mode: Only the heat pump is allowed to operate, which provides the highest efficiency of all modes. The control strategy is simple and depends only on the temperature sensor reading. According to the GE website, the tank offers a temperature control of +/-3°F (GE Appliances 2015).

Cold Climate Efficiency (CCE) Mode: Cold Climate Efficiency mode is new to the third generation of this product. Under normal operating circumstances, it appears to operate either the heat pump or the upper element (but never the lower element). Test data suggest that the upper element engages only when the upper portion of the tank is cold. This differs from Hybrid mode which, according to previous work, activates the resistance elements more readily and in response to a rate of temperature change instead of just temperature measurement at one location. Once activated, the top element heats the water until it reaches 120°F, regardless of the setpoint, and then shuts off. The remainder of the tank is heated with the heat pump compressor. In this way, the control strategy quickly provides usable hot water to the tank top, minimizes element runtime, and maximizes compressor runtime.

Hybrid Mode: Hybrid mode is the default mode in which the product is shipped from the factory. From the data available in observing the tests, Hybrid mode appears to operate in a manner largely similar to the previous generations of equipment. That is, all three heating components – the lower element, upper element, and heat pump – can operate. In response to large draws, the lower element is favored over the heat pump to reheat the tank. Unlike in CCE mode, a heating cycle can be completed with the elements alone, resulting in more energy use.[3]

High Demand Mode: As in Hybrid mode, all three heating components can operate. This study did not directly investigate this mode. Previous work showed that in High Demand mode, the unit operated in much the same way as in Hybrid mode, except that the lower and upper elements showed a propensity to turn on sooner (Larson, Logsdon 2012).

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.

[3] See previous work by Larson and Logsdon for more details (2012).

4. Findings: Testing Results

4.1. First Hour Rating and Energy Factor

The DOE has established two tests to rank the comparative performance of HPWHs (DOE 1998). The first (1-hour) test produces a first hour rating that determines how much usable 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 DOE revised the test procedure for residential water heaters in 2014 (DOE 2014). While the DOE does not yet require use of the new test, it may become mandatory as early as December 2015. In preparation for the implementation of the new procedure, the lab ran the unit using the new 24-hour test, which is designed similarly to its predecessor to produce a uniform energy factor. The main difference in the new test procedure is the draw pattern, which no longer concentrates flow only at the beginning of the test. The 1-hour test remains largely the same.

The lab conducted all of the tests with the GEH50DFEJSRA in both Hybrid and Cold Climate Efficiency modes. 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 and 50°F inlet water, which are the conditions used to determine the Northern Climate Energy Factor.

Table 2. Performance Characteristics for GE GEH50DFEJSRA

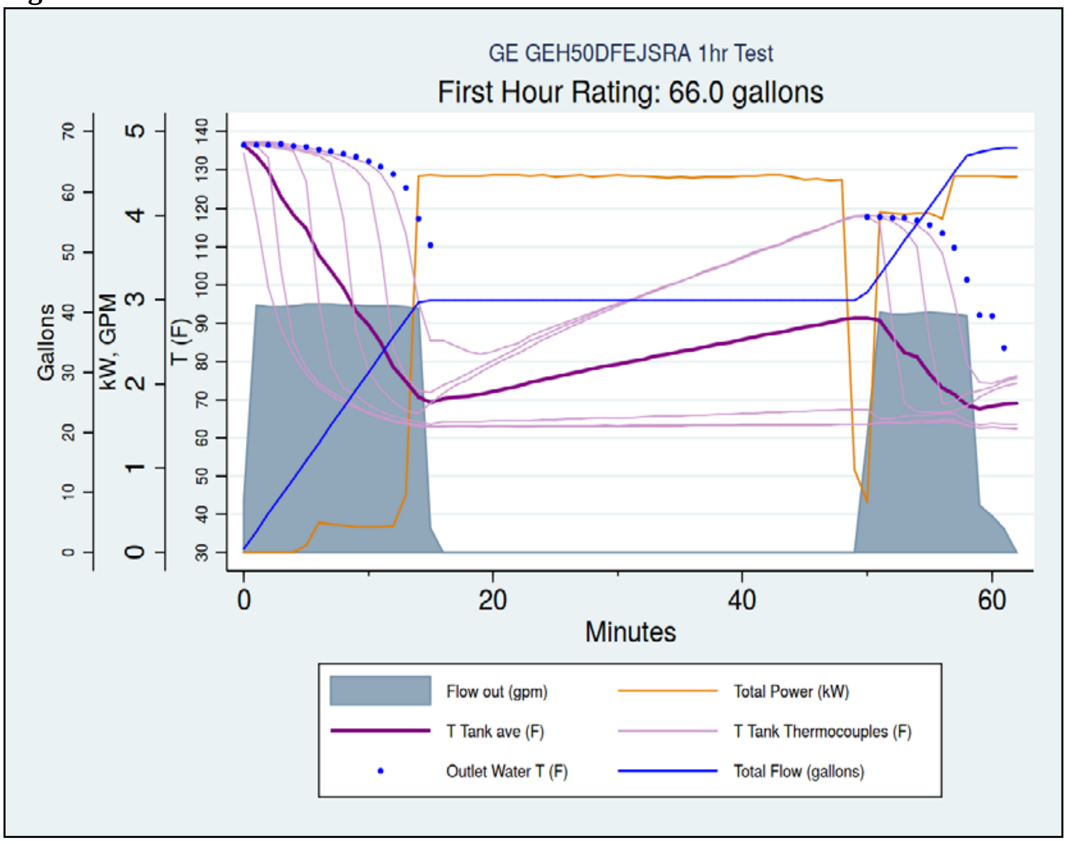
Metric	Measured Value in Hybrid Mode	Measured Value in CCE Mode
First Hour Rating (gal)	66	66
Energy Factor (std. conditions)	3.19	3.19
Energy Factor @ 50°F ambient	1.43	2.27
Northern Climate Energy Factor	2.07	2.54
Tank Heat Loss Rate (Btu/hr° F)	3.28	3.28

4.1.1 1-Hour Test

Figure 5 shows the plotted data from the 1-hour test. The test begins with a three gpm draw. Approximately five minutes into the first draw, the tank temperature has fallen enough to activate the heat pump, followed quickly by the resistance element (yellow line showing 4.5 kW). As the draw continues past fifteen minutes, the water temperature at the outlet has fallen more than 25°F, so the first draw is terminated. The heat pump and upper elements continue to heat the tank while a draw begins again around fifty minutes and continues for several minutes. The components continue heating, cycling between lower and upper elements in response to the tank temperature conditions. Since the last draw was still in process at sixty minutes, per test procedure it was continued until the outlet temperature reached 25°F below the set-point, shortly after sixty minutes.

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 GEH50DFEJSRA, the test data show thirty-eight gallons, equivalent to eighty-five percent of the measured tank volume.

Figure 5. DOE 1-Hour Test



Notes: The bright blue line shows the cumulative water drawn during the test. The yellow 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.

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 eighteen hours of standby. The standard test conditions are 67.5°F, fifty percent relative humidity (RH) ambient air, 135°F tank setpoint and 58° F incoming water temperature. As with the first hour rating, the lab used the equipment in both operating modes. 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 test results demonstrated the variation in performance with varied ambient conditions.

The EFs used for all the tests are displayed above 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 EFs 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. For the temperature bins below that cutoff, the procedure assumes performance equal to that of resistance heating. The higher the compressor cutoff temperature, the lower the overall EF_{NC} will be.[4] In the calculations, Ecotope used the 37°F temperature bin as measured in the compressor cutoff test.

Figure 6 shows the first eight hours of the test to allow examination of the draw events and recovery in more detail. Figure 7 shows the full twenty-four hours, which also illustrates the tank heat loss rate. These two figures plot the same type of data as Figure 5.

Figure 6 also plots the instantaneous coefficient of performance (COP), a measure of the amount of heat 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). The COP for electric resistance heat is 1.0; 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 6 toward the end of each recovery cycle reflects the warming tank temperature. The scatter in the COP plots is due to uneven fluctuations in the tank temperature measurements, but the general trend is clear. The COP begins near 4 and then drops toward 2 as the tank temperature increases (the heat pump is less efficient when working against a larger temperature difference).

[4] For details, see the Northern Climate Heat Pump Water Heater Specification, NEEA 2013.

Figure 6. DOE 24-Hour Simulated Use Test, First Eight Hours, Cold Climate Efficiency Mode

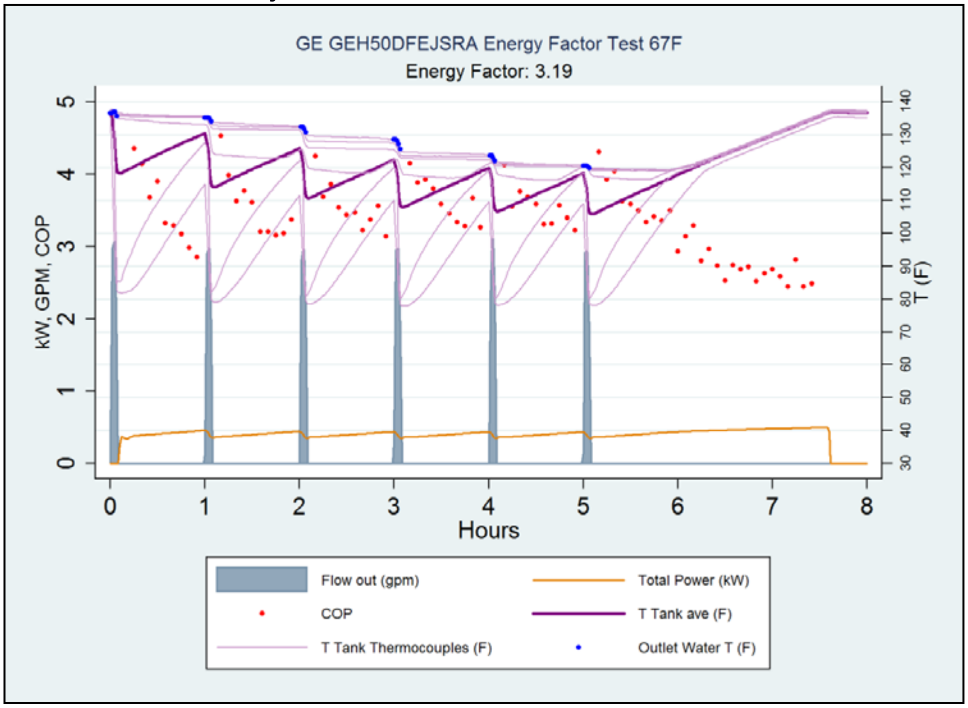


Figure 7. DOE 24-hour Simulated Use Test, Full Twenty-Four Hours, Cold Climate Efficiency Mode

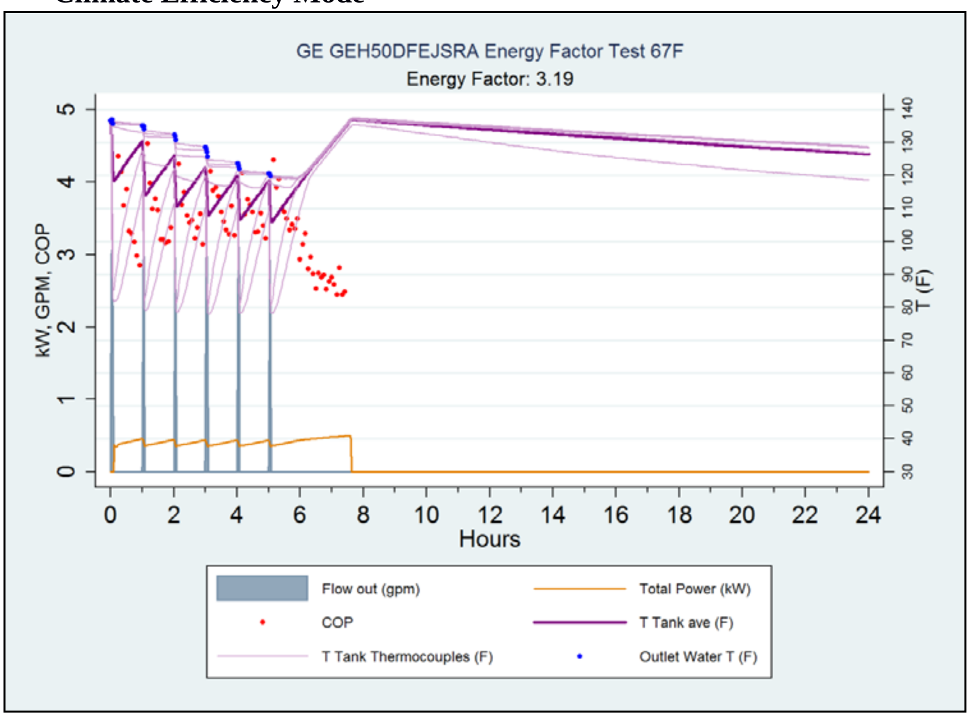


Figure 8 and Figure 9 show graphic results of the same tests performed with the unit in Hybrid mode. Performance on the standard 24-hour tests is nearly identical in either mode. In fact, since no difference exists in compressor operation (and no resistance element use occurs), the difference in test results indicates more about the variability of conducting the tests than about the differences between modes.

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

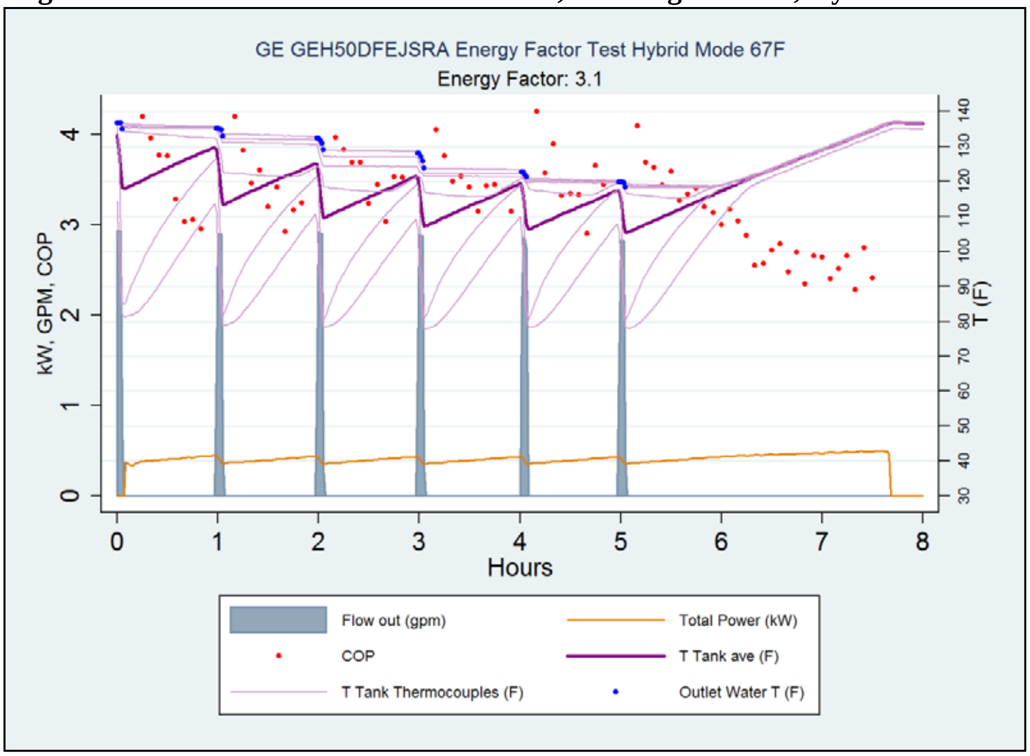


Figure 9. DOE 24-hour Simulated Use Test, Full Twenty-Four Hours, Hybrid Mode

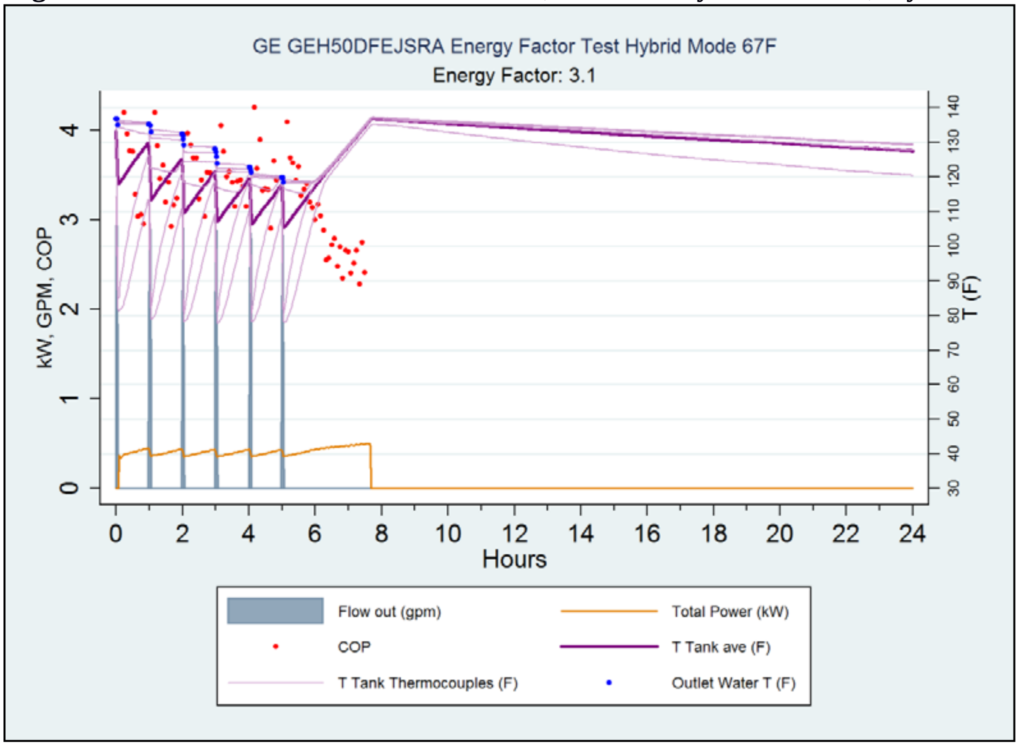


Figure 10 and Figure 11 plot the heat pump behavior for the 50°F ambient air and 50°F inlet water 24-hour testing conditions in Cold Climate Efficiency mode. The graphs look similar to those plotted for 67°F ambient air, with the exception that the upper resistance element turns on after the fifth draw. This significantly lowers the energy factor in this test compared to the warmer 24-hour test. Interestingly, the draw on the tank is smaller than in the 1-hour test so, in this case, once the upper portion reaches 120°F, the upper element switches off and the lower element does not engage. The compressor alone is used to reheat the bottom portion of the tank and the remaining temperature difference at the top between 120°F and the designated setpoint.

Figure 10. DOE 24-hour Simulated Use Test, 50°F Ambient Air/50°F Inlet Water, First Eleven Hours, Cold Climate Efficiency Mode

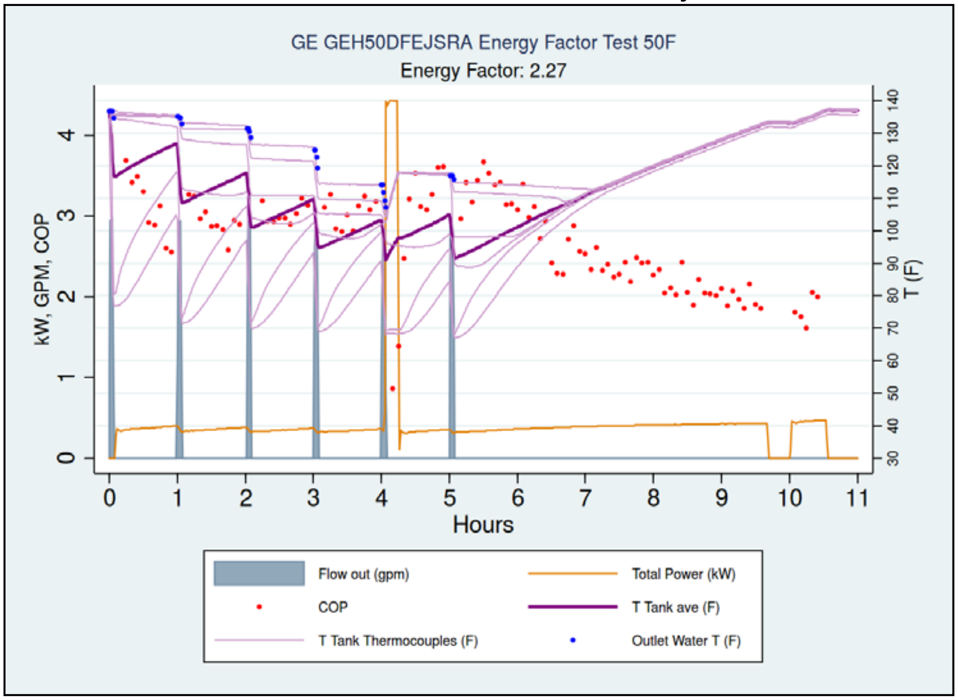


Figure 11. DOE 24-hour Simulated Use Test, 50°F Ambient Air/50°F Inlet Water, Full Twenty-Four Hours, Cold Climate Efficiency Mode

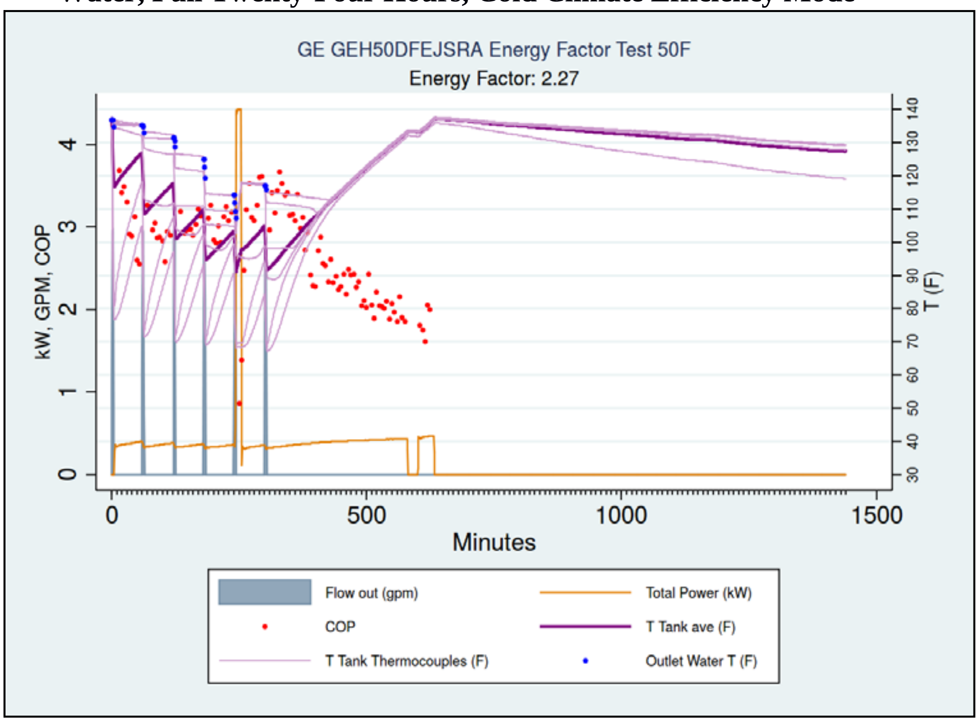


Figure 12 and Figure 13 again plot the same lower-temperature tests, but in Hybrid mode. Results from this mode indicate a substantial difference in the operation of the unit across temperatures. The lower resistance element, acting in concert with the compressor, engages twice to finish reheating the tank, and a standby-loss recovery heating event occurs during the waiting period. Use of the resistance element results in a substantially-lowered COP.

Figure 12. DOE 24-hour Simulated Use Test, 50°F Ambient Air/50°F Inlet Water, First Eleven Hours, Hybrid Mode

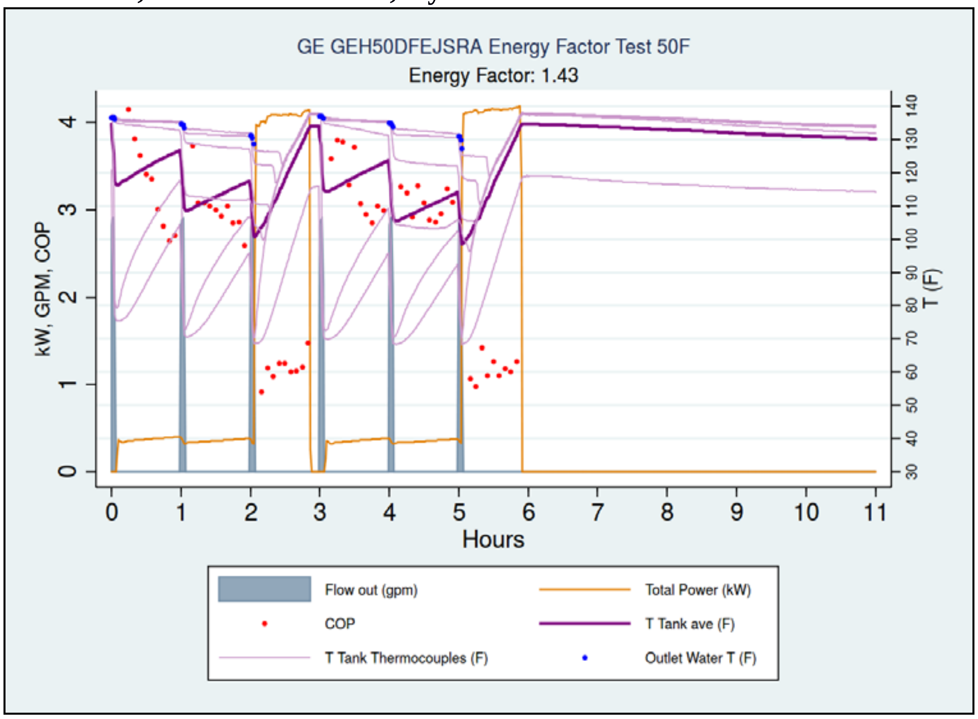


Figure 13. DOE 24-hour Simulated Use Test, 50°F Ambient Air/50°F Inlet Water, Full Twenty-Four Hours, Hybrid Mode

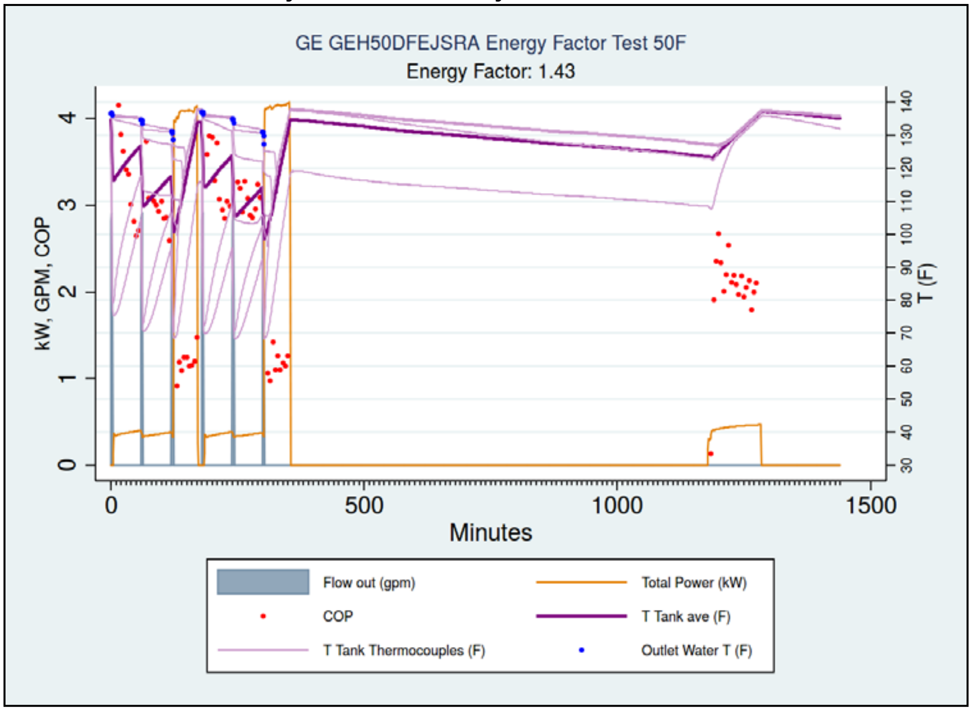


Figure 14 through Figure 17 show the tests using the new 2014 DOE standard. These figures show test results using both 67°F and 50°F, and both Cold Climate Efficiency and Hybrid modes. The distributed nature of the draw patterns yielded no discernable difference between the Cold Climate Efficiency and Hybrid modes. In addition, the only significant difference between the tests run at 67°F and those run at 50°F is that each time the compressor runs, it runs for a longer period of time.

Figure 14. DOE 2014 24-hour Simulated Use Test, Full Twenty-Four Hours, Cold Climate Efficiency Mode

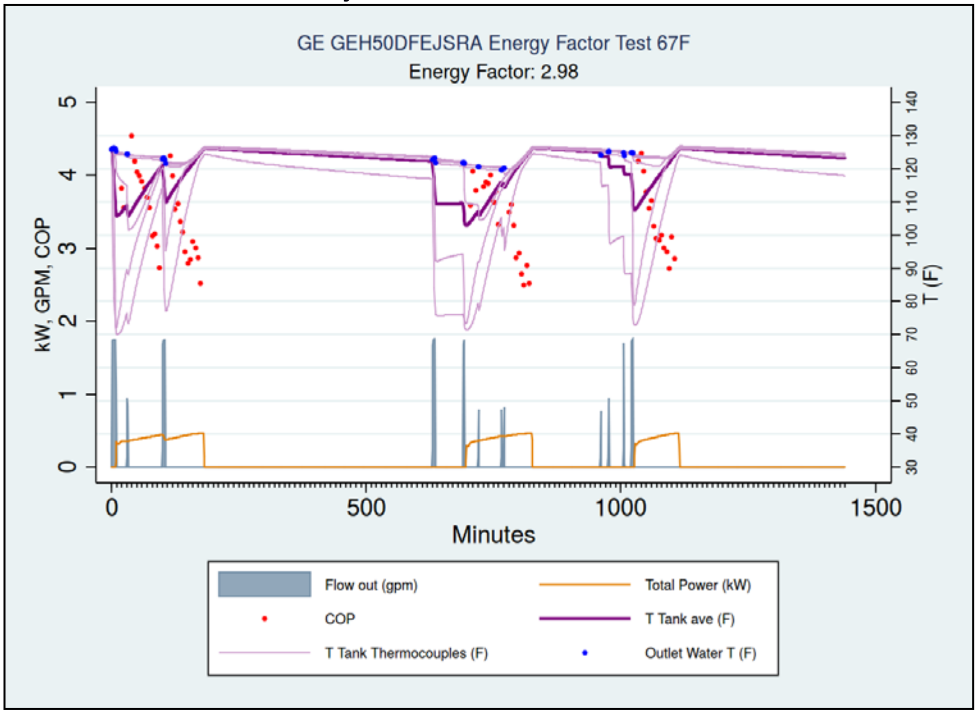


Figure 15. DOE 2014 24-hour Simulated Use Test, 50°F Ambient Air/50°F Inlet Water, Full Twenty-Four Hours, Cold Climate Efficiency Mode

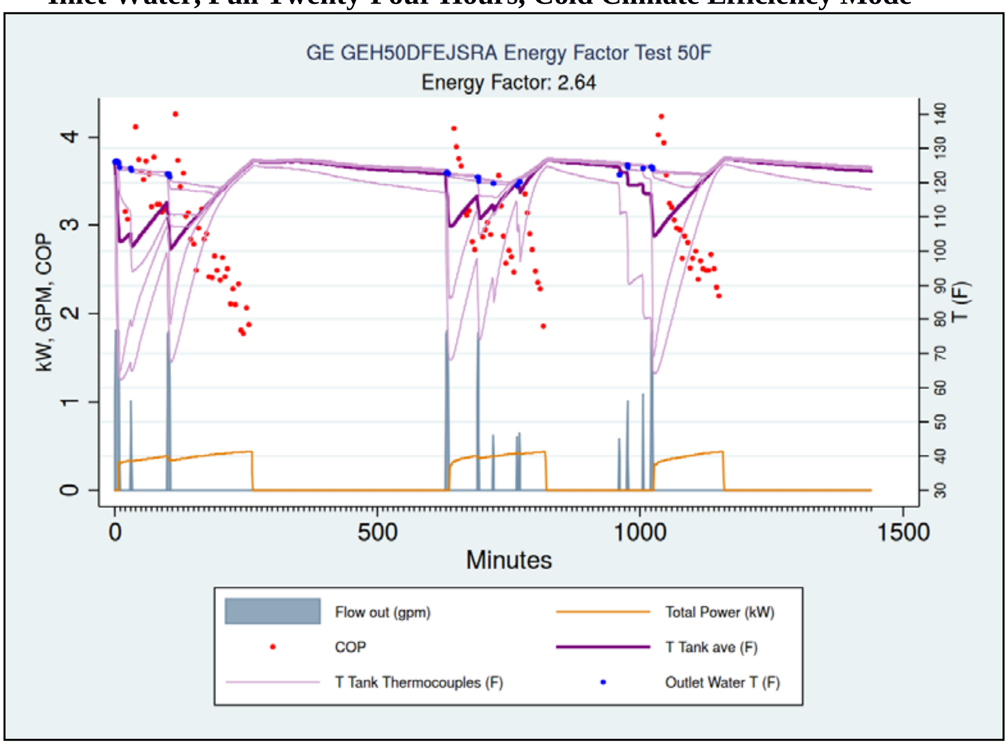


Figure 16. DOE 2014 24-hour Simulated Use Test, Full Twenty-Four Hours, Cold Climate Efficiency Mode

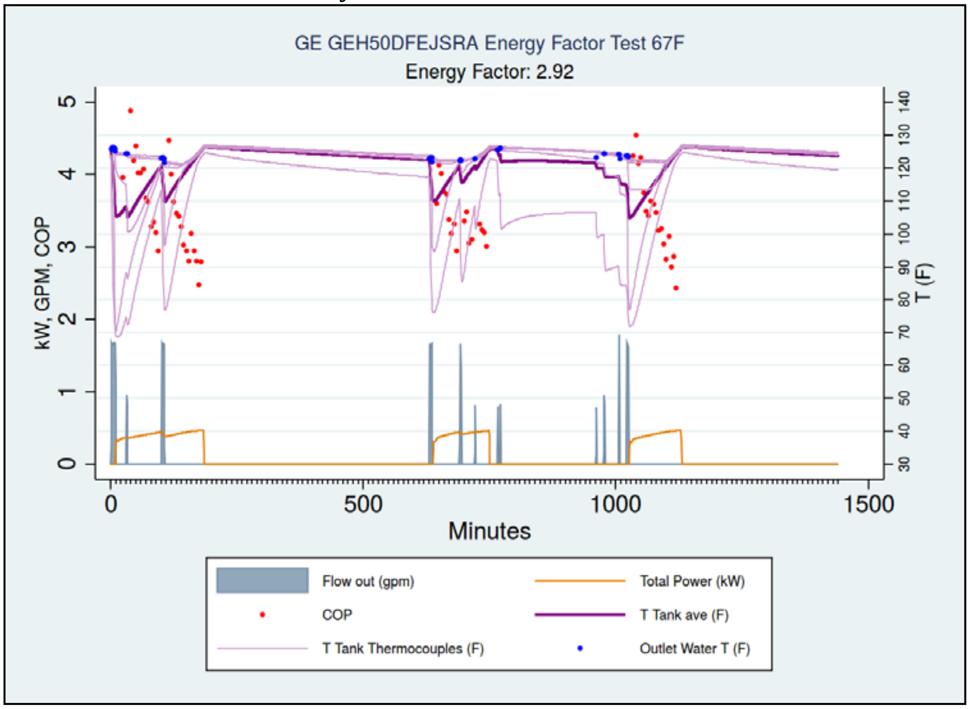
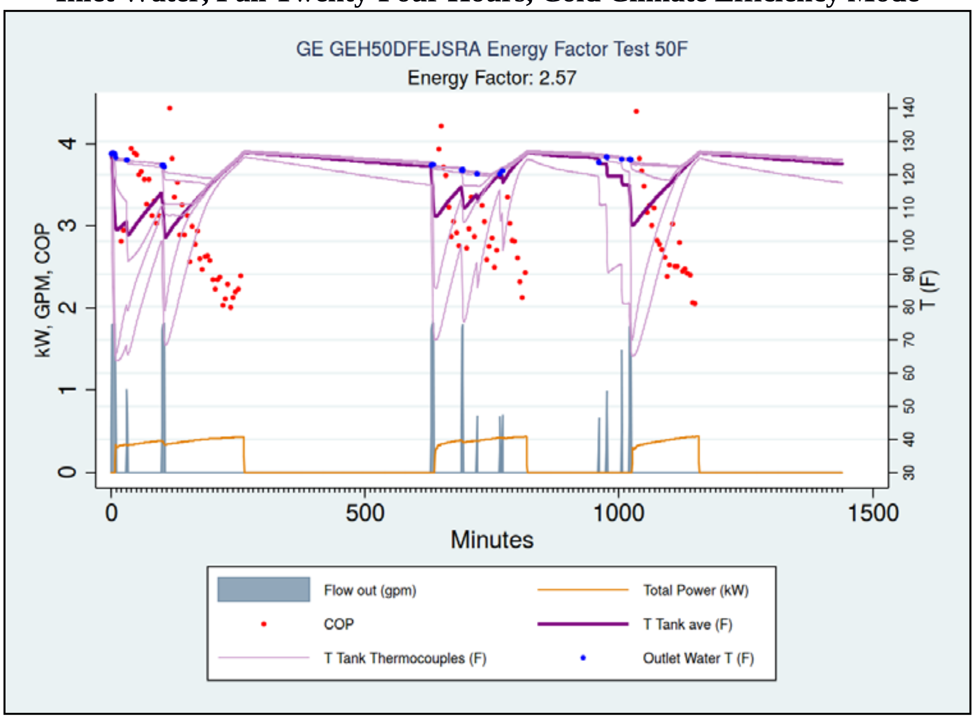


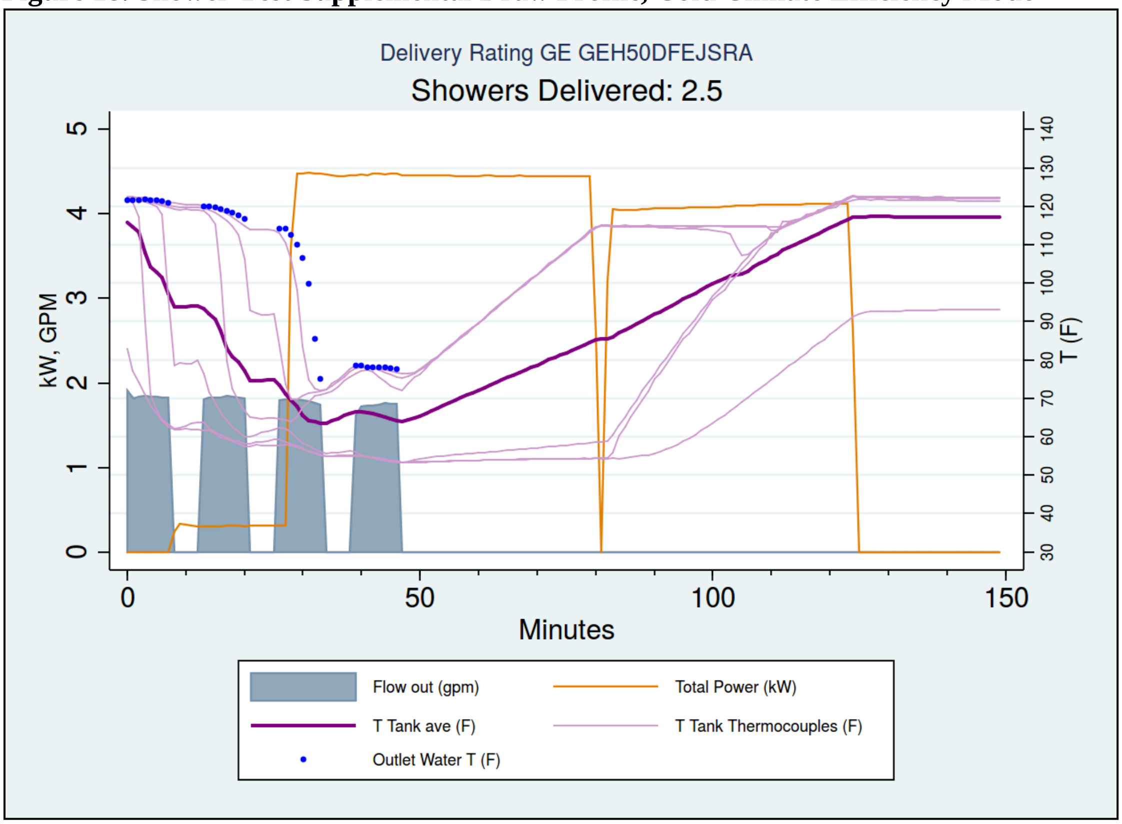
Figure 17. DOE 2014 24-hour Simulated Use Test, 50°F Ambient Air/50°F Inlet Water, Full Twenty-Four Hours, Cold Climate Efficiency Mode



4.2. Efficient Showers Test

In addition to the old and new DOE tests, the Northern Climate HPWH Specification calls for a delivery rating test to aid in better understanding performance. This simulated-use "Shower Test" (DP-SHW) describes the number of efficient hot showers the HPWH is capable of providing. The test specifications call for 50°F ambient air, 50°F inlet water, and 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 were separated by a five-minute lag time and continued until either the resistance element activated or the outlet temperature fell below 105°F. When one of these events occurred, the test allowed the current draw to finish, the tank to recover, and then the test concluded. The test yields a useful rating: the number of consecutive, efficient showers available. Based upon the findings of this test, the GEH50DFEJSRA water heater provides 2.5 consecutive efficient showers (illustrated in Figure 18).

Figure 18. Shower Test Supplemental Draw Profile, Cold Climate Efficiency Mode



Both the DOE 1-hour test and the number-of-showers test amount to delivery ratings. The Uniform Plumbing Code (UPC) (IAPMO 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 addresses 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 the tests in this study. Those older types of tanks, with only one means by which to heat water, could use two outputs from the DOE 24-hour test – the recovery efficiency and energy factor – to reliably describe the operational efficiency during the 1-hour tests. In contrast, typical hybrid HPWHs have two distinct heating efficiencies depending on which of the two heating methods the control strategies use. Further, heat pump efficiency changes over the course of a test. Consequently, the number-of-showers 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 the number of bathrooms and bedrooms in a house. Both are proxies, respectively, for water demand and number of people in a house. The UPC requires a minimum first hour rating of sixty-seven gallons for three bedrooms and 2 to 3.5 baths. The next-lower rating of fifty-four gallons covers three bedrooms with up to 1.5 baths, or two bedrooms with up to 2.5 baths.

The GEH50DFEJSRA tests show that although the product satisfies the capacity requirements of the UPC recommendations, it may satisfy these requirements with efficiency less than that of a heat pump. For a household with at least two to three bedrooms (three or four people) and two bathrooms, three consecutive morning showers are a distinct possibility. The DP-SHW test shows the resistance elements engage early in the third shower and do not shut off for nearly an hour. While the household hot water needs would theoretically be met according to the UPC and first hour rating, it would occur with heavy reliance on resistance elements. The scenario demonstrates that households with three morning showers, using Hybrid mode, would see reduced efficiency benefits for that usage. Achieving COPs much above 1 for usage beyond the first two showers in the test would necessitate increasing the tank storage volume or changing the HPWH controls to CCE mode so the lower heating element is not used in the recovery process.

4.3. Low Temperature Limit

The lab testing observed the compressor operating at 37°F but not at 32°F. Per the Northern Climate Specification, the compressor cutoff temperature is set at 37°F, which is slightly warmer than the manufacturer's specification of 35°F.[5] An ambient temperature below this value will cause the unit to run exclusively in resistance mode, dramatically reducing its efficiency.

4.4. Noise Measurements and Additional Observations

The lab also measured the sound level of the equipment. Researchers placed the unit 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, at an ambient temperature for the test of ~72°F. Table 3 shows the background noise levels and the averages of the five measurements.

Table 3. Sound Level Measurements for GE GEH50DFEJSRA

Decibel Weighting	Background	HPWH on
dBA	38	55
dBC	60	64

[5] This study did not test at the manufacturer's specification of 35°F.

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

5. Conclusions

This final section discusses observations, in no particular order, on the equipment design and their implications for operation and performance.

- The GEH50DFEJSRA offers a significant redesign, if not a totally new design, compared to previous offerings from GE. It endeavors to meet all criteria for the Northern Climate Tier 3 Qualification, including a substantial increase in the efficiency of the compressor system.

- The GEH50DFEJSRA has an EF of 3.10 and an EF_{nc} of 2.13 in Hybrid mode, and an EF of 3.10 and an EF_{nc} of 2.66 in Cold Climate Efficiency mode. Overall, the heat pump system alone shows higher efficiency than previous generations of GE equipment, which helps its delivery of higher EF ratings. The lab observed a lower operating range to 37°F for the GEH50DFEJSRA, which further helps to improve its Northern Climate Energy Factor.

- The Cold Climate Efficiency mode setting offers a significant improvement in hybrid HPWH control strategies. The mode limits the use of resistance elements only to times when the tank is close to running out of hot water. Then, it engages the upper element but only long enough to heat the upper tank to a usable temperature of 120°F. Once the water at the top is hot, the rest of the tank reheats with the heat pump. In this mode, the tank will likely deliver the performance promised by a heat pump for most users.

- The tank has the highest Energy Factor at 67.5°F observed to date for any of the integrated HPWHs tested by Cascade Engineering and Ecotope. Its EF at 50°F is lower, due in large part to a smaller storage volume than sixty- or eighty-gallon tanks.

- The revised control strategy in Cold Climate Efficiency and Hybrid modes will lead to different energy use in the field than that of previous equipment. First, the compressor is set to run concurrently with either of the resistance elements, which will increase the relative efficiency. Second, in large draw situations, once the top of the tank is hot, the control logic favors reheating the bottom portion with both the compressor and the resistance element. Using the lower resistance element in this way, as opposed to solely the compressor, will increase energy use. For small draws, the lower element is not used. The inclination of the unit to engage the resistance element when in the default Hybrid mode substantially reduces the COP in relation to Cold Climate Efficiency mode.

- Overall, the smaller physical (size than others currently on market) of the GEH50DFEJSRA will allow the tank to fit in to more houses and locations. On the other hand, the combination of a smaller storage capacity and revised hybrid operating mode controls will likely lead to lower operating efficiencies than larger tank sizes.

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Appendix A: Testing Matrices

Testing Matrix: GE GEH50DFEJSRA

DOE Standard Rating Point Tests

Test Name	Ambient Air Conditions					Inlet Water		Outlet Water		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	57	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	57	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	57	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	149	57	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	149	57	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	149	57	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	120	49	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, and 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 List

Equipment	Make and Model	Function	Accuracy	Calibration Expires on
Walk-in Chamber	Make: ESPEC Model: EWSX499-30CA	Test environment temperature and relative humidity control	±1°C	8/11/2015
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	9/9/2015
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*	5/23/2015
Power Source	Fluke 5520	Power meter comparison/calibration	AC Current ±0.15%	4/14/2015
Current Transformer (25:5)	Make: Midwest Model: 3CT625SP	Use with Acuvim Power meter for total UUT power and heater power measurement	0.4% at 5VA	Note 1
Flow Meter	Make: Seametrics Model: SPX-050 and FT420 Indicator	Water flow measurement	±1% of full scale	Oct 2014 (Factory calibrated)
Flow Controller	Make: Watlow Model: F4P	Control timing of flow pattern	NA	NA
Hand-held temperature and humidity meter	Omega RH820W	Lab environment temperature and humidity measurement	± 0.5°C	6/11/2015
Electronic Scale	Dogain Model: TS300K Range 300 Kg	Measurement of water mass	300 x 0.05 Kg 660 x 0.1 lb	3/9/2015

Note 1 – See Calibration manual