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NEEA Report: Laboratory Assessment of General Electric GeoSpring™ Hybrid Heat Pump Water Heater

Prepared by:
Ben Larson and Michael Logsdon
Ecotope, Inc.
4056 9th Avenue NE
Seattle, WA 98105

Northwest Energy Efficiency Alliance
PHONE
503-688-5400
FAX
503-688-5447
EMAIL
info@neea.org

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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 General Electric (GE) GeoSpring model # GEH50DEEDSR hybrid heat pump water heater (HPWH) for northern climate installations. Cascade Engineering evaluated the GeoSpring 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. 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. Overall, the results suggest the GeoSpring 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:
  - The GeoSpring qualifies for Tier 1 status under the Northern Climate Heat Pump Water Heater Specification (Northwest Energy Efficiency Alliance, 2012. *Northern Climate Qualified Heat Pump Water Heaters.* Retrieved from http://neea.org/docs/northern-climate-heat-pump-water-heater-specification/qualified-products-list.pdf?sfvrsn=6)
  - Northern Climate Energy Factor: 1.92
  - Percent of tank drained before resistance elements engage in 1-hour test: 64%
  - Number of consecutive, 16-gallon, efficient showers: 2.5
  - Sound level: 54.6 dBA

- The tank is well-insulated and the heat pump system is efficient.

- The 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).

- The hybrid mode GeoSpring controls are configured in such a way as to favor resistance element operation on tank recovery over the compressor, which limits the operating efficiencies that the tank could achieve. Updating the control strategy to heat the lower portion of the tank with the heat pump and not with the lower element would improve system performance. Further, increasing the compressor output capacity and tank storage volume would similarly improve performance.

- The heat pump ambient temperature operating range is limited to 45°F-120°F and there is no exhaust air ducting capability for the unit.

1 Introduction

The Northwest Energy Efficiency Alliance (NEEA) contracted with Ecotope, Inc. and Cascade Engineering Services Inc., to conduct a laboratory assessment of the General Electric (GE) GeoSpring heat pump water heater (HPWH) for northern climate installations. Cascade Engineering Services, of Redmond, WA, evaluated the GeoSpring model # GEH50DEEDSR 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); 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.

Ecotope previously evaluated the older model #GEH50DNSRSA under a contract with the Bonneville Power Administration (BPA) (Larson and Logsdon 2011. Retrieved from http://www.bpa.gov/energy/n/emerging_technology/pdf/HPWH_Lab_Evaluation_Final_Report_20111109.pdf) Both models are nominally 50 gallons in size. According to GE literature, the new model is built in Louisville, Kentucky as opposed to the previous one which was assembled in an overseas location. Ecotope inspected the equipment in the lab to reveal several more differences between the older and newer models. First, the new model has a different color scheme with a red color around the upper compressor and fan housing. Second, more significant to operation, the new model has a different air filter and airflow path. The filter sits atop the device, snapped on, at the air intake. The air flows down into the filter and is exhausted out the back. The previous model used a side-to-side airflow path. Third, the fan is a single, metal-blade, axial type replacing the two plastic-blade axial fans. The testing did not determine if the fan was variable speed as in earlier models.

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 those tests were all conducted 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**Error! Reference source not found.** shows the HPWH installed inside the thermal chamber. The test plan did not require tightly-controlled conditions for the verification of the operating modes so those tests were conducted in the large lab space at the conditions encountered at the time (typically 55°F-70°F). Additionally, Cascade Engineering conducted the airflow measurements and any one-time measurements of system component power levels under these conditions. 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 **Error! Reference source not found.**– 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**Error! Reference source not found.** and Figure 5**Error! Reference source not found.**). 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

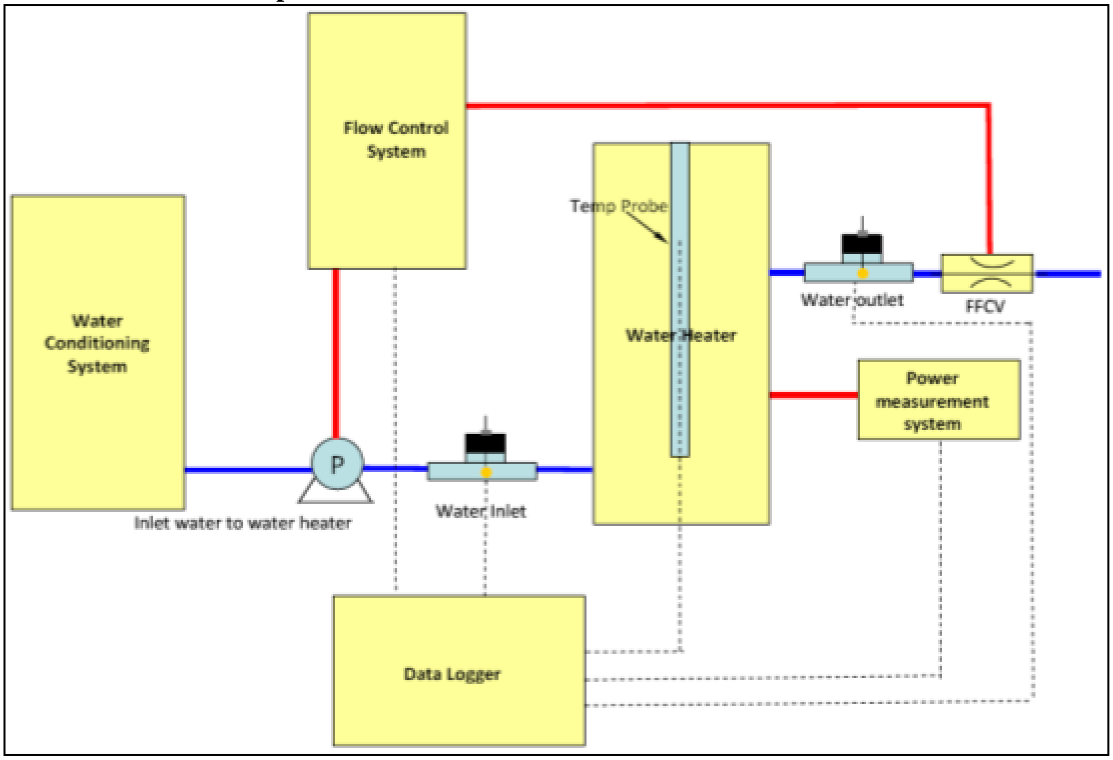


Figure 3. Thermocouple Temperature Tree

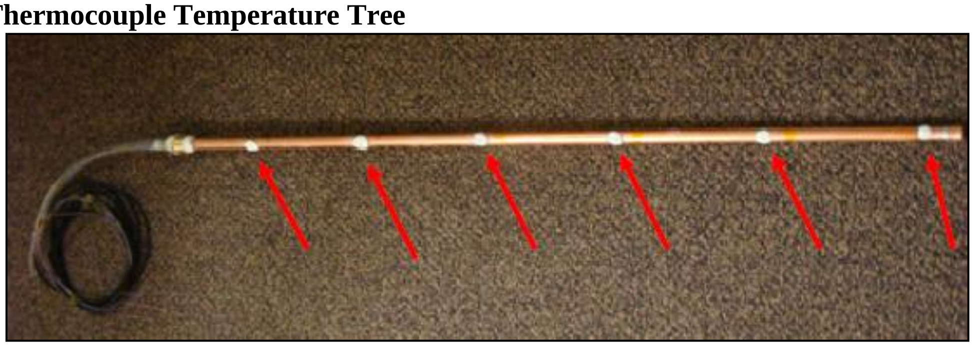


Figure 4. Power Measurement Current Transducers

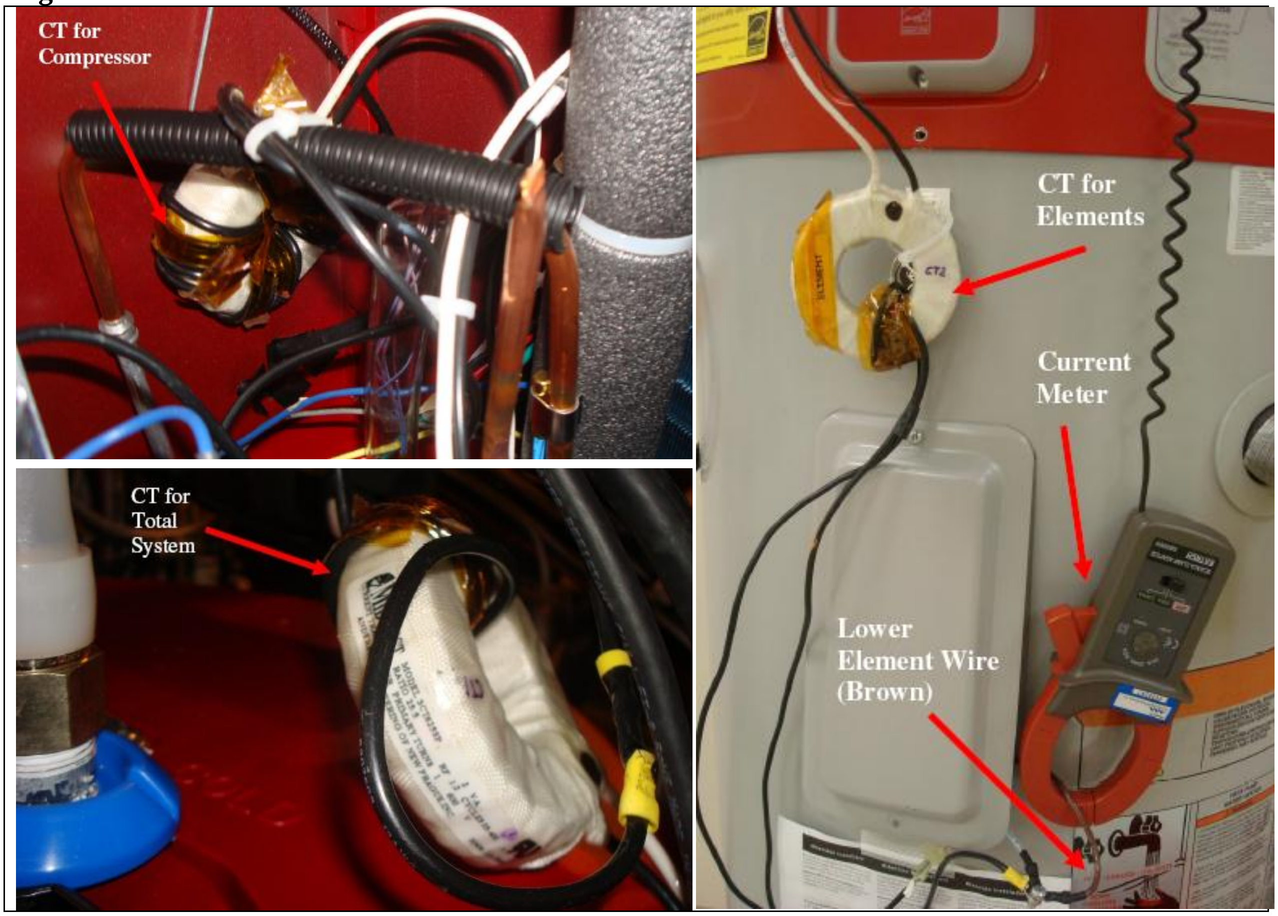
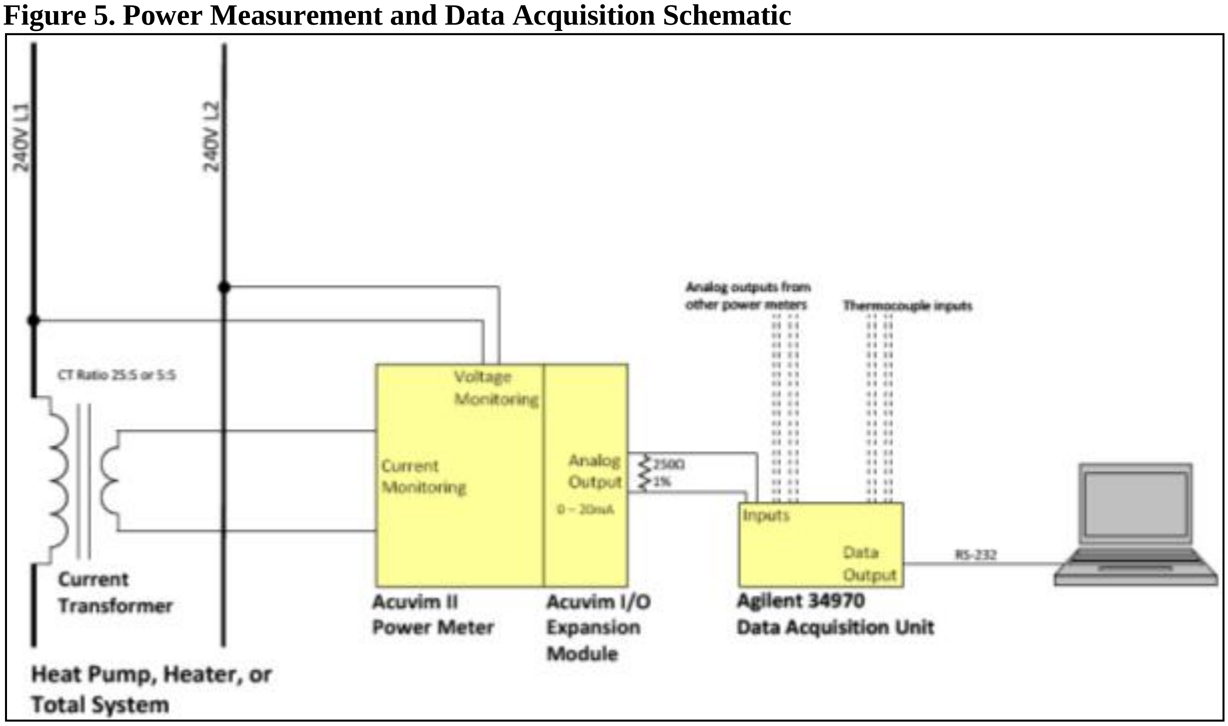


Figure 5. Power Measurement and Data Acquisition Schematic



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 and not the 40+psi of the spec.
- Water inlet and outlet supply piping consisted of the cross-linked polyethylene (PEX) variety and not 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 GeoSpring 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. An axial 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 back. 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. For reference purposes, the table also shows the values given by GE's equipment specifications.

As with traditional electric tank water heaters, the GeoSpring contains two electric resistance heating elements. Located in the upper and lower portions of the tank, each element draws 4.5kW. The third heating component for the tank is the heat pump compressor. Measurements show the compressor draws 380W[1] to 590W[2] depending on both tank water and ambient air conditions. The controls for the GeoSpring are configured to operate each of the three heating components – compressor, upper resistance elements and lower resistance element – only one at a time. No concurrent operation of heating sources takes place.

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 GeoSpring has a nominal 50-gallon capacity, but measurements showed the unit in the lab held 45.1 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. The difference in nominal size versus 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 GeoSpring

	Laboratory Measurement	Manufacturer's Specification
Upper Element (W)	4500	4500
Lower Element (W)	4500	4500
Compressor* (W)	380-590	na
Standby (W)	1	--
Fan (W)	30	--
Airflow Path	Inlet on top. Exhaust out the back.	Inlet on top. Exhaust out the back.
Refrigerant	R-134a	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 GeoSpring has four basic modes of operation, shown below in order of most efficient to least efficient:

- "Heat Pump" – compressor only
- "Hybrid" – combination of compressor and resistance elements
- "High Demand" – combination of compressor and resistance elements where the elements engage more readily than in Hybrid mode
- "Standard" – no compressor usage – upper and lower elements only

A fifth operating mode – "Vacation" – exists, but is basically a tank temperature setback option for use while the occupants are not in the house for extended periods (3-14 days).

Earlier studies allowed only loose quantification of the operating modes of the previous GeoSpring model (Advanced Energy 2011, Larson and Logsdon 2011, Pacific Gas and Electric 2010, NREL 2011). In an attempt to quantify those operating modes clearly enough for use in detailed computer simulations, the test plan called for an in-depth investigation of the control strategies of the GEH50DEEDSR. The lab performed several tests specifically designed to observe when the individual heating components turned on and off. The operating mode tests involved placing the unit in a specific mode, starting with a hot tank, drawing two GPM for three minutes, waiting three minutes, and then repeating the draw. Throughout, the lab observed the status of the upper and lower elements and the heat pump. Each test lasted until all of the anticipated heating components fired in each mode. The lab also examined all the other tests listed in Appendix A for clues as to when the heating components turned on and off. Together, the tests form a composite picture of when the upper and lower elements and the heat pump are used in the different modes.

To start, the lab examined the water heater printed circuit control board for sensor inputs that could be used in any control strategy. They found one temperature input leading back to the tank. No other sensor inputs existed for either water flow or further temperature measurements.

Further investigation showed the single temperature sensor is placed at a height equivalent to somewhere between the top two sensors of the thermocouple tree, approximately 1/6 of the tank height below the tank top.

Over the various 24-hour, 1-hour, and number of showers (DP-SHW) tests, Ecotope observed that different heating components operated at different times even for the same tank temperature. In other words, the tank temperature history or draw pattern likely influenced which components were used when. Given that the unit has only one temperature sensor, Cascade Engineering suggested examining the rate of temperature change in the upper portion of the tank. This proved useful in explaining the control strategy. Greater rates of change correspond to larger and more rapid water draws, which Ecotope saw in the DP-SHW and DOE 1-hour tests. Lesser rates of change correspond to the draws used for the 24-hour tests.

Together, Ecotope and Cascade Engineering compiled the descriptions of control strategies given below.

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. Retrieved from http://products.geappliances.com/ApplProducts/Dispatcher?REQUEST=SpecPage&Sku=GEH50DEEDSR). The lab observed that the heat pump turned on when the upper tank temperature reached almost 3°F below setpoint, suggesting the heat pump operates on a 3°F deadband for this mode.

Hybrid Mode: In hybrid mode, all three heating components – the lower element, upper element and heat pump – can operate. In response to a draw or decrease in tank temperature, the heat pump turns on the same as in heat pump-only mode, that is, when the temperature sensor notices a 3°F difference from setpoint. If the tank temperature falls further, either the lower element or upper element will engage. The lower element engages when a large temperature rate of change occurs. Ecotope observed this to be in excess of 1°F/minute. Further, the upper tank temperature also appears to be ~20°F below setpoint when the lower element activates. When either element engages, the heat pump turns off. Continued draws on the tank show that when the temperature sensor falls ~30°F below setpoint, the upper element switches on and the lower element switches off. When recovering from a large tank draw, the upper element operates until the tank temperature sensor is just below setpoint and then the lower element takes over to heat the rest of the tank all the way to setpoint. When recovering from a smaller rate of temperature change and, hence, a smaller tank draw, the upper element operates until the tank is just below setpoint and then the heat pump takes over to heat the rest of the tank all the way to setpoint.

High Demand Mode: As in hybrid mode, all three heating components can operate. In the high demand mode, the tests showed the unit operated in much the same way as in hybrid mode, except the lower and upper elements showed a propensity to turn on sooner. Under the same draw conditions, the lower element turned on at ~7°F below setpoint instead of ~20°F. The upper element cycled on and the lower element off when the temperature fell to more than 30°F below setpoint. Insufficient testing precluded confirmation of the recovery behavior in high demand mode; however, it appeared similar to the hybrid mode and certainly for the large draws, recovered in the same way – with the elements only and without the use of the heat pump.

Standard Mode: In standard mode only the upper and lower elements can operate. Ecotope did not investigate standard mode because the efficiency of the elements is identical. Only the time at which water is available at the top of the tank is influenced by which elements operate when.

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 GeoSpring in hybrid mode – the default setting on the equipment when shipped by GE. 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.

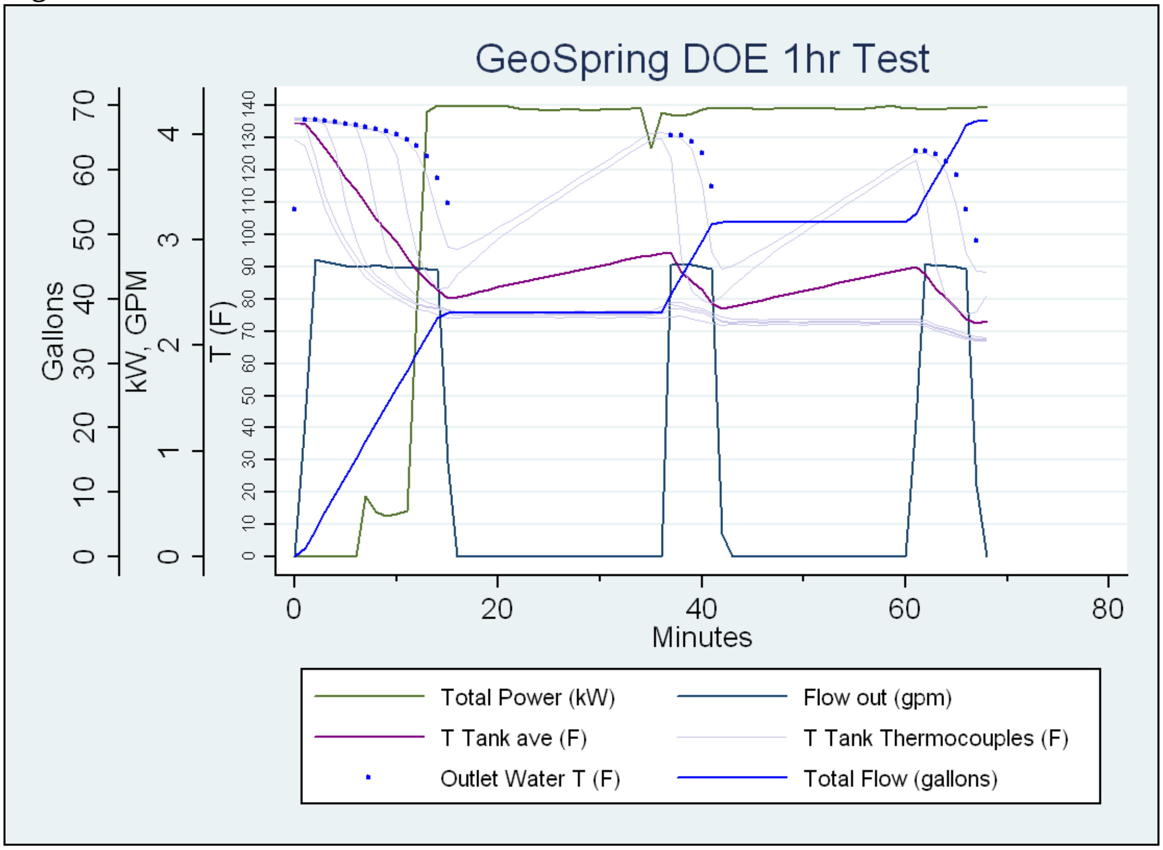
Table 2. Performance Characteristics for GeoSpring GEH50DEEDSR

	Laboratory Measurement	Specification Sheet
First Hour Rating (gal)	66	65
Energy Factor (std conditions)	2.42	2.4
Energy Factor @ 50°F Ambient	1.92	-
Northern Climate Energy Factor	1.93	-
Tank Heat Loss Rate (Btu/hr°F)	3.6	-

4.1.1 1-hour Test

The data from the 1-hour test are plotted in Figure 6**Error! Reference source not found.**. The test begins with a 3gpm draw. Approximately 6 minutes into the first draw, the heat pump activates (green line showing 0.4kW). As the draw continues past 12 minutes, the water temperature at the sensor falls far enough and quickly enough to trigger the lower element. As the upper tank temperature continues to fall to more than 30°F below the setpoint, the tank switches to use the upper element at minute 15. At 35 minutes, the upper portion of the tank has recovered to setpoint, so the equipment switches back to the lower 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 42 and the unit is in recovery for the remainder of the 60-minute test.

Figure 6. 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 GeoSpring, the test data show 28.9 gallons, equivalent to 64% 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 hybrid 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. 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 Heat Pump Water Heater Specification). In the calculations, Ecotope used a 45°F temperature cutoff as found in the GE Installation Instructions (GE Appliances. Retrieved from http://products.geappliances.com/ApplProducts/Dispatcher?REQUEST=SpecPage&Sku=GEH50DEEDSC) and verified by Cascade Engineering.

Figure 7 shows the first eight hours of the test so the draw events and recovery can be examined in more detail. Figure 8**Error! Reference source not found.** shows the full 24 hours, which also demonstrates the tank heat loss rate. The figures plot the same type of data as Figure 6**Error! Reference source not found.**. One distinction 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 7 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 7 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 2 and 3 throughout each recovery period, decreasing as the tank temperature warms (the heat pump is less efficient when working against a larger temperature difference).

Figure 7. DOE 24-Hour Simulated Use Test, First Eight Hours

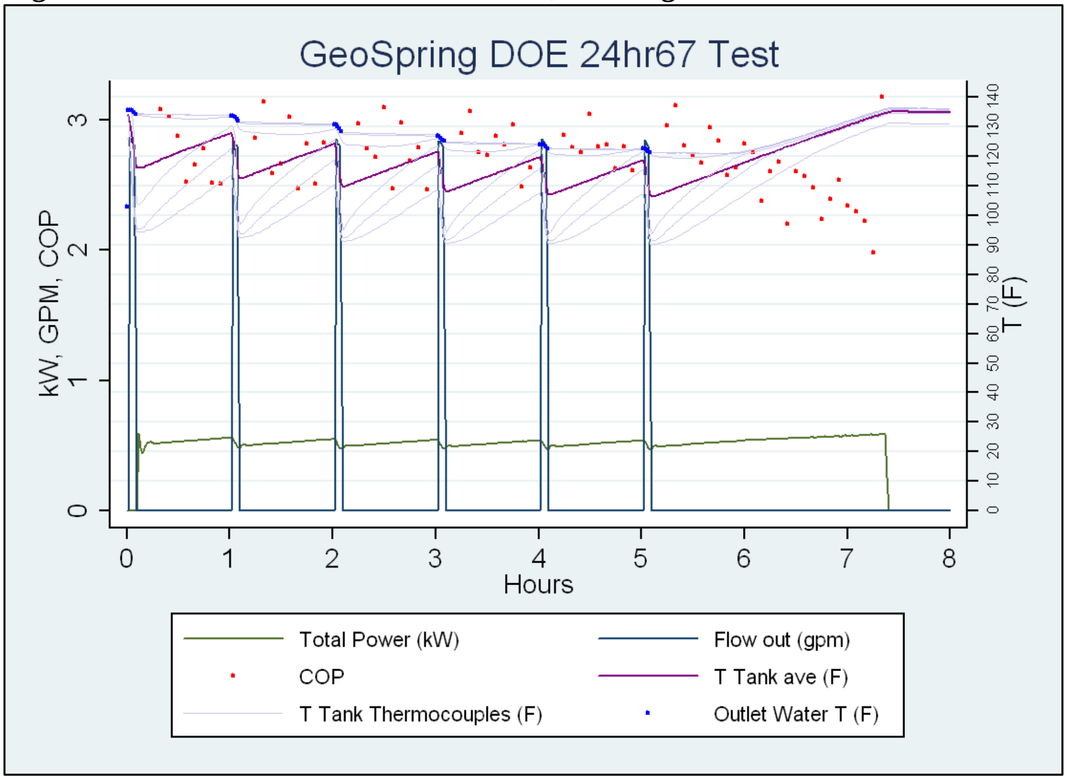


Figure 8. DOE 24-hour Simulated Use Test. Full 24 hours.

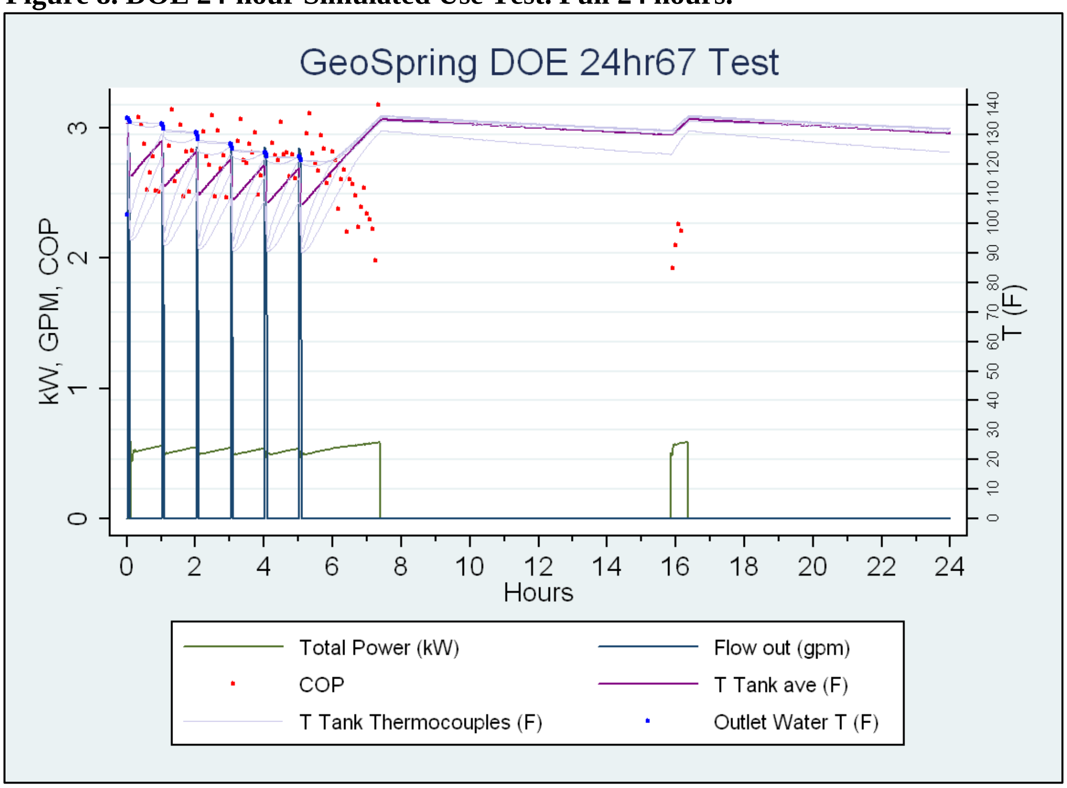


Figure 9 and Figure 10**Error! Reference source not found.** plot the heat pump behavior for the 50°F ambient air and 50°F inlet water 24-hour testing conditions. Most significantly, in contrast to the 67°F ambient air / 58°F inlet water test, Figure 9 shows the tank activates the upper resistance heating element during the end of the sixth water draw. The element activates in this case because the colder incoming water temperature has pulled down the tank temperature far from its setpoint. Further, the tank recovery finishes at hour 9, 1.4 hours longer than with the standard conditions for the 24-hour test, which is to be expected given the difference in air temperature. The outlet water temperature in the 50°F ambient air case 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. The temperature hovers at 110°F and dips to 108°F – barely above the minimum 105°F considered necessary for useable hot water. A final note on the 50°F test is that the increased heat loss through the tank is witnessed through two recoveries in the standby portion of the test.

Figure 9. DOE 24-hour, 50°F Ambient Air 50°F Inlet Water. First 10 hours.

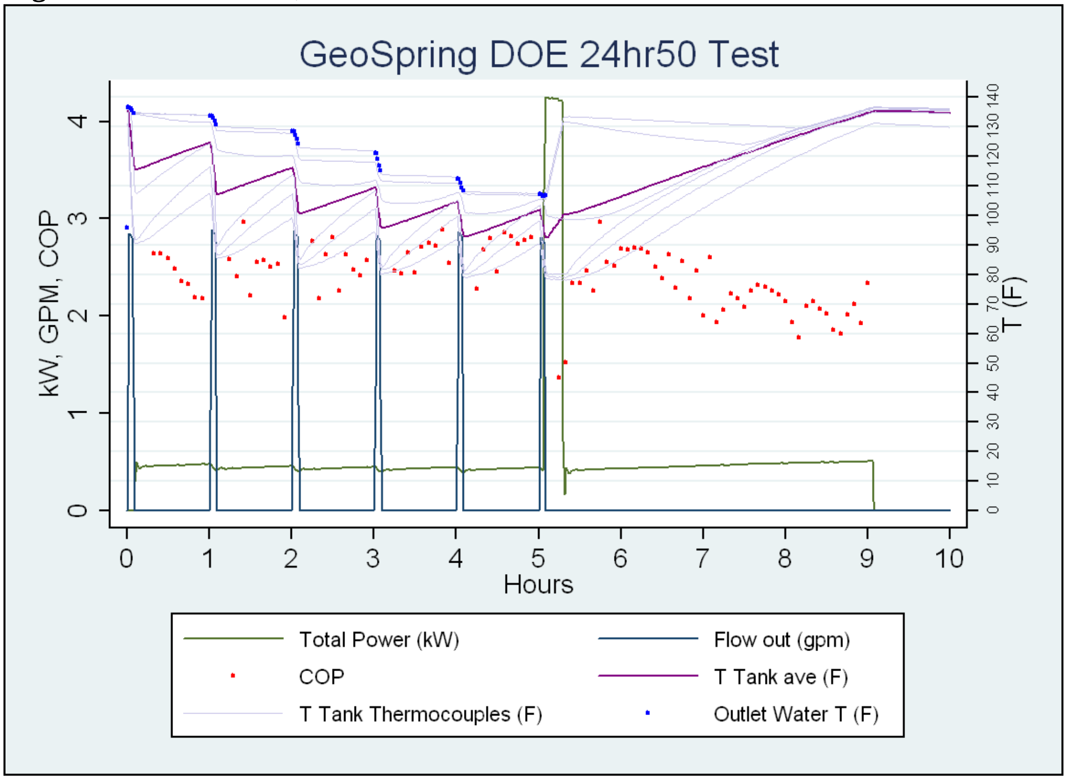
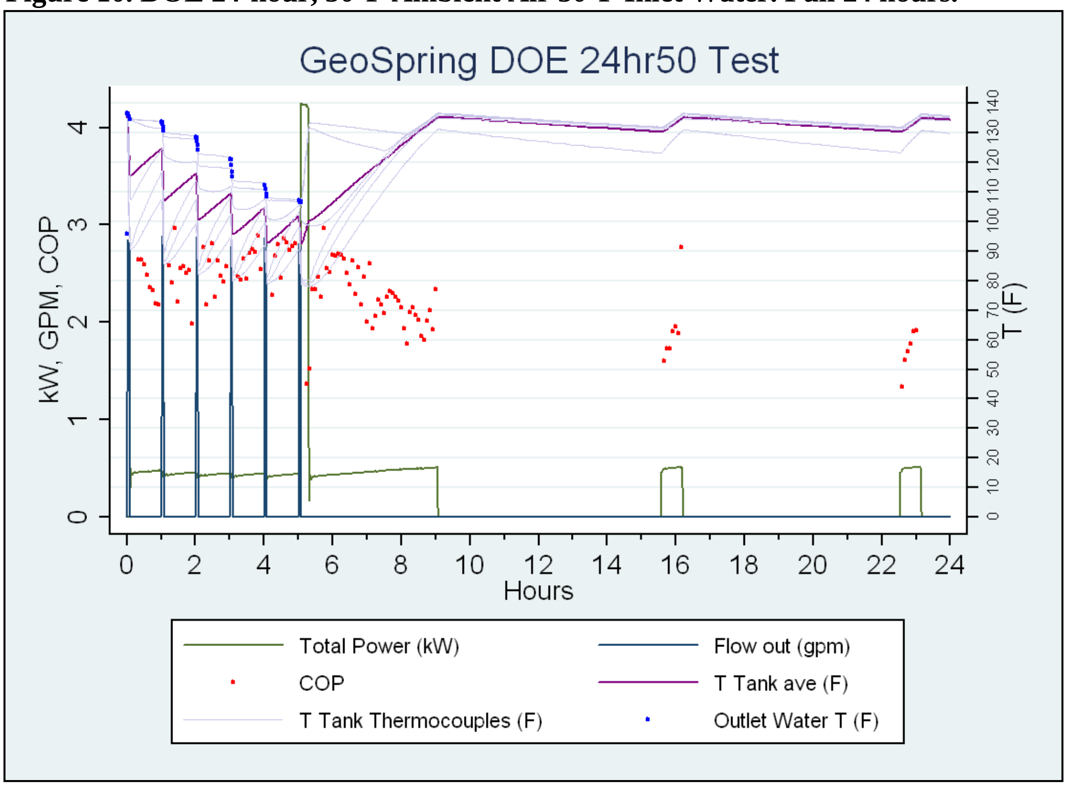


Figure 10. DOE 24-hour, 50°F Ambient Air 50°F Inlet Water. Full 24 hours.



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, 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 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, the tank to recover, and the test concludes. The test yields a useful rating: the number of consecutive, efficient showers available. The GeoSpring water heater provides 2.5 consecutive efficient showers. The results of the test are displayed in Figure 11.

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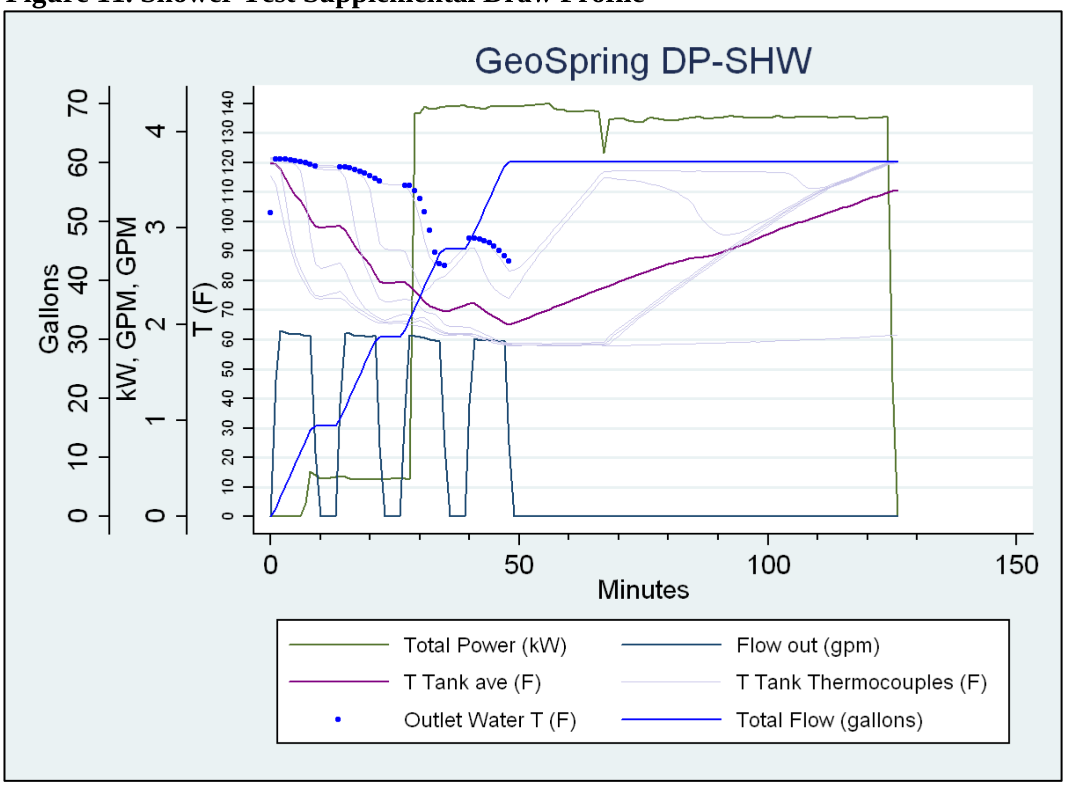
Figure 11. Shower Test Supplemental Draw Profile



Both the DOE 1-hour and DP-SHW tests amount to 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 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. Further, the capacity calculator on the GE website recommends a minimum capacity rating of 65 gallons for households with up to four people and two bathrooms or three people and three bathrooms (GE Water Heaters. Retrieved from http://www.geappliances.com/products/water/water_heaters.htm). With a first hour rating of 65 gallons, the GeoSpring could conceivably be used to meet any of the aforementioned scenarios and thus meet the requirements of the UPC.

The DP-SHW test shows that although the capacity requirements of both the UPC and the GE recommendations are satisfied, it may satisfy these requirements with only the efficiency of a standard resistance tank rather than 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 until the tank is recovered. The household hot water needs will be theoretically met according to the UPC and first hour rating, but it will occur with heavy reliance on resistance elements. The heat pump runs for twenty minutes in this scenario, providing approximately 1/16 of the total water heating need with the rest coming from the resistance elements. The scenario demonstrates that households with three morning showers, using hybrid mode, will see only small efficiency benefits for that usage. To achieve COPs above 1 for usage beyond the first two showers in the test, the tank storage volume needs to be increased so that resistance heating is not used in the recovery process. Moreover, for similar efficiency reasons, the control strategy for hybrid mode needs to switch on the heat pump instead of the lower elements once the upper element has finished bringing the top of the tank to setpoint.

In addition the test showed that using the 120°F setpoint, the outlet water temperature fell below 105°F halfway through the third shower. Overall, the tank provided 40 gallons of hot water before this happened, but the end of the third shower would certainly be cold.

[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.

4.2.2 Supplemental 24-hour Tests

The lab conducted two more supplemental draw profile tests to better understand the control logic. They are similar to the DOE 24-hour test with the following exceptions: the draw profile is half as much, twice as often (the total draw volume is the same); the ambient air is set to 50°F; and the inlet water is set to 50°F. Using those conditions, the lab conducted a test at 135°F and 120°F setpoints. **Error! Reference source not found.**Figure 12 and Figure 13**Error! Reference source not found.** show the test results. Notably, as expected, the heat pump COPs for the 120°F setpoint are consistently higher than those for the 135°F setpoint. Using the same procedure as the DOE method, but substituting in altered test condition values where relevant, Ecotope calculated an energy factor for each of these tests:

- EF_{50h135}: 1.82
- EF_{50h120}: 2.18

Figure 12. Supplemental 24-hour Test. Half draw twice as often 135F setpoint.

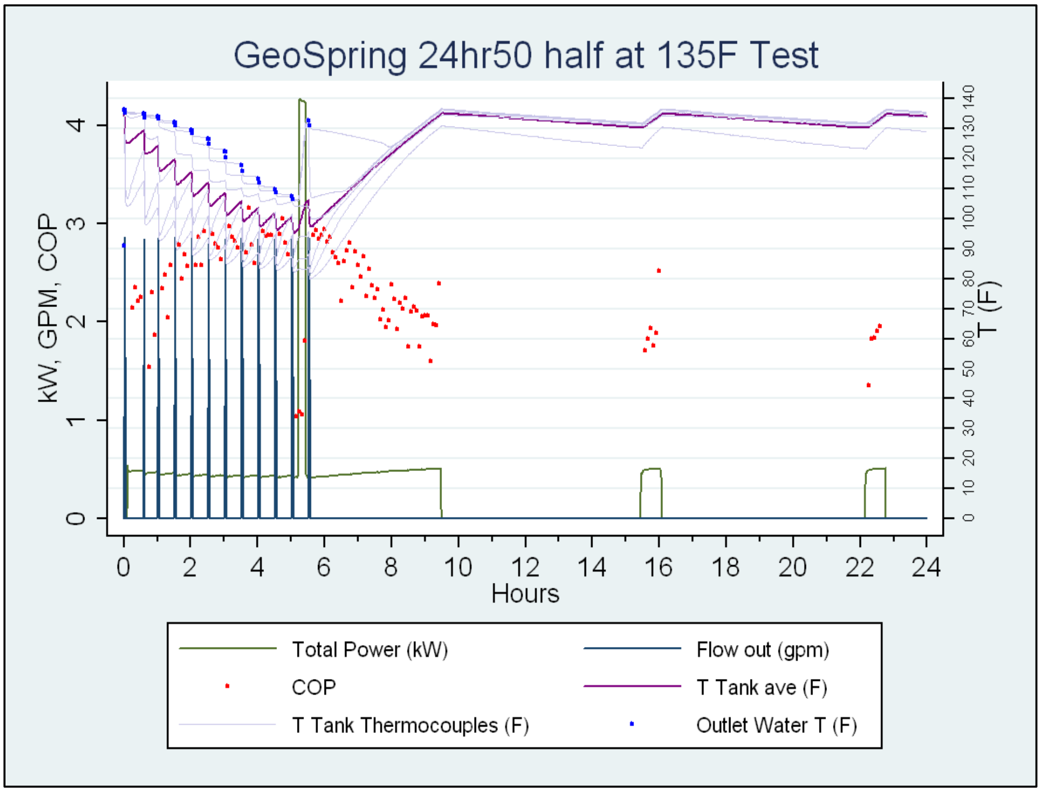
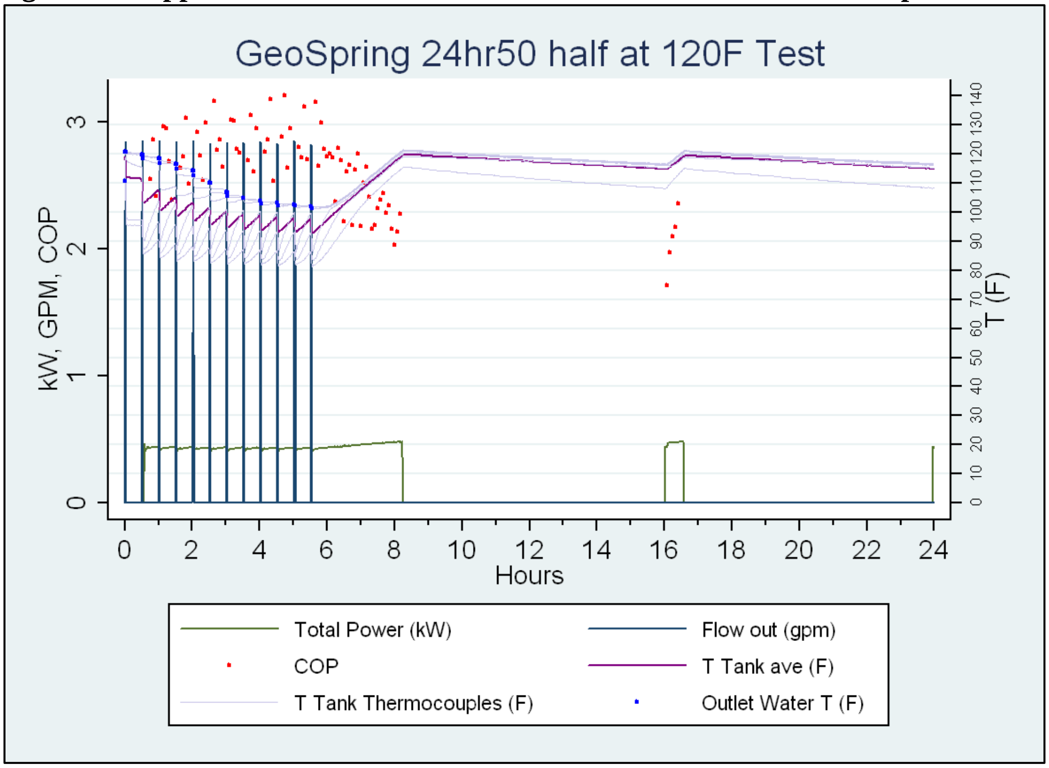


Figure 13. Supplemental 24-hour Test. Half draw twice as often 120F setpoint.



4.3 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 dBA of 37.9 and dBC of 58.6). The averages of the five measurements were:

- 54.6 dBA
- 61.6 dBC

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 heat pump system offers high COPs when it runs. The component selection for the compressor, evaporator coil and fan create an efficient heat pump system. COPs ranged from 2-3 for the 24-hour tests even at the lower 50°F ambient air condition. A high heat pump operational COP is necessary for overall efficient system performance.

- The tank is well-insulated, exhibiting a low heat loss rate, which reduces the number of standby recoveries needed throughout a year.

- The air filter on the previous GeoSpring model could be easily accessed, but the redesigned one on this model, GEH50DEEDSR, is even more accessible. Its clear visibility on the top of the tank increases the likelihood that the homeowner will clean the filter on a regular basis which will be beneficial for long-term operation and performance.

- The equipment operating modes offer a mix of strategies to meet the water demands of a variety of draw patterns. From an efficiency perspective, however, the strategies could be improved. In most hybrid-mode test cases observed in the lab, once resistance elements engaged, the heat pump did not participate in the recovery cycle. In other words, the controls are configured to favor the lower resistance element over the compressor. The upper element is designed to engage to meet immediate water needs by heating the upper portion of the tank quickly. Once that condition is met, the most efficient way to heat the rest of the tank is with the heat pump and not with the lower element. Reconfiguring the control strategies would result in higher operational efficiencies.

- The DP-SHW number-of-showers test shows that, in hybrid mode, the tank can efficiently meet the morning shower needs of two people. More showers or heavier peak water use reduce the tank efficiency because the hybrid mode resorts to resistance element usage. Therefore, taking advantage of heat pump heating for larger households would necessitate several changes to the water heater. First, increasing the tank storage volume would meet the demands of larger households while simultaneously allowing the water heater to operate in heat pump mode more often. Second, updating the hybrid mode control strategy to use the heat pump instead of the lower heating element would greatly increase operational efficiency when recovering from large draws.

- Another way to increase the overall tank efficiency is to increase the compressor capacity, which is currently relatively limited. For instance, at 67°F ambient air, heating the tank after a complete draw-down (a bath, for example) takes 6-7 hours. A larger compressor would increase heating capacity. The smaller output capacity can ultimately reduce overall tank performance because it extends the recovery cycle, making it more likely resistance heat will be used when new draws occur before recovery is complete.

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Appendix A: Testing Matrices

Testing Matrix: GE GeoSpring GEH50DEEDSR

DOE Rating Point Type-Tests

Test Name	Ambient Air Conditions					Inlet Water		Outlet Water		Operating Mode	Notes
	Dry-Bulb		Wet-Bulb								
	F	C	F	C	RH	F	C	F	C		
DOE-1-hour	67.5	20	57	14	50%	58	14	135	57	Factory Default	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	135	57	Factory Default	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	135	57	Factory Default	Follow test sequence in Federal Register 10 CFR Part 430 Section 5.1.5 but replace ambient conditions with those given in this table.
DOE-24-hour-50-H135	50	10	44	7	58%	50	10	135	57	Factory Default	Follow test sequence in Federal Register 10 CFR Part 430 Section 5.1.5 but replace ambient conditions with those given in this table and use the draw pattern: 5.35 gal at 3gpm every 30 minutes until 64 gallons drawn.
DOE-24-hour-50-H-120	50	10	44	7	58%	50	10	120	49	Factory Default	

Draw Profiles

DP-SHW-50	50	10	44	7	58%	50	10	120	49	Factory Default	Draw Profile: DP-SHW. Conduct identical, repeated draws until ending conditions observed.

Additional Observations

AO-VOL	Measure tank water volume	na	

Noise Measurement

NOI	Measure combined fan and compressor noise	Heat Pump running

Operating Mode Testing

OP-HP	AMBIENT	58	14	120	49	Heat Pump	1. Heat up to setpoint. 2. Draw 6 gallons at 2 GPM and wait 3 minutes. If nothing happens continue the process. Determine "deadband" as components switch on and off. 3. Allow to reach "setpoint" again. 4. Observe unique features.
OP-HY	AMBIENT	58	14	120	49	Hybrid	
OP-HD	AMBIENT	58	14	120	49	High Demand	

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□o
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	