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NEEA Report: Laboratory Assessment of Rheem HB50RH 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 Rheem Prestige Series model #HB50RH hybrid heat pump water heater (HPWH) for northern climate installations. Cascade Engineering evaluated the HB50 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 (NEEA 2012, *Northern Climate Heat Pump Water Heater Specification*). The testing plan included observing heat pump efficiency at lower ambient temperatures; conducting the standard 24-hour and 1-hour rating tests; measuring noise output levels; quantifying the number of efficient showers delivered at 50°F ambient; and observing the lowest ambient temperature at which the compressor continuously operates. Overall, the results suggest the HB50 is an efficient heat pump water heater for use under small to medium hot water loads, and is appropriate for many, but not all, applications in the Pacific Northwest. Specific findings include:

- Measured Northern Climate Specification Metrics:
    - Northern Climate Energy Factor: 2.18
    - Percent of tank drained before resistance elements engage in 1-hour test: 73%
    - Number of consecutive, sixteen-gallon, efficient showers: 2.5
    - Sound level: 57 dBA

- The tank is well-insulated and the heat pump system is efficient. The evaporator heat exchanger is wrapped around nearly the entire upper periphery of the unit save for the area needed for the display. Compared to other integrated HPWHs, this design creates a larger heat exchange surface, which improves efficiency.

- The heat pump ambient temperature operating range runs from ~38°F to 120°F, making the unit well-suited for any garage, basement, or buffer space installation in the Northwest. Although the low-range temperature is only a handful of degrees colder than the more typical 45°F, the expanded range helps to ensure that the equipment can run in buffer spaces the vast majority of the year using the heat pump.

- The number-of-showers test shows the small storage volume and compressor output capacity will tend to reduce operating efficiencies for households with more than 2.5 morning showers (or other similar peak demands). In contrast, the relatively large compressor output capacity will work to provide more heated water more quickly with the heat pump, without having to resort to resistance backup.

1. Introduction

The Northwest Energy Efficiency Alliance (NEEA) contracted with Ecotope, Inc. and Cascade Engineering Services Inc., to conduct a laboratory assessment of the Rheem Prestige Series model #HB50RH hybrid heat pump water heater (HPWH) for northern climate installations. Cascade Engineering Services of Redmond, WA evaluated the HB50 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 (NEEA 2012, *Northern Climate Heat Pump Water Heater Specification*). 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 measurements of basic characteristics and performance, including first hour rating and Department of Energy (DOE) Energy Factor (EF); determining heat pump efficiency at lower ambient temperatures; conducting a number-of-showers test at 50°F ambient; and observing the lowest ambient temperature at which the compressor continuously operates. A table describing all tests performed for this report is included in Appendix A.

Ecotope previously evaluated the Rheem EcoSense model #HP50RH HPWH under contract with the Bonneville Power Administration (Larson and Logsdon 2011, National Renewable Energy Laboratory 2011). The HB50 marks significant changes in design and improvements in performance over the previously-evaluated model. Instead of circulating water out of the tank to heat it, the new HB50 uses a wrap-around heat exchanger similar to many other integrated HPWHs on the market. The HB50 also has a larger air-to-refrigerant heat exchanger and operates to lower ambient temperatures than did the previous model. Furthermore, observations in the lab indicated that the HB50 appears to have altered control strategies. In all, the changes make for a new HPWH with improved performance characteristics.

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 for use in a Bonneville Power Administration project (Ecotope 2010).
- Northern Climate Specification for Heat Pump Water Heaters (Northwest Energy Efficiency Alliance 2012)
- Department of Energy (DOE) testing standards (DOE 1998) from Appendix E to Subpart B of 10 CFR 430
- American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) Standard 118.2-2006 (ASHRAE Std 118.2)

The general approach and methodological overview for this test are 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.

Because the DOE and Draw Profile type tests require tight controls on the ambient air conditions, Cascade Engineering conducted all 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 any one-time measurements of system component power levels, so those tests were conducted 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 shows 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, including others in addition to those mentioned here, plus their rated accuracies.

Figure 2. General Test Setup

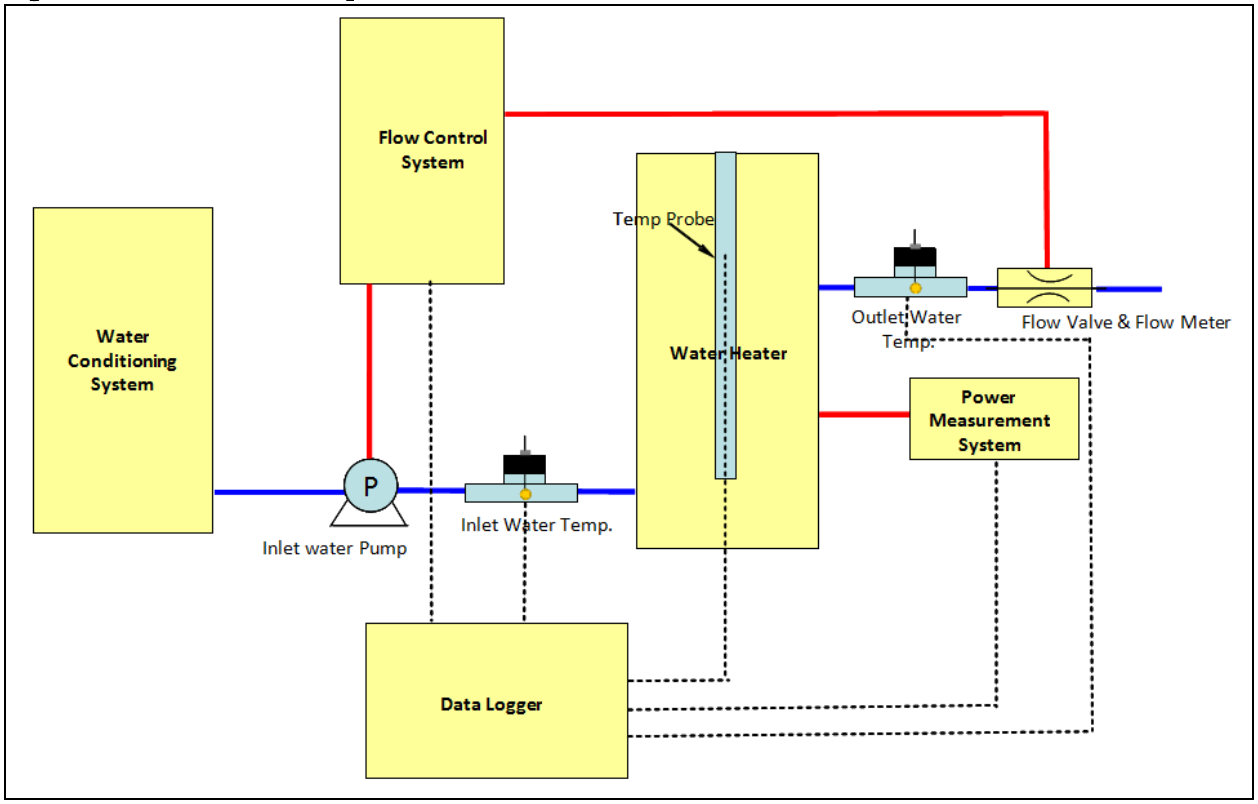


Figure 3. Thermocouple Temperature Tree

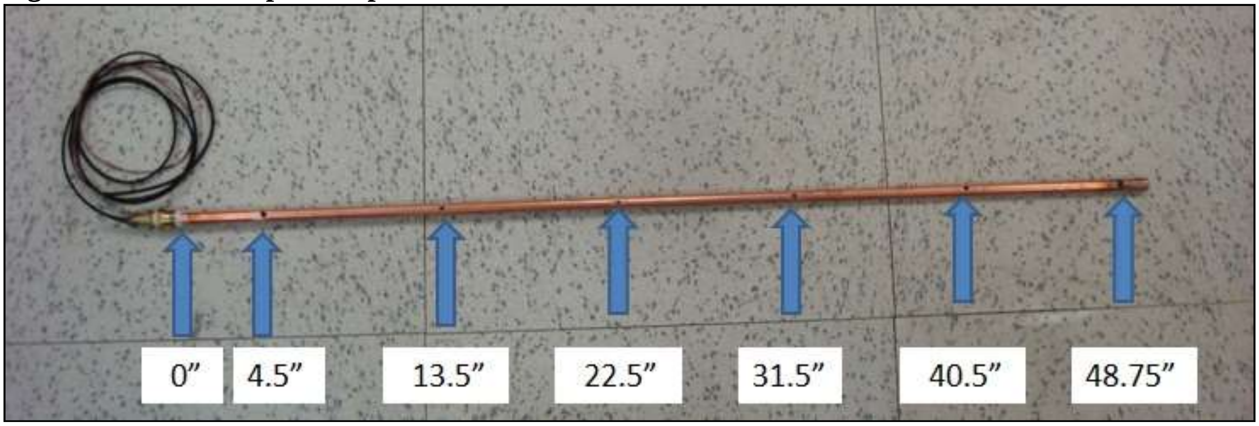


Figure 4. Power Measurement Current Transducers

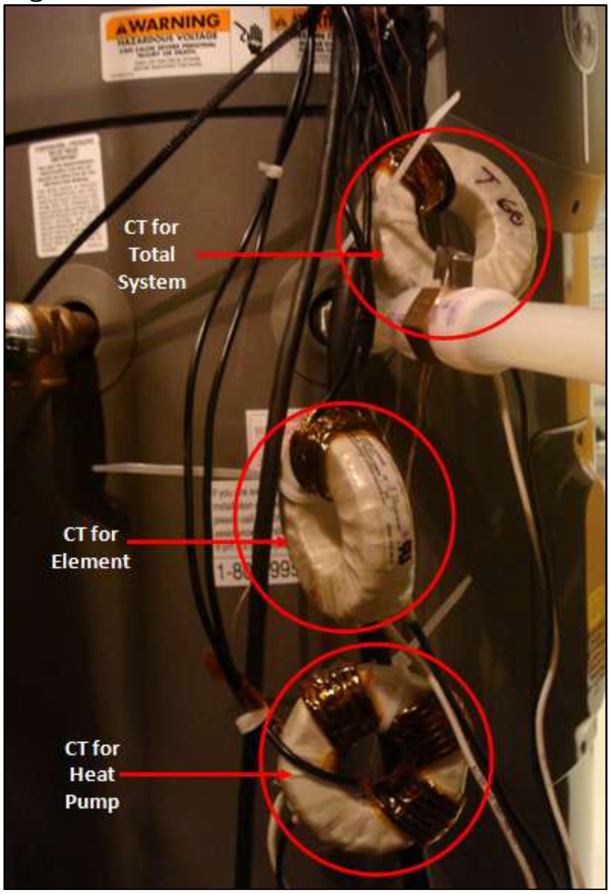
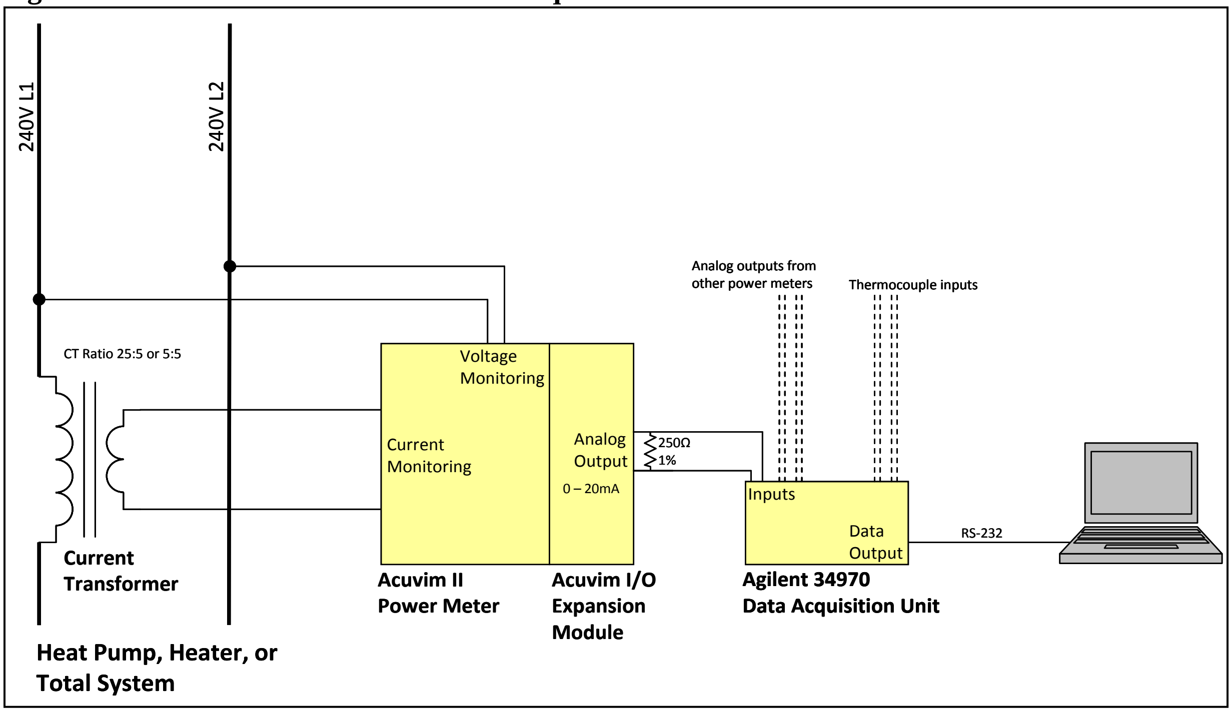


Figure 5. Power Measurement and Data Acquisition Schematic



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 rather than copper.
- The lab took inlet and outlet water temperature measurements two feet from the tank.

In all, Ecotope expects the deviations from the standard protocol to produce minimal differences in testing outcomes. If anything, it expects the differences in platform and piping to slightly reduce the heat loss rate of the tank, thereby improving performance.

3. Findings: Equipment Characteristics

3.1. Basic Equipment Characteristics

The HB50 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 axial fan draws ambient air from above the unit, pulls it through the filter, across the evaporator coils, and exhausts colder air around the periphery. The unit is designed to operate in free-standing air with no inlet or outlet ducting attached. The refrigerant condenser, which transfers heat to the water, is wrapped around the lower portion of the tank underneath the insulation but outside the tank wall.

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 Rheem's equipment specifications (Rheem Water Heating *Spec Sheet*).

As with traditional electric tank water heaters, the HB50 contains two electric resistance heating elements. The upper element draws 4.5kW while the lower element in the tank draws 2.5kW. The third heating component for the tank is the heat pump compressor. Measurements show the compressor draws 560W[1] to 1,030W[2] depending on both tank water and ambient air conditions. Depending on the operating mode of the equipment, the controls for the HB50 are configured to operate each of the three heating components – compressor, upper resistance element, and lower resistance element – concurrently or independently.

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 ~11W[3], and the control circuits use a constant ~1W. According to the manufacturer, the fan changes between low and high speed based on ambient and refrigerant temperatures.

The HB50 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 in nominal size versus actual size is not unique to HPWHs and occurs with traditional electric resistance and gas tanks as well.

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[1] Observed during the number-of-showers test with water temperature near the condenser of ~60°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.
[3] Fan has high and low speeds – power measured at unknown speed.

The HB50 uses R-410a refrigerant. R-410a has lower condensing temperatures than does 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 HB50 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 Rheem HB50

	Laboratory Measurement	**Manufacturer's Specification**
Upper Element (W)	4,500	4,500
Lower Element (W)	2,500	2,500
Compressor* (W)	590-1,030	790-1,000
Standby (W)	1	--
Fan† (W)	11	--
Airflow Path	Inlet on top. Exhaust to periphery.	Inlet on top. Exhaust to periphery.
Airflow (CFM)	--	200-350
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 ambient air temperature range from 50°F to 68°F.
†Fan has high and low speed – power measured at unknown speed.

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. Rheem has developed several control strategies, referred to as operating modes, to determine equipment operation. The HB50 has four basic modes, shown below in order of most efficient to least efficient:

- "Heat Pump Only" – compressor only
- "Energy Saver" – combination of compressor and resistance elements
- "High Demand" – combination of compressor and resistance elements where the elements engage more readily than in Energy Saver mode
- "Electric Heat Only" – 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 (from two to twenty-eight days, or indefinitely).

The testing protocol did not call for a rigorous quantification of operating modes. Instead, this report presents a qualitative description with both observations from the tests themselves and input from the manufacturer. The tank has two temperature sensors, which monitor the upper and lower parts of the tank. As the temperature changes at each sensor, the control logic will decide to activate the heat pump, lower element, or upper element.

Heat Pump Only Mode: As the name implies, only the compressor runs in this mode, in which no resistance heat used. The heat pump engages when the lower temperature sensor gets cold enough.

Energy Saver Mode: All of the testing was conducted with the HPWH in "Energy Saver" mode, which provides the most observational data of all the modes. In this mode, the tank first responds to decreases in tank temperature by activating the heat pump. If a hot water draw continues, as in the DOE 1-hour test, and the upper portion of the tank cools, the heat pump turns off and the upper element engages. After the upper portion of the tank is heated, either the lower element or the heat pump will engage to heat the bottom portion of the tank. In the case of recovery from deep draws, the lower element appears to be used to heat the lower tank some of the way back to setpoint, and then the heat pump engages to finish the recovery. In this mode, only one heating component operates at a time.

High Demand Mode: According to Rheem, this mode uses a combination of heat pump and elements to heat the water. The tank will respond to all situations with simultaneous use of the heat pump and elements. In such a way, the equipment provides more heating capacity to the water.

Electric Heat Only Mode: The mode will use only the resistance elements in the usual way a typical all-resistance heater operates. No compressor is used.

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. The first (1-hour) 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 HB50 in Energy Saver mode – the default setting on the equipment when shipped by Rheem. 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, the conditions used to determine the Northern Climate Energy Factor.

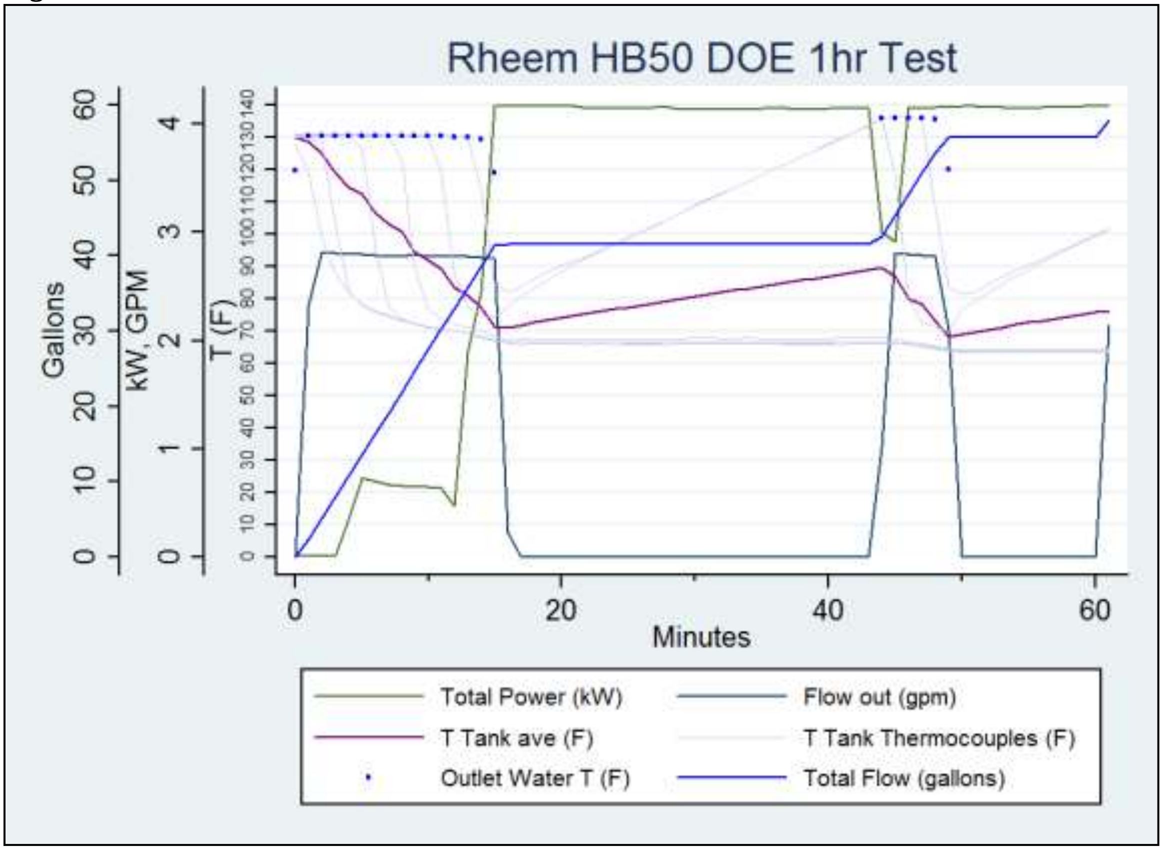
Table 2. Performance Characteristics for Rheem HB50

	Laboratory Measurement	Specification Sheet
First Hour Rating (gal)	56	57
Energy Factor (std conditions)	2.48	2.45
Energy Factor @ 50°F Ambient	2.23	--
Northern Climate Energy Factor	2.18	--
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. The test begins with a 3gpm draw. Approximately four minutes into the first draw, the heat pump activates (green line showing 0.6kW). As the draw continues past thirteen minutes, the water temperature at the upper sensor falls, which triggers the upper resistance element. The element continues to run until minute forty-three. At that time, the upper portion of the tank has recovered to setpoint, thus switching off the upper element. Per the DOE test method, this triggers another draw since the water at the top of the tank is now hot. That draw terminates six minutes later, while the upper element reactivates and stays on to the conclusion of the test.

Figure 6. DOE 1-Hour Test



Notes: 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 HB50, the test data show 32.8 gallons, equivalent to seventy-three percent 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 eighteen 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 test results demonstrated 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. 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 (for details, see the Northern Climate Heat Pump Water Heater Specification). In the calculations, Ecotope used the 42°F temperature bin cutoff as determined in lab testing discussed in subsequent sections.

Figure 7 shows the first seven hours of the test so the draw events and recovery can be examined in more detail. Figure 8 shows the full 24 hours, which also illustrates the tank heat loss rate. These two figures plot the same type of data as Figure 6. The figures show a distinct difference between the 1-hour and 24-hour tests. During the former, the tank uses both compressor and resistance heat to meet the high demands of the test while the latter exclusively uses the compressor.

Figure 7 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 generally assumed to be 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 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 2.1 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 7. DOE 24-Hour Simulated Use Test, First Seven Hours

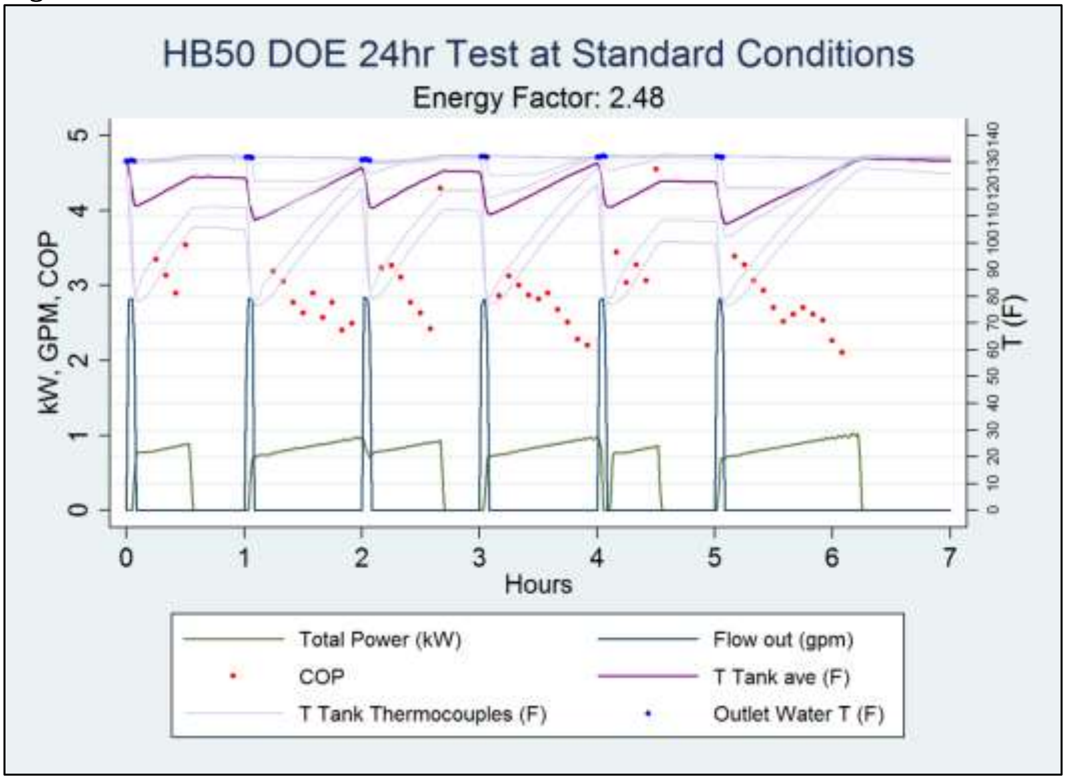


Figure 8. DOE 24-hour Simulated Use Test. Full 24 hours.

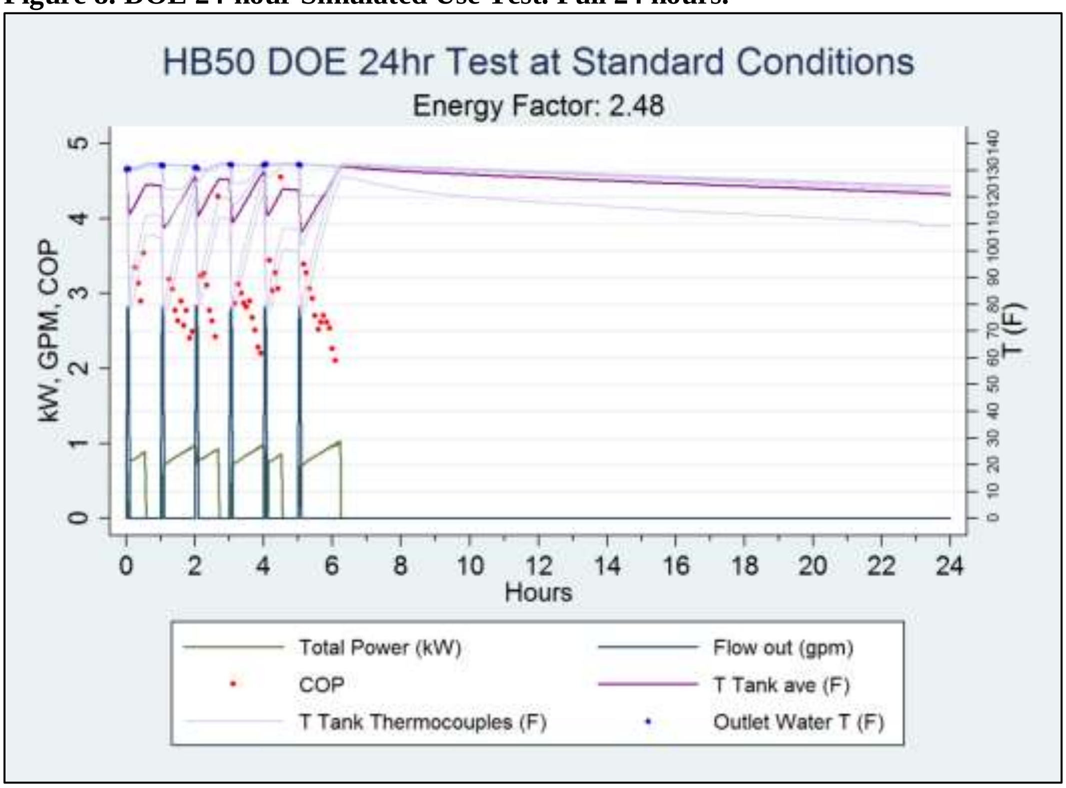


Figure 9 and Figure 10 plot the heat pump behavior for the 50°F ambient air and 50°F inlet water 24-hour testing conditions. For the 50°F ambient test, the lab found it necessary to use a tank setpoint of 137°F. That setpoint achieved the acceptable test starting condition with the tank temperature 135°F±5°F. In contrast to the test at 67°F ambient air, the unit runs almost the entire time between the start of the test and hour 6.5, when the tank is fully recovered. As expected with the lower ambient air temperature, the equipment runs approximately 1.5 hours longer to recover the tank. Accordingly, the compressor COPs also show up lower at 50°F ambient, ranging from 1.9 to 3.3.

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

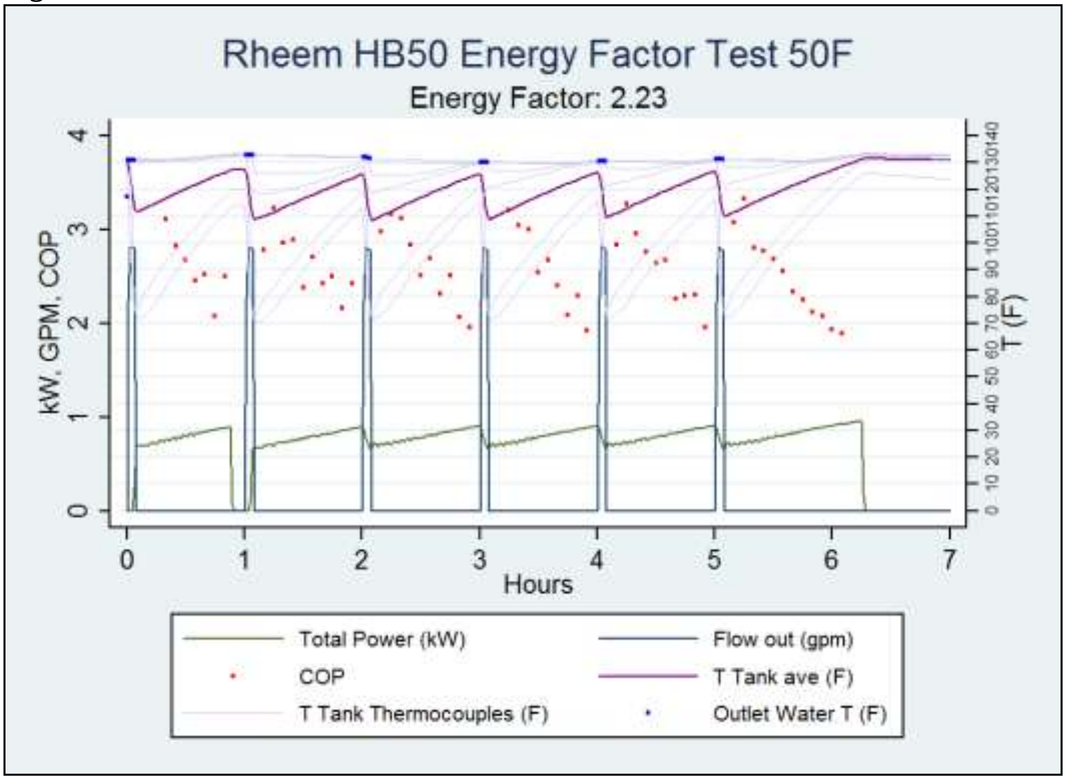
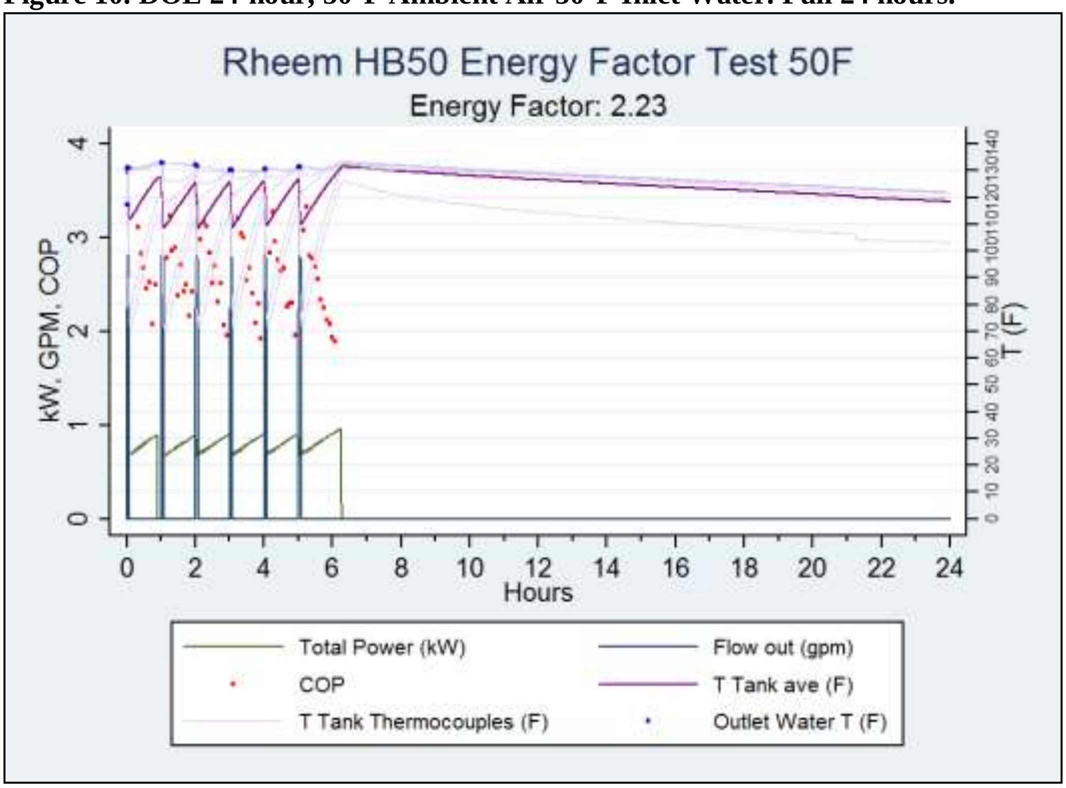


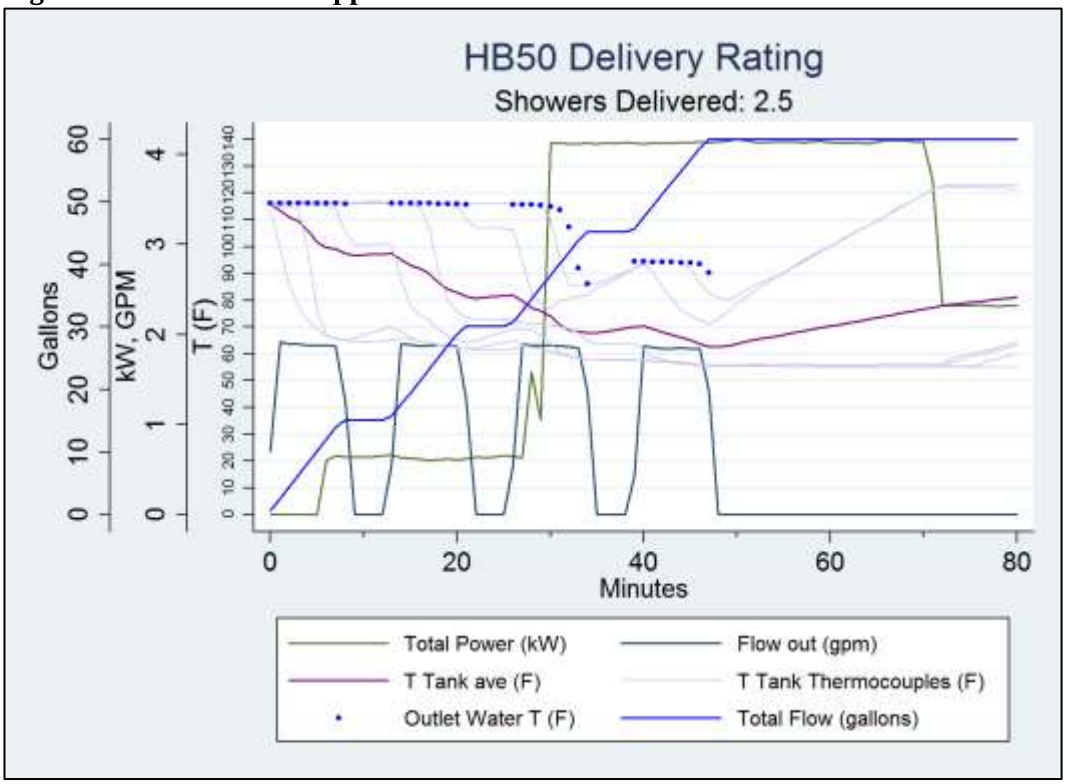
Figure 10. DOE 24-hour, 50°F Ambient Air 50°F Inlet Water. Full 24 hours.



4.2. Efficient Showers Test

In addition to the standard and modified DOE tests, the Northern Climate Specification calls for a delivery rating test to better understand performance. This simulated-use, "Shower Test" (DP-SHW) 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 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 current draw was allowed to finish, the tank to recover, and the test concluded. Based upon the findings of this test, the HB50 water heater provides 2.5 consecutive efficient showers. The results of the test are displayed in Figure 11.

Figure 11. Shower Test Supplemental Draw Profile



Both the DOE 1-hour and DP-SHW tests amount to delivery ratings. 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. Those tanks, with only one means with 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, 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.[4] 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 baths, or two bedrooms with up to 2.5 baths. The HB50's first hour rating of 56 gallons shows that it can satisfy the latter of the two 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 provide 2.5 consecutive morning showers without using the resistance elements, demonstrating its suitability for medium-sized households. 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. For larger draws (i.e. more or longer showers in the morning), both the DP-SHW and DOE 1-hour tests show, in the default Energy Saver mode, the HB50 tank will switch to the less-efficient resistance heating.

4.3. Low Temperature Limit Tests

To calculate the Northern Climate Energy Factor and to explore the low temperature operating limits of the HB50 heat pump system, Cascade Engineering conducted several low temperature limit tests. Following the method used in the Northern Climate specification, the tests look for the lowest temperature at which the compressor will continuously run. Using the heat-pump-only mode, the lab placed the HB50 inside the thermal chamber, allowed the ambient air temperature to stabilize, allowed the HPWH water to stabilize, and then initiated the test with a fifteen-gallon draw. The test is deemed successful if the compressor runs and the tank temperature recovers.

The Northern Climate test procedure sets the ambient air temperature in steps of 5°F-wide temperature bins (for example: 32°F, 37°F, 42°F, 47°F). The lab tested the HB50 first at 37°F and 42°F, and then in individual increments of one degree, to pinpoint the low temperature limit. The testing showed intermittent compressor operation at 37°F and continuous operation at 42°F. Further investigation showed the lower operating limit to be 40°F for this particular unit. Close examination of the test data showed that the actual ambient temperature inside the chamber fluctuated usually one, but sometimes two, degrees Fahrenheit during the test – an expected

[4] 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.

fluctuation given how thermal chambers operate. More importantly, this level of fluctuation is within the tolerances of the testing specifications. Consequently, Ecotope concluded that the compressor operates to 40°F±2°F. That finding shows a slightly higher temperature than the manufacturer's reported low compressor cutoff of 37°F and below.

4.4. Noise Measurements and Additional Observations

The lab also 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 at ~65°F. Table 3 shows the background levels and the averages of the five measurements.

Table 3. Sound Level Measurements for Rheem HB50

	Background	HPWH On
dBA	38	56.9
dBC	63	66.9

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.

4.4.1. Compressor Output Capacity

All the test data show that the system was designed to maximize compressor output and efficiency within the geometric constraints of the integrated HPWH shape. The evaporator heat exchanger, wrapped around the upper periphery of the unit, is sized large enough to support the compressor at an output of nearly three-quarters of a ton. More specifically, the 24-hour testing at 67.5°F showed the compressor has an average heating capacity of roughly 2.4kW or 8,100 Btu/hr. At 50°F, for the modified 24-hour test, the average capacity is 2.1kW or 7,100 Btu/hr. The drop in capacity is expected given the decreased ambient air temperature; nevertheless, the large heat exchange area acts to preserve the capacity as the ambient temperature decreases. Starting with a high heating capacity and maintaining it as the temperature drops is an important indicator that the heat pump will perform well in actual installations. A higher capacity means the tank can heat up more quickly with solely the heat pump, which can then obviate the need for more backup resistance heating.

5. Conclusions

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

- The tank is well-insulated and the heat pump system is efficient. The evaporator heat exchanger is wrapped around nearly the entire upper periphery of the unit save for the area needed for the display. Compared to other integrated HPWHs, this design creates a larger heat exchange surface, which improves efficiency.

- The compressor output is sized large enough to exploit heat pump efficiency. Further, the compressor maintains a relatively high output as the temperature drops, which is an important indicator that the heat pump will perform well in actual installations. A higher capacity means the tank can heat up more quickly solely with the heat pump, which can obviate the need for more backup resistance heating.

- The heat pump ambient temperature operating range runs from ~38°F to 120°F, making the unit well-suited for any garage, basement, or buffer space installation in the Northwest. Although the low-range temperature is only a few degrees colder than the more typical 45°F, the expanded range helps to ensure that the equipment can run in buffer spaces the vast majority of the year using the heat pump.

- The results of the number-of-showers test show that the small storage volume and compressor output capacity will tend to reduce operating efficiencies for households with more than 2.5 morning showers (or other similar peak demands). In contrast, the relatively large compressor output capacity will provide more water heat more quickly with the heat pump without having to resort to resistance backup.

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Appendix A: Testing Matrices

Testing Matrix: Rheem HB50

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	67.5	20	57	14	50%	58	14	135	57	0.0"	"Energy Saver"	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	0.0"	"Energy Saver"	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	0.0"	"Energy Saver"	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"	"Energy Saver"	Draw Profile: DP-SHW. Conduct identical, repeated draws until ending conditions observed.

Compressor Cut-off Temperature

CMP-T	*	*	*	*	60%	58	14	135	57	0.0"	"Heat Pump Only"	Goal is to verify low temperature limit to compressor operation.

Additional Observations

AO-VOL	Measure tank water volume			
AO-PWR	One-time measurements of component power		"Energy Saver"	Make one-time measurement of fan power draw, circuit board power draw (if possible), and of any system components.

Noise Measurement

NOI	Measure combined fan and compressor noise	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 using a hand-held meter.

Appendix B: Measurement Instrumentation List

Equipment	Make and Model	Function	Accuracy	Calibration Date
Walk-in Chamber	Make : ESPEC, Model No.: EWSX499-30CA	Test environment temperature and relative humidity control	±1 °C	8/13/2012
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	7/31/2012
Thermocouple	OMEGA, T type	Temperature measurement	0.8 °C	Note 1
Power Meter	Acuvim II – Multifunction Power Meter with AXM-I02 I/O Module	Continuous power measurement as necessary (system, 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	Note 2
Power Meter	Voltech PM100 Single Phase Power Analyzer	One-time fan power measurement	Voltage: +/- 0.1% Current: +/- 0.1% Power: +/- 0.2%	10/5/2012
Flow Control	Control: Systems Interface Inc. Flow meter: Signet 2537 paddlewheel	Water draw rate and amount control	Note 3	Note 3
Electronic Scale	OXO "Good Grips" Scale	Measurement of water mass	5.0 Kg full scale with 1 g increment	8/16/2012
Hand-held Temperature and Humidity Meter	Omega RH820W	Lab environment temperature and humidity measurement	± 0.5° C	Note 6
Electronic Scale	Dymo Pelouze Model: 4040 Range 180 Kg	Measurement of water mass	± 0.2 Kg	Note 6
Air Flow Meter	Digital Pressure Gauge Model DG-2, Make: Energy Conservatory	Air flow pressure and air flow rate measurement		Note 4
Inlet Water Conditioning System	Temp control: TCS-4010	Conditioning of unit under test inlet water temperature	± 1 °C	Note 5

Notes:

1. Thermocouples are calibrated using Omega CL1500 system.
2. Each Acuvim II along with current transformer is checked against a calibrated power/current meter.
3. Flow control is checked by actual collected water weight measurement at required GPM.
4. Airflow meter is provided by Ecotope.
5. This is not used for inlet water temp data used in calculations.
6. Checked against calibrated instrument/device.