NEEA Report: Laboratory Assessment of A. O. Smith SHPT-50 Heat Pump Water Heater

Prepared by:
Ben Larson, Nicholas Kvaltine, 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 A. O. Smith model # SHPT-50 heat pump water heater (HPWH) for northern climate installations, the third HPWH in A. O. Smith’s Voltex line. Cascade Engineering evaluated the SHPT-50 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 2012). 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 SHPT-50 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: 2.09
  - Percent of tank drained before resistance elements engage in 1-hour test: 41%
  - Number of consecutive, sixteen-gallon, efficient showers: 2.5
  - Sound level: 54 dBA

- The SHPT-50 offers a significantly changed, if not totally new, design compared to the 60- and 80-gallon Voltex HPWHs from A. O. Smith. The compressor, fan, user interface, component layout, airflow path, and control strategy all differ from the larger A. O. Smith models; in addition, the manufacturer has replaced the lower resistance element with one capable of 4.5 kW output, compared to 2 kW for the larger models.

- The tank has the highest energy factor (EF), at 67.5°F, observed to date for any integrated HPWH tested by Cascade Engineering and Ecotope.

- As with some other 50-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 that 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 heat pump ambient temperature operating range reached as low as 42°F, in contrast to the 45°F of the other Voltex equipment. In further contrast to the larger Voltex HPWHs, this unit has no exhaust air ducting capability.

- Overall, the smaller physical size of the SHPT-50 will allow the tank to fit in 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 those of the 60- and 80-gallon tanks when presented with large water draws.
1. Introduction

The Northwest Energy Efficiency Alliance (NEEA) contracted with Ecotope, Inc. and Cascade Engineering Services, Inc. to conduct a laboratory investigation of the A. O. Smith model # SHPT-50 heat pump water heater (HPWH) for northern climate installations. Cascade Engineering Services of Redmond, WA evaluated the SHPT-50 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 2012). 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 U.S. 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 SHPT-50 is the third product in A. O. Smith’s Voltex line. It adds to the 60- and 80-gallon products currently available and previously evaluated under the Northern Climate HPWH Specification (Larson and Logsdon, February 2012). As the product model number implies, the new water heater has a 50-gallon storage tank, making it the smallest in the lineup. The equipment measures 22” in diameter and 63” tall, in contrast to 24.5” in diameter and 67” tall for the 60-gallon tank. The smaller footprint means the tank can squeeze into tighter spaces. In addition to its smaller tank size, this HPWH appears to be significantly redesigned compared to the earlier, larger Voltex models. The fan, airflow path, and compressor differ from those in the 60- and 80-gallon sizes. The air in this HPWH is drawn in through the top of the unit and exhausted on one side instead of being drawn across from one side to the other. The new tank also has a 4.5 kW lower heating element, compared to the 2 kW element of the larger models. It retains a 4.5 kW upper heating element.
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
- Northern Climate Specification for Heat Pump Water Heaters
  [http://neea.org/northernclimatespec](http://neea.org/northernclimatespec)
- U.S. Department of Energy (DOE) testing standards from Appendix E to Subpart B of 10 CFR 430

This section provides 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 cut-off 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. General Test Setup
Figure 2 is a schematic of the general test setup. Cascade Engineering installed an instrumentation package to measure the required points specified by the DOE test standard as well as additional points to gain further insight into HPWH operation. A tree of six thermocouples positioned at equal water volume segments measured tank water temperature (Figure 3 – arrows indicate measurement points). Cascade Engineering measured inlet and outlet water temperatures with thermocouples immersed in the supply and outlet lines. Three thermocouples mounted to the surface of the evaporator coil at the refrigerant inlet, outlet, and midpoint monitored the coil temperature to indicate the potential for frosting conditions. Power for the equipment received independent monitoring for the entire unit, the compressor, and the resistance elements (Figure 4). 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

Figure 4. Power Measurement and Data Acquisition Schematic

Ecotope, Inc. 5
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 the following exceptions:

- 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 20 psi 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 A. O. Smith SHPT-50 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, and

(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. For reference purposes, the table also shows the values given by A. O. Smith’s product specifications (A. O. Smith 2014).

As with traditional electric tank water heaters, the SHPT-50 contains two electric resistance heating elements. Located in the upper and lower portions of the tank, each element draws 4.5 kW. The third heating component for the tank is the heat pump compressor. Measurements show the compressor draws 350W\(^1\) to 580W\(^2\) 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 ~38W, and the control circuits use a constant ~1W.

The SHPT-50 has a nominal 50-gallon capacity, but measurements showed the unit in the lab held 45 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.

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\(^1\) 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 A. O. Smith SHPT-50

<table>
<thead>
<tr>
<th></th>
<th>Laboratory Measurement</th>
<th>Manufacturer's Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Element (W)</td>
<td>4500</td>
<td>4500</td>
</tr>
<tr>
<td>Lower Element (W)</td>
<td>4500</td>
<td>4500</td>
</tr>
<tr>
<td>Compressor* (W)</td>
<td>350-580</td>
<td>na</td>
</tr>
<tr>
<td>Standby (W)</td>
<td>1</td>
<td>--</td>
</tr>
<tr>
<td>Fan (W)</td>
<td>38</td>
<td>--</td>
</tr>
<tr>
<td>Airflow Path</td>
<td>Inlet on top. Exhaust out the side.</td>
<td>Inlet on top. Exhaust out the side.</td>
</tr>
<tr>
<td>Refrigerant</td>
<td>R-134a</td>
<td>R-134a</td>
</tr>
</tbody>
</table>

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.

Compared to the 60- and 80-gallon products in A. O. Smith’s HPWH line, the 50-gallon tank shows differences that are likely to alter operational and performance characteristics. Previous work provides details on the 60- and 80-gallon tanks and is referenced throughout the remainder of this section (Larson and Logsdon, 2011 and Larson and Logsdon, February 2012). First, the compressor draws less power and also provides less heating capacity. The larger equipment draws 550-1100W of power at the compressor, approximately double that of the SHPT-50. Second, the airflow regime is altered by using a smaller, axial fan than that used in the larger models; in addition, the air in the SHPT-50 flows from the top of the tank and exhausts to the side. Given the lower power measured on the new fan, the previously-available ducting kits will likely not work with the 50-gallon tank. Third, the lower resistance element in this model is 4500W instead of 2500W. The upper element remains at the same power. A larger-capacity lower element will decrease the time it will take to reheat a completely cold tank in all resistance operation.
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. A. O. Smith has developed several control strategies, referred to as operating modes, to determine equipment operation. The SHPT-50 has three basic modes of operation, shown below in order of most efficient to least efficient:

- “Efficiency” – compressor only
- “Hybrid” – combination of compressor and resistance elements
- “Electric” – no compressor usage – upper and lower elements only

Another operating mode – “Vacation” – exists, but is basically a tank temperature setback option (to 60°F) for use while the occupants are not in the house for extended periods (1-99 days).

By referencing the operating manual and observing the equipment during testing, Ecotope compiled the descriptions of control strategies given below.

**Efficiency Mode:** Only the heat pump is allowed to operate. It provides the highest level of efficiency and heats only with the refrigeration cycle. The heat pump appears to operate on a 10°F temperature dead band; when the temperature in the lower portion of the tank drops 10°F below the setpoint, whether through a draw event or standby heat losses, the heat pump turns on. If the ambient temperature conditions exceed the operating range, which is listed in the user manual as ambient air between 45°F and 120°F and tank water above 59°F, the resistance elements will be used until the temperatures return to a normal range.

**Hybrid Mode:** In hybrid mode, all three heating components – the lower element, upper element, and heat pump – can operate. Moreover, the heat pump and one of the elements may operate together in tandem. In response to a draw or decrease in tank temperature, the heat pump turns on as it does in Efficiency (heat pump-only) mode, that is, when the temperature sensor notices a drop in temperature from the setpoint. As the temperature drops further, the compressor remains activated while one of the resistance elements engages. Testing showed that the upper element generally engages first while the heat pump remains on. For large draws, such as those in the first hour rating or number of showers tests, after the upper element reheated the top of the tank, the controls switched on the lower element, concurrent with the heat pump, to finish reheating the entire tank. In contrast, for smaller draws, such as in the 24-hour tests, once the upper portion of the tank was hot, the controls turned off all elements to allow the tank to recover with the heat pump alone. The controls difference is dramatic for the efficiency of the reheat cycle. The exact temperature dead bands were not determined through either testing or literature review.

**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.
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 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 lab conducted the tests with the SHPT-50 in hybrid mode – the default setting on the equipment when shipped by A. O. Smith. 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>
<thead>
<tr>
<th>Metric</th>
<th>Measured Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Hour Rating (gal)</td>
<td>63.5</td>
</tr>
<tr>
<td>Energy Factor (std. conditions)</td>
<td>2.69</td>
</tr>
<tr>
<td>Energy Factor @ 50°F Ambient</td>
<td>1.85</td>
</tr>
<tr>
<td>Northern Climate Energy Factor</td>
<td>2.09</td>
</tr>
<tr>
<td>Tank Heat Loss Rate (Btu/hr°C F)</td>
<td>2.9</td>
</tr>
</tbody>
</table>

4.1.1. 1-hour Test
The data from the 1-hour test are plotted in Figure 5. The test begins with a 3 gpm draw. Approximately five minutes into the first draw, the tank temperature has fallen enough to activate the heat pump, followed quickly by a resistance element (yellow line showing 4.5 kW). As the draw continues past 13 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 37 minutes and continues for several minutes. The components continue heating, cycling between upper and lower elements in response to the tank temperature conditions. The final draw (per the DOE test method) triggers around 57 minutes. Since this draw was still in process at 60 minutes, per test procedure it was continued until the outlet temperature reached 25 degrees below the setpoint, at the 63rd minute.

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 SHPT-50, the test data show 18.6 gallons, equivalent to 41% 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 lab used the equipment in 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 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 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 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 24 hours, which also illustrates the tank heat loss rate. These two figures plot the same type of data as Figure 5. Figure 7 shows that as the overall tank temperature falls approximately 10° F below the setpoint, the compressor engages (near hour 22) to reheat the water.

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 generally taken 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 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).

Figure 8 and Figure 9 plot the heat pump behavior for the 50° F ambient air and 50° F inlet water 24-hour testing conditions. The graphs look similar to those plotted for 67° F ambient air, with the exception that the upper resistance element turns on after the fourth draw. This significantly lowers the energy factor in this test compared to the other 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 is hot, 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.
Figure 6. DOE 24-Hour Simulated Use Test, First Eight Hours

Figure 7. DOE 24-hour Simulated Use Test, Full 24 Hours
Figure 8. DOE 24-hour, 50° F Ambient Air 50° F Inlet Water, First Ten Hours

Figure 9. 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 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 specification is 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 SHPT-50 water heater provides 2.5 consecutive efficient showers. The results of the test are displayed in Figure 10.

Figure 10. Shower Test Supplemental Draw Profile

Both the DOE 1-hour and number of showers 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 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. Those 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, the 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 number of bathrooms and bedrooms. Both are proxies, respectively, for water demand and number of people in a house. The UPC requires a minimum first hour rating of 67 gallons for 3 bedrooms and 2 to 3.5 baths. The next-lower rating of 54 gallons covers 3 bedrooms with up to 1.5 baths, or 2 bedrooms with up to 2.5 baths. With the manufacturer-reported first hour rating of 67.5 gallons in hybrid mode, the SHPT-50 would meet the requirements of the UPC for any of the aforementioned scenarios.

The SHPT-50 test shows that although it satisfies the capacity requirements of the UPC recommendations for a 3 bedroom 2 bath house, its efficiency would suffer because of reliance on the electric heating elements. 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 that the resistance elements engage early in the third shower and do not shut off for nearly an hour. 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 scenario demonstrates that households with three morning showers, using hybrid mode, will see reduced efficiency benefits for that usage.

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.

### 4.3. Low Temperature Limit

The lab testing observed the compressor operating at 47°F and 42°F, but not at 37°F. The Northern Climate Specification sets the compressor cut-off temperature at 42°F, which is slightly colder than the manufacturer’s specification of 45°F. 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. The lab conducted the test at an ambient temperature of ~72°F. Table 3 shows the background noise levels and the averages of the five measurements.

| Table 3. Sound Level Measurements for A. O. Smith SHPT-50 |

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3 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.
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.

<table>
<thead>
<tr>
<th>Decibel Weighting</th>
<th>Background</th>
<th>HPWH on</th>
</tr>
</thead>
<tbody>
<tr>
<td>dBA</td>
<td>37</td>
<td>54</td>
</tr>
<tr>
<td>dBC</td>
<td>57</td>
<td>66</td>
</tr>
</tbody>
</table>
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 SHPT-50 offers a significant redesign compared to the 60- and 80-gallon Voltex HPWHs from A. O. Smith. The compressor, fan, user interface, component layout, airflow path, and control strategy are different, and the lower resistance element has been replaced with one capable of 4.5 kW output, compared to 2 kW for the larger models.

- The new unit, in hybrid mode, boasts an energy factor of 2.75 and an $\text{EF}_\text{NC}$ of 2.09. Overall, the heat pump system alone has a higher efficiency than the 60- and 80-gallon Voltex equipment, which helps deliver a higher EF rating. The lab observed a slightly lower operating range for the SHPT-50, to 42° F, which helps to improve its Northern Climate Energy Factor.

- The tank has the highest energy factor, at 67.5° F, observed for any integrated HPWH tested by Cascade Engineering and Ecotope to date. Due in large part to its smaller storage volume than the 60- or 80-gallon Voltex models, its EF at 50° F is lower.

- The SHPT-50’s revised control strategy in hybrid mode will yield energy use in the field that differs from the larger Voltex HPWHs. 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 addition to the compressor will increase energy use. For small draws, the lower element is not used.

- The SHPT-50’s heat pump output capacity is smaller than that of the larger Voltex tanks. The smaller output increases the relative size of the evaporator coil (and therefore efficiency), but trades off against recovery time when running the compressor.

- Overall, the smaller physical size of the SHPT-50 will allow the tank to fit in 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 in-field operating efficiencies than those of the 60- and 80-gallon tanks when presented with large water draws.
References


https://conduitnw.org/_layouts/Conduit/FileHandler.ashx?RID=1522


Appendix A: Testing Matrices

Testing Matrix: A. O. Smith SHPT-50

### DOE Standard Rating Point Tests

<table>
<thead>
<tr>
<th>Test Name</th>
<th>Ambient Air Conditions</th>
<th>Inlet Water</th>
<th>Outlet Water</th>
<th>Airflow</th>
<th>Operating Mode</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry-Bulb</td>
<td>Wet-Bulb</td>
<td>RH</td>
<td>F</td>
<td>C</td>
<td>F</td>
</tr>
<tr>
<td>DOE-1-hour</td>
<td>67.5</td>
<td>20</td>
<td>57</td>
<td>14</td>
<td>50%</td>
<td>58</td>
</tr>
<tr>
<td>DOE-24-hour</td>
<td>67.5</td>
<td>20</td>
<td>57</td>
<td>14</td>
<td>50%</td>
<td>58</td>
</tr>
<tr>
<td>DOE-24-hour-50</td>
<td>50</td>
<td>10</td>
<td>44</td>
<td>7</td>
<td>58%</td>
<td>50</td>
</tr>
</tbody>
</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, & 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

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Make and Model</th>
<th>Function</th>
<th>Accuracy</th>
<th>Calibration Expiration Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walk-in Chamber</td>
<td>Make: ESPEC, Model No.: EWSX499-30CA</td>
<td>Test environment temperature and relative humidity control</td>
<td>±1 °C</td>
<td>8/13/2013</td>
</tr>
<tr>
<td>Data Acquisition System</td>
<td>Make: Agilent Technologies, Model No.: Agilent 34970A</td>
<td>Log temperature, power, and flow rate data</td>
<td>Voltage: 0.005% of reading + 0.004% of range</td>
<td>7/31/2013</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Temperature: (Type T):1.5 °C</td>
<td></td>
</tr>
<tr>
<td>Thermocouple</td>
<td>OMEGA, T type</td>
<td>Temperature measurement</td>
<td>0.8 °C</td>
<td></td>
</tr>
<tr>
<td>Power Meter</td>
<td>Acuvim II – Multifunction Power Meter with AXM-102 I/O Module</td>
<td>Continuous power measurement as necessary (system, heater, and heat pump)</td>
<td>Main Unit: 0.2% full scale for voltage and current AXM-102 Analog Output: 0.5% full scale + 1% resistor tolerance</td>
<td>Note 2</td>
</tr>
<tr>
<td>Power Meter</td>
<td>Voltech PM100 Single Phase Power Analyzer</td>
<td>One-time fan power measurement</td>
<td>Voltage: +/- 0.1% Current: +/- 0.1% Power: +/- 0.2%</td>
<td>10/5/2013</td>
</tr>
<tr>
<td>Flow Control</td>
<td>Control: Systems Interface Inc. Flow meter: Signet 2537 paddlewheel</td>
<td>Water draw rate and amount control</td>
<td>Note 3</td>
<td></td>
</tr>
<tr>
<td>Electronic Scale</td>
<td>OXO “Good Grips” Scale</td>
<td>Measurement of water mass</td>
<td>5.0 Kg full scale with 1 g increment</td>
<td>8/16/2013</td>
</tr>
<tr>
<td>Hand-held Temperature and Humidity Meter</td>
<td>Omega RH820W</td>
<td>Lab environment temperature and humidity measurement</td>
<td>± 0.5 °C</td>
<td>Note 5</td>
</tr>
<tr>
<td>Electronic Scale</td>
<td>DYMO Pelouze Model: 4040 Range 180 Kg</td>
<td>Measurement of water mass</td>
<td>± 0.2 Kg</td>
<td>Note 5</td>
</tr>
<tr>
<td>Inlet Water Conditioning System</td>
<td>Temp control: TCS-4010</td>
<td>Conditioning of unit under test inlet water temperature</td>
<td>± 1 °C</td>
<td>Note 4</td>
</tr>
</tbody>
</table>

**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. This is not used for inlet water temperature data used in calculations.
5. Checked against calibrated instrument/device.