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Laboratory Assessment of Rheem Generation 5 Series Heat Pump Water Heaters

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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 Rheem's next generation (Generation 5 or "Gen5") heat pump water heaters (HPWHs). The water heater series consists of two distinct lines: a Premium/Plus line and a Builder line, each aimed at different market segments. Each line includes four tank sizes: 40, 50, 65, and 80 gallons. Cascade Engineering evaluated the 40-gallon Premium, 50-gallon Premium, and 50-gallon Builder products using a testing plan developed by Ecotope to assess HPWH performance.[1]

The goal of the work was to evaluate the products using the Advanced Water Heater Specification (AWHS) (NEEA 2019). The test matrix, specified fully in Appendix A, includes the standard US Department of Energy (DOE) 24- and 1-hour tests (the "UEF" tests released in 2014), as well as low-ambient temperature tests, a high volume draw test, and sound level measurements.

Overall, the results suggest that the Rheem Generation 5 Premium and Builder water heaters, also referred to in this report as the Gen5p and Gen5b, are highly efficient. Comprehensive results were achieved through a combination of direct observation at Cascade Engineering Services and a collaborative test result reporting effort from Rheem.

Specific findings from testing at Cascade Engineering Services include the following:

	Unit		
Metric	**Gen5p40**	**Gen5p50**	**Gen5b50**
Uniform Energy Factor from 24-hour test at 50 °F	2.81	2.91	2.76
Percent of 1st draw cluster before resistance elements engage in high volume test	74.3%	69.6%	67.9%
Compressor low-ambient temperature cutoff	37 °F	37 °F	37 °F
Sound Level	51.4 dBA[2]	49.6 dBA	49.0 dBA

Rheem provided the following data for tests previously conducted at their facility:

		Tank Size			
Product Line	**Metric**	**40**	**50**	**65**	**80**
Premium	UEF	3.78	3.86	3.85	4.0
	First Hour Rating (gal)	60	67	75	87
Builder	UEF	3.5	3.5	3.5	3.5

[1] Rheem contracted for the evaluation of the 50-gallon Premium and Builder products in accordance with the Advanced Water Heater Specification while NEEA separately funded research on the 40-gallon product and this comprehensive report.

[2] Sound level not representative of final production unit. This early-production model was shipped missing an insulation blanket on the compressor, which did exist on the Gen5p50. Sounds levels were lower when insulation blanket present. Consequently, the Gen5p50 is taken as the representative reading for the Premium/Plus product line.

First Hour Rating (gal)	60	67	75	87

The heat pump components within a product line are identical, which makes it possible to extend results (sound level, compressor cutoff, etc.) from different size units within the line. Consequently, combining the data from Cascade Engineering Services and Rheem yields the following Cool Climate Efficiencies for the 40-, 50-, 65-, and 80-gallon tanks respectively:

- Premium Product CCE[3]: 3.07, 3.16, 3.16, 3.21
- Builder Product CCE[4]: 2.94, 2.95, 2.94, 2.94

Taken as a whole, the results show the Premium/Plus product line meets the qualifications for Tier 4 within the AWHS, while the Builder product line meets the Tier 3 level. Other notable features include:

- The default operating mode, "Energy Saver," does not operate the lower resistance element in either product line.
- The Premium line offers load shifting grid connectivity by implementing the CTA-2045A standard on the water heater. The line also implements Rheem's integrated EcoNet® on-board Wi-Fi.
- The Builder line offers connectivity via Rheem's integrated EcoNet® on-board Wi-Fi.

[3] The E50 test was not conducted for the 65- and 80-gallon Premium products. To calculate the CCE, the E50 was set equal to the 50-gallon product due to identical heat pump components across platforms.
[4] The E50 test was not conducted for the 40-, 65-, and 80-gallon Builder products. To calculate the CCE, the E50 was set equal to the 50-gallon product due to identical heat pump components across platforms.

1. Introduction

The Northwest Energy Efficiency Alliance (NEEA) contracted with Ecotope, Inc. and Cascade Engineering Services, Inc. to conduct a laboratory assessment of Rheem's next generation (Generation 5 or "Gen5") heat pump water heaters (HPWHs). The water heater series consists of two distinct lines: A Premium/Plus line and a Builder line, each aimed at different market segments. Each line includes four tank sizes: 40, 50, 65, and 80 gallons. Cascade Engineering evaluated the 40-gallon Premium, 50-gallon Premium, and 50-gallon Builder products using a testing plan developed by Ecotope to assess HPWH performance.[5]

The tests included measurement of basic characteristics and performance including first hour rating and Department of Energy (DOE) Uniform Energy Factor (UEF); description of operating modes; measuring heat pump efficiency at lower ambient temperatures; conducting a high volume draw test; and measuring sound levels. Appendix A contains a table describing all tests performed for this report.

The Generation 5 Premium and Builder Series, also referenced in this report as the Generation 5 or Gen5, encompasses the following models from the Rheem, Richmond, and Ruud brands:

Premium/Plus Product Models

PROPH40 T2 RH375-SO	PROUH40 T2 RU375-SO	PROUH40 T2 RU375-30	10E40-HP515
PROPH50 T2 RH375-SO	PROUH50 T2 RU375-SO	PROUH50 T2 RU375-30	10E50-HP515
PROPH65 T2 RH375-SO	PROUH65 T2 RU375-SO	PROUH65 T2 RU375-30	10E65-HP515
PROPH80 T2 RH375-SO	PROUH80 T2 RU375-SO	PROUH80 T2 RU375-30	10E80-HP515
XE40T10HS45U0	XE40T10H45U0	10E40-HP530	XE40T10H22U0
XE50T10HS45U0	XE50T10H45U0	10E50-HP530	XE50T10H22U0
XE65T10HS45U0	XE65T10H45U0	10E65-HP530	XE65T10H22U0
XE80T10HS45U0	XE80T10H45U0	10E80-HP530	XE80T10H22U0
10E40-HP5S30	PROPH40 T2 RH375-30	PROUH40 T2 RU375-15	PROPH40 T2 RH375-15
10E50-HP5S30	PROPH50 T2 RH375-30	PROUH50 T2 RU375-15	PROPH50 T2 RH375-15
10E65-HP5S30	PROPH65 T2 RH375-30	PROUH65 T2 RU375-15	PROPH65 T2 RH375-15
10E80-HP5S30	PROPH80 T2 RH375-30	PROUH80 T2 RU375-15	PROPH80 T2 RH375-15

Builder Product Models

PRO H40 T2 RH310BM	PRO H40 T2 RU310BM
PRO H50 T2 RH310BM	PRO H50 T2 RU310BM
PRO H65 T2 RH310BM	PRO H65 T2 RU310BM
PRO H80 T2 RH310BM	PRO H80 T2 RU310BM

[5] Rheem contracted for the evaluation of the 50-gallon Premium and Builder products in accordance with the Advanced Water Heater Specification; NEEA separately funded research on the 40-gallon product and this comprehensive report.

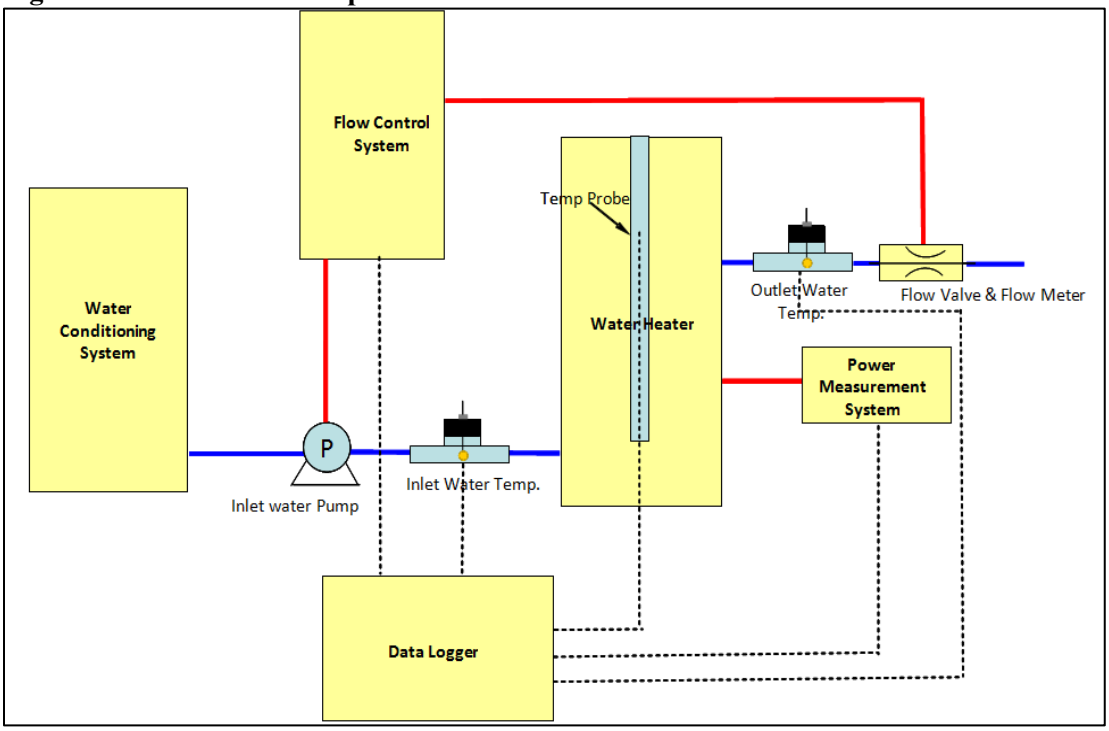
2. Methodology

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 (Ecotope 2010)
- Advanced Water Heater Specification (AWHS) for Heat Pump Water Heaters (NEEA 2019)
- Department of Energy testing standards from Appendix E to Subpart B of 10 CFR 430 (DOE 2014, DOE 1998)
- American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Standard 118.2-2006 for the Method of Testing for Rating Residential Water Heaters (ASHRAE 2006)

Figure 1 shows a schematic representation of the test setup.

Figure 1. General Test Setup



Ambient temperature control is provided by an ESPEC Model # EWSX499-30CA walk-in 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. Temperature conditions are controlled within 1°F.

Conditioned water is stored 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 and maintain water pressure. A flow meter measures and reports the actual water flow.

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. Cascade Engineering measured inlet and outlet water temperatures with thermocouples immersed in the supply and outlet lines.

A data acquisition (DAQ) system collected all the measurements at three-second intervals and logged 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.

3. Findings: Equipment Characteristics

3.1. Basic Equipment Characteristics

The Generation 5 product series is comprised of two distinct product lines of four tank sizes each: 40, 50, 65, and 80 gallons. From an energy use perspective, the main difference between the Premium/Plus and Builder product lines is the evaporator fan. The Premium fan can operate at two speeds and is more efficient. This report addresses the 40-gallon and 50-gallon Premium models and the 50-gallon Builder model. Figure 2 shows the 50-gallon Premium unit set up in the test chamber. Table 1 describes the properties of the Gen5 units.

Figure 2. Generation 5 Premium (Gen5p) 50-gallon HPWH being set up in the test chamber

Table 1. Properties of the Gen5 Series

	Unit		
Observation	**40-Gallon Premium**	**50-Gallon Premium**	**50-Gallon Builder**
Tank Volume (nominal gallons)	40	50	50
Tank Volume (measured gallons)	36.1	45.4	45.3
Tank Heat Loss Rate (Btu/hr°F)	5.0	4.5	4.9
Refrigerant	R-134a	R-134a	R-134a
Airflow Path	Top to Side	Top to Side	Top to Side
Upper Element (W)	4500	4500	4500
Lower Element (W)	4500	4500	4500
Compressor (W)	270-500	270-500	270-500
Standby (W)	2	2	2
Fan (W)	20.5 (max)	20.5 (max)	20.5 (max)
Low-Temperature Cutoff (°F)	37	37	37

Notable and differentiating features of the Gen5 Series include the following:

- The default operating mode, "Energy Saver," does not operate the lower resistance element in either product line.
- The Premium line offers load shifting grid connectivity by implementing the CTA-2045A standard on the water heater. The line also implements Rheem's integrated EcoNet® on-board Wi-Fi.
- The Builder line offers connectivity via Rheem's integrated EcoNet® on-board Wi-Fi.
- Ducting can be attached to the unit via an adapter at the intake or the exhaust or both. To accommodate the higher static pressure associated with ducting, the Premium line has a two-speed fan, both settable by the user and automatically changed by the water heater, with the higher fan speed designed to maintain adequate airflow over considerable duct run lengths.
- The inside of the housing is encased with foam padding to both dampen noise and insulate components of the refrigerant system. The net effect is the quietest measured hybrid heat pump water heater on the market.
- The tank comes with an electronic leak detection system. The system is comprised of two parts – a leak sensor for the water heater drain pan to notify occupants of any catastrophic leaks, and a leak sensor located inside the condensate collection pan to notify the occupant of blockage in the normal operation of the condensate drain.

3.2. Operating Modes

Heat Pump Mode: Only the heat pump is allowed to operate. It provides the highest level of efficiency and heats only with the refrigeration cycle. If the ambient temperature drops below that specified in Table 1 as the "Low-Temperature Cutoff," the compressor will not operate. This mode was not tested. The researchers expect operation (temperature control points and dead bands) to be similar to compressor operation in Energy Saver mode.

Energy Saver Mode: The default mode from the factory, Energy Saver Mode, will engage both the compressor and the resistance elements according to the tank's internal logic. Testing indicates the compressor will engage when the lower third of the tank drops 20 °F below the setpoint (125 °F in the testing). If hot water use continues and the tank temperature drops, testing indicates the upper element will engage when the top third of the tank is 25–30 °F below the setpoint. In no case in Energy Saver Mode does the lower element run (as long as the heat pump is in normal operating range). While the upper element runs, the compressor runs concurrently, effectively maximizing output.

High Demand Mode: This mode was not tested. The name and operating manual description imply a faster tank recovery rate, suggesting the compressor and resistance elements may turn on sooner than in Energy Saver Mode and the elements may stay on longer.

Electric Mode: In electric mode, the heat pump does not run, and the equipment operates as a conventional resistance tank. The test team did not investigate this mode in detail as it provides no efficiency improvements over a conventional system.

4. Findings: Testing Results

4.1. Uniform Energy Factor Tests at 50 °F Ambient Conditions

As described in the Methodology section, Cascade Engineering carried out tests per DOE and AWHS procedures. Per the 2014 DOE test procedure, the first hour rating sets which draw pattern to use in the Uniform Energy Factor (UEF) test. Accordingly, Cascade Engineering used the Medium Usage Pattern for the 40- and 50-gallon tanks.

Figure 3, Figure 4, and Figure 5 show the testing behavior for the three units. Typical of other current products on the market, only the compressor runs during the 24-hour test. The efficiency is expectedly lower than at the warmer ambient conditions of the standard UEF test.

Figure 3. 24-Hour UEF Test 50 °F—Gen5p40

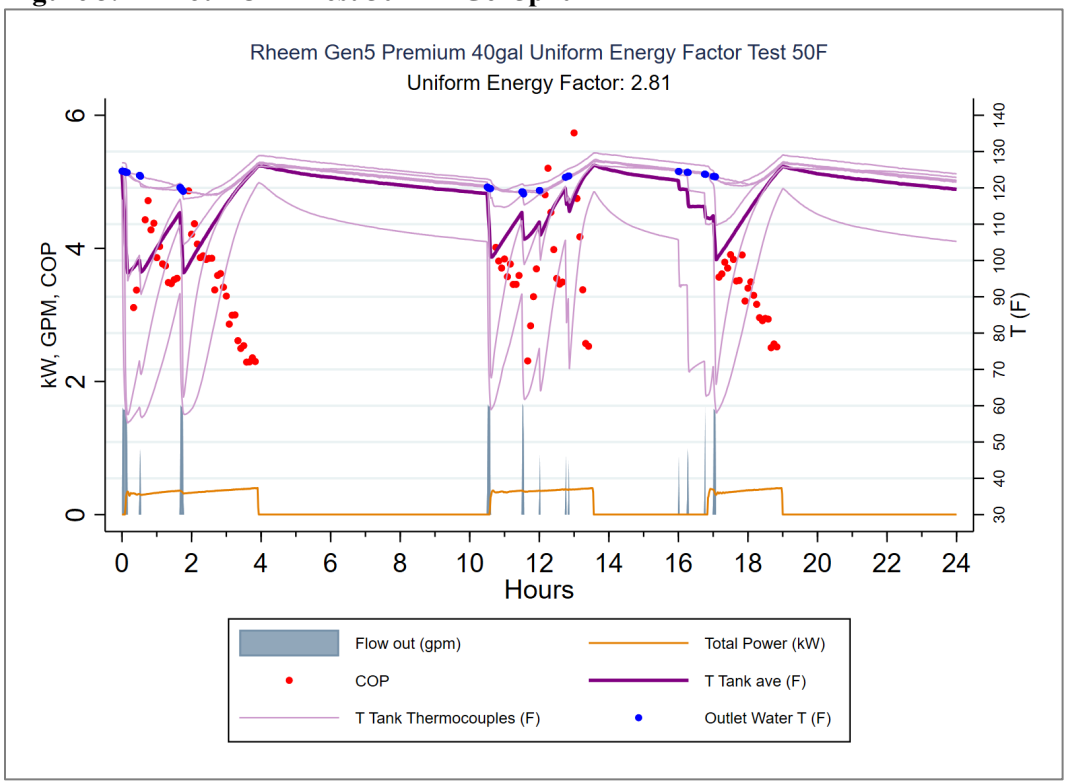


Figure 4. 24-Hour UEF Test 50 °F—Gen5p50

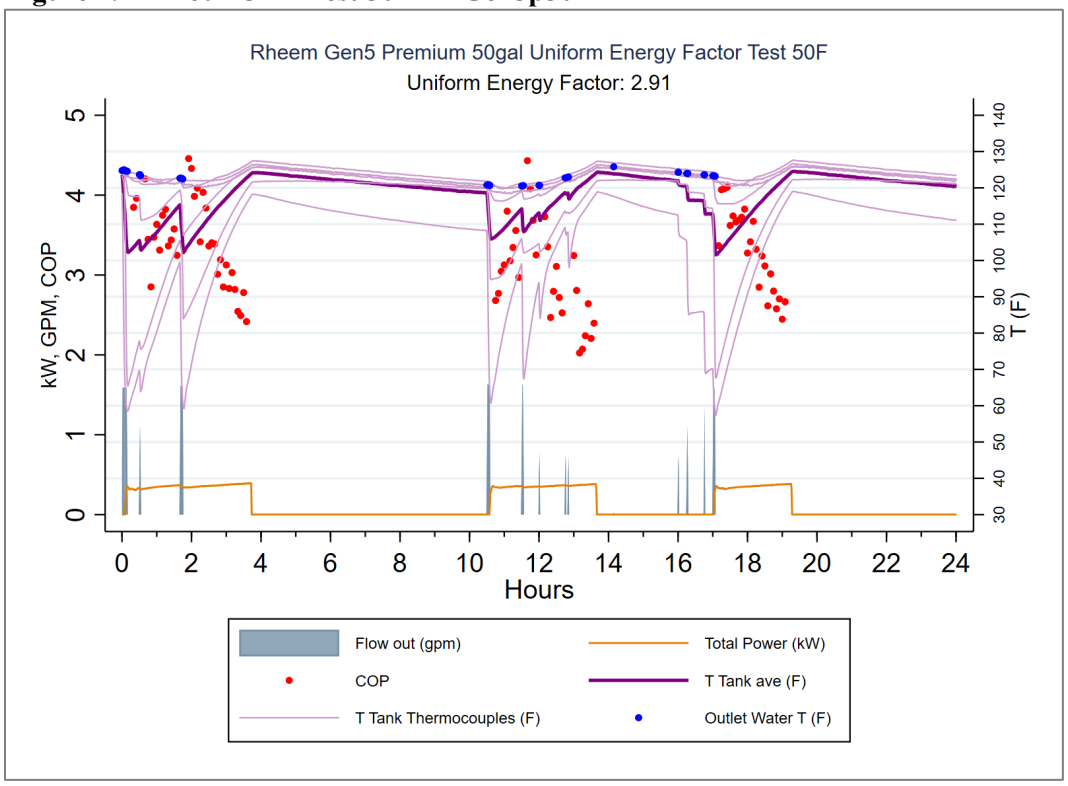
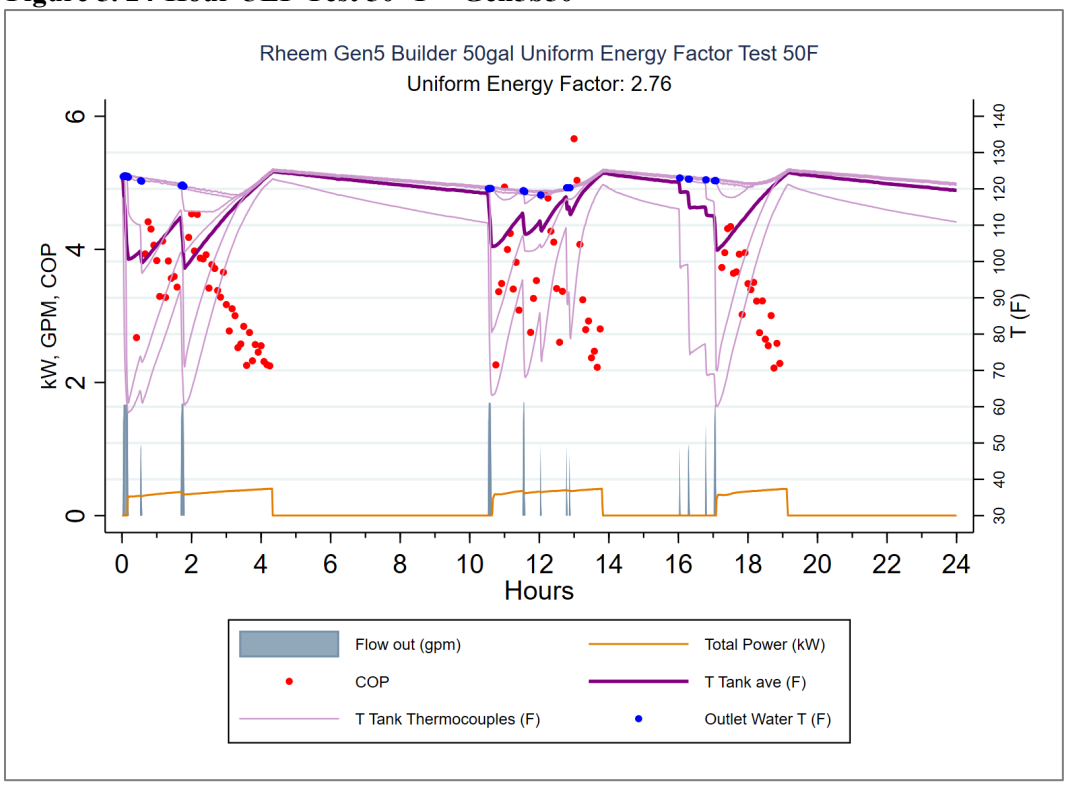


Figure 5. 24-Hour UEF Test 50 °F—Gen5b50



4.2. High Volume Draw Test

The high volume draw test is new to the AWHS in version 7 (NEEA 2019). Energy savings vetting activities by the Regional Technical Forum (RTF) and field measurements by others have demonstrated the need to better understand when resistance heating is used (RTF 2016, Ecotope 2015). Accordingly, the test is intended to elicit electric resistance element use in hybrid water heaters and may stress the capability of the water heater. The test output will be used to inform and calibrate predictions/simulations of heat pump water heater energy use. The test is neither a simulated use test nor a direct rating test nor a representation of an average day; rather, its goal is to better inform the conditions under which resistance elements are used. Consequently, the tank may run out of hot water during the test. This is an acceptable, even expected, outcome.

The AWHS requires reporting the number of gallons in each draw cluster before resistance element use occurs. Figure 6, Figure 7, and Figure 8 illustrate the results of the AWHS high volume draw test. Table 2 reports the numeric results. The table shows that for both the Premium and Builder models, only the upper element is used in the default operating mode.

Table 2. High Volume Draw Test Results

	Gallons Drawn in Cluster before Electric Resistance Element Use (Out of Total Possible)			Upper Element Used	Lower Element Used
Unit	**GC1**	**GC2**	**GC3**		
40-gallon Premium	33.3 (44.8)	30.4 (30.4)	28.8 (28.8)	Y	N
50-gallon Premium	38 (56)	38 (38)	36 (36)	Y	N
50-gallon Builder	39 (56)	38 (38)	36 (36)	Y	N

Note that in the high volume draw tests, the observed outlet water temperature is colder than the top of the tank, likely due to a malfunctioning thermocouple measuring the outlet water temperature. The malfunction is immaterial to the high volume draw tests because the key observations are the temperatures within the tank and the unit power draw.

An additional note concerns the power draw of the resistance elements. These early production units used non-standard elements, which drew less current and power. The standard elements to be used in full production are the typical 4500W. Again, the element output capacity is not the focus of the test but rather the control observations of when the elements engage (or not). The tests were still successfully conducted regardless of the element size.

Figure 6. High Volume Draw Test—Gen5p0

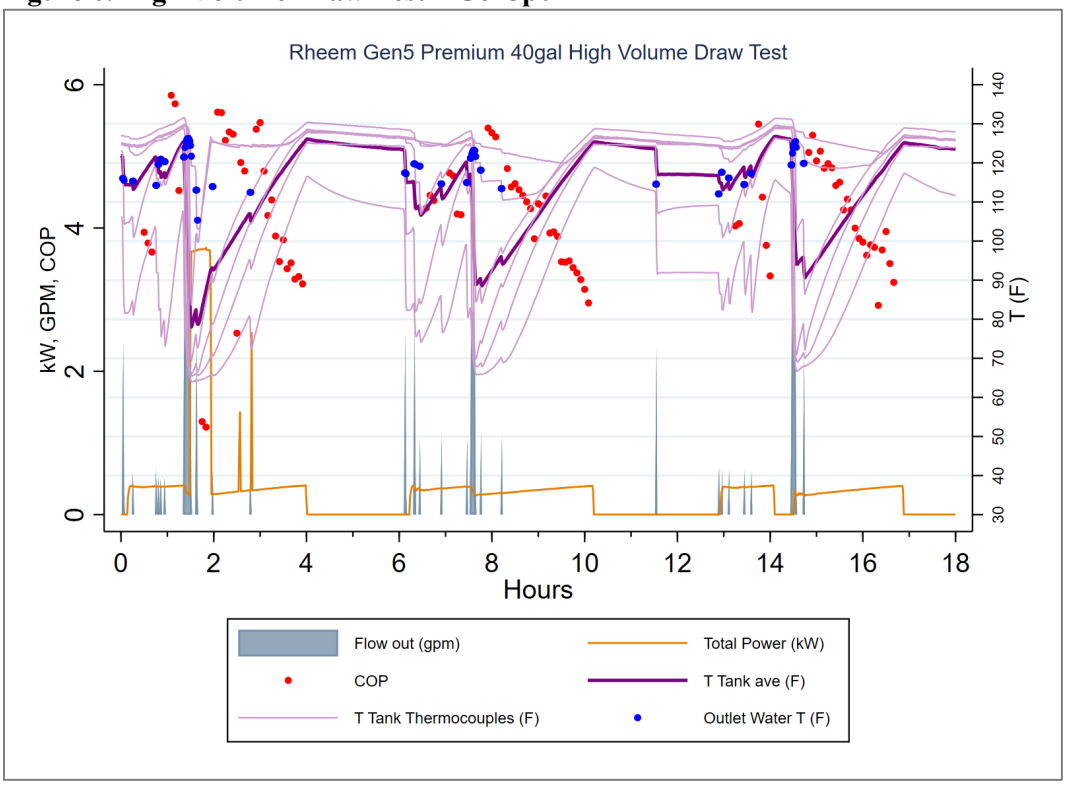


Figure 7. High Volume Draw Test—Gen5p50

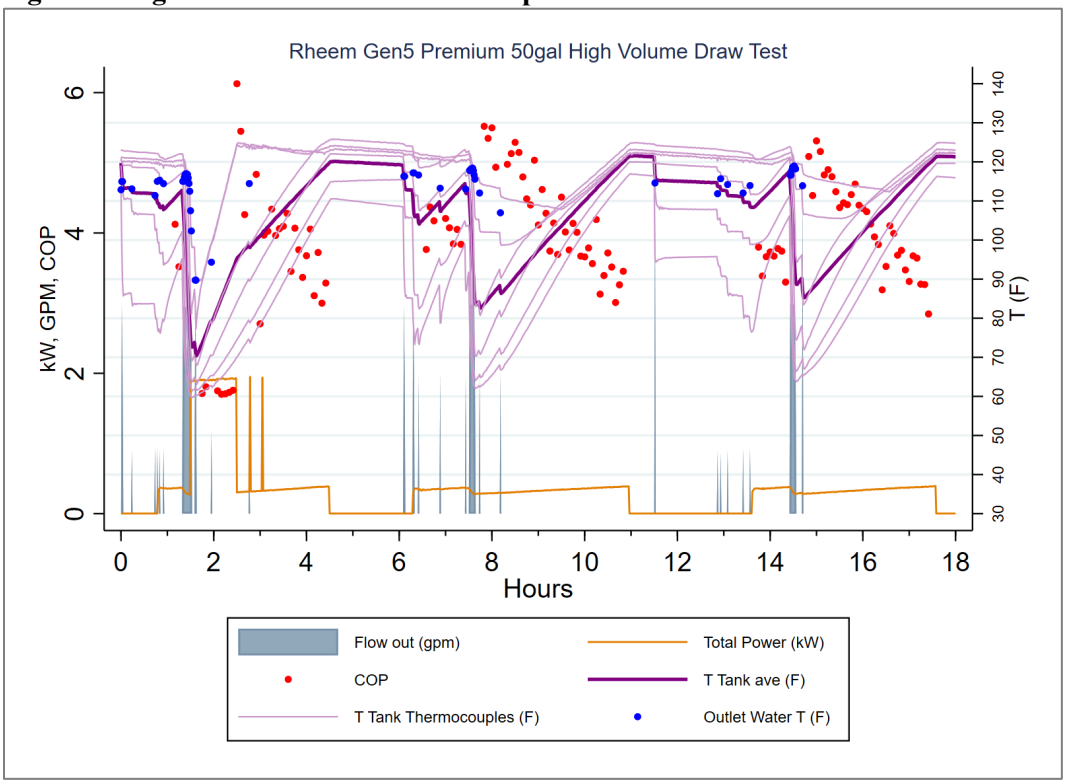
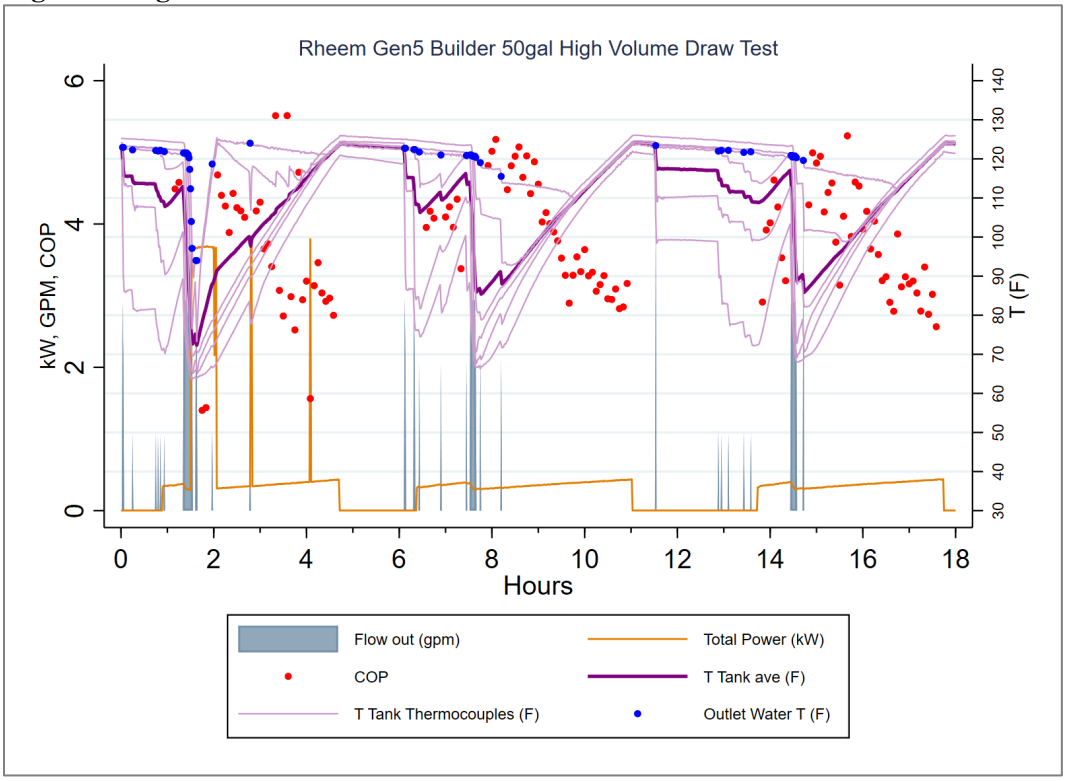


Figure 8. High Volume Draw Test—Gen5b0



4.3. Low Temperature Limit

Testing showed none of the units in the series will operate the compressor at an ambient temperature below 37 °F. Resistance elements are used exclusively below this temperature.

4.4. Sound Level Measurements

The lab also measured the sound level of the equipment. Researchers placed the units 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 ambient temperature for the test was ~72 °F. The decibel levels when the units are running are:

- 40-Gallon Premium: 51.4 dBA
- 50-Gallon Premium: 49.6 dBA
- 50-Gallon Builder: 49 dBA

The sound level measured for the 40-gallon product is not representative of the final production unit. This early-production model was shipped missing an insulation blanket on the compressor, which did exist on the Gen5p50 and resulted in lower sound levels for that product. Consequently, the Gen5p50 is taken as the representative reading for that product line.

4.5. Airflow Measurements

The Premium product has a two-speed fan which changes speed based on observed airflow. If the flow is too low, the fan boosts to high speed to increase airflow. The speed is indicated in the measurement results of Table 3.

Table 3. Airflow Measurements

Unit	Fan Speed	Airflow (CFM)
50-gallon Premium	Low	150
50-gallon Premium	High	203
50-gallon Builder	n/a	191

4.6. Standard UEF Conditions and First Hour Rating Results

To round out our understanding of the product line across all sizes, and deliver the necessary inputs to determine the Cool Climate Efficiency (CCE), Rheem provided the testing results shown in Table 4.

Table 4. Test Results at Standard Conditions for all Tank Sizes

Product Line	Metric	Tank Size 40	50	65	80
Premium	UEF	3.78	3.86	3.85	4.0
	First Hour Rating (gal)	60	67	75	87
Builder	UEF	3.5	3.5	3.5	3.5
	First Hour Rating (gal)	60	67	75	87

5. Conclusions

Overall, the results suggest that the Rheem Generation 5 water heaters are highly efficient units. Specifically, the investigation found the following:

- The Premium product line meets the specifications for a Tier 4 water heater under the AWHS, while the Builder product line meets the Tier 3 specifications.
- The Cool Climate Efficiency (CCE) ratings are as follows for the 40-, 50-, 65-, and 80-gallon tanks respectively:
    - Premium Product CCE: 3.07, 3.16, 3.16, 3.21
    - Builder Product CCE: 2.94, 2.95, 2.94, 2.94
- The default operating mode, "Energy Saver," does not operate the lower resistance element in either product line.
- Sound levels for both lines are ≤ 50 dBA.
- The Premium line offers load shifting grid connectivity by implementing the CTA-2045A standard on the water heater. The line also implements Rheem's integrated EcoNet® on-board Wi-Fi.
- The Builder line offers connectivity via Rheem's integrated EcoNet® on-board Wi-Fi.

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Appendix A—Testing Matrix

All tests were conducted in the default operating mode unless otherwise noted.

DOE Standard Rating Point Tests

Test Name	Ambient Air Dry-Bulb			Inlet Water		Tank Set Point		Notes	Tanks Tested
	°F	°C	RH	°F	°C	°F	°C		
DOE 1-hour	67.5	20	50%	58	14	125	52	Provided by Rheem	All
DOE 24-hour	67.5	20	50%	58	14	125	52	Provided by Rheem	All
DOE 24-hour-50	50	10	58%	50	10	125	52	Follow test sequence in Federal Register 10 CFR Part 430 Section **5.1.5,** but replace ambient conditions with those given in this table.	40 Prem, 50 Prem, 50 Build
Compressor Cutoff Temperature									
CMP-T	37	2.8	60%	58	14	125	52	Withdraw minimum 10 gallons water until compressor cut-in achieved. Then observe recovery cycle. See AWHS v7 Appendix B.2.	40 Prem, 50 Prem, 50 Build
Draw Profiles									
DP-HVT	67.5	20	58%	58	14	125	52	Draw Profile: DP-HVT. See AWHS v7 Appendix B.3.	40 Prem, 50 Prem, 50 Build
Noise Measurement									
NOI	Measure combined fan and compressor sound level							Measure sound at 1 meter away, 1.8 meters high at points specified in AWHS v7 Appendix D.	40 Prem, 50 Prem, 50 Build
Airflow Measurement									
AIRFLOW	Measure airflow across the evaporator							Using 6 feet of straight ducting with an adjustable damper, measure pressure in middle of length while adjusting damper from 0.0" to 0.2" water column. See AWHS v7 Appendix F.	40 Prem, 50 Prem, 50 Build