Water Heater Data

Introduction

DOE obtained the attached data in an investigation of the effect of different draw patterns during 24-hour simulated use tests on the resultant measured efficiency. This document describes the draw patterns that were applied, the units that were tested to date, the calculation methods to arrive at an efficiency, and the data that were obtained.

Units tested

The data described herein were obtained from tests performed on three water heaters described in Table 1:

Table 1. Water heaters tested.

Identifier	**Rated Volume**	**Input Rate**
Heat Pump Water Heater	50 gallons	550 W (HP) 4500 W (resistance)
Gas Tankless	n/a	Up to 199.9 kBtu/h
Electric Resistance Storage	50 gallons	4500 W

Draw patterns

Water heaters were tested under some or all of the following draw profiles during a 24-hour simulated-use test to determine the energy efficiency.

Table 2. Modified Simulated-Use Draw Patterns.

Draw Pattern Number	**Total Volume Removed (gallons)**	**Number of Draws**	**Range of flow rates (gallons per minute)**
1: Current DOE pattern	64.3	6	3
2	43.7	37	3
3	64.3	37	3
4	43.7	37	0.8, 3.65
5	64.3	37	0.8, 3.65
6	64.3	10	2
7	52	11	1, 1.7
8	64.3	11	1, 1.7
9	115	11	1, 1.7, 3.4
10	64.3	13	2
11	64.3	13	2
12	64.3	25	2

Draw Pattern 1: DOE Profile

The pattern matches that currently implemented in the test specified in the current DOE test procedure. Six draws of 10.7 gallons each are taken from the water heater at the start of the first 6 hours of the test at a flow rate of 3 gallons per minute (gpm). The water heater remains in standby mode for the duration of the 24 hours.

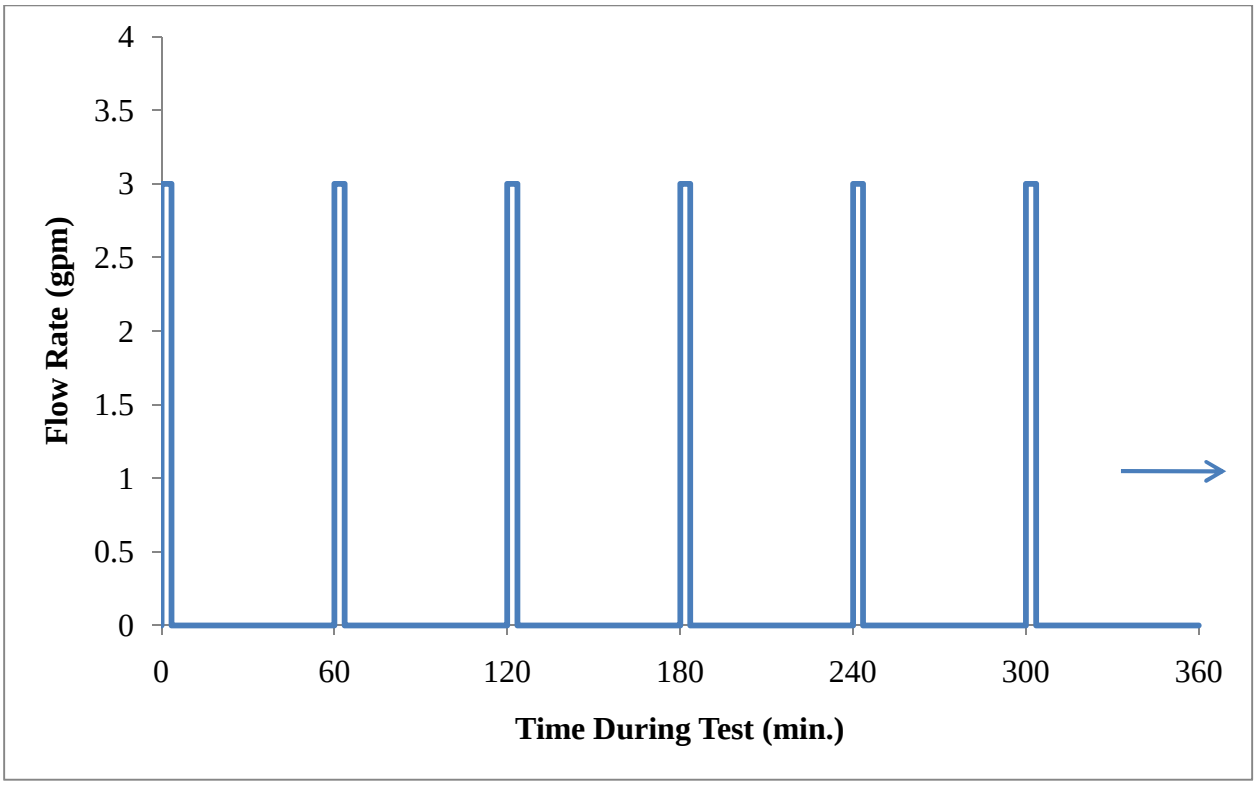

Figure 1. Flow rates during Draw Pattern 1.

Draw Patterns 2, 3, 4, 5:

These patterns are comprised of 37 draws. One is a long draw, 18 are short draws separated by a standby period of 10 minutes, and 18 are short draws separated by a standby period of 1 minute. Patterns 2 and 4 involve a total draw per day of approximately 44 gallons, while patterns 3 and 5 remove 64 gallons per day. Patterns 3 and 5 look similar to those shown below, with the total amount removed in each draw scaled up to achieve a total of 64 gallons per day.

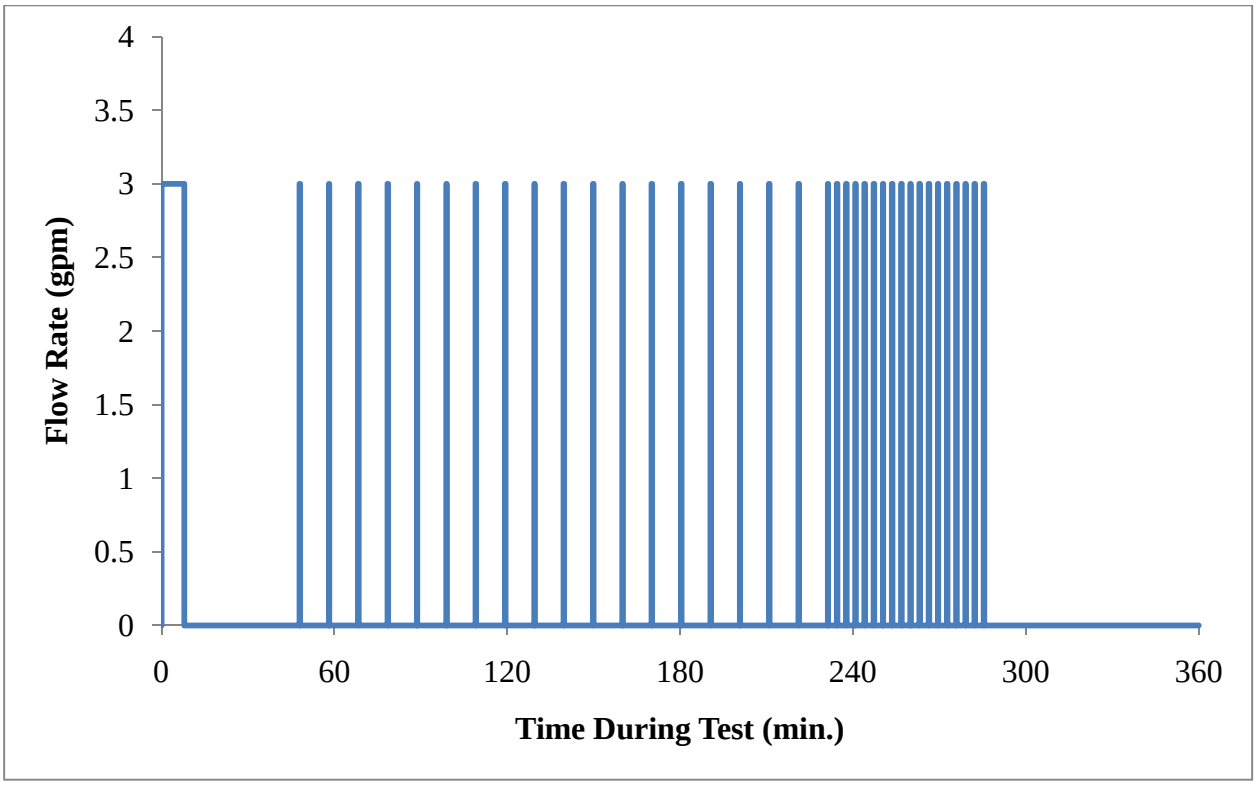

Figure 2. Flow rates during Draw Pattern 2

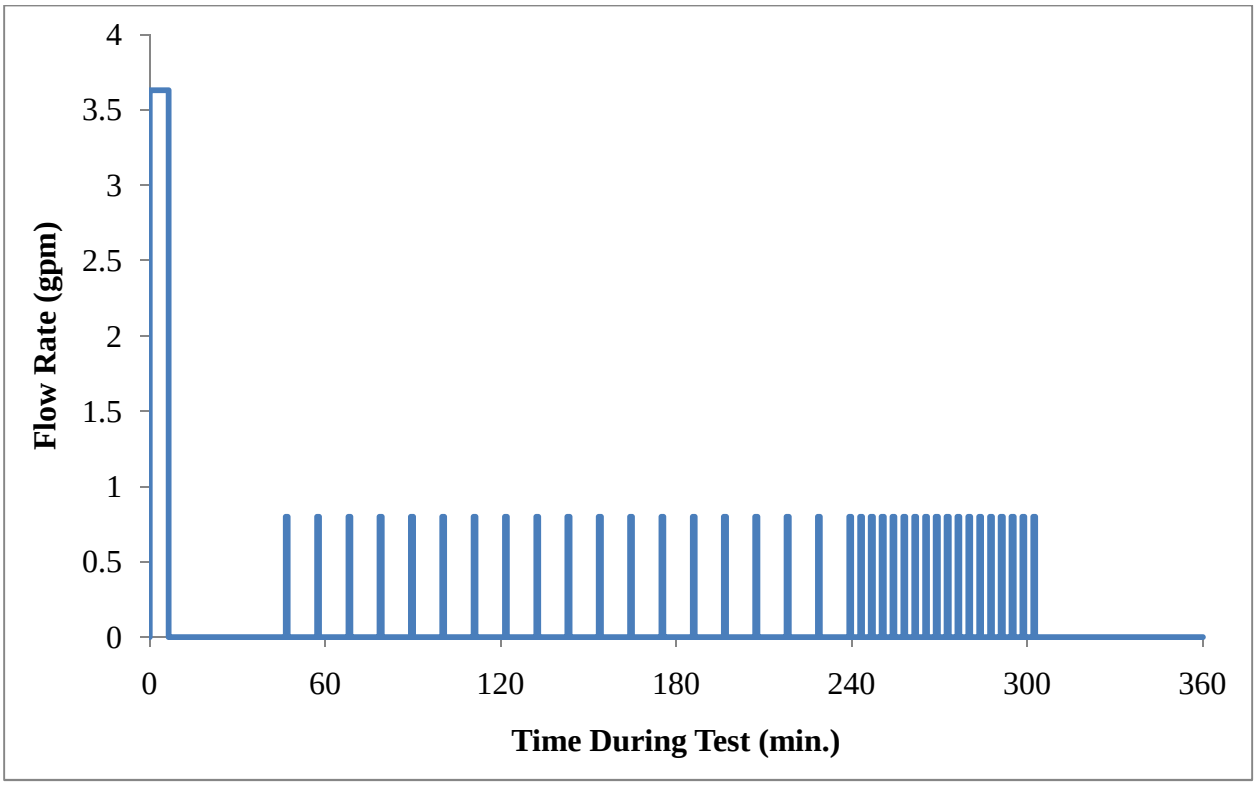

Figure 3. Flow rates during Draw Pattern 4

Draw Pattern 6

10 draws per day spread out to represent draws in morning and at night. The draws are configured to provide a nominal value of 64.3 gallons per day.

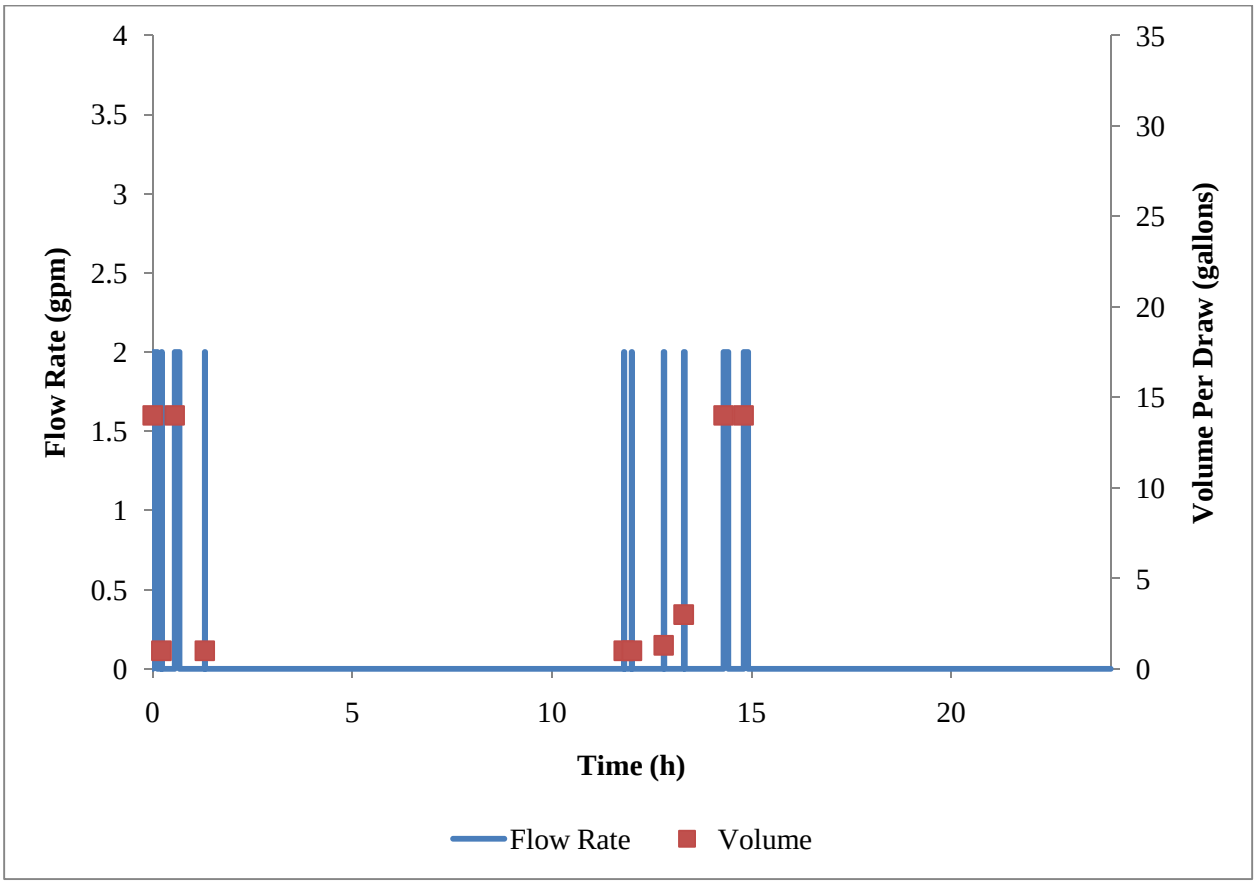

Figure 4. Flow rates and volume per draw for Draw Pattern 6.

Draw Patterns 7, 8

11 draws per day spread out to represent draws taken during a day. Total volume drawn per day is 52 gallons. Draw pattern 8 is achieved by scaling up the volume removed in each draw by (64.3/52) to achieve a total daily draw of 64.3 gallons.

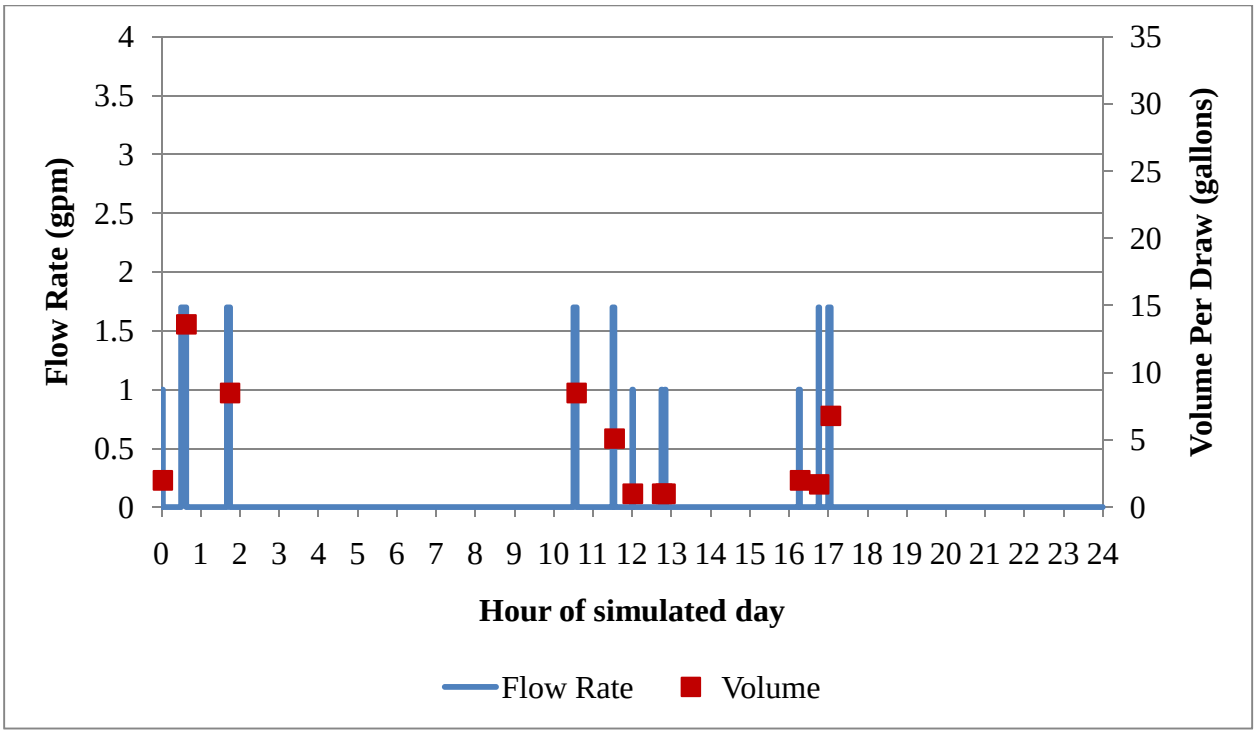

Figure 5. Flow rates and volume per draw for Draw Pattern 7.

Draw Pattern 9:

Eleven draws per day for total draw of 115 gallons.

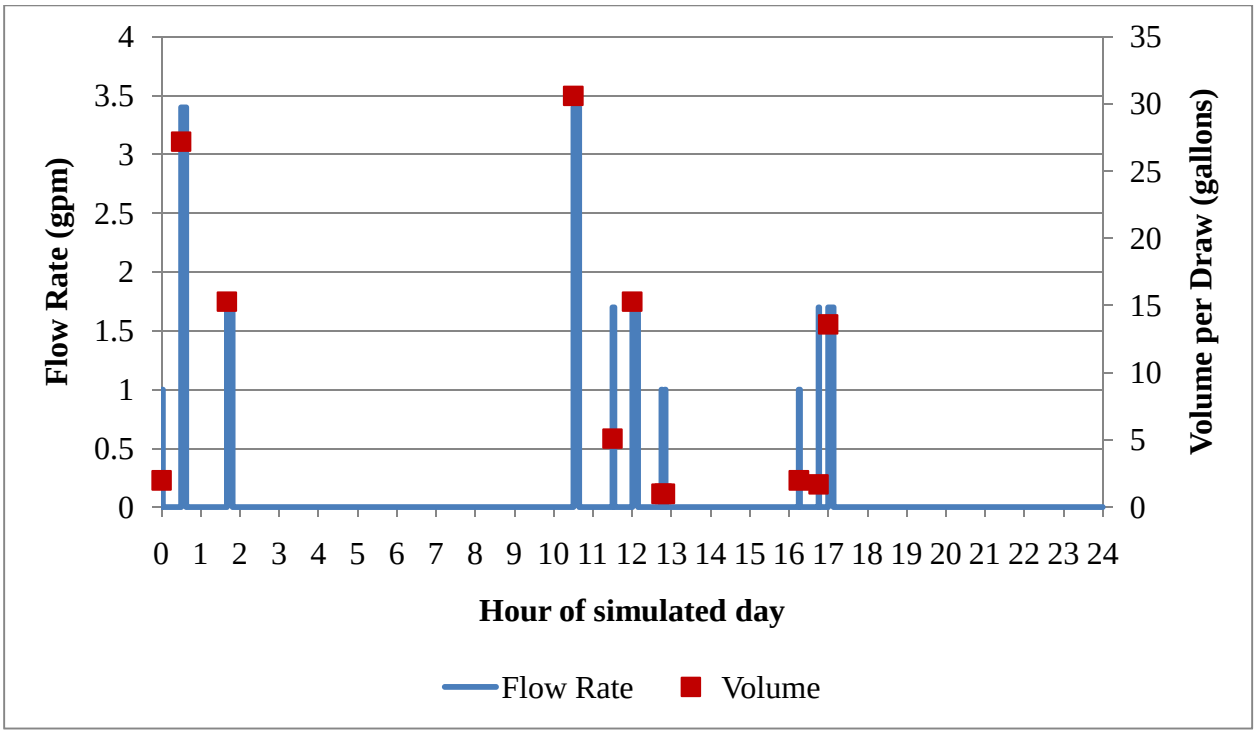

Figure 6. Flow rates and volume per draw for Draw Pattern 8.

Draw Pattern 10:

Thirteen draws taken during the day at the start of 13 different hours. Different flow rates and total volumes are taken in each draw as shown in Figure 7.

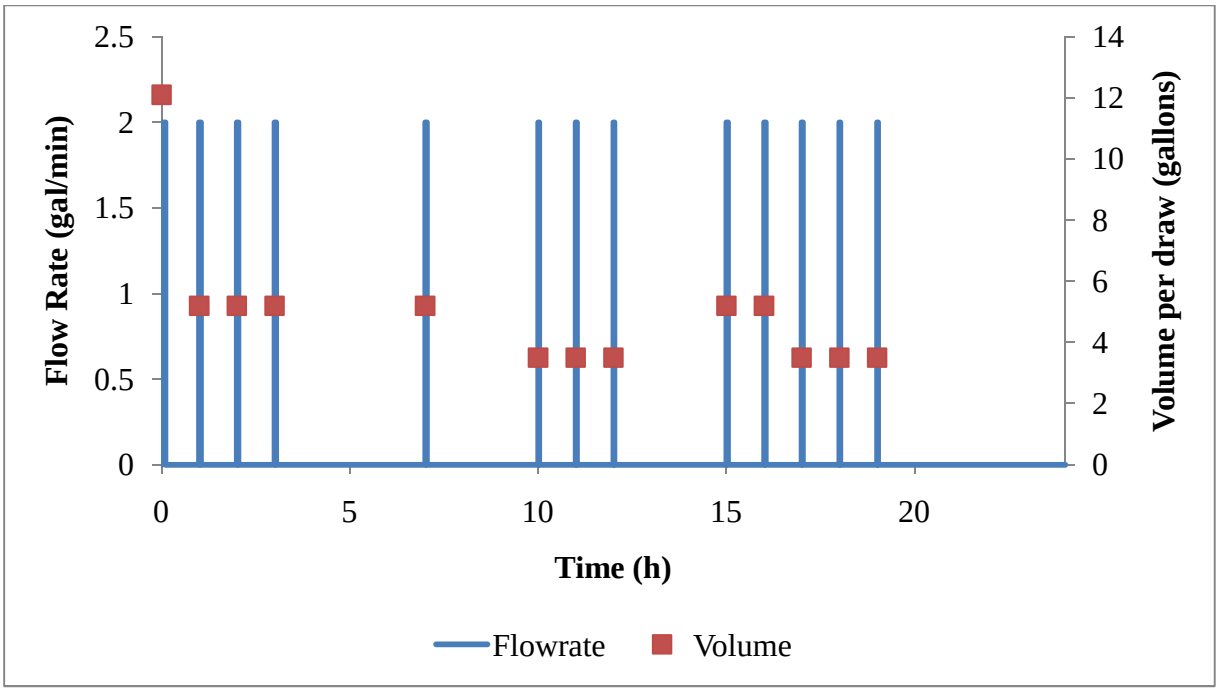

Figure 7. Flow rates and volume per draw for Draw Pattern 10.

Draw Pattern 11:

The same flow rates and volumes taken in Draw Pattern 9, but sets of the draws are clustered as shown in Figure 8.

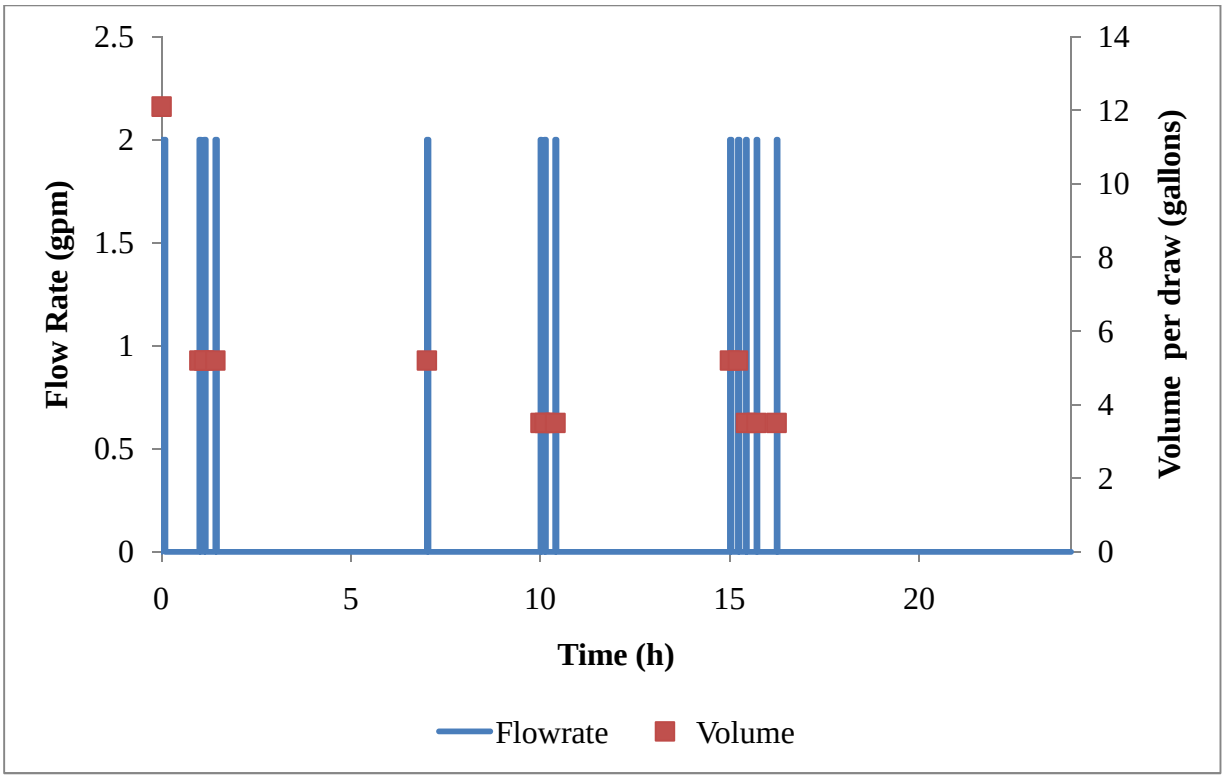

Figure 8. Flow rates and volume per draw for Draw Pattern 11.

Draw Pattern 12:

Based on pattern 9, the volumes drawn in hours 2, 3, 15, and 16 are broken into multiple draws, yielding the profile shown in Figure 9.

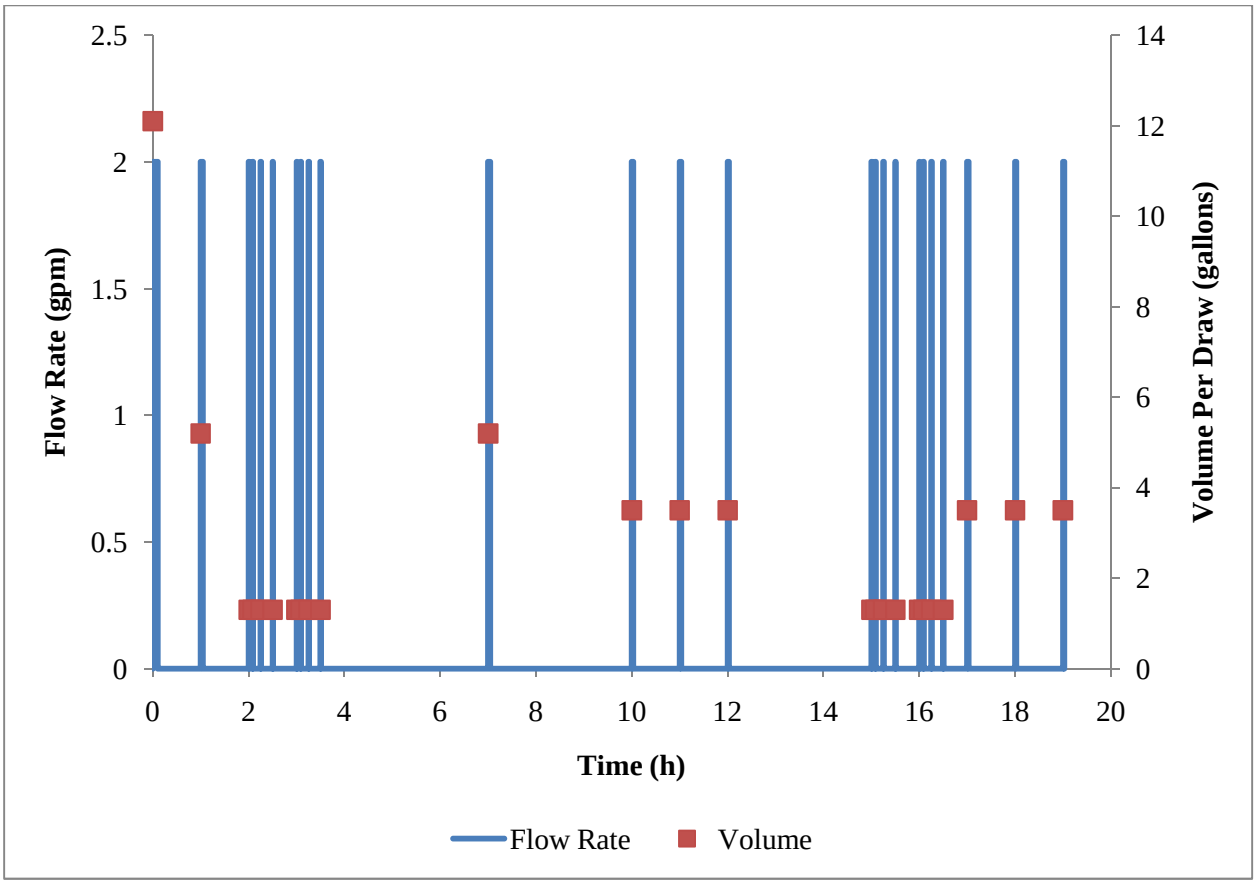

Figure 9. Flow rates and volume per draw for Draw Pattern 12.

Conduct of Tests

Tests were conducted by first implementing a predraw before commencement of the test. This predraw is carried out by drawing water from the unit until the heating element or burner is energized. For storage water heaters, the 24 hour test is begun after the heating element cuts out and it is determined that the average temperature within the water heater has peaked. For tankless water heaters, the test is started shortly after the computer-controlled valve that regulates the flow rate is set up, which occurs approximately one minute following the end of the predraw. For storage water heaters, tests on the same draw pattern were conducted on subsequent days, with the test starting immediately following the end of the previous day's test and without a predraw being taken. It has been found in previous work that the use of a predraw to start the test can affect results, and it is thought that tests conducted on subsequent days offer a more accurate result since the temperature of the water within the tank is similar at the beginning of the test as it is at the end. This condition requires less of a correction for stored energy in the tank. Repeating tests on consecutive days was also done for many of the tests on the instantaneous water heaters, but the implementation of a predraw has been found to have less of

an impact on the results. Therefore, tests on some draw patterns were only conducted a single time on instantaneous water heaters.

The flow rates were controlled using a variable positioned valve. Prior to testing, experiments were carried out to characterize the flow rates through the system as a function of valve position. This relationship was used to adjust the valve position automatically through the data control system. The valves were found to be very sensitive, resulting in situations where the desired flow rates were not achieved to tolerance. Results from these tests, however, are still included in the plots that are presented.

Calculation of daily efficiency

To determine the efficiency for these simulated use tests, the general approach given in the current DOE test method was used with some modifications.

The first modification relates to the determination of the energy removed in the hot water drawn from the water heater. The current DOE test indicates that the energy removed in each draw be calculated as:

$$E_i = m_i c_{p,i}\left(\bar{T}_{i,out} - \bar{T}_{i,in}\right)$$

where E_i: the energy removed in draw i

m_i: mass of water removed in draw i

$c_{p,i}$: the specific heat of the water removed in draw i, computed at the mean of the average outlet temperature and inlet temperature measured during the draw

$\bar{T}_{i,out}$: average outlet water temperature during draw

$\bar{T}_{i,in}$: average inlet water temperature during draw

For all water heaters except tankless units with variable inputs, the average inlet and outlet water temperatures are determined based on data gathered starting 15 seconds after the draw is initiated. For instantaneous water heaters with variable input, the DOE test procedure specifies that the average inlet and outlet water temperatures are determined based on data gathered starting 5 seconds after the draw is initiated. For the tests reported here, data during draws are taken at 3 second intervals, and the average temperatures for the modified simulated use tests are computed using data from the start of the draws as opposed to waiting 15 s. This approach was taken in an attempt to more accurately capture the energy removed, especially during short draws, and should take into account delays in delivering water at the specified temperature.

Another modification taken during these tests is that temperature data of the ambient and stored water temperature are taken at 1 minute intervals instead of the 15 minute intervals specified in the test method.

Since tests were run with nominal delivery temperatures of 120 °F and 135 °F, an alternative method was used to correct for deviations from these nominal conditions. For storage water heaters, the equation presented in Section 6.1.6 for to adjust for standby losses at different tank to ambient temperature differences is changed to:

$$Q_{da} = Q_d - [(T_{stby,2} - T_{a,stby,2}) - (T_{set} - 67.5\ ^{o}F)]\ UA\tau_{stby,2}$$

$$Q_{da} = Q_d - [(T_{stby,2} - T_{a,stby,2}) - (T_{set} - 19.7\ ^{o}C)]\ UA\tau_{stby,2}$$

where: Q_{da} = the adjusted daily water heating consumption

Q_d = the daily water heating energy consumption

$T_{stby,2}$ = the mean tank temperature during the standby portion of the 24-hour test

$T_{a,stby,2}$ = the mean ambient temperature during the standby portion of the 24-hour test

UA = standby heat loss coefficient of the storage tank

$\tau_{stby,2}$ = the time during the 24-hour test when water is not being withdrawn from the water heater

T_{set} = the nominal water delivery temperature (120 °F [49 °C] or 135 °F [57 °C])

The equations presented in Section 6.1.6 (storage) and 6.2.3 (instantaneous) to normalize the delivered energy to the specified outlet to inlet temperature difference are changed to:

$$Q_{hw,set} = \sum_{i=1}^{N} \frac{m_i c_{p,i}(T_{set} - 58\ ^{\circ}F)}{\eta_r}$$

$$\sum_{i=1}^{N} \frac{m_i c_{p,i}(T_{set} - 14.4\ ^{\circ}C)}{\eta_r}$$

where: $Q_{hw,set}$: The energy required to heat the amount of water drawn over the nominal temperature rise

i: draw number

N: number of draws per day

η_r: recovery efficiency

m_i, $c_{p,i}$, T_{set}: as defined previously

The determination of the energy factor, EF, in Section 6.1.7 (storage) and 6.2.4 (instantaneous) is modified by the following equation:

$$EF = \sum_{i=1}^{N} \frac{m_i c_{p,i}(T_{set} - 58\ °\text{F})}{Q_{dm}}$$

$$\sum_{i=1}^{N} \frac{m_i c_{p,i}(T_{set} - 14.4\ °\text{C})}{Q_{dm}}$$

where: i, N, m_i, c_{pi}, T_{set}: as defined previously

Q_{dm}: modified daily water heating energy consumption

Gas energy consumption is determined by measuring the amount of cubic feet of natural gas consumed and multiplying that value by the calorific value of the gas. A gas calorimeter pulls gas continuously from the line feeding the water heater and provides the heating value per standard cubic foot (i.e., at standard temperature and pressure). This value is corrected to provide the heating value per cubic foot of gas that is going through the meter by measuring the actual pressure and temperature at the meter during draws. The electricity consumption is determined with precision power meters. It should be noted that the instantaneous water heater tested consumed both natural gas and electricity; both energy consumptions were measured and factored into the energy efficiency.

Results

Table 3 provides the efficiency data for the tests done to date on the three water heaters under the various draw patterns. Where multiple tests have been carried out to determine repeatability, results from each test are averaged to yield the number shown in Table 3. Boxes without data indicate that the test specified has not been conducted on that water heater. Some caveats are warranted regarding these data.

1) The electric storage water heater tested here was an older model that has undergone significant testing in the past, so the fact that the measured results are below the current minimum efficiency standard is not cause for concern.

2) Tests conducted on the Heat Pump Water Heater were carried out without the ambient temperature and humidity control specified in the test method because of temporary maintenance being conducted on environmental chambers in which tests were conducted. The average

ambient temperature and relative humidity measured over the course of the 24 hour tests are reported in Table 3.

Table 3. Efficiency results from modified simulated use tests carried out on three water heaters at different setpoint delivery temperatures.

Draw Pattern	Setpoint Temperature (°F)	Electric Storage		HPWH		Gas Tankless Efficiency
		Efficiency, 1 predraw	Efficiency, No predraw	Efficiency	Ambient Conditions (T, RH)	
1	120	0.863	0.881	2.633	70 °F, 47 %	0.778
	135	0.854	0.867	2.454	74 °F, 50 %	0.774
2	120					0.742
	135			2.090	74 °F, 41 %	0.716
3	120					
	135					
4	120					0.767
	135			1.157	72 °F, 30 %	0.746
5	120					0.699
	135					0.703
6	120	0.855	0.856	2.734	73 °F, 52 %	0.780
	135	0.851	0.864	1.044	70 °F, 47 %	0.786
7	120	0.837	0.855	2.580	75 °F, 45 %	0.752
	135	0.830	0.832	2.310	76 °F, 44 %	0.755
8	120	0.865	0.877	2.747	73 °F, 48 %	0.773
	135	0.848	0.860	2.341	68 °F, 50 %	0.762
9	120	0.910	0.917			0.767
	135	0.901	0.909			0.769
10	120	0.865	0.887			0.734
	135	0.860	0.867			0.729
11	120	0.866	0.884			0.747
	135	0.847	0.869			0.761
12	120	0.865	0.886			0.719
	135	0.856	0.868			0.698

Plots of the data are presented in the following section. For the gas tankless water heater, additional data points were obtained in tests using the patterns described above but with flow rates maintained at 3.5 gpm.

Electric Resistance Storage Water Heater

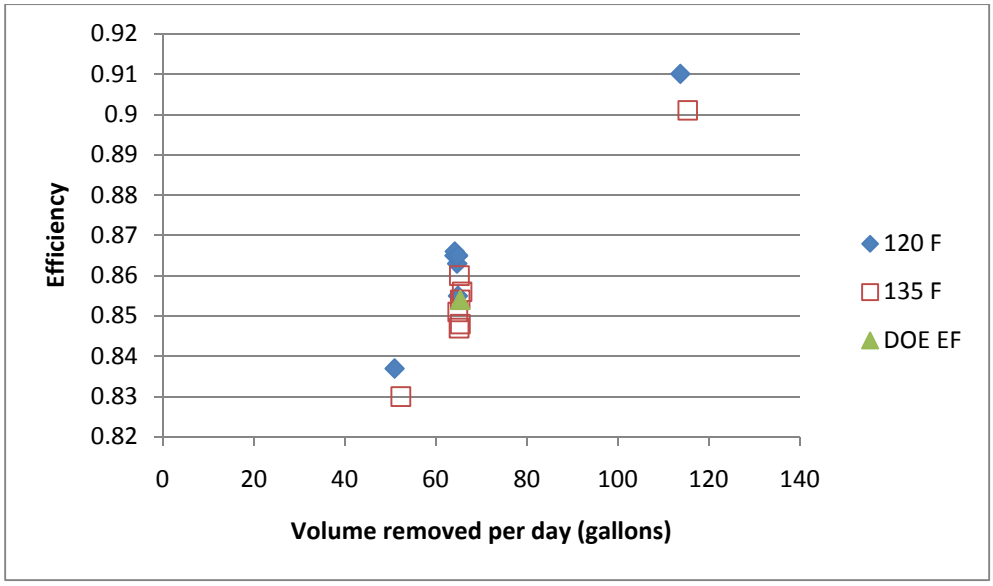

Figure 10. Daily efficiency as a function of total volume removed. Electric storage water heater, one predraw prior to beginning of 24-hour simulated-use test.

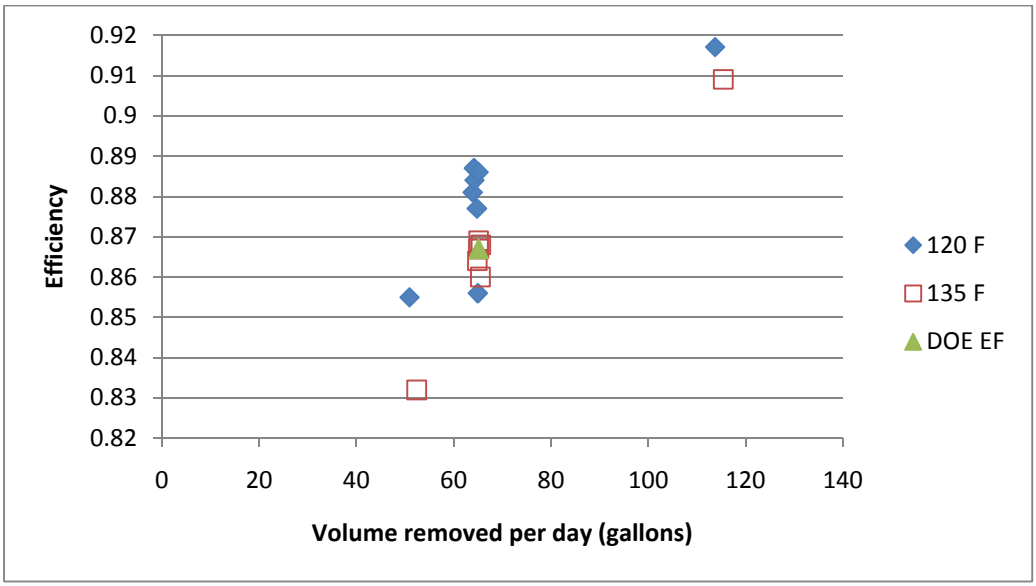

Figure 11. Daily efficiency as a function of total volume removed. Electric storage water heater, no predraws implemented prior to test; test started immediately at end of previous day's simulated-use test using the same draw pattern.

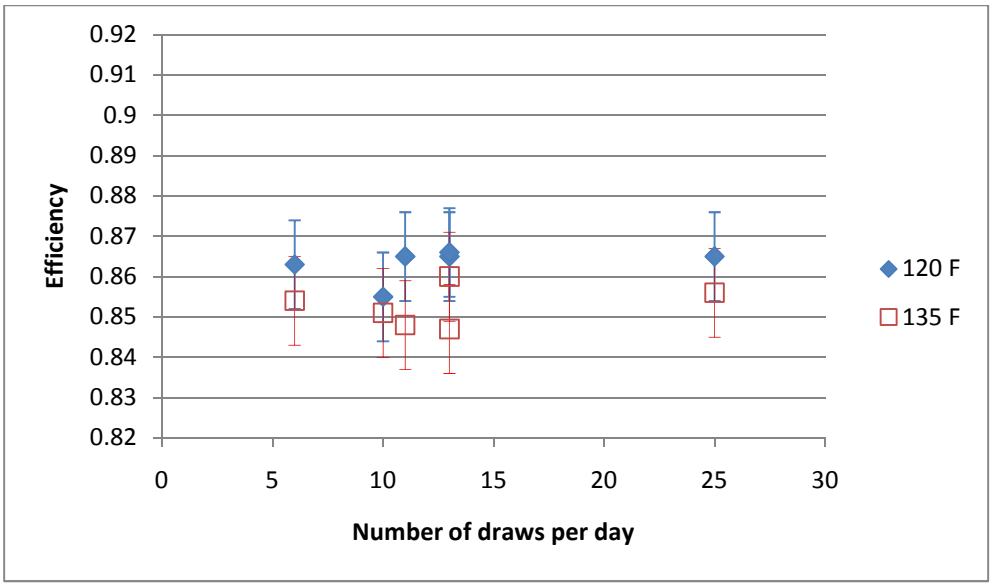

Figure 12. Daily efficiency as a function of number of draws per day. Electric storage water heater, one predraw prior to beginning of 24-hour simulated-use test. Total daily consumption for all tests is 65 ± 1 gallons.

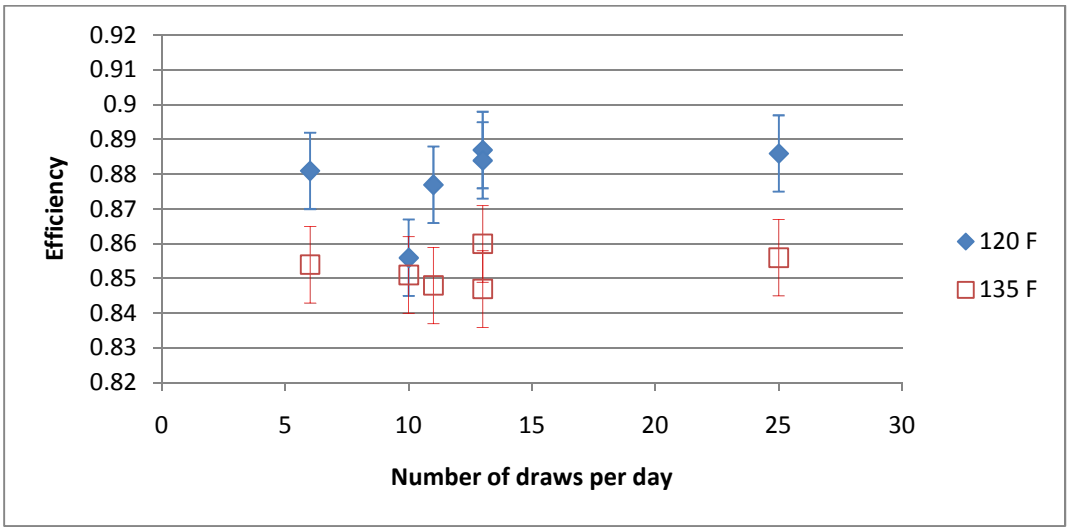

Figure 16. Daily efficiency as a function of number of draws per day. Electric storage water heater, no predraws implemented prior to test; test started immediately at end of previous day's simulated-use test using the same draw pattern. Total daily consumption for all tests is 65 ± 1 gallons.

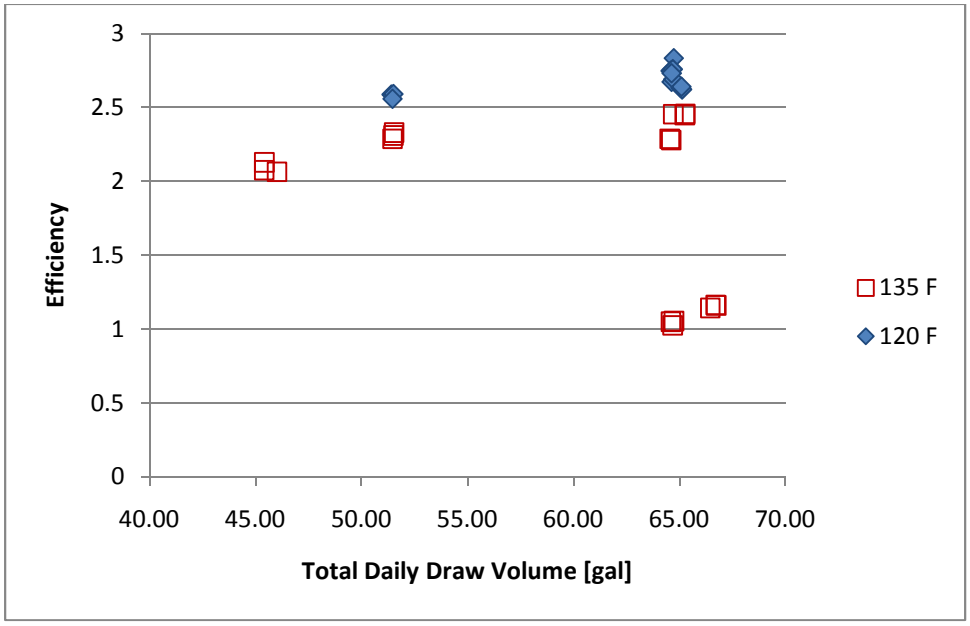

Figure 17. Daily efficiency as a function of total volume removed. Heat Pump water heater, multiple tests for each draw pattern.

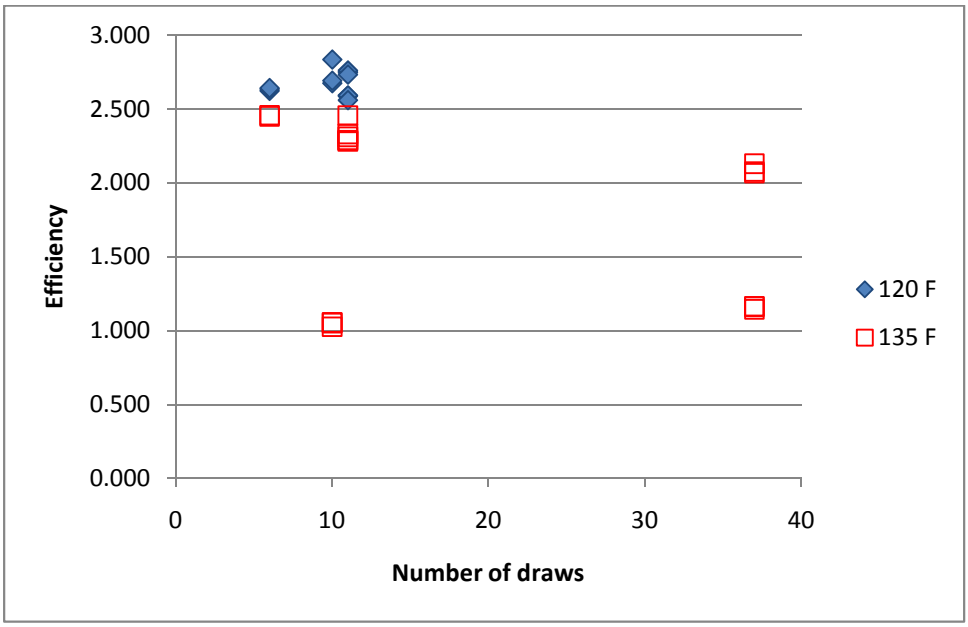

Figure 18. Daily efficiency as a function of number of draws per day. Heat pump water heater, multiple tests for each draw pattern. All data considered regardless of draw volume.

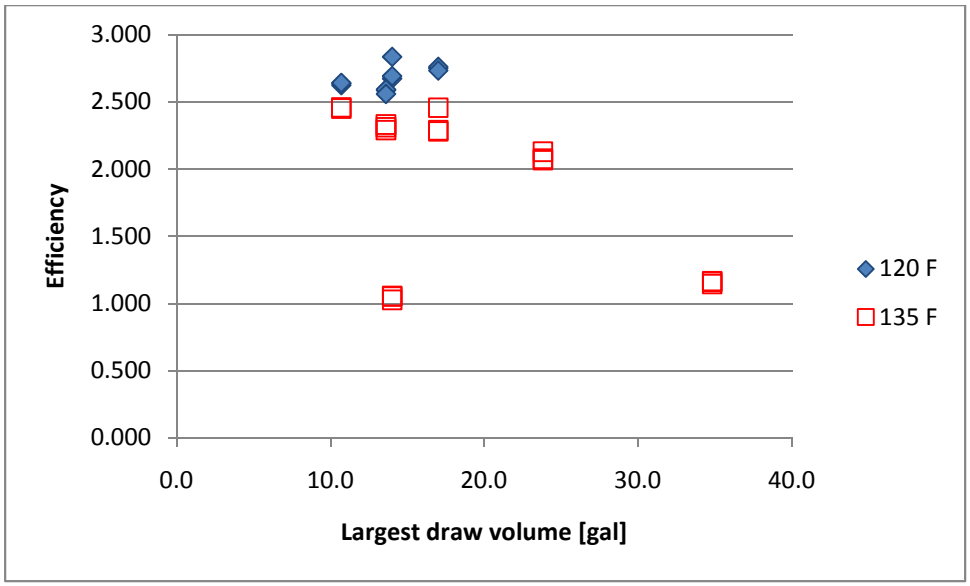

Figure 19. Daily efficiency as a function of largest volume of single draw during simulated use test. Heat pump water heater, multiple tests for each draw pattern.

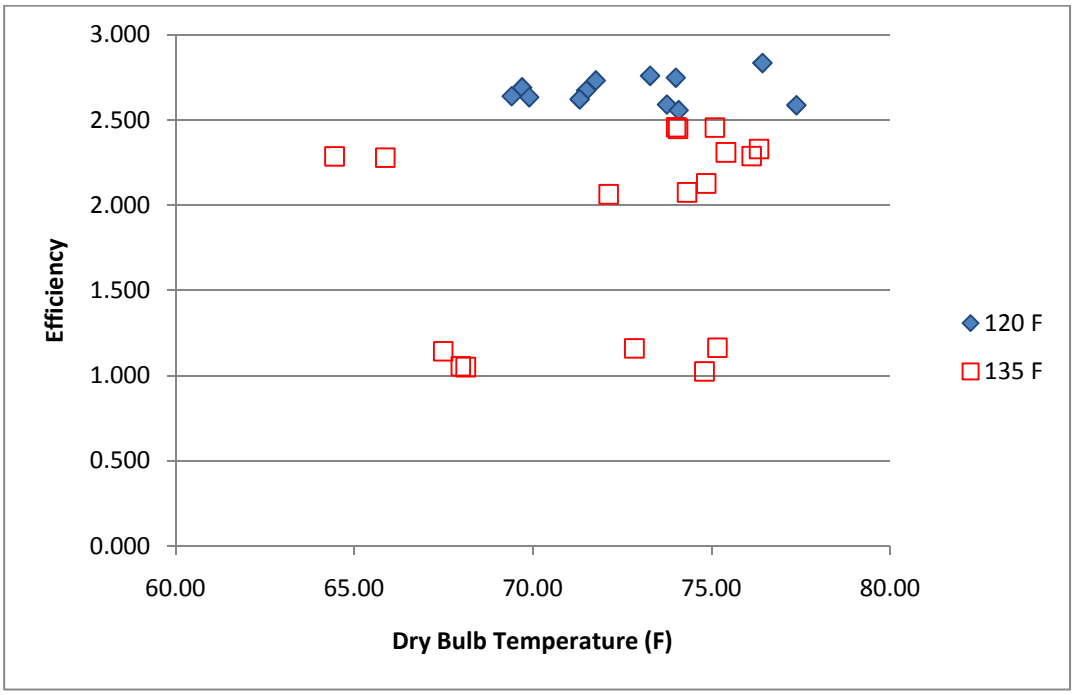

Figure 20. Daily efficiency as a function of average dry bulb temperature over the course of the 24 hour simulated use test. Heat pump water heater, multiple tests for each draw pattern.

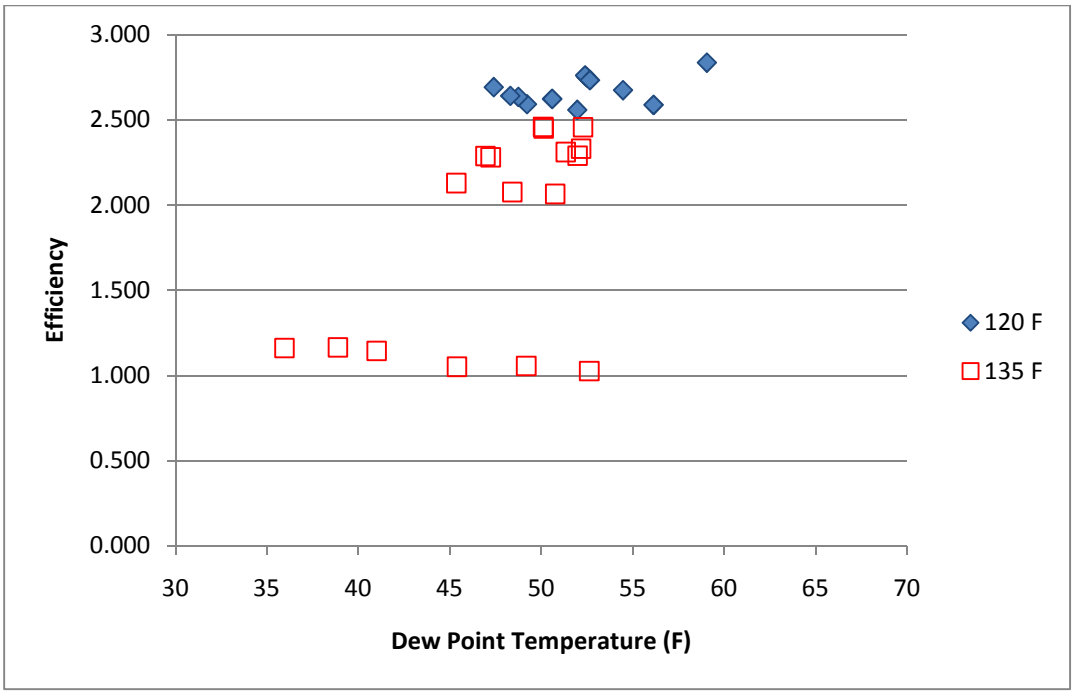

Figure 21. Daily efficiency as a function of average dew point temperature over the course of the 24 hour simulated use test. Heat pump water heater, multiple tests for each draw pattern.

Gas Tankless Water Heater

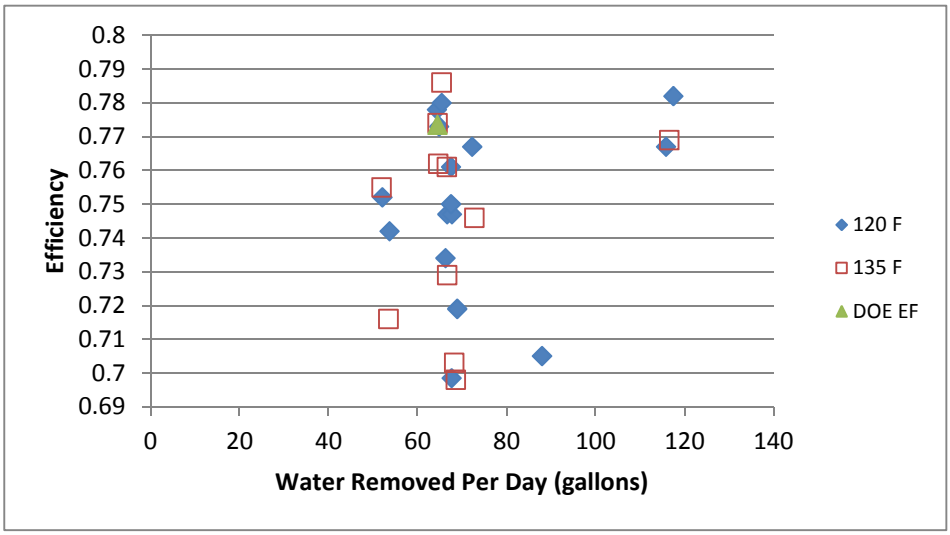

Figure 22. Daily efficiency as a function of water removed per day. Gas tankless water heater, one predraw.

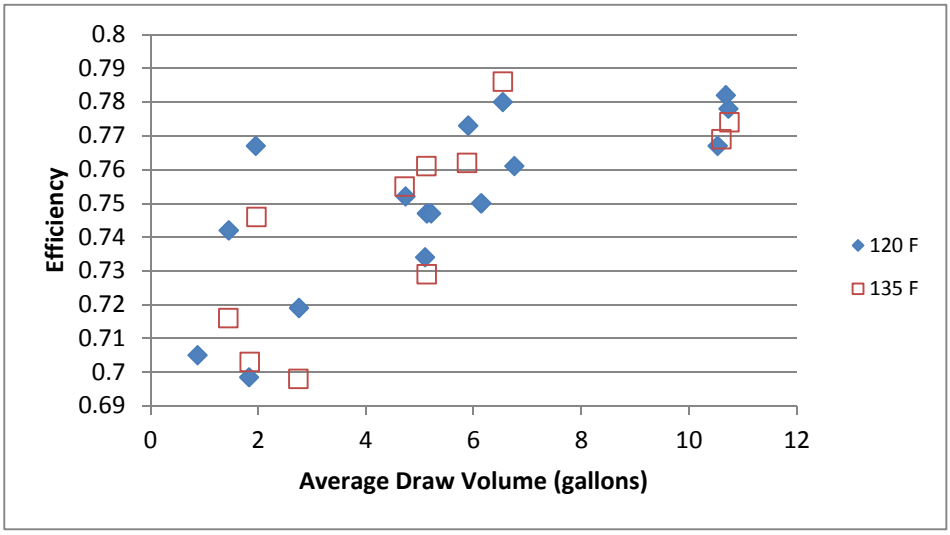

Figure 23. Daily efficiency versus average draw volume; gas tankless water heater.

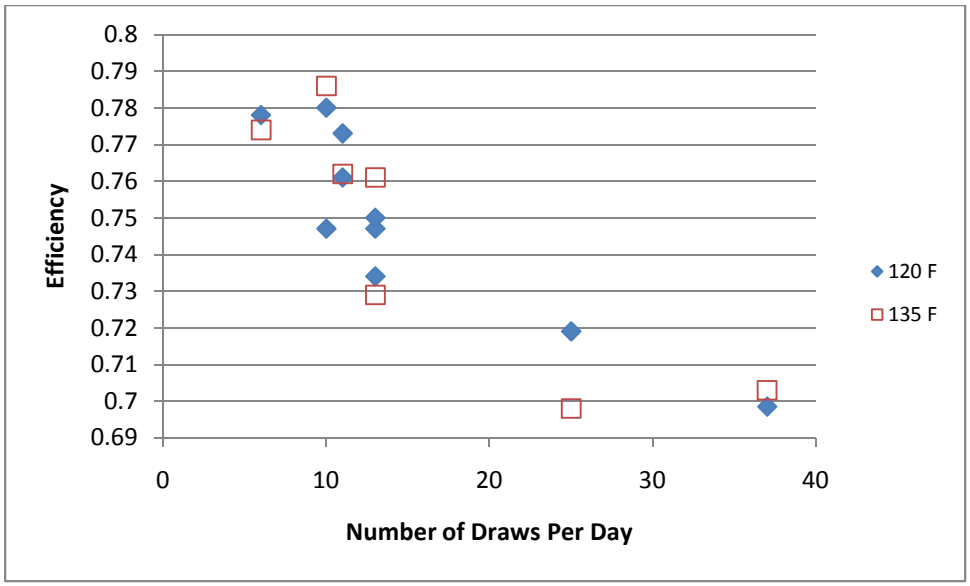

Figure 24. Daily efficiency versus number of draws per day for tests in which the total draw volume was 66 ± 3 gallons. Gas tankless water heater.