DAVIS ENERGY GROUP INCORPORATED

Field and Laboratory Testing of Tankless Gas Water Heater Performance

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1 Background and Objectives

Instantaneous, or tankless gas water heaters have the potential to significantly improve residential water heating energy efficiency due to higher combustion efficiencies and the elimination of the standby losses common to gas storage water heaters. In the last decade a new breed of instantaneous gas water heaters with Energy Factors of 0.80 or higher have been introduced to the market, considerably higher than the typical 0.60 Energy Factor for gas storage water heaters. These newer tankless models represent a significant improvement over units of twenty to thirty years ago as a result of both eliminating standing pilots and by integrating sophisticated controls that vary burner capacity to meet supply water setpoints under varying flow rates. Eliminating the standby heat loss results in a significant efficiency advantage that increases as hot water loads decrease.

Both tankless and storage gas water heaters are tested under procedures defined by the U.S. Department of Energy[1]. The Energy Factor testing procedure prescribes six equal hot water draws (totaling 64.3 gallons) at one-hour intervals. The remainder of the 24-hour test period is used to account for standby losses. Although storage water heaters are not significantly affected by the hot water draw profile, tankless units experience greater sensitivity to the number and frequency of draws since the heat exchanger must be raised to temperature for each draw event.

The primary goal of this study is to assess the performance implications of hot water draw patterns on tankless gas water heater performance. Data collected from an occupied house currently being monitored under the Building America program was used to document field performance of a tankless gas water heater. In addition, a second tankless unit was tested at Davis Energy Group's shop facility to support field findings and facilitate data collection under more controlled conditions. More information on tankless water heater performance issues can be found in Appendix A.

2 Testing Methodology

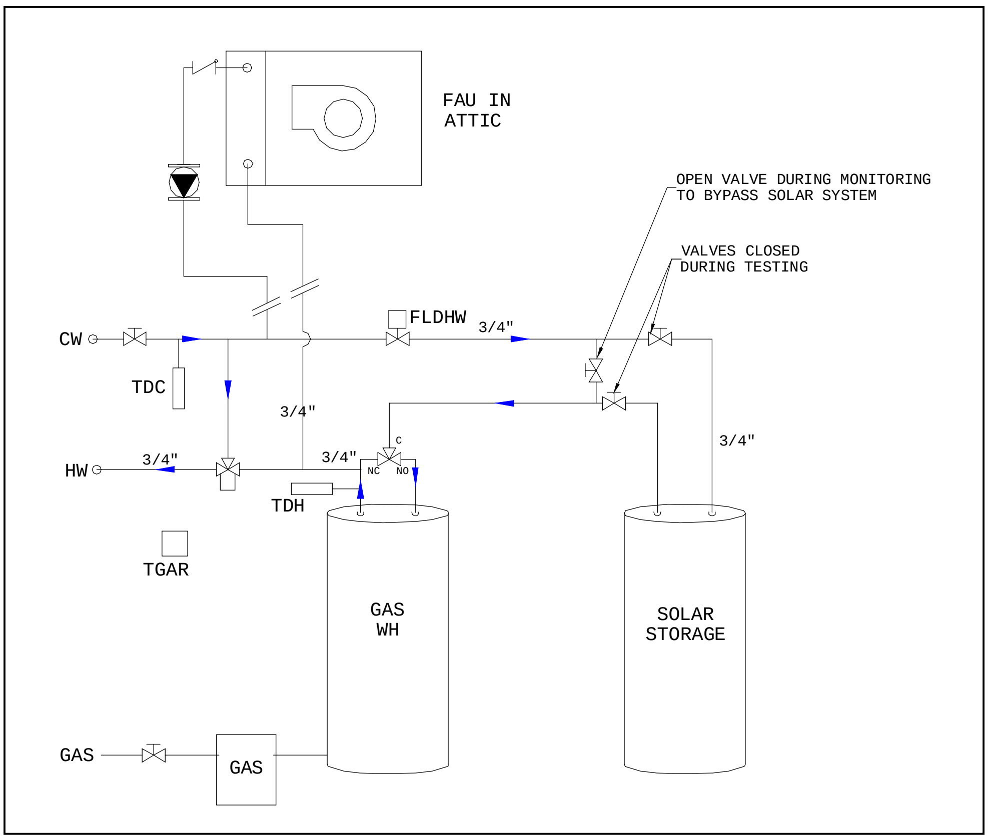
As part of a DOE Building America sponsored project, an existing home was selected in 2003 for field monitoring to assess performance of the existing gas storage water heater, followed by the installation and monitoring of a tankless gas unit. A working middle-aged couple occupied the home. The original water heater was a 50-gallon gas storage water heater (AO Smith Conservationist 90, 40,000 Btuh input, Model #PGCG-50) used for both space and domestic water heating. A solar system with hot water preheat tank was also connected, but for the purposes of this project, the solar hot water tank and space heating loop were bypassed during the test period. Figure 1 provides a schematic of the original storage water heater installation and installed monitoring equipment. (FLDHW represents a high resolution inline flow meter, GAS is a gas meter with a

[1] See Federal Register 10 CFR Chapter II, Pt. 430, Subpt. B, App. E

pulsing digital output[2], and TDH and TDC represent immersion thermocouples in the hot and cold water lines.)

At the end of October 2003 the gas storage water heater was removed and a Rinnai 2532FFU tankless water heater was installed. The water heater was mounted in the same location as the original gas storage tank and connected to the solar storage tank and the space heating fan coil. The Rinnai water heater (0.82 Energy Factor and 82% Recovery Efficiency) has a capacity range of 15,000 to 180,000 Btu/hour with modulating controls that adjust burner capacity to meet the factory set 120°F supply temperature under varying flow rates and cold water inlet temperatures. Figure 2 shows the Rinnai installation, and the revised piping schematic is shown in Figure 3. The schematic also shows location of the flowmeter and temperature sensors used for monitoring.

Figure 1: Existing Gas Storage System Configuration



A Science Electronics DataTaker DT-50 datalogger was used to monitor and log data. The datalogger was configured to log temperatures, hot water flow, gas consumption, and heating capacity on 15-second intervals whenever hot water flow occurred. Each hot

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[2] Original monitoring was performed with a standard 1 pulse/ft^3 gas meter pulser. This was later replaced with the 20 pulse/ft^3 pulser to improve data resolution.

water draw could then be characterized by a start time and end time, volume of water drawn from the water heater, Btu's delivered from the water heater, and gas consumption.

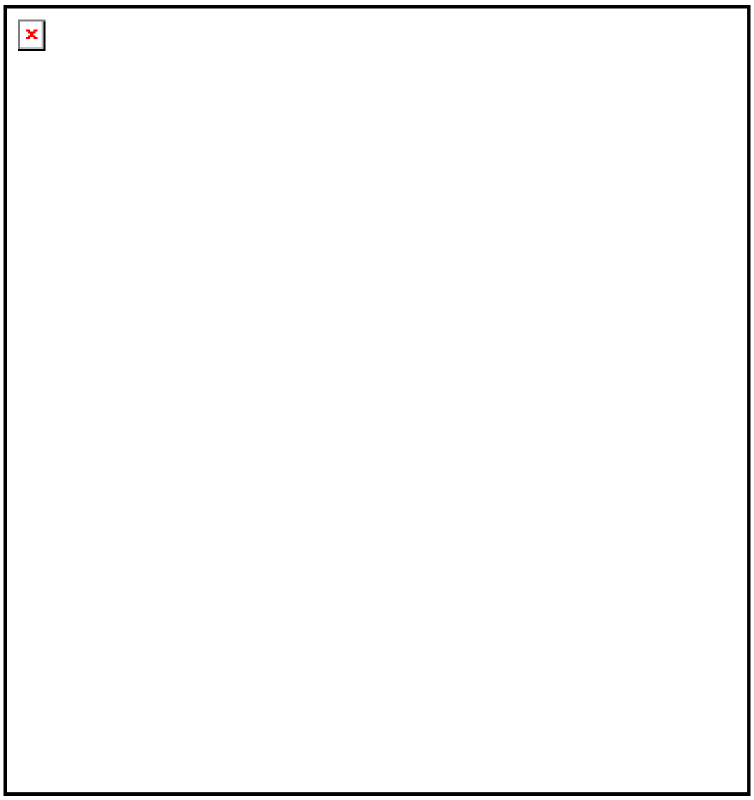
Efficiency was defined as follows:

Efficiency = Q_{out} / Q_{in}

Where Q_{out} = Volume x 8.3 x (TDH – TDC)
Q_{in} = Gas ft^3 x 1013 Btu/ft^3

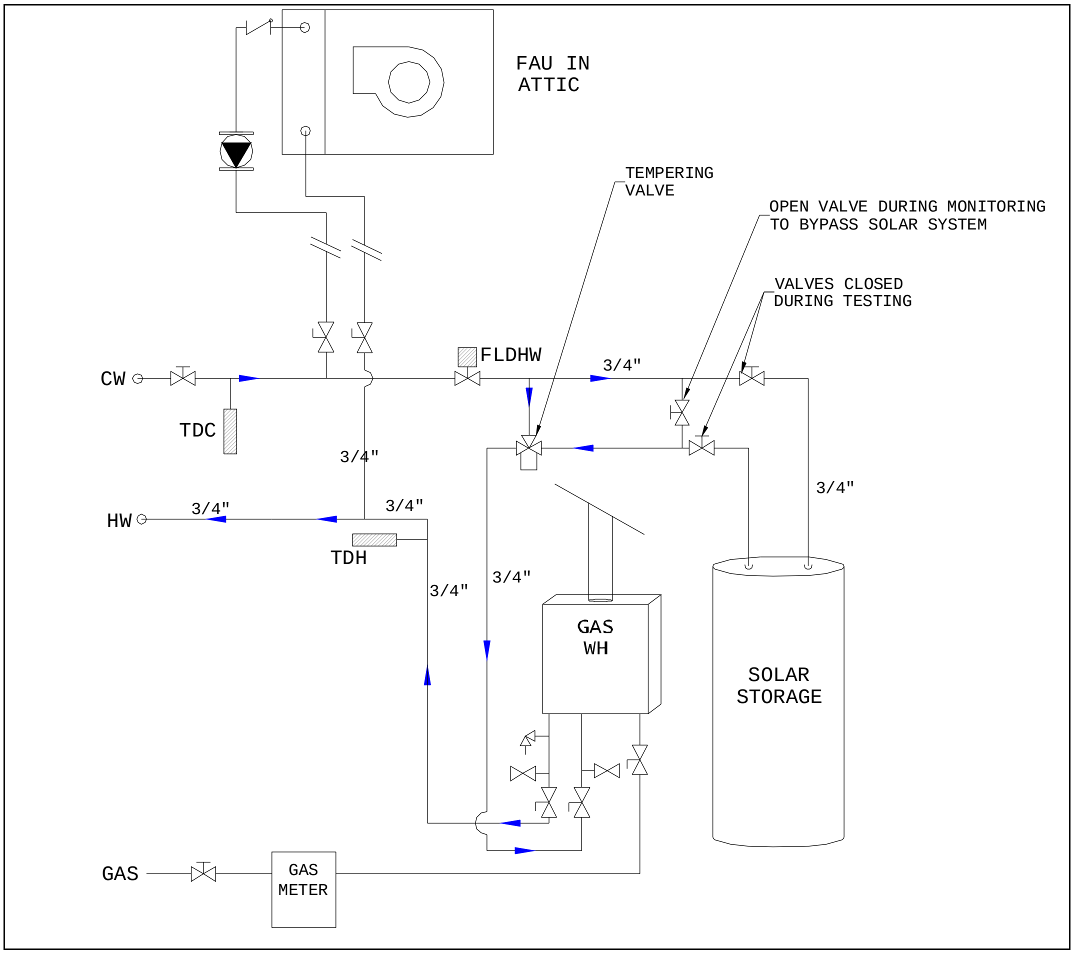
Efficiency could then be calculated either on per draw basis or summed to compute a daily efficiency.

Figure 2: Rinnai Water Heater Field Site Installation



In addition to the field testing, a second tankless unit was obtained for testing at Davis Energy Group's shop/test facility. A Takagi T-K Jr. (19,500 to 140,000 Btu/hour capacity, 0.81 Energy Factor, 81.6% Recovery Efficiency) was installed with monitoring hardware equivalent to that utilized in the field test (gas meter with 20 pulse/ft^3 resolution, factory calibrated Onicon flow meter, and immersion thermocouples for cold and hot water temperature). The goal of the lab testing was to evaluate the performance of a tankless unit under more controlled conditions by varying flow rate, draw volume, and time interval between draws.

Figure 3: Instantaneous Water Heater Installation Schematic



3 Results

The Building America monitoring effort was directed towards comparing performance of a conventional storage gas water heater to a tankless unit. Figure 4 plots initial data comparing the daily efficiency for both the storage water heater and the instantaneous unit. Clearly the storage gas water heater performance is impacted to a greater degree at low daily hot water draw volumes as the standby loss represents an increasingly larger fraction of the total energy consumed. The instantaneous unit also demonstrated some performance degradation at low draw volumes, presumably due to increased cycling. With these preliminary results, Davis Energy Group decided to install the 20 pulse/ft^3 gas meter to increase data resolution at smaller draw volumes. With the higher resolution gas meter in place, data were collected from August 17, 2005 through September 9, 2005 and January 1, 2006 through January 24, 2006[3]. Figure 5 plots the calculated efficiency as a function of the volume of each individual draw during

[3] The interval between the two data periods was used for testing of combined solar and instantaneous water heater performance.

Figure 4: Comparison of Daily Water Heater Efficiency

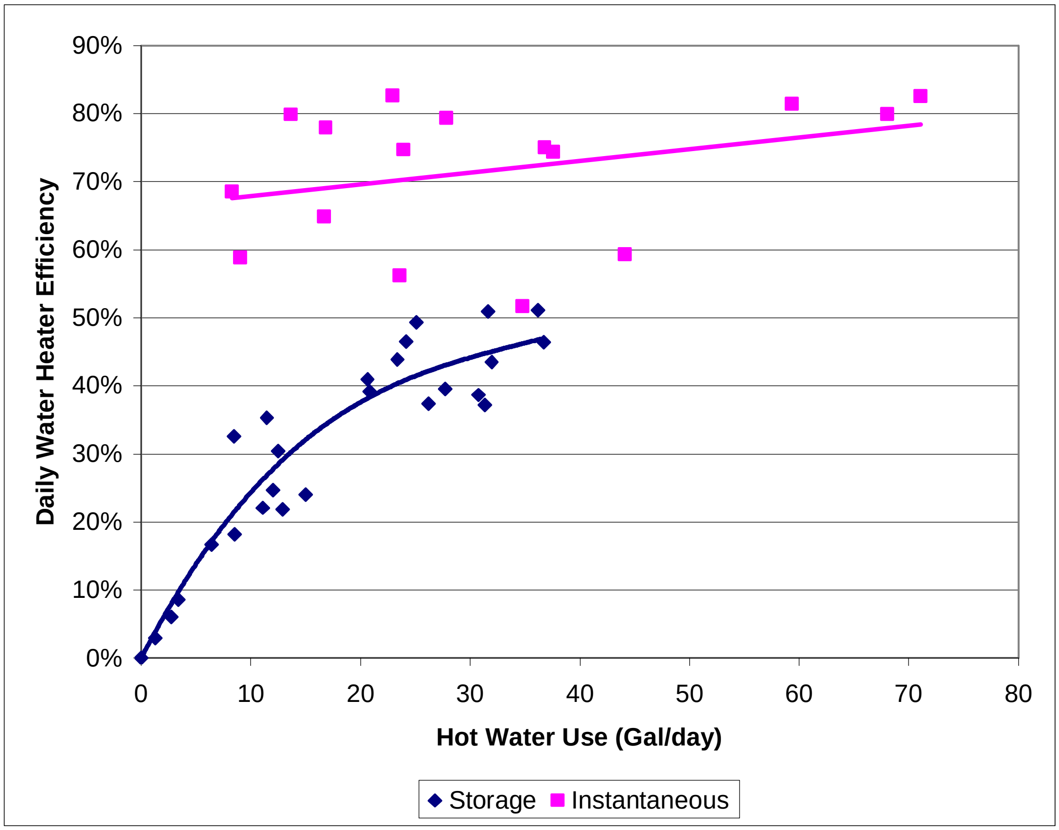
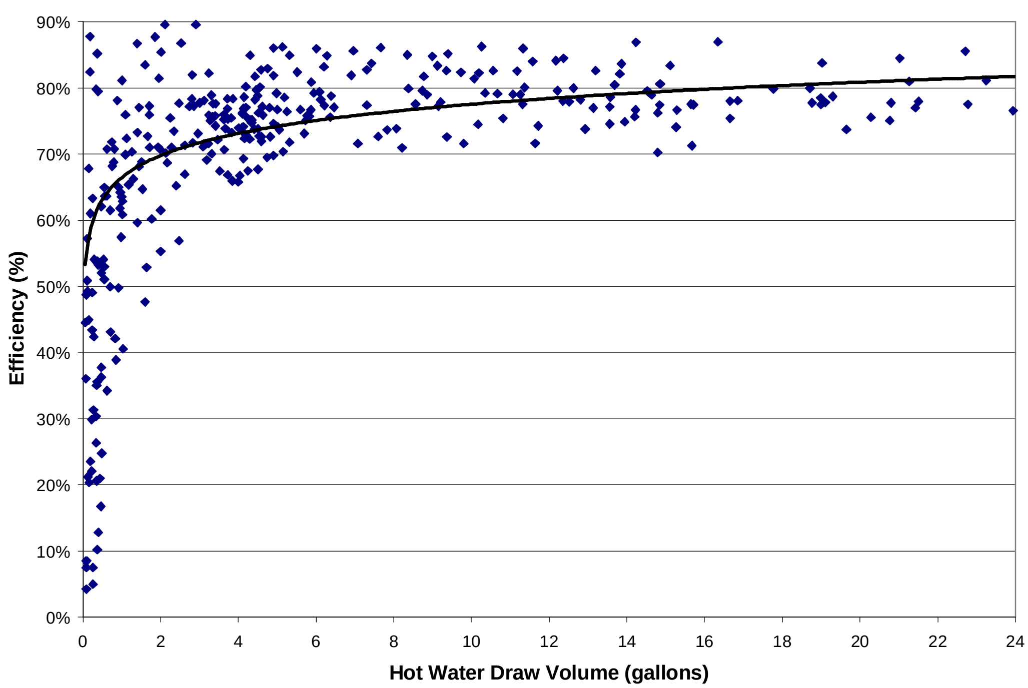


Figure 5: Monitored Field Efficiency of Tankless Water Heater #1



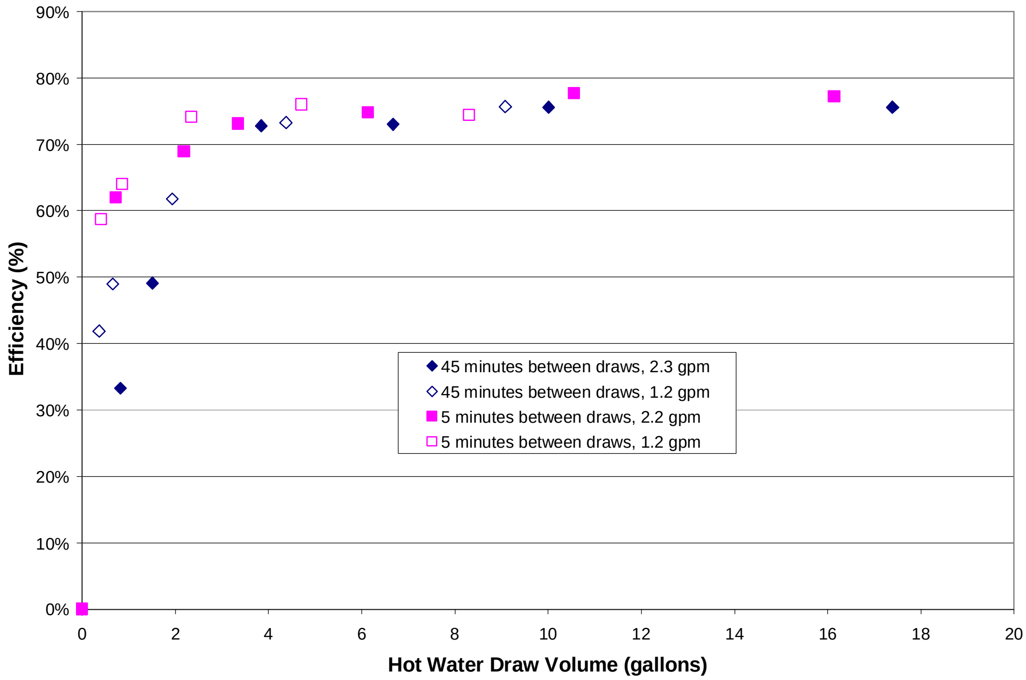
this period excluding any heating season draws where the system was operating in combined hydronic heating mode. The data demonstrate a sharp drop off in efficiency at draw volumes under 4 or 5 gallons. There is also significant scatter, especially as the hot water draw volumes approach zero. One factor affecting the scatter remains the resolution of the gas meter. Even at a high resolution rate of 20 pulses per cubic foot (~50 Btu/pulse), any one draw could potentially over or underestimate gas consumption by a maximum of two pulses (one pulse at each end of the draw). For a two gallon hot water draw with a 60°F hot to cold water temperature difference, a 100 Btu inaccuracy could affect the calculated efficiency by ~ ± 6%. The second factor is the time interval between hot water draws. For draws with just a few seconds between firing cycles, the impact on efficiency of heat exchanger "cool down" is insignificant since the heat exchanger is close to operating temperature. However as the time between draws increases, more of the initial firing energy is needed to bring the heat exchanger up to temperature. The impact of this initial firing energy becomes insignificant in large draws (> 10 gallons) where the warm up energy is negligible related to the total energy delivered.

In addition to the field testing, further monitoring was completed at the Davis Energy Group shop on the Takagi T-K Jr. to better understand performance degradation at low draw volumes with varying flow rates and time intervals between draws. Figure 6 plots data from a series of tests with varying flow rates (1.2 to 2.3 gpm) and varying time intervals between hot water draws (5 and 45 minutes[4]) at the default factory temperature setting of 122°F. The data demonstrate a relationship similar to that shown for the field measurements, but Figure 6 more clearly depicts the impact of cool down time on system efficiency. The "5 minutes between draw" tests show an ~ 10-15 percentage point drop in efficiency at draw volumes of 1 gallon (relative to 10 – 15 gallons), while the "45 minutes between draws" show a much more significant drop. This efficiency disparity is largest at small volumes and approaches zero at about 4 gallon draw volumes. The impact of flow rate appears to be negligible for the "5 minute" data, although the "45 minute" interval data does demonstrate some variation due to flow rate. This is largely due to the effect of the lower flow rate allowing more time for the heat exchanger to achieve temperature than at a higher flow rate.

Understanding typical residential hot water draw schedules is a critical step in evaluating the impact of usage patterns on tankless water heater performance. Unfortunately hot water usage data characterizing typical California residential usage (both in magnitude and use pattern) is very limited. We relied on two sources to develop a load profile for use in estimating a Load Dependent Energy Factor (LDEF) for tankless water heaters. The first source was detailed monitoring completed under a separate Building America project. A new home in Elk Grove, California was instrumented with monitoring hardware similar to that used in this study. In addition, surface mount thermocouples were installed on the copper lines immediately upstream of each of the hot water use points to determine the end use location of each hot water draw. The datalogger was

[4] At 45 minutes, the heat exchanger had essentially cooled to room temperature.

Figure 6: Monitored Lab Efficiency of Tankless Water Heater #2



configured to initiate logging at 2 second intervals whenever hot water flow was sensed by the flowmeter. Continuous data were collected from October 2003 through August 2004. Although not statistically valid, the single data point does provide insight to hot water use patterns for one particular two-person household. Figure 7 plots the eleven months of data disaggregated by both draw volume and time interval between draws. Sixty one percent of the daily average 43 gallon day usage occurred in draws greater than eight gallons. The small draws (<4 gallons) that would affect tankless water heater performance amounted to 29% of total hot water consumption. Of these "< 4 gallon" draws, 65% occurred within 15 minutes of a prior draw and 17% occurred more that 60 minutes after a prior draw. These results suggest that the derating of the tankless unit should be more heavily weighted towards the "5 minute interval" data.

A second information source for characterizing hot water usage is the load profiles used in the HWSIM modeling for determination of distribution system multipliers for the 2005 Title 24 Standards. Although these hot water usage schedules were constructed to meet a floor area based hot water recovery load, they are based on a broad sample of prior monitoring studies characterizing hot water usage in terms of volume/draw and draws/day for different end use points. Figure 8 compares the breakdown of hot water usage for the Building America data and the sample used in the 2005 Standards analysis. The agreement between the two is surprisingly good with both showing close to 70% of the usage occurring at draw volumes greater than 4 gallons (the point at which the time interval between draws has little or no effect on efficiency). For the 30% of draws with hot water volumes less than 4 gallons, both the Building America data and HWSIM schedule were reviewed to assess the time interval between draws since this will be a key factor affecting performance.

Figure 7: Characterization of Hot Water Loads at Building America Site

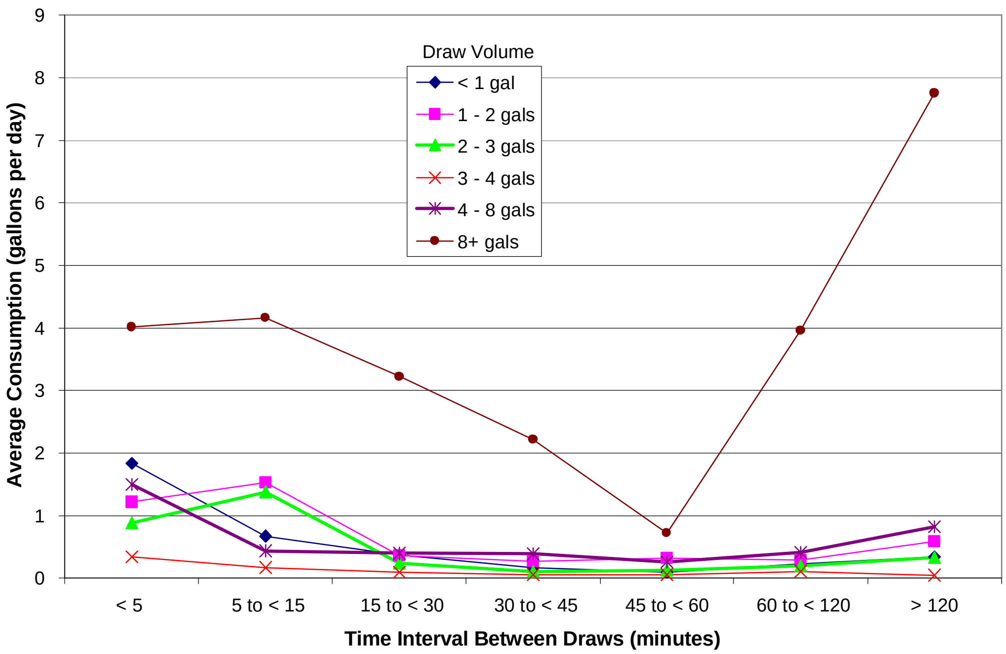


Figure 8: Comparison of Hot Water Draw Volumes

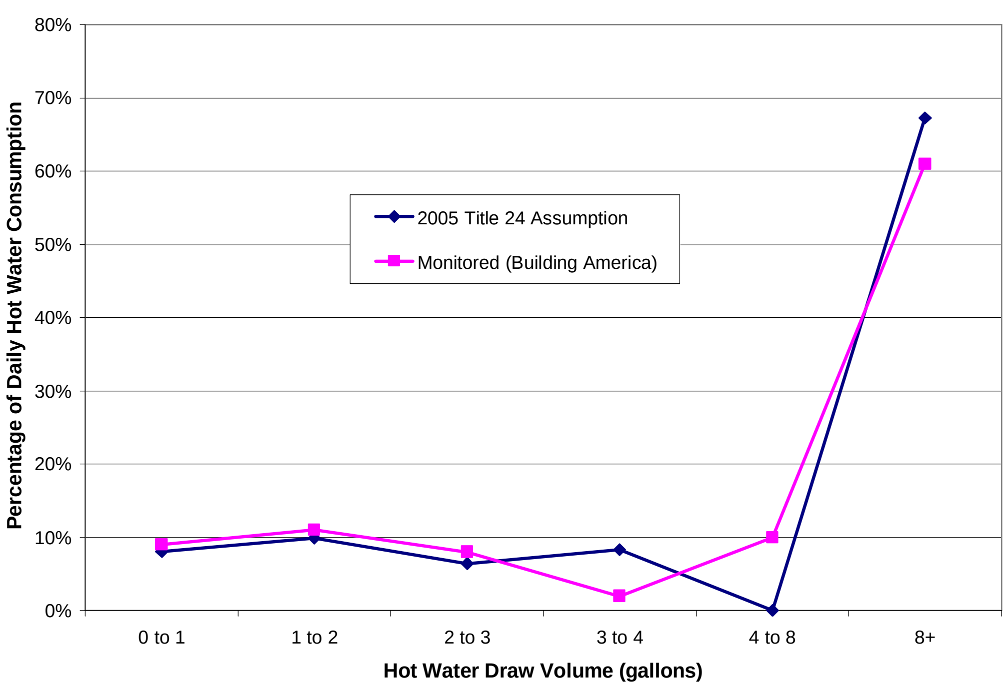


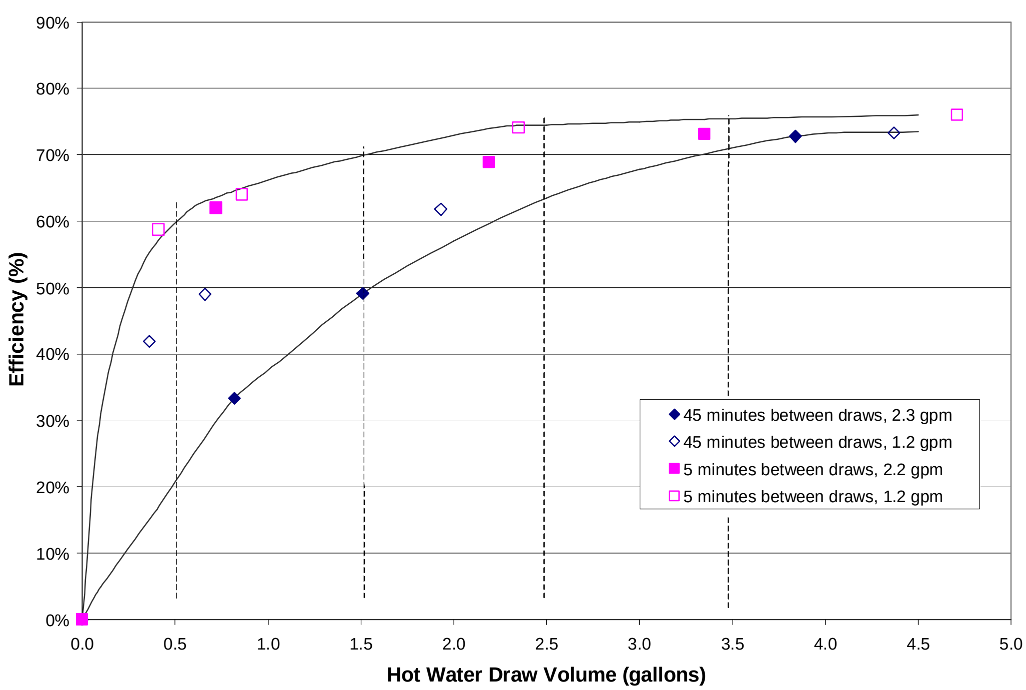
Table 1 summarizes the time interval data. The field monitoring data shows more low volume hot water consumption within five minutes of the prior draw than that assumed in the HWSIM schedules. Both show slightly over 20% of small draws occur at an interval greater than 45 minutes, the point at which the heat exchanger has generally completely cooled off.

Table 1: Summary of Time Intervals Between Low Volume Draws

	Time Interval Between Draws (minutes)			
	<5	5 to < 15	15 to < 45	> 45
Building America data	34%	31%	13%	22%
HWSIM (2005 Standards)	14%	35%	29%	22%

Figure 9 presents a subset of the data shown in Figure 6 (hot water volumes less than 5 gallons), since this is the region where tankless performance is subject to the greatest degradation. For the zero to four gallon draw volume range we propose to evaluate performance under two cool down scenarios: 5 minute cool down and 45 minute cool down (at 2.3 gpm flow rate). Figure 9 shows a smoothed curve through the lab monitored data points. In addition vertical lines are shown at 0.5, 1.5, 2.5, and 3.5 gallons. A representative efficiency can be defined where the vertical lines intercept the curve. For example, at 0.5 gallons, efficiencies of 21% and 60% are estimated, for 45 and 5 minute intervals, respectively.

Figure 9: Efficiency as a Function of Volume and Time Between Draws



The final step in developing a realistic degradation term for tankless water heaters involves applying the efficiency curves to the assumed load profiles. Table 2 disaggregates the assumed hot water load into one gallon bins using the average of the relationships shown in Figure 8. The assumption is also made that at an eleven gallon hot water draw, the efficiency of a tankless unit is equal to the rated recovery efficiency[5], in this case 81.6%. Estimated efficiencies for draws of four gallons or less are based on Figure 9. From five through ten gallons, a linear relationship is assumed. As shown in Table 2, ~90% of the performance degradation occurs for draw volumes less than four gallons. This is due to the low efficiencies and fairly high usage at low volume, as well as the absence of degradation at large draws where 70% of the usage is assumed to occur. The difference between hot (77.3%) and cold starts (70.3%) is fairly significant when compared the assumed nominal 81.6% efficiency.

Table 2: Projected Typical Tankless Performance (Cold and Hot Start)

		"Cold Start"		"Hot Start"	
Hot Water Draw Vol (gallons)	% of Total Load	Estimated Thermal Efficiency	Weighted Efficiency	Estimated Thermal Efficiency	Weighted Efficiency
1	9.0%	***21.0%***	1.9%	***60.0%***	5.4%
2	10.0%	***49.0%***	4.9%	***70.0%***	7.0%
3	7.0%	***63.0%***	4.4%	***74.0%***	5.2%
4	5.0%	***71.0%***	3.6%	***76.0%***	3.8%
5	2.0%	72.5%	1.5%	76.8%	1.5%
6	2.0%	74.0%	1.5%	77.6%	1.6%
7	1.0%	75.5%	0.8%	78.4%	0.8%
8	4.0%	77.1%	3.1%	79.2%	3.2%
9	5.0%	78.6%	3.9%	80.0%	4.0%
10	5.0%	80.1%	4.0%	80.8%	4.0%
11	6.0%	81.6%	4.9%	81.6%	4.9%
12	8.0%	81.6%	6.5%	81.6%	6.5%
13	8.0%	81.6%	6.5%	81.6%	6.5%
14	8.0%	81.6%	6.5%	81.6%	6.5%
15	5.0%	81.6%	4.1%	81.6%	4.1%
16	4.0%	81.6%	3.3%	81.6%	3.3%
17	3.0%	81.6%	2.4%	81.6%	2.4%
18	3.0%	81.6%	2.4%	81.6%	2.4%
19	3.0%	81.6%	2.4%	81.6%	2.4%
20	2.0%	81.6%	1.6%	81.6%	1.6%
Overall Efficiency			70.3%		77.3%

[5] Eleven gallons corresponds to approximately the draw volume used in the Energy Factor test (one sixth of 64.3 gallons).

4 Conclusions and Recommendations

Laboratory and field testing completed in this study confirm that tankless water heater performance is affected by low volume draws, as well as the time interval between draws. In the lab testing we have completed test with "hot" and "cold" heat exchangers. The projected impact on efficiency under an assumed load profile is fairly significant, ranging from an average "daily" efficiency of 70.3% for a cold heat exchanger to 77.3% for a hot heat exchanger. In reality, the expected degradation will lie somewhere between these two points. Given the lack of solid data on hot water usage patterns, load magnitude, and time between draws, we propose applying a 40% weighting factor to "cold" and a 60% weighting to "hot". The resulting seasonal efficiency is calculated to be 74.5%, or 8.8% below the nominal 81.6% efficiency.

Our recommendations for ACM rules in regards to tankless water heaters are as follows:

1. The ACM should degrade the listed Energy Factor for gas tankless water heaters by 8.8%.

2. For units with a continuously burning pilot, 500 Btu/hour of pilot energy should be assumed, unless a value is available in the CEC's Appliance Directory for small natural gas instantaneous water heaters.

The proposed 8.8% Energy Factor degradation would be uniformly applied in the ACM, regardless of the magnitude of the hourly hot water load. Although this approach is technically not accurate on a "per draw" basis (smaller draws have larger performance degradation and large draws have little or no degradation), the proposed approach does provide accurate answers on a daily or annual time scale. In addition, given the lack of knowledge on hot water usage patterns in California, it is premature to propose a more detailed modeling methodology that could focus on time steps shorter than the current one hour interval used in the ACM.

APPENDIX A:

Instantaneous Gas Water Heater Performance Issues

Tankless gas water heaters offer significant performance advantages over standard gas storage water heaters common to over 85% of California households. Currently they are starting to become more common in the new construction market as builders embrace the Title 24 credits and buyers appreciate their energy efficiency and new technology status. However there are issues related to the performance of these units. A brief review of the key issues follows.

<u>Delay in hot water delivery</u>

When hot water is drawn a storage water heater, hot water flows immediately into the piping system. Tankless water heaters have a startup delay and then a delay associated with bringing the heat exchanger up to operating temperature. Takagi T-K Jr. product literature suggests a three second delay in burner firing and an additional three second delay before hot water is delivered. We verified the initial three second firing delay for both the Takagi and Rinnai water heaters that were tested. However detailed one second interval data collection indicate significantly longer times before hot water is delivered. Figures 1 and 2 plot hot (supply) and cold (inlet) water temperatures at different flow rates and with different time intervals (5 or 45 minutes) since the prior hot water draw. With a 122° factory default temperature setting and a flow rate of 1.9 gpm, it took 26 seconds to reach 115°F supply water temperature with a hot heat exchanger and a 36 seconds with a cold heat exchanger. Figure 2 shows similar data at a higher 3.3 gpm flow rate. The impact of the higher flow rate was negligible (29 and 37 seconds, respectively). The added time delay may or may not be a concern for homeowners, depending upon their expectations and the type and configuration of their hot water distribution system.

Figure 1: Tankless Start Up Performance at 1.9 gpm (Hot and Cold Start)

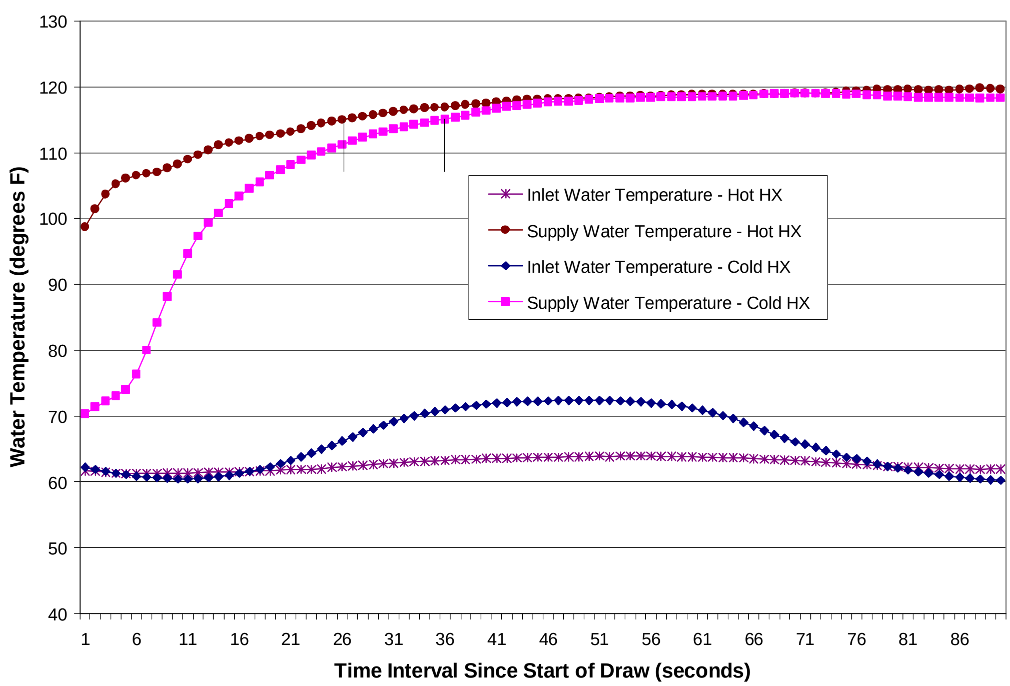
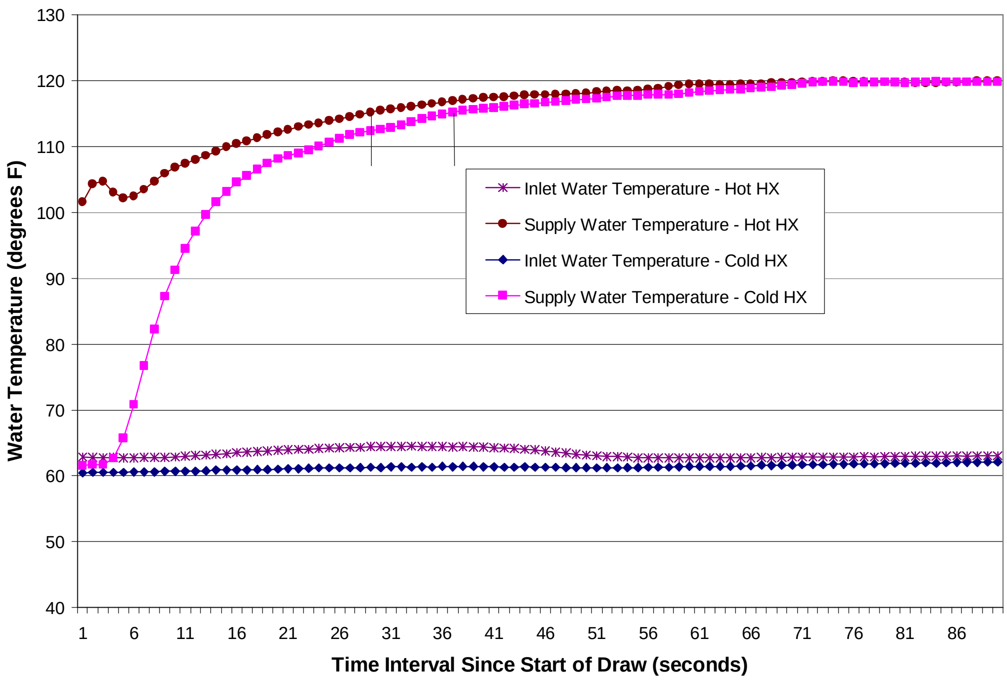


Figure 2: Tankless Start Up Performance at 3.3 gpm (Hot and Cold Start)



<u>Endless hot water</u>

Tankless units will not run out of hot water provided the maximum flow rate for the given inlet and supply water conditions is not exceeded. Many energy efficiency advocates are concerned about the potential for increased energy consumption with tankless water heaters. The logical culprit would be showers. In homes constrained by the recovery capacity of conventional storage water heaters, tankless water heaters may result in longer showers. To our knowledge, no data exists to support this hypothesis. The Building America field site was pre-monitored with a gas storage water heater prior to installation of the tankless unit. For the two-person household, hot water use did increase slightly when using the tankless unit. Given their variable occupancy patterns and use characteristics, it does not appear that the tankless unit played a role in the change in hot water usage[6].

<u>Minimum flow rates</u>

Tankless water heaters have a minimum flow rate to initiate burner operation. The minimum typically ranges from 0.5 to 0.8 gpm. This can be both a benefit and a hindrance. With single lever kitchen and bath faucets the centered position of the lever virtually insures that a small volume of hot water will be pulled from a storage water heater for each draw regardless of the user's intent. In addition many low flow rate and short duration sink draws are not initiated with an expectation of obtaining hot water. In these cases, a tankless unit will eliminate heating of the water provided that the flow rates are lower than the threshold. Problems may occur during low flow rate draws where hot water is desired at the fixture. The simple solution is to increase the

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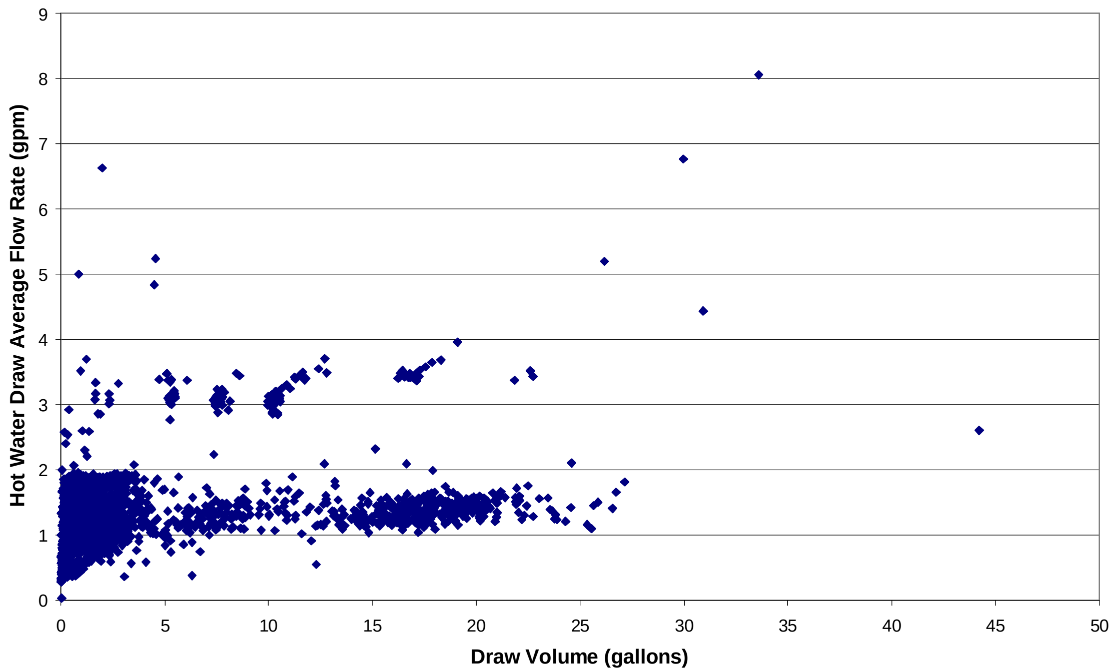
[6] The homeowners maintain that they have not changed their hot water usage characteristics with the tankless unit.

flow rate, although this has implications for both water and energy use. Figure 3 presents eleven months of monitored hot water usage data documenting individual draws from Building America site reported on in the body of this report (Figure 7). For this site, 30% of the total hot water draws were for volumes of less than 4 gallons. In terms of flow rate, ~ 0.25% of all hot water flows occurred at flow rates less than 0.5 gpm, and less than 2% at flow rates below 0.8 gpm. Based on this one house, issues related to minimum flow rate do not appear to be significant.

Figure 3: Monitored Hot Water Draw Characteristics



<u>Scaling Concerns</u>

The water supply in many areas of California has high mineral content, increasing the potential for heat exchanger scaling. Detailed assessment of this issue was outside the scope of this project. Discussions with one plumber who has installed approximately 75 tankless units indicated his strong preference for requiring water softeners on houses with tankless units. His company has performed flushing of the heat exchanger (with a mild acid solution) on about four of the units he has installed. Longer term field monitoring of scaling and plumber/homeowner maintenance practices is recommended.

<u>Impact of Temperatures on Operating Efficiency</u>

Many of the main tankless water heater manufacturers factory set the temperature on their water heaters to ~120°F. This relatively low setting can be used due to the high burner capacity of the unit relative to storage water heaters which must relied on storage capacity to supplement burner output during high load events. The ~120°F setting also provides some level of safety from scalding. Although the temperature setting can generally be adjusted, it is our impression that there is typically no need to adjust the temperature. To evaluate the impact of outlet temperature, one set of tests were run at 140°F setpoint and compared to the prior 122°F results. Figure 4 plots the two efficiency curves at a typical residential flow rate of 1.2 gpm. The limited data suggests that outlet temperatures do not significantly impact efficiency.

Figure 4: Thermal Efficiency as a Function of Outlet Temperature