Energy Efficiency Potential of Gas-Fired Commercial Hot Water Heating Systems in Restaurants

An Emerging Technology Field Monitoring Study

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Acknowledgments

The PG&E Food Service Technology Center (FSTC) acknowledges the support provided by Charles Bohlig, East Bay Municipal Utility District (EBMUD), in monitoring the total water use of this facility and installing low-flow pre-rinse spray valves in the restaurant kitchen.

The FSTC recognizes the commitment of the participating national restaurant chain to increasing the energy efficiency of its facilities and eagerness to support this emerging technology initiative. The enthusiasm of the restaurant staff to accommodate our on-site visits and needs was appreciated.

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ABSTRACT

The hot water load represents a significant portion of the energy and water consumed in a commercial food service operation. The objective of this field study was to characterize the hot water demand and associated energy use of a standard efficiency gas-fired, tank-type (storage) water heater, compare its performance to that of a high efficiency (condensing) gas-fired, tank-type (storage) water heater, and to investigate the applicability of an instantaneous (tankless) water heater at a full-service restaurant. The study was conducted at a multi-unit (chain) casual dining restaurant located in San Ramon, California. All work was done under the auspices of the Pacific Gas and Electric (PG&E) Company within the scope of the statewide Emerging Technologies (ET) Program.

The high efficiency, condensing water heater demonstrated efficiencies that were nominally 8 to 15 percentage points higher than the base case, standard efficiency water heating system depending on the level of system optimization. This translated to gas savings (and annual cost savings) in the range of 10 to 20% ($850 to $1700). Given the relatively high peak water demands (potentially up to 20 gpm on an instantaneous basis), it is projected that a tankless water heating system would require a capacity of 800,000 Btu/h (three or four tankless units depending on individual rating) to match the performance of a 600,000 Btu/h, high efficiency two-tank (200 gallon storage capacity) system. The FSTC recommends that the restaurant chain that participated in this study continue to specify high efficiency, tank-type water heaters.

It further is recommended that PG&E, in parallel with its California Energy Commission (CEC) Public Interest Energy Research (PIER) study on water heating efficiency potential, develop design guidelines for water heating systems in commercial food service. In support of the "gas savings" goals within PG&E's energy efficiency programs, an incentive should be developed to encourage both the sale and purchase of high-efficiency, condensing water heaters for commercial applications.

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Executive Summary

The hot water load represents a significant portion of the energy and water consumed in a commercial food service operation. The objective of this field study was to characterize the hot water demand and associated energy use of a standard efficiency gas-fired, tank-type (storage) water heater, compare its performance to that of a high efficiency (condensing) gas-fired, tank-type (storage) water heater, and to investigate the applicability of an instantaneous (tankless) water heater at a full-service restaurant. The study was conducted at a multi-unit (chain) casual dining restaurant located in San Ramon, California. All work was done under the auspices of the Pacific Gas and Electric (PG&E) Company within the scope of the statewide Emerging Technologies (ET) Program.

This restaurant was designed with a 400,000 Btu/h, 100-gallon standard efficiency water heater with a hot water re-circulation system that was in continuous operation. The FSTC contracted to have a 300,000 Btu/h 100-gallon high efficiency (condensing) water heater installed along side the existing heater. The plumbing was arranged so that the two water heaters could be operated independently or simultaneously, in either series or parallel configurations. The installation allowed the hot water circulation return line to be configured to enter the inlet of either tank. The water heaters and all associated plumbing and monitoring equipment were housed in an enclosed room adjacent to the kitchen. The instrumentation package included a water meter on the cold water supply along with temperature probes on the inlet to and outlet from the water heaters. Flow meters were installed on the gas supply to both the standard efficiency and high efficiency water heater. A data acquisition system logged average water consumption, gas consumption and temperatures over 5-minute intervals. System efficiency was calculated by dividing the energy transferred to the heated water by the gas (energy) consumed by the water heater(s).

Measuring the actual hot water use and associated load profile for this restaurant operation was fundamental to evaluating the performance of the water heating system and projecting the energy saving associated with an increased water heater efficiency. The daily hot water consumption in this restaurant ranged from a low of 1400 gallons to a high of 3700 gallons, with an average usage of 2100 gallons per day. The peak demand (based on the average over a 5-minute period) was up to 9 gpm (gal/min) on typical hot-water-use periods and up to 16 gpm on high hot-water-use periods. It is important to note that these flow rates are based on 5-minute averages and may not represent the peak instantaneous demand for hot water (the actual peak demand would be somewhat higher). This is important with respect to establishing the design capacity of a tankless water heating system. Figure ES-1 illustrates a typical load profile for an average hot-water-use day.

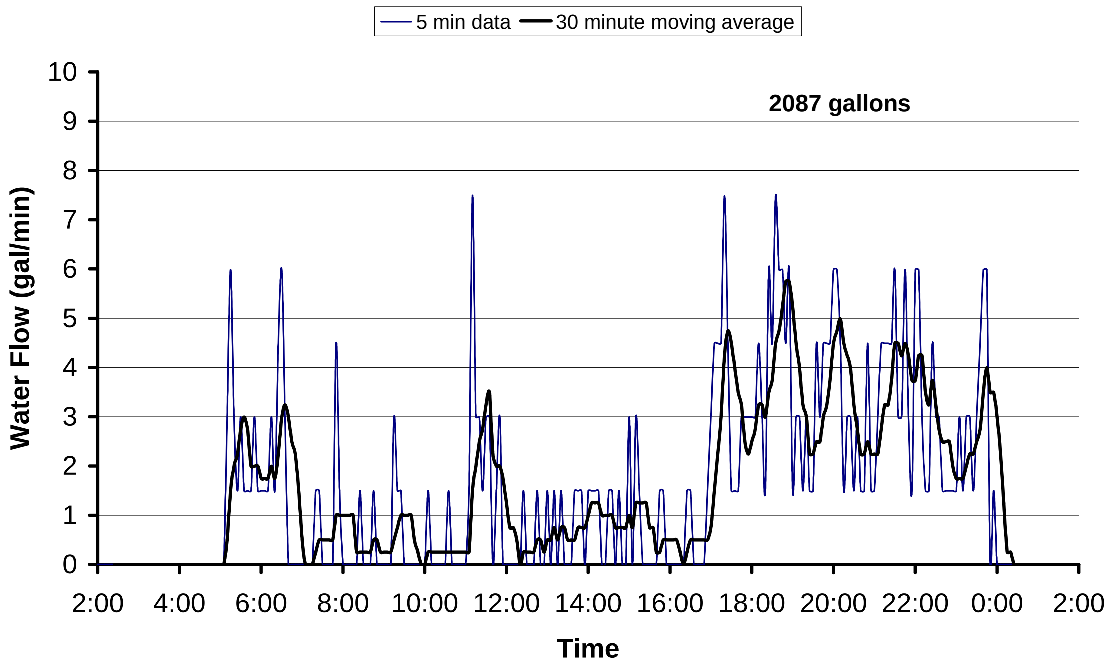

Figure ES1. Typical daily hot water load profile

Testing was conducted in three general configurations:

Configuration 1: The standard efficiency heater was operated independently as it was originally installed in the restaurant. This "as-installed" condition was designated configuration 1(a).

Configuration 2: The high efficiency tank heater was tested in series (upstream the standard efficiency tank heater) with the hot water circulation line returning to the inlet of the high efficiency water heater, designated configuration 2(a).

Configuration 3: Also in a series arrangement, designated 3(a), the high efficiency tank (still upstream the standard efficiency tank) was tested with the hot water re-circulation line returning between the two tanks (i.e., at the inlet to the standard efficiency heater versus the high efficiency tank).

Optimized Configurations, 1(b), 2(b), 3(b): Subsequently all three configurations were testing in an optimized mode. This included turning off the re-circulation pump for 10 hours per day and placing the automatic flue damper switch (on the standard efficiency tank) in the "on" position. These optimized configurations were designated 1(b), 2(b) and 3(b), respectively.

Each configuration typically was tested for a two-week period. Although the intent had been to operate the high efficiency tank as a stand-alone unit for a direct comparison to the base-case standard efficiency unit, this option was not tested; there was concern that the water-heating capacity of the high efficiency heater (300,000 Btu/h at 95% efficiency) was lower than the water-heating capacity of the standard efficiency heater (400,000 Btu/h at 80%).

System efficiencies, projected annual gas consumption, operating costs and savings are tabulated in Table ES-1 for the various test configurations and level of optimization.

Table ES-1. System efficiency, projected annual gas consumption, cost and saving

Configuration:	1(a) Std. efficiency base case	1(b) Std. efficiency optimized**	2(a) High efficiency non-optimized recirc line to high efficiency	2(b) High efficiency optimized** recirc line to high efficiency	3(a) High efficiency non-optimized recirc line to std efficiency	3(b) High efficiency optimized** recirc line to std efficiency
System Efficiency (%)	67.6	75.6	75.2	83.1	80.0	84.5
Projected Gas Consumption (therms/year)*	7496	6703	6738	6098	6334	5997
Projected Annual Cost ($/year)*	$8995	$8043	$8129	$7361	$7644	$7240
Cost savings over base case, ($/year)*		$952	$866	$1634	$1351	$1755

*Based on 365 day/year operation, 2083 gal/day hot water flow, 80°F temperature rise, $1.20/therm. Includes electricity costs attributed to blower motor on high efficiency tank (based on $0.15/kWh).
**Automatic flue damper operational (on std. efficiency unit), hot water re-circulation pump turned off 10 h/d by time clock.

As originally installed in configuration 1(a), the standard efficiency tank exhibited a system efficiency of 67.6%. When optimized in configuration 1(b), by commissioning the automatic flue damper and placing the circulation pump on a time clock, the water heating system efficiency increased to 75.2%. When the high-efficiency tank was operated in configuration 2(a), which was considered a typical installation with the hot water re-circulation line returning to the inlet of the high efficiency tank, a system efficiency of 75.2% was recorded. This was a gain of 7.6 percentage points above the standard efficiency tank in its "as-installed" configuration 1(a) and effectively no gain over the optimized standard configuration 1(b). It was hypothesized that the higher temperature of the circulation loop return flow under low water use and standby periods was limiting the efficiency of the condensing water heater (i.e., higher temperatures of water entering the water heater reduce efficiency as less heat is extracted from the flue gases). However, when a time clock was activated on the circulation pump, the efficiency of configuration 2(b) increased to 83.1%, a gain of 15.5 percentage points over the standard efficiency configuration 1(a) and 7.9 percentage points over the optimized standard efficiency system, configuration 1(b).

The high efficiency water heater in its most optimized configuration 3(b) (series connection with the standard efficiency tank downstream, hot water circulation line returning between the two tanks, circulation pump controlled by a timer) returned an average system efficiency of 84.5%, for a 16.9 percentage point gain over the base-case standard efficiency heater.

Annual cost savings (based on $1.20/therm) associated with the installation of the high efficiency water heater was projected to be as high as $1755 while operating in the fully optimized configuration 3(b). In what would be more typical with the re-circulation line entering the inlet to the high efficiency tank, configuration, 2(b), the projected cost saving was $1634. In a non-optimized condition, configuration 2(a) demonstrated an $866 saving over the base case, standard efficiency heater. Although the annual cost savings associated with simply optimizing the operation of the standard efficiency heater was estimated at $952 (it was estimated that about half of this saving was due to the re-circulation pump time clock and about half due to the flue damper setting), maintaining a flue damper on a standard efficiency tank in its "on" position is a "best practice" that may not always be implemented or sustained within a commercial food service operation.

Conclusions and End–User Recommendations. The high efficiency, condensing water heater demonstrated efficiencies that were nominally 8 to 15 percentage points higher than the base case, standard efficiency water heating system. This translated to gas savings (and annual cost savings) in the range of 10 to 20% ($850 to $1700). Although the purchase price of a high efficiency heater is more than a standard efficiency heater, the design group for this restaurant chain reported that a reduced installation cost for the condensing water heater (due to the less expensive PVC venting) offset the higher first cost of the heater itself. In this case, the payback on a high-efficiency water heating system would be immediate. Within the scope of this field study, it was not possible to independently compare installation costs, as the FSTC only covered costs to install the high-efficiency unit. The FSTC team suspects that there could be a cost premium, particularly for independent operators. But even if this premium were as high as $2000, the investment in a high efficiency water heating system would be recouped within two to three years.

The FSTC recommends that the restaurant chain that participated in this study continue to specify high efficiency, tank-type water heaters. Given the current focus on redundancy (the policy of this multi-unit operation is to shut down the restaurant if the water heating system fails), a further recommendation would be to install two 300,000 Btu/h high-efficiency tank-type heaters in a parallel configuration.

Specifying a time clock for the re-circulation loop pump is a stand-alone recommendation. Although a series connection might extract an additional percentage point or two on system efficiency, this would be counter to industry practice and is not recommended. One option, which might gain a small efficiency benefit at no significant cost, would be to plumb the return line from the circulation loop to an upper port in the tank, rather than "tee" into the supply water inlet port. It is recommended that a second high efficiency water heater be installed in the San Ramon facility to replace the standard efficiency heater that is currently operating in series with a high efficiency heater.

Application of Tankless Water Heaters. Given the relatively high peak water demands (potentially up to 20 gpm on an instantaneous basis), it is projected that a tankless water heating system would require a capacity of 800,000 Btu/h (three or four tankless units depending on individual rating) to match the performance of a 600,000 Btu/h, high efficiency two-tank (200 gallon storage capacity) system. Although the installation and field testing of a tankless system was beyond the scope of this ET project, a review of performance data published by GAMA[1] shows that the thermal efficiencies for tankless water heaters are generally only a few percentage points higher than reported efficiencies for standard tank-type heaters (e.g., 84% vs. 80%). Since the stand-by loss from a tank-type heater represents a small fraction of the overall water heating load in a commercial food service facility, the real-world system efficiency will be directly proportional to the steady state efficiency for a given water heater. This implies that application of a tankless water heating system would not have a large "energy cost saving benefit" for this full-service restaurant operation. It should be noted, that high-efficiency tankless water heaters (e.g. with efficiencies greater than 90%) are not widely available in North America. Utilizing a tankless water heater in conjunction with a tank-type heater may be an option to provide redundancy without the space penalty associated with an additional tank heater. The associated cost and "foot print" saving benefits would need to be established by the restaurant design team.

Future Research and Testing. For all configurations tested, there was a significant day-to-day variation in system efficiencies for similar daily consumptions of hot water. The parameters causing this variation need to be investigated under more controlled conditions. If this phenomenon can be explained, it might provide design insight that could raise the overall efficiencies of water heating systems.

The regression of heater efficiency against daily water consumption (for all configurations tested) indicated a slight decrease in efficiency with reduced hot water use. This implies that over sizing the capacity of a water heating system could negatively impact its energy performance. This "over sizing" factor should be investigated and quantified under laboratory conditions. Laboratory testing (or further

[1] Gas Appliance Manufacturers Association (GAMA) Consumers' Directory of Certified Efficiency Ratings for Heating and Water Heating Equipment, February 16, 2007.

field monitoring) also should to be conducted to support our hypothesis that connecting the return line from the circulation loop at a port near the top of the tank rather than “tee” the return line into the inlet water line may increase the efficiency of a condensing-type water heater.

For all future laboratory and field studies, it is recommended that the flow meters and data acquisition system be specified with sufficient resolution and capacity to permit data collection on at least a 1-minute interval. It also is recommended that this emerging technology project be extended to cover monitoring of the system with a second high efficiency water heater, installed to replace the standard efficiency heater that is currently operating in series with a high efficiency heater.

PG&E Focus. PG&E, in parallel with its California Energy Commission (CEC) Public Interest Energy Research (PIER) study on water heating efficiency potential, should develop design guidelines for water heating systems in commercial food service. In support of the “gas savings” goals within PG&E’s energy efficiency programs, an incentive should be developed to encourage both the sale and purchase of high-efficiency, condensing water heaters for commercial applications.

Background

The hot water load represents a significant portion of the energy and water consumed in a commercial food service operation. A cursory estimate by the FSTC suggests that gas load associated with water heating in California commercial food service facilities could be as high as 400 million therms per year, closely matching the gas load associated with commercial cooking equipment. Both estimates are the target of a more in-depth study to be conducted by the PG&E Food Service Technology Center (FSTC) within the scope of a California Energy Commission (CEC) Public Interest Energy Research (PIER) project.

Objective

The objective of this field study was to characterize the hot water demand and associated energy use of a standard efficiency gas-fired, tank-type (storage) water heater, compare its performance to that of a high efficiency (condensing) gas-fired, tank-type (storage) water heater, and to investigate the applicability of an instantaneous (tankless) water heater at a full-service restaurant. All work was done under the auspices of the Pacific Gas and Electric (PG&E) Company within the scope of the statewide Emerging Technologies (ET) Program.

Site Description

The study was conducted at a multi-unit (chain) casual dining restaurant located in San Ramon, California. This restaurant featured a bar and full service dining room with a seating capacity for 192 people. A 100-gallon, 400,000 Btu/h standard efficiency tank type water heater (GAMA reported Thermal Efficiency of 80% with Standby Loss of 1387 Btu/h), located in a mechanical room adjacent to the kitchen, handled all water-heating needs for the restaurant, which included a dishwasher, several pre-rinse spray valves, and several general wash stations. A hot water circulation pump was set to operate 24 hours per day. The purpose of this hot water circulation system was to ensure that hot water would be quickly available at all faucets and hot water using appliances within the restaurant. The large capacity of the room allowed for easy installation of the high efficiency tank and all associated plumbing and monitoring equipment. Ambient temperature in the room remained fairly constant throughout the test period.

Water Heater Technologies

A high efficiency water heater differs from a standard efficiency unit in its ability to transfer energy from the combustion gases to the water. Generally, a high efficiency unit will utilize a multi-pass heat exchanger design as opposed to the single pass system of most standard efficiency units. The former allows for substantially more heat to be extracted from the hot combustion gasses and transferred to the water. In this case, these gasses are cooled below the dew point temperature, causing water vapor in the combustion product to condense. High efficiency (condensing) water heaters exhibit thermal efficiencies around 95%, as opposed to 80% for standard efficiency, non-condensing units.

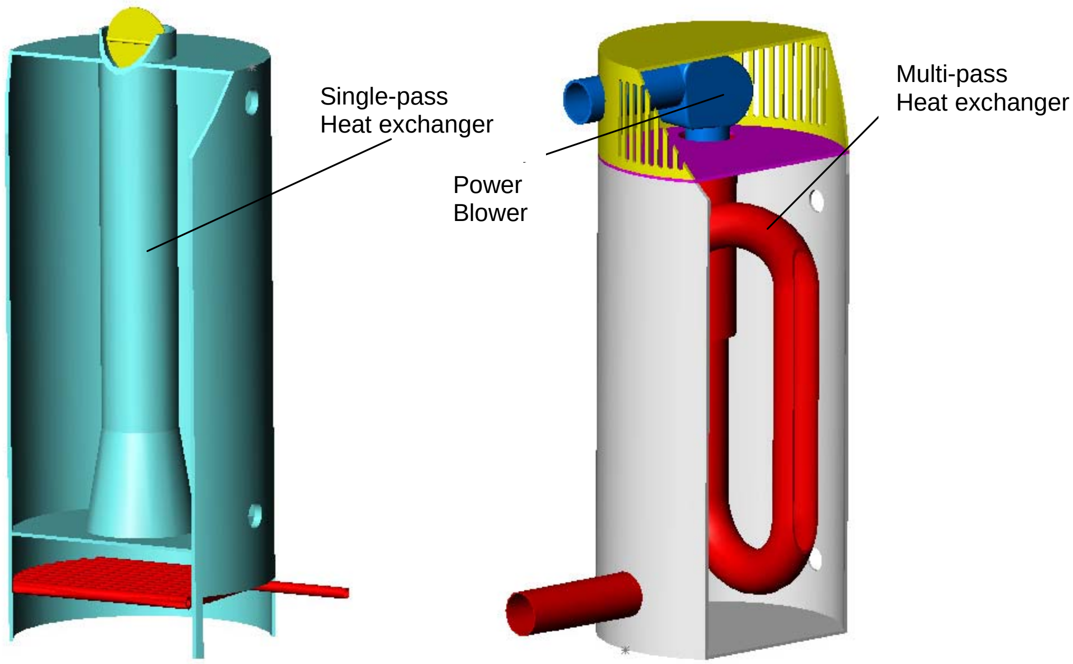

Figure 1. Single-pass and multi-pass heat exchangers

A tankless (or instantaneous) water heater, as its name implies, has no hot water storage capacity. This results in a water heating system that does not have the stand-by losses associated with tank style heaters. However, in a restaurant application, the standby loss from a conventional storage tank is small in proportion to the overall water-heating load. Thus, the energy saving benefit associated with reducing standby losses from a residential water heating system does not automatically transfer over to a commercial food service system. Another drawback of tankless water heaters is the fact that an individual unit will have maximum water flow rate for a given temperature rise (e.g., 5 gpm at a 70°F rise) whereas a tank type heater can handle large transient loads because of its storage capacity. In the case of a full-service restaurant, multiple tankless units would be needed to meet peak hot water demands. Although high efficiency (condensing) tankless heaters are on the market in Japan, most of the models offered in the U.S. are standard efficiency, with reported thermal efficiencies from the low to mid 80% range[2].

Field Test Protocol

A 100-gallon, 300,000 Btu/h high efficiency (condensing) tank type water heater (GAMA reported Thermal Efficiency of 92% with Standby Loss of 1044 Btu/h), along with all associated plumbing and instrumentation, was installed adjacent to the existing standard efficiency unit in the mechanical room as shown in the illustration and photos. Insulation was added to all hot water lines within the room. The plumbing was designed so that the water heaters could be operated individually or simultaneously in a series configuration (i.e., high efficiency unit upstream the standard efficiency unit).

Figure 2. Standard efficiency tank as originally installed

[2] GAMA Product Directories: http://www.gamanet.org/

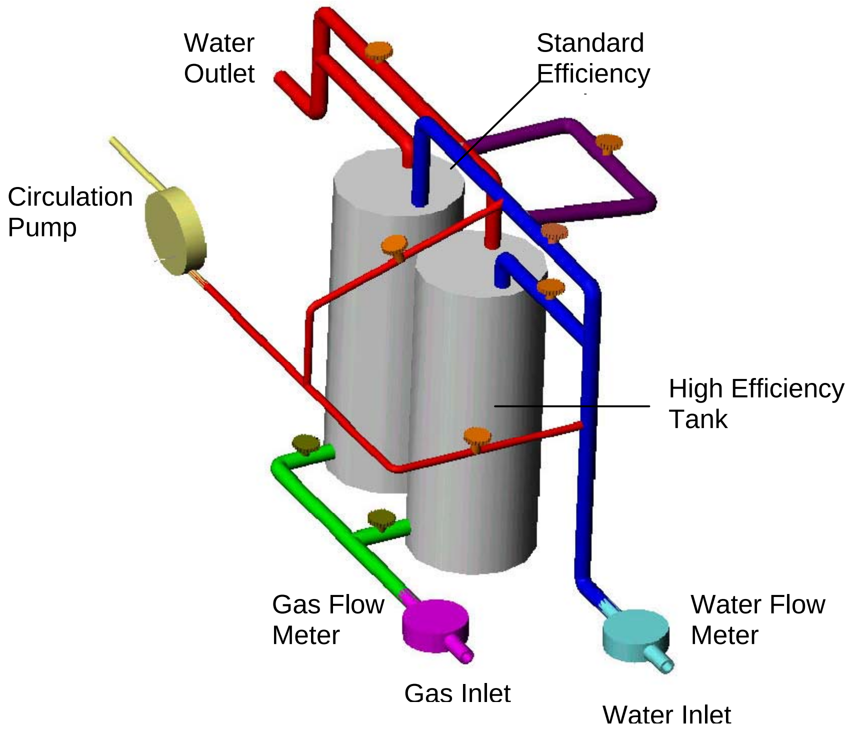

Figure 3. Water heater test arrangement

Figure 4. Water heaters installed for monitoring

Testing was conducted in three general configurations, illustrated schematically in the Figures 5, 6 and 7.

Configuration 1: The standard efficiency heater was operated independently as it was originally installed in the restaurant. This "as-installed" condition was designated configuration 1(a).

Configuration 2: The high efficiency tank heater was tested in series (upstream the standard efficiency tank heater) with the hot water circulation line returning to the inlet of the high efficiency water heater, designated configuration 2(a).

Configuration 3: Also in a series arrangement, designated 3(a), the high efficiency tank (still upstream the standard efficiency tank) was tested with the hot water circulation line returning between the two tanks (i.e., at the inlet to the standard efficiency heater versus the high efficiency tank).

Optimized Configurations, 1(b), 2(b), 3(b): Subsequently all three configurations were testing in an optimized mode. This included turning off the re-circulation pump for 10 hours per day and placing the automatic flue damper switch (on the standard efficiency tank) in the "on" position. These optimized configurations were designated 1(b), 2(b) and 3(b), respectively.

Each configuration typically was tested for a two-week period, on a cyclic basis, over the duration of the project. Although the intent had been to operate the high efficiency tank as a stand-alone unit for a direct comparison to the base-case standard efficiency unit, this option was not tested; there was concern that the water-heating capacity of the high efficiency heater (300,000 Btu/h at 92% efficiency) was lower than the water-heating capacity of the standard efficiency heater (400,000 Btu/h at 80%). Having the option to run both water heaters together in series allowed for the high efficiency heater to handle the majority of the water-heating load, and for the standard tank to handle any remaining load. During the test period, there were instances of high water flow rates where this situation did occur.

All pertinent data was logged at five-minute intervals. The parameters of interest were temperature of the incoming cold water, temperature of outgoing hot water, water flow rate through the water heaters, and gas consumption by both water heaters.

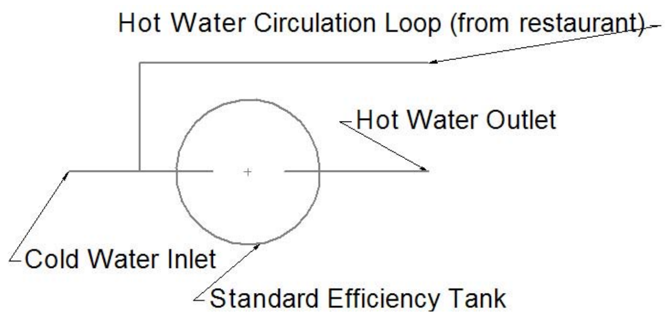

Figure 5. Test Configuration 1 (standard efficiency tank)

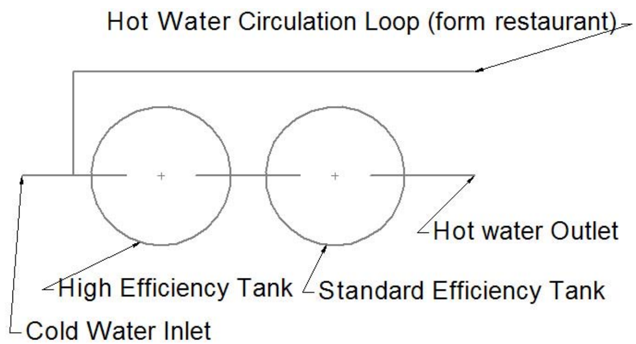

Figure 6. Test Configuration 2 (high efficiency tank in series with standard efficiency tank, circulation loop entering high efficiency tank)

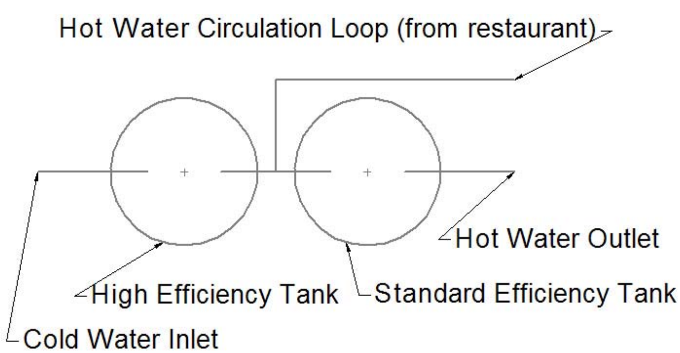

Figure 7. Test Configuration 3 (high efficiency tank in series with standard efficiency tank, circulation loop entering standard efficiency tank)

Results and Discussion

Average daily total (cold and hot) water consumption for the restaurant was found to range from approximately 3000 gal/day to 5300 gal/day depending on the season. Overall flow rates where higher during the summer months due to irrigation. No seasonal variation in hot water use was observed.

The average daily hot water consumption over the duration of the test period was 2083 gallons/day. With the exception of a major holiday, with limited operating hours, where the hot water consumption was only 157 gallons, the minimum measured daily hot water usage was 1384 gallons. The maximum was 3741 gallons. The wide range in daily hot water consumption is illustrated in Figure 8.

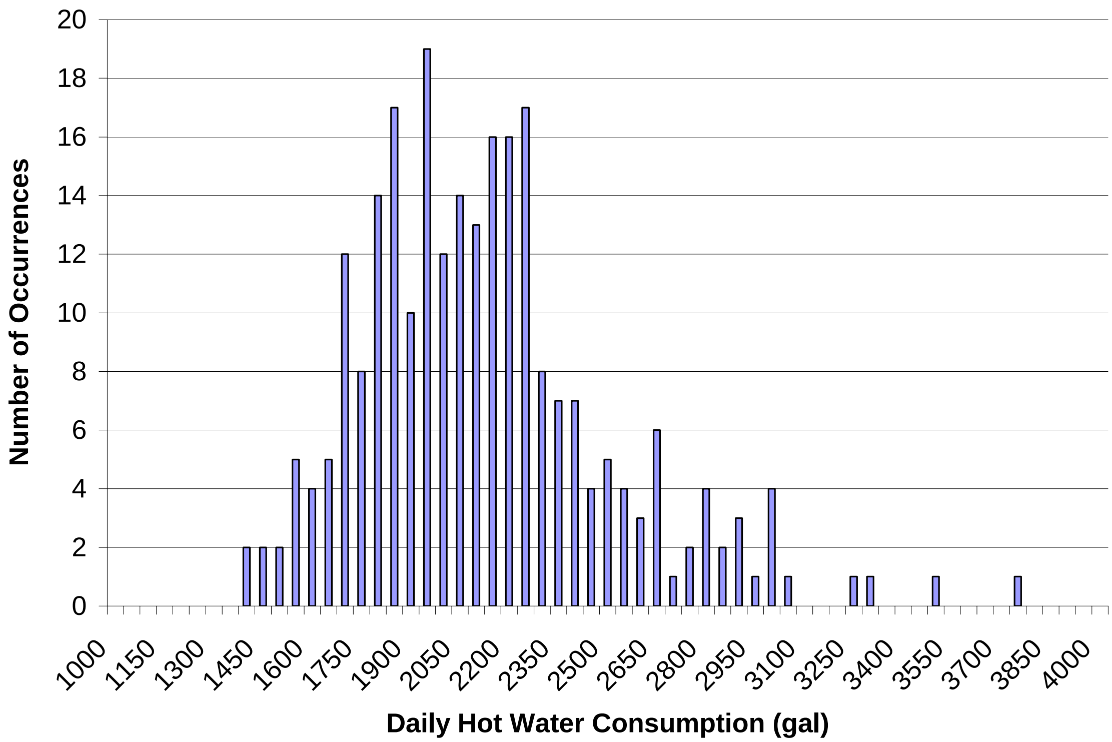

Figure 8. Hot water consumption frequency distribution

The peak demand (based on the average over a 5-minute period) was within the range of 9 gpm (gal/min) to 16 gpm. Representative profiles of daily hot water flow are shown in Figures 9 and 10, profiles from high and low hot water use days are depicted in Figures 11 and 12 respectively, and a profile containing a peak flow interval is shown in Figure 13.

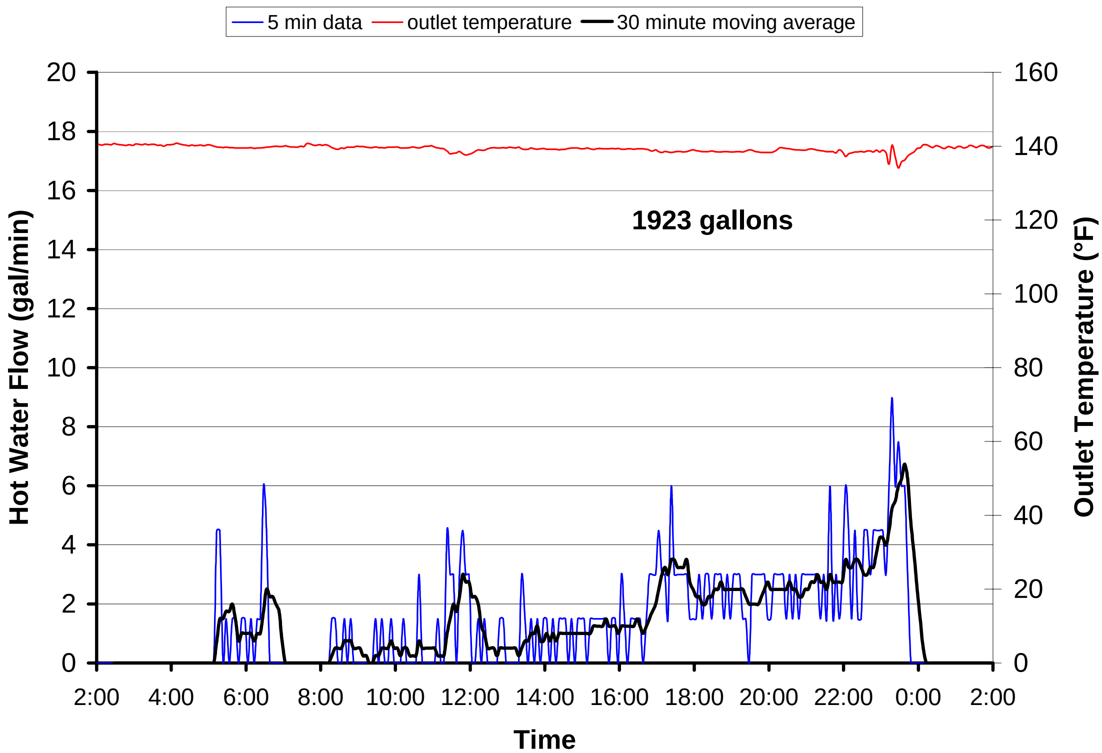

Figure 9. Typical average daily hot water load

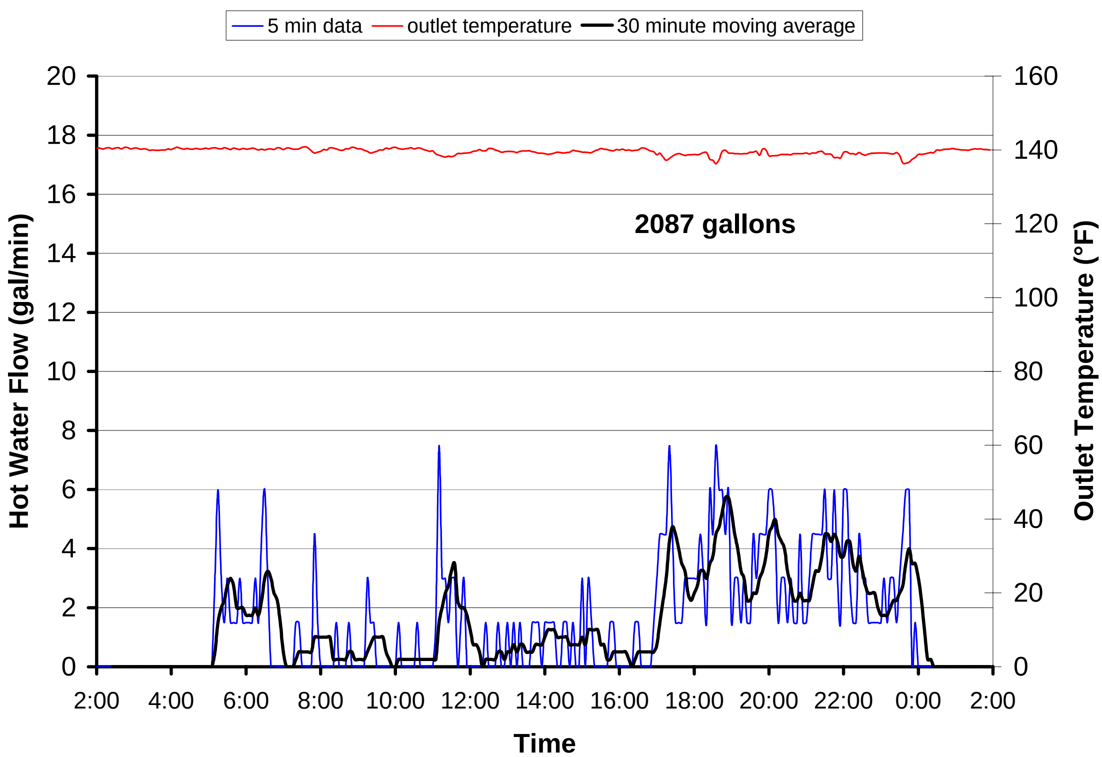

Figure 10. Typical average daily hot water load profile

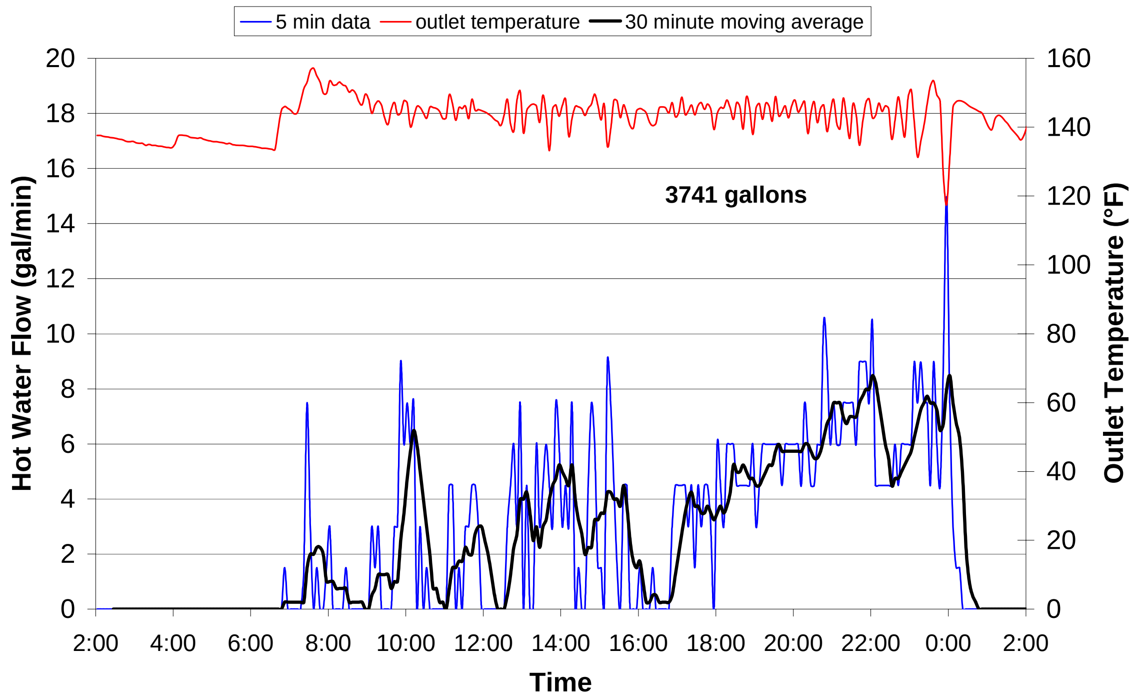

Figure 11. A high flow daily hot water load profile and exit temperature

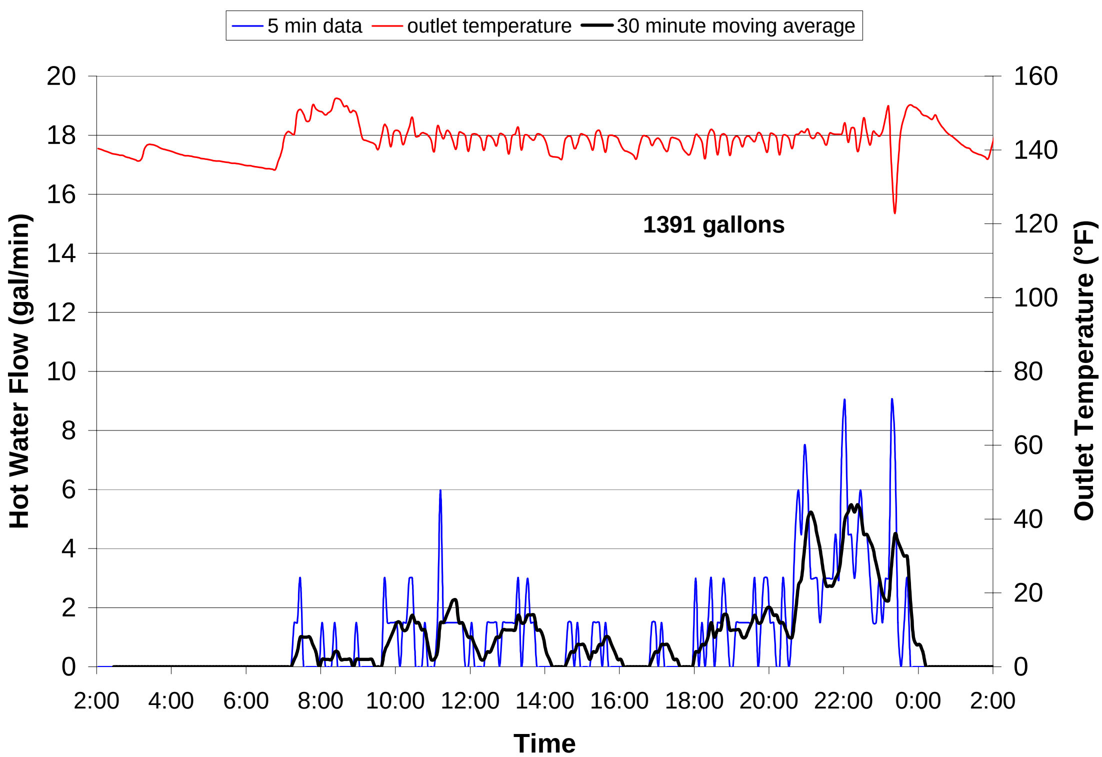

Figure 12. A low flow hot water daily load profile and exit temperature

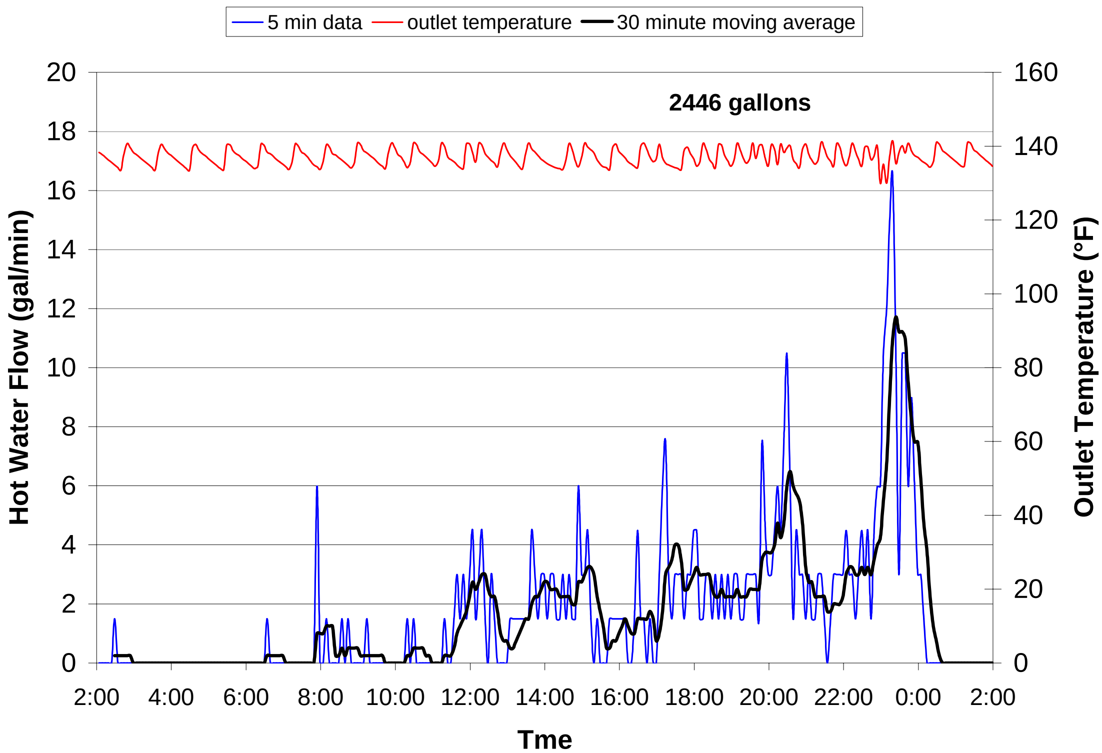

Figure 13. Peak flow interval

Water heater system efficiency was defined as the amount of energy required to heat the daily water volume (from the measured inlet temperature to the measured outlet temperature) divided by the daily gas consumption of the water heater(s). As such, the calculated system efficiency included the heat losses associated with the hot water (re-) circulation loop. After collecting and analyzing the data, daily system operating efficiencies were calculated for the different modes of operation using the following formula:

Eff = Energy into Water / Energy Consumed by Heater

$$Eff = (100 * \text{mass flow}_{water}[lb/day] * \Delta T_{water}[°F] * C_{water}[Btu/lb*°F]) / (flow_{gas}[ft^3/day] * HHV_{gas}[Btu/ft^3])$$

In calculating these daily efficiencies, only days where total hot water usage was within one standard deviation of the mean daily usage were considered. $\textit{Mass flow}_{water} * \Delta T_{water}$ was computed for each five-minute test interval, and then summed over the day. This technique eliminated the inclusion of any "no-water-flow" temperature data. During no-flow periods, the measured temperature in the outlet pipe would drop below the tank temperature. If this data were included in the average ΔT_{water} calculation, the efficiency would be understated. A higher heating value (HHV) of 1020 Btu/ft^3, representative of gas supply in San Ramon, was used in all efficiency calculations. Average system efficiencies, daily water use, measured gas consumption, and the average water temperature rise for each test configuration is reported in Table 2. Parameters used for the efficiency determination are illustrated in Figure 14.

Table 2. System efficiencies, daily gas and hot water consumption, and average temperature rise.

	Average Daily System Efficiency (%)	Average Daily Hot Water Usage (gallons)	Average Daily Gas Consumption (ft^3)			Average Daily Water Temperature Rise (°F)
			High Eff.	Stand. Eff.	Total	
Std. Efficiency Tank 1(a) - non-optimized	67.6	2036		2060	2060	81.5
Std. Efficiency Tank 1(b) - optimized	75.6	2183		1843	1843	74.0
High Efficiency Tank 2(a) - circ line returning to high efficiency tank, non-optimized	75.2	2090	1838	37	1875	80.1
High Efficiency Tank 2(b) - circ line returning to high efficiency tank, optimized	83.1	2068	1592	110	1702	81.0
High Efficiency Tank 3(a) - circ line returning to standard efficiency tank, non-optimized	80.0	2074	1390	391	1781	81.8
High Efficiency Tank 3(b) - circ line returning to standard efficiency tank, optimized	84.5	2018	1127	336	1463	70.5

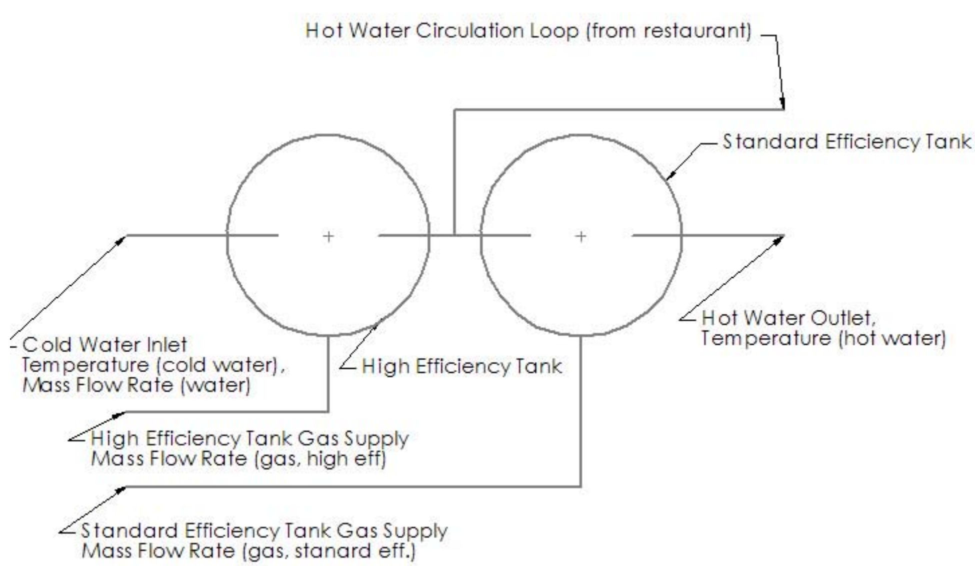

Figure 14. Parameters that were monitored

In configuration 1(a), the "as installed" standard efficiency water heater performed at an average daily system efficiency of 67.6%. In its optimized configuration 1(b), with the re-circulation pump on a time clock (turned off for 10 hours/day) and the automatic flue damper operational, the daily system efficiency increased to 75.6%. Utilizing the high efficiency water heater upstream of the standard efficiency tank, configuration 2(a), where the re-circulation line was returned to the inlet of the high efficiency tank, the daily system efficiency was measured at 75.2%. In the optimized configuration 2(b) with the re-circulation pump on a time clock, an increase in system efficiency to 83.1% was observed. In configuration 3(a), with the high efficiency tank upstream of the standard tank and the hot water circulation line returning between the two tanks, the average daily system efficiency was 80.0%. But in optimized configuration 3(b), when the pump was controlled by a time clock, the system efficiency edged up to 84.5%. Note that the standard efficiency tank was a backup to the high efficiency tank in configuration 2 and 3. In configuration 3, it also was responsible for making up the heat loss from the re-circulation loop. This presumably reduced overall system efficiency to some degree. System efficiencies are summarized graphically in Figure 15 and 16, for the non-optimized and optimized configurations, respectively.

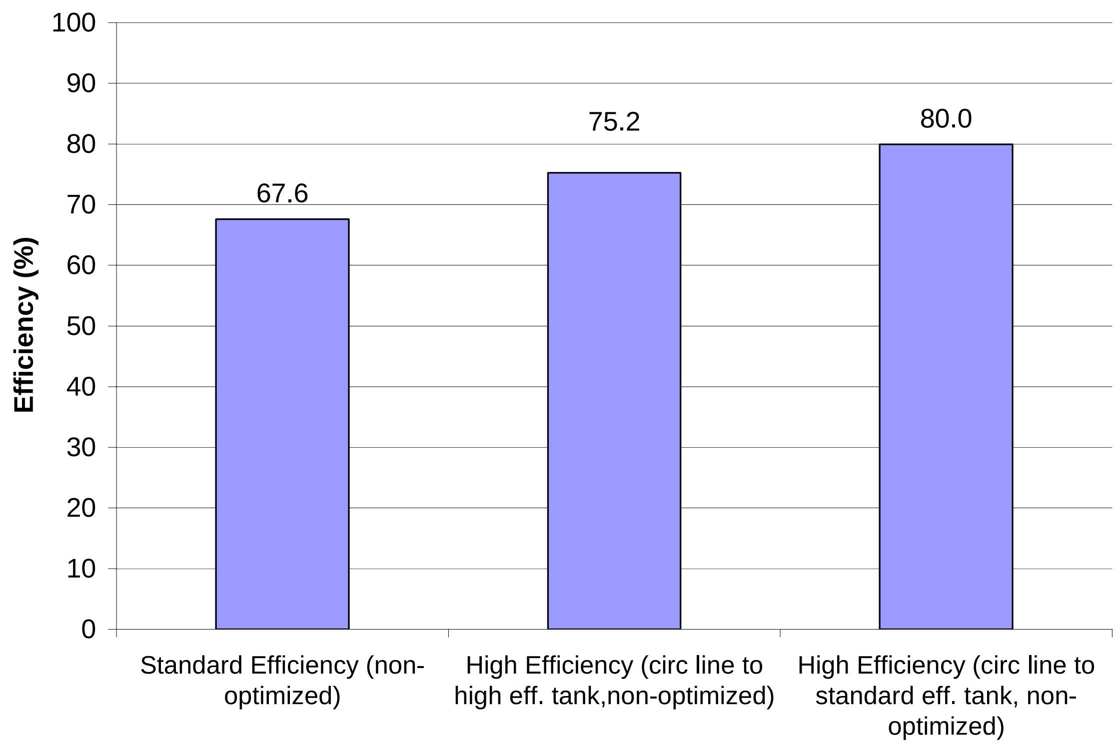

Figure 15. Daily system operation efficiencies (non-optimized)

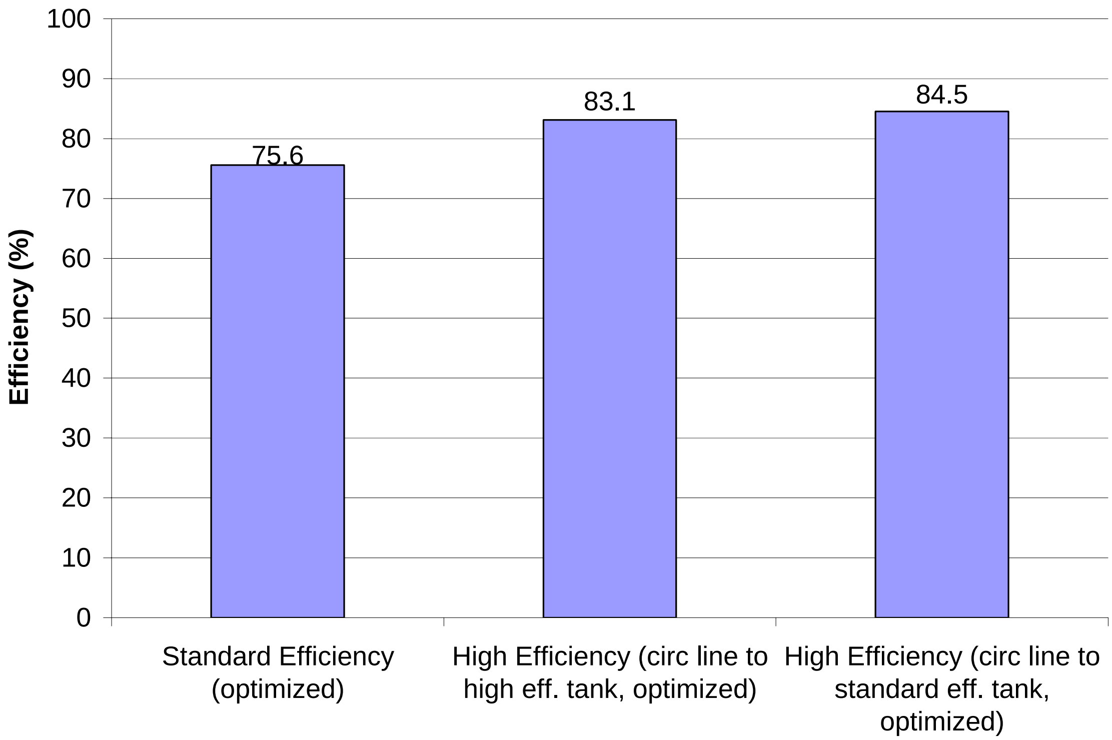

Figure 16. Daily system operation efficiencies (optimized)

Discrepancies in gas consumption, and consequently system operating efficiency, corresponding to certain days with nearly identical hot water consumption were observed. The plots of system efficiency versus water use in Figures 17 through 22 illustrate this inconsistency. Figure 23 depicts a similarly large variation in gas consumption at a given water use. This alleviated the concern that an inaccuracy in the bulk water temperature measurements (and energy-to-water calculation) was causing the inconsistency. This discrepancy in efficiency variation may be related to the variation in daily load profiles and effect on water heater performance. This phenomenon was observed on reported[3] field test data for a residential comparison of water heater efficiency. Even under stand-by conditions (periods of no water flow), large variations in gas consumption were observed (Figures 24 and 25). Further investigation is warranted.

Figure 26 compares the energy rates during no-water-flow periods (between 2:00 am and 5:00 am) for the standard efficiency tank and the high efficiency tank, with and without the re-circulation pump on a time clock.

[3] Davis Energy Group, March 2004, CEM2008, "Residential Feasibility Assessment of Gas Tankless Water Heaters in PG&E Service Territory" Pacific Gas and Electric Company.

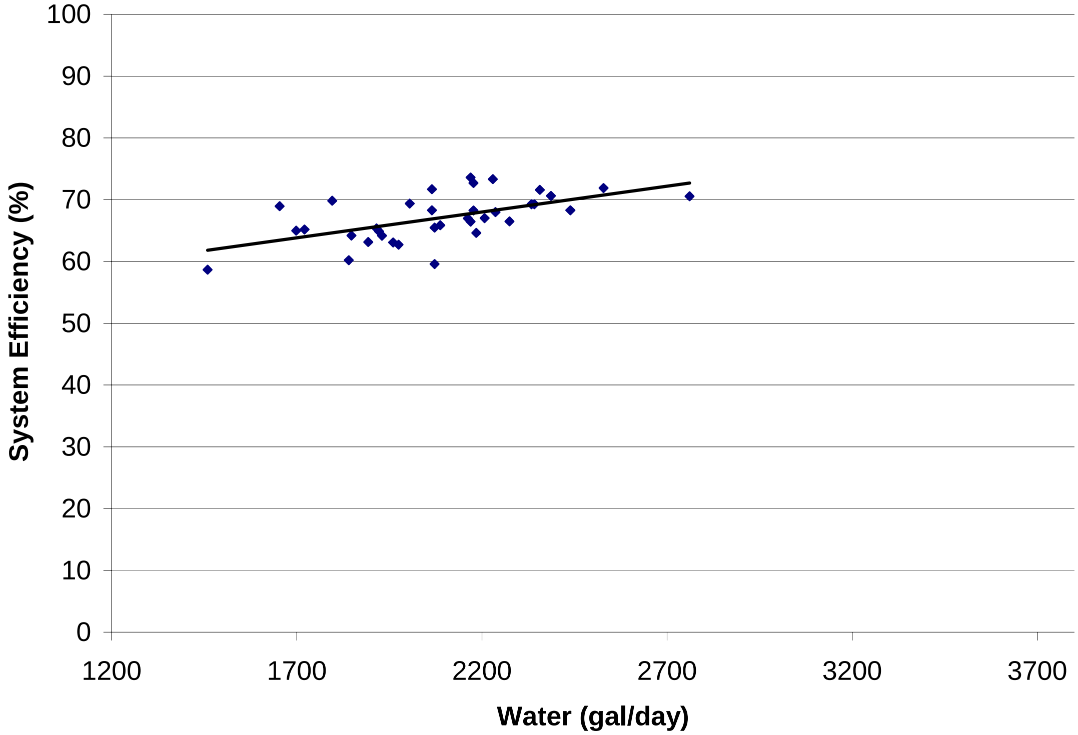

Figure 17. System efficiency versus daily water use (standard efficiency, configuration 1a)

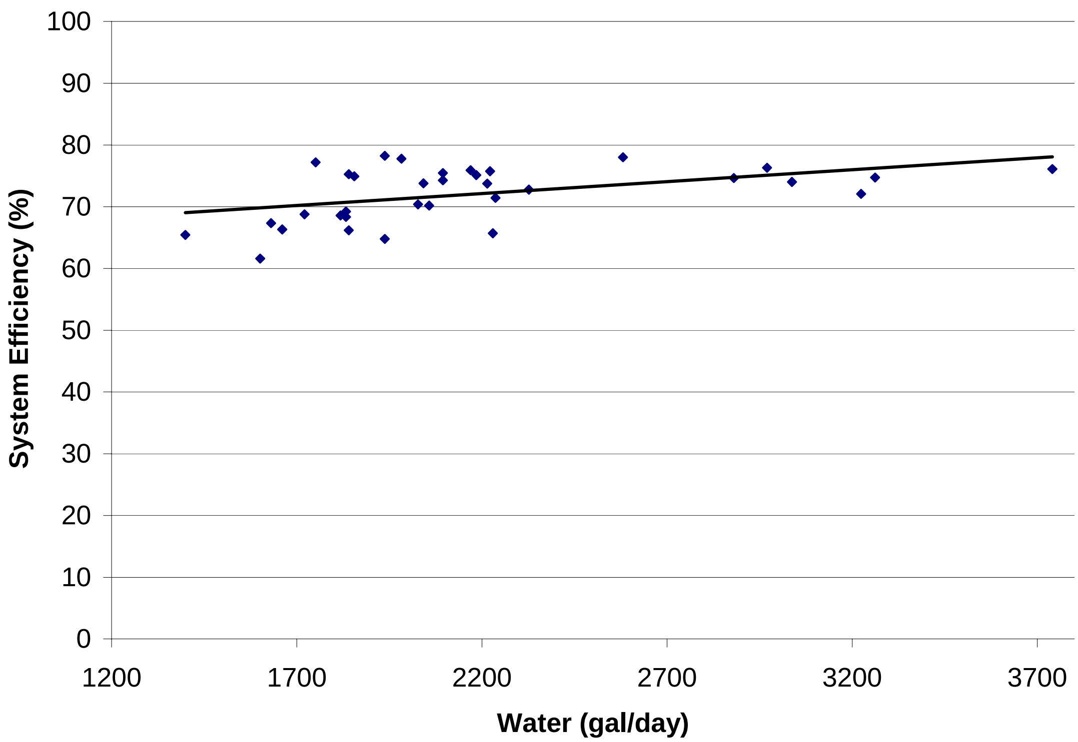

Figure 18. System efficiency versus daily water use (standard efficiency, configuration 1b)

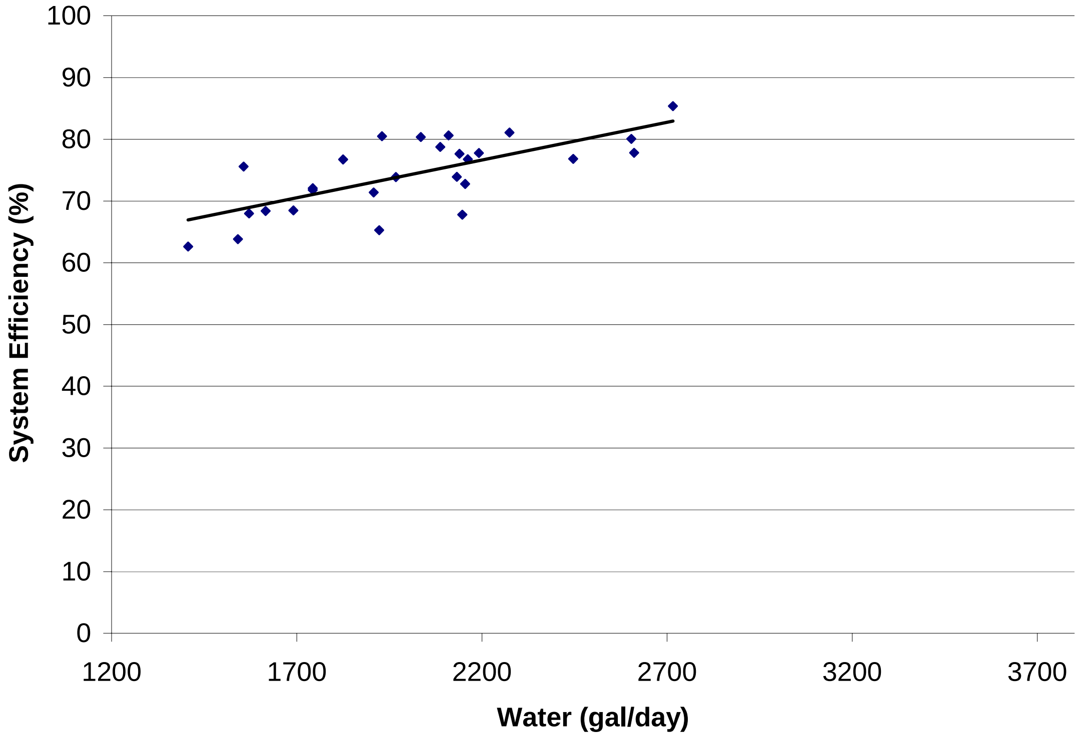

Figure 19. System efficiency versus daily water use (high efficiency, configuration 2a)

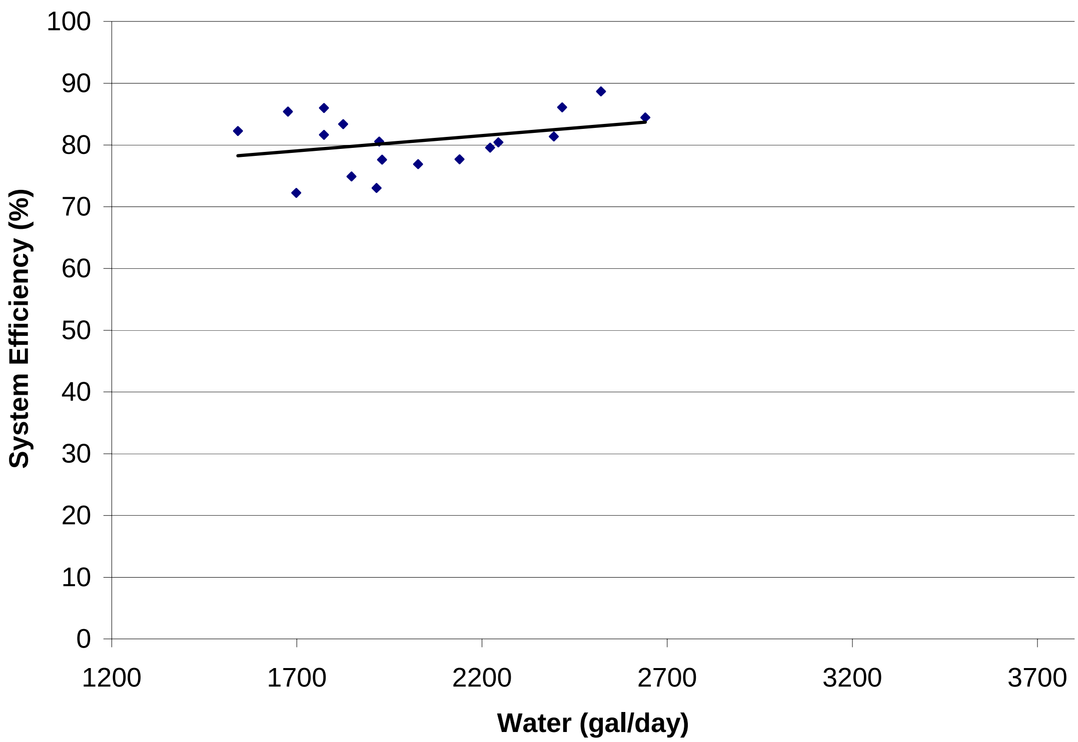

Figure 20. System efficiency versus daily water use (high efficiency, configuration 2b)

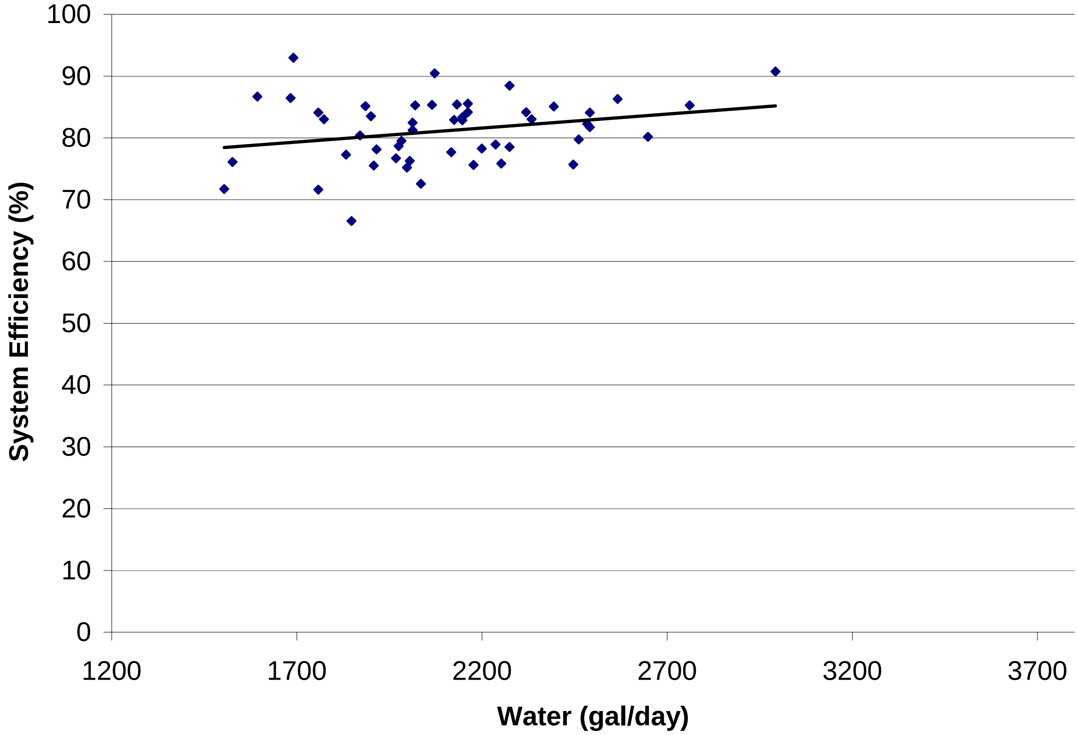

Figure 21. System efficiency versus daily water use (high efficiency, configuration 3a)

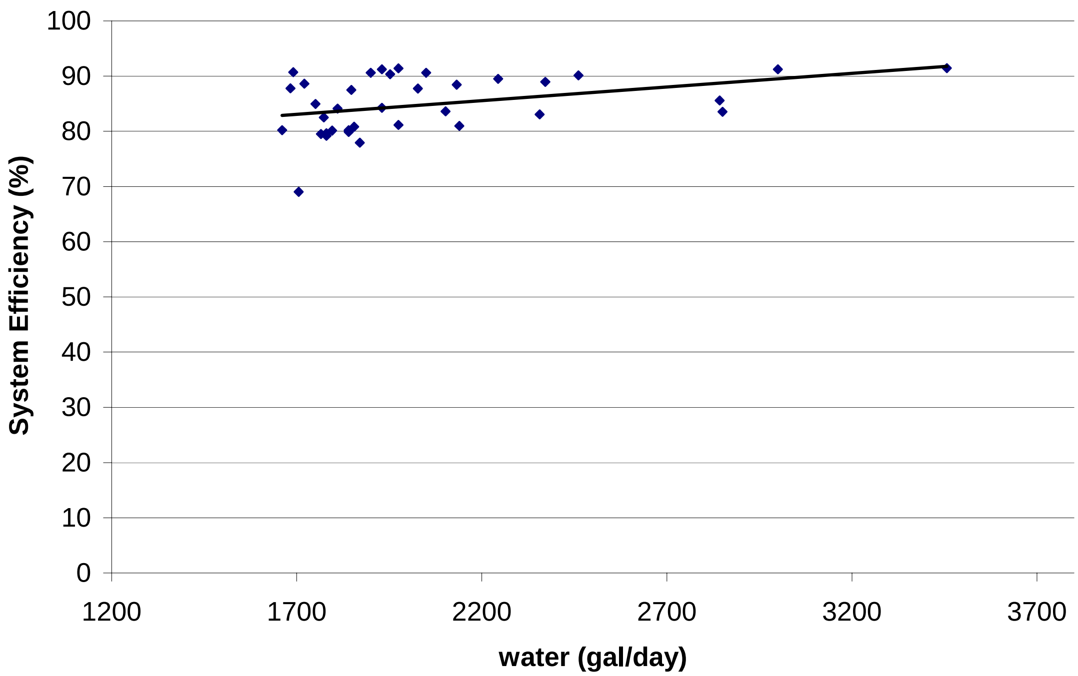

Figure 22. System efficiency versus daily water use (high efficiency, configuration 3b)

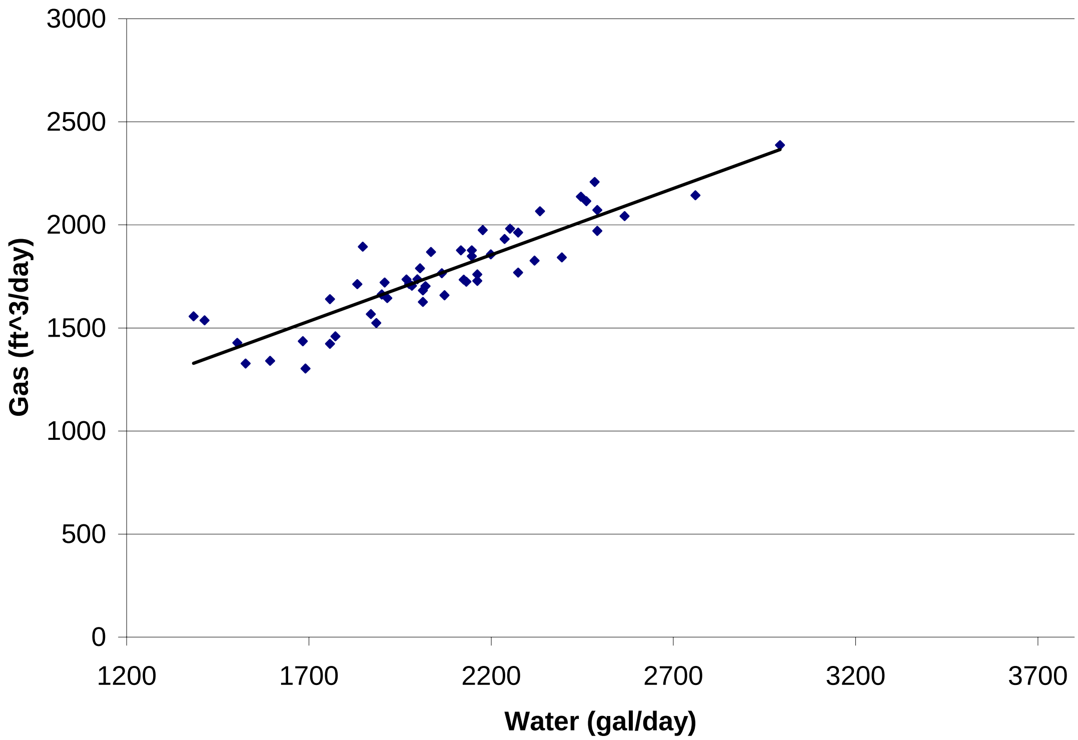

Figure 23. Gas consumption versus daily water use (configuration 3a)

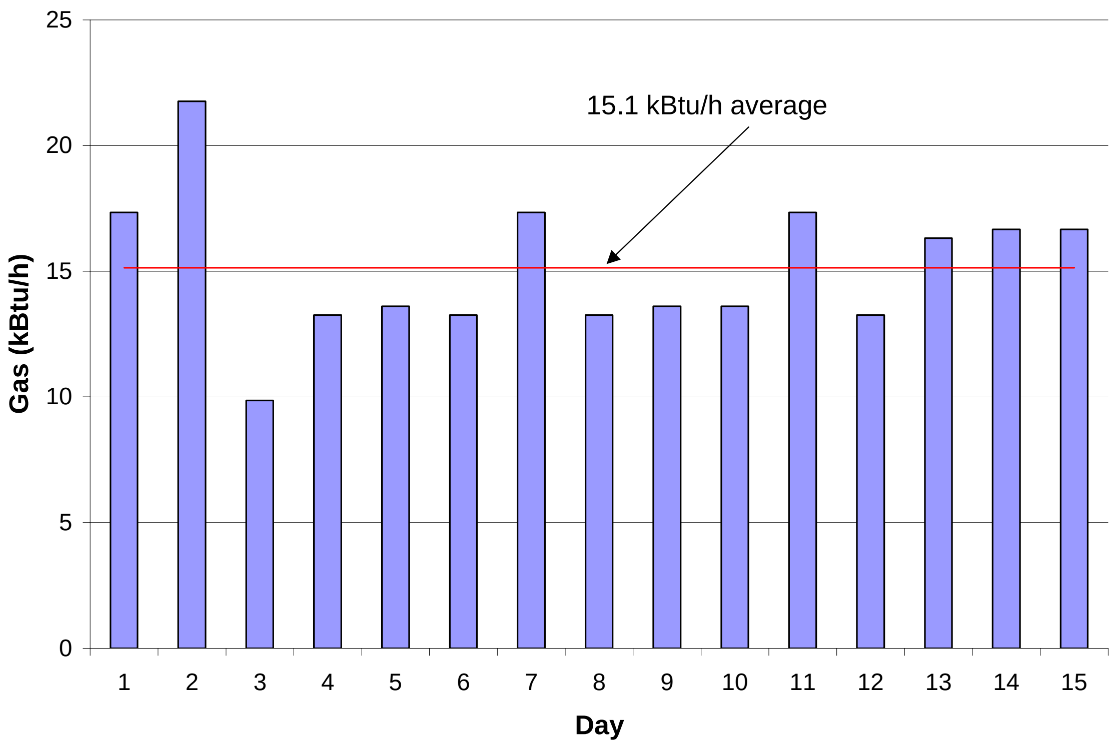

Figure 24. Fluctuation in gas consumption for no-water-flow intervals (2am-5am, configuration 1a)

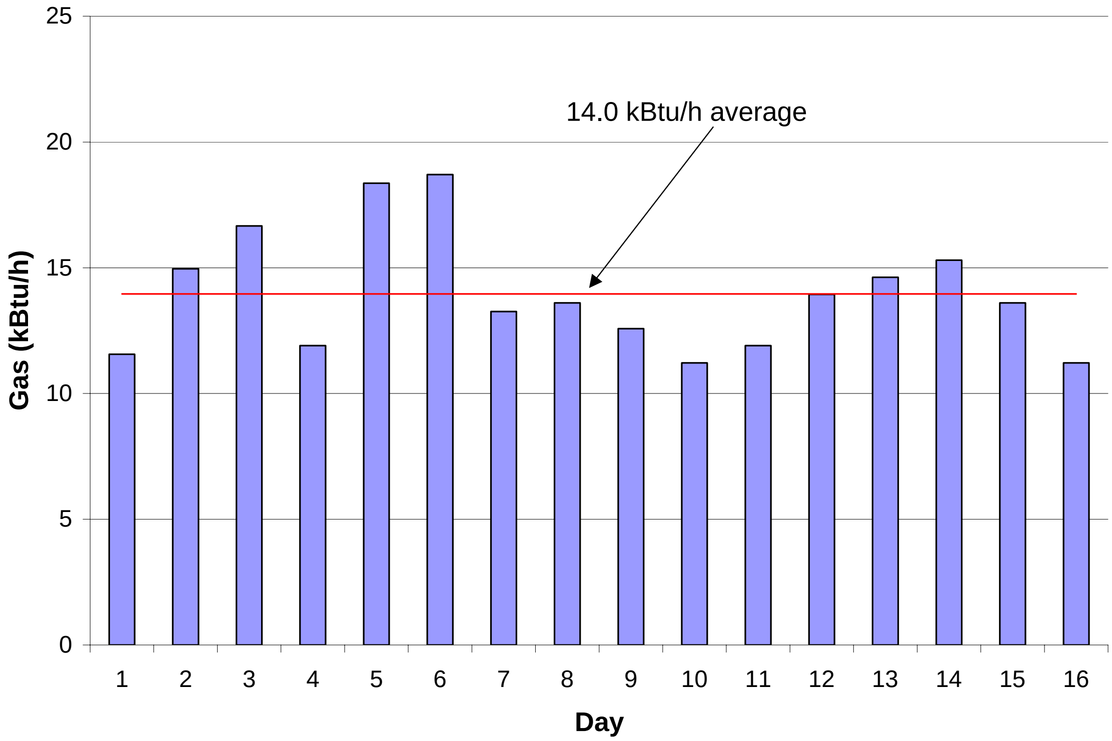

Figure 25. *Fluctuation in gas consumption for no-water-flow intervals (2am-5am, configuration 2a)*

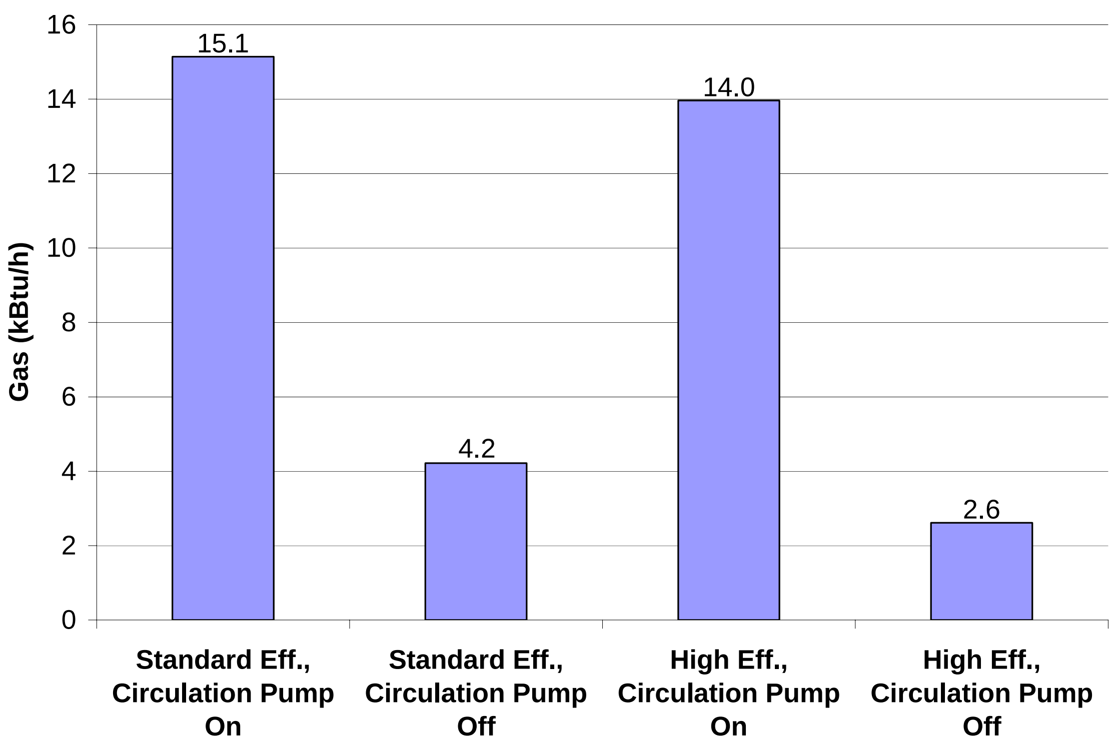

Figure 26. No-water-flow energy rates for various operating configurations

Energy Cost Savings

Using the system efficiency determined for a particular operating configuration, a normalized annual gas consumption was calculated assuming a standard temperature rise of 80°F (based on the average inlet water temperature of 60°F and outlet water temperature of 140°F). When estimating gas consumption on an annual basis (or when comparing one configuration to another over an extended time period), it is important to consider the seasonal variation in supply water temperature, and consequently a variation in the amount of energy required to heat this water to a constant outlet temperature. A swing of approximately 17°F in supply water temperature was observed in Figure 27 over the course of the monitoring period (12/05-10/06). The seasonal variation of inlet water temperature was closely approximated by the Sine function illustrated in the figure. The gap in the inlet and outlet temperature data is a result of a break in monitoring during part of June and July. System monitoring ended in October.

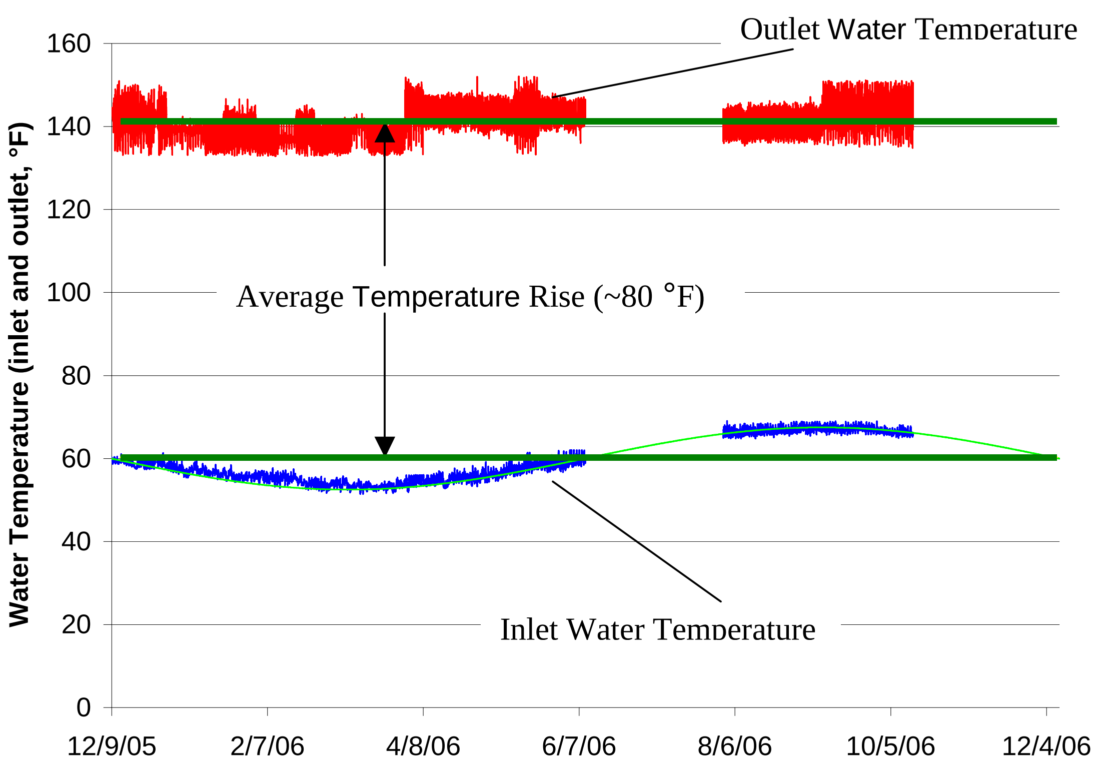

Figure 27. Inlet and outlet water temperatures over the course of the monitoring period

The energy cost saving associated with the operation of a high efficiency storage water heater compared to a standard efficiency storage water heater in this study was considered significant. When compared to the base case configuration (standard tank, flue damper off, hot water circulation pump not controlled by a time clock), the fully optimized high efficiency system returned an annual saving of $1755 (at a natural gas price of $1.20/therm). In what would be more typical with the re-circulation line entering the inlet to the high efficiency tank, configuration 2(b), the projected cost saving was $1634. Based on discussion with the design group for this restaurant, it was felt that the incremental cost of the high efficiency water heater was offset by lower installation costs. In this case, the return on an investment in high efficiency water heaters would be immediate. The FSTC team suspects that in some cases there will be a cost premium, particularly for independent operators. But even if this premium were as high as $2000, the investment in a high efficiency water heating system would be recouped within two to three years.

Table 3. Efficiencies, gas consumption, annual costs and projected savings

Configuration:	1(a) Std. efficiency base case	1(b) Std. efficiency optimized**	2(a) High efficiency non-optimized recirc line to high efficiency	2(b) High efficiency optimized** recirc line to high efficiency	3(a) High efficiency non-optimized recirc line to std efficiency	3(b) High efficiency optimized** recirc line to std efficiency
System Efficiency (%)	67.6	75.6	75.2	83.1	80.0	84.5
Projected Gas Consumption (therms/year)*	7496	6703	6738	6098	6334	5997
Projected Annual Cost ($/year)*	$8995	$8043	$8129	$7361	$7644	$7240
Cost savings over base case, ($/year)*		$952	$866	$1634	$1351	$1755

*Based on 365 day/year operation, 2083 gal/day hot water flow, 80°F temperature rise, $1.20/therm. Includes electricity costs attributed to blower motor on high efficiency tank (based on $0.15/kWh).
**Automatic flue damper operational (on std. efficiency unit), hot water re-circulation pump turned off 10 h/d by time clock.

Significant savings were realized by simply optimizing the standard efficiency water heating system. By installing a timer on the hot water circulation pump and exploiting the automatic flue damper, annual cost savings of $952 (again, assuming gas cost of $1.20/therm) were achieved. However, maintaining a flue damper on a standard efficiency tank in its “on” position is a “best practice” that may not always be implemented or sustained within a commercial food service operation.

Application of Tankless Water Heaters

The primary advantages of tankless water heaters are their smaller size, no stand-by losses and ability to provide an “endless” supply of hot water (at some maximum flow rate specific to the capacity of the heater and associated temperature rise). While the savings generated by the lack of stand-by losses may be substantial in low-water consuming applications (e.g., residential, office buildings, etc.), this is not the case for a restaurant application where the stand-by losses from the tank itself are a small fraction of the overall water heating load.

The feature that allows instantaneous water heaters to operate with no stand-by losses (i.e., no storage tank) consequently limits their capacity to deliver hot water during transient periods of high water consumption, such as those depicted in Figure 13. Most tankless water heaters have a control strategy that will restrict water flow as a means to ensure the specified water temperature is met. Depending on the particular application, this “flow limiting” characteristic may or may not be acceptable. In some instances, limiting hot water flow may interfere with the performance of other equipment, such as a ware washing machine. In other cases, it might only slow production a bit (i.e., time to fill a wash tub with hot water may increase). It is therefore important to determine the minimum acceptable peak flow rate for a given application. This is not necessarily determined from a load profile generated for a storage-type system.

Given the relatively high peak water demands shown in Figure 13 (potentially up to 20 gpm under instantaneous flow), it is probable that a tankless water heating system would require a capacity of 800,000 Btu/h – 1,000,000 Btu/h (probably three or four units) to be able to match the performance of a 600,000 Btu/h, high efficiency, two-tank (200 gallon storage capacity) system. Although the installation and field testing of a tankless system was beyond the scope of this ET project, a review of performance data published by GAMA[4] shows that the thermal efficiencies for tankless water heaters are generally only a few percentage points higher than reported efficiencies for standard tank-type heaters (e.g., 84% vs. 80%). Since the stand-by loss from a tank-type heater represents a small fraction of the overall water heating load in a commercial food service facility, the real-world system efficiency will be directly proportional to the steady state efficiency for a given water heater. This implies that application of a tankless water heating system would not have a large “energy cost saving benefit” for this full-service restaurant operation. It should be noted that high-efficiency tankless water heaters (e.g. with efficiencies greater than 90%) are not widely available in North America. Utilizing a tankless water heater in conjunction with a tank-type heater may be an option to provide redundancy without the space penalty associated with an additional tank heater. The associated cost and “foot print” saving benefits would need to be established by the restaurant design team. Installation on an outside wall or roof, which reduces or

[4] Gas Appliance Manufacturers Association (GAMA) Consumers’ Directory of Certified Efficiency Ratings for Heating and Water Heating Equipment, February 16, 2007.

eliminates the vent piping, may be an option (although this approach may be limited to more moderate climate zones).

Conclusions and Recommendations

The high efficiency, condensing water heater demonstrated efficiencies that were nominally 8 to 15 percentage points higher than the base case, standard efficiency water heating system. This translated to gas savings (and annual cost savings) in the range of 10 to 20% ($850 to $1700). Although the purchase price of a high efficiency heater is more than a standard efficiency heater, the design group for this restaurant chain believed that a reduced installation cost for the condensing water heater (due to the less expensive PVC venting) offset the higher first cost of the heater itself. In this case, the payback on a high-efficiency water heating system would be immediate. Within the scope of this field study, it was not possible to independently compare installation costs, as the FSTC only covered costs to install the high-efficiency unit. The FSTC team suspects that there could be a cost premium, particularly for independent operators. But even if this premium were as high as $2000, the investment in a high efficiency water heating system would be recouped within two to three years.

It is possible that due to reliability concerns, product availability or higher equipment cost, retrofitting a high efficiency heater may not be desired or considered cost effective by a restaurant operator. In the event where a high efficiency water heater retrofit is not practical, efforts to optimize the current standard efficiency system (hot water line insulation, flue damper control, and hot water circulation pump control) should be pursued.

Test results (before optimizing each configuration) had suggested that a series connection (i.e., installing the high efficiency tank upstream a standard efficiency tank with the circulation line returning between the two tanks) would be a design option worth exploring. When the re-circulation pump was operated on a time clock, the high-efficiency heater (with the re-circulation loop returning to the inlet of that tank) demonstrated efficiencies that were close to those of the series configuration with the re-circulation line returning between the two tanks. This series configuration with the re-circulation line entering the inlet of the high efficiency tank should emulate a high-efficiency heater by itself or in parallel with another high-efficiency tank.

End-User Recommendations. The FSTC recommends that the restaurant chain that participated in this study continue to specify high efficiency, tank-type water heaters. Given the current focus on redundancy (the policy of this multi-unit operation is to shut down the restaurant if the water heating system fails), a further recommendation (which is consistent with current design) would be to install two 300,000 Btu/h high-efficiency tank-type heaters in a parallel configuration. Specifying a time clock for the re-circulation loop pump is a key recommendation.

Although a series connection might extract an additional percentage point or two on system efficiency, this would be counter to industry practice and is not recommended. One option, which should gain a small efficiency benefit at no significant cost, would be to plumb the return line from the circulation loop to an upper port in the tank, rather than "tee" into the supply water inlet port (this port exists on the high-efficiency water heater being specified by this chain). It is recommended that a second high efficiency water heater be installed in the San Ramon facility to replace the standard efficiency heater that is currently operating in series with a high efficiency heater. The recommended installation arrangement is represented schematically in the Figure 28.

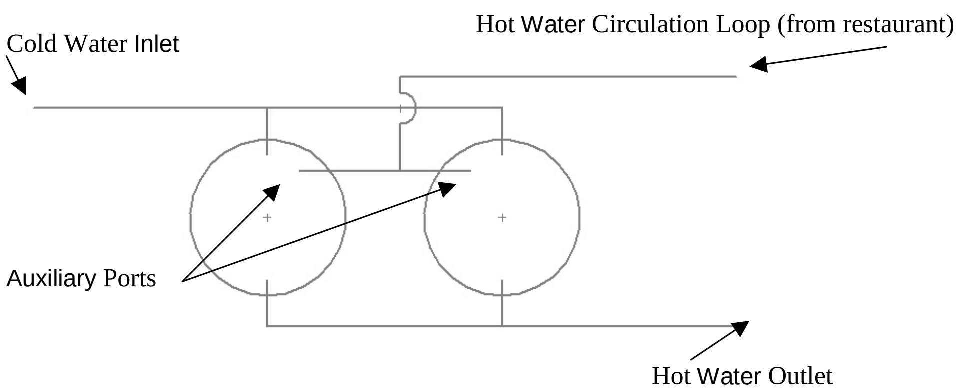

Figure 28. Recommended water heater installation configuration

With respect to the application of tankless water heaters, further field testing and evaluation is recommended before this chain considers the design a tankless water heater system as standard practice. Possible hybrid configurations with a tank type unit in series with an instantaneous model may have benefits and could be investigated.

Future Research and Testing. Water heater testing should continue both in field and laboratory environments. As more field studies are completed, the FSTC will have a better understanding of hot water use profiles for various types of commercial food service facilities. These load profiles can be replicated in the laboratory, where, through the use of more sophisticated data acquisition equipment than that used in the field, the FSTC will gain a better understanding of the driving parameters behind the inconsistency in system efficiency as discussed above in this report.

For all configurations tested, there was often a significant variation in system efficiencies for similar consumption of hot water. The parameters causing this variation need to be investigated under more controlled conditions. If this phenomenon can be explained, it might provide design insight that could raise the overall efficiencies of water heating systems. If this discrepancy is related to a deficiency in the test protocol, it needs to be rectified in future field monitoring projects.

The regression of heater efficiency against daily water consumption (for all configurations tested) indicated a slight decrease in efficiency with reduced hot water use. This implies that over sizing the capacity of a water heating system could negatively impact its energy performance. This "over sizing" factor should to be investigated and quantified under laboratory conditions. Laboratory testing (or further field monitoring) also should to be conducted to support our hypothesis that connecting the return line from the circulation loop at a port near the top of the tank rather than "tee" the return line into the inlet water line may increase the efficiency of a condensing-type water heater.

For all future laboratory and field studies, it is recommended that the flow meters and data acquisition system be specified with sufficient resolution and capacity to permit data collection on at least a one-minute interval to better define peak demands.

Consideration could be given to extending this emerging technology project to monitor the system with a second high efficiency water heater installed to replace the standard efficiency heater that is currently operating in series with a high efficiency heater.

PG&E Focus. PG&E, in parallel with its California Energy Commission (CEC) Public Interest Energy Research (PIER) study on water heating efficiency potential, should develop design guidelines for water heating systems in commercial food service. In support of the "gas savings" goals within PG&E's energy efficiency programs, an incentive should be developed to encourage both the sale and purchase of high-efficiency, condensing water heaters for commercial applications.