Case Studies in Restaurant Water Heating

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ABSTRACT

This paper presents an overview of hot water use and the associated energy loads in the commercial food service and restaurant sector, with a focus on the potential to reduce these loads by improving hot water use and increasing water heater system efficiency. Recent results from field studies are presented for a full-service and quick-service restaurant. The performance of gas-fired standard efficiency tank-type heaters, high efficiency (condensing) tank-type heaters, and instantaneous (or "tankless") heaters are compared. The parasitic impact of the re-circulation loop on hot water system efficiency is illustrated for the full-service operation. Field testing results indicate restaurants can save 8.6 to 19.5% by installing high efficiency water heaters—either tank-type or tankless. The study also suggests that operators of full-service facilities can save up to 10% by installing pipe insulation, flue damper controls, and hot water circulation pump controls. Research on hot water use in commercial food service facilities should be expanded and water heater testing should continue to validate this energy saving potential. In support of the "gas savings" goals of California utilities and the California Energy Commission, an incentive should be considered to encourage retro-commissioning and installation of high-efficiency water heaters for commercial applications.

Introduction

The food service industry consumes the highest level of energy use in the commercial building sector when measured on a square footage basis (EPRI 1998). A significant portion, in the order of 18% (Claar, Mazzucchiand and Heidell 1985), of the energy consumed in a commercial food service operation can be attributed to the domestic hot water heating load. This load has been the subject of study by Pacific Gas & Electric Company (PG&E) and, as such, the company initiated field studies in this area in collaboration with the PG&E Food Service Technology Center (FSTC) in San Ramon. In addition to the field effort, PG&E is setting up a Water Heating Laboratory in San Ramon, California to test a variety of commercial water heater units and systems in order to build upon the field-study knowledge and to identify innovative strategies for optimizing system design. Critical to this ongoing effort, are the results of the FSTC field studies intended to characterize the hot water demand and associated energy use of high efficiency (condensing) gas-fired tank-type (storage) water heaters, standard-efficiency gas-fired tankless (i.e., instantaneous) water heater, and high efficiency gas-fired tankless gas water heaters installed in full and quick serve restaurants. The collaboration of the individual restaurant owners has been invaluable to this effort.

This paper presents an overview of hot water use and the associated energy loads in the commercial food service and restaurant sector and how to reduce these loads by minimizing hot water use and increasing efficiency. Recent results from field studies are presented for a full-service and quick-service restaurant. The performance of a gas-fired standard efficiency tank-type heater is compared to a high efficiency (condensing) tank-type heater in the full-service restaurant while a high-efficiency tank heater is compared to both a standard efficiency instantaneous (or “tankless”) heater and a high efficiency instantaneous heater in the quick service restaurant. The parasitic impact of the re-circulation loop on hot water system efficiency is illustrated for the full-service operation. The study demonstrates the economic benefit of specifying high-efficiency water heaters for both quick-service and full-service restaurant operations.

Technology Comparisons

The field studies referred to in this paper are based on four types of commercially available hot water heaters: a standard efficiency tank type, a high efficiency tank type, a standard efficiency tankless and a high efficiency tankless water heater (PG&E 2007, PG&E 2007a). A high efficiency tank heater differs from a standard efficiency unit in its ability to transfer energy from the combustion gases to the water. A high efficiency tank heater will use a multi-pass heat exchanger design versus the single pass system of standard efficiency units. The multi-pass design allows substantially more heat to be extracted from the hot combustion gases and transferred to the water. The combustion gases are cooled below the dew point temperature, causing water vapor in the combustion product to condense. High efficiency (condensing) water heaters have thermal efficiencies in the order of 95%, compared to 80% for standard efficiency, non-condensing units (GAMA 2007). Tank type heaters must be sized correctly, based on gas input rates combined with tank volumes that are calculated based on desired recovery rates.

An instantaneous or tankless water heater, as the name implies, has no storage capacity, although it may be integrated with an external storage tank and temperature controlled recirculation pump. A tankless water heating system does not have the stand-by losses associated with tank style heaters. Thermal efficiencies for standard tankless heaters typically range from 80 to 84%, with one high-efficiency model available in the U.S. reporting a thermal efficiency of 92% (manufacturer’s specification sheet).

The instantaneous water heater will have a 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. Depending on the particular application, this “flow limiting” characteristic may or may not be acceptable. Limiting hot water flow may interfere with the performance of kitchen equipment such as a warewashing machine or impact food production slightly (e.g., time to fill a kettle with hot water may increase). The designer’s need to accurately assess the minimum acceptable peak flow rate for an individual restaurant cannot be understated. In restaurants without high hot water demand processes or equipment, such as quick service facilities without dishwashers, the restricted peak flow from one tankless heater may be adequate. However, a full service facility with high peak water demand will require several tankless units to satisfy hot water requirements.

While the energy 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 small relative to the overall water-heating load. The designer should distinguish between Energy Factor (EF) and Thermal Efficiency (TE) reported in the GAMA directory (GAMA 2007). The Energy Factor rating is applicable only to residential water heaters while Thermal Efficiency is applied to commercial water heaters. The Energy Factor accounts for residential standby losses whereas Standby Loss for commercial hot water heaters is reported as a separate parameter in the GAMA directory.

Venting requirements will affect water heater installation costs. High efficiency, fully condensing water heaters may use less expensive PVC venting that can offset the cost premium associated with this type of heater (compared to a standard efficiency tank heater). Instantaneous heaters require the use of stainless steel Category III venting. This additional cost can be reduced with strategic placement of the heater in order to minimize the required length of venting. Installation on an outside wall or roof (in mild climates) may be an option that reduces or eliminates the vent piping may.

Quick Service Restaurant (QSR)

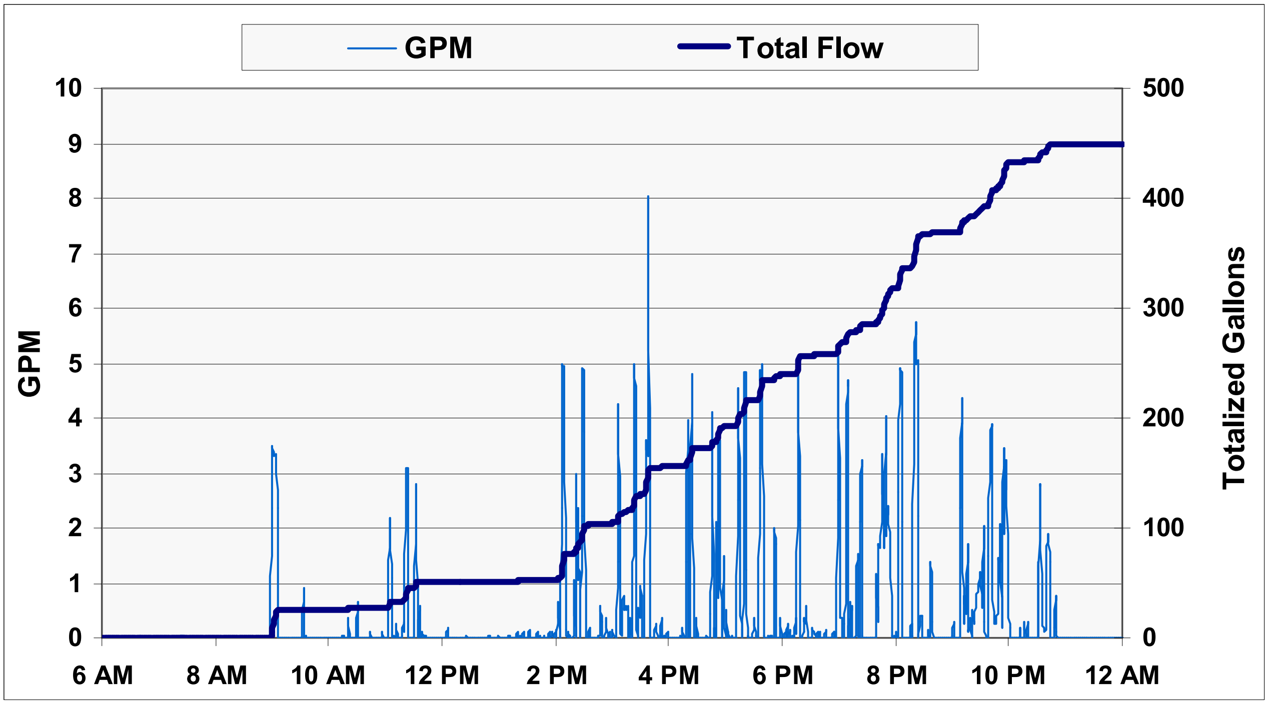
A quick service restaurant (QSR) is, as the name implies, a business that serves its customers with essentially a "take away" menu and which does not have dishes or other utensils requiring cleaning in a hot water intensive warewasher. This water heater field test was conducted at a multi-unit (chain) quick-service restaurant with a hamburger-themed menu located in Pleasant Hill, California. The restaurant-design team's participation was motivated by a desire to determine if there would be an energy cost saving benefit if an instantaneous water heater is chosen over their current high efficiency, tank-type heater specification.

The installed water heater was a 125,000 Btu/h, 60-gallon high efficiency water heater with a reported TE of 95% with Standby Loss of 560 Btu/h (GAMA 2007). A standard-efficiency 236,000 Btu/h tankless water heater with a TE of 82% (calculated using the manufacturer's input rate and capacity specifications) was installed alongside the existing heater. Later in the program, a high efficiency tankless heater with an input rate of 199,000 Btu/h (TE of 91.7% from manufacturer's specification sheet) was installed in place of the standard-efficiency tankless unit. The plumbing was arranged so that either the tank-type or tankless water heater could be "valved" in or out and operated independently. All data was logged at one-minute intervals, including the temperature of incoming cold water and outgoing hot water, water flow though the heater and its natural gas consumption. System efficiency was calculated by dividing the energy transferred to the heated water by the gas (energy) consumed by the water heater(s).

The daily hot water consumption averaged approximately 500 gallons per day, nominally ranging from 200 gallons to 900 gallons per day over the monitoring period. A peak flow (1-minute period average) of 10 gpm was recorded for the high efficiency tank heater. A tankless heater typically will restrict the flow of hot water to maintain a constant [setpoint] outlet temperature. The measured peak water flow with the tankless heaters in operation was approximately 5 gpm. Since this restaurant did not have any flow-sensitive equipment such as a dishwasher, this flow rate limitation did not pose a problem. Figure 1 illustrates a typical load profile for an average hot-water-use day with the tank-type heater in operation. Figure 2 shows a plot of daily energy efficiency versus daily hot water use for the three water heaters.

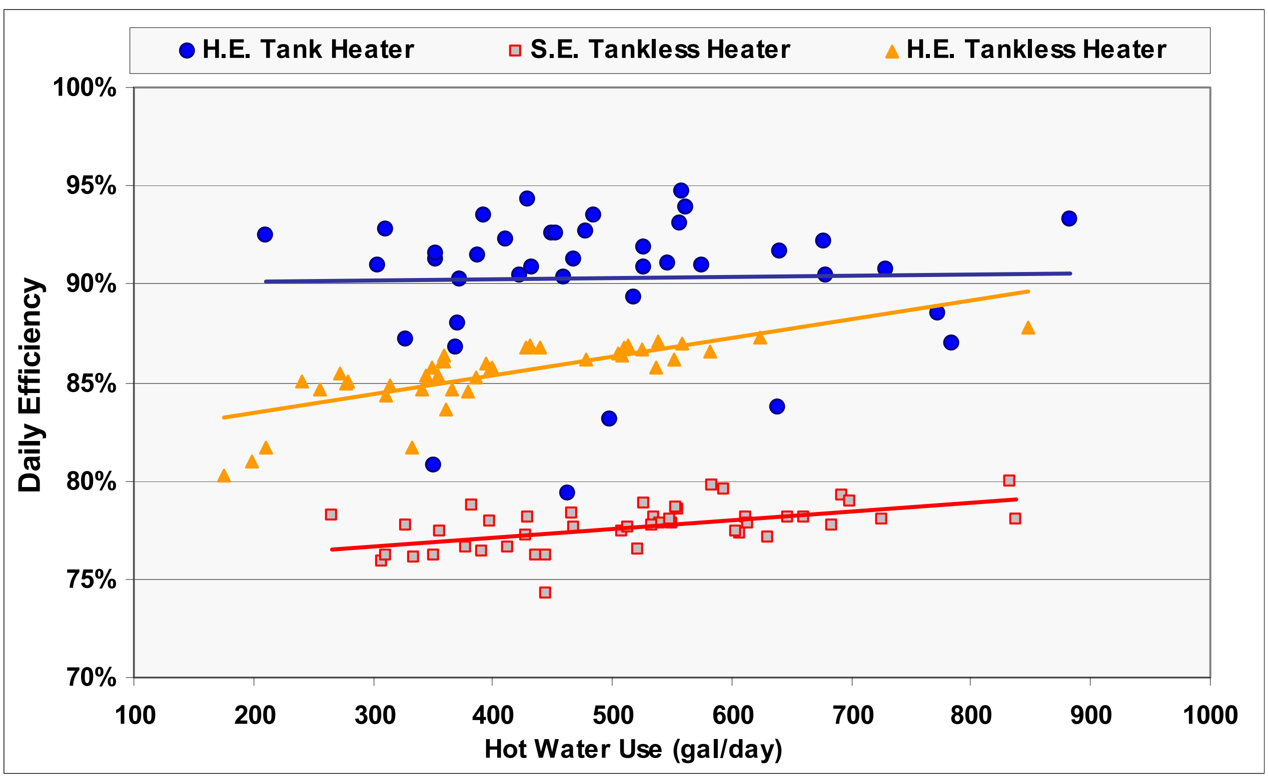
Calculated water heating energy efficiencies, projected annual gas consumption and operating costs for the three heaters are shown in Table 1. Results are normalized for the average water consumption of 500 gal/day and a 70°F temperature rise. Daily system energy efficiencies averaged 90.3% for the high efficiency (H.E.) tank heater, 77.6%, for the standard efficiency (S.E.) tankless heater and 85.4% for the high efficiency (H.E.) tankless heater.

Figure 1. Typical Daily Hot Water Use Profile and Load for QSR



Source: PG&E (2007a)

Figure 2. Daily Water Heater System Efficiency for QSR



Source: PG&E (2007a)

Table 1. Summary of Results and Energy Cost Projections for QSR.

	High Efficiency Tank Heater	Standard Efficiency Tankless Heater	High Efficiency Tankless Heater
Outlet Temperature Setpoint	135°F	140°F	140°F
Average Water Consumption (gal/day)	493	516	403
Average Gas Consumption (cu. ft./day)	312	419	231
Mass-Weighted Average Outlet Temperature	135.9°F	136.0°F	133.7°F
Mass-Weighted Average Inlet Temperature	65.5°F	61.5°F	74.3°F
Mass-Weighted Average Temperature Rise	70.4°F	74.5°F	59.4°F
Time-Averaged Outlet Flow Temperature	137.8°F	126.6°F	122.1°F
Average Daily Efficiency (%)	90.3 %	77.6 %	85.4 %
Projected Gas Consumption (therm/year)*	1178	1371	1246
Projected Annual Cost ($/year)**	$1,442	$1,663	$1,514

* Results normalized to 365 day/year operation, 500 gal/day hot water use and a 70°F temperature rise. Heating Value = 1020 Btu/ft^3

** Based on $1.20/therm. Includes electricity costs attributed to water heater blower motors, based on $0.15/kWh.

Source: PG&E (2007a)

The annual energy cost for the three heaters tested ranged from $1442 to $1663. The high efficiency tank heater energy cost saving would be $221 per year over the standard efficiency tankless unit and a marginal $72 per year over the high efficiency tankless heater. Similarly, the high efficiency tankless unit would save $149 over its standard efficiency tankless counterpart. Assuming a daily water heating efficiency of 70%, a standard efficiency tank-type water heater (not tested) would have an annual energy cost of $1,830. In this case, there would be a $388 per year saving with the high efficiency tank heater, a $316 per year saving with the high efficiency tankless heater and a $167 per year saving with the standard efficiency tankless heater.

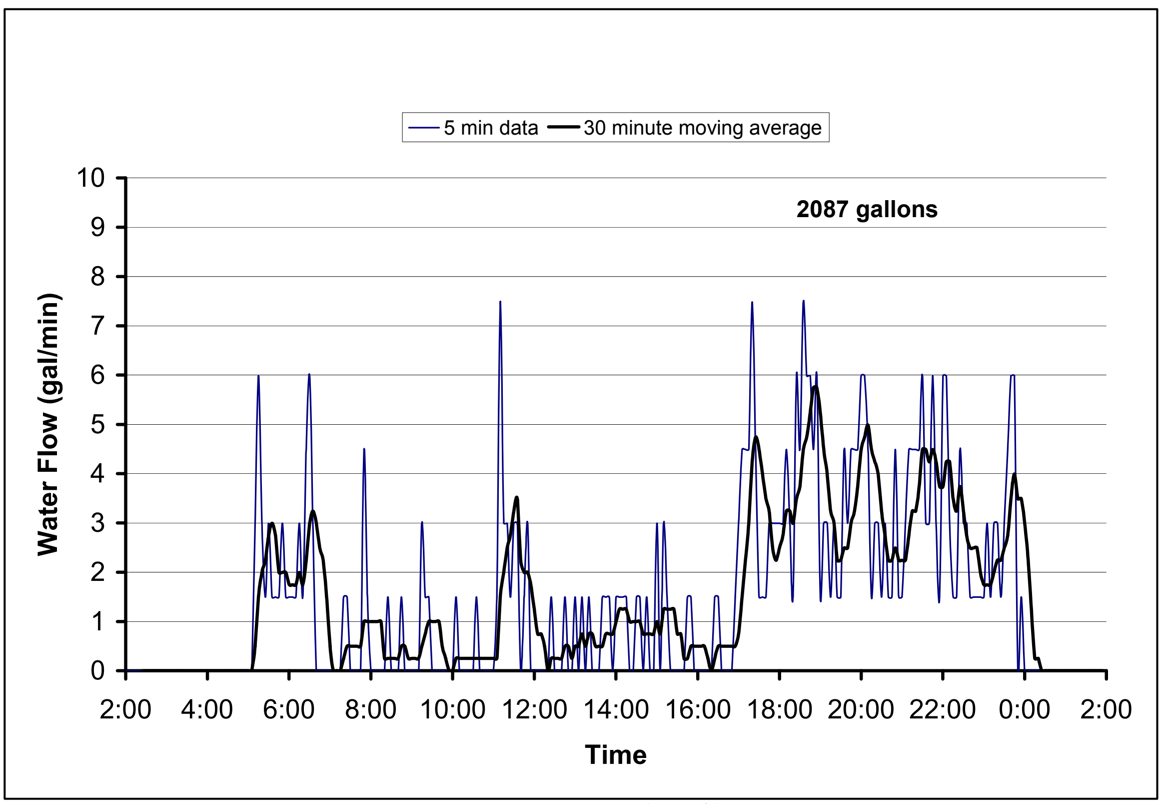
Full Service Restaurant (FSR)

Compared to a quick service operation, a full service restaurant (FSR) has a dramatically different hot water heating requirement. In most cases there is a five fold increase in water demand plus the addition of a re-circulation loop to provide immediate hot water at different stations/locations within the full service facility.

The full service restaurant hot water system selected for monitoring was comprised of a 400,000 Btu/h, 100-gallon standard efficiency gas water heater with a reported TE of 80% with Standby Loss of 1387 Btu/h (GAMA 2007) with a hot water re-circulation system that was in continuous operation. A new 300,000 Btu/h 100-gallon high efficiency (condensing) water heater with a reported TE of 92% with Standby Loss of 1044 Btu/h (GAMA 2007) was installed alongside the existing heater. The two water heaters were plumbed so that each could be operated independently or simultaneously, in either series or parallel configurations and the hot water circulation return line was configured to enter the inlet of either tank. Monitoring instrumentation included a water meter on the cold water supply, temperature probes on the inlet to and outlet from the water heaters, and gas supply flow meters on each supply line to the two heaters. The 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).

The FSR's daily hot water consumption 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 approximately 8 gpm during typical hot-water-use periods and up to16 gpm on high hot-water-use periods. The flow rates were 5-minute averages and may not represent the peak instantaneous demand for hot water. Actual peak demands could be higher requiring a more accurate determination of peak demand in order to intelligently establish the design capacity of a tankless water heating system. Figure 3 illustrates a typical load profile for an average hot-water-use day.

Figure 3. Typical Daily Hot Water Load Profile for the FSR



Source: PG&E (2007b)

Testing Configurations

Performance testing was conducted using three configurations to evaluate energy use. Configuration 1 is a standard efficiency heater operated independently as it was originally installed in the restaurant. This "as-installed" condition was designated configuration 1a.

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

Configuration 3 is a series arrangement, with the high efficiency tank (upstream of the standard efficiency tank) and 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), designated configuration 3a.

Subsequently all three configurations were tested again with an optimized mode which 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 1b, 2b and 3b, respectively.

Each configuration was tested for a two-week period. Although the intent was 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 because the host facility operator was concerned that the 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%) which could compromise facility hot water demands. It also had become the policy of this chain restaurant operator to design redundancy into the water heating system by specifying two heaters.

Table 2 compares the results of the testing series in both optimized and non-optimized configuration. The originally installed standard efficiency tank, configuration 1a, exhibited a system efficiency of 67.6% increasing to 75.6% in the optimized configuration 1b (commissioning the automatic flue damper and installing a time clock on the circulation pump). When the high-efficiency tank was operated in configuration 2a the system efficiency is 75.2% reflecting a gain of 7.6% above the standard efficiency tank in its "as-installed" configuration 1a.[1]

However, no advantage was observed over the optimized standard configuration 1b. The evaluating team 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). When the circulation pump time clock was activated, the efficiency of configuration 2b increased to 83.1%, reflecting a gain of 15.5% over the standard efficiency configuration 1a and 7.9% over the optimized standard efficiency system configuration 1b.

The high efficiency water heater in configuration 3b exhibited an average system efficiency of 84.5%, for a 16.9% gain over the base-case standard efficiency heater and a 4.5% increase over configuration 3a.[2]

[1] The typical high-efficiency tank installation included a hot water re-circulation line connected to the inlet of the high efficiency tank.

[2] Configuration 3b uses a series connection with the standard efficiency tank downstream, hot water circulation line returning between the two tanks, circulation pump controlled by a timer.

Table 2. System Efficiency, Projected Annual Gas Use, Cost and Saving for the FSR

Configuration:	1a Std. efficiency base case	1b Std. efficiency optimized**	2a High efficiency non-optimized recirc line to high efficiency	2b High efficiency optimized** recirc line to high efficiency	3a High efficiency non-optimized recirc line to std efficiency	3b 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.

Source: PG&E (2007b)

The annual water heating cost for this full-service restaurant using the standard efficiency water heater was projected to be $8995. Annual cost savings associated with the installation of the high efficiency water heater is projected to be as high as $1755 or 19.5% while operating in the fully optimized configuration 3b (assuming gas cost of $1.20/therm). The projected cost saving is $1634 or 18.2% for typical installations with the re-circulation line entering the inlet to the high efficiency tank (configuration 2b). The annual savings is $866 or 9.6% for non-optimized high efficiency heater configuration 2a. The annual cost savings associated with simply optimizing the operation of the standard efficiency heater is estimated at $952 or 10.6%. 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. Installing a high efficiency tank in series upstream of a standard efficiency tank with a circulation line returning between the two tanks is a design option meriting consideration. When the re-circulation pump is 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.

Water Heater Retro Commissioning (RCx)

In many instances FSTC staff found water heating systems were being minimally maintained, if at all, and this finding indicates a need for water heater retro-commissioning (RCx) at existing food service establishments. Whereas additional monitoring programs should be conducted in the field and laboratory to increase the size of the data base, initial observations indicate maintaining flue dampers and adding a time clock to recirculation pumps to shut down when restaurants are closed, could provide energy savings up to 10% at minimal cost. A supplemental site monitoring program in other full-service restaurants is in progress and will be the subject of a future paper and/or FSTC report.

Recommendations

Based on the efficiency and energy cost saving results obtained from the testing at the two types of restaurants (QSR and FSR), the authors recommend that prospective purchasers of hot water heaters specify high efficiency water heaters—either a tank-type heater or tankless unit. For the QSR facility, the increased Thermal Efficiency of the high efficiency tankless heater (i.e., 92%) reduces the energy cost difference between the high efficiency tank heater (Thermal Efficiency of 95%) to the point where the selection of the heater type by the restaurant design team becomes a function of installation and maintenance cost coupled with any "foot print" reduction credit. Although the high efficiency heater commands a premium price over the standard heater, reduced installation cost for the condensing water heater (due to lower cost PVC venting) will offset the capital cost, making high-efficiency heaters more competitive with their standard efficiency counterpart.

That said, reliability concerns, product availability and higher equipment cost may preclude retrofitting a high efficiency heater by a restaurant operator. In this case, operators should implement retro-commissioning action to improve efficiency by installing pipe insulation, engaging the automatic flue damper control, and hot water circulation pump control. Although data from the full service restaurant field study indicate that 8 to 10% of the water heating gas load can be reduced by installing a time clock on the recirculation pump and, in the case of the standard efficiency tank, commissioning the automatic flue damper, the authors believe that it is optimistic to extrapolate these level of savings across the board. Based on preliminary field monitoring data,[3] the reduction associated with retro-commissioning may be less than documented by this study. The authors hypothesize that the length of the recirculation piping and degree of insulation varies significantly from one restaurant design to another.

In summary, hot water load characterization in commercial food service facilities should be expanded and water heater testing should continue both in field and laboratory environments. As more field studies are completed, the industry 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, with more sophisticated data acquisition equipment than that used in the field, PG&E will gain a better understanding of the driving parameters for overall system efficiency. The PG&E Food Service Technology Center (FSTC) and Emerging Technology (ET) Program, in parallel with its California Energy Commission (CEC) Public

[3] The PG&E FSTC is conducting a field study within the scope of PG&E's Emerging Technologies Program to more accurately predict the savings that can be derived from retro-commission water heating systems in full-service restaurants.

Interest Energy Research (PIER) study on water heating efficiency potential, plans to develop design guidelines and energy cost modeling tools for water heating systems in commercial food service facilities. In support of the "gas savings" goals of California utilities and the California Energy Commission, an incentive should be considered to encourage both the sale and purchase of high-efficiency, condensing water heaters for commercial applications.

Conclusions

The installation of high-efficiency water heaters in restaurants can significantly reduce the associated gas use. When installed in a full-service restaurant (FSR), the high efficiency tank-type water heater demonstrated efficiencies that were nominally 8 to 15% higher than the standard efficiency water heating system depending on the specific configurations and level of optimization being compared. Associated gas savings for this case study restaurant range from 10 to 20% which translate to annual cost savings from $850 to $1700 (calculated at $1.20 per therm).

In the quick-service restaurant (QSR) case study, the high efficiency tank-type water heater increased the daily energy efficiency by 20% over a standard efficiency tank-type heater, saving the operator an estimated $388 per year in gas costs. The standard efficiency tankless water heater increased the daily efficiency by 8% while the high-efficiency tankless showed a 15% gain over a standard efficiency tank heater. The calculated annual cost savings are $167 and $316, respectively. These efficiency gains and cost saving projections for the QSR are based on an assumed operating efficiency of 70% for a standard efficiency tank heater as this option was not tested.

The study demonstrated that retro-commissioning a standard efficiency water heating system in the full-service restaurant (engaging the automatic flue damper control and installing a time clock on recirculation pump) can increase efficiency up to 10%. Further field studies are needed to confirm this saving potential before extrapolating to other restaurants.

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