Energy Saving Potential for Commercial Water Heating Through Retro-Commissioning

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Disclaimer

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Executive Summary

The hot water load represents a significant portion of the gas consumption in a commercial food service operation, with an opportunity for gas savings. The objective of this field study was to investigate several water heating system retro-commissioning measures and quantify their gas saving potential. The retro commissioning measures included reinstating the operation of the flue damper, adding insulation to accessible un-insulated hot water lines and installing a timer on the circulation loop pump.

A 2007 FSTC water heater field study yielded a system efficiency increase of 8% and projected gas savings of 800 therms per year by installing a circulation pump timer and pipe insulation, and activating the flue damper [1]. The study generated enthusiasm for a possible retro-commissioning program, and this follow-up study was initiated to confirm the energy saving potential. Applied to three full-service restaurant facilities (designated FSR#1, FSR#2 and FSR#3), the same retro-commissioning practices yielded a system efficiency increase of 2% in all three. As shown in Table ES-1, the efficiency increase yielded annual gas saving projections of 392, 208 and 189 therms per year for FSR #1, FSR #2 and FSR #3 respectively, or an average reduction of 260 therms per year, unfortunately showing lesser energy savings. Due to the large variation in the efficiency gains between studies, additional site monitoring is recommended to establish a more accurate projection of the energy saving potential.

The lower-than-expected gas saving diminishes the prospects of an independent third-party program being instituted to retro-commission water heating systems in commercial food service facilities. However, advocating the retro-commissioning measures directly with restaurants through best-practice education or identifying measures and initiating change during PG&E site surveys are avenues to pursue. Collaboration with existing third-party programs that are already working with restaurants to incorporate applicable retro-commissioning measures is another viable strategy.

Other retro-commissioning measures investigated included thermostat setpoint reduction to address the unnecessarily high setpoints that are often found in commercial foodservice facilities and the installation of aquastats that control circulation loop water flow. A 5°F thermostat setpoint reduction in facility FSR #2 yielded a 6% or 438 therms per year energy savings. While this action could be applied to many facilities, the savings would be difficult to capture reliably as existing analog thermostats are not accurate and can easily be tampered with by restaurant personnel, reversing any savings from a thermostat setpoint reduction. The aquastats generated modest efficiency gains but resulted in elevated average outlet temperatures, negating any potential gas savings; therefore, without further investigation, a general aquastat retrofit is not recommended at this time.

Table ES1. Combined Summary of Results

Facility	FSR #1	FSR #2	FSR #3
Rated Gas Input Rate (Btu/hour)	500,000	277,000	277,000
Tank Size (gallons)	80	100	100
Baseline System Efficiency	64.6%	71.3%	73.5%
Optimized System Efficiency*	66.6%	73.2%	75.5%
System Efficiency Increase	2.0%	1.9%	2.0%
Normalized Temperature Rise	75°F	75°F	75°F
Normalized Hot Water Use (gallons/day)	3,700	2,500	2,300
Projected Baseline Annual Gas Use (therms)**	13,061	7,996	7,136
Projected Optimized Annual Gas Use (therms)**	12,669	7,788	6,947
Projected Annual Gas Savings (therms)	392	208	189
Projected Baseline Annual Gas Cost***	$15,673	$9,595	$8,563
Projected Optimized Annual Gas Cost***	$15,202	$9,346	$8,336
Projected Annual Cost Savings	$471	$249	$227

* Optimized system consists of installation of circulation pump timer, operation of flue damper, and adding insulation to the accessible hot water pipes leading from the water heater

** Calculated using 365 day/yr operation.

*** Calculated using gas utility cost of $1.20/therm

Looking beyond retro-commissioning, an effective strategy to realize energy savings from thermostat setpoint reduction would be to develop and apply a lockable thermostat design. Some high-efficiency condensing water heaters with central processing units already have clear and accurate controls with diagnostic and performance features to boot. By collaborating with manufacturers, new units could be configured to incorporate a thermostat lockout option, which could be used by restaurant management to enable a permanent thermostat setpoint reduction for lasting energy savings in the facility.

Objective and Scope

This field study was conducted to quantify the potential energy savings from gas-fired storage water heating systems with the application of field-implemented efficiency improvement measures. The measures incorporated within the scope of this field study included:

1. Re-commissioning the flue damper
2. Adding insulation to any un-insulated lines in proximity to the water heater
3. Installing a time clock on the circulation pump

Additional measures including reducing the thermostat setpoint and the installation of an aquastat were added to the scope as the project was implemented.

Three full-service restaurants were selected for this field study, each employing a water heating system that comprised a standard efficiency gas storage water heater equipped with a dysfunctional automatic flue damper and a constantly operating circulation pump. Standard efficiency water heaters were selected for the study because they represent the majority of the installed base and have the highest potential for saving through retro-commissioning. The heaters supplied hot water to hand sinks, pre-rinse spray valves, dishwashers, general wash stations and mop sinks.

All work in this project was done under the auspices of the Pacific Gas and Electric (PG&E) Company within the scope of its Emerging Technologies Program. Water heating systems are the target of a more in-depth study being conducted by the PG&E Food Service Technology Center (FSTC) within the scope of a California Energy Commission Public Interest Energy Research project. The goal is to quantify the gas saving potential and develop design guidelines and energy cost modeling tools for water heating systems in commercial food service facilities.

Background

The FSTC estimates that the gas load associated with water heating in California commercial food service facilities is more than 300 million therms per year. With water heating systems operating in the 60-70% efficiency range, there is an opportunity to significantly increase system efficiencies and reduce gas load. In addition to the continued encouragement for the commercial sector to specify and use high-efficiency water heaters, many facilities could benefit from energy saving measures implemented on their existing water heating systems. The FSTC, through site survey experience, has discovered that many water heating systems in food service facilities are candidates for retro-commissioning. A 2007 FSTC water heater field study yielded an energy efficiency increase of 8% and projected gas savings of 800 therms per year by installing a circulation pump timer, pipe insulation and activating the flue damper [1]. The study generated enthusiasm for a possible retro-commissioning program, and this follow-up study was initiated to confirm the energy saving potential. Following are descriptions of the examined measures.

Circulation pump timer: The circulation loop and pump ensures that there is hot water in the pipes near all required draw points such as hand sinks and dishwashers at all times. As the hot water circulates continuously to maintain elevated temperatures, it loses heat more rapidly through the piping to its surroundings. Stopping the flow with a circulation pump timer during unoccupied periods will reduce energy loss from the system. This measure is applicable to all commercial food service facilities (with circulation loops) that are closed for some portion of the day. Exceptions would include hospitals, 24-hour hotel kitchens and other facilities that operate around the clock.

Automatic flue damper: Flue dampers are placed on top of commercial water heaters to minimize convective heat loss from the tank heat exchanger and venting system when the burners are off. Water heater specifications that are listed in the GAMA directory show reported standby loss values that are determined with an active flue damper (for models so equipped) [2]. FSTC site-survey experience and feedback from the plumbing trade has indicated that automatic flue dampers are perceived to have a high failure rate and are often disabled to minimize service calls. If they fail in the closed position, the heater will not fire, and the remedy is to either replace the device or to force the mechanism open in order to bypass the automatic function entirely. If they fail in the open position, this condition will likely go unnoticed. However, discussions with water heater manufacturers indicate that the current generation of flue damper is reliable and the practice of disabling should be discouraged.

Pipe insulation: Adding insulation to all accessible portions of hot water piping is one of the simplest energy efficiency measures, yet many facilities have supply and return lines that are not insulated.

Aquastat: Circulation loop aquastats sense hot water return line temperatures and switch the pump off once the return water temperature reaches the setpoint temperature of the aquastat, thereby circulating hot water intermittently as needed, reducing heat loss through the pipes.

Temperature setpoint: Water heater thermostats are often found set to a higher temperature than necessary, which proportionally increases the hot water energy load. Although not categorized as a hardware modification, maintaining an optimal thermostat setpoint is fundamental to energy savings.

Field Test Configurations and Protocol

Test Configurations:

1) Baseline
   - Monitoring of existing system as found, confirming disabled flue damper and noting thermostat setpoint
2) Optimized
   - Addition of circulation loop pump timer
   - Activation (or repair) of flue damper
   - Installation of pipe insulation to the supply line and recirculation line within the vicinity of the water heater

Additional Measures:

- Installation of aquastat (clamped on at hot water return line)
- Temperature setpoint reduction (to 140°F if amenable to facility personnel)

Measurement points:

- Water inlet temperature
- Water outlet temperature
- Hot water return temperature
- Water flow
- Gas flow

Monitoring Equipment:

- Thermocouples: Type K Thermocouples affixed to outer pipe walls and the interface treated with heat-sink compound, wrapped with tape and covered with foam pipe insulation
- Gas meter: Diaphragm type positive displacement gas meter with a 1 pulse/cubic foot output
- Water Meter: Multi-jet turbine water meter with a 1 pulse/gallon output
- Data Logger: Campbell Scientific CR-10 configured to record thermocouple and flow meter inputs at 5-minute intervals

Calculations:

System efficiency is defined as the amount of energy required to heat a volume of water by a measured temperature rise (as measured from the cold supply inlet to the hot outlet) divided by the gas energy consumption of the water heater. Standby losses of the entire heating and circulation system are taken into account. System efficiency was calculated on a daily basis using the following formula:

$$System\ Efficiency = \frac{Energy\ into\ Water}{Energy\ Consumed\ by\ Heater}$$

$$System\ Efficiency = \frac{Mass_{water}[lb] * \Delta T_{water}[°F] * C_{p\_water}\left[\frac{Btu}{(lb * °F)}\right]}{Volume_{gas}[ft^3] * High\ Heating\ Value_{gas}\left[\frac{Btu}{ft^3}\right]}$$

In calculating *Energy into Water*, $Mass_{water} * \Delta T_{water}$ was computed for each five-minute test interval; the five-minute interval products were summed for each day and then divided by the daily gas energy to calculate daily system efficiency. A higher heating value of 1020 Btu per ft^3, representative of gas supply in the area, was used in all efficiency calculations.The reported system efficiency for each configuration was determined from the daily efficiency versus daily hot water use curves (Figure 4, 8, 12) where they intersected the average hot water use value.

Projected annual gas use calculations were normalized to a 75°F temperature rise (to account for varying inlet temperatures and/or thermostat setpoints) and to the average daily hot water use using the following formula:

$$Annual\ Gas\ Use = \frac{Mass\ Flow_{water}\left[\frac{lb}{day}\right] * C_{p\_water}\left[\frac{Btu}{(lb * °F)}\right] * \Delta T_{water}[°F] * 365\left[\frac{days}{year}\right]}{100{,}000\left[\frac{Btu}{therm}\right] * System\ Efficiency}$$

Where:

$Mass\ Flow_{water} = Average\ Hot\ Water\ Use\ [gal/day] * Density_{water}\ [lb/gal]$

$Density_{water} = 8.33\ lb/gal$

$C_{p\_water} = 1\ Btu/lb \cdot °F$

$\Delta T_{water} = normalized\ temperature\ rise = 75°F$

System Efficiency = Efficiency at the average hot water use

Reported mass-weighted inlet and outlet temperatures (representing the bulk water temperatures in and out of each heater) were calculated by dividing the daily sum of five-minute $Mass_{water} * T_{water}$ products by the $Mass_{water}$ daily total.

Site Monitoring Synopsis and Data Presentation

Once the baseline data set was gathered, the retro-commissioning modifications were made to the systems and the optimized configuration tested.

Pump timer: Readily available and inexpensive plug-in outlet timer to control the circulation pumps were installed and set to turn the pumps on at 10AM and off at midnight. In the optimized profiles, effects from the timer can be best seen during nighttime periods with the lower circulation return temperature and the less frequent gas firings. Note: the elevated outlet temperatures at night are a result of heat soak in the pipes above the tank when cycling with no water flow.

Insulation: When designing this retro-commissioning study, it was hypothesized that un-insulated distribution lines would be encountered, with the ability to apply insulation to a substantial portion of the lines for testing in the optimized configuration. Upon retro commissioning, the amount of pipe insulation installed in all three facilities was limited to only a few feet of exposed piping between the heaters and the adjacent walls. It was unknown whether the pipe runs within the walls or ceiling areas were insulated. Although the limited amount of pipe insulation inherently contributed somewhat to the overall energy savings, it was considered negligible relative to the other modifications.

Flue damper: Initially, all three facilities were found with inactive automatic flue dampers, and in two sites, the dampers were broken. They were tested in the baseline configuration and, subsequently, the two dampers were repaired and all three were activated for the optimized testing.

Aquastat: The aquastat installation was not included in the original scope of work but was added because of the small effort required to incorporate into the retro-commissioning plan. Aquastats were installed as part of the original optimized configurations, but upon review of the data, it was observed that they caused an effective hot water capacity reduction coupled with erratic outlet temperature profiles. This warranted removing the aquastats from the systems and retesting for new optimized data sets. Results and further discussion of the aquastat-configured systems are presented separately and placed in Appendix A. At this time, the FSTC does not recommend a general retrofit of aquastats on water heating systems.

Thermostat temperature setpoint: Thermostat setpoints were lowered to 140°F when amenable to facility personnel. Resultant energy savings are not factored into the reported projected gas savings as the setpoint effects are negated in the analyses by the 75°F temperature rise normalization. Direct savings from setpoint reductions are further characterized in the Discussion section of the report.

Site Characterization and Test Results

For each monitored site there is a water heater description, a photo showing the heater and test set-up, a typical operating profile for three consecutive days in each configuration, a daily system efficiency plot and a table of results.

FSR #1 - Dublin, CA

FSR #1 utilized a 500,000 Btu per hour, 80-gallon water heater. Average daily hot water consumption during the monitoring period was 3,700 gallons per day. The tank thermostat setpoint temperature was found and left set to 140°F. The automatic flue damper was found to be in the hold-open position and not functional. It was discovered that the switch was damaged from impact, and once repaired, the damper operated properly. In the optimized configuration, there was a marked reduction in nighttime standby gas use. The projected gas reduction as a result of a 2% efficiency gain was 392 therms per year. Figures 2 and 3 show typical operating profiles in the baseline and optimized configurations respectively. Figure 4 shows a graph of daily efficiency versus hot water use for both configurations.

Figure 1. Water Heater in FSR #1 – Dublin, CA

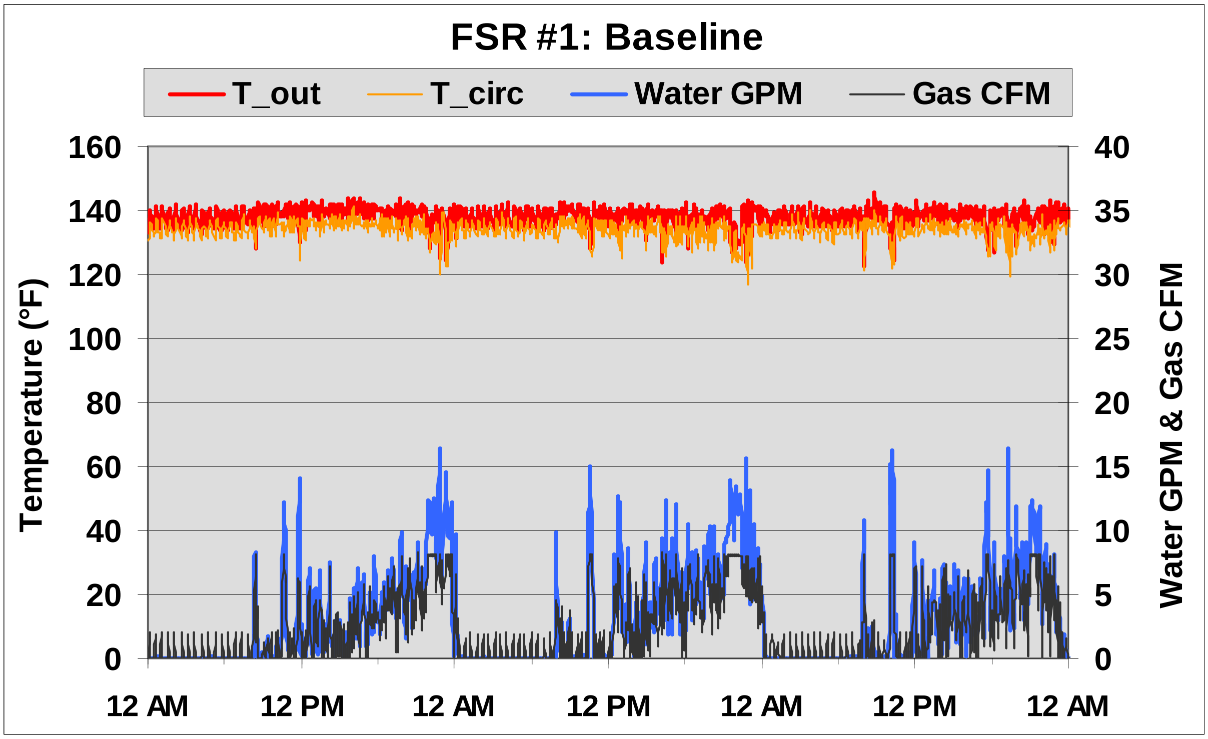


Figure 2. FSR #1 - Typical Baseline Operating Profile

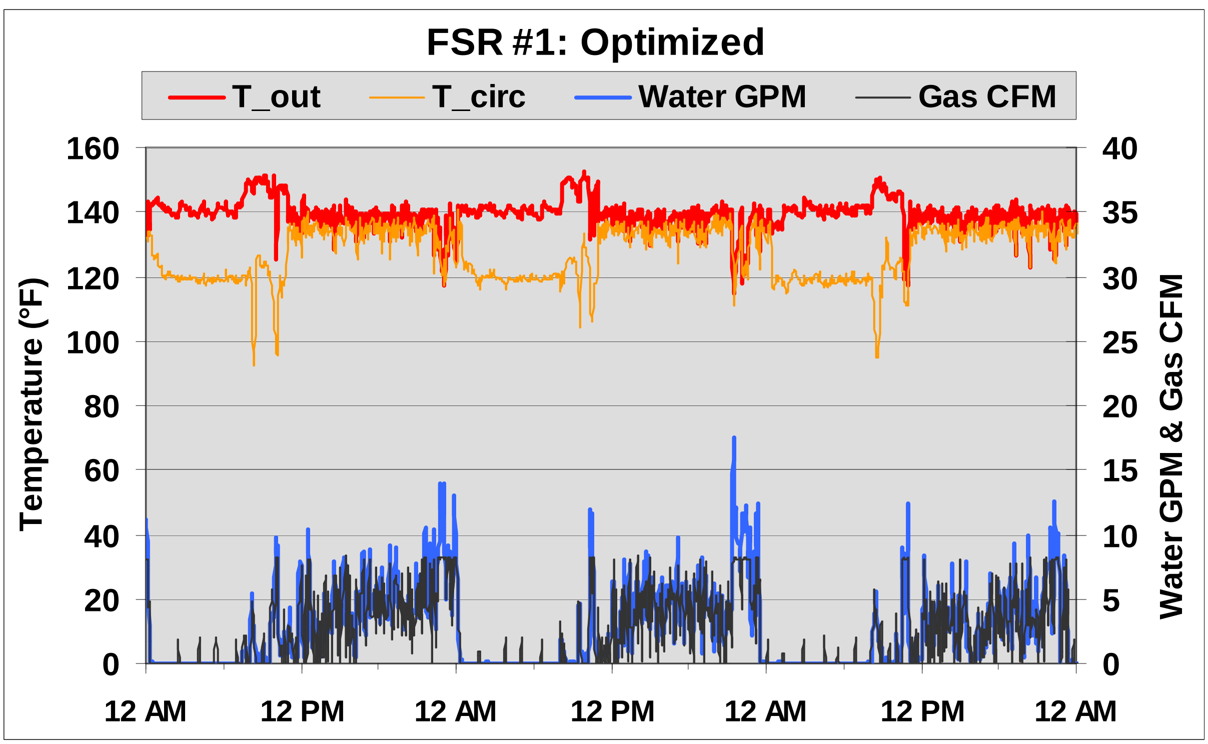


Figure 3. FSR #1 - Typical Optimized Operating Profile

Table 1. FSR #1 Summary of Results

Recorded Data	Baseline	Optimized
Thermostat Setpoint	140°F	140°F
Average Daily Hot Water Use (gallons)	3,706	3,645
Average Daily Gas Use (cubic feet)	3,337	3,376
Mass-Weighted Average Outlet Temperature	136.8°F	135.5°F
Mass-Weighted Average Inlet Temperature	65.2°F	60.2°F
Mass-Weighted Average Temperature Rise	71.6°F	75.3°F
Normalized Results		
Normalized Temperature Rise	75°F	
Normalized Daily Hot Water Use (gallons)	3,700	
System Efficiency	64.6%	66.6%
Projected Annual Gas Use (therms)*	13,061	12,669
Projected Annual Cost**	$15,673	$15,202
Projected Annual Gas Savings (therms)*	--	392
Projected Annual Cost Savings**	--	$471

* Calculated using 365 day/yr operation
** Calculated using gas utility cost of $1.20/therm

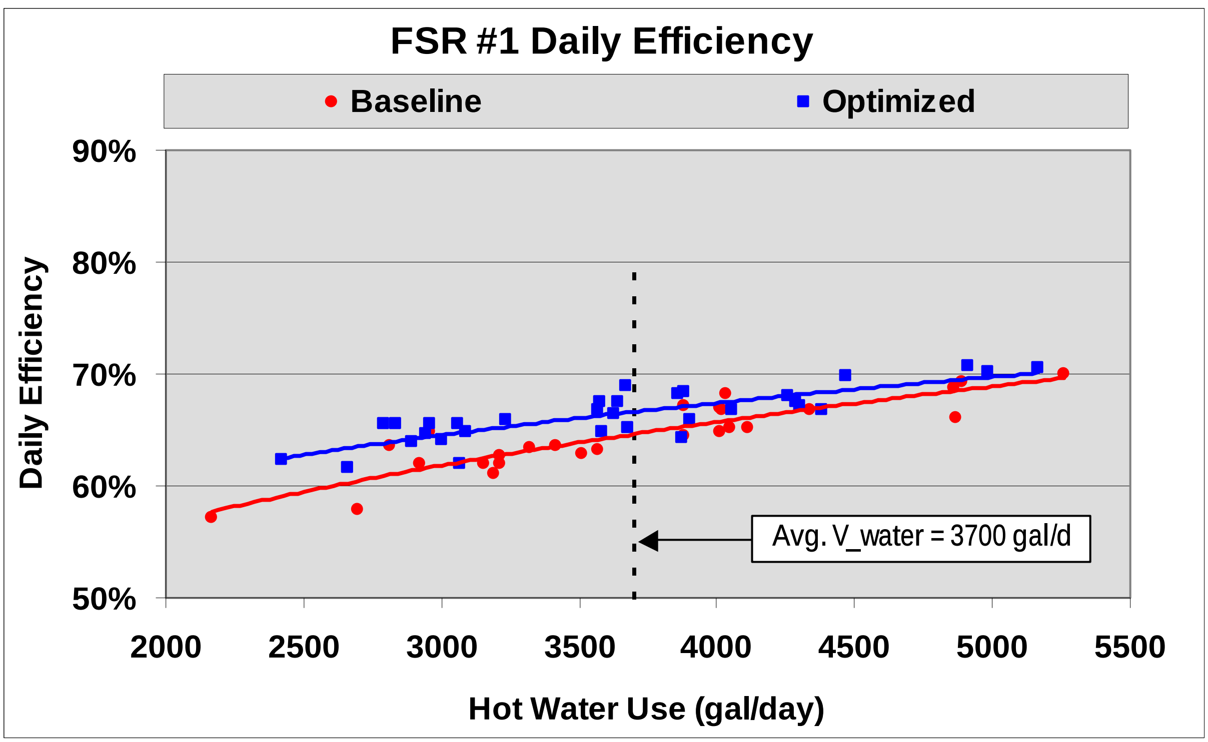


Figure 4. FSR #1 - Daily Efficiency versus Hot Water Use

FSR #2 - Dublin, CA

FSR #2 was designed with a 277,000 Btu per hour, 100-gallon heater. The automatic flue damper was found switched to the hold-open position and functioned properly when switched to automatic mode for testing in the optimized configuration. The thermostat setpoint was lowered by 5°F for the optimized configuration testing; this was not factored into the normalized results. Average daily hot water consumption during the monitoring period was 2,500 gallons per day. There was a 2% efficiency increase in the optimized configuration, yielding a projected gas saving of 208 therms per year. Typical operating profiles for three consecutive days in the standard and optimized configurations are displayed in Figure 6 and 7, and an efficiency plot is shown in Figure 8.

Figure 5. Water Heater in FSR #2 – San Ramon, CA

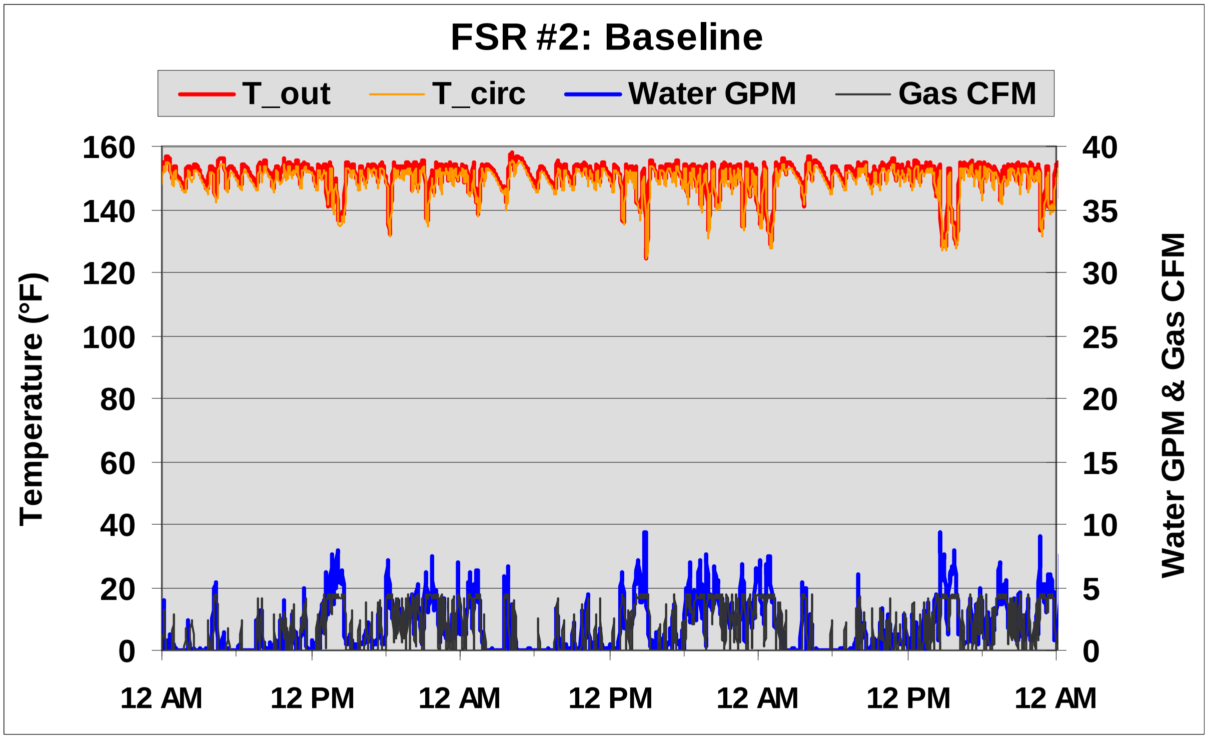


Figure 6. FSR #2 - Typical Baseline Operating Profile

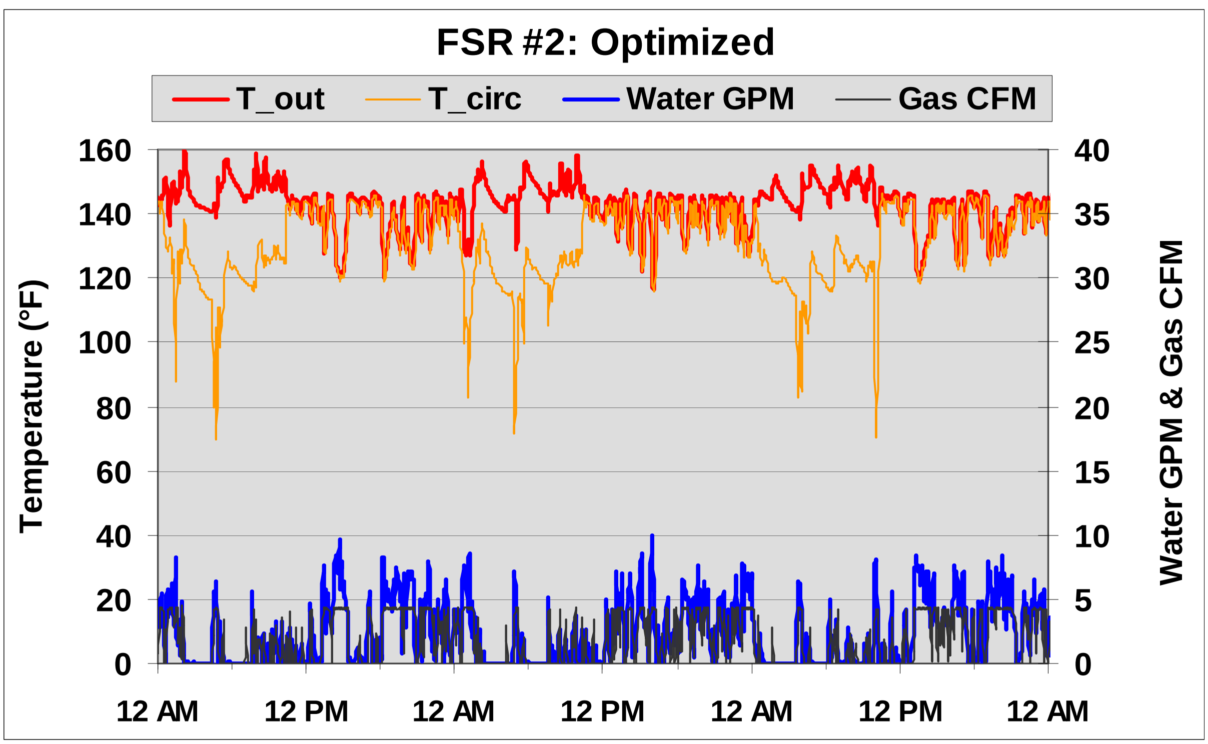


Figure 7. FSR #2 - Typical Optimized Operating Profile

Table 2. FSR #2 Summary of Results

Recorded Data	Baseline	Optimized
Thermostat Setpoint	150°F	145°F
Average Daily Hot Water Use (gallons)	2,288	2,660
Average Daily Gas Use (cubic feet)	2,051	2,289
Mass-Weighted Average Outlet Temperature	144.1°F	139.7°F
Mass-Weighted Average Inlet Temperature	65.8°F	61.4°F
Mass-Weighted Average Temperature Rise	78.3°F	78.3°F
Normalized Results		
Normalized Temperature Rise	75°F	
Normalized Daily Hot Water Use (gallons)	2,500	
System Efficiency	71.3%	73.2%
Projected Annual Gas Use (therms)*	7,996	7,788
Projected Annual Cost**	$9,595	$9,346
Projected Annual Gas Savings (therms)*	--	208
Projected Annual Cost Savings**	--	$249

* Calculated using 365 days per year operation

** Calculated using gas utility cost of $1.20 per therm

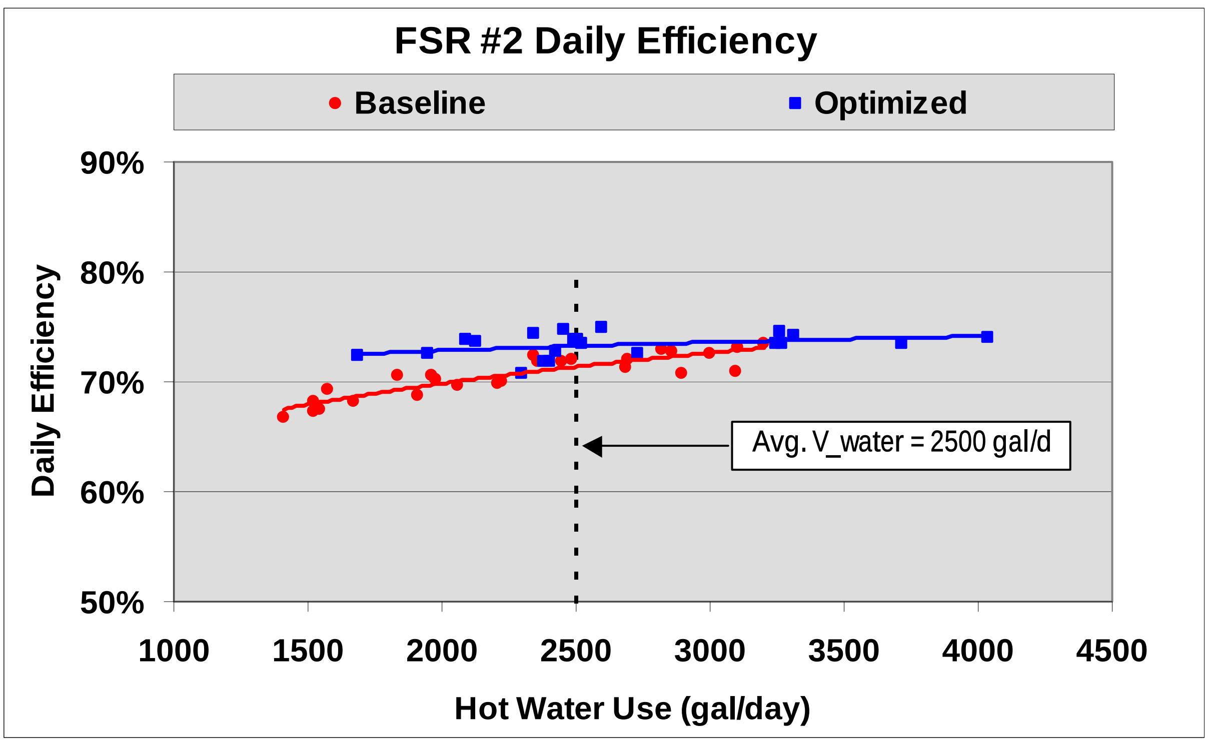


Figure 8. FSR #2 - Daily Efficiency versus Hot Water Use

FSR #3 – San Ramon, CA

FSR #3 was from the same chain and nearly identical to FSR # 2 with the same model 277,000 Btu per hour, 100-gallon water heater. Average daily hot water consumption during the monitoring period was 2,300 gallons per day. The flue damper was found in the open position, and it did not respond when switched to automatic mode. With further troubleshooting, it was discovered that the flue damper wiring had been bypassed (likely done to eliminate all chance of failure); it was then rewired and functioned properly for optimized mode testing. The thermostat setpoint was reduced 5°F after baseline testing as the outlet temperatures initially were running high at 145°F. (During the optimized test, facility personnel had raised the thermostat setpoint by 10°F to 150°F, altering the dataset.) This heater also exhibited a 2% increase in efficiency, which translated to a projected gas saving of 189 therms per year. Typical operating profiles for three consecutive days in the standard and optimized configuration are displayed in Figure 10 and 11. Note: The circulation return line operating profile (T_circ) of this facility is incongruent with those of the first two facilities. Cross-flow of cold water into the hot water line, believed to be from the toggle switch installed at each hand sink, created fluctuations and a reduction in the temperature of the circulation line.

Figure 9. Water Heater FSR #3 – San Ramon, CA

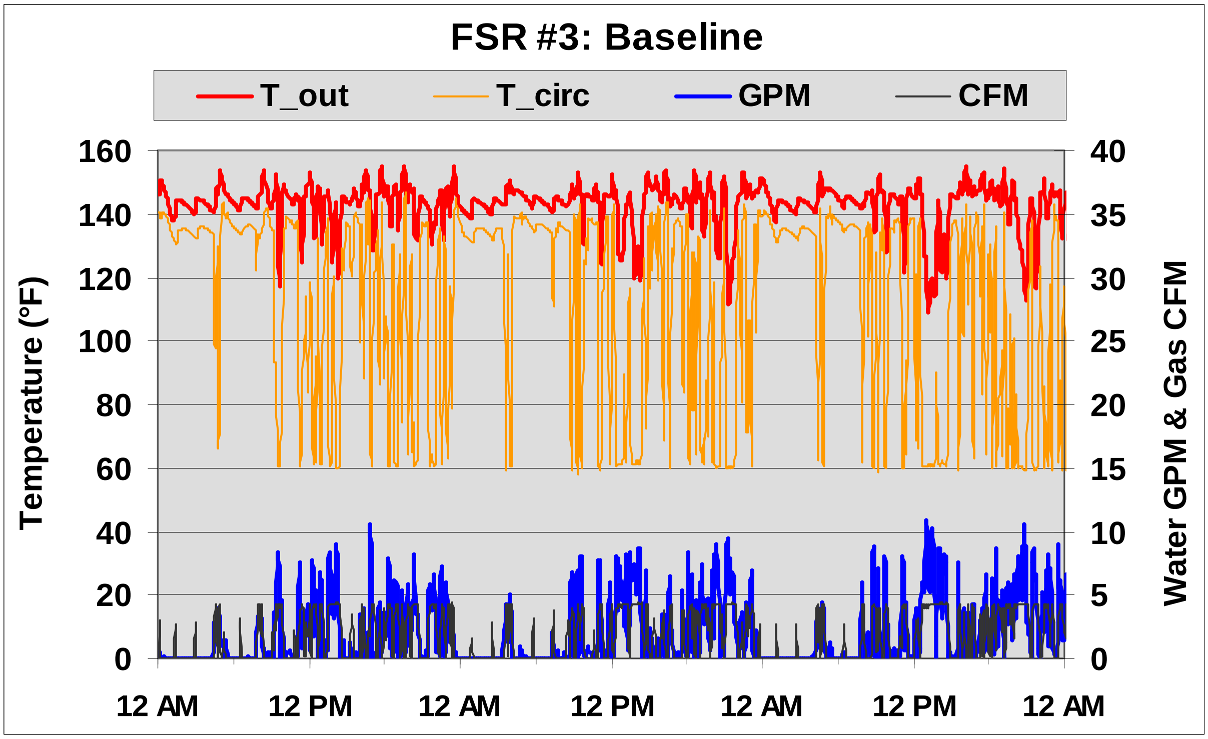


Figure 10. FSR #3 - Typical Baseline Operating Profile

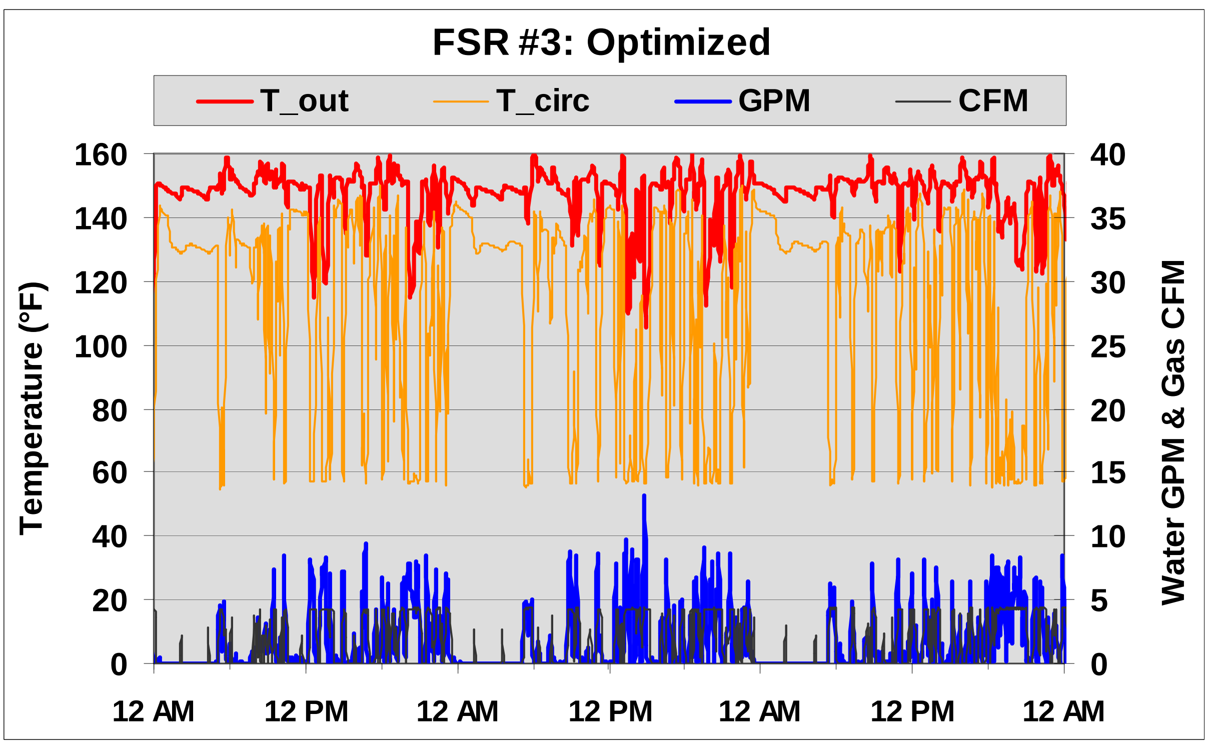


Figure 11. FSR #3 - Typical Optimized Operating Profile

Table 3. FSR #3 Summary of Results

Recorded Data	Baseline	Optimized
Thermostat Setpoint	145°F	150°F
Average Daily Hot Water Use (gallons)	2,212	2,554
Average Daily Gas Use (cubic feet)	1,881	2,089
Mass-Weighted Average Outlet Temperature	140.9°F	138.9°F
Mass-Weighted Average Inlet Temperature	63.5°F	65.1°F
Mass-Weighted Average Temperature Rise	77.4°F	73.8°F
Normalized Results		
Normalized Temperature Rise	75°F	
Normalized Daily Hot Water Use (gallons)	2,300	
System Efficiency	73.5%	75.5%
Projected Annual Gas Use (therms)*	7,136	6,947
Projected Annual Cost**	$8,563	$8,336
Projected Annual Gas Savings (therms)*	--	189
Projected Annual Cost Savings**	--	$227

* Calculated using 365 days per year operation

** Calculated using gas utility cost of $1.20 per therm

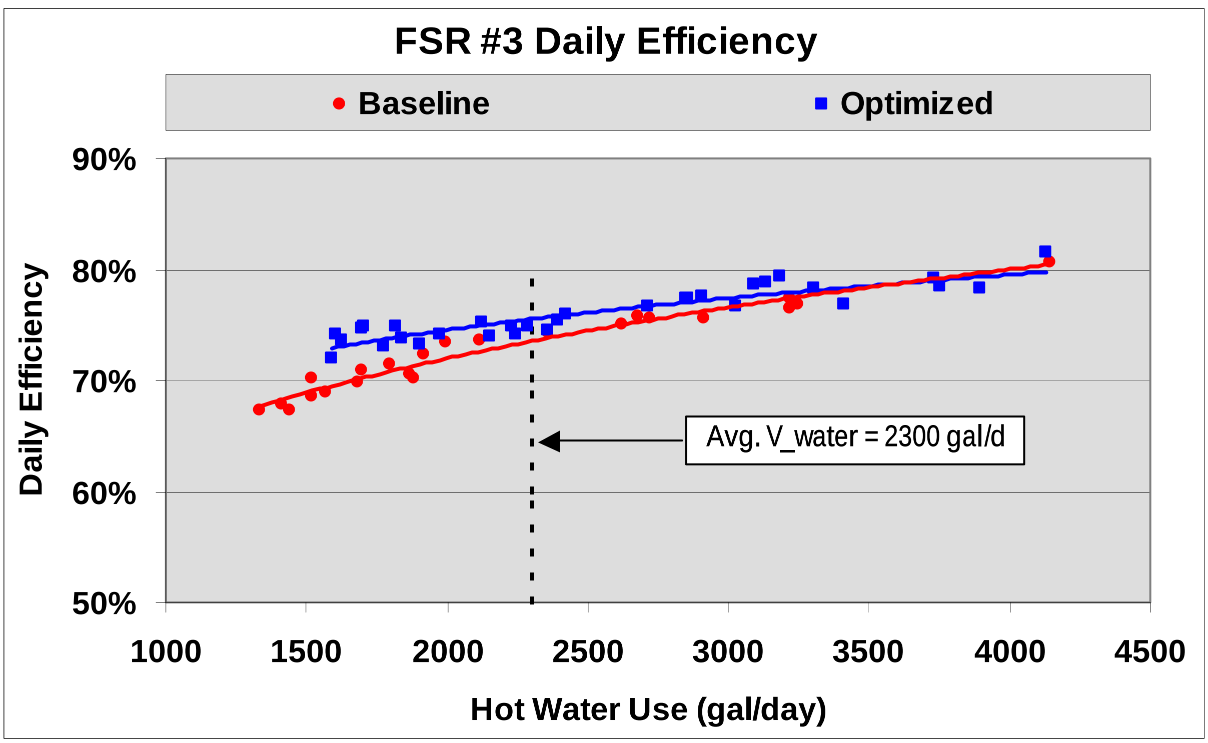


Figure 12. FSR #3 - Daily Efficiency versus Hot Water Use

Discussion

The figure below summarizes the system efficiency increase reported in this study (FSR #1-3) and a similar field study in 2007 (designated FSR #4 in the table) after the addition of a circulation pump timer and pipe insulation and activating the flue damper. Considering the consistent 2% increase in all three sites presented in this study and the considerably higher 8% increase shown in the former study, a conservative estimate of the energy efficiency increase for other full-service operations is 2.5%—weighted down from the 3.5% average increase for the four sites. This conservative estimate of a 2.5% efficiency gain translates to a normalized gas saving potential of 280 therms per year per facility, calculated using a nominal baseline system efficiency of 70%, a temperature rise of 75°F and an average hot water consumption of 2500 gallon per day. Although it could not be quantified within the scope of this study, it is hypothesized that the larger efficiency gain in FSR #4 resulted from a lack of interior pipe insulation and a lower ambient air temperature at the water heater (which was installed in an external utility room that would encounter lower temperatures, having a greater effect on efficiency gains derived from flue damper and circulation pump control).

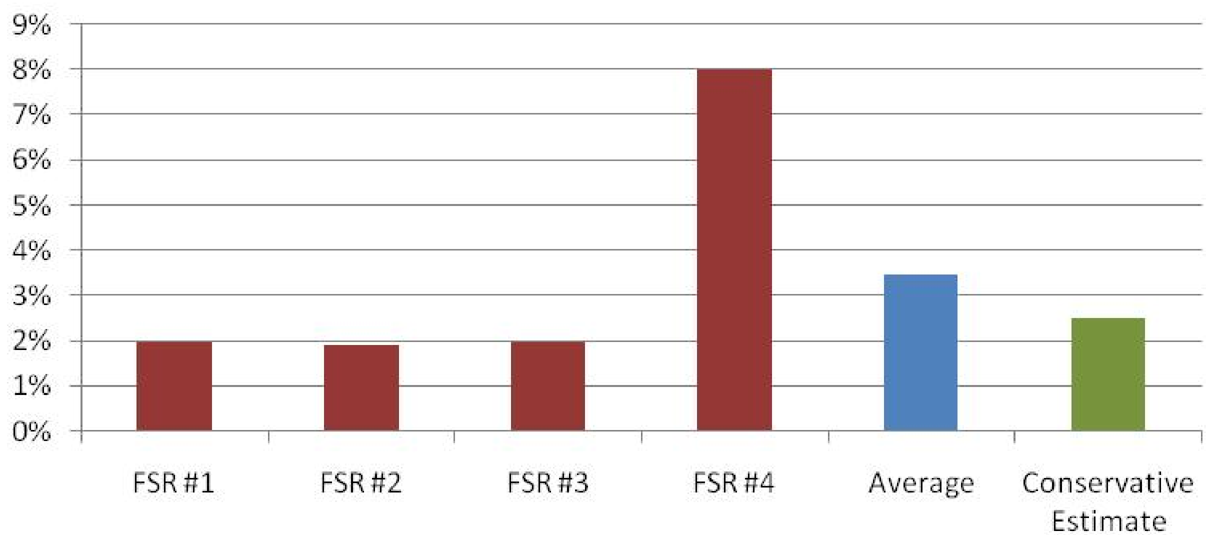


Figure 13. Site-Monitored Efficiency Increase through Retro-Commissioning

In the optimized configuration, the circulation pump timer, pipe insulation, and activated automatic flue damper were all operated and monitored collectively. Due to the uncontrolled test conditions of working restaurants and the relatively small variance between the measured baseline and optimized efficiencies, it was not possible to disaggregate the individual energy efficiency contribution. The nuance testing required would be more applicable to a controlled laboratory environment. The PG&E Applied Technologies Services Water Heating Laboratory adjacent to the FSTC is an ideal location for such testing. Additionally, through controlled testing, the secondary variables that can effect system efficiency and perhaps explain the large variance in the energy efficiency increase between studies can be investigated (e.g., ambient temperature, setpoint temperature, pipe insulation, circulation loop size and pump flow rate).

The retro-commissioning measures discussed up to now were designed to generate energy savings by improving water heating system efficiency, but apart from system efficiency improvements, perhaps a more direct and fundamental means to conserve energy is to simply avoid an excessive water heater operating temperature. There is a tendency to increase the water heater thermostat setting in kitchens with poorly performing low-temperature dishwashers – ironically a practice that negates the direct energy-saving benefit of using a low-temperature dishwasher design. There is also a tendency to increase the setpoint in an attempt to increase the hot water capacity to compensate for an undersized water heater that runs low on hot water during peak hot-water-use periods; however; raising the setpoint temperature will not significantly improve capacity unless the hot water supplied to major kitchen fixtures and equipment is tempered by a mixing valve at the output of the water heater.

During the initial site survey prior to baseline efficiency testing in FSR # 2, the water heater thermostat was found mistakenly set to 180°F. After consultation with restaurant management, it was adjusted to a preferred setting of 150°F. Based on this 30°F temperature reduction, the projected energy saving is 27%, or 3,200 therms per year. Although this may be a an atypical example, the savings resulting from this simple adjustment far outweighed any that could ever be expected from retro-commissioning efficiency improvements or even the installation of a high-efficiency condensing water heater. In the baseline configuration, testing at the 150°F thermostat setpoint and then reducing the setpoint to 145°F resulted in a 4.4°F outlet temperature reduction, yielding a 6% or 470 therms per year gas savings.

The pitfall of energy saving measures such as a thermostat setpoint reduction is that they are elastic. Turning down the thermostat can be effective one day, but staff practices can easily change and setpoints can easily be overridden. This is exactly what happened in FSR #3 during the optimized configuration test. After the FSTC researchers lowered the thermostat by 5°F to correct the elevated initial baseline outlet temperature, facility personnel unexpectedly raised the thermostat setpoint by 10°F.

Thermostat tampering could be prevented to lock in the energy savings through staff education and tamperproof designs. Presently, central processing units already installed on some condensing tank water heaters potentially could be expanded to provide a lockout feature for use by restaurant management, allowing for an effective and non-elastic reduction in gas consumption by maintaining the thermostat setpoint at its minimum.

Conclusion and Recommendations

This study confirmed the energy saving benefits of three best practice retro-commissioning measures for existing facilities: 1) verifying the correct operation of the flue damper on standard-efficiency tank water heaters; 2) adding insulation to the accessible hot water pipes; 3) adding a timer to the circulation pump (if the facility has a pump).

The water heater systems presented in this report exhibited an average energy efficiency increase of 2% (representing a reduction in gas use of 260 therms per year) through retro-commissioning, which is considerably less than the 8% efficiency increase (with a 800 therms per year saving) reported by the 2007 study. Considering all four monitored facilities, the energy efficiency potential is conservatively estimated at 2.5%. Based on these results, given that the energy-efficiency potential is lower than first thought, it is no longer viable to pursue a path for development of a third-party program to upgrade existing food service facilities with these retro-commissioning measures. However, advocating the retro-commissioning measures directly with restaurants through best-practice education or identifying measures and initiating change during PG&E site surveys are avenues to pursue. Collaboration with existing third-party programs that are already working with restaurants to incorporate applicable retro-commissioning measures is another viable strategy.

Due to the large variation in the energy efficiency increase between this study and the 2007 study, additional site monitoring is recommended to establish a more accurate estimate of the savings potential. Any future water heating system field monitoring conducted by the FSTC should include examination of the same retro-commissioning optimizations as part of the test protocol, and laboratory testing could better scrutinize the variables affecting the efficiency differences.

Looking forward, apart from improving water heating system efficiency, a more direct opportunity to save energy would be by reducing elevated water heating temperatures in systems. With further research and development, new water heaters with smart controls and thermostat-lockout capability could ensure that setpoints are being maintained at recommended values. Future research investigating the effectiveness and applicability of smart controls to maintain optimum output temperatures is recommended.

References

[1] PG&E Food Service Technology Center. 2007. Energy Efficiency Potential of Gas-Fired Commercial Hot Water Heating Systems in Restaurants: An Emerging Technology Field Monitoring Study. FSTC Report 5011.07.04.

[2] GAMA Product Directories: http://www.gamanet.org. Gas Appliance Manufacturers Association (GAMA) Consumers' Directory of Certified Efficiency Ratings for Heating and Water Heating Equipment, March 31, 2008.

Appendix A: Aquastat Installation

Although not included in the original scope of work, aquastat testing was added to the study in an effort to increase the retro-commissioning savings potential. The addition of aquastat to the optimized configuration yielded mixed results, and therefore the analysis is presented here separately. Although there was an energy efficiency percentage improvement, there was also an adverse effect on water heater performance, characterized by an elevated average outlet temperature and erratic outlet temperature profiles with higher spikes during low flow periods and lower dips during high flow periods (as seen in operating profiles below).

The elevated outlet temperature, simulating a thermostat setpoint increase, negated the efficiency percentage gains and resulted in no direct gas savings derived from the aquastat installation. In FSR #1 for example, while there was a 2% energy efficiency increase in the optimized with aquastat case, there was also a 3.9°F increase in the outlet temperature, resulting in a higher gas load and no actual energy reduction. FSR #2 had similar results, with a 1% efficiency increase and a 2.5°F temperature increase. (In FSR #3, cross flow of cold water into the hot water return line, believed to be from the toggle switch installed at each hand sink, created fluctuations and a reduction in the circulation line temperature, diminishing the effectiveness of the aquastat altogether.) With the addition of the aquastat, the efficiency increase would only translate into input gas savings if the thermostat were to be turned down after installation to match the original outlet temperature. The table below summarizes the "optimized with aquastat" configuration testing and shows the effects on the outlet temperature and energy consumption.

The lower temperature dips during peak draw periods (compared to similar water flow without the aquastat) are indicative of colder inlet water passing through the tank without being fully heated. Even though the test results show a mass-weighted average temperature increase with the aquastat, the resultant thermal stratification essentially reduces the hot water capacity to some degree. The exact cause of the observed outlet temperature effects is not fully understood, and though a complete investigation is beyond the scope of this project, it is speculated that the constant flow from the circulation loop minimizes thermal stratification within the tank by mixing the water throughout to a more uniform temperature, which also may allow for improved thermostat interaction and control of the burner cycling pattern for an even more stable outlet temperature profile.

Though more research may lead to a better understanding of these behaviors, for now, the FSTC is not recommending the installation of aquastats on systems. Furthermore, it would not be practical for a third-party-program contractor to first install the aquastats, then lower the thermostat setpoints and perform an outlet temperature measurement and verification.

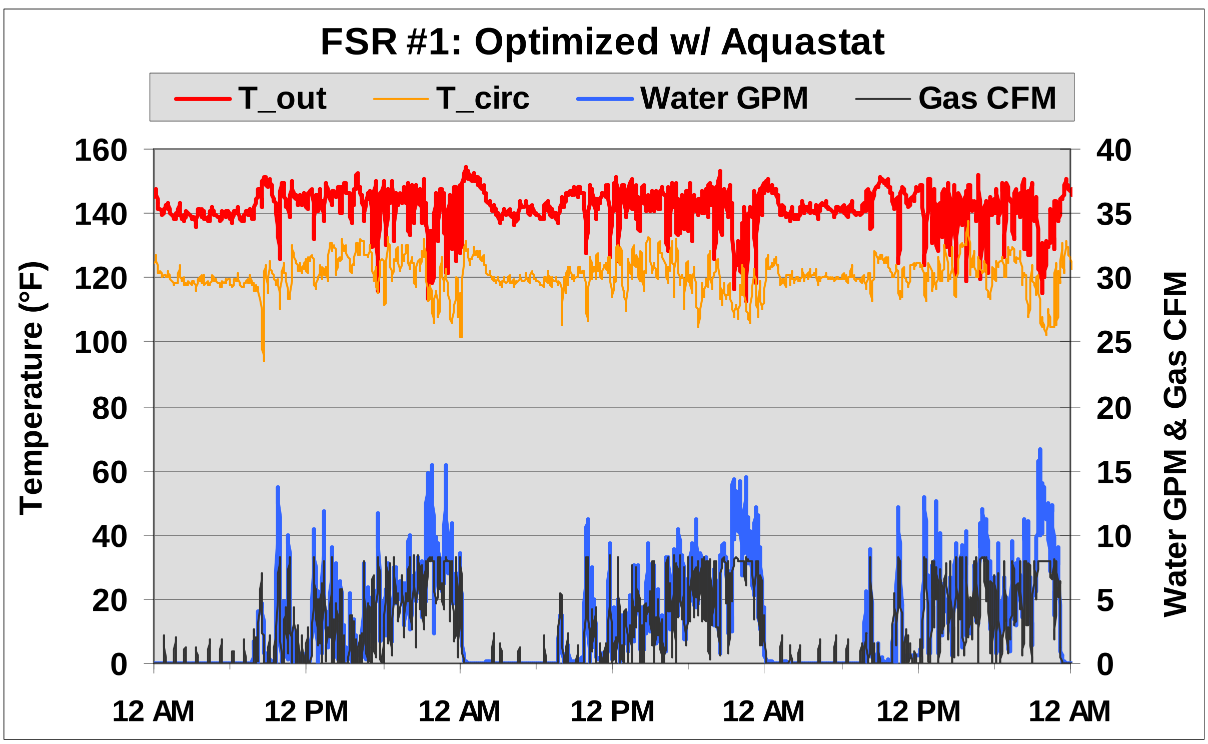
Aquastat Summary of Results

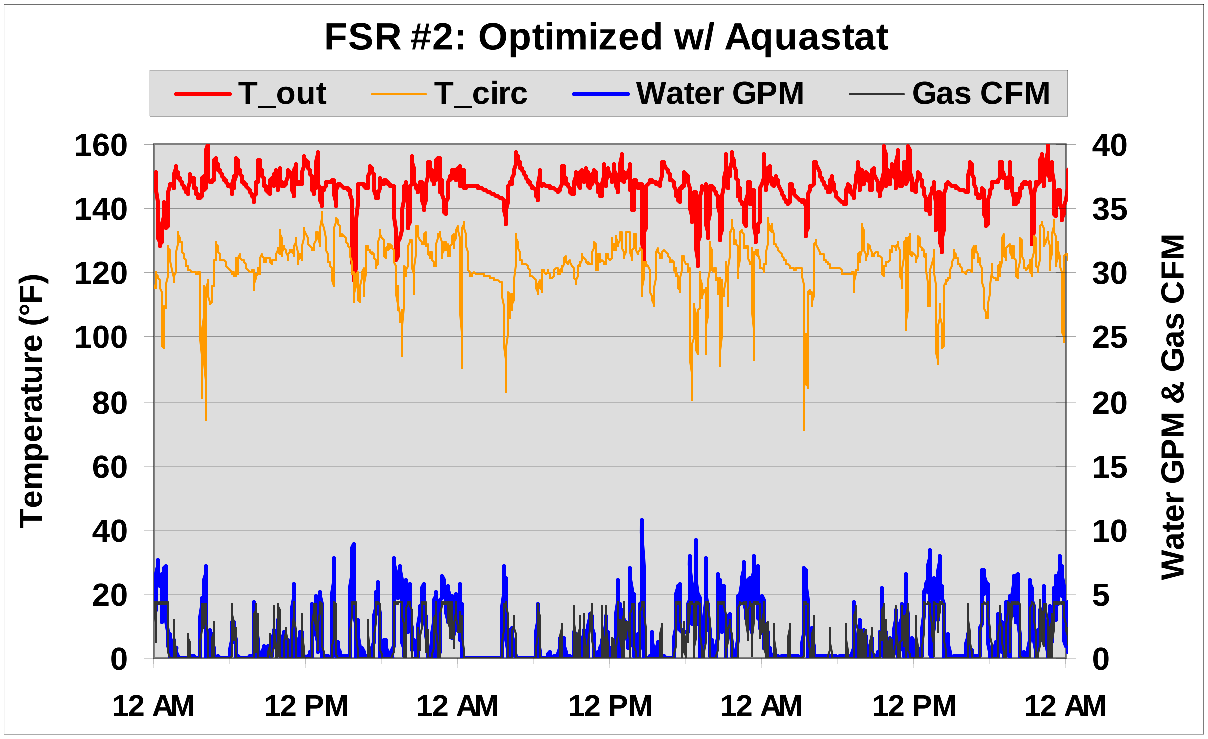
	FSR #1	FSR #2	FSR #3
Normalized Daily Hot Water Use (gallons)	3,700	2,500	2,300
Normalized Temperature Rise	75°F	75°F	75°F
Outlet Temperature Increase with Aquastat	3.9°F	2.5°F	n/a
Adjusted Temperature Rise with Aquastat	78.9°F	77.3°F	n/a
Optimized Daily Efficiency without Aquastat	66.6%	73.2%	75.5%
Optimized Daily Efficiency with Aquastat	68.5%	74.3%	75.2%
Optimized Projected Annual Gas Use (therms)*	12,317	7,673	6,974
Projected Annual Gas Use with Aquastat (therms)**	12,958	7,928	n/a
Annual Gas Use Savings (therms)	*-289*	*-140*	n/a

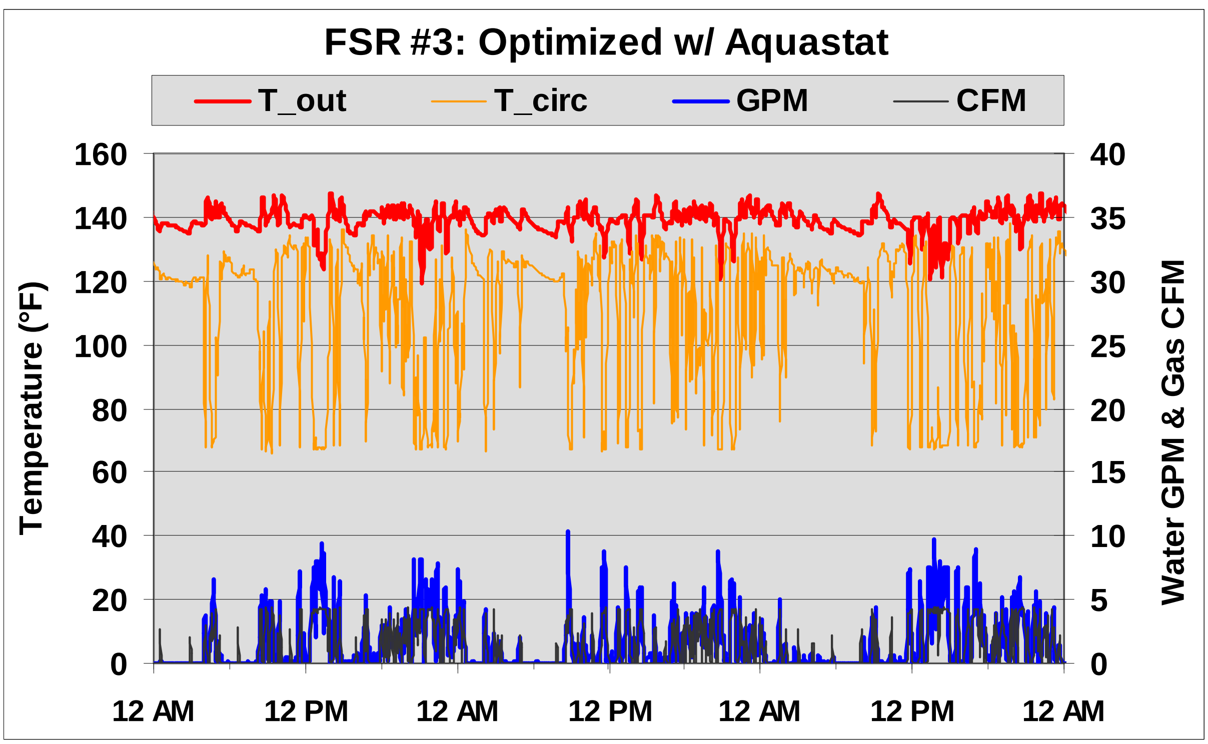
* Calculated using 365 days per year operation

** Assuming no accompanying thermostat temperature setpoint reduction

Optimized with Aquastat Operating Profiles




FSR #2: Optimized w/ Aquastat
T_out
T_circ
Water GPM
Gas CFM
Temperature (°F)
Water GPM & Gas CFM
160
140
120
100
80
60
40
20
0
40
35
30
25
20
15
10
5
0
12 AM
12 PM
12 AM
12 PM
12 AM
12 PM
12 AM


FSR #3: Optimized w/ Aquastat
T_out
T_circ
GPM
CFM
Temperature (°F)
Water GPM & Gas CFM
160
140
120
100
80
60
40
20
0
40
35
30
25
20
15
10
5
0
12 AM
12 PM
12 AM
12 PM
12 AM
12 PM
12 AM