Energy-Efficiency with Domestic Water Heating in Commercial Buildings

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ABSTRACT

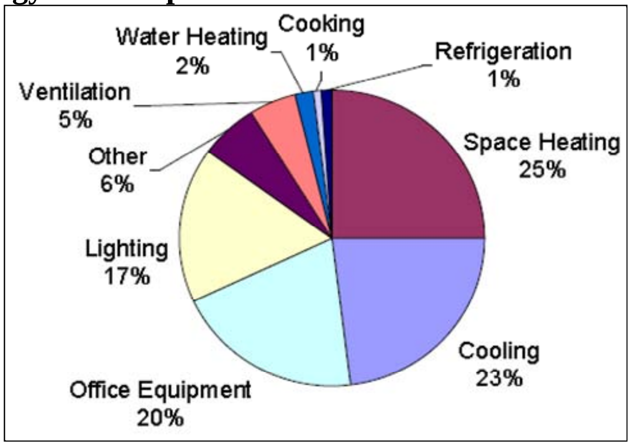
This paper presents measured energy savings data from implementation of one simple control strategy—turning off hot water re-circulating pumps during unoccupied hours in commonly used central storage type DHW systems in a commercial office building. Though turning off water heaters and/or recirculation pumps during unoccupied hours sounds simple and straightforward, it is not a common practice. Costs for retrofit controls have to be weighed against potential energy costs savings for economic decisions. The estimation of energy savings with any good degree of confidence can be time consuming and difficult. This paper presents field monitored data of such savings from a large 267,000 sq. ft. commercial office building with no-cost/low-cost measures. Water heating energy savings of 27% is demonstrated in gas fired water heating systems, and another potential 23% is identified if the heating burners could be cost effectively turned off during unoccupied periods. Excellent payback period of about 3 months was recorded from the simple recirculation pump cycling control alone.

Introduction

Energy use for Domestic Hot Water (DHW) units is relatively small, about 2% of the building energy use as shown in Figure 1. It generally does not receive much attention in energy efficiency/conservation programs. But every unit of energy saved is important to mitigating global warming as well as reducing operating costs.

Domestic Hot Water (DHW) systems are needed in commercial buildings to provide hot water to restrooms, kitchens, special activity rooms like Gymnasiums etc. Storage type DHW systems include a small hot water recirculation pump that circulates hot water in large commercial buildings so that hot water is available at the tap immediately are very common. Without recirculation, the cold standing water in the piping network has to run out before hot water is available. The commercial office buildings are typically unoccupied for nearly 108 hours out of 168 in typical commercial buildings, and with large recirculation piping network, the DHW system continues to lose heat from bare pipes. Turning off the recirculation pump not only saves pump energy use, but reduces heat loss from the bare pipes. This paper presents water heating energy use profiles with and without recirculation pump cycling during unoccupied hours. Energy savings from avoiding standby losses are calculated. Control schemes such as resetting the hot water temperature during unoccupied hours are also explored. The data will help in estimating energy savings from avoiding losses under different control schemes and can help economically justify adopting cost effective control schemes.

Figure 1. Energy Consumption Breakdown – Commercial Office building



U.S. EPA 2007 [1]

In a typical commercial building, the DHW system is placed in a mechanical room on penthouse or in basement of a building. The water heaters can be electric or gas fired. In a gas fired heater, the natural gas is burned in a combustion chamber of the water tank. The hot flue gases also heat up the water before exiting the tank as shown in Figure 2. [Waterheatertimer.org 2006, Whirlpool Water Heaters 2009]. This flue gas is exhausted through an overhead duct. The heated water is fed to the building using two sets of piping:

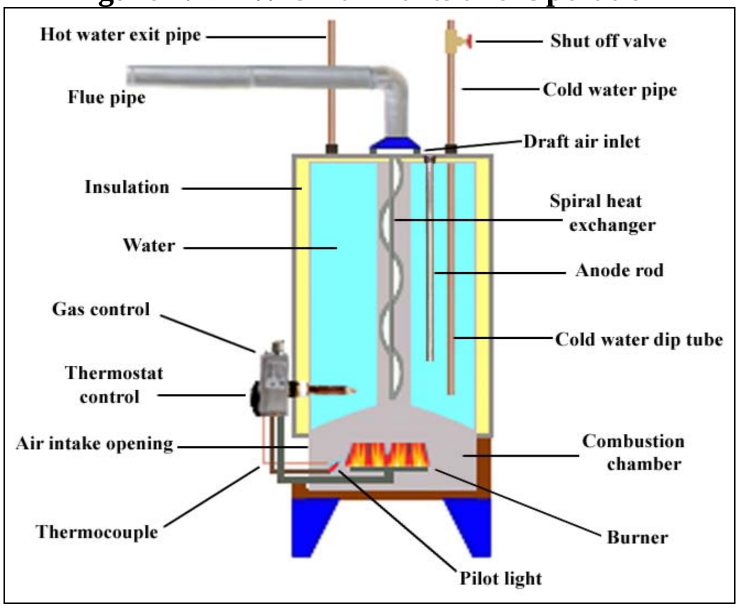
- A main feeder to all the floors in the building. At each floor, the feeder branches out to respective restrooms etc. to provide bulk hot water supply.
- An alternate smaller feeder pipe is connected to a recirculation pump and feeds the main feeder in all branches near the faucets. This piping ensures that hot water is available immediately after the faucet is opened by an end user. In general, these recirculation pumps are operating 24 hrs a day.

The primary sources of energy losses are:

1. Standby losses from the storage tank to surrounding air: Increased insulation helps reduce these losses. In addition, insulation of any piping connected to the hot tank that can act as 'fins'—either hot, cold or drain pipe—even if it is just the first feet or so the piping, has shown measurable savings in standby losses and is recommended.
2. Heat dissipation losses from pipes: The hot water pipe has no insulation and circulated hot water is at high temperatures. Though a temperature of 115°F is acceptable, some systems are kept it much higher temperatures. The pipes travel through regular occupied spaces and building shafts. During unoccupied times, this will lead to loss of heat by modes of radiation and convection. These standby losses have been small and ignored by the industry in the past. In winter space heating mode, these losses can keep the building warm, and may not be considered as 'real' loss. However, in the summer cooling mode, these are heat gains and must be cooled by the air conditioning systems. Thus overall, the effect, at the least, cancels out during summer and winter months in moderate climates. Thus, curbing the standby losses at nighttime should be considered.
3. Stack effect losses: While the above two losses apply to electric or gas fired system, the stack effect losses only apply to gas-fired systems. The cold air will continue to flow

through the passage of the flue gases—through the burner section, warmed up from the hot water and exit the at the top as the exhaust gas. This is why large boilers now come with features like stack dampers that are synchronized with the firing time of the boiler. For a DHW systems which generally do not have stack dampers, these losses will continue occur even during unoccupied times. This in turn cools the water inside the tank and triggers the firing up of the boiler just to maintain the temperature at the thermostat. This firing is wastage during unoccupied times. Data on firing durations during unoccupied hours, without and with recirculation pump controls were recorded.

Figure 2. DHW Unit – Parts and Operation



waterheatertimer.org [3]

The following are simple and straightforward no-cost/low-cost energy-efficiency options related to DHW and their plumbing systems:

1. **Shutting off recirculation pump during unoccupied times**: This option is explored in details in this paper. The idea here is to install either a manually programmable timer or connect the pump to a building energy management and controls system to control the on/off times based on building occupancy times. Here, energy savings come from two sources: First, straight reduction in electrical energy consumption by the pump. This savings can be small because these pumps are small in size. Second, the energy consumption by the gas heater is reduced. When the pump is operating, the water temperature returning back from the building is colder than the supply temperature. This will eventually trigger the thermostat to turn on the heater. Thus energy is wasted by unnecessarily firing up the boiler during unoccupied hours. Avoiding this can lead to measurable savings was demonstrated from the field data.
2. **Shutting-off boiler during unoccupied times** – This logically follows from the explanation in the previous section. Not running the recirculation pump can reduce heater run time during unoccupied times (see Results section), but it does not reduce on the standby losses from the storage tank unit. Shutting the boiler off will gradually reduce the water temperature in the storage tank as it loses heat. With lower temperature, losses are

further reduced. Admittedly the heater has to work extra to heat up the colder tank water when occupancy begins, but the saving of the heat losses are not small. This option is simpler to implement in Electric heaters compared to Gas heaters. For Electric heaters, the power input can be controlled at the circuit breaker and then timed using a programmable timer or a BMS based controller. There are some solutions for the gas heaters such as interrupting thermostat or power to the gas valve. This was, however, not implemented at the tests, but energy savings from such a measure was extrapolated from the data. The authors continue to explore low cost practical solution.

3. **Resetting heater set-point temperature**: The water temperature should be set to minimum acceptable levels. If the water is used only in the restrooms, and if the user has to open both hot and cold water taps to mix the water to suitable temperature, obviously, the hot water temperature can be lowered. The authors found that limiting the hot water temperature to 115°F seemed to be the sweet spot between cold/hot water mixing and complaints for water not being hot enough. This option, though not discussed in details in this paper is a recognized issue and should be optimized for high no-cost savings. If higher water temperature is required, such as for dish washing, consider a booster water heater or a separate water heater.

Test Case Description

The controls schemes were tested in a 267,694 sq. ft. facility in Redwood Shores, California. The DHW unit is located on the penthouse of this 14 floor building. Following are the key components:

- DHW heater – A.O.Smith, Model FGR752750, 75gal, Input = 76kBtuh (0.76therm/hr)
- Recirculation pump – Bell & Gossett, NBF-22, 115V, 0.8A, 92W
- Main feeder pipe – Copper pipes with the main line going vertically down having 1.5in diameter
- Recirculation piping – Copper pipes. 0.75in diameter.
- Supply Temperature - 114°F.

The following Figure 3 shows the components mentioned above. The pump is controlled by a central building automation and control system. The timing of operation of this pump can be set on a web console. Initially the recirculation pump was running 24hrs a day, 7 days a week. The new time settings were set as follows. These are shown schematically in Figure 4:

- Monday – Friday: On for 6am -6pm and 10:00pm - 11:30pm. The first set is for occupied times for the building. The second set of timing is to provide hot water for the building cleaning crew at night. Thus the total operation time of the pump is 13.5 hrs per day for 5 days a week.
- Saturday – Sunday: Not on. Thus total operating time is 0hrs.

Three test cases were studied and analyzed:

- Case 1 (Tuesday Comparison): This is representative of weekday operations.
- Case 2 (Saturday Comparison): For Weekend savings calculation.

- Case 3 (Sunday Comparison): Sunday is considered different from Saturday since the cleaning crew workdays are Sunday – Thursday. This changes the Sunday consumption as compared to Saturday.

Figure 3. Test Case Setup

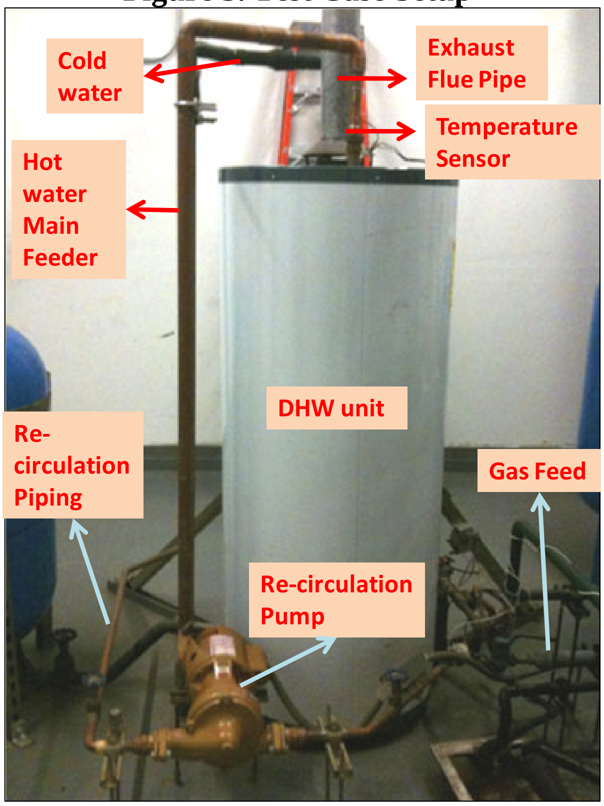
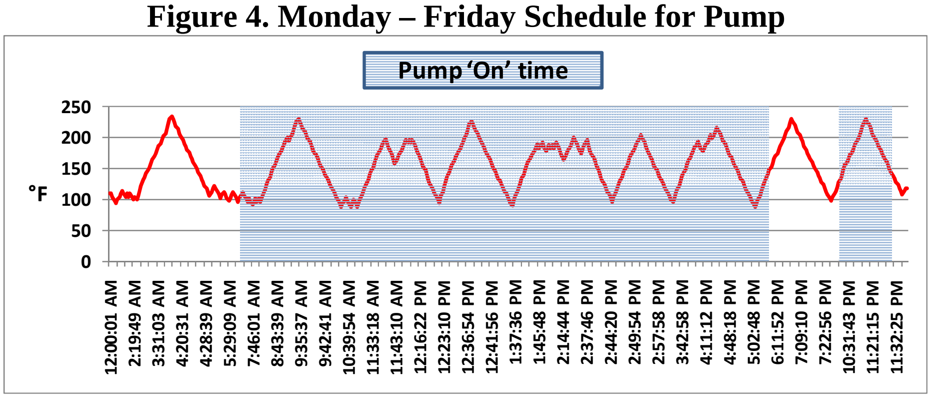


Figure 4. Monday – Friday Schedule for Pump



In each of the test cases, both pump and DHW unit savings are identified. The DHW unit savings are analyzed for 3 different scenarios:

1. Full Day: Comparing the entire day 'on-state' times. This will then be converted to cost based on the unit's firing capacity and typical gas rates

2. Unoccupied hrs: Comparing consumption between 6pm-6am, i.e., unoccupied times. This is compared because comparing the entire day follows with the assumption that the occupied period loads are the same. While, comparing back to back weeks can minimize the change in occupational load, the relevant comparison is of unoccupied times because (a) Change should be minimal in consumption pattern in unoccupied times between back to back weeks, (b) Unoccupied times is when the energy-efficiency option actually takes effect and should be compared for calculating direct savings. This scenario comes with the inherent assumption of occupied timing consumption being the same
3. Unoccupied + 1 hrs: Comparing consumption between 6pm-7am. Scenario 2 neglects the effect of the extra recovery period operation of the DHW unit in the first hour of the day if the unit is not operating all night. Thus Scenario 3 adds the first hour of the day along with the unoccupied timing to compare the runtime difference between running the system all night and not running the system all night but increasing runtime in the first hour. Scenario 3 is not applicable to Cases 2 and 3 since on these days the pump does not come on at all. Thus there is no recovery period.

Figure 5. Burner On/Off profile

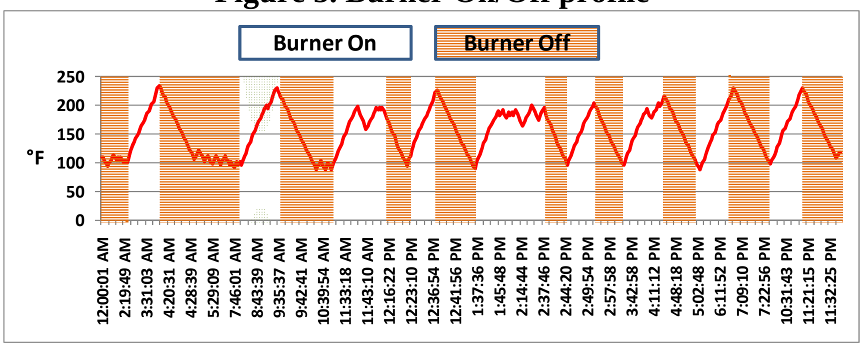
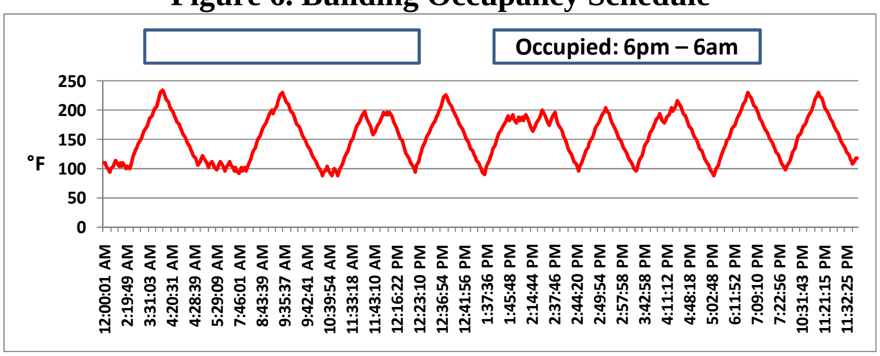


Figure 6. Building Occupancy Schedule



Estimating boiler 'on/off' time. There was no direct signal available from the water heater to indicate when the gas fired on or turned off. We installed a thermocouple in the exhaust flue gas and measured its stack temperature. This was the stack temperature of the flue gases coming out of the DHW unit. A constant increase in temperature, when the final temperature reaches above 180°F, is considered on-state. Any subsequent zero slope line with minor aberrations is also considered on-state. Similarly an off-state is a constant decrease to lower than 110°F followed by any zero slope line with minor aberrations. This is shown schematically in Figure 5. The actual on/off time can be slightly different from the inferred data; this is one of the limitations of this field test.

Results

Case 1 (Tuesday Comparison)

Table 1. Presents the energy consumption comparison for before and after implementation. The day is a Tuesday. The estimated annual savings are 251 kWh and 326 therms.

Table 1. Case 1 (Tuesday Comparison) Results

<table>
<tr><th></th><th colspan="2">Pump Operation (hrs)</th><th colspan="2">Burner – Full Day (hrs)</th><th colspan="2">Burner - Unoccupied (hrs)</th><th colspan="2">Burner – Unoccupied + 1 (hrs)</th></tr>
<tr><td>Before</td><td colspan="2">24</td><td colspan="2">8.9</td><td colspan="2">3.5</td><td colspan="2">3.5</td></tr>
<tr><td>After</td><td colspan="2">13.5</td><td colspan="2">7.2</td><td colspan="2">2.0</td><td colspan="2">2.7</td></tr>
<tr><td>Savings</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Pump runtime (hrs)</td><td>10.5</td><td>43.8%</td><td colspan="6" rowspan="2">NA</td></tr>
<tr><td>Electricity (kWh)</td><td>251</td><td>43.8%</td></tr>
<tr><td>Burner runtime (hrs)</td><td colspan="2" rowspan="2">NA</td><td>1.7</td><td>22.9%</td><td>1.5</td><td>41.7%</td><td>0.8</td><td>22%</td></tr>
<tr><td>Natural Gas (therms)</td><td>326</td><td>22.9%</td><td>288</td><td>41.7%</td><td>152</td><td>22%</td></tr>
<tr><td>Weekday Savings ($/yr)</td><td colspan="2">$25 (251 kWh)</td><td colspan="2">$326 (326 therms)</td><td colspan="2"></td><td colspan="2"></td></tr>
</table>

Based on Natural Gas prices of $1/therm, Electricity prices of $0.1/kWh

The savings calculation (in $) is based on the rated values of power/heat input to the pump and DHW unit as mentioned in the Test case section. The following formula is used:

$$Savings(\$) = \frac{hrs\_saved}{day} \times \frac{\sum_{Mon}^{Fri} days}{week} \times \frac{weeks}{year} \times \frac{Rated\_Capacity}{hrs} \times \frac{Energy\_\Pr ice}{Capacity} \quad (1)$$

The data was polled every second but recorded in the database only when there was a ±5°F change in temperature. Thus data is not available for each second. Also the number of data points for two days can differ. So it should be noticed that the x-axis is not synonymous in both cases. The following chart in Figure 7 gives the comparison of flue gas temperatures.

Figure 7. Daily Flue Gas Temperature profile (Tuesday)

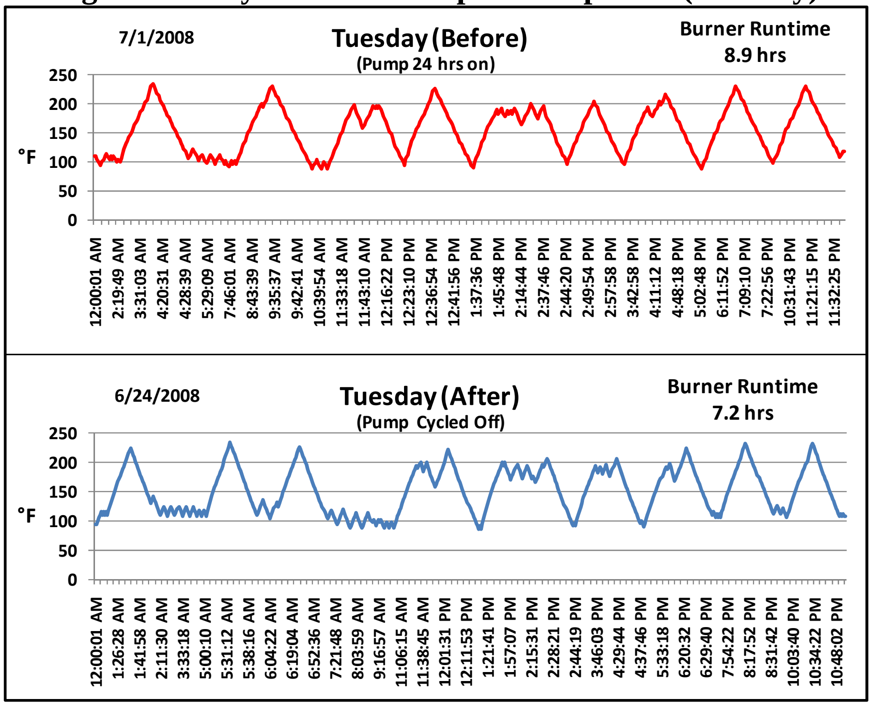
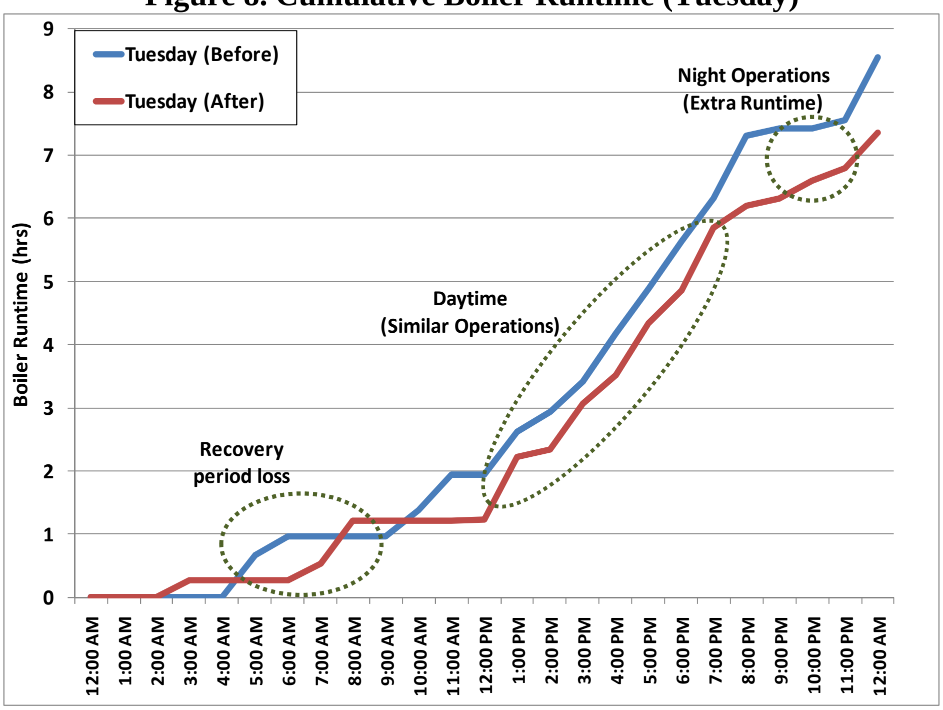


Figure 8 shows the analysis of cumulative boiler run hours vs. time of the day.

Figure 8. Cumulative Boiler Runtime (Tuesday)



Case 2 (Saturday Comparison)

Table 2. Shows case 1 run time and energy consumption for two Saturdays, before and after the implementation. The estimated annual savings are 115 kWh and 68 therms.

Table 2. Case 2 (Saturday Comparison) Results

	Pump Operation (hrs)		**Burner – Full Day (hrs)**		**Burner - Unoccupied (hrs)**	
Before	24		3.6		1.7	
After	0		1.9		1.3	
Savings						
Pump runtime (hrs)	24	100%	NA			
Electricity (kWh)	115	100%				
Burner runtime (hrs)	NA		1.7	22.9%	0.4	41.7%
Natural Gas (therms)			68	47.5%	16	41.7%
Savings ($/yr)	$11.5 (115 kWh)		$68 (68 therms)			

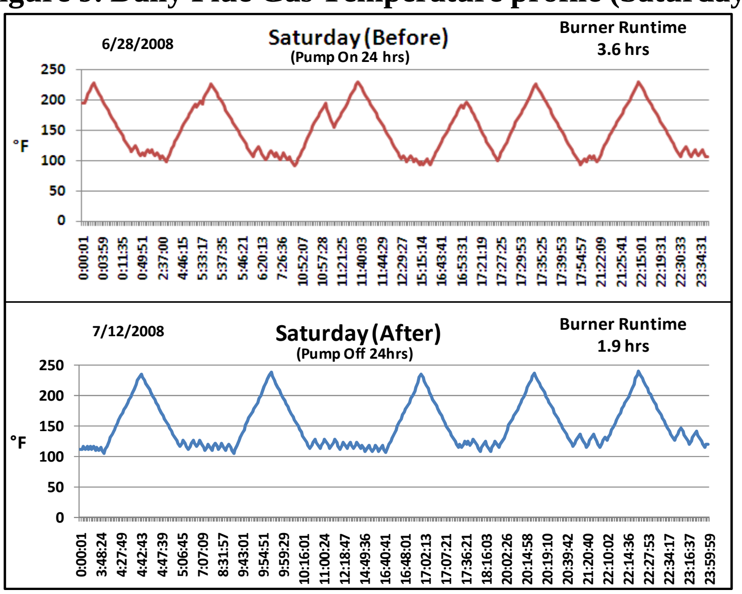
Based on Natural Gas prices of $1/therm, Electricity prices of $0.10/kWh

The savings calculation (in $) is based on the rated values of power/heat input to the pump and DHW unit as mentioned in the Test case section. The following formula is used:

$$Savings(\$) = \frac{hrs\_saved}{day/week} \times \frac{weeks}{year} \times \frac{Rated\_Capacity}{hrs} \times \frac{Energy\_Price}{Capacity} \qquad (2)$$

The following chart in Figure 9 gives the comparison of the flue gas temperatures.

Figure 9. Daily Flue Gas Temperature profile (Saturday)



Case 3 (Sunday Comparison)

Table 3. Shows case 1 run time and energy consumption for two Sundays, before and after the implementation. The estimated annual savings are 115 kWh and 175 therms.

Table 3. Case 3 (Sunday Comparison) Results

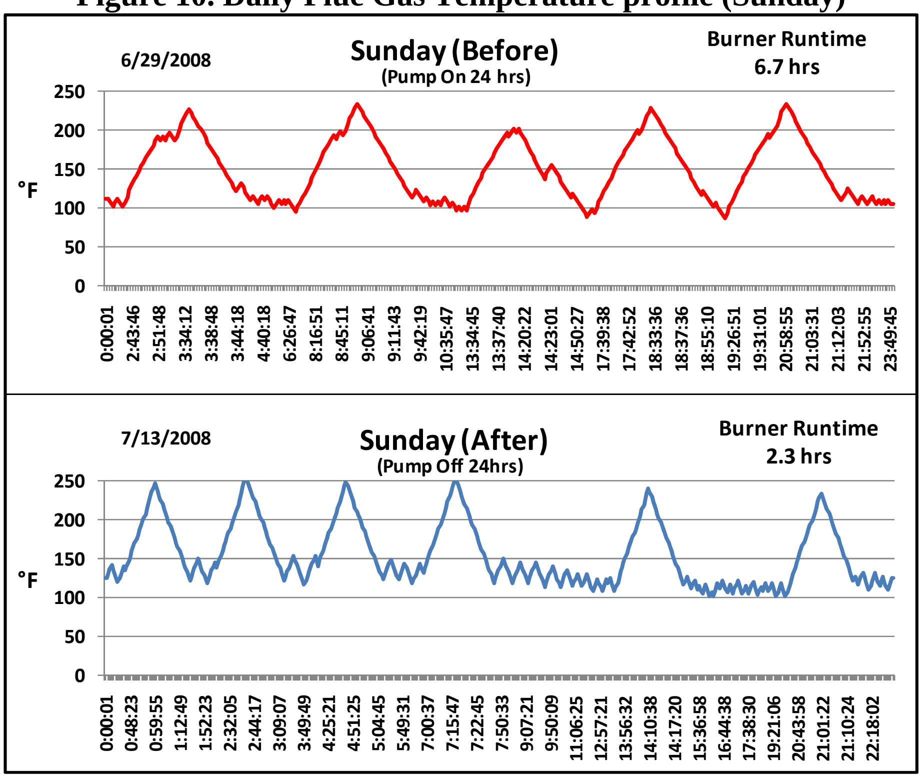
	Pump Operation (hrs)		Burner – Full Day (hrs)		Burner - Unoccupied (hrs)	
Before	24		6.7		4.4	
After	0		2.3		1.5	
Savings						
Pump runtime (hrs)	24	100%	NA			
Electricity (kWh)	115	100%				
Burner runtime (hrs)	NA		4.4	22.9%	2.9	41.7%
Natural Gas (therms)			175	65.9%	115	65.3%
Sunday Savings ($/yr)	$11.5 (115 kWh)		$175 (175 therms)			

Based on Natural Gas prices of $1/therm, Electricity prices of $0.10/kWh

The savings calculation (in $) is based on the rated values of power/heat input to the pump and DHW unit as mentioned in the Test case section. The Formula (2) in the previous section is used.

The following Figure 10 gives the comparison of the flue gas temperature

Figure 10. Daily Flue Gas Temperature profile (Sunday)



Total Savings and Payback

The data is summarized below for quick perusal:

- Annual gas energy used for water heating without any controls: 2311 therms
- Annual gas energy used for water heating with pump on/off control: 1696 therms
- Annual water heating energy savings from pump control: 615 therms
- Annual water heating energy savings from pump control: 27%
- Additional potential energy savings by turning off burner at night: 495 therms
- Additional potential energy savings by turning off burner at night: 23%

The total annual energy savings is estimated to be 481 kWh in Pump electricity savings and 615 therms in Natural Gas savings (estimated to be $663). The initial cost for this project will vary with location. If a BMS is in place, the pump can be controlled by the same. Otherwise, a manually programmable timer can also be used. In the author's case, the cost of timer including installation was $150. This delivered a very attractive simple payback period of about 3 months.

Future Work and Recommendation

In this study, out of the three no-cost/low-cost energy-efficiency measures, only the first on—cycling off the recirculation pump on weekdays and completely shutting it off on weekends—could be implemented.

The second measure called for shutting off the burner completely during unoccupied hours to reduce standby losses. Though this could not be implemented, we used the measured data to extrapolate savings. Using the data in the above tables, it can be estimated that potential additional savings could be of the order of 495 therms (~ $495) or 23%. The authors continue to look for cost effective controls to accomplish it in existing water heaters.

The authors recommend that all water heaters should have either a timer or be controlled by the central building energy management and controls system. The control should include both the recirculation pump as well as the heating element, since even if just controlling the burner might seem to give a high % of savings during night, not turning off the recirculation pump at night can lead to high burner on time during the recovery period in the morning. This applies to both electric or gas water heaters.

Conclusions

This paper presents measured data on the effect of turning off hot water re-circulating pumps during unoccupied hours. An in-depth analysis was performed for weekdays and weekends separately. The analysis showed that the savings on weekends is higher than weekdays. Also, against common perception, the savings obtained during unoccupied hours is not completely negated during the initial recovery period of the building. The net savings are estimated to be $663 for a 267,694 sft facility. This is a conservative estimate based on a summer data. While the saving itself is not high on an absolute scale, the payback of this energy-efficiency option was found to be about 3 months.

According to 2009 Buildings Energy Data Book at the DOE website, the US had 74.8 billion square feet of commercial space in 2006 and used $11.4 billion for water heating alone. In

2010, water heating in commercial buildings is expected to account for 1.09 quads out of a total of 18.77 quads of primary energy used in commercial buildings. This represents a 5.8% of the total primary energy, though its share of commercial office buildings energy use is generally is less than 2%. The natural gas accounts for more than 50% of the water heating energy use in the commercial buildings. If the use of the control schemes as discussed in this paper, which demonstrated savings of 27-48% of natural gas in gas fired systems water heating systems, and if only 10% of the commercial buildings could potentially use this cost effective control scheme, the national energy savings will be .015 to .027 quads of energy annually for the US. This could reduce water heating costs in gas fired heating systems alone by $260-550 million annually.

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