A Scaled Field Placement: A Dual Setpoint Controller for Combination Service Hot Water Boilers

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ABSTRACT

A proprietary dual setpoint temperature reset controller is proven to save an average of 20% natural gas fuels for combination service hot water boilers in apartment complexes typically found in Southern California. Southern California Gas Company (SoCalGas) Emerging Technologies conducted M&V in a rigorous assessment test for 4 boilers, and then a scaled field placement test for 30 boilers at 8 sites the following year, aiming at creating a new incentive offer to the multi-family customers.

The tests were conducted for boilers with capacity in the range of 0.5-1.5 MMBtu/hr, where builders installed one boiler system to service both space heating and domestic hot water and left the long term energy expenses with the owners and tenants. There are thousands of such systems existing in the Southwest region and new units are still being installed to date.

When outside air temperature is mild or warm, there is no space heating load and the domestic hot water temperature can be lowered safely and comfortably. This controller sets hot water to 140°F when outside air temperature is lower than a predetermined temperature (~60°F) ; and sets it to approximately 120°F when air is warmer. The controller also optimizes the staging of the multiple burners to reduce purging losses in excessive start-stop cycling.

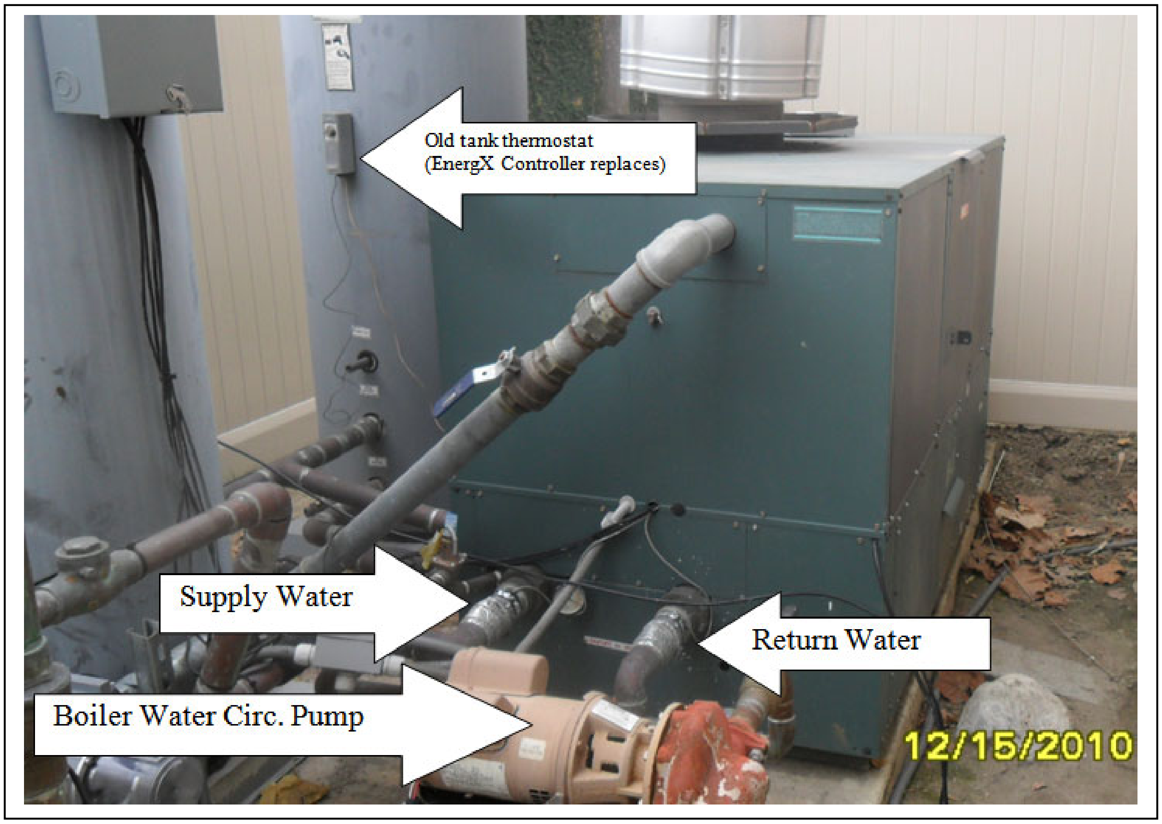
When comparing to many other temperature reset devices on the market, this controller design is unique, very effective at about 20% average gas savings, and will benefit an under-served customer segment, which otherwise would not be motivated to save. This measure has successfully been transferred to Energy Efficiency Programs. The project success has deep implications in program success, in helping to overcome the split-incentive challenge between apartment owners and residents. It helps to remove a barrier to a largely ignored market segment for energy savings.

Introduction

Project Background

The dual setpoint system is a hot water feedback controller that alters boiler staging, storage tank thermostatic temperature setting, and recirculation pump configuration in accordance with local ambient and return water temperatures. The system is applicable for multi-stage boilers that are part of a "Combi-system", where the hot water is used for both domestic hot water consumption and space heating. Space heating is accomplished by piping the hot water through a fan coil present in each attached apartment unit. The fan coil connects back to the return line for recirculation back to the boiler. The fan coils must therefore be rated for potable water. Figure 1 shows a photograph of a typical boiler setup for this application. A representative plumbing diagram is shown further below in section "Monitored Data Points".

Figure 1. Typical Boiler Setup Applicable To This Controller Technology



Source: (IES 2011).

According to the vendor, the dual setpoint controller "achieves savings [from an installed combi-system] by a combination of strategies that include resetting the water temperature based on outside air temperature, reducing the volume of water recirculated during reduced loads and the summer months by installing a variable speed drive on the pump(s), and by improving the boiler control system with staged burner firing.".

This project was conducted in two stages, beginning with an assessment test for 4 boilers at two (2) sites, and then a scaled field placement test for 30 boilers at eight (8) sites the following year. The results of the assessment test were significant for the design of the scaled field placement test, and are therefore included here. The assessment test is described in further detail in (Woo 2010); the scaled field placement is described in further detail in (IES 2011).

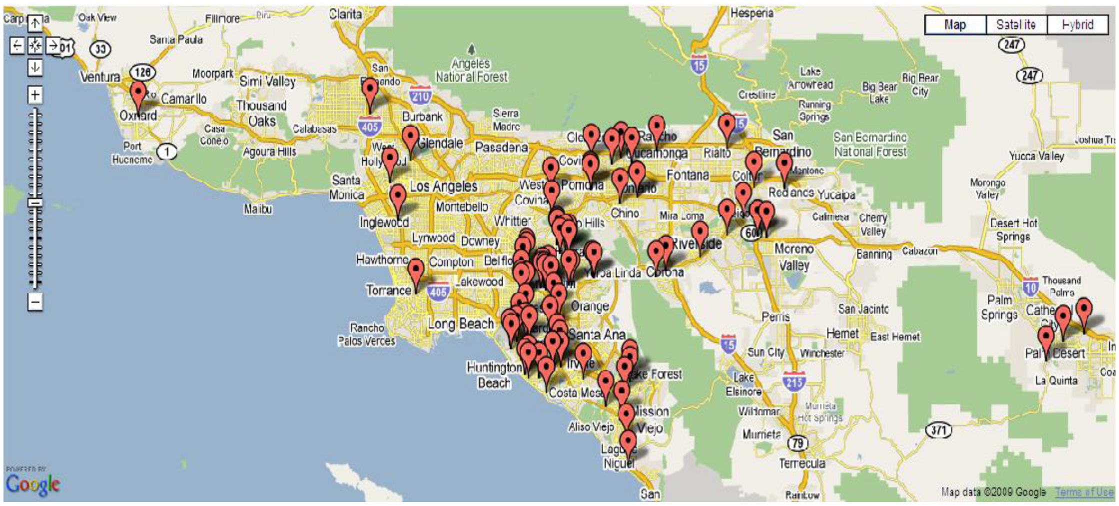
Savings Opportunity

According to the vendor, combi-systems were heavily marketed from the 1960s to 1980s. The original boiler developer and manufacturer recommends setting the temperature of the hot water storage tank permanently to 140°F in order to accommodate potentially heavy loads of simultaneous space heating and domestic hot water consumption. Actual tank setpoints found in the field vary with no discernible pattern between 130°F and 140°F, according to the controller manufacturer's project experience. A single combi-system can service forty apartment units.

These large residential boilers can each consume about 400 therms annually per dwelling unit, creating a sizeable opportunity for natural gas savings. According to the vendor, “hundreds if not thousands of these systems were installed” during the two decades they were sold.

Hot water in the multi-family segment of SCG’s energy efficiency programs is a relatively untapped market segment for energy savings. Figure 2 shows a map of combi-systems known to SoCalGas in their service territory.

Figure 2. Map of Raydronics system in SCG territory



Source: (Woo 2010)

Controller Technology Description

Depending on the application and number of boiler stages, one to four O.E.M. programmable logic controllers are used to process the temperature(s) in the storage tank and cycle the stages of the boiler on/off. An additional temperature controller and relays are integrated into the control to measure the ambient air temperature and change the water temperature set-point back to a higher temperature as space heating is required. The outside air (ambient) temperature will determine if the high (winter) or low (summer) set-point is used. Even as the temperature is increased the controller will still optimize the firing rate/stages of the boiler. The boiler controller uses a proprietary temperature sensor that collects the temperature of the water in the storage tank. This becomes an important factor when controlling/staging the boiler firing rates.

Note that at no time is the system locked out (demand limiting) – hot water is always available to occupants and the boiler Control System will cause the boiler to maintain the tank water temperature set-point. No fuzzy logic is used to automate the temperature set point adjustments. It is expected that operator only needs to set it once with little if any adjustments throughout the change of seasons.

The controller has two tank water temperature set-points, referred to here as high temperature and low temperature. When the ambient temperature rises, the boiler controller will place the boiler water set-point at the low temperature setting to conserve energy. Conversely, if the ambient air temperature is detected to be below the threshold (such as at night or a cold day) the boiler will be placed on the high water temperature set-point in order to be able to provide more heat to the apartment fan coils. The high temperature set-point is typically approximately

140°F while the low temperature set-point is approximately 120°F. Domestic water at 120°F is considered sufficient for bathing, washing, etc. Even with 120°F water being supplied to the fan coils, reduced heat is still available from the apartment fan coil units in the even that a resident were to adjust their thermostat to call for heating. The system therefore should not have any noticeable comfort impact (although a comprehensive comfort impact study was not in scope).

The dual setpoint controller will toggle between the large/winter pump and small/summer pump depending on the 60°F ambient temperature threshold. When running the small/summer pump, the (optional) variable speed drive will determine the speed of the pump based on the return water temperature. Please see figure 3 for a photograph of the controller as deployed at one of the sites.

Figure 3. Photograph Of Controller As Deployed

Source: (IES 2011)

Project Organization

Project Objective

The primary objective of this study is to monitor the performance of the dual septpoint controller installed on multiple combi-systems, quantify any energy savings observed, and discuss whether the technology can be recommended for statewide support by SCG programs.

The three factors contributing to energy savings – setpoint changes, boiler staging, and VFD on the summer pump –were studied separately and together.

The design of the scaled field test was influenced by the results of the assessment test, in that only the aspects of the energy savings strategy that performed well and seemed worthwhile to be confirmed on a larger scale were in scope.

Test Site Description: Assessment Test

For the assessment test (project stage one), two test sites were chosen by the vendor and approved by the authors in Alta Loma and Laguna Beach, CA. The Alta Loma site is a representation of systems installed in San Bernardino County while the Laguna Beach site represents installs in Orange County. These two counties are where combi-systems are most commonly installed and currently operating. The test was conducted on two boilers at each site.

The only criteria for each boiler was a dedicated billing gas meter (i.e. no laundry rooms or pool heaters connected to the same gas meter).

The apartment in Alta Loma is a 240-unit campus with eight, twelve, or sixteen units attached to each building. The two boilers chosen for this site each have two-stage 900,000 Btu/h burners (600,000 Btu/h low fire). Boiler #4 feeds 32 units while Boiler #6 feeds 24 units. Both boilers have a dedicated billing meter for natural gas and are surrounded by a locked fence outside of each set of buildings. The boiler systems are exposed to ambient conditions.

The apartment in Laguna Beach is a 421-unit campus with several streets of buildings. Boiler #4 chosen for testing has a two-stage 500,000 Btu/hr burner (250,000 Btu/hr low fire) while Boiler #5 has a two-stage 650,000 Btu/hr burner (325,000 Btu/hr low fire). Each boiler at Club Laguna also has a dedicated natural gas billing meter and 24 units attached. Each boiler is also partially enclosed with free access in and out through openings in the fences.

All four boilers are used in a standard combi-system configuration.

Test Site Description: Scaled Field Placement

For the scaled field placement, eight sites were chosen to represent the various conditions found throughout the San Bernardino County and Orange County. Site selection also took into consideration whether or not gas meters were already installed to measure gas consumed at each boiler. Test sites in Orange County and San Bernardino County were represented in this study, with both northern and southern locations covered for maximum representativeness. We are omitting boiler details of each site for brevity; with one exception (as it turned out), all are representative of the target market for this technology. Sites were located in Anaheim, Costa Mesa, Huntington Beach, Moreno Valley, Pomona, Rancho Cucamonga, Redlands, and San Dimas.

Measurement and Verification Approach: Assessment Test

The entire assessment test period was divided into four separate rounds – two during the designated shoulder season and two during summer – plus an interim round between the two seasons. During the shoulder rounds, two baseline temperatures (130°F and 140°F) were tested in order to compare the results of both controller aspects individually (boiler staging and variable speed drive summer pump), and the full vendor technology setup combined. During the summer rounds, only the full vendor package was compared to both baseline temperature settings. The interim round consisted of a two-week, isolated observation of the VSD summer pump versus normal 130°F system operation. For the assessment test, we are therefore differentiating between the following five operating modes:

Baseline I. Boiler is operated in the original configuration and absent of the dual setpoint controller. The storage tank mechanical thermostat is set at 140°F, as specified by the manufacturer. The Winter Pump is operational. There is no boiler staging.

Baseline II. Same as Baseline I except with the mechanical thermostat set at 130°F.
Boiler staging only. Boiler burner is staged automatically based on storage tank temperature[1]; storage tank temperature varies based on ambient temperature. The Winter Pump is operational. This will demonstrate burner control but not pump control.

[1] Above 60°F ambient: Stage1: 118°F, Stage 2: 113°F; 2°F hysteresis.

Automated pump control only. Vendor's controller will toggle between the large/winter pump and small/summer pump depending on the 60°F ambient temperature threshold. When running the small/summer pump, the variable speed drive will determine the speed of the pump based on the return water temperature. Boiler burner only operates at high fire (i.e. no burner staging) – this will demonstrate pump control but not burner control. Tank setpoint is 130°F.

Fully automatic. Both boiler staging and automated pump control are used simultaneously as described above to demonstrate the as-designed operation of the controller.

The savings of the assessment test is reported as is and not annualized for climate variations. It should be expected that winter savings are significantly lower or nil due to the hotter water is needed then.

Measurement and Verification Approach: Scaled Field Placement

Total study length was scheduled for 12 months. Where possible each optimized boiler was selected as a pair with another un-optimized boiler as a baseline. Both optimized and baseline boilers in each pair are the same size and have roughly the same load (number of apartment units). In the case of Anaheim, Costa Mesa, Huntington Beach, Pomona, Redlands and San Dimas some boilers have been changed from optimized to baseline by changing the control sequence used by the dual setpoint boiler controller to a simulated baseline mode. This was done because the load on the boilers was either known to be different between the two buildings due to laundry facilities in one building and not in the other or to make sure that the possibility of different loads was controlled for. For data analysis purposes, both site by site and average per unit-day savings figures were prepared as well as direct boiler to boiler comparisons.

The scaled field placement is therefore slightly different from the assessment test, in the following ways:

1. Total savings were not broken down by savings mechanism (i.e. dual setpoints vs. burner staging)
2. The measurement period was significantly longer and included all seasons. The results are therefore representative of an entire year.
3. The summer water circulation pump was not upgraded to variable speed (the savings from this measure were insufficient to justify further testing)
4. It was not specified that only the summer pump was to be run. Rather, the *same* pump needs to run at any point in time within a pair of optimized and un-optimized boilers. However, which pump that is does not matter and will be driven by typical seasonal operations.
5. Only a single "hot" temperature setpoint of 140F was evaluated, as opposed to both 130°F and 140°F.

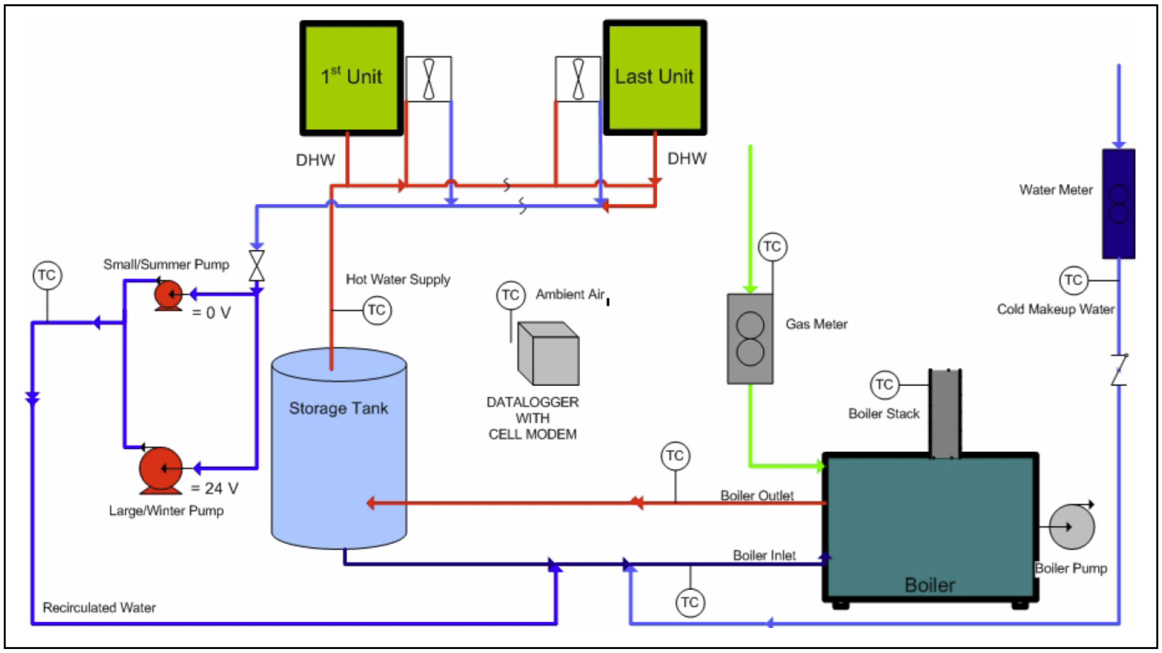
Monitored Data Points & Metering Equipment

Monitoring of gas and water flows, various temperatures, and recirculating pump runtimes were the critical components of a thorough analysis of each system. Apartment occupancy data was collected were available. A representative schematic plumbing diagram of

Below 60°F ambient: Stage 1: 135°F, Stage 2: 127°F; 3°F hysteresis.

the combi-systems with all thermocouple data points is shown in Figure 4; a summary and description of all applicable data points is provided in Table 1. Some data that would have been desirable to have for the final analysis but that was not or only partially available is shown as "Not avail." or "Limited", respectively.

Figure 4. Schematic Plumbing Diagram and Thermocouple Placement



Source: (Woo 2010)

Table 1. List of Data Points, Equipment and Applicability to Each Site Test

Data Point Name	Equipment Description	Assessment Test	Scaled Field Placement
Gas Consumption (Aggregate)	SoCal Gas Billing Meter	X	X
Gas Flow (over time)	Pulse Counter	X	
Gas Pressure (one-time!)	Manometer	X	
Makeup Water	Inline Pulse Water Meter	X	
Hot Water Temperature	Thermocouple	X	X
Return Water Temperature	Thermocouple	X	X
Cold Water Temperature	Thermocouple	X	X
Boiler Inlet Temperature	Thermocouple	X	X

Data Point Name	Equipment Description	Assessment Test	Scaled Field Placement
Boiler Outlet Temperature	Thermocouple	X	X
Boiler/Storage Tank Temperature	Thermocouple or dial	X	X
Stack Temperature	Thermocouple	X	
Gas Temperature	Thermocouple	X	
Ambient (Outside Air) Temperature	Thermocouple	X	X
Winter Pump Run State	Relay	X	
Boiler Pump Run State	Current Transformer		X
Apartment Occupancy	Via Facility Management	X	X
Building Cold or Total Water Usage	n/a	Not avail.	Not avail.

Source: Compiled from (Woo 2010) and (IES 2011)

The monitored data points facilitated the calculation of energy consumption and savings through characterization of the system and conditions. The assessment test gathered more points than was necessary in order to be completely rigorous while the scaled field test reduced the number of monitored points for simplicity and cost concerns. The water temperatures allowed for confirmation of proper controller operation and would have allowed for boiler efficiency and heat loss calculations if those had been necessary. The ambient temperature was recorded to corroborate the claimed use of temperature threshold-dependent controller settings. The aggregate gas consumption was recorded to determine gross savings over each monitored period of time. In general, the data points were used to determine controller operation and savings over monthly intervals. Savings and operation at high time resolution were not evaluated. Also, any changes in fan usage at the heating coils was not monitored.

Note the instrument setup between the assessment test and the scaled field placement was nearly identical, and mainly differed by instrument manufacturer and by the method of collecting the data (the assessment test had a cell modem, the scaled field placement did not). The scaled field placement test also omitted a few sensors that turned out to be unnecessary for the energy savings evaluation, and added run states for the summer and boiler pumps. Instrument manufacturers, calibration details, and so on are omitted here for brevity.

Data was recorded in 1-minute intervals during the assessment tests, and in 5-minute intervals during the scaled field placement (except for total gas consumption from the billing meter, which was recorded less often).

Results

All data was processed and analyzed using Microsoft Excel. After the one-minute or five-minute data from the data loggers were downloaded into spreadsheets, calculations were performed for corrected gas flow, water flow, and weekly totals of gas and hot water consumption, and averages of all temperatures collected. The 24V signal from the relay or current information from the transformer (for the assessment vs. field placement test, respectively) provided weekly runtime of the applicable pumps. Apartment occupancy data was matched up with the corresponding weekly averages and totals, and then used to normalize all pertinent numbers on a per-unit basis. A small number of unplanned issues resulted in some data losses that were dealt with by omission, repeat measurement, etc.

Assessment Test

Looking at both assessment test sites together, vendor's fully automatic operating mode generated the most gas savings, averaging 19.6% and 36.5% when compared to the 130°F baseline, and between 29.1% and 49.7% when compared to 140°F baseline. These figures are not annualized, but represent the assessed shoulder and summer seasons.

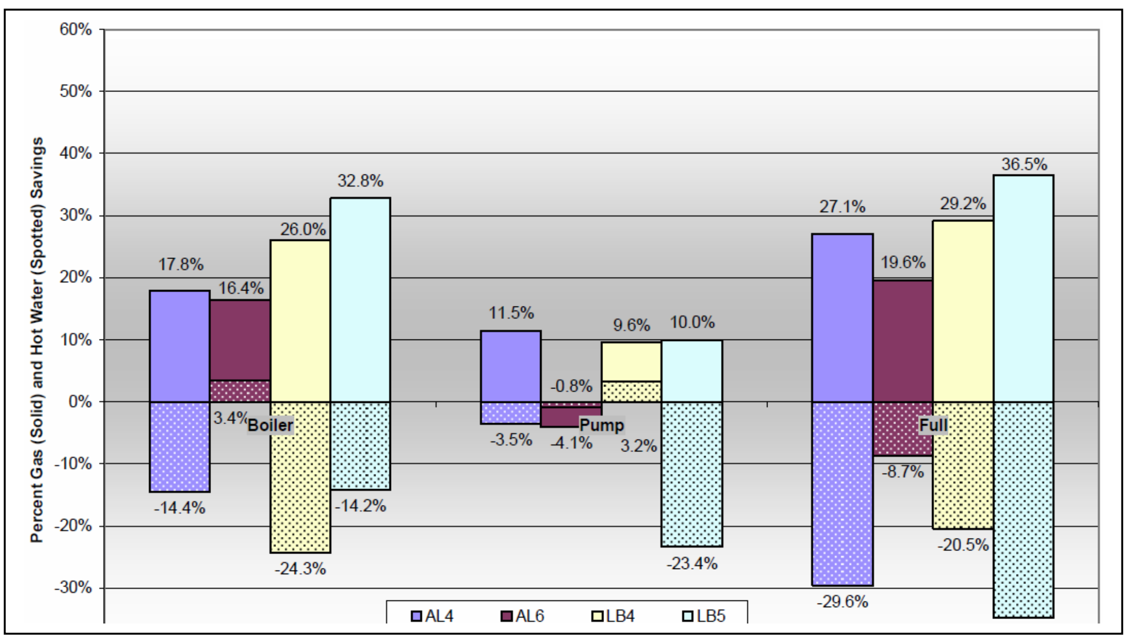
Hot water consumption generally increased, except for the pump control test at Laguna Beach Boiler #4. When the vendor controller was fully operational, Alta Loma boilers' hot water usage increased by an average of 19.1% and 42% when compared to the 130°F baseline and 140°F results, respectively, and increased 27.6% and 30.9% at Laguna Beach, respectively. Because total water (cold plus hot) consumption was not tracked, it is unknown whether the amount of cold water that is used to compensate for varying hot water temperatures changed.

The automatic pump function of the controller provided mixed results – in the isolated case during the summer, 20.9% and 23.3% (Boilers #4 and #5, respectively) gas savings were generated in Laguna Beach; however, only 8.5% and 1.1% (Boilers #4 and #6, respectively) gas savings occurred in Alta Loma during the same time period.

Throughout testing onsite maintenance crews were asked by SoCalGas about any tenants' hot water complaints from the boilers tested. Neither site reported any such complaints.

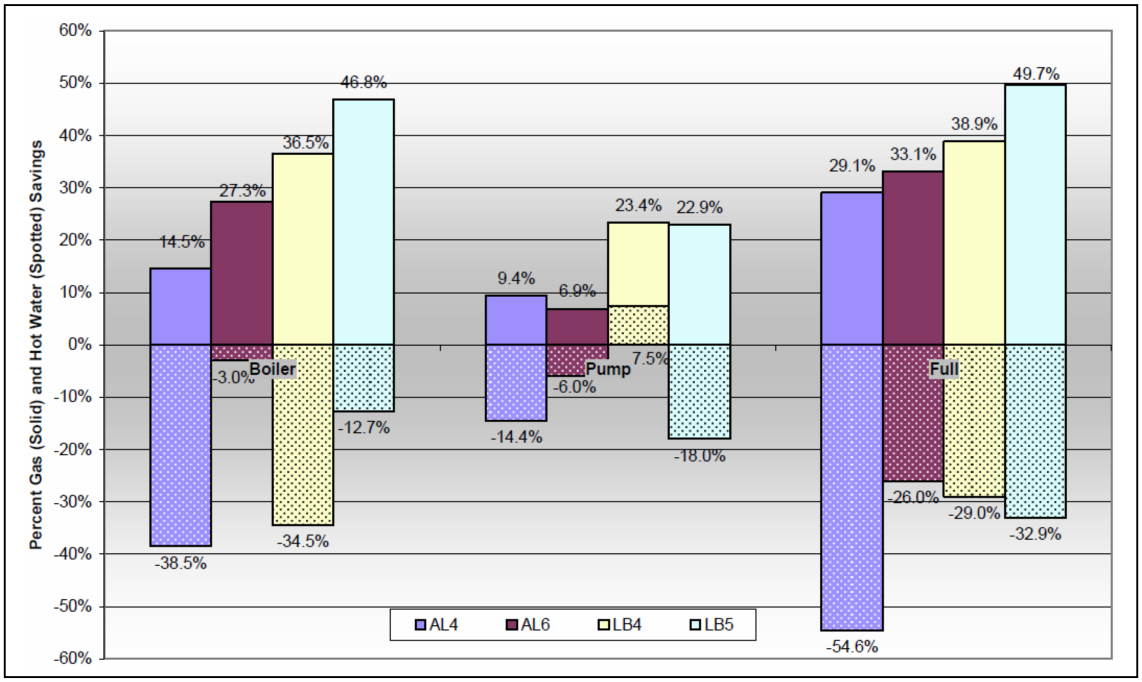
Figures 5 and 6 show the assessment test results for Baselines I and II, respectively. In these figures, data is separated into three distinct groups – one for each of the test modes (boiler control only, pump control only, and fully automatic). As seen in Figure 5, the only instance in which gas savings were not achieved when compared to the 130°F baseline was pump control only on Alta Loma boiler #6. Otherwise, significant gas savings were observed in all cases.

Figure 5. Assessment Test – Gas and Hot Water Savings (per Unit-Day) – 130°F Baseline



AL=Alta Loma, LB=Laguna Beach, followed by Boiler Number. Source: (Woo 2010).

Figure 6. Assessment Test – Gas and Hot Water Savings (per Unit-Day) – 140°F Baseline



AL=Alta Loma, LB=Laguna Beach, followed by Boiler Number. Source: (Woo 2010).

Scaled Field Placement

For the scaled field placement, the focus was shifted from quantifying individual savings mechanisms to calculating total gas savings for multiple sites, and thereby – presumably – confirming the consistency of the technology, and its readiness to perform well across the market. The analysis involved calculating the natural gas consumption per day and per unit for each boiler and comparing baseline consumption to optimized consumption. When two boilers at the same property are the same size and have roughly the same load (same number of apartments served) we can compare the two boilers directly by making the assumption that the optimized boiler would behave in the same way as the baseline boiler if the controller had not been installed. This eliminates the need correct for weather or other differences. Performance data over time for all tested sites is shown below in Figure 7.

Figure 7. Scaled Field Placement – Therms Consumed (per Unit-Day)

City	Boiler Name	Dec-10	Jan-11	Feb-11	Mar-11	Apr-11	May-11	Jun-11	Jul-11	Sep-11	Oct-11
Anaheim	BLDG F (#5)	n/a	1.59	1.36	1.47	1.36	1.20	1.20	1.15	1.03	0.83
Anaheim	BLDG B (#6)	n/a	1.15	0.94	1.00	0.97	0.82	0.80	0.72	0.64	0.64
Costa Mesa	#2 (middle)	n/a	0.99	0.97	0.83	0.76	n/a	n/a	0.77	0.71	0.73
Costa Mesa	#3 (back)	n/a	1.11	0.94	1.21	1.13	n/a	n/a	0.66	0.60	0.57
Huntington Beach	BLDG F	1.13	1.53	1.28	1.32	1.25	1.14	1.02	0.96	0.95	0.95
Huntington Beach	BLDG C	1.02	1.36	1.06	1.14	1.02	0.84	1.21	1.10	1.06	1.07
Moreno Valley	Phase 1-2	n/a	1.15	n/a	1.05	0.94	0.75	0.76	0.59	0.55	0.56
Moreno Valley	Phase 2-2	0.93	1.22	n/a	1.11	0.98	0.75	0.71	0.54	0.48	0.49
Moreno Valley	Phase 1-1	0.71	0.94	n/a	0.82	0.71	n/a	0.59	0.43	0.42	0.41
Moreno Valley	Phase 2-1	0.82	1.08	n/a	0.99	0.82	0.60	0.53	0.40	0.36	0.36
Pomona	400 Ferrara	0.75	0.88	0.83	n/a	0.86	0.66	0.70	0.58	0.50	0.59
Pomona	400 Portofino	0.72	0.96	0.86	0.89	1.01	0.79	0.67	0.53	0.47	0.50
Pomona	460 Ferrara	0.54	0.70	0.63	0.63	0.61	0.56	0.55	0.45	0.31	0.36
Pomona	420 Lucera	n/a	0.71	0.66	0.79	0.71	0.58	0.66	0.36	0.29	0.31
Pomona	420 Portofino	0.63	0.71	0.55	0.55	0.54	0.45	0.54	n/a	0.45	0.48
Pomona	470 Lucera	0.51	0.62	0.57	0.64	0.57	0.49	0.44	0.38	0.33	0.36
Pomona	480 Portofino	0.48	0.55	0.52	0.52	0.45	0.35	0.31	0.27	n/a	0.39
Rancho Cucamonga	#5	0.80	n/a	0.82	1.09	1.00	0.87	0.61	0.59	0.50	0.44
Rancho Cucamonga	#8	1.34	1.89	1.71	1.43	1.27	0.99	0.96	0.78	0.73	0.49
Rancho Cucamonga	#1	0.99	1.18	1.00	0.96	0.96	0.68	0.62	0.50	0.36	0.45
Rancho Cucamonga	#2	0.67	1.13	0.79	0.71	0.65	0.49	0.44	0.38	0.47	0.38
Redlands	#2	0.81	1.13	n/a	0.85	0.74	0.70	0.56	0.34	0.40	0.37
Redlands	#3	0.73	1.03	n/a	0.86	0.83	0.71	0.59	0.57	0.45	0.43
Redlands	#5	0.67	1.01	n/a	0.85	n/a	0.89	0.52	n/a	0.36	0.33
Redlands	#8	0.62	1.03	n/a	0.77	0.72	0.58	n/a	0.62	0.53	0.40
Redlands	#9	0.66	1.19	n/a	0.89	0.83	0.70	0.62	0.57	0.46	0.36
Redlands	#11	0.82	0.98	n/a	n/a	1.00	0.47	0.40	0.50	0.33	0.38
San Dimas	#1	n/a	n/a	1.45	2.06	1.36	n/a	0.96	0.82	0.82	0.79
San Dimas	#3	n/a	n/a	0.91	0.83	n/a	0.74	0.95	0.69	0.46	0.49

Turquoise: Optimized Boiler Mode. Salmon: Baseline Boiler mode (140F). Source (IES 2011)

Table 2 shows the final, annualized savings resulting from the scaled field placement study. Note that it turned out during the test that the Redlands site had its tanks plumbed incorrectly leading to the water short-cycling, and that the baseline boilers were already controlled in a dual-stage configuration to match load. Redlands results should be ignored.

Table 2. Scaled Field Placement Savings

Site	Average therms consumed per Apartment Unit per Day (baseline)	Average therms consumed per Apartment Unit per Day (optimized)	% Savings
Anaheim	1.23	0.84	32%
Costa Mesa	0.9	0.77	15%
Huntington Beach	1.17	1	15%
Moreno Valley	0.81	0.65	19%
Pomona	0.63	0.48	23%
Rancho Cucamonga	0.97	0.71	26%
Redlands	0.67	0.64	4%
San Dimas	1.12	0.79	29%
Averages (excluding Redlands, see text)	*0.98*	*0.75*	*23%*

Source: (IES 2011)

Discussion

The assessment test has shown that boiler staging and setpoint changing are both very effective gas savings mechanisms. The effect of variable speed pump is significantly less pronounced, and it is questionable whether the extra cost can be justified. Vendor's controller in fully automatic operating mode generated the most gas savings. The scaled field test has shown estimated average gas savings of 23%, or about 70 therms per year per apartment unit. The scalable field test savings were accomplished without variable speed pump upgrades. Fuel but not hot water usage was tracked as part of the field test. The results of this project are plausible and encouraging. Based on the testing conducted by SoCalGas and its consultants, we believe the vendor's controller can achieve significant natural gas savings in its intended application, especially in climates where significant periods of the year require little or no space heating.

Overall, heating supply and demand both diminish as the weather warms up in the spring and then summer months. The controller should therefore allow greater percentage of energy savings during warmer weather, and consequently in warmer climates, when the cooler water temperature set-point will be engaged for a greater percentage of the time. This pattern was however not observed as consistently as had been expected. Gas and hot water consumptions were normalized by weekly reported unit occupancies. Number of individuals per unit, work and school schedules, tenant space heating usage, and other related factors could not feasibly be accounted for and may be the cause of the lacking pattern. A consistent causal relationship was however never observed, therefore any relationship between ambient conditions and gas savings remains undetermined. We attribute this to the great diversity of human behaviors.

We have not evaluated the technology with respect to financial metrics such as Simple Payback, ROI, or NPV. There are many variables to each particular project, such that an accurate prediction of financial aspects is difficult. Therefore it is advised that each building operator does his or her own due diligence. Note though that this technology has been successfully transitioned into SoCalGas programs; incentives or rebates may be available. A unique conclusion and benefit that can be surmised from these studies is that the technology presents an opportunity for energy savings in a previously untapped market segment. Using the controller at the boiler and storage tank allows for the incentive and cost to be absorbed entirely by the complex owner. Other strategies focusing on the end-use locations of the heat demand split-incentives between the owner and resident. Split-incentives can be an obstacle for apartment complex energy savings projects. The controllers described here do not have such an obstacle, allowing for more rapid customer involvement. Future studies of this kind could be made more accurate by metering hot *and* cold water, by obtaining more detailed occupancy data, and by confirming (and aligning) the deadbands of existing and new thermostats used in the scope of the test.

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