Southern California Gas Company

Emerging Technologies Program

Project ID ET12SCG0004

Combination Boiler Reset Controller Field Evaluation

Final Report

Prepared For

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Disclaimer

While SoCalGas and the authors of this report did their best to come up with sensible results and recommendations, this report is provided as-is. The models, figures, formulas, and recommendations may not be appropriate or accurate for some situations. It is the reader's responsibility to verify this report, and apply the findings appropriately when used in other settings or context. Readers are responsible for all decisions and actions taken based on this report and for all consequences thereof.

Executive Summary

Most Californians use natural gas for domestic hot water and for space heating. The average California household consumes 354 therms of natural gas (KEMA, 2010). Water heating accounts for 49% of that, or 173 therms, and space heating accounts for 37%, or 131 therms. Therefore, energy savings opportunities in gas-fired residential water heating systems and space heating can have a large impact. The objective of this study was to evaluate the energy and cost savings of five retrofit boiler controllers that save energy by providing more sophisticated control than constant storage tank water setpoint with an aquastat. The tested controllers either provide outside air reset, dynamically modify setpoint dead-band by delaying burner firing, or measure proxy demand data to determine periods of low demand when a lower setpoint is acceptable.

In particular, the controllers are tested here on integrated combination boilers (i.e. "Raydronics") systems that provide both domestic hot water and heating hot water for fan coils in a single loop to multiple residencies in a multi-family residence (MFR) complex. The test site is located in Laguna Beach, California. Boiler systems in California must comply with the California Mechanical Code and the Title 24 Part 6 Building Energy Efficiency Standards.

Four of the five controllers functioned as expected at the test site and savings were shown. Each of the four controllers saved roughly 10% natural gas usage. The list price of each controller is approximately $1000; installation cost varies by site, and may be approximately another $1,000. At a total product and installation cost of $2000, simple payback period was around three years for each of the four controllers at the test site. Note that payback will substantially vary for differently sized boilers and for different load curves. Please also note that extrapolation of these results is limited given that only one controller of each was installed, and there were several real life factors that could not be precisely controlled. The savings results for a simple and a more complex statistical approach are shown below.

Controller	Period	Two Parameter Model (Simple Regression)					Three Parameter Change Point Model				
		R^2	Cond. Num.	Annual Therms	Annual % saved	Annual $ saved	R^2	Cond. Num.	Annual Therms	Annual % saved	Annual $ saved
1	Baseline	0.68	908	5663			0.68	908	5696		
	Retrofit	0.82	845	5139	9.3%	$524	0.82	845	5183	9.0%	$513
2	Baseline	0.61	931	6074			0.61	931	6123		
	Retrofit	0.83	816	5482	9.7%	$592	0.83	816	5520	9.9%	$603
4	Baseline	0.75	900	5822			0.75	900	5842		
	Retrofit	0.68	814	5137	11.8%	$685	0.68	814	5178	11.4%	$665
5	Baseline	0.76	879	6400			0.76	879	6506		
	Retrofit	0.49	815	5668	11.4%	$733	0.49	815	5730	11.9%	$777

These controllers as installed could potentially qualify for SoCalGas's rebate program for "Central Demand Hot Water Controllers" for multifamily complex property owners.

The primary benefit of these controllers is that, when configured and applied correctly, they save gas usage and cost without impacting occupant comfort. Product cost is favorable as long as the boiler serves a substantial load such as at this test site. However, configuration of these controllers is complex and troubleshooting can be difficult. Facility staff has to monitor controller operation in order to guarantee savings; building occupant complaints are not a suitable proxy for certain types of faults.

For future study, it is recommended that additional controllers be deployed or prior SoCalGas test results be used in tandem with this study before these products are qualified for automatic rebates. It would also be worthwhile to test controllers with fault detection or remote access and configuration capability since those products would better ensure persistent energy savings.

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Introduction

According to the 2010 California Residential Appliance Saturation Survey (KEMA, 2010), residential water heating and space heating in California are predominantly accomplished with natural gas and they are the two largest end uses of average annual residential natural gas consumption. The survey states that 90% of residential water heating and 86% of residential space heating in California is accomplished with natural gas as opposed to electricity or other fuels. The average California household consumes 354 therms of natural gas. As shown in Figure 1 below from (KEMA, 2010), water heating accounts for 49% of that, or 173 therms, and space heating accounts for 37%, or 131 therms. Therefore, energy savings opportunities in gas-fired residential water heating systems and/or space heating can have a large impact.

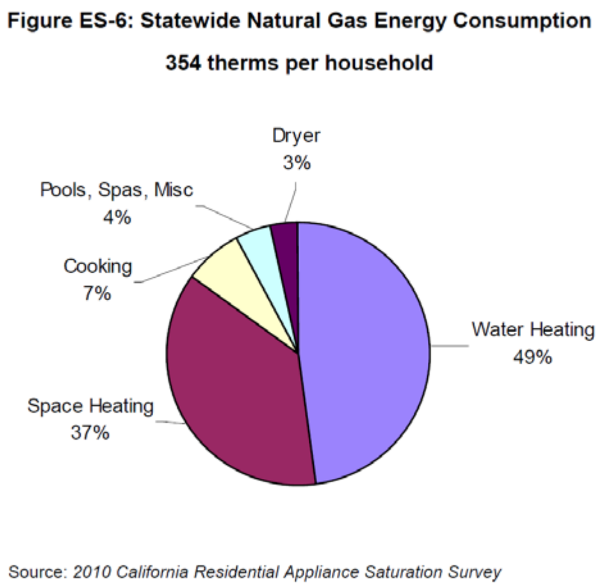

Figure 1: Residential Natural Gas End Uses in California (KEMA, 2010)

According to the Residential Water Heating Program (Gas Technology Institute, 2012), “Combined hydronic systems present an attractive option for high efficiency homes because these systems utilize one heat source that provides both space heating and domestic hot water.” In other words, implementing energy savings measures in such combined systems provides good value since the two largest gas end uses are addressed at one location.

Such combination boiler systems are often used in multi-family residences (MFR), providing even greater value since each system serves more than one family and is therefore even larger in capacity and average annual load. The test site for this project is at an MFR complex and each studied heating plant serves about 24 families.

Five retrofit boiler controller technologies are studied here. Each senses when demand is low and then either resets the supply water temperature or delays boiler firing in order to reduce gas consumption.

Project Objective

The goal of the evaluation is to assess the feasibility of controlling the supply water temperature on combined hydronic systems based on demand (or a proxy for demand) and to quantify the energy savings and pros and cons of five retrofit controllers on the market. The energy and cost savings will be quantified to the extent possible, either for the measurement period or annualized when possible. While each utilized hydronic system serves about 24 homes and all are at the same MFR complex, inherent differences in occupant behavior make it difficult to compare any one boiler directly to another. Therefore, the baseline for each controller will be its respective boiler with the controller disabled and with the tank supply water temperature set to a constant setpoint.

To accomplish this, the following will be completed,

- Describe system setup, operations, and functionality before and after installation
- Quantify energy and cost savings per controller:
    - Calculating energy and cost savings for each controller
    - Investigating what types of systems and buildings are most suitable for the technology
    - Recommending to the utilities how they can further support the technologies
    - Discussing anomalies that may cause variations in energy, cost, and payback times

Normalization of energy use against uncontrolled independent variables such as weather will be performed as needed. Please refer to Appendix B: Measurement & Verification Plan for more details about the approach.

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Project Methodology

Technology Overview

The five technologies under study are controllers meant to be retrofitted onto boilers in order to save operating energy and cost and they have differing strategies to achieve those savings. The most common control strategy is to alter the temperature setpoint of the hot supply water based on either outside air temperature or return water temperature. To preserve vendor anonymity, the controllers will be referred to as Controllers 1 through 5 and photos of the controllers will not be provided. Descriptions of each controller follow. Please note that the focus of these descriptions is on the features and configurations that were tested in this project. Not all vendor features will be discussed.

Controller 1 consists of a storage tank water sensor, a well assembly, boiler inlet and outlet sensors, an outdoor air dry bulb temperature sensor, and the controller itself. The water and well assembly are installed in place of the existing tankstat (a.k.a. aquastat) on the water storage tank. The outdoor air temperature sensor is mounted in a shady area. The controller has its own relays, a small display, and buttons for user configuration. It is connected to power, the sensors, and to the binary inputs on the boiler control board that control the furnace stages. The energy saving feature of this model is linear outdoor temperature setpoint reset as shown in Figure 2. The shown temperatures are for illustration purposes only. The temperatures chosen in this project were different. Furthermore, while not shown in the figure, the set point is constant at “Boil Design” for outside air temperatures less than “Outdoor Design” and constant at “Boil Start” for outside air temperatures greater than “Outdoor Start”.

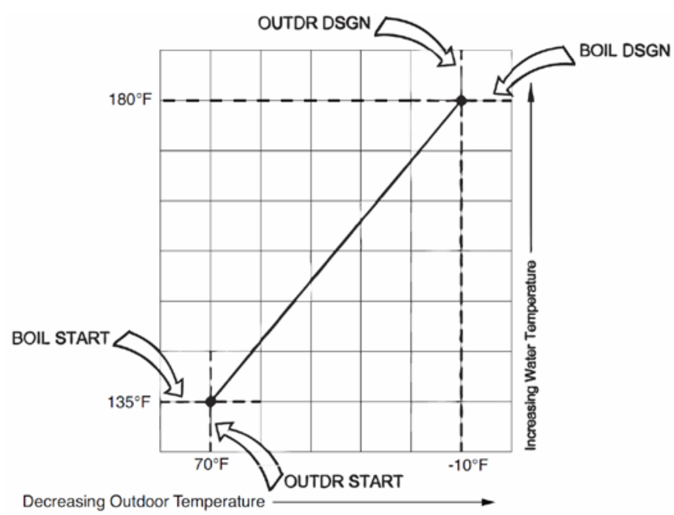

Figure 2: Controller 1 outdoor air reset strategy plot

Controller 2 is essentially identical to Controller 1 except that the curve used to determine the supply water temperature between the user-configurable high and low points has the curved shape of a second order polynomial as opposed to being linear (see Figure 3).

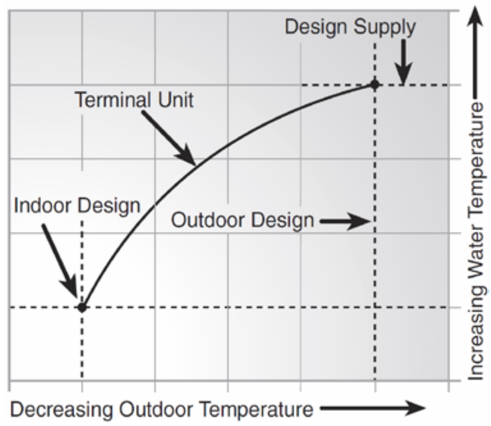

Figure 3: Controller 2 outdoor air reset strategy plot

Controller 3 is a retrofit boiler controller that delays burner firing up to a minimum supply temperature set point limit, thus creating somewhat of a dynamic operating differential with feedback. See Figure 4 for a diagram of typical operation. The controller wiring is spliced into the burner enable signal wiring and delays firing when demand is low. Note that this controller does not directly modify the aquastat set point and differential. Rather, this controller is meant to be used as an added component on top of an existing, constant setpoint controller. Controller 3 is programmed with a delay time setting and a minimum temperature setting. The existing controller will attempt to maintain the setpoint and Controller 3 will delay firing until either programmed setting is satisfied. This controller will need to be installed on a boiler that has an existing constant setpoint control mechanism. Controller 3 is designed for single service systems but can theoretically work for combination boiler systems. It saves energy by reducing overall burner firing time and cycle frequency.

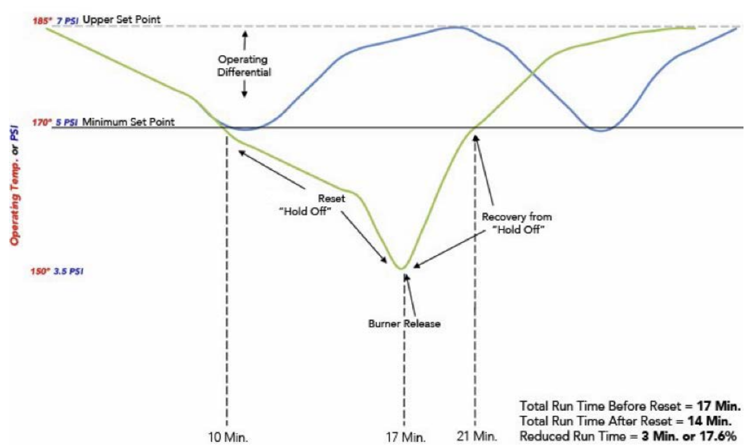

Figure 4: Controller 3 firing delay strategy plot

Controller 4 is a demand-based controller. Similar to the previous controllers, Controller 4 is designed for single service systems but may be applied to combination boiler systems. The controller monitors demand and use based on return water temperature and saves the lagging week usage patterns to optimize the setpoint each day. If the differential between the building supply and return temperatures is consistently low, the controller will reduce the supply water setpoint.

Controller 5 utilizes outside air reset similar to Controller 1 except that a step function is used instead of a linear relationship. When outside air temperature is below 56 F, the supply water setpoint is constant at a programmed low value. Otherwise, it is constant at a programmed high value. The included sensors are a storage tank water sensor, a well assembly, an outdoor air dry bulb temperature sensor, the controller itself, *and* a tank supply water temperature sensor at the tank supply outlet pipe.

Other measures supported by some of these controllers but not tested here include pump speed control, pump staging control, burner firing staging control, multiple setpoint thresholds, setpoint dead-band adjustment, and use of zone temperature data and other demand patterns for optimization. Some of these features would require additional sensors.

Host Site Overview

The test sites for this project are six existing integrated combination boiler (ASHRAE, 2012) central plant setups, all at a single apartment complex in California climate zone 6 in Laguna Beach, CA. Each boiler supplies hot water to a storage tank which holds water for a single, direct recirculation loop that services domestic hot water (DHW) and hydronic fan coil end-use points. Two pumps – a warm weather, low-flow pump and cool weather, high-flow pump – are manually switched based on season, outdoor air temperature, or facility staff discretion. This particular configuration shown as a schematic in Figure 5 is often called “Raydronics” or more generically an integrated combination boiler system. It is a common legacy installation in the Southern California area. Although contemporary designs of combined hydronic and DHW systems typically use separate circulation loops, indirect DHW heating, or splitting tempering valves, there are an estimated 2,000-3,000 Raydronics installations in Southern California Gas territory.

The boiler heats water for storage in a storage tank, from which hot water is circulated to the units. The circulation loop services DHW taps and space heating fan coils simultaneously. The service loop has continuous circulation in order to provide heat and DHW on demand. Makeup water (MUW) feeds into the storage tank inlet line. Since the heat delivery to the hydronic components cannot be turned off or reduced during the warmer months of the year, it is likely that boilers and storage tanks are often oversized or run at higher temperatures than necessary in order to meet the variable demand. This inherent excess consumption provides an opportunity for energy savings measures.

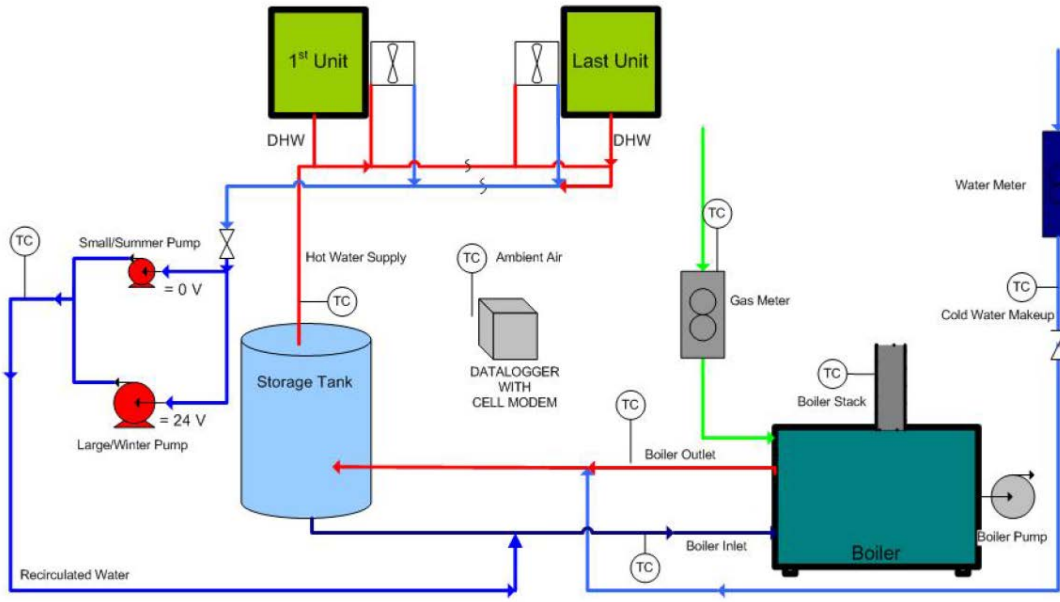

Figure 5: Combination boiler system at test site

Other combination boiler configurations may have indirect heating of the DHW via a heat exchanger coil in the storage tank to provide heat to a second, isolated loop. This is sometimes advisable since DHW temperatures can be significantly lower than hydronic hot water or may be required to meet potable water standards. Additionally, combined systems may have two separate loops converging at the storage tank or boiler, one for DHW and one for hydronic heating, each with its own pump. This type allows for shutdown of the hydronic circulation during the warmer months of the year. These loops may be modulated by control valves which regulate the proportions of hot and cold water.

The specific test location was selected based on its use of single hot water loops and the management's dedication to energy savings measures. In addition to this study, the location has been used in the past for a similar study of a single model of Raydronics boiler controller not included here. A single apartment building complex was chosen for testing of all the controllers so that boilers, maintenance staff, building type, climate, and installations are consistent. Since this is a pilot study with one instance of each controller, diversification of these factors is not necessary or prudent. Any possible future scaled tests may want to consider variation of these factors in order to understand applications under differing conditions and for extrapolation.

The existing boiler systems at each site was inspected and characterized before installation of the new technology. All the selected boilers are 2-stage, 500,000 Btu/hr non-condensing units (see Table 1). For photos of a typical system on site, see Figure 6.

Site	Boiler Make & Model	Boiler Capacity [kBtu/hr]	No. of Housing Units Served	Building Orientation
Baseline	Raypak H3-0502B	500	24	North East
Controller 1	Raypak WH3-0502A	500	24	East
Controller 2	Raypak W3-0502A	500	24	West
Controller 3	Raypak W3-0502A	500	24	North
Controller 4	Raypak W3-0502A	500	23	South West
Controller 5	Raypak WH3-0502A	500	24	East

Table 1: Boiler schedule

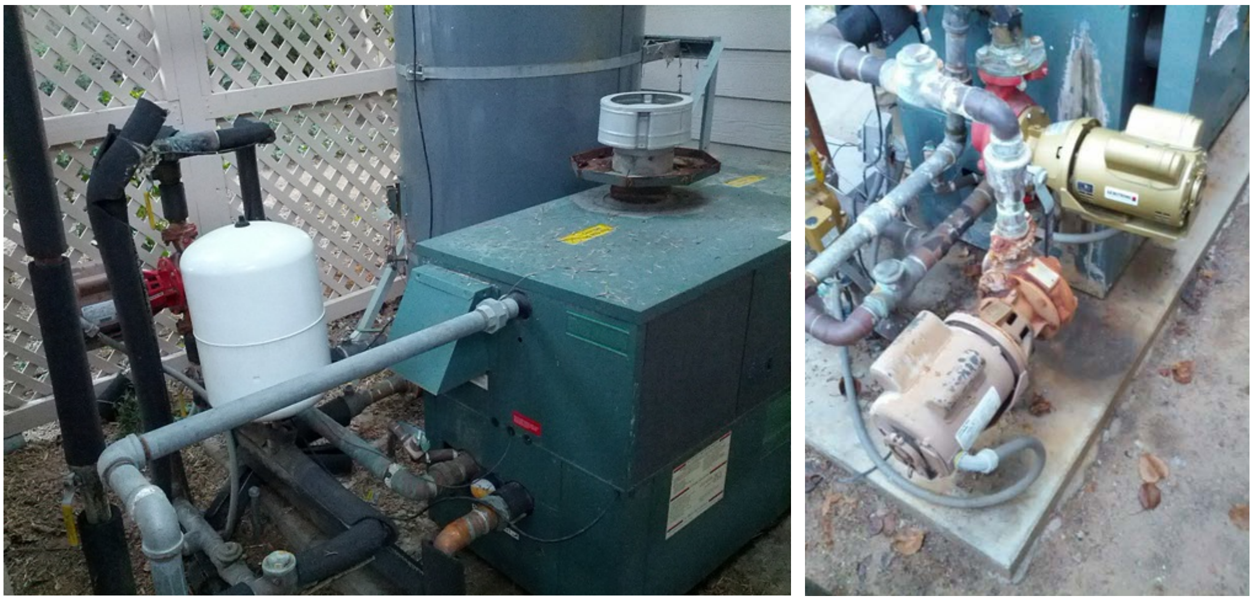

Figure 6: Typical boiler, storage tank, and recirculation pump arrangement

Measurement & Verification Plan Overview

The goal of this project is to assess energy savings (with little or no impact to comfort) of various retrofit boiler controllers. A previous study found average savings from a setpoint and staging control strategy to be about 23% of annual gas consumption (Engineering Analysis Center, SoCalGas, 2010). This evaluation will add to the previous project by evaluating savings across various strategies. This will be accomplished by high measurement frequency of all relevant points, statistical analysis, and minimizing mid-project incidents that can skew the results, such as uncontrolled setpoint or operation parameter changes.

For further details, please refer to Appendix B: Measurement & Verification Plan.

Market Overview

Opportunity

As stated in the Introduction, the average California household consumes 354 therms of natural gas (KEMA, 2010). Water heating accounts for 49% and space heating accounts for 37%, or a total of roughly 304 therms. As an arbitrary example, let's assume that boiler controllers were installed to serve 3,000 California housing units that are served by integrated combination boiler systems with constant supply water setpoint and that it saved 10% of total water heating and space heating gas usage per housing unit. This is for illustration purposes only and not meant to suggest that such market penetration will be accomplished. Energy savings in this scenario would then be about 91,199 therms.

Products and Systems

A list of vendors selling products competing in this market sector is provided below in alphabetical order. Some of these products may be a better representation of the products in this study than others.[1]

- Beckett
- Belimo
- Cleaver-Brooks
- Energx
- Honeywell
- IntelliDyne
- Johnson Controls
- Lochinvar
- Pro-Temp Controls
- Raypak TempTracker
- Taco HVAC
- Tekmar
- Weil-McLain

[1] The list is in alphabetical order, provided as is, not exhaustive, and the selection is arbitrary. The authors of this report do not endorse or guarantee, and disclaim any responsibility for: the content, products or services offered, their performance or suitability, and any consequences or damages, incidental or otherwise, that may result from their consideration or use.

Applicable Codes and Standards

Boiler installations in California must comply with the 2013 California Mechanical Code (IAPMO, 2013) and the 2013 Building Energy Efficiency Standards (CEC, 2014).

Chapter 10 "Steam and Hot Water Boilers" of the 2013 California Mechanical Code includes various design, installation, and maintenance related requirements. The 2013 Building Energy Efficiency Standards include a table (Table 110.2-K) indicating the minimum efficiency requirements. For the boilers at the test site (gas-fired and 500,000 Btu/h heating capacity), the minimum efficiency is a thermal efficiency of 80%.

Neither of these codes have specific requirements for the controllers. However, the 2012 ASHRAE Handbook – HVAC Systems and Equipment (ASHRAE, 2012) has valuable design and control guidance.

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Project Results & Discussion

Detailed Host System Description

Controller parameter fields will inherently vary between controllers. They were chosen to be as equivalent as possible for fairness. The baseline boiler setpoint and configuration was selected to represent typical on-site operation: constant single aquastat setpoint of roughly 130 °F with both boiler stages jumpered together. To maintain consistency throughout the project, both pumps were intended to always be enabled for the duration of the project. The five boilers with controllers were configured either in baseline mode or retrofit mode. All the preferred set points are shown below in Table 2. Please note that there were some irregularities in the collected data that will be discussed later.

Mode	Temperature Parameter [°F]	Baseline	Controller 1	Controller 2	Controller 3	Controller 4	Controller 5
Baseline	Fixed tank setpoint	130	130	130	130	130	130
Retrofit	Highest tank setpoint	n/a	130	130	130	130	130
	Lowest tank setpoint	n/a	120	120	120	120	122
	Highest OSA DB at highest tank setpoint	n/a	55	55	n/a	n/a	55
	Lowest OSA DB at lowest tank setpoint	n/a	75	75	n/a	n/a	55

Table 2: Controller Settings

System Deployment and Operations-Related Roles and Responsibilities

The water and gas meters for M&V and the controllers were installed by a licensed plumber. NegaWatt configured their loggers and either configured and/or maintained the controllers with assistance from the vendors. The on-site facility staff continued with their normal duties of responding to occupant comfort complaints. NegaWatt informed them of any non-controller related issues they discovered and the facility staff handled those related maintenance or repair tasks. NegaWatt occasionally asked them to photograph some items between site visits. The facility staff refrained from switching the pumps or modifying the tank set points unless it was necessary to satisfy occupant complaints.

List of Controlled Points

Please refer to Table 3 below for a list of monitored and/or controlled points per controller.

Data Point	Baseline	Controller 1	Controller 2	Controller 3	Controller 4	Controller 5
Tank Temp. (in well)	X	X	X		X	X
Tank Temp. (at pipe outlet)						X
Boiler Firing	X	X	X	X	X	X
Outdoor Air Temp.		X	X			X
Building Return Temp.					X	
Boiler Supply Temp.		X				
Boiler Return Temp.		X		X		

Table 3: Monitored and/or Controlled Points

Sequence of Operations

See section titled Technology Overview above for descriptions of the control strategies of each controller.

System Cost and Cost-Influencing Factors

There are a number of factors that can vary between sites and between controlled and baseline measurements. We will quantitatively normalize our results for these factors where possible and provide a sensible impact discussion otherwise:

1) Boiler size and efficiency.
2) Make-up water temperature (the warmer, the less heating) and seasonal variations.
3) DHW and space heating demand.
4) Number of apartments and occupants (coupled to point 3).
5) Weather patterns and heating degree days.
6) Circulation loop flow rates.
7) Make-up water replacing DHW use and leakage.
8) Circulation loop dimensions and insulation.

Verification of System Operation and Design

After appropriate configuration of each controller, all but Controller 3 functioned properly. There were two main reasons Controller 3 didn't function properly: the controller relied on an existing aquastat that didn't operate as the vendor or the researchers expected and the controller was not intended for integrated combination boiler systems. With the controller in bypass mode, the aquastat did not maintain a constant tank water setpoint as expected. Instead, it exhibited outside air reset type behavior: setpoint was lower for low outside air temperatures and vice versa. The researchers noticed the same behavior on the baseline boiler and two other baseline boilers that were monitored midway through the project for additional evidence.

The remaining controllers functioned properly but each required sophisticated configuration and subsequent monitoring. Controller 2 had an unexpected range limitation on a configuration parameter that required the researchers to add the extra step of a calculation. Controller 4 required some troubleshooting to identify what appears to be unusual behavior: the setpoint was always at its minimum regardless of varied weather and presumably building load. As it turned out, the controller was functioning properly. The sequence of operations determined that the building load was consistently very low so the setpoint never increased. It would have been useful if the controller display indicated this reasoning and/or suggested parameter modifications to fine tune the configuration. The Controller 5 vendor configured their controller themselves and provided prompt troubleshooting assistance. This helped greatly in ensuring proper operation of that controller.

Evaluation of Impact to Host Site Staff

The host site staff had a few extra duties and a few extra variables to consider in the case of occupant heating or hot water complaints during this study given the M&V equipment and the use of 5 controllers. In a real installation, a host site would choose one controller according to their preference and for simplicity of maintenance and there would be no M&V equipment whatsoever. In any case, they would either need good support from the vendor or be attentive to boiler operation to ensure proper controller operation.

Customer Feedback

The host site staff did not notify us of any occupant complaints aside from a complaint during M&V equipment installation when the hot water system was temporarily disabled. However, despite our requests and for undetermined reasons at various boilers, pumps were occasionally disabled and/or tank aquastat setpoints were modified. These controls are visible and not secured. In real installations where boilers are not reverted between baseline and retrofit modes, less tampering is expected.

Energy & Cost Savings

Savings were calculated for Controllers 1, 2, 4, and 5. The baseline period for each was each respective boiler itself with the controller hardware installed, including a new tank water sensor, but with all controller functionality disabled. This helped to control for differences in DHW usage and heating load.

Controller 3 savings were not calculated because the baseline period for that boiler exhibited an unusual pattern as described in section Verification of System Operation and Design above. The Controller 3 hardware did not include a tank sensor so the existing aquastat was used without modification. The tank supply water temperature was lower for lower values of outside air temperature during the baseline period even though Controller 3 was fully bypassed, the aquastat was set for constant tank supply water temperature, the dead-band was constant, and only one stage of the aquastat was used.

To determine if this behavior was common among the aquastat-only-controlled boilers at the test site, tank supply water temperature was logged at a total of three other aquastat-only-controlled boilers. The data for all exhibited the same pattern (see Figure 7). Please note that the subplot titled “Aquastat 4” is the baseline period for the Controller 3 boiler. Please also note that for every boiler minutely tank supply water data was collected but aggregated daily data is plotted.

The reason for the unexpected behavior is not clear but the researchers have the following hypothesis. These aquastat installations are more than a few years old. Perhaps the aquastats are not properly seated and sealed in their wells or there is insufficient thermal paste. This could cause the aquastats to measure a weighted average of the tank water and outside air temperature. The sensor would incorrectly register lower water temperatures for lower outside air temperature. Consequently, the aquastat would enable boiler firing longer than necessary for lower outside air temperature and lead to a higher than expected supply water temperature. Similarly, the supply water temperature would be lower than expected for higher outside air temperature. Thus, outside air reset of supply water temperature is thus unintentionally and inappropriately built-in and is not configurable.

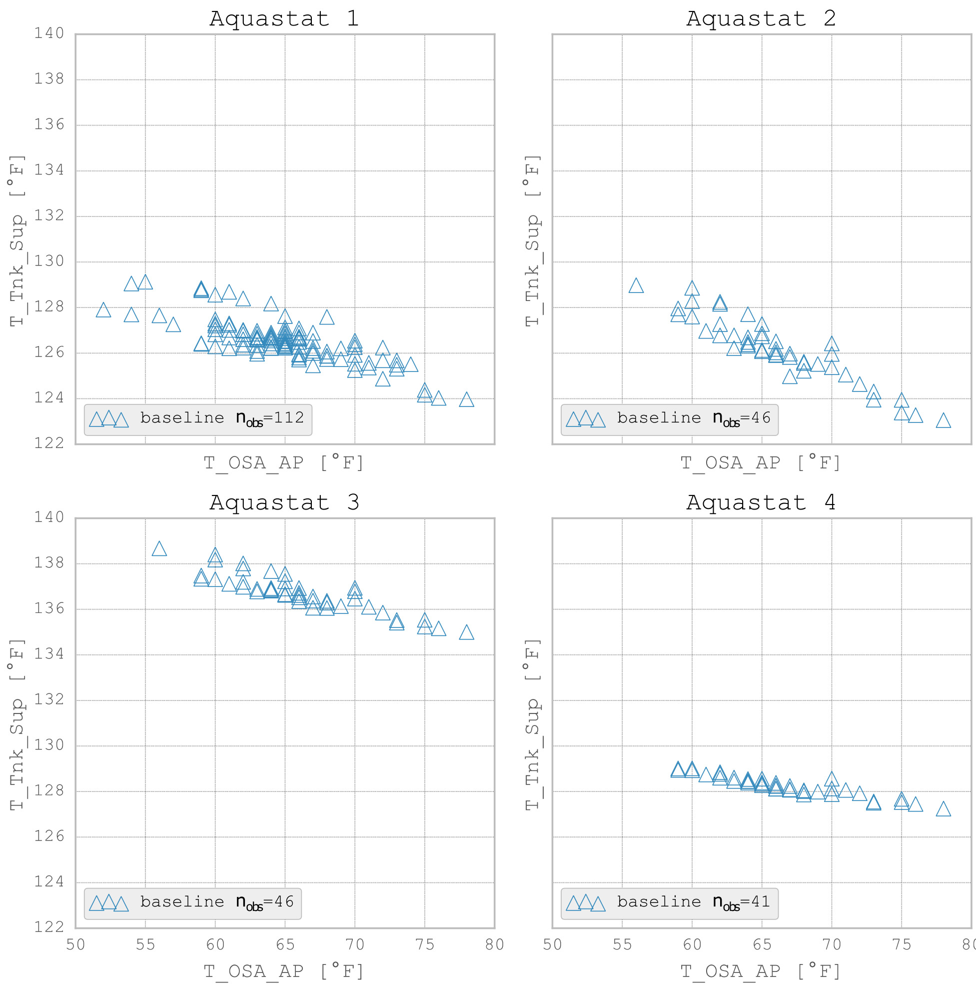

Figure 7: Tank supply water temperature vs. outside air temperature for aquastat boilers

Figure 8 shows tank supply water versus outside air temperature for the boilers with Controllers 1, 2, 4, and 5. In contrast to the aquastat-only-controlled boilers, the tank supply water temperature during the baseline periods were mostly constant over variable outside air temperature. However, the researchers were unsuccessful in maintaining the same tank supply water temperature setpoint during the baseline periods for all of these boilers due to real world circumstances of the project site. In the case of Controller 5, some baseline data points had incorrectly low setpoints. This data wasn't omitted because it helped the regression modeling.[2] So, energy savings calculations are not directly comparable between the boilers and each boiler savings calculation is an approximation of savings potential.

[2] Please note that some Controller 5 retrofit data at high outside air temperature incorrectly included periods with the boiler stages not jumpered as intended. This data wasn't omitted either since it helped the modeling.

The retrofit data series exhibits the expected behavior. The tank supply temperature of Controllers 1 and 2 vary linearly for mid-range outside air temperatures (the gap for Controller 2 is solely due to a lack of measurements at those outside air temperatures). Controller 4, which is return water temperature based, remains mostly at its programmed lower set point limit, due apparently to boiler oversizing. This assumption of boiler oversizing was tested by disabling one boiler stage and one pump for a few weeks.

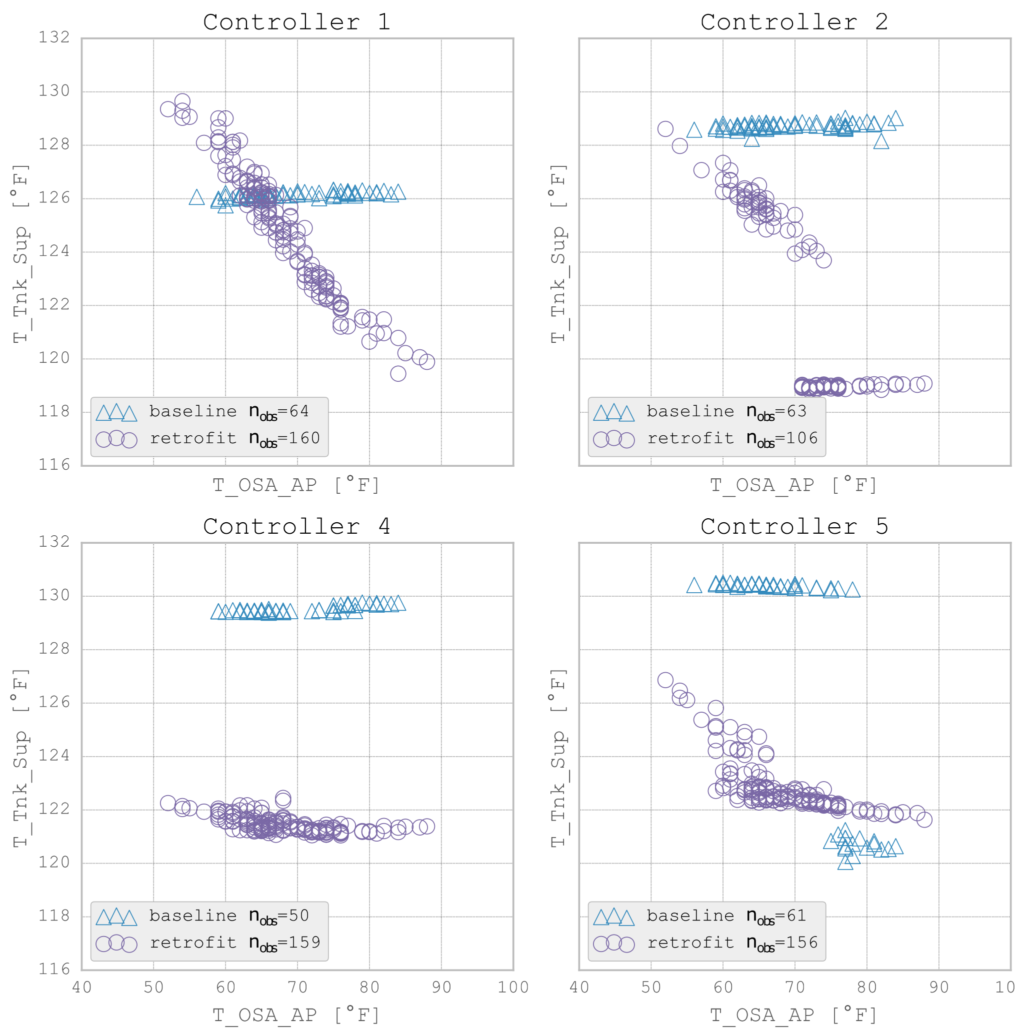

Figure 8: Tank supply water temperature vs. outside air temperature for Controller boilers

Even at this much reduced maximum capacity, the controller occasionally but very rarely increased the setpoint and there were no occupant complaints. Controller 5, as expected, shows somewhat of a step function in set point temperature at low outside air temperatures. That step function shape is partially obscured by the daily interval data aggregation and a lack of extremely cold days.

Before explaining the savings calculation, it is important to note that the data showed that two independent variables had to be considered: outside air temperature and make-up water temperature. Outside air temperature affects the quantity of water heating and space heating load desired by the occupants. At colder temperatures, the occupants will likely desire hotter showers and also use their space heating more often. Colder outside air temperatures also cause more heat loss to the atmosphere for outdoor mounted components such as the storage tank. The make-up water has a large effect since it enters the system for every use of domestic hot water and must be heated from its temperature to the tank supply temperature. The outside air and make-up water temperatures are of course correlated but the data shows some significant deviations, especially since the baseline and retrofit periods were often measured at significantly different times of the year. Also, daily outside air temperature swings tend to be larger than the make-up water temperature swings. For a scatter plot comparing the two temperatures, see Figure 9. Note that the baseline and retrofit shapes are somewhat different and that a wide range of outside air temperature often occurs for a roughly similar make-up water temperature.

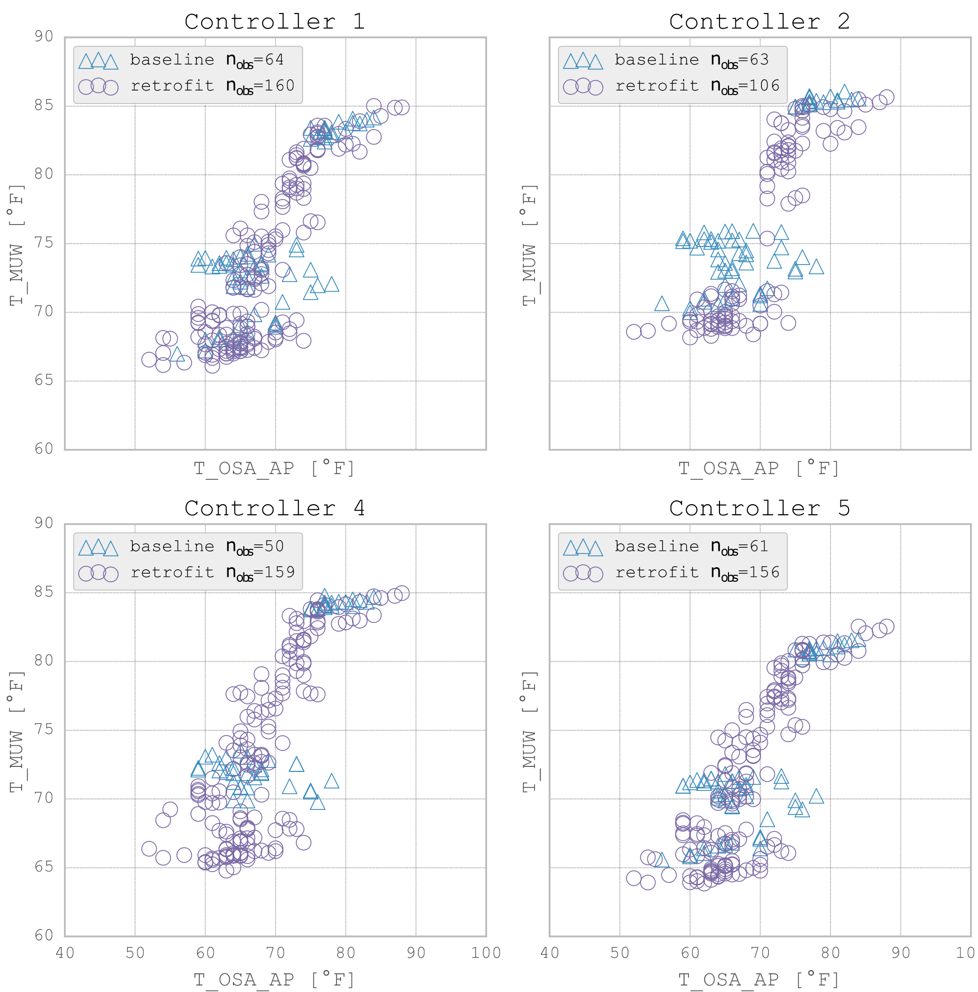

Figure 9: Make-up water temperature vs. outside air temperature for boilers with Controllers

After creating many different regression models, the researchers settled on two models for which to present boiler natural gas savings calculations. Both models are ordinary least square regression models with one independent variable that are linear in the parameters and are based on daily interval data. One model is a two parameter model, meaning that there is no change point, and the other is a three parameter change point model. In both models, the independent variable is a calculated "pseudo" ambient temperature. That pseudo temperature is the average of outside air temperature and make-up water temperature. The method came from (James, 2014) where the authors explained the usefulness of combining two highly but not exactly correlated independent variables. The statistics for these models are shown in Table 4 and a scatter plot is shown in Figure 10.

Controller	Period	Two Parameter Model (Simple Regression)					Three Parameter Change Point Model				
		R^2	Cond. Num.	Annual Therms	Annual % saved	Annual $ saved	R^2	Cond. Num.	Annual Therms	Annual % saved	Annual $ saved
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	Retrofit	0.83	816	5482	9.7%	$592	0.83	816	5520	9.9%	$603
4	Baseline	0.75	900	5822			0.75	900	5842		
	Retrofit	0.68	814	5137	11.8%	$685	0.68	814	5178	11.4%	$665
5	Baseline	0.76	879	6400			0.76	879	6506		
	Retrofit	0.49	815	5668	11.4%	$733	0.49	815	5730	11.9%	$777

Table 4: Savings Results using Pseudo Ambient Temperature as Independent Variable

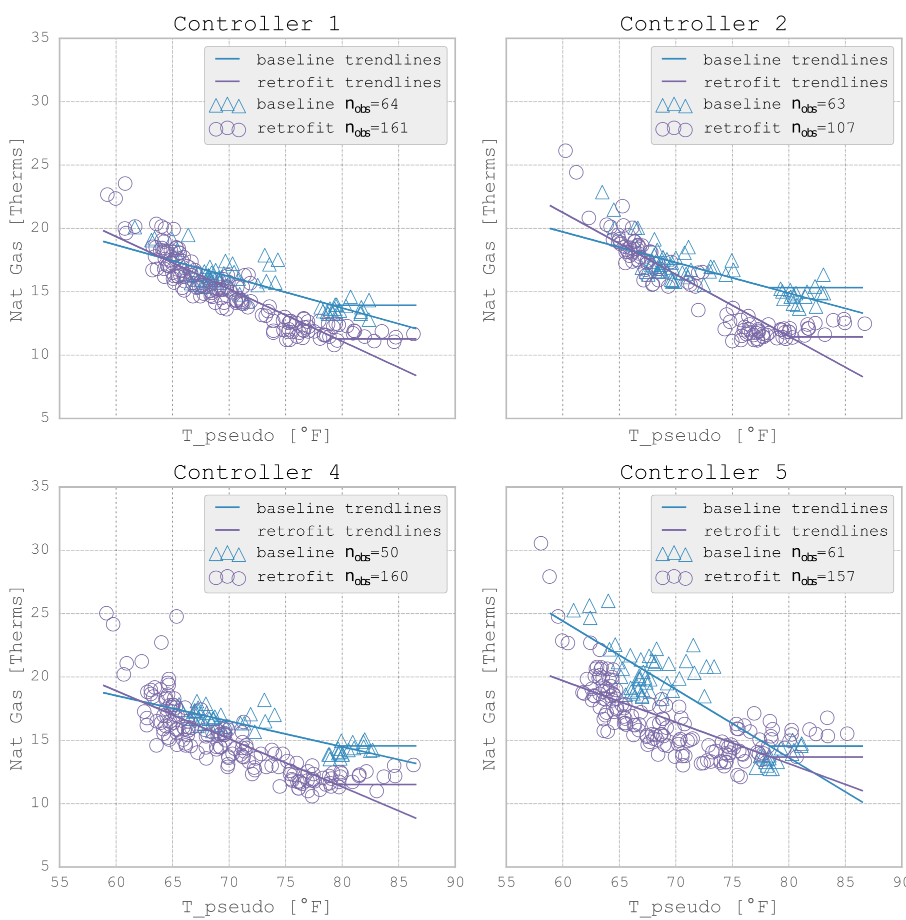

Figure 10: Natural Gas vs. Pseudo Ambient Temperature Scatter Plots

Each table shows the coefficient of determination (R^2), condition number, annual natural gas therms for each measurement period, annual percent energy savings, and annual cost savings at an assumed blended rate of $1/therm. The higher the R^2, the better the apparent fit of the model. The condition number is a metric for how sensitive the model is to error. Lower values are better and higher values might indicate that the model is over-fitted (i.e. there might be too many parameters).

Controller cost varies slightly and installation cost is not precisely known. Assuming $2000 total for each controller and using the three parameter model, the simple payback period for Controllers 1, 2, 4, and 5 is 3.9 years, 3.3 years, 3.0 years, and 2.6 years.

The annual natural gas calculations consist of applying both the baseline and the retrofit models to one year of independent variable data. This data was calculated using NOAA temperature data and an extrapolation of the measured make-up water temperature data. One year of temperature data from the same NOAA station used in this study ending on the last day of the overall data collection period was used. The make-up water temperature data used was the same data collected for one of the boilers and a simple linear interpolation was performed over the data gap.

For additional reference, Figure 11 and Figure 12 are provided in Appendix C: Additional Scatter Plots, showing plots of natural gas usage versus outside air temperature and versus make-up water temperature. Savings were calculated but results are not shown because R^2 was too poor.

Applicability of Existing Rebate and Incentive Programs

The studied controllers are not guaranteed to qualify for rebates or incentives. As far as rebates, they could potentially be listed as available products with flat rebates for residential customers or property managers and owners (i.e. Multifamily) that are business customers. Within the multifamily category on the SoCalGas business rebates website (SoCalGas, 2015), the appropriate sub-category is “Central Demand Hot Water Controllers”. As far as incentives for business customers, the controllers could potentially qualify for the Energy-Efficiency Calculated Incentive Program (SoCalGas, 2015) that pays $1 per therm.

Project Error Analysis

Project Plan Deviation

The M&V Plan indicated that a “baseline” boiler with aquastat control would be used as the baseline for all other boilers with controllers installed. This was not done since the “baseline” boiler exhibited unusual aquastat control behavior. Instead, each boiler with a controller installed was switched between baseline and retrofit modes.

The M&V Plan indicated that the baseline temperature setpoint would be 140 °F. However, 130 °F was used instead to prevent the possibility of scalding, and because 130 °F was the default baseline setting at the test site. The researchers did not want to modify the baseline just for the test.

The M&V Plan indicated that the pumps would be controlled in a sophisticated (site-appropriate) manner. Instead, both pumps were enabled for each boiler for the full duration of the study. This was done for simplicity and to reduce the potential for error and the number of uncontrolled variables.

Anomalous Data and Treatment

The following treatments were performed to the data to improve accuracy:

- Data was aggregated to higher intervals. Daily interval data was used for savings calculations
- Days when data was picked up and/or the operation mode was changed were ignored.
- Periods when central heating plant system settings were incorrect were ignored[3]
- Major holidays were ignored

Technical, Statistical, and Error Analysis

The coefficient of determination (R^2) and condition number are indicated in section Energy & Cost Savings. The M&V Plan indicates the accuracy of the measurement equipment.

[Over, please]

[3] In a few cases, the data was not ignored to achieve an acceptable range of the independent variable.

Conclusions

Benefits

The primary benefit of these controllers is that, when configured and applied correctly, they save gas usage and cost without impacting occupant comfort. They decrease the supply water temperature during periods in which the occupants will not notice, and ensure that there is sufficiently hot water during periods of high demand. Product cost is favorable as long as the boiler serves a substantial load such as at this test site (i.e. 24 units served per boiler).

Possible Risks

Configuration of these controllers is complex and troubleshooting can be difficult. The property owner cannot simply wait for occupant complaints, as complaints are not viable proxy for some fault scenarios. Unless the issue is severe, the occupants will not notice the difference between a controller maximizing energy savings, and a controller saving no energy beyond the pre-retrofit central plant operation. Another downside is that the presence of these controllers add one more source of potential failure.

System & Technology Improvement Opportunities

The controllers would benefit from having easily accessible historical data to prove whether the controller is functioning properly. The digital display and buttons should be easy to use and navigate. The vendor should be readily available to answer questions during installation and throughout the life of the product. None of the controller should re-use existing aquastats since they may be inaccurate.

Applicability of Case Study Findings to Other Load Types and Sectors

Advanced setpoint control of integrated combination boiler systems may have particular benefit in mild climates where heating demand is low for most of the year with short seasonal periods of high demand. It may also have high benefit in extreme climates where a high setpoint differential between winter and summer temperatures exists.

Although we will not extrapolate results to a population of boilers or other conditions, we believe the results from our test could potentially provide a good basis for extrapolation to other climate zones, demand patterns, and loads.

Considerations for Large-scale and Persistent Market Implementation

It is most appropriate to deploy these controllers on large boilers with substantial load. The added complexity and the total controller installation cost would not be worthwhile otherwise. The vendors should also consider developing partnerships with large property owners or third party contractors such that it is cost effective to provide training and technical assistance.

Possible Future Study

Each controller was only be tested at a single boiler. As such, it may be difficult to claim that the results are statistically representative. Therefore, the results may provide a starting point for a larger study to include multiple boilers for each controller type, if necessary for further program development.

It would also be useful to test controllers that have fault detection and/or remote access built in. Those features would help ensure that savings are persistent.

Acronyms

Abbreviation	Meaning
OSA	Outside air
DB	Dry bulb temperature
Temp.	Temperature
CMC	California Mechanical Code
T24	2013 Building Energy Efficiency Standards, Title 24, Part 6
CEC	California Energy Commission
Cond. Num.	Condition number
DHW	Domestic hot water
MUW	Make-up water
Nat Gas	Natural gas

References

ASHRAE. (2002). *ASHRAE Guideline 14-2002 Measurement of Energy and Demand Savings.* Atlanta: ASHRAE.

ASHRAE. (2012). *2012 ASHRAE Handbook - HVAC Applications.* Atlanta: ASHRAE.

CEC. (2014). *2013 Building Energy Efficiency Standards*. Retrieved from California Energy Commission: http://www.energy.ca.gov/title24/2013standards/index.html

Engineering Analysis Center, SoCalGas. (2010). *Project Test Report: Recirculating Hot Water Controller on Raypak's Raydronics System.* Irwindale.

Gas Technology Institute. (2012). *Residential Water Heating Program.* Sacramento: CEC. Publication: CEC-500-2013-060.

IAPMO. (2013). *2013 California Mechanical Code.* Retrieved 01 23, 2013, from IAPMO Group: http://www.iapmo.org/Pages/2013CaliforniaMechanicalCode.aspx

James, W. H. (2014). *An Introduction to Statistical Learning with Applications in R.* New York: Springer.

KEMA. (2010). *2009 California Residential Appliance Saturation Study.* Sacramento: CEC. Publication: CEC-200-2010-004-ES.

SoCalGas. (2015). *Incentives for Energy-Efficiency Improvements*. Retrieved from SoCalGas: http://socalgas.com/for-your-business/rebates/equipment-incentives.shtml

SoCalGas. (2015). *Rebates for Property Managers and Owners*. Retrieved from SoCalGas: http://www.socalgas.com/for-your-home/rebates/multifamily/

Appendix A: Project Plan

Southern California Gas Company
Emerging Technologies Program
Project ID ET12SCG00xx

Combination Boiler Reset Controller Field Evaluation

Project Plan

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3/10/2014

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Description of the technology under investigation

Since water heating accounts for 49% of the average yearly residential natural gas consumption [1], energy savings opportunities in residential hot water production can have a large impact. California's total yearly natural gas consumption is 2,111 million therms for water heating, alone. For buildings with DHW and hydronic heating, using combined service boilers can save energy cost-effectively over separate by using a single, high-efficiency heat source and integrated control. This integrated control of the two separate uses and boiler firing presents an attractive target for energy savings technology.

Combination boiler systems are often used in multi-family residence (MFR) complexes in order to provide hot water for domestic use and hydronic space heating. There are various possible system configurations, but the assumed system legacy installation (Raydronics) is shown in Figure 1. The boiler heats water for storage in a buffer tank, from which hot water is circulated to the units. The circulation loop services DHW taps and space heating fan coils simultaneously. The service loop has continuous circulation in order to provide heat and DHW on demand. Makeup water (MUW) feeds into the storage tank or boiler inlet lines. This will be the assumed host site system unless others are encountered as the project moves forward. Since the heat delivery to the hydronic components cannot be turned off or reduced during the warmer months of the year, it is likely that boilers and storage tanks are often oversized or run at higher temperatures than necessary in order to meet the variable demand. This inherent excess consumption provides an opportunity for energy savings measures.

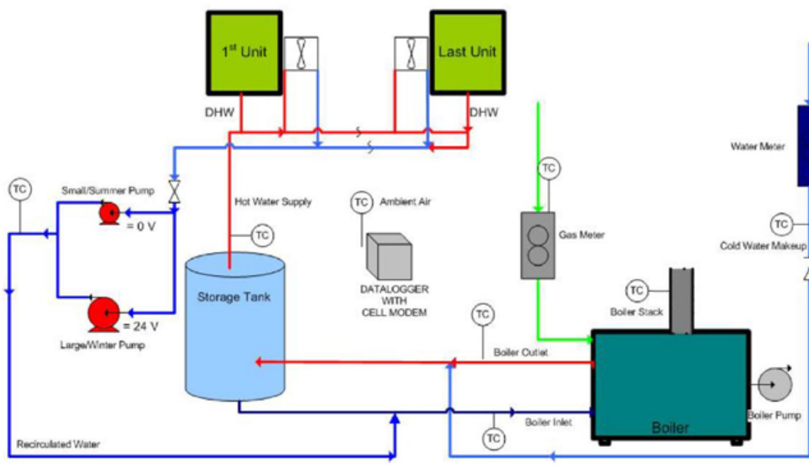

Figure 1 – Combination boiler servicing space heating fan coils and indirect DHW [6].

Other combination service configurations may have indirect heating of the DHW via a heat exchanger coil in the storage tank to provide heat to a second, isolated loop. This is sometimes advisable since DHW temperatures can be significantly lower than hydronic hot water or may be required to meet potable water standards. Additionally, combined systems may have two separate loops converging at

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the storage tank or boiler, one for DHW and one for hydronic heating, each with its own pump. This type allows for shutdown of the hydronic circulation during the warmer months of the year. These loops may be modulated by control valves which regulate the proportions of hot and cold water.

The technologies under study are combination boiler reset controllers (CBRC) with various strategies for achieving energy savings. The most common control strategy is to alter the setpoint of the hot water leaving the boiler, the supply water, or the storage tank temperature based on the outside air temperature. This is often called the outdoor reset strategy. For example, the setpoint control could be a step function with a low and high setting based on an outdoor temperature threshold. Alternatively, there could be a floating setpoint that varies linearly (or otherwise) between a high and low setting based on outdoor temperature. Other measures include pump control, valve modulation, burner firing staging control, burner firing delay, multiple setpoint thresholds, setpoint deadband adjustment, or use of zone temperature data and demand patterns for optimization. Some advanced controllers have the ability to monitor and use lagging historical data to optimize setpoint and gas usage specific to the MFR conditions and demand patterns. Often, these controllers require multiple zone inputs from thermostats or temperature sensors.

Multiple competing versions of CBRCs will be evaluated in this study. Savings strategies that could be investigated include boiler controls such as the following

a. Outdoor temperature-based linear reset of setpoint
b. Outdoor temperature-based non-linear reset of setpoint
c. Demand-based deadband control for delay of firing during low demand
d. Demand-based control for lowering of setpoint during low demand periods

In addition, an advanced boiler control strategy based upon continuous monitoring, data acquisition, and site-specific control algorithms will be evaluated. This technology incorporates a monthly fee structure rather than a stand-alone, one-time purchase due to its highly specialized and advanced use of cloud-based management, data collection, and consulting. This technology is custom for any given site and uses fault detection to identify energy savings opportunities in addition to standard control practices.

Description of incumbent technology (or existing standard practice, etc.)

Combination boilers have been prevalent in new construction for more than 30 years and may be increasing in popularity in California. Research and testing of combination hydronics systems is being done in order to develop new standards for system ratings and modeling for future Title 24 updates [1]. However, there is no requirement for a setpoint, outdoor reset, or flow control system for combined service configurations as seen in Figure 1. Therefore, the baseline technology will be a static setpoint control without consideration given to demand or outside temperature, adherent to Title 24 standards. The specific setpoint will be chosen based upon site preferences or the lowest possible setting that can satisfy demand year-round.

Goals of the assessment project

The goal of the evaluation is to assess the feasibility of controlling legacy Raydronics systems and to quantify the energy efficiency and savings capabilities of various CBRCs, including the four strategies listed above. The energy savings will be quantified and the financial benefits will be assessed. The energy savings will be in reference to a baseline of incumbent technology at the site, without control or with a constant setpoint, and will also be compared between models.

To accomplish this, the following will be completed,

1) Describe system setup, operations, and functioning before and after installation.
2) Quantify direct energy efficiency, energy savings, and cost savings potential. This includes:
    a. Calculating annual energy consumption and energy and cost savings for each controller.
    b. Investigating what types of systems and buildings are most suitable for the technology.
    c. Providing recommendations as to how California Utilities could further support this technology.
    d. Commenting on circumstantial factors that may cause variations in energy savings, cost, and payback times.

Normalization of results to variables will be performed as needed (see M&V plan for details).

Application and generalization of project results

Raydronics system control may have particular benefit in mild climates where heating demand is low for most of the year. Conversely, it may have high benefit in particularly cold climates where setpoints are especially high during cold weather.

There are a number of factors that can vary between sites and between controlled and baseline measurements. We will quantitatively normalize our results for these factors where possible and provide a sensible impact discussion otherwise:

1) Boiler size and efficiency.
2) Make-up water temperature (the warmer, the less heating) and seasonal variations.
3) DHW and space heating demand.
4) Number of apartments and occupants (coupled to point 3).
5) Weather patterns and heating degree days.
6) Circulation loop flow rates.
7) Make-up water replacing DHW use and leakage.
8) Circulation loop dimensions and insulation.

Although we will not extrapolate results to a population of boilers or other conditions, we believe the results from our test could potentially provide a good basis for extrapolation to other climate zones, demand patterns, and loads. Each controller will only be tested at a single boiler. As such, it may be

COMBINATION BOILER RESET CONTROLLER FIELD EVALUATION NEGAWATT CONSULTING

difficult to claim that the results are statistically representative. Therefore, the results may provide a starting point for a larger study to include multiple boilers for each controller type, if necessary for further program development.

All variables will be documented and discussed so that reviewers of the report may individually infer applicability of the results to their own circumstances.

Measurement and Verification Plan

The goal of this project is to assess energy savings (with little or no impact to comfort) of the control strategies listed on page 4. A previous study found average savings from a setpoint and staging control strategy to be about 23% of annual gas consumption [6]. This evaluation will add to the previous project by evaluating savings across various strategies. This will be accomplished by high measurement frequency of all relevant points, statistical analysis, and minimizing mid-project incidents that can skew the results, such as uncontrolled setpoint or operation parameter changes.

Testing criteria includes

- One MFR location in Orange County will be selected,
- measurement period will be long enough to include hot, cold, and shoulder months,
- and the installation should minimize any changes in DHW and space heating availability to the customers in order to maintain satisfaction.

The control systems will be evaluated at 1 Orange County site and data collection will span 6-9 months in order to capture cold, shoulder, and hot month data. A similar, central Raydronics boiler servicing 10-20 units with a constant setpoint will be used as baseline.

For further details on the Measurement Plan, see [3].

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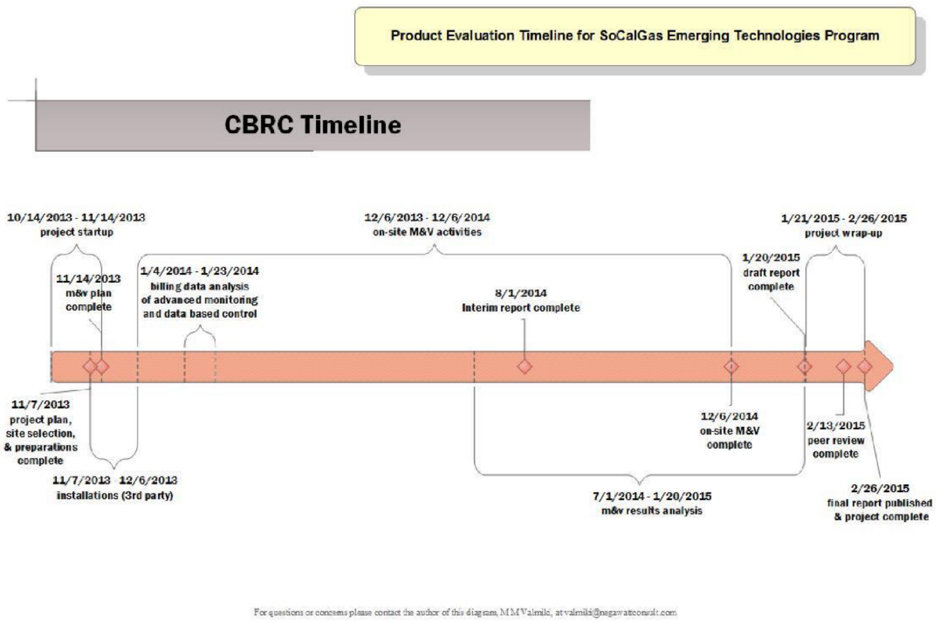
Project Milestones



Milestones are subject to change as project develops.

Etcetera

This assessment follows the scientific rigor protocol described in [4] and will adhere to IPMVP Option B.

The final report for this project will be made available as [5] on www.etcc-ca.org. Additional references will be contained therein.

This project will be tracked in NegaWatt's project management tools once the project plan has been approved. The document repository for this project is NegaWatt's secure file server. Please contact the authors of this project plan if you need access to these systems or to any of the referenced documents.

References

[1] Gas Technology Institute, 2012. *Residential Water Heating Program*. Prepared for the California Energy Commission, publication number CEC-500-2013-060.

COMBINATION BOILER RESET CONTROLLER FIELD EVALUATION NEGAWATT CONSULTING

[2] *2008 Building Energy Efficiency Standards, Residential Compliance Manual*. California Energy Commission, publication number CEC-400-2008-016-CMF-Rev 1.

[3] Combination Boiler Reset Controller Field Evaluation Measurement Plan.docx

[4] Draft ETP assessment protocol 061610.docx

[5] Combination Boiler Reset Controller Field Evaluation Final Evaluation Report.docx

[6] Woo, Kevin. Engineering Analysis Center – Applied Technologies, Southern California Gas Company. *Project Test Report: Recirculating Hot Water Controller on Raypak's Raydronics System.* Feb 2010.

Appendix B: Measurement & Verification Plan

Southern California Gas Company

Emerging Technologies Program

Project ID ET14SCGxxxx

Combination Boiler Reset Controller Field Evaluation

Measurement Plan

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Introduction

This measurement plan is an integral part of the project described in *Combination Boiler Reset Controller Field Evaluation Project Plan* [1].

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It follows the guidelines established in [2].

It has been designed to accurately assess both the baseline performance of the incumbent technology (or standard practice in the absence of an incumbent) and the performance of the technology under study.

It has been designed in compliance with one of the evaluation methods identified in the International Performance Measurement and Verification Protocol (IPVMP) except where site- or technology-specific circumstances dictated a deviation from one of these protocols [2]. The Measurement Plan identifies selected IPMVP method to be used or the justification for any deviations from IPMVP.

All instrumentation under the control of evaluation staff shall be calibrated in accordance with guidelines established in the IPMVP as described therein.

For field evaluations, all reasonable efforts shall be made to calibrate or replace any customer-owned instrumentation or where this is not possible, to document the calibration status of such instrumentation.

All instrumentation will be commissioned prior to initiating data collection to ensure that measurement and logging systems are functioning properly, to minimize risk of unusable data sets.

Any anomalous data will be investigated and explained. Following investigation, careful consideration will be given to whether such data should be incorporated in the analysis, excluded, or replaced by additional data collection.

Any events that occur at customer premises during the data collection period that are likely to compromise the validity of the assessment project and that are beyond the control of evaluation staff will be communicated to program management without delay.

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Test Site Description

The test sites for this project are six existing central boiler setups, all at a single apartment complex in California climate zone 6. Each boiler supplies hot water to a storage tank which holds water for a single, direct recirculation loop that services domestic hot water (DHW) and hydronic fan coil end-use points. Two pumps – a warm weather, low-flow pump and cool weather, high-flow pump – are switched based on season or outdoor air temperature. This particular configuration shown in Figure 1 is called Raydronics and is a common legacy installation in the Southern California area. Although contemporary designs of combined hydronic and DHW systems typically use separate circulation loops, indirect DHW heating, or splitting tempering valves, there are an estimated 2,000-3,000 Raydronics installations in Southern California Gas territory.

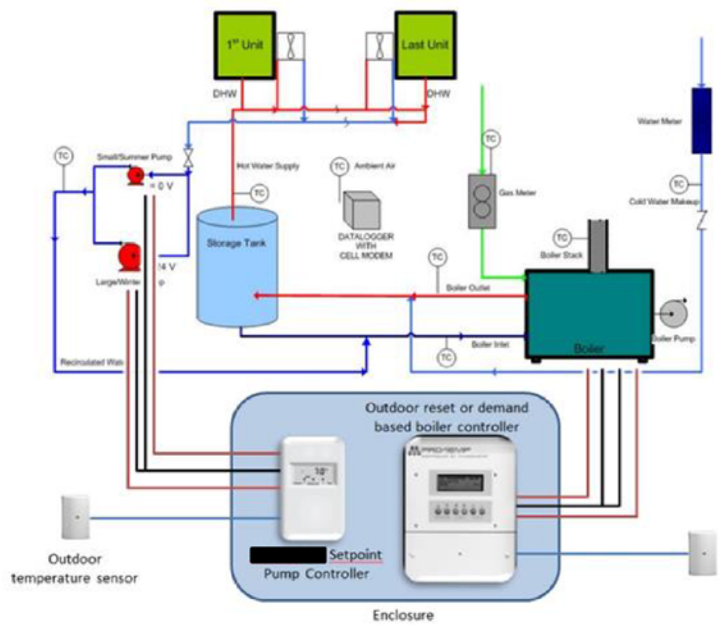

Figure 1 - Raydronics system configuration with retrofit control box under evaluation (adapted from [3])

The specific test location was selected based on its use of Raydronics hot water loops and the management's dedication to energy savings measures. In addition to this study, the location has been used in the past for a similar study of a single model of Raydronics boiler controller not included here. A single apartment building complex was chosen for testing of all the controllers so that boilers, maintenance staff, building type, climate, and installations are consistent. Since this is a pilot study with one instance of each controller, diversification of these factors is not necessary or prudent. Any possible

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future scaled tests may want to consider variation of these factors in order to understand applications under differing conditions and for extrapolation.

Table 1 - Site Characteristics

Site	Boiler Model	Boiler Rated Size [kBtu/hr]	Number of Serviced Units	Building Orientations
Baseline	Raypak H3-0502B	500	24	North East
Controller 1	Raypak WH3-0502A	500	24	East
Controller 2	Raypak W3-0502A	500	24	West
Controller 3	Raypak W3-0502A	500	24	North
Controller 4	Raypak W3-0502A	500	23	South West
Controller 5	Raypak WH3-0502A	500	24	East

Figure 2 – Typical boiler, storage tank, and recirculation pump arrangement for a single Raydronics loop

The existing boiler systems at each site will be inspected and characterized before installation of the new technology. All the selected boilers are 2-stage, 500,000 Btu/hr non-condensing units. Of the boilers located on the premises, priority of selection will be given to those that

- Do not supply hot water to pools, public restrooms, or laundry facilities
- Have similar numbers of serviced apartment units with similar solar gain
- Have similar boiler size, age, or model
- Have similar recirculation pump size, age, or model

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Wherever the above factors cannot be made consistent across all boilers, normalization or qualitative discussion of the results will be performed for fair comparison. In addition to the above factors, energy consumption of a Raydronics boiler depends on the following:

- Make-up water (MUW) temperature and seasonal variation
- DHW and space heating demand
- Occupancy
- Weather patterns and heating degree days
- Volume and flow rates of MUW replacing DHW use and leakage

Controller and setpoint parameter fields will inherently vary between controllers. In order to fairly compare the different controllers, minimum and maximum setpoints must be roughly equivalent. This is to ensure that energy savings depend upon reset strategy and load matching, rather than unfair settings. The baseline boiler setpoint will be selected to represent typical operation. In the absence of setpoint reset, it is standard to have the storage tank kept at a constant setpoint. This constant setpoint is often selected to meet maximum demand, thus enforcing overconsumption for much of the year. In order to ensure fair comparison between the controlled and baseline boilers, the following settings will be used:

Table 2 - Boiler controller settings (May be updated after consultation with subcontractors)

	Baseline	Controller 1	Controller 2	Controller 3	Controller 4
Base/High Setpoint	140	140	140	140	140
EE/Low Setpoint	n/a	125	125	120	120
Outdoor Temp Low [F]	n/a	40	40	n/a – return water temp based	n/a – return water temp based
Outdoor Temp High [F]	n/a	70	70	n/a – return water temp based	n/a – return water temp based
Recirc Pump Switch Outdoor Temp [F]	55	55	55	55	55

The settings in Table 2 are informed by previous studies [3, 4] and service provider best practices and experience. Note that values of setpoints and outdoor air temperature control values may change during installation, after consultation with contractors, or if occupant demands are not being satisfied. Every attempt to control the values for consistency will be made, but each controller's unique algorithm may necessitate variation in setpoints while the test is underway.

Controller 1 can be installed as a retrofit onto 2- or 4-stage light commercial gas boilers. The energy saving feature of this model is a linear outdoor temperature setpoint reset as shown in Figure 3.

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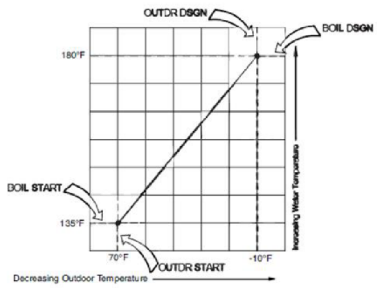

Figure 3 – Controller 1 and example outdoor reset ratio

Controller 2 is a retrofit boiler controller for 2-stage light commercial gas boilers. Controller 2 employs a proprietary, non-linear outdoor temperature setpoint reset curve. The curve relationship with outdoor temperature depends on selected settings, such as system type (DHW, hydronic, indirect combined, etc).

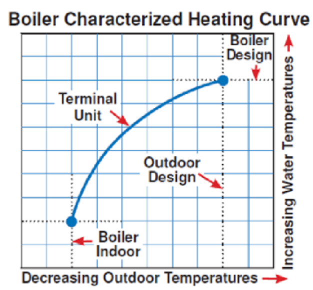

Figure 4 – Controller 2 and outdoor reset example

Controller 3 is a retrofit boiler controller that delays burner firing based on relative changes in return water temperature. The controller is inserted in the burner electrical line and delays firing when demand is low. Note that this controller does not energize pumps or have a setpoint control mechanism. Rather, this controller is meant to be used as an added component on top of an existing, constant setpoint controller. Controller 3 is programmed with a delay time setting and a minimum temperature setting. The existing controller will attempt to maintain the setpoint and Controller 3 will delay firing until either programmed setting is satisfied. This controller will need to be installed on a boiler that has an existing constant setpoint control mechanism. Controller 3 is designed for single service systems, but since Raydronics is dual service on a single loop, it may be applied. It saves energy by reducing overall burner firing time and cycle frequency.

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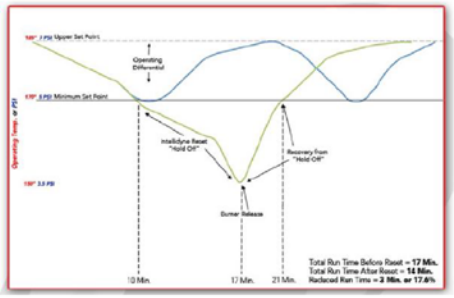

Figure 5 – Controller 3 with firing delay example: blue line is setpoint under typical operation, green line represents delayed firing

Controller 4 is a demand-based controllers for 2-stage boilers. Similar to the previous controllers, Controller 4 is designed for single service systems, but may be applied to Raydronics. The controller monitors demand and use based on water temperature and saves the lagging week usage patterns to optimize the setpoint each day.

Since none of the above controllers have recirculation pump control features, it is necessary to also include a pump control mechanism. The Raydronics system is configured with warm and cool weather pumps that switch to a higher flow rate when demand is higher during the colder weather. Typically, the pumps are toggled using a simple electrical switch which are controlled by the facility staff. Ideally the pumps would be switched seasonally, but observational evidence suggests that this is not likely. In order to automate the pump control and toggling, an outdoor temperature relay will be included in the control box. This relay will energize the smaller, warm weather pump when the outdoor temperature is above 55 and the larger, cold weather pump when the outdoor temperature is below 55.

In order to determine savings due to setpoint control only, the baseline boiler will also be outfitted with a pump controller similar to the other boilers. The test may also include turning off baseline recirculation pump control so that pumps are in constant high flow-rate use, as is the existing baseline without intervention.

Following site selection and initial assessments, the controllers will be installed and baseline conditions ensured. A licensed hydronic plumbing service provider with boiler control expertise will install and commission all equipment. A log for staff to note any system maintenance or changes will be included in each enclosure, which will be locked to prevent tampering.

(Over, please)

COMBINATION BOILER RESET CONTROLLER FIELD EVALUATION NEGAWATT CONSULTING

Data Collection Procedures

The main objectives of this project, as specified in the Project Plan [1], are to assess the feasibility of application of off-the-shelf central boiler controllers to legacy Raydronics systems, quantify the energy savings capabilities of various EE strategies, and compare savings and strategies between the available products. The data required to meet these objectives under the IPMVP Option B standard include equipment and building data, water temperatures, water flow rates and consumption, gas consumption, and controller settings.

The following general assumptions and preliminary comments informed the measurement plan and data point selection:

- Demand will depend upon ambient temperature conditions
- Use patterns will vary between buildings
- Sequencing of burner stages will not be optimized for energy savings, but rather by standard methods for protecting boiler health and for reducing short-cycling
- Other energy savings measures such as nighttime setback, scheduling, and others will not be used
- The controller power consumption is negligible compared to the Raydronics system and is fairly consistent across models
- 9 months of data will be sufficient to capture all weather conditions and form correlations

If any of these assumptions are not met during the installation and monitoring phases, the conflicts will be documented and analyzed. Any necessary changes to the data collection procedures or data points will be justified and explained in detail. Also, any attempt to disable or re-program the controllers or customer dissatisfaction will be documented and considered in the Final Report.

Data Points

The continuously monitored data that is necessary to achieve the specified objectives [1] under the IPMVP standard include the following:

- 15-minute aggregate water consumption at the cold makeup and hot supply lines
- 15-minute aggregate gas consumption at the boiler gas supply line
- 15-minute boiler supply, and return, and make-up water temperatures
- 15-minute hot water storage tank supply temperature.
- 15-minute ambient dry-bulb temperature at controller outdoor temperature sensor location

All of these data points will be continuously collected at each of the 6 boilers for the test duration. Memory capacity of the on-site data loggers will require periodic downloading of data from logging equipment. We may attempt to independently verify any data logging or measurement capabilities of the technology itself; for example, we may verify the calibration and accuracy of temperature sensors used with any of the controllers. All measurements used in the analysis will be taken with independent sensors and loggers. The outdoor temperature sensors for both data collection and controller inputs will be located in consistent locations (i.e. north facing wall) such that all controllers and data have similar outdoor air

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temperature values. This location will be chosen according to industry standard practice or installation manual guidelines. The recommended location for an outdoor air reset sensor is a north or northeastern facing wall for most buildings, in the shade, and away from any heating or cooling sources.

Prior to installation and commissioning of the controllers, an initial assessment will characterize the models and specifications of all site equipment and the number of apartment units served and building orientations. In addition to these measurements, spot measurements of the required recirculation pump electrical power will be taken. Although the primary focus of the study is quantify gas savings of the boiler controllers, a brief analysis of pumping electricity savings may be included if the available data are sufficient.

To establish the existing operating performance of the individual boilers, once installed, each new controller will be commissioned to operate each boiler with a constant storage tank setpoint of 140F (i.e. no reset control), similar to the baseline boiler. These settings will remain in effect for seven days, then the data will be collected and usage values will be normalized and compared across all six boilers. This monitoring period will occur during the cooling season, therefore, this will establish a non-weather dependent baseline usage for each boiler.

The controllers will then be re-programmed and commissioned with their respective energy efficient reset controls, and continuous measurements will be taken for 9 months in order to capture the boiler operation under all weather conditions: heating, cooling, and shoulder seasons.

At the end of the 9 month monitoring period, all controllers will be re-programmed once again to operate with a constant setpoint of 140F and monitoring will continue for another seven days. Data will be collected and compared across all six boilers. This monitoring period will occur during the heating season, therefore, this will establish a non-weather dependent baseline usage for each boiler.

If clear correlations with weather patterns become apparent before the 9 months are complete, the test may be shortened in order to expedite project results.

Data Sampling, Recording, and Collection Intervals

The gas consumption and savings will be calculated using the IPMVP Option B approach. The outdoor air temperature will be logged at each boiler with the temperature sensor located on a shaded wall consistent with the outdoor temperature sensors used by the controllers. The 6 boiler locations will each have 4 temperature measurement points, 2 water flow measurement points, and 1 gas flow measurement point. The temperature points will be recorded at an interval of 15 minutes. The gas and water flows will activate pulses at a rate of 1 pulse/CF and 1 pulse/10 gal, respectively. These pulsed flow rates will be aggregated into 15-minute values for correlation and analysis with 15-minute temperature values.

As a secondary objective, electrical consumption savings realized by pump switching may be quantified by assuming the amount of time that the smaller recirculation pump is activated. This calculation will follow the IPMVP Option A approach. The savings will be estimated by calculating the total yearly hours

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above the pump switching temperature and comparing yearly energy consumption of a single, large recirculation pump and the two-pump system. To do this, spot measurements of the pump power will be recorded during installation at each of the six sites. It will be assumed that the demand from each pump will remain constant throughout the duration of the field evaluation.

Instrumentation

The following table lists the instrumentation to be used in the continuous measurements and the relevant specifications. Each measurement will be logged in a time series of 15-minute daily points. Where possible, existing dedicated gas meters will be used and outfitted with a pulser for logging purposes.

Table 3 - Measurement and instrumentation specifics

Measurement	Location	Unit	Instrument	Accuracy
Temp data logging	Temp sensors	n/a	Hobo U12-006 data logger	±1 minute per month time accuracy
Gas and water data logging	Flow sensors	n/a	Hobo UX90-001M data logger	±1 minute per month time accuracy
MUW temperature	MUW pipe surface	°F	Onset strap-on temp sensor TMCx-HE or TMCx-HD	±0.45°F
Supply water temperature	Supply water pipe surface	°F	Onset strap-on temp sensor TMCx-HE	±0.45°F
Return water temp	Return water pipe surface	°F	Onset strap-on temp sensor TMCx-HE	±0.45°F
Ambient temperature	Shaded building wall	°F	Onset air temp sensor TMCx-HD	±0.45°F
Gas consumption	Boiler gas line	CF	Gas meter with pulser: Itron A675 with RIOTronics PulsePoint, Elster American Meter AC-630, or equivalent. Will use existing meters where possible), 1 pulse/CF	About ±1.0% reading
MUW	MUW line	gal	Flowmeter with pulser, Jerman DLJ 200 with 10 gal/pulse reed contact pulser	±1.5% reading
Supply water	Supply water line	gal	Flowmeter with pulser, Jerman DLJ 200 with 10 gal/pulse reed contact pulser	±1.5% reading

In addition to these continuous measurements, the power of each recirculation pump will be taken during installation using a Fluke 1735 meter. This meter has an accuracy of ±2.5% of the reading.

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Data Analysis Procedures

As stated in the Introduction, all data will be reviewed before analysis and any anomalies will be investigated and explained. Anomalous data will be evaluated on a case-by-case basis to determine whether it shall in used in analysis, corrected, or excluded. The data analysis will be designed to achieve the objectives in [1].

Data Manipulation (Aggregation, Statistical Analysis, etc)

All data will be collected as comma separated value files and manipulated in Microsoft Excel or with additional software tools such as ECAM or Python scripts. Gas and water usage will be aggregated to hourly or daily intervals in order to achieve quality heating degree day (HDD) and DHW consumption correlations. In order to match aggregated usage values, temperature and timestamps will be averaged over corresponding hourly or daily intervals.

The time-dependent gas, water, and temperature series will allow for correlation of usage to ambient conditions and HDD. Note that HDD correlations will be used to annualize data but not for extrapolation to other climate zones. If there exists any high degree of variability associated with operating conditions or changes over the duration, such as holidays, boiler performance, abnormal weather conditions, maintenance, etcetera, adjustment of data may be performed. It is unavoidable that each test site will have varying demand patterns and the data may require normalization to factors beyond MUW and HDD (such as number of served units, occupancy, and boiler efficiency). In general, the data will be manipulated in order to identify MUW-normalized gas usage per HDD. This should allow fair comparison between all controller models and baseline consumption.

Calculation of Energy Savings

After gas consumption (E_i) has been normalized to all necessary variables (which may include MUW consumption, pumping flow rates, HDD, number of units, etc.), the calculation of energy savings is straightforward.

The normalized gas savings is calculated using E_i-$E_{baseline}$ and will be presented in units of therms/apartment-HDD and percent savings. This value will then be used to calculate therm values of average annual consumption and savings for a typical year and serviced building.

In addition to presenting normalized savings from baseline to controlled boiler, energy savings from the outdoor temperature pump switching may be presented. This energy savings in kWh will be calculated using

$$\Delta E_{pump} = 365\ days * 24 hours * P_C - (t_W P_W + t_c P_c)$$

where P_i is the spot measured pump power, t_i is the estimated annual run time in hours, *w* designates warm weather pump, and *c* designates cool weather pump.

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Calculation of Cost Savings

Energy cost savings due to the boiler controllers may be realized from SoCalGas natural gas rates. Additionally, cost savings from the pump switching control may be realized from SCE electricity rates. Cost savings will be presented for all controllers as compared to the baseline in terms of annual dollars and dollars/apartment unit. Payback will not be calculated since these controllers are being implemented as a custom engineered solution which is not representative of any of the current manufacturer offerings. Thus, the installed costs of the systems in the study will not be representative of any possible commercialized costs.

References

[1] Combination Boiler Reset Controller Field Evaluation Project Plan.docx

[2] Draft ETP assessment protocol 061610.docx

[3] Kevin Woo, *Recirculating Hot Water Controller on Raypak's Raydronics System*, prepared by SoCalGas Engineering Analysis Center for SoCalGas Emerging Technologies, 2010.

[4] Information & Energy Services Inc., *A Dual Setpoint Controller for Combination Service Boilers*, Prepared for SoCalGas Emerging Technologies, 2011.

(End of document)

Appendix C: Additional Scatter Plots

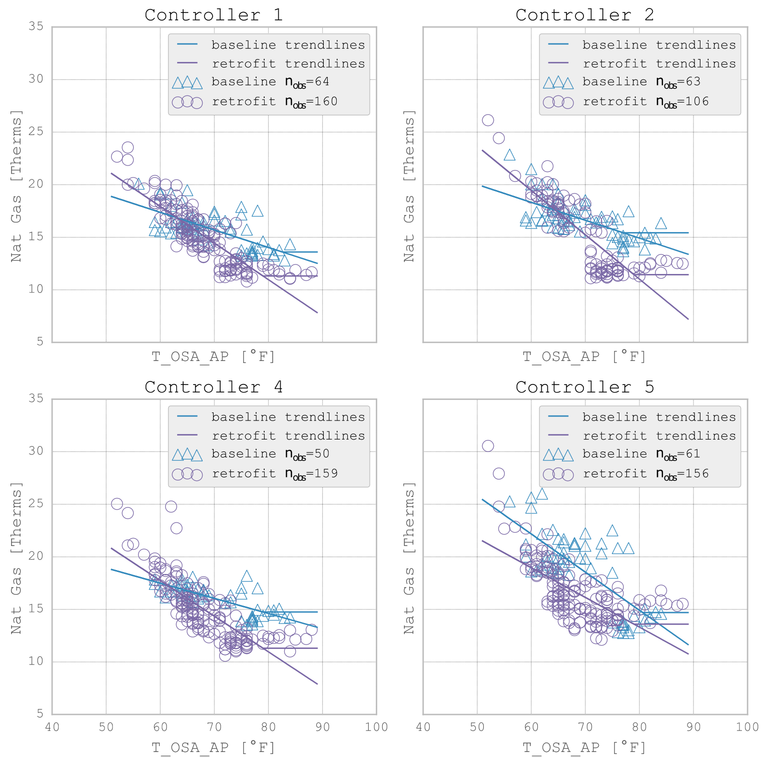

Figure 11: Natural Gas vs. Outside Air Temperature Scatter Plots

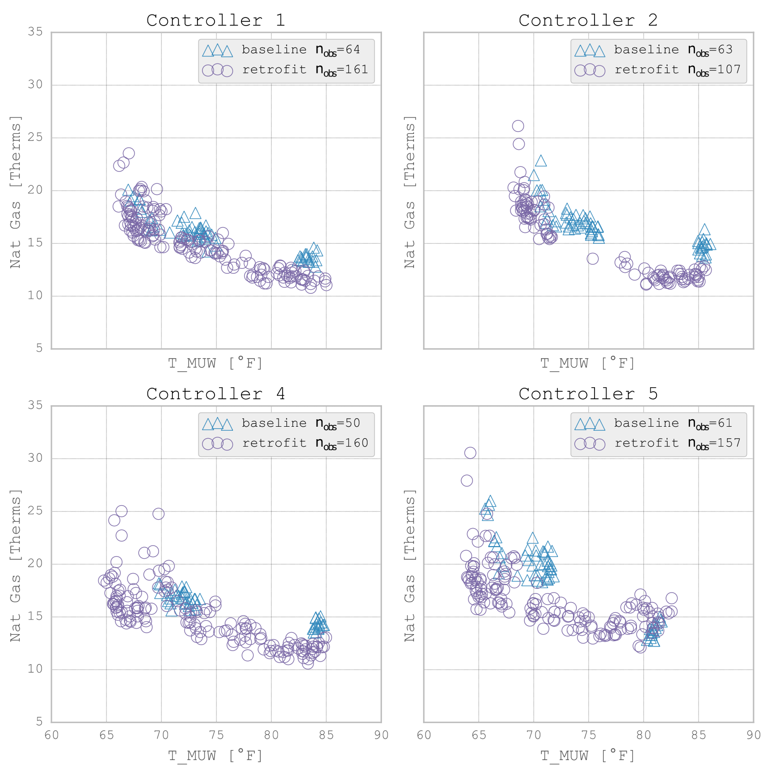

Figure 12: Natural Gas vs. Make-Up Water Temperature Scatter Plots

Appendix D: Peer Review Certificate