CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

PROCESS BOILERS

2013 California Building Energy Efficiency Standards

California Utilities Statewide Codes and Standards Team October 2011

This report was prepared by the California Statewide Utility Codes and Standards Program and funded by the California utility customers under the auspices of the California Public Utilities Commission.

Table of Contents

List of Figures

1. Introduction

This report is a part of the California Investor-Owned Utilities (IOUs) Codes and Standards Enhancement (CASE) effort to develop technical and cost-effectiveness information for proposed regulations on building energy efficiency design practices and technologies.

This report proposes new requirements for boilers serving process loads in the Title 24 nonresidential standards. Throughout 2010 and early 2011, the CASE Team (Team) evaluated costs and savings associated with each code change proposal described below. The Team engaged industry stakeholders to solicit feedback on the code change proposals, energy savings analyses, and cost estimates. The contents of this report were developed with feedback from building departments, contractors organizations, and other related industries and the California Energy Commission (CEC) into account.

2. Overview

2.1 *Project Title*

Process Boilers

2.2 *Description*

This paper presents four proposals that affect certain sizes of new boilers that serve process loads:

- Combustion air positive shut off
- Combustion fan VFD
- Parallel position control
- Oxygen trim control

The first measure analyzed is combustion air positive shut off. This measure would apply to new, natural draft (atmospheric) boilers. Natural draft boilers rely on buoyancy forces to pull combustion air into the combustion chamber. This measure does not include forced draft boilers, which rely on a fan to provide the appropriate amount of air into the combustion chamber. Combustion air positive shut off is generally achieved with use of automatic draft controls such as a flue damper or vent damper. Installed dampers can be interlocked with the gas valve so that the damper closes and inhibits air flow through the heat transfer surfaces when the burner has cycled off, thus reducing standby losses. Natural draft boilers receive the most benefit from draft dampers because they have less resistance to airflow than forced draft boilers. Forced draft boilers rely on the driving force of the fan to push the combustion gases through an air path that has relatively higher resistance to flow than in a natural draft boiler. Positive shut off on a forced draft boiler is most important on systems with a tall stack height or multiple boiler systems sharing a common stack. Draft controls are interlocked with the fuel control valve so that the flue damper closes and inhibits air flow through the heat transfer surfaces when the burner has cycled off, thus reducing standby losses.

The second measure analyzed is variable frequency drive (VFD) on the combustion air fan. Electricity savings result from run time at part-load conditions; as the boiler firing rate decreases, the combustion air fan speed can be decreased.

The third measure analyzed is parallel position control. Boilers mix air with fuel (usually natural gas although sometimes diesel or oil) to supply oxygen during combustion. Stoichiometric combustion is the ideal air/fuel ratio where the mixing proportion is correct, the fuel is completely burned, and the oxygen is entirely consumed. Boilers operate most efficiently when the combustion air flowrate is slightly higher than the stoichiometric air-fuel ratio. However, common practice almost always relies on excess air to insure complete combustion, avoid unburned fuel and potential explosion, and prevent soot and smoke in the exhaust. Excess air has a penalty, which is increased stack heat loss and reduced combustion efficiency.

The base case boiler control is known as single-point positioning control and consists of a mechanical linkage connecting the combustion air damper and the fuel supply valve via a common jack-shaft driven from a single motor. This jack-shaft rod modulates as needed to adjust the air and fuel supply to meet the hot water supply temperature setpoint and thus the heating load. One limitation of this open-loop control configuration is the ability to provide a consistent amount of excess air throughout the boiler firing range. At best, optimized (just above stoichiometric) combustion occurs at a single fire rate, while higher excess air is present during all other fire rates. As a boiler load decreases and the fuel valve modulates more closed, the combustion air flow decreases at a lower rate. This results from the non-linearity of the linkage between the fuel valve and the combustion air damper. This yields increased excess air at medium and low fire, which results in worse efficiencies. The advantage is safety and always ensuring sufficient excess air.

Parallel positioning controls optimize the combustion excess air to improve the combustion efficiency of the boiler. It includes individual servo motors allowing the fuel supply valve and the combustion air damper to operate independently of each other. This system relies on preset fuel mapping (i.e., a pre-programmed combustion curve) to establish proper air damper positions (as a function of the fuel valve position) throughout the full range of burner fire rate. Developing the combustion curve is a manual process, performed in the field with a flue-gas analyzer in the exhaust stack, determining the air damper positions as a function of the firing rate/fuel valve position. Depending on type of burner, a more consistent level of excess oxygen can be achieved with parallel position compared to single-point positioning control, since the combustion curve is developed at multiple points/firing rates, typically 10 to 25 points. Parallel positioning controls allow excess air to remain relatively low throughout a burner's firing rate. Maintaining low excess air levels at all firing rates provide significant fuel and cost savings while still maintaining a safe margin of excess air to insure complete combustion.

The fourth measure analyzed is oxygen trim control. This control strategy relies on parallel positioning hardware and software as the basis but takes it a step further to allow operation closer to stoichiometric conditions. Oxygen trim control converts parallel positioning to a closed-loop control configuration with the addition of an exhaust gas analyzer and PID controller. This strategy continuously measures the oxygen content in the flue gas and adjusts the combustion air flow, thus continually tuning the air-fuel mixture.

Detecting and monitoring excess air is easy because oxygen not consumed during combustion is present in the exhaust gases. Detecting and monitoring carbon monoxide assures the air/fuel ratio is not too rich as the excess air is trimmed. Based on the exhaust gas analysis, a control algorithm maintains close to stoichiometric combustion by commanding a servo motor to adjust the combustion air damper and another servo motor to adjust the fuel supply valve.

2.3 *Type of Change*

All three measures are proposed as mandatory requirements for certain sizes of new process boilers.

2.4 *Energy Benefits*

The energy savings for all units installed the first year are presented here:

Measure	Statewide Power Savings (MW)	Statewide Electricity Savings (GWh)	Statewide Natural Gas Savings (million therms)	Total TDV Savings ($) over EUL
Flue damper	-	-	0.03	$ 378,200
VFD	-	0.7	-	$ 1,298,186
Parallel position	-	-	0.47	$ 6,791,175
O2 trim	-	-	0.61	$ 8,835,860
Total	-	0.7	1.1	$ 17,303,421

Figure 1 Statewide Annual Savings for 1st Year of Code Requirements

2.5 *Non-Energy Benefits*

None.

2.6 *Environmental Impact*

There are no significant adverse environmental impacts of this measure.

The effect on air quality is presented here in pounds of various emissions:

First year	NOX	SOX	CO	PM10	CO2
Flue damper	257	174	78	26	298,576
VFD	107	644	156	51	393,424
Parallel position	4,615	3,124	1,399	466	5,361,405
O2 trim	6,005	4,064	1,820	607	6,975,615
Total	10,985	8,006	3,453	1,149	13,029,020

Figure 2 Statewide Avoided Emissions, First Year (lbs)

15-yr EUL	NOX	SOX	CO	PM10	CO2
Flue damper	3,069	2,077	930	310	3,565,000
VFD	1,283	7,692	1,866	603	4,697,486
Parallel position	55,109	37,296	16,700	5,567	64,015,176
O2 trim	71,701	48,525	21,728	7,243	83,288,842
Total	131,161	95,589	41,223	13,722	155,566,504

Figure 3 Statewide Avoided Emissions, 15-year Total (lbs)

The following Figure 4 shows the estimated increase in materials usage for all proposed measures. The associated assumptions and the materials usage for each individual measure are presented in the section Appendix A: Environnemental Impact.

	Mercury	Lead	Copper	Steel	Plastic	Others
Per boiler	No change	No change	0.25	1.1	0.22	No change
Per Prototype Building	No change	No change	0.25	1.1	0.22	No change

Figure 4 Increase in Materials Usage for All Proposed Measures (lbs)

2.7 *Technology Measures*

This measure utilizes technology that is widely available and in widespread use. Energy savings from these measures will persist for the life of the system.

2.8 *Performance Verification*

No additional performance verification or acceptance testing is required for these proposed measures. Standard commissioning of these systems is prudent to ensure they are performing as designed.

2.9 *Cost Effectiveness*

These measures are cost effective as described in the Results and Analysis section. Life cycle costs (LCC) were calculated using the California Energy Commission Life Cycle Costing Methodology for each proposed measure. Results of the analysis are summarized in the following table. Details of the analysis are included in the Analysis and Results section.

The benefit/cost ratio is 1.0 for flue dampers (combustion air positive shut-off), 2.7 for combustion fan VFD, 1.8 for parallel positioning controls, and 1.8 for oxygen trim control. These benefit/cost values are specific to the smallest boilers subject to each proposed measure. These values improve as boiler capacity increases.

a	c	d	e	f	g	
Measure Name	Additional Costs[1]– Current Measure Costs (Relative to Basecase) ($)	Additional Cost[2]– Post-Adoption Measure Costs (Relative to Basecase) ($)	PV of Additional[3] Maintenance Costs (Savings) (Relative to Basecase) (PV$)	PV of[4] Energy Cost Savings – Per Proto Building -15 yr measure life (PV$)	LCC Per Prototype Building ($)	
	Per Unit	Per Unit	Per Unit		(c+e)-f Based on Current Costs	(d+e)-f Based on Post-Adoption Costs
Combustion air positive shutoff	$1,500 for 2.5 MMBtu/h unit	$1,500	$112	$1,660	-$48	-$48
Combustion fan VFD	$4,249 for 10 HP motor	$4,249	$597	$13,264	-$8,418	-$8,418
Parallel position control	$9,000 for 5 MMBtu/h unit	$9,000	$4,775	$24,756	-$10,981	-$10,981
Oxygen trim control	$27,000 for 10 MMBtu/h unit	$27,000	$9,550	$66,554	-$30,004	-$30,004

Figure 5 Summary of Life Cycle Cost Analysis for All Measures

2.10 *Analysis Tools*

The methodology for evaluating the cost effectiveness of these measures was to develop spreadsheet-based energy savings calculations. This analysis was done independent of climate zones as processes rather than climate dominate the loads.

2.11 *Relationship to Other Measures*

No other measures are impacted by these changes.

3. Methodology

This section summarizes the methods used to collect data and conduct the analysis for this CASE project for the following proposals, all of which are proposed as mandatory requirements:

- Combustion air positive shut off
- Combustion fan VFD
- Parallel position control
- Oxygen trim control

These measures affect new boilers that serve process loads. The methodology for evaluating the cost effectiveness of these measures was to develop spreadsheet-based energy savings calculations. This analysis was done independent of climate zones as processes rather than climate dominate the loads.

AEC (Architectural Energy Corporation) provided energy costs for use in the analysis. The average TDV (Time Dependent Valuation) of energy across all California climate zones for 15-year nonresidential measures is $14.59/therm and $1.86/kWh.[1] On an annual basis, this translates to an average of $1.22/therm and $0.16/kWh. In other words, these are the PV energy costs averaged over the measure lifetime. The LCCA (Life Cycle Cost Analysis) payback threshold is 11.94 years, which is the present worth multiplier for the measure lifetime of 15 years.

Process loads occur over a wide range of time of the day, day of the week, and season. This analysis uses these average TDV energy costs rather than trying to predict the particular hours of the year of process boiler operation. Otherwise, the results can be quite varied if the operation is in the morning (no TDV peaks) or afternoon (many TDV peaks).

Each individual measure and the associated analysis are described in more detail in the next section.

3.1 *Statewide Energy Savings*

The statewide energy savings associated with the proposed measures were calculated by multiplying the annual statewide installed boiler capacity by the measure savings. Details on the method and data source of the new construction forecast are presented in the section: Analysis and Results.

[1] Architectural Energy Corporation. Life-Cycle Cost Methodology. 2013 California Building Energy Efficiency Standards. November 16, 2010. Prepared for California Energy Commission.

4. Analysis and Results

4.1 *Combustion air positive shut off (flue or vent damper)*

The first measure analyzed is combustion air positive shut off. This measure would apply to new, natural draft (atmospheric) boilers. The incremental cost to implement combustion air positive shutoff on medium and large boilers will be about the same as a small boiler but the energy savings will be much greater. Therefore, if the measure is cost effective for a smaller boiler then it is clearly cost effective for larger systems as well.

4.1.1 Energy Analysis

This measure was evaluated by developing a spreadsheet-based energy savings calculation. This analysis was done independent of climate zones as the loads are dominated by processes rather than climate. The following assumptions were used in the analysis:

- Base case has no combustion air positive shut off.
- Combustion air positive shut off saves 30% of total standby losses.[4]
- Standby losses are 2% of rated fuel input.[4]
- 2920 hrs/year boiler operation (8-hour shift x 365 days/year). This includes time in standby and firing. This assumption is conservative as most boilers will operate much longer to serve process loads.
- 760 hrs in standby mode, from 2920 hrs x 26% per Figure 7.
- Fuel is natural gas at $1.22/therm. This is the PV therm averaged over the measure lifetime.
- LCCA payback threshold is 11.94 years. This is the present worth multiplier for the measure lifetime of 15 years

The analysis method is to solve for the smallest boiler capacity that yields break even cost effectiveness. In other words, such that the lifecycle cost savings is zero (simple payback is 11.94 years). The analysis proceeds as follows, while the measure cost is explained later in this section.

$$\text{simple payback} = \frac{\text{measure cost}}{\text{annual cost savings}}$$

Where annual cost savings = Fuel cost * savings * standby loss * boiler input * hours standby

$$11.94 = \frac{\$1612}{\$1.22 * 30\% * 2\% * \text{Boiler input} * 2920\text{ Hrs} * 26\%\text{ active standby}}$$

Solving for the boiler input yields 2.43 MMBtu/h (2,430,000 Btu/h).

The next step is to select a boiler capacity just larger than the break even size. This should be an even number that is reasonable per available boiler systems and is favorable to ease of compliance. In this case boiler systems with an input capacity of 2.5 MMBtu/h (2,500,000 Btu/h) and above is a reasonable requirement.

4.1.2 Energy Results

The annual fuel savings realized by implementing this measure is given by:

Annual fuel savings = savings * standby loss * boiler input * hours operation

In the case of the smallest boiler subject to the requirement, the result is:

Annual fuel savings = 30% * 2% * 2.5 * 2920 * 26%

= 11.4 MMBtu (114 therms/yr)

At $1.22/therm, the annual energy cost savings for a 2.5 MMBtu/h boiler is $139. The PV energy savings over the 15-year measure lifetime is $1,660.

4.1.3 Incremental Installed Cost

Incremental cost data was provided by a flue damper manufacturer. The incremental cost to a boiler manufacturer for a flue damper is $750. The boiler manufacturer mark-up to the end user was conservatively estimated to be 100% for a total incremental installed cost of $1500.

4.1.4 Maintenance Cost

This measure has a different repair cost as compared to the basecase (no combustion air positive shut off). Thus, the cost premium discounts the future costs to present value at a discount rate of 3%. Incremental maintenance cost data was provided by a flue damper manufacturer. This consists of a $50 controller replacement every 10 years with an associated one hour of labor at a rate of $100/hr. The present value of maintenance costs that occurs in the nth year is calculated as follows (where d is the discount rate):

$$\text{PV Maint Cost} = \text{Maint Cost} \times \left\lfloor \frac{1}{1+\text{d}} \right\rfloor^{n}$$

In this case, Maint Cost = $150; d = 3%; n = 10.

This yields a present value maintenance cost of $112.

4.1.5 Life Cycle Cost Results

The total incremental cost is the sum of the incremental installed cost ($1,500) and the PV maintenance cost ($112) for a total incremental cost of $1,612.

In the case of the smallest boiler subject to the requirement (input capacity of 2.5 MMBtu/h), the annual energy cost savings is $139 (at $1.22/therm). The PV energy cost savings over the 15-year measure lifetime is $1,660. As shown in Figure 6, the measure is cost effective.

Incremental Installed Cost	$1,500
Maintenance	$150
PV of Maintenance (Year 10)	$112
Total Incremental Cost	$1,612
PV of Energy Savings	$1,660
Lifecycle cost savings	$48
Benefit/Cost Ratio	1.0

Figure 6 Combustion Air Positive Shut Off: Lifecycle Cost Results

4.1.6 Statewide Energy Savings

The statewide annual fuel savings realized by implementing this measure is given by:

Annual fuel savings = savings * standby loss * boiler input * hours standby * % applicable boilers

The boiler input is the annual statewide installed boiler capacity of 4,709 MMBtu/h.

The % applicable boilers is from data provided by the South Coast AQMD, which indicates that 12% of boilers are atmospheric.

Annual fuel savings = 30% savings * 2% * 4,709 * 2920 hrs * 26% standby * 12%

= 2,600 MMBtu (26,000 therms/yr)

At $1.22/therm, the statewide annual energy cost savings is $32,000. Applying the present worth multiplier of 11.94, the energy savings and energy cost savings over the 15-year measure lifetime for all units installed in the first year is 310,000 therms and $382,000.

4.2 *Combustion fan VFD*

The second measure analyzed is variable frequency drive (VFD) on the combustion air fan.

4.2.1 Energy Analysis

This measure was evaluated by developing a spreadsheet-based energy savings calculation. This analysis was done independent of climate zones as the loads are dominated by processes rather than climate. The following assumptions were used in the analysis:

- 2920 hrs/year boiler operation (8-hour shift x 365 days/year). This includes time in standby and firing. This assumption is conservative, as most boilers will operate much longer to serve process loads.
- Motor load factor is 0.7
- Electricity cost is $0.16/kWh. This is the PV kWh averaged over the measure lifetime.

- LCCA payback threshold is 11.94 years. This is the present worth multiplier for the measure lifetime of 15 years.

The analysis method is to solve for the smallest size VFD that yields break even or better cost effectiveness. In other words, such that the lifecycle cost savings is at least zero (simple payback is less than 11.94 years). The analysis proceeds as follows:

1. Use the boiler firing rate bin hours as shown in the run time histogram in Figure 7. Enovity, Inc. provided this histogram, which is a compilation of boilers they monitored as part of their third-party commercial and industrial boiler program.

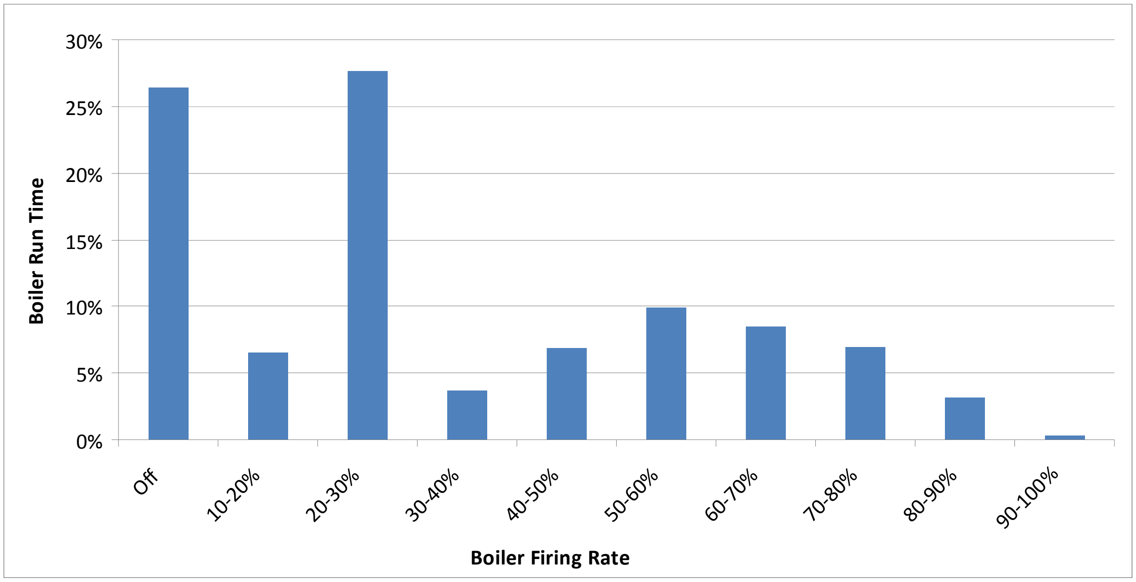

Figure 7 Boiler Run-Time Histogram

2. The baseline motor load is assumed at 100% and includes 0.7 load factor and motor efficiency related to nameplate HP per NEMA Premium Efficiency standards.
3. The VFD fan speed was developed using a correlation of firing rate vs. VFD speed from a field study conducted by the project team at a University of California campus as part of this proposal. This correlation is shown below in Figure 8:

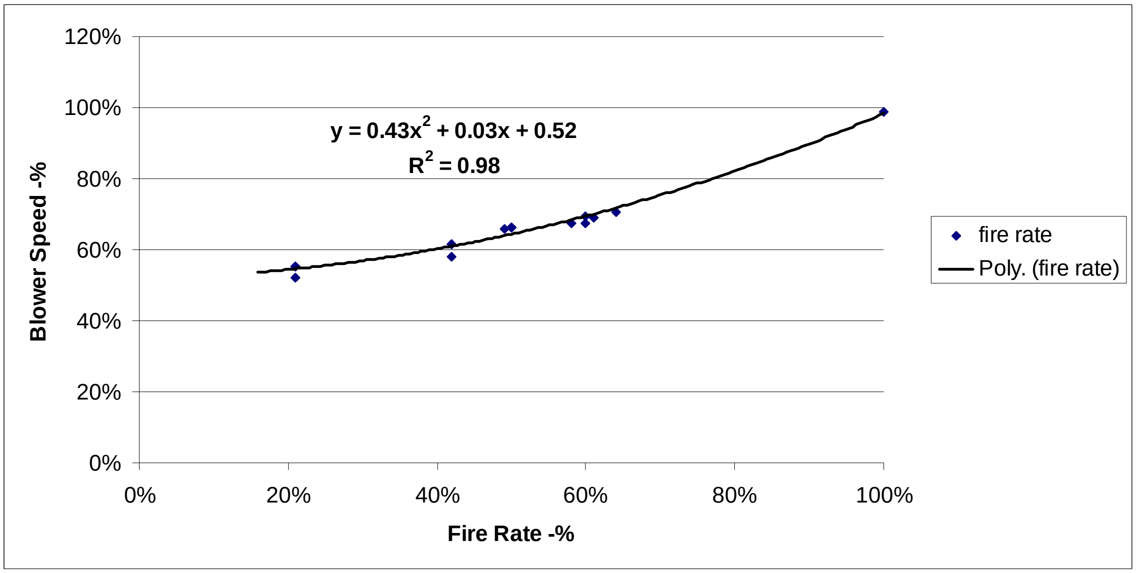

Figure 8 Blower Speed vs. Fire Rate

4. VFD fan motor load is calculated using the fan affinity laws and an exponent smaller than ideal for conservativeness. The fan affinity laws describe an ideal case where the ratio between two fan speeds and the related power at each speed follows a cubic relationship. (BHP2/BHP1) = (RPM2/RPM1)^3. However, using the ideal exponent of 3 for realistic situations tends to overestimate savings. Many engineers prefer to use a smaller exponent to account for losses (such as friction) that occur in realistic situations. Typically values for the exponent range from 2.0-2.8, but there is no widespread support of any particular value. This analysis uses an exponent of 1.8 to provide an extremely conservative estimate of savings.
5. Repeat this calculation over a range of motor sizes to solve for the smallest size VFD that yields break even or better cost effectiveness.

4.2.2 Energy Results

This section presents the annual electricity savings realized by implementing this measure. Figure 9 below shows the savings calculation inputs and results for a 5 HP motor.

Boiler Firing rate	% time	Hours	Baseline fan motor load, kW	Baseline Energy Use, kWh/yr	VFD Fan speed, %	VFD Fan motor load, kW	VFD Energy Use, kWh/yr	Savings, kWh/yr
0%	26.4%	772	2.9	0	0	0.0	0	0
15%	6.5%	191	2.9	556	54%	0.9	181	375
25%	27.6%	807	2.9	2,355	56%	1.0	818	1,536
35%	3.7%	107	2.9	312	58%	1.1	119	193
45%	6.9%	202	2.9	589	62%	1.2	251	338
55%	9.9%	290	2.9	845	67%	1.4	410	436
65%	8.4%	247	2.9	720	72%	1.6	402	318
75%	7.0%	204	2.9	594	79%	1.9	386	208
85%	3.1%	91	2.9	267	86%	2.2	203	64
95%	0.3%	10	2.9	30	94%	2.6	26	3
		2,920		6,267			2,795	**3,472**

Figure 9 VFD Energy Savings Results for 5 HP Motor

This calculation was repeated for a range of motor sizes to solve for the smallest size VFD that yields break even or better cost effectiveness. The present value (PV) energy savings over the effective useful life (EUL) of 15 years is the product of the annual energy savings, the electricity rate of $0.16/kWh, and 11.94 years. These results are summarized in Figure 10.

Size (hp)	Annual Energy Savings, kWh/yr	PV of Energy Savings over EUL
3	2,083	$3,979
5	3,472	$6,633
7.5	5,207	$9,947
10	6,943	$13,264
15	10,415	$19,897
20	13,886	$26,528
25	17,358	$33,161
30	20,829	$39,792
40	27,772	$53,056
50	34,715	$66,320
60	41,658	$79,583

Figure 10 VFD Energy Savings and Present Valued Energy Cost Savings over 15 Years for Various Motor Sizes

4.2.3 Incremental Installed Cost

Incremental cost data was provided by RS Means and verified with cost data from PECI's California retrocommissioning (RCx) program data. The cost data from RS Means is dated 2008. These prices were escalated 3% per year for five years to yield 2013 costs. Installation consists of 8 hours of controls programming at $100/hr for a total of $800 installation cost per PECI's RCx project data. The total installed cost is the sum of the 2013 equipment cost and the installation cost. These data are shown below in Figure 11.

Size (hp)	2008 Equipment Cost	2013 Equipment Cost	Controls Programming: 8 hrs	Incremental Installed Cost	Cost/HP
3	$2,375	$2,753	$800	$3,553	$1,184
5	$2,500	$2,898	$800	$3,698	$740
7.5	$2,975	$3,449	$800	$4,249	$567
10	$2,975	$3,449	$800	$4,249	$425
15	$3,725	$4,318	$800	$5,118	$341
20	$4,950	$5,738	$800	$6,538	$327
25	$5,950	$6,898	$800	$7,698	$308
30	$6,900	$7,999	$800	$8,799	$293
40	$9,350	$10,839	$800	$11,639	$291
50	$10,500	$12,172	$800	$12,972	$259
60	$11,900	$13,795	$800	$14,595	$243

Figure 11 VFD Installed Costs

4.2.4 Maintenance Cost

The incremental maintenance cost is a very conservative estimate of half an hour per year at a labor rate of $100/hr. The PV of the annual maintenance discounted by 3% over 15 years is $597. Adding the PV of the annual maintenance to the incremental installed cost yields the total incremental cost as shown in Figure 12.

Size (hp)	Incremental Installed Cost	PV of Annual Maint.	Total Incremental Cost
3	$3,553	$597	$4,150
5	$3,698	$597	$4,295
7.5	$4,249	$597	$4,846
10	$4,249	$597	$4,846
15	$5,118	$597	$5,715
20	$6,538	$597	$7,135
25	$7,698	$597	$8,295
30	$8,799	$597	$9,396
40	$11,639	$597	$12,236
50	$12,972	$597	$13,569
60	$14,595	$597	$15,192

Figure 12 VFD Total Present Valued Incremental Costs including Equipment, Installation, and the Present Value of 15 years of Maintenance Costs

4.2.5 Life Cycle Cost Results

As shown in Figure 13, the measure is cost effective for combustion fan motors 5 HP and larger. This is the smallest motor size with a benefit/cost ratio greater than 1.0 and simple payback less than 11.9 years, which is the maximum allowed per Title 24 life cycle cost analysis (LCCA) methodology.

Size (hp)	Total Incremental Cost	Annual Energy Savings, $/yr	PV of Energy Savings over EUL	Lifecycle Cost Savings	Benefit/Cost Ratio	Payback, yrs
3	$4,150	$333	$3,979	($171)	0.96	12.5
5	$4,295	$556	$6,633	$2,338	1.5	7.7
7.5	$4,846	$833	$9,947	$5,102	2.1	5.8
10	$4,846	$1,111	$13,264	$8,418	2.7	4.4
15	$5,715	$1,666	$19,897	$14,182	3.5	3.4
20	$7,135	$2,222	$26,528	$19,392	3.7	3.2
25	$8,295	$2,777	$33,161	$24,866	4.0	3.0
30	$9,396	$3,333	$39,792	$30,396	4.2	2.8
40	$12,236	$4,444	$53,056	$40,819	4.3	2.8
50	$13,569	$5,554	$66,320	$52,750	4.9	2.4
60	$15,192	$6,665	$79,583	$64,391	5.2	2.3

Figure 13 VFD: Lifecycle Cost Results

Communication with stakeholders indicates a VFD on the combustion fan motor is available down to 1.5 HP but is most commonly installed on 10 HP fan motors and larger. For this reason and for a conservative approach, our team proposes that combustion air fans with motors 10 horsepower or larger shall be driven by a variable frequency drive.

In the case of the smallest motor subject to the requirement (10 HP), the annual energy savings is 6,943 kWh. The annual energy cost savings is $1,111. The PV energy savings over the 15-year measure lifetime is $13,264. The results of the lifecycle cost analysis for this 10 HP motor are shown in Figure 14.

Incremental Installed Cost	$4,249
Incremental Annual Maintenance	$50
PV of Annual Maintenance	$597
Total Incremental Cost	$4,846
PV of Energy Savings	$13,264
Lifecycle cost savings	$8,418
Benefit/Cost Ratio	2.7

Figure 14 VFD: Lifecycle Cost Results for 10 HP Motor

4.2.6 Statewide Energy Savings

The statewide energy savings analysis relies on the following data provided by stakeholders:

- 10 HP combustion fan motor used for boilers in the range 2-20 MMBtu/h
- 40 HP combustion fan motor used for boilers in the range 20-50 MMBtu/h
- 50 HP combustion fan motor used for boilers in the range 50-100 MMBtu/h
- 29% of boilers are not low NOx or ultra low NOx burners and thus do not come with VFD on combustion air fan
- 88% of boilers are forced draft; this measure applies to forced draft units

Statewide Annual Energy Savings, kWh/yr	Statewide Annual Energy Savings, $/yr	Energy Savings over EUL, kWh	PV of Energy Savings over EUL
679,536	$108,726	8,113,663	$1,298,186

Figure 15 VFD: Statewide Savings

4.3 *Parallel position control*

The third measure analyzed is parallel position control. Parallel position controls optimize the combustion excess air to improve the combustion efficiency of the boiler.

4.3.1 Energy Analysis

This measure was evaluated by developing a spreadsheet-based energy savings calculation. This analysis was done independent of climate zones as the loads are dominated by processes rather than climate. The following assumptions were used in the analysis:

- Parallel positioning control is standard with low- and ultra-low NOx burners per communication with stakeholders
- Base case is boiler with single-point control and without low- or ultra-low NOx burner
- Measure case is parallel positioning control and without low- or ultra-low NOx burner
- Base case excess air (oxygen) ranges from 40% (6.5%) at high fire to 80% (10%) at low fire[2]
- Measure case excess air (oxygen) is 28% (5%)[3]
- Net temperature difference (stack temp – intake temp) is 170˚F, a conservative estimate[4]

---

[2] Carpenter, Kevin, C. Schmidt, and K. Kissock. 2008. "Common Boiler Excess Air Trends and Strategies to Optimize Efficiency." ACEEE Summer Study on Energy Efficiency in Buildings.

[3] Department of Energy (DOE). 2009. *Energy Matters newsletter*. Fall 2009- Vol. 1, Iss. 1. Washington, DC: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Industrial Technologies Program.

- 2920 hrs/year boiler operation (8-hour shift x 365 days/year). This includes time in standby and firing. This assumption is conservative as most boilers will operate much longer to serve process loads.
- Fuel is natural gas at $1.22/therm. This is the PV therm averaged over the measure lifetime.
- LCCA payback threshold is 11.94 years. This is the present worth multiplier for the measure lifetime of 15 years.

The analysis method is to solve for the smallest boiler capacity that yields break even cost effectiveness. In other words, such that the lifecycle cost savings is zero (simple payback is 11.94 years). The analysis proceeds as follows:

1. Use the boiler firing rate bin hours as shown in the run time histogram in Figure 7. Enovity, Inc. provided this histogram, which is a compilation of boilers they monitored as part of their third-party commercial and industrial boiler program.
2. Look up the boiler combustion efficiencies associated with the base case and measure case levels of excess oxygen. A pre-calculated combustion efficiency table is used for this purpose.[4] The table used for natural gas fired boilers is shown below in Figure 16. The combustion efficiencies at 170˚F net temperature difference are used for the most conservative approach. The data of interest is shown plotted in Figure 17.

Excess	Excess	Excess	Combustion Efficiency at Net Temperature Difference								
Air %	O2 %	CO2 %	170F	220F	270F	330F	380F	430F	480F	530F	580F
0%	0%	12	86.3	85.3	84.2	83.0	81.9	80.8	79.7	78.6	77.5
5%	1%	11	86.2	85.1	84.0	82.7	81.6	80.5	79.3	78.2	77.0
10%	2%	11	86.1	84.9	83.8	82.4	81.2	80.1	78.9	77.7	76.5
15%	3%	10	85.9	84.7	83.5	82.1	80.9	79.7	78.4	77.2	75.9
21%	4%	10	85.7	84.5	83.2	81.7	80.5	79.2	77.9	76.6	75.3
28%	5%	9	85.5	84.2	82.9	81.3	80.0	78.6	77.3	75.9	74.5
36%	6%	8	85.3	83.9	82.5	80.9	79.5	78.0	76.6	75.2	73.7
45%	7%	8	85.0	83.5	82.1	80.3	78.8	77.3	75.8	74.3	72.8
55%	8%	7	84.7	83.1	81.6	79.7	78.1	76.6	74.9	73.3	71.7
67%	9%	7	84.3	82.7	81.0	79.0	77.3	75.6	73.9	72.2	70.4
82%	10%	6	83.9	82.1	80.3	78.2	76.4	74.5	72.7	70.8	68.9
99%	11%	6	83.4	81.5	79.5	77.2	75.2	73.2	71.2	69.2	67.1
120%	12%	5	82.7	80.6	78.5	75.9	73.8	71.6	69.4	67.2	64.9
146%	13%	5	82.0	79.6	77.3	74.4	72.0	69.6	67.1	64.7	62.2
180%	14%	4	81.0	78.3	75.7	72.4	69.7	67.0	64.2	61.5	58.7
224%	15%	3	79.6	76.6	73.5	69.8	66.7	63.5	60.4	57.2	54.0

Figure 16 Combustion Efficiency Table for Natural Gas

[4] Sam Dukelow, 1991. The Control of Boilers, 2nd Edition. Research Triangle Park, NC.

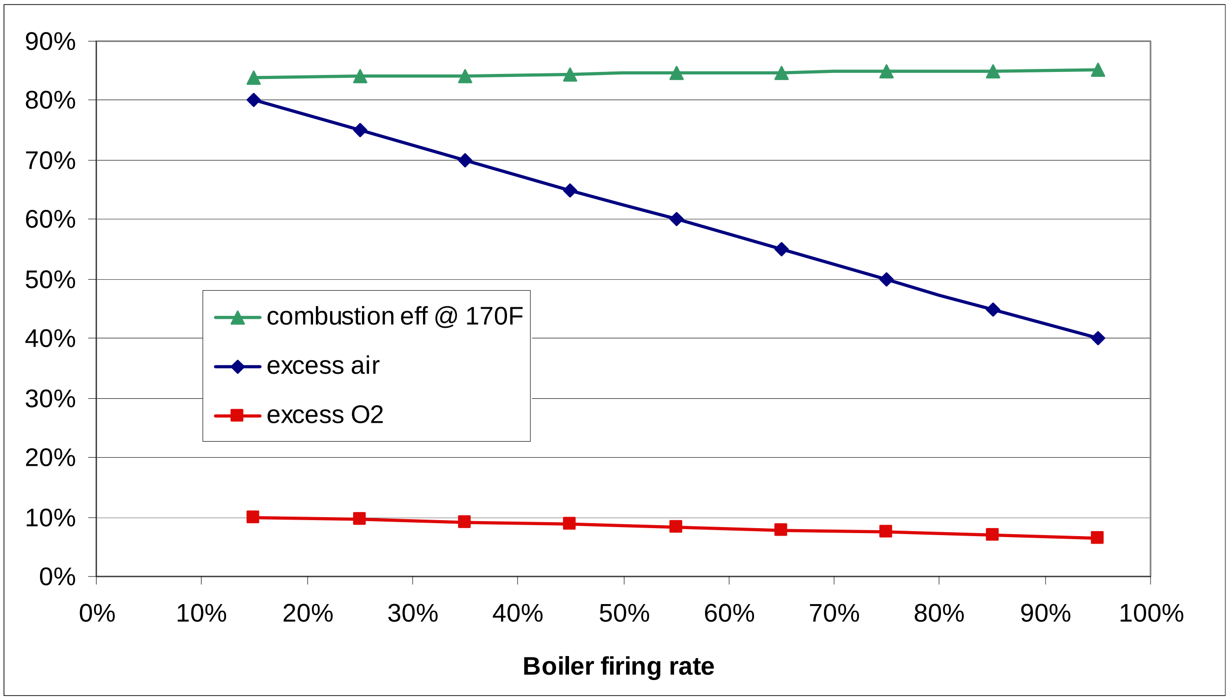

Figure 17 Combustion Efficiency and Excess Air Curves for Natural Gas

3. Calculate the annual fuel savings over the full range of boiler firing rates using the following equation:

   Annual fuel savings = input capacity * hrs/yr * (1/base efficiency – 1/measure efficiency)

4. Repeat this calculation over a range of boiler sizes to solve for the smallest size boiler that yields break even or better cost effectiveness.

4.3.2 Energy Results

This section presents the annual fuel savings realized by implementing this measure. Figure 18 below shows the savings calculation inputs and results for a 2.0 MMBtuh boiler.

Boiler Firing rate	% time	Hours	Baseline excess O2	Baseline efficiency	Parallel Positioning excess O2	Parallel Positioning efficiency	Savings, therms/yr for 2 MMBtuh
0%	26.4%	772	0%	0	0%	0	
15%	6.5%	191	10.0%	83.9%	5%	85.5%	83
25%	27.6%	807	9.6%	84.1%	5%	85.5%	317
35%	3.7%	107	9.1%	84.2%	5%	85.5%	37
45%	6.9%	202	8.7%	84.4%	5%	85.5%	62
55%	9.9%	290	8.3%	84.5%	5%	85.5%	76
65%	8.4%	247	7.8%	84.7%	5%	85.5%	54
75%	7.0%	204	7.4%	84.9%	5%	85.5%	36
85%	3.1%	91	7.0%	85.0%	5%	85.5%	12
95%	0.3%	10	6.5%	85.2%	5%	85.5%	1
		2,920					**680**

Figure 18 Parallel Positioning Energy Savings for 2 MMBtuh Boiler

This calculation was repeated for a range of boiler sizes to solve for the smallest size boiler that yields break even or better cost effectiveness. The present value (PV) energy savings over the effective useful life (EUL) of 15 years is the product of the annual energy savings, the electricity rate of $0.16/kWh, and the present worth multiplier of 11.94 years. These results are summarized in Figure 19 and Figure 20.

			Boiler Input, MMBtuh					
Boiler Firing rate	**% time**	**Hours**	**2.0**	**2.8**	**5.0**	**10.0**	**20.0**	**50.0**
0%	26.4%	772						
15%	6.5%	191	83	116	208	416	832	2,080
25%	27.6%	807	317	444	793	1,586	3,172	7,929
35%	3.7%	107	37	52	93	187	373	933
45%	6.9%	202	62	87	155	309	618	1,546
55%	9.9%	290	76	107	191	382	763	1,909
65%	8.4%	247	54	76	136	272	544	1,360
75%	7.0%	204	36	51	91	181	362	906
85%	3.1%	91	12	17	31	62	124	309
95%	0.3%	10	1	1	2	5	9	23
Savings, therms/yr:			**680**	**952**	**1,700**	**3,399**	**6,798**	**16,995**

Figure 19 Parallel Positioning Energy Savings for Range of Boilers

Boiler Input, MMBtuh	2.0	2.8	5.0	10.0	20.0	50.0
Savings, therms/yr:	680	952	1,700	3,399	6,798	16,995
Savings, $/yr @ $1.22/therm:	$829	$1,161	$2,073	$4,147	$8,294	$20,734
NPV of energy savings over 11.94 yrs:	$9,903	$13,864	$24,756	$49,513	$99,026	$247,564

Figure 20 Parallel Positioning Energy Savings and PV Savings

4.3.3 Incremental Installed Cost

Incremental cost data was provided by boiler controls reps from Autoflame, Alzeta, Cleaver Brooks, and Fireye. The total installed incremental costs from all four sources were in close agreement and ranged from $8,000 to $9,000. The price does not vary with boiler capacity, at least between 50 HP (1.7 MMBtuh) and 1500 HP (50 MMBtuh).

4.3.4 Maintenance Cost

A boiler's air/fuel ratio is adjusted during boiler tuning. This occurs during installation and start-up and during maintenance activity, which is usually once per year. This occurs for both the base case and the measure case but requires more time for the measure case. The incremental maintenance cost is a conservative estimate of 4 hours per year at a labor rate of $100/hr, or $400 per year. The PV of the annual maintenance discounted by 3% over 15 years is $4,775.

4.3.5 Life Cycle Cost Results

The total incremental cost is the sum of the incremental installed cost ($9,000) and the PV maintenance cost ($4,775) for a total incremental cost of $13,775.

As shown in Figure 21, the measure is cost effective for boilers 2.8 MMBtuh and larger. This is the boiler size with a benefit/cost ratio of 1.0 and simple payback of 11.9 years, which is the maximum allowed per Title 24 life cycle cost analysis (LCCA) methodology.

Boiler Input, MMBtuh	2.0	2.8	5.0	10.0	20.0	50.0
Savings, therms/yr:	680	952	1,700	3,399	6,798	16,995
Savings, $/yr @ $1.22/therm:	$829	$1,161	$2,073	$4,147	$8,294	$20,734
NPV of energy savings over 11.94 yrs:	$9,903	$13,864	$24,756	$49,513	$99,026	$247,564
Total incremental cost:	$13,775	$13,775	$13,775	$13,775	$13,775	$13,775
Benefit/Cost ratio:	**0.7**	**1.0**	**1.8**	**3.6**	**7.2**	**18.0**
Simple payback, yrs	16.6	11.9	6.6	3.3	1.7	0.7

Figure 21 Parallel Positioning: Lifecycle Cost Results

Communication with stakeholders indicates parallel positioning is available down to 5 HP (0.17 MMBtuh) but is most commonly installed on 50 HP (1.7 MMBtuh) boilers and larger. An ASHRAE Journal article states that parallel positioning control systems are extremely economical and now are often applied to boilers as small as 150 HP (5 MMBtuh).[5] For these reasons and for a conservative approach, our team proposes that boilers 150 HP (5 MMBtuh) or larger shall have parallel positioning control.

The annual energy savings for a 5 MMBtuh boiler is 1,700 therms. The annual energy cost savings is $2,073. The PV energy savings over the 15-year measure lifetime is $24,756. The lifecycle cost savings is $24,756 - $13,775 = $10,981.

The Title 24 standards language traditionally specifies performance requirements rather than specific technologies. Thus, instead of specifying a particular technology such as parallel positioning control, this proposal will specify a maximum value of 5.0% for excess oxygen. This is the value used in the LCCA.

4.3.6 Statewide Energy Savings

The statewide energy savings analysis relies on the following data provided by stakeholders:

- 29% of boilers are not low NOx or ultra low NOx burners and thus do not come with parallel position controls

The projected statewide energy savings and energy cost savings is:

Savings, therms/yr:	466,209
Savings, $/yr @ $1.22/therm:	$568,775
Savings, therms over 11.94 yrs:	5,566,537
PV of energy savings over 11.94 yrs:	$6,791,175

Figure 22 Parallel Position Control: Statewide Savings

4.4 *Oxygen trim control*

The fourth measure analyzed is oxygen trim control. Oxygen trim controls optimize the combustion process with respect to excess air to improve the combustion efficiency of the boiler.

4.4.1 Energy Analysis

This measure was evaluated using the same methodology as the parallel position control analysis with the following change:

- Measure case excess air (oxygen) is 15% (3%)[6]

---

5 David Eoff, 2008. Understanding Fuel Savings in the Boiler Room. ASHRAE Journal.

6 Department of Energy (DOE). 2009. *Energy Matters newsletter*. Fall 2009- Vol. 1, Iss. 1. Washington, DC: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Industrial Technologies Program.

4.4.2 Energy Results

This section presents the annual fuel savings realized by implementing this measure. Figure 23 below shows the savings calculation inputs and results for a 2.0 MMBtuh boiler.

Boiler Firing rate	% time	Hours	Baseline excess O2	Baseline efficiency	O2 trim excess O2	Measure efficiency	Savings, therms/yr for 2 MMBtuh
0%	26.4%	772	0%	0	0%	0	
15%	6.5%	191	10.0%	83.9%	3%	85.9%	104
25%	27.6%	807	9.6%	84.1%	3%	85.9%	405
35%	3.7%	107	9.1%	84.2%	3%	85.9%	49
45%	6.9%	202	8.7%	84.4%	3%	85.9%	84
55%	9.9%	290	8.3%	84.5%	3%	85.9%	108
65%	8.4%	247	7.8%	84.7%	3%	85.9%	81
75%	7.0%	204	7.4%	84.9%	3%	85.9%	58
85%	3.1%	91	7.0%	85.0%	3%	85.9%	22
95%	0.3%	10	6.5%	85.2%	3%	85.9%	2
		2,920					**914**

Figure 23 Oxygen Trim Energy Savings for 2 MMBtuh Boiler

This calculation was repeated for a range of boiler sizes to solve for the smallest size boiler that yields break even or better cost effectiveness. The present value (PV) energy savings over the effective useful life (EUL) of 15 years is the product of the annual energy savings, the electricity rate of $0.16/kWh, and the present worth multiplier of 11.94 years. These results are summarized in Figure 24 and Figure 25Figure 20.

			Boiler Input, MMBtuh					
Boiler Firing rate	**% time**	**Hours**	2.0	5.0	5.5	10.0	20.0	50.0
0%	26.4%	772						
15%	6.5%	191	104	260	285	520	1,039	2,599
25%	27.6%	807	405	1,013	1,112	2,025	4,051	10,127
35%	3.7%	107	49	122	134	245	490	1,224
45%	6.9%	202	84	210	230	419	838	2,095
55%	9.9%	290	108	270	296	540	1,079	2,698
65%	8.4%	247	81	203	223	406	813	2,032
75%	7.0%	204	58	146	160	292	584	1,461
85%	3.1%	91	22	56	61	112	223	559
95%	0.3%	10	2	5	6	10	20	51
		Savings, therms/yr:	**914**	**2,284**	**2,509**	**4,569**	**9,138**	**22,845**

Figure 24 Oxygen Trim Energy Savings for Range of Boilers

Boiler Input, MMBtuh	2.0	5.0	5.5	10.0	20.0	50.0
Savings, therms/yr:	914	2,284	2,509	4,569	9,138	22,845
Savings, $/yr @ $1.22/therm:	$1,115	$2,787	$3,061	$5,574	$11,148	$27,870
PV of energy savings over 11.94 yrs:	$13,311	$33,277	$36,550	$66,554	$133,109	$332,772

Figure 25 Oxygen Trim Energy Savings and PV Savings

4.4.3 Incremental Installed Cost

Incremental cost data was provided by boiler controls reps from Autoflame, Alzeta, and Fireye. The total installed incremental costs from these three sources ranged from $19,500 to $27,000. The analysis uses the highest cost of $27,000 for a conservative approach. The price does not vary with boiler capacity, at least between 50 HP (1.7 MMBtuh) and 1500 HP (50 MMBtuh).

4.4.4 Maintenance Cost

A boiler's air/fuel ratio is adjusted during boiler tuning. This occurs during installation and start-up and during maintenance activity, which is usually once per year. This occurs for both the base case and the measure case but requires more time for the measure case. The incremental maintenance cost is a conservative estimate of 8 hours per year at a labor rate of $100/hr, or $800 per year. The PV of the annual maintenance discounted by 3% over 15 years is $9,550.

4.4.5 Life Cycle Cost Results

The total incremental cost is the sum of the incremental installed cost ($27,000) and the PV maintenance cost ($9,550) for a total incremental cost of $36,550.

As shown in Figure 26, the measure is cost effective for boilers 5.5 MMBtuh and larger. This is the boiler size with a benefit/cost ratio of 1.0 and simple payback of 11.9 years, which is the maximum allowed per Title 24 life cycle cost analysis (LCCA) methodology.

Boiler Input, MMBtuh	2.0	5.0	5.5	10.0	20.0	50.0
Savings, therms/yr:	914	2,284	2,509	4,569	9,138	22,845
Savings, $/yr @ $1.22/therm:	$1,115	$2,787	$3,061	$5,574	$11,148	$27,870
PV of energy savings over 11.94 yrs:	$13,311	$33,277	$36,550	$66,554	$133,109	$332,772
Total incremental cost:	$36,550	$36,550	$36,550	$36,550	$36,550	$36,550
Benefit/Cost ratio:	**0.4**	**0.9**	**1.0**	**1.8**	**3.6**	**9.1**
Simple payback, yrs	32.8	13.1	11.9	6.6	3.3	1.3

Figure 26 Oxygen Trim: Lifecycle Cost Results

For a conservative approach, our team proposes that boilers 300 HP (10 MMBtuh) or larger shall have oxygen trim control.

The annual energy savings for a 10 MMBtuh boiler is 4,600 therms. The annual energy cost savings is $5,600. The PV energy savings over the 15-year measure lifetime is $66,600. The lifecycle cost savings is $30,000.

The Title 24 standards language traditionally specifies performance requirements rather than specific technologies. Thus, instead of specifying a particular technology such as oxygen trim control, this proposal will specify a maximum value of 3.0% for excess oxygen. This is the value used in the LCCA.

4.4.6 Statewide Energy Savings

The projected statewide energy savings and energy cost savings is:

Savings, therms/yr:	606,575
Savings, $/yr @ $1.22/therm:	$740,022
Savings, therms over 11.94 yrs:	7,242,508
PV of energy savings over 11.94 yrs:	$8,835,860

Figure 27 Oxygen Trim Control: Statewide Savings

5. Recommended Language for Standards Document, ACM Manuals, and the Reference Appendices

Definitions:

COMBUSTION AIR POSITIVE SHUT-OFF is a means of restricting air flow through a boiler combustion chamber, used to reduce standby heat loss, e.g. flue damper or vent damper.

PROCESS is an activity or treatment that is not related to the space conditioning, lighting, service water heating, or ventilating of a building as it relates to human occupancy.

PROCESS LOAD is a load resulting from a process.

PROCESS BOILER is a boiler serving a process load.

Section 120.6(d) Mandatory Requirements for Commercial and Process Boilers

Combustion air positive shut-off shall be provided on all new process boilers as follows:

1. All process boilers with an input capacity of 2.5 MMBtu/h (2,500,000 Btu/h) and above, in which the boiler is designed for negative or zero pressure operation.

2. All process boilers where one stack serves two or more boilers with a total combined input capacity per stack of 2.5 MMBtu/h (2,500,000 Btu/h).

Process boiler combustion air fans with motors 10 horsepower or larger shall meet one of the following for new boilers:

1. The fan motor shall be driven by a variable speed drive.

2. The fan motor shall include controls that limit the fan motor demand to no more than 30 percent of the total design wattage at 50 percent of design air volume.

New process boilers with input capacity 5 MMBtu/h (5,000,000 Btu/h) to 10 MMBtu/h (10,000,000 Btu/h) shall maintain excess (stack-gas) oxygen concentrations at less than or equal to 5.0% by volume on a dry basis over the entire firing range. Combustion air volume shall be controlled with respect to firing rate or flue gas oxygen concentration. Use of a common gas and combustion air control linkage or jack shaft is prohibited.

New process boilers with input capacity greater than 10 MMBtu/h (10,000,000 Btu/h) shall maintain excess (stack-gas) oxygen concentrations at less than or equal to 3.0% by volume on a dry basis over the entire firing range. Combustion air volume shall be controlled with respect to firing rate or flue gas oxygen concentration. Use of a common gas and combustion air control linkage or jack shaft is prohibited.

6. Stakeholder Input

All of the main approaches, assumptions and methods of analysis used in this proposal have been presented for review at a number of public Stakeholder Meetings. At each meeting, the utilities' CASE team invited feedback on the proposed measures and analysis and then sent out a summary of what was discussed at the meeting, along with a summary of outstanding questions and issues.

A record of the Stakeholder Meeting presentations, summaries and other supporting documents can be found at www.calcodesgroup.com. Stakeholder meetings were held on the following dates and locations:

- First Stakeholder Meeting: May 25, 2010, San Ramon Valley Conference Center, San Ramon, CA
- Second Stakeholder Meeting: January 19, 2011, San Ramon Valley Conference Center, San Ramon, CA
- Third Stakeholder Meeting: March 2011, via webinar.

The project team also contacted individuals at the following companies while investigating these measures:

- AHM Associates, Inc.
- Ajax Boiler
- Alzeta
- Autoflame
- Babcock & Wilcox
- Cleaver-Brooks
- Enovity, Inc.
- Field Controls
- Fireye
- Heat Transfer Solutions
- Johnson Burners
- One Source Engineering
- Proctor Sales
- RF McDonald
- Southern California Boiler Inc
- Weishaupt

7. Bibliography and Other Research

Architectural Energy Corporation. Life-Cycle Cost Methodology. 2013 California Building Energy Efficiency Standards. November 16, 2010. Prepared for California Energy Commission.

Carpenter, Kevin, C. Schmidt, and K. Kissock. 2008. "Common Boiler Excess Air Trends and Strategies to Optimize Efficiency." ACEEE Summer Study on Energy Efficiency in Buildings.

David Eoff, 2008. Understanding Fuel Savings in the Boiler Room. ASHRAE Journal.

Department of Energy (DOE). 2009. Energy Matters newsletter. Fall 2009- Vol. 1, Iss. 1. Washington, DC: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Industrial Technologies Program

Sam Dukelow, 1991. The Control of Boilers, 2nd Edition. Research Triangle Park, NC.

8. Appendix A: Environnemental Impact

Compliance with the combustion air positive shut off proposal can be achieved by installing a flue damper or vent damper with associated controls. This hardware typically is composed of materials such as steel, copper, and plastic. Additional control logic may have little to no impact on the materials used in the controls. A rough estimate of additional materials usage per boiler is shown in the table below. This is based on a typical unit weight of approximately half a pound and composed of roughly 0.3 pounds of steel, 0.1 pounds of copper, and 0.1 pounds of plastic. The measure lifetime is 15 years with one boiler per prototype building.

	Mercury	**Lead**	**Copper**	**Steel**	**Plastic**	**Others**
Per boiler	No change	No change	0.007 lbs/yr	0.02 lbs/yr	0.007 lbs/yr	No change
Per Prototype Building	No change	No change	0.007 lbs/yr	0.02 lbs/yr	0.007 lbs/yr	No change

Compliance with the combustion fan VFD proposal can be achieved by installing a VFD on the boiler combustion air fan motor. This hardware typically is composed of materials such as steel, copper, and plastic. Additional control logic may have little to no impact on the materials used in the controls. A rough estimate of additional materials usage per boiler is shown in the table below. This is based on a typical unit weight of approximately 11 pounds per product specification sheets. This is composed of roughly 8 pounds of steel, 2 pound of copper, and 1 pounds of plastic. The measure lifetime is 15 years with one boiler per prototype building.

	Mercury	**Lead**	**Copper**	**Steel**	**Plastic**	**Others**
Per boiler	No change	No change	0.1 lbs/yr	0.5 lbs/yr	0.07 lbs/yr	No change
Per Prototype Building	No change	No change	0.1 lbs/yr	0.5 lbs/yr	0.07 lbs/yr	No change

Compliance with the 5% excess oxygen proposal can be achieved by installing a parallel position control system. This system typically includes two or three servo motors, a UV scanner, temperature detector, pressure sensors, and a control system, which are composed of materials such as steel, copper, and plastic. However, this system displaces the baseline case of jackshaft control linkage, which is composed of steel. Additional control logic may have little to no impact on the materials used in the controls. A rough estimate of additional materials usage per boiler is shown in the table below. This is based on a typical unit weight of approximately 8 pounds, net the displaced jackshaft control linkages. This is composed of roughly 6 pounds of steel, 1 pound of copper, and 1 pound of plastic. The measure lifetime is 15 years with one boiler per prototype building.

	Mercury	Lead	Copper	Steel	Plastic	Others
Per boiler	No change	No change	0.07 lbs/yr	0.4 lbs/yr	0.07 lbs/yr	No change
Per Prototype Building	No change	No change	0.07 lbs/yr	0.4 lbs/yr	0.07 lbs/yr	No change

Compliance with the 3% excess oxygen proposal can be achieved by installing an oxygen trim control system. Beyond the parallel position control system described above, this system includes a set of exhaust gas sampling probes and exhaust gas analyzer, which are composed of materials such as steel, copper, and plastic. Additional control logic may have little to no impact on the materials used in the controls. A rough estimate of additional materials usage per boiler is shown in the table below. This is based on an estimated weight of approximately 5 pounds for the exhaust gas sampling probes and exhaust gas analyzer. This is composed of roughly 3 pounds of steel, 1 pound of copper, and 1 pound of plastic. The measure lifetime is 15 years with one boiler per prototype building.

	Mercury	Lead	Copper	Steel	Plastic	Others
Per boiler	No change	No change	0.07 lbs/yr	0.2 lbs/yr	0.07 lbs/yr	No change
Per Prototype Building	No change	No change	0.07 lbs/yr	0.2 lbs/yr	0.07 lbs/yr	No change

.