CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

COMMERCIAL BOILERS

2013 California Building Energy Efficiency Standards

California Utilities Statewide Codes and Standards Team — October 2011

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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 commercial buildings in the Title 24 nonresidential standards. Throughout mid 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.

2. Overview

2.1 *Project Title*

Commercial Boilers

2.2 *Description*

This paper presents three proposals that affect certain sizes of new boilers that serve commercial buildings:

- Combustion air positive shut off
- Combustion fan VFD
- Parallel position 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. Installed flue 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.

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	-	-	0.02	$ 298,450
VFD	-	1.5		$ 2,271,100
Parallel position	-	-	0.26	$ 3,991,610
Total	-	1.5	0.28	$ 6,561,160

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	195	132	59	20	226,340
VFD	231	1,387	337	109	847,105
Parallel position	2,606	1,764	790	263	3,027,178
Total	3,032	3,283	1,185	392	4,100,622

Figure 2 Statewide Avoided Emissions, First Year (lbs)

15-yr EUL	NOX	SOX	CO	PM10	CO2
Flue damper	2,327	1,575	705	235	2,702,500
VFD	2,762	16,562	4,018	1,299	10,114,431
Parallel position	31,116	21,058	9,429	3,143	36,144,500
Total	36,204	39,194	14,152	4,677	48,961,431

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 B: Environmental Impact.

	Mercury	**Lead**	**Copper**	**Steel**	**Plastic**	**Others**
Per boiler	No change	No change	0.18	0.92	0.15	No change
Per Prototype Building	No change	No change	0.18	0.92	0.15	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 2.1 for flue dampers (combustion air positive shut-off), 1.3 for combustion fan VFD, and 1.2 for parallel positioning controls. 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	$3,460	-$1848	-$1848
Combustion fan VFD	$4,249 for 10 HP motor	$4,249	$597	$6,333	-$1,487	-$1,487
Parallel position control	$9,000 for 5 MMBtu/h unit	$9,000	$4,775	$15,984	-$2,209	-$2,209

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 and run an eQUEST model. This was used to generate boiler loads to identify the number of hours within each part-load range by climate zone. The next step was to develop and use a spreadsheet-based energy savings calculation.

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

These measures affect new boilers that serve commercial buildings. The methodology for evaluating the cost effectiveness of these measures was to develop and run an eQUEST model. This was used to generate boiler loads to identify the number of hours within each part-load range by climate zone. The next step was to develop and use a spreadsheet-based energy savings calculation.

AEC (Architectural Energy Corporation) provided TDV (Time Dependent Valuation) energy costs for use in the analysis. The average TDV 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 PV energy costs averaged over the measure lifetime excluding the summer months July, August, and September are $1.27/therm and $0.13/kWh. Boilers installed in commercial buildings should rarely operate during the summer months, thus these costs of $1.27/therm and $0.13/kWh were used throughout this analysis.

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.

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 per unit estimate with the statewide estimate of new construction in 2014. 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 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 an eQUEST model to generate boiler loads to identify the number of hours within each part-load range by climate zone. The next step was to develop and use a spreadsheet-based energy savings calculation. 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]
- 2722 hrs/year boiler operation per eQUEST model. This includes time in standby and firing.
- 1524 hrs in standby mode, from 2722 hrs x 56% per Figure 7.
- Fuel is natural gas at $1.27/therm. This is the PV therm averaged over the measure lifetime excluding the summer months.
- 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 operation

$$11.94 = \frac{\$1612}{\$1.27 * 30\% * 2\% * \text{Boiler input} * 2722\ \text{Hrs} * 56\%\ \text{active standby}}$$

Solving for the boiler input yields 1.2 MMBtu/h (1,200,000 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 and matches the proposed requirement for process boilers.

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 * 2722 * 56%

= 22.9 MMBtu (229 therms/yr)

At $1.27/therm, the annual energy cost savings for a 2.5 MMBtu/h boiler is $290. The PV energy savings over the 15-year measure lifetime is $3,460.

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 $290 (at $1.27/therm). The PV energy cost savings over the 15-year measure lifetime is $3,460. 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	$3,460
Lifecycle cost savings	$1,848
Benefit/Cost Ratio	2.1

Figure 6 Combustion Air Positive Shut Off: Lifecycle Cost Results

4.1.6 Statewide Energy Savings

The statewide energy savings analysis relies on the following new construction forecast data:

- 27,700,000 sf new floor area for large offices
- 9,975,000 for new floor area for schools
- 9,098,000 for new floor area for hotels
- 8,600,000 sf new floor area for hospitals
- 7,400,000 sf new floor area for colleges
- 62,773,000 total new floor area for these occupancies

These are the occupancy types that would see a boiler 2.5 MMBtuh and larger, which is the proposed standard. 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 forecast new installed boiler capacity of 1,794 MMBtu/h, which is derived from the new construction forecast presented above.

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

Annual fuel savings = 30% * 2% * 1,794 * 1,524 * 12%

= 1,970 MMBtu (19,700 therms/yr)

At $1.27/therm, the statewide annual energy cost savings is $25,000. 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 235,000 therms and $300,000.

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 an eQUEST model to generate boiler loads to identify the number of hours within each part-load range by climate zone. The next step was to develop and use a spreadsheet-based energy savings calculation. The following assumptions were used in the analysis:

- 2722 hrs/year boiler operation per eQUEST model. This includes time in standby and firing.
- Motor load factor is 0.7
- Electricity cost is $0.13/kWh. This is the PV kWh averaged over the measure lifetime excluding the summer months.
- 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. This histogram was developed from the set of eQUEST runs.

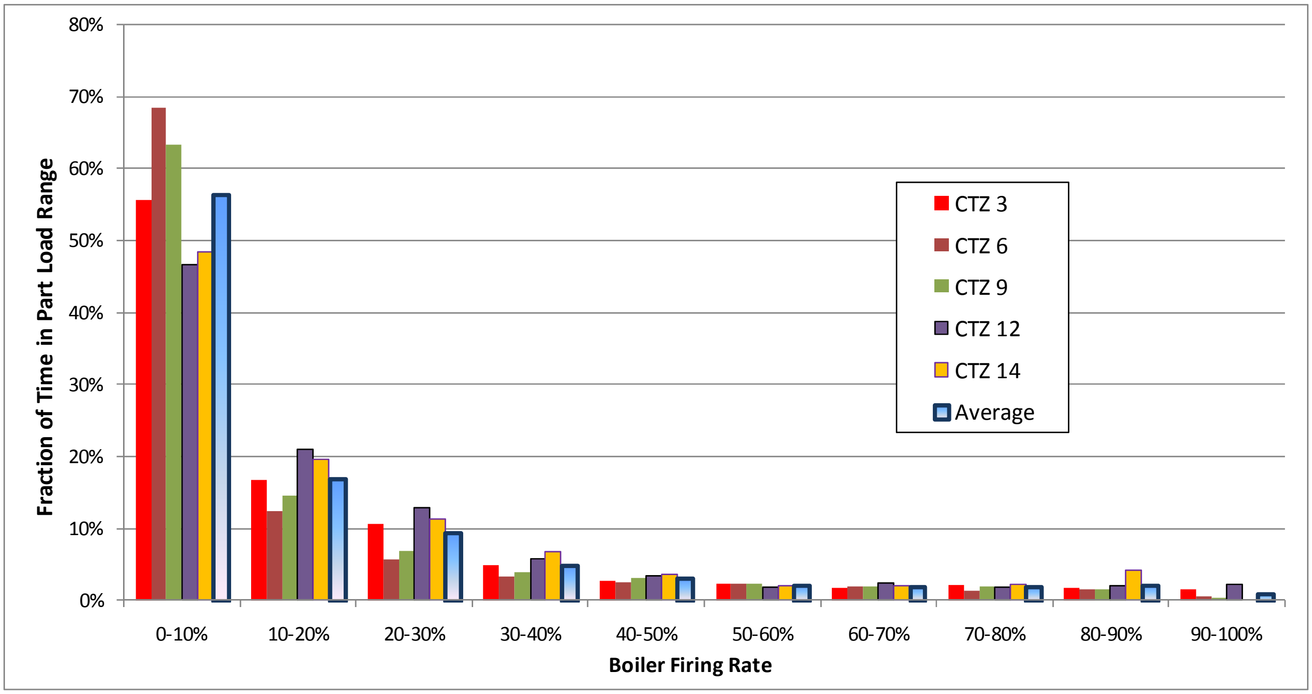

Figure 7 Boiler Run-Time Histogram

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:

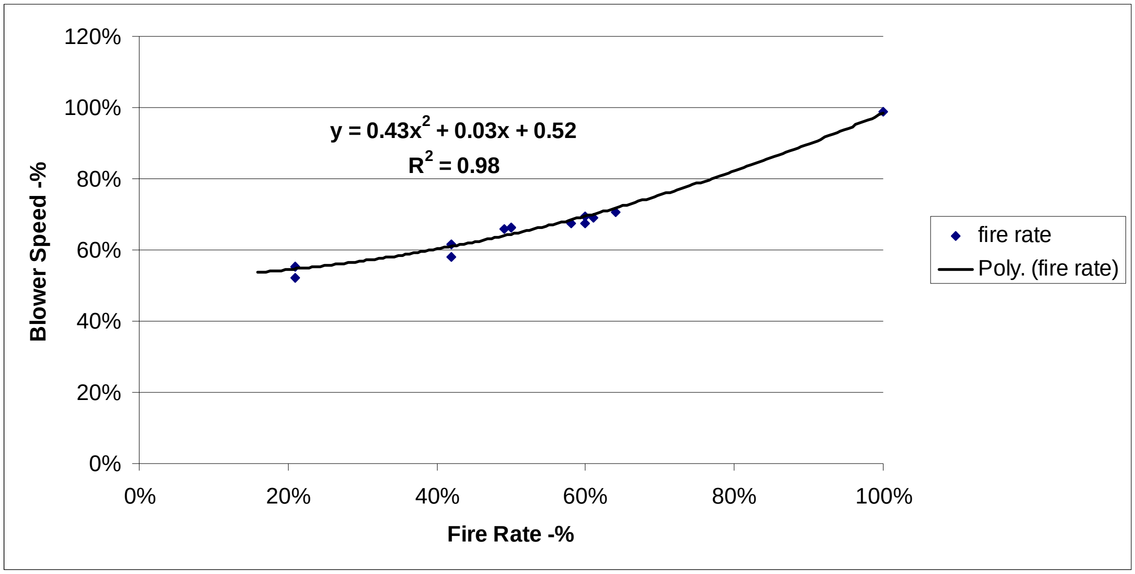

Figure 8 Blower Speed vs. Fire Rate

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 10 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%	56.5%	1537	5.8	0	0	0.0	0	0
15%	16.9%	459	5.8	2,677	54%	1.9	870	1,807
25%	9.5%	259	5.8	1,509	56%	2.0	524	984
35%	4.9%	134	5.8	784	58%	2.2	298	485
45%	3.1%	83	5.8	486	62%	2.5	207	279
55%	2.2%	59	5.8	346	67%	2.8	168	179
65%	2.0%	54	5.8	317	72%	3.3	177	140
75%	2.0%	53	5.8	310	79%	3.8	201	109
85%	2.1%	58	5.8	341	86%	4.4	259	82
95%	0.9%	25	5.8	146	94%	5.2	130	15
		2,722		6,916			2,835	**4,080**

Figure 9 VFD Energy Savings Results for 10 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 $0.13/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	1,224	$1,900
5	2,040	$3,166
7.5	3,060	$4,750
10	4,080	$6,333
15	6,120	$9,499
20	8,161	$12,668
25	10,201	$15,834
30	12,241	$19,000
40	15,707	$24,380
50	19,634	$30,476
60	23,560	$36,570

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)	2013 Equipment Cost	Controls Programming: 8 hrs	Incremental Installed Cost	Cost/HP
3	$2,753	$800	$3,553	$1,184
5	$2,898	$800	$3,698	$740
7.5	$3,449	$800	$4,249	$567
10	$3,449	$800	$4,249	$425
15	$4,318	$800	$5,118	$341
20	$5,738	$800	$6,538	$327
25	$6,898	$800	$7,698	$308
30	$7,999	$800	$8,799	$293
40	$10,839	$800	$11,639	$291
50	$12,172	$800	$12,972	$259
60	$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 10 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	$159	$1,900	($2,250)	0.46	26.1
5	$4,295	$265	$3,166	($1,129)	0.7	16.2
7.5	$4,846	$398	$4,750	($96)	1.0	12.2
10	$4,846	$530	$6,333	$1,487	1.3	9.1
15	$5,715	$796	$9,499	$3,784	1.7	7.2
20	$7,135	$1,061	$12,668	$5,532	1.8	6.7
25	$8,295	$1,326	$15,834	$7,539	1.9	6.3
30	$9,396	$1,591	$19,000	$9,604	2.0	5.9
40	$12,236	$2,042	$24,380	$12,144	2.0	6.0
50	$13,569	$2,552	$30,476	$16,907	2.2	5.3
60	$15,192	$3,063	$36,570	$21,377	2.4	5.0

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 per the LCCA, 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	$6,333
Lifecycle cost savings	$1,487
Benefit/Cost Ratio	1.3

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
378,938	$49,262	4,524,525	$588,188

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 an eQUEST model to generate boiler loads to identify the number of hours within each part-load range by climate zone. The next step was to develop and use a spreadsheet-based energy savings calculation. 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.

- 2722 hrs/year boiler operation per eQUEST model. This includes time in standby and firing.
- Fuel is natural gas at $1.27/therm. This is the PV therm averaged over the measure lifetime excluding the summer months.
- 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. This histogram was developed from the set of eQUEST runs.
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.

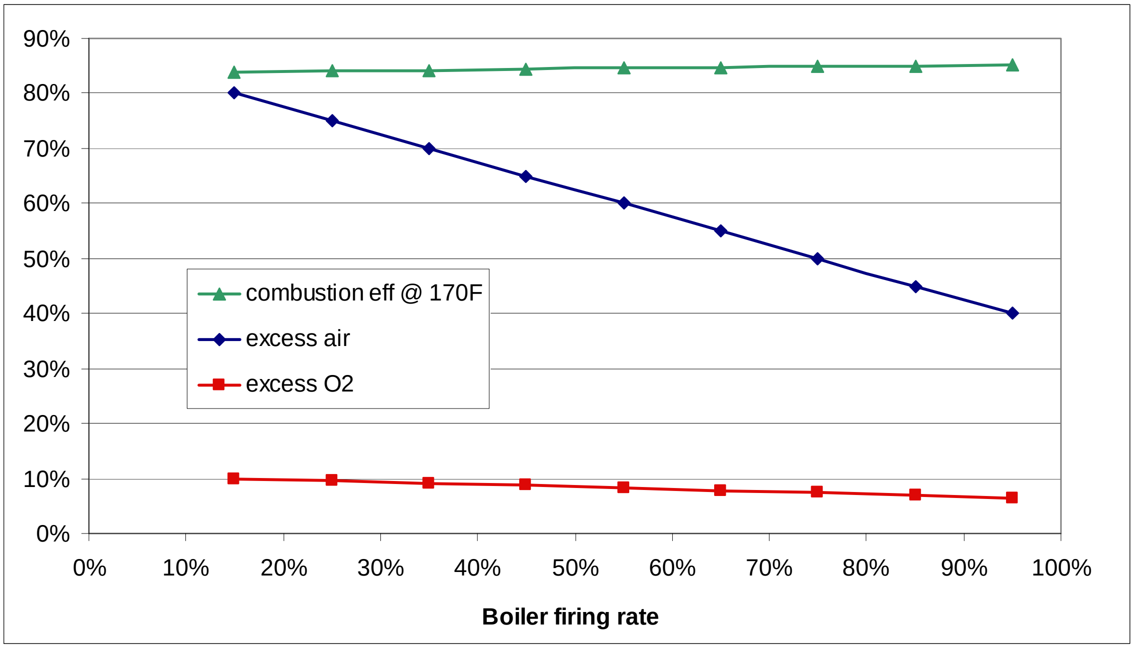

Figure 17 Combustion Efficiency and Excess Air Curves for Natural Gas

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	Measure efficiency	Savings, therms/yr for 2 MMBtuh
0%	56%	1537	0%	0	0%	0	
15%	16.9%	459	10.0%	83.9%	5%	85.5%	200
25%	9.5%	259	9.6%	84.1%	5%	85.5%	102
35%	4.9%	134	9.1%	84.2%	5%	85.5%	47
45%	3.1%	83	8.7%	84.4%	5%	85.5%	26
55%	2.2%	59	8.3%	84.5%	5%	85.5%	16
65%	2.0%	54	7.8%	84.7%	5%	85.5%	12
75%	2.0%	53	7.4%	84.9%	5%	85.5%	9
85%	2.1%	58	7.0%	85.0%	5%	85.5%	8
95%	0.9%	25	6.5%	85.2%	5%	85.5%	2
		2,722					***422***

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 fuel rate of $1.27/therm, 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	4.5	5.0	10.0	20.0	50.0
0%	56%	1537						
15%	16.9%	459	200	451	501	1,001	2,002	5,006
25%	9.5%	259	102	229	254	508	1,016	2,540
35%	4.9%	134	47	106	117	235	470	1,174
45%	3.1%	83	26	57	64	128	255	638
55%	2.2%	59	16	35	39	78	156	391
65%	2.0%	54	12	27	30	60	120	300
75%	2.0%	53	9	21	24	47	94	236
85%	2.1%	58	8	18	20	40	79	198
95%	0.9%	25	2	5	6	12	23	58
Savings, therms/yr:			422	949	1,054	2,108	4,216	10,541

Figure 19 Parallel Positioning Energy Savings for Range of Boilers

Boiler input, MMBtuh:	2.0	4.5	5.0	10.0	20.0	50.0
Savings, therms/yr:	422	949	1,054	2,108	4,216	10,541
Savings, $/yr @ $1.27/therm:	$535	$1,205	$1,339	$2,677	$5,355	$13,387
PV of energy savings over 11.94 yrs:	$6,394	$14,386	$15,984	$31,969	$63,938	$159,845

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 4.5 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	4.5	5.0	10.0	20.0	50.0
Savings, therms/yr:	422	949	1,054	2,108	4,216	10,541
Savings, $/yr @ $1.27/therm:	$535	$1,205	$1,339	$2,677	$5,355	$13,387
PV of energy savings over 11.94 yrs:	$6,394	$14,386	$15,984	$31,969	$63,938	$159,845
Total incremental cost:	$13,775	$13,775	$13,775	$13,775	$13,775	$13,775
Benefit/Cost ratio:	**0.5**	**1.0**	**1.2**	**2.3**	**4.6**	**11.6**
Simple payback, yrs	25.7	11.4	10.3	5.1	2.6	1.0

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 1,054 therms. The annual energy cost savings is $1,339. The PV energy savings over the 15-year measure lifetime is $15,984. The lifecycle cost savings is $15,984 - $13,775 = $2,209.

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.

Note in Figure 16 Combustion Efficiency Table for Natural Gas, the corresponding efficiency is 85.5% for a boiler operating at 5.0% excess oxygen and 170F stack differential. This proposal thus includes an exemption for units with full load thermal efficiency 85% or greater.

4.3.6 Statewide Energy Savings

The statewide energy savings analysis relies on the following new construction forecast data:

- 27,700,000 sf new floor area for large offices

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

- 8,600,000 sf new floor area for hospitals
- 7,400,000 sf new floor area for colleges

These are the occupancy types that would see a boiler 5 MMBtuh and larger, which is the proposed standard. The projected statewide energy savings and energy cost savings is:

Savings, therms/yr:	263,199
Savings, $/yr @ $1.27/therm:	$334,263
Savings, therms over 11.94 yrs:	3,142,594
PV of energy savings over 11.94 yrs:	$3,991,095

Figure 22 Parallel Position 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.

COMMERCIAL BOILER is a boiler serving a space heating or water heating load in a commercial building.

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

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

1. All 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 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).

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 boilers with input capacity 5 MMBtu/h (5,000,000 Btu/h) or greater 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.

EXCEPTION: Boilers with steady state full-load thermal efficiency 85% or higher.

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

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8. Appendix A: Non-Residential Construction Forecast Details

Summary

The Non-Residential construction forecast dataset is data that is published by the California Energy Commission's (CEC) demand forecast office. This demand forecast office is charged with calculating the required electricity and natural gas supply centers that need to be built in order to meet the new construction utility loads. Data is sourced from Dodge construction database, the demand forecast office future generation facility planning data, and building permit office data.

All CASE reports used the statewide construction forecast for 2014. The TDV savings analysis is calculated on a 15 or 30 year net present value, so it is correct to use the 2014 construction forecast as the basis for CASE savings.

Additional Details

The demand generation office publishes this dataset and categorizes the data by demand forecast climate zones (FCZ) as well as building type (based on NAICS codes). The 16 climate zones are organized by the generation facility locations throughout California, and differ from the Title 24 building climate zones (BCZ). The Heschong Mahone Group (HMG) has reorganized the demand forecast office data using 2000 Census data (population weighted by zip code) and mapped FCZ and BCZ to a given zip code. The construction forecast data is provided to CASE authors in BCZ in order to calculate Title 24 statewide energy savings impacts. Though the individual climate zone categories differ between the demand forecast published by the CEC and the construction forecast, the total construction estimates are consistent; in other words, HMG has not added to or subtracted from total construction area.

The demand forecast office provides two (2) independent data sets: total construction and additional construction. Total construction is the sum of all existing floor space in a given category (Small office, large office, restaurant, etc.). Additional construction is floor space area constructed in a given year (new construction); this data is derived from the sources mentioned above (Dodge, Demand forecast office, building permits).

Additional construction is an independent dataset from total construction. The difference between two consecutive years of total construction is not necessarily the additional construction for the year because this difference does not take into consideration floor space that was renovated, or repurposed.

In order to further specify the construction forecast for the purpose of statewide energy savings calculation for Title 24 compliance, HMG has provided CASE authors with the ability to aggregate across multiple building types. This tool is useful for measures that apply to a portion of various building types' floor space (e.g. skylight requirements might apply to 20% of offices, 50% of warehouses and 25% of college floor space).

The main purpose of the CEC demand forecast is to estimate electricity and natural gas needs in 2022 (or 10-12 years in the future), and this dataset is much less concerned about the inaccuracy at 12 or 24 month timeframe.

It is appropriate to use the CEC demand forecast construction data as an estimate of future years construction (over the life of the measure). The CEC non-residential construction forecast is the best publicly available data to estimate statewide energy savings.

Citation

"NonRes Construction Forecast by BCZ v7"; Developed by Heschong Mahone Group with data sourced August, 2010 from Abrishami, Moshen at the California Energy Commission (CEC)

9. Appendix B: Environmental 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 excess oxygen proposal can be achieved by installing a parallel position control system. This system typically includes two servo motors 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