CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

# Draft Measure Information Template – Process Boilers

## *2013 California Building Energy Efficiency Standards*

California Utilities Statewide Codes and Standards Team, March 2011

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# 1 Purpose

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.

This is a preliminary draft version of the CASE Report. A final version will be completed by Summer/Fall 2011.

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# 2 Overview

## 2.1 *Project Title*

Process Boilers

## 2.2 *Description*

This paper presents three proposals, all of which affect boilers that serve process loads:

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

The first measure analyzed is combustion air positive shut off. There are two types of boiler systems this measure would apply to: natural draft (atmospheric) and forced draft. 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. 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

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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 process boilers.

## 2.4 *Energy Benefits*

The energy savings over the first year and the 15-year measure lifetime for all units installed the first year are presented here:

| | First year | | 15 years EUL | |
|---|---|---|---|---|
| | MMBtu | MWh | MMBtu | MWh |
| Flue damper | 4,884 | - | 58,320 | - |
| VFD | - | 2,624 | - | 31,336 |
| Parallel position | 158,989 | - | 1,898,332 | - |
| Total | 163,874 | 2,624 | 1,956,652 | 31,336 |

## 2.5 *Non-Energy Benefits*

None.

## 2.6 *Environmental Impact*

There are no significant potential 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 | 484 | 327 | 147 | 49 | 561,709 |
| VFD | 415 | 2,488 | 604 | 195 | 1,519,454 |
| Parallel position | 15,740 | 10,652 | 4,770 | 1,590 | 18,283,765 |
| Total | 16,638 | 13,468 | 5,520 | 1,834 | 20,364,928 |

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| 15-yr EUL | NOX | SOX | CO | PM10 | CO2 |
|---|---|---|---|---|---|
| Flue damper | 5,774 | 3,907 | 1,750 | 583 | 6,706,800 |
| VFD | 4,954 | 29,707 | 7,207 | 2,329 | 18,142,280 |
| Parallel position | 187,935 | 127,188 | 56,950 | 18,983 | 218,308,157 |
| Total | 198,662 | 160,802 | 65,907 | 21,896 | 243,157,237 |

## 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.

| 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 Proto Building | Per Unit | Per Proto Building | Per Unit | Per Proto Building | | (c+e)-f Based on Current Costs | (d+e)-f Based on Post-Adoption Costs |
| Combustion air positive shutoff | $1,500 for 0.70 MMBtu/h unit | | $1,500 | | $112 | | $1,791 | -$179 | -$179 |
| 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 |

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## 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.

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# 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 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.[i] On an annual basis, this translates to an average of $1.22/therm and $0.16/kWh. In other words, these are the NPV 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.

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# 4 Analysis and Results

## 4.1 *Combustion air positive shut off*

The first measure analyzed is combustion air positive shut off. 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.[iv]
- Standby losses are 2% of rated fuel input.[iv]
- 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 NPV 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 operation

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

Solving for the boiler input yields 0.632 MMBtu/h (632,000 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 0.70 MMBtu/h (700,000 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:

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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% * 0.70 * 2920

= 12.3 MMBtu (123 therms/yr)

At $1.22/therm, the annual energy cost savings for a 0.70 MMBtu/h boiler is $150. The NPV energy savings over the 15-year measure lifetime is $1,791.

### 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):

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

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 NPV 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 0.70 MMBtu/h), the annual energy cost savings is $150 (at $1.22/therm). The NPV energy cost savings over the 15-year measure lifetime is $1,791. As shown in Figure 1, the measure is cost effective.

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| | |
|---|---|
| Incremental Installed Cost | $1,500 |
| Maintenance | $150 |
| NPV of Maintenance (Year 10) | $112 |
| Total Incremental Cost | $1,612 |
| NPV of Energy Savings | $1,791 |
| Lifecycle cost savings | $179 |
| Benefit/Cost Ratio | 1.1 |

**Figure 1 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 operation * % applicable boilers

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

The % applicable boilers consists of:

- 20%: Estimate of the percentage of boilers that are serving both a process + space heating/DHW load
- 30%: Percent applicable boilers; from South Coast AQMD: 12% of boilers are atmospheric and flue damper always applies; 88% of boilers are forced draft and damper applies 20% of the time:

| | **draft** | **forced** | |
|---|---|---|---|
| type | 12% | 88% | |
| damper applies | 100% | 20% | |
| total | 12% | 18% | **30%** |

Annual fuel savings = 30% * 2% * 4,709 * 2920 * 20% * 30%

= 4,884 MMBtu (48,840 therms/yr)

At $1.22/therm, the statewide annual energy cost savings is $59,600. 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 583,200 therms and $711,500.

## 4.2 *Combustion fan VFD*

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

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### 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 NPV 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 2. Enovity, Inc. provided this histogram, which is a compilation of boilers they monitored as part of their third-party commercial and industrial boiler program.

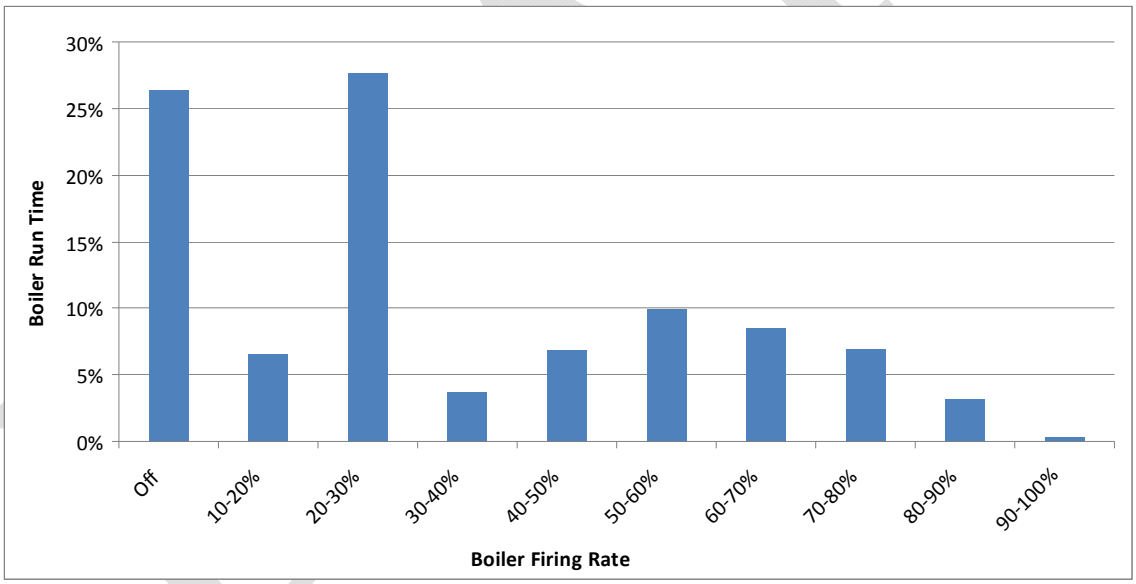


**Figure 2 Boiler Run-Time Histogram**

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 California university as part of this proposal. This correlation is shown below in Figure 3:

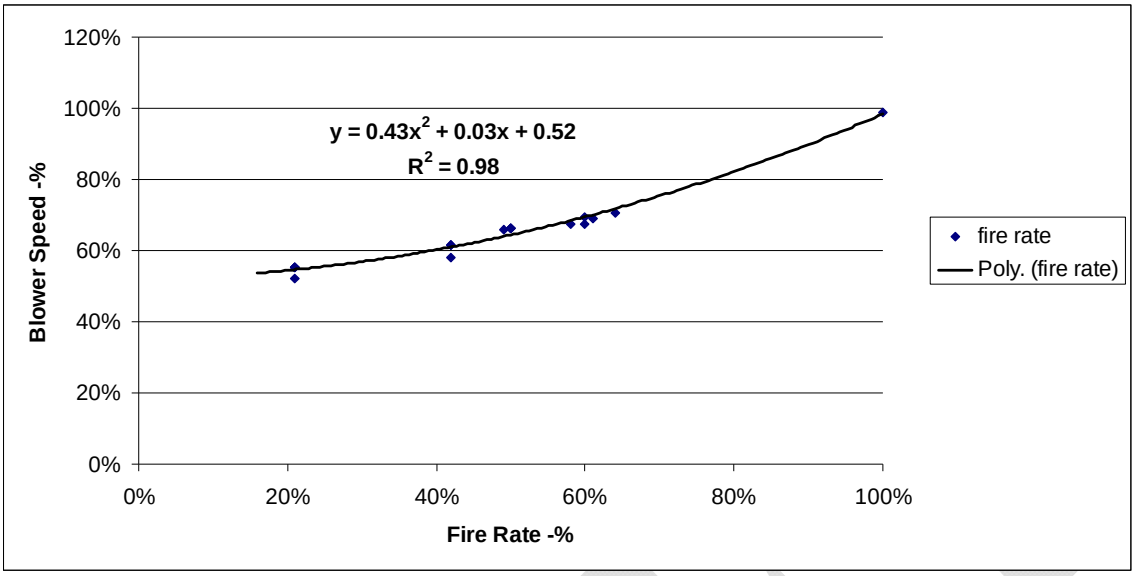


**Figure 3 Blower Speed vs. Fire Rate**

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 over estimate 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 remain ultra conservative.
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 4 below shows the savings calculation inputs and results for a 5 HP motor.

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| 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 4 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 Net Present Value (NPV) 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 5.

| Size (hp) | Annual Energy Savings, kWh/yr | NPV 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 5 VFD Energy Savings Results 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 inflated by 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 6.

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| 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 6 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 NPV of the annual maintenance discounted by 3% over 15 years is $597. Adding the NPV of the annual maintenance to the incremental installed cost yields the total incremental cost as shown in Figure 7.

| Size (hp) | Incremental Installed Cost | NPV 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 7 VFD Total Installed Incremental Costs**

### 4.2.5 Life Cycle Cost Results

As shown in Figure 8, 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.

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| Size (hp) | Total Incremental Cost | Annual Energy Savings, $/yr | NPV 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 8 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 NPV 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 9.

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

**Figure 9 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

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| Statewide Annual Energy Savings, kWh/yr | Statewide Annual Energy Savings, $/yr | Energy Savings over EUL, kWh | NPV of Energy Savings over EUL |
|---|---|---|---|
| 2,624,454 | $419,913 | 31,335,981 | $5,013,757 |

## 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[ii]
- Measure case excess air (oxygen) is 28% (5%)[iii]
- Net temperature difference (stack temp – intake temp) is 170˚F, a conservative estimate[iv]
- 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 NPV 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 2. 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.[iv] The table used for natural gas fired boilers is shown below in Figure 10. 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 11.

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| 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 10 Combustion Efficiency Table for Natural Gas**

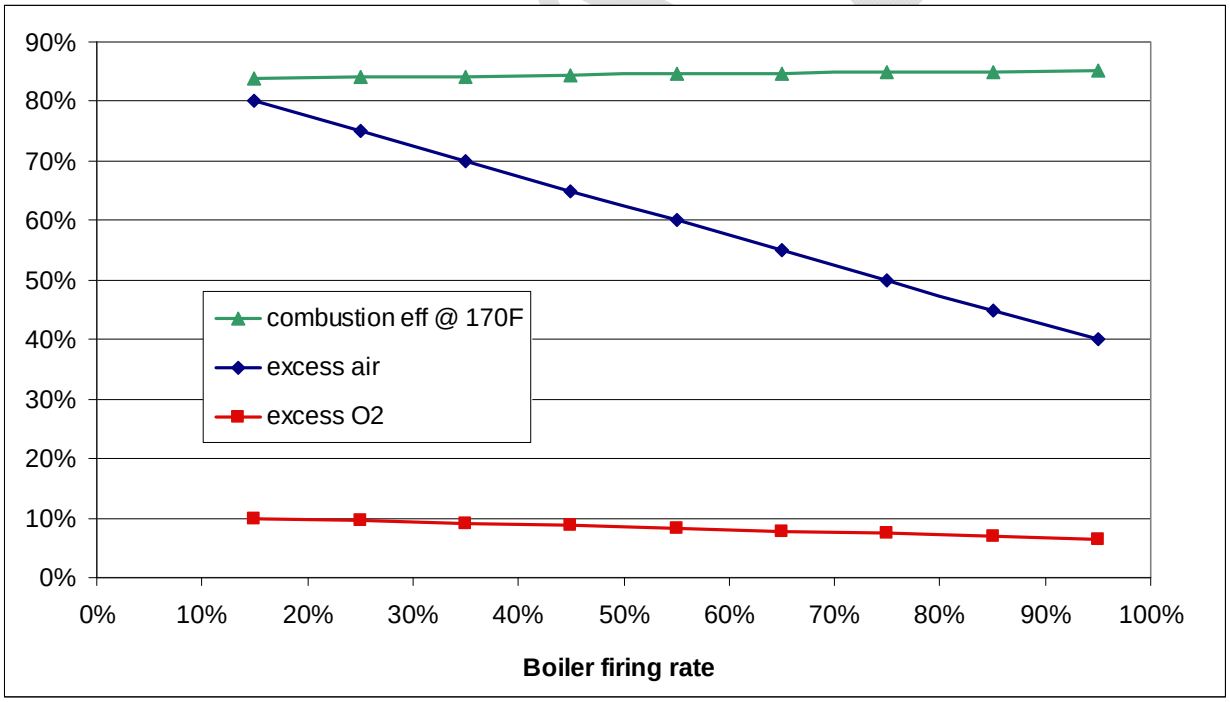


**Figure 11 Combustion Efficiency and Excess Air Curves for Natural Gas**

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 12 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 12 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 Net Present Value (NPV) 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 13 and Figure 14.

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| | | | 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 13 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 14 Parallel Positioning Energy Savings and NPV 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 NPV 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 NPV maintenance cost ($4,775) for a total incremental cost of $13,775.

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As shown in Figure 15, 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 15 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).[v] 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 NPV 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 for the base case in the LCCA.

### 4.3.6 Statewide Energy Savings

The projected statewide energy savings and energy cost savings is:

| | |
|---|---|
| Savings, therms/yr: | 1,589,893 |
| Savings, $/yr @ $1.22/therm: | $1,939,669 |
| Savings, therms over 11.94 yrs: | 18,983,318 |
| NPV of energy savings over 11.94 yrs: | $23,159,648 |

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

Combustion air positive shut-off shall be provided on all natural draft and forced draft process boilers as follows:

1. All process boilers with an input capacity of 0.70 MMBtu/h (700,000 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 0.70 MMBtu/h (700,000 Btu/h).

3. All process boilers when combustion air positive shut-off would significantly reduce air flow, and consequently boiler heat loss, during standby and shutdown periods.

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

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.

Process boiler systems with input capacity 5 MMBtu/h (5,000,000 Btu/h) or larger 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.

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# 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

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# 7 Bibliography and Other Research

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[iii] 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.

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

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

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