Evaluation study of a commercial gas boiler energy efficiency program

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Abstract

This paper provides evaluation, measurement, and verification findings for a commercial gas boiler energy efficiency program in California. The program provided incentives for low, medium, and high efficiency natural gas boilers with output capacities ranging from 422 to 2,110 GJ/hour and rated efficiencies ranging from 82 to 98 percent. The evaluation adhered to the International Performance Measurement and Verification Protocol (IPMVP).[1] Field measurements of boiler efficiencies were made using combustion efficiency analyzers.[2] Hours of operation were monitored using motor loggers installed on the combustion supply-air fan. Ex-post energy savings were based on field measurements and customer billing data. Statistical sampling methods were used extrapolate mean savings estimates from sample measurements to the population and to evaluate precision.

Net ex-post program savings were 38,252 ± 4,357 GJ/year and 765,044 ± 34,662 GJ lifecycle. The first-year net realization rate was 0.87 ± 0.10. This was due to field-measured efficiencies and full-load operating hours being less than ex ante values. Field-measured boiler efficiencies were generally 4 to 12 % lower than manufacturers' ratings due to higher inlet and lower outlet temperature conditions. Manufacturer ratings are based on 26.7 ± 1.67°C inlet and 82.2 ± 0.91°C outlet temperatures according to ANSI Z21.13-2000. The ANSI inlet and outlet temperatures are not typical of normal operation where average inlet temperatures are 46.1 ± 4.4°C and outlet temperatures are 63.3 ± 4.7°C. In-situ field measurements of old boilers found pre-retrofit combustion efficiencies of 75 % consistent with ex ante values.

The incentives offered by the program ranged from 20 to 30 % of the cost of the boilers. The program design was based on manufacturers' reported performance data and product literature. Future programs should be based on field-verified boiler efficiency ratings rather than manufacturers' ratings. Problems encountered during the evaluation included loss of equipment and data due to internal explosions on two boilers. The program cost was $ 1,142,857, and the evaluation study cost was $ 48,820.

Introduction

This paper provides evaluation, measurement, and verification findings for a program that provided incentives for low (82-84 %), medium (85-92 %), and high (93-97 %) efficiency gas boilers or water heaters to hard-to-reach small commercial building owners and businesses. Low efficiency boilers received incentives of $ 2.50 per GJ/hour, medium efficiency boilers received incentives of $4 per GJ/hour, and high efficiency boilers received incentives of $ 7 per GJ/hour. The program helped building owners save energy and meet strict emissions requirements of the South Coast Air Quality Management District for boilers and water heaters. The program was implemented dur-

1. See International Performance Measurement & Verification Protocols, DOE/GO-102000-1132, October 2000.

2. Combustion efficiency was measured on 73 gas boilers consistent with ANSI Z21.13-2000 except for in situ inlet and outlet water temperatures.

Table 1. Ex Ante First Year Load Impacts for Commercial Boiler Energy Efficiency Program

Description	Ex Ante Qty.	Ex Ante Efficiency	Ex Ante Full Load Hours (hrs)	Gross Ex Ante Unit Savings (GJ/yr)	Gross Ex Ante Program Savings (GJ/yr)	Ex Ante Net-to-Gross Ratio	Net Ex Ante Program Savings (GJ/yr)
Low Eff. Boilers (82 to 84%)	115	84.5%	2,000	190	21,834	0.8	17,468
Medium Eff. Boilers (85 to 92%)	30	91.4%	2,000	345	10,348	0.95	9,830
High Eff. Boilers (93 to 97%)	43	96.0%	2,000	411	17,689	0.95	16,805
Total	**188**			**265**	**49,871**	**0.88**	**44,102**

Table 2. Ex Post First Year Load Impacts for Commercial Boiler Energy Efficiency Program

Description	Ex Post Qty.	Ex Post Efficiency	Ex Post Full Load Hours (hrs)	Gross Ex Post Unit Savings (GJ/yr)	Gross Ex Post Program Savings (GJ/yr)	Ex Post Net-to-Gross Ratio	Ex Post Net Program Savings (GJ/yr)	Ex Post Net Realization Rate
Low Eff. Boilers (82 to 84%)	184	81.2%	1,869	159	29,345	0.96	28,172	1.61
Med. Eff. Boilers (85 to 92%)	15	80.9%	1,971	196	2,940	0.96	2,822	0.29
High Eff. Boilers (93 to 97%)	20	87.3%	1,850	378	7,561	0.96	7,258	0.43
Total	**219**			**182**	**39,846**	**0.96**	**38,252**	**0.87**

ing 2002-03 in the Southern California Gas Company service area with public good charge funding under the auspices of the California Public Utilities Commission. The program cost was $ 1,142,857, and the study cost was $ 48,820.

The study included a load impact evaluation and process evaluation. The load impact evaluation included field measurement and verification activities at a statistically significant random sample of 71 customer sites. The load impact evaluation followed the International Performance Measurement and Verification Protocols (IPMVP) Option B.[3] Field measurements of boiler thermal efficiencies were made using a combustion efficiency analyzer (ANSI 2000, Federal Register 2000).[4] Hours of operation were evaluated using motor loggers installed on the blower fan which turns on every time the boiler fires. The on-site data collection efforts analyzed baseline and measure assumptions by taking measurements and collecting billing data at customer sites. Statistical sampling methods were used to analyze the data and extrapolate mean savings estimates from the sample measurements to the population and to evaluate the statistical precision of the results.

The process evaluation included a statisitically random sample of 40 participants and 20 non-participants. The approach for the process evaluation involved designing and implementing surveys to measure participant satisfaction, and to obtain suggestions to improve the program's services and procedures. Survey interviews included questions about market barriers to energy efficiency and the success of the program in meeting the needs of hard-to-reach small commercial customers. Analysis of process evaluation survey data included a summary of what works, what doesn't work, and the level of need for the program.

3. IPMVP Option B is referred to as retrofit isolation where savings are determined by field measurement of the energy use of the systems to which the measure was applied, separate from the energy use of the rest of the facility. Short-term or continuous measurements of hours of operation are taken throughout the post-retrofit period.

4. Boiler efficiency measurements are consistent with the American National Standards Institute (ANSI) procedures except for the inlet and outlet temperatures where in-situ values were used for the application.

Load Impact Evaluation Findings

Load impact evaluation findings indicate the program exceeded its goals. Ex post cost effectiveness was 38 percent greater than the ex ante assumptions, but the first year net realization rate was 0.87 ± 0.10. This was due to field measured efficiencies and full load operating hours being less than ex ante values. The ex ante first year load impacts are summarized in **Table 1**. The gross first year ex ante load impacts for the program are 49,871 Giga joule (GJ) per year. The ex ante net-to-gross ratio (NTGR) was 0.80 for early replacement low efficiency boilers and 0.95 for medium and high efficiency boilers, and the net ex ante program savings are 44,102 GJ per year.[5] Ex post first year load impacts are summarized in **Table 2**. The ex post first-year net program savings are 38,252 ± 4,357 GJ per year at the 90 percent confidence level. The first-year net realization rate for energy savings is 0.87 ± 0.10. This was due to field measured efficiencies and full load operating hours being less than ex ante values. Ex post field measured efficiencies are lower than rated efficiencies due to markedly different inlet and outlet temperature conditions compared to the ANSI Z21.13-2000 test conditions under which boilers are rated. Another reason for the reduced efficiency might be due to the performance of randomly selected boilers in the field compared to manufacturer test results which are done for a selected sample of manufactured boilers. Field measured efficiencies might also be lower due to piping insulation, buried versus unburied piping and weather conditions that affect annual operating efficiency, and fuel consumption of the boilers. In-situ field measurements of old boilers were performed and the pre-retrofit combustion ef-

5. NTGR represents the net program load impact divided by the gross program load impact.

Table 3. Lifecycle Load Impacts for the Commercial Boiler Energy Efficiency Program

Measure	Net Ex Ante Program Savings (GJ/yr)	Ex Ante Effective Useful Life (EUL)	Net Ex Ante Lifecycle Program Savings (GJ)	Net Ex Post Program Savings (GJ/yr)	Ex Post Effective Useful Life (EUL)	Ex Post Net Lifecycle Program Savings (GJ)	Ex Post Net Realization Rate
Low Eff. Boilers (82 to 84%)	17,468	3	52,403	28,172	20	563,433	10.75
Med. Eff. Boilers (85 to 92%)	9,830	20	196,605	2,822	20	56,443	0.29
High Eff. Boilers (93 to 97%)	16,805	20	336,092	7,258	20	145,168	0.43
Total	**44,102**		**585,100**	**38,252**		**765,044**	**1.31**

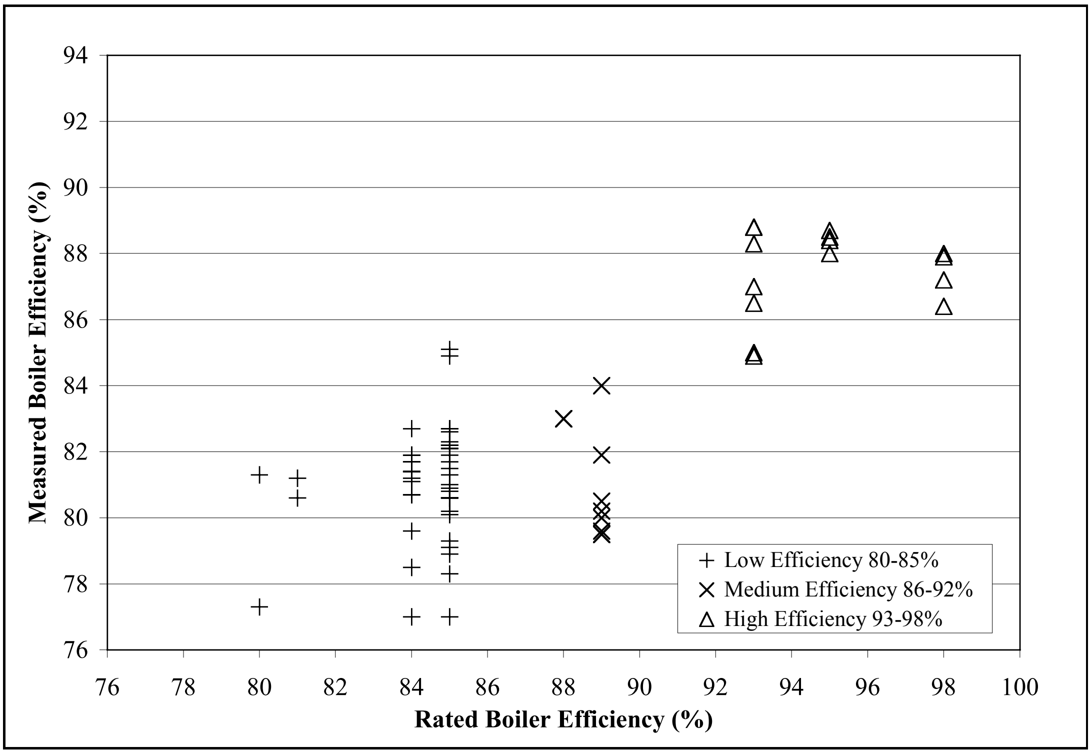

Figure 1. Measurements of Low, Medium, and High Efficiency Boilers

ficiency values were in the 75 % range and generally consistent with the ex ante pre-retrofit efficiency values.

Lifecycle energy savings are summarized in **Table 3**. The ex-ante net lifecycle savings are 585,100 GJ. The EM&V study ex-post net lifecycle savings are 765,044 ± 34,662 GJ. The ex-post net lifecycle realization rate is 1.31 ± 0.06. The lifecycle net realization rate is greater than one due to the ex post NTGR and effective useful life (EUL) being greater than ex ante values (CPUC 2003).[6]

Most of the program net ex post energy savings are from greater sales of low efficiency boilers (184 ex post versus 115 ex ante), and the greater ex post net-to-gross ratio (0.96 ex post versus 0.8 ex ante). The realization rates from medium and high efficiency boilers were 0.29 and 0.43 respectively primarily due to lower field measured boiler efficiencies. Field measured efficiencies were generally found to be 4 to 12 percent lower than manufacturer ratings due to higher inlet and lower outlet temperature conditions as shown in **Figure 1** (Mowris et al. 2004b).

Manufacturer ratings are based on ANSI Z21.13-2000 with 26.7 ± 1.67°C inlet and 82.2 ± 0.91°C outlet temperatures. The ANSI inlet and outlet temperatures are not typical of normal operation. The study found average inlet temperatures of 46.1 ± 4.4°C and outlet temperatures of 63.3 ± 4.7°C. In-situ field measurements of old boilers found pre-retrofit combustion efficiencies in the 75 % range and generally consistent with ex ante values. The highest measured efficiency for all boilers tested was 89 % including boilers with rated efficiencies of 98 %. Measured efficiencies were generally closer to rated efficiencies for lower efficiency boilers with a 3.3% difference. The difference was 7.7 % for medium efficiency, and 7.5 % for high efficiency boilers. Based on field measurements, the average medium efficiency boiler was 0.1 % more efficient than low efficiency, and high efficiency was 6.2 % more efficient than medium efficiency.

6. Ex post 0.96 NTGR and 20 year EUL are based on previous evaluation and retention studies, see Energy Efficiency Policy Manual, Version 3, Chapter 4, prepared by the California Public Utilities Commission, 2003.

Process Evaluation Findings

Process evaluation surveys were conducted in-person and over the telephone with 40 participants and 20 non-participants. Surveys were randomly selected to include at least two surveys from the following building types: Laundromats, hotels, fabricators, small health care facilities, schools, and institutions. Interviews assessed how the program influenced awareness of linkages between efficiency improvements and bill savings. The process surveys were used to evaluate participant satisfaction and obtain suggestions to improve the program's services and procedures. Participants were asked why and how they decided to participate in the program. Non-participants were asked why they chose not to participate. The surveys identified reasons why program marketing efforts were not successful with non-participants as well as to identify additional hard-to-reach market barriers.

Process evaluation findings indicated 92 percent of participants were satisfied with the program and felt that others would benefit from participating. Approximately 70 % believed the program increased their understanding of the linkage between energy efficient boilers and bill savings. The average conditioned floor area for participants is 116,326 ft^2 and 40 % leased their space. The primary language of participants is as follows: 80 % English, 7.5 % Spanish, 5 % Hindi, 5 % Chinese, and 2.5 % Vietnamese. The participant businesses were identified as follows: 22.5 % laundromats, 20 % schools, 17.5 % motels, 10 % health care, 7.5 % office, 7.5 % health club, 5 % church, 2.5 % theater, 2.5 % city pool, 2.5 % farm, and 2.5 % food service. Process survey responses indicated that 40 % of interviewed customers shared program information with 7.2 times as many peers (16 participants shared information with 115 businesses). Approximately 40 % of these businesses (i.e., 46) decided to install similar measures or participate in the program. The program helped expand impacts beyond the participant group to a larger group through direct installation of measures. The multiplier effect for the program is estimated at 42 %.[7]

Non-participant evaluation findings show significant demand for the program with 100 % of participants indicating that they think all businesses would benefit from the program. Approximately 45 % of non-participants would have participated if they knew the program provided rebates for new high efficiency boilers. The following reasons were given for not participating: 45 % didn't know about the program (i.e., information cost barrier), 35 % said that they are waiting for the air quality management district deadline of January 1, 2006 to replace their boilers, 20 % said that they didn't have the money to replace their boilers, 20 % indicated that their existing boilers didn't need replacing, 7.5 % gave other reasons for not participating. The cost barriers associated with installing efficient boilers are significant. Typical boiler installation costs range from $ 9,000 to $ 14,000 for standard boilers with an incremental cost of $ 3,000 to $ 10,000 for low to high efficiency boilers. Although condensing boilers have been available in the US market for over a decade and there are significant operating cost savings from them, they have very little market penetration due to the higher incremental cost. The incentives offered by the program ranged from 20 to 30 % of the total cost of the boilers and this was the most important reason given for participation.

Approximately 45 % non-participants suggested improving the program with better advertising through boiler dealers, boiler installers, utility bill inserts, or mail. This is consistent with 45 % who indicated they would have participated if they knew about the program. Non-participant demographics are as follows: 55 % leased their building, 95 % spoke English as their primary language, and 5 % spoke Chinese as their primary language. The non-participating businesses included the following categories: 30 % motel, 25 % Laundromat, 25 % health care, 10 % retail, 5 % office, and 5 % food preparation.

The program implementer designed the program based on manufacturer reported performance data and product literature. Future programs should be based on field verified boiler efficiency ratings rather than manufacturer ratings which were found to be overstated especially for high efficiency boilers examined in this study. Results from the study will be used to inform planners and decision makers about future boiler incentive programs. Problems encountered during the evaluation included loss of equipment and data due to internal explosions on two boilers.

Conclusions

The load impact evaluation findings indicate that the commercial gas boiler energy efficiency program exceeded its goals. Net ex-post program savings for the program were 38,252 ± 4,357 GJ/year and 765,044 ± 34,662 GJ lifecycle. Ex post cost effectiveness was 38 percent greater than the ex ante assumptions, but the first year net realization rate was 0.87 ± 0.10. This was due to field measured efficiencies and full load operating hours being less than ex ante values. Field-measured boiler efficiencies were generally 4 to 12 % lower than manufacturers' ratings due to higher inlet and lower outlet temperature conditions. Manufacturer ratings are based on 26.7 ± 1.67°C inlet and 82.2 ± 0.91°C outlet temperatures according to ANSI Z21.13-2000. The ANSI inlet and outlet temperatures are not typical of normal operation where average inlet temperatures are 46.1 ± 4.4°C and outlet temperatures are 63.3 ± 4.7°C. In-situ field measurements of old boilers found pre-retrofit combustion efficiencies of 75 % consistent with ex ante values. The highest measured efficiency for all boilers tested was 89 % including boilers with rated efficiencies of 98 %. Measured efficiencies were generally closer to rated efficiencies for lower efficiency boilers with a 3.3 % difference. Based on field measurements, the average medium efficiency boiler was 0.1 % more efficient than low efficiency, and high efficiency was 6.2 % more efficient than medium efficiency. This is important information for consumers who might be misinformed about performance based on inaccurate labels.

Process evaluation findings indicated 92 percent of participants were satisfied with the program and felt others would benefit from participating. Approximately 70 % believed the program increased their understanding of the link between energy efficient boilers and bill savings. The program helped expand impacts beyond the participant group to a larger group through direct installation of measures with a multiplier effect

7. Spillover of 97 percent is calculated based on 146 businesses adopting at least one spillover measure based on information shared by a group of 68 participants who adopted five measures (i.e., 146 × (1÷ 5) ÷ 69 = 0.42).

of 42 %. Non-participant evaluation findings show significant demand for the program with 100 % of participants indicating that they think all businesses would benefit from the program. The most common reasons given for not participating include: not knowing about the program, waiting to replace their boilers due to high costs, and insufficient money available to replace their boilers. Typical boiler installation costs range from $ 9,000 to $ 14,000 for standard boilers with an incremental cost of $ 3,000 to $ 10,000 for low to high efficiency boilers. Although condensing boilers have been in the US market for over a decade and there are significant operating cost savings from them, they have very little market penetration due to the higher incremental cost. The incentives offered by the program ranged from 20 to 30 % of the total cost of the boilers and this was the most important reason given for participation. The program implementer designed the program based on manufacturer reported performance data and product literature. Future programs should be based on field verified boiler efficiency ratings rather than manufacturer ratings which were found to be overstated especially for high efficiency boilers examined in this study.

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