RESEARCH SUMMARY

Commercial Condensing Boiler Optimization

BACKGROUND

Condensing boilers are one of the most promising natural gas technologies for reducing Minnesota commercial energy use. However, many newly installed systems only achieve a fraction of their expected energy savings.

The efficiency of condensing boilers is extremely sensitive to operating conditions — in particular the temperature of the water entering the boiler. Often, an effective retrofit requires modifications of the boiler system controls and/or piping because the equipment and controls are based on standard boiler operating conditions, which are different than the low temperature and load conditions needed for condensing boilers to perform best.

The availability and high market penetration of high-efficiency condensing boilers provides significant cost-effective savings potential for commercial building owners and for conservation improvement programs (CIP) offerings. However, the actual savings achieved in the buildings is less clear. Although the sensitivity of condensing boiler efficiency to field operating conditions is widely recognized in the industry, information about the impact of actual field operating conditions in Minnesota buildings has generally been limited to varied anecdotal sources.

Figure 1: Three wall-mount condensing boilers in a commercial building.

This field research looked at how real operating conditions in commercial buildings impact the achieved efficiency of condensing boilers and identified methods for utility programs to improve their performance.

METHODOLOGY

This field study involved long-term monitoring of key operating conditions at 11 buildings that were chosen to be representative of characteristics common among commercial condensing boiler installations in Minnesota. Key characteristic variations represented in the chosen sites include building type (e.g. education), boiler system size, boiler system piping, type of controls, and whether it was a condensing boiler system exclusively or a hybrid system (i.e. systems containing a mix of condensing and non-condensing boilers). The operating conditions were monitored through building automation systems and data loggers with cellular modems to capture data on entering boiler water temperature, load fluctuations, burner tuning (excess air), and staging control. Using the data collected, the investigators analyzed the efficiencies at which the boilers were found to be operating, identified measures to provide energy savings, and then calculated potential savings. An industry contacts survey provided more informed guidance for utility program development and refinement.

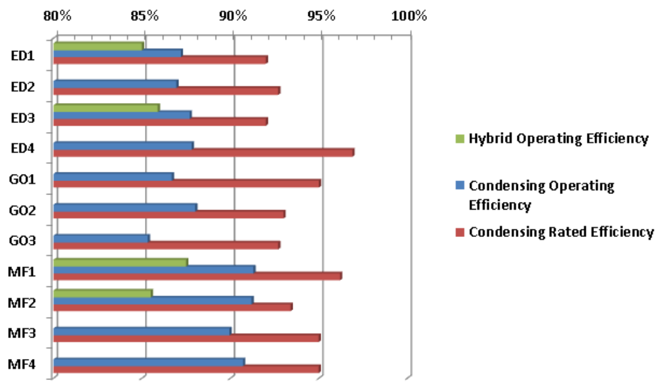
RESULTS

As-found operating efficiencies

While there were significant variations between building types and individual sites, the condensing boilers achieved ***a little over half of the savings that might be expected from the rated efficiency alone*** (compared to a common 80% efficiency baseline for non-condensing boilers). Figure 2 shows the annual average efficiency of the condensing boilers at each site along with the rated efficiency (and the efficiency of the combination of all boilers for hybrid sites).

cee
Center for Energy and Environment

Figure 2: As-operated efficiencies of condensing boilers and hybrid systems.



Some key findings are outlined below.

- The average achieved efficiency of the condensing boilers was 88.4%, 5.6 percentage points below the average rated efficiency of 94%.
- Multifamily buildings as a group had higher condensing boiler efficiency than other sites because of lower boiler system water temperatures — especially in mild heating season weather.
- The largest single factor impacting operating efficiency was that the water temperatures entering the condensing boilers were far above the 80°F value used in rating tests.
- Hybrid systems at four of the sites had non-condensing boilers that remained operating in order to provide enough capacity at low outdoor temperatures, reducing the overall efficiency by another 1.8 to 5.7 percentage points below the operating efficiencies of the condensing boilers.
- High entering water temperatures, sub-optimal tuning, sub-optimal staging control, and impacts of non-condensing boilers at four sites caused an average boiler plant efficiency of 87.2%, 6.8 percentage points below the average rated efficiency of the condensing boilers.

Optimization opportunities

The study estimated savings for a number of measures with the potential to cost-effectively improve efficiency both at the time of boiler installation and afterwards. However, the maximum achievable efficiency in this study was still found to be below the rated efficiency because the rated test return water temperature of 80°F is too low to provide adequate heat to the buildings through the radiators and/or air handlers. Savings estimates were based on assumptions about the degree to which recommended control changes would change the boiler operating conditions (e.g. entering water temperature, cycling, firing rate, and load distribution among boilers).

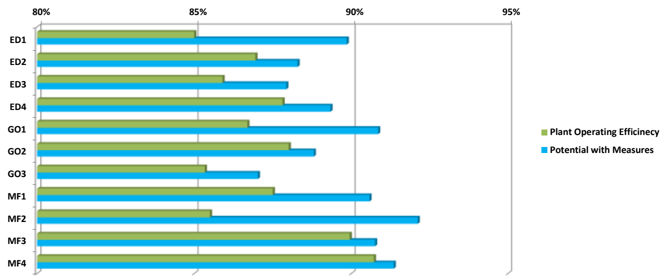
Table 1 shows the frequency and average savings of potential measures by category. ***About 80% of the identified savings can be achieved with a simple cost-payback period under five years.*** The relatively low-cost control and tuning changes could increase average savings of boiler energy use by about 3%, and more extensive piping changes could achieve another 2% in boiler energy savings in half of the buildings.

Table 1: Summary of savings by measure type.

Measure type	# of sites	Avg. sites w. measure	Avg. across all sites	Avg. [therms] savings for sites w. measure
Reset Control	10	1.54%	1.40%	1,289
Burner Tune Up	10	0.80%	0.72%	574
Staging control	8	1.15%	0.83%	975
Variable Speed Pumping	10	0.48%	0.44%	230
Piping Change	5	2.06%	0.94%	979
Total	11	-	3.97%	2,372

Figure 3 shows the annual average boiler system efficiency as found along with the potential efficiency by site if recommended improvements are applied. All of the sites have some low-cost opportunities to improve boiler efficiency; the vast majority of monitored sites could improve performance with more optimal adjustment of a number of different items, most notably boiler temperature control. Improvements in technical details of piping layout (typically combined with control adjustments) provide an opportunity for additional savings at about half the sites. A few of the sites have opportunities for very large potential efficiency improvements. ***Hybrid boiler systems had the largest potential for increased savings through better optimization.*** *There was a savings potential of more than 2% through staging control improvement for two of these systems and opportunities for improvement of sub-optimal piping in three out of four of the hybrid systems.*

Figure 3: Observed and achievable efficiencies by site.



Industry contacts survey results

Local boiler industry professionals were surveyed to gauge the perceived value of utility program features to increase condensing boiler efficiency. The survey results provide further evidence of the prevalence of opportunities to improve controls and highlight the perceived value of commissioning and operator training. The survey responses that highlighted the importance of commissioning and operator training are indicative of the general study findings that numerous technical details can impact the achieved efficiency and savings of condensing boilers in Minnesota's commercial buildings.

RECOMMENDATIONS FOR CIP

With the largest potential for savings found for hybrid boiler systems, CIP refinement and development efforts should focus on these systems. Additional key CIP-related findings are summarized below. The first three recommendations highlight opportunities to increase program impacts while the last three explain how current program impacts may be less than previously assumed.

1. ***Additional savings potential.*** Greater savings can be achieved through various control, piping, pumping, and burner tuning optimization, especially with hybrid systems. CIP enhancements such as new requirements and/or services can potentially achieve greater savings among condensing boiler rebate program participants.
2. ***Cost-effectiveness of changes.*** About three-fourths of the identified savings potential can be achieved with a payback of five years or less. Burner tuning, outdoor reset control, and staging control are the most common and cost-effective options. The vast majority of identified savings potential could be found by focusing enhancements to CIP entirely on burner tuning and boiler system controls.
3. ***Perceived value of possible CIP enhancements.*** Trade allies that were surveyed as a part of this study recognize value in a number of possible CIP changes that would improve operating efficiency, even if such enhancements are more complicated. This was especially true for commissioning and training as well as with support for changing existing installation control settings.
4. ***Market penetration.*** Condensing boilers dominate the commercial boiler market across all building types and sizes. Any CIP evaluation should consider that a high percentage of participants are still likely to have installed condensing boilers in the absence of a program.
5. ***In-field efficiency.*** The operating efficiencies of commercial condensing boilers are typically well below their rated efficiencies. CIP savings should be based on conservative estimates.
6. ***Tune-up savings magnitude.*** While the same degree of burner tune-up adjustment to a condensing boiler has more impact than for a non-condensing boiler, the potential savings identified in this study were still far below current burner tune-up assumed savings. A fresh evaluation of boiler tune-up program savings is needed for CIP.

CONCLUSIONS

Condensing boilers can be an efficient, cost-effective investment for Minnesota commercial buildings. However, the widespread prevalence of suboptimal control settings that led to high return water temperatures, short-cycling and other suboptimal staging control of boilers highlighted the potential benefits of achieving better control optimization through training, commissioning, and more technical program requirements. The research identified opportunities for significant savings from low-cost optimization of temperature control settings, staging controls, and burner adjustments. Although less cost effective, piping changes and pump variable speed controls provided additional savings potential.