Boiling Down Complexity: Innovative Program Approaches to Optimize Efficient Commercial Boiler Systems

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ABSTRACT

Natural gas used to fuel commercial boiler systems represents 51 percent of total natural gas expenditures for non-mall commercial buildings in the U.S. Highly efficient technologies are commercially available, and there are many established practices that encourage optimized boiler system design; however, many systems are not optimized to reach their energy savings potential. Savings depend heavily upon the system as a whole. For example, if a system is designed such that return water temperatures are too high to allow the unit to condense latent heat from exhaust gases, then savings will remain on the table and the end user may not recoup the initial investment in the higher cost.

Achieving intended savings in the commercial boiler market is a key challenge and opportunity for many efficiency program administrators. This paper will build off of findings from the Consortium for Energy Efficiency (CEE) High Efficiency Commercial Boiler Systems Initiative and the 2011 CEE Commercial Boiler Systems Program Summary to further explore efficiency program approaches that seek to promote system optimization. The paper first highlights common technical challenges that influence the ability for commercial boiler systems to achieve system optimization. It then explores existing commercial boiler program approaches through the lens of energy efficient tune-up measures and activities that promote Quality Installation with a focus on rightsizing. Through this channel, comparisons are drawn to help expose the opportunities and challenges of undertaking a given program approach. The paper then translates the successful aspects of these program approaches into guidance for efficiency program administrators seeking to create innovative strategies for capturing savings from the entire commercial boiler system.

Introduction

This paper addresses hot water, commercial packaged boiler systems[1] between 300,000 to 4 million British thermal units (Btus) capacity. This size range is intended to capture the bulk of the mass market for commercial boiler systems (AHRI 2012). It emphasizes the capacity of the system, rather than the boiler itself, as residential boilers may be staged in commercial applications such that the overall system capacity is 300,000 Btu/h or greater. The scope of this paper does not include systems used for process heating, steam systems, or domestic hot-water boilers used for potable water. This is because the major sources from which this paper draws upon (the CEE Initiative and Program Summary) were efforts that began by targeting space heating boilers. This choice was made because, at the time, program administrators needed greater guidance for achieving efficiency in complex heating systems, and greater efficiency potential was deemed to exist in hot water systems. Future CEE efforts may strive to provide

[1] Commercial packaged boiler systems are defined as is a pressure vessel consisting of a tank or water tubes, heat exchangers, fuel burners, exhaust vents and controls. (CEE 2011).

recommendations on how efficiency program administrators may achieve savings in these other important areas as well.

Commercial boilers use 709 trillion Btus of natural gas annually in the U.S. for space heating, representing 32 percent of commercial floor space and 51 percent of total natural gas expenditures for non-mall commercial buildings (DOE 2003). Estimates indicate that the existing U.S. building stock operates at approximately 76 percent thermal efficiency (Et) (DOE 2007). Under optimal system design, commercial boilers have the potential to perform well above 90 percent Et (with some boilers achieving up to 98 percent Et). If it were to be assumed that 60 percent of boilers performing at 76 percent Et were to begin performing at 90 percent Et, they would save approximately 510 million therms annually (CEE 2011a). This is the equivalent to the emissions from energy use in over 200,000 homes (CEE 2011a). Based on this, it is clear that boiler systems represent a major energy end use and represent an area of significant energy savings for the commercial sector.

System Optimization

The challenge that energy efficiency program administrators face is to transform this market towards higher efficiency. In order to help highly efficient commercial boiler systems become widely available in the market place, a number of technical challenges related to system optimization must be surmounted. Some of the more common technical challenges that influence the ability to achieve an optimized system design are highlighted below.

High efficiency condensing boilers[2] have different installation requirements than conventional boilers, including system design considerations for return water temperatures, venting, and condensate drainage. This may be a particular barrier for retrofit applications where the existing system may not be able to adequately handle a condensing boiler and would need to be upgraded with appropriate venting materials. It is also important to note that addressing these technical considerations in retrofit applications may not always be cost effective (CEE 2011a).

Additionally, the rapid introduction of new boiler technologies is perceived by industry to be outpacing installer training. This includes the incorporation of appropriate control schemes for a given system. Often control schemes for conventional boiler systems are incorrectly generalized and may be applied to condensing boiler systems. This may result in less optimal operation of the boiler system, reducing the overall efficiency and potentially shortening the life of the boiler and increasing the annual maintenance costs. With no defined best practices for control schemes for condensing systems, selecting an appropriate control scheme is left up to the design engineer and installer (CEE 2011a).

Commercial boilers are currently rated in terms of steady state efficiency, which is considered to be an inadequate metric as boilers typically operate at part loads. This is particularly true due to advances in modulating burners and boiler staging that yield more savings, but are not currently captured in the ANSI-Z21.13 or BTS-2000 test standards. Without a test procedure that adequately captures part load operations throughout the year, program administrators are unable to accurately estimate infield efficiency of the system. This may negatively impact the payback period for higher efficiency systems designed to take advantage of part load operation, which, in turn, may make it more difficult to make the financial case to building owners for the investment in efficiency (CEE 2011a).

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[2] Condensing boilers are defined as any boiler designed to condense water vapor in the flue gas on heat exchanger surfaces to capture latent energy and drain away captured condensate (Landers 2007)

Energy savings from commercial boilers can be improved not only by increasing the efficiency of the unit itself, but also by considering the whole system including auxiliaries, quality installation, and proper maintenance. Table 1 identifies several potential areas of energy loss throughout a boiler system. The efficiency of transferring heat from a boiler into the system—and in just the right amount and at just the right time—is a truer measure of high performance than just the rating on the boiler (Vastyan 2005).

Table 1. Boiler System Losses

Potential Area for Energy Loss		**Estimated Loss**
Burner		1-5%
Boiler		--
	Flue Gas Loss	5-15%
	Convection & Radiation	5%
	Latent Heat	10%
	Burner Control Method	5-30%
Distribution System		25-30%
	Piping Leaks	15-20%
	Standby Radiant Loop Loss	10%
Operations & Maintenance		10-15%

Source: CEE 2011a

This also means that the entire system can impact the efficiency of a boiler. For example, if a system is designed such that return water temperatures are too high to allow the boiler to condense, then savings will remain on the table and the end user may not recoup the initial investment in the higher cost of the condensing boiler (CEE 2011a). Therefore, the unit cannot be addressed in a vacuum, but rather the entire system must be understood when considering an upgrade of a commercial boiler.

Enabling Technologies

Two common technologies that can achieve significant savings and increase the system efficiency are supply water reset control functionality and modulating burners. Other common technologies and practices associated with improving system performance and energy savings include piping insulation, tank insulation, flue dampers, and outside air reset controls (AHRI 2012).

CEE has defined the term supply water temperature reset control functionality to be a means of reducing the temperature of the water to the lowest temperature required to meet the system demand. With this definition, a specific technical path is not being defined, but rather the functionality desired. Through this ability to adjust the water temperature, the system has a better match between the boiler output and the actual space heating needs, which in turn reduces the cycling of the boiler and radiant heat loses. Supply water temperature reset control functionality can increase the efficiency of the system by 5 percent (CEE 2011a). Most condensing boilers on the market include this functionality, either as a built-in or optional component (AHRI 2012).

Modulating burners provide improved control over the combustion of flue gases, allowing the burner to reduce the firing rate when there is lower demand. Modulation is typically defined by the turndown ratio, which is an indication of the burner's minimum firing capability compared to the maximum firing rate. For example, a 5:1 turndown means that a boiler can operate at continuous turn down until 1/5 of the nameplate rating. Modulation can achieve up to 3 percent in fuel savings (CEE 2011a). Most condensing boilers on the market already contain modulating burners. Efficiency program administrators may also see savings through burner retrofits by replacing the existing burner with a multi-stage or modulating burner. This in itself can achieve significant savings and help to optimize the system.

Approaches and System Optimization

In 2011, there were at least 43 efficiency program administrators providing rebates and incentives to address commercial boiler system efficiency (CEE 2011b). Of these 43 program administrators, the approaches vary widely from straightforward prescriptive measures for residentially sized boilers in small commercial applications to more complex programs with incentives varying by boiler size and measure type. Some programs simply address the boiler itself, while others address the entire system by incorporating measures for controls, other auxiliaries, or tune-up programs, among others.

To help efficiency program administrators capture more of the large savings potential in commercial boiler systems, CEE and its members developed the High Efficiency Commercial Boiler Systems Initiative, which provides program recommendations and equipment and functionality specifications. CEE has developed this comprehensive approach to address the multifaceted set of technical issues and opportunities, market forces and barriers, and business drivers at work. The following program approaches and related recommendations build on work that the Initiative has set forth.

Commercial boiler systems are technically complex, and the energy solutions span across various technologies and installation practices. Understanding the relationship between the system design and various energy solutions is important to help maximize energy savings over time. Because of this, it is vital that efficiency program administrators develop well-informed and leveraged energy efficiency solutions. To better help efficiency program administrators address energy savings opportunities in commercial boiler systems, it is important that efficiency program administrators are informed of the various types of program approaches that exist and their related ability to encourage optimized system designs.

In 2011, CEE captured information from 43 program administrators that reported offering a variety of commercial boiler system program measures. Table 2 provides a high level overview of these measures.

Table 2. 2011 CEE Member Commercial Boiler System Program Offerings

Measure Type	Total # CEE Members Offering Rebates
Prescriptive Boiler Unit Offering	43
Custom	39
Steam Trap	22
Reset Controls	15
Pipe Insulation	14
Boiler Tune-Up	10
Tank Insulation	9
Modular Burner Controls	6

Source: CEE 2011b

The majority of these programs provide custom rebates as well as prescriptive rebates for the boiler itself. As noted in Table 2 above, many other programs provide additional rebates or incentives on related boiler components. Others encourage Quality Installation (QI) of the system through various tactics such as requiring heat load calculations from the contractor at the point of installation. Each of these additional measures that go beyond the traditional unit measure is meant to encourage savings across the entire boiler system rather than just the unit itself.

There are many different measures that an efficiency program administrator can choose to include as part of their overall commercial boiler system program approach. While all of these measures have their own attributable savings, energy efficient tune-ups and QI with a focus on rightsizing practices can be particularly important—and challenging—to implement effectively. These measures can be more complex than, for example, implementing pipe insulation or steam traps measures. Despite their complexity, these measures have the potential to help ensure optimization both at the start and throughout the lifetime of the system. The below sections focus particularly on the reasons behind why and how different program administrators may choose to include energy efficient tune-ups and rightsizing activities within their overall program approaches, as well as the challenges they may face when implementing such measures. It is important to note, however, that rightsizing and tune-ups are just two activities out of many that help to achieve system optimization. Efficiency program administrators may consider including these, as well as many other measures, within their program offerings. These two activities and related program recommendations are explored in more detail within the sections below

Quality Installation with a Focus on Rightsizing

As with all HVAC systems, QI is an important aspect for optimizing the performance of both the boiler as a standalone unit and the system as a whole; however, it is not a commonly incentivized measure. QI is a standard set of key actions that must be undertaken during installation of the boiler system to help ensure the system will operate efficiently. Generally, a non-modulating boiler operates at its maximum efficiency when producing the rated heating output. This results from reductions in the cycling and jacket losses of a boiler. Therefore, in order to achieve the savings associated with a specific performance level, it is essential that a boiler is sized correctly to meet the demands of a specific application. Additionally, an optimally sized boiler will reduce the maintenance costs, as the reduced cycling generally causes less wear on the boiler (Manczyk 2001).

In commercial boiler applications, rightsizing is particularly critical for ensuring high efficiency operation. Many boiler systems are significantly oversized in both new construction and retrofit applications. A boiler system is oversized when it meets a higher demand than that of a specific application.

Installers often oversize systems for a number of reasons such as avoiding potential complaints and call-backs from property owners if the system is under-sized, or to account for future expansions to the building or higher occupancy rates. A particularly common occurrence in retrofit situations is to replace the boiler with the same capacity unit, perpetuating the problem of oversizing (ACCA 2010). In these instances, “rules of thumb” may be too heavily relied upon, or heat load calculations may not have been properly conducted or followed. It should be noted that there are applications, such as schools, where redundancy requirements must be adhered to, which may mean that the project is required to be over-sized.

Over-sizing the boiler can create increased boiler cycling, which relates to the turning on and off of the boiler as there is a demand for space heating. This in turn creates inefficiencies in use and can result in up to 10 to 15 percent loss in efficiency (CEE 2011a). Increased boiler cycling has the potential to increase maintenance needs and costs over the boiler’s lifetime. Therefore, addressing boiler over-sizing is critical to optimizing a boiler’s performance.

Program administrators try to address the issue of rightsizing in a variety of ways. Two common program approaches are explored further below to highlight common challenges and related program recommendations.

Program Approach 1: Requiring or recommending heat load calculations. Some efficiency program administrators recommend or require that a heat load calculation be conducted by a contractor or design engineer when a system is installed. Understanding a building’s heat load, which is the amount of heat that must be supplied to a building in order to maintain a specific temperature in the space, is a key component of appropriately sizing a boiler system.

This calculation is considered by many program administrators to be the primary method of verifying savings claims for individual projects; however, some program administrators find that heat load calculations are not being performed by contractors, or that the contractor’s results do not provide enough information to draw conclusions about whether the system has truly been appropriately sized. In other instances, program administrators find that not all contractors know how to do heat load calculations properly. This is a common challenge for both new construction and retrofit applications. Installing replacement equipment in a retrofit application without re-evaluating the building’s heat load is a common missed opportunity that could lead to problems with rightsizing since the original equipment size may have been incorrect (ACCA 2010).

Some of these issues stem from the fact that heat load calculations can be labor intensive and require additional personnel to conduct. Requiring heat load calculations can also be seen as a disincentive because it may add to the cost of the installation or create barriers to project approvals through the program. Program administrators that have reported the most success with requiring heat load calculations are those that have been able to incentive the cost or minimize the administrative burden of requiring heat load calculations and related paper work for contractors. Other program administrators have found success when partnering with trade allies or providing trainings themselves to help educate their contractor base on how to properly utilize heat load calculations in the context of commercial boiler systems.

Program Approach 2: Close review of project proposals. In this scenario, efficiency program administrators trust the contractor or design engineer to appropriately size the system. This leaves the onus of rightsizing largely placed on the contractor or design engineer. The program administrators that have reported the most success with this approach are those that closely review the project proposals to ensure that they are not drastically oversized. When reviewing the project, if the program administrator notices that the system seems over-sized, the facility owner, contractor, or design engineer would be contacted; however, a number of these program administrators report that it is rare for the submitted projects to be oversized. This may not be the case in many service territories, and because of this, program administrators are encouraged to closely understand the make up of their contractor base before utilizing this program approach. As noted above, the existence of strong contractor training programs that have a focus on quality installation can impact the contractor's ability to conduct a successful heat load calculation and rightsize a system.

Summary of program recommendations. The reasoning behind why requiring heat load calculations may work for some program administrators more so than others is dependent on many factors and can be challenging to tease out. At a minimum, it is recommended that efficiency program administrators closely review each project submitted to ensure that it is appropriately sized. Where practical, it could be effective to make heat load calculations mandatory within a given service territory or municipality.

Similarly, messaging to contractors about program requirements and the importance of quality installation with a focus on rightsizing is also an important practice that efficiency program administrators can undertake. Contractor training sessions, trade publications, or even hiring staff dedicated to the task of trade outreach are some effective ways to communicate these messages.

In addition, program administrators are strongly encouraged to require that heat load calculations be conducted by contractors using trusted calculation methods, such as the Manual N Calculation, which was developed by ACCA for commercial load calculations (ACCA 2010). By at least recommending a particular tool be used, it can help ensure that the projects that go through any one program are as consistent as possible.

Another consideration for program administrators is to provide monetary rebates or incentives for rightsized boiler systems or properly submitted heat load assessments. The incorporation of rightsizing measures into programs would emphasize the value of this practice and incentivize contractors to move away from the current practice of improperly estimating a building's heat load or conducting like for like replacements.

As of the 2011 Program Summary, CEE was not aware of any direct rebates or incentives for rightsizing. Program administrators have noted that the savings potential is difficult to justify and that more research needs to be done to understand where offering that rebate or incentive would be most effective (such as through a mid-stream rebate, for example).

By focusing on the importance of rightsizing, with messaging, requirements, or incentives, efficiency program administrators can help address this key barrier to enhanced commercial boiler system performance. CEE and its membership are continuing to discuss lessons learned and innovative ways to address this important area of savings.

Quality Operations and Maintenance with a Focus on Energy-Efficient Tune-Ups

Quality operations and maintenance are two key aspects of ensuring safe operation and capturing savings in high efficiency boiler systems. There is a key distinction between maintenance and tune-ups – maintenance items are ongoing, routine actions that are conducted over the life of the product to keep the system in good working order—generally conducted every year or two. One resource that some efficiency programs use to address maintenance is the *ASHRAE/ACCA Standard 180: Standard Practice for Inspection and Maintenance of Commercial Building HVAC Systems*.

On the other hand, tune-ups go beyond traditional maintenance and focus on getting the equipment back to its original performance. To this end, resources such as the *ANSI/ACCA Standard 5: HVAC Quality Installation Specification* might be a better resource when working to get the equipment back to its original performance.

Energy efficient tune-ups are an important way for efficiency programs to realize more savings. One major challenge is that even a high efficiency boiler right-sized and installed correctly will perform poorly if not properly operated or maintained. This is where energy efficient tune-ups become important ways to return the equipment to its original performance. Energy efficient tune-up practices help ensure that the system is optimized throughout its lifetime.

It is estimated that boiler systems can lose between 10 to 15 percent in efficiency from improper operations and maintenance (CEE 2011a). Many high efficiency systems are staged systems requiring additional control over the operation to ensure optimization. Couple this with the importance of regular maintenance throughout the significantly long lifetimes of commercial boilers, and it is clear that such measures will help to ensure the persistence of savings.

Many efficiency programs already offer measures for boiler system tune-ups to ensure that savings continue to be realized. When it comes to energy efficient tune-up offerings, efficiency programs may face varying constraints which can change by service territory. Three common constraints are explored further below to illuminate potential similarities across service territories and to highlight related program recommendations.

Program Constraint 1: Tune-ups required in service territory; Programs may or may not be offered. In some service territories, tune-ups are a requirement of the state or province. When this occurs, the efficiency programs within that service territory either do not provide tune-up program offerings or are required to manage the tune-up program without claiming savings. For example, in regions where there are strict air quality requirements, mandated tune-up programs are common and are seen as necessary to ensure public health. In these service territories, contractors are required to conduct tune-ups to meet air quality levels. If this tune-up is not conducted properly, or if a customer does not tune up their boiler, efficiency will likely drop from buildup and the system may contribute to an overall decline in air quality. This scenario presents the challenge of free ridership, as it is considered inappropriate for contractors to be incented to undertake activities that they are legally required to conduct.

Program Constraint 2: Programs do not provide tune-up offerings because of lack of savings. There are other programs that do not run or have canceled their tune-up programs because their program evaluations were not able to identify significant savings from the program as a whole. One factor that impacts whether a tune-up program will be successful is the customer make-up within the service territory. For example, if a service territory has many large customers that do not qualify to receive program offerings, a tune-up program may struggle to achieve savings. Additionally, if many of the semi-large customers who are eligible to participate in the program already have their own maintenance staff doing boiler tune ups, it is also difficult for a tune-up program to achieve intended savings across a service territory.

Program recommendations. Program administrators should, at a minimum, message to the importance of quality operations and maintenance and the value provided by tune-up programs. Similar to the QI program recommendations noted above, messaging and outreach to trade allies can be a powerful way to ensure that program requirements are understood and that the value of tune-up activities is expressed.

In exploring additional measures beyond messaging, program administrators should consider offering tune-up incentives or rebates directly to the customer, or through a mid-stream channel to the contactor if it is a possibility within their service territory. This is an important way for program administrators to demonstrate the value of conducting energy efficient tune-ups.

It is also important that the specific requirements within a program administrator's tune-up program are carefully thought out to ensure that the tune-up activities implemented will adequately address system needs and improve performance as much as possible. CEE members have expressed interest in learning more about the savings potential associated with specific tune-up practices to help better define innovative ways to address this important area of savings.

Conclusion

By exposing and analyzing the above program approaches, it is hoped that efficiency program administrators will better appreciate the various ways in which they can encourage the optimization of the boiler system as a whole. Each individual program administrator will need to identify what will be the most complimentary approach given the conditions under which they operate. By comparing and contrasting these various approaches, the benefits and drawbacks of each approach become more apparent to program administrators considering new programs or re-evaluating existing approaches.

The challenges to achieving an optimized boiler system are technically complex, and must be carefully taken into consideration when designing program offerings. In addition to understanding the technical challenges that need to be addressed to optimize the system, it is important for efficiency program administrators to become adept at targeting their customers with succinct messaging. Similarly, establishing strong contractor networks is a key way that program administrators can help to ensure that high efficiency projects are conducted with more frequency and with better precision.

Commercial boiler systems are truly multifaceted—there are many technical considerations to take into account that must come together in a joint effort to achieve a truly optimized system. Despite the challenge that this presents, a significant opportunity exists to capture savings for end users, efficiency program administrators, and the market as a whole.

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