

OPTIMAL BOILER SIZE AND ITS RELATIONSHIP TO SEASONAL EFFICIENCY

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INTRODUCTION

In addition to installing high efficiency boilers and maintaining them in good condition, facility managers can employ other strategies to ensure that a heating plant serves the facility efficiently. These include ensuring that the system is optimally sized and that the system operates at an output that is appropriate for the demands of the facility throughout the heating season.

Most heating boilers are designed to operate at maximum efficiency when producing their rated heat output in Btu/hr. Since most boilers only operate at 60 percent or less time at their rated capacity for 90 percent of the heating season, boiler seasonal efficiency is significantly reduced and primary energy resources are wasted.

Seasonal efficiency in a boiler can be improved in several ways. This discussion focuses on three methods: Ensuring that the boiler system is optimally sized to the demand of the facility based on established outdoor temperature and the standard indoor design temperature of 70°F

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at which most people feel comfortable; use of a modular system of boilers to meet that demand since the fuel economy drops off rapidly as the demand versus boiler maximum heat output falls; and the calculations used to evaluate the seasonal efficiency of the system. The calculations will evaluate how the use of a night setback on the heating system affects the boiler overall run-time and its seasonal efficiency.

SEASONAL EFFICIENCY

Seasonal operating efficiency is the ratio of the total seasonal heat output *actually used by the facility* to the total seasonal fuel input. This efficiency is dependent on the boiler's steady-state efficiency, standby losses, and cycling losses, *all of which constitute the Total Seasonal Input*

Seasonal efficiency = Total *Useful* Seasonal Output/Total Seasonal Input

Since most boilers operate most efficiently at full capacity, the longer a boiler operates at full capacity, the higher the seasonal efficiency. When a boiler shuts off, the heat in the boiler continues to radiate through its jacket. In addition, boiler-room ambient air continues to flow throughout the boiler after the burner shuts off. When the boiler turns on again, it must reheat the boiler medium to the operating temperature or pressure. A boiler that is smaller than required will more closely match the heating load of the building for a larger part of the season because of fewer on and off cycles. The more often the boiler cycles, the greater the amount of heat would be wasted. (See the Weil-McLain website, <http://www.weil-mclain.com/netdocs/straighttalk.num>.)

OPTIMAL SIZING

Boiler systems must be optimally sized to meet the maximum facility demand during the normal heating season. Essentially, the system must provide the heat output required to meet the facility's total demand at the lowest expected temperature of the heating season. Systems that are sized beyond the optimal output capacity, (oversized) boilers, will have lower seasonal efficiency. Properly sized boilers will also reduce maintenance costs by starting and stopping less frequently. Oversized boilers waste fuel and, because of short cycling, ultimately shorten the life of the system. (The "Oversized Boiler Equations" section of this article shows calculations that permit one to determine the extent to which a boiler is oversized.)

Optimally sized equipment operates more efficiently by cycling properly, thus saving fuel. A U.S. Department of Energy Office of Industry Technologies "Energy Tips" report discusses this (see "Minimize Boiler Short Cycling Losses". (<http://www.oit.doe.gov/bestpractices>)).

A boiler cycle consists of a firing interval, a post-purge, an idle period, a pre-purge, and a return to firing. Boiler efficiency is the useful heat provided by the boiler divided by the energy input (useful heat plus losses) over the cycle of duration. Boiler "short cycling" occurs when an oversized boiler prematurely satisfies space heating demands and then shuts down until heat is again required. Efficiency decreases when short cycling occurs because heat demand is smaller than the boiler output.

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This decrease in efficiency occurs in part because fixed energy losses are magnified under lightly loaded conditions. For example, if the radiation loss from the boiler enclosure is 1% of the total heat input at full load, at half load the losses increase to 2%; and at one quarter load, the loss is 4%.

Standby Losses Report published by Tri-State Generation and Transmission Association, Inc (<http://tristate.apogee.net/et/ehubsbl.htm>) states that about 1.5% to 2.0% of rated boiler fuel input is lost to the boiler room. While this "standby loss" is small in comparison to useful output when boilers operate at or near their rated capacity, it can be significant where boilers operate frequently at low loads. For example, imagine a boiler rated at 10 million Btu/hr fuel input, but operating at a 2 million Btu level. The standby loss of 2% of 10 million Btu is 200,000 Btu/hr, or 10% of the 2 million Btu operating output level. This is the reason why plants with large summer to winter variations in steam use install small boilers to operating during the summer rather than operate large boilers year round.

One can also avoid short cycling by adding small boilers to a boiler facility to provide better flexibility and high efficiency at all loads. (This strategy is discussed in "Modular Boiler Systems, below.) Consider when one boiler with a seasonal efficiency of 73% (E1) is replaced with three modular boilers resulting in a seasonal efficiency of 79% (E2).

The Annual Fuel Savings

$$AFS=(E2 -E1)/E2 (100\%)$$

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$$(0.79-0.73)/0.79 (100)=7.6\%$$

E1=Seasonal Efficiency with One Boiler

E2=Seasonal Efficiency with Three Boilers

AFS=Annual Fuel Savings

If the original boiler used 100,000 MMBtu of fuel annually, the savings from switching to smaller boilers given a fuel cost of \$5.00/MMBtu is calculated as follows:

Annual Cost =

(Annual fuel consumption)(Annual Fuel Savings)(Cost/MMBtu)

$$(100,000 \text{ MMBtu})(0.076)(\$5.00) = \$38,000$$

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Savings at this level can yield a payback period for the new or modified boiler system of less than one year which could be financed directly from operating budget savings resulting from the new system.

MODULAR BOILER SYSTEM

Seasonal efficiency can be increased by replacing a single boiler with a network of smaller modular boilers, as shown below. Since modular boilers can be fired independently each module would be fired on demand at 100 percent capacity with load fluctuations being met by firing more or less boilers. When the first boiler can no longer keep up with the heat demand, a second boiler picks up the extra heat load. Also, modular boilers have low thermal inertia which provides rapid response and low heat-up and cool-down losses.

Outdoor temperature fluctuations during the heating season reduce the seasonal efficiency of even optimally sized boilers and boiler systems. There are relatively few periods during the heating season when it will be running at its rated output or point of maximum efficiency.

The following demonstrates that the percentage of run-time for a optimally sized boiler is less if there is a temperature set-back during the unoccupied hours than if the building were to be kept at a constant temperature throughout the heating season.

ESTIMATING THE ANNUAL RUNTIME OF A BOILER SYSTEM

Estimating the annual runtime of a boiler system is important in assessing whether to use a large, single boiler or several smaller, modular units to optimize seasonal efficiency of the system. It is based on estimating the annual heat loss of a building and dividing that by the hourly output of the boiler system.

Heat Loss Calculation Method

To estimate the runtime of a boiler system a practical method of estimating heat loss is being utilized, called the Bin Method.

The Bin Method is the summation of the total heat loss at each given average Bin temperature for a year. A Bin is a 5°F spread of temperature, for example, 55°F to 59°F, where there are 26 Bins from 100°F to -30°F, and these Bins are usually referred to by their average temperature – Bin 57°F is 55°F to 59°F. One Bin hour is formed when the outside temperature stays for one hour inside a Bin (one Bin hour at the 57°F Bin requires the temperature to be between 55°F and 59°F for one hour). Therefore, all 8,760 hours of the year can be accounted for with an outside air temperature in the 26 Bins--100°F to -30°F (continental United States).

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A Bin hour table is split into three eight-hour shifts – 12:30 a.m. to 8:30 a.m., 8:30 a.m. to 4:30 p.m. and 4:30 p.m. to 12:30 a.m. This recognizes that facilities often have different desired indoor temperatures during different operating shifts.

When using the Bin hour table for heat loss estimation, the average Bin hour temperature is subtracted from the desired indoor temperature for the shift, and the difference is then multiplied by the hours in the Bin, or the hours in the portion of the Bin needed. This is then multiplied by the heat loss per hour per degree, and the heat loss amounts in each of the Bins are totaled to obtain the total heat loss. This is a more accurate method of calculating the heat loss for a whole year, or any portion of the year.

Runtime Comparison, with vs. without Setback

The following section is a detailed calculation comparing the runtime of an optimally sized boiler system with and without a night setback. The comparison uses Bin hour data for the average heating system for the Rochester, New York, area for a system operating for a single shift, Monday through Friday. It shows that the night setback reduces the system runtime for both optimally and oversized boiler systems by up to 10%.

CONCLUSION

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Controlling heating costs for a facility doesn't only involve incorporating efficient boilers and optimizing fuel utilization in the heating system and maintaining the facility itself efficiently. It also involves how the heating system itself is designed and how it is used. This article has shown that carefully sizing the boilers to the heating demand of the facility, designing flexible, modular boiler systems, and incorporating features such as setback temperatures in the system can significantly contribute to seasonal boiler efficiency improvement, thus reducing the operating cost of the system.