Five Design Factors To Help Optimize A Boiler Plant

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When designing boiler plants for today's facilities, engineers need heat and hot water solutions that save installation time, lower construction costs and deliver superior performance to save energy and increase return on investment (ROI). The best solutions to satisfy these parameters are systems with the highest efficiencies and smallest footprints.

Condensing boilers are one piece of this design puzzle. They match output to the building load under all circumstances to improve plant efficiency by eliminating many of the temperature and flow requirements associated with non-condensing units. They are normally equipped with a modulating blower, modulating gas valve and mesh burner capable of firing at very low rates. In addition, these boilers are generally made from materials that can withstand the corrosive nature of exhaust gas condensate associated with low return water temperatures, which significantly improves condensing boiler efficiency (*Figure 1*).[1]

These boilers rely on proper air/fuel mixture, a highly efficient heat exchanger and low oxygen content in the exhaust to increase the condensing dew point of the exhaust gases.[2] Thus, the boiler can condense at 130°F (54°C) or lower when the exhaust O_2 is approximately 5%. If the O_2 is higher, the exhaust condensing dew point will be lower, requiring lower exhaust and return water temperatures to achieve the same condensing ability.

Other considerations affect boiler plant efficiency. Engineers need to consider five important factors to reap the greatest ROI:

- Design for plant function;
- Piping design;
- Boiler selection;
- Boiler controller; and
- Remote access.

Design for Plant Function

Plant designs can range from space heating only to

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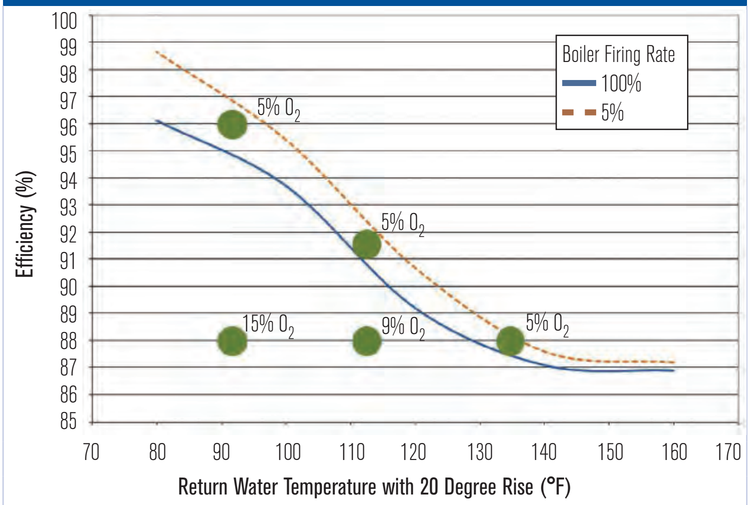
systems with multiple functionality, such as indirect hot water (DHW), reheat, etc. For combination plants where there will be multiple temperature setpoints, three design options are available:

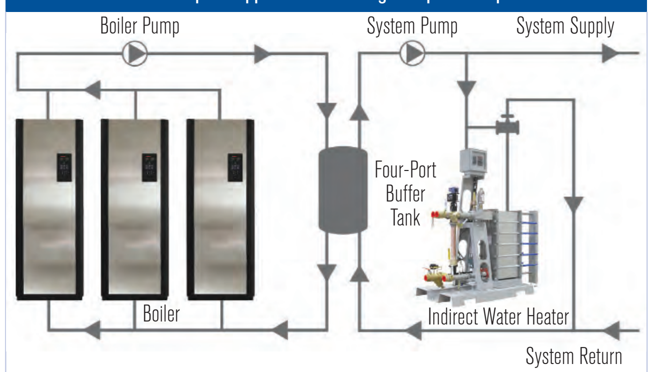
FIGURE 1 Thermal efficiency of a condensing boiler at different firing rates at 5% O_2.



Temperature Priority

Temperature priority designs (*Figure 2*) allow the temperature to be raised to satisfy the needs of the higher of the two temperatures. There are two notable disadvantages—one side will sacrifice its temperature to satisfy the other (thereby reducing comfort) and overall plant efficiency will decrease. Even if additional valves and controls are used to improve temperature control, overall plant efficiency is lowered because the whole system supply and return temperatures are increased.

FIGURE 2 Combination plant application with single setpoint temperature control.



Two Independent Plants

Another option is to have two independent plants, each with its own boilers, pumps, controls and piping. This approach requires a larger plant size and brings additional learning curve requirements. Furthermore, if $N+1$ redundancy is desired, an additional boiler is necessary for both plants, increasing major equipment costs.

Single Plant with Smart Controller

The most efficient approach is one plant with a smart controller that can meet temperature and load requirements without the large oversizing associated with two independent plants and dedicated controls. It also significantly improves the overall plant efficiency without sacrificing comfort and temperature control.

What makes all this possible is the swing boiler concept, which allows certain boilers to be assigned for space heating while others are for DHW. In normal operation, each boiler is equipped with its own integrated controller. The integrated controller of the master/manager boiler manages all the slave/client boilers and swing valves. This controller is mounted on the front of the boiler and manages all the boilers' electronic inputs and outputs, allowing boilers with swing valves to be easily switched from space heating to DHW or vice versa, depending on load requirements.

This design adds a layer of security, as well. For example, if the DHW boiler cannot meet its load, the controller will direct the swing valves to divert its designated boilers from space heating to DHW. As per ASHRAE, it is assumed that both space heating and DHW peak loads may not happen concurrently.[3] This offers a major benefit in reducing the number of boilers required to meet plant peak load, shrinking the footprint.

Another benefit is that the boiler system condenses more because the high and low temperature supply are separated. Models with dual returns can leverage this by allowing boilers to condense significantly more when the lower temperature return water is fed into a special inlet designed to reduce flue gas temperatures further. When combined with a low-mass boiler and its faster adaptation to plant load changes, the footprint of the plant becomes even more compact.

Piping Design

Primary-secondary piping has been used much longer, as it was developed to help protect non-condensing boilers from thermal shock and condensation. Initially, both primary and secondary loops had fixed speed pumps. Through the years, variable speed pumps were introduced into the system loop. Though this improved system efficiency, its full potential was not realized because the difference in flow between the two loops under low loads caused reverse flow in the connecting common pipe, decoupling the two loops. The result was a short-circuiting boiler loop that reduced plant supply and return ΔT temperature control and was slower to respond to load changes.

Variable-primary piping (*Figure 3*) leverages the abilities of condensing boilers and ECM/variable speed pumps to modulate to meet the system load through flow reduction in boilers. System ΔT is improved, which in turn reduces return water temperature to improve boiler efficiency and lower pumping electrical energy.

In variable-primary piping, engineers design a bypass line between the supply and return before the boilers to help improve whole-building efficiency. This allows the pump to flow some of the building return to mix with the boiler supply back to the building. In these cases, the boiler plant will be running at low firing rates, and the flow through the plant will be very low. This allows the boilers to condense more.

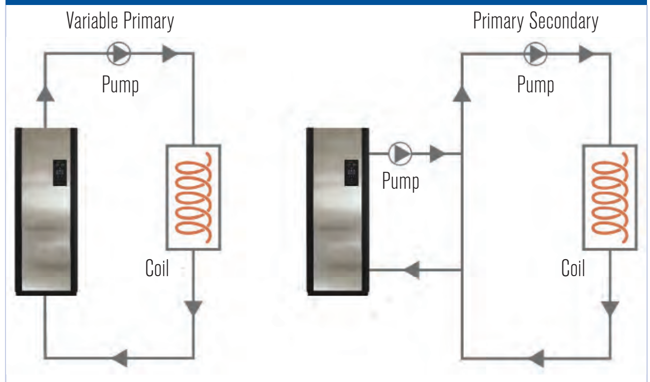
Another factor is if the boiler is fire- or water-tube. Generally speaking, fire-tube boilers have lower pressure drop across the heat exchanger (HX), making them ideal for variable-primary piping. Conversely, water-tube boilers tend to have higher pressure drop and minimum flow requirements, so primary-secondary piping is typically used.

Design ΔT

Commercial heat and hot water systems are normally designed with 20°F to 30°F (11°C to 17°C) temperature drop across the heating plant water supply and return. Since condensing boiler efficiency can significantly improve if the return water temperature is dropped, it is best to design for a higher ΔT.

Increasing the building ΔT to a minimum of 40°F (22°C) helps improve the boiler plant efficiency and saves on pump energy since it is correlated to flow. In fact, a change in ΔT from 20°F to 40°F (11°C to 22°C)

FIGURE 3 Piping design concepts.



should require half the flow. That in turn, based on the affinity laws, equates to reducing the pump energy use.

Boiler Selection

Plant square footage plays a role in the type of boiler selected. Most condensing fire-tube boilers are low-mass and have smaller footprints, making it easier to fit through doors, stairs and elevators. If width is too large or height is taller than a door or an elevator, walls may need to be demolished and rebuilt and/or cranes may be needed, adding installation time and cost.

Turndown is another criterion. Smaller ratios produce short cycling at low-load conditions, which are common in mild weather. These "shoulder months" are crucial, as they represent the majority of the heating season (*Table 1*).[4]

Figure 4 shows the operation of two 3,000 MBH (900 kW) boilers in a facility located in New York City. As indicated, the plant operates at less than 10% of load for 10% of the year. Boilers with a turndown ratio of 15:1 can reduce output to as little as 7% of its capacity, which will lower energy costs during the shoulder months, compared to units with turndown ratios of 5:1 and 10:1.

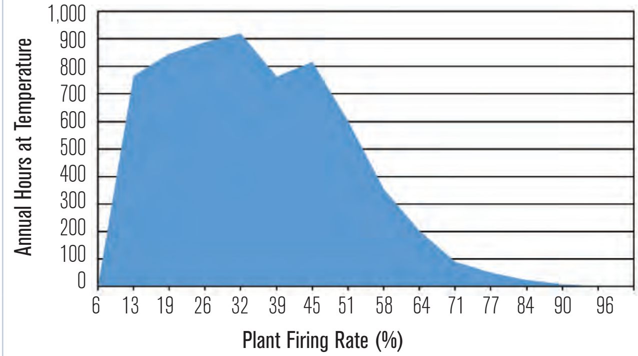
Proper Boiler Material

Unlike non-condensing units, condensing boilers must withstand continuous exposure to the acidic exhaust gases associated with natural gas combustion. Stainless steel has been the material of choice for this corrosive environment. Boilers made of other materials, such as copper, cupronickel or cast iron, normally have an additional stainless steel heat exchanger at the end to handle the condensation. Under certain circumstances, however, some condensation may take place in the first non-stainless steel heat exchanger, which can significantly

TABLE 1 ASHRAE weather data vs. Btu load: New York, N.Y.

TEMPERATURE	ANNUAL HOURS AT TEMPERATURE	OPERATING LOAD (BTU/H)	PLANT FIRING RATE	EFFICIENCY
–10°F to –5°F	0.3	5,500,000	96%	89.6%
–5°F to –0°F	0.8	5,133,333	90%	89.6%
0°F to 5°F	7.1	4,766,667	84%	89.6%
5°F to 10°F	23.6	4,400,000	77%	90.1%
10°F to 15°F	51	4,033,333	71%	90.7%
15°F to 20°F	90.2	3,666,667	64%	91.2%
20°F to 25°F	201.6	3,300,000	58%	91.7%
25°F to 30°F	355.2	2,933,333	51%	92.2%
30°F to 35°F	600.9	2,566,667	45%	92.7%
35°F to 40°F	815.4	2,200,000	39%	93.2%
40°F to 45°F	764	1,833,333	32%	93.6%
45°F to 50°F	921.3	1,466,667	26%	94.6%
50°F to 55°F	887.5	1,100,000	19%	95.2%
55°F to 60°F	846.6	733,333	13%	95.5%
60°F to 65°F	765.2	366,667	6%	96.0%

FIGURE 4 Approximately 10% of the time the plant shall be running below 10% load. *Data is based on New York City climate zone using ASHRAE bin data.



reduce equipment life and increase downtime.

Different Return Temperatures and Dual Returns

Many facilities combine different heating systems to provide the optimum solution. Often, the systems require dissimilar supply temperatures, as well as different return temperatures. Depending on the system, it is important to factor the low-temperature return loops. Some loop temperatures can be reduced further by feeding the return of a high-temperature loop into the supply of a low-temperature loop. In these cases, the lower return water temperatures significantly improve boiler plant efficiency.

These benefits can be optimized by designing plants with dual return boilers. Normally, the lower inlet return is used for the lower temperature return to significantly improve overall plant efficiency by as much as 7%.

Building Height and Boiler Pressure Rating

When designing boilers for high-rise buildings, it is important to consider the whole system's operating pressure. Using equipment or components below the required pressure may complicate system design and add significant costs by requiring additional pumps, valves, heat exchangers or pressure reducing stations. A better approach is to design a plant using boilers and all the required components with pressure ratings of 150 psi to 160 psi—ideal for high-rise buildings.

Boiler Controller

Building management systems (BMS) are common options to control many building elements, specifically HVAC equipment. Integration of boiler plant components into the building automation system (BAS)/BMS allows communication over multiple BAS protocols, including BACnet and Modbus. Boilers and equipment with multiple integrated BAS protocols and transmission options gives the controls contractor the ability to choose the one that provides the best equipment control and monitoring without the additional complications associated with gateways.

Outdoor Reset

Boiler controls can also be used for outdoor reset and to establish setback schedules for ongoing operational benefits. Reset helps more efficiently meet heating loads while maintaining a comfortable environment. An outdoor air temperature sensor determines the boiler supply temperature. When the outdoor air temperature drops, the boiler supplies higher temperature water to meet high load requirements. As the warmer weather arrives, less energy is needed for space heating and lower temperature water is supplied to the heating coils. Return water temperatures are also lowered. The result is higher boiler efficiency.

Parallel Modulation

It requires less energy for a group of modulating boilers, each firing in parallel at "part load," to heat a building than for a single boiler operating at "full fire" to carry the entire workload. In low-mass and mid-mass boilers, operating at lower inputs with the same HX surface area results in a more efficient heat transfer. This is converse to more traditional non-condensing, high-mass boiler plants that fire to 100% before bringing on the next unit.

Backup Manager

In a multiboiler plant, one unit serves as the "manager" while the others are "clients." Advanced controls establish the next in command if the "manager" is offline due to maintenance, repair or other issues. Advanced controllers can make this shift automatically to eliminate short cycling and ensure optimal operating efficiency.

Remote Access

Arming the facility owner and maintenance personnel with remote monitoring reduces the time spent physically monitoring the system. When it is combined with maintenance and service alerts, the maintenance team is immediately notified of issues that may improve performance or reduce tenant complaints. The staff is also made aware so it can provide maintenance to help keep plant warranty and optimized performance.

Summary

Designing a heating and hot water plant for maximum efficiency and performance requires engineers to consider several factors from the outset. Recognizing the specific needs of the facility, selecting the proper high-efficiency condensing boiler to best meet the load requirements, integrating advanced controls and incorporating the optimized loop design early in the process will save installation time, lower construction and operation costs and deliver superior performance.

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3. *2019 ASHRAE Handbook—HVAC Applications*, Chap. 51, Figure 25, "Sizing Factor for Combination Heating and Water-Heating Boilers."
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