Boiler systems: Economics and efficiencies

Engineers can meet a building's hot water needs with today's boiler systems.

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When a hot water heating system is designed, all the components must work together in order to achieve maximum system efficiency, while minimizing first cost.

Hot water heating accounts for 40% to 50% of the market, and while noncondensing boilers have been employed for decades and engineers and facility operators know how to design, specify, maintain, and operate them, the popularity of condensing boilers has risen steadily over the past decade. In 2011 alone, sales increased 20% over the previous year, according to figures from the Air-Conditioning, Heating, and Refrigeration Institute. That's because the seasonal efficiency, which is the overall effectiveness of the boiler over the entire season, for today's noncondensing boilers is roughly at 70% to 75%, compared to 84% to 92% for new condensing boilers.

But, achieving these high efficiencies in the field isn't a simple task. System components and configuration, outdoor air temperatures, equipment size, and manufacturer support all determine boiler system effectiveness in real time.

From the traditional, noncondensing boilers to today's new condensing boilers and hybrid configurations that use both condensing and noncondensing boilers, the specifying engineer has a number of options when choosing the right water heating system for each application.

Noncondensing boilers

The traditional, noncondensing boiler should operate without condensing the flue gases within the pressure vessel. It can be a Scotch marine-style boiler (frequently referred to as "fire tube boiler"), flexible water tube, firebox, or cast iron. These boilers are used in commercial, healthcare, and educational facilities for heating and are rated by boiler horsepower, with one unit of boiler horsepower being equal to 33,475 Btu/hour. Noncondensing boilers normally operate using natural gas as their primary fuel and fuel oil #2 as secondary fuel.

Fireside corrosion will occur when the flue gases are cooled below the dew point and come in contact with carbon steel pressure vessel. To avoid corrosion, the heating systems should be designed to operate in a way that ensures a minimum return water temperature of 150 F to the boiler. (Note: It is important to verify the return water temperature with the manufacturer's literature to avoid corrosion.) All heating components should be selected to operate with a minimum supply water temperature of 170 F, assuming 20 F differential temperature across supply and return water lines.

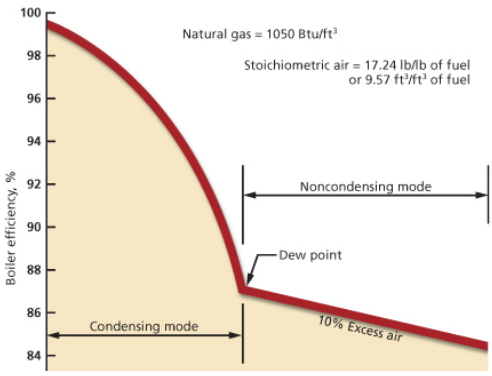
Condensing boilers

While condensing boilers have grown in popularity since their debut on the U.S. market more than a decade ago, their performance will continue to play out in the coming years. Engineers specifying them can choose from so many different manufacturers with different designs and quality of materials, they may sometimes have a difficult time specifying condensing boilers to be equal in design and construction in the competitive bid process. When choosing condensing boilers, some questions to ask may include: What type of maintenance support is available to the facility engineers? How are the components put together? How easy will it be to replace these parts as necessary to maintain the equipment and desired efficiency? Can all specified boilers work on a common flue? Is the master controller on all specified boilers compatible with the BAS?

While condensing boilers currently have a limited heating capacity compared to noncondensing boilers, manufacturers will continue to enhance this feature in the coming years, and as the technology improves, the condensing boiler will emerge as the future choice for hot water boiler systems.

Condensing boilers work by allowing the flue gas water vapor to change phase and condense out of the flue gas products. The phase change occurs on the heating surfaces of the heat exchanger, providing additional energy, while latent heat is transferred to the water within the heat exchanger and therefore increases boiler efficiency. Condensing boilers should be constructed from corrosion-resistant materials throughout the combustion chamber and heat exchanger.

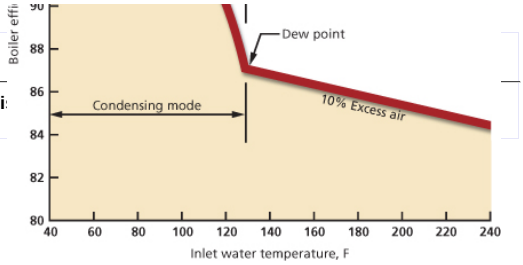
Figure 1 from the 2008 ASHRAE Handbook Chapter 31 on boilers shows the effect of the inlet water temperature on boiler efficiency, dew point, and the condensing range. As the return water temperature to the boiler decreases, boiler efficiency increases.



Over the past decade a large number of manufacturers have designed new boilers to be able to operate in condensing mode and therefore offer higher efficiencies. These boilers can be fire-tube, water-tube, cast-iron, or cast-aluminum design.

The first cost of condensing boilers is higher than that of the traditional noncondensing boilers. Therefore, the challenge the designer faces is to ensure that return water temperature to the boiler stays below 130 F; otherwise, boiler efficiency drops and the condensing boiler operates in noncondensing mode.

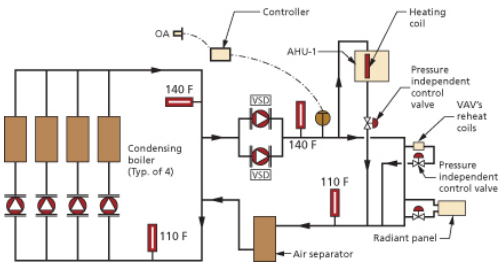
As shown in Figure 1, with a system return water temperature



of 130 F, condensing boilers are approximately 87% efficient, but this efficiency can go as high as 98%, with a return water temperature of 60 F. In addition to increasing boiler efficiency, a lower supply and return water temperature also will reduce the piping loop heat losses, and at low load condition, the controllability can be improved with higher gpm across control valves.

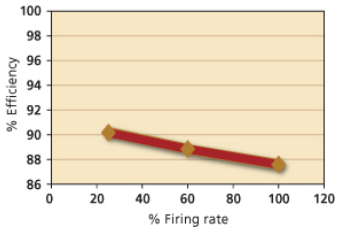
The condensate occurring in both the boiler and the flue gas pipeline with new condensing boilers should be removed in accordance with local codes and regulations. The conditions for the discharge of condensates into the public drainage systems are determined by the local authorities. Normally a neutralization system should be added in the drain pipe to increase the pH of the condensate. The neutralization media should be periodically replaced as necessary.

Figure 2 shows a heating system serving the air-handling unit's heating coils, variable air volume (VAV) reheat coils, and radiant heating panels. The system includes four condensing gas-fired boilers piped in parallel, each with a dedicated constant volume pump as part of the primary loop. The secondary loop consists of two pumps, each with a variable speed drive (VSD), an air separator, and an expansion tank.



How well the condensing boilers fit within boiler systems design and operate in condensing mode depends on the return water temperature. Therefore, the design engineer should select the heat users in a way that will allow the system to meet the design-day load with 140 to 150 F. However, this adds cost to the project and the designer may have to sacrifice a bit on efficiency to reduce first cost.

To achieve the highest systems efficiency and run time, condensing boiler system controls should include the following:



- Master boiler management controller: The master controller will stage the boilers and modulate firing rates to achieve the highest boiler efficiency. The controller will also rotate the lead/lag/stand-by boilers on a time schedule to distribute run time hours. This functionality also could be performed by a BAS. Refer to Figure 3 for increase in boiler efficiency as the firing rate decreases, with all other variables remaining constant.
- Outside air temperature (OAT) input: The hot water supply temperature setpoint should be reset based on the outside air temperature to conserve energy and reduce return water temperature to the boilers. While this strategy is most common when there is a direct correlation between OAT, load, supply water temperature, and delivered capacity, the emergence of direct digital control systems has introduced other approaches. One of the more common is a trim-and-respond approach that keeps lowering supply water temperature until one or more reheat valves are nearly fully open. If one or more valves actually drive fully open, then the supply water temperature is ratcheted up a bit until you get back to one or more valves that are almost—but not quite—fully open.
- The outside air sensor can be wired directly to the boiler master controller or the reset logic can reside in the BAS with a supply water temperature setpoint output to the boiler master controller. Most condensing boilers operate with natural gas as the primary and propane as the secondary source of fuel. There are one or two manufactures that have units that can operate with natural gas and fuel oil #2.

If the facility or its design requires condensing boilers to operate with propane as a secondary source of fuel, it is important to check local codes; some may restrict the amount of propane storage (e.g., as in the city of Chicago), while other municipalities may allow the storage of propane outside the building.

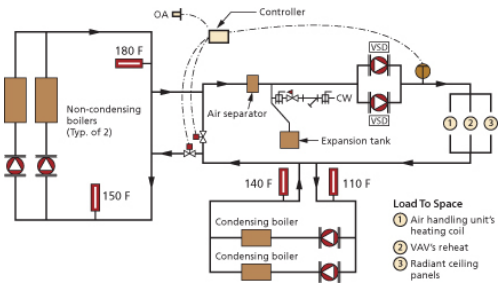
Both condensing and noncondensing boilers are constructed in accordance with ASME Boiler and Pressure Vessel Code, Section IV, and controls and fuel valve train for both should follow ASME CSD-1 and UL standards. Other codes, such as NFPA 54, National Fuel Gas Code, also apply to these installations.

The design engineer should review the facility's insurance underwriter requirements in case they are not in alignment with applicable codes, to find a mutually acceptable common ground.

Hybrid heating systems

A hybrid system containing both non-condensing and condensing boilers may be used when an owner is trying to reduce initial cost and also wants to enhance operational efficiencies.

Figure 4 shows a hybrid heating system serving the air-handling unit's heating coil, VAV's reheat coil, and radiant ceiling panels. The heat users are selected to meet the design-day load with 180 to 190 F supply water temperature, and 150 to 160 F return water temperature. Noncondensing boilers are piped in parallel as part of the primary loop, each with a dedicated pump, while condensing boilers are piped in parallel as part of the secondary loop, each having a dedicated pump. Two distribution pumps, each with a variable speed drive, serve the heat users.



When the required system's supply water temperature is 180 to 190 F, which is too high for condensing boilers to condense, the system will operate with the less expensive, noncondensing boilers.

Based on OAT, the system's supply water temperature shall be adjusted. When it is relatively warm outside, the supply water temperature can be reduced and the system can maintain space design conditions with lower supply water temperature, during which the condensing boilers will operate in condensing mode and water will circulate through the secondary loop only.

Controls for a hybrid heating system are more complicated than those for a heating system with either noncondensing or condensing boilers. System water temperature should be monitored continuously to determine which boiler should be enabled. To achieve the highest systems efficiency, the controls should include the following:

- Master boiler management controller: The master controller will stage the boilers and modulate firing rates to achieve the

highest boiler efficiency. The controller will also rotate the lead/lag/stand-by boilers on a time schedule to distribute run time hours. This functionality can also be performed by a BAS.

- Outside air temperature input: The hot water supply temperature setpoint should be reset based on OAT to conserve energy. The outside air sensor can be wired directly to the boiler master controller or reset logic can reside in the BAS with a supply water temperature setpoint output to the boiler master controller. The range of reset schedule should be selected to coincide with the operating conditions of the condensing and noncondensing boiler operations.
- Automatic isolation valves to switch between condensing and noncondensing boiler operation: The automatic isolation valves will operate as two-position to switch between condensing and noncondensing modes of operation. The OAT should be used to determine when to switch between condensing and noncondensing modes of operation.

Even though the hybrid heating system can reduce the initial costs of a heating system, the facility operating engineers must receive specific training on the operating differences between the condensing and noncondensing modes of operation.

The two position valves shown in Figure 4 also could be used in modulating fashion to warm up the noncondensing boiler loop fairly quickly, minimizing the amount of time the boiler condenses during warm-up; it also can minimize the thermal shock potential by blending colder return water with the boiler loop gradually.

What's next?

While the high operational efficiencies of condensing boilers will drive their future specification, noncondensing boilers will continue to be employed in retrofit applications where legacy design issues apply and where cost is a major factor, until higher operational efficiencies are mandated under new energy use codes. Until then, hybrid systems will provide a middle road for the energy-conscious, fiscal building owner.

Tabrizi is vice president at Environmental Systems Design and has more than 25 years of experience in the design of mechanical solutions for pharmaceutical facilities, research and development laboratories, food processing plants, and commercial buildings. As project engineer, he works closely with the other discipline managers to establish and implement project requirements, schedules, and budgetary parameters.

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