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Using condensing and modulating boilers to increase operating efficiency

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According to the U.S. Department of Energy, almost 60% of boilers in the United States are more than 25 years old. Furthermore, it is widely accepted that these older-style, conventional boilers typically deliver less than 80% energy efficiency.

As facilities managers across the country begin to retrofit their aging boiler plants, they have the opportunity to upgrade to a new generation of gas-fired hydronic boilers. This new breed of equipment is specially designed to condense and modulate – features that enable them to operate at up to 99% thermal efficiency. This improved performance can translate to tens or hundreds of thousand of dollars of fuel savings each year.

Condensing operation increases efficiency

Condensing occurs when water vapor is changed into a liquid state. Water vapor, which is a by-product of the gas-fired combustion process, is found within a boiler's exhaust gases and contains significant energy. For every pound of water vapor that is forced into a liquid state, approximately 1,000 BTU of latent energy is released in the form of heat. When this change of state takes place in the heat exchanger of a high-efficiency boiler, it is referred to as condensing operation. From within the heat exchanger, the recaptured energy can be transferred into the loop water, turning more of the boiler's fuel into

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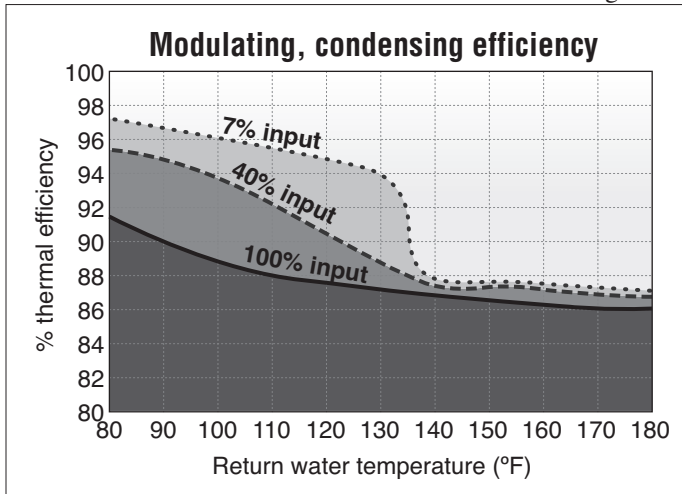


Condensing and modulating boilers can make significant contributions toward energy efficiency when effectively applied and controlled in hydronic heating applications.

usable heat. Despite its ability to deliver an estimated 11% to 12% increase in energy efficiency, not every boiler is designed for condensing operation.

While clearly desirable from an efficiency perspec-

tive, condensing has long been known to be damaging to boilers. When latent energy is extracted from the water vapor, acidic condensate remains on the surface of the heat exchanger. Unless the heat exchanger has been built from corrosion-resistant materials and is designed to



Regardless of whether a user has a conventional or high-efficiency boiler, flowing cold water into the heat exchanger will automatically cause most units to begin to condense, yielding greater efficiencies.

drain freely, condensate will damage and destroy it over time. According to *ASHRAE Handbook 2008*, non-condensing boilers, which are fabricated using less expensive materials such as copper, cast iron and carbon steel, will corrode because of acidic condensate. Boilers designed using these materials must rely upon protective system designs to prevent condensing operation. In contrast, the heat exchangers of today's high-efficiency boilers are manufactured from superior materials such as stainless steel and aluminum, and can withstand years of condensing with no significant corrosion.

Low return-water temperatures essential for condensing

Importantly, condensing happens naturally when the water vapor in the exhaust falls below its dew point. The required change of state will occur when the exhaust gases come into contact with a cool heat exchanger surface, such as when cool return water is brought to the boiler. Simply by flowing cold water (less than 130 F) into the heat exchanger, just about any boiler – conventional or high-efficiency – will automatically begin to condense to yield greater efficiencies. However, if the

heat exchanger surface is not cool enough, even a condensing boiler will not operate in condensing mode.

Consequently, to leverage today's high-efficiency equipment, the system design must promote condensing operation by returning low-temperature water (less than 130 F) to the boiler, according to *ASHRAE Handbook 2008*. Whereas conventional system designs specifically employed ancillary devices such as boiler pumps, mixing valves and temperature-averaging components to pre-warm water entering the unit above 140 F to protect the boiler, today's condensing boilers can be installed directly on the heating loop. And, in addition to increasing the opportunity for condensing operation, this approach streamlines the system design, reduces project costs and helps to minimize maintenance for the life of the system.

To exploit the potential of today's condensing boilers, the *ASHRAE Handbook 2008* indicates engineers must rethink conventional 20-degree ΔT applications (i.e. 180 F supply/160 F return) in favor of high ΔT designs that promote low return water temperatures (i.e. 160 F supply/120 F return). In addition to the increased efficiency, using a 40-degree or greater ΔT also reduces pumping capacity, piping sizing and more to cut materials, installation and operational costs across the entire system. Even if somewhat constrained by an existing system's design, facility engineers can employ aggressive outdoor reset and night setback schedules to foster the low return-water temperatures needed to trigger condensing operation.

Modulation saves energy, improves comfort

Conventional boiler designs have only one level of power - 100%; they either run or are shut down. Each time a unit shuts down, the heat exchanger cools off and must be fully re-heated before transfer can begin again. When the unit is on, the 100% firing rate may be far more than what is required to meet the building's load. Such operating conditions, common in most space heating applications, lead to repeated cycling and can cause valve hunting and poor temperature control at the terminal units. The customer pays the price for cycling losses in their fuel bill and also sacrifices occupant comfort in systems that can exhibit a 10 F to 20 F variance in supply water.

Modulation refers to a boiler's ability to match firing rate – input – to meet the heating demand – output – of the system. Modulating boilers offer turndown ratios of

3:1, 4:1, 5:1 – even as high as 20:1 – to operate at less than 100% input. For example, a 1 million BTU-per-hour boiler with 20:1 turndown can operate at just 5% of its maximum capacity (that’s just 50,000 BTU-per-hour) before it cycles off. Such units will then increase output in 1% increments – sometimes called “infinite” modulation – up to 100% capacity. Instead of cycling on and off, modulation allows the units operate (near) continuously, at lower capacity, to minimize cycling losses and wasteful overshoot.

According to *ASHRAE Handbook 2008*, modulating controls typically offer more precise water temperature control and higher efficiency than on/off or high/low controls.

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When modulating boilers operate at part-load, less fuel is burned and energy transfer is enhanced to generate greater fuel savings. Constant operation maintains temperatures within the heat exchanger so no energy is wasted to soak the heat exchanger until it reaches optimum heat transfer condition. Such steady operation also helps maintain a constant temperature throughout the system for enhanced comfort. In addition, a low firing rate increases the time and surface


area available for combustion gases to be in contact with the heat exchanger. Such enhanced contact promotes greater energy transfer.

Using multiple-unit control to maximize savings

Part-load efficiency can be further leveraged by using a boiler management system to coordinate the operations

of multiple modulating units. However, not all multiple boiler controllers are created equal. Many are programmed to coordinate the operation of non-modulating boilers, bringing units online sequentially where each is assumed to be operating at 100% of capacity. While this makes sense with a plant consisting of on-off boilers, it won’t maximize the enhanced part-load performance of today’s fully-modulating boilers.

To demonstrate, consider a boiler plant that consists of five 2-million BTU-per-hour units, each with 20:1 turndown. While the plant can deliver anywhere between 100,000 to 10 million BTU-per-hour, it requires less fuel for all five units operating at 60% of capacity to meet a 6 million BTU-per-hour load than it would for just three of the units firing at 100%. Consequently, an appropriate control strategy would engage all five units, each firing at less than full capacity, to meet demand, rather than to only bring on three units as would occur using a sequentially staged, multiple-unit controller.

Condensing and modulating boilers can make significant contributions toward energy efficiency when effectively applied and controlled in hydronic heating applications. While equipment with these capabilities is considered to be the latest generation of high-efficiency boiler, the technologies are by no means new. In fact, commercially-sized condensing and modulating boilers have been available in the U.S. for the past 20 years. Both their operating reliability and their ability to reduce fuel bills have been performance-proven. 

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