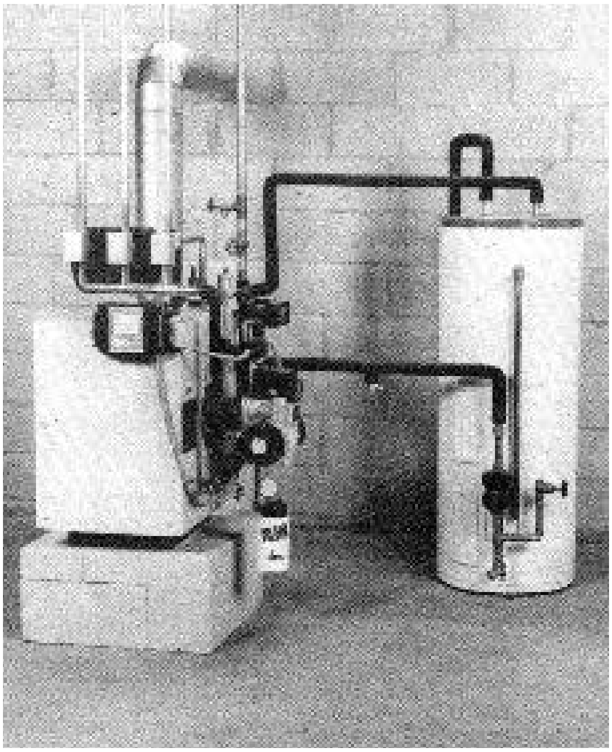
Guide to High Performance Hydronics:

by John Seigenthaler

Condensing boilers work best in low-temperature applications. For other uses, consider power venting and boiler purging.



By capturing residual heat during the boiler's off-cycle, the System 2000, from Energy Kinetics, achieves near the efficiency of condensing boilers without the complications.

Since the energy crisis in the early 1970s, manufacturers have devised a number of new strategies aimed at extracting more heat from a given amount of fuel. At the same time, they've developed new approaches to handling exhaust gases and reducing off-cycle heat losses. This article will take a brief look at these new approaches, and provide some practical guidance for their selection and use.

Condensing Boilers

Until recently, most boilers were designed so that water vapor—a byproduct of fossil-fuel combustion—would not condense within the boiler. This prevented corrosion of the cast-iron or steel boiler parts exposed to the flue gases. Rising energy costs, however, as well as competition in the boiler market, have changed all that.

Many manufacturers now offer boilers specifically designed to condense water within the appliance. Condensing is now desirable because it offers one way for manufacturers to improve boiler efficiencies. The goal is to get the most heat output for each unit of fuel consumed.

Significant amounts of heat can be recaptured if the water vapor, produced as a byproduct of natural gas combustion, can be condensed *within the boiler*. To accomplish this, the exhaust gases must be cooled below their "dew-point temperature." This temperature depends on a number of combustion-related factors, but is usually in the range of 125°F to 140°F for natural gas boilers. Cooling the exhaust gases below this temperature forces some of the water vapor molecules to merge into liquid droplets.

A good analogy to condensing boilers is seen in the exhaust from a car on a cold winter day. When the car is first started, the temperature of the exhaust pipe and muffler is low enough to cause the water vapor produced by combustion to condense within the exhaust system. Under these conditions, water can often be seen dripping from the tailpipe. As the exhaust system warms above the dew point of the combustion gases, the water vapor no longer condenses, and the dripping from the tailpipe stops.

Under typical conditions, each therm of natural gas (one therm = 100,000 Btus energy content) produces approximately 1.15 gallons of water vapor during combustion. If all this vapor could be condensed within the boiler, approximately 10,100 Btus of heat would be recovered from the exhaust gases. This represents about 10% of the original energy content of the therm of natural gas, which, in a non-condensing boiler, is lost up the flue.

Oil-fired condensing boilers do not offer the same benefits as their gas-fired counterparts. To begin with, fuel oil has a lower hydrogen content than natural gas. Because of this, less water vapor is formed during combustion, and hence its recovery would represent a smaller gain in performance. The return water temperature necessary to induce condensation becomes even more critical than for a gas-fired boiler. Return temperatures of 125°F or less would be required for consistent condensing-mode operation. Hence such boilers are suitable for only low-temperature systems.

Another practical problem is how to avoid the formation of soot within the boiler heat exchanger. This problem is aggravated when exhaust gases are cooled low enough to allow condensation. When soot does accumulate, it will decrease boiler efficiency because it inhibits heat transfer from the combustion gases to the boiler water.

The actual amount of water vapor recovered in a condensing boiler, however, depends upon the temperature of the return water. The rule is: *the lower the return water temperature, the greater the amount of condensation within the boiler, and hence the higher its efficiency*. Consequently, condensing boilers make the most sense in low-temperature applications. Figure 1 (next page) shows how the efficiency of a boiler changes depending on return water temperature.

Low-water-temperature applications such as radiant floor heating, swimming-pool heating, or even snow melting, are good candidates for condensing boilers. Systems that adjust water temperature based on outside temperature are also good candidates for condensing boilers, due to their ability to operate at lower water temperatures during mild weather. Examples include units from Tekmar, Ista, Animat, and Honeywell.

Traditionally designed hydronic baseboard systems, sized at higher supply water temperatures, typically 180° to 200°F, will seldom yield return water temperatures low enough for condensation to occur. A condensing boiler in such an application will not consistently operate in a condensing mode. Hence its performance will be about the same as a non-condensing boiler.

If you're considering a condensing boiler, be sure the site has provisions for drainage of the condensate. In a typical residential system, *several gallons of condensate can be formed each day*. Never assume the condensate will simply evaporate or dissipate downward through cracks or small holes in a concrete floor slab. The condensate is slightly acidic (pH 4.1), which could cause deterioration of the surface of a concrete slab if allowed to accumulate.

Most plumbing codes allow condensate to be routed into the sewer system. Studies performed in the Netherlands have shown that the condensate, when mixed with normal sewage, has no negative effects on sewer systems or sewage treatment plants.

Also be certain that the flue piping used with a condensing boiler is com-

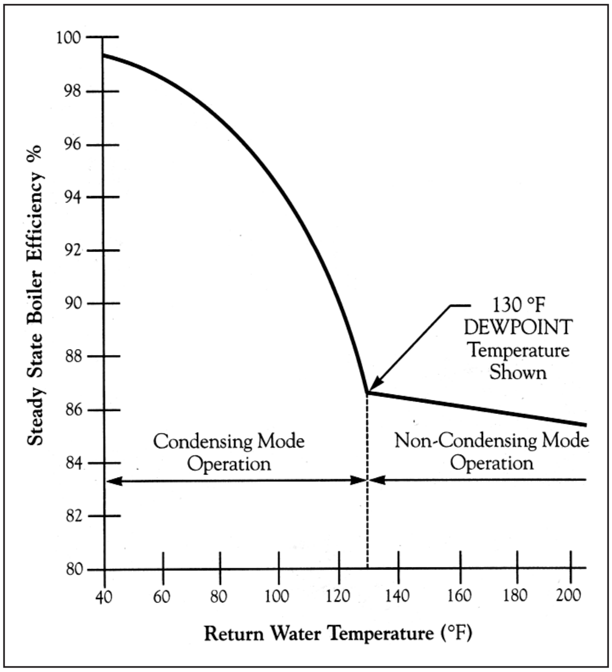


Figure 1. *Note that the lower the temperature of the return water, the higher the efficiency of a boiler. Consequently, condensing boilers are best for low-temperature applications, such as radiant floors and swimming pools.*

patible with the temperatures and acidic condensate. CPVC and other synthetic materials are currently specified for such applications. The exhaust system should not terminate directly behind shrubbery, under porches or decks, or near windows. In addition, exhaust piping should not be tied into existing chimney flues. The cool temperature of the exhaust may not be sufficient to create proper draft in the flue, even with the assist of power venting.

Leakage, or "backdrafting" of toxic gases such as carbon monoxide from cracked or unlined flues, other appliance connections, or cleanouts, obviously must be avoided. Be sure not to create low points in the exhaust piping which could act like plumbing traps and eventually fill with water that condenses after leaving the boiler. Eventually such an accumulation of water could shut down boilers with draft-proving safety switches. If the low point were exposed to freezing temperatures, the exhaust pipe could burst, leading to water damage and leakage of exhaust gases.

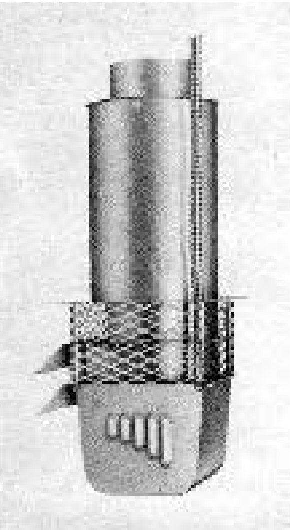


Figure 2. *Power-vent kits, like this one from Field Controls, Inc., enable most boilers to directly vent exhaust gases out the sidewall, and avoid the need for a conventional chimney.*

Boiler maintenance is also a key concern with condensing equipment. Be sure that the contractor who installs the condensing boiler is familiar with the equipment, and can be relied upon for maintenance. Look for someone who has been trained by the manufacturer.

New Concepts in Hydronic Boilers

To wrap up, let's briefly examine two of the new concepts being used with hydronic boilers: power venting, and boiler purging.

With power venting, the boiler's exhaust gases are routed directly outside the building, saving the cost of a conventional chimney. This is often referred to as "sidewall venting" since the exhaust pipe often penetrates the building envelope through an exterior wall.

The venting action is driven by a small electric blower compatible with the temperatures and chemical makeup of the exhaust gases. Power-vent systems use a "draft-proving switch," which verifies the proper negative pressure in the exhaust system before allowing the burner to fire. Such a fail-safe system protects the occupants in the event of a blocked flue.

Several manufacturers offer boilers which combine power venting with sealed combustion (Weil-McLain AHE series, Hydrotherm Hydropulse series, and Ener-Quip's Nataheat series). Such boilers draw their combustion air directly from the outside through plastic pipes or coaxial flue systems. This "uncouples" the combustion air flow from the building and provides excellent protection against backdrafting.

With power venting, exhaust gases are routed outside through either metal or synthetic exhaust piping which can withstand high temperatures. The latter material is not affected by condensation. Galvanized-steel exhaust piping should only be used where condensation can not occur in the exhaust system. Power-venting systems are currently available from several manufacturers for both gas and oil-fired boilers. Figure 2 shows one type of system.

Boiler purging is an innovative concept used on "System 2000" boilers from Energy Kinetics, Inc. (see lead photo). Boiler purging means leaving very little residual heat in the boiler or distribution piping which would be lost during an "off-cycle." This is accomplished by running the circulating pump after the room thermostat has been satisfied, until the system's water temperature has dropped to approximately 105°F. The residual heat of the system's water is released into either the building or to a domestic-hot-water storage tank rather than being lost up the flue. Since the boiler contains

Boiler Performance: The Rating Game

The word "efficiency" is often used in describing boiler performance. This term can take on several meanings depending upon what assumptions accompany it. For example: The *steady-state efficiency* of a boiler indicates what percentage of the fuel is actually converted to heat *under continuous firing, with no interruptions.*

Continuous firing yields high efficiency relative to that obtained when a boiler cycles on and off several times an hour. This is like the higher gas mileage a car gets under steady highway driving compared to stop-and-go city driving.

Unfortunately, boilers seldom operate under steady-state conditions, especially if they are significantly oversized relative to the building's heating load. Under these "real world" conditions, boiler efficiency drops (as do mileage ratings).

Annual Performance

In 1978, the U.S. Department of Energy (DOE) instituted a test procedure for establishing efficiency values that account for intermittent boiler operation. The result of this test procedure is called the *Annual Fuel Utilization Efficiency*, or AFUE for short. The AFUE of a boiler is a more realistic indicator of its average seasonal efficiency. Since nearly all boilers sold in the United States are tested for the AFUE, it also provides a consistent means of comparing boiler performance.

The AFUE is also the appropriate efficiency rating to use when computing seasonal fuel requirements. For example: Assume that the calculated seasonal heating requirement of a given home is 60 million Btus (60 MBtus). The home is equipped with a gas-fired boiler that has an AFUE value of 82%. We could easily estimate the seasonal fuel usage as follows:

$$\text{Season fuel usage} = \frac{\text{Seasonal heating load}}{\text{AFUE}} = \frac{60\ \text{MBtu}}{0.82} = 73.17\ \text{MBtu}$$

$$\text{This would convert to:} \quad \frac{73{,}170{,}000\ \text{Btu}}{100{,}000\ \text{Btu/therm}} = 731.7\ \text{therms of gas}$$

Other Performance Indicators

Heating output values supplied by boiler manufacturers are often stated in the form of one or more of the "IBR" ratings. IBR stands for the Institute of Boiler and Radiator Manufacturers, a former testing and rating organization which is today known as the Hydronics Institute. The two basic IBR ratings used by nearly all U.S. boiler manufacturers, are the "IBR Gross Output" and "IBR Net Output."

The IBR Gross Output rating is the actual heat transferred to boiler water under steady-state firing. Heat losses from the boiler housing are measured, but are not considered to contribute to the building's heating load. The IBR Net Output rating is obtained from the IBR gross output rating by deducting 15% for the assumed piping heat losses of a typical distribution system, as well as a factor called "pickup."

The allowance for piping heat loss is based on an average system water temperature of 170°F. Lower temperature systems, such as radiant floor heating, will have smaller losses. The term "pickup" refers to the energy needed to bring the thermal mass of the boiler and water up to operating temperature. Low-mass residential boilers, closely sized to the building design heating load will have minimal pickup energy requirements.

Another heating output rating, known as "DOE Heating Capacity," also appears along with the IBR ratings. DOE Heating Capacity values are higher than IBR Gross Output values because they assume all heat loss from the boiler housing contributes to the building's heating load.

The preferred capacity rating for use in boiler selection actually depends upon how, and where, the boiler and distribution piping will be located. IBR Gross Output is applicable in situations where the boiler is in unheated space such as a cool basement or crawlspace, but the distribution piping is mostly within heated space. If the boiler and distribution piping are both located in unheated space, the IBR Net Output rating is preferred.

For example, if you were replacing a boiler in the same unheated space as its predecessor, heat losses from the boiler housing and distribution piping would continue to be wasted without any offsetting effect on heating load. In these situations, the IBR Net Output rating would provide a built-in safety factor in boiler selection. If the boiler and distribution piping were both located in heated space, however, the DOE Heating Capacity would be more appropriate since losses from both the boiler housing and distribution piping will offset a portion of the building's heating load.—*J.S.*

Euro-Radiators: High-style Hydronics

The mainstay of hydronic radiators in the U.S. has been the finned-tube baseboard. Such units consist of a 1/2-inch or 3/4-inch copper tubing with closely spaced aluminum fins, mounted in a steel enclosure at the base of exterior walls. Such units rely almost entirely on convection (the passive flow of heated air upward through the finned-tube element) to transfer heat into the room. Heat output of average residential units is typically in the range of 550 Btuh *per foot of length* for water temperatures of 180°F. In some cases baseboard radiation is limited by the amount of unobstructed wall space available in the building. Even when the wall space is adequate, furniture placement can often interfere with convective air flow.

Plate-style Radiators

An alternative to the conventional finned-tube radiator is the "plate radiator." These units are largely of European origin, and have only recently been produced in the U.S.

They consist of either pressed steel sheets or flattened steel tubes joined to supply and return manifolds. Some manufacturers have literally hundreds of various sizes and shape to select from. Most units protrude about 2 to 3 inches from the wall surface, and are supported by wall brackets. Supply and return connections are usually at the bottom. It is common practice in Europe to have 6 to 8 inches of exposed piping between the bottom of the radiator and floor. This piping is usually steel rather than copper for physical durability against vacuum cleaners, etc. The piping is usually painted to match the radiator. Often the heat output of the radiators is controlled by a non-electric thermostatic radiator valve placed in the return pipe just below the radiator.

One advantage of plate-type radiators is that a higher percentage of their heat output is delivered by infrared radiation rather than convection. This improves comfort and tends to reduce temperature stratification within the room. Such radiators can be used with low- to medium-temperature heat sources such as hydronic heat pumps when sized to compensate for the lower water temperatures. They are a good alternative to radiant floor heating.

Some manufacturers offer the option of finned surfaces on the rear face of the radiator panel to increase heat output via convection. This is often necessary for low-profile radiators (6 to 12 inches in height) mounted under windows. The rising air current reduces condensation on the glass during extremely cold weather.

Another feature of most European plate radiators is the quality of their finish. A baked-enamel finish seems to be the standard. The quality is comparable to an automotive finish and many manufacturers offer several colors to choose from.

A popular option offered by most manufacturers of plate radiators is the "towel warmer" model. This usually consists of a brass or chrome-plated towel bar attached to the front of the radiator through which hot water flows. Wet towels are quickly dried and warmed when hung over this tube.

What does all this European style cost? Typically more than average residential finned-tube baseboard. A 2x3-foot panel radiator capable of delivering 3,400 Btuh using 180°F water will have a list cost of between $150 and $250 depending on the manufacturer and options. A comparable amount of average residential grade baseboard would have a list cost of about $70 assuming straight runs without endcaps, corner trim, etc.

A mix of conventional and plate-style radiators is often used in buildings with restricted wall space in some areas and ample space in others. This is a good compromise. The aesthetics, of course, are in the eye of the beholder. Judge for yourself.

—J.S.

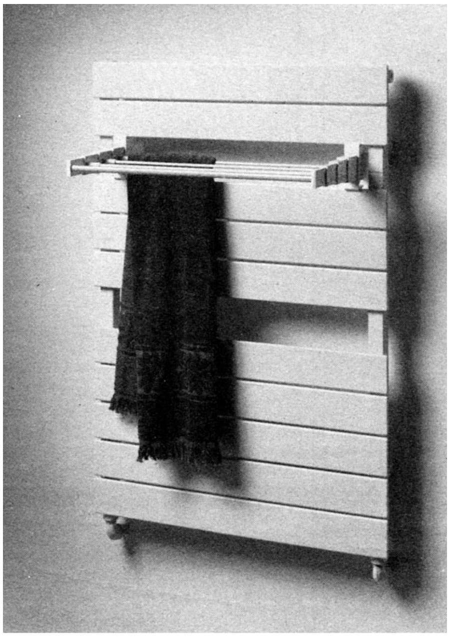


Plate radiators come in hundreds of sizes and shapes, can use low water temperatures, and deliver much of their heat by radiation. The Runtal unit (left) doubles as a bathroom towel rack. The Fellingsbro unit (below) appears as wainscotting.

For More Information

Manufacturers of plate-type radiators

Acova
4444 W. St. Catherine St.
#103
Montreal, PQ H3 Z 1R2
Canada
514/932-8767

Buderus
Delcon Inc.
P.O. Box 1748
Jackson Hole, WY 83001
307/733-6733

Fellingsbro
c/o Enerjee, Int'l
32 S. Lafayette Ave.
Morrisville, PA 19067
215/295-0557

Runtal North American, Inc.
187 Neck Road
Ward Hill, MA 01835
508/373-1666
800/526-2621

Stelrad Ideal
c/o Northland Corp.
34 Industrial Park Place
Middletown, CT 06457
203/632-7227

Wheatley GASCO, Inc.
P.O. Box 2069
Tulsa, OK 74101
918/446-4551

only 2.5 gallons of water, no significant overshoot of room temperature occurs during this operation.

Boiler purging allows the System 2000 boiler to retain nearly steady-state efficiency, even when fired for only three minutes each hour. This significantly reduces the cost penalty of operating an oversized boiler. According to a study at Brookhaven Labs, a System 2000 boiler oversized by a factor of three (relative to design heating load), loses only about 1.3% in seasonal efficiency relative to a boiler sized equal to design heating load. By comparison, a standard boiler that's three times oversized loses about 23% in seasonal efficiency. One that is twice the proper size loses about 12%.

The AFUE rating of the oil-fired System 2000 boiler is 87.5% according to recent testing. Although slightly lower than the possible efficiencies of condensing boilers, this is nonetheless excellent performance.

Summary

When selecting a boiler:

- Match condensing boilers with low-temperature systems for highest efficiency.
- Compare AFUE ratings for competing boilers.
- Choose an appropriate indicator for heating capacity based on where the boiler and distribution piping will be located.
- Always do an accurate heat-load calculation for the building.
- Don't needlessly oversize the boiler.
- Use an indirectly fired DHW storage tank to handle peak DHW loads. ■

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For More Information

Manufacturers of outdoor temperature reset control systems:

Tekmar Control Systems, Ltd.
4611 23rd Street
Vernon, BC V1T 4K7
Canada
604/545-7749

Animat
c/o Enerjee, International
32 S. Lafayette Avenue
Morrisville, PA 19067
215/295-0557

ISTA Energy Systems Corp.
P.O. Box 618
Roselle, NJ 07203
201/241-8880

Honeywell
1885 Douglas Drive North
Minneapolis, MN 55422
612/542-3357

Manufacturers of power venting systems:

The Field Controls Company
2308 Airport Road
Kinston, NC 28501
919/522-3031

Tjernlund Product, Inc.
1601 Ninth Street
White Bear Lake, MN 55110
612/426-2993