# TOTAL SYSTEM EFFICIENCY: CONDENSING BOILERS IN RETROFIT APPLICATIONS

**David Grassl | PE**
**Mechanical Engineer | Principal**

DYNAMIC CONSULTING ENGINEERS

Each retrofit has its own set of challenges, but having a solid understanding of the various pumping and piping configurations available will lead to the correct design for each project. Following are the steps necessary to evaluate piping applications, pumping configurations and control strategies necessary for a successful retrofit that increases overall hot-water-system efficiency.

## COMMON ITEMS IN ALL RETROFITS

The first step in the retrofit process is to evaluate the building loads, including any potential loads that are suitable for low-temperature applications such as domestic water heating, pool heating, or radiant applications including snow melt or in-floor heating. Once the loads are fully identified, the next step is to evaluate the system design temperatures currently in use to determine if they may be modified to increase efficiency, remembering that the goal is to reduce the hot-water-return temperature as much as possible while still meeting the building load to increase boiler efficiency. When converting traditional, non-condensing systems, it is standard for the hot water system to be designed with a hot-water-supply temperature in the range of 180°F to 200°F. Since it is customary for heating systems to have redundancy and safety factors included in the calculations that overestimate the true load, it is important to determine the actual boiler capacity required. Similarly, the minimum and maximum loads should be observed over time to assist in boiler sizing and selection to match system turndown and redundancy with the required loads.

Next, the control used at the heating coils should be reviewed to determine the method of coil and pump control. Traditional, non-condensing boiler systems typically have three-way temperature control valves at each coil in the system, which allows for variable flow at the coil as the load varies; however, any flow that is not required by the coil is bypassed around the coil and creates constant flow in the system. By using two-way control valves, the wasted water that bypasses the coil is eliminated while reducing the flow in the system when it is not required. The temperature-control-valve conversion literally can be a replacement of the valves, or it can be accomplished by fully closing the balancing valve in the bypass piping circuit and keeping the existing piping in place. Remember, in the conversion from three-way valves to two-way valves, it is important that the system minimum flows be maintained for the pumps and/or boilers by one of the methods described.

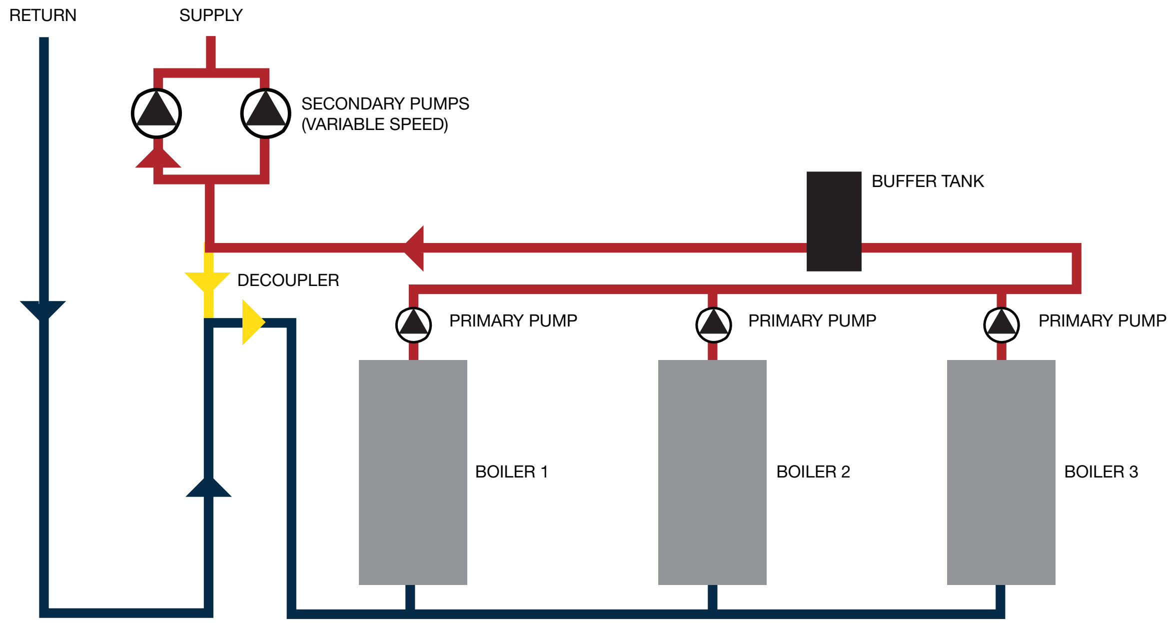
To maintain maximum system efficiency, as the control valves are converted to two-way control valves, the distribution pumps should also be converted to provide variable flow. Variable speed pumping can be accomplished by adding a variable frequency drive to the existing pump, providing a new pump with either a remote VFD or an intelligent pump with a built-in VFD or microprocessor. Regardless of the method used to vary the pump speed, note that it is important for pumps with variable speed drives to have shaft grounding rings. The use of variable frequency drives has the potential to induce harmful electrical voltages on the motor shaft, which can lead to pitting and premature failure of the shaft.

## PIPING & PUMPING MODIFICATIONS

In a retrofit application, the existing hot water system can be piped in a variety of different configurations, including constant volume, variable volume, variable-flow-primary, or primary-secondary. Regardless of how the system was previously piped, almost always there will be a need to adjust the piping configuration to maximize system efficiency. Although it is impractical to attempt to cover every application, this paper will discuss some of the more common retrofit configurations.

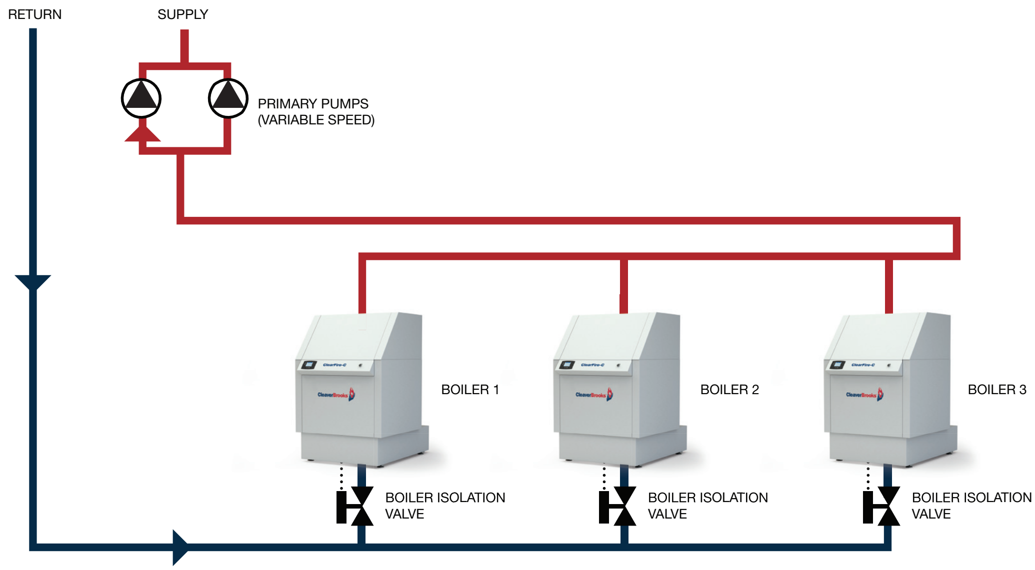
The first and likely most-common retrofit condition is converting a primary-secondary system with non-condensing boilers into a fully condensing boiler plant. This system is a cost-effective way to incorporate condensing boilers, but it uses low-mass boilers, which have a reduced life expectancy compared to high-mass boilers. In this configuration, all the existing non-condensing boilers can be replaced with similar condensing boilers in the same primary-secondary configuration. Low-mass condensing boiler systems typically require a design ΔT of 20°F to 30°F due to the amount of water in the system. At the same time, if the hot water system does not have the overall system volume necessary, it may be necessary to expand system volume, which can be accomplished by adding a primary-secondary buffer tank. With this approach, a few different functions can be accomplished with a single device. The primary and secondary systems can interact at a pipe common to both systems such as an air separator, buffer tank, or the common pipe. Remember, it is important to analyze each condition, especially in a retrofit condition, by comparing the style of boilers removed from the system with the new boilers being added. For example, if high-mass boilers are removed and replaced with low-mass boilers, the system water volume may be significantly reduced and require a buffer tank. However, if the reverse were true, a buffer tank may not be required in the new system. A second method to accomplish the same task is to use a buffer tank in the primary piping as shown in Figure 1.

**Figure 1: Low-mass condensing boiler system in a primary-secondary configuration with a buffer tank.**




If high-mass condensing boilers are used in lieu of low-mass condensing boilers, it is possible to eliminate the buffer tank because the system volume is accomplished within the boiler itself. Because of this, it is possible to modify the piping configuration from a primary-secondary system to a full variable-flow-primary system and remove the secondary pumps as shown in Figure 2. Since the boilers are condensing units, any water temperature that satisfies the building load is sufficient for the boilers to operate, and only the necessary flow is distributed to the system to minimize pumping energy. With this system, it is critical to install two-position, two-way isolation control valves that eliminate flow to the boilers only when they are not in operation to prevent bypassing the boilers and mixing water downstream of the boilers Figure 2: High-mass boiler system in a variable-flow-primary configuration.

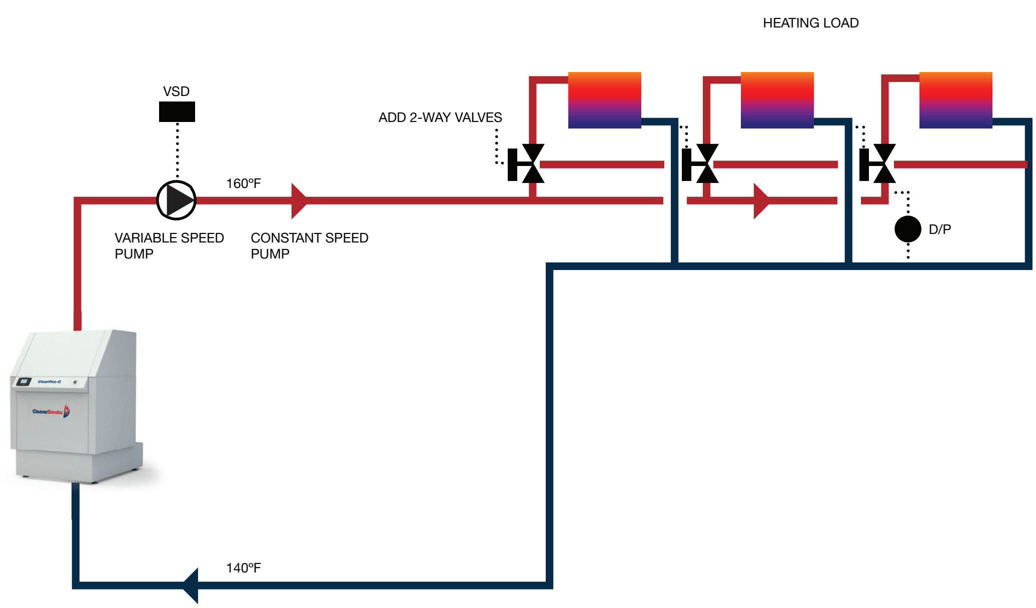
**Figure 2: High-mass boiler system in a variable-flow-primary configuration.**




A third approach is to use a system with a dual return. Applications for a dual-return system include systems that have a consistent low-temperature return that can be used to condense the boiler flue gases that might otherwise be lost by mixing the low hot-water-return temperature with high-temperature hot water. In a system with consistently low temperatures, the low-temperature hot water return is piped back to the boiler independently of the other hot water return piping to increase system efficiency. This allows the boiler to operate in a condensing mode even if a majority of the load requires non-condensing temperatures, increasing the boiler operating efficiency.

Another common retrofit is converting a traditional, non-condensing, constant-speed pumping system to a modern, condensing, variable-speed pumping system. By replacing the boiler with a condensing unit, providing a variable frequency drive on the pump with pump controls, providing two-way control valves, and reducing the hot water supply and return temperatures, the system can be converted as shown in Figure 3. Although this example shows a single boiler, it can be used for multiple boilers in parallel.

**Figure 3: Retrofit option from a constant speed, non-condensing boiler system to a variable speed, condensing boiler system.**



A slightly more complex, but still common retrofit application is converting a larger primary-secondary, non-condensing boiler system with multiple boilers to a configuration that can maximize system efficiency by either partially or fully replacing the non-condensing boilers with condensing boilers. In the existing non-condensing boiler system, each unit has a primary pump that operates when the boiler's primary function is producing hot water for the secondary loop. The primary and secondary loop are connected by a common pipe that hydraulically decouples the loops from each other (also known as a decoupler). Depending on the hot-water-supply temperatures required by the system, this enables a couple of potential piping options.

The simplest configuration is to completely replace all the boilers in the plant with condensing ones and reduce the system hot water supply temperature to meet the load. Under this configuration, with the use of high-mass boilers it is possible to operate a variable-flow-primary system with a single set of primary pumps to distribute water to the entire building. This option will yield the highest efficiency as the entire boiler plant would be condensing and the system would experience only the pumping energy required to meet the load. However, this option has the highest first cost as condensing boilers are more expensive than similar-sized non-condensing boilers. This method also assumes that lower hot water supply temperatures can be used by the system to maximize system efficiency.

A second approach is to maintain the primary-secondary pumping configuration with a hybrid of condensing boilers and non-condensing boilers as shown in Figure 4. In this configuration, condensing boilers are installed upstream of the non-condensing boiler to allow the coldest water to come in contact the condensing boilers first. The condensing boilers can then heat the hot water for the non-condensing boiler, or in some cases during low loads, to satisfy the entire load required for the building. The pumping configuration at the condensing boilers should be set up to operate based on a ΔT pumping configuration to maintain a hot-water-return temperature to the non-condensing boiler appropriate to prevent condensing. One advantage of this system is the primary-secondary pumping configuration is maintained for simplicity and familiarity, but it enables higher efficiencies since the condensing boilers are upstream of the non-condensing boiler.

**Figure 4: Hybrid plant with primary-secondary pumping.**

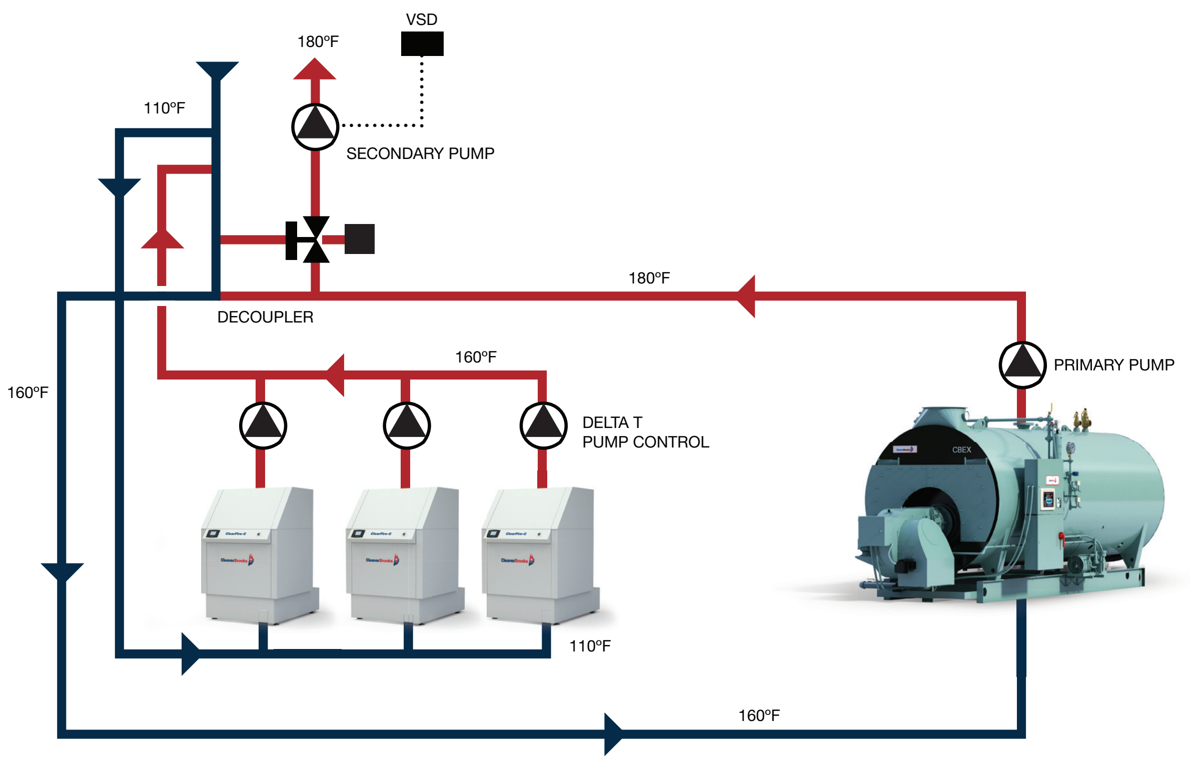
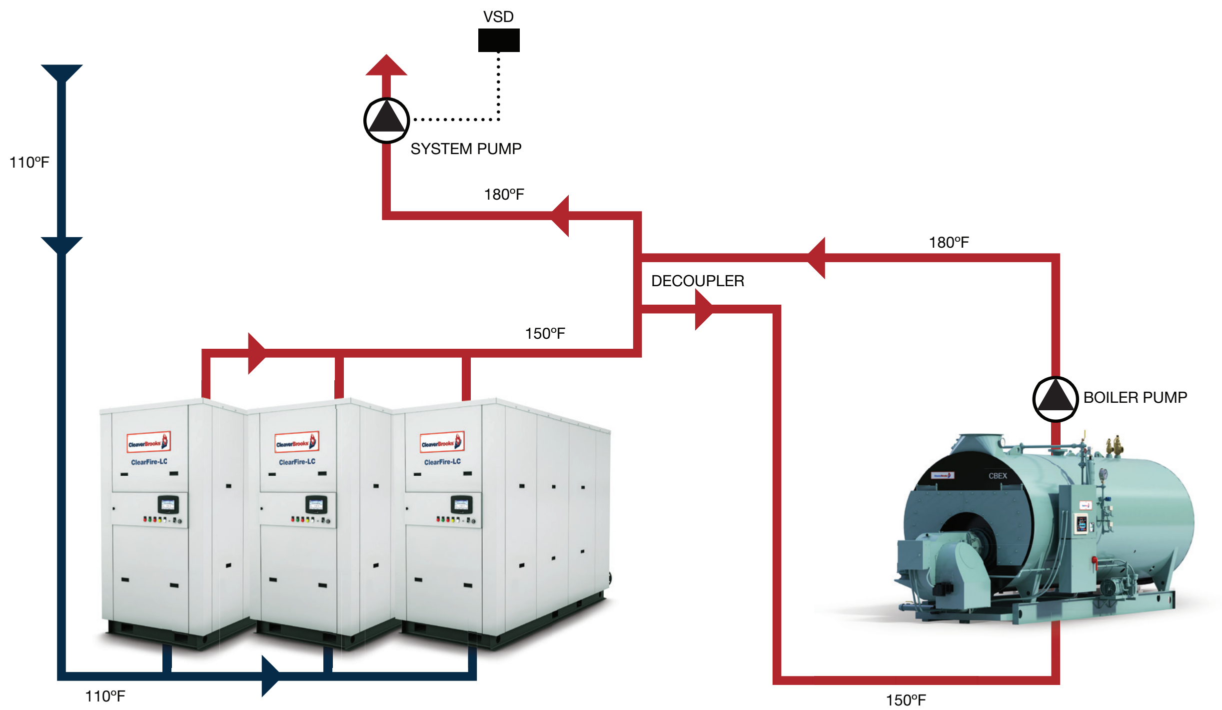


Figure 5 shows another hybrid configuration that focuses more on a variable-flow-primary pumping arrangement while using a non-condensing boiler in a side-car configuration. Similar to the first hybrid configuration, the condensing boilers are the first boilers in the boiler plant to see the hot water return so that condensing conditions can be maximized as much as possible while also providing water at a sufficient temperature to protect the non-condensing boiler. By having the non-condensing boiler configured in its own loop with a dedicated pump, should additional heat be required by the system, the control strategy utilized by the primary-secondary configuration can be utilized. As additional heat is required by the system, the non-condensing boiler pump turns on and increases the hot-water-supply temperature to the primary loop through a common pipe or decoupler, which maintains its hydraulic independence from the rest of the system.

**Figure 5: A second hybrid configuration with variable-flow-primary pumping.**




This configuration, like the other hybrid approach, provides the ability to retain a non-condensing boiler and reduce retrofit costs in lieu of purchasing an entirely new condensing boiler plant. The advantage of this system compared to the first one is the ability to operate in a true variable-flow configuration, which uses less horsepower compared to primary-secondary systems and has less equipment to maintain.

## CONTROL STRATEGIES

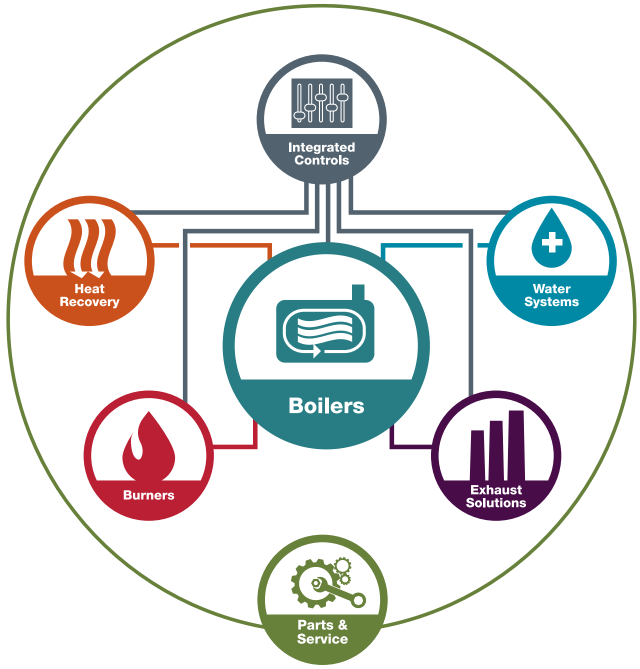
Similar to pumping and piping configurations requiring modification in a retrofit, the standard control strategy that has been used in non-condensing boilers needs a refresh as well. In traditional boiler systems, it is common practice to operate boilers in a lead-lag staging configuration to maintain the hot-water-supply setpoint. In this setup, the first boiler in the plant operates and stages capacity in order to meet the system setpoint in the main supply header. If the first boiler is unable to maintain setpoint, the control indicated that the boiler could not provide enough capacity, and an additional boiler was brought online to increase the hot-water-supply temperature. In theory this is a good solution, but what actually occurs in the system is that the boilers online operate with uneven firing rates and different hot-water-supply temperatures. Because of this, it is common for the first boiler online to overshoot the hot-water-supply temperature setpoint and produce hot-water-supply temperatures above the setpoint at full load in order to compensate for the second boiler at part load, producing hot water temperatures below setpoint as mixing downstream of the boilers occurs. This leads to unstable and unpredictable hot water temperatures from each boiler in the system, thereby reducing efficiency and increasing boiler cycling.

In modern condensing applications, boilers typically operate in parallel, regardless of the system load. Contrary to the traditional method of control, system efficiency with condensing boilers improves at part-load condition as more surface area is available for condensing. Similarly, a consistent hot-water-supply temperature can be produced from each boiler in parallel to the distribution system. With the condensing boilers operating in a true parallel configuration at similar loads, controls strategies can be used to further maximize system efficiency. For example, systems that require high hot-water-supply temperatures based on a traditional design can operate with an aggressive hot-water-reset schedule based on outside air to promote condensing during the summer or periods when there are low loads in the system. This can be combined with a night setback schedule to promote the use of lower hot-water-supply temperatures when there may not be any occupants in the space.

Adding VFDs requires new control strategies to provide variable-speed pumping. This can be accomplished in a variety of ways with the most common method being to control the pump speed based on the differential pressure at a defined location in the system. As the system pressure changes based on the control valve position at any given time, the pump speed modulates to provide only the required pressure and flow the system needs, saving pumping energy.

Understanding the principles of condensing boiler technology is required to properly apply it in a retrofit project. For a retrofit application, and even for a new application, it is important to work with the boiler manufacturer to ensure you are designing within the requirements of the boiler. Similarly, it is critical to understand the building load and attempt to reduce the hot-water-return temperature as much as possible to achieve higher boiler efficiency. The pumping configuration and control strategies are just as critical to promote condensing conditions with consistent hot-water-supply temperatures.

Finally, when selecting a condensing boiler for your new or retrofit application, there are a variety of technologies available. Some condensing boilers require more maintenance than others, or have specific piping, pumping, and flow requirements. High mass firetube condensing boilers have been developed to overcome many of these obstacles, and can be piped in a variety of systems with success. Therefore, it is important to understand each boilers’ operating requirements, as well as total cost of ownership, when making a boiler selection.




# Providing energy-efficient, environmentally friendly boiler room solutions

Cleaver-Brooks is one of only a few boiler room solution providers in the world to operate a dedicated research and development facility. Having pioneered several industry-leading technologies, we remain just as committed today to introducing technology and products that enable a more energy-efficient and environmentally friendly generation of steam and hot water.

We distribute our products through the Cleaver-Brooks Representatives Association, or CBRA, an alliance of independently owned and operated companies that provide boiler room products and service. CBRA companies can be counted on to provide Cleaver-Brooks products and parts, engineering support, customer training, technical service and system maintenance. To find a CBRA representative near you, please visit cleaverbrooks.com/reps.

CleaverBrooks®

**Packaged Boiler Systems**
221 Law Street • Thomasville, GA 31792 USA
800-250-5883 • info@cleaverbrooks.com
cleaverbrooks.com


CB-XXXX
1/17