

TOTAL SYSTEM EFFICIENCY: CONTROL STRATEGIES & SYSTEM DISTRIBUTION

David Grassl | PE
Mechanical Engineer | Principal

This is the second paper in the total system efficiency series that will detail various control strategies available in boiler system designs and explain some of the various system distribution configurations that can be used to maximum system efficiency. The goal of a condensing boiler system design is to operate with the hot water return temperature as low as possible while still effectively heating the building. A condensing system should run in the condensing mode as often as feasible, otherwise efficiency will be lower than expected.

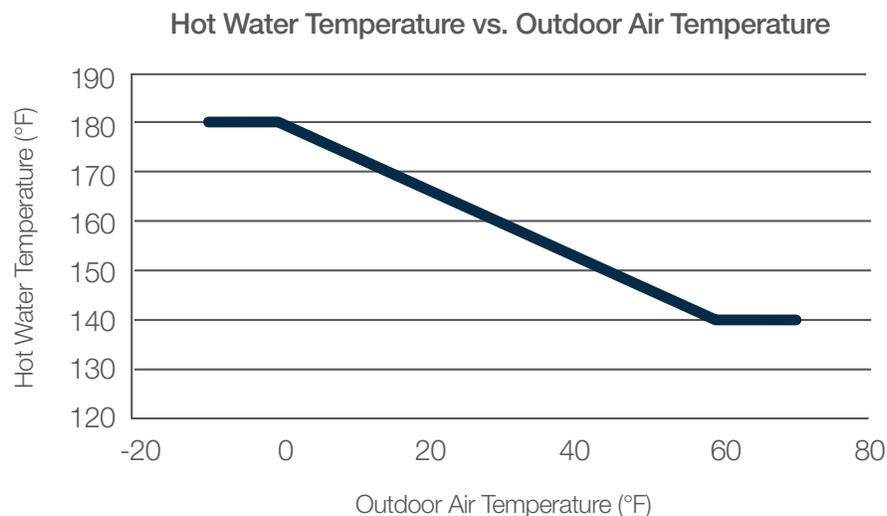
CONTROL STRATEGIES

Selecting a boiler to handle the building load as described in the first paper is a critical first step in the design process. After selecting the proper boiler size, achieving the maximum efficiency is determined by system design and controls. There are several control strategies that maintain a low hot water return temperature and optimize pumping energy used.

HOT WATER SUPPLY TEMPERATURE RESET

Hot water supply temperature reset is a basic control strategy that is very popular and has been utilized for quite some time. This control strategy resets the hot water supply temperature based on a system variable, typically outside air temperature. The ability to reset the hot water supply temperature centers on the principle that the building heating load is proportional to the outside air temperature. So, at a higher outside air temperature less heating is required and can be achieved with a lower-than-design hot water supply temperature. Energy savings is achieved when the outside air temperature increases since a lower hot water supply temperature can maintain comfortable space conditions. An additional benefit of hot water reset is that it minimizes distribution and stack losses at lower temperatures and limits interior temperature swings due to overheating. A typical hot water reset algorithm is a linear function with an upper and lower limit based on the outside air temperature as shown in Figure 1. The payback for implementing a hot water reset strategy is typically between one and three years. Many condensing boilers have algorithms with this functionality built into their onboard controls.

Figure 1: Hot water reset curve based on outside air temperature.



PUMP CONTROL

Strategies utilizing pump controls are an alternative that can work in conjunction with hot water reset for additional energy savings. This paper will discuss three strategies to reduce system energy consumption: ΔP pumping, ΔT pumping, and valve position with critical zone reset.

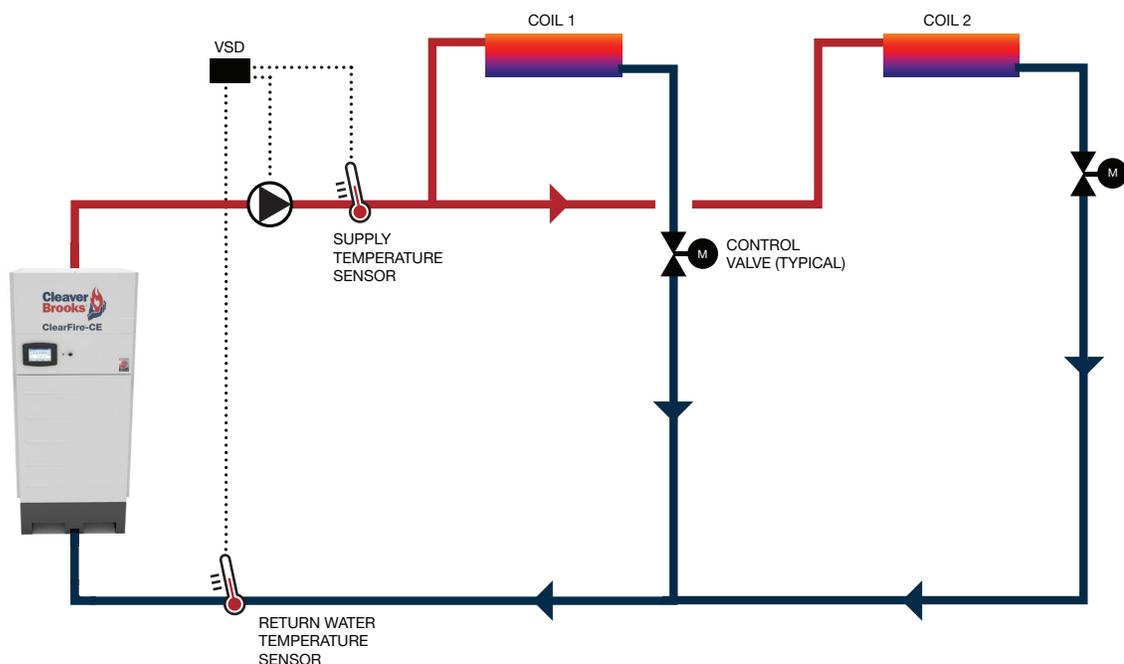
Delta P Pumping

The most common method of pump control for variable-speed pumping applications is ΔP pumping that includes a differential pressure transmitter located in the distribution loop. The location of the transmitter is important to ensure a good representation of the hydronic system pressure drop at the remote coil is provided. Alternatively, multiple differential pressure transmitters can be provided in the system and compared to make sure the worst-case condition is satisfied, assuming the pumps are using the same control signal. At the differential pressure transmitter, a small pipe is connected to the supply piping and a second pipe to the return piping to determine the downstream pressure differential. As system control valves modulate open and closed, the system pressure at the location of the differential pressure transmitter changes, reflecting the need for more or less flow to maintain a constant ΔP setpoint. Based on the setpoint and control point, the distribution pump variable-frequency drive is adjusted to increase or decrease the amount of flow to maintain the system pressure setpoint. The best application for a ΔP pumping configuration is at the secondary pumps in a primary-secondary system, and it can also be utilized in variable-flow-primary systems.

Delta T Pumping

A second method of pump control uses a similar process, but evaluates system ΔT as a control signal. Pumps have recently become more adaptive and controllable with the use of a built-in microprocessor that automatically adjusts system flow based on a defined condition. Controlling to a defined ΔT is a relatively new concept. It utilizes return and supply water temperature sensors that are connected to the pump and the microprocessor to vary the output based on maintaining a design ΔT between the hot water supply and hot water return piping as shown in Figure 2. By setting the differential temperature to be constant, when the system load changes, the flow rate will vary to match the required heat output at the heating coils and terminal units. In addition to reducing flow at low loads, this also maximizes system efficiency as the hot water return to the boiler will consistently be at design conditions, resulting in more operating time in the condensing mode, additional boiler on time, and increased total system efficiency. Pump control using ΔT can be utilized in a primary-secondary system on the boiler primary pumps to ensure a constant return water temperatures to the boiler as firing rates change.

Figure 2: ΔT pumping with hot water supply and return water temperature sensors to modulate pump speed



Valve Position with Critical Zone Reset

A third strategy to control the distribution pumps is to monitor valve position and the critical zone in the system to reset pump speed. Similar to the other methods, this approach utilizes the DDC system to monitor valve positions throughout the system and ensure that the control valve for one of the zones is fully open. By monitoring valve positions, it is possible to reset the pressure setpoint in order to maintain one control valve fully open, which saves energy compared to having all the valves closed at varying percentages. With this method, one can also employ a trim-and-respond control strategy where the setpoint is gradually trimmed, or lowered, to see how the system responds. If the pressure setpoint reset sufficiently satisfies the system, after a defined amount of time, the setpoint is trimmed further until it reaches a pressure setpoint that affects more than the single zone. A typical sequence of operations would be that a pressure request is generated when a coil is greater than 95% open and removes it when it drops below 80% open, with adjustability in the percentages to influence the pressure setpoint. If desired, a zone or coil can be added or removed from the trim and respond algorithms depending on the overall system influence the change has on the system. This strategy is effective at operating the system at the lowest possible pressure by continuously resetting the pressure until the minimum pressure required by the system is reached. Since feedback for this control strategy is directly from the load, the energy savings is typically higher compared to the outside air reset strategy.

In this strategy, a temperature control contractor must program the control, unlike in the hot water reset strategy where the boiler manufacturer sets the control through the boiler management system. So, the relative cost of this control strategy is higher because of the additional programming required in the building automation system by a separate contractor. Although this system is more complex than the other methods, it provides additional energy savings since it operates only at the necessary pressure and capacity to satisfy the system. This control strategy can be utilized on both variable-primary-flow and primary-secondary distribution systems.

BOILER MANAGEMENT

Boiler management should be discussed during the project with regard to who is ultimately responsible for controlling the hot water system and staging the boilers. Typically, the boiler manufacturer has the ability to control the system and usually has more flexibility to control multiple boilers and burners to achieve maximum system efficiency. The boiler manufacturer also has a better understanding of boiler safeties required for appropriate system operation, such as maintaining a minimum hot water return temperature. Finally, the controls have been factory-tested and will reduce commissioning and start-up time in the field.

A temperature-controls contractor can provide boiler system sequencing, but this approach often results in simple control algorithms, which can reduce overall system efficiency. A typical control sequence from a temperature-controls contractor generally relies on pre-configured solutions for relatively standard, simple systems and the sequences are applied to the designed systems, which may or may not be the best fit based on the multiple factors that influence total system efficiency. In this application, due to the variety of temperatures and algorithms involved, it is recommended to allow the boiler manufacturer to control the boiler staging, but provide an interface to the control settings within the building automation system. The building management system can deliver boiler plant enable/disable, or supply setpoint, however it is recommended to allow the boiler controls to stage the boilers when implementing condensing boilers.

BOILER SEQUENCING

Condensing boilers tend to have design guidelines that differ from standard, non-condensing boilers, and boiler sequencing is no different. Condensing boilers typically operate best when the maximum number of boilers are online at part-load to increase the heat-exchanger surface area relative to boiler input in order to promote additional condensing. The critical point in this concept is maintaining the minimum flow rate to the boiler that is required to maintain condensing conditions, as high-mass condensing boilers typically have no- or low-minimum flow requirements. However, low-mass

boilers often require constant speed pumping, or near constant speed, and therefore the required flow rates must be maintained at all times.

Non-condensing boilers historically operate in a cascading sequence to maximize the load on each boiler prior to sequencing an additional boiler online. In a cascading system, the boilers are individually sequenced on until they are nearly fully loaded prior to initiating the next boiler online. For non-condensing boilers, this provides the most efficient option as the boilers are enabled to match the load closer at lower loads, limiting boiler cycling and associated purge cycles that reduce efficiency and deteriorate equipment over time.

SYSTEM DISTRIBUTION

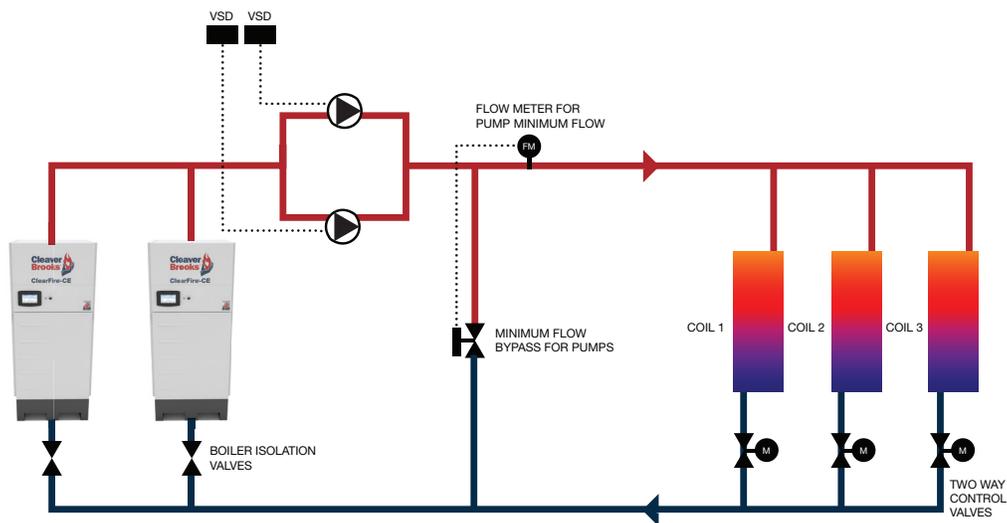
Similar to the variety of system control options available to designers, there are a number of system distribution configurations available. Depending on the system installed and whether the boiler is new one or a replacement one likely dictates the pumping configuration. There are two system configurations that are commonly found in hot water systems today.

VARIABLE-PRIMARY-FLOW SYSTEMS

One of the main benefits of a condensing boiler is its ability to condense the flue gases and operate at a lower hot water return temperature. In addition, a condensing boiler is capable of handling variable flow in the system as well as through the boiler. Depending on the type of condensing boiler selected, the ability to handle variable flow can differ. Low-mass boilers typically require constant flow to protect the heat exchanger, while high-mass boilers are able to support variable flow. In the past, non-condensing boilers were notorious for not being able to accept the variation in system flow, primarily to maintain the hot water return temperature to the boiler above condensing operation. With condensing boilers, this concern is eliminated, and the ability to use a variable-primary-flow system has emerged as a popular design option for hydronic hot water systems.

Variable-primary flow operates based on the principle that one set of pumps will distribute water to the entire system, including the boilers and all heating coils. In this system, the entire system is exposed to variable flow, which allows the system to benefit from lower flow and energy savings at reduced loads with two-way control valves at the coils. In addition to the control valves at the heating coils, two-way isolation control valves should be provided at the boilers to eliminate flow through a boiler when the boiler is not in operation to avoid unnecessary mixing in the supply header. An example of a variable-primary-flow hot water system can be seen in Figure 3.

Figure 3: A variable primary flow distribution system



One concern with this configuration is the minimum flow the system can withstand, but from a boiler standpoint, in a high-mass boiler system, the minimum flow required for the distribution pump is typically the limiting factor, not the boiler itself. The boiler minimum flow for a high-mass boiler can be determined by the boiler output capacity, maintaining the design delta T across the boiler at low fire and the boiler turndown. For example, for a 500 MBH condensing boiler operating at 92% efficiency has an output capacity of 460 MBH. Based on the boiler operating at a 40°F ΔT with a 5:1 turndown, the minimum flow is less than 5 GPM. If this flow rate is compared to the system pumps, a pump can typically operate down to 30% of the best efficiency point, or based on the example above, this would equate to approximately 7 GPM.

Regardless of what device dictates the minimum flow requirements, the minimum flow in the system can be maintained by two methods. The first method is to provide a minimum-flow bypass somewhere in the system, which is a two-way temperature control valve in a bypass pipe between the hot water supply and return piping. This pipe can be located anywhere in the system from the mechanical room to the top floor of the building. In addition to the two-way control valve, a flow meter is in the hot water supply piping to the system that measures the system flow rate, and when the minimum flow is not met by system demand, the minimum flow bypass control valve modulates open to satisfy the minimum flow requirements. It is important to note that this bypass is only required to provide the minimum flow for one pump or boiler, so the sizing is typically relatively small. This solution involves additional control programming and logic, but is a common technology that has been used in chilled water systems for many years.

A second method to provide system minimum flow is to locate three-way control valves at select heating coils in the system. The quantity of three-way control valves required in the system will depend on the minimum flow rate of the boiler or pump as well as the flow rate at the coils with the three-way control valves. One disadvantage of this configuration is when the spaces with the three-way control valve do not require full heating, the control valve closes to the coil and bypasses the remaining flow around the coil that provides variable flow at the coil but constant flow to the terminal unit. This causes additional system flow that would not otherwise be required under this load condition. Three-way valves are also more expensive and require additional piping and valves, increasing the first cost; however, they do not require additional control logic as discussed in the first option. This is a standard control sequence that is nearly foolproof. This method also provides flow out in the system at all times, resulting in a quicker response when a nearby zone requires heat.

PRIMARY-SECONDARY SYSTEMS

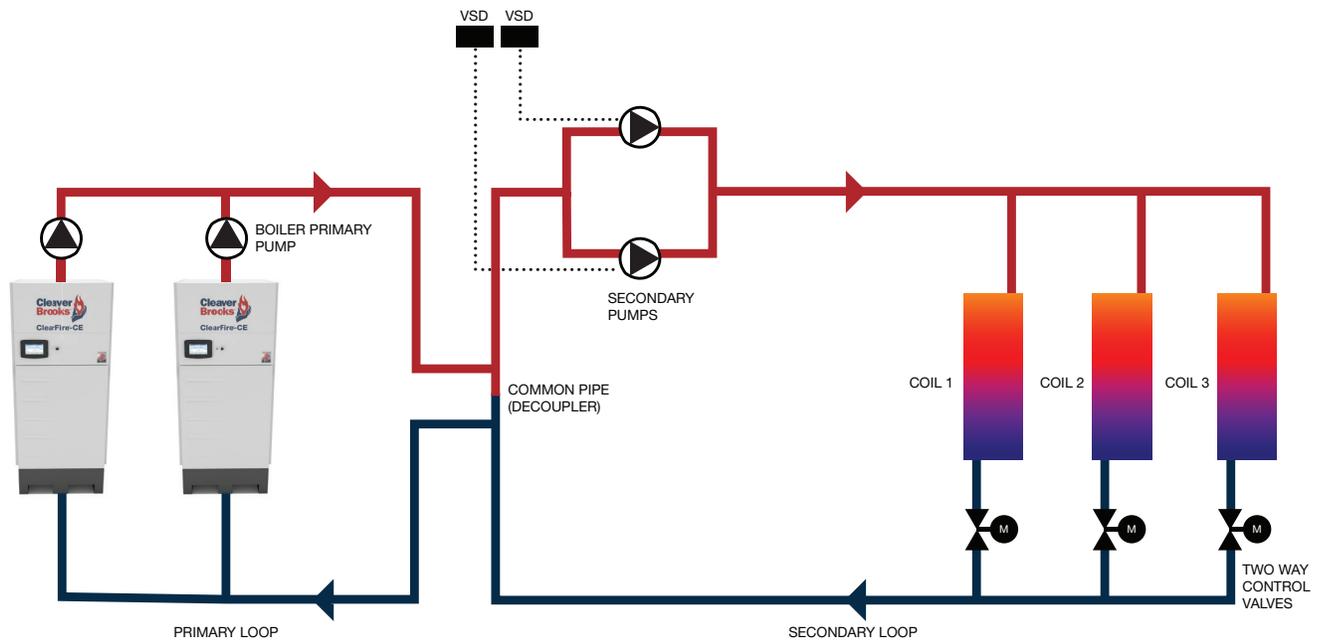
Primary-secondary systems have been around for a long time and are typically recognized as the standard in hot water systems. In a typical primary-secondary system, the primary pump is a constant-volume, low-flow, inline circulator pump that is dedicated to the specific boiler that it serves. The control of the boiler pump is straightforward in that the pump turns on when the boiler turns on and runs until the boiler is turned off. Generally, it is recommended to pump into low mass boilers to prevent steaming and maintain the proper operating pressure, and pump away from high mass boilers for optimum control. The secondary pump typically is a base-mounted, high-flow, high-head pump, which is more efficient than the primary pump. The secondary pump distributes water to all of the heating coils and terminal units throughout the system that are provided with two-way control valves. As the load at the coil varies, the control valve modulates, and system flow responds based on the control strategies described earlier.

The primary and secondary loops are connected by a common pipe that is part of both the primary and secondary systems. By design, the common pipe is configured with closely spaced tees that have a low resistance to flow so the water can travel in either direction, depending on the demands of the primary and secondary loops. The common pipe hydraulically separates the two loops so flow in one loop does not affect flow in the other loop. There should not be a check valve or isolation valve in it as flow is encouraged to operate naturally in both directions. A minimum flow bypass is generally not required in this system because the constant-volume pumps protect the

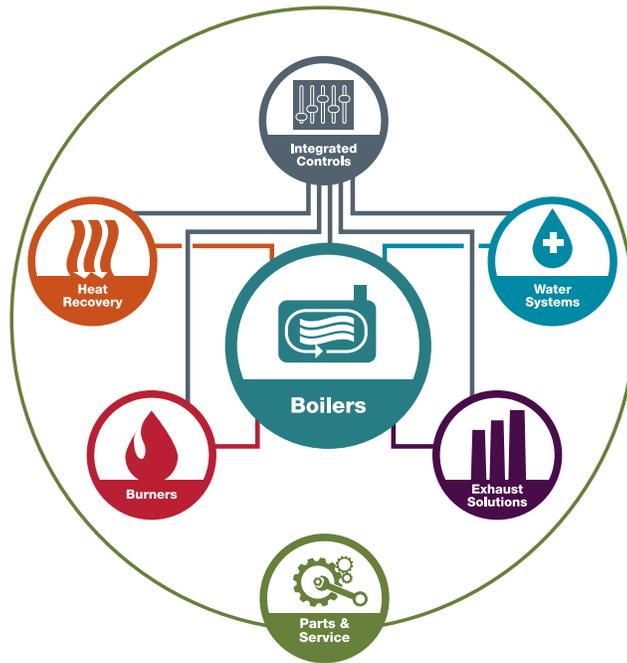
boiler, and the variable-volume pumps in the distribution system typically does not modulate below the pump minimum flow. However, if this is not the case, a method to provide minimum flow similar to that described in the variable-primary-flow system is necessary to protect the secondary pump. A typical primary-secondary pumping configuration can be seen in Figure 4.

A variation on this system is to use variable-speed primary pumps in addition to the secondary pumps. In this configuration, the primary pump speed can be controlled to match the firing rate of the boiler to optimize the hot water return temperature to the boiler as discussed in ΔT pumping. This reduces mixing at the common pipe, which promotes higher system efficiencies.

Figure 4: A primary-secondary distribution system.



This paper explained a variety of control and system piping options that may be encountered in new or existing system designs. In all condensing boiler designs, the main goal is to maintain the minimum hot water return temperature to the boiler allowable by the system to operate in condensing mode as much as possible. At the same time, system controls should be sequenced to maximize efficiency at the lowest system energy consumption. The next paper in this series will explore additional non-traditional system applications and designs that can benefit from the use of condensing boilers.



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/rebs.



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