

TOTAL SYSTEM EFFICIENCY: SYSTEM APPLICATIONS & DESIGNS

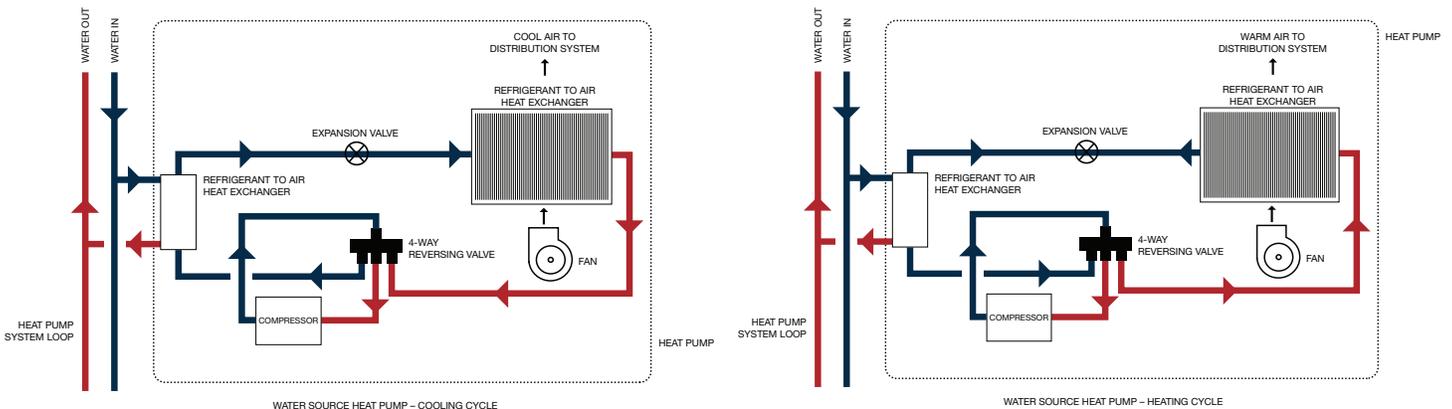
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Similar to traditional boiler systems, condensing boiler systems have many designs they can operate within as they are built to handle a range of hot water temperatures. The best application for condensing boilers, though, is one that utilizes a low-temperature, hot water design because it facilitates condensing that yields efficiency gains. In addition, most condensing boilers in these types of applications warrant only a simple piping configuration that avoids mixing valves, which is beneficial because mixing valves ultimately raises the hot-water- return temperature back to the boiler above the condensing point. This paper will discuss how incorporating condensing boilers into non-traditional systems and designs can lead to better system efficiency.

WATER SOURCE HEAT PUMPS

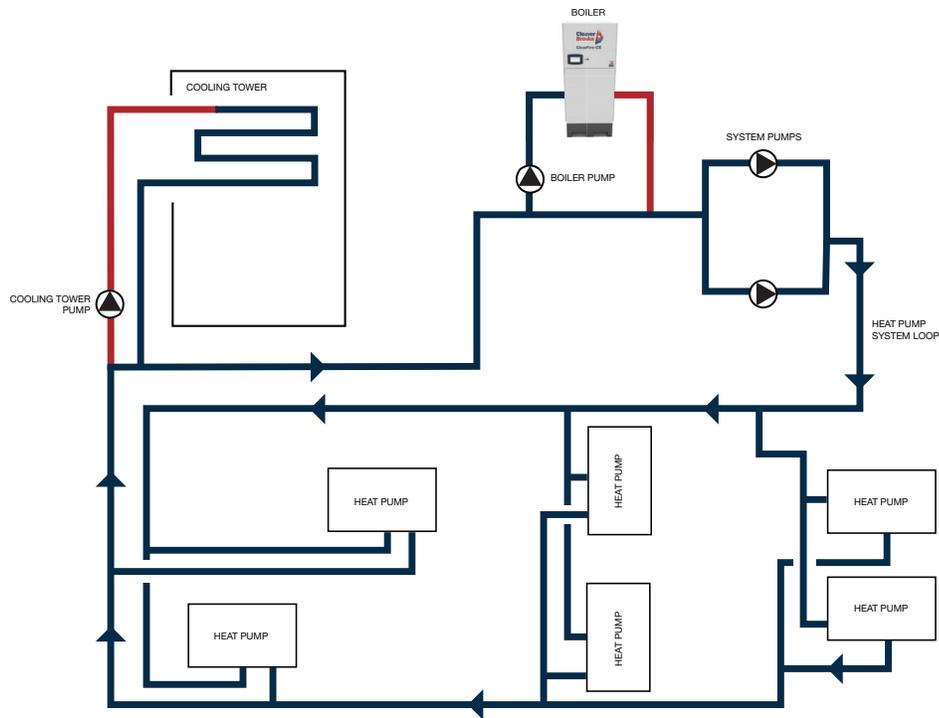
In the push toward energy efficiency, water-source, heat-pump systems should be considered as energy can be transferred from zone-to-zone to be reused instead of expending new energy to heat or cool the zone. This form of energy recovery is highly efficient and also provides the ability to independently control each zone based on heating or cooling demand. Each zone consists of a heat pump, which is a self-contained heating and cooling unit, that utilizes the vapor compression cycle with a refrigerant-to-air heat exchanger and a refrigerant-to-water heat exchanger. This creates two heat-exchange coils that operate as either the condenser or evaporator, and each coil is dependent upon the heat-pump mode of operation. The heat pump also has a compressor, expansion valve, and a reversing valve that allows the refrigerant flow in the heat pump to change directions based on the mode of operation. In this system, the refrigerant-to-water coil uses a water source that is distributed throughout the building to either pull heat from the loop or reject heat to the loop for space heating or cooling purposes as shown in Figure 1.

Figure 1: Typical heat pump operation using a water loop for heat addition or heat rejection.



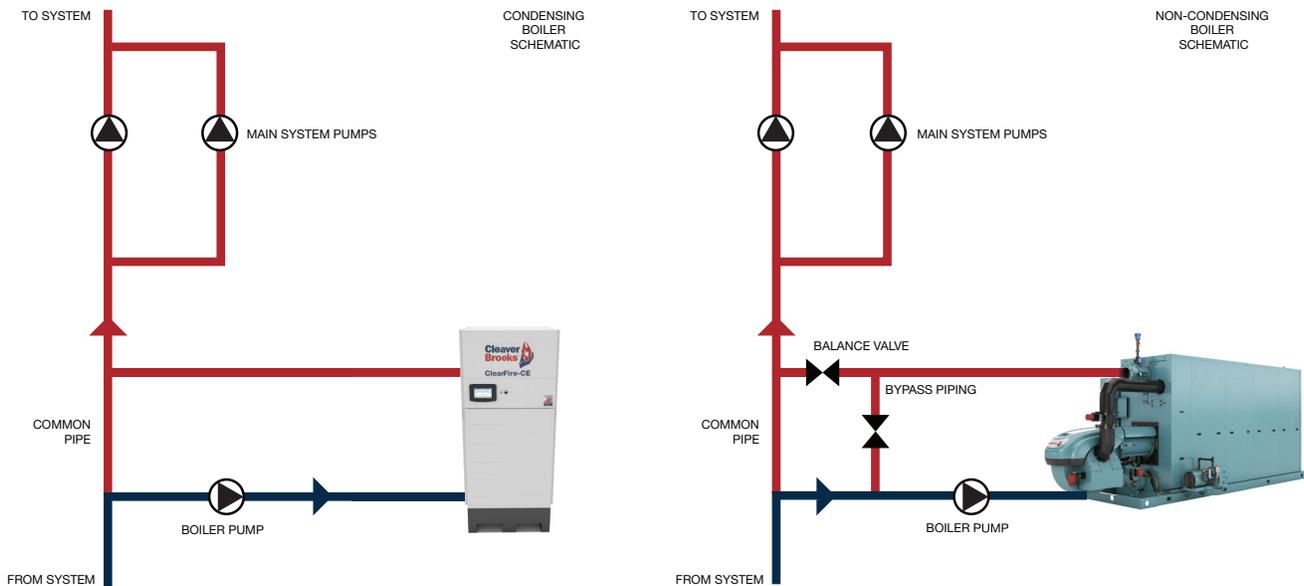
By operating in this configuration, the heat-pump system provides continuous heat recovery throughout the building and assumes the building has the need for simultaneous heating and cooling. The intent of the water loop is to maintain the temperature within a range of approximately 60°F to 90°F for the heat pumps to be able to utilize the loop based on the individual space needs. A heat source is added to increase the amount of heat to the loop to maintain the loop temperature: (1) when the loop temperature drops below the predetermined temperature during periods of high-heating demand at design load, (2) when the spaces needing heat exceed the amount of heat available from the cooling units, or (3) during morning warm-up. Similarly, the system typically utilizes a closed-circuit cooling tower to reject heat from the building during periods of high cooling demand as shown in Figure 2.

Figure 2: Water source heat pump system piping configuration.



The methods of pumping and piping can be debated, but regardless of the method used, a boiler is typically added to increase heat to the system. Since the water temperature in the heat-pump loop is medium-grade, the need for a high water temperature from a standard, non-condensing boiler is unnecessary and wasteful as it overheats the loop temperature. The system also has a strong need for modulation due to the wide variation in load that matches well with a condensing boiler, which can provide high turndown at the desired water temperature. Similarly, a condensing boiler does not require mixing valves to maintain the hot water temperature above the condensing temperature of the flue gases as required for non-condensing boilers, making them a good fit with less complexity. A comparison of the piping requirements for a condensing and non-condensing boiler in a water-source, heat-pump system can be viewed in Figure 3.

Figure 3: Piping configuration for condensing vs. non-condensing boilers in a heat pump system.



GEOTHERMAL HEAT PUMPS

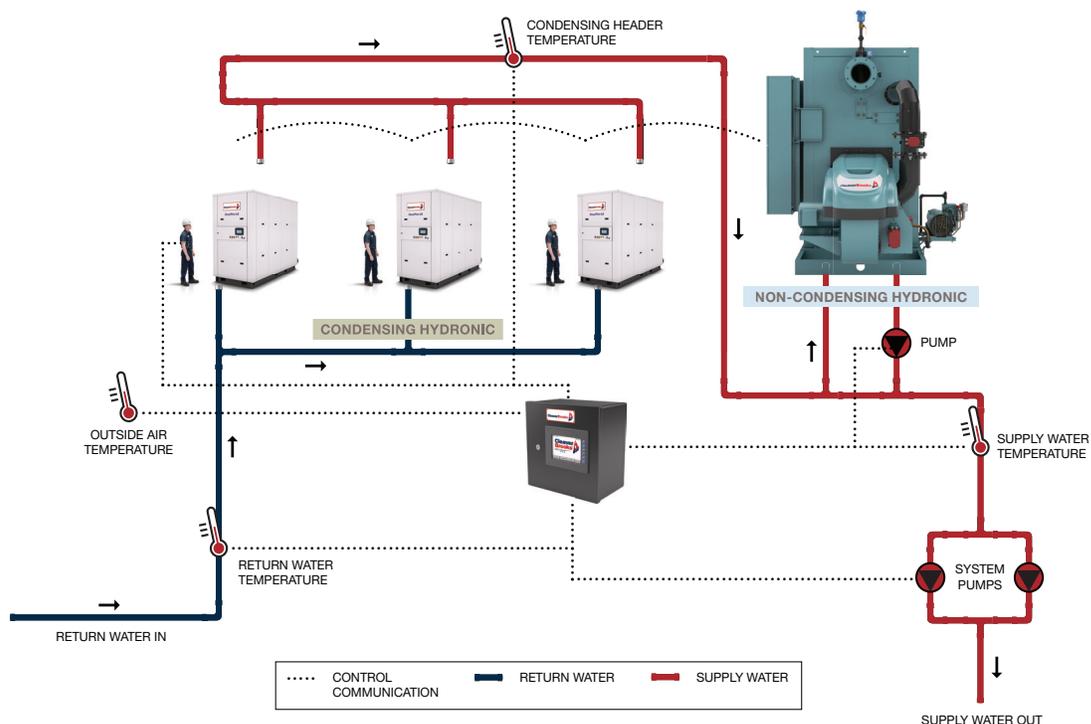
Geothermal heat pumps operate in the same manner as water-source heat pumps with a ground, geothermal well, or a body of water such as a lake or pond acting as the heat sink/source for the system in lieu of a boiler and/or cooling tower. For this type of system, the first cost of a geothermal well field may be cost prohibitive due to the capacity required to satisfy the entire load. In this instance, adding a condensing boiler can be a viable option as a peak shaving device when the capacity of the geothermal field is limited and does not handle the entire load, allowing the remaining portion of the load to be handled by the boiler.

HYBRID (CONDENSING & NON-CONDENSING) SYSTEMS

A hybrid system is a system that consists of both condensing and non-condensing boilers in the same system. Due to the more robust construction of a condensing boiler as well as the materials necessary to protect it from the acidic condensate, a condensing boiler is more expensive compared to a similar-sized non-condensing boiler. If the cost for a fully condensing boiler plant exceeds the budget, the best approach is a hybrid system that can use the advantages of each system to its benefit based on the hot water return temperature. Hybrid applications also work well in retrofit applications, where a legacy, non-condensing boiler is maintained for design-load days, while a more efficient condensing boiler is utilized whenever possible. In addition, a hybrid solution is an excellent one for a boiler plant that requires #2 fuel oil back-up because condensing boilers are best suited for operating on natural gas or propane while non-condensing boilers can be operated as dual-fuel.

In a hybrid system, condensing boilers should be positioned upstream of non-condensing boilers, as shown in Figure 4. This allows the condensing boilers access to the lowest hot water return temperature, enabling them to operate in the condensing mode for maximum efficiency. If additional heat is needed above the capacity of the condensing boilers, the non-condensing boiler can provide it, given that it has a higher hot water return temperature to prevent the boiler from condensing and subsequent damage. Also, this configuration is very beneficial during low loads as the condensing boiler can be used as the first boiler to operate based on hot water reset conditions or when lower hot water supply temperatures can provide the required capacity for the system.

Figure 4: Typical piping configuration for a hybrid system with the condensing boilers upstream of the non-condensing boiler.



HEAT RECOVERY CHILLER SYSTEMS

Heat-recovery chiller systems, or high-lift chiller applications, also can be used with condensing boilers as the systems complement one another, similar to a hybrid system. In this application, the intent of the heat-recovery chiller is to provide hot water at a temperature high enough to heat the building, whereas a condensing boiler requires a low hot water return temperature to promote condensing. Utilizing both systems provides redundancy in operation when there is not the ability to run the heat-recovery chiller, which requires a constant cooling load to function properly. This configuration also provides fuel flexibility, enabling the system to operate with either the heat-recovery chiller or condensing boiler based on fuel price for the lowest operating cost.

IN-FLOOR HYDRONIC RADIANT HEATING & SNOW-MELT SYSTEMS

In-floor hydronic radiant heating is a relatively cost-effective way to provide heat that can be concealed architecturally within a space. In-floor heating requires a low hot-water-supply temperature in the range of 100°F to 120°F, an excellent condition for condensing boilers. Although hot water return temperatures naturally will be low, the temperatures will remain low by keeping the tubing spaced closely together, reducing the floor resistance, installing the tubing near the top of the slab, and providing insulation below the tubing. In addition to boiler-efficiency improvements, in-floor heating embeds the tubing within the slab, which conceals it from any damage. It also eliminates finned heat exchangers or enclosures that can corrode, become physically damaged, or need to be replaced over time.

Snow-melt systems are similar to in-floor hydronic radiant systems in that hot water supply and return temperatures are very similar, but the tubing is used in exterior applications, and glycol often is used to prevent freezing within the piping system. Depending on the building's heating system, a plate-and-frame heat exchanger can be used to separate the snow-melt system loop from the main building heating system loop, or a dedicated boiler to the snow-melt system can be provided.

DOMESTIC WATER HEATING

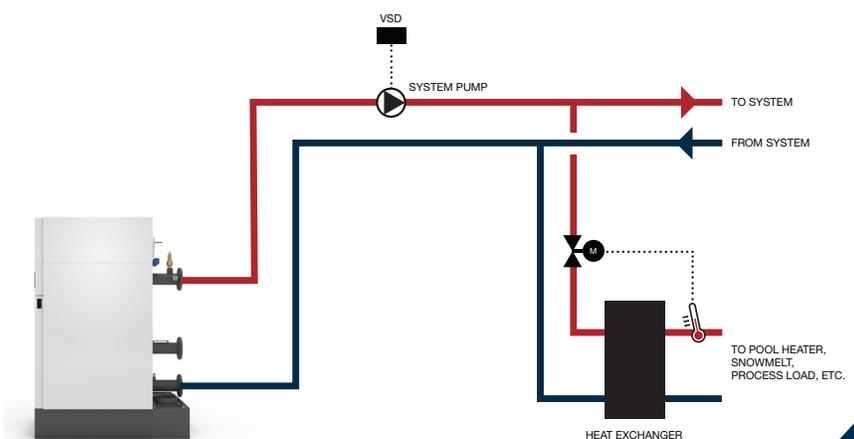
The process for a domestic water heater is identical to the process for heating hot water in that fuel is burned and the combustion gases are removed through the exhaust flue, so a majority of the energy exits through the stack. In a condensing domestic water heater, a secondary heat exchanger exists within the water heater that allows the combustion gases to come in contact with the domestic cold water entering the water heater. This secondary heat exchanger creates additional surface area and removes the latent energy from the flue gases as they condense to heat the domestic water prior to discharging the exhaust to the atmosphere.

Another method to create domestic hot water involves operating hydronic hot water boilers to heat domestic water in a storage tank with either a shell-and-tube or plate-and-frame heat exchanger. Because domestic hot water supply temperatures typically are around 120°F, this enables condensing on a regular basis. This is also a good application for a dual-return condensing boiler, which is discussed later in this paper.

POOL HEATING

Pool heating is similar to domestic water heating in that pool heat requires only low-grade heat to maintain the pool water temperature below 90°F, as shown in Figure 5. Return water temperatures leaving the heat exchanger can be near or at the temperature of the pool, meaning the return water temperature back to the boiler is ideal for condensing. Again, the low water temperature is a perfect application to utilize condensing equipment to recover the energy that would otherwise be wasted in the flue gases. Hot water for pool heating can be provided either with a condensing, domestic water heater or a condensing boiler with heat exchangers. Similarly, pool heating is a good application for a dual-return condensing boiler.

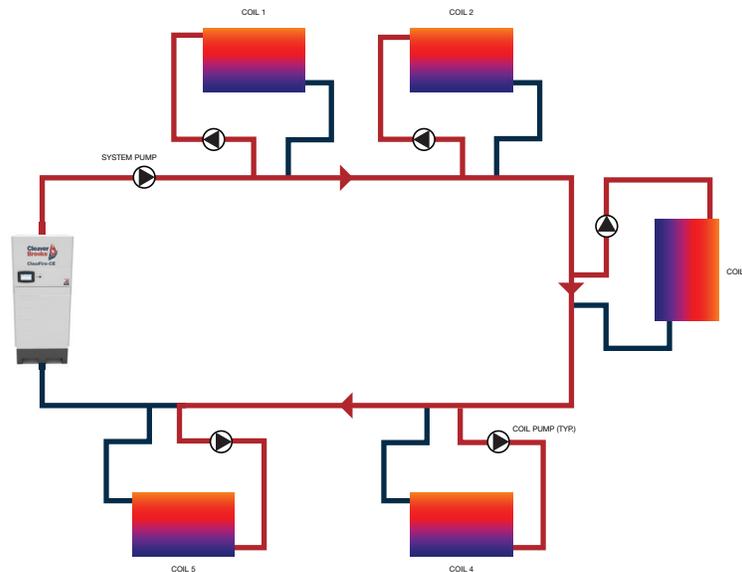
Figure 5: Basic schematic of a heat exchanger being used for pool heating, snowmelt, or other process load.



SERIES CIRCUIT WITH LOAD PUMPS

Another unique system that is advantageous for condensing boilers is a series circuit with load pumps as shown in Figure 6. This system is a modified primary-secondary system with pumped coils and common piping at each coil. In this configuration, the coils do not have control valves, but are instead controlled based on the coil pump or injection pump in the secondary loop.

Figure 6: Series circuit with load pumps.

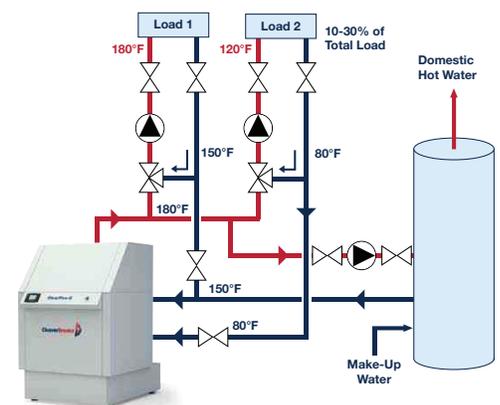


This configuration requires the designer to size each coil slightly differently as the water temperature decreases the further away the coil is from the hot water production source, so the hot water supply to each coil is slightly lower than the previous coil. The benefit of this arrangement is the cascading approach that enables an increased system ΔT . For example, the coils at the end of the loop with the lowest hot water supply temperatures can be loads that require low-grade heat, as previously described, to further drive the hot-water-return temperature to the boiler as low as possible, which promotes additional condensing with increased efficiency.

DUAL RETURN

Some boilers today are equipped with a dual-return capability that allows hot water return from two sources within the building, as shown in Figure 7. The intent of the dual return is to maximize the efficiency of the boiler that might otherwise be lost due to mixing the hot water return from all sources in the system as some coils or building functions may have a high load and design ΔT while other coils or functions may have a low load and small ΔT . With a dual-return system, if there are applications that utilize low hot water temperatures, similar to any of the systems mentioned earlier, this loop can be kept separate from the higher hot water return temperature loop back to the boiler. Then, the two return loops are piped to the boiler separately with the lower temperature hot water return loop piped into the boiler where it will come in contact with the cooler temperature flue gases, and the warmer hot water return loop is piped to the connection that comes in contact with the hotter flue gases to extend the condensing conditions. This dual-return approach promotes site-specific customization to optimize operation and condensing within the boiler that would otherwise be lost due to the system piping configuration.

Figure 7: Dual return system schematic with two temperature zones and domestic hot water.



Although this approach may use additional piping, the design strategy maximizes the condensing zone prior to blending the lower and higher return water temperatures within the boiler. In order to effectively use this piping setup, it is critical to keep the water loops separated and ensure that at least 10% of the flow be provided to the low-temperature connection. Depending on the boiler type and

pumping arrangement, check valves are potentially required on both return connections to prevent the reversal of flow to the other return loop. If pumping away from the boiler, check valves are likely not required.

BUFFER TANKS

As the design paradigm has shifted from non-condensing boilers to condensing boilers, another notable change in boiler design involves boiler mass or the water volume within the boiler, which was defined and discussed in the first white paper. Older boiler systems had a large system mass or volumes of water so the system could ride out rapid temperature changes within the system. Today, a majority of boilers are shifting to low mass with very little water volume in the boiler, which results in boiler cycling, poor temperature control, and less-consistent system operation.

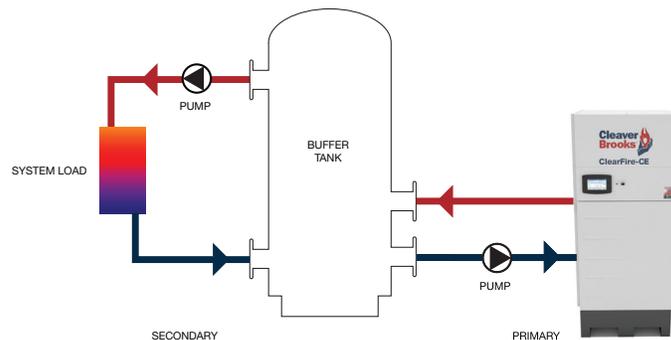
$$\frac{\left(\frac{\text{MANUFACTURER'S RECOMMENDED MINIMUM BOILER CYCLE TIME (MINUTES)}}{\left(\frac{\text{MINIMUM BOILER OUTPUT (BTU/HR.)} - \text{MINIMUM SYSTEM LOAD (BTU/HR.)}}{\text{TEMPERATURE DIFFERENTIAL WITHIN TANK (°F)}} \right)} \right) \times 500}{\text{TEMPERATURE DIFFERENTIAL WITHIN TANK (°F)}} = \text{TOTAL BUFFER TANK SIZE (GALLONS)}$$

The use of a buffer tank reduces the concern of boiler cycling during low loads (or no loads) and enables the system to ride out these potential temperature fluctuations.

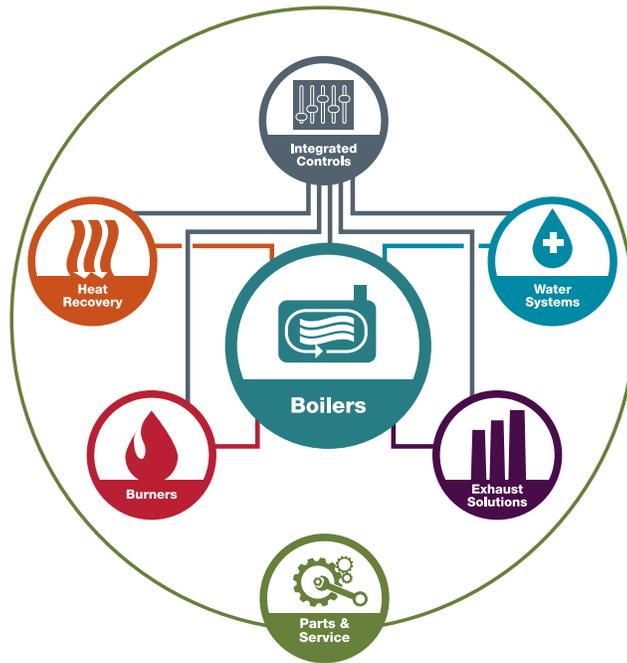
A buffer tank is nothing more than a tank within the piping configuration that adds mass back into the system. The buffer tank is full of water and helps store the excess energy in the system and prevent boiler cycling to provide better temperature control. Since boilers have a minimum run time and off time prior to restart, the tank acts as a buffer until the boiler can be turned back on again. To properly size a buffer tank, some system characteristics are important, including the boiler performance capabilities with the desired firing rates, and allowable temperature drop in the system to limit boiler cycling based on the manufacturer's requirements. If no guidelines are provided, it is recommended to limit cycling to less than five times per hour. Additionally, the minimum boiler output at the lowest turndown should be compared to the minimum heating load in the system. With these parameters, a buffer tank should be selected above the calculated tank volume, as defined in the equation below, to provide sufficient system mass.

Buffer tanks can be used in both variable-primary-flow systems and primary-secondary systems as the intent is to increase system volume. In a variable-primary-flow system, the tank can be located anywhere in the system, but is typically located near the boiler. In a primary-secondary system, the tank can act as the common pipe providing hydraulic separation between the primary and secondary loops, while also providing a location where air can be removed. This can eliminate the need for an air separator as the tank provides low velocities allowing air entrained in the system to be removed as shown in Figure 8. By effectively separating the distribution system flow from the boiler loop, a more constant delivery temperature can be achieved along with longer boiler operational cycles, which leads to reduced boiler cycling and increased system efficiency. The calculation for a buffer tank is something that should always be checked during the system design, but there may be some systems where a buffer tank is not required. For example, in a system with a high mass boiler, it is possible that the boiler itself may have enough mass, acting as the buffer tank, and negate the need for an additional tank in the system distribution piping.

Figure 8: Buffer tank location for a primary-secondary system.



This paper covered a variety of system applications that demonstrate the benefits of using a condensing boiler in the system design. In all designs with condensing boilers, the main goal is to maintain the minimum hot water return temperature to the boiler allowable by the system to operate in the condensing mode, thereby increasing energy efficiency and reducing costs. The next paper will detail additional advantages and disadvantages of condensing boiler applications.



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