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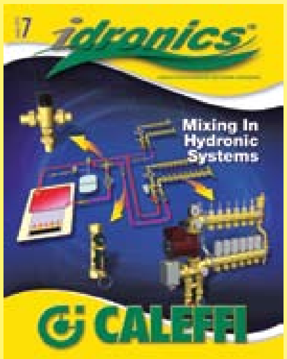
JOURNAL OF DESIGN INNOVATION FOR HYDRONIC PROFESSIONALS

Mixing In Hydronic Systems

CALEFFI



A Technical Journal
from
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Dear Hydronic Professional,

Welcome to the 7th edition of *idronics*, Caleffi's semi-annual design journal for hydronic professionals.

Mixing is a key element in many modern hydronic heating systems. When properly performed it: Improves comfort and minimizes energy consumption; Protects low-temperature heat emitters from high-temperature heat sources such as storage tanks heated by solar collectors or wood-fired boiler systems; Prevents sustained production of corrosive flue gas condensation when a conventional boiler is used as a heat source to a low-temperature distribution system.

Over the past 20 years, mixing products have advanced into more intelligent and durable devices. A solid understanding of how they function and how to apply them will enable maximum heating system performance. This issue of idronics discusses a wide range of mixing options for use in both standard and specialized applications.

We encourage you to send us feedback on this edition of idronics by e-mailing us at idronics@caleffi.com.

If you are interested in previous editions of *idronics*, please go to www.caleffi.us where they can be freely downloaded. You can also register to receive future issues online.

Sincerely,

Mark Olson
General Manager,
Caleffi North America, Inc.

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MIXING IN HYDRONIC SYSTEMS

1. EARLY APPROACHES TO MIXING

Early North American hydronic heating systems had limited control of the water-temperature supplied to their heat emitters. The temperature of water arriving at the heat emitters was close to that leaving the heat source. As combustion conditions changed within the boiler, so did the water-temperature it supplied to the distribution system.

During the mid-1900s, North American hydronic heat emitters were primarily cast iron radiators, and convectors with steel fin-tube elements. Such heat emitters could physically tolerate a wide range of water-temperature. However, comfort was adversely affected as the water-temperature from the heat source varied.

The first use of radiant panel heating brought new requirements for water-temperature control. First-generation hydronic floor heating systems used iron or steel piping embedded in concrete floor slabs as seen in figure 1-1. Radiant panels were also constructed of copper tubing embedded in plaster ceilings and walls as shown in figure 1-2.

Figure 1-1

System designers soon learned that directly connecting boilers to radiant panel distribution systems resulted in several problems including:

• Wide variations in floor surface temperatures depending on how the heat source was controlled

Figure 1-2

• Cracking of slabs or plastered surfaces due to thermal expansion as supply water-temperature varied over a wide range

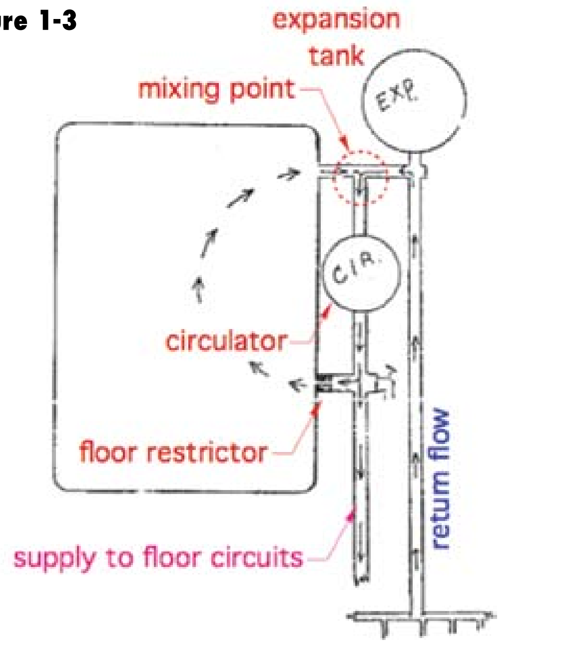
• Failure of embedded metal tubing due to cyclical stresses from variations in water-temperature

• Sustained flue gas condensation on the combustion side of boiler heat exchangers, which leads to rapid corrosion of both the heat exchanger and vent connector piping. Eventually, it also damaged chimney flues. It quickly became clear that better water-temperature control was necessary.

The first attempts at hydronic mixing were relatively unsophisticated by today's standards. Figure 1-3 shows an enhanced 1949 sketch for a boiler supplying radiant heating circuits. Cooler water returning from the floor circuits is being blended with hot water leaving the boiler in a tee near the boiler outlet. The mixed flow then passes through the circulator. Some of the mixed water flows back into the boiler, while the remainder flows to the supply side of the radiant floor circuits.

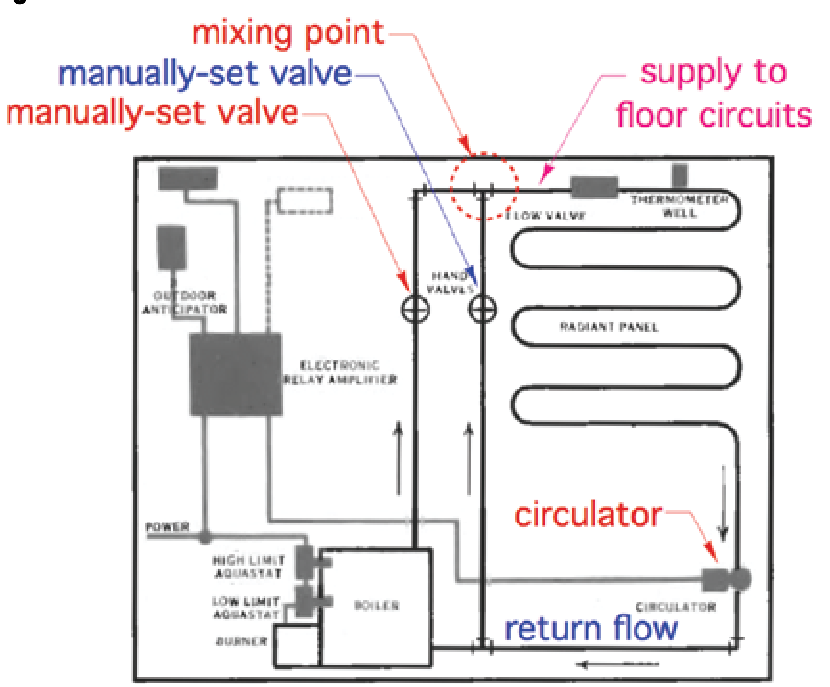
A flow-restrictor on the pipe entering the boiler creates resistance that prevents the majority of the blended flow from short circuiting through the boiler. The flow-restrictor, in combination with the flow resistance of the distribution system, and the circulator's pump curve determined the flow proportions into the mixing point. These proportions

Figure 1-3



would not change regardless of the water-temperature leaving the boiler, or the water-temperature returning from the distribution system. This would allow for wide variations in supply water-temperature, especially as the system first warmed up.

Figure 1-4



Source: Minneapolis Honeywell

Another early approach to mixing (circa 1950) is shown in figure 1-4. Two valves, one in the hot supply line from the boiler, and the other in a cool water bypass, control the flow proportions entering a tee downstream of both valves.

This configuration allowed for better adjustment of flow proportions relative to the fixed flow-restrictor approach shown in figure 1-3. However, the manually operated valves cannot compensate for changes in water-temperature from either the boiler or in the return pipe from the radiant panel circuits. Thus, relatively wide variations in the supply water-temperature were still possible.

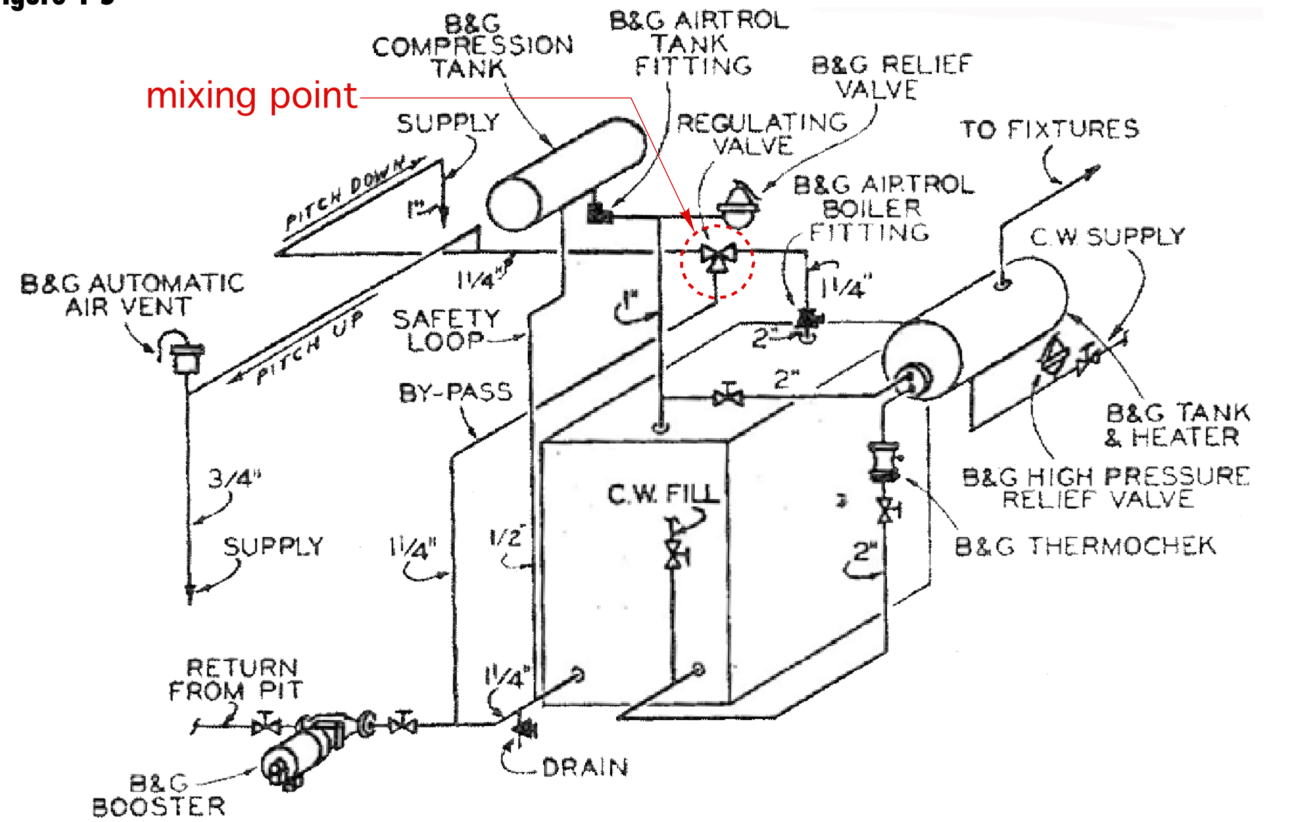
Another approach to mixing - dating from the 1940's - is shown in figure 1-5. Here, mixing of hot water from the boiler, and cooler water returning from the distribution system takes place within a 3-port valve body labeled "regulating valve."

As was the case for the system in figure 1-3, some of the cool water returning from the distribution system "bypasses" the boiler and enters the "cool" port of the regulating valve. The remainder of the return flow moves through the boiler where it is reheated and then passes to the "hot" port of the regulating valve. The flow proportions could be adjusted by moving a single shaft on the regulating valve. The mixed flow leaving the regulating valve goes to the supply side of the radiant panel circuits.

Figure 1-6 shows a diagram from the 1960s depicting an early form of injection mixing. After being relatively dormant for several decades, injection mixing was redeployed in the 1990 using modern hardware and control techniques. It remains popular today, and is discussed at length in section 6.

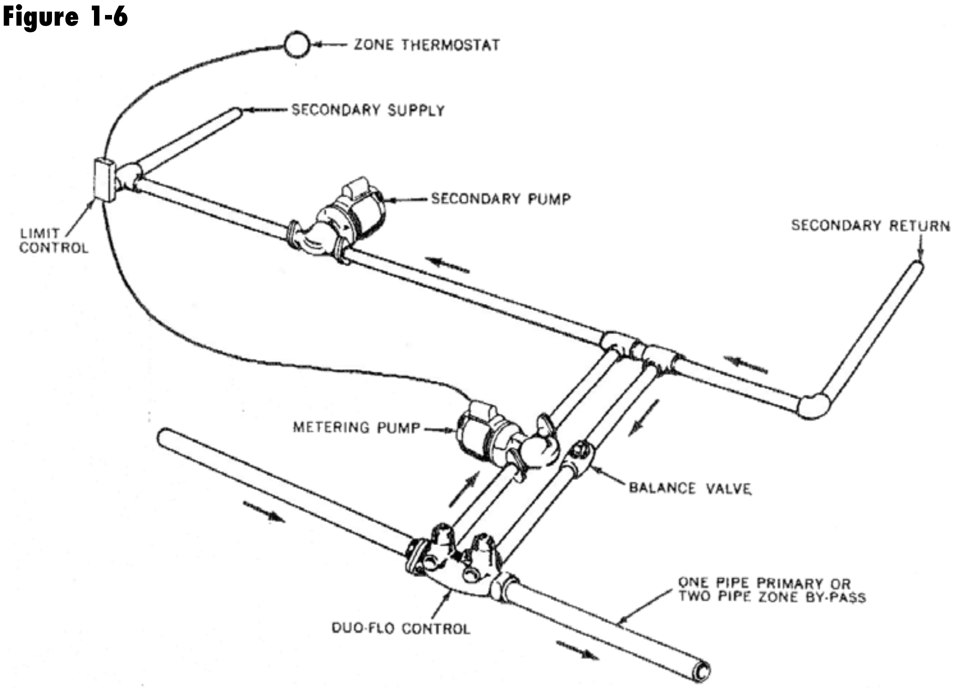
All of these early mixing configurations blended hot water from the heat source with cool water returning from the distribution system. The systems in figure 1-3, 1-4 and 1-6 mixed the entering flow streams within a tee. The system in figure 1-5 mixed these entering streams within a valve body. From the standpoint of thermodynamics, the hardware to bring these flow streams together is irrelevant. This will be discussed further in section 3.

Figure 1-5



Source: Bell & Gossett

Figure 1-6



Source: Bell & Gossett

A key difference between most of these older systems and modern mixing hardware is that the former lacked means of automatically controlling the proportions of hot and cool water entering the mixing point. Without such control, it is impossible to provide stable and appropriate supply water-temperature to the load. Much of what follows in this issue of *idronics* describes and illustrates why this is important and how it's accomplished.

2. THE PURPOSE(S) OF MIXING

Mixing is used for different tasks depending on the type of heat source and heat emitters used in the system.

The most apparent objective of mixing is to reduce the temperature of water supplied to a "low-temperature" distribution system. An example would be a slab-type floor heating system supplied from a typical cast iron boiler. The boiler may produce water at a temperature of 160ºF, while the floor heating system only requires water at 110ºF. As the water travels through the floor circuits its temperature drops to perhaps 95ºF. By blending some of the 95ºF water returning from the floor circuits with the proper amount of the 160ºF water from the boiler, one can achieve the desired supply temperature of 110ºF. In concept, this is just like blending hot and cold water in the proper proportions to achieve a comfortable shower temperature.

Although this description of how mixing works seems rational, it begs another question: If the floor circuits only require water at 110ºF, why not simply set the controls on the boiler to produce this water-temperature, and route the water directly to the floor circuits? Understanding the answer requires a discussion of what happens inside a boiler.

When any hydrocarbon fuel such as natural gas, propane, fuel oil or wood is burned, one of the chemical compounds produced is water. High-temperatures inside the combustion chamber ensure this water exists as a superheated vapor. As such, it is essentially invisible, compared to saturated steam from a teakettle.

The superheated water vapor, along with other hot combustion byproducts, transfers heat to the metal surfaces of the boiler's heat exchanger. If those surfaces are at a sufficiently low-temperature, they can cool the water vapor and other combustion byproducts in the exhaust stream below their respective dewpoint temperatures. This causes the water vapor and other compounds to condense (e.g. change from vapor to liquid) on the metal surfaces of the heat exchanger.

The "chemical soup" that results from flue gas condensation is highly corrosive to boiler heat exchangers made of cast iron, steel or copper. If not prevented, sustained flue gas condensation can quickly and severely pit, scale and otherwise deteriorate the boiler's heat exchanger, as well as damage burner surfaces located beneath the heat exchanger. It can also damage the galvanized steel vent piping used with many boilers.

Figure 2-1 shows a boiler heat exchanger made of copper fin-tube elements and cast iron end sections after being removed from a boiler operating with sustained flue gas condensation. The fin-tube elements are heavily scaled, and severely restrictive to flue gas passage. Heavy surface oxidation and pitting are also apparent on the combustion chamber side of the cast iron end sections.

Figure 2-1

Courtesy of Dave Stroman

Figure 2-2

Figure 2-2 shows a vent pipe that had been in service for about one year. The lower portion of the elbow is severely corroded and crumbling due to flue gas condensation in the chimney directly above. Again, this was the result of sustained flue gas condensation within the vent piping and chimney.

These corroded components adversely affect boiler operation and service life. They also represent imminent danger to occupants because they could allow carbon monoxide leakage into the building.

Preventing sustained flue gas condensation:

Maintaining the boiler's inlet water-temperature above a specified value prevents sustained flue gas condensation. That value varies with the design of the boiler and the type of fuel being burned. Boiler manufacturers should be consulted for specific minimum inlet water-temperature requirements. In the absence of manufacturer recommended values, an inlet water-temperature of 130ºF or higher is usually sufficient to prevent sustained flue gas condensation in boilers constructed with cast iron, steel, or copper tube heat exchangers. Such boilers are herein referred to as "conventional" boilers. They are built for applications and operating conditions that do not create sustained flue gas condensation.

Maintaining boiler inlet temperature high enough to prevent sustained flue gas condensation is the reason conventional boilers should not be operated at the low supply water-temperatures required by many radiant panel heating systems.

One of the most reliable methods of controlling boiler inlet water-temperature is through use of a properly controlled mixing assembly. To be effective, however, that mixing assembly must measure and react to changes in boiler inlet temperature. *Any mixing assembly that does not measure and react to boiler inlet temperature cannot ensure that the boiler is properly protected against sustained flue gas condensation.* This will be discussed more in later sections.

In summary: The two purposes of mixing assemblies in hydronic heating systems with conventional boilers are:

1. Regulate supply water-temperature to the distribution system.
2. Maintain boiler inlet temperature high enough to prevent sustained flue gas condensation.

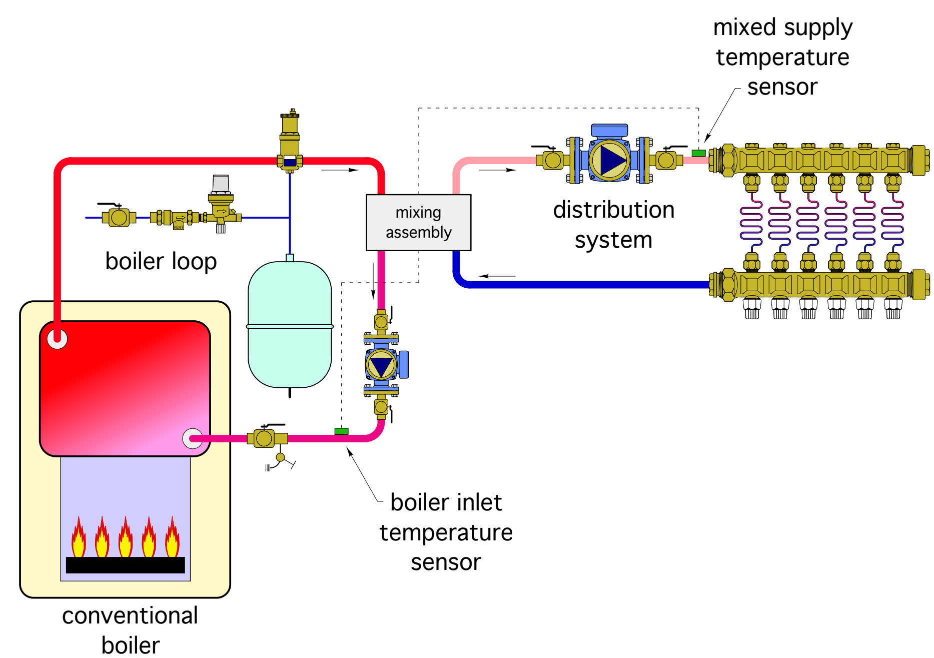
3. MIXING FUNDAMENTALS

A mixing assembly is a collection of hardware and control logic that collectively regulates the rate of heat transfer from the heat source to the heating distribution system. The mixing assembly can be composed of many different hardware options. These options will be discussed in later sections. However, all hardware options for the mixing assembly must accomplish the same two objectives:

- Regulate supply water-temperature to the distribution system
- Maintain the inlet temperature to a conventional boiler high enough to prevent sustained flue gas condensation.

Figure 3-1 shows how a mixing assembly acts as a "bridge" connecting a boiler loop to a distribution system. All heat reaching the distribution system must pass through the mixing assembly.

Figure 3-1



Thermodynamics of mixing:

The first law of thermodynamics states that energy cannot be created or destroyed — only changed in form. This principle always holds true when flow streams are mixed together in hydronic heating systems. In such applications it is convenient to express the first law as follows:

The rate of heat flow into a mixing assembly must equal the rate of heat flow out of the assembly.

It is also true, based on the continuity equation of fluid mechanics, that the flow rate of an incompressible fluid entering any fluid-filled component in a hydronic system must equal the flow rate leaving that component. Common hydronic system fluids like water, or a mixture of water and antifreeze are incompressible, and thus this relationship must hold true. For a mixing assembly it can be stated as:

The total flow rate of fluid entering a mixing device must equal the total flow rate of fluid leaving the mixing device.

When these two physical relationships are combined mathematically the result is a simple but powerful formula for determining the temperature on the outlet side of any mixing device. It is stated as formula 3-1:

Formula 3-1

$$T_{mix} = \frac{(T_1 \times f_1) + (T_2 \times f_2)}{f_1 + f_2}$$

Where:

T_{mix} = resulting temperature of the mixed fluid stream
T_1 = entering temperature of fluid stream #1
T_2 = entering temperature of fluid stream #2
f_1 = flow rate of fluid stream #1
f_2 = flow rate of fluid stream #2

The temperatures and flow rates used in formula 3-1 can be expressed in any consistent system of units. In this publication, we will use customary U.S. units of gallons per minutes (gpm) for flow rate, and degrees Fahrenheit (ºF) for temperature.

Formula 3-1 applies to water or other fluids such as antifreeze solutions, provided the same type of fluid enters both inlets to the mixing assembly.

This formula holds true regardless of the physical device in which the fluid streams come together. It applies to a tee, a tank, or any type of mixing valve as illustrated in figure 3-2. The type of mixing hardware used has no bearing on the results of the formula.

Example: Hot water is supplied from a conventional boiler at a temperature of 170ºF and flow rate of 5 gpm. It flows into the hot port of a 3-way mixing valve as shown in figure 3-3. Cooler water returns from the distribution system at 110ºF and 8 gpm. Determine the mixed supply water-temperature to the distribution system under these conditions.

Solution: Enter the values for temperature and flow rate of each entering fluid stream entering into formula 3-1 and solve:

$$T_{mix} = \frac{(T_1 \times f_1) + (T_2 \times f_2)}{f_1 + f_2} = \frac{(170 \times 5) + (110 \times 8)}{5 + 8} = 133^{o} F$$

Figure 3-2

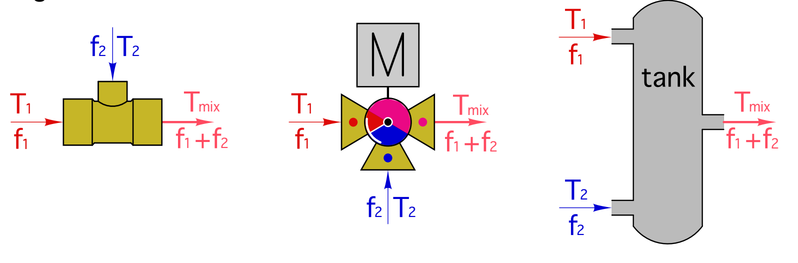
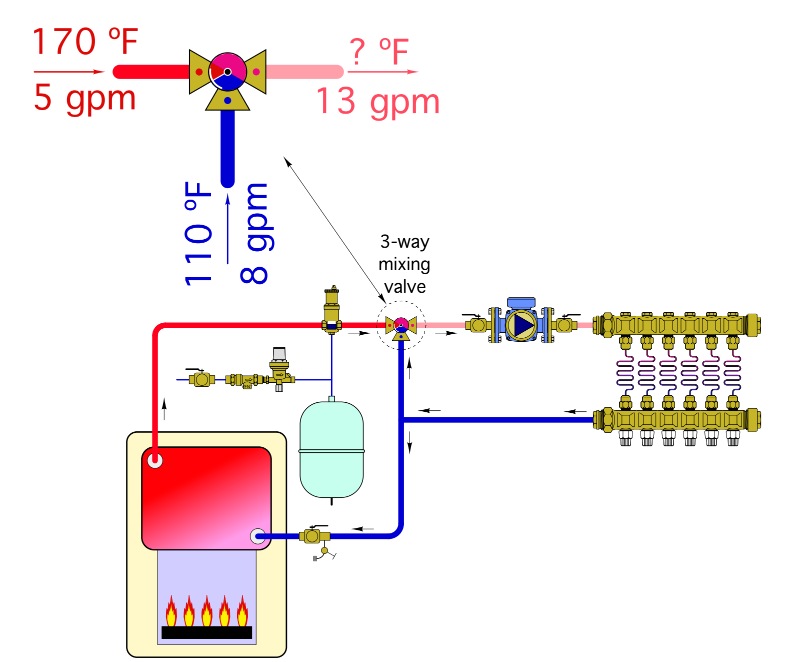


Figure 3-3



There are situations where more than two fluid streams converge within a hydronic heating system. One example is several distribution circuits connected to a common return manifold. In such cases, the previous formula can be expanded to handle any number of converging fluid streams. For example, to calculate the mixed temperature of four fluid streams coming together in a return manifold, the previous formula can be expanded as follows:

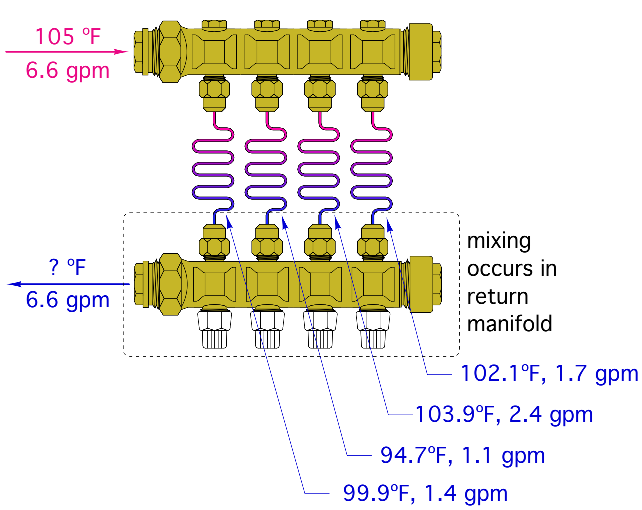
Formula 3-2:

$$T_{mix} = \frac{(T_1 \times f_1) + (T_2 \times f_2) + (T_3 \times f_3) + (T_4 \times f_4)}{f_1 + f_2 + f_3 + f_4}$$

T_1 through T_4 are the temperatures of the entering fluid streams. f_1 through f_4 are the respective flow rates of those streams.

Example: Water enters the supply manifold of a 4-circuit radiant floor system at 105ºF and 6.6 gpm. The flow splits up among the circuits as indicated in figure 3-4. The return water-temperature for each circuit has been listed. Determine the temperature of the water stream exiting the return manifold.

Figure 3-4



Solution: Put the temperatures and associated flow rates into formula 3-2 and carefully do the math:

$$T_{mix} = \frac{(99.9 \times 1.4) + (94.7 \times 1.1) + (103.9 \times 2.4) + (102.1 \times 1.7)}{1.4 + 1.1 + 2.4 + 1.7} = 101^{\circ} F$$

Notice that the water-temperature leaving the manifold is higher than the return temperature of some zone circuits, and lower than the return temperature of other zone circuits. This temperature results from the fact that the total mass and thermal energy entering the manifold from the four circuits must equal the total mass and thermal energy exiting the manifold.

Thermal equilibrium:

Every hydronic system seeks a condition where the rate of heat release from the water passing through the distribution system equals the rate heat is added to the water by the heat source. This condition is called thermal equilibrium.

If not for the intervention of temperature limiting controls, every system would eventually stabilize at a supply water-temperature where thermal equilibrium exists. This temperature may or may not provide the proper heat input to the building. It may or may not occur at conditions that are safe, efficient or ensure a long system life. In a manner of speaking — the system "doesn't care" if it's delivering the proper amount of heat to the building, or if it's operating safely, efficiently, or at conditions that ensure a long life. The system only "cares" that a balance exists between the rates of heat input and heat release. As such, the system is simply complying with the first law of thermodynamics.

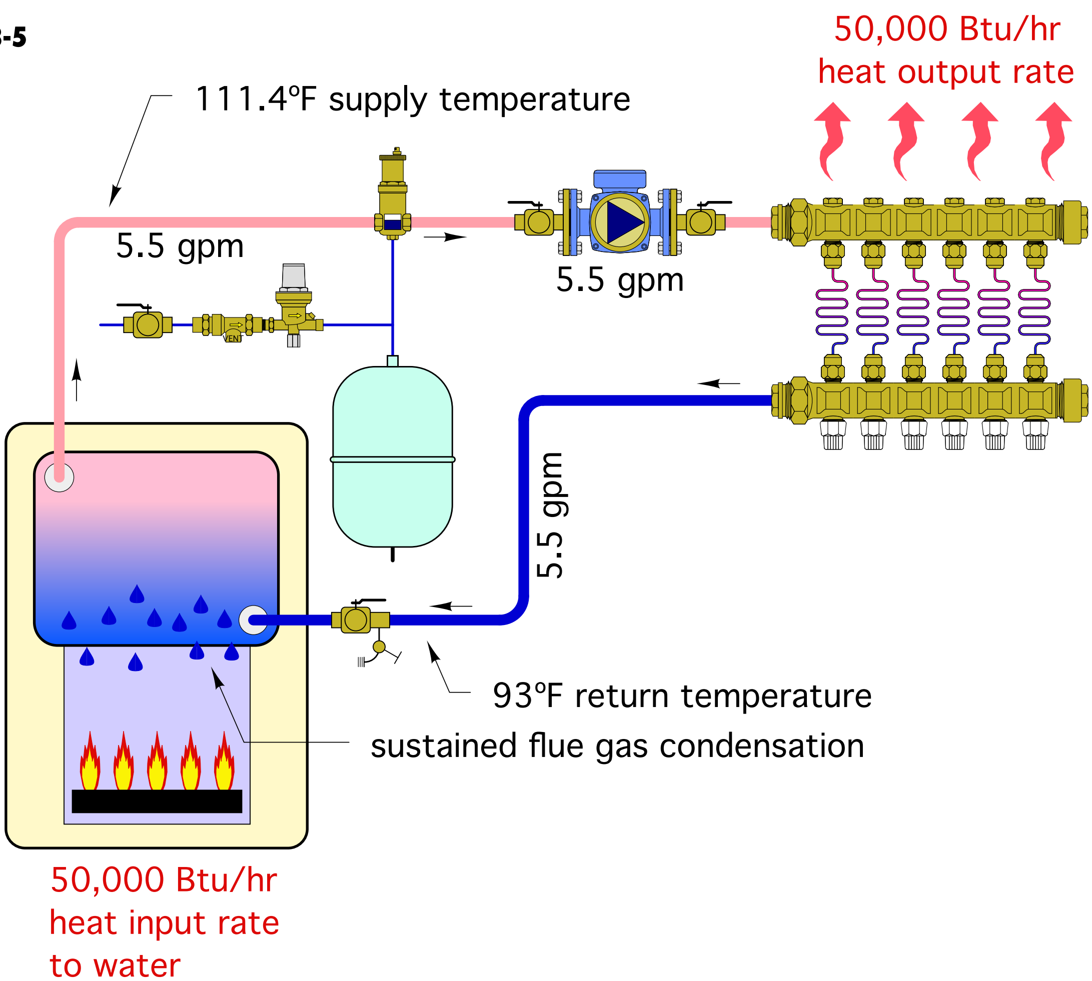
If a hydronic distribution system removes heat from the water circulating through it faster than the heat source generates heat, the water-temperature in the entire system will decrease, often well below the temperature that may be set on a high limit control device.

Imagine, for example, a hydronic floor heating system having six 300-foot circuits of 1/2-inch PEX tubing embedded in a bare concrete slab. The system is directly piped to a 50,000 Btu/hr cast iron boiler as shown in figure 3-5. The circulator used provides a flow rate of 5.5 gpm to the manifold station. The boiler's temperature limit controller is set for 125ºF because the installer thinks that is the proper supply temperature for the floor circuits.

When the system is turned on the water-temperature rises and stabilizes at a supply temperature at 111.4ºF. What's wrong with the system?

Actually there's nothing wrong. When the supply water-temperature reaches 111.4ºF the distribution system is able to dissipate 50,000 Btu/hr — exactly the same rate of heat transfer the boiler is delivering to the water stream. At this condition the system is in thermal equilibrium. There is no need of the water-temperature

Figure 3-5



increasing any higher. Adjusting the temperature controller setting to a higher value would have no effect on this operating condition.

Under these thermal equilibrium conditions, the return water-temperature to the boiler is about 93ºF. This would allow sustained flue gas condensation within the boiler. Thus, although the system operates at thermal equilibrium, these conditions are NOT good for the boiler.

Preventing sustained flue gas condensation:

The water-temperature in any hydronic system decreases whenever the rate of heat delivery to the heat emitters exceeds the rate at which the heat source adds heat to the water. This is common when a distribution system, particularly one with high thermal mass, is starting up or recovering from a setback period. These conditions can be present hundreds, even thousands of times over the life of the system.

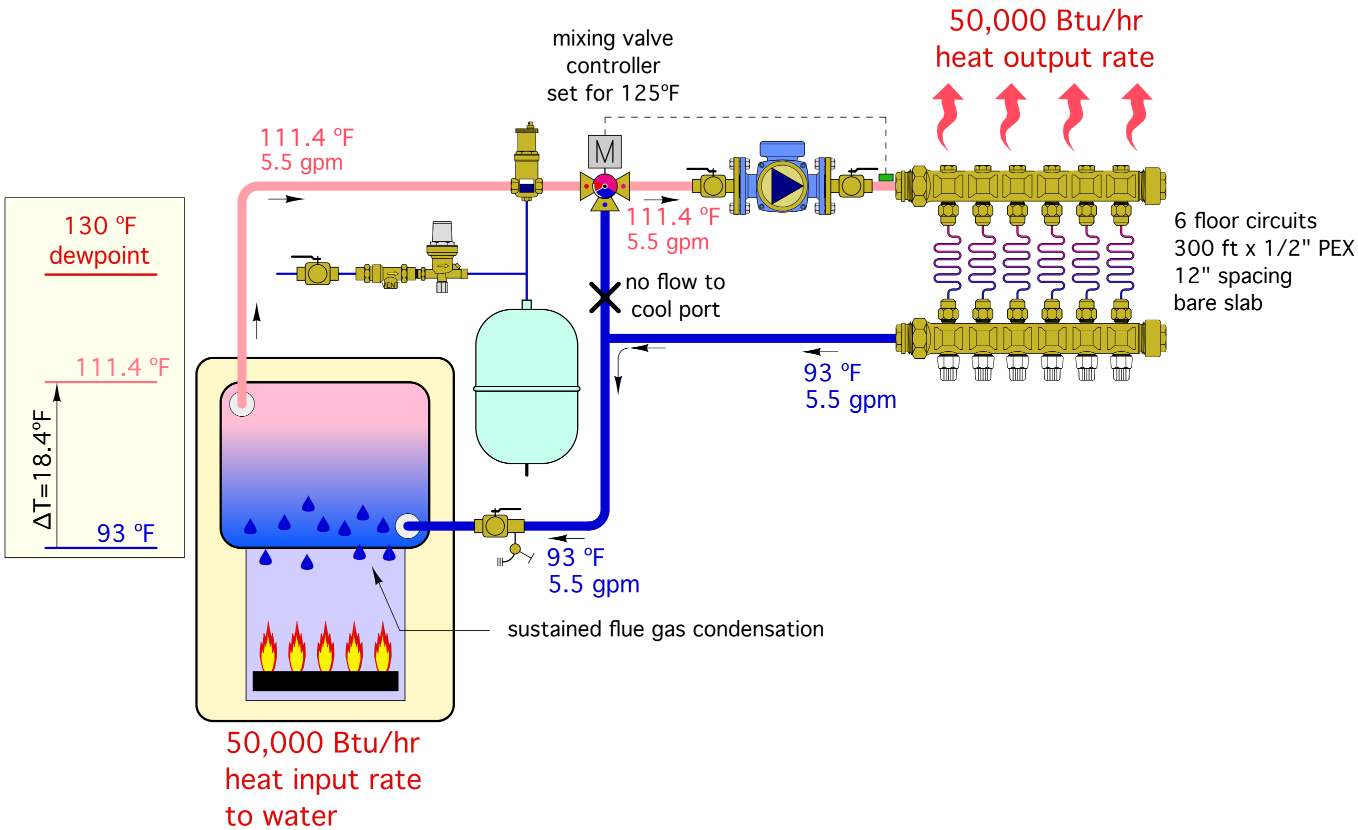
To prevent sustained flue gas condensation the mixing assembly must prevent the distribution system from extracting heat from the water faster than the boiler can add heat to the water.

Proper boiler protection can only be achieved by a mixing assembly that monitors boiler inlet temperature and compares it to a set minimum value. Whenever the boiler inlet temperature is at or below this minimum value, the mixing assembly must reduce the rate of hot water flow from the boiler to the distribution system. This action “lifts” the combustion side of the boiler’s heat exchanger above the dewpoint of the exhaust gases.

Without measuring boiler inlet temperature, the mixing assembly is “blind” to what is happening at the boiler inlet, and cannot assure the boiler is protected against sustained flue gas condensation.

Controlling supply water-temperature to a distribution system, and protecting a boiler from sustained flue gas

Figure 3-6



condensation also requires two mixing points within the piping system. One mixing point regulates supply water-temperature; the other boosts boiler inlet temperature.

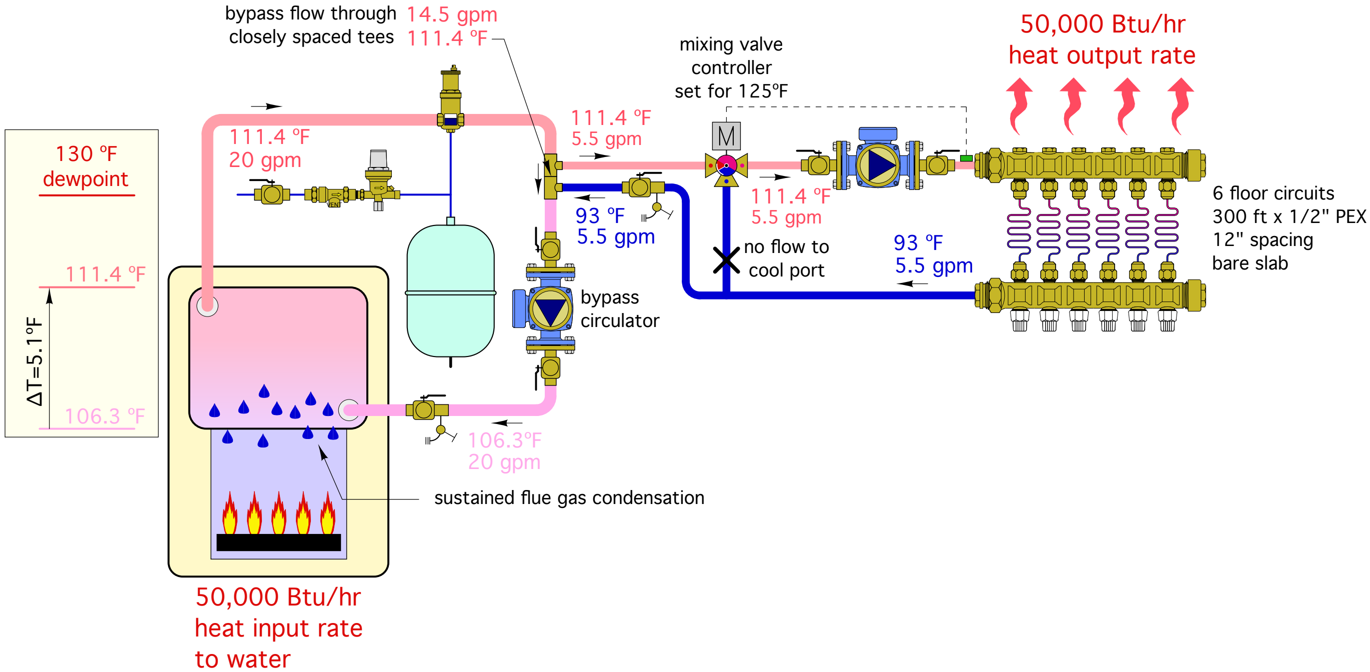
These details, or the consequences of not having them, are illustrated in the systems of figure 3-6 through 3-8. These systems all use a 3-way mixing valve to control the temperature of the water going to the distribution system. The manifold station in each system serves six floor heating circuits, each being 300 feet of 1/2-inch PEX tubing embedded at 12-inch spacing in a 4-inch thick bare concrete slab. All of these systems have a conventional boiler with a rated output of 50,000 Btu/hr, and a high limit setting of 180ºF. The controller operating the mixing valve in each system is set with the intention of maintaining a supply temperature of 125ºF to the manifold station.

The system in figure 3-6 does NOT measure boiler inlet temperature. The water-temperatures shown are those established based on thermal equilibrium, with the boiler in continuous operation. They are the temperatures necessary for this specific distribution system to dissipate 50,000 Btu/hr — exactly the same as the boiler heat output rate.

Because the mixing valve controller is trying to achieve a supply water-temperature of 125ºF, and only has water at 111.4ºF available from the boiler, the hot port of the mixing valve is fully open, and the cool port completely shut. Hence, the mixing valve is simply "passing through" the entering water stream directly to the manifold station. No mixing occurs.

All water exiting the return manifold flows directly into the boiler at 93ºF. This temperature is low enough to cause sustained flue gas condensation within the boiler. This is true even though the boiler is in continuous operation at full rated capacity. This situation is unacceptable for any type of conventional boiler. It demonstrates that a mixing assembly that does not monitor and react to boiler inlet temperature cannot protect the boiler.

Figure 3-7



The system in figure 3-7 adds a bypass circulator between the boiler and mixing valve. The 3-way mixing valve is correctly coupled to the boiler bypass piping using a pair of closely spaced tees. The intended purpose of the bypass circulator is to mix higher temperature water leaving the boiler into the cooler water flow returning from the distribution system, and thus boost boiler inlet temperature.

The temperatures shown are those necessary for thermal equilibrium between this specific manifold station and boiler.

Although the bypass circulator increases the flow rate through the boiler, it cannot adjust the rate of heat transfer to the distribution system relative to the rate of heat production in the boiler. To dissipate the 50,000 Btu/hr added to the water by the boiler, the manifold station still requires 111.4°F water at 5.5 gpm flow rate, and returns the same flow at 93°F. The hot port of the mixing valve is again fully open, and passing all entering hot water directly to the manifold station. No mixing occurs in the mixing valve.

The bypass circulator and boiler loop create a second mixing point within the lower of the two closely spaced tees. This mixing slightly boosts boiler inlet temperature, but not high enough to prevent sustained flue gas condensation within the boiler.

If a larger bypass circulator were used, flow rate through the boiler would increase, as would boiler inlet temperature. The temperature rise across the boiler would decrease in response to the higher flow rate. Logic dictates that the boiler's inlet temperature could never reach its outlet temperature, regardless of how fast flow passes through it.

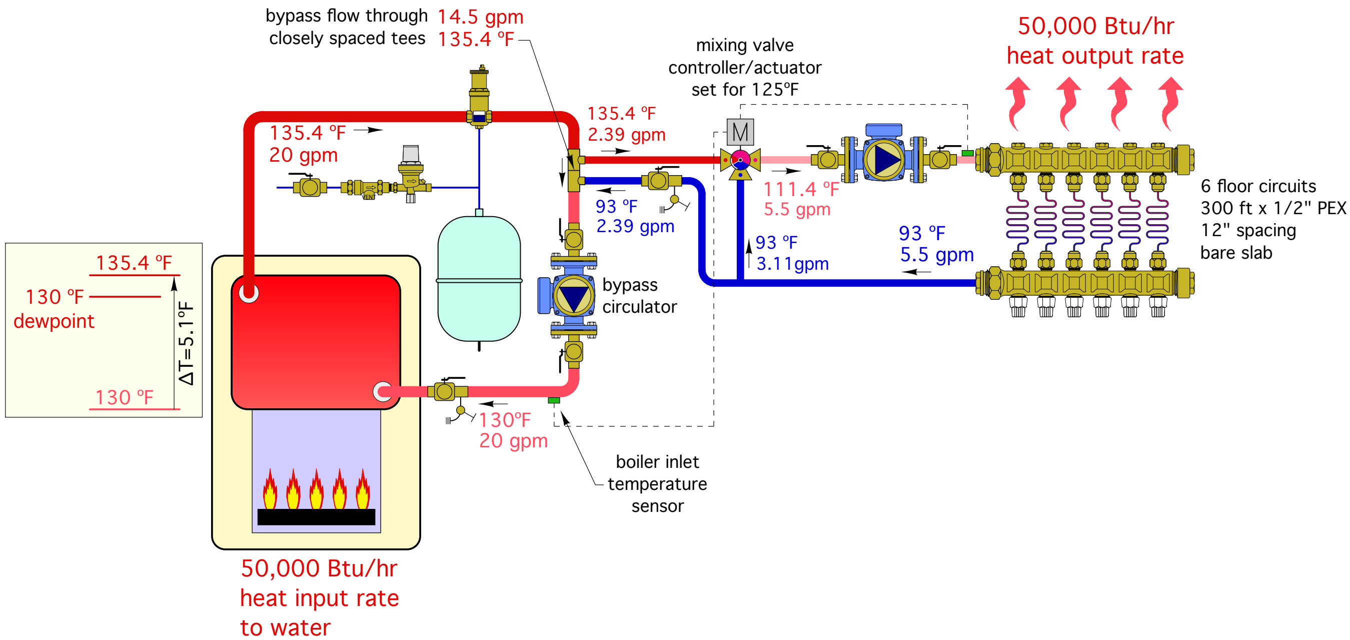
Sustained flue gas condensation will again occur within the boiler. The boiler bypass circulator by itself is insufficient to protect the boiler. The missing element is a mixing system that senses and reacts to boiler inlet temperature.

The system shown in figure 3-8 includes a mixing valve controller that measures boiler inlet temperature. The logic within the controller gives priority to maintaining the boiler inlet temperature above a user-selected minimum value, which in this example will be 130°F.

Notice that the water-temperature entering the boiler is 130°F. Given the same 20 gpm flow rate through the boiler, the temperature rise across it will be 5.1°F, and thus its outlet temperature will be 135.4°F. This higher water-temperature now enters the hot port of the mixing valve.

Because hot water is now available to the mixing valve at 135.4°F one might assume the mixing valve controller would adjust the valve for a mixed supply

Figure 3-8



temperature of 125°F (e.g., the setting of the mixing valve's controller). However, if the water-temperature supplied to the floor circuits were to increase, so would heat output from the floor. Under such conditions, the floor circuits would release heat faster than the boiler can add heat to the water. The resulting thermodynamic imbalance would force the water-temperature entering the boiler to drop. The boiler inlet temperature sensor would immediately detect this and the mixing controller would reduce the rate at which hot water enters the hot port of the mixing valve until the boiler inlet temperature increased back to 130°F.

The net effect is that the manifold continues to be supplied with water at 111.4°F, the manifold station releases heat at 50,000 Btu/hr and boiler inlet temperature continues to stabilize at the controller's set minimum value of 130°F. Thermal equilibrium between the boiler and distribution system is achieved, and boiler inlet temperature is high enough to avoid flue gas condensation.

The key to the successful strategy shown in figure 3-8 is a mixing assembly that senses and reacts to boiler inlet temperature. This detail was lacking in the systems shown in figures 3-6 and 3-7.

4. OUTDOOR RESET CONTROL

As outdoor temperatures change, so does the heating load of a building. Ideally, every heating system would continually adjust its rate of heat delivery to match its building's current rate of heat loss. This would allow inside air temperature to remain constant regardless of outside conditions. Outdoor reset control was developed with this goal in mind.

An outdoor reset controller continuously calculates the ideal "target" supply water-temperature to a hydronic system. This temperature depends on the type of heat emitters in the system as well as the current outdoor temperature. Thus, the target supply water-temperature may change from one moment to the next.

In addition to making this calculation, an outdoor reset controller operates one or more devices within the system in an attempt to hold the supply water-temperature reasonably close to this target value.

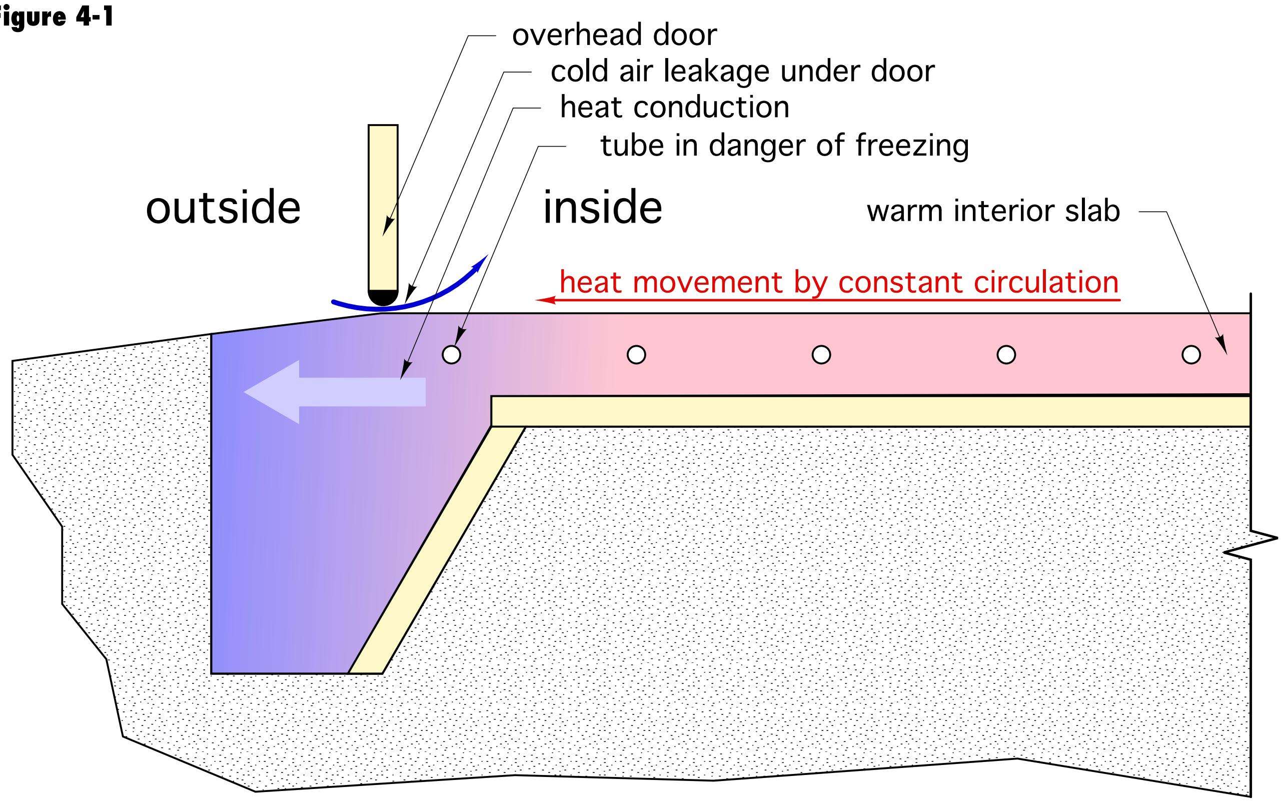
Benefits of outdoor reset control:

There are several benefits associated with the use of outdoor reset control in hydronic radiant panel heating systems. They include:

• *Stable indoor temperature:* Outdoor reset control reduces fluctuation of indoor temperature. When the reset control is properly adjusted, the water-temperature supplied to the heat emitters is just high enough for the prevailing heating load. The rate of heat delivery is always maintained very close to the rate of building heat loss. This yields very stable indoor temperature compared to less-sophisticated hydronic systems that deliver water to the heat emitters as if it were always the coldest day of winter. In the latter case, the flow of heated water to the heat emitters must be turned on and off to prevent overheating under partial load conditions. This often creates an easily detected and undesirable sensation that the heat delivery system is on versus off. With properly adjusted outdoor reset control, building occupants should have no sensation that heat delivery is on or off, just a sensation of continuous comfort.

• *Near-continuous circulation:* Because outdoor reset control supplies water just hot enough to meet the prevailing load, the distribution circulator remains on most of the time. Flow through the distribution system stops only when necessary to prevent overheating due to internal heat gains from sunlight, equipment, interior lighting, or a gathering of people.

Figure 4-1



Near-continuous circulation reduces the potential for expansion noises from piping and heat emitters, especially in systems using PEX tubing and/or fin-tube convection elements.

Another benefit of near-continuous circulation is the ability to redistribute heat within a heated concrete slab. This is desirable in situations where portions of the slab experience high heat loss. One example is a floor area just inside an overhead door, such as shown in figure 4-1. If flow through floor heating circuits was turned off for several hours during cold weather, water in the tubing just inside the door could freeze. If this occurs, flow through the entire circuit is blocked. Thawing the floor can be difficult.

However, if the circulator remains on, as it would when a properly set outdoor reset controller is used to regulate water-temperature, the circulating water redistributes heat stored in the interior portion of the slab to the areas of higher heat loss. This can prevent freezing for many hours, perhaps even days in high mass systems, should a failure of the heat source occur.

The redistribution of heat within a slab due to near-continuous circulator also helps move heat stored in slab areas covered with higher R-value flooring, to areas with lower-resistance flooring. This reduces the tendency for the latter to become noticeably cooler during what might otherwise be lengthy periods of no flow.

• *Reduced Thermal Shock:* Outdoor reset control reduces the possibility of thermal shock to either the heat source or distribution system. Hot boilers are less likely to receive slugs of cold water from zones that have been off for several hours. Wood floors over heated subfloors are less prone to thermal stress when undergoing gradual temperature changes associated with outdoor reset control.

• *Indoor Temperature Limiting:* When water is supplied to the heat emitters at design temperature regardless of the load, occupants can choose to set the thermostat to a high-temperature and open windows and doors to control overheating. Although this sounds like a foolish way to control comfort, it's often done in rental properties where tenants don't pay for their heat. However, if supply water-temperature is regulated by outdoor reset control, it's just warm enough to meet the heating load with the windows and doors closed. Wasteful use of energy is discouraged.

• *Reduced Energy Consumption:* Outdoor reset control has demonstrated its ability to reduce fuel consumption in hydronic heating systems. The savings are a combination of reduced heat loss from boilers, reduced heat loss from distribution piping, and, in the case of condensing boilers, increased time in condensing mode operation. Exact savings will vary from one project to another. Conservative estimates of 10-15% are often cited.

The mathematics of outdoor reset control:

Outdoor reset controllers use the following formula to determine the target water-temperature to a hydronic distribution system:

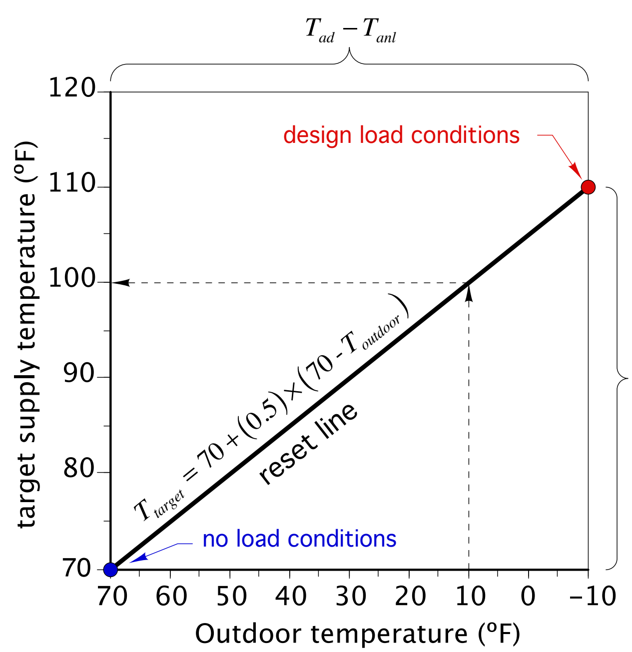
Formula 4-1

$$T_{target} = T_{indoor} + (RR) \times (T_{indoor} - T_{outdoor})$$

Where:

T_{target} = the "ideal" target supply water-temperature to the system
T_{indoor} = desired indoor air temperature
RR = reset ratio (slope of reset line)

Figure 4-2



$$RR = \frac{T_{wd} - T_{wnl}}{T_{ad} - T_{anl}} = \frac{110 - 70}{70 - (-10)} = \frac{40}{80} = 0.5$$

$$T_{target} = 70 + (0.5) \times (70 - T_{outdoor})$$

The reset ratio (RR) is determined as follows:

Formula 4-2

$$RR = \frac{T_{wd} - T_{wnl}}{T_{ad} - T_{anl}}$$

Where:

T_{wd} = required supply water-temperature to distribution system at design load
T_{wnl} = water-temperature supplied to distribution system at no load
T_{ad} = outdoor air temperature at design load
T_{anl} = outdoor air temperature at no load

The graph in figure 4-2 is a good way to visualize these relationships.

The red dot in the upper right of the graph represents design load conditions (e.g., the coldest day of winter). The blue dot in the lower left corner represents no load conditions (e.g., where no heat output is needed from the heat emitters). The sloping line that connects these two dots is called the reset line.

The reset ratio (RR) is the slope of the reset line. It is found by dividing the vertical temperature difference between the red dot and blue dot by the horizontal temperature difference between the same dots. In this case, the reset ratio is:

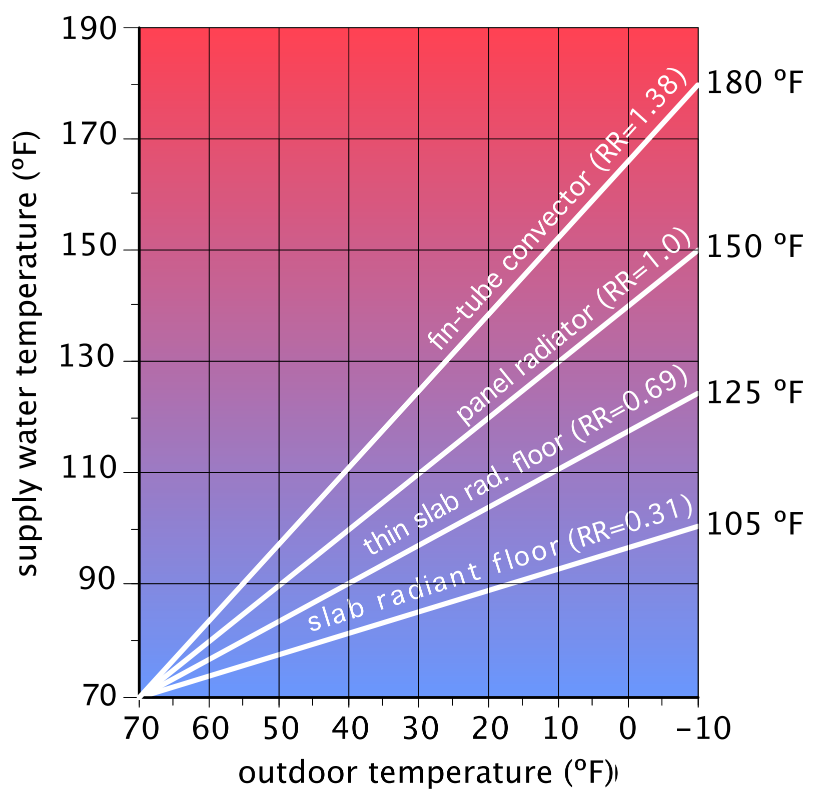
$$RR = \frac{T_{wd} - T_{wnl}}{T_{ad} - T_{anl}} = \frac{110 - 70}{70 - (-10)} = \frac{40}{80} = 0.5$$

The target water-temperature for any outdoor temperature is found by first locating the outdoor temperature on the horizontal axis. Next, draw a vertical line up to intersect the reset line. Finally, draw a horizontal line from this intersection to the vertical axis and read the required target water-temperature. For example, when the outdoor temperature is 10ºF, the reset line in figure 4-2 indicates the target supply water-temperature is 100ºF.

The target water-temperature can also be determined by entering the outdoor temperature into the formula for the reset line. For the line shown in figure 4-2 the target water-temperature when the outdoor temperature is 10ºF would be:

$$T_{target} = 70 + (0.5) \times (70 - 10) = 70 + 30 = 100^{\circ} F$$

Figure 4-3



Every hydronic distribution system, in combination with the building it's installed in, yields a unique reset line. For example, a building equipped with slab-type floor heating will have a different reset line compared to the same building using fin-tube baseboard convectors. This is due to the difference in supply water-temperatures for these two types of heat emitters. A sampling of some "typical" reset lines for different types of heat emitters is shown in figure 4-3.

High-temperature heat emitters, such as fin-tube baseboard, require "steep" reset lines (e.g. higher value for the reset ratio RR). Low-temperature heat emitters, such as heated floor slabs, require more "shallow" reset lines.

To determine the correct reset line for a given system, one must first determine the required supply water-temperature to the distribution system under design load conditions. Doing so is a routine part of any system design.

Indoor temperature sensing:

Under some conditions an outdoor reset controller may not supply the appropriate water-temperature to the distribution system. One such situation is a building with a large area of unobstructed south-facing windows. At times, solar heat gain through these windows may provide much, if not all the heat a building requires, even when the outdoor temperature is low. Because a basic reset controller only monitors outdoor temperature, it does not know this is occurring. The controller simply calculates the target water-temperature based on what it "sees." This can result in overheating. The same situation can occur due to internal heat gains from lights, people, fireplaces, etc.

Because internal heat sources are present in most buildings, it's best to equip outdoor reset control systems with an indoor temperature sensor that allows the control to sense how the room temperature is tracking. Then, if internal heat gain causes indoor temperatures to rise, the controller can respond by reducing further heat input to the distribution system regardless of outdoor temperature.

When the reset controller is equipped with indoor temperature sensing, its priority is to maintain the proper indoor temperature regardless of the outdoor temperature. Using an outdoor reset controller without an interior temperature sensing should only be considered in buildings with little or no internal heat gain.

Figure 4-4 illustrates the control logic used by a reset controller that controls an on/off heat source. The sloping blue line represents the "target temperature" (e.g., the ideal supply water-temperature for the distribution system over a range of outdoor temperatures). For example, if the outdoor temperature is 10ºF, the blue line in figure 4-4 indicates a target temperature of 105ºF (as indicated by the blue dot).

As soon as the reset controller is powered on, it measures outdoor temperature, uses this measurement along with its settings to calculate the target temperature, and compares the calculated target temperature to the measured supply water-temperature.

If the measured supply water-temperature is equal or close to the target temperature, no control action is taken. However, if there is sufficient deviation between these temperatures, the reset controller takes action.

The settings represented in figure 4-4 would result in the following control actions when the outdoor temperature is 10ºF:

• If the temperature at the supply sensor is above 100ºF (e.g. 105 less one half the control differential of 10ºF), the contacts in the reset controller remain open, and the heat source remains off.

Implementing outdoor reset control:

There are three ways to implement outdoor reset control in hydronic systems:

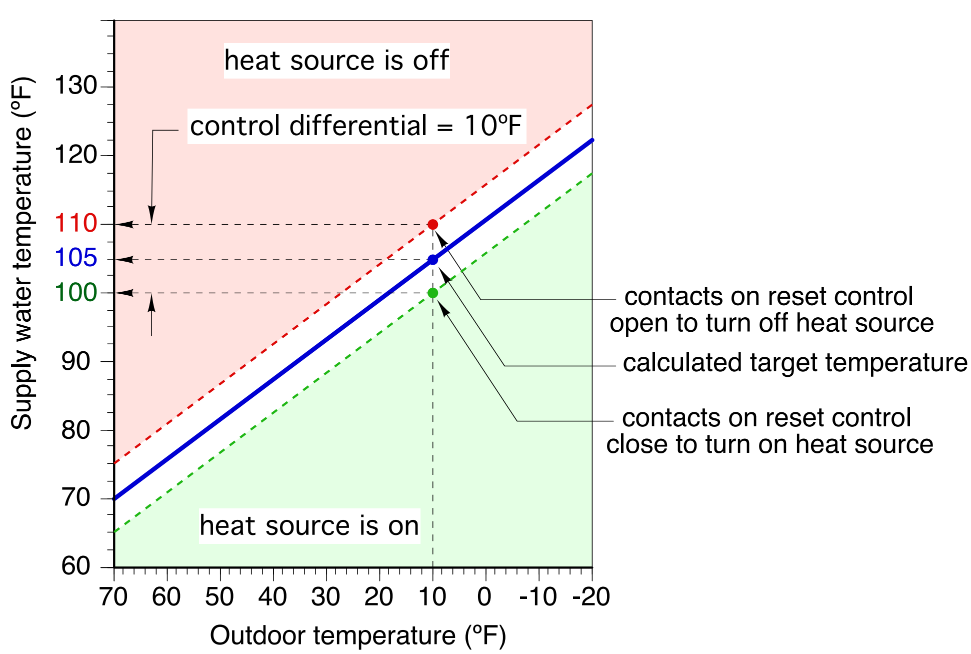
• Heat source reset (for on/off heat source)
• Heat source reset (for modulating heat source)
• Mixing reset

These techniques can be used individually or together.

Heat source reset (for on/off heat sources):

The temperature of water supplied to a distribution system can be controlled by turning a heat source such as a boiler or heat pump on and off.

Figure 4-4



• If the temperature at the supply sensor is below 100ºF, the contacts in the reset controller close to turn on the heat source. Once turned on, the heat source would remain on until the supply sensor reaches a temperature of 110ºF (105 plus one half the control differential) or higher.

The 10ºF control differential between the temperatures at which the heat source is turned on and off discourages short cycling. The value of the control differential can be adjusted on most reset controllers. Smaller control differentials reduce the variation in supply water-temperature both above and below the target temperature. However, if the control differential is too small, the heat source will cycle on and off excessively. This is not good for the life of components such as boiler ignition systems or heat pump compressors and contactors.

The optimum control differential value varies depending on the heat source and the heat delivery system. In theory, it's the smallest value that allows the desired run cycle duration without creating noticeable changes in comfort or other undesirable effects such as piping expansion sounds. In practice, it is often determined by trial and error once the system is operational.

The process of measuring outdoor temperature, calculating target temperature, comparing the measured supply water-temperature to the target temperature, and generating a control action based on the difference in these temperatures takes place continuously as long as the reset controller is turned on.

Heat source reset (for modulating heat sources):

Many modern boilers, and even some heat pumps, have the ability to adjust their heat output over a relatively wide range. This is called modulation, and it allows the heat source to better track the heating load. Modulation reduces issues such as short cycling and temperature variations that are more common in systems using on/off heat sources.

Modulating heat sources usually have their own internal outdoor reset controllers. They continually measure outdoor temperature, calculate the target supply water-temperature and compare it to the measured supply water-temperature. Deviations between these temperatures cause the reset controller to regulate the speed of the combustion air blower on a modulating boiler or compressor speed on a modulating heat pump. The goal is to keep the measured supply temperature very close to the calculated target temperature.

The ideal modulating heat source would vary its heat output from 100 percent all the way down to 0 percent. Currently, the only heat source that can do this is a properly controlled electric resistance element. Modulating burners, as well as modulating compressors, can typically reduce output down to approximately 20 percent of their full rated output. When loads require lower output, these devices must turn on and off. Future developments will likely reduce the lower end of the modulation range, but it's unlikely that range will be lower than 10 percent of rated output.

Figure 4-5

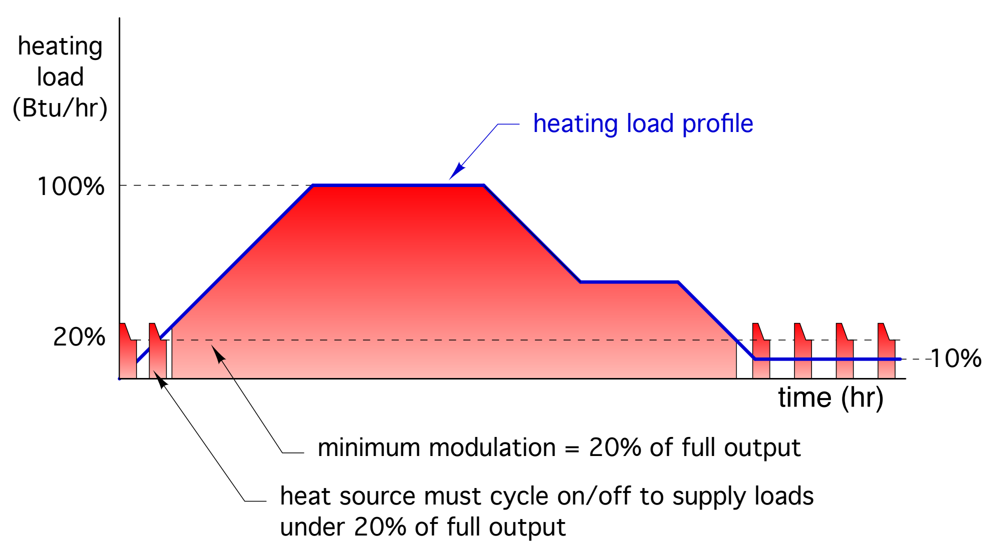


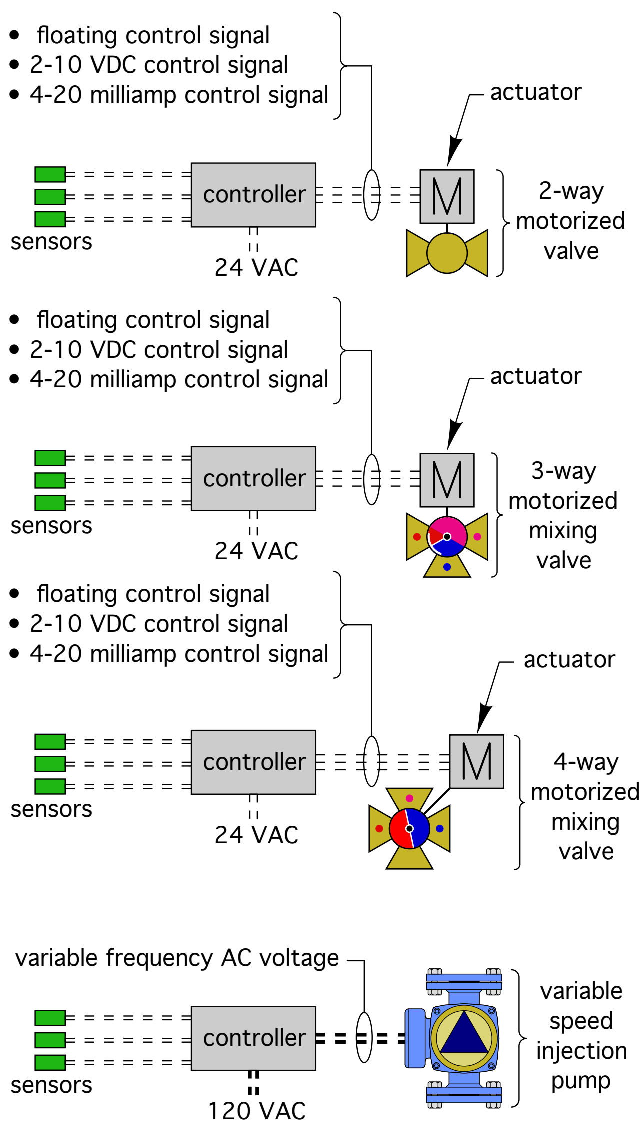
Figure 4-5 shows how the output of a modulating boiler capable of reducing its heat output to 20 percent of rated output matches its heat output to a hypothetical load profile.

The blue line that borders the shaded area represents how the heating load varies over a period of a few hours. The load begins at zero, steadily increases to a maximum value and then reduces itself in various slopes and plateaus over time, eventually returning to zero.

The areas with red shading represent the heat output from the modulating heat source. The "spikes" near the beginning and end of the load profile result from the boiler turning on at 100 percent output, then quickly reducing output to the lower limit of 20 percent and finally turning off for a short period of time. This is characteristic of current modulating burner technology.

The large red shaded area shows that the boiler can accurately track the load whenever that load is 20 percent or more of the maximum load. This is ideal.
The boiler tracks load by varying supply water-temperature in response to outdoor reset control. As the load increases, so does the water-temperature supplied by the boiler.

Figure 4-6



Mixing reset:

The final way of implementing outdoor reset control is through mixing. This can be done using a variety of mixing devices such as 3-way valves, 4-way valves or injection mixing. These mixing devices are discussed in detail in later sections.

The logic used for mixing reset is similar to that already described for modulating heat sources. The outdoor temperature is measured. The target temperature is calculated. The measured supply temperature is then compared to the target temperature. The deviation between these temperatures determines the output signal from the reset controller. The output signal may be one of the following:

• DC voltage within the range of 2-10 volts
• DC current within the range of 4-20 milliamps
• Closure of one of two relays (referred to as floating control)
• Variable frequency, AC voltage waveform

These control outputs are illustrated in figure 4-6.

Various mixing devices are designed to accept and respond to one or more of these control signals. In doing so, the mixing device can produce a mixed water-temperature anywhere between the temperatures of the hot water supplied to the mixing device and the return temperature from the distribution system. Because the mixing device can completely block input of hot water, the mixed water-temperature can ultimately be as low as the room air temperature. A properly sized mixing device can thus supply heat at a rate suitable for design load conditions, all the way down to zero load conditions.

Either type of heat source reset can be combined with mixing reset in the same system. A later schematic will illustrate when and how this is accomplished.

"Dumb" versus "intelligent" mixing devices:

Mixing devices can be categorized based on their ability to sense and react to water-temperature. Some, such as a standard 3-way mixing valve shown in figure 4-7, can neither sense nor react to water-temperature. As such they can be considered "dumb" mixing devices.

Others, such as a thermostatically controlled 3-way mixing valve shown in figure 4-8, can both sense and react to water-temperature. Such devices are called "intelligent" mixing devices.

Figure 4-7

Figure 4-8

Modern mixing devices that provide reset control typically use electronic controllers to measure the required temperatures and generate the necessary control signals. These signals operate an actuator attached to the mixing valve. The actuator translates these control signals into shaft movement (rotary or linear) to operate the valve.

Dumb mixing devices have no motorized or thermostatic actuators. The position of their shaft is adjusted manually. In a given system, and at given operating conditions, the position of the shaft determines the mixed temperature(s) from the dumb mixing valve. If the temperature or flow rate of fluid entering any port of a dumb mixing valve changes, so does the outlet temperature(s) from that valve. The valve can do nothing on its own to change these conditions. It is "blind" to what is happening with entering or leaving temperatures and flow rates. As such, dumb mixing devices cannot be relied upon to provide stable output temperatures, outdoor reset control or to protect conventional boilers from sustained flue gas condensation. Dumb mixing devices do however have application in some hydronic systems, but they are far more limited than intelligent mixing devices.

Proportional reset control:

Some hydronic systems require two or more simultaneous supply water temperatures. One example is a system that supplies low-temperature water for basement slab heating and medium-temperature water for panel radiators on the first floor.

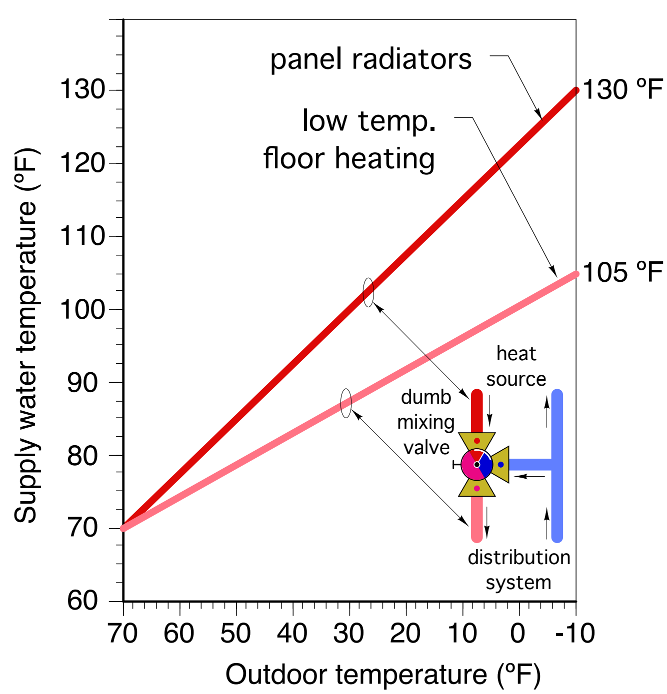
One method of providing simultaneous supply water-temperatures is called proportional reset control. It uses a combination of a device (heat source or mixing assembly) operated by outdoor reset control and a dumb mixing device such as a manually set 3-way mixing valve.

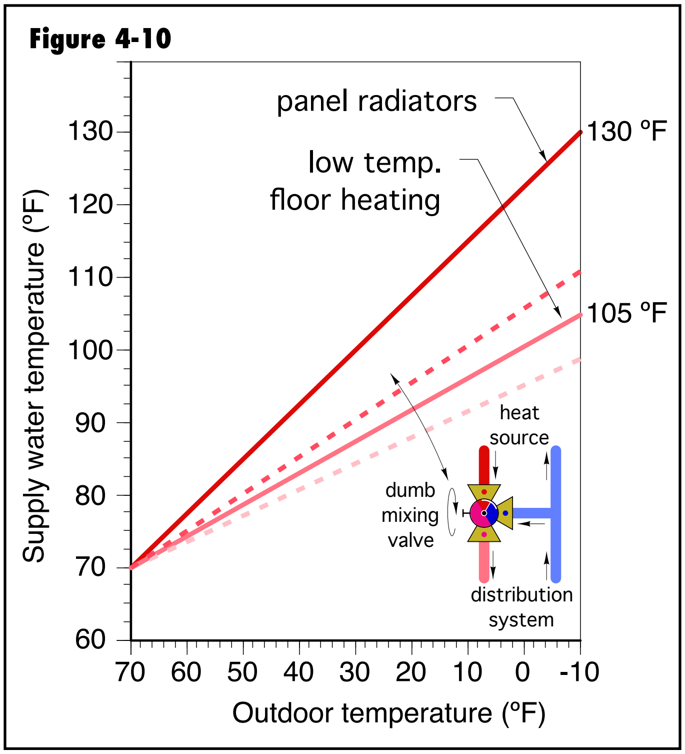
When the water-temperature entering the hot port of the dumb mixing valve is regulated based on outdoor reset, the mixed water-temperature leaving that valve will also track along a reset line as shown in figure 4-9.

The upper reset line indicates the water-temperature supplied from the heat source. The lower line is the water-temperature supplied to the portion of the distribution system served by the dumb mixing valve.

The slope of the lower reset line can be adjusted by turning the knob on the 3-way mixing valve. Allowing more hot water into the valve increases the slope of the line. Allowing more cool water into the valve decreases the slope, as shown in figure 4-10.

Figure 4-9



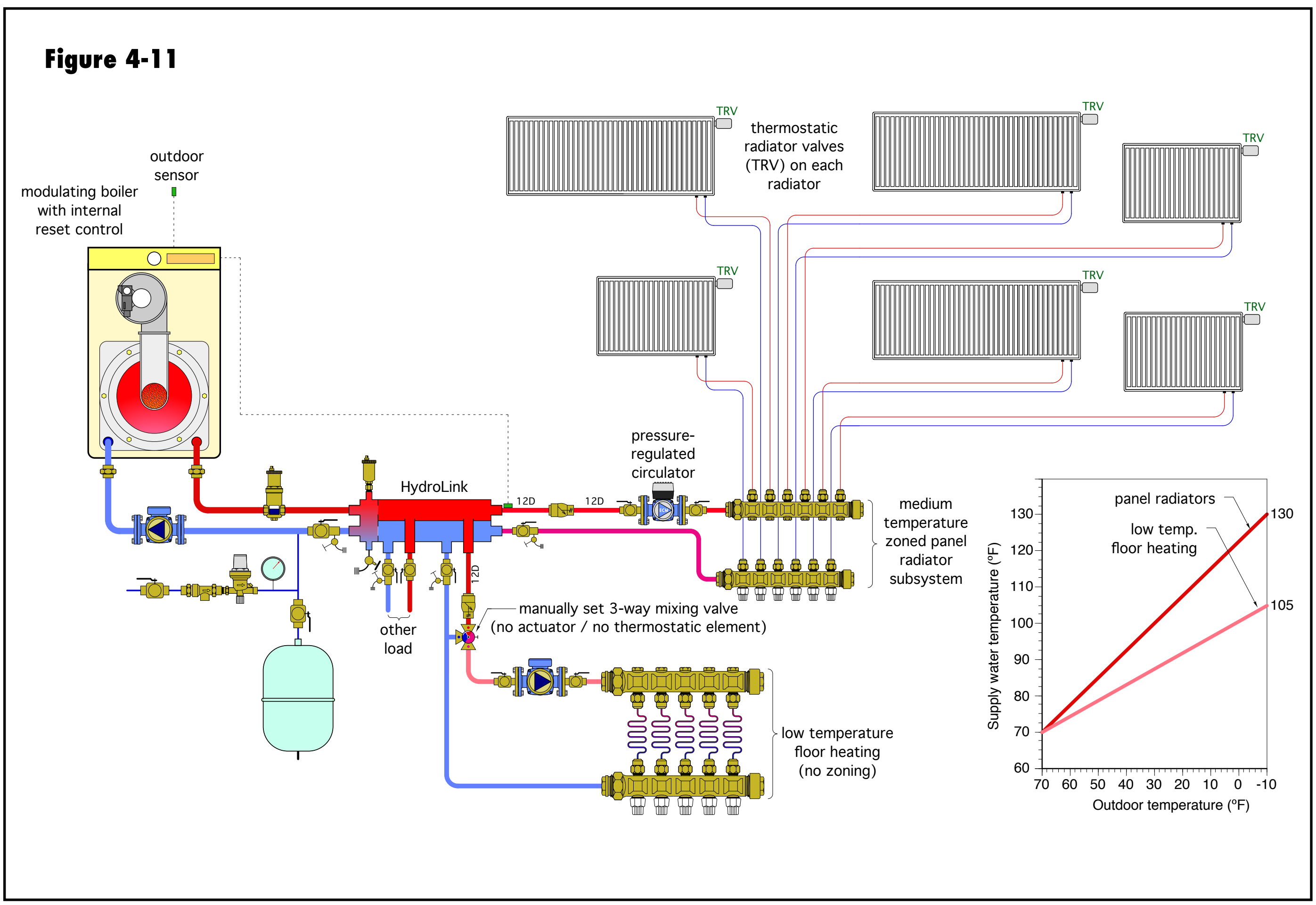


The system shown in figure 4-11 shows one way proportional reset control can be applied.

Hot water is supplied from the modulating boiler to the HydroLink. Some of it passes straight through the HydroLink to the panel radiator subsystem. In this case, the reset line indicates that 130°F water is supplied to the panel radiators when the outdoor temperature is –10°F.

The HydroLink also supplied boiler water to the hot port of the manually set 3-way mixing valve. Cool water from the return side of the low-temperature distribution system flows into the cool port of this mixing valve. Under these conditions, the outlet temperature from the mixing valve tracks the lower reset line. The low-temperature subsystem will receive water at 105°F when the outdoor temperature is –10°F. No reset controller or actuator is required on the mixing valve to produce these results.

If a third supply water-temperature were required, it could be created by installing another 3-way dumb mixing valve supplied from the remaining HydroLink connections.



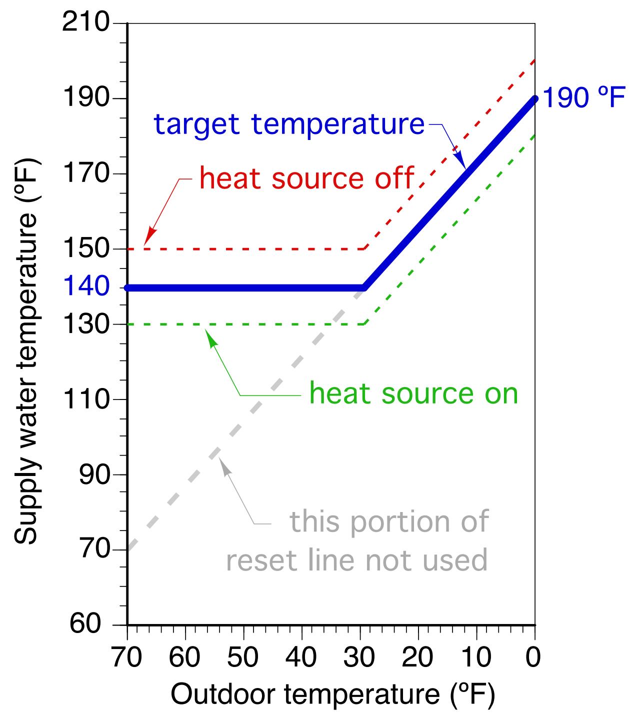
Limitations of proportional reset:

It's important to recognize situations in which proportional reset is appropriate. It should only be used to supply subsystems that are NOT zoned and NOT subject to setback temperatures. The reason is that zoning and/or setback conditions create variations in the flow rate and temperature of the water returning from the lower-temperature subsystem to the cool port of the mixing valve. A dumb mixing device cannot respond to these variations. If they are present, the outlet temperature of the dumb mixing device could potentially vary over a wide range.

The medium-temperature subsystem in figure 4-11 is zoned using thermostatic valves on each of the panel radiators. This is fine because it is not the subsystem using proportional reset control. The low-temperature floor heating subsystem is using proportional reset control and is not zoned or subject to temperature setback.

In situations where two or more supply water-temperatures are required to subsystems that are all zoned and/or subject to temperature setback, it is better to use an intelligent mixing device on each subsystem. Examples of this approach are given in section 8.

Figure 4-12



Full versus partial reset control:

The ideal reset control strategy would vary the supply water-temperature to the distribution system from its peak design load value all the way down to room temperature. In doing so, it regulates heat output from maximum down to zero. This approach is called "full reset" control. It has been illustrated in many previous figures, such as figure 4-3.

Although full range variation of water-temperature is ideal for the distribution system, it is not ideal for convention boilers that require protection from sustained flue gas condensation. To provide this protection, reset controllers operating conventional boilers should have a minimum supply water-temperature setting. An example of how this "partial reset" control strategy operates is shown in figure 4-12.

The lower portion of the reset line (shown in dashed gray) is not used. In this example, the reset controller limits the target supply water-temperature to no lower than 140°F, regardless of outdoor temperature.

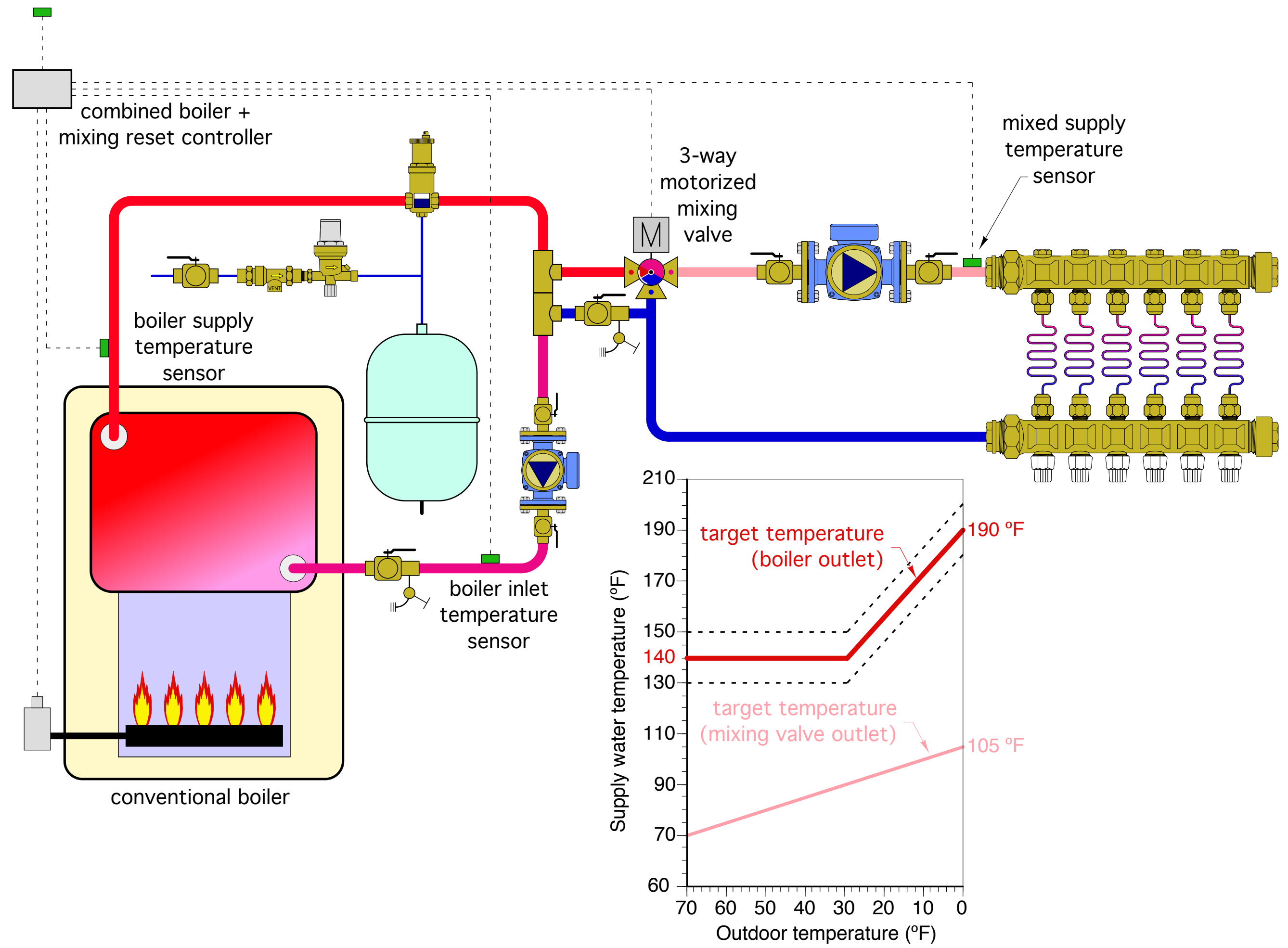
The reset controller associated with figure 4-12 has been set to produce a target temperature of 190°F when the outdoor temperature is 0°F. It has also been configured with a 20°F control differential. The dashed green line shows the supply water-temperature at which the reset controller turns on the heat source. This temperature is 10°F (e.g. one half the 20°F control differential) below the target temperature. Similarly, the red dashed line indicates the supply water-temperature at which the heat source is turned off. It is 10°F above the target temperature. These settings allow the lowest water-temperature entering the boiler, for any sustained period of time, to remain at or above 130°F. That temperature is usually able to prevent sustained flue gas condensation in most boilers.

Partial reset control is a compromise on the ideal objective of reset control — a compromise that's necessary to protect a conventional boiler from sustained flue gas condensation and ensure long life.

Partial reset control is not necessary, nor desirable, for heat sources that are not damaged by condensing flue gases. These include condensing boilers, hydronic heat pumps, electric heating devices or solar thermal systems.

Partial reset control of a conventional boiler can be combined with mixing reset to yield a full range of supply water-temperature to the distribution system. This can be done using two independent reset controllers: One for the boiler and another for the mixing device. It can also be done using a combined reset control to handle

Figure 4-13



both functions. An example of a system using the latter is shown in figure 4-13.

Heat source switching:

Another use of outdoor reset controllers is in selecting the heat source that will supply a space heating load based on the temperature of a preferred heat source. An example of such a heat source is a storage tank in either a solar thermal system or system supplied by a wood-fired boiler. An example of the former is shown in figure 4-14.

Whenever there is a call for space heating, an on/off outdoor reset controller measures outdoor temperature and calculates the minimum temperature at which the water in the storage tank could supply the heating load. It then compares this calculated temperature to the actual temperature near the top of the tank. If the tank is above the minimum temperature, minus half the control differential, the reset controller does not energize the 3-way diverting valve. This allows water from the tank to flow through the diverter valve from port (AB) to port (B), and on to the closely spaced tees where it is handed off to the distribution system.

If the water temperature in the tank is below this value, the reset controller energizes the diverter valve to route flow through the boiler. It also turns on the boiler to supply heat to the system.

The control logic described above is illustrated in figure 4-15.

Notice that a 3-way mixing valve is also installed in the distribution system. Its purpose is to protect the low-temperature distribution system from potentially high-temperature water in the solar storage tank.

Figure 4-14

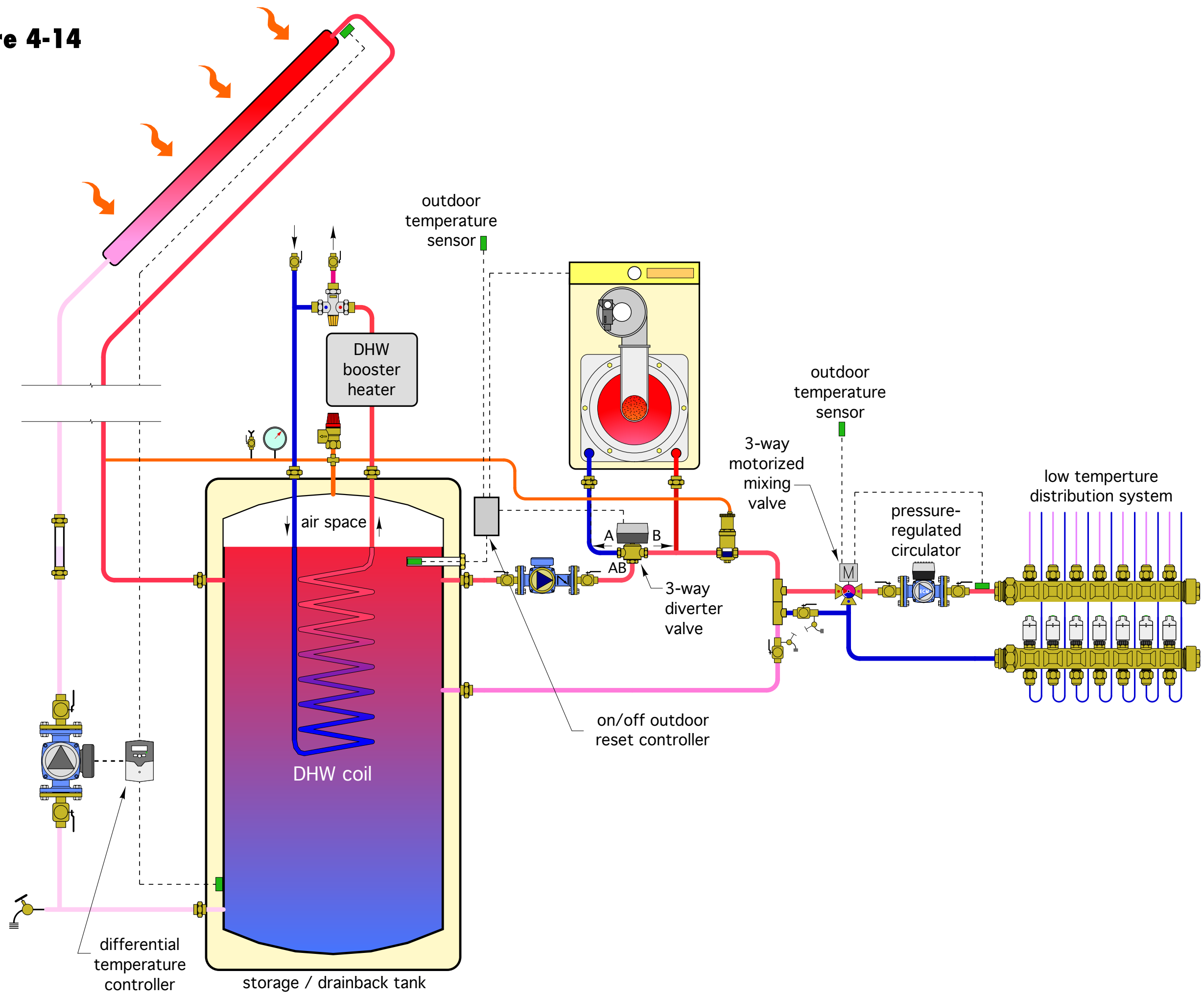
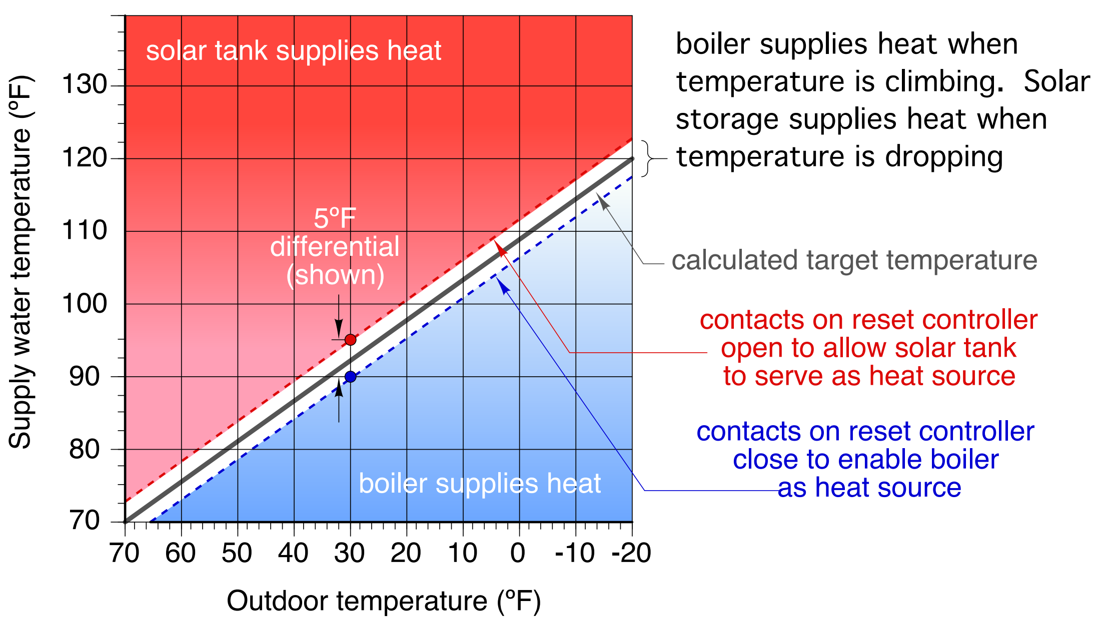


Figure 4-15



5. WHEN IS MIXING REQUIRED?

Not all low-temperature hydronic heating systems require a mixing assembly between their heat source and distribution system. This section discusses several combinations of heat source and heat emitters. For each combination, it lists the essential purposes of mixing, as well as other possible purposes.

Essential purposes are critical to the proper functioning of the system. They are not optional. *Other possible purposes* depend on the application. For example, in some systems it may be desirable to maintain a fixed supply water-temperature to the load whenever that load is operating. In other systems it may be desirable to provide full outdoor reset control of supply water-temperature. Both are possible, often using the same mixing hardware but with different settings.

Any system that uses a single hydronic heat source to supply multiple simultaneous water-temperatures to two or more subsystems will also require one or more mixing assemblies. Section 8 discusses these systems in more detail.

Systems that require mixing assemblies:

The following systems require mixing assemblies for one of more of the stated purposes:

a. Conventional boilers supplying low- & medium-temperature distribution systems

Essential purposes:
- Reduce supply water-temperature to the distribution system (figure 5-1)
- Protect the boiler from sustained flue gas condensation (figure 5-1)

Other possible purposes:
- Provide fixed (setpoint) control of supply water-temperature (figure 5-1)

Figure 5-1

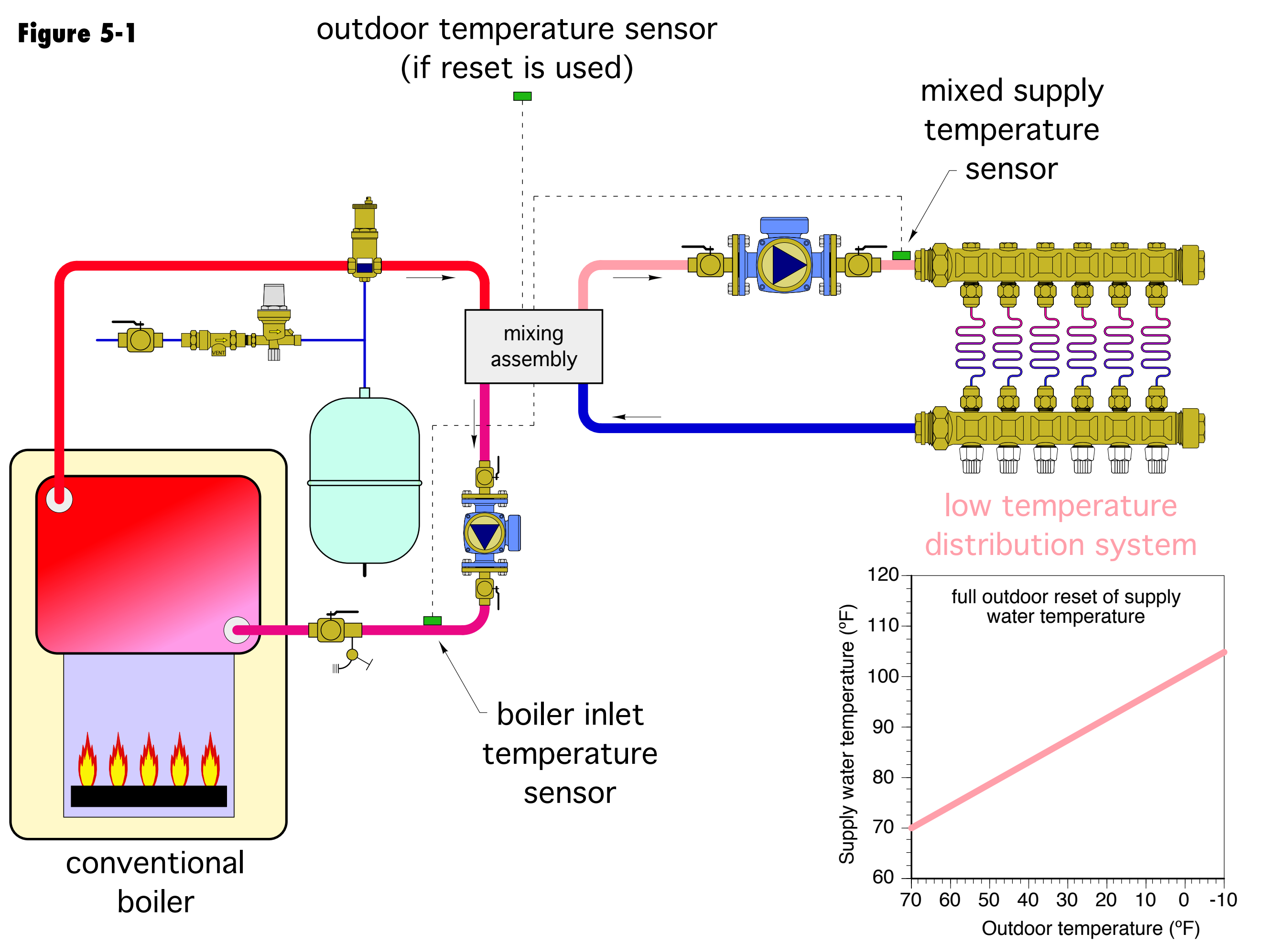
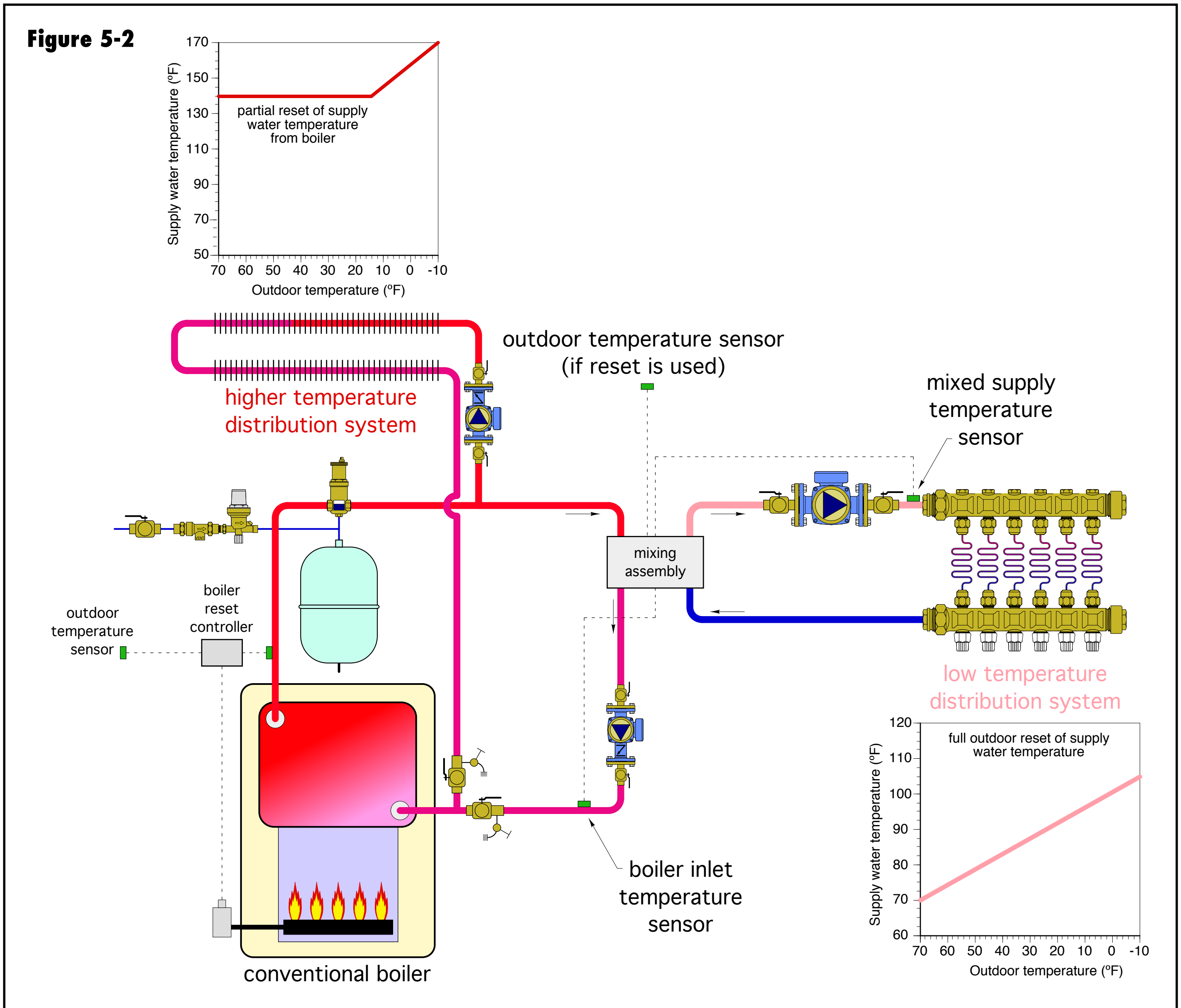


Figure 5-2



- Provide full outdoor reset control of supply water-temperature (figure 5-1)
- Provide multiple simultaneous supply water-temperatures (figure 5-2)

b. Conventional boilers supplying higher-temperature distribution systems

Essential purposes: none

Possible Purposes:

- Provide full outdoor reset of supply water-temperature (figure 5-3)
- Provide multiple simultaneous supply water-temperatures (figure 5-4)

c. Low- and medium-temperature distribution systems supplied from a solar thermal subsystem

Essential purpose:

- Protect distribution system from potentially high-temperatures in the solar collectors or storage tank (figure 5-5)

Other possible purposes:

- Provide fixed (setpoint) control of supply water-temperature (figure 5-5)
- Provide full outdoor reset control of supply water-temperature (figure 5-5)
- Protect conventional boiler against sustained flue gas condensation (figure 5-6)

Figure 5-3

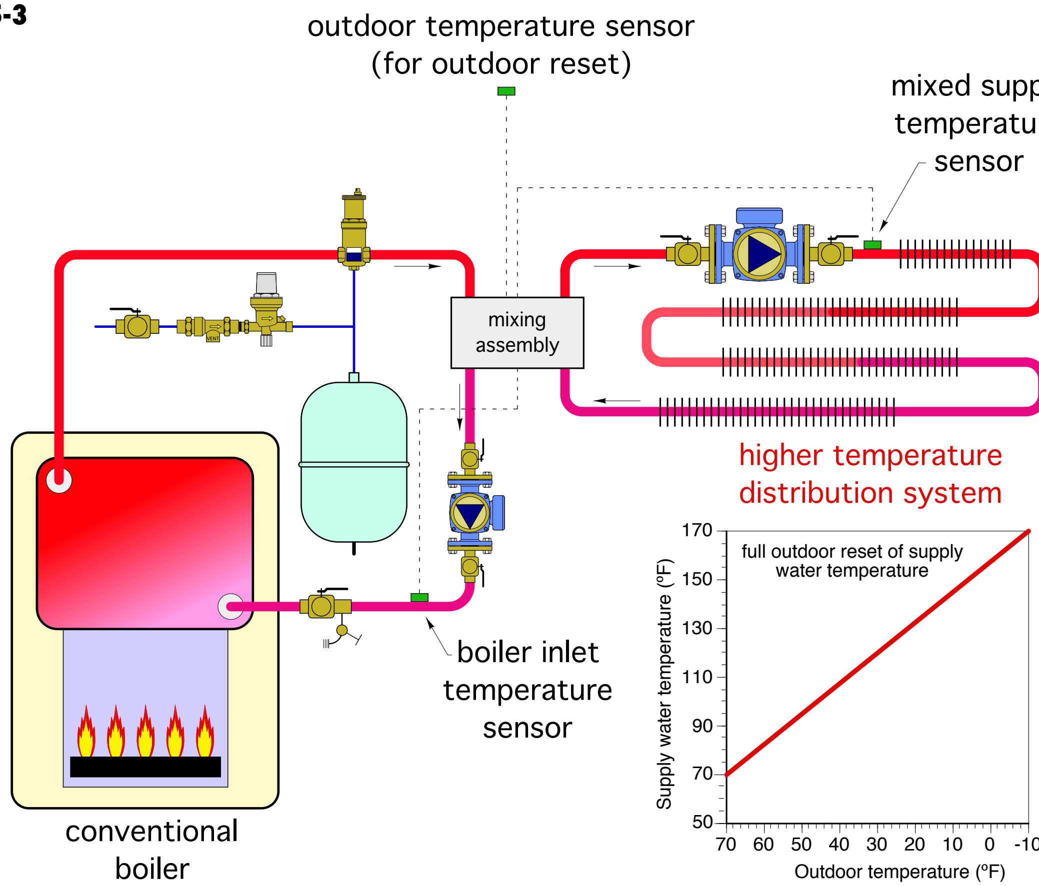


Figure 5-4

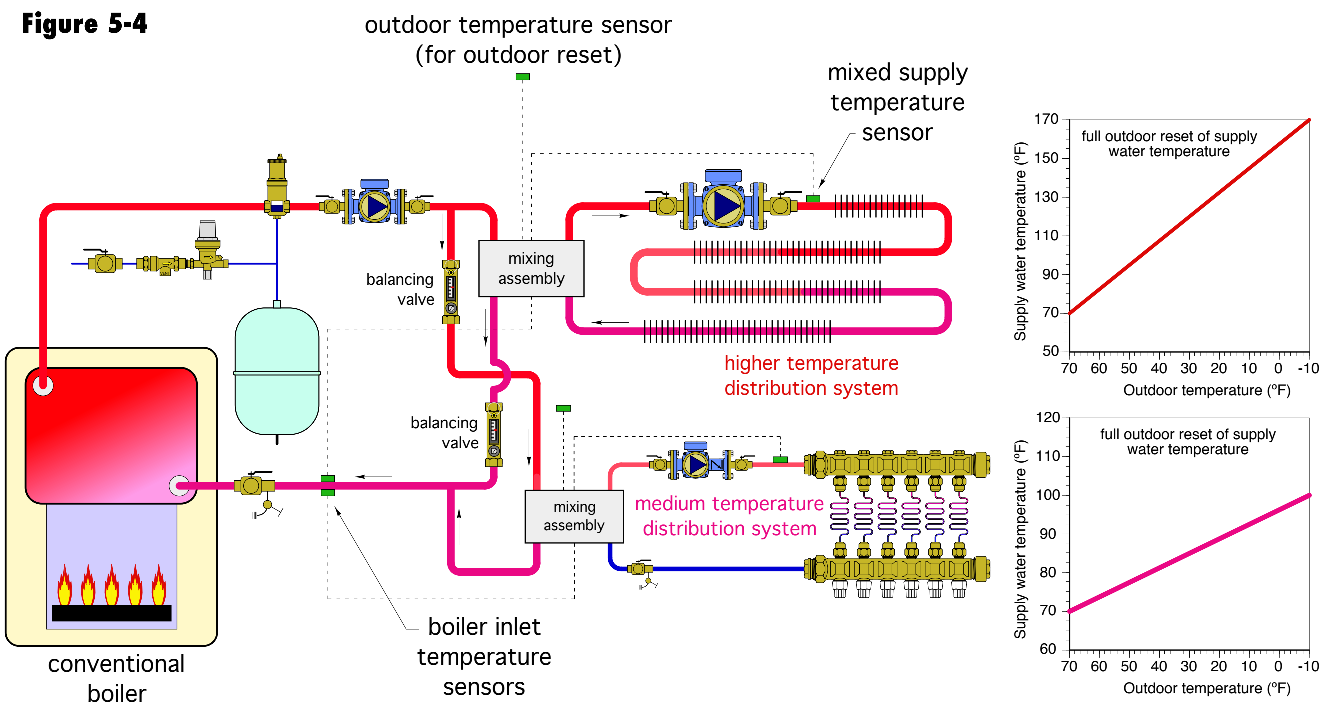


Figure 5-5

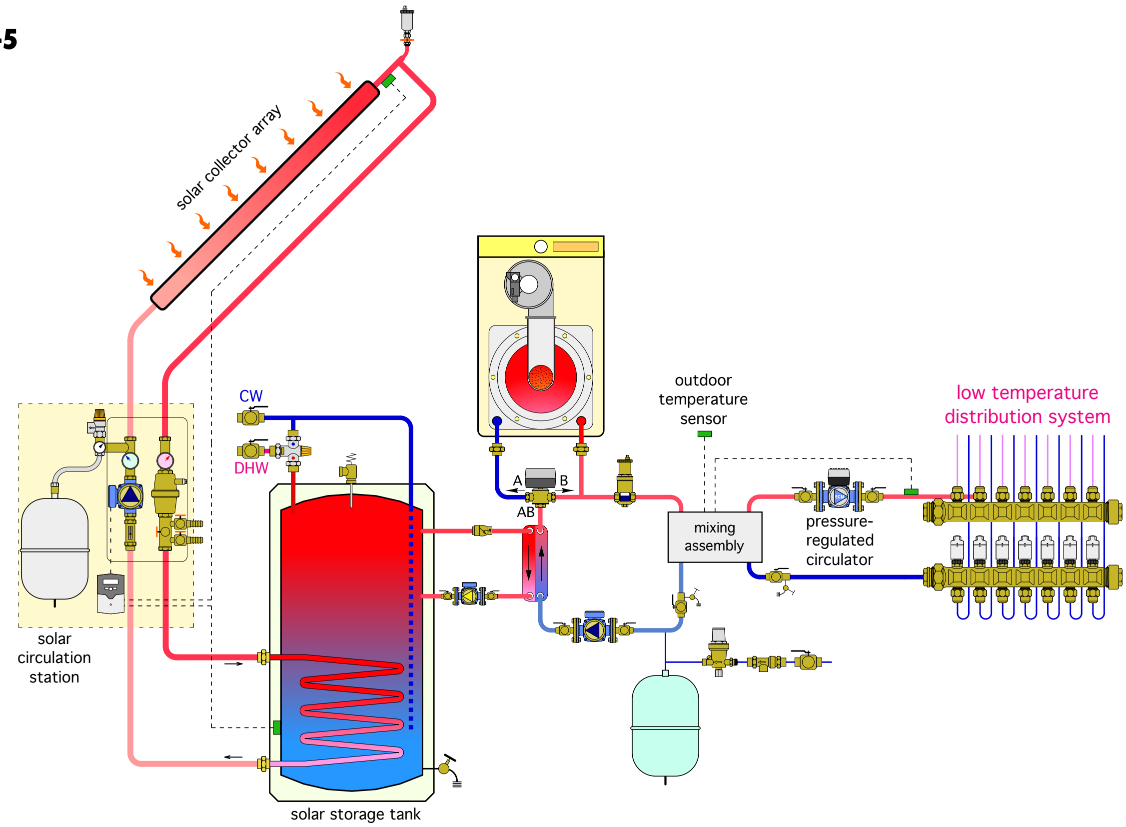


Figure 5-6

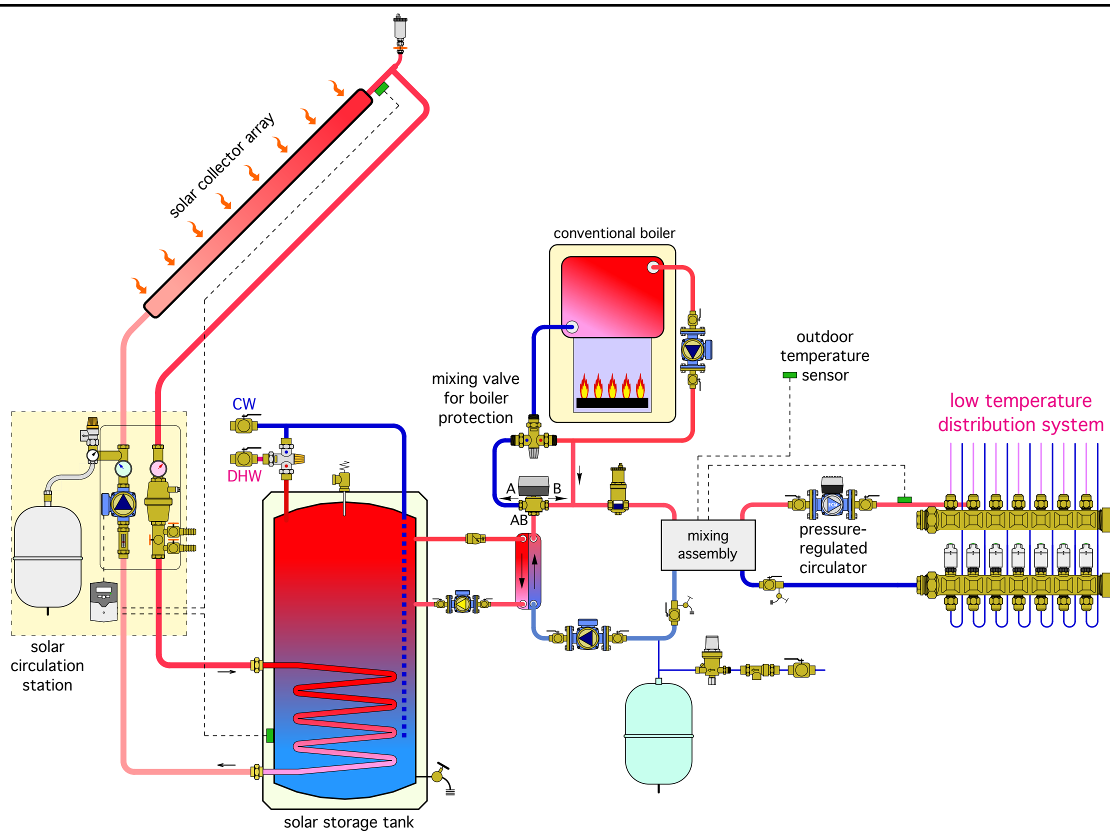
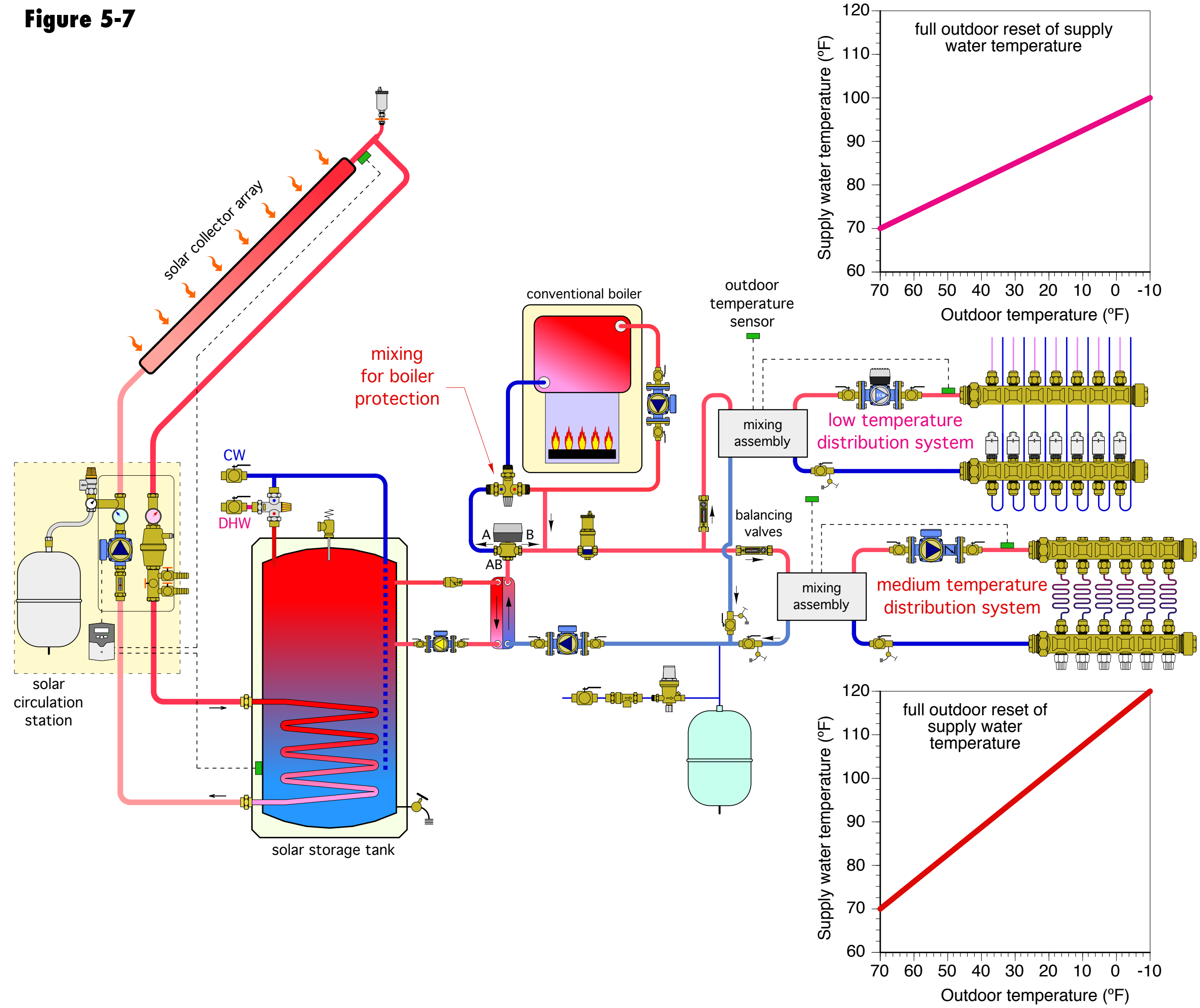


Figure 5-7



• Provide multiple simultaneous supply water-temperatures (figure 5-7)

d. Low- and medium-temperature distribution systems supplied from solid-fuel boilers

Essential purpose:

• Protect distribution system from potentially high-temperatures in the boiler or storage tank (figure 5-8)

Other possible purposes:

• Provide fixed (setpoint) control of supply water-temperature (figure 5-8)

• Provide full outdoor reset control of supply water-temperature (figure 5-8)

• Provide multiple simultaneous supply water-temperatures (figure 5-9)

e. Systems using non-combustion heat sources supplying multiple- temperature distribution systems

Essential purpose:

• Provide multiple simultaneous supply water-temperatures (figure 5-10)

Other possible purposes:

• Provide fixed (setpoint) control of supply water-temperature (figure 5-10)

• Provide full outdoor reset control of supply water-temperature (figure 5-10)

Figure 5-8

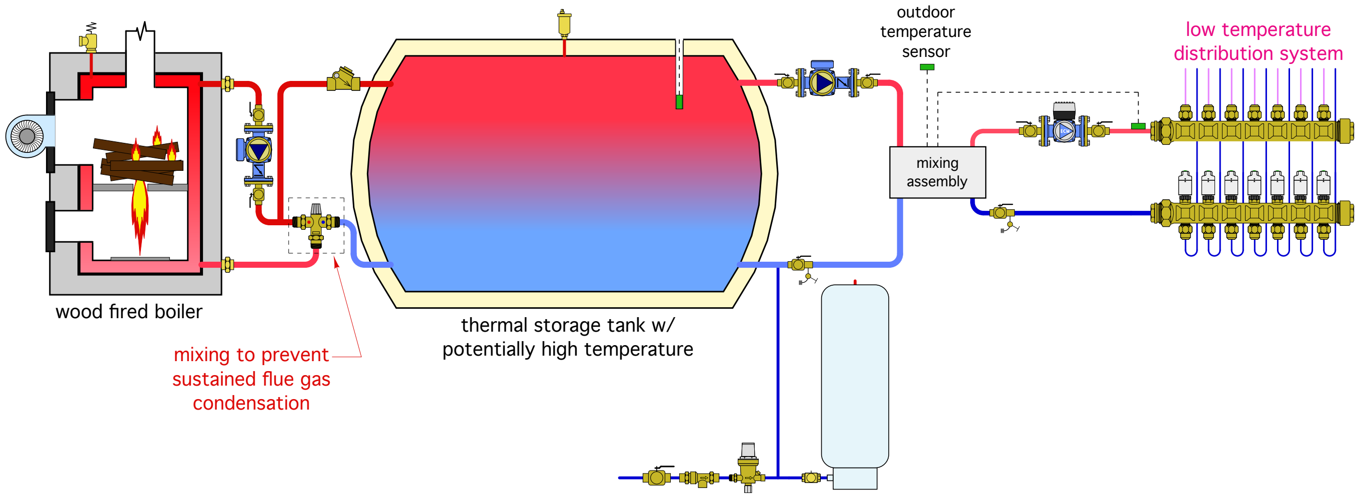


Figure 5-9

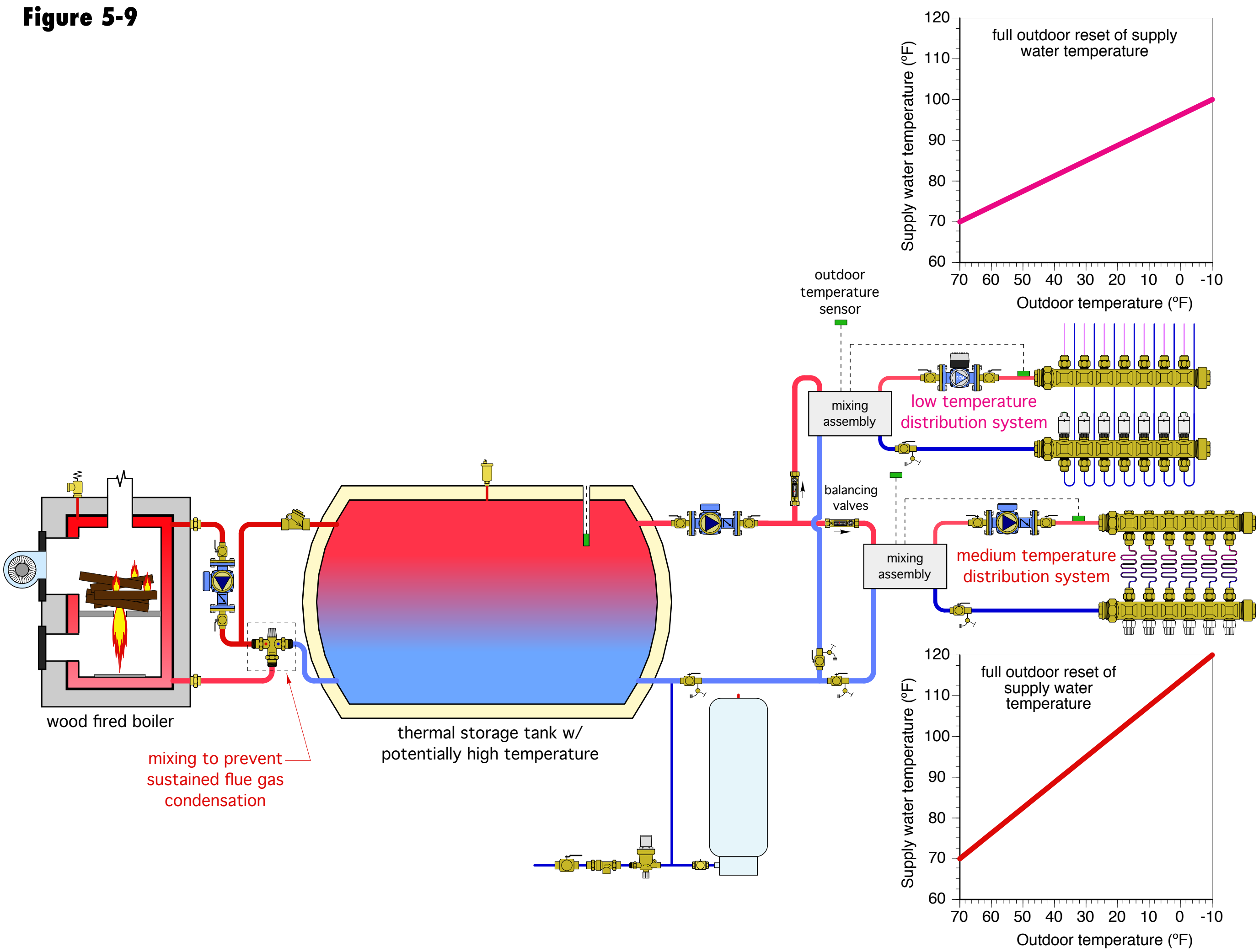
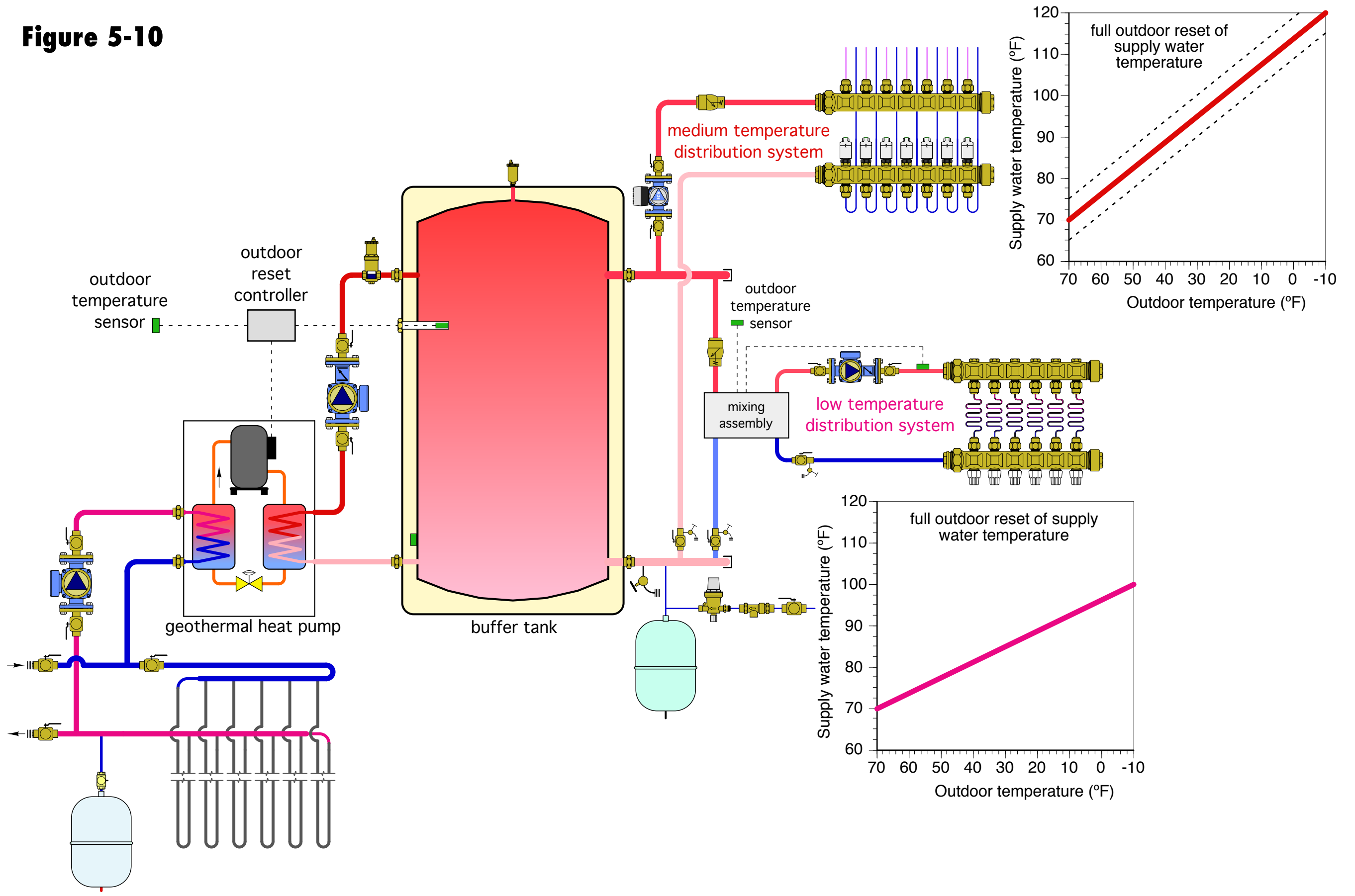


Figure 5-10



f. Systems using non-combustion high-temperature heat sources supplying low-temperature distribution systems

Essential purpose:

- Protect distribution system from potentially high-temperatures in storage tank (figure 5-11)

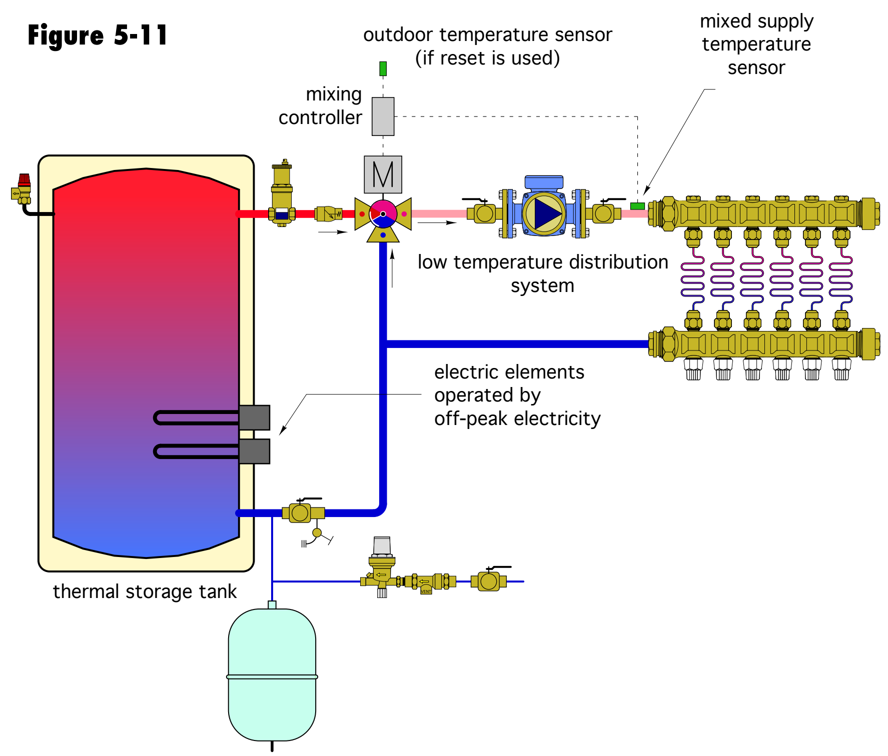
Other possible purposes:

- Provide fixed (setpoint) control of supply water-temperature (figure 5-11)
- Provide full outdoor reset control of supply water-temperature (figure 5-11)

Systems that do not require mixing assemblies:

There are several types of hydronic systems that do not require mixing assemblies. These systems use heat sources that do not require protection against sustained flue gas

Figure 5-11



condensation to supply distribution systems that operate at either at a single setpoint temperature or with a single outdoor reset line. Examples include:

• Electrically heated boilers or water heaters supplying a fixed or fully reset water-temperature to the entire distribution system. If outdoor reset is used, it may be provided by either on/off or modulating control of the electric heat elements in the boiler.

• Electrically operated heat pumps supplying a fixed or fully reset water-temperature to the entire distribution system.

• Modulating/condensing boilers supplying a fixed or fully reset water-temperature to the entire distribution system.

• Conventional boilers supplying a fixed or partially reset water-temperature to a higher-temperature distribution system (with boiler inlet temperatures high enough to prevent sustained flue gas condensation).

For all heat sources other than the modulating boiler, the variation in supply water-temperature required for outdoor reset control is usually accomplished through on/off control of the heat source. Sufficient control differential is needed to prevent short cycling.

Modulating/condensing boilers typically have their own internal reset controllers that modulate burner capacity as necessary to achieve the proper supply water-temperature.

6. MIXING WITH 3-WAY & 4-WAY VALVES

One of the most widely used hardware options for mixing is a 3-way or 4-way mixing valve. Both are introduced and compared in this section.

3-way mixing valves:

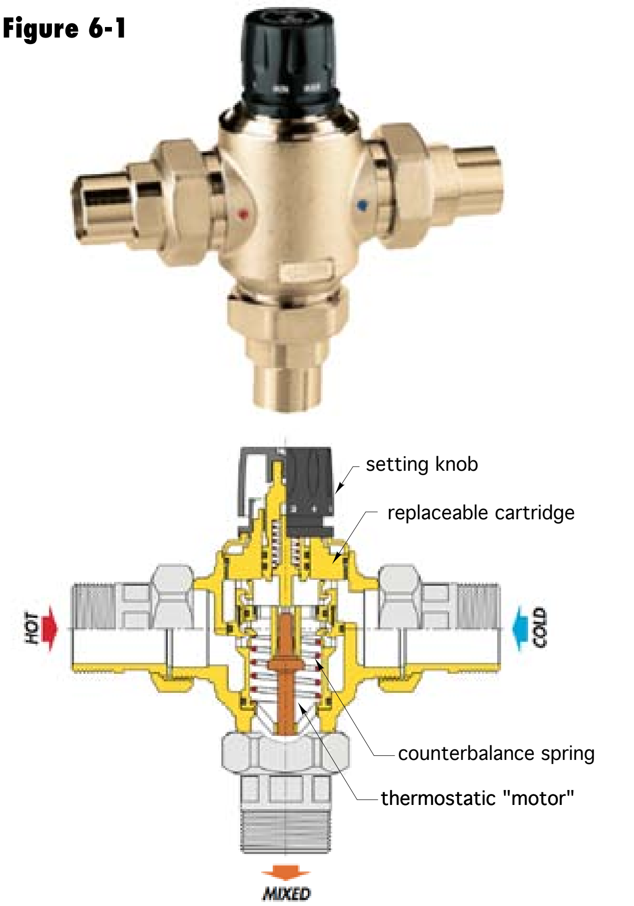
All 3-way mixing valves have two inlet ports, one for hot fluid and the other for cool fluid, and a single outlet port for the mixed fluid. 3-way mixing valves differ in their design, depending on the type of actuator used to operate the valve.

3-way thermostatic mixing valves:

An example and cut-away section of a 3-way thermostatically operated valve is shown in figure 6-1.

The knob on the valve sets the desired mixed water-temperature.

Figure 6-1



The thermostatic motor inside the valve contains a specially formulated wax compound. As the wax warms, it expands, and vice versa. The force generated by the expanding wax is counterbalanced by an internal spring. The expansion and contraction of the thermostatic motor moves the double-seated piston, which controls the openings allowing hot and cool fluid into the valve. If the mixed fluid temperature flowing across the thermostatic motor decreases below the valves setting, the valve's hot port begins to open as its cold port simultaneously closes. If the mixed fluid temperature flowing across the thermostatic motor rises, the hot port begins to close as the cool port opens. Thus the valve constantly monitors and responds to the fluid temperature leaving its mixed port. High-quality thermostatic mixing valves can respond to temperature changes within a few seconds.

When selecting a 3-way thermostatic valve for a hydronic mixing application, it is important to consider its flow resistance. The head loss across the valve at a given flow rate can be calculated by knowing the valve's flow coefficient (also known as its Cv). The relationship between head loss, flow rate and valve Cv is given by formula 6-1:

Formula 6-1

$$H_{loss} = \left(\frac{2.308}{C_v^{\,2}}\right) f^2$$

Where:
H_{loss} = head loss across valve (ft)
Cv = flow coefficient of valve
f = flow rate through mixed port of valve (gpm)

For example, the head loss experienced across a 3-way thermostatic valve with a Cv of 3.5, while passing 6 gpm through its mixed port would be:

$$H_{loss} = \left(\frac{2.308}{C_v^{\,2}}\right) f^2 = \left(\frac{2.308}{3.5^2}\right) 6^2 = 6.8\,ft$$

This head loss is equivalent to about 98 ft of 3/4-inch type M copper tubing operating at the same 6 gpm flow rate, or 343 feet of 1-inch type M copper tubing operating at 6 gpm. This is a relatively high head loss that could significantly reduce flow through the distribution system.

A guideline in selecting 3-way thermostatic valves is to match the Cv of the valve with the full-load flow rate through the valve (e.g., with all downstream zones operating). This guideline will result in a nominal 1 psi pressure drop and a nominal 2.3-foot head loss across the valve. Some 3-way thermostatic valves also have minimum and maximum mixed flow rate requirements for thermal stability. Caleffi recommends the following flow rate ranges for its 3-way thermostatic valves:

Figure 6-2

	Min. (gpm)	Max. (gpm)
3/4" - 1" (523066A)	2	24
1" 523060A - 523068A - 1 1/4"	4.5	40
1 1/2" - 2"	13	83

Piping for 3-way thermostatic mixing valves:

The piping configuration used for 3-way thermostatic mixing valves depends on the heat source used. If that heat source requires protection from sustained flue gas condensation, it is necessary to install two 3-way valves, as shown in figure 6-3.

Assume the upper valve in figure 6-3 is set for 130ºF, and the lower valve is set for 105ºF. When the boiler is first fired, the water-temperature leaving the boiler is much

Figure 6-3

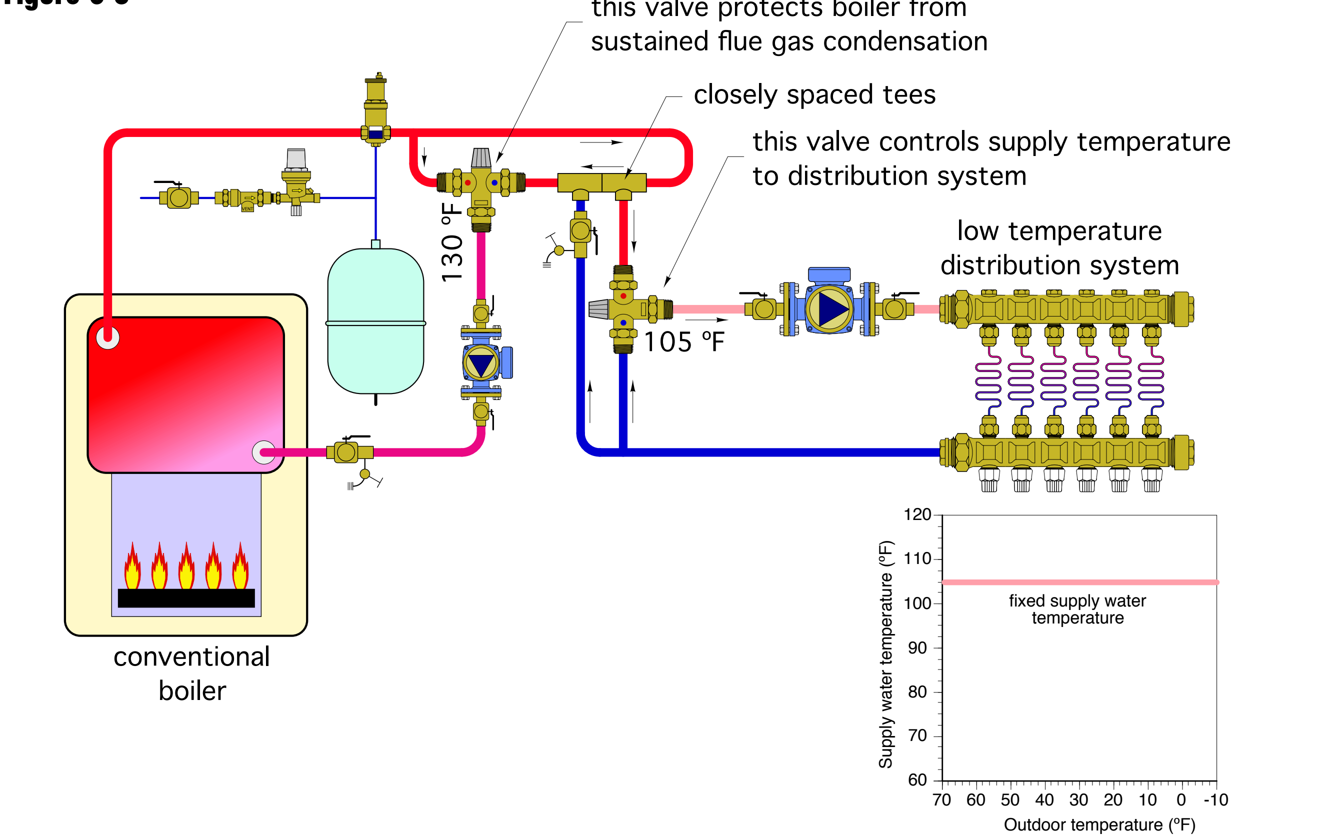
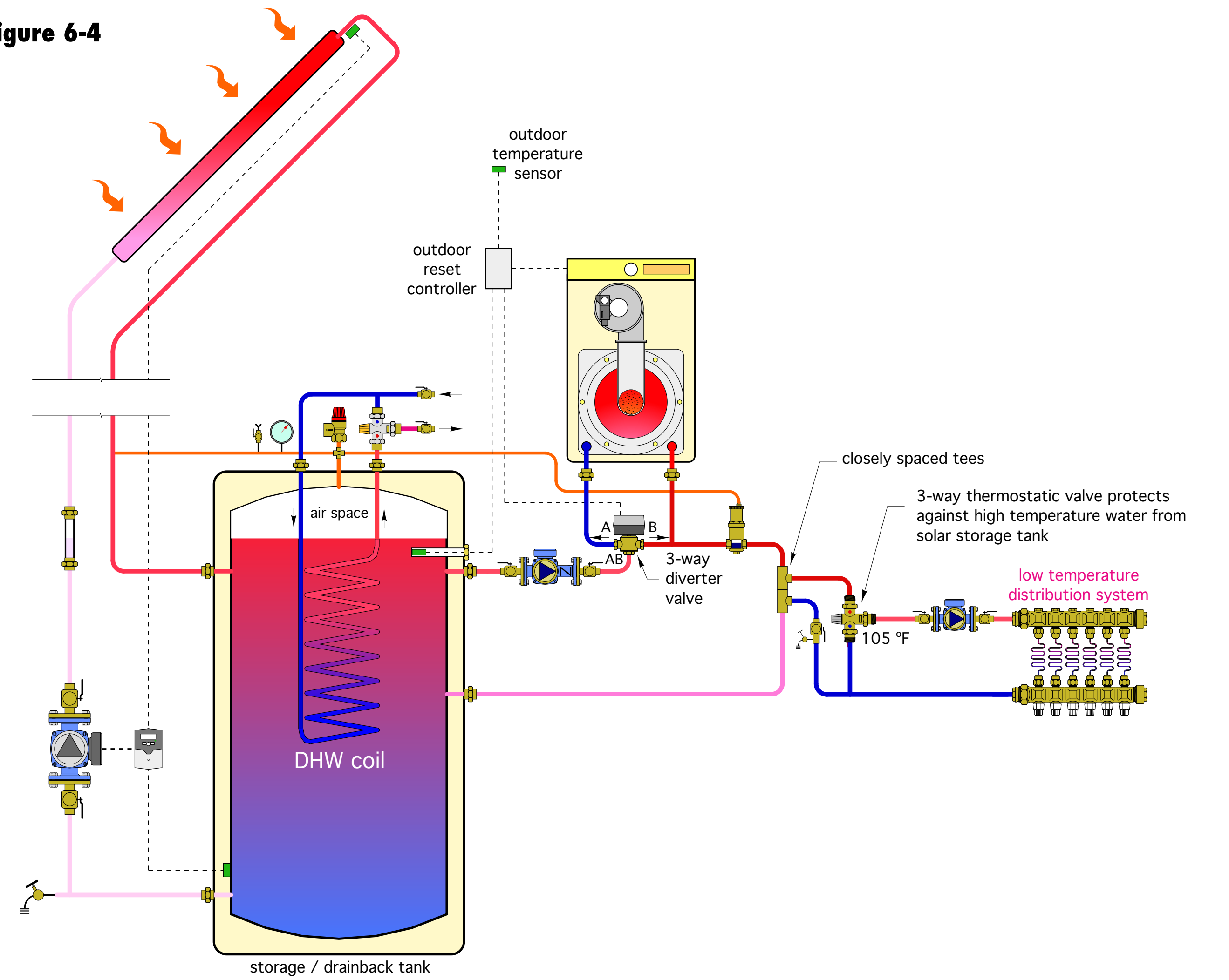


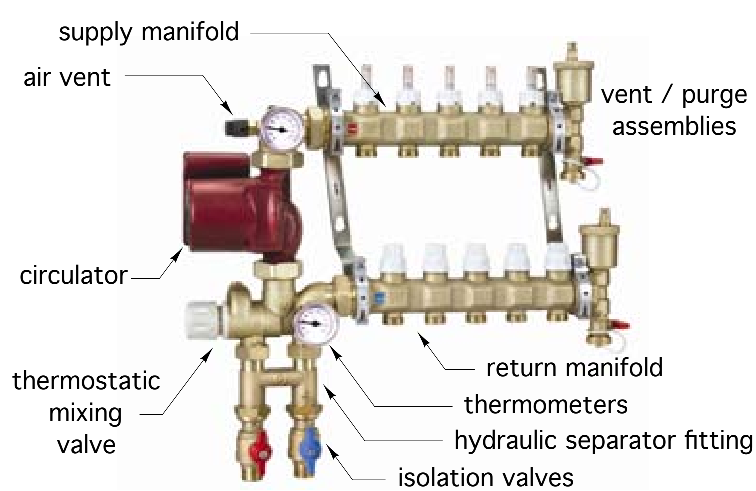
Figure 6-4



lower than 130ºF. Under this condition, the hot port of the upper 3-way valve is fully open while its cold port is fully closed. This routes all water coming from the boiler back to the boiler's inlet. None of this water is "released" to the remainder of the distribution system.

The lower thermostatic valve also has its hot port fully open, and its cold port fully closed when the system first turns on. All flow returning from the manifold station is routed to the left side of the closely spaced tees. Since no flow is entering the right-side tee, the cool water entering the left tee makes a "U-turn" and heads back to the hot port of the lower mixing valve. From there it passes out to the distribution systems, albeit without picking up any heat for the time being.

Figure 6-5



Because no heat is being released to the load, the boiler is now warming up as fast as possible. Once the temperature of the water leaving the upper mixing valve reaches 130ºF it begins opening its cold port and closing its hot port in an attempt to keep the mixed water-temperature close to 130ºF. Heated water can now pass around the upper right side of the schematic, enter the right side of the closely spaced tees and pass down to the hot port of the lower 3-way valve. The lower valve will adjust itself as necessary to maintain a 105ºF supply temperature to the manifold station.

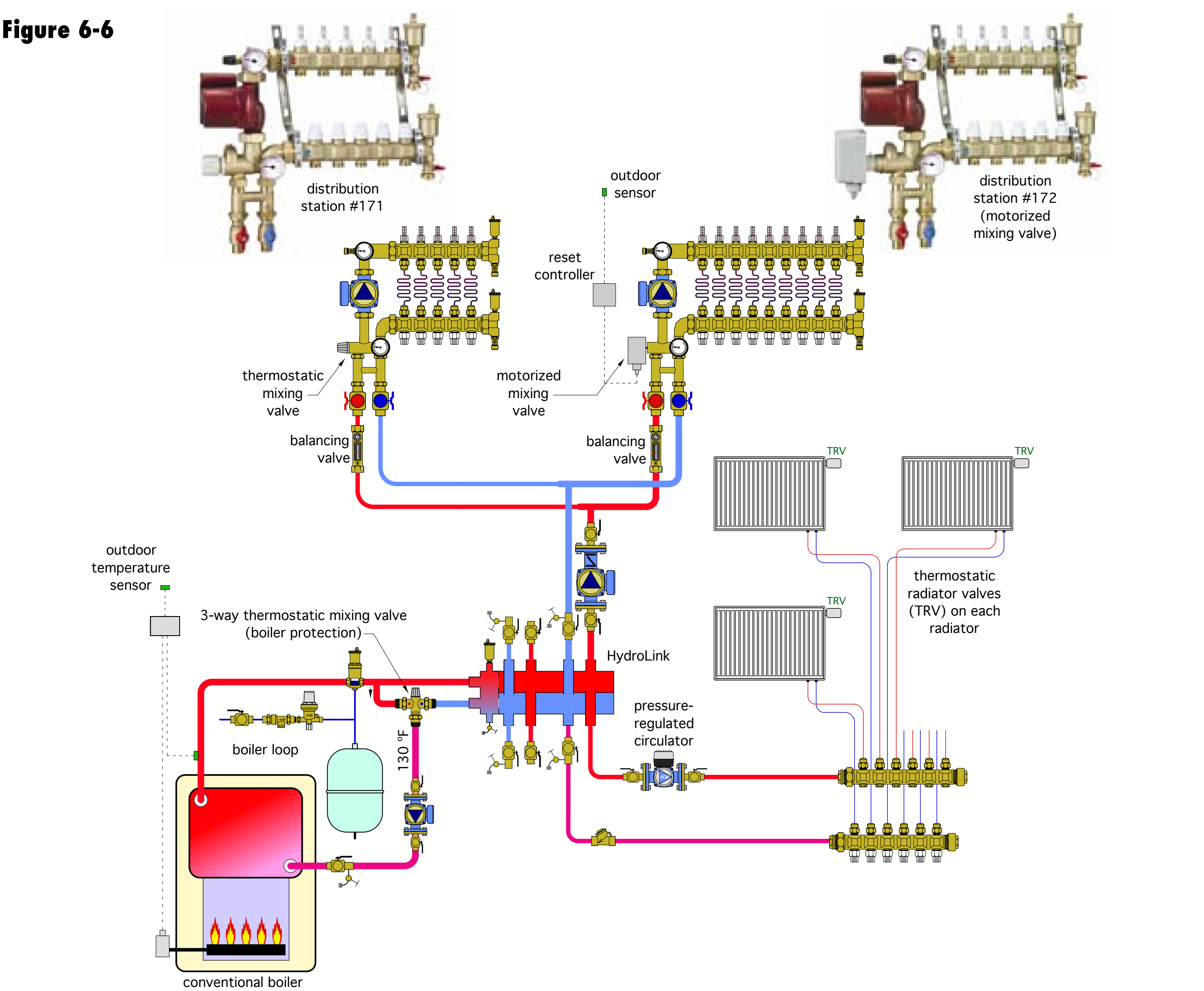
The combination of two valves prioritizes protection against sustained flue gas condensation and then provides stable supply water-temperature to the distribution system.

The graph in figure 6-3 emphasizes that this configuration of 3-way thermostatic mixing valves provides a fixed supply water-temperature. Automatic outdoor reset control is not possible with 3-way thermostatic valves.

When the heat source(s) in the system do not require protection against sustained flue gas condensation, a single 3-way thermostatic valve can be used to provide regulation of supply water-temperature. An example of such an application is shown in figure 6-4.

The function of the 3-way thermostatic valve is to protect the distribution system against potential high-temperature water in the solar storage tank. In this system it is assumed set at 105ºF, which is the supply temperature requirement of the low-temperature distribution system at design load. Whenever water from the solar storage tank exceeds this temperature, the valve mixes in a portion of the cooler water returning from the manifold station to

Figure 6-6



maintain supply temperature close to 105ºF. Since the tank also supplies domestic hot water, the temperature in its upper portion will typically be 120ºF or above.

Distribution stations using 3-way thermostatic valves:

The combination of a 3-way thermostatic mixing valve, circulator and manifold station is an often-used piping assembly. Caleffi has combined these components, along with a means of hydraulic separation, into a pre-engineered mixing station as seen in figure 6-5.

This distribution station reduces installation time and space requirements. Its integral thermostatic (or motorized) mixing valve reduces incoming water-temperature to that required by the manifold circuits. The distribution station also provides hardware for venting and purging, and indication of both supply and return temperatures.

Figure 6-6 shows how two of these distribution stations could be supplied from a single connection on a HydroLink assembly.

Each distribution station can be set up with different numbers of circuits, and each can operate at a different supply temperature. Any combination of thermostatic or motorized mixing can be used. The boiler must supply water at or above the highest of these supply temperatures. In this system, a separate 3-way thermostatic valve is installed to protect the boiler from sustained flue gas condensation.

3-way motorized mixing valves:

3-way mixing valves can also be combined with motorized actuators that are operated by electronic controllers. The types of 3-way valve bodies used for motorized operation are different from those used for thermostatic operation. Rotary valve bodies are commonly used for motorized 3-way valves. This is in contrast to the linear shaft movement used in most thermostatically controlled 3-way mixing valves.

A typical 3-way rotary valve is shown in figure 6-7a. The knob allows for manual adjustment. This knob is removed if a motorized actuator is attached to the valve. The motorized actuator mounts to the four threaded eyelets seen on the periphery of the valve body.

The rotating spool within the valve is a segmented cylinder. Its angular position within the body determines how much hot versus cool water enters the valve. Clockwise rotation increases cool water entry while simultaneously decreasing hot water entry and vice versa. The two flow streams come together within the valve. Turbulence within the valve creates relatively good mixing. Still, depending on temperatures, flow rates, and spool position, mixing may not be 100 percent complete as flow exits the valve. For this reason, it's good practice to place any temperature sensors that measure mixed water-temperature well downstream of the mixing valve outlet. Ideally, these sensors would be located downstream of the circulator that supplies the distribution system.

Figure 6-7a

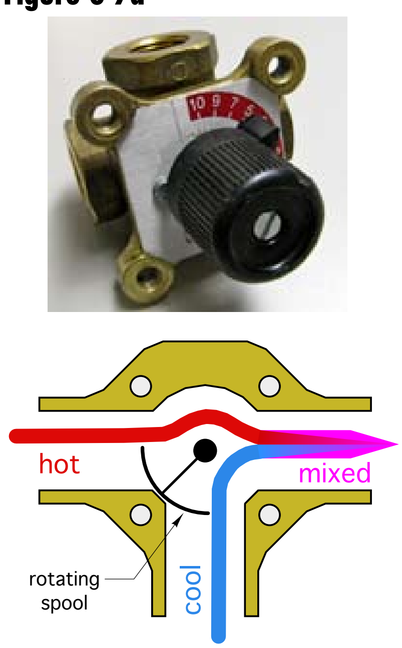


Figure 6-7b

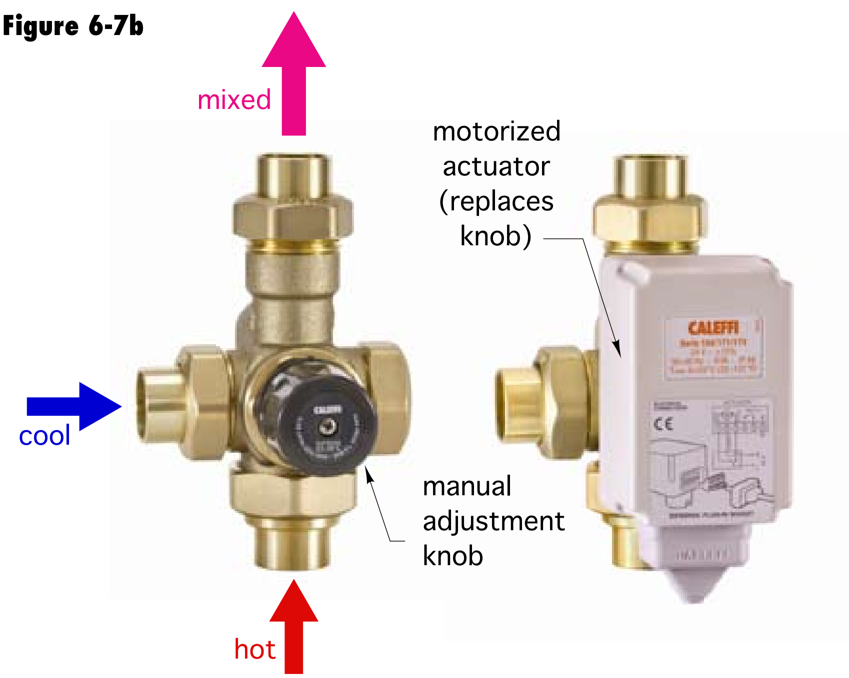


Figure 6-8

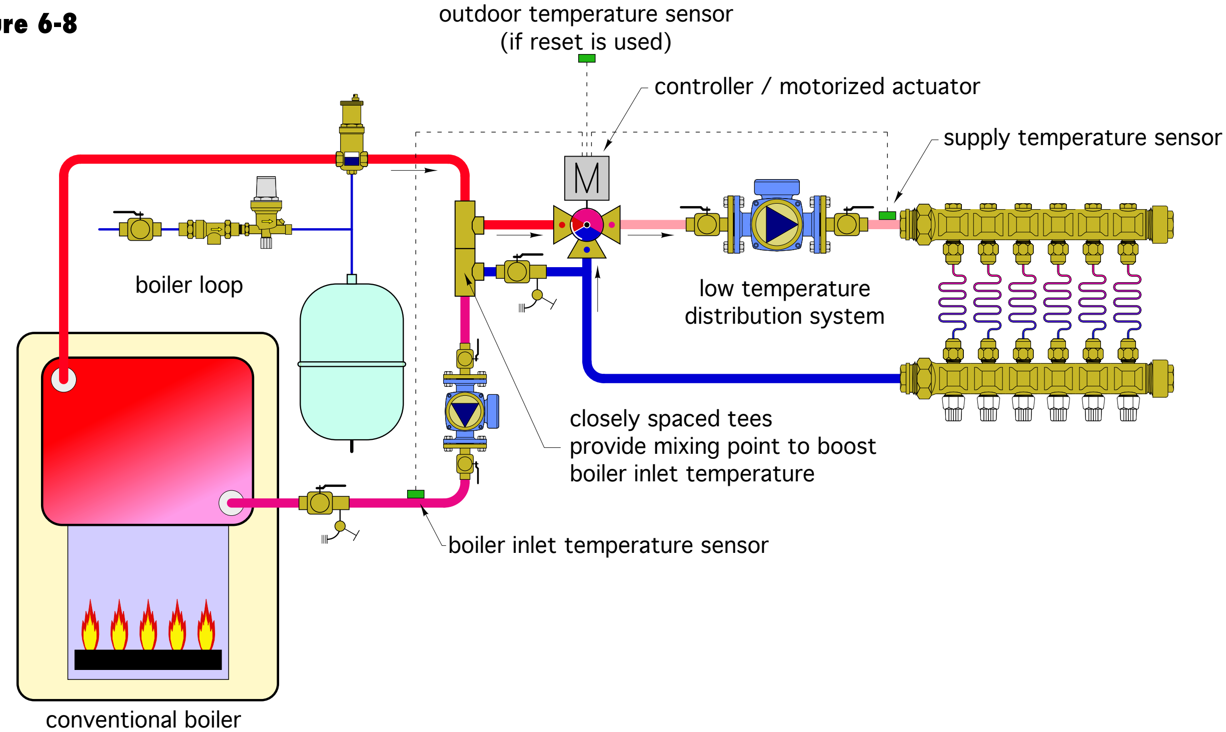
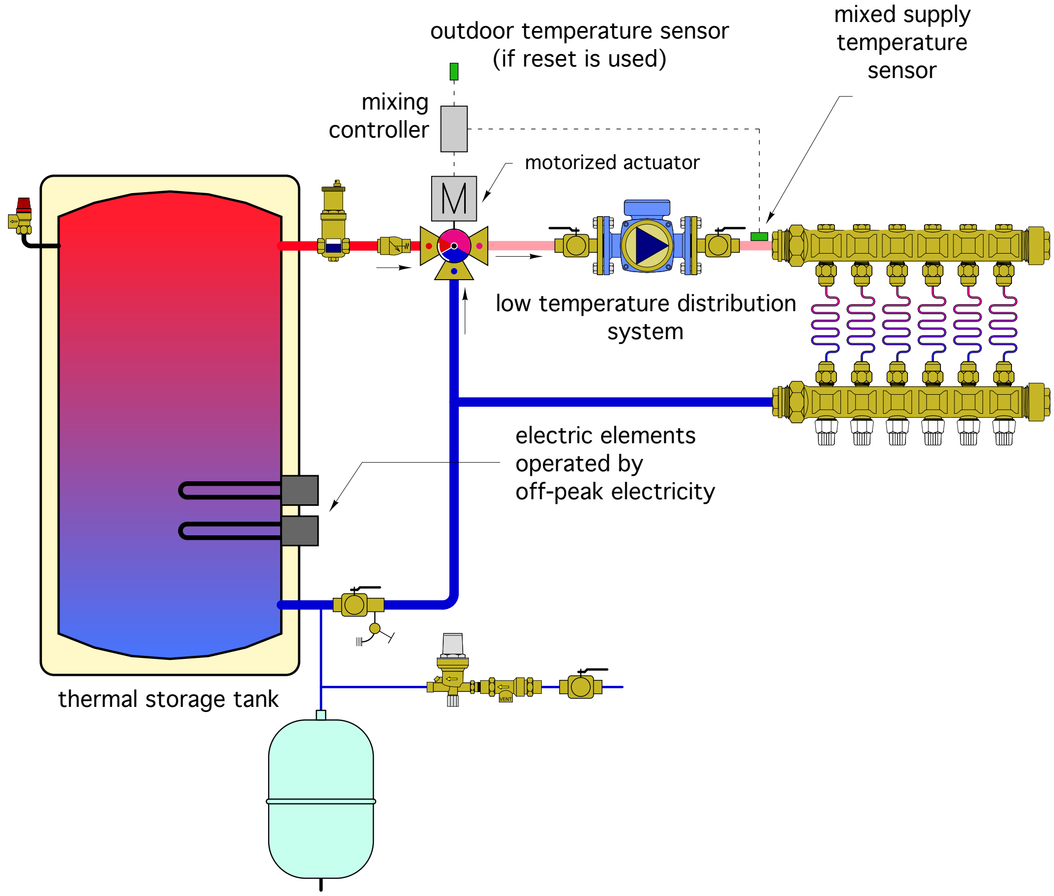


Figure 6-9



An example of a Caleffi 3-way mixing valve with motorized actuator is shown in figure 6-7b. The motorized actuator fastens to the valve body. The actuator's shaft is coupled to the valve's shaft. The gear motor assembly inside the actuator provides very slow rotation of the valve's shaft. Slow rotation prevents rapid temperature changes, and improves control stability. A typical motorized actuator can require two to three minutes to rotate the valve's shaft through 90 degrees.

Piping for 3-way motorized mixing valves:

Typical piping for a 3-way motorized valve is shown in figure 6-8.

Most modern mixing controllers that operate motorized valves are equipped with a sensor to measure boiler inlet temperature. The controller can then respond to this temperature by automatically reducing hot water flow into the mixing valve when boiler temperature is at or below a user-selected minimum temperature that prevents sustained flow gas condensation. This feature allows a single 3-way motorized mixing valve to protect the boiler and regulate supply water-temperature. Most mixing valve controllers also have the option of providing either a fixed setpoint or full outdoor reset of the water-temperature supplied to the distribution system.

The boiler loop shown in figure 6-8 is essential for creating a second mixing point (within the lower of the two closely spaced tees). The mixing point boosts boiler inlet temperature as necessary to prevent sustained flue gas condensation within the boiler.

3-way motorized mixing valves can also be used with heat sources that don't require protection from flue gas condensation. In such cases, it is not necessary to install a boiler return sensor or create a second mixing point. An example would be a system the uses off-peak electricity to heat a storage tank, as shown in figure 6-9.

4-way motorized mixing valves:

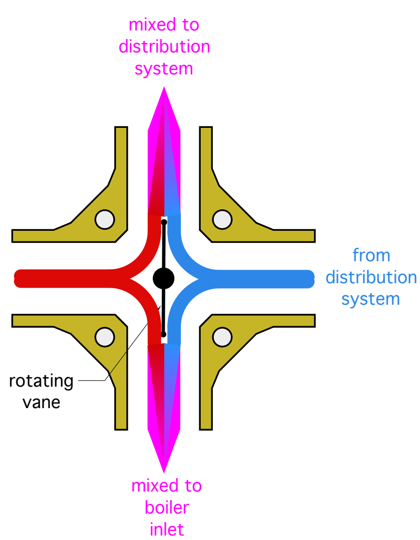
4-way mixing valves have the advantage of creating two mixing points within the same valve body, one for supply temperature control, and the other for boiler protection. These valves were specifically designed to pair low flow resistance conventional boilers with low-temperature distribution systems. In such applications the boiler loop circulator can be eliminated. This circulator was required to provide the second mixing point needed for boiler protection in all previous schematics using 3-way mixing valves.

Figure 6-10 shows a 4-way motorized mixing valve with the actuating motor mounted. As with 3-way motorized mixing valves, the geared motor assembly inside the actuator provides very slow rotation of the valve's shaft with significant torque. A typical motorized actuator requires about 3 minutes to rotate the valve's shaft through its 90-degree rotational range.

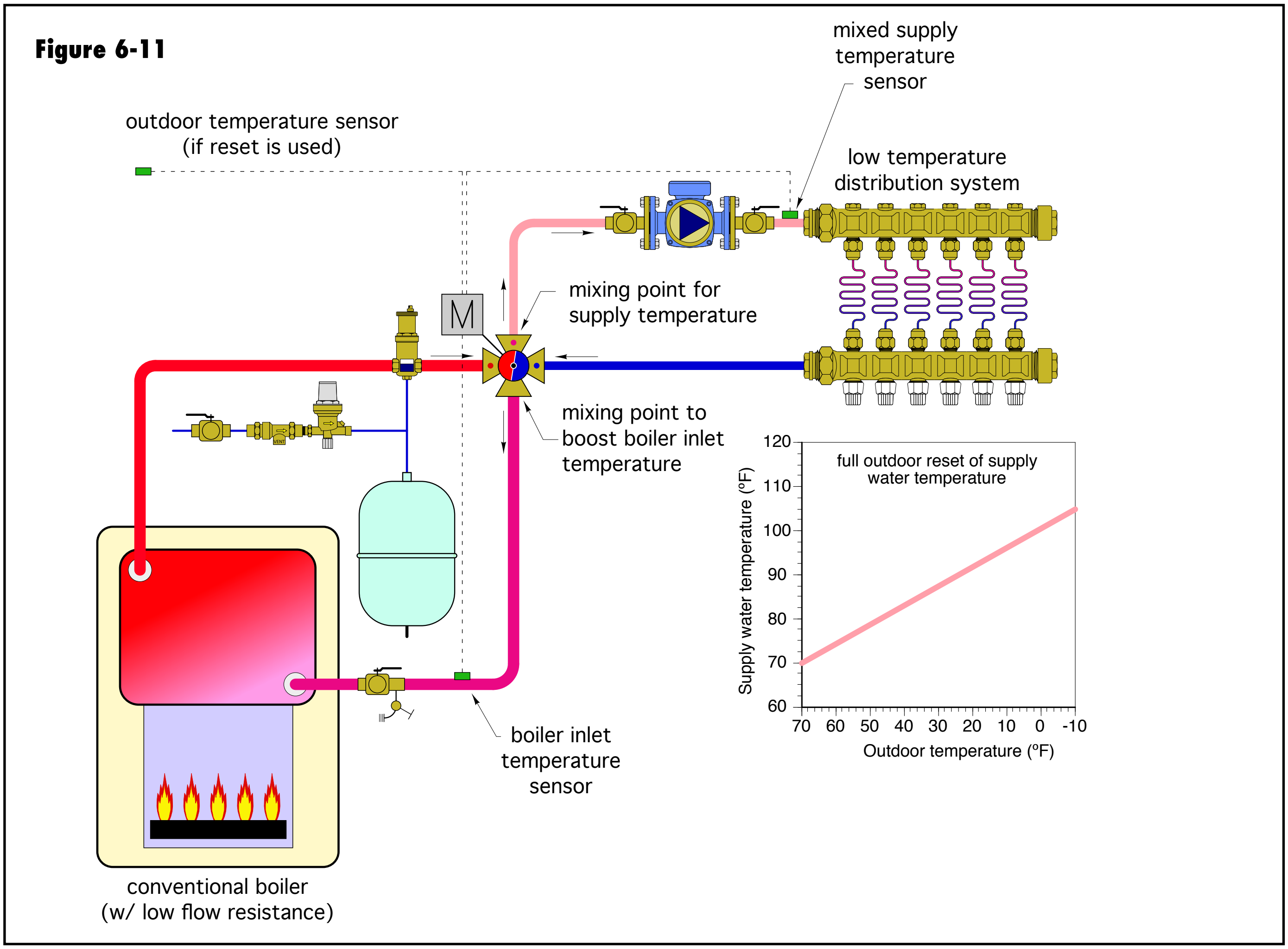
Piping for 4-way motorized mixing valves:

The preferred piping for a 4-way motorized mixing valve depends on the heat source used in the system. Figure 6-11 shows the preferred piping method when the 4-way valve is used with a low flow resistance conventional boiler.

Figure 6-10



The piping circuit through the boiler should be kept relatively short and generously sized. This, in combination with the low flow resistance of the boiler, allows the 4-way valve to move flow through the boiler circuit using the momentum of water returning from the distribution system. This eliminates the need for a circulator on the boiler side of the mixing valve. Installation cost, and more importantly, *operating cost* of the system is reduced relative to systems using the same type of heat source and a 3-way motorized mixing valve.



The mixing valve controller and actuator operate the same as with a 3-way motorized valve. The controller continually senses boiler inlet temperature and regulates flow of hot water into the mixing valve as necessary to maintain the boiler free of sustained flue gas condensation.

A 4-way motorized mixing valve can also provide full outdoor reset control of the supply water-temperature to the distribution system.

In systems where a 4-way motorized valve is coupled with a high flow resistance boiler, or where the boiler piping circuit creates significant head loss, a boiler loop circulator should be added, as shown in figure 6-12. In such situations, there is no advantage in using a 4-way versus a 3-way mixing valve.

Sizing 4-way mixing valves:

The head loss through 4-way mixing valves should be kept in the range of 0.7 to about 2.5 feet when the valve is passing full design flow to the distribution system. Formula 6-1 can be used to determined the head loss through the valve based on its Cv rating and the system's design flow rate.

$$H_{loss} = \left(\frac{2.308}{C_v^{\ 2}} \right) f^2$$

Where:
Hloss = head loss across valve (ft)
Cv = flow coefficient of valve
f = flow rate through mixed port of valve (gpm)

Summary of mixing with 3-way and 4-way valves:

Figure 6-13 summarizes the approaches to mixing with 3-way and 4-way valves. The details of each mixing assembly are shown, along with the piping connections A, B, C and D, that allow each assembly to fit the generic piping layout of a boiler loop connected to a distribution system with the mixing assembly as the bridge.

Figure 6-12

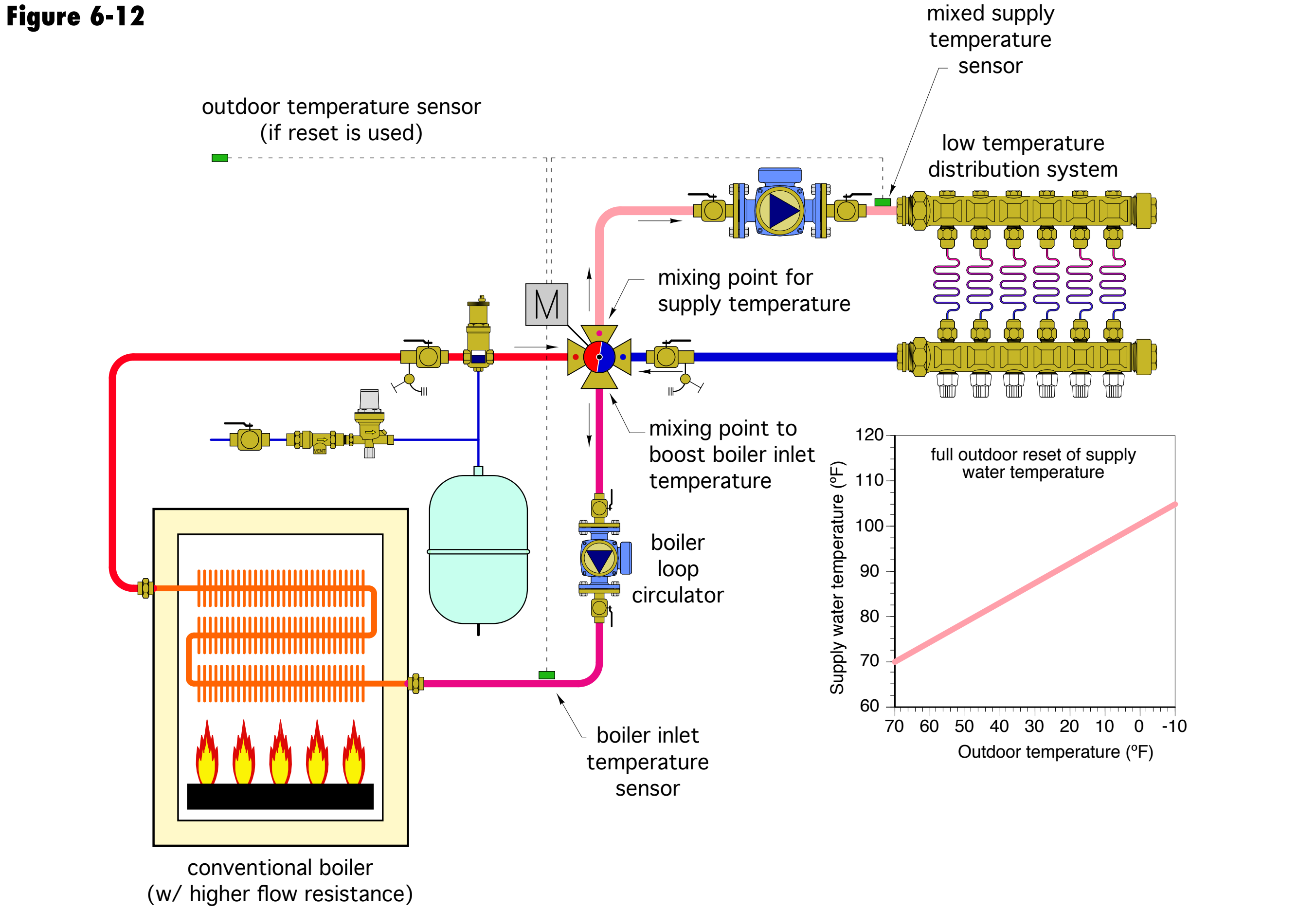
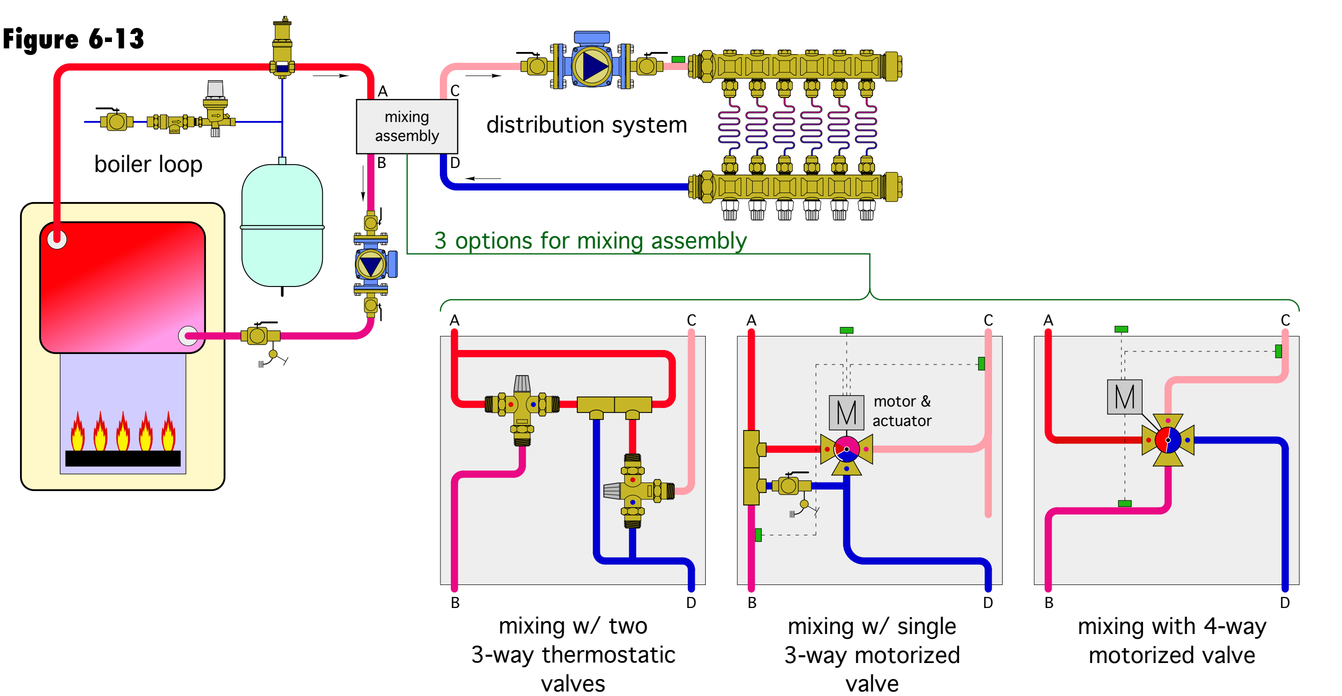


Figure 6-13



7. INJECTION MIXING

As discussed in section 3, mixing doesn't have to take place within a valve. It can also take place in a tee, a tank or other device in which a hot and cool fluid stream come together.

The term injection mixing applies to any assembly in which heated water is pushed into a tee within a circulating distribution system. An equal amount of cool water simultaneously exits through another tee. The concept is shown in figure 7-1.

Hot water flows down the riser to the side port of the downstream tee and begins blending with cool water passing through the run of the tees. Because the distribution system is completely filled, cooler water must exit at the same rate hot water is injected. *The greater the rate of hot water injection, the warmer the mixed supply temperature, and the greater the heat output of the distribution system.* This concept applies to all forms of injection mixing, regardless of the hardware used to implement it.

Due to stratification effects and significant differences in flow rates, the mixing process may not be complete as flow exits the downstream tee. This undesirable effect is illustrated in figure 7-2.

A temperature sensor placed near the outlet of the right-side tee will not detect the final blended temperature supplied to the distribution system. This can cause erratic operation of the mixing controller. To avoid this situation, place the supply temperature sensor downstream of the distribution circulator, as shown in figure 7-1. In a multiple circulator system, place the sensor downstream of at least one 90-degree elbow. This fitting will induce turbulence that helps finalize blending prior to flow passing across the supply temperature sensor location.

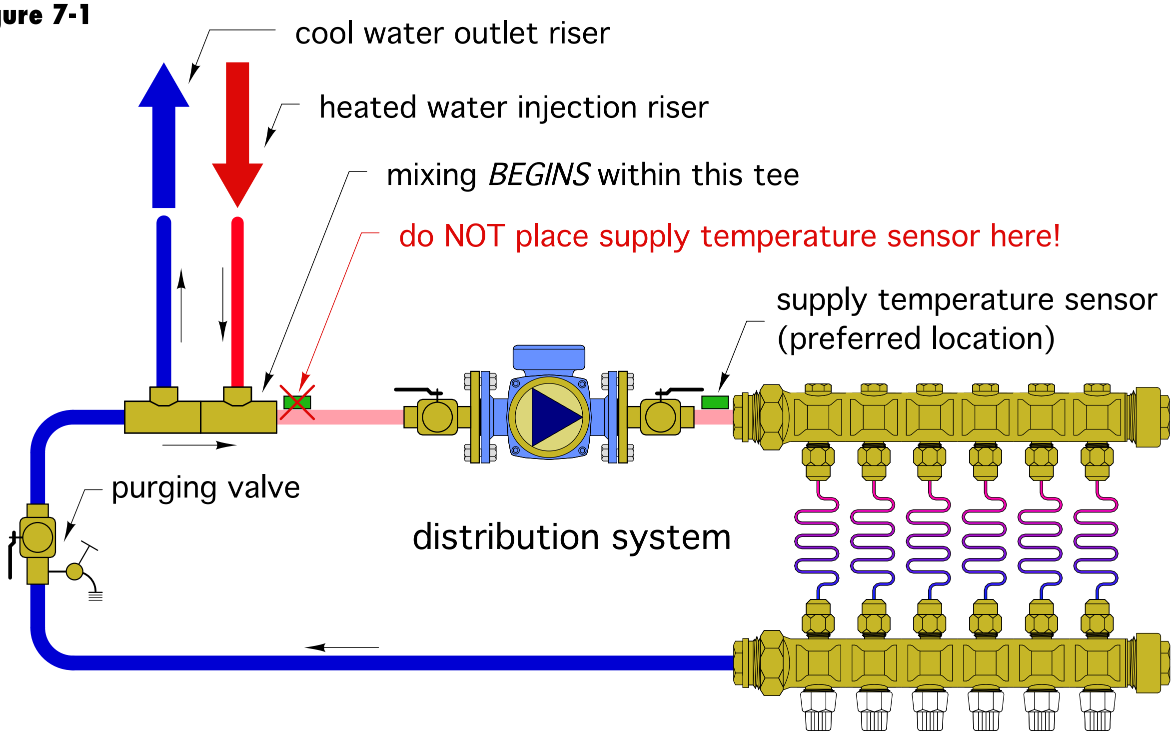
The injection flow rate needed to establish a given rate of heat transfer into the distribution system can be calculated using formula 7-1.

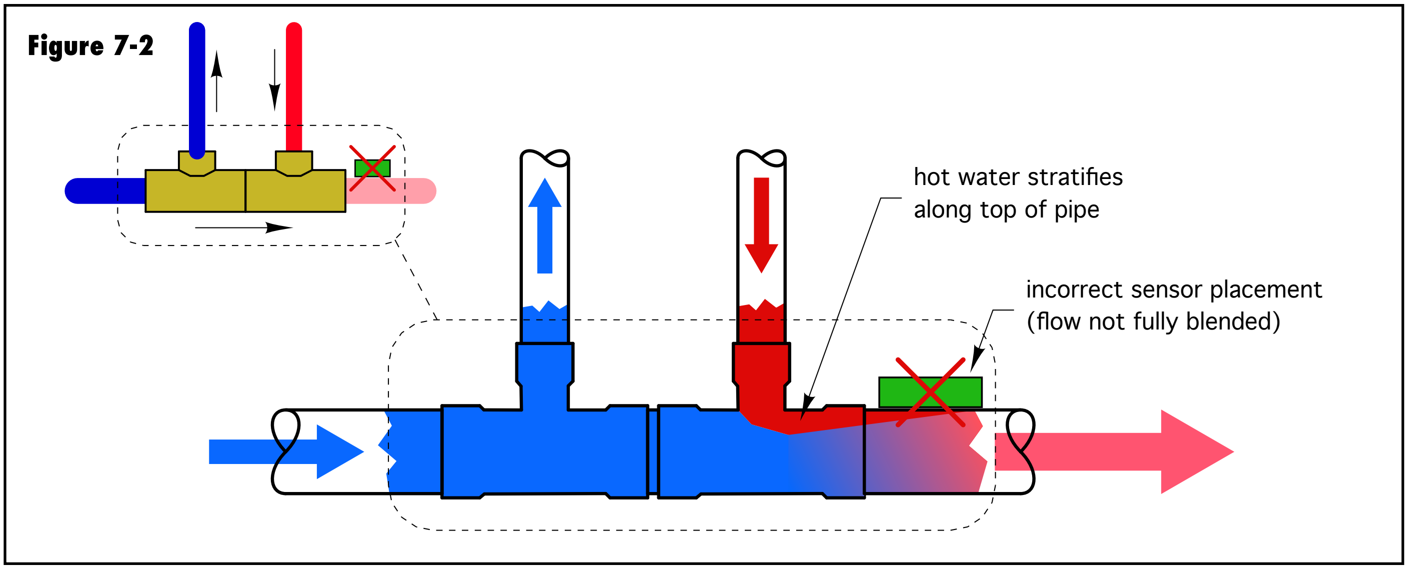
Formula 7-1

$$f_i = \frac{Q}{k \times \Delta T}$$

Where:
f_i = required injection flow rate (gpm)
Q = rate of heat transfer to distribution system (Btu/hr)
ΔT = temperature difference between supply and return injection risers (ºF)
k = a constant depending on fluid used (for water k=490, for 30% glycol solution k=479, for 50% glycol solution k = 450)

Figure 7-1





For example: Assume a system needs to supply a design load of 80,000 Btu/hr to a low-temperature radiant panel system. That distribution system requires a supply water-temperature of 110ºF at design load, and returns water at 90ºF under these conditions. Injection mixing will be used to supply the low-temperature distribution system. A conventional oil-fired boiler will supply 180ºF water for injection. Determine:

a. The required flow rate in the distribution system
b. The required injection flow rate

The flow rate through the distribution system will be determined based on the 20ºF temperature drop and required rate of heat transfer.

$$f_{system} = \frac{Q}{k \times \Delta T} = \frac{80{,}000}{495 \times (110 - 90)} = 8.1 gpm$$

The injection flow rate can be determined using formula 7-1:

$$f_i = \frac{Q}{k \times \Delta T} = \frac{80{,}000}{490 \times (180 - 90)} = 1.8 gpm$$

These flow rates are illustrated in figure 7-3.

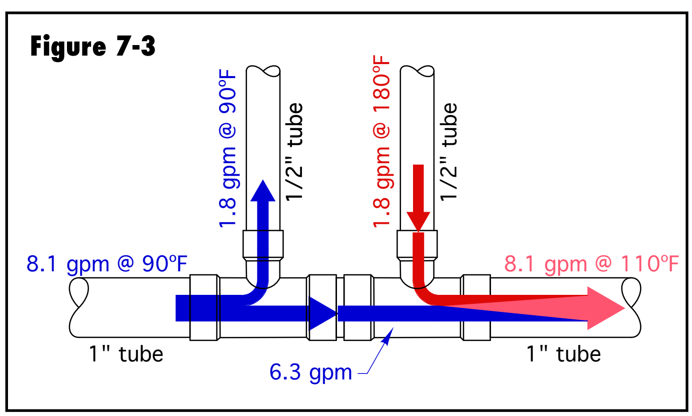
The injection flow rate is only about 22 percent of that in the distribution system. A 1/2-inch copper tube could easily accommodate this flow rate.

These results are based on the thermodynamics implied by formula 7-1. They demonstrate that a low flow rate of high-temperature water can transfer a substantial amount of heat into a low-temperature distribution system. *The greater the temperature difference is between the hot water being injected, and cool water returning from the distribution system, the lower the required injection flow rate will be.* This makes injection mixing well suited for low-temperature distribution systems supplied by conventional boilers operating at temperatures above 150ºF under design load.

Hardware options for injection mixing:

There are several hardware options that can be used for injection mixing assemblies. Some use valves while others use variable-speed circulators as the injection control device.

These options all share the characteristic that they only need to accommodate the hot portion of what eventually becomes the supply stream to the distribution system. In contrast, all previously discussed mixing valve systems using 3-way or 4-way valves must accommodate *the full flow rate of the distribution system*, and therefore must be larger in size. The difference in size between



mixing valves and injection mixing hardware can lead to significant cost savings when the latter is used in larger systems requiring high rates of heat transfer.

Injection mixing with 2-way modulating valves:

A 2-way modulating valve assembly consists of a valve body and an actuator that moves the stem of the valve. Valve types include ball and globe-style internal design with either rotary or linear shaft movement. Actuators include non-electric thermostatic devices, as well as electrically operated gear motor assemblies and "heat motors." Many combinations of valve bodies and actuators are possible depending on control requirements, hardware size requirements and other, project-specific details.

This section discusses the following combinations:

- Non-electric thermostatic actuators with globe-style valve body
- Electrically operated motorized actuator with globe-style valve body

Figure 7-4

Injection mixing with 2-way thermostatic valves:

A non-electric thermostatic actuator mounted to a 2-way valve body is shown in figure 7-4.

When the actuator is mounted to the valve body, its actuating pin is fully retracted. This allows the spring-loaded valve to remain fully open.

The sensor bulb measures the temperature of the water supplied to the distribution system. The sensor bulb is connected to the actuator with a capillary tube – a very small diameter tube resembling a bare metal wire, – but none-the-less a tube.

A piping system in which this valve/actuator serves as the injection control device is shown in figure 7-5.

Figure 7-5

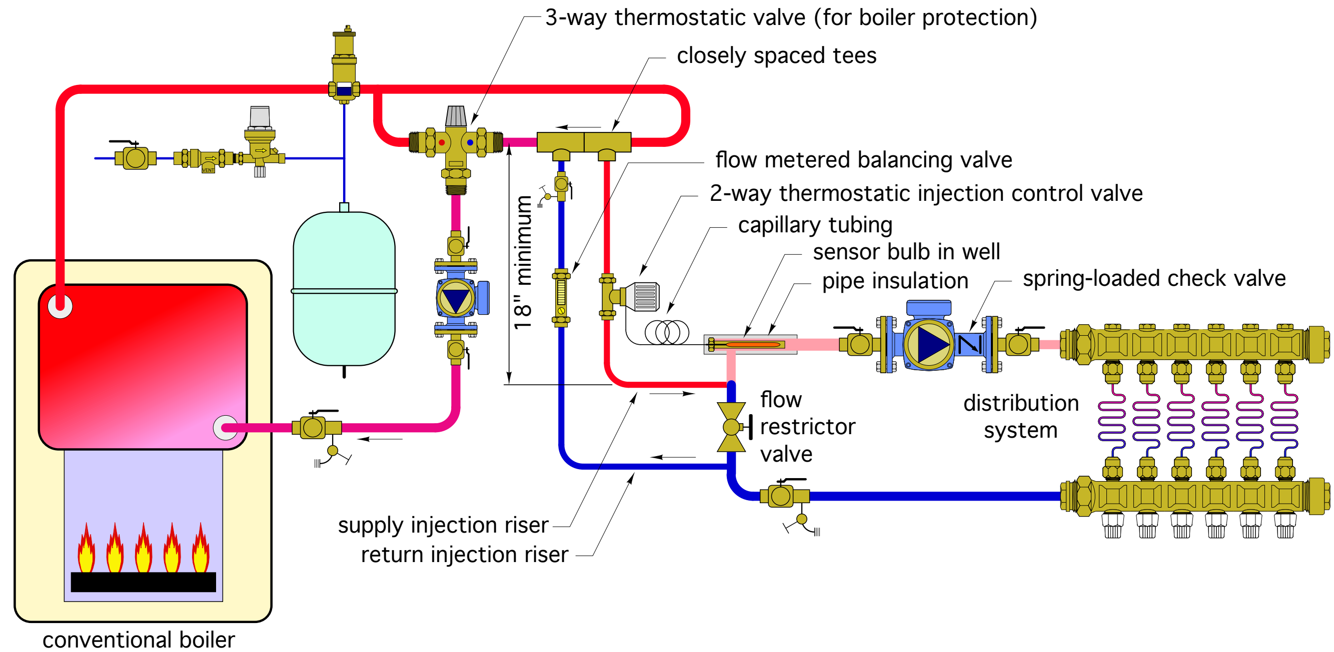


Figure 7-6

The flow-restrictor valve in the distribution system is set to create a slight pressure difference between the injection risers. This pressure difference motivates flow to move up the return injection riser and down the supply injection riser whenever the injection valve is partially or fully open.

A metered balancing valve is installed in the return injection riser. Its purpose is to indicate the injection flow rate and, when necessary, allow the flow resistance of the injection riser to be increased to properly tune the system. An example of a metered balancing valve is shown in figure 7-6. Proper use of this valve is discussed later in this section.

Hot water flowing down the supply injection riser enters a tee in the distribution system, where it begins mixing with cool water returning from the distribution system. The mixed flow passes across a sensor well mounted within a tee in the distribution system piping. This well contains the sensing bulb for the injection valve.

If the water flowing past the sensor well is hotter than the temperature set on the actuator knob, pressure within the sensor bulb and capillary tube increases. This increased pressure is transferred to the actuator where it creates a force that moves the stem of the injection control valve in the closing direction.

If the temperature at the sensor bulb is cooler than the set supply temperature, pressure in the sensing bulb decreases. This allows the valve to open and increases injection flow rate.

When the temperature at the sensing bulb matches the temperature set on the actuator knob, the injection valve holds at its current position.

A separate 3-way thermostatic mixing valve protects the conventional boiler against sustained flue gas condensation. Its operation is identical to that described for the system shown in figure 6-3.

The piping containing the sensor bulb well should be several inches away from the tee where hot water is injected into the distribution system. This section of piping should also be wrapped with pipe insulation. Also verify that the sensor bulb fits snugly into the well.

If a well cannot be used, the sensor bulb can be tightly strapped to the outside of a straight length of copper tubing. Be sure the strapping material used will not deteriorate over time. Also be sure the piping area around the sensor bulb is wrapped with tight-fitting insulation to prevent surrounding air from influencing the sensor temperature.

The advantages of injection mixing with 2-way thermostatic valves include:

- No electrical wiring is needed for water-temperature control
- Relatively small hardware can handle substantial rates of heat transfer

The disadvantages include:

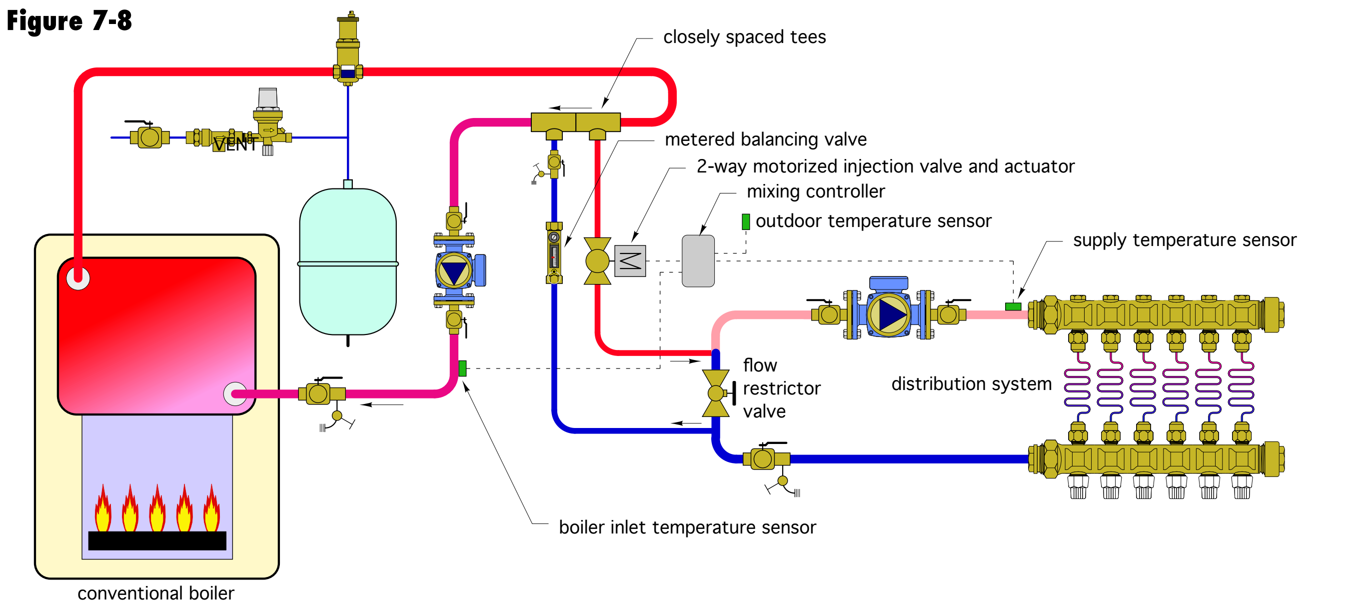
- Inability to provide outdoor reset control of supply water-temperature
- Inability to allow constant circulation through the distribution system

Injection mixing with 2-way motorized valves:

Another variation on injection mixing uses a single 2-way motorized valve to control injection flow rate. An example of a 2-way valve body fitted with a motorized actuator is shown in figure 7-7. A schematic using this type of valve for injection mixing is shown in figure 7-8.

Figure 7-7

Figure 7-8



The controller operating the 2-way motorized valve may be incorporated into the actuator or mounted separately and wired to the actuator. This controller could be similar, or even identical to that used for a 3-way or 4-way motorized mixing valve. It can measure supply water-temperature, boiler inlet temperature and outdoor temperature. It can provide fixed setpoint or full outdoor reset control of supply water-temperature. It can control the injection valve as necessary to prevent sustained flue gas condensation in the boiler.

Advantages of injection mixing with 2-way motorized valves include:

• A single valve can regulate supply temperature as well as provide boiler protection.
• Relatively small hardware can handle substantial rates of heat transfer
• The ability to provide outdoor reset control of supply water-temperature
• The ability to allow constant circulation through the distribution system

The disadvantage of this approach is:

• Low-voltage electrical wiring is required to operate the mixing system

Selecting and tuning a 2-way valve injection mixing assembly:

For optimal performance, the injection control valve and the flow-restrictor valve need to be properly selected and adjusted. The following procedure applies to both 2-way thermostatic and 2-way motorized injection control valves.

1. Begin by determining the required injection flow rate under design load conditions. This can be determined using formula 7-1.

Formula 7-1

$$f_i = \frac{Q}{k \times \Delta T}$$

Where:
f_i = required injection flow rate at design load (gpm)
Q = rate of heat transfer to distribution system at design load (Btu/hr)
ΔT = temperature difference between supply and return injection risers (ºF)
k = a constant depending on fluid used (for water k=490, for 30% glycol solution k=479, for 50% glycol solution k=450)

2. Determine the flow rate through the distribution system under design load conditions using formula 7-2.

Formula 7-2

$$f_{system} = \frac{Q}{k \times \Delta T}$$

Where:
f_{system} = flow rate in distribution system at design load (gpm)
Q = rate of heat transfer to distribution system at design load (Btu/hr)
ΔT = temperature drop of distribution system at design load (ºF)
k = a constant depending on fluid used (for water k=495, for 30% glycol solution k=479, for 50% glycol solution k=450)

3. Select a valve body for the injection control valve. The Cv of this valve body should be approximately equal to the calculated injection flow rate at design load.

4. Calculate the Cv of the flow-restrictor valve using formula 7-3:

Formula 7-3

$$Cv_{frv} = \frac{0.707\left(f_{system}\right)\left(Cv_i\right)}{f_i}$$

Where:

Cv_{frv} = Cv required of flow-restrictor valve

f_{system} = flow rate in distribution system at design load (gpm)

C_{vi} = Cv of selected injection control valve

f_i = required injection flow rate at design load (gpm)

Select a globe-type flow-restrictor valve with a Cv rating approximately equal to that calculated using formula 7-3.

After the hardware is sized and installed, it needs to be "tuned" for optimal performance. As a result of tuning, the injection control valve should be fully open at design load conditions.

The following procedure is used to tune the injection mixing assembly:

1. After the system is filled and purged of air, fully open the flow-restrictor valve, the injection control valve and the metered balancing valve. If the distribution system is zoned, open all zones so flow through the distribution system represents design load conditions. The actuator on the injection control valve may have to be temporarily removed to ensure the valve is fully open.

2. Turn on the boiler circulator and the distribution circulator, then read the flow rate – if any – passing through the metered balancing valve in the injection riser.

3. If the flow rate indicated by the metered balancing valve is higher than the calculated injection flow rate, slowly close the plug on the metered balancing valve until the flow reading equals the calculated injection flow rate. Proceed to step 5.

4. If the flow reading on the metered balancing valve is less than the calculated injection flow rate, slowly begin to close the flow-restrictor valve until the flow rate on the metered balancing valve equals the calculated injection flow rate.

5. Mark and/or note the position of each valve stem. Reinstall the actuator on the injection control valve. The tuning procedure is complete.

Injection mixing with a variable-speed pump:

One of the most popular methods of injection mixing uses a variable-speed pump as the injection flow control device. The piping concept is shown in figure 7-9.

A small circulator serves as the injection pump that forces hot water from the boiler loop into the distribution system. The rate of hot water injection, and hence the rate of heat transfer to the distribution system can be regulated by varying the speed of this pump. This is called variable-speed injection mixing. It relies on a controller specifically designed to adjust the speed of a small circulator. Controllers have been developed for both AC wet rotor circulators and small DC pumps. Such controllers can usually be configured to provide a fixed supply temperature or fully reset supply water-temperature.

Two piping details are critical to proper operation of this injection mixing assembly:

1. The tees connecting the injection riser piping to the boiler loop should be installed as close as possible. This is also true for the tees connecting the injection risers to the distribution loop.

2. The closely spaced tees connecting to the boiler loop must be at least 18 inches higher than those connecting the risers to the distribution system.

Closely spaced tees create hydraulic separation between the injection riser piping and both the boiler loop and distribution system. This minimizes any tendency for flow in either the boiler loop or distribution system to induce flow through the injection risers when the injection pump is off. Hydraulic separation also allows the boiler loop to operate to serve other loads, such as domestic water heating, without inadvertently injecting heat into the distribution system. It also allows the option of continuous circulation in the distribution system without heat migration.

The vertical separation of the sets of tees creates a "thermal trap" that discourages downward migration of hot water when the injection pump is off.

The use of a weighted flow check or spring-loaded check valve in the injection risers to stop heat migration is *not* recommended because it can cause surging of the injection pump at low speeds. However, circulators with lightly loaded internal check valves can be used as variable-speed injection pumps.

Figure 7-9

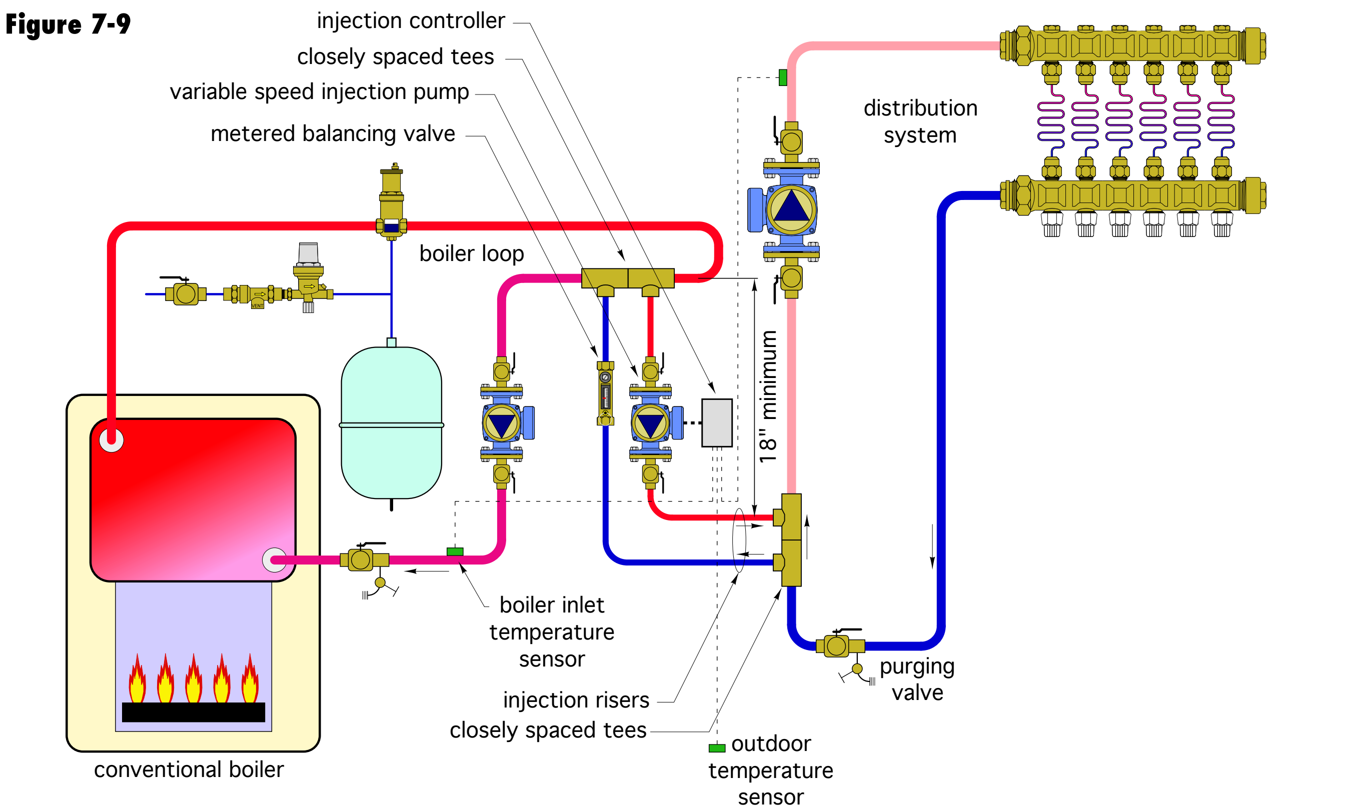
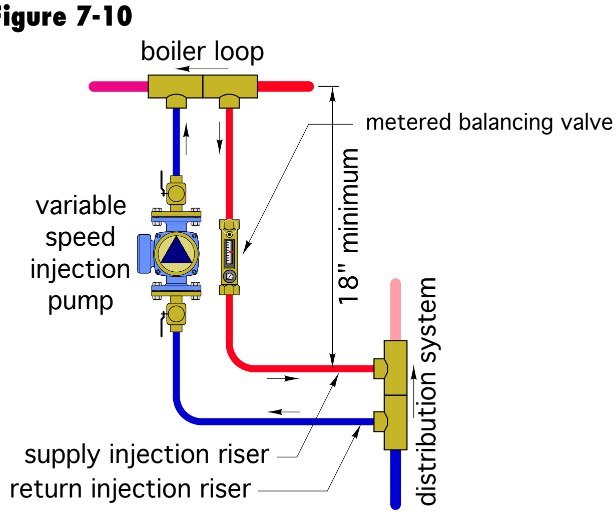


Figure 7-10



Allow at least 6 pipe diameters of straight pipe upstream of each set of closely spaced tees and a minimum of 4 pipe diameters of straight pipe downstream of each pair of tees. This distance minimizes turbulence in the vicinity of the tees, which helps prevent unintentional induced flow through the injection risers.

A purging valve should always be installed in the distribution system to allow efficient air removal at start-up.

Figure 7-9 shows the "traditional" location of the injection pump in the supply injection riser. The injection pump can also be mounted in the return injection riser, as shown in figure 7-10, with no difference in flow performance. Mounting the pump on the return injection riser has the advantage of allowing the pump to operate at lower temperatures.

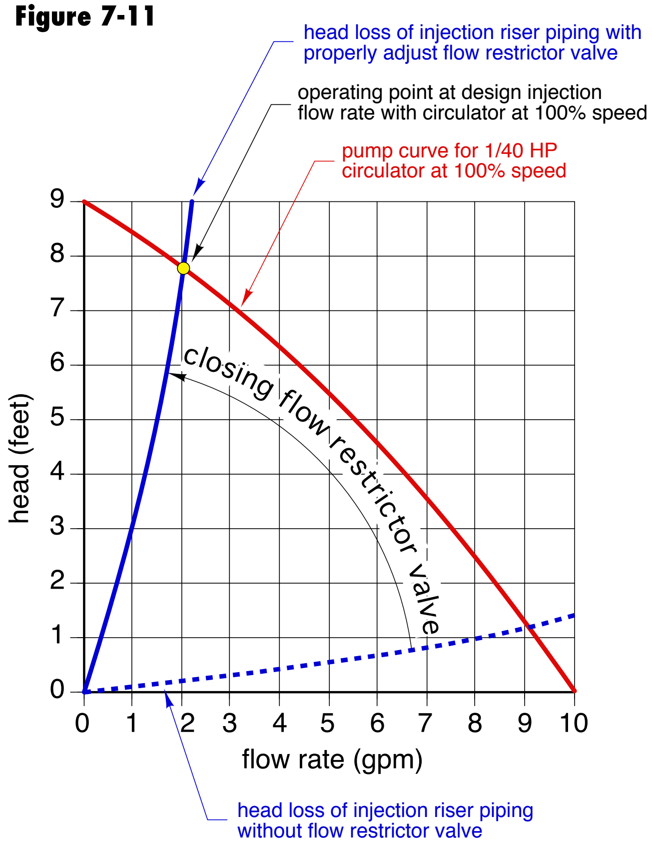
Purpose of the flow-restrictor valve:

In theory, the power requirement for an injection pump operating in a residential-size system, with relatively short (2 to 4-foot long) injection risers is very low. For example, a system with 8 feet of 1/2-inch copper injection riser piping operating at an injection flow rate of 2 gpm requires *less than 1 watt* of electrical input power to the injection pump (assuming a 25% wire-to-water efficiency). Such ultra-low wattage circulators are currently not available in the North American market. Thus it is common to use a small "zone circulator" as the injection pump.

Although a typical zone pump is acceptable, it is far more powerful, even at only 50 watts power input, than what's needed for proper injection flow.

If a zone circulator is installed as the injection pump, it will seldom operate at more than 10 percent of full

Figure 7-11



speed. This effectively "wastes" 90 percent of the speed adjustment range of the circulator and reduces the ability of the mixing assembly to fine-tune supply water-temperature.

The work-around is to install a flow-restrictor valve in one of the injection risers to significantly increase the head against which the injection pump operates. The flow resistance created by this valve greatly steepens the head loss curve of the injection risers as shown in figure 7-11.

Setting the flow-restrictor valve:

The goal in setting the flow-restrictor valve is to allow the calculated design load injection flow rate through the injection risers, while the injection pump operates at full speed.

For example: Assume the design injection flow rate is 2 gpm. By progressively closing the flow-restrictor valve the head loss curve in figure 7–11 steepens from its original position (shown in blue dashed lines) to a position where it intersects the pump curve at the desired flow rate of 2 gpm. The pump curve is for a small (1/40 horsepower) circulator operating at full speed. Once this intersection is achieved, the flow-restrictor valve is properly set.

Properly setting the flow-restrictor valve is straight forward when that valve includes a flow meter. An example of such a valve is shown in figure 7-12.

The first step in setting the flow-restrictor valve is to calculate the necessary injection flow rate under design load conditions. The procedure is identical to that described for injection mixing with valves. Use formula 7-1:

Formula 7-1

$$f_i = \frac{Q}{k \times \Delta T}$$

Where:
f_i = required injection flow rate at design load (gpm)
Q = rate of heat transfer to distribution system at design load (Btu/hr)
ΔT = temperature difference between supply and return injection risers (ºF)
k = a constant depending on fluid used (for water k=490, for 30% glycol solution k=479, for 50% glycol solution k=450)

Once the injection flow rate is calculated, turn on the injection pump at full speed. For AC circulators this can be done by either setting the injection controller to full-speed mode or by wiring a line cord to the circulator and plugging it in. If a multi-speed injection pump is used, set it for the lowest speed setting.

Figure 7-12

The next step is to throttle down the flow-restrictor valve until the indicated flow rate matches the calculated design injection flow rate. If this cannot be achieved with the pump on its low speed setting, change to higher speeds – as required – to achieve the required injection flow rate. The flow-restrictor valve is now properly set.

Special application #1 for variable-speed injection mixing:

Some larger floor heating systems have manifold stations located far away from the mechanical room. If mixing for supply water-temperature control is done in the mechanical room, the flow rate to each manifold station is determined by the temperature differential of that manifold station.

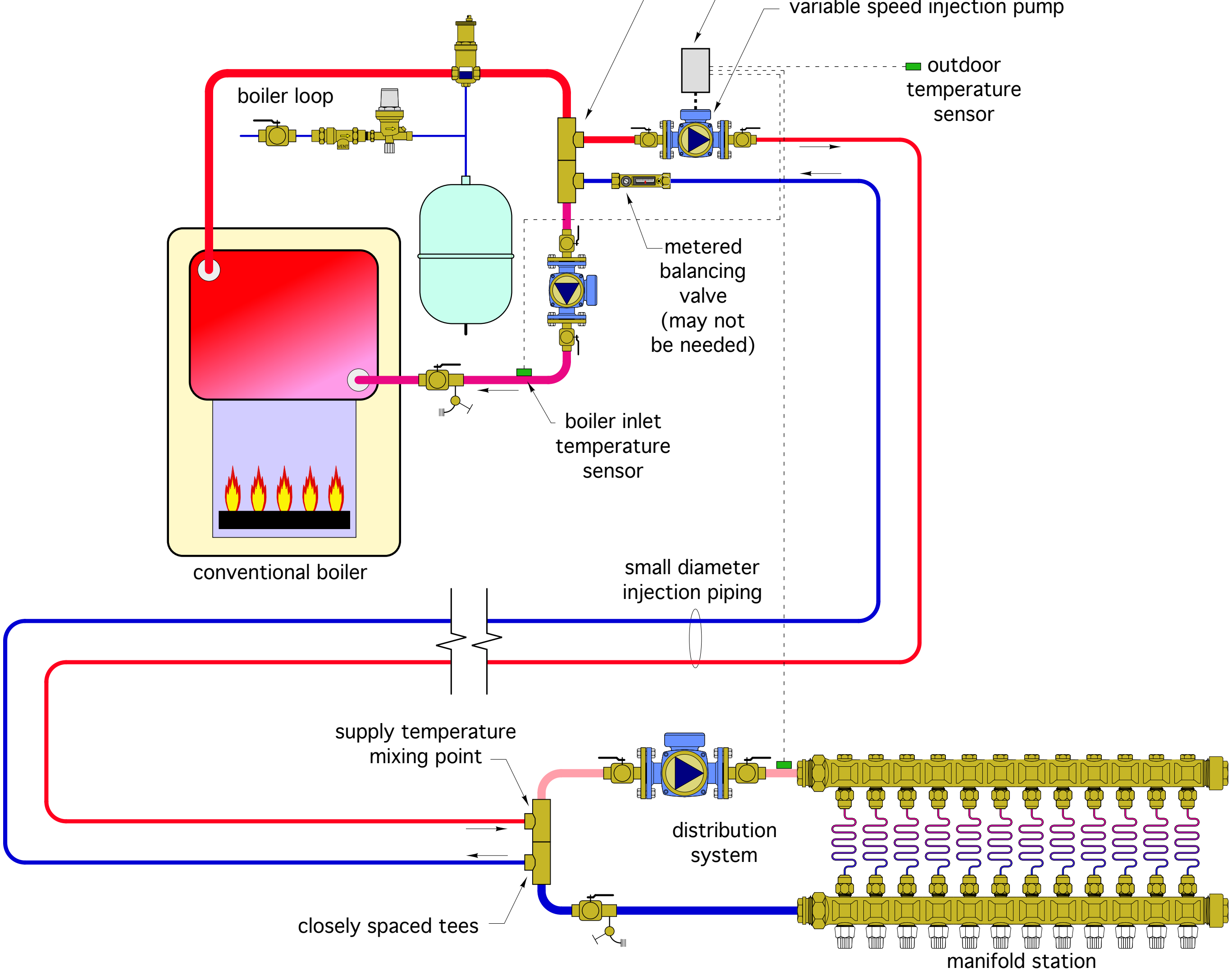
For example, imagine a manifold station serving a large number of floor heating circuits. At design load conditions the manifold requires 250,000 Btu/hr of heat input, and it is located 200 feet away from the mechanical room. At design load the floor circuits operate at a nominal 20ºF temperature drop. The flow rate that must be supplied to the manifold station is:

$$f = \frac{Q}{k \times \Delta T} = \frac{250{,}000}{495 \times 20} = 25.3gpm$$

This would require 2-inch piping between the mechanical room and manifold station. Allowing for the vertical displacement of overhead piping, and the horizontal path from the mechanical room to the manifold station, the round trip circuit to this manifold station could require 500 feet of piping.

An alternative is to move the mixing function to the manifold station. The normally short injection riser piping shown in previous diagrams of injection mixing systems are lengthened to carry higher-temperature water from the mechanical room to the manifold station, as shown in figure 7-13.

Figure 7-13



Like all injection mixing systems, this approach exploits the large temperature difference between hot water from the boiler and cooler water returning from a low-temperature distribution system. The large temperature difference allows a relatively low flow rate to carry a substantial amount of heat from the mechanical room to the manifold station. This allows the piping between the mechanical room and manifold station to be significantly smaller compared to systems where mixing is done in the mechanical room.

Here's a comparison: Assume the manifold station shown in figure 7-13 dissipated 250,000 Btu/hr at design load conditions. Water from the boiler is available at 180ºF. The manifold station requires a supply temperature of 110ºF, and operates at a 20ºF temperature drop. Thus its return temperature is 90ºF. Determine the required injection flow rate and the pipe size necessary to handle this flow rate without exceeding a flow velocity of 4 feet per second.

Solution: The injection flow rate is calculated using formula 7-1:

$$f = \frac{Q}{k \times \Delta T} = \frac{250,000}{490 \times (180 - 90)} = 5.7\,gpm$$

A 3/4-inch tube can accommodate this flow rate with the flow velocity remaining under 4 feet per second.

If used as an alternative to the "mix-in-the-mechanical-room approach," this method would replace the 500 feet of 2-inch tubing previous described with 500 feet of 3/4-inch tubing. The latter could be copper, PEX or PEX-AL-PEX. The installed cost savings for this single manifold would likely be several thousand dollars. An example of a large (24-circuit) manifold station using this approach and being served by 1-inch injection piping is shown in figure 7-14. This manifold station delivers 500,000 Btu/hr to the floor circuits at design load.

Figure 7-14

This design concept can also be used to supply multiple manifold stations, as shown in figure 7-15.

Each manifold station operates as a separate zone. Each zone has its own variable-speed injection pump and associated injection controller. This allows for different supply water-temperatures, reset ratios and setback schedules for each zone.

The distribution circulators at each manifold station are sized for the flow rate and head loss of that manifold station and a short piping loop containing the circulator, a purging valve and a set of closely spaced tees. There is no need to size these circulators for any head loss associated with heat conveyance from the mechanical room. The injection pumps handle the latter.

Injection piping to each manifold station should be sized so the total head loss of the supply and return injection piping allows the injection pump to operate at close to full speed when supplying the design injection flow rate to its manifold station. This often eliminates the need for a flow balancing valve in the injection piping. It also makes better use of the head produced by a small wet-rotor circulator relative to systems with short injection risers.

A single or multiple boiler plant can be controlled by outdoor reset, and thus operated at lower temperatures and higher efficiency during partial-load conditions. This will not interfere with the injection mixing subsystems since supply water-temperature will be reduced in proportion to load.

Special application #2 for variable-speed injection mixing:

Injection mixing can also be used for the sole purpose of protecting a conventional boiler from sustained flue gas condensation. A typical scenario is when a boiler or multiple boiler system supplies heat to a low- or medium-temperature load with high thermal mass. An example is shown in figure 7-16.

When the load is at a low-temperature, its thermal mass may be able to absorb heat fast enough to significantly depress the boiler's inlet temperature. An injection mixing

Figure 7-15

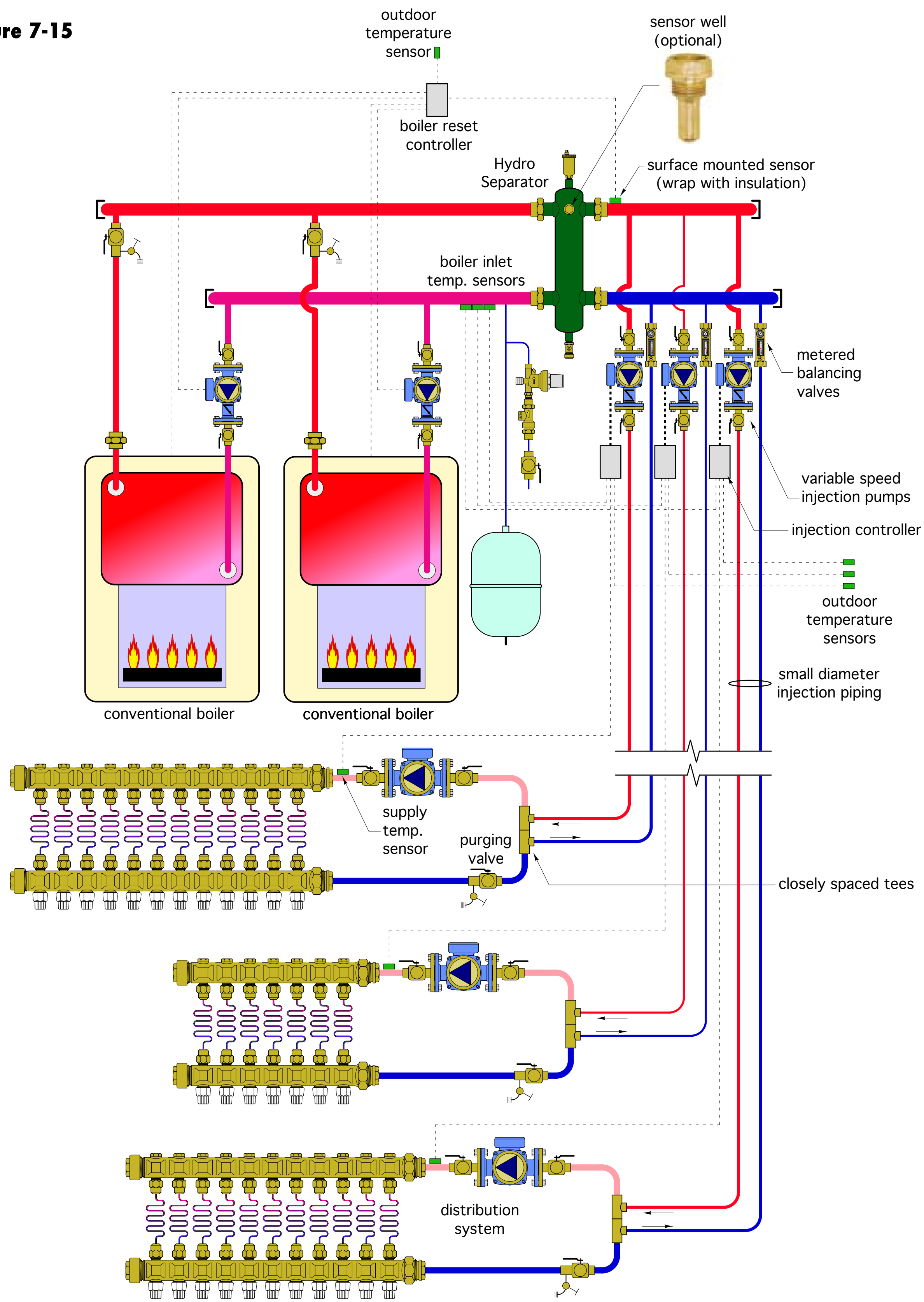
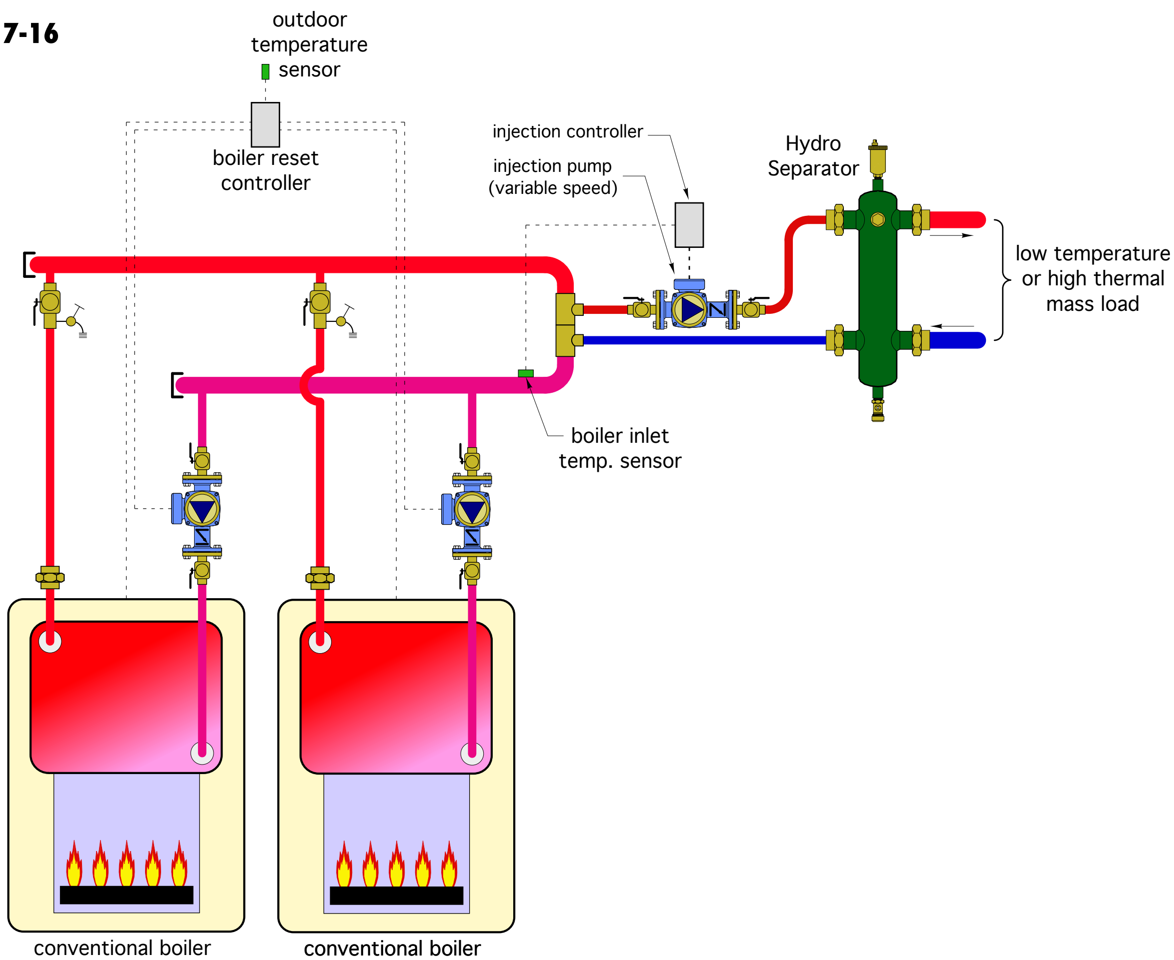

outdoor
temperature
sensor
sensor well
(optional)
boiler reset
controller
Hydro
Separator
surface mounted sensor
(wrap with insulation)
boiler inlet
temp. sensors
metered
balancing
valves
variable speed
injection pumps
injection controller
outdoor
temperature
sensors
small diameter
injection piping
conventional boiler
conventional boiler
supply
temp.
sensor
purging
valve
closely spaced tees
distribution
system

Figure 7-16



assembly installed between the load and boiler(s) can act as a "thermal clutch" to prevent the load from absorbing heat faster than the boiler(s) can produce it. This mixing assembly uses a single temperature sensor to measure boiler inlet temperature. If that temperature is below a minimum setting, the variable-speed injection pump reduces speed. This decreases the rate at which heat is being removed from the boiler loop and transferred to the hydro separator. As boiler inlet temperature increases above the minimum setting, the injection pump increases speed to transfer more of the boiler's heat output to the hydro separator, and on to the load. As long as the boiler inlet temperature is at or above its minimum, the injection pump will eventually reach full speed.

The injection pump must be sized to transfer the full output of the boiler(s) to the load using the expected temperature difference between the water supplied by the boiler and the water returning from the load under design load conditions.

Many injection mixing controllers can provide boiler protection and control the temperature supplied to the load based on either a setpoint or outdoor reset control. Such a controller could be used as shown in figure 7-17.

In this system, the injection controller monitors tank temperature and constantly compares it to a desired setpoint. When the tank requires heat, the injection controller enables the boiler controller, operates the injection pump as necessary to protect the boilers and eventually terminates heat input when the tank reaches the desired temperature setting.

Injection mixing summary:

Figure 7-18 summarizes the approaches to injection mixing discussed in this section. The details of each mixing assembly are shown, along with the piping connections A,B, C and D, that allow each assembly to fit the generic piping layout of a boiler loop connected to a distribution system with the mixing assembly as the bridge.

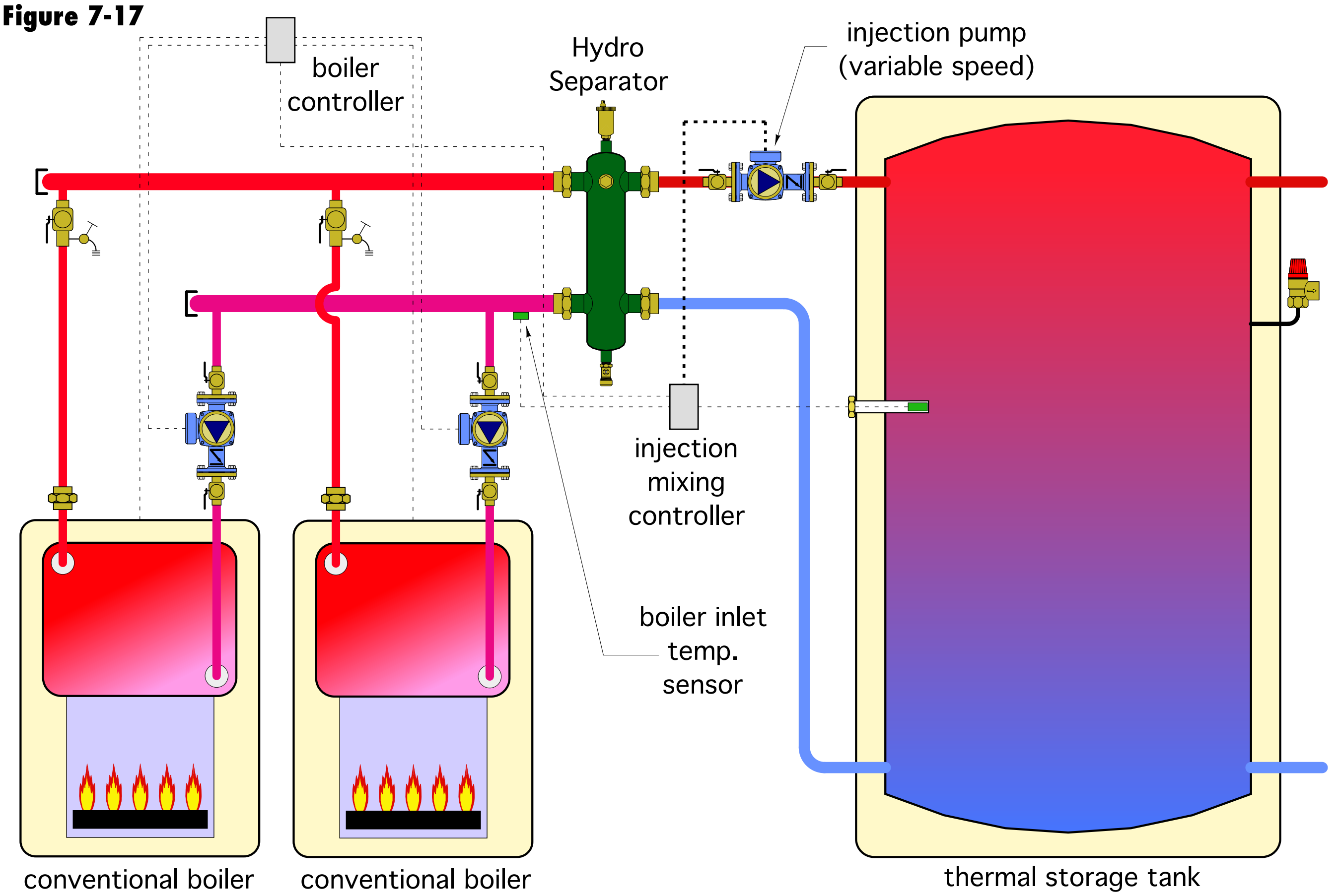


Figure 7-17

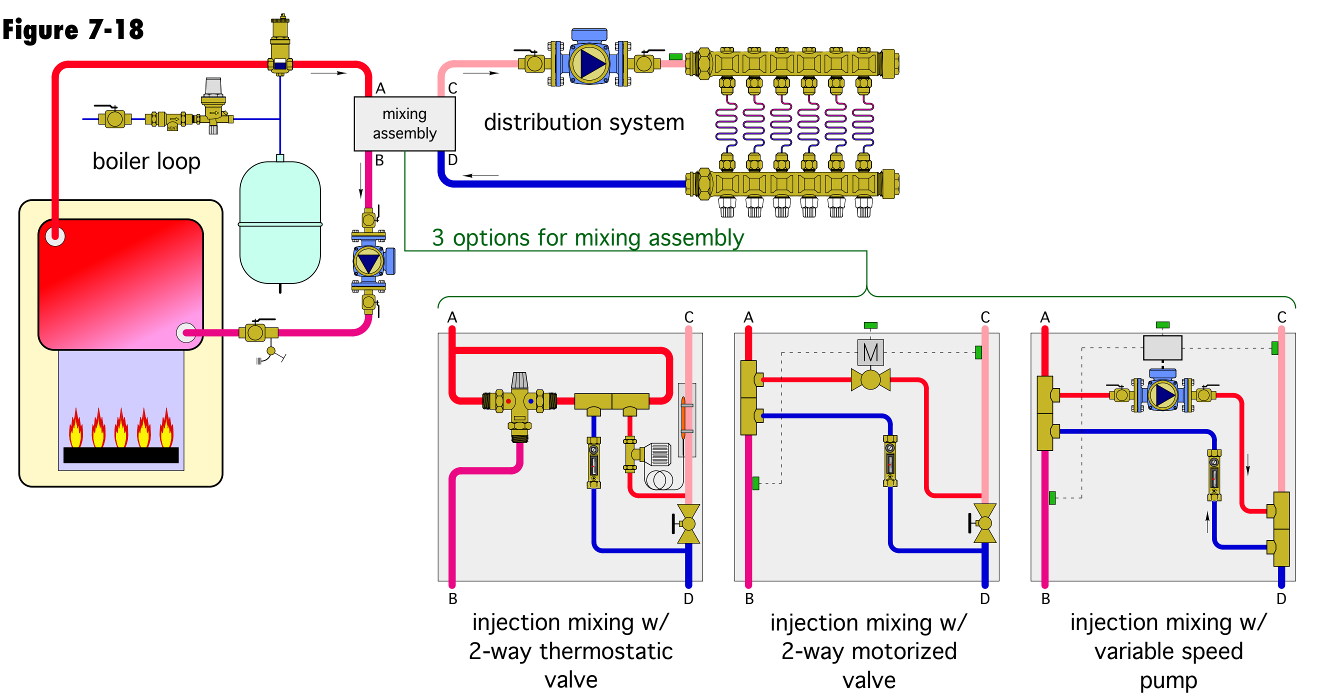


Figure 7-18

8. SYSTEMS WITH MULTIPLE SUPPLY TEMPERATURES

A unique benefit of modern hydronic heating is the ability to select different heat emitters for different performance or aesthetic requirements. For example, it may be advantageous to use floor heating in the basement slab, along with panel radiators on the main living level. These heat emitters require significantly different supply water-temperatures, which can be provided through multiple mixing assemblies.

From the standpoint of cost alone, it's ideal to not have any mixing assemblies in a system. This is possible when water-temperature is always well-regulated by the heat source and the operating temperature of the distribution system is such that it doesn't adversely affect the heat source (i.e., the return water-temperature from the distribution system doesn't create sustained flue gas condensation within a conventional boiler). This approach precludes use of heat sources where supply water-temperature could vary widely. Solar collectors and wood-fired boilers are examples of such heat sources.

The next best option is a single mixing assembly that can supply all heat emitters in the system. This is possible when all heat emitters have the same or similar supply water-temperature requirements. An example would be a house with heated floor slabs and similar floor coverings throughout, supplied by a conventional boiler.

Systems with two or more independent mixing systems are often necessary when heat emitters with significantly different water-temperature requirements are present. A house with a heated floor slab in the basement, and panel radiators on the main living level is one example. Another is a house with a heated floor slab in the basement and underfloor tube-and-plate floor heating on other levels.

Reducing number of supply water-temperatures:

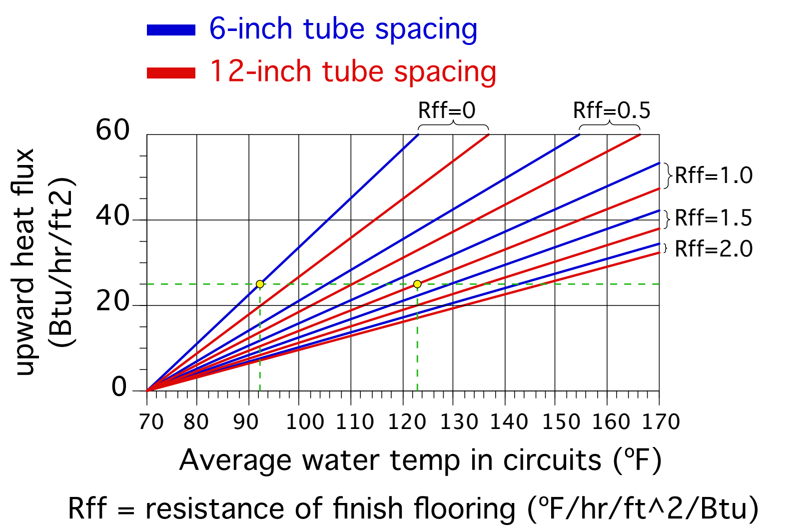
Although it's possible to use multiple mixing assemblies to accommodate multiple supply water-temperatures, it may be more cost effective to first examine possibilities for reducing the number of supply temperatures required.

The following design options can reduce the supply temperature requirement of various heat emitters:

- Decrease building heat loss.
- Decrease tube spacing in radiant panels.
- Decrease finish floor resistance over heated floors.
- Increase size of panel radiators.
- Increase length of fin-tube convectors.
- Specify larger coil or a multiple tube row coil in air handlers.

Figure 8-1 demonstrates the possibilities for increasing or decreasing water-temperature based on tube spacing and finish floor resistance associated with a heated floor slab.

Figure 8-1 Upward heat output vs. average circuit water temperature for 4" concrete slab Room temperature = 70 °F



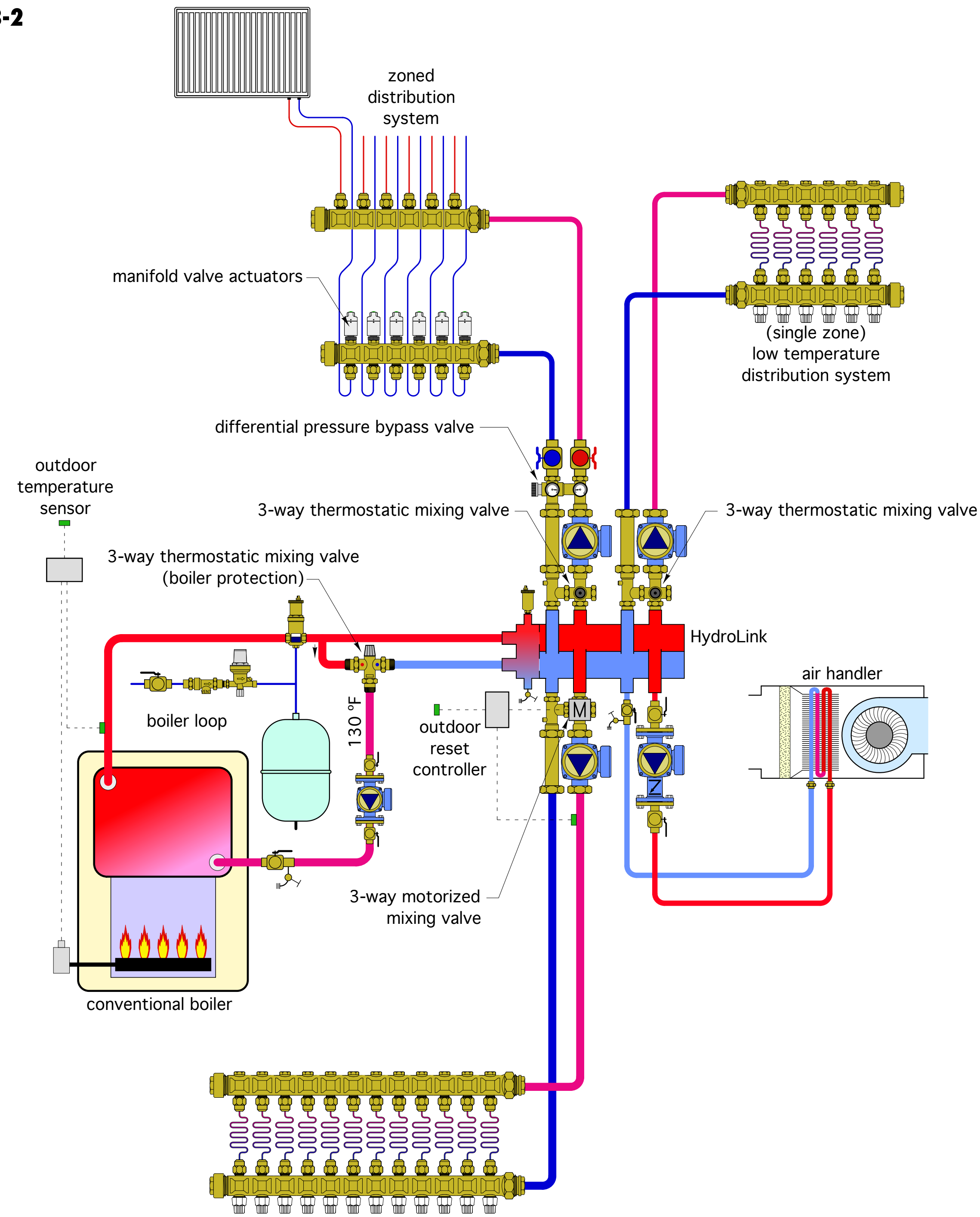
[To achieve a design output of 25 Btu/hr/ft^2, a bare slab with 6-inch tube spacing requires an average circuit water-temperature of about 92°F. If the same slab were covered with a finish floor having a thermal resistance of 1.0°F•hr•ft^2/Btu, and installed with tubes spaced 12-inches apart, the required average circuit water-temperature would be about 123°F.

If these two subsystems were supplied from the same conventional boiler, the 31°F difference in average circuit temperatures would necessitate two mixing assemblies.

To bring these water-temperatures closer together one might:

1. Increase tube spacing in the bare slab from 6-inch to 12-inch tube spacing. This would increase the average circuit temperature to about 98°F.

Figure 8-2



2. Use a lower-resistance floor covering (R=0.5°F•hr•ft²/Btu) and decrease tube spacing on the covered slab from 12 to 6-inches. This would reduce the average circuit temperature to about 105°F.

Although these two average circuit temperatures are still about 7°F apart, experience has shown they could likely still be supplied from a single mixing assembly set for the average of these temperatures.

Similar trade-offs between sizing and water-temperature could be evaluated for other heat emitters in an attempt to "homogenize" the supply temperatures to the point where it's possible to eliminate one of the mixing assemblies. If

Figure 8-3

the supply temperatures of all heat emitters can be brought to within 10°F of each other, those heat emitters can probably be served by a common mixing assembly.

The life-cycle cost of the resized heat emitter or building load reduction should then be compared to the life-cycle cost of the additional mixing assembly. Keep in mind that each mixing assembly has a least one circulator associated with it, and as such has both a first cost and *operating cost* associated with it. The latter is present for the life of the system.

Multiple intelligent mixing devices:

When a building area is zoned, experiences different internal heat gains, or operates with a setback schedule, it's best to use an intelligent mixing device for each supply water-temperature required. Intelligent mixing devices include:

- 3-way thermostatic valves
- Thermostatic 2-way valve
- Motorized (2-way, 3-way, 4-way) mixing valves with a controller
- Variable-speed pump injection mixing assemblies

Intelligent mixing devices can react independently to changing conditions within the system. For example, if there is a sudden decrease in supply water-temperature because a different portion of the system has just turned on, intelligent mixing devices can react within seconds to maintain the proper water-temperature to their respective distribution systems.

An example of a system that supplies multiple mixed temperatures using a variety of intelligent mixing devices is shown in figure 8-2.

In this system, preassembled mixing units are mounted to a common HydroLink. The HydroLink provides hydraulic separation between each mixing unit, as well as between the mixing units and boiler circulator. It also supplies the same water-temperature to the hot side of each mixing unit. This beneficial feature is not provided by systems where multiple mixing units are connected in sequence around a common piping loop.

Caleffi mixing units are available in several configurations. Each can be directly connected to a HydroLink. They range from base units with a 3-way thermostatic mixing valve to units with a circulator, differential pressure bypass valve and thermometers. An example of the latter is shown in figure 8-3.

The system shown in figure 8-2 supplies four loads; three have mixed supply temperatures. The fourth, an air handler, is an "unmixed" load.

The subsystem in the upper left of the schematic uses manifold valve actuators to provide independent control of each circuit. With valve-based zoning, it's important to regulate differential pressure across the manifold station as zone circuits open and close. The differential pressure bypass valve incorporated into the mixing unit provides this regulation. The integral 3-way thermostatic valve controls supply water-temperature. A check valve, built into the mixing unit, prevents flow reversal through the mixing assembly and its subsystem when other portions of the system are active.

The lower-temperature distribution system in the upper right corner operates as a single zone, and thus doesn't need differential pressure regulation. A simple mixing unit is selected for this portion of the system. The integral 3-way thermostatic valve again controls supply water-temperature. A check valve within the mixing unit prevents flow reversal.

The subsystem in the lower left corner has a flow requirement large enough to require a 3-way motorized mixing valve on the mixing unit. An electronic controller operates the actuator attached to this valve based on outdoor reset control. A check valve within the mixing unit prevents flow reversal.

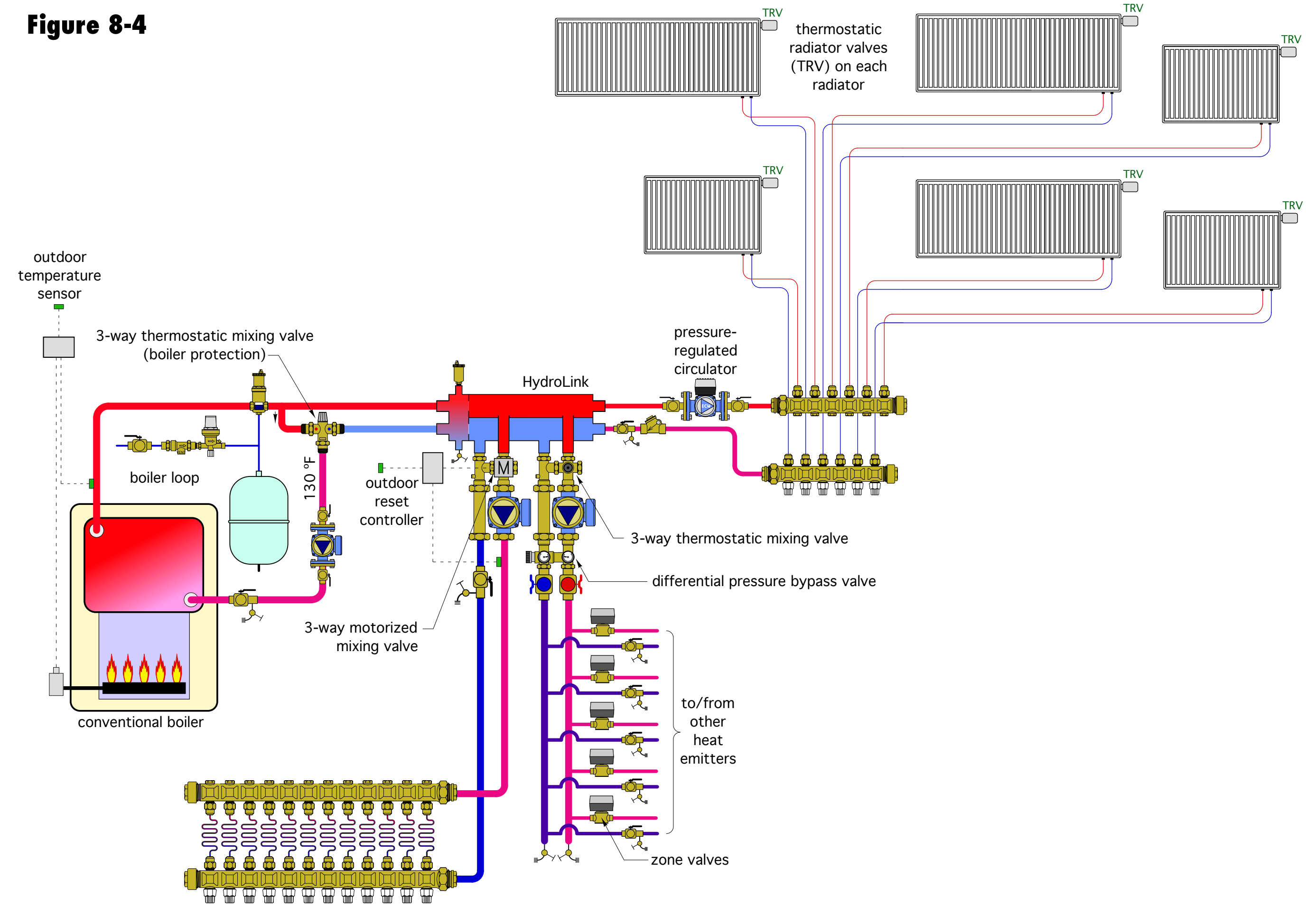
The air handler operates without mixing. The water-temperature supplied by the boiler is supplied to the coil of the air handler. A circulator with integral check valve prevents flow reversal.

Because the system uses a conventional boiler, and some of the loads operate at temperatures low enough to cause sustained flue gas condensation, the boiler loop includes a 3-way thermostatic valve to boost boiler inlet temperature when necessary.

It is also possible to combine fixed-speed and variable-speed circulators on the same HydroLink, as shown in figure 8-4.

In this system, a pressure-regulated variable-speed circulator supplies a group of panel radiators that are individually zoned using thermostatic radiator valves. No mixing is used on this subsystem.

Figure 8-4



The other two subsystems have mixed supply temperatures. One is regulated by a motorized 3-way valve, the other by a 3-way thermostatic valve. A mixing unit with differential pressure bypass is used on the latter since it is zoned using valves.

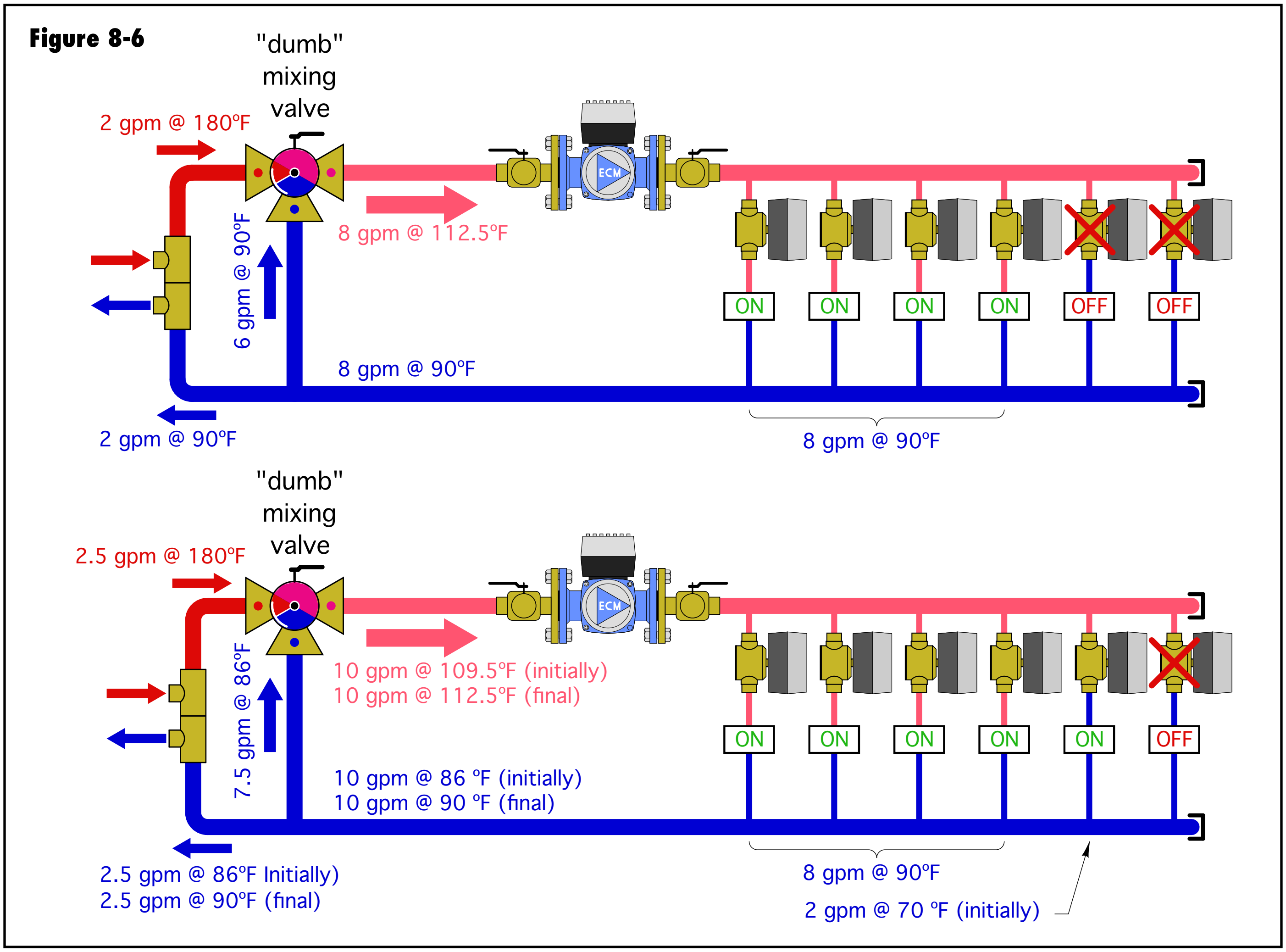
Mixing with "dumb" mixing valves:

Any mixing valve that is not controlled by a thermostatic actuator or a motorized actuator responding to an electronic controller is a "dumb" mixing valve. It may be of the finest construction and impeccably installed, but without an actuator, it cannot respond to changes in entering water-temperature or entering flow rate. An example of a dumb 3-way mixing valve supplying a manifold station is shown in figure 8-5.

Notice that the 3-way mixing valve has threaded eyelets to which an actuator could be attached. It is the same valve body that would be used with a motorized actuator, but in this system no actuator was installed.

Dumb mixing valves operate just like a simple (non-thermostatic, non-pressure- compensated) single-lever shower valve. If the temperatures, and flow rates of the entering hot and cool water do not vary, the mixed outlet temperature and flow rate from the valve remain steady. However, if either entering temperatures or flow rates change, so will the outlet temperature and flow rate.

Figure 8-5



Assuming the differential pressures across the valve do not change, the stationary spool within the mixing valve will maintain approximately the same *proportions* of entering hot and cool water.

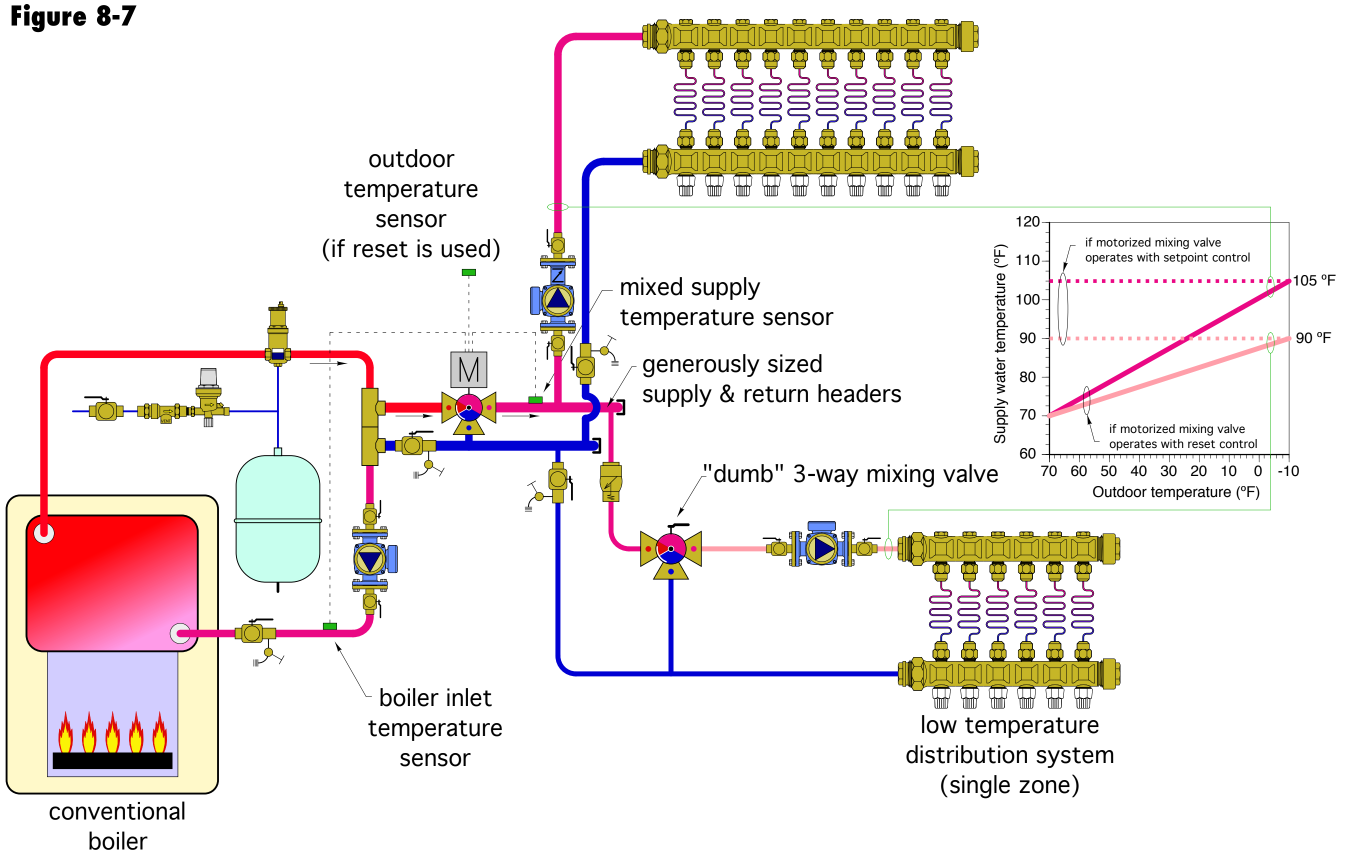
Here's an example: Consider the dumb 3-way mixing valve shown in figure 8-6. Initially, it's set to produce an outlet temperature of 112.5ºF based on the entering temperatures and flow rates shown, and with four identical zone circuits operating. A few minutes later, an additional zone circuit turns on. This circuit has been off for several hours and has piping filled with water at room temperature. This cool water combines with the return flow from the other zones. The water-temperature entering the cool port of the mixing valve quickly drops from 90ºF to 86ºF. This temporarily lowers the supply water-temperature leaving the mixing valve from 112.5ºF to 109.5ºF.

The dumb mixing valve cannot adjust to compensate for this change in supply temperature, and thus the supply temperature to the previously operating zones is reduced. The duration of this temperature depression is largely determined by the load and thermal mass of the zone that just turned on. If it's a zone with high thermal mass (i.e., a heated floor slab) the disturbance could last for several hours. This is not a desirable effect, and thus is not an acceptable application for a dumb mixing valve.

One acceptable application for a dumb mixing valve is shown in figure 8-7. The valve is used to reduce the water-temperature supplied to a heated basement floor. An upstream mixing assembly regulates the hot water-temperature supplied to the dumb mixing valve. That assembly may be configured to supply a fixed setpoint temperature or operate based on outdoor reset control.

The entire basement floor operates a single zone. When the basement zone circulator is on, flow rate within the subsystem is constant. Furthermore, the thermostat operating the basement zone is assumed to

Figure 8-7



have a fixed setting. No temperature setback schedule is used. Under these conditions, the performance of the dumb mixing valve will be acceptable. However, if either of the above-described constraints is not present, an intelligent mixing device should be used for the lower temperature distribution system.

SUMMARY:

Mixing is a critical element in modern hydronic systems. When properly executed, it improves comfort and reduces energy consumption. It also protects lower-temperature heat emitters from potential high-temperature heat sources such as storage tanks heated by solar collectors or wood-fired boiler systems. Mixing also reduces noises associated with the expansion and contraction of piping within the system.

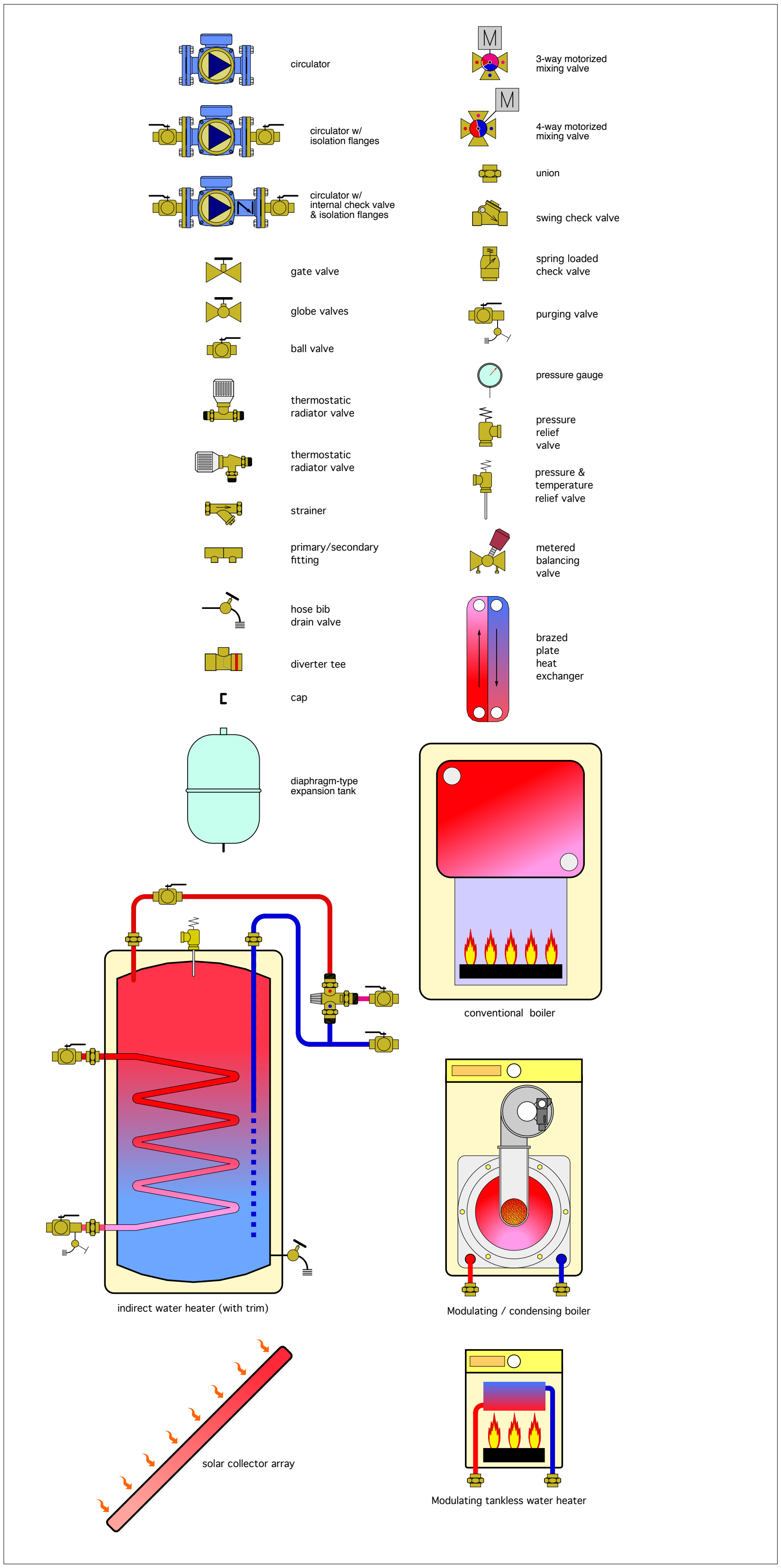
Whenever conventional boilers are used as a heat source for a low-temperature distribution system, the mixing assembly must prevent that boiler from operating with sustained flue gas condensation. This can only be done using intelligent mixing devices that sense and react to boiler inlet temperature.

Modern mixing methods and hardware make it easy to regulate one or more supply water-temperatures in a wide range of applications. These temperatures can be a fixed setpoint or reset based on outdoor temperature.

Properly sizing the mixing hardware to the flow rate and energy transfer rate of the distribution system is critical to good performance.

APPENDIX A: Piping Symbol Legend

GENERIC COMPONENTS



CALEFFI COMPONENTS