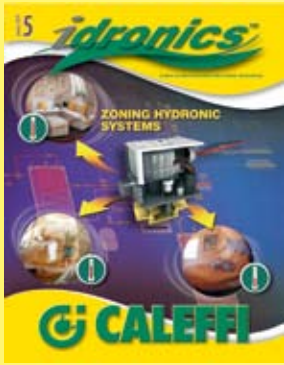


## ZONING HYDRONIC SYSTEMS





A Technical Journal  
from  
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Dear Hydronic Professional,

Welcome to the 5th edition of *idronics*, Caleffi's semi-annual design journal for hydronic professionals.

Zoned heating systems have been used for centuries. Even before hydronic heating was available, buildings were often divided into two or more areas in which comfort could be independently controlled — often through the use of individual heat sources such as fireplaces or stoves.

Today, zoning is a preeminent benefit of hydronic heating and cooling. When properly applied, it provides unsurpassed comfort control, flexibility and energy conservation.

To take full advantage of these benefits, designers must understand several principles that let zoned systems quickly adapt to constantly changing interior and exterior conditions. As has been the custom with *idronics*, these principles are discussed at a level appropriate for hydronic design professionals. They are then demonstrated in a wide variety of application drawings based on the latest hardware and design techniques. The goal is to facilitate zoned hydronic systems that are flexible, reliable, simple to build and highly energy efficient.

We trust you will find this issue a useful educational tool and a handy reference for your future system designs. We encourage you to send us feedback on this issue by e-mailing us at [idronics@caleffi.com](mailto:idronics@caleffi.com).

Finally, if you are interested in previous editions of *idronics*, please go to [www.caleffi.us](http://www.caleffi.us) where they can be downloaded for free. You can also register to receive future issues online.

Sincerely,

Mark Olson  
General Manager,  
Caleffi North America, Inc.

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# ZONING HYDRONIC SYSTEMS

## 1. INTRODUCTION

The purpose of any heating system is to provide comfort in all areas of a building throughout the heating season. Doing so requires a system that can adapt to the lifestyle of the building occupants, as well as constantly changing thermal conditions inside and outside of a building.

Imagine a building in which all rooms have the same floor area. Someone not trained in heating technology might assume that each room, because they are all the same size, requires the same rate of heat input at all times. Although such an assumption might be intuitive and simplistic, it fails to recognize differences in the thermal characteristics of the rooms.

Some rooms may have only one exposed wall, while other rooms might have two or three exposed walls. Some rooms might have a generous window area, while other rooms have no windows. The air leakage and potential for sunlight to enter through windows might also vary from one room to another.

Beyond these differences are conditions imposed by the occupants. One person might prefer sleeping in a room maintained at 65°F, while another feels chilled if their bedroom is anything less than 72°F. One occupant might prefer a living room maintained at 70°F while relaxed and reading, while another wants the temperature in the exercise room at 62°F during a workout.

The combination of room thermal characteristics, weather conditions and occupant expectations presents a complex and dynamic challenge for the building's heating system as it attempts to meet its purpose.

One of the methods that has long been used to help meet this challenge is dividing the building's heating system into multiple zones.

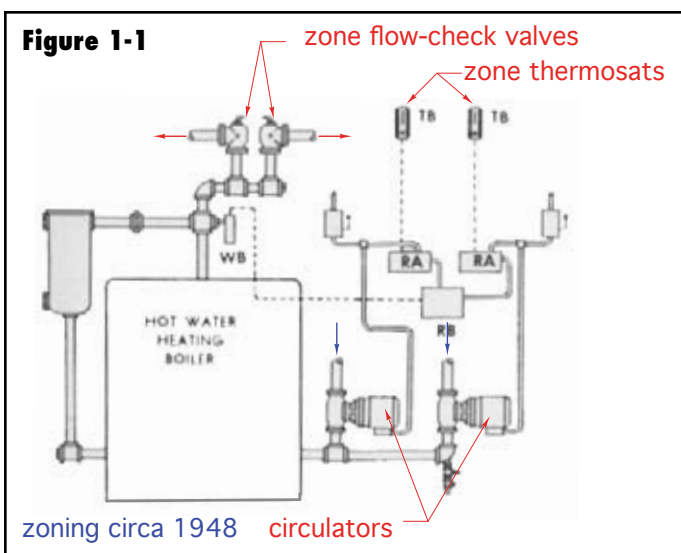
## WHAT IS A ZONE?

A zone is any area of a building for which indoor air temperature is controlled by a single thermostat (or other temperature sensing device). A zone can be as small as a single room, or it may be as large as an entire building.

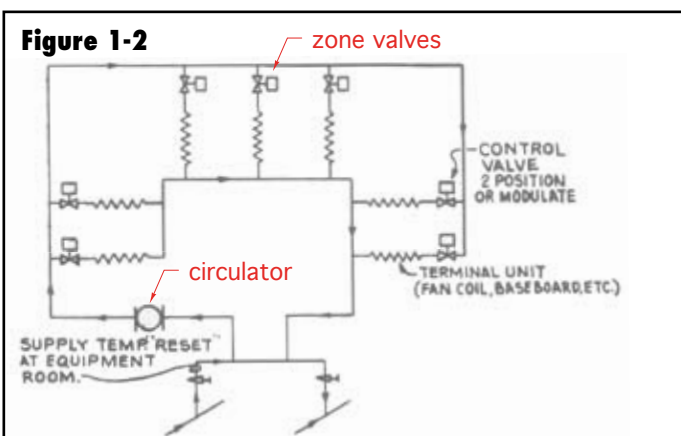
The number of zones in a building can range from one to as many rooms as are in the building. The latter scenario is called room-by-room zoning.

The greater the number of zones in a building, the more flexibility the occupants have in selecting comfort levels well-suited to the activities taking place within the building. However, the quality and performance of a zoned heating system is not necessarily determined solely by the number of zones it has.

Zoning has been used in hydronic systems for decades, as evidenced by the piping diagrams in figures 1-1 and 1-2.



Source: ITT Bell & Gossett Handbook, 2<sup>nd</sup> Edition (1949)



Source: ITT Bell & Gossett Primary Secondary Pumping Application Manual (1968)

Even earlier systems without circulators or electrical controls allowed for zoning through the use of manually operated valves to regulate flow through various portions of the system. By regulating flow through a hydronic heat emitter it's possible to regulate heat output from that emitter.

Although these early systems were rudimentary in comparison to modern hydronics technology, they recognized and addressed the need for zoning. They also demonstrated that zoning was easy to accomplish in hydronic systems relative to how it is achieved in other types of heating systems.

Multi-zone hydronic heating systems are easy to create and control, much easier than an equivalently zoned forced-air system. There are many hardware options currently available for hydronic zoning, and several of them will be presented and compared in this issue of *idronics*.

## WHAT DOES ZONING ACCOMPLISH?

The two most generalized benefits of zoning are:

1. It allows occupants to remain comfortable in all areas of the building during a variety of activities.
2. It provides the ability to reduce energy use by lowering temperatures in unoccupied areas of the building.

Any successful means of providing these benefits recognizes that the conditions representing comfort vary from one individual to another, as well as from one activity to another. Furthermore, these conditions are subject to constant change due to occupant activities or weather-related conditions. A well-executed zoning strategy must be dynamic and employ feedback control techniques.

## 2. ZONE-PLANNING CONSIDERATIONS

Before designing a zoned hydronic distribution system, it's important to assess the building along with its planned usage. The goal is to achieve the benefits of a zoned system while at the same time avoiding a system that's overly complex, expensive or difficult to control.

Given the variety of hardware now available for hydronic zoning, one might assume that the more zones a system has, the better that system was designed. This is not necessarily true. Just because it's easy to design and install a hydronic system in which every room is controlled as a separate zone doesn't mean it's the wisest choice. "Over zoning" adds to installed cost and complexity without returning commensurate benefits. It can also lead to issues

such as short cycling of the system's heat source, which lowers efficiency and adds to maintenance costs.

So what should be considered when planning a zoned hydronic system?

The following considerations all play a part in planning a zoned system.

### THE EFFECT OF THERMAL MASS:

People sometimes assume that a zoned heating system should be able to reduce the temperature within a space as soon as the thermostat setting is lowered. This is not possible because of the thermal mass of the building materials and heating system components within the space.

Thermal mass is the ability of materials to store heat. All materials have some amount of thermal mass, depending on their specific heat and density. Concrete, masonry and plaster have higher thermal mass per unit of volume than do materials such as wood or fabric.

The greater the total thermal mass within a room, the slower the air temperature will drop when the thermostat setting is reduced. Keep in mind that most thermostats are simply temperature-operated switches. Lowering the thermostat setting several degrees simply opens an electrical circuit and stops further heat input to the heat emitters in the space. It does not prevent the materials within that space from releasing their stored heat as soon as the air temperature or surface temperature of objects within that space becomes lower than the temperature of those materials.

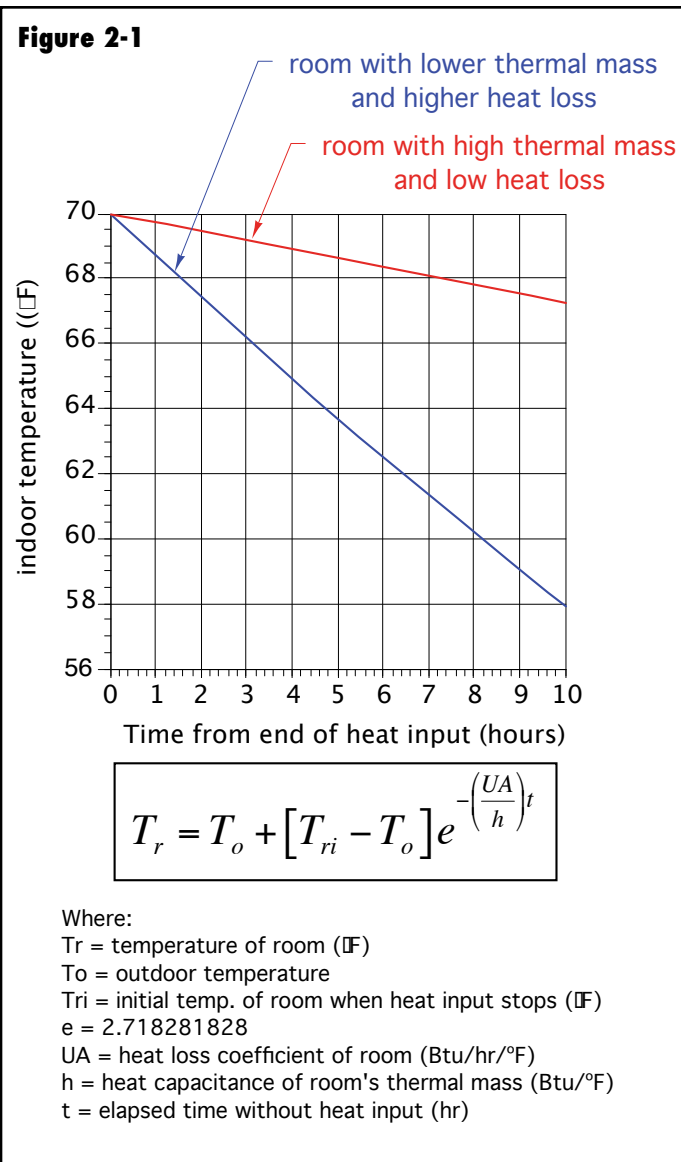
For example, consider a well-insulated room with a heated concrete floor slab. Assume the occupant reduces the thermostat setting in this room from 70°F to 65°F before heading to bed on a cold winter night. This action prevents further heat input to the slab by stopping water flow through the tubing embedded within it, or in systems with constant circulation, by stopping further heat input to the flowing water.

The combination of a well-insulated building envelope with high internal thermal mass might only allow the air temperature in this room to drop by 2°F or 3°F by the time the occupant wakes in the morning. The results would be the same if the thermostat had been turned down 10°F or even 20°F at bedtime. The energy savings achieved by this temperature reduction would be very small.

Now imagine the same room without the heated floor slab. Instead, the room is heated by a forced-air delivery system with very low thermal mass. Under the same

setback schedule and weather conditions, this room might drop to the reduced setpoint of 65°F within a couple of hours. At that point the heating system would add heat to keep the room temperature at about 65°F. Assuming this condition was maintained for the duration of the night, the room would lose heat to the outdoors at a significantly reduced rate (about 9 percent lower heat loss assuming the outdoor temperature is 0°F). The energy savings associated with this reduced temperature setting would be greater than that for the case of higher thermal mass.

The drop in room temperature as a function of elapsed time without further heat input is shown in figure 2-1. The greater the thermal capacitance (h) of the room relative to its heat loss coefficient (UA), the slower the drop in room temperature.



Thermal mass also affects the rate at which a space can be warmed to a higher temperature. Spaces with greater thermal mass can be significantly slower to warm compared to spaces with low thermal mass.

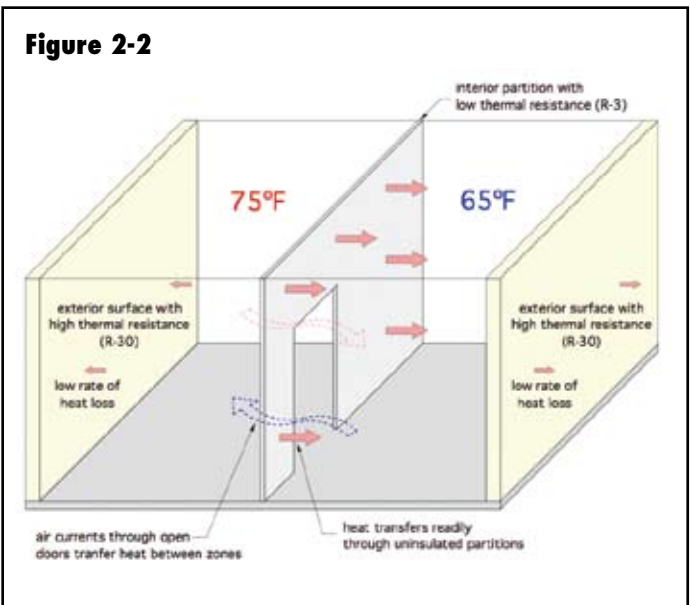
If rooms with significantly different thermal mass are combined into a single zone, their response characteristics will be very different, and it's likely this response won't be acceptable to the occupants.

Thus, when two or more rooms are being considered to operate as a single zone, it's important to ensure they have similar thermal mass in both their interior materials as well as their heat emitters. For example, it would not be wise to add a room with a heated floor slab onto the same zone as a room with a panel radiator.

### HEAT TRANSFER BETWEEN ZONES:

Imagine a building in which each zone is a separate "compartment" that's thermally isolated from the other zones. In such a scenario, one could set the temperature of one zone at perhaps 70°F and the temperature of an adjoining zone at say 60°F. The heat emitter(s) within each zone would release only the heat necessary to maintain these temperatures. One could walk between these zones without disturbing these temperatures.

In reality, such a scenario doesn't exist. The separation between zones is often an uninsulated interior partition. In many cases there are also open doorways or hallways connecting zones, as shown in figure 2-2. Even in cases where zones are separated by closed interior doors, those doors seldom provide much resistance to heat flow.



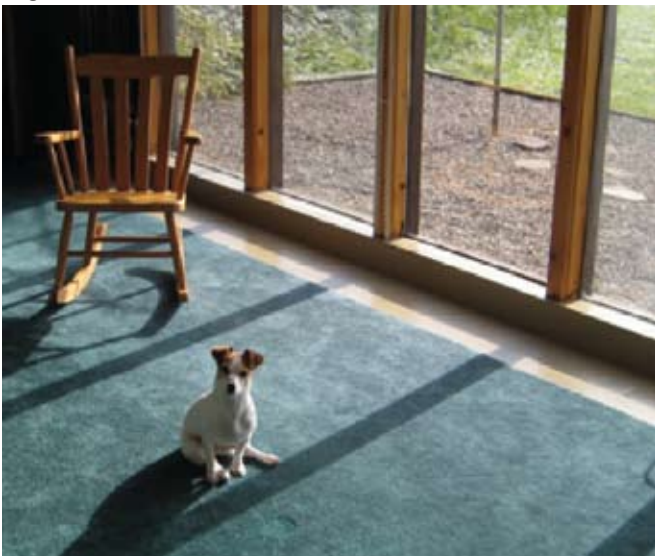
The relatively weak thermal separation of most interior zones results in uncontrolled heat flows between them. A room maintained at 70°F will transfer heat through the relatively low thermal resistance of a typical interior partition to an adjoining room at a lower temperature. This effect is even more pronounced in buildings having exterior surfaces with high thermal resistance. It makes it difficult to maintain temperature differences of more than about 5°F between rooms, even when the doors in those rooms are kept shut. This effect partially defeats one of the often-intended uses for zoning. It also suggests that it does not always make sense to put adjacent rooms on separate zones if the intent is to maintain significant temperature differences between them.

In cases where it is desirable to maintain higher temperature differences between zones, interior partitions should be insulated, and interior doors between those zones must provide a relatively tight seal against interior air flow. Although this type of construction and usage is possible, it's not customary in modern residential or commercial buildings.

### **INTERNAL HEAT GAINS:**

All buildings experience heat input from sources other than their heating system. These effects are called internal gains. Examples include heat from sunlight entering windows, or heat generated by equipment, lights or occupants in the space. Buildings with few windows and low occupancy typically have low internal heat gain, while buildings with significant window areas on east, south or west walls, or which contain a variety of equipment and/or people, may have very high internal heat gains (see figure 2-3).

**Figure 2-3**



Internal heat gain plays a significant role in determining thermal comfort, and as such, must be considered when planning zones. In general, areas in which high internal heat gains are expected should not be on the same zone as rooms with minimal internal heat gains.

An example would be a house with significant window areas on the east, south or west sides. As the sun moves across the sky on a clear day, rooms with east-facing glass will warm first due to solar heat gain. Next to warm will be rooms with southerly facing windows. During the afternoon, rooms with west-facing glass will experience solar heat gains. During this same time, rooms with north-facing glass will experience very little solar heat gain. Maintaining comfort in all these rooms requires they be operated as separate zones. This allows heat input to each zone to be reduced as necessary to compensate for the solar heat gains. Equally important in this situation would be heat emitters with relatively low thermal mass, and hence the ability to quickly increase or decrease heat input in response to internal heat gains.

The internal heat gains from occupants depend on the number of people present and their activity level. For example, a sedentary adult will typically generate 350 to 400 Btu/hr of metabolic heat output. The same person engaged in a strenuous activity could generate close to 2,000 Btu/hr.

Internal heat gain from electrically operated devices within a space is relatively easy to estimate once the wattage of the devices is determined. The rate of heat generation is simply the wattage of the device multiplied by 3.413 to convert to Btu/hr.

### **OCCUPANCY SCHEDULE:**

Zoning allows the temperature of unoccupied spaces to be reduced, which leads to lower energy use. To take advantage of this, zones must be planned in a way that recognizes and separates the spaces where this temperature setback is likely from zones where temperature setback is unlikely.

Zoning sleeping areas separately from daytime occupied areas is usually a good idea. Occupants might also want to zone a bathroom area separately from a sleep area, so the former can be brought to a comfortable condition for showering or dressing at wake-up time, even when bedrooms are at a lower temperature.

Rooms that are only used occasionally are also good candidates for separate zoning. Examples include a guest room, workshop area or a recreation room. If such

areas are zoned separately, it's also important to consider the time required to bring them from a setback temperature to full comfort. Zones maintained at significantly reduced temperatures and having high thermal mass can take several hours to recover 5°F to 10°F. If this is unacceptable, those spaces should be heated with low mass heat emitters that release a significant portion of their output as radiant heat. This allows comfort to be established quickly, even before the air temperature in the space has increased to the new setpoint.

Areas with significantly different occupancy schedules should not be included on the same zone.

### ROOM-BY-ROOM ZONING:

There are several ways in which each room of a building can be operated as a zone. In some cases this can be accomplished at very little additional cost. In other cases, it adds thousands of dollars to the system's installed cost.

Given the previously described zone-planning considerations, it often seems that room-by-room zoning is the "ultimate" way to divide a heating system to provide the greatest adaptability to factors such as differences in thermal mass, internal heat gain or occupancy schedules. If the building is such that each room is operated as an isolated compartment capable of experiencing wide variations in occupancy, temperature setbacks and internal gain, then room-by-room zoning does make sense. However, such a scenario is not very common. It might be possible in a nonresidential building, where doors between the rooms are often closed, where several people may gather in any of these rooms at any time or where rooms are otherwise subject to wide variations in heat gain.

In some cases, room-by-room zoning is selected based on the desire to maintain rooms at different temperatures. In many cases this can be accomplished by adjusting the flow rate through the heat emitters serving each room. Flow rates would be reduced for rooms that are to be kept at lower temperatures.

One could argue that it's simpler to reduce the size of the heat emitter in rooms to be kept at lower temperatures. While this is possible, it's also a more permanent decision compared to sizing each heat emitter so it's capable of maintaining its associated room at normal comfort conditions, and then temporarily lowering its heat output by reducing the flow rate.

In some cases, occupants use room-by-room zoning as a means of balancing the system. The thermostats in each room are adjusted to the desired setting and

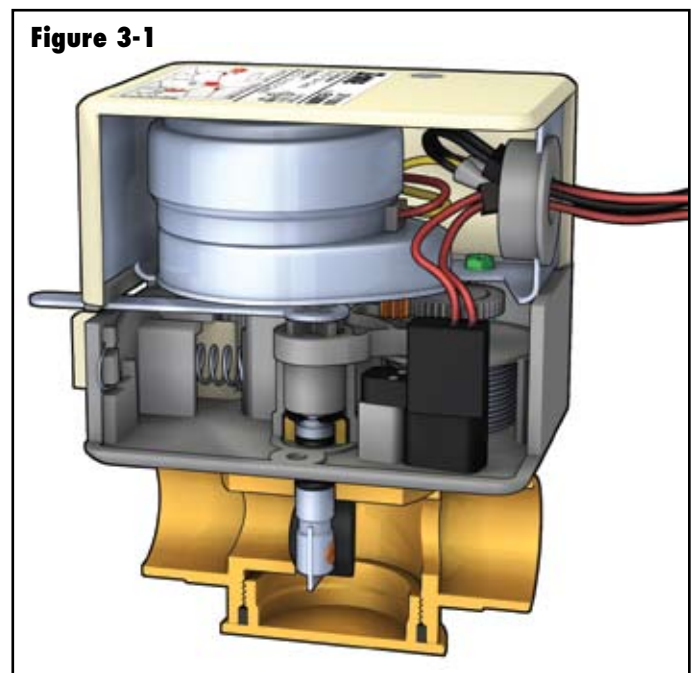
then left at that setting. Although this does allow for different temperatures in different rooms, it's often much more expensive than providing for and making flow rate adjustments to each zone.

In situations where the temperature of each room will be varied on a *regular basis*, it does make sense to provide room-by-room zoning. This also makes sense when the added cost to provide room-by-room zoning is minimal. An example of the latter would be panel radiators equipped with thermostatic radiator valves and piped using a manifold distribution system.

### 3. ON/OFF ZONING WITH ELECTRICALLY OPERATED VALVES

#### 2-WAY ELECTRICALLY OPERATED ZONE VALVES:

One of the most traditional methods for zoning hydronic systems is based on 2-way electrically operated zone valves. An example of such a valve is shown in figure 3-1.



Most hydronic zone valves have brass bodies. The inlet and outlet ports are configured with either threaded or solder connections. Within the valve's body is a high-temperature polymer disc secured to a rotating shaft. As the shaft is rotated through its full range of motion, the disc moves from a position where it completely covers the orifice through the valve to a position where maximum flow can pass through the valve. The shaft is sealed into the body with multiple O-rings to prevent leakage.

The upper portion of a zone valve is called its actuator. It provides the rotary motion of the shaft when electrical power is applied.

Some zone valves use “heat motor” actuators. Linear movement of the valve’s shaft is created by thermal expansion of a wax compound that is sealed within an expandable chamber and heated by an electrically powered resistor. This type of actuator usually requires two to three minutes to reach its fully open position after electrical power is applied.

Most modern zone valves have actuators that use a small synchronous motor coupled to a gear assembly to rotate the valve’s shaft. These valves usually open in two to three seconds after electrical power is applied.

Both types of actuators have been used in the hydronic industry for many years.

As the actuator opens the valve, it also winds up an internal spring. This spring provides the torque necessary to close the valve when electrical power is removed. The ability of the valve to remain closed under various system operating conditions depends on the strength of this spring. Stronger springs provide greater “close-off pressure.” The close-off pressure rating of a zone valve must be equal to or greater than the maximum differential pressure the valve will experience in a given system. This, in turn, depends on how differential pressure is regulated in the system, which is discussed in section 5.

Most modern zone valves allow the actuator to be quickly separated from the valve body. This allows the valve body to be installed without the possibility of damaging the actuator. It also allows a failed actuator to be quickly replaced without having to remove the valve body or draining system fluid.

On/off zone valves are intended to operate in either their fully open or fully closed position. This distinguishes them from *modulating* valves, which are intended to operate fully open, fully closed or anywhere in between.

When a 2-way on/off zone valve is closed, it prevents any flow through its associated circuit. When open, it allows flow in the circuit to a degree dependent on the circuit’s hydraulic characteristic, which is partially determined by the zone valve itself, as well as the other piping components in the circuit and the system circulator.

Zone valves that are closed when the actuator is not energized are called “normally closed” valves. This is the

most common type of zone valve used in hydronic heating systems. However, there are applications where it may be desirable to have the valve open until power is applied to the actuator to close it. In this case, a “normally open” actuator would be attached to the valve. A normally open actuator closes the valve when power is applied.

### FLOW COEFFICIENT:

As with other valves, the relationship between the flow rate through a zone valve and the corresponding pressure drop across the valve is described by the flow coefficient (or Cv value) of the valve. By definition, the Cv of a valve is the flow rate of 60°F water passing through the valve, measured in gallons per minute, that produces a pressure drop of 1 pound per square inch (psi) across the valve. The Cv is always determined with the valve in its fully open position.

The mathematical relationship between pressure drop, flow rate, density of the fluid and the valve’s Cv is given as formula 3-1:

Formula 3-1:

$$\Delta P = \left( \frac{D}{62.4} \right) \left( \frac{f}{C_v} \right)^2 = \left( \frac{D}{62.4} \right) \frac{f^2}{C_v^2}$$

Where:

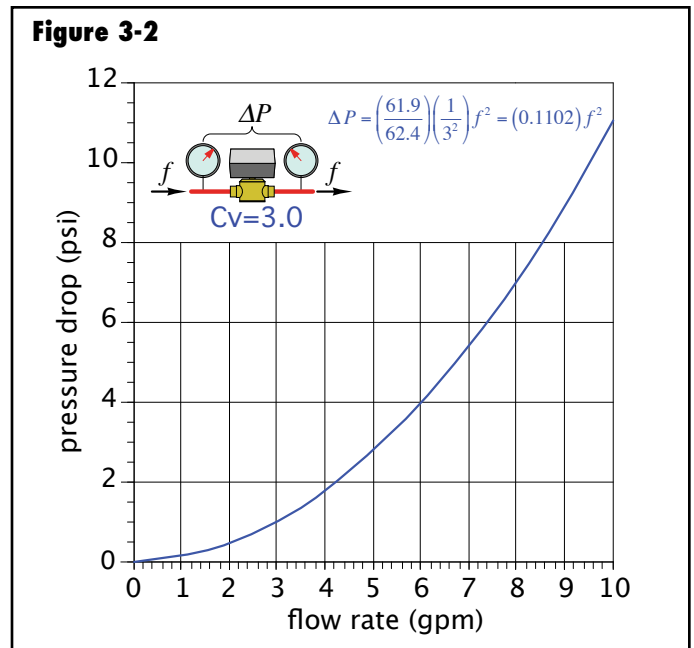
$\Delta P$  = pressure drop across valve (psi)

D = density of fluid passing through the valve (lb/ft<sup>3</sup>)

f = flow rate through valve (gpm)

Cv = flow coefficient of the valve

62.4 = density of water at 60°F





Formula 3-1 implies that doubling the flow rate through a valve increase the pressure drop across that valve by a factor of four. This effect causes the pressure drop across the valve to increase rapidly with increasing flow rate. This effect is shown in figure 3-2 for a valve with a Cv value of 3.0, and operating with water at 100°F.

Zone valves of a given pipe size are often available with several Cv ratings. The Cv is usually determined by the size of the orifice within the valve.

Customarily, zone valves are often selected with a Cv value approximately equal to the flow rate expected through them when the zone is open. The pressure drop across the valve under such conditions would be approximately 1 psi.

### ELECTRICAL OPTIONS FOR 2-WAY ZONE VALVES:

Zone valves can be equipped with actuators that operate at different voltages. The most common operating voltage for zone valves in standard heating systems is 24 volts supplied by alternating current (abbreviated as 24 VAC). This voltage is supplied by a step-down transformer within the system. It allows the zone valve to be classified as a class 2 device under the National Electrical Code (NEC). As such, it can be wired with standard thermostat cable. This cabling does not have to be enclosed in conduit.

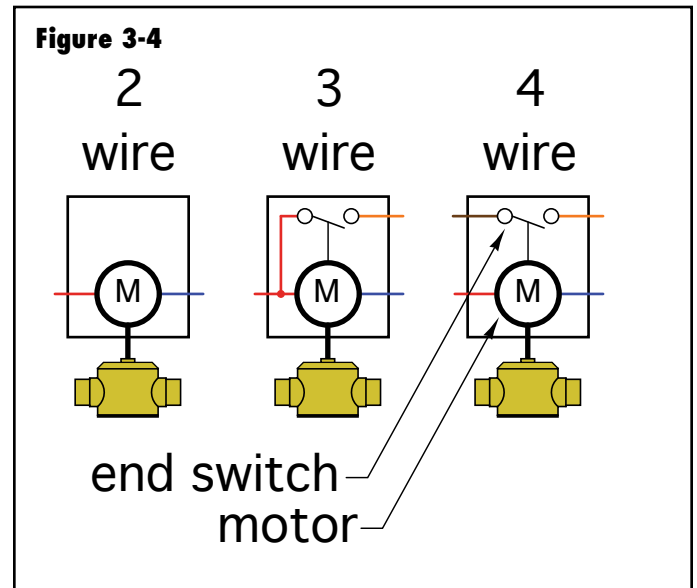
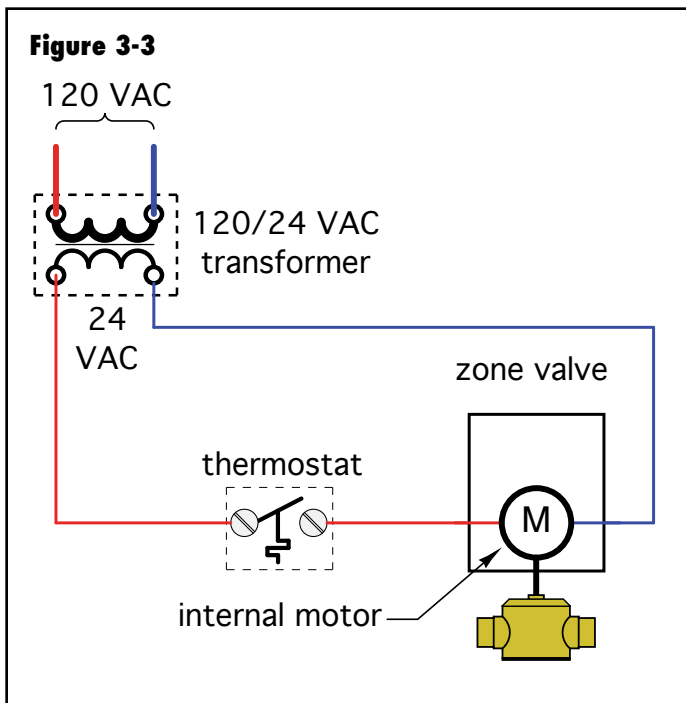
In some cases, it may be desirable to operate a zone valve using either 120 VAC or 240 VAC. Actuators suitable for these voltages are available. All wiring at these line voltages has to be protected based on both the NEC and any local electrical codes. An approved line voltage connector must be used to secure the power cable to the actuator housing.

Zone valves are usually controlled by a thermostat. The most common configuration is one zone valve with one associated thermostat. The thermostat serves as a temperature-operated switch. When the air temperature within the zone decreases slightly, the contacts within the thermostat close. Voltage passes through these contacts and on to the actuator motor in the zone valve. A second wire from the zone valve connects to the low-voltage (or common) side of the power supply. This is illustrated for a typical 24VAC zone valve in figure 3-3.

There are three internal wiring configurations for 24-volt zone valves. They are named based on the number of wires coming from the valve:

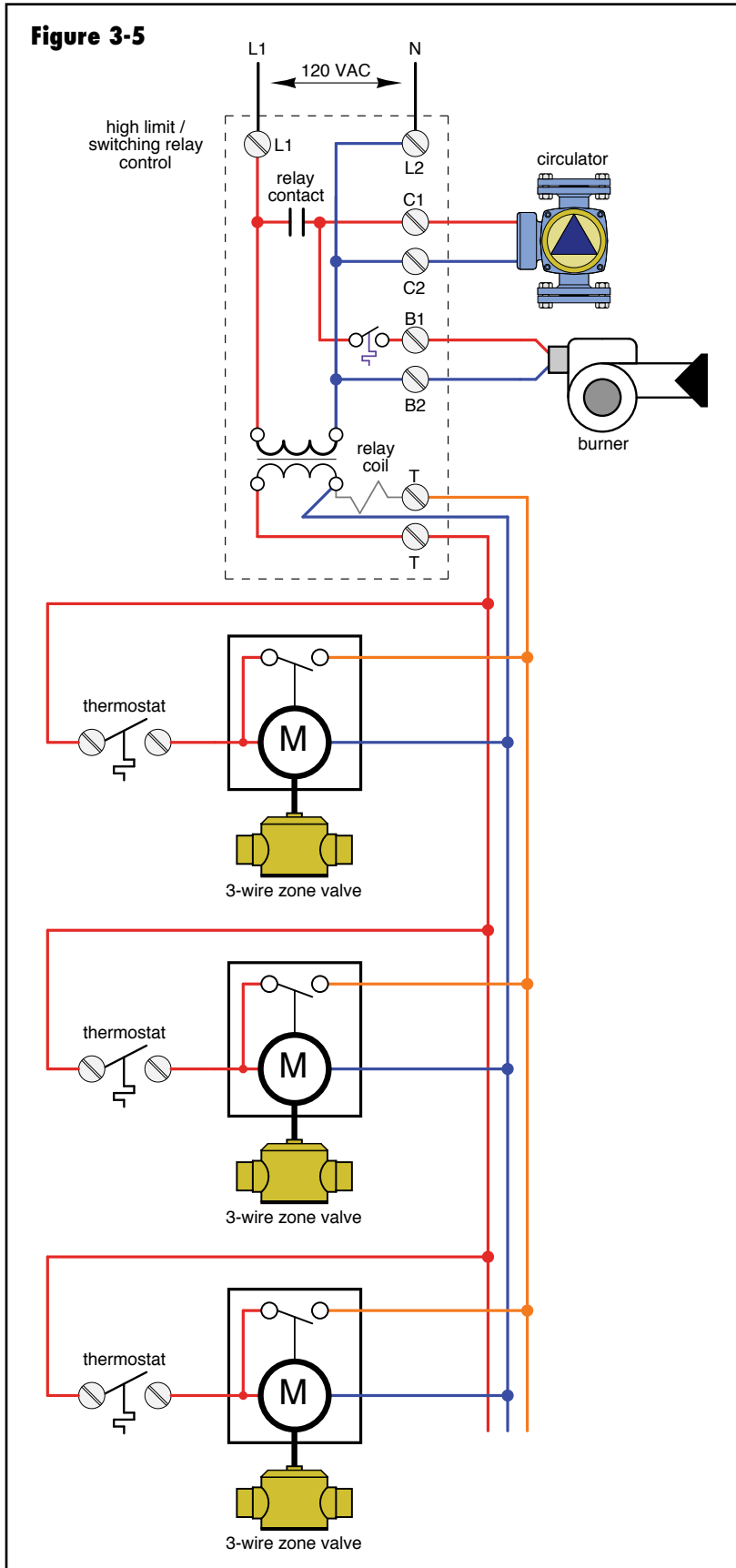
- 2-wire
- 3-wire
- 4-wire

Figure 3-4 illustrates the differences in internal wiring.



A 2-wire zone valve has only the wires necessary to operate its motor. In most cases, these wires are not polarity sensitive. One wire brings 24 VAC power to the valve's motor, and the other connects back to the common side of the transformer.

**Figure 3-5**



A 3-wire zone valve adds an end switch to the actuator. This switch is mounted so that it closes when the zone valve reaches its fully open position (e.g., the “end” of its travel). The closed switch verifies that the valve is fully open and can be used to initiate operation of other devices in the system, such as the circulator, heat source and a mixing device. Reed type end switches that are fully sealed from atmospheric conditions provide the longest service life.

The internal wiring in a three-wire zone valve is such that the 24 VAC voltage used to operate the actuator’s motor also passes through the valve’s end switch when it closes. An electrical schematic showing how 3-wire zone valves are used in combination with a boiler high-limit controller is shown in figure 3-5.

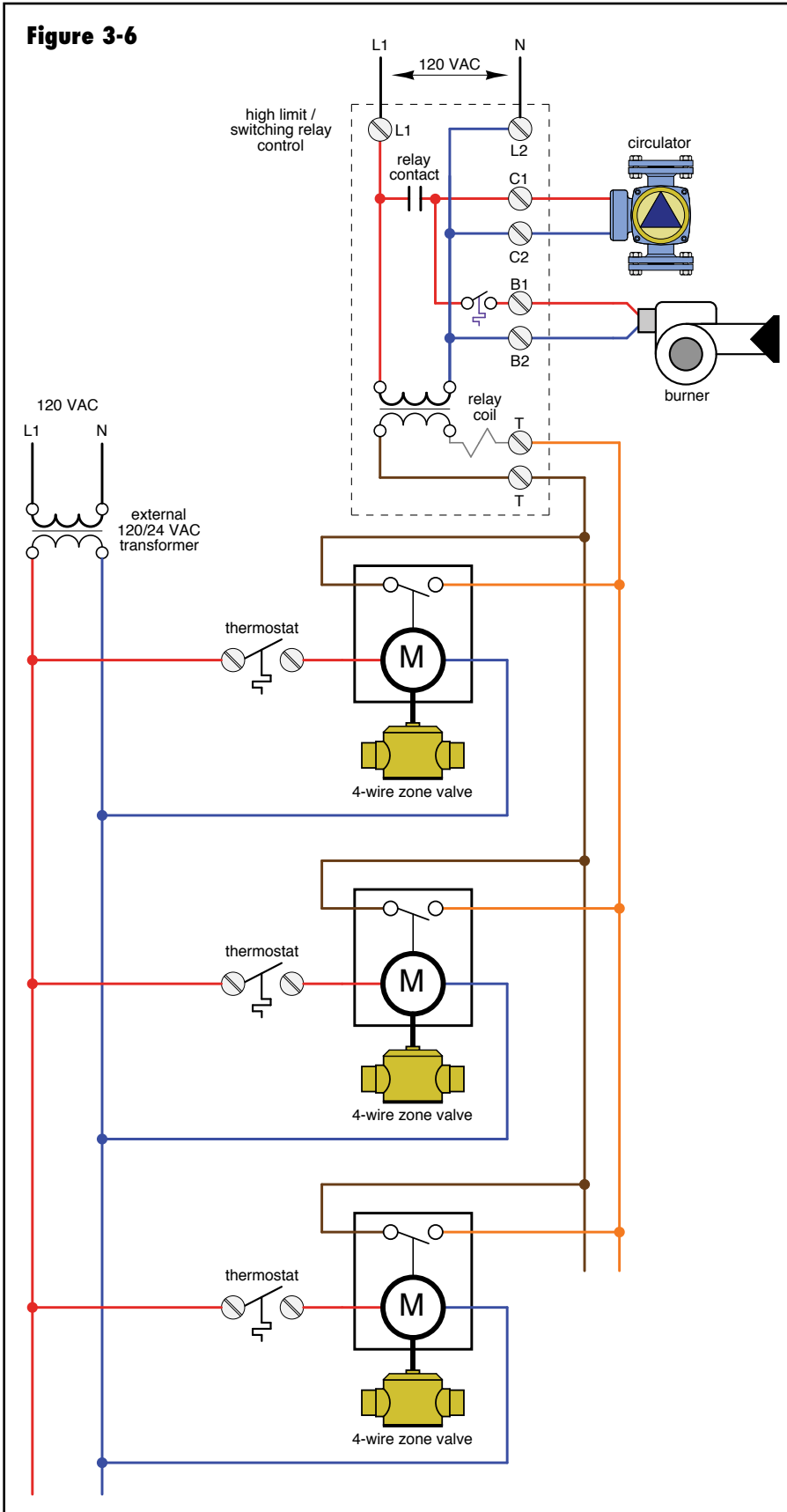
In this wiring arrangement, the 3-wire zone valves are powered from the transformer within the boiler high-limit controller. This is acceptable provided the internal transformer provides sufficient external power capability. However, if the total power required by all attached zone valves exceeds this capability, the transformer can be damaged.

The electrical power required to operate the zone valve’s actuator is expressed in volt-amps (abbreviated VA). The VA rating of a zone valve operated by alternating current is slightly higher than the wattage required by the actuator. This is due to the inductance effect of the actuator motor.

The VA required to operate a zone valve is specified by its manufacturer and is usually listed on the side of the actuator enclosure. Modern zone valves typically require 2 to 7 VA each while operating.

When multiple zone valves are powered from the same transformer it’s important that the transformer’s VA rating is slightly higher than the total VA required by all valves powered by it. A safety factor of 10 VA above the sum of the VA rating of all connected valves and other equipment operated by the transformer is suggested. Failure to adequately size the transformer can lead to overload and burnout. It may also cause damage to the motor in the zone valve.

**Figure 3-6**



A four-wire zone valve also contains an end switch. However, this switch is electrically isolated from the wiring used to operate the actuator motor. As such, it is sometimes referred to as a “dry contact.” Because it is electrically isolated from the actuator motor, this end switch can be part of a separate circuit and can convey voltage from a transformer other than the one used to operate the valve’s actuator. A typical wiring diagram for a four-wire zone valve is shown in figure 3-6.

### PIPING FOR 2-WAY ZONE VALVES:

A piping schematic showing a typical hydronic heating system using 2-way normally closed zone valves is shown in figure 3-7.

The zone valves are located on the supply side of the zone circuits, just above the supply header. This allows the closed valve to block heat migration from inactive zone circuits due to the presence of hot water in the supply header.

In this system, a fixed-speed circulator operates whenever any zone valve is powered on by its associated thermostat. If a 3-wire or 4-wire zone valve is used, the end switch of any active zone valve provides the signal necessary to turn on the circulator and enable the boiler to fire. Heated water is circulated through any zone circuit that happens to be on. This continues until the thermostat for the zone is satisfied. At that point, the zone valve is turned off and closes. When no zones require heat, the circulator and burner are also turned off.

Notice that purging valves are shown on the return side of each zone circuit. These allow each circuit to be rapidly purged of air when the system is first installed or after it is serviced. Another purging valve is shown near the boiler inlet to ensure thorough bulk air removal from the header piping. Purging of zoned systems is discussed in section 9.

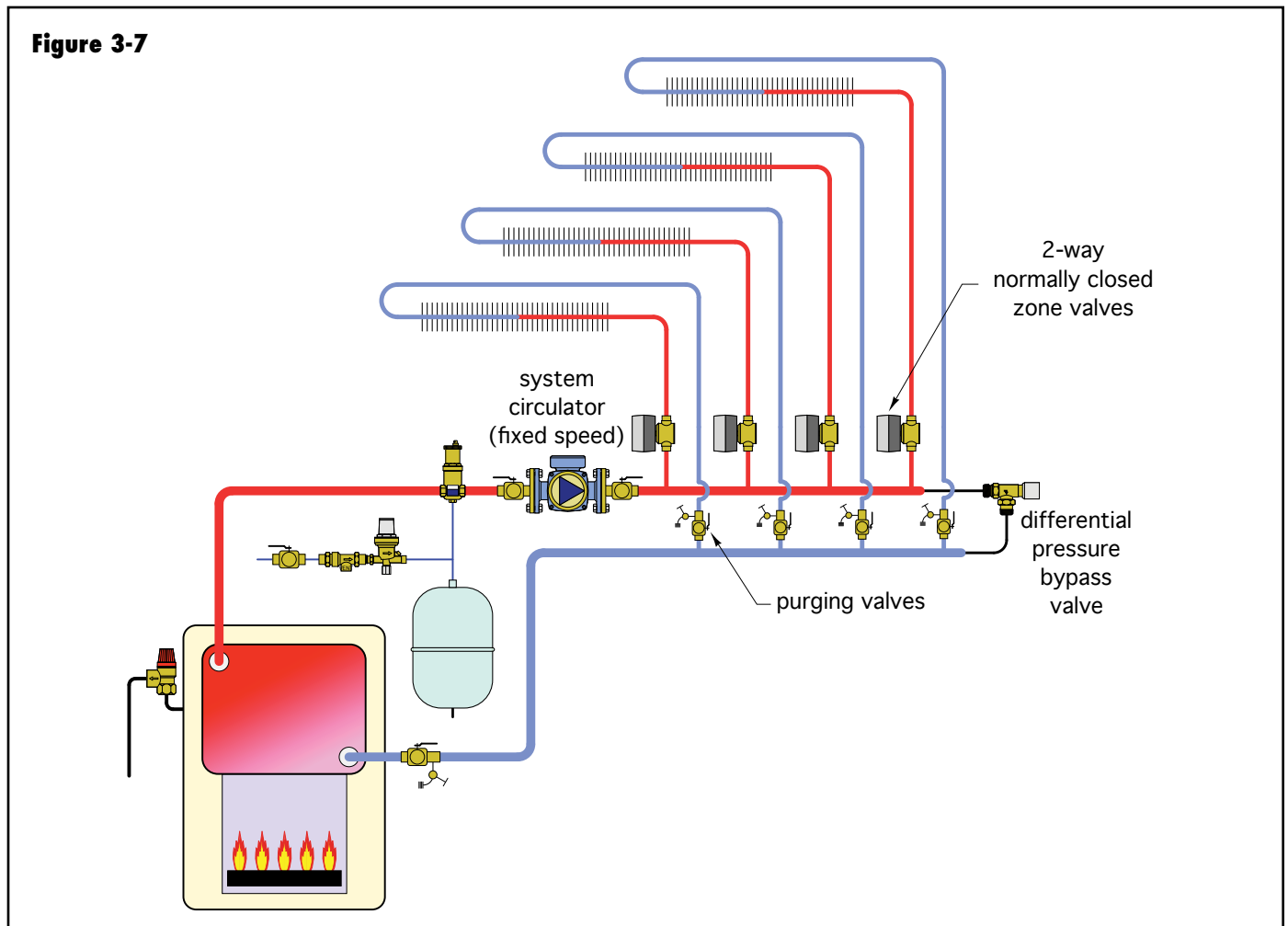
The system in figure 3-7 has a differential pressure bypass valve installed at the end of the headers. This valve prevents excessively high differential pressure from occurring in situations where a fixed-speed circulator is used, and only one or two zone circuits are operating. A detailed discussion of how this valve operates is given in section 5.

An alternative piping system using the same 2-way normally closed zone valves is shown in figure 3-8. This system uses a variable-speed pressure-regulated circulator in place of the fixed-speed circulator shown in figure 3-7. This circulator contains electronics that automatically control its speed as the number of active zone circuits increases or decreases. By controlling its speed, this circulator can maintain a constant differential pressure across the supply and return headers. This eliminates the need for a differential pressure bypass valve. It also reduces the power required by the circulator under partial load conditions when not all zones are operating. The use of such circulator is also discussed in detail in section 5.

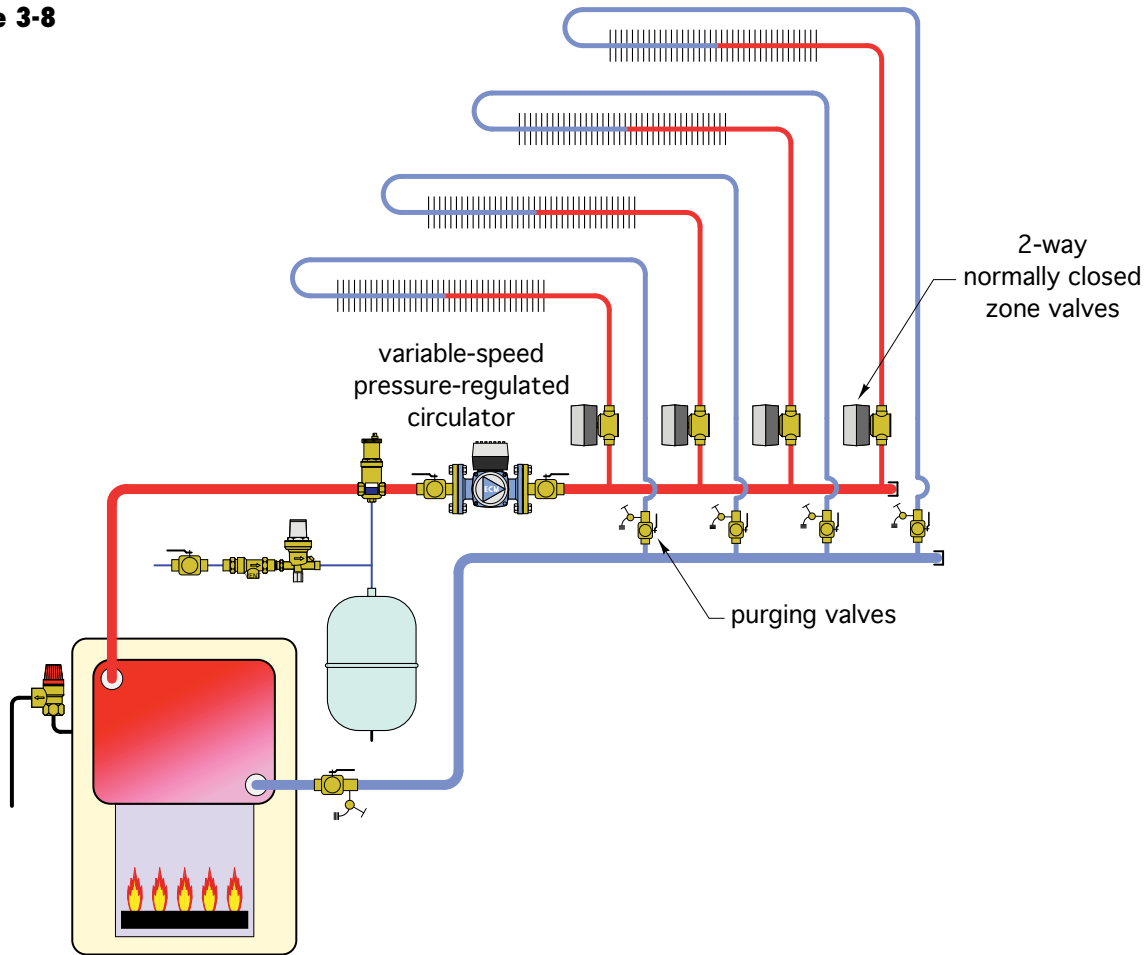
### 3-WAY ELECTRICALLY OPERATED DIVERTING VALVES:

There are situations where it's necessary to redirect fluid streams within hydronic systems. This is called diverting, and it can be done using a 3-way diverter valve. The internal construction of such a valve is shown in figure 3-9.

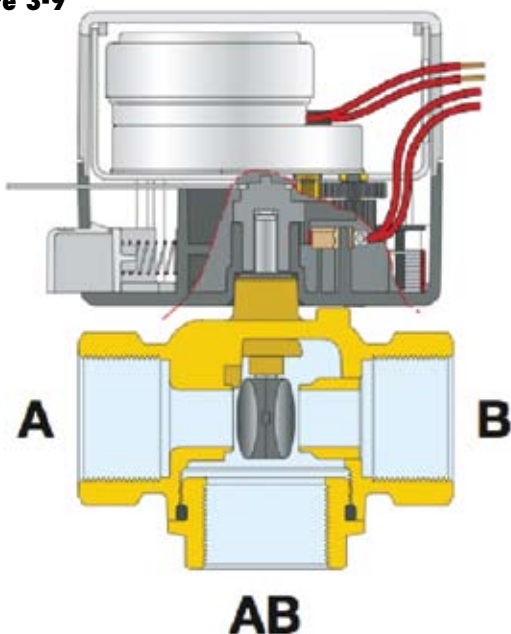
In a 3-way diverter valve, the disc is designed so it can cover the orifice leading to either side port of the valve. When the actuator is not powered, the disc covers the "A" port of the valve, blocking flow through it. At the same time, the "B" port is fully open. When the actuator is energized, the disc rotates to cover the valve's "B" port, and the "A" port is now fully open. The "AB" or "common" port of the valve is open at all times. 3-way diverter valves only operate in these two positions and are different from 3-way mixing valves, which can position the flow control element anywhere along its full range of travel.



**Figure 3-8**



**Figure 3-9**

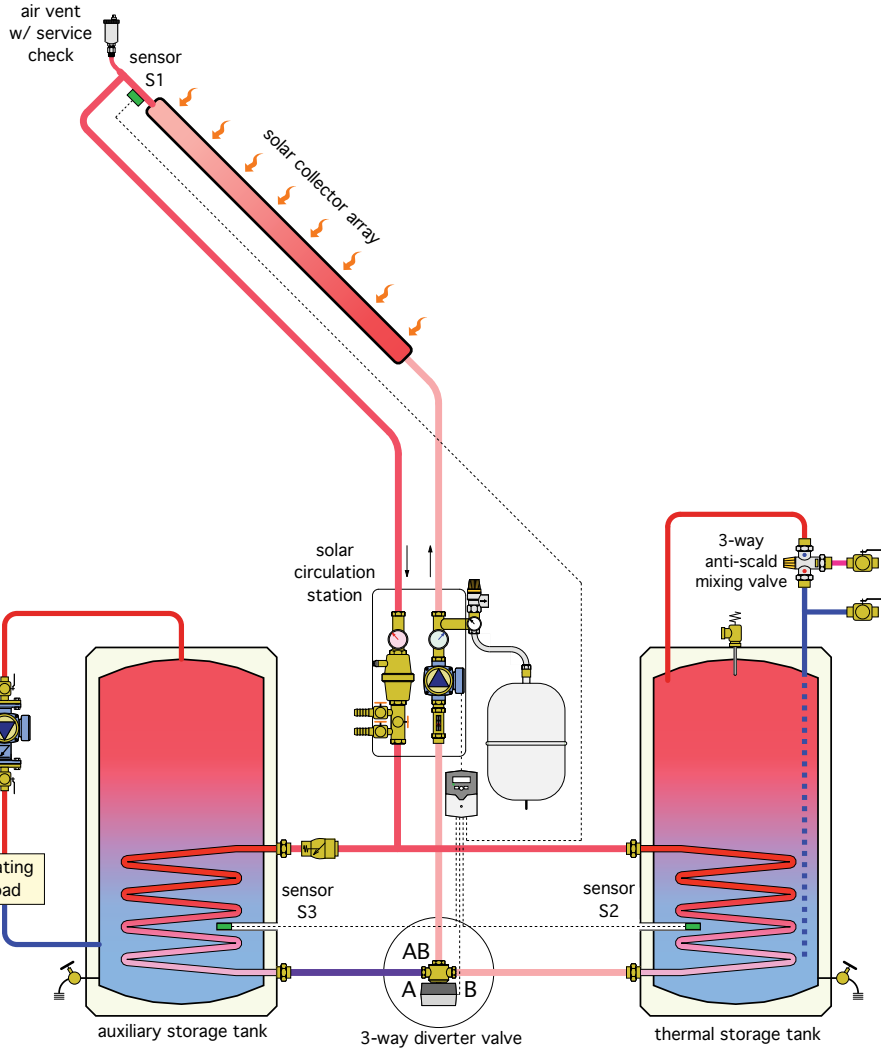


As with 2-way valves, the relationship between flow rate and pressure drop through a 3-way diverter valve depends on the valve's Cv rating. Valve bodies having the same nominal pipe size are available with different Cv ratings for different applications.

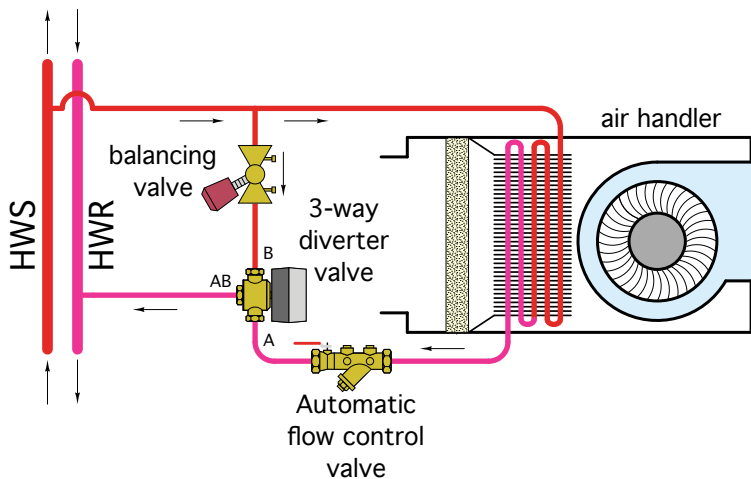
An example of a diverting application is shown in figure 3-10. In this system, the diverter valve is used to route the hot antifreeze solution returning from the solar collector array to a second storage tank. When the main storage tank reaches a preset upper temperature limit, the valve's actuator is energized to close the "B" port and open the "A" port. In both cases, flow passes through the common "AB" port. The valve is located on the outlet side of the heat exchangers to reduce exposure to potentially high temperatures.

3-way diverting valves have also been used to control flow through air handler coils, as shown in figure 3-11. In this configuration, water from the hot supply riser passes through the bypass pipe and the "B" port of

**Figure 3-10**

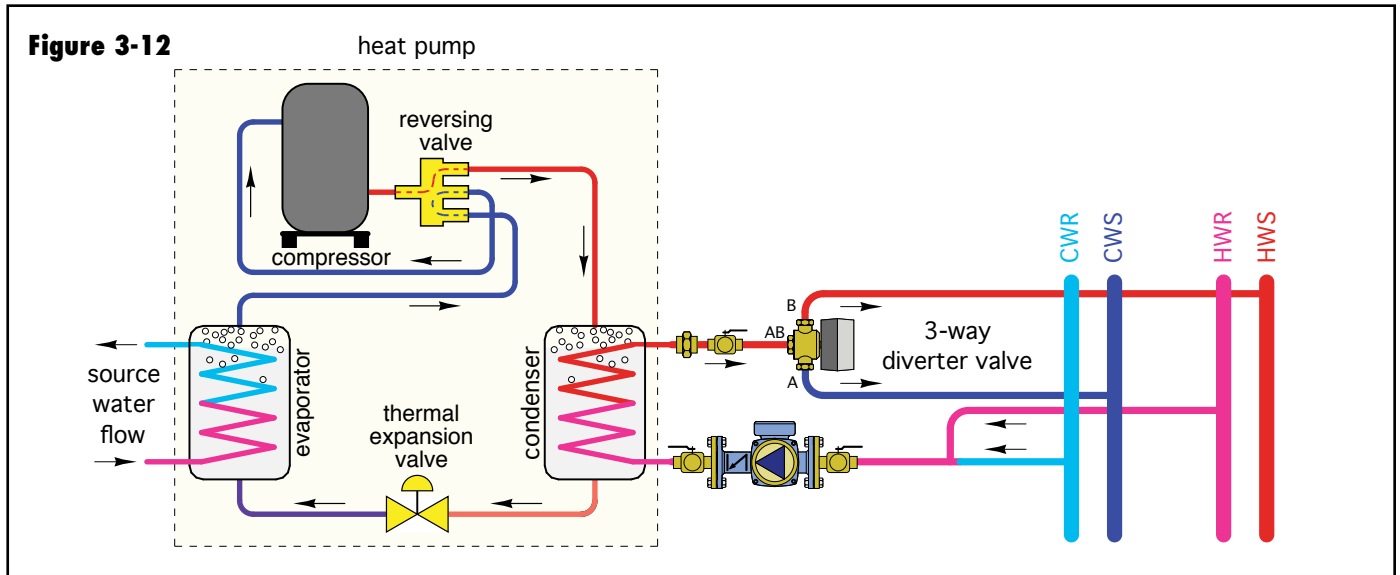


**Figure 3-11**



the diverter valve when the air handler does *not* require heat. It then flows back to the hot water return. The balancing valve in the bypass pipe limits the flow rate through the bypass. When the air handler operates, the 3-way diverter valve closes the “B” port and opens the “A” port to direct flow through the air handler coil. An automatic flow control valve limits flow through the coil.

3-way diverter valves can also be used to direct the flow leaving a combined heating/ cooling source, such as a heat pump, to the appropriate distribution riser



system, as shown in figure 3-12. In this diagram, the risers for hot water supply and return, as well as those for chilled water supply and return, are serving as headers that are hydraulically separated from load circuits. The circulator on the right side of the heat pump creates flow through these risers.

In the heating mode, the circulator pushes water from the heating water return riser into the heat pump's condenser. The higher temperature water leaving the heat pump flows through the "B" port of the diverter valve and on to the hot water supply riser. In the cooling mode, cool water returns to the heat pump, is chilled to a lower temperature, and then passes through the "A" port of the 3-way diverter valve on its way to the chilled water supply riser.

In the past, 3-way diverting valves were used for zoning. They allowed flow not needed in a zone circuit to return to the boiler. In doing so, they limited changes in differential pressure within the distribution system. However, this approach does not necessarily reduce circulator energy consumption under partial-load conditions. It also requires more piping than a system using 2-way zone valves, a fixed-speed circulator and a differential bypass valve. The availability of variable-speed pressure-regulated circulators has made this method of zoning obsolete.

### ZONING WITH MANIFOLD VALVE ACTUATORS:

One of the most modern approaches to hydronic zoning is based on the use of manifold stations. This type of system is similar to one using 2-way on/off electrically operated zone valves. However, the valves are now integrated into a single preassembled component rather than individually mounted. This approach also makes

use of flexible PEX or PEX-AL-PEX tubing, rather than traditional rigid piping, to supply each of the system's heat emitters. This combination is often called a "homerun distribution system" because water flows from a central manifold station, through a separate tube to each heat emitter, and then back to the manifold station.

**Figure 3-13**



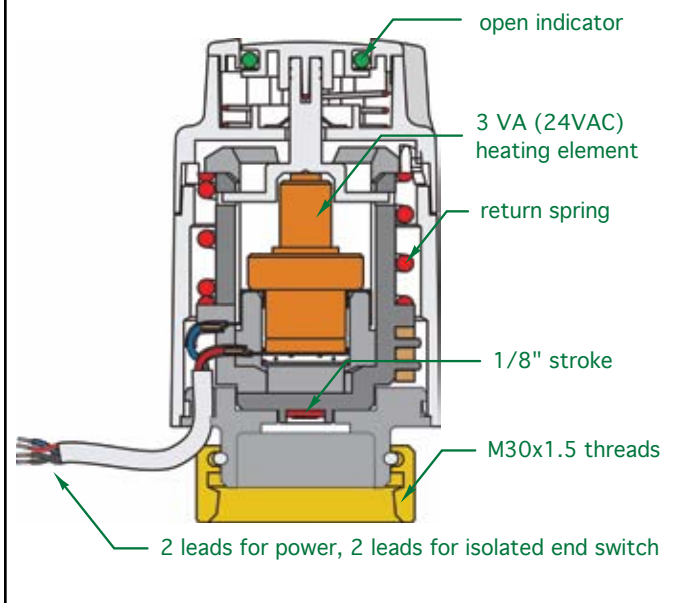
**Figure 3-14**



Figure 3-13 shows an example of a circuit valve built into the return manifold. These valves are opened and closed with a simple linear (versus rotational) movement of their shaft. Manifold valves are spring loaded. The spring force maintains the valve in its open position. A manifold valve can be manually adjusted by rotating the plastic knob that covers each valve stem.

The operation of manifold valves can be automated by adding an electric valve actuator to each valve, as shown in figure 3-14. The actuator supplies the force needed to move the valve's spring-loaded stem.

**Figure 3-15**



The actuator remains in the open position as long as power is applied. During this time, it gives off a very small amount of heat (2 to 4 watts). When power is removed, the wax cools and contracts. An internal spring assists in lowering the actuator shaft to fully close the manifold valve. As the actuator closes, its end switch opens, signaling other equipment that heat is no longer required in that circuit. The preferable mounting orientation for manifold valve actuators used in heating systems is either upright or horizontal. This reduces the chance of water entering the actuator body should a leak occur above the actuator. In chilled water systems, the actuators should never be mounted upside down.

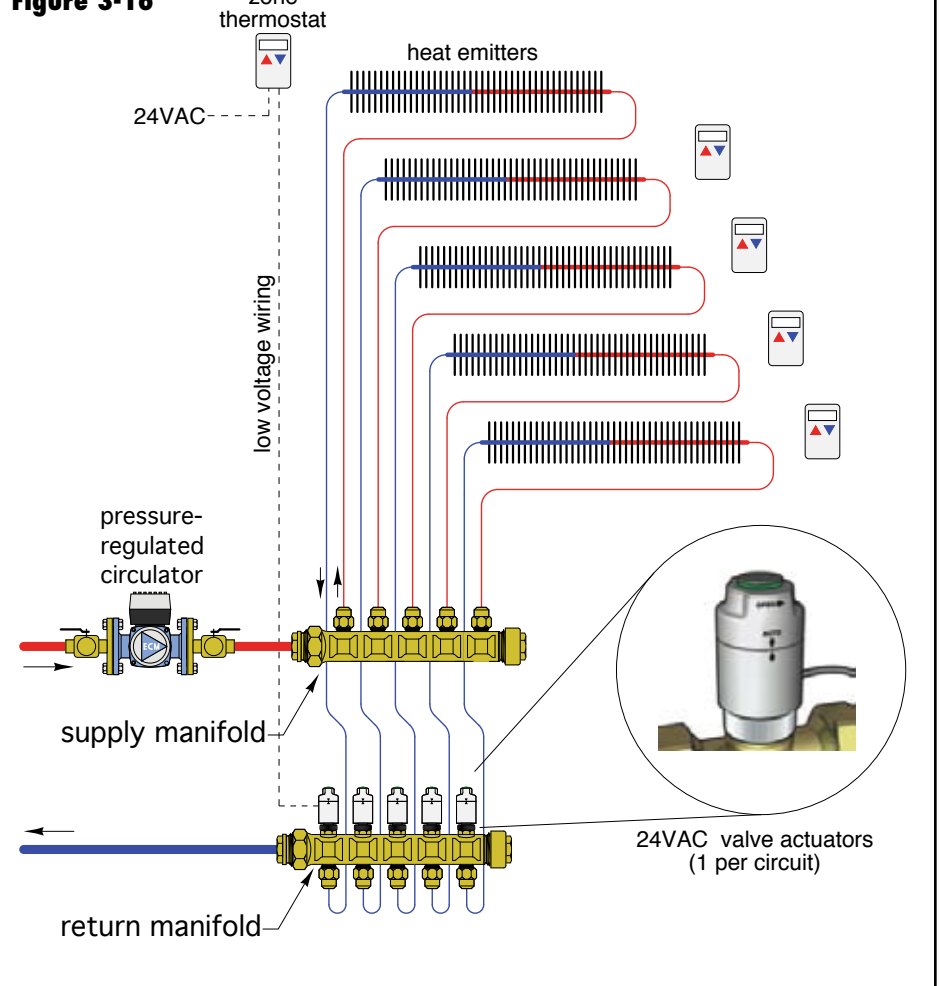
An example of a distribution subsystem using a manifold station with valve actuators is shown in figure 3-16.

In this system, each heat emitter is connected to the supply and return manifolds using separate runs of small diameter PEX or PEX-AL-PEX tubing. Each heat emitter represents a zone and has an associated zone

Electric valve actuators are also available with end switches and can be wired the same as a zone valve. An illustration of a 4-wire valve actuator is shown in figure 3-15.

The heart of a valve actuator is its heat motor. It's a sealed assembly containing a small piston and a specially formulated wax compound. When 24 VAC power is applied to the actuator, this assembly is heated by a wrap-around resistor element. As the wax warms, it expands, forcing the piston assembly upward. This retracts the actuator's shaft, allowing the spring-loaded shaft of the manifold valve beneath to open. The total movement of the actuator shaft is only about 1/8 of an inch. The movement of the shaft is slow. A typical actuator reaches its fully open position two to three minutes after power is first applied. If the actuator is equipped with an end switch, that switch closes when the actuator reaches its fully open position. As with 4-wire zone valves, the isolated end switch can be used to signal other equipment in the system that a zone circuit is now open and ready to accept flow of heated water.

**Figure 3-16**





thermostat. When one of these thermostats calls for heat, 24 VAC is applied to the associated valve actuator on the return manifold. Within two to three minutes, the actuator retracts its shaft, allowing the spring-loaded manifold valve to open. At this point, flow can pass from the supply manifold, through the heat emitter, and back to the return manifold. As with a 4-wire zone valve, an end switch inside the valve actuator can be used to initiate operation of the circulator and heat source. When the zone thermostat is satisfied, power is removed from the valve actuator and the manifold valve closes.

An example of a manifold station with valve actuators mounted on each circuit of the return manifold is shown in figure 3-17.

**Figure 3-17**



#### 4. MODULATING ZONE CONTROL USING NON-ELECTRIC THERMOSTATIC VALVES

There are also ways to zone hydronic systems that don't require electricity to operate the zoning hardware. Instead, flow through individual zone circuits is regulated by non-electric thermostatic radiator valves (abbreviated as TRV).

Thermostatic radiator valves consist of a valve body and non-electric thermostatic operator as shown in figure 4-1.

The operator is attached to the valve body by screw thread or setscrew. It provides the physical force necessary to move the valve's shaft. In some operators, this force is generated by the expansion of a wax compound sealed within

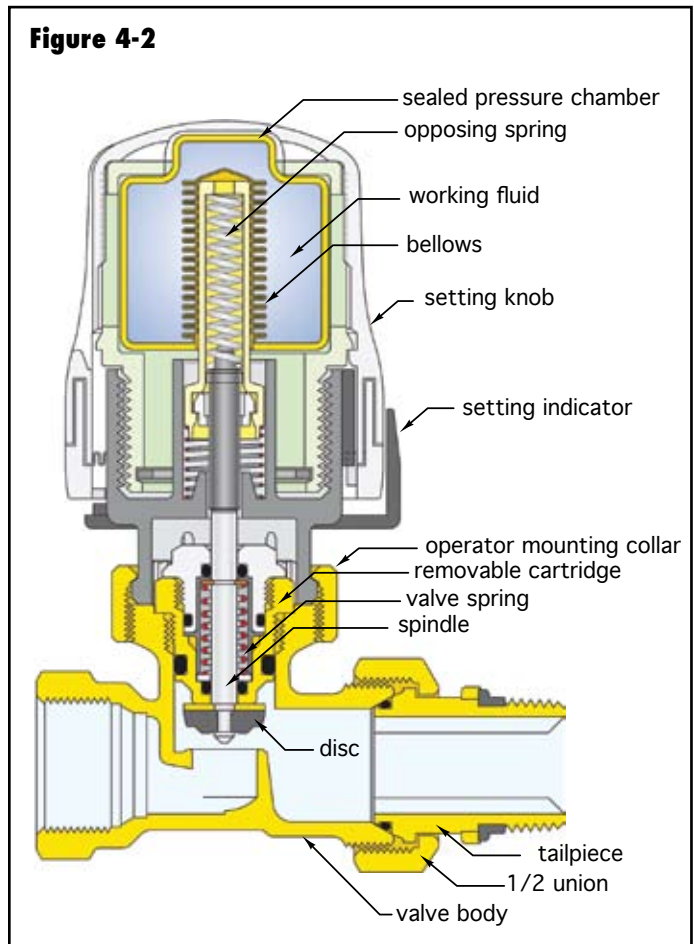
**Figure 4-1**

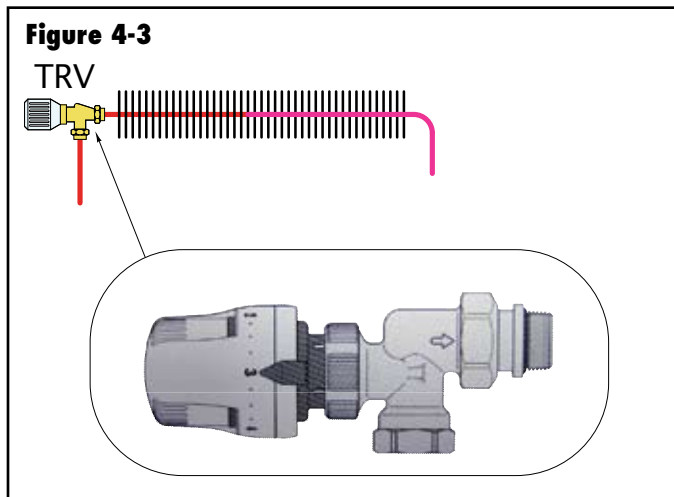


the operator. In others, it's generated by the thermal expansion of a sealed gas against a pressure diaphragm. In either case, the force generated pushes inward on the valve's spring-loaded shaft. This brings the valve's disc closer to the orifice, and thus reduces flow. If necessary, the operator can completely close the valve to prevent any flow to the heat emitter. A cross section through a thermostatic operator and attached valve is shown in figure 4-2.

Thermostatic radiator valves are adjusted similar to an electric room thermostat. The outer portion of the operator is a knob. It can be manually rotated to select the desired comfort level for the zone. Rather than temperature settings, the knob uses numbers from 1 to 5 as relative

**Figure 4-2**





indicators of comfort. A setting of 1 provides a cool room, while a setting of 5 provides a warm room. Occupants can set the knob anywhere within this range based on their preferences. This encourages occupants not to associate comfort with a specific room temperature. It also allows the operator to be used worldwide without regard to temperatures measured in Fahrenheit or Celsius.

The knob setting plays a part in the positioning of the operator's shaft. So does the temperature of the room air that passes through slots in the operator's body. Together, the knob setting and room air temperature determine if the operator's shaft moves inward, outward or remains at the same position.

Unlike the previously described electric zone valves and electrical valve actuators, thermostatic radiator valves are *modulating* devices. They control the flow rate through a heat emitter over a wide range, rather than simply turning it on and off. This ability to continually fine-tune flow through each heat emitter helps minimize room temperature variations.

There are many different types of radiator valves and thermostatic operators. One of the most common is a manually adjusted knob/operator assembly that fastens directly to a 2-way spring-loaded valve, as shown in figure 4-1. Such a valve is typically mounted near the inlet of a heat emitter, with the operator in a horizontal position. Care must be taken not to mount the operator so that warm air rising from the heat emitter goes directly by the operator. This will force the operator to close the valve very shortly after hot water begins flowing through the heat emitter.

The same operator can also be mounted to an "angle pattern" valve, which provides a 90-degree angle between the inlet and outlet ports of the valve, as shown in figure 4-3.

The latter is useful when the pipe feeding the heat emitter comes up through the floor or out from a wall.

In some situations, it's not convenient for occupants to bend over to adjust the operator on a thermostatic radiator valve. To handle these situations, manufacturers provide operator assemblies where the knob can be mounted on the wall similar to an electrical thermostat. The valve body can be located several feet away. A capillary tube filled with a temperature-reactive gas connects the knob to the operator on the valve body. An example of a radiator valve fitted with a remote knob actuator assembly is shown in figure 4-4.

**Figure 4-4**



When this type of thermostatic radiator valve is used, it's important not to damage or cut the capillary tube as it's installed. Doing so might allow the precharged gas to escape and render the operator useless.

Some panel radiators come with integral valves that can be equipped with thermostatic operators. An example of such a panel is shown in figure 4-5.

The valve body is preassembled into the radiator and comes equipped with a cap that can be rotated to adjust the valve's shaft.

Water enters a connection at the bottom of the radiator and flows up to the inlet of the integral valve through a small steel tube. If the valve is fully closed, no water can flow through the panel. If the valve is partially or totally open, water flows through the valve, and across the upper header of the radiator's water plate. The flow divides up among the vertical channels and flows downward to the lower header. Eventually, the lower header directs flow to an outlet connection at the bottom of the panel.

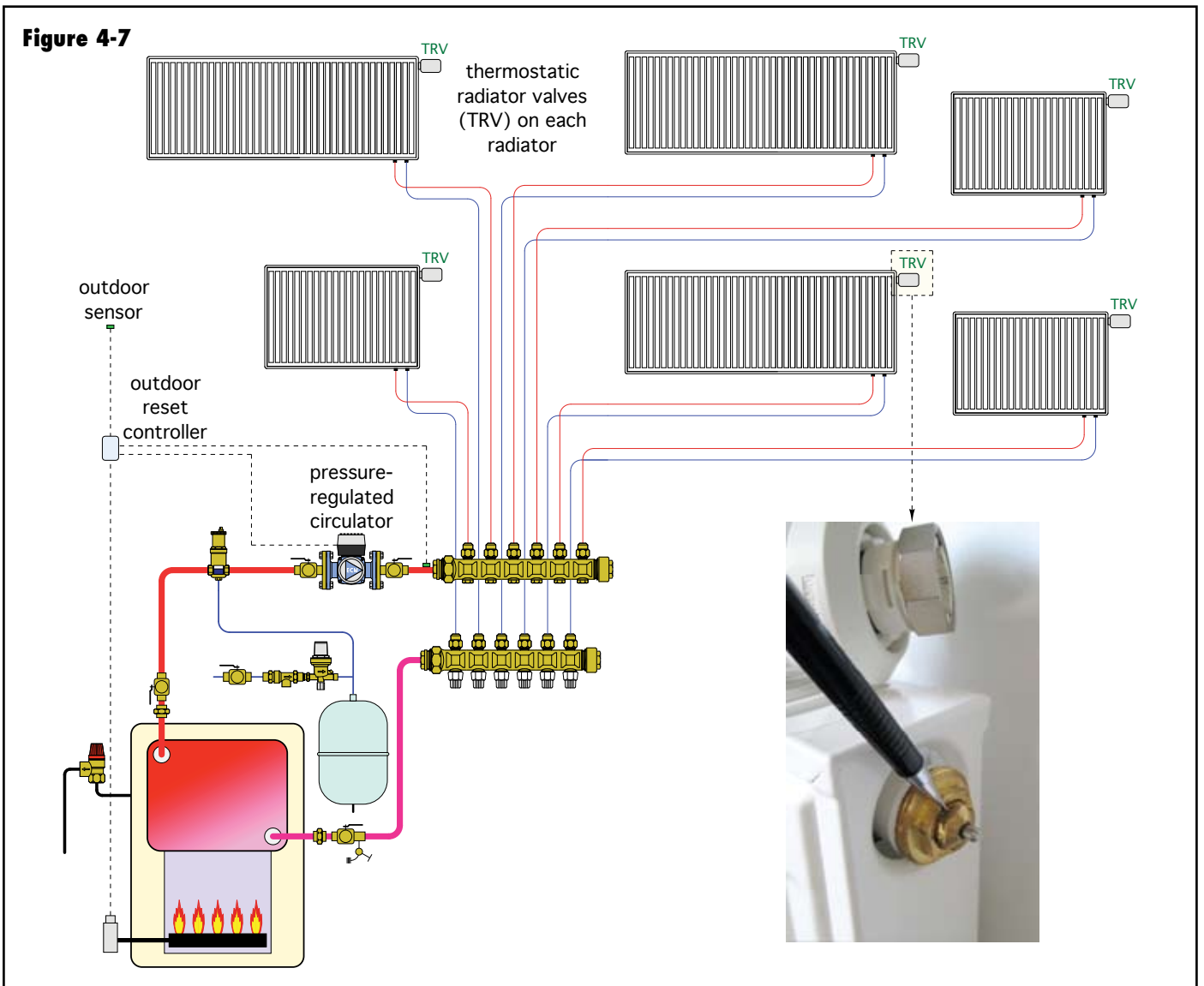
**Figure 4-5**



**Figure 4-6**



**Figure 4-7**



To convert the radiator to thermostatic operation, the original valve knob is unscrewed and replaced with a thermostatic operator. With this configuration, the radiator's heat output will continually respond to variations in room temperature. An example of a panel radiator with a thermostatic operator mounted to its integral valve is shown in figure 4-6.

A piping schematic that combines panel radiators equipped with integral thermostatic valves into a manifold-based distribution system is shown in figure 4-7.

In this system, each panel radiator constitutes a zone. A common approach is to size each radiator for the design heating load of the room it serves. Thus, room-by-room zoning is achieved without need of electrical thermostats or wiring between each zone and a central mechanical room.

The variable-speed pressure-regulated circulator must operate whenever any radiator requires heat. Unlike the previously described electric zoning systems, there are no end switches within the radiator valves to signal the circulator to operate. Instead, the circulator operates continuously during the heating season. It is usually turned on when the outdoor temperature reaches a preset value at which the building starts to require heat. This is usually handled by an outdoor reset controller or a separate outdoor thermostat. Once it is powered, the pressure-regulated circulator seeks an operating speed based on the differential pressure it "feels" in the distribution system in comparison to its differential pressure setting. If only one radiator valve is open, or partially open, the circulator operates at a low speed and associated low power consumption. As additional radiator valves open, the circulator senses the system's attempt to lower differential pressure and reacts by increasing its speed. In essence, this response provides "cruise control" for flow through the distribution system. Only the flow necessary at a given time is provided. This significantly lowers the electrical energy used by the circulator over a heating season.

The boiler shown in figure 4-7 is operated by an outdoor reset controller. This device continually measures outdoor temperature and calculates the ideal supply water temperature to the distribution system based on its settings. Outdoor reset control of boiler temperature has an established record of reducing fuel use. Savings of 15 percent or more are often cited. Outdoor reset control minimizes variations in heat output, and thus helps provide very stable room temperature. It's an ideal match for the variable-speed pressure-regulated circulator, as well as the thermostatic radiator valves.

## 5. DIFFERENTIAL PRESSURE CONTROL

Whenever a hydronic system is zoned using valves, the differential pressure between the supply and return headers should be regulated. Without such regulation, wide variations in pressure can occur between these headers. This leads to significant variation in flow rates within the zone circuits.

If differential pressure between the supply and return header becomes too high, flow velocity through one or more zone circuits can become excessive. This often leads to objectionable noise from the piping as well as more flow-restrictive components such as valves. Flow velocities in excess of 4 feet per second are not recommended for hydronic systems where noise is to be minimized. Flow velocities in excess of 7 feet per second can cause erosion of copper tubing and fittings as well as flow noise. Such erosion can eventually cause failure of the piping and/or components.

High differential pressure between the supply and return headers can also cause "valve stem lift." This is a condition in which a closed zone valve is forced partially open due to the pressure differential developed across it by the system. When it occurs, heated water can flow through zone circuits where there is no need for heat, and thus create overheating. It can also eventually damage the zone valves.

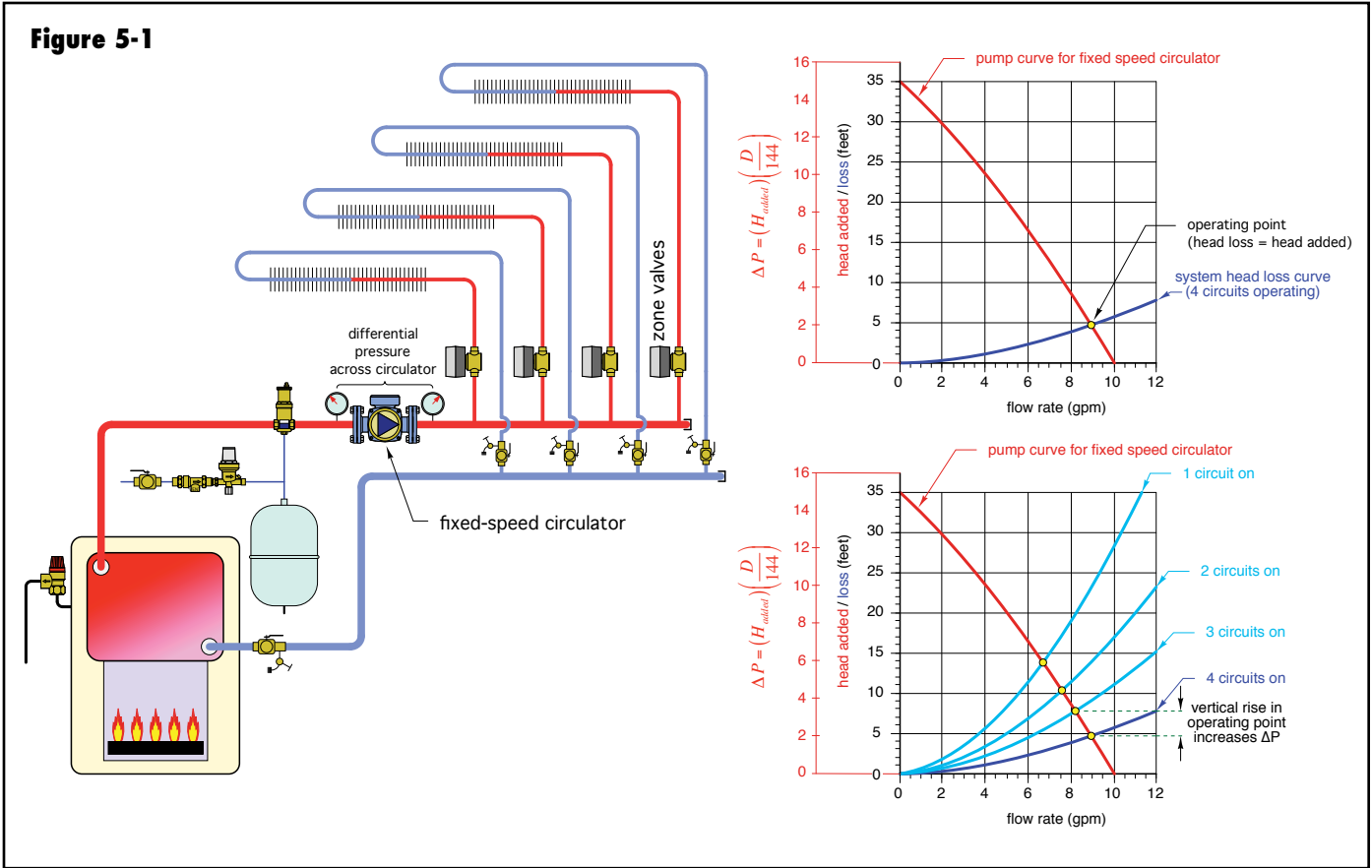
To see why differential pressure varies in a hydronic system zoned with valves, consider the typical system shown in figure 5-1.

At design load, all four zone circuits are on. Under this condition, the distribution system presents its lowest flow resistance, which is represented by the dark blue system head loss curve on the upper graph. This curve indicates the head loss of the distribution system, when all four zones are open, for any flow rate between 0 and 12 gpm.

The red curve on the graphs is the pump curve for a fixed-speed circulator. This curve shows the head energy added to fluid as it passes through the circulator at any flow rate in the range of 0 to 10 gpm.

As soon as the circulator turns on, this system, like every other hydronic system, immediately seeks a point of "hydraulic equilibrium" (e.g., where the head energy added by the circulator is exactly equal to the head energy dissipated by friction as flow passes through the system). This condition occurs where the pump curve and system head loss curve cross. That point is called the "operating point" for the system (in its current state).

**Figure 5-1**



The outer vertical scale on the graphs indicates the differential pressure associated with the exchange of head energy. This would be the pressure increase across the circulator, as well as the pressure drop across the distribution system. The differential pressure associated with head energy input by the circulator, or head energy loss by the distribution system, can be calculated using the formula shown on the vertical axis of the graphs.

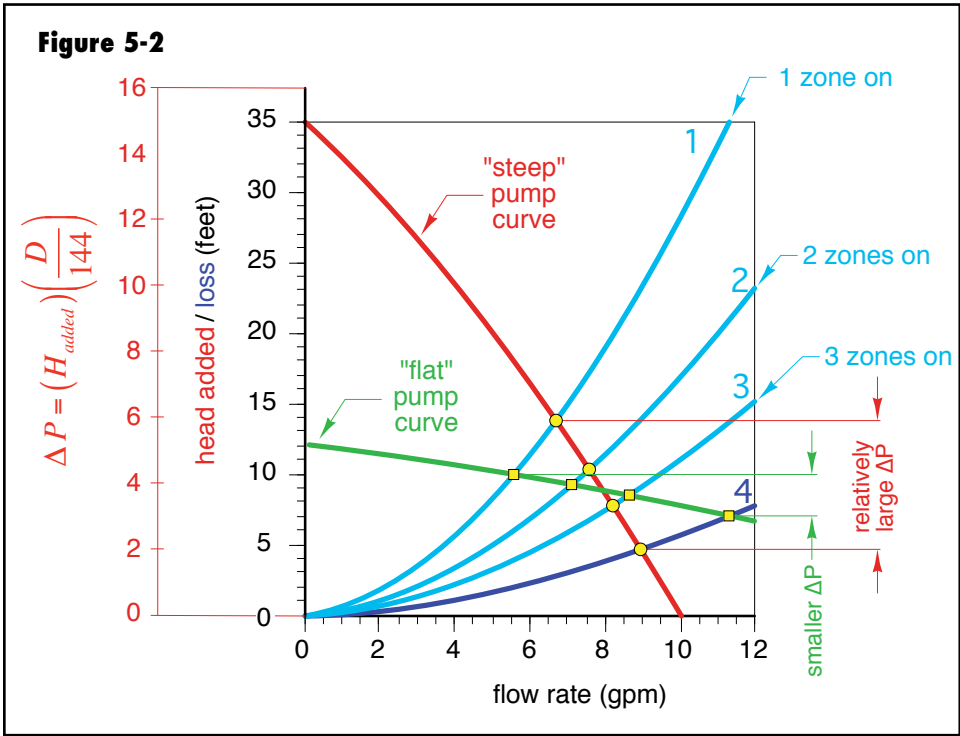
When a zone valve closes, the system head energy loss curve gets steeper, as shown by the light blue curves on the lower graph. This happens because the distribution system, as a whole, now presents a greater flow resistance compared to the previous situation.

The fixed-speed circulator immediately seeks to reestablish hydraulic equilibrium. This results in the operating point shifting to where the pump curve and revised system curve cross. The movement of the operating point to the left means that flow through the system as a whole has decreased. The upward movement of the operating point means there is now greater differential pressure developed across the circulator, and hence between the supply and return headers. The zones that remain open “feel” this increased differential pressure, and their flow rates immediately increase.

The scenario repeats itself when another zone valve closes. The system’s head loss curve again steepens, and the operating point shifts left and upward to the new intersection between the pump curve and revised system curve. Flow in the zones that remain on increases, while the flow through the circulator decreases.

The extent of this shift in the system’s operating point depends on the piping configuration of each zone circuit, the common piping and the circulator being used. In some systems, it may be of little consequence. In others, it may be sufficient to create flow noise, pipe erosion and valve stem lift.

The conservative correction for this phenomenon is to reduce or eliminate the upward movement of the operating point while allowing it to move to the left. This minimizes or eliminates changes in zone-circuit flow rates as other zone valves turn on and off. There are three common methods for accomplishing differential pressure control. Their ability to limit variations in differential pressure varies considerably from “partially effective” to ideal.



An example of a five-zone system with a DPBV installed across the headers is shown in figure 5-4

When properly set, a DPBV is fully closed when all zone circuits are operating. With this setting, the DPBV has no effect on the system under design load conditions. As zone valves close and the differential pressure across the headers increases, the DPBV should begin opening when the differential pressure reaches 0.5 to 1 psi above the differential pressure present when all zone circuits are open.

The point where the DPBV begins to open is called the "threshold" setting and is shown on the graph in figure 5-3. At that point, the action of the DPBV limits the upward increase in differential pressure to an almost horizontal

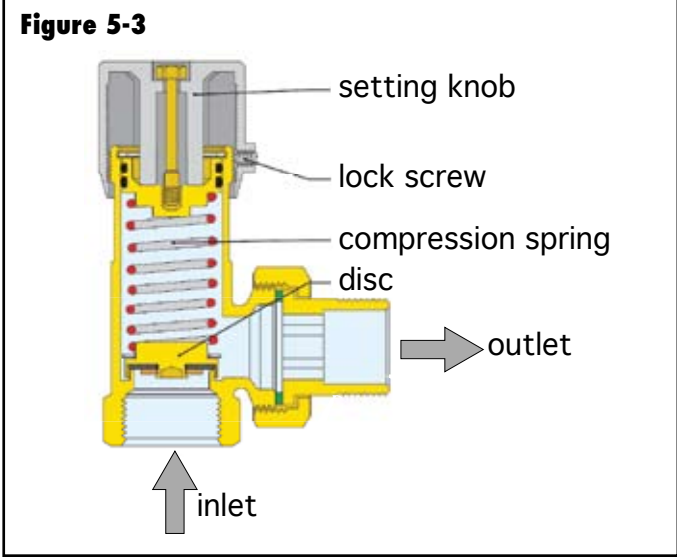
**USE OF "FLAT-CURVE" CIRCULATORS**

One way to limit the undesirable increase in differential pressure as zone circuits turn off is to use a circulator with a relatively flat pump curve, as shown in figure 5-2. Although the operating points still climb upward as zone valves close, the vertical shift is much less for the circulator with the "flatter" pump curve (shown in green) compared to the shift experienced with the previous circulator (shown in red). This demonstrates why circulators with flatter pump curves are better suited for systems using zone valves compared to circulators with steep pump curves.

**DIFFERENTIAL PRESSURE BYPASS VALVES:**

Another method for limiting differential pressure increase in systems using fixed-speed circulators is installation of a differential pressure bypass valve (DPBV). A cross section of such a valve is shown in figure 5-3.

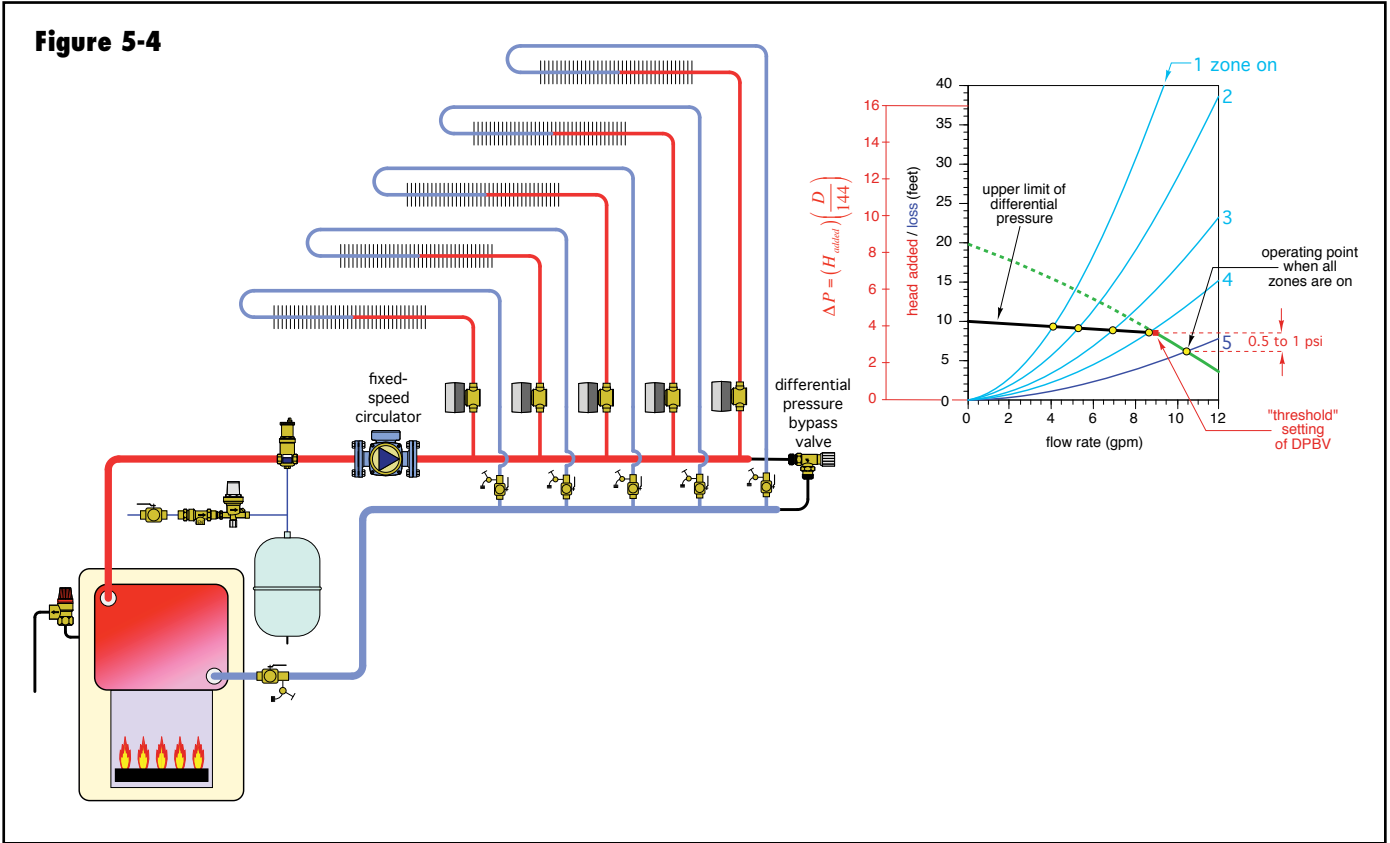
The setting knob adjusts the force exerted by the compression spring on the disc. This force determines the differential pressure between the valve's inlet and outlet at which the disc begins to lift off its seat. If conditions in the system attempt to increase the differential pressure across the valve, the disc moves farther off the seat to compensate. This allows increased flow through the valve with minimal variation in the differential pressure between the inlet and outlet ports.



line that begins at the threshold setting and slopes upward very slightly to the left. The slight upward slope is caused by increased flow through the DPBV as the system head loss curve steepens.

As zones close, the operating point shifts to the left along this limit line rather than tracking up the pump curve. The result is minimal vertical movement in the operating point, and thus minimal change in the differential pressure between the supply and return headers.

**Figure 5-4**



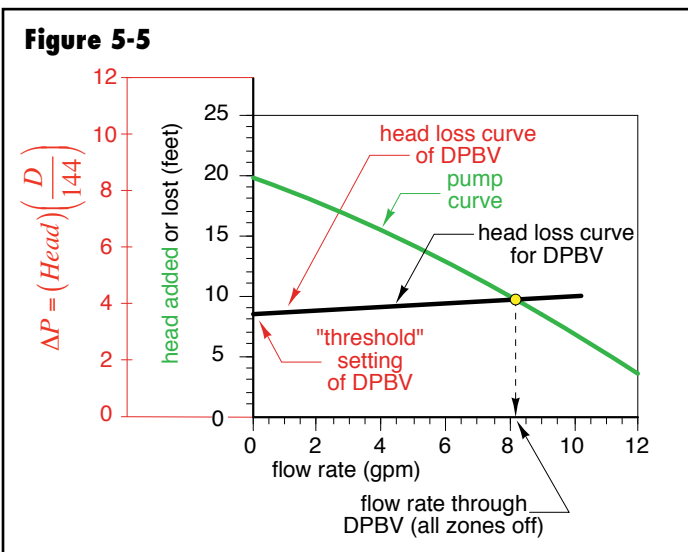
**SIZING DIFFERENTIAL PRESSURE BYPASS VALVES:**

To properly size a DPBV, it's necessary to estimate the flow through it assuming all zone circuits are closed. This is possible in systems using thermostatic radiator valves, or even electric zone valves or valve actuators, when the circulator's operation is not based on a "call" for

heat from an end switch. In systems where the circulator would only operate when at least one zone circuit is active, the following procedure is conservative.

With all zone circuits closed, the only flow path is through the DPBV. It's possible to estimate the flow under these conditions by plotting the head loss curve for the DPBV along with the pump curve for the circulator, and finding where they intersect, as shown in figure 5-5. A vertical line drawn downward from this point indicates the flow rate through the DPBV under this condition. A properly sized DPBV can then be selected based on the manufacturer's maximum recommend flow rate for a given valve size.

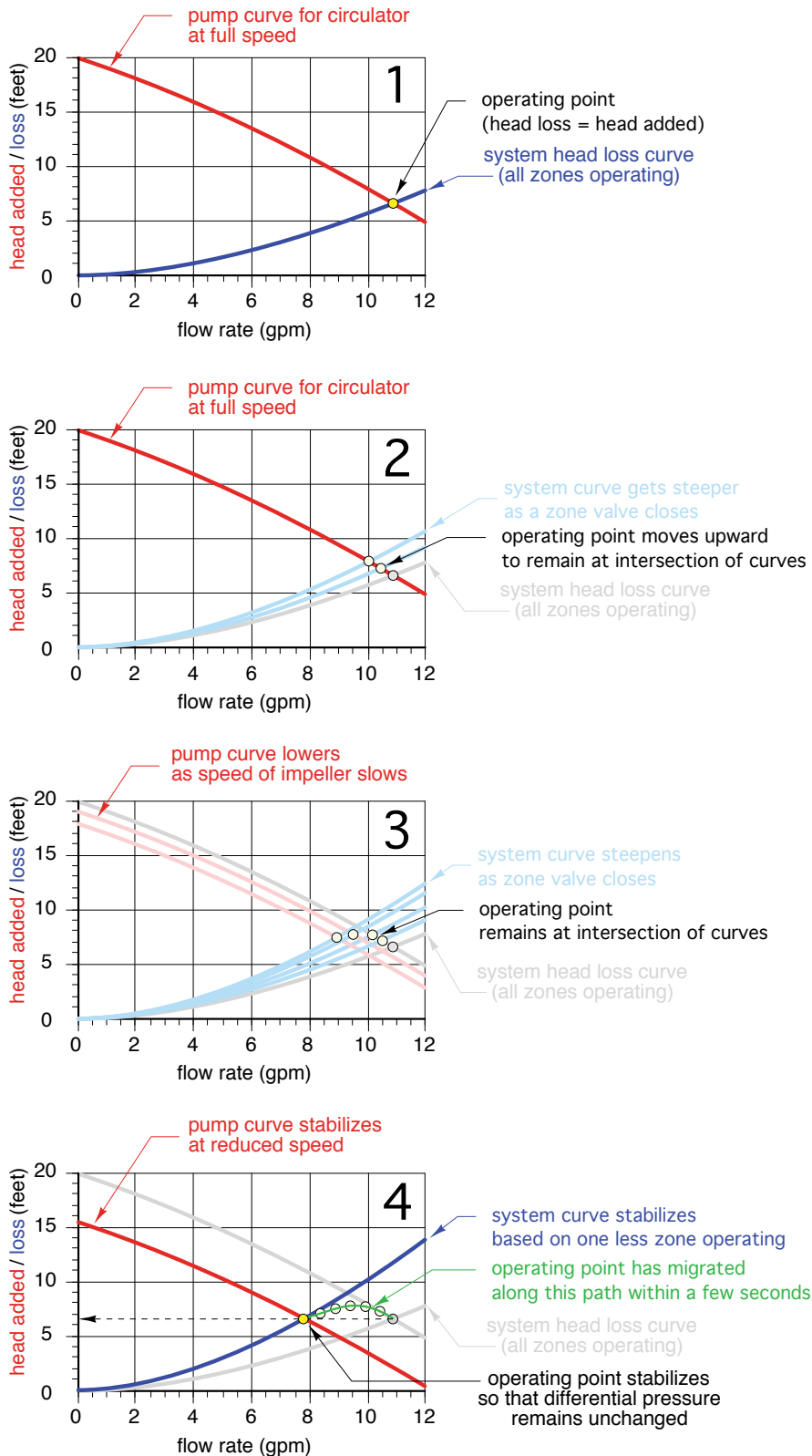
**Figure 5-5**



**PRESSURE-REGULATING CIRCULATORS:**

Another way of regulating differential pressure in hydronic systems is through the use of a variable-speed circulator. This method has been used in larger hydronic systems for several years. Emerging technology involving electronically commutated motors (ECM) now makes it possible to scale this technique down to residential and light commercial systems. It is ideally suited to hydronic systems that use valves for either on/off or modulating flow control through zone circuits. These variable-speed circulators eliminate the need for a differential pressure bypass valve.

**Figure 5-6**



A variable-speed pressure-regulated circulator provides what could be considered “cruise control” for differential pressure. The microprocessor-based speed controller within the circulator is set to maintain the differential pressure required by the distribution system when all branch circuits are fully open. Using electronic sensing techniques, the circulator constantly monitors the differential pressure it produces. When a valve in a branch circuit closes or modulates for less flow, the circulator senses an “attempt” for the differential pressure across the circulator to increase. It quickly reacts by lowering its speed to “cancel out” the attempted change in differential pressure. As other valves in other branch circuits close or modulate for less flow, the circulator continues to decrease its speed as necessary to maintain its set differential pressure. This sequence, which typically takes place within a few seconds after the zone valve action, is depicted in figure 5-6. Similarly, when zone valves open or modulate for increased flow, the circulator senses the attempted decrease in differential pressure and responds by increasing speed to cancel out the attempted change.

Some pressure-regulated circulators offer two operating modes:

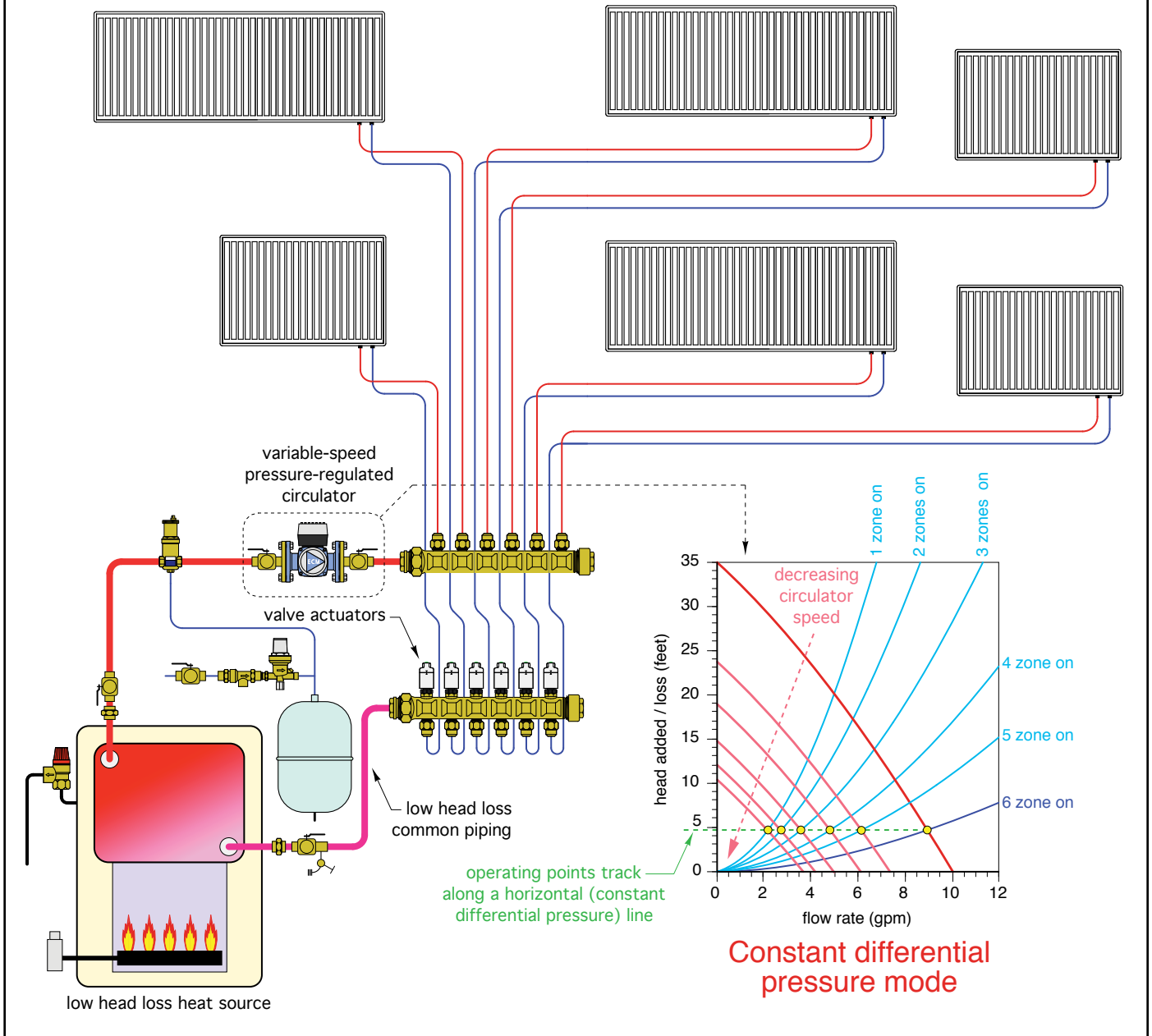
- Constant differential pressure control
- Proportional differential pressure control

These operating modes are designed to best match the variable-speed capability of the circulator to the needs of the distribution system.

*Constant differential pressure control* is well suited to systems where the majority of the head loss occurs in the zone circuits, with minimal head loss occurring in the common piping. An example is a manifold-based system with valve actuators, a heat source with low head loss and



**Figure 5-7**



minimal “common piping” between the manifold and heat source, as shown in figure 5-7.

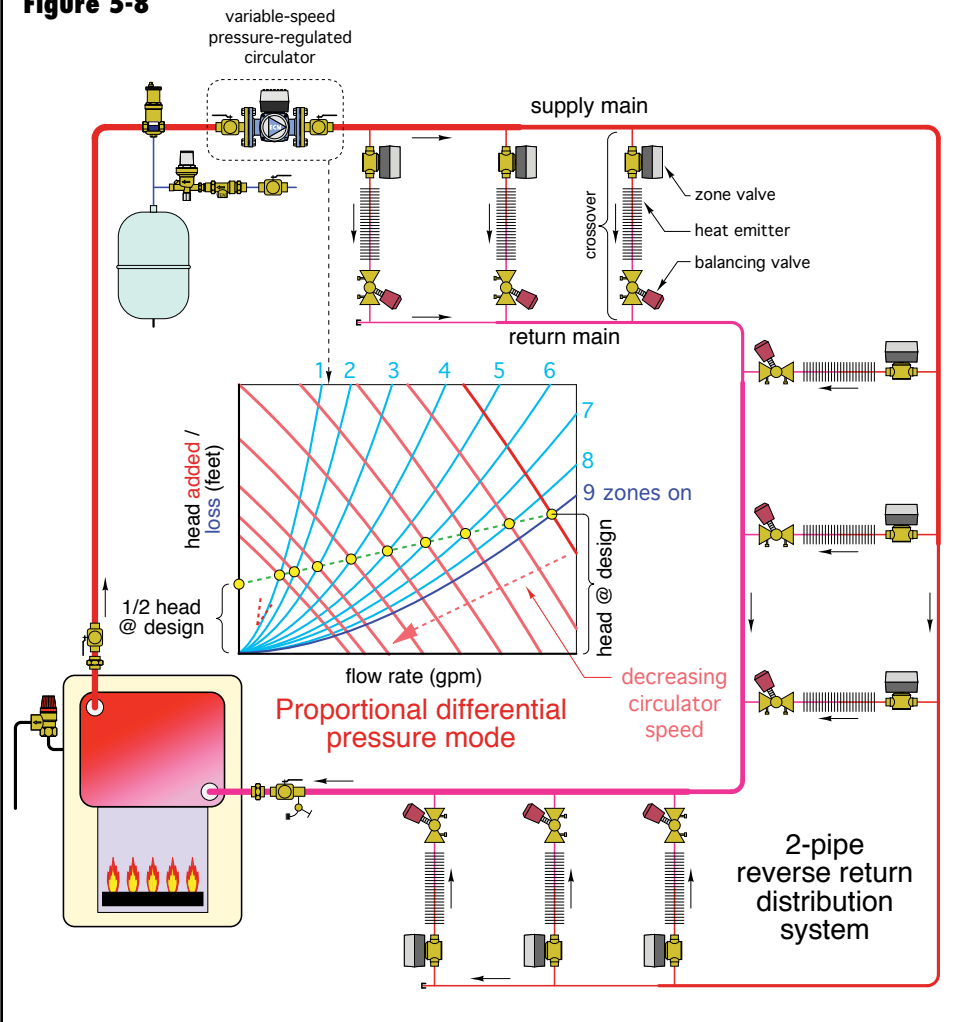
If a modulating/condensing boiler with a compact heat exchanger serves as the heat source, the head loss of the common piping can be kept low by hydraulically separating the boiler from the remainder of the system and creating flow through the boiler using a separate circulator.

As the zone valves or valve actuators close or modulate for less flow, the head loss curve for the distribution system steepens, as shown on the graph in figure 5-7. When the circulator is controlled for constant differential

pressure, it reduces speed, so the net effect is reduced flow rate in the distribution system, but no change in differential pressure across the manifold station (the operating points track along a horizontal line). This prevents changes in flow rate through the zone circuits that remain on, allowing them to operate “unaffected” by the closure or modulation of other zone valves.

Another operating mode for variable-speed pressure-regulating circulators is called *proportional differential pressure control*. This mode is appropriate when the distribution system experiences significant head loss in the supply and return mains that serve parallel “crossover”

**Figure 5-8**



zone circuits. A two-pipe reverse return system, as shown in figure 5-8, is a good example.

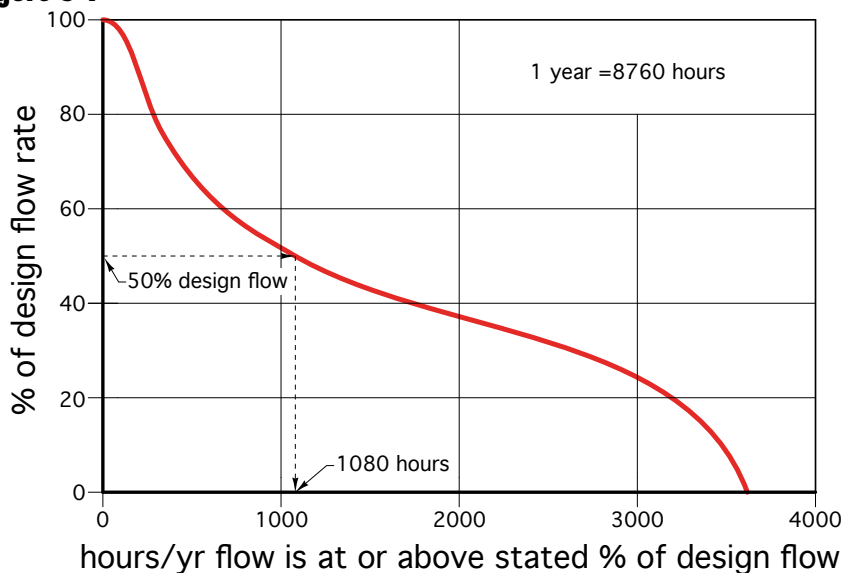
When set for proportional differential pressure mode, the pressure-regulated circulator establishes a line for the operating points that begins where the full-speed pump curve intersects the system head loss curve with all zones fully open. The line slopes downward and ends at one-half the design head when the flow rate is zero. This line minimizes differential pressure variations across the active zone circuits as other zones turn on and off. It compensates for the head loss of the parallel zone crossovers, as well as along the supply and returns.

In addition to pressure regulation, modern variable-speed circulators with electronically commutated motors use significantly less electricity when operating at full speed, and especially when operating at reduced speeds.

Partial-speed operation is possible during much of a typical heating season due to internal heat gains and setback schedules that allow zones to remain off. This situation has been studied in Europe, and a typical circulation percentage distribution curve has been developed, as shown in figure 5-9.

This curve shows the number of hours per year that total system flow rate is at or above a given percentage of design flow rate. For example, the flow rate in the system represented by this curve is at or above 50 percent of design flow approximately 1080 hours per year. Considering that this is only about one quarter of the hours in a typical heating season, it's evident that the flow

**Figure 5-9**



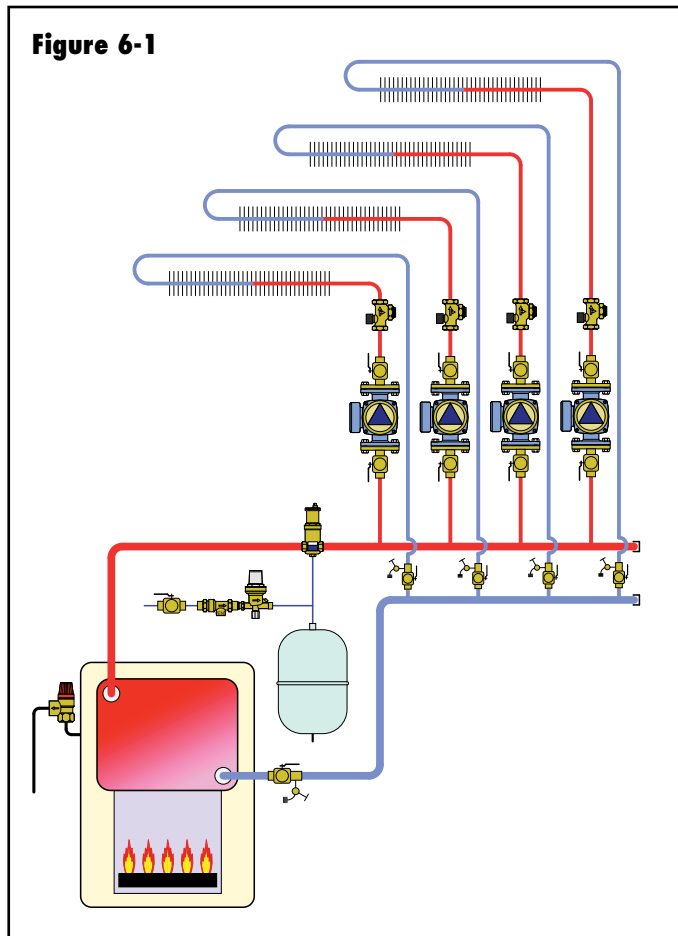
rate in a typical zoned hydronic system is often well below the design flow rate, and thus the potential for reducing electrical energy consumption based on reducing circulator speed is significant.

Simulations of currently available ECM-based variable-speed circulators against this standard flow profile indicate electrical savings of 60 percent or more are possible relative to current generation wet-rotor circulators with permanent split capacitor motors, and equivalent peak circulation ability.

Variable-speed pressure-regulated circulators are significantly more expensive than standard wet-rotor circulators. However, since they eliminate the need for a differential pressure bypass valve and significantly reduce electrical energy use, they often provide a good return on investment.

## 6. ZONING WITH CIRCULATORS

Small wet-rotor circulators were introduced to North America in the 1960s. Their small size and relatively low cost soon led to their use as a way to zone hydronic



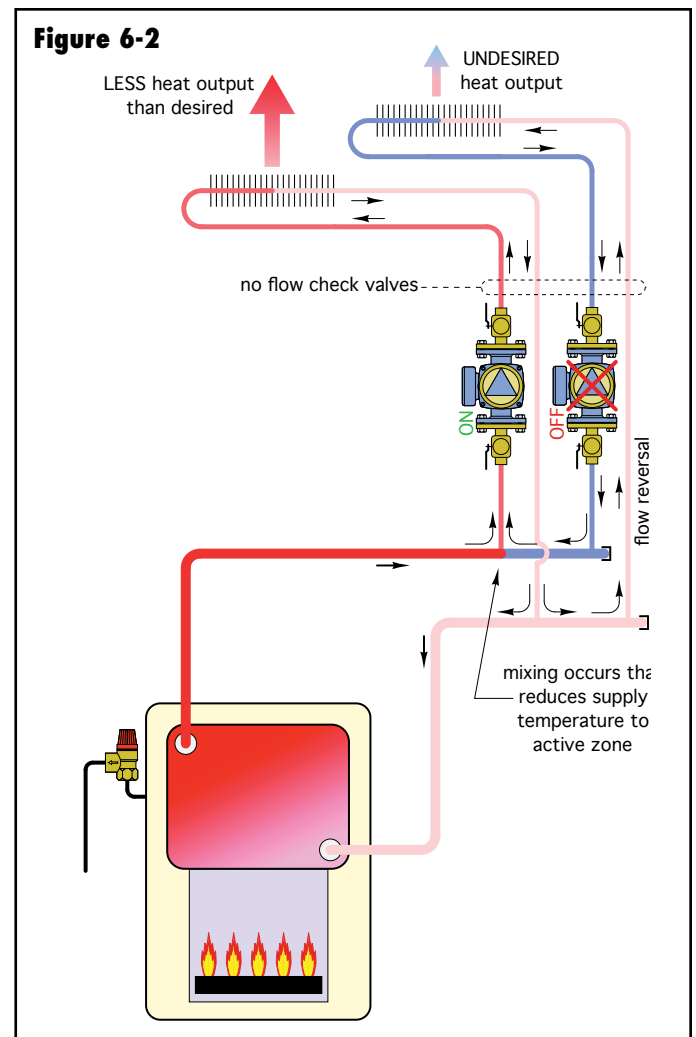
systems. The concept of a central circulator with zone valves was challenged by the concept of using a circulator on each zone. An example of such a system is shown in figure 6-1.

With circulator-based zoning, it's necessary to provide a flow-check valve in each zone circuit. This valve must provide two functions:

- preventing flow reversal through inactive zone circuits
- preventing migration of heated water into inactive zone circuits

In the absence of flow-check valves, flow reversal is possible because a standard circulator cannot block flow created by some other source of differential pressure. A typical scenario is shown in figure 6-2.

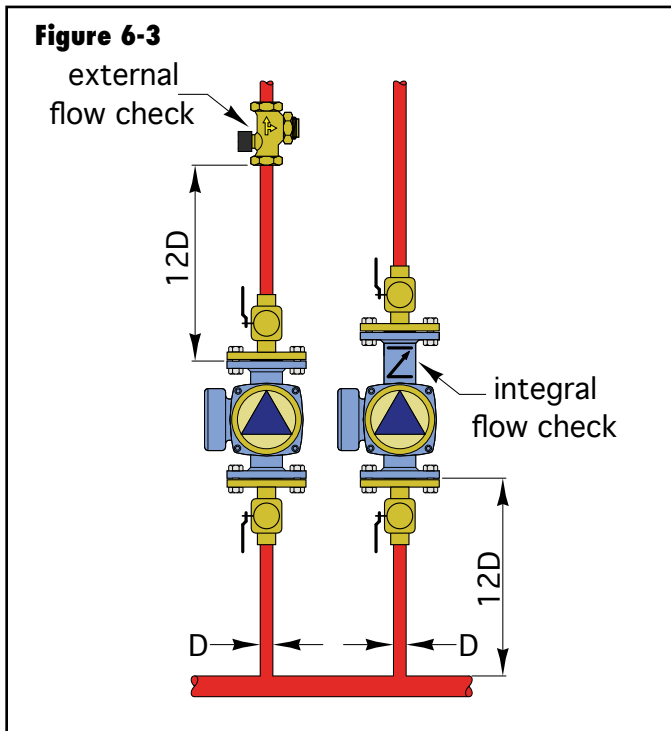
Installing a flow-check valve in each circuit prevents flow reversal. The slight forward opening resistance of a flow-check valve also prevents hot water from rising into



inactive zone circuits due to its lower density. A swing-check valve does not provide this forward opening resistance and is not an option to either a weighted flow-check or spring-loaded check valve.

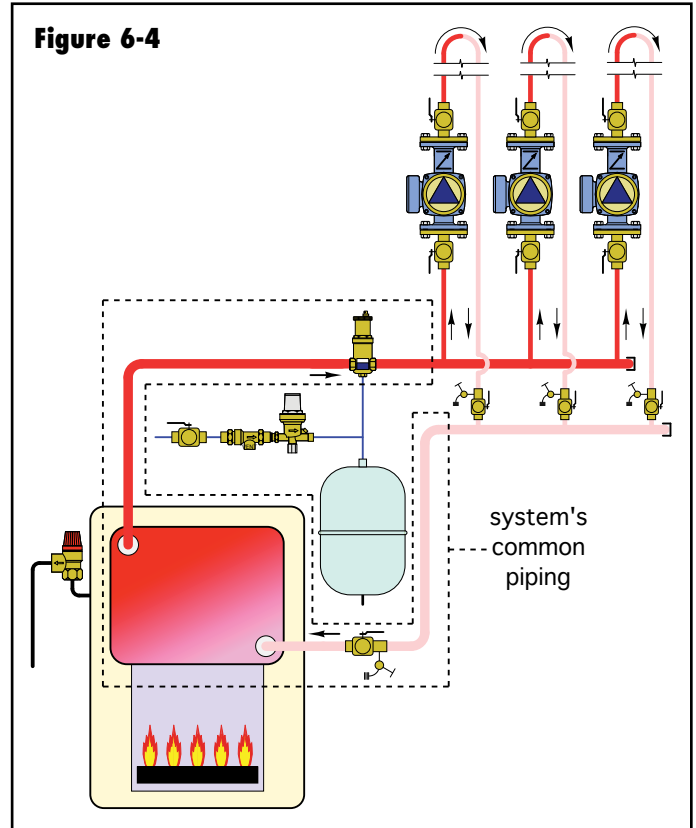
The flow-check valve can be external to the circulator, on the outlet side or integral to the circulator volute or isolation flange. When an external flow-check is used, it should be located at least 12 pipe diameters downstream of the circulator outlet, as shown in figure 6-3. This reduces turbulence into the check valve and minimizes noise. Likewise, circulators should also be mounted with at least 12 pipe diameters of straight pipe on their inlet side. External flow-check valves should have a polymer seat and/or plug to eliminate metal-to-metal rattling sounds.

When circulator-based zoning is used, all zone flow will pass through a portion of the system called the “common piping,” as shown in figure 6-4.



The flow rate and head loss through the common piping changes depending on how many zone circuits are operating. This head loss affects flow in the zone circuits. It allows an operating zone circulator to “sense” that other circulators are also operating. This causes flow-rate variations in a given zone circuit based on how many other zones are operating and the head loss through the common piping.

To avoid such interference, it’s important to minimize the head loss of the common piping. Flow velocities of 2 to

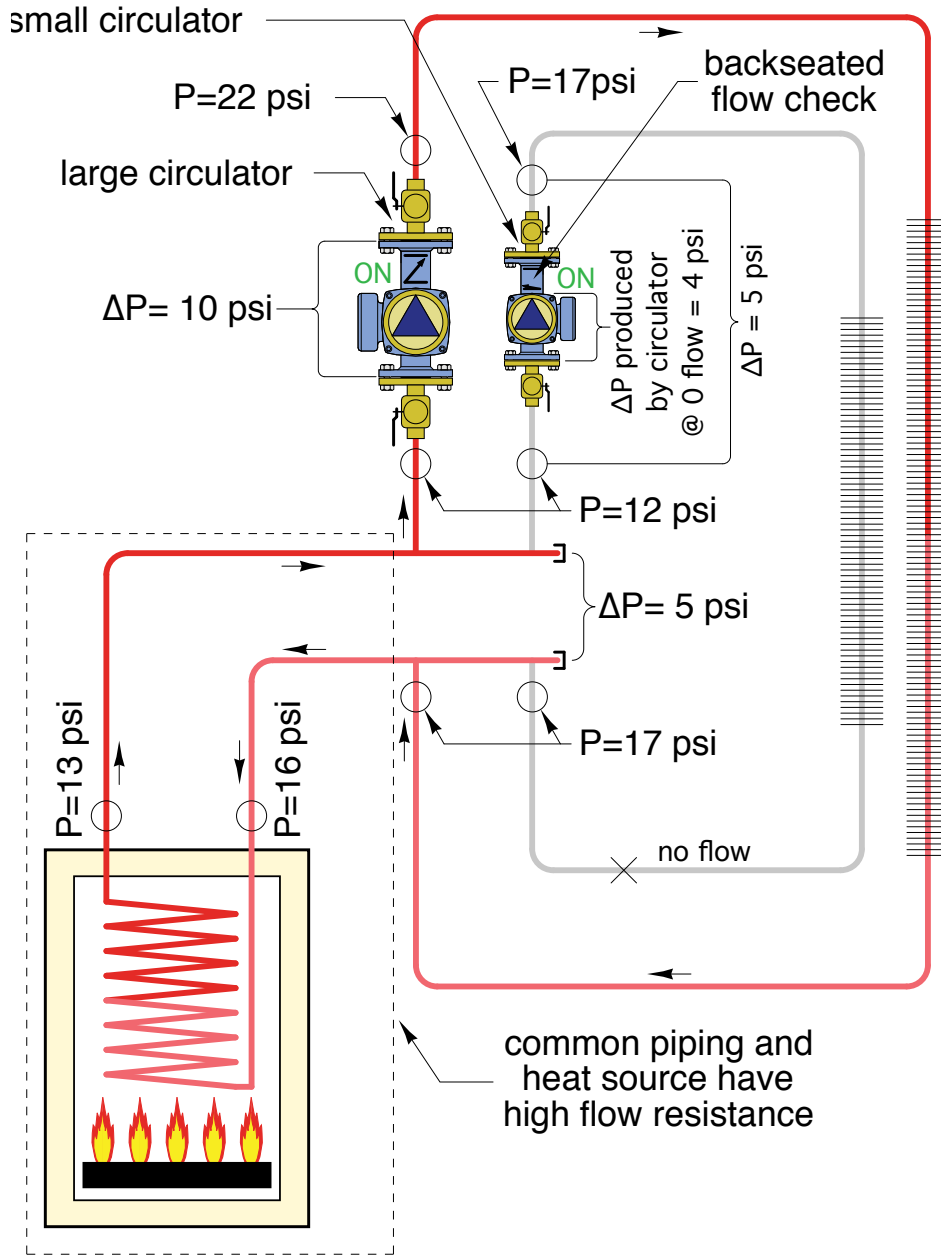
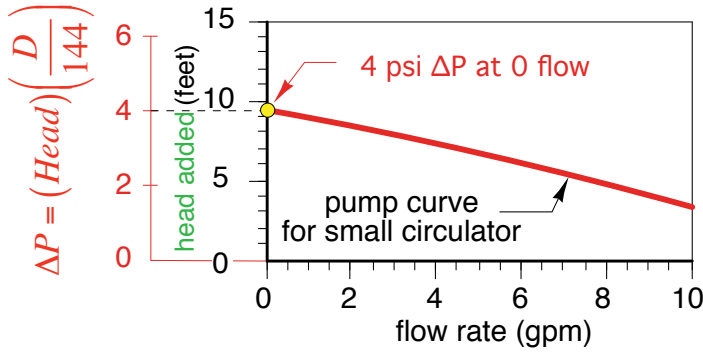


4 feet per second in the common piping will keep head loss to a minimum and approximate hydraulic separation between the simultaneously operating zone circulators. Not doing so can lead to unexpected results, especially when zone circulators of different capacity are used and the common piping has a high flow resistance. An example of such a situation is shown in figure 6-5.

In this system, the larger circulator pushes sufficient flow through the high flow resistance common piping and heat source to generate a pressure differential of 5 psi between the supply and return headers. The higher pressure is at the return header.

The smaller circulator is only capable of generating 4 psi between its inlet and outlet ports — even at zero flow. Thus, the check valve in the smaller circulator is held shut by the greater pressure at its outlet relative to its inlet. Although the smaller circulator will continue to run, it is “dead-headed” by this situation, and will not create flow as long as the larger circulator is operating. Under this condition, the smaller circulator will heat up to dissipate its wattage. For small wet-rotor circulators operating with relatively low wattage, this condition doesn’t generally create a safety hazard. However, larger circulators in this same predicament can generate sufficient heat to create steam in the volute. Under severe conditions, this can

**Figure 6-5**



cause the volute to explode. Obviously, such a situation must be avoided.

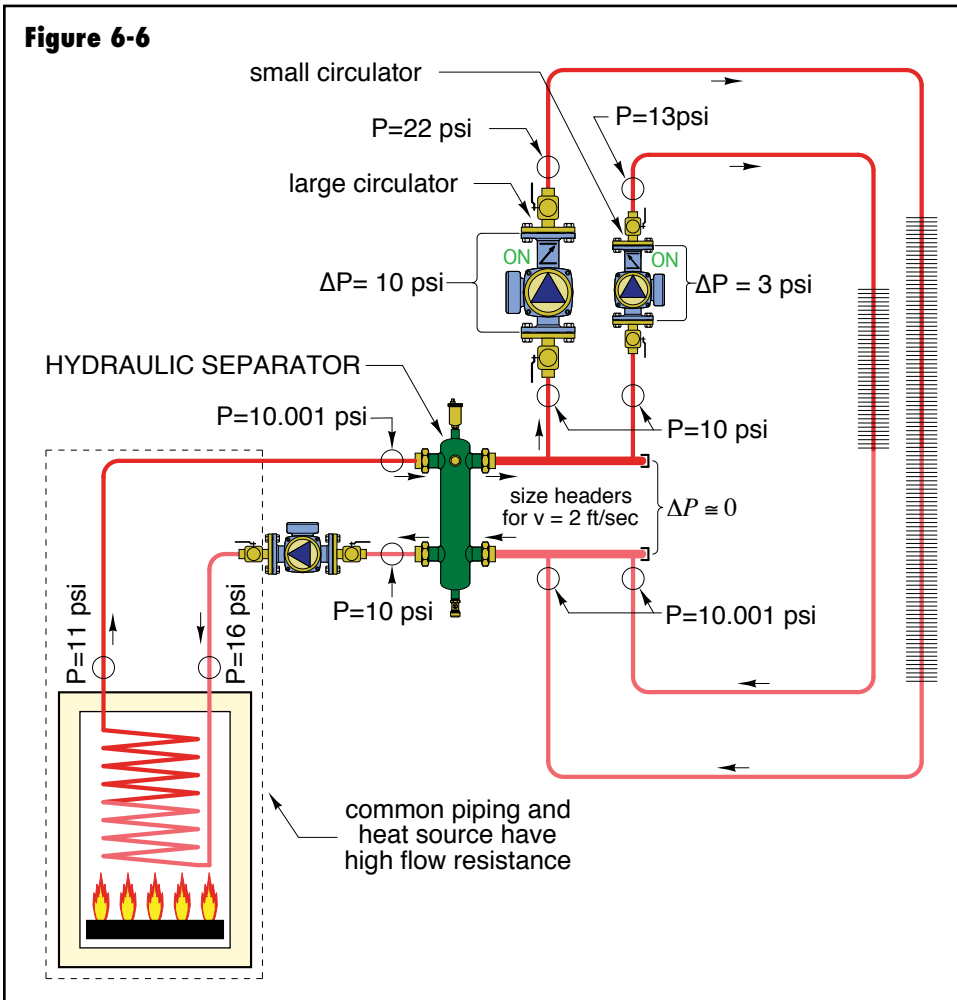
The situation can be corrected by hydraulically isolating the high flow resistance common piping and heat source from the remainder of the system. One way to do this is by installing a hydraulic separator, as shown in figure 6-6.

The hydraulic separator has very low internal velocity, and thus very little dynamic pressure drop from top to bottom. This allows the supply and return headers on the right side of the hydraulic separator to operate at essentially the same pressure. These headers should be sized for a maximum flow velocity of 2 to 4 feet per second under full-flow conditions. This keeps the pressure drop along the length of the header almost zero.

The differential pressure developed by a given zone circulator can be significantly different from that developed by other zone circulators, as is the case in figure 6-6. However, each zone circuit will create a corresponding pressure drop along its length. One can think of the pressure differential developed by each circulator as being “used up” by a corresponding pressure drop along its associated zone circuit. This prevents interference between the circulators and allows for stable flow rates in each active zone circuit, regardless of what other zone circuits are operating.

Flow through the common piping and heat source is created by a separate circulator. Almost all of the

**Figure 6-6**



differential pressure created by this circulator is dissipated by pressure drop through the common piping and heat source. There is virtually no pressure drop between the upper and lower connections on the left side of the hydraulic separator.

The hydraulic separator also serves as an air separation and dirt separation device for the system.

Another method that prevents interference between simultaneously operating zone circulators is shown in figure 6-7. This system uses a HydroLink, which provides for the combined function of hydraulic separation and headers.

The chamber on the left side of the HydroLink provides hydraulic separation between the boiler circulator and the zone circulators. The generously sized manifold chambers generate very little pressure drop along the length of the HydroLink, and thus effectively hydraulically isolate each zone circuit from the others.

## 7. THERMAL STABILITY IN ZONED SYSTEMS

If hydronic heating systems served steady heating loads, their design would be simple: Just select a boiler to match the required load and operate it continuously. Unfortunately, this is far from the typical situation. Even single-zone heating systems face space-heating loads that are constantly changing due to weather variations and changing internal heat gains from people, sunlight and equipment.

When a hydronic system is divided into zones, the challenge of matching the output of the heat source to the instantaneous heating needs of the building is even greater. This is especially true when the heat source is a fixed output (on/off) device, such as a non-modulating boiler or single-speed heat pump.

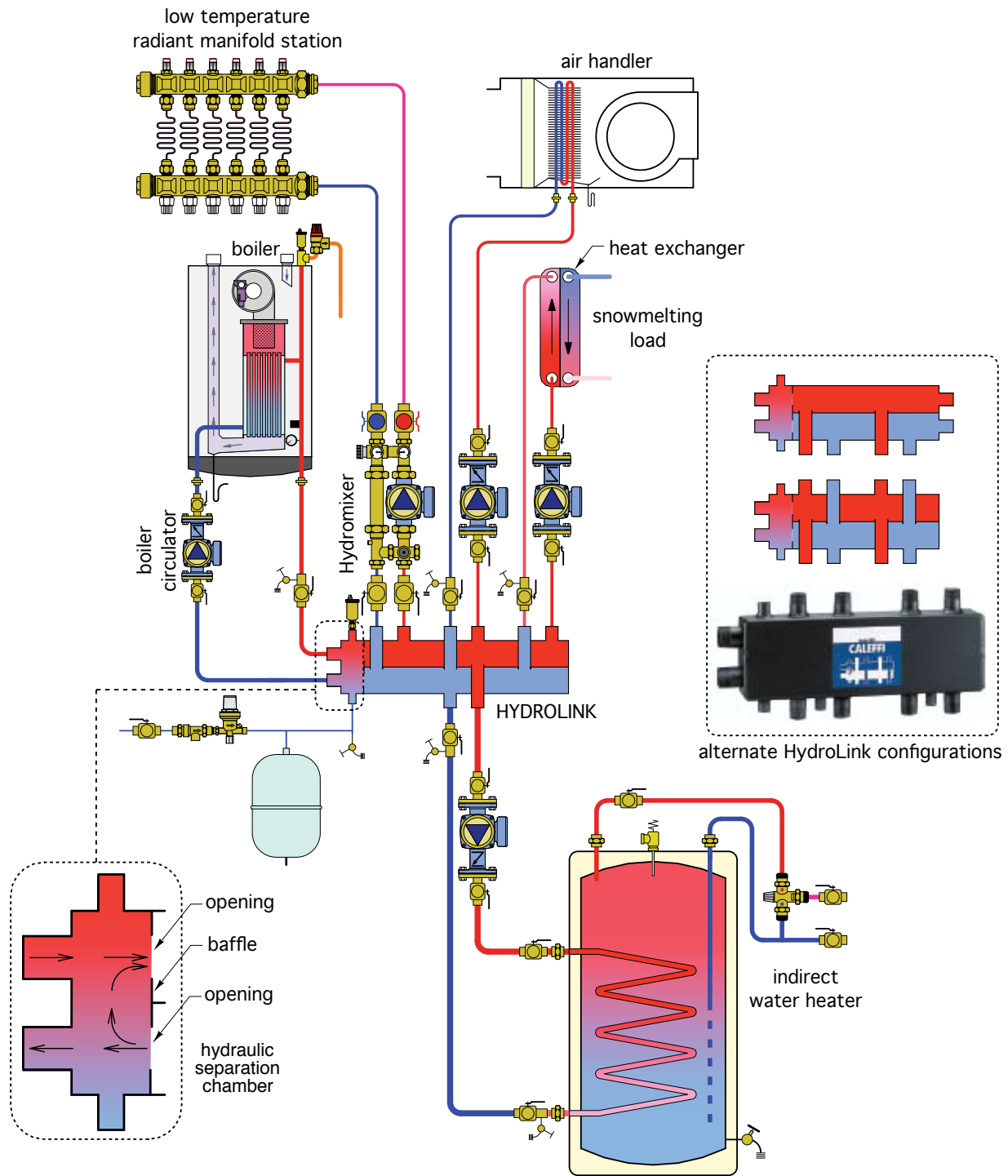
The greater the number of independently controlled zones in the system, and the lower their thermal mass, the greater the potential mismatch between the

rate of heat production and the rate at which the building requires heat. If not properly addressed, this situation can cause the heat source to “short cycle,” a situation in which the heat source operates for a short period of time, often less than one minute, and then shuts off. The off-period may be equally short and then the cycle repeats itself. Such a condition is undesirable for several reasons:

- It causes premature wear on system components such as ignition systems or compressor contactors.
- It lowers the efficiency of the heat source.
- It increases emissions from combustion-type heat sources.
- It may create objectionable operating noises within the building.

The heating industry does not precisely define what constitutes a short cycle. Arguably, some heat sources such as electric boilers are less affected by repeated on/off cycle than other equipment. For the sake of discussion, consider 10 minutes to be a reasonable minimum operating cycle once a heat source has turned on.

**Figure 6-7**



To provide such a cycle length under very low load conditions, it's necessary to provide thermal mass within the system that can absorb the excess heat generated by the heat source over that dissipated by the load.

In systems with cast iron boilers or boilers containing several gallons of water, the heat source alone may provide sufficient thermal mass to minimize short cycling. Such heat sources have considerably more thermal mass

than compact mod/con boilers, as demonstrated by the following example:

Consider a nominal 75,000 Btu/hr low-mass mod/con boiler with a 15-pound stainless steel heat exchanger that holds 0.8 gallons of water. The total thermal capacitance of the water-filled heat exchanger is:

$$M_T = (m_w)(c_w) + (m_s)(c_s) = (15 \text{ lb}) \left( 0.12 \frac{\text{Btu}}{\text{lb} \cdot \text{F}} \right) + \left( 0.8 \text{ gal} \times 8.33 \frac{\text{lb}}{\text{gal}} \right) \left( 1.00 \frac{\text{Btu}}{\text{lb} \cdot \text{F}} \right) = 8.46 \frac{\text{Btu}}{\text{F}}$$

Next, consider a nominal 75,000 Btu/hr cast iron boiler with a 300-pound cast iron heat exchanger and 8.7-gallon water content. The total thermal capacitance of this water-filled heat exchanger is:

$$M_T = (m_w)(c_w) + (m_s)(c_s) = (300 \text{ lb}) \left( 0.11 \frac{\text{Btu}}{\text{lb} \cdot \text{F}} \right) + \left( 8.7 \text{ gal} \times 8.33 \frac{\text{lb}}{\text{gal}} \right) \left( 1.00 \frac{\text{Btu}}{\text{lb} \cdot \text{F}} \right) = 105.5 \frac{\text{Btu}}{\text{F}}$$

In this example, the cast iron boiler has over 12 times more thermal capacitance than the compact boiler. This implies it can “soak up” over 12 times as much heat for the same temperature rise.

Traditional boilers with multi-hundred-pound metal heat exchangers and several gallons of water content usually provide enough thermal mass that short cycling can be

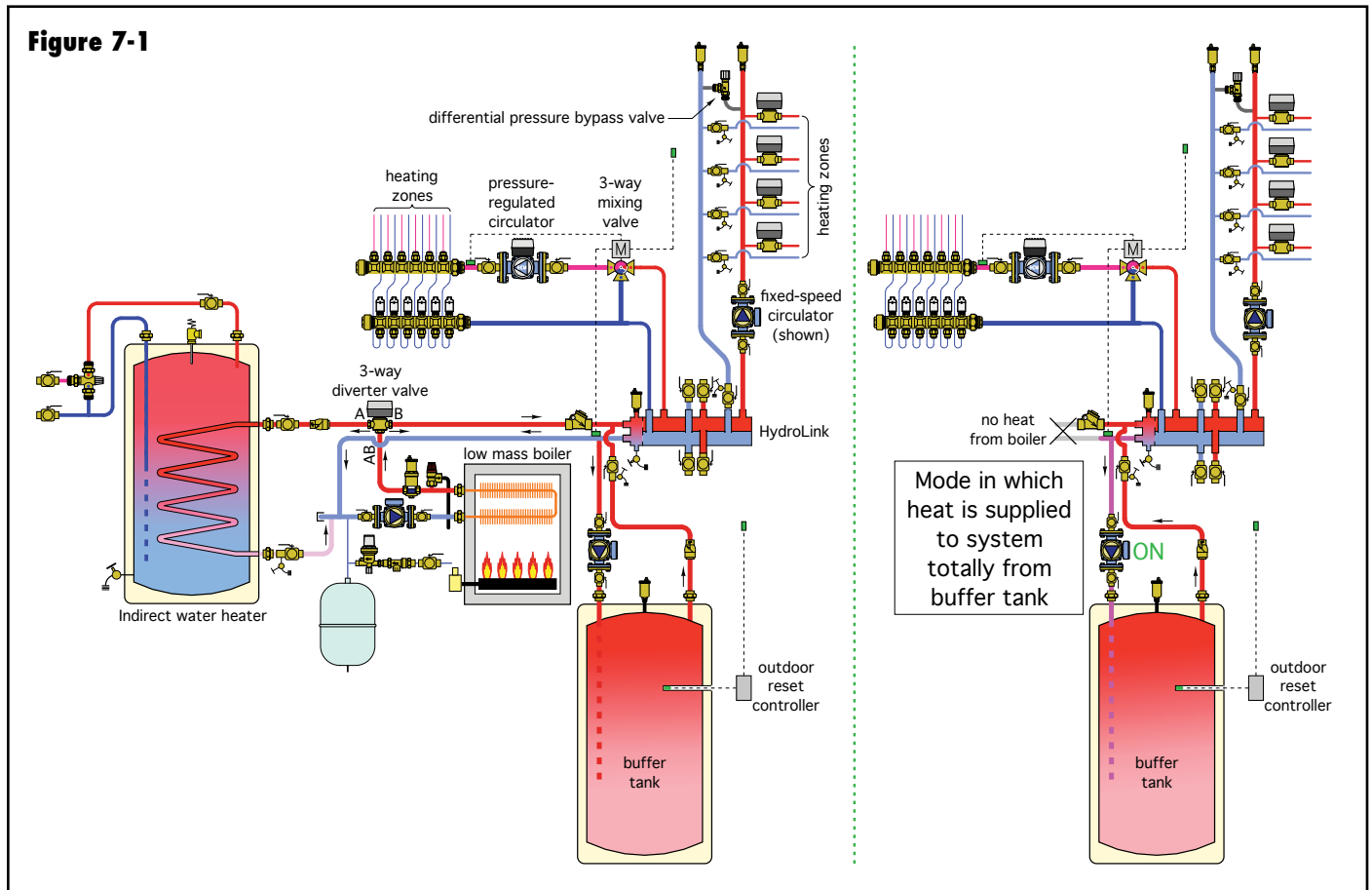
avoided in traditional systems with 3 or 4 independently controlled zones. However, modern trends toward more zones and lower-mass boilers have created a significantly different situation, one in which additional thermal mass is needed to stabilize the system.

### BUFFER TANKS:

One way to achieve fewer but longer heat source operating cycles is to add thermal mass to the system in the form of an insulated buffer tank. The added water volume acts as a “thermal battery” that can absorb excess heat output from the heat source when necessary and deliver it to the distribution system as needed at a later time.

There are several possible ways to pipe a buffer tank into a hydronic system. One technique is shown in figure 7-1.

In this system, the low-mass boiler delivers heat to the indirect water heater as a priority load and without need of heating the buffer tank. Upon a call for domestic water heating, the 3-way diverting valve directs flow from the boiler to the heat exchanger of the indirect water heater. Since the indirect water heater provides its own thermal mass, it’s not necessary or desirable to involve





the buffer tank during this mode. Doing so would delay heat delivery to the domestic water heater. It would also result in greater standby heat loss, especially in warmer weather when the only load this system supplies is domestic water heating.

When there is a call for space heating, and no concurrent call for domestic water heating, the outdoor reset controller measures the temperature of the buffer tank. If it is sufficiently warm from a previous boiler cycle, the buffer tank circulator is turned on, and all heat required by the zone circuits is provided by the buffer tank.

When the buffer tank cools to a temperature where it can no longer supply the heating load, the boiler is fired and the 3-way diverter valve directs flow from the boiler to the space-heating side of the system. The buffer tank circulator remains on. Heat flows to both the currently active heating zones and the buffer tank. The latter absorbs the difference between the rate of heat generation by the boiler and the rate of heat dissipation by the active zone circuit(s). When the buffer tank reaches a sufficiently high temperature, the boiler is turned off and the buffer tank continues to supply the active zone

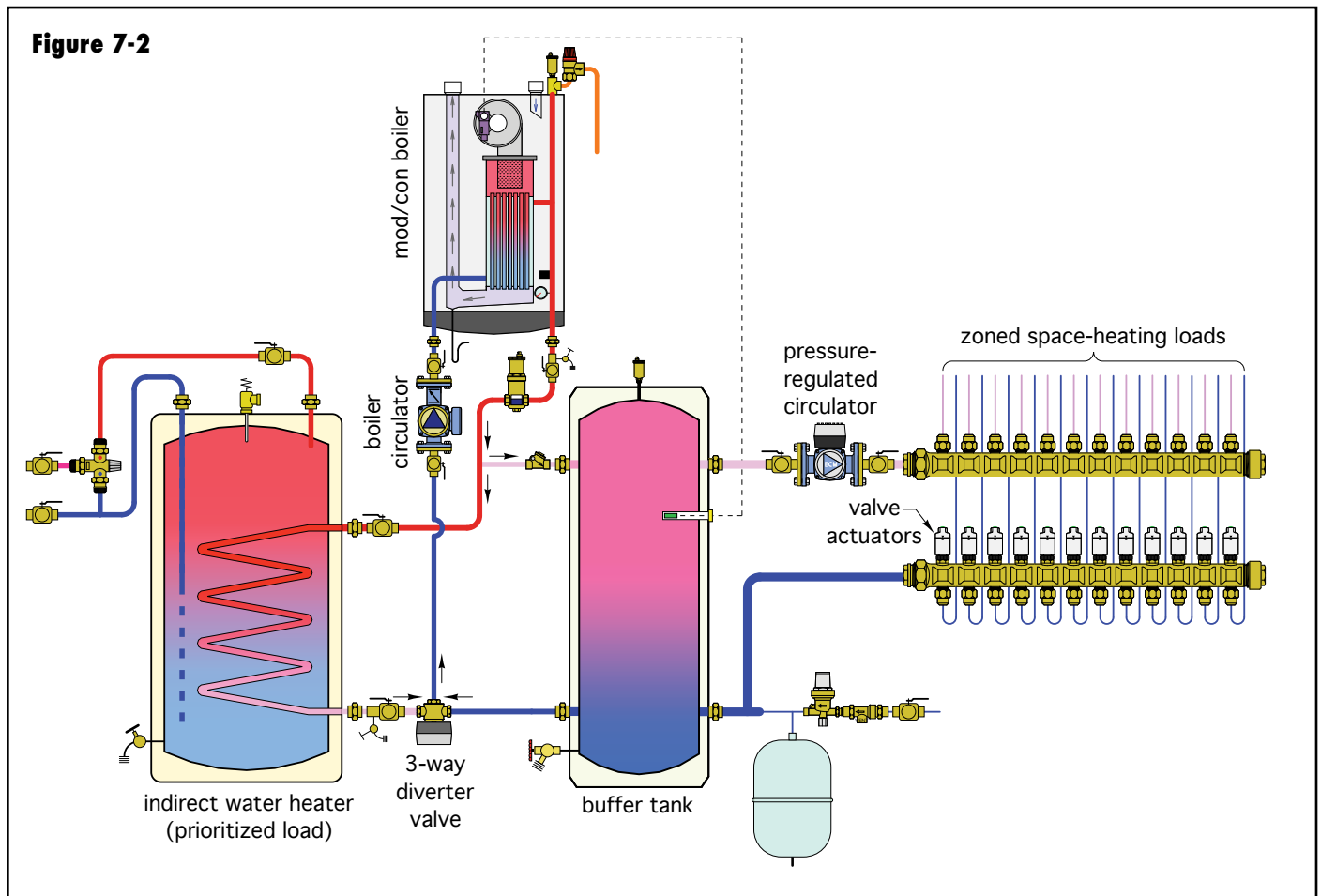
circuits. It is also possible that the boiler could operate for domestic water heating, while the buffer tank supplies heat to the active space-heating zones.

### BUFFER TANKS FOR MOD/CON BOILERS:

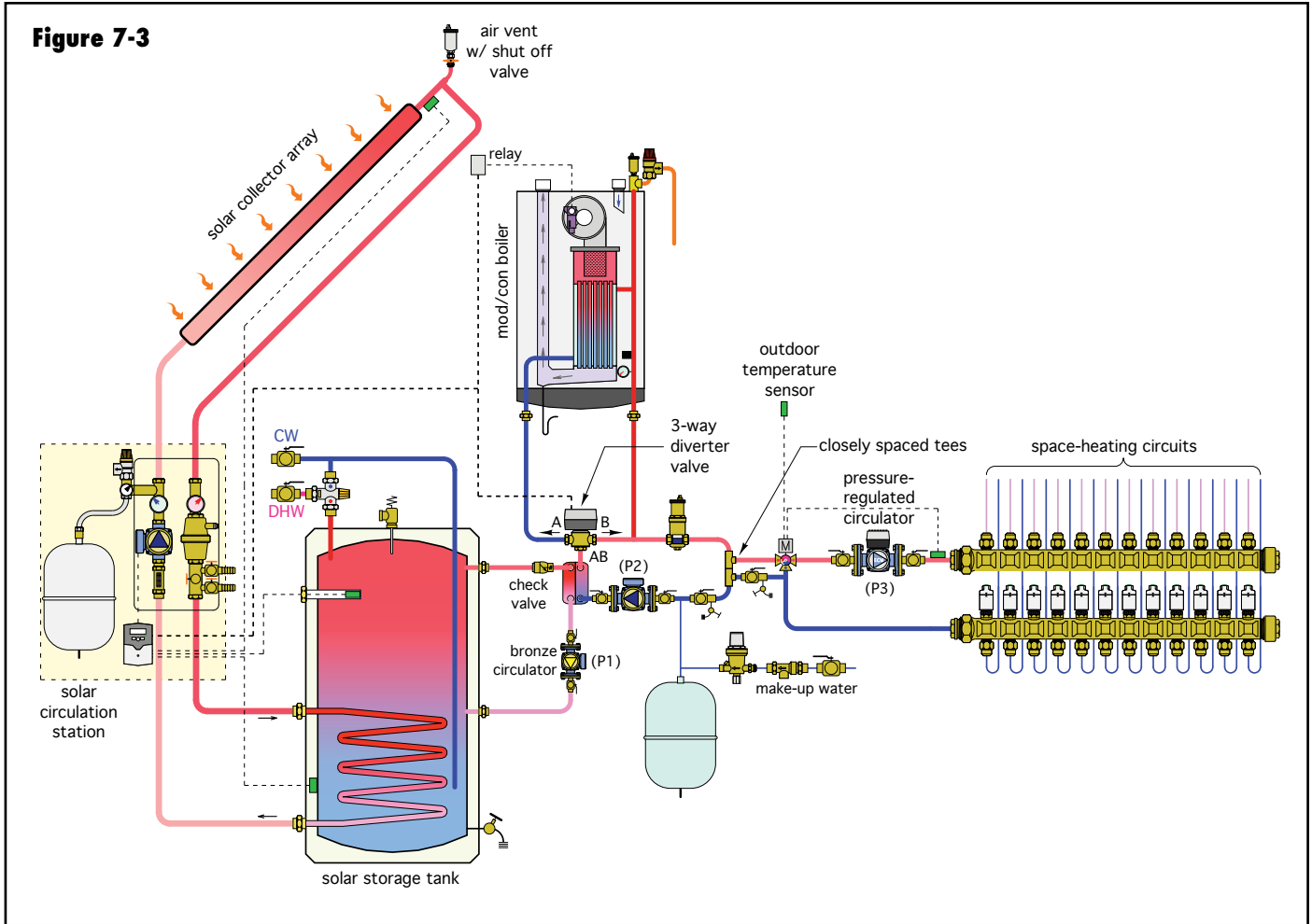
If modulating boilers could modulate all the way from full output to zero output, there would be no need for a buffer tank in the system. However, most currently available modulating boilers are limited to a modulating range from full output down to approximately 20 percent of full output.

It is possible that extensively zoned systems can, at times, place “micro loads” on the system. An example would be when a single towel warmer radiator is the only load. Assume it dissipated 2,000 Btu/hr. The boiler in the system has a rated capacity of 80,000 Btu/hr and a minimum stable firing rate of 16,000 Btu/hr (e.g., 20 percent of full output). Under this condition, the minimum firing rate is still eight times greater than the heat required by the load. This will lead to short cycling.

A buffer tank can be added to the system as shown in figure 7-2.



**Figure 7-3**



In this system, domestic water heating is controlled as a priority load. When the domestic water requires heating, the boiler fires to a suitably high temperature and all flow leaving the boiler is directed to the indirect water heater. The 3-way diverter valve ensures this is the only available flow path.

When the indirect water heater is satisfied and space heating is required, the 3-way diverter valve allows flow between the boiler and the buffer tank. The boiler is now controlled based on maintaining a suitable temperature in the buffer tank. This temperature can be based on a fixed setpoint or on outdoor reset control. The load side of the buffer tank operates independently of the heat source, with the possible exception of using the end switches in the manifold valve actuators to signal that a space-heating demand exists. This type of system can deliver a very small “trickle” of heat to one of the zones without short-cycling the heat source.

The buffer tank in this system also serves as a hydraulic separator between the boiler and zone circuits. It prevents interference between the boiler circulator and

the variable-speed pressure-regulated circulator in the distribution system.

Another way in which buffering thermal mass can be incorporated into a system is shown in figure 7-3.

This system uses the upper portion of the domestic hot water storage tank as a buffering thermal mass for the highly zoned distribution system. Heat can also be added to the storage tank from the solar collector subsystem. The boiler maintains the upper portion of the storage tank at a preset temperature sufficient to supply domestic hot water whenever it's needed.

Heat is supplied from the storage tank to the zoned distribution system as follows: Upon a demand for heat from any valve actuator, a temperature controller determines if the storage tank is warm enough to supply the load. This decision can be based on a minimum setpoint temperature or outdoor reset control. The latter allows the possibility for the storage tank to continue supplying the load to lower temperatures under

partial-load conditions, and thus helps maximize solar energy utilization. However, since the tank also supplies domestic hot water, its temperature cannot be reduced below the point where domestic hot water delivery is compromised. If the tank is warm enough to supply the space-heating load, the bronze circulator (P1) circulates domestic hot water through the stainless steel heat exchanger. The loop circulator (P2) also operates, and the diverter valve directs flow from port AB to port B. No flow passes through the boiler. Heat is transferred to the distribution system at the closely spaced tees, which provide hydraulic separation between circulators (P2) and (P3). A 3-way motorized mixing valve provides outdoor reset control of the temperature supplied to the distribution system. It also protects the distribution system from potentially high temperature water supplied from the solar storage tank. Flow through the distribution system is controlled by the variable-speed pressure-regulated circulator (P3).

When the storage tank temperature drops below the minimum acceptable temperature for domestic hot water, the boiler fires and flow is directed through the A port of the diverter valve. Circulators (P1) and (P2) operate. Heat from the boiler continues to be supplied to the distribution system through the closely spaced tees. Any heat produced in excess of what the distribution system needs is stored in the upper portion of the tank. If the distribution circulator (P3) is temporarily turned off, the full output of the boiler can be delivered to the storage tank for the fastest possible recovery.

### SIZING BUFFER TANKS:

The required volume of a buffer tank depends on the rates of heat input and release, as well as the temperature rise of the tank from when the heat source is turned on to when it is turned off. The greater the tank's volume, and the wider the operating temperature differential, the longer the heat source cycle length.

Formula 7-1 is used to calculate the necessary volume of a buffer tank based on a specified minimum heat source on-time, tank temperature differential, and rate of heat transfer:

Formula 7-1

$$v = \frac{t(Q_{\text{heat source}})}{500(\Delta T)}$$

Where:

v = required volume of the buffer tank (gallons)  
 t = desired duration of the heat source's "on cycle" (minutes)

$Q_{\text{heat source}}$  = heat output rate of the heat source (Btu/hr)  
 $\Delta T$  = temperature rise of the tank from when the heat source is turned on to when it is turned off (°F).

For example, assume a 75,000 Btu/hr heat source is to have a minimum on cycle of 10 minutes. The boiler turns on when the buffer tank drops to 130°F and off when the tank reaches 160°F. Determine the minimum required tank volume.

Solution:

$$v = \frac{t(Q_{\text{heat source}})}{500(\Delta T)} = \frac{10(75,000)}{500(160 - 130)} = 50 \text{ gallons}$$

If a tank larger than the required volume is used, the on-cycle length could be increased or the temperature differential through which the tank cycles could be reduced.

Any buffer tank should be very well-insulated to minimize standby heat loss. A complete insulation jacket with a minimum of 2 inches of rigid polyurethane insulation is suggested, with 3 inches preferred.

## 8. DISTRIBUTION ENERGY USE IN ZONED SYSTEMS

As previously discussed, hydronic zoning can be done using either valves or circulators. Both have strengths and potential limitations. When comparing valve-based versus circulator-based zoning, it's reasonable to ask which has a lower electrical operating cost. To make such a comparison, as well as to contrast hydronic zoning to forced-air zoning, it's helpful to define the efficiency of any heating distribution system.

Efficiency represents the ratio of a desired output quantity divided by the necessary input quantity. For a heating distribution system, one could define "distribution efficiency" as follows:

$$n_d = \frac{Q_{\text{delivered}}}{w_e}$$

Where:

$n_d$  = distribution efficiency (Btu/hr/watt)  
 $Q_{\text{delivered}}$  = rate of heat delivery (Btu/hr)  
 $w_e$  = electrical power required by the distribution system (watts)

For example: Consider a zoned hydronic system with four circulators. Each circulator requires 75 watts when operating. At design load, with all four circulators operating, the system delivers 100,000 Btu/hr to the building.

The distribution efficiency of this system at design load conditions would be:

$$n_d = \frac{Q_{delivered}}{w_e} = \frac{100,000 \frac{Btu}{hr}}{4 \times 75 \text{ watt}} = 333.3 \frac{Btu / hr}{\text{watt}}$$

The number 333.3 Btu/hr/watt can be interpreted as follows: For each watt of electrical energy required by the distribution system, it delivers 333.3 Btu/hr to the building.

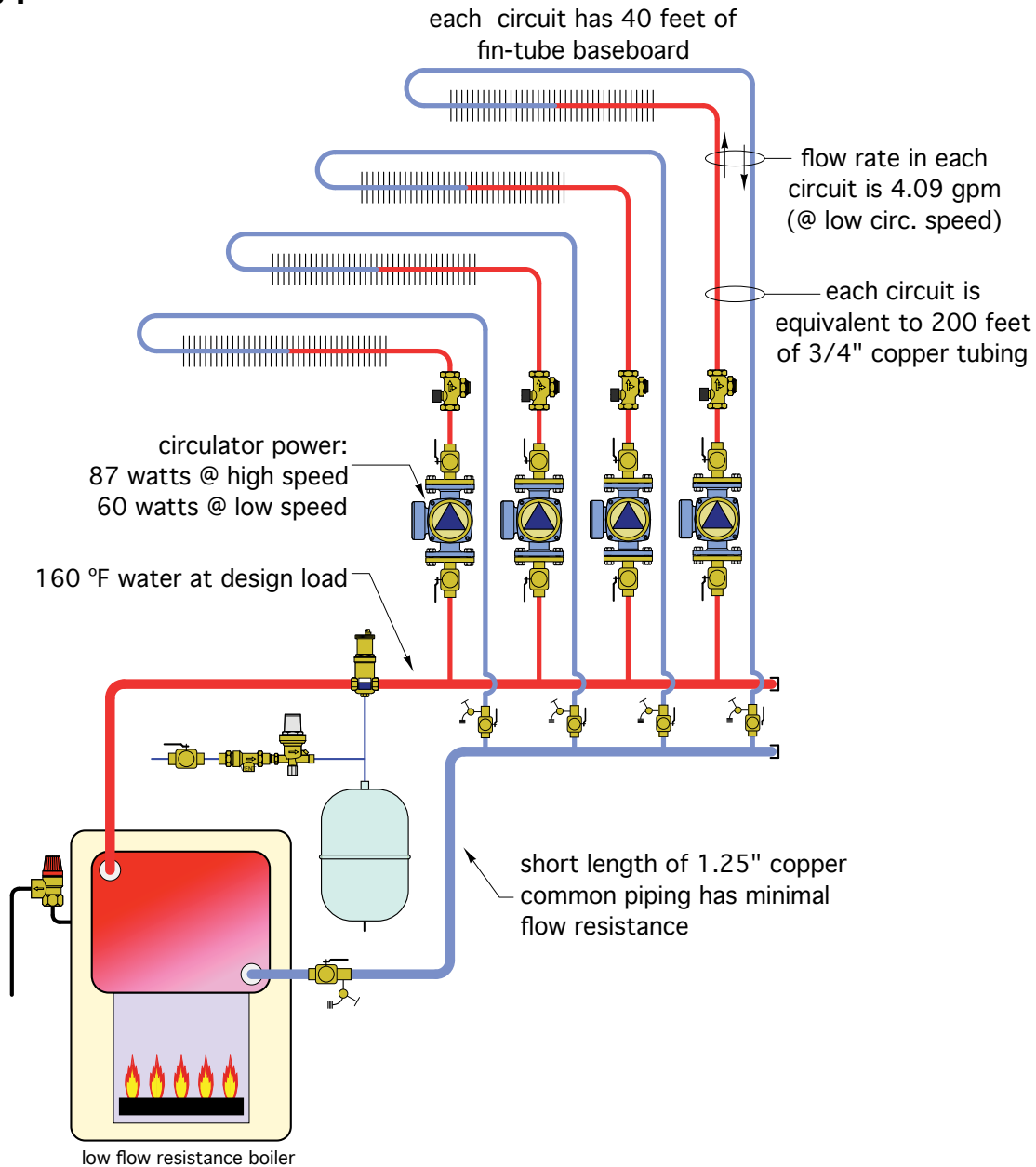
The number 333.3 means little without something to compare it to. To provide such a comparison, consider

a forced-air furnace with a blower that requires 550 watts while delivering 80,000 Btu/hr to the building. The distribution efficiency of this system is:

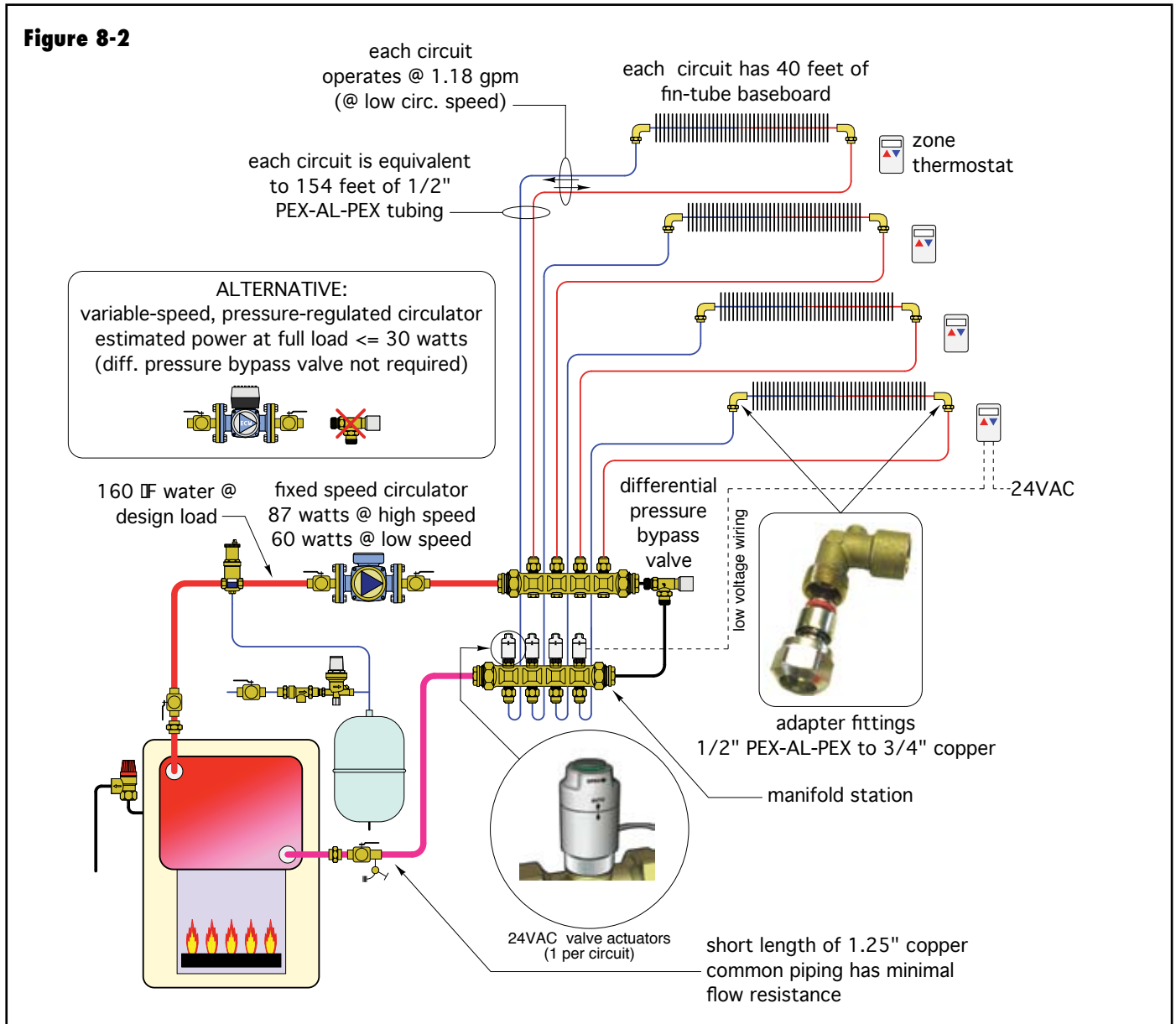
$$n_d = \frac{Q_{delivered}}{w_e} = \frac{80,000 \frac{Btu}{hr}}{550 \text{ watt}} = 145.5 \frac{Btu / hr}{\text{watt}}$$

In this comparison, the forced-air system has less than half the distribution efficiency of the hydronic system. This implies that the forced-air system requires over twice the electrical power as the hydronic system to deliver the same amount of heat to the load.

**Figure 8-1**



**Figure 8-2**



The concept of distribution efficiency can be used to compare competing hydronic system designs.

Imagine that the four-zone system cited in the previous example is configured as shown in figure 8-1.

Each zone is assumed to have an equivalent length of 200 feet of 3/4" copper tubing. Each zone circuit contains 40 feet of fin-tube baseboard and is equipped with a 3-speed circulator operating on the high-speed setting where electrical input is 87 watts. The supply water temperature to all zone circuits is 160°F. Assume the system's common piping and headers have very low head loss, and thus provide good hydraulic separation between the zone circuits.

This system can be simulated to find its thermal and hydraulic equilibrium operating conditions. The results of this simulation indicate the flow rate in each zone will be 5.96 gpm, and total heat output of the baseboard in each zone is 12,675 Btu/hr.

The distribution efficiency of this system with all four zones operating is:

$$n_d = \frac{Q_{delivered}}{w_e} = \frac{(4 \times 12,675) \frac{Btu}{hr}}{(4 \times 87) watt} = 146 \frac{Btu / hr}{watt}$$

If the circulator is changed to its low-speed setting, the input wattage drops to 60 watts, and the zone flow rates drop to 4.09 gpm each. The heat output of each zone also drops to 12,310 Btu/hr. The distribution efficiency is now:

$$n_d = \frac{Q_{delivered}}{w_c} = \frac{(4 \times 12,310) \frac{Btu}{hr}}{(4 \times 60) watt} = 205 \frac{Btu / hr}{watt}$$

In this case, reducing the zone circulator speed from high to low reduced electrical power input by 31 percent, and heat output by only 2.9 percent. Thus, the higher flow rate has minimal effect on increasing heat output. Operating the circulators at their low speed setting also increased distribution efficiency by 40 percent.

If each zone circulator was set to low speed and operated for 3000 hours per year, the total electrical energy used by the distribution system would be:

$$4(60watt) \left( \frac{3000hr}{yr} \right) \left( \frac{1kwhr}{1000watt \cdot hr} \right) = 720kwhr / yr$$

Let's compare this to a system using a single fixed-speed circulator to supply four zones, each regulated by a manifold valve and actuator. A schematic for this system is shown in figure 8-2.

Each zone circuit contains the same 40 feet of 3/4" fin-tube baseboard, as well as 150 feet of 1/2" PEX-AL-PEX tubing. With the single circulator on high speed (87 watts), the heat output of each zone circuit is simulated to be 11,221 Btu/hr, and the flow rate through each zone is 1.76 gpm. The distribution efficiency of the system with all four zones operating is:

$$n_d = \frac{Q_{delivered}}{w_c} = \frac{(4 \times 11,221) \frac{Btu}{hr}}{(87) watt} = 516 \frac{Btu / hr}{watt}$$

If the circulator is switched to low speed (60 watts), each zone delivers 10,521 Btu/hr, on a flow of 1.18 gpm. The distribution efficiency now becomes:

$$n_d = \frac{Q_{delivered}}{w_c} = \frac{(4 \times 10,521) \frac{Btu}{hr}}{(60) watt} = 701 \frac{Btu / hr}{watt}$$

Adjusting the operating hours of the zone valve-based system so that it delivers the same total heat as the zone circulator system, its seasonal electrical usage is:

$$1(60watt) \left( \frac{3000hr}{yr} \right) \left( \frac{1kwhr}{1000watt \cdot hr} \right) \left( \frac{12,310 Btu / hr}{10,521 Btu / hr} \right) = 211kwhr / yr$$

In this comparison, the system using zone valves delivers the same total heat using only 29 percent of the electrical energy required by the system using zone circulators. Note that the ratio of the distribution efficiencies between the two systems, where all circulators operate at 60 watts, is also  $(205/701) \times 100 = 29.2$  percent.

Finally, if a pressure-regulated circulator with ECM motor

were used in combination with the valve-based zoning, its projected power usage at full-load conditions would be approximately 26 watts. Its total electrical energy use over a typical heating season would likely be less than half that of the 60-watt fixed-speed circulator.

The relative performance of a zone valve-based system versus a system using zone circulators will vary between any two systems. However, this example was based on common practice in a typical residential system and shows a distinct advantage of valve-based zoning from the standpoint of electrical energy consumption.

## 9. FILLING AND PURGING ZONED SYSTEMS

For efficient operation, all hydronic systems should be virtually free of air. This is partially accomplished through proper filling and purging techniques. It is completed through the action of a microbubble air separator. This section discusses filling and purging techniques appropriate for zoned systems.

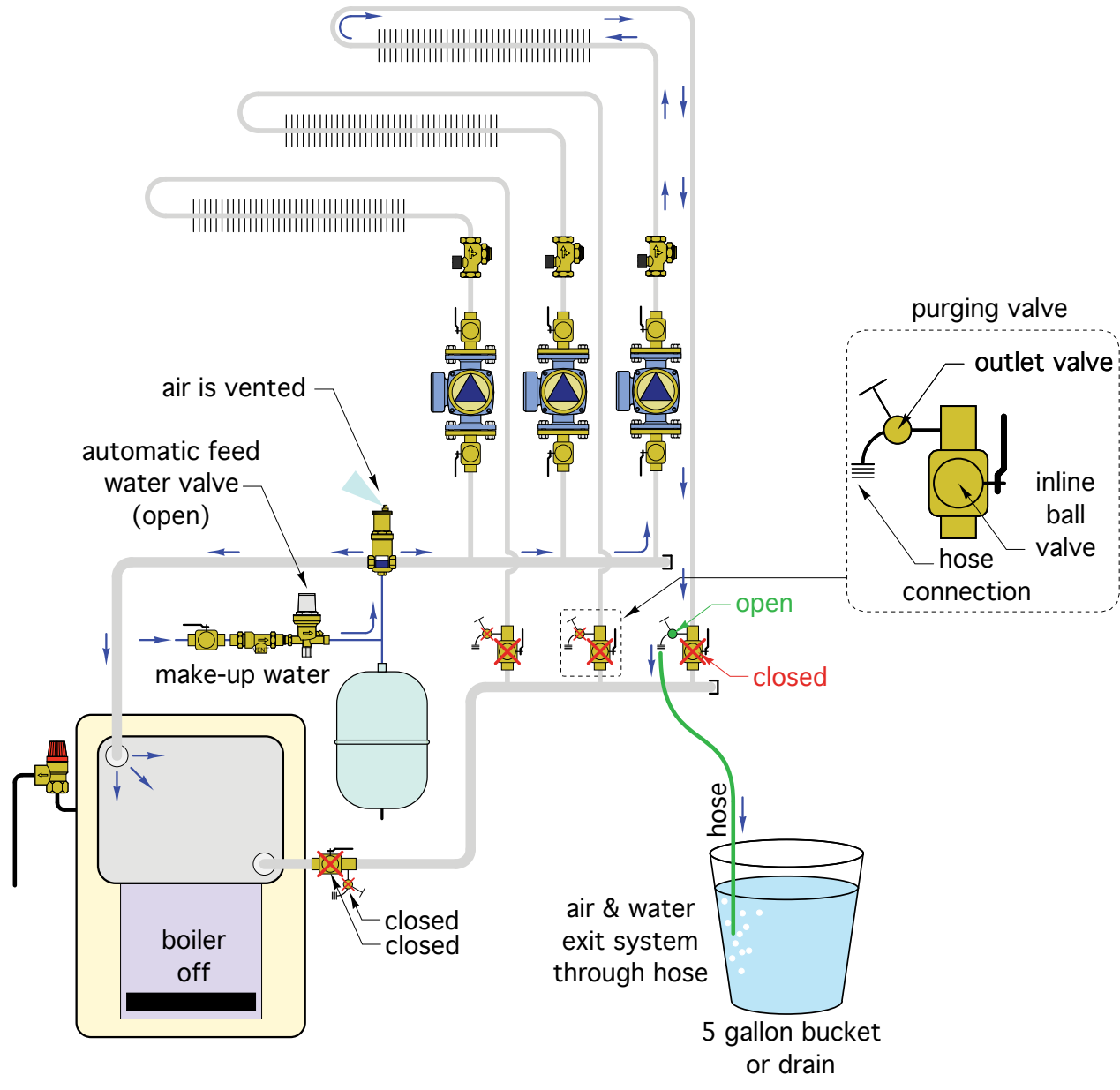
### PURGING SYSTEMS WITH ZONE CIRCULATORS:

Consider the system shown in figure 9-1. Each zone circuit has its own circulator. A purging valve is installed on the return end of each circuit.

The procedure to fill and purge this type of system is as follows:

1. Close all the inline ball valves on the zone-circuit purging valves.
2. Open the side outlet valve on the purging valve for the zone being purged and connect a hose to it. This hose should lead to a large bucket or a floor drain.
3. Close the inline ball valve and side outlet valve on the purging valve at the boiler inlet.
4. Enable the fast-fill function of the automatic feedwater valve. This allows water to rapidly enter the system. Some water will flow into the boiler, and some will pass rapidly through the open zone circuit, pushing air in the piping toward the return end of the circuit and eventually through the outlet of the purging valve.
5. After the return stream is free of bubbles for several seconds, turn off the outlet of the purging valve. A Caleffi autofill valve will automatically stop admitting water to the system at this point. The fast-fill function on other feed water valves may have to be manually turned off.

**Figure 9-1**



6. Move the discharge hose to the side outlet on the purging valve of the next zone circuit and repeat the procedure.

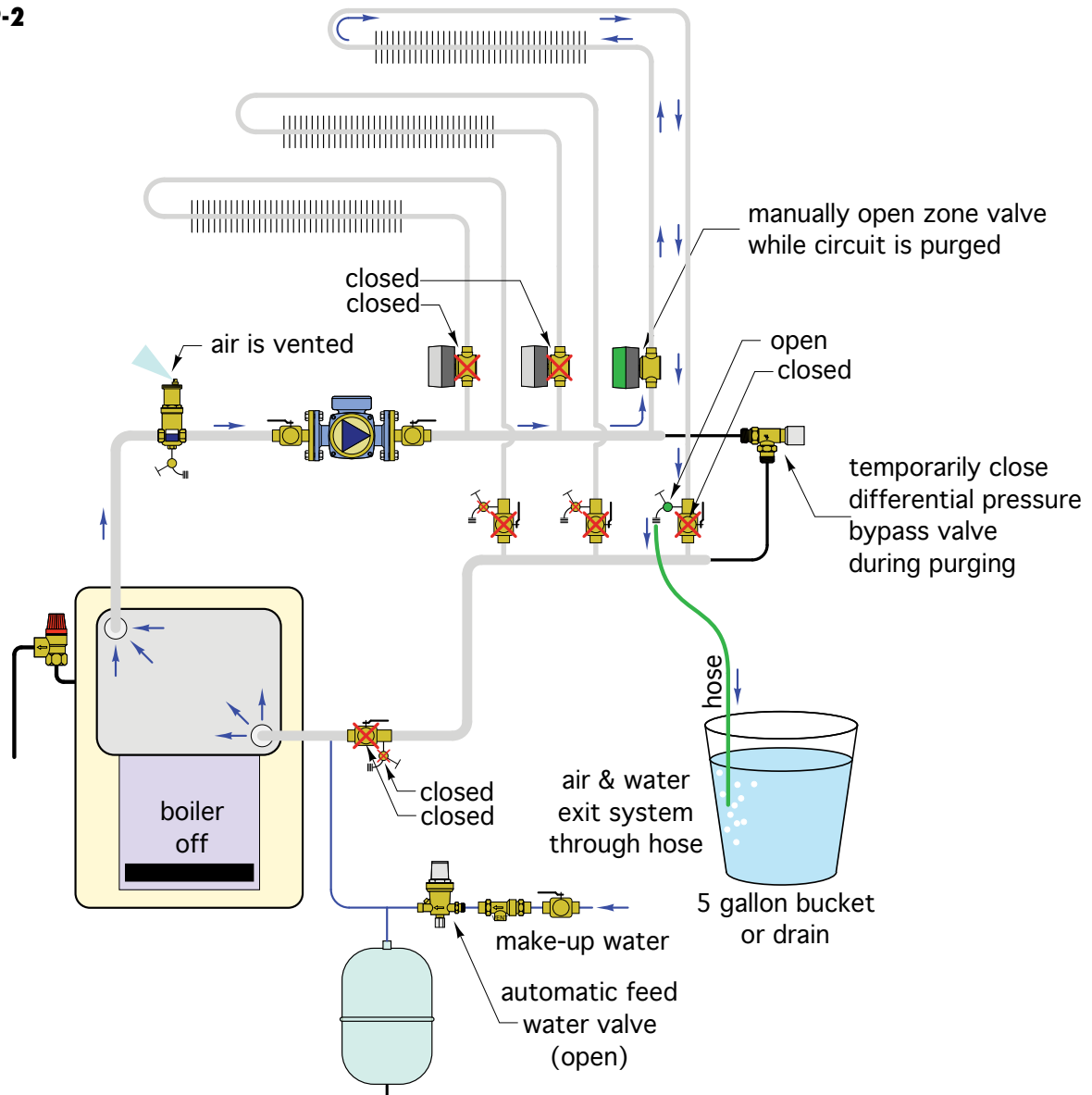
purging valve where it can be removed. Continue to purge until the discharge stream is free of visible air.

7. When all zone circuits have been purged, move the discharge hose to the purging valve at the boiler inlet. Open all inline balls on the circuit purging valves, then open the automatic feedwater valve. Turn on all the zone circulators to maximize system flow rate. Open the side outlet port on the purging valve at the boiler inlet and allow flow to pass through the discharge hose until the stream runs free of air bubbles for several seconds. This final purging flow should move any air bubbles in the return header toward the lower

8. Once all purging is complete be sure all inline balls in all purging valves are open and all outlet valves are fully closed.

9. At this point there may still be some small air bubbles in the system. The newly added water also contains molecules of dissolved gases such as oxygen and nitrogen. The microbubble air separator should remove this residual air over the course of several heating cycles.

**Figure 9-2**



### **PURGING SYSTEMS WITH ZONE VALVES:**

A similar purging procedure can be used with systems having manifold valve actuators or zone valves, as shown in figure 9-2

In this system, the make-up water assembly is located on the inlet side of the boiler. This alternative placement to that shown in figure 9-1 allows air to easily exit from the boiler as it fills with water. It also exposes the expansion tank to slightly cooler water as the system operates. It is an acceptable placement provided the heat source and piping leading from the heat source to the system circulator has low flow resistance. This creates minimal

head loss between the point where the expansion tank attaches to the system and the circulator inlet. If this is not the case, the make-up water assembly should be connected to the bottom of the air separator, as shown in figure 9-1.

A system like that shown in figure 9-2 should be purged as follows:

1. Close all the inline ball valves on the zone purging valves.
2. Open the outlet port on the purging valve for the zone being purged and connect a hose to it. This hose should lead to a large bucket or a floor drain.



3. Manually open the zone valve on the circuit to be purged, and be sure all other zone valves are closed.
4. Close the inline ball valve on the purging valve at the inlet of the boiler. Also be sure the differential pressure bypass valve is closed.
5. Enable the fast-fill function of the automatic feedwater valve. This allows water to rapidly enter the boiler, displacing air toward the boiler outlet. Some air will exit through the air separator. Water flow will continue through the open zone circuit, pushing air in the piping toward the return end of the circuit and eventually through the outlet of the purging valve.
6. Once the discharge from the hose is free of bubbles, turn off the outlet port of that purging valve. If the automatic feedwater valve does not automatically stop admitting water, turn off its fast-fill function.
7. Move the discharge hose to the outlet port of the purging valve on the next circuit and repeat the previous procedure.
8. When all zone circuits have been purged, move the discharge hose to the outlet port of the purging valve at the boiler inlet. Close all zone valves and fully open the differential pressure bypass valve. Turn on the system circulator to maximize flow. Open the outlet port on the purging valve at the boiler inlet and allow flow to pass through the discharge hose until the stream runs free of air bubbles for several seconds. This should push any air in the bypass valve, its piping and the return header toward the boiler and out through the purging valve.
9. Once all purging is complete, be sure all inline ball valves are open and all outlet ports are fully closed
10. At this point there may still be some small air bubbles in the system. The newly added water also contains molecules of dissolved gases such as oxygen and nitrogen. The microbubble air separator should remove this residual air over the course of several heating cycles.

## SUMMARY:

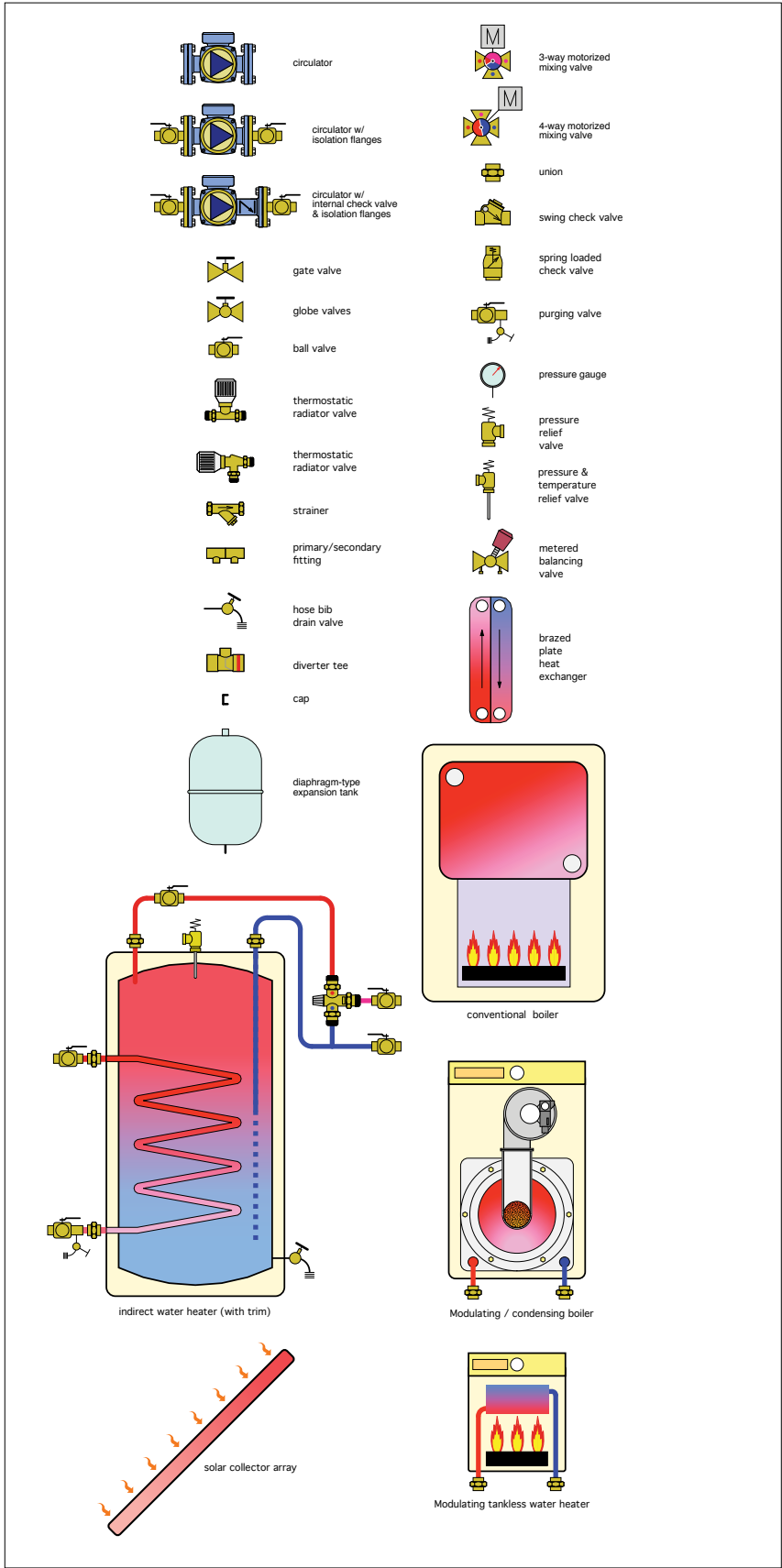
The ability to easily create and control zones is a long-established benefit of hydronic systems. Zoning allows occupants to customize the comfort conditions within a building and often lower operating cost in the process. A zoned system allows heat output to adapt to constantly changing conditions created by internal heat gain, room occupancy changes or changes in activity that require different interior temperatures to maintain comfort.

Modern zoning techniques and hardware enhance these traditional benefits by providing simpler installation, smoother heat delivery and significant reduction in distribution energy requirements.

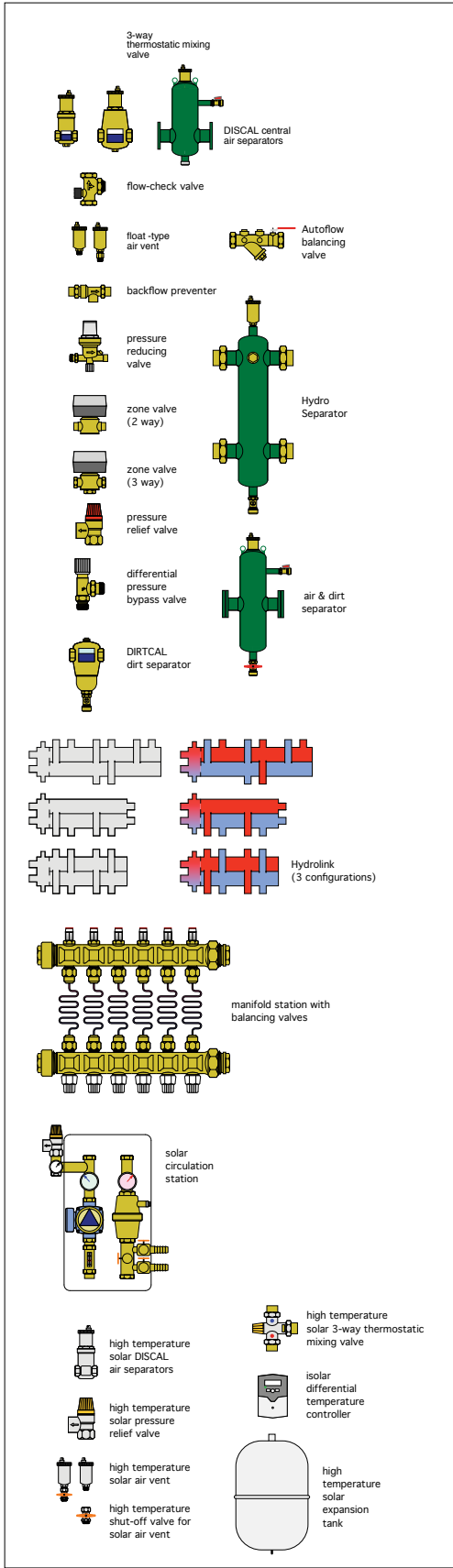
To maximize the benefits of hydronic zoning, keep the following points in mind:

- Select zoning strategies based on occupancy, internal heat gains and activities conducted in various spaces.
- Don't combine heat emitter systems with significantly different thermal mass on the same zone.
- If adjacent rooms are to be maintained at significantly different temperatures, the partitions separating these rooms should be insulated and the doors to the rooms closed to prevent natural convection from equalizing room temperatures.
- When zoning with circulators, be sure the circulators are hydraulically separated from each other. This is done by keeping the flow resistance of the "common piping" shared by all zones to a minimum. Headers should be as short as possible and sized for a maximum flow velocity of 2 to 4 feet per second to provide minimal resistance. It can also be done through use of specific hardware for hydraulic separation.
- When zoning with circulators, a check valve must be included on the supply side of each zone circuit to prevent flow reversal. The check valve should have a weighted plug or spring-load disc to prevent heat migration due to the buoyancy of hot water. The check valve can be a separate component or integral to the zone circulator.
- When zoning with valves and a fixed-speed circulator, include a properly set differential pressure bypass valve to minimize variations in differential pressure as zones open and close.
- When a system will be extensively zoned, the ability of the heat source to reduce its heat output to match what could be a very small heating load should be carefully evaluated. When an "on/off" heat source is used, or when the heat source's minimum modulation rate is significantly greater than the smallest zone load, a buffer tank should be used to add thermal mass for stable operation.
- Although zoning can be accomplished with either zone circulators or zone valves, the latter approach usually results in significantly lower electrical energy use. It also takes full advantage of variable-speed pressure-regulated circulators.

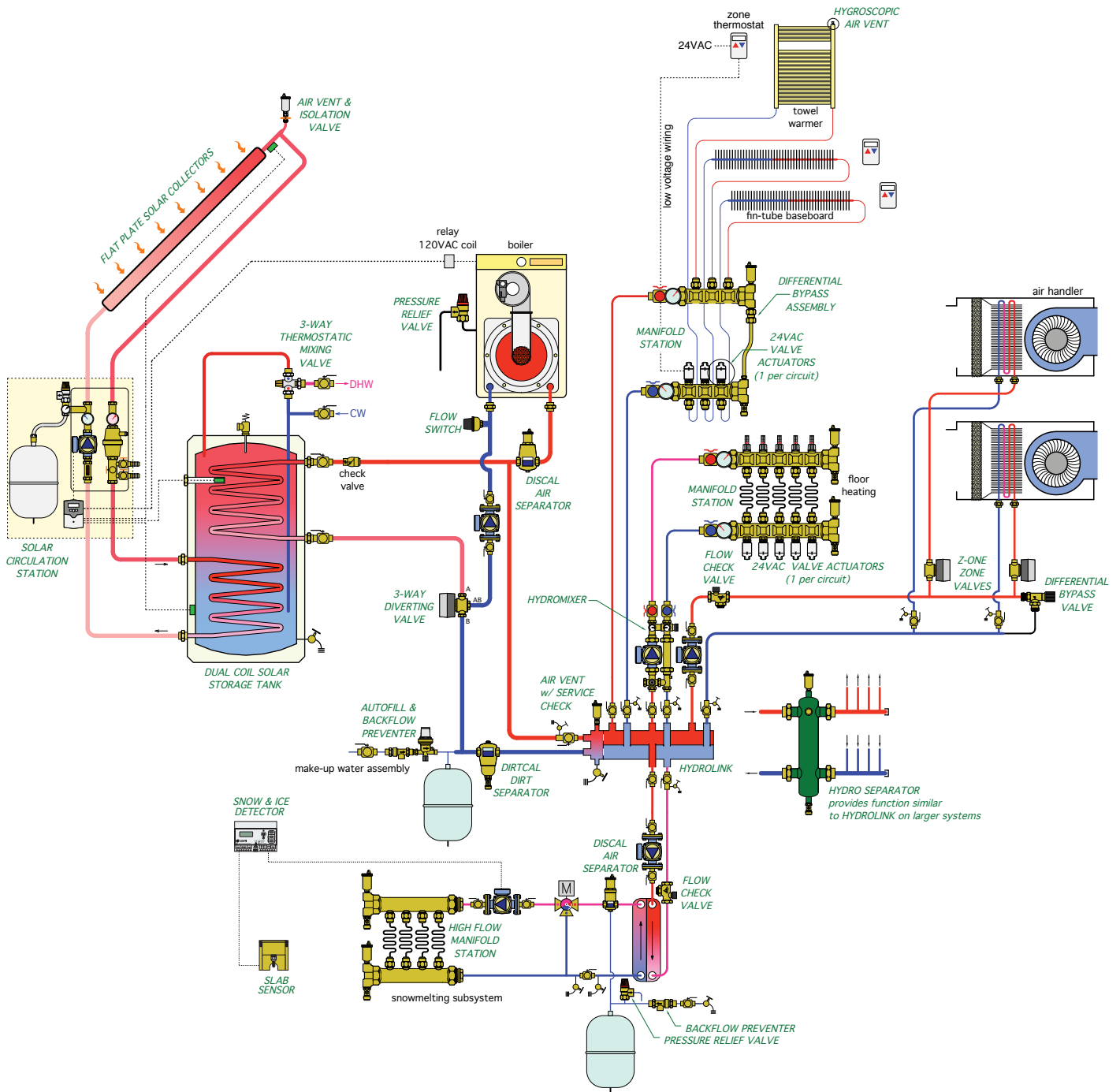
# GENERIC COMPONENTS



# CALEFFI COMPONENTS



CALEFFI manufactures a wide variety of innovative, high quality components for hydronic and solar thermal systems. These products help designers and installer provide reliable, energy efficient, and environmentally friendly comfort systems. For full descriptions of the components shown below please visit [www.caleffi.us](http://www.caleffi.us) and download product brochures for both hydronic and solar thermal products.



## Z series



• US Patent 7,048,251; others pending

### Function

Z-one valves are used to automatically shut-off the flow or redirect hot and chilled water in hydronic heating and air conditioning systems.

The motorized two position, on/off, spring return Z1 series actuator has a end mounted push button for quick installation to valve body. The actuator is equipped with or without auxiliary switch and configured Normally Closed or Normally Open with wire or terminal connections.

The zero leakage high temperature zone valve body Z2 series is 2-way straight through and the valve body Z3 series is 3-way diverting. The Z1 series actuator is easily attached by a push button lock and without tools.

The high temperature and high close-off performance characteristics of these zone valves, combined with the compact size, makes them suitable to fit inside baseboard or directly in fan coils units.

### Quick Order Code Numbers: 24VAC Normally Closed Actuator and 2-way Valve Body Combinations

| Code     | Description   | Connection |
|----------|---|------------|
| Z40      | Z111000 with auxiliary switch, 18 inch wire connection + Z200043 flare body + NA61241K              | Inverted   |
| Z40F     | Z111000 with auxiliary switch, 18 inch wire connection + Z200043 flare body + two NA10006 sweat     | 3/4"       |
| Z42      | Z111000 with auxiliary switch, 18 inch wire connection + Z200053 flare body                         | 1/2" SAE   |
| Z44      | Z111000 with auxiliary switch, 18 inch wire connection + Z200432 sweat body                         | 1/2"       |
| Z45      | Z111000 with auxiliary switch, 18 inch wire connection + Z200537 sweat body                         | 3/4"       |
| Z46      | Z111000 with auxiliary switch, 18 inch wire connection + Z200637 sweat body                         | 1"         |
| Z47      | Z111000 with auxiliary switch, 18 inch wire connection + Z200737 sweat body                         | 1 1/4"     |
| Z50      | Z151000 with auxiliary switch, screw terminal connection + Z200043 flare body + NA61241K            | Inverted   |
| Z50F     | Z151000 with auxiliary switch, screw terminal connection + Z200043 flare body + two NA10006 sweat   | 3/4"       |
| Z54      | Z151000 with auxiliary switch, screw terminal connection + Z200432 sweat body                       | 1/2"       |
| Z55      | Z151000 with auxiliary switch, screw terminal connection + Z200537 sweat body                       | 3/4"       |
| Z56      | Z151000 with auxiliary switch, screw terminal connection + Z200637 sweat body                       | 1"         |
| Z57      | Z151000 with auxiliary switch, screw terminal connection + Z200737 sweat body                       | 1 1/4"     |
| NA10005  | Inverted flare nut with attached copper sweat tail piece  | 1/2"       |
| NA10006  | Inverted flare nut with attached copper sweat tail piece  | 3/4"       |
| NA10007  | Inverted flare nut with attached copper sweat tail piece  | 1"         |
| NA61241K | Inverted flare extension adaptor to retrofit body into an old style asymmetrical zone valve opening | Inverted   |
| NA10124  | SAE flare nut with attached copper sweat tail piece   | 3/4"       |

### Technical specification

#### Valve body

Material: - body: forged brass  
 - seat: machined brass  
 - stem: stainless steel  
 - two o-ring seals and paddle: EPDM

Flow: 1 to 7.5 Cv (0.9 to 6.5 kv)  
 Medium: water and glycol, low pressure steam  
 Maximum percent of glycol: 50%  
 Temperature range: 32 to 240°F (0 to 115°C)  
 Max. static pressure: 15 psi (1 bar) steam  
 300 psi (20 bar)

Max. closeoff Δ pressure: 20 to 75 psi (138 to 517 kPa)

Connection: - sweat: 1/2", 3/4", 1" & 1 1/4"  
 - NPT female: 1/2", 3/4" & 1"  
 - SAE flare: 1/2"  
 - inverted flare: 1/2", 3/4" & 1" sweat fittings separate

#### Actuator

Material: - base and cover: polycarbonate  
 - baseplate: aluminum

AC voltage: 24V - 120V - 208V - 230V - 277V; 50/60 Hz  
 Power requirements: 6.5 W, 7 VA

Power connections: - terminal screws with auxiliary switch: 24V only  
 - wire lead length: 18" (45 cm) 24V only  
 6" (15 cm) 120, 208, 230, 277V

Auxiliary switch capacity: 0.4A, 24V (24V only)  
 5.0A, 250V (120, 208, 230, 277V)

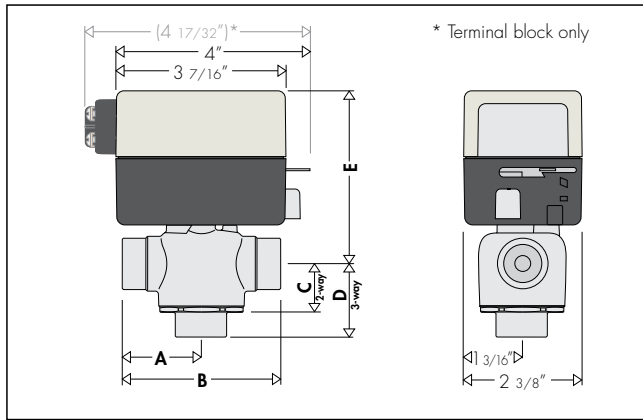
Ambient temperature range: 32 to 104°F (0 to 40°C) 24, 120V  
 32 to 170°F (0 to 77°C) 208, 230, 277V

Humidity: 95% non-condensing

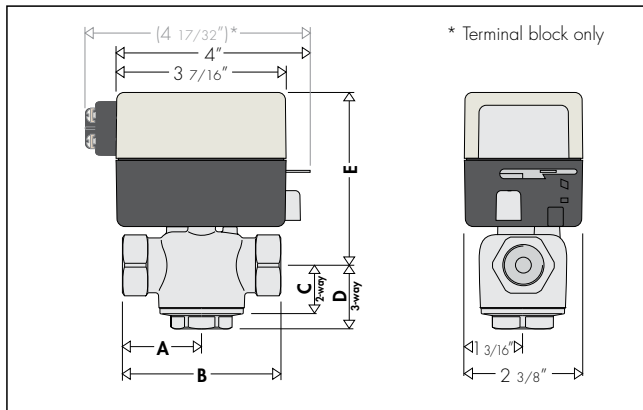
Full Stroke Time: - open < 60 seconds  
 - close: < 10 seconds

Approvals: UL, cUL Listed & CE

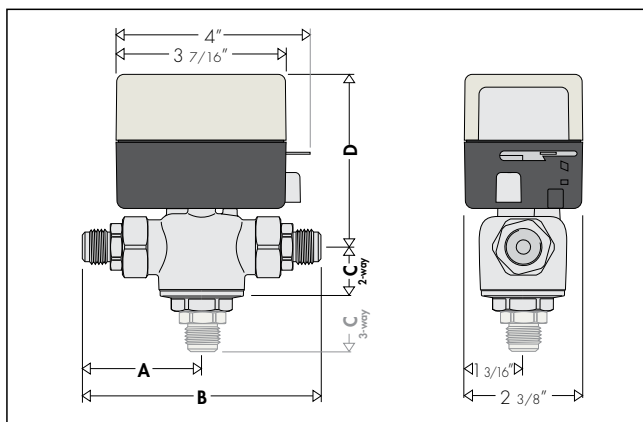
## Dimensions



| Connections  | A        | B      | C      | D        | E        |
|--------------|----------|--------|--------|----------|----------|
| 1/2" sweat   | 1 5/16"  | 2 5/8" | 15/16" | 1 5/16"  | 3 1/2"   |
| 3/4" sweat   | 1 3/8"   | 2 3/4" | 15/16" | 1 1/2"   | 3 1/2"   |
| 1" sweat     | 1 11/16" | 3 3/8" | 15/16" | 1 9/16"  | 3 11/16" |
| 1 1/4" sweat | 1 13/16" | 3 5/8" | 15/16" | 1 11/16" | 3 11/16" |



| Connections             | A        | B       | C      | D        | E        |
|-------------------------|----------|---------|--------|----------|----------|
| 1/2" NPT                | 1 7/16"  | 2 7/8"  | 15/16" | 1 1/4"   | 3 1/2"   |
| 3/4" NPT                | 1 9/16"  | 3 1/16" | 15/16" | 1 1/4"   | 3 11/16" |
| 1" NPT                  | 1 13/16" | 3 5/8"  | 15/16" | 1 11/16" | 3 11/16" |
| Inverted flare          | 1 3/8"   | 2 3/4"  | 15/16" | 1 1/4"   | 3 1/2"   |
| with adaptor (NA61241K) | 1 3/8"   | 3 1/2"  | 15/16" | 1 1/4"   | 3 1/2"   |



| Connections          | A        | B        | C      | D      |
|----------------------|----------|----------|--------|--------|
| 2-way 1/2" SAE Flare | 2 11/32" | 4 11/16" | 15/16" | 3 1/2" |
| 3-way 1/2" SAE Flare | 2 11/32" | 4 11/16" | 2 1/8" | 3 1/2" |

## Operating principle

The Z-one actuator has a synchronous motor that winds the return spring and moves the valve paddle to the desired position. When power is removed the actuator spring returns the valve paddle. The Zone actuator is equipped with or without auxiliary switch.

### Operation of normally closed valve

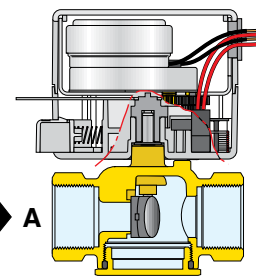
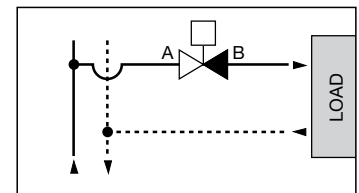
|                        | 2-way           | 3-way  |
|------------------------|-----------------|--|
| N.C. without power     | Port "A" closed | Port "A" closed<br>Port "B" open<br>Port "AB" open     |
| N.C. opened with power | Port "A" opened | Port "A" opened<br>Port "B" closed<br>Port "AB" open   |
| N.C. manually opened   | Port "A" open   | Port "A" opened<br>Port "B" opened<br>Port "AB" opened |

### 2-way

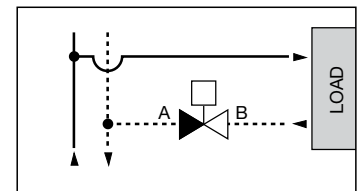
(with the power off, passage A is closed)



### 2-way installed on the flow side



### 2-way installed on the return side

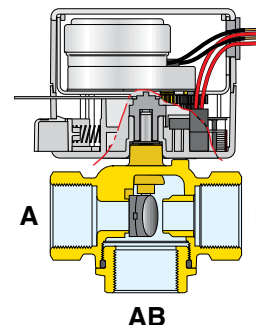
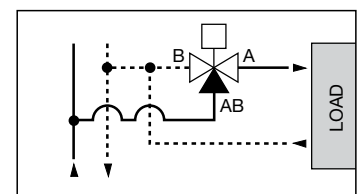


### 3-way

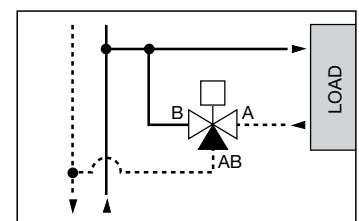
(with the power off, passage A is closed)



### 3-way installed on the flow side as a diverting valve configuration



### 3-way installed on the return side as a mixing valve configuration



# Differential Pressure By-Pass Valve



## 519 series



519709A



519599A

### Function

The differential pressure by-pass valve is used in systems with a fixed speed circulating pump supplying several zones controlled by two way zone valves. This valve ensures that the head pressure of the pump is proportional to the number of two way valves being closed. It will by pass the differential pressure created by the pump as the zone valves close, thus eliminating water hammer noise.

### Product range

|              |  |   |
|--------------|--|---|
| Code 519502A | Adjustable differential pressure by-pass valve with graduated scale, flow up to 9 gpm  | Size 3/4" Male NPT x 3/4" Male NPT outlet         |
| Code 519599A | Adjustable differential pressure by-pass valve with graduated scale, flow up to 9 gpm  | Size 3/4" Sweat x 3/4" Sweat outlet               |
| Code 519600A | Adjustable differential pressure by-pass valve with graduated scale, flow up to 40 gpm | Size 1" Female NPT x 1" Male NPT outlet           |
| Code 519609A | Adjustable differential pressure by-pass valve with graduated scale, flow up to 40 gpm | Size 1" Female NPT x 1" sweat outlet              |
| Code 519700A | Adjustable differential pressure by-pass valve with graduated scale, flow up to 45 gpm | Size 1 1/4" Female NPT x 1 1/4" Female NPT outlet |
| Code 519709A | Adjustable differential pressure by-pass valve with graduated scale, flow up to 45 gpm | Size 1 1/4" Female NPT x 1 1/4" sweat outlet      |

### Technical specifications

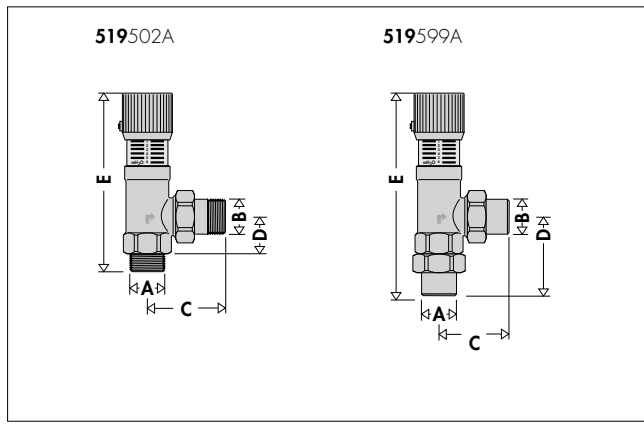
#### Materials

|                    |                      |
|--------------------|----------------------|
| Body:              | brass                |
| Valve plug:        | brass                |
| Valve plug gasket: | EPDM                 |
| O-Ring seals:      | EPDM                 |
| Union seals:       | asbestos free AFM 34 |
| Control knob:      | ABS                  |
| Spring:            | stainless steel      |

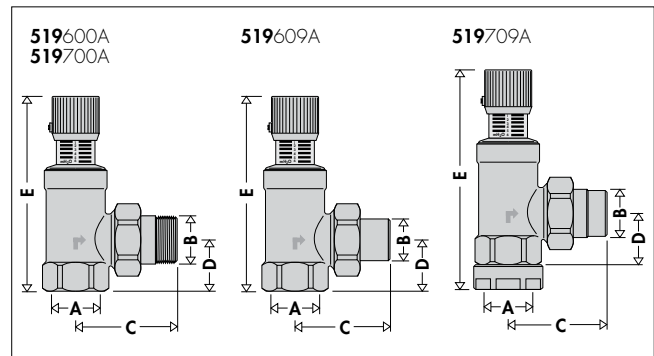
#### Performance

|                           |   |
|---------------------------|---|
| Medium:                   | water, glycol solutions   |
| Max percentage of glycol: | 30%   |
| Temperature range:        | 32-230°F (0-110°C)  |
| Maximum working pressure: | 150 psi (10 bar)  |
| Flow rates:               | 3/4" flow up to 9 gpm<br>1" flow up to 40 gpm<br>1 1/4" flow up to 45 gpm |
| Setting range:            | 1 - 6 m w.g. (2 - 10 psi)   |

#### Dimensions



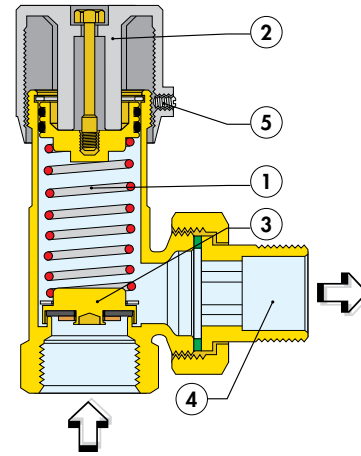
| Code    | A          | B          | C      | D      | E       | Weight (lb) |
|---------|------------|------------|--------|--------|---------|-------------|
| 519502A | 3/4" M NPT | 3/4" M NPT | 2 1/4" | 1 7/8" | 5"      | 1           |
| 519599A | 3/4" SWT   | 3/4" SWT   | 2 1/8" | 2 1/2" | 5 9/16" | 1           |



| Code               | A            | B            | C        | D        | E      | Weight (lb) |
|--------------------|--------------|--------------|----------|----------|--------|-------------|
| 519600A<br>519700A | 1" F NPT     | 1" M NPT     | 3 13/16" | 2 1/16"  | 6 5/8" | 1.4         |
| 519609A            | 1" F NPT     | 1" SWT       | 2 13/16" | 2 1/16"  | 6 5/8" | 1.4         |
| 519700A            | 1 1/4" F NPT | 1 1/4" M NPT | 3 15/16" | 2 11/16" | 7 3/8" | 1.5         |
| 519709A            | 1 1/4" F NPT | 1 1/4" SWT   | 3"       | 2 11/16" | 7 3/8" | 1.5         |

## Operating principle

When the spring (1) compression is adjusted using the control knob (2), the force balance acting on the valve plug (3) changes, thus modifying the set pressure value of the valve. The valve plug opens, activating the by-pass circuit, only when it is subjected to a differential pressure sufficient to generate a thrust greater than the thrust exerted by the spring. This allows the flow discharge through the outlet (4), limiting the difference in pressure between the two points in the system where the valve is fitted.

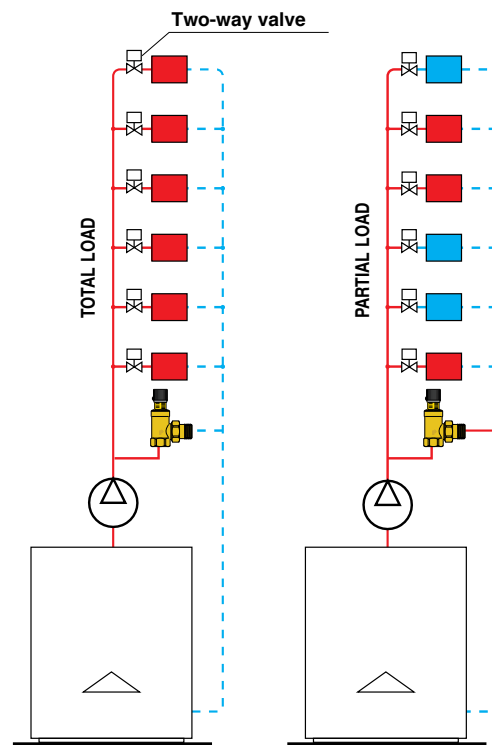
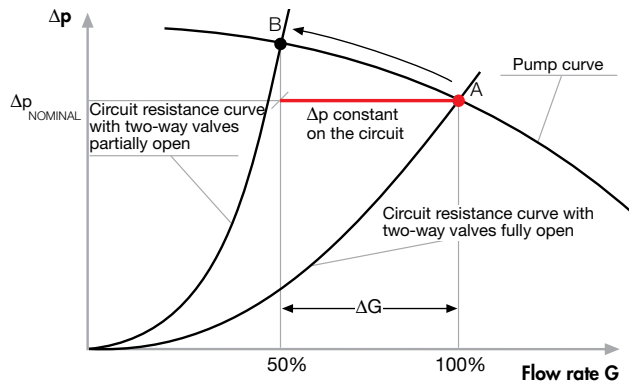


## System operation

The job of the differential pressure by-pass valve is to maintain the pump operating point as close as possible to its nominal value (point A on the graph shown below). If the by-pass valve is not used, when the flow rate in the circuit decreases due to partial closure of the two-way zone valves, the head loss in the circuit increases, point B.

The by-pass valve, set to the nominal head value of the pump, enables to limit the pressure increase, by-passing the flow rate  $\Delta G$ . This behavior is guaranteed at any closing condition of the system two-way zone valves. In fact, once the position of the valve control knob has been established, the set pressure value is more or less constant as the discharge flow rate varies (see hydraulic characteristic diagrams).

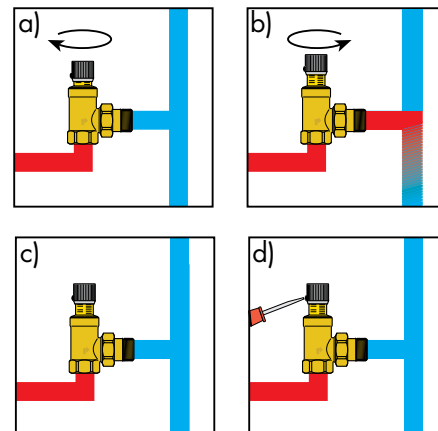
A proper valve sizing must guarantee a sufficient flow rate by-pass to keep the pump at its nominal operating point in all system operating conditions, for example when the first zone valves are closed.



## Setting

To regulate the valve, turn the knob to the required value on the graduated scale: the values correspond to the differential pressure in psi or meters w.g. to open the by-pass.

For a quick setup adjustment of the differential pressure by-pass valve, use the following manual method. As an example, a hydronic system with several zone valves: the system must be operating, the zone valves must be fully open and the by-pass valve must be set to the maximum value (a) (clockwise). Gradually open the differential pressure by-pass valve using the control knob (counterclockwise). Use a thermometer, or simply your hand, to check that the hot water is flowing into the by-pass circuit (b). As soon as a rise in the temperature is noted, turn control knob (clockwise) one half turn closed so hot water stops flowing into the by-pass (c). Lock the knob in this position (d) with the locking screw.



# Z-one™

ZONE VALVES

“With the proven reliability of Caleffi zone valves, I am more convinced than ever that zoning with valves is preferable to pumps.”

*A. Hagen  
Radiant Engineering, Inc.  
Bozeman, MT*



“On a zone valve job that absolutely must perform season after season, I go with Caleffi valves — highly engineered like all of their products.”

*Zbigniew “Zibi” Jonak  
Jonak Advanced H&P  
Chicago, IL*



## UNIVERSAL ZONE VALVE FOR ALL APPLICATIONS

[www.caleffi.us](http://www.caleffi.us)

Caleffi Z-one valves are designed and built to be the best zone valve ever.

Actuators are in 24V, 120V, 208V, 230V and 277VAC, either normally opened or normally closed.

Valve bodies are 2-way and 3-way rated at 300 PSI, with Cv rating of 1.0, 2.5, 3.5, 5.0, and 7.5, and are configured in sizes from 1/2" to 1-1/4" with sweat, NPT, SAE flare and inverted flare connections .

- Compact design that fits inside baseboards and fan coils
- 7VA current draw allows for up to five valves per 40VA transformer
- All temperature components for chilled or hot water up to 240° F
- Large valve cavity for quieter flow and reduced water hammer
- Large in-line push button release for easy removal and installation

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