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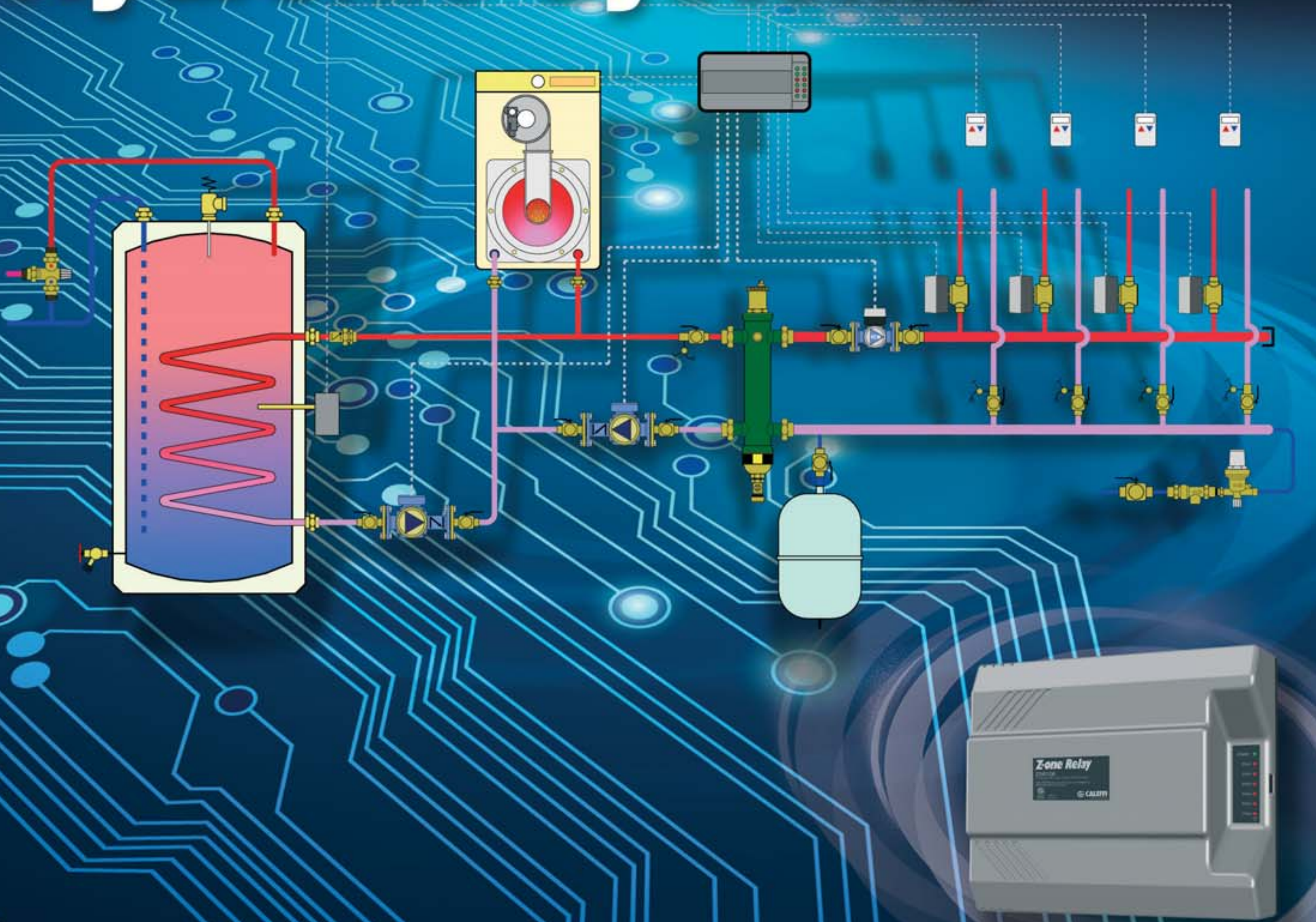
idronics™

JOURNAL OF DESIGN INNOVATION FOR HYDRONIC PROFESSIONALS

Controlling Hydronic Systems



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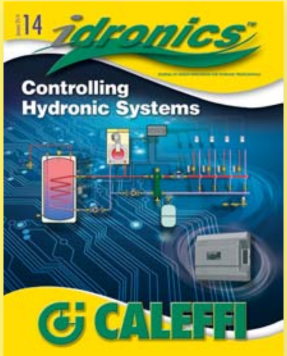

A Technical Journal
from
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Dear Hydronic and Plumbing Professional,

Many professionals in our trade are naturally curious. They ask questions such as:

"What does the diaphragm do inside that tank?"
"How does that mixing valve keep water temperature steady?"
"Why does opening this valve cause a pressure drop over there?"

Naturally curious individuals seek answers that improve their ability to design, install and troubleshoot systems.

In this issue of **idronics** we shift away from the *hydraulic* side of hydronic systems, which has been the main focus of previous issues, to the *controls* side of these systems. We answer questions such as What types of hydronic controls are available? How are they constructed? How do they work? Where are they best applied? How do they interact with other devices to form a complete control system?

If you have been curious about controls, this issue of idronics will enhance your understanding of basic concepts used in a wide variety of devices. It will also show you how to apply them to smoothly regulate state-of-the-art hydronic heating and cooling systems.

We hope you enjoy this issue and encourage you to send us any feedback about *idronics* by e-mailing us at idronics@caleffi.com.

For prior issues, please visit us at www.caleffi.us and click on the idronics icon. There you can download the PDF files. You can also register to receive hard copies of future issues.

Mark Olson

General Manager & CEO

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Controlling Hydronic Systems

1. INTRODUCTION

Controls are the "brains" of hydronic systems. They regulate the time, and often the rate, at which water is heated by the heat source. They also regulate the timing, rate and location of heat delivery. Hydronic systems that have properly selected and adjusted controls can provide efficient energy transfer from the heat source(s) to the load(s), while also enhancing comfort and minimizing operating noise. Systems with poorly selected or improperly adjusted controls can be a constant source of frustration, wasted energy and compromised comfort.

This issue of *idronics* begins with a brief history of controls, and then moves into a discussion of the fundamental concepts and basic hardware that are the building blocks of control systems. A solid understanding of these fundamental concepts and devices is essential in designing and configuring complete control systems.

Later sections show examples of complete piping systems, along with their associated control diagrams. These examples use extensive cross-referencing between devices shown in the system's piping schematic and those same devices within the system's electrical wiring diagram. A full description of operation is given that allows those installing or servicing the system to follow the operating sequence of all controlled devices within that system.

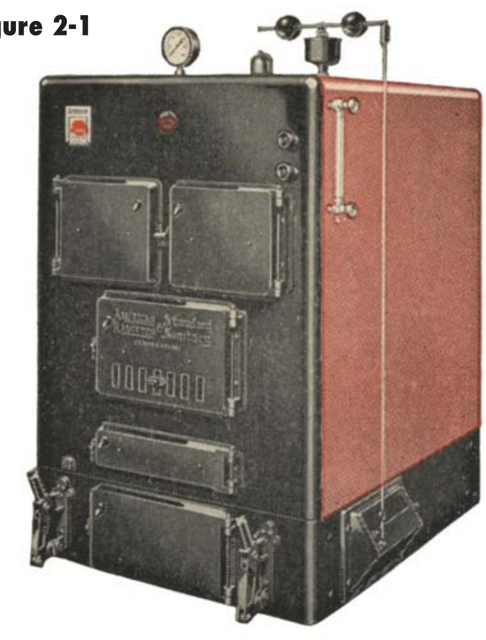
As is true for many of the past topics covered in *idronics*, the topic of hydronic system controls is vast, and rapidly expanding as new products come to market on a continuous basis. This issue doesn't attempt to be an exhaustive reference of all types or variations in control hardware or techniques. Instead, it focuses on fundamental concepts that, if properly understood, can be implemented using a wide variety of hardware.

2. A BRIEF HISTORY OF HYDRONIC CONTROLS

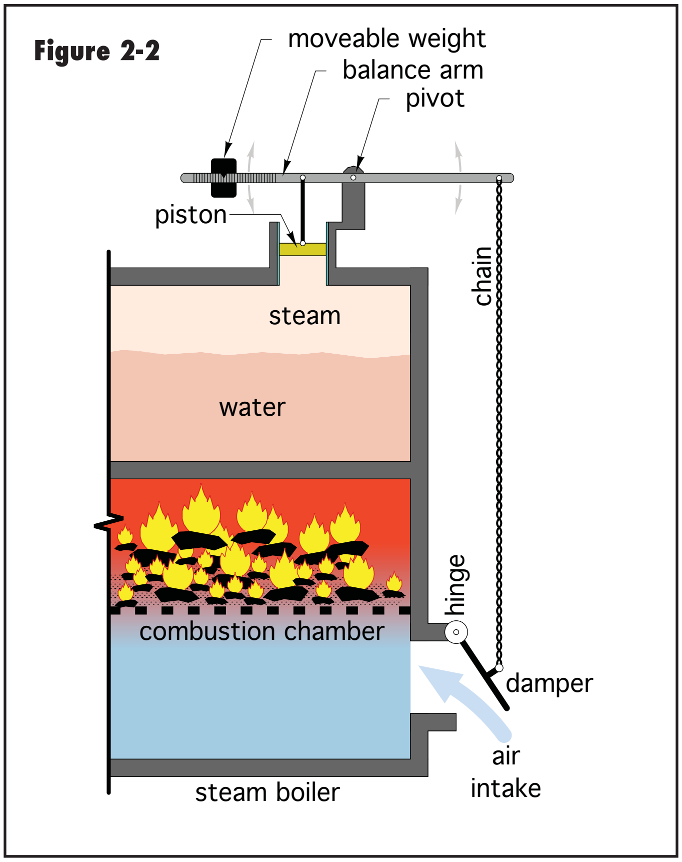
Before electrical control devices were available, the transfer of heat within hydronic systems was regulated by manually operated valves, pressure-operated valves and some thermostatically operated devices.

During the 1800s, and an early part of the 1900s, the rate of heat output from coal-fired steam and hot water boilers was regulated through a combination of shoveling coal into the combustion chamber and regulating the rate of airflow into that chamber. Some boilers used manually adjusted shutters to regulate air intake. Early steam boilers, such as shown in Figure 2-1, used mechanisms involving weights adjusted on lever arms to balance the force created by steam pressure against a piston.

Figure 2-1



As steam pressure increased to some preset level, a mechanism would lift or lower a chain that regulated combustion airflow through a hinged damper, as seen in Figure 2-2.



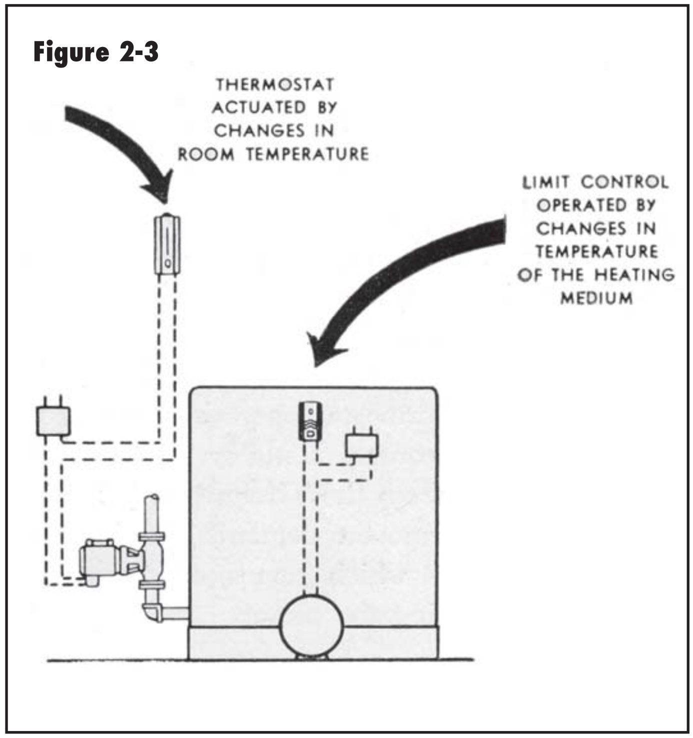
Increasing the rate of air supply to the burning coal increased the rate of combustion, and thus increased the heat output from the boiler. In most systems, mechanical air damper controls were adjusted to close the air intake damper as the boiler approached a preset upper temperature limit or pressure limit. However, this early form of “high limit control” could not completely stop the combustion process, as is possible with modern boilers burning automatically supplied fuels. Thus, some fuel was inevitably wasted due to “stand-by” combustion when the building load was small or temporarily zero.

Non-electric thermostatic controls continued to be used even as automatically supplied fuels such as natural gas became available. The standing pilot flame method of initiating combustion was common until concerns over the cost and availability of natural gas and propane to supply the pilot flame lead to it to be replaced by other methods. Still, many boilers and water heaters using standing pilot lights continue to operate in North America.

ELECTROMECHANICAL CONTROLLERS

Electricity became widely available in America during the 1930s. Fuels such as natural gas, propane and fuel oil also became popular for central heating because they freed homeowners from having to feed coal or wood into boilers or other heating devices. This led to the development of electromechanical controllers for regulating the water temperature produced by boilers by varying the on/off status of fuel burners.

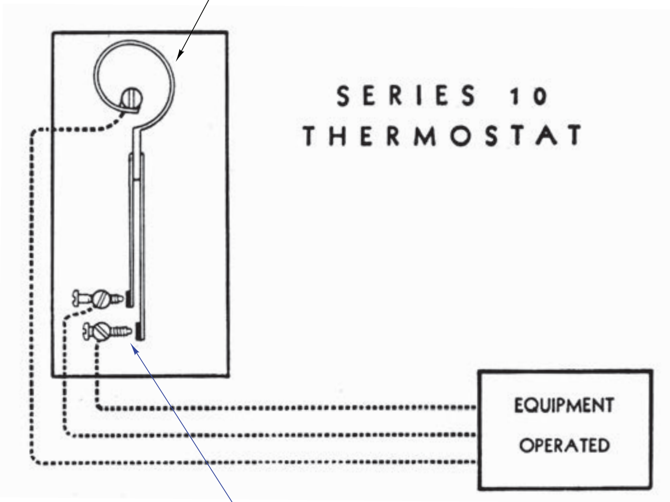
Figure 2-3 shows a 1949 example of such a controller wired to the fuel burner of a boiler. A wall thermostat is also shown wired to the circulator.



Courtesy of Bell & Gossett

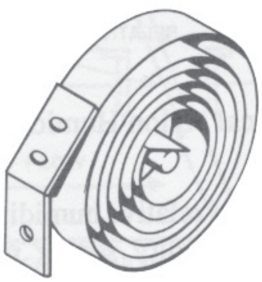
Room thermostats were one of the first types of electromechanical controllers used in hydronic systems. In essence, all thermostats are temperature-operated switches. Early thermostats used a bimetallic element to convert a change in temperature to movement. Bimetallic elements consist of two strips of different metals (usually steel and brass) that are mechanically joined at their ends and along their length. Because these metals have different coefficients of expansion, any change in temperature causes one strip to expand or contract more than the other. This creates a very repeatable flexing movement of the element. When heated, the element flexes in one direction. When cooled, it flexes in the opposite direction. This flexing was used to move electrical contacts together or apart, as shown in Figure 2-4, which depicts a vintage thermostat from 1949. When the contacts closed, an electrical current could flow through the thermostat to operate a device such as a circulator.

Figure 2-4



Courtesy of Bell & Gossett

Figure 2-5



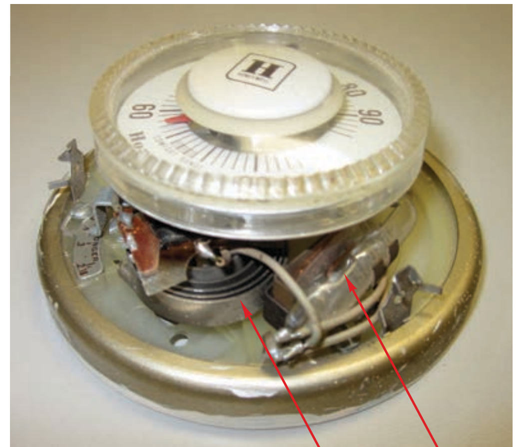
Courtesy of Honeywell

By coiling the bimetallic element into a spiral, as shown in Figure 2-5, a greater amount of movement, and thus greater temperature sensitivity, could be created within a smaller space.

A coiled bimetallic element was used in millions of Honeywell T87 round thermostats, as shown in Figure 2-6.

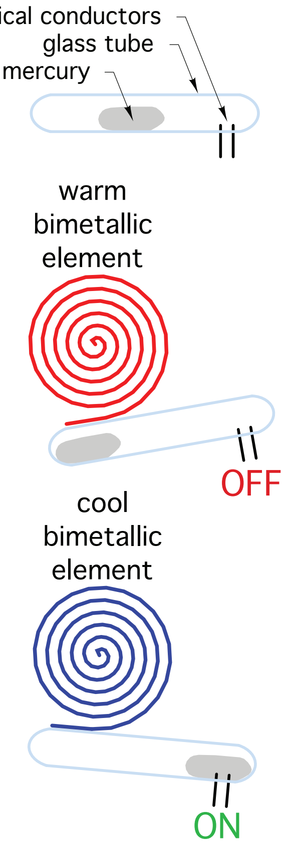
Figure 2-6

Figure 2-7



In this thermostat, flexing of the bimetallic element caused movement of a sealed glass capsule containing a small amount of mercury. Figure 2-7 shows both this capsule and the coiled bimetallic element that causes it to move.

Figure 2-8



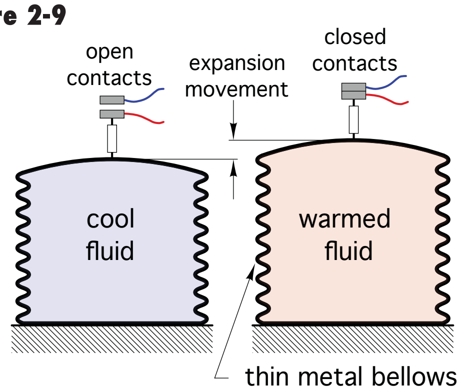
When the bimetallic element cooled, it rotated the glass capsule so the mercury, which is highly conductive to electricity, would slide to the end containing two electrical conductors and complete the circuit between them. As it warmed, the bimetallic element would eventually rotate the capsule so the mercury would slide away from these conductors, and thus open the circuit. Figure 2-8 illustrates this concept.

Although some mercury-based thermostats are still in use, they are no longer manufactured or sold due to concerns over disposal of devices containing mercury.

EXPANDING BELLOWS CONTROLLERS

Other early generation thermostatic controls used a fluid-filled metal bellows to convert changes in temperature into movement. The bellows is a very thin metal can with corrugated sides. During manufacturing, air was evacuated from the bellows. It was then filled with a fluid having known expansion characteristics, and sealed. When warmed, the fluid expands inside the bellows, causing its length to increase. When it cools, the fluid contracts, causing the bellows to shorten. This expansion/contraction was used to move electrical contacts together or apart, as illustrated in Figure 2-9.

Figure 2-9



Bellows-type mechanisms where also used in combination with remote temperature sensing bulbs that were connected to the bellows using very small diameter “capillary” tubing, as shown in Figures 2-10 and 2-11.

PNEUMATIC CONTROLLERS

In commercial, institutional and industrial buildings, it was once common to find pneumatic controllers that were operated by regulating the flow of compressed air through small-diameter flexible tubing. Pneumatic-based actuators, operated directly by compressed air and responding to pneumatic temperature-sensing devices, would control the position of dampers in forced air systems or valves in hydronic systems. Diaphragm actuators, such as shown in Figure 2-12, were also used to control the position of on/off valves.

Pneumatic actuators can generate considerable force or torque relative to comparably sized electrical actuators, and thus are well suited to control large valves. An example of such a valve with an attached pneumatic actuator is shown in Figure 2-13.

Figure 2-10

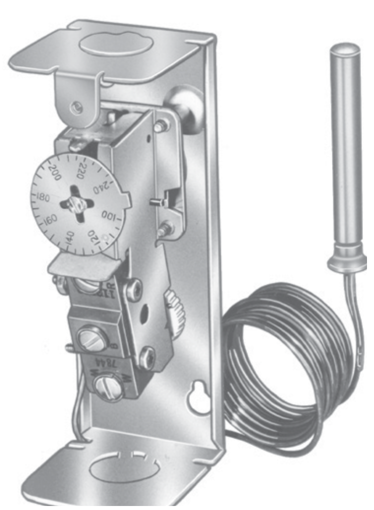
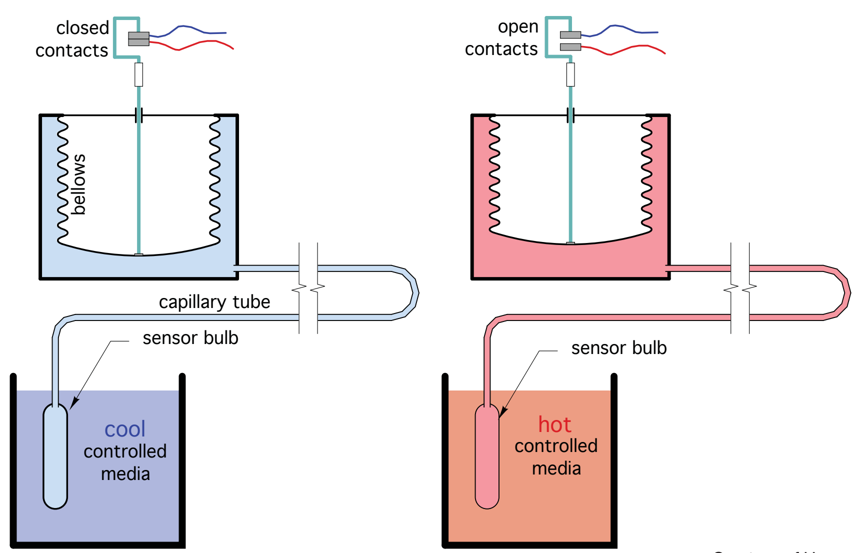


Figure 2-11



Courtesy of Honeywell

Figure 2-12

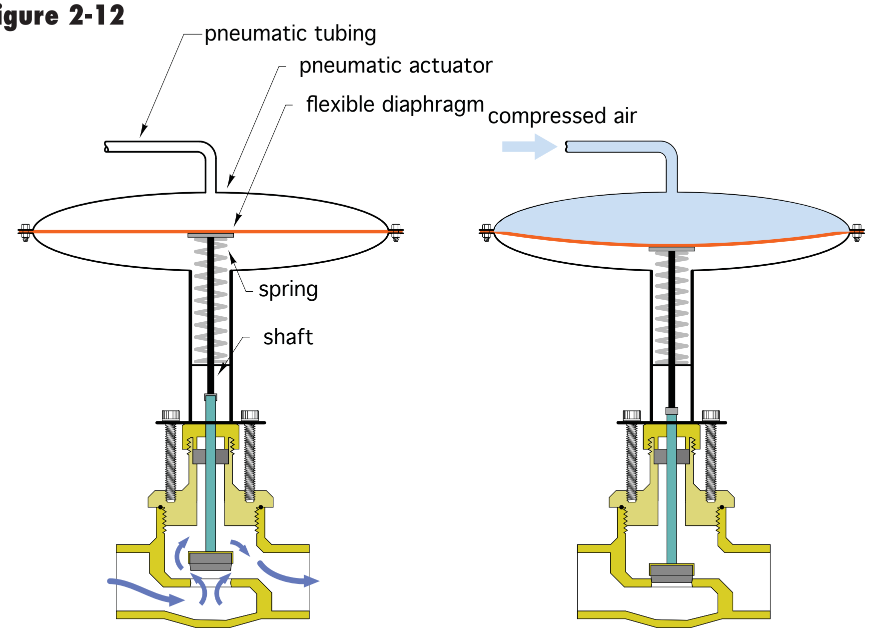


Figure 2-13

Although very few residential or light commercial hydronic systems are specified with pneumatic controls, thousands of large heating systems continue to operate with such controls. In some systems, the original pneumatic sensing devices and control logic have been replaced by microprocessor-based controllers and electric-to-pneumatic transducers, while the pneumatic actuators used to control valves and dampers remain in operation. Pneumatic-based control systems are also extensively used to control industrial piping systems.

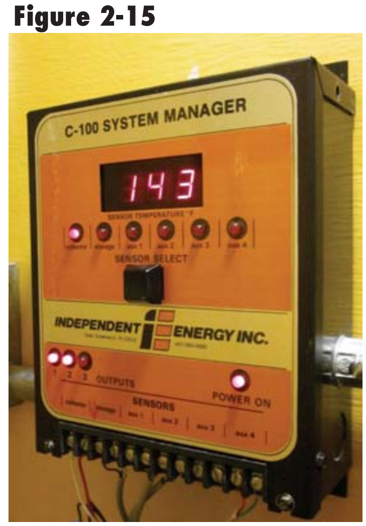
ELECTRONIC CONTROLLERS

Advances in solid-state temperature-sensing devices allowed manufacturers to create electronic temperature controllers that have largely replaced electromechanical controllers in newer hydronic systems. The most common of these controllers is the electronic wall thermostat. Early versions of such thermostats appeared in the 1970s. Many were battery powered and had relatively small digital temperature displays. Most used internal micro relays to provide a contact closure suitable to complete the low voltage (24 VAC) circuit often used in smaller HVAC systems. An example of such a thermostat is shown in Figures 2-14.

Figure 2-14

Many other electronic controllers were developed for hydronic systems during the 1970s. These included differential temperature controllers, outdoor reset controllers, multiple boiler controllers and temperature setpoint controllers. Figure 2-15 shows an early generation electronic differential temperature controller for a solar thermal system. Notice the large LED displays used in early electronic controllers. LED displays have largely been replaced by lower power consuming LCD displays in modern controllers.

Figure 2-15



Most current generation controllers for modern hydronic systems use microprocessor-based digital electronics, with very few mechanical components. Several of these controllers are discussed in later sections of this issue.

Figure 2-16 shows an example of a modern microprocessor-based controller that can coordinate the operation of a solar thermal system, as well as auxiliary boilers, multiple system circulators, mixing devices and thermal energy-measuring sensors.

Figure 2-16

The latest technology to be incorporated into hydronic controllers is wireless Internet access using a Wi-Fi link between the device and a local wireless router. Figure 2-17 shows an example of a modern Wi-Fi-enabled room thermostat that can be programmed for specific temperatures at different times. Programming can be through a touchscreen interface or from any Wi-Fi-enabled device connected to the Internet.

Figure 2-17

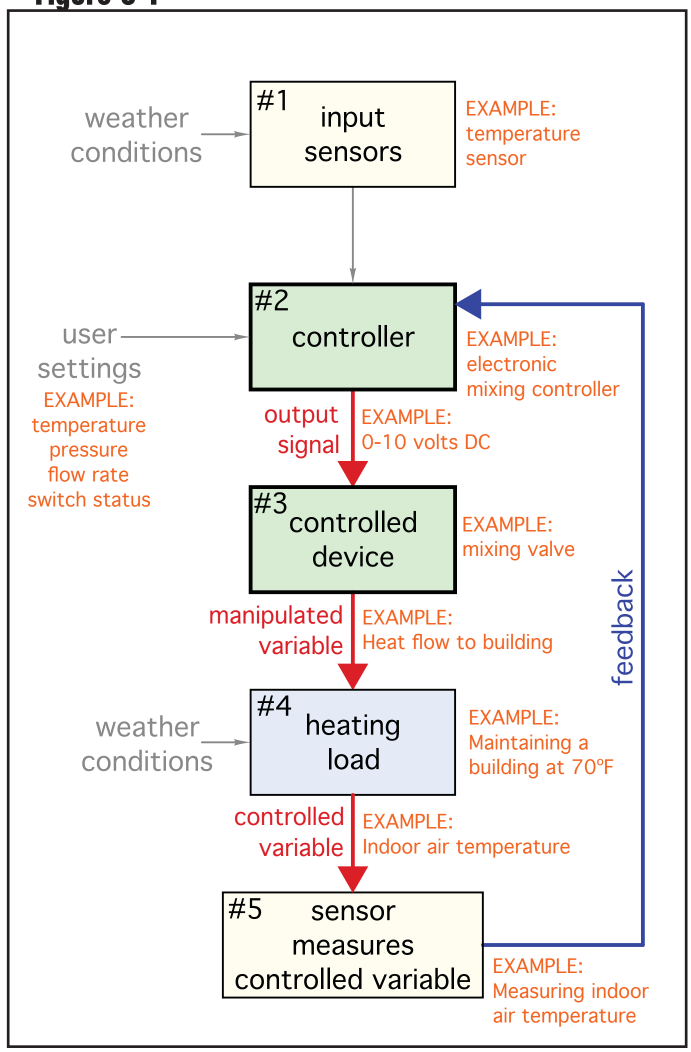
3. CONTROL CONCEPTS

CLOSED-LOOP CONTROL SYSTEMS:

Hydronic heating systems rely on fundamental control concepts to stabilize their operation. It is important for heating professionals to understand these concepts before attempting to specify controllers that use them.

Figure 3–1 represents a simple closed-loop control system for hydronic heating. Some of the boxes shown represent information, while others represent physical devices.

Figure 3-1



Block #1 represents information sent to the control system by one or more sensors. In hydronic systems, weather conditions are usually limited to outdoor air temperature. However, future control systems may expand this information to include measurements of wind speed, relative humidity and solar radiation intensity. This information may be sent to the controller as an electrical signal, such as a variable resistance, voltage or current. It might also be sent as a digitally encoded signal.

Additional information comes into the process as user settings. Examples include desired “target” temperatures, pressures, flow rates or switch status. The first three of these are examples of *analog* inputs. They represent physical conditions that can be measured, and which change over a continuous range of numerical values. For example, outdoor temperature may be represented by a number anywhere within the range of -46ºF to 120ºF, or a flow rate may by a value anywhere between 0 and 75 gpm. The last example of user settings—switch status—is a *digital* input that can only have one of two states: open or closed.

Block #2 represents a physical device called the controller. It accepts information from the input sensor(s) represented by block #1. It also accepts and stores the user settings. The controller also receives information called feedback sent from one or more sensors that measure the result of the controlled process. This result is represented by a controlled variable. In most hydronic systems, the controlled variable is indoor air temperature.

The controller uses all this information to compare the measured value of the controlled variable with a user set target value. The latter is the desired “ideal” value of the controlled variable. Any deviation between the target value and the measured value is called error. In the context of control systems, the word “error” does not imply that a malfunction has occurred. It means there is some deviation between the target value and measured value of the controlled variable.

The controller uses a stored set of instructions called a control processing algorithm to generate an output signal based on the error. This output may be a simple switch contact closure, a precise DC voltage, a precise current or a digitally encoded signal. This output signal is passed to a controlled device represented by block #3. The controlled device responds by changing the manipulated variable (which in a heating system is usually a rate of heat transfer). The change in the manipulated variable causes a change in the process being controlled. This causes a corresponding change in the controlled variable, such as a change in indoor air temperature. The change is sensed by the sensing element (block #5), which then provides feedback to the controller. This entire process is continuous whenever the system is operating.

Closed-loop control systems can be tuned for very stable operation. The feedback inherent in their design makes them constantly strive to eliminate any error between the target value and measured value of the controlled variable.

PID CONTROL:

One of the most common control processing algorithms used in the above-described process is called proportional-integral-derivative control, which is often abbreviated as PID control. This processing algorithm continually examines the error (e.g., the difference between the target value of the controlled variable and the measured value). The goal is to achieve and maintain zero error. In most cases, a properly tuned PID control process can maintain the error very close to zero.

Three distinct mathematical concepts are used in PID. They can be summarized as follows:

Proportional control response: The value of the output signal is directly proportional to the error. For example, assume that at a given moment there is an error of 2ºF between the target temperature and measured temperature at some location in the system, and the output signal from the controller, which attempts to bring this error back to zero, is a voltage of 1 volt. If the error increases to 3ºF (a 50% increase from the previous error) after a few seconds have passed, then the proportional response of the controller is to increase the output signal by 50% (e.g., from 1 volt to 1.5 volts). On the other hand, if the error had decreased to only 1ºF, the proportional response of the controller would be a reduction in the output voltage from 1 volt to 0.5 volts. Proportional response can be summarized as follows: *The greater the error, the greater the output signal attempting to correct that error.*

All devices that use proportional control have mathematical limits to how their output can vary as it attempts to zero out any error present in a control system. These limits are called the proportional band of the controller. For example, imagine an electronic controller that produces a 2–10 volt DC output signal to regulate a controlled device based on temperature. As the temperature at the sensor increases, the output signal from the controller decreases, and vice versa. If the proportional band of this controller is 6ºF, the output signal of the controller would be at its maximum level of 10 volts if the sensor temperature was 3ºF (e.g., half the proportional band) *or more* below the target temperature. The output signal would be at its minimum output of 2 volts if the measured temperature was 3ºF *or more* above the target temperature. In effect, the proportional band of a temperature controller can be thought of as the temperature change over which the controller’s output signal varies from its minimum to its maximum value.

Integral Control Response: A shortcoming of proportional-only control is that the error can only be held to zero under one calibrated output condition. If the system operates at other conditions, there will be some perpetual "offset" between the target and measured value of the controlled variable. This deficiency can be corrected by adding an integral response to the proportional response. Integral control examines the duration over which the error exists. The longer the error exists, the greater the output signal that is sent by the controller to eliminate the error. One can think of the integral response as the "patience" of a controller. The longer the error exists, the more impatient and aggressive the controller becomes in trying to eliminate that error. Given sufficient time, the combined use of proportional and integral control can eliminate the offset inherent in proportional-only controllers, and thus provide more accurate control of the process over a wide range of conditions.

Derivative Control Response: Many control processes require controllers to be fast acting. An example would be steering the engine nozzles on a rocket such that the rocket remains on a precise flight path as it passes through gusting winds. This type of control requires a measurement of how fast the error is changing, in additional to how much error is present (e.g., proportional response) and how long the error has existed (e.g., integral response). The derivative response provides this reaction to the rate of change of the error. The faster the error changes, the stronger the control signal becomes in attempting to zero out that error.

Fortunately, hydronic systems do not require high-speed control response, and thus the contribution of the derivative control response is relatively small. Keeping this response characteristic small also helps stabilize the system against an undesirable condition called "hunting." If hunting occurs, the control system is unable to stabilize. Instead, it responds by repeated and rapidly overshooting and undershooting the target value of the controlled variable. This leads to accelerated wear on the controlled equipment.

PID can be mathematically expressed as Formula 3-1:

Formula 3-1:

$$O = c_p(e) + c_i\int(e)dt + c_d\left(\frac{de}{dt}\right) + M$$

Where:

O = output signal value
e = error between the target and measured value of the controlled variable
c_p = proportional gain constant
c_i = integral gain constant
c_d = derivative gain constant
M = a number representing the output value when the error is zero

The output signal from a PID controller, at any instant, is the algebraic sum of the contributions from the proportional, integral and derivative components. In some cases, one or more of these contributions may be positive, while others are negative.

The factors c_p, c_i and c_d are called gain constants. They are numbers that determine the relative effect of the proportional, integral, and derivative responses to the overall process. The larger any one of these gain constants is, relative to the others, the more "weight" that aspect of the control response gets for influencing the total PID output signal. Control manufacturers typically set these values to provide stable operation and seldom allow the values to be changed by installers.

Figure 3-2 compares the ability of proportional-only (P) control, to proportional + integral (PI), and proportional + integral + derivative (PID) control, as all three methods attempt to zero out the initial error between the target and measured value of a controlled variable, such as the temperature at some location in a hydronic system.

Figure 3-2

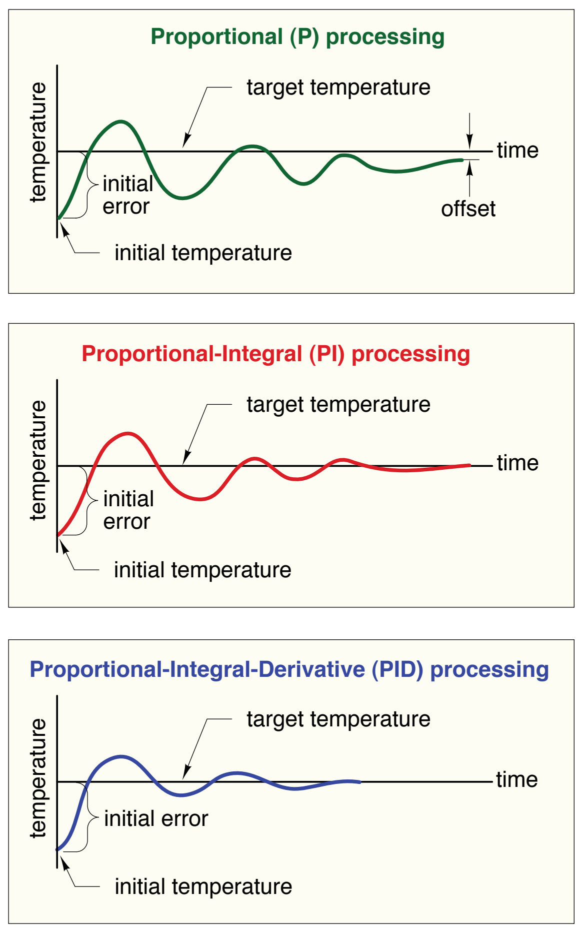
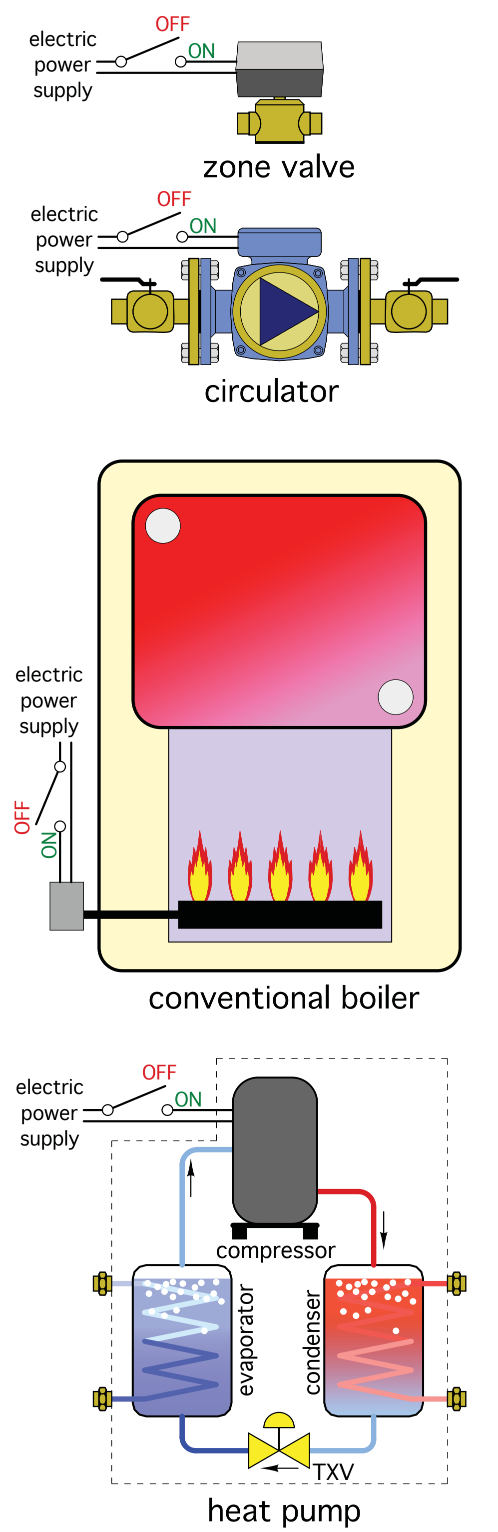


Figure 3-3



Notice how adding the integral function to the proportional processing algorithm eliminates the offset. It is also evident that the system using PID control stabilizes to the target value faster than does the system using PI control.

ON/OFF CONTROL:

Many devices used in hydronic heating systems are controlled by being turned on and off. These include conventional boilers, heat pumps, zone valves, zone circulators and diverter valves. On/off control only allows the controlled device to have one of two states: on or off. For example, when a zone valve is on, flow through the zone circuit is enabled. The flow rate through the circuit is determined by the hydraulic characteristics of the circuit and the circulator creating the flow. When the zone valve is off, there is no flow in the circuit. The same holds true for zone circulators. When the burner of a conventional boiler is turned on, it converts fuel into heat at some rated rate, such as 50,000 Btu/hr. When turned off, it produces no heat output. Figure 3-3 shows several common hydronic components that use on/off control.

Although on/off control is one of the simplest control concepts to implement, it is also limited in its ability to match heat flow from a source to a load, especially if that load is highly variable. Still, on/off control remains very common in residential and light commercial hydronic systems.

MODULATING CONTROL:

The word "modulating" simply means variable. For example, a modulating boiler can vary its rate of heat production from some maximum rate down to some minimum rate. Currently available modulating boilers used in residential and light commercial hydronic systems can usually modulate their heat production from some maximum rating down to approximately 20% of that rating. Thus, a 50,000 Btu modulating boiler can reduce its heat output rate down to about 10,000 Btu/hr and still remain in constant operation. If the required heat output is less than the minimum modulation rate, the burner has to cycle on and off to prevent excess heat production relative to the load.

In the context of heat sources, the term "turndown ratio" is often used to express the ability of the heat source to reduce (e.g., modulate) its heat production. A turndown ratio of 5:1 means that the minimum stable heat output rate of the heat source is 1/5th of its maximum heat output rate. A turndown ratio of 10:1 would indicate the ability to reduce heat output to 1/10th of the heat source's maximum heat output rate. In theory, the greater the turndown ratio, the better the ability of the heat source to continually match a varying heating load. In practice, most combustion-based heat sources are currently limited to 5:1 turndown, with exception of some recently introduced boilers that can achieve a 10:1 turndown. Some electric heat sources that use solid-state devices to regulate current flow to resistance heating elements can achieve very high turndown ratios.

Modulation is also used to control certain types of valves. For example, a 3-way mixing valve that blends hot and cool streams of water to achieve a specific target outlet temperature cannot operate with simple on/off control. Instead, the hot and cold inlet ports of the valve need to be adjusted over a wide range to regulate the incoming flow rates. Modulation is also used to vary the speed of circulators in modern hydronic systems.

STAGING CONTROL:

Space-heating loads, as well as loads such as domestic water heating, often vary in magnitude over a wide range. At some times, both of these loads are zero. At other times, they are both at some maximum (e.g., “design”) value. Ideally, the heat source(s) within the system would be able to maintain a precise match between the instantaneous heating load and the rate of heat production by the heat source. However, this is not possible with most on/off heat sources because their output is limited to either fully on or completely off.

One way to improve the match between such heat sources and a highly variable load is to use two or more heat sources that can be independently operated, rather than a single large on/off heat source. This is called staging control, and it can be used with several types of on/off heat sources, such as boilers and heat pumps.

Figure 3-49 shows a hypothetical heating load profile in which the load begins at zero, steadily increases over time to some maximum “design” value, holds at the value for a while, and then decreases to half the design value and remains there. This simple load profile is generic. It could represent a space-heating load, domestic water-heating load or some other thermal load. Assume the time over which the load exists is several hours.

Figure 3-5 shows how heat transfer from a single on/off heat source—one that’s sized to the design load—occurs as this heat source attempts to match the load profile.

Figure 3-4

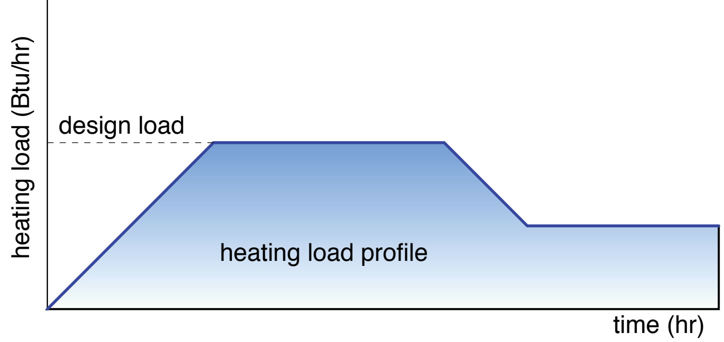
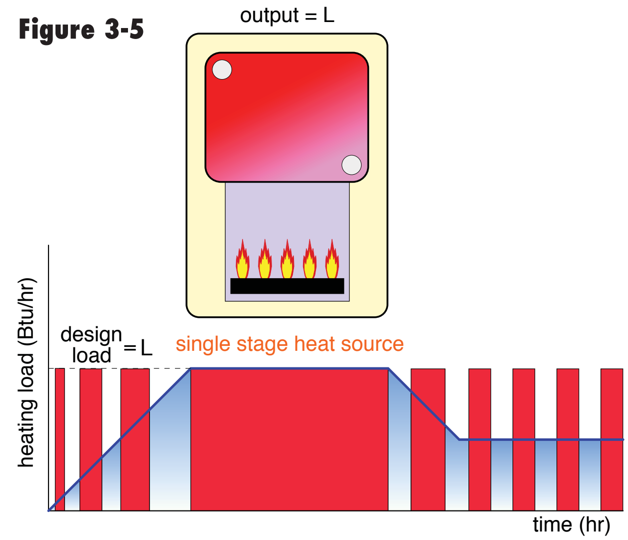


Figure 3-5



Notice that the heat source operates in “pulses” as the load starts to increase. The red shaded area above the blue load profile line represents excess heat production (e.g., the heat source is generating heat at a significantly higher rate than required). The gray areas under the load profile line represent times when the heat source is off, and thus there is insufficient heat transfer to the load. The ability of the single on/off heat source to match the heating load over the initial duration of this load is not good.

Whether or not this matching between heat production and load produces acceptable performance in terms of comfort and wear on the mechanical system components depends in part on the thermal mass of the system. If the system has high thermal mass, it may be able to absorb some of the excess heat production and release it during times when the heat source is off. In the case of space heating, this mass could “smoothen” the transfer of heat to the load so that the comfort level is acceptable. However, if the system has low thermal mass, it’s very likely that unacceptable variations in interior temperature will occur due to the mismatch between heat production and load.

Once the load reaches its maximum “design” value, the heat source, which has been sized to this design load, remains on. This is desirable for heat sources such as conventional boilers and heat pumps because it allows those heat sources to operate at steady-state conditions. These conditions improve efficiency and decrease wear on components such as ignition systems and compressor contactors. As the load begins to drop, the heat source must resume sending heat to the load in pulses.

Figure 3-6 shows the match between the same heating load in a system where two equal stages of heat input are used. These stages could represent on/off boilers, heat pumps or other on/off heat sources that each produce 50% of the design load when they operate. Notice that the mismatch between heat production and load has been reduced in comparison to that created by the single on/off heat source. There is less excess heat production during partial load conditions and fewer blue areas where no heat production takes places. Overall, the red shaded areas under the load profile are a closer match to the load profile.

The improvement in matching heat generation to load is even more evident when four stages of heat production, each one a quarter of the design load, are used, as shown in Figure 3-7.

In theory, the greater the number of stages, the better the ability to match heat output to load. However, the cost of the installation also increases with an increasing number of stages. In residential and light commercial buildings, it is generally not cost effective to use more than four stages of heat production. In many cases, two or three stages are sufficient. In larger buildings, up to eight stages of heat production are used in systems where all heat production takes place in a central mechanical room.

Figure 3-6

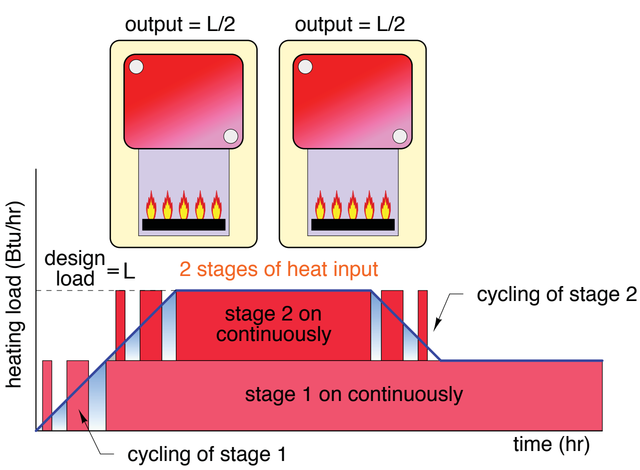


Figure 3-7

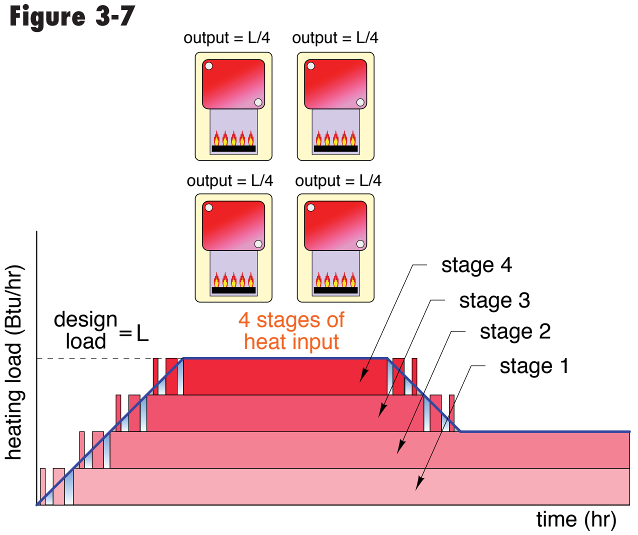
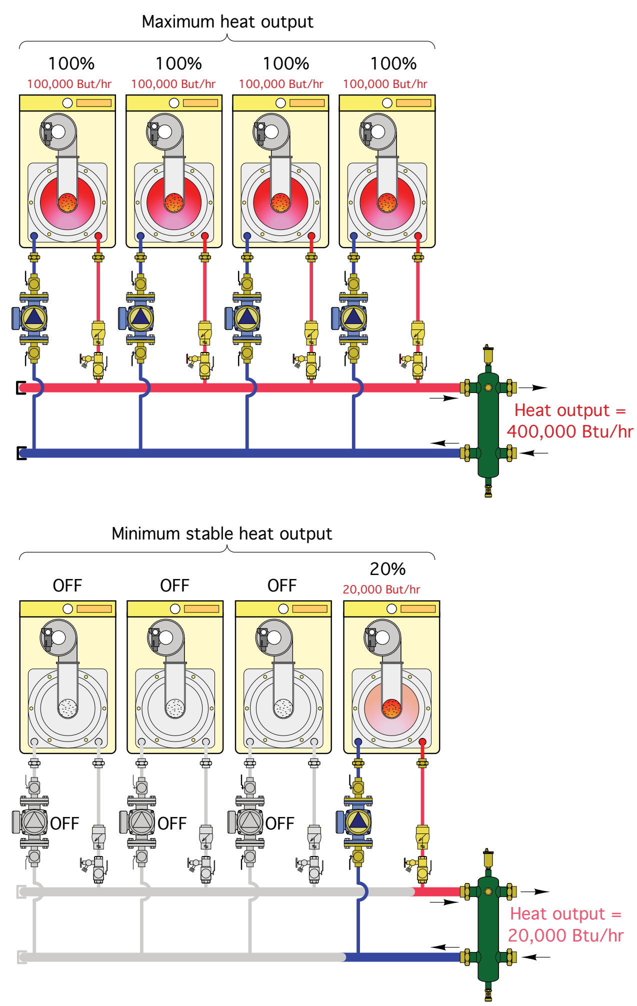


Figure 3-8



$$\text{system turndown ratio} = \frac{400{,}000 \text{ Btu/hr}}{20{,}000 \text{ Btu/hr}} = 20/1$$

Multi-stage heat production also provides partial heat production in situations where one of the heat sources is off due to maintenance or malfunction.

It is also possible to use staging in combination with modulating heat sources. For example, consider a system using four independently controlled modulating boilers, each capable of a 5:1 turndown, as shown in Figure 3-8.

Assume that each boiler produces heat at a rate of 100,000 Btu/hr at full output. When all four boilers are operating at maximum output, total heat production is 400,000 Btu/hr. When three boilers are off and the fourth boiler is operating at its minimum stable firing rate, heat production is 20,000 Btu/hr. Thus, the total range of heat production by the multiple boiler system varies from 400,000 Btu/hr down to 20,000 Btu/hr. That represents a "system turndown ratio" of 400,000/20,000 = 20:1. This can also be interpreted as the ability to reduce heat output from the maximum rate down to only 1/20 or 5% of that maximum rate. Such a system could provide an excellent match between heat production and load over a wide range of conditions.

4. CONTROLLER OUTPUT SIGNALS

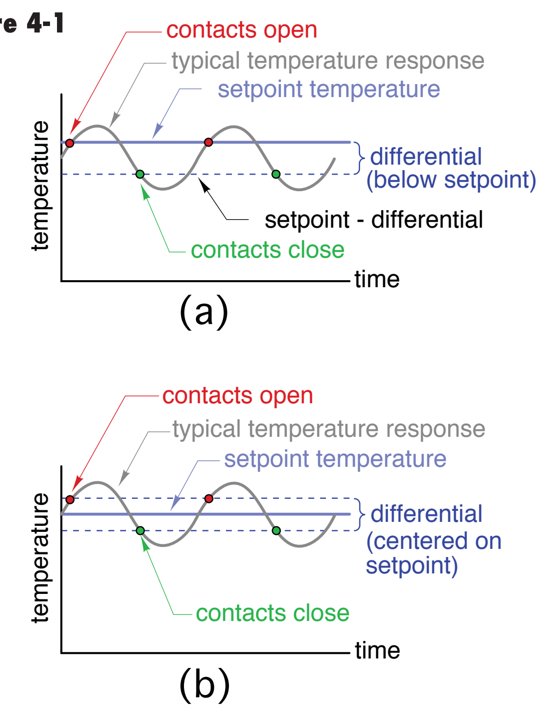
There are several ways in which a controller can communicate with a controlled device. In some cases, the output from the controller is a simple opening or closing of an electrical contact. In others, the output may be a constantly changing voltage or current. It's critical to match the output signal from the controller with a compatible input signal to a controlled device.

ON/OFF OUTPUT:

In on/off control, the controlled device can only have one of two possible control states at any moment. If the controlled device is a valve, it can be either fully open or fully closed, but never at some partially open condition. If the controlled device is a heat source, it must be fully on or completely off. On/off output signals are usually generated by a set of electrical contacts within the controller.

When used to control heating equipment, on/off controllers send heat to the load in pulses rather than as a continuous process. In such applications, all on/off controllers must operate with a differential. This is the change in the controlled variable between where the controller output switches on and where it switches off. In heating systems, the controlled variable is usually the temperature at some location in the system or the building it serves. On some controllers, the differential is below the setpoint temperature, as shown in Figure 4-1a. In others, the differential is centered on the setpoint, as shown in Figure 4-1b.

Figure 4-1



The smaller the differential, the smaller the deviation in temperature from the target value. However, if the differential is too small, the controller operates the controlled device in short but frequent cycles. This undesirable "short-cycling" increases the wear on the device.

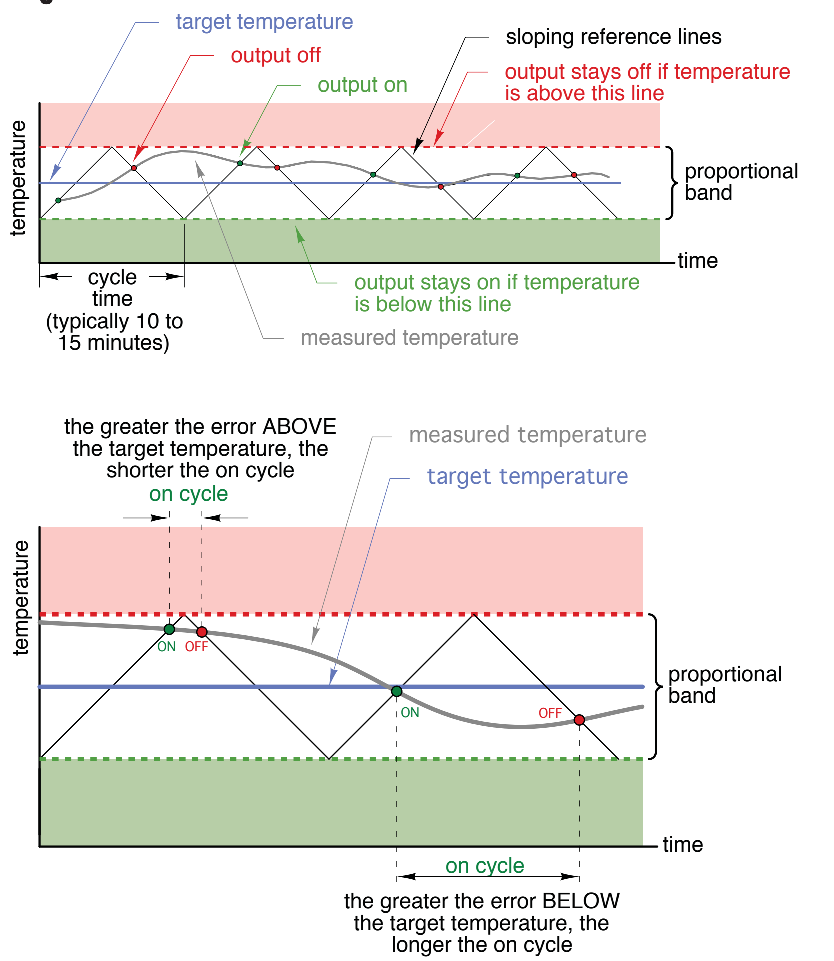
If the differential is too wide, there can be large deviations between the target value and measured value of the controlled variable. In some situations, this is acceptable; in others, it is not. For example, the large thermal mass of a heated slab-on-grade floor can usually accept variations in water temperature of several degrees Fahrenheit without creating wide swings in room air temperature. However, a room thermostat with a differential of 4°F or more would cause wide swings in room air temperature that would likely lead to complaints.

PULSE WIDTH MODULATION OUTPUT:

When on/off control is used in heating systems, heat transfer begins only when the temperature being measured drops a certain amount below the target value. After the heat source is turned on, the cool thermal mass of the heat emitters and distribution piping absorb some of the initial heat transferred. This causes a further drop in room air temperature before it begins to rise. Heat is added to the room as a result of the room air temperature repeatedly dropping below the desired target value. Over time, the average room temperature becomes slightly less than the desired value. This effect is called "droop," and is inherent to controllers that use proportional-only control response.

Ideally, the heating system would supply sufficient heat to keep the indoor temperature precisely at the target value. Doing so requires a control response that varies the amount of heat supplied to the room based on the magnitude of the error between the desired target temperature and the measured temperature. If the measured temperature is above the target value, the rate of heat transfer needs to decrease, but not necessarily to zero. Likewise, if the measured temperature is below the target value, the rate of heat transfer should increase, but not necessarily to full design load output. Even when the error is zero, a certain rate of heat transfer must be maintained to to keep the room temperature stable and prevent thus prevent droop.

Figure 4-2



One control response that provides this action is called pulse width modulation (abbreviated as PWM). A PWM controller varies the duration of the heat input cycle based on the magnitude of the error (e.g., how far the measured temperature is from the target value). The greater the error, the longer the "on-time" of the heat input cycle. This concept is illustrated in Figure 4-2.

When used to regulate heat transfer to a load, PWM control transfers energy to the load in proportion to the error present. Most PWM controllers use integral (I) and in some cases derivative (D) processing to quickly stabilize the system and eliminate droop. When the error is small, the controller gently "nudges" the controlled device in an attempt to eliminate the error without overshooting the desired temperature. When the error is large, the controller operates the controlled device more aggressively to reduce the error quickly and eliminate residual offset.

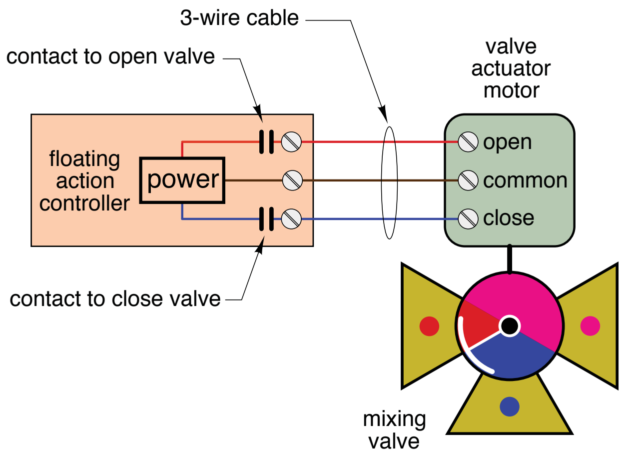
FLOATING ACTION OUTPUT:

Another way of regulating heat transfer to a load with relatively simple electrical wiring is called floating action control. This control output was developed to operate motorized mixing valves and dampers that need to be powered open as well as powered closed. In hydronic heating systems, floating action control is often used to operate 3-way and 4-way motorized mixing valves. Figure 4-3 shows a 3-way motorized mixing valve that is designed to be operated by floating action control.

Figure 4-4 shows how a floating action controller would be wiring to this type of a motorized mixing valve.

Figure 4-3

Figure 4-4

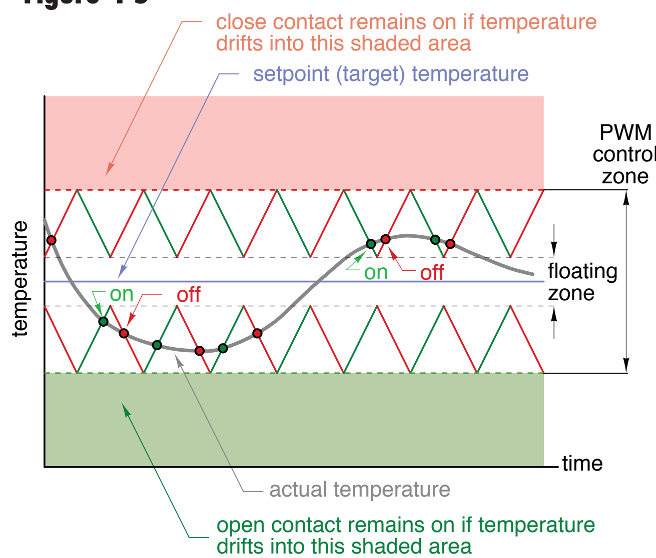


One electrical contact in the controller closes to drive the valve's actuating motor in a clockwise (CW) direction. The other contact closes to drive the actuator motor counterclockwise (CCW). Only one contact can be closed at any time. The actuator uses a gear train between its internal motor and output shaft that causes the valve's shaft to turn very slowly. Most floating action actuators used with mixing valves require about 3 minutes to rotate the valve's shaft over its full rotational range of 90 degrees. This slow operation is desirable since it allows the temperature sensor mounted downstream from the outlet of the mixing valve sufficient time to provide feedback to the controller, which helps stabilize operation. Some floating action controllers automatically check the rotational speed of the actuator motor and the range of rotation of the driven device (i.e., a valve stem), and self-calibrate their operation to match these constraints.

When the measured temperature at the outlet of the mixing valve is very close to the target temperature, the valve's actuator does not run. This portion of the control range is called the "floating zone." Within this floating zone, the error between the target temperature and measured temperature is small enough that it doesn't warrant any correcting action. The ability to hold the valve at a partially open condition allows some heat transfer to the load even when the error is at or close to zero.

As the measured temperature drifts above or below the floating zone, the controller responds with an output that is proportional to the error, as shown in Figure 4-5. The greater the error, the greater the duration of the output

Figure 4-5



signal that opens or closes the valve. If the error drifts above or below the PWM control zone, the actuator motor remains on in either the open or closed mode. This usually only occurs while the system is starting up and a large error is present between the measured and target temperatures.

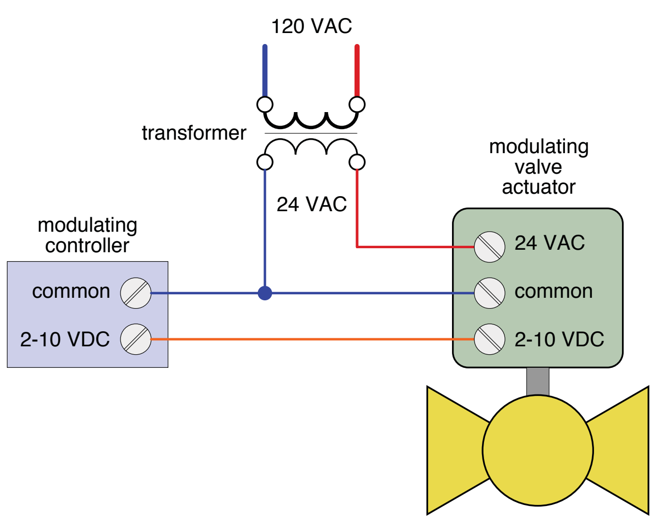
Floating action control is sometimes called "three-wire control," because three wires are required between the controller and the actuating motor.

MODULATING OUTPUT:

On/off control, PWM control and floating control all use electrical contacts that open or close to send signals from the controller to the controlled device. This type of output is not suitable for all devices. For example, none of these outputs could smoothly regulate the speed of a motor.

In modern hydronic systems, many controlled devices require a continuous analog signal. Such systems often use a variable voltage between 2–10 DC, or an electrical current between 4–20 milliamps DC, as a continuous analog signal between the controller and controlled device. The controller generates a continuous voltage or current within these ranges and sends that signal to the controlled device. The controlled device responds by operating at a position or speed that is proportional to the input signal. For example, a controller output of 2 volts DC supplied to a motor-speed controller means that the motor should be off, whereas a 10-volt signal to the same controller means the motor should be running at full speed. A controller output signal of 6 volts DC, which is 50% of the overall range of 2–10 volts, implies that the motor should be running at 50% speed.

Figure 4-6



The reason these control signals do not begin at zero voltage or current is to prevent electrical interference or "noise" from affecting the controlled device. Wires that run close to other electrical equipment can experience induced voltages and currents due to electrical or magnetic fields. In most situations, raising the starting threshold to 2 volts DC, or 4 milliamps, prevents such interference. A 4–20 ma output signal can also be converted to a 2–10 VDC signal, by passing the current through a precision 500-ohm resistor and using the voltage drop across that resistor as the 2–10 VDC signal.

Modulating valves and variable-speed circulators are now available that can accept 2–10 VDC or 4–20-milliamp control inputs. These signals are for control only and do not supply the power to drive the device. For example, the wiring of a 2–10 VDC modulating valve is shown in Figure 4-6. Notice that 24 volts AC power must be supplied to the valve to power the motor and the actuator's circuitry. Likewise, a variable-speed circulator that is controlled by a 2–10 VDC or 4–20 milliamp signal requires line voltage (single phase 120 or 240 VAC, or 3-phase electrical input) to operate the circulator's motor.

5. REGULATING HEAT OUTPUT FROM HEAT EMITTERS

There are two fundamental ways to control the heat output of hydronic heat emitters:

1. Vary the water temperature supplied to the heat emitter, while maintaining a constant flow rate through the heat emitter.

2. Vary the flow rate through the heat emitter, while maintaining a constant supply water temperature to the heat emitter.

Both approaches have been successfully used in many types of hydronic heating applications over several decades. It is important for system designers to understand the differences, as well as the strengths and weaknesses of each approach.

VARIABLE WATER-TEMPERATURE CONTROL:
The heat output of any hydronic heat emitter is approximately proportional to the difference between supply water temperature and room air temperature. This can be represented mathematically as Formula 5-1:

Formula 5-1

$$Q_o = k(T_s - T_r)$$

Where:

Q_o = rate of heat output from heat emitter (Btu/hr)
k = a constant dependent on the heat emitter used
T_s = fluid temperature supplied to the heat emitter (ºF)
T_r = air temperature of room where heat emitter is located (ºF)

A graph of Formula 5-1 is a straight line, as shown in Figure 5-1. For this graph, the value of "k" in Formula 5-1 is 250.

If water is supplied to the heat emitter at room temperature (whatever that temperature happens to be), there will be zero heat output from the heat emitter. As the temperature of the water supplied to the heat emitter rises above room air temperature, its heat output also increases. The graph in Figure 5-1 shows that when the supply water temperature is 40ºF above the room air temperature, the heat emitter will release 10,000 Btu/hr into the room. If the supply water temperature climbs to 80ºF above the room's air temperature, the heat emitter releases 20,000 Btu/hr into the room. Thus, doubling the temperature difference doubles the heat output.

Figure 5-1

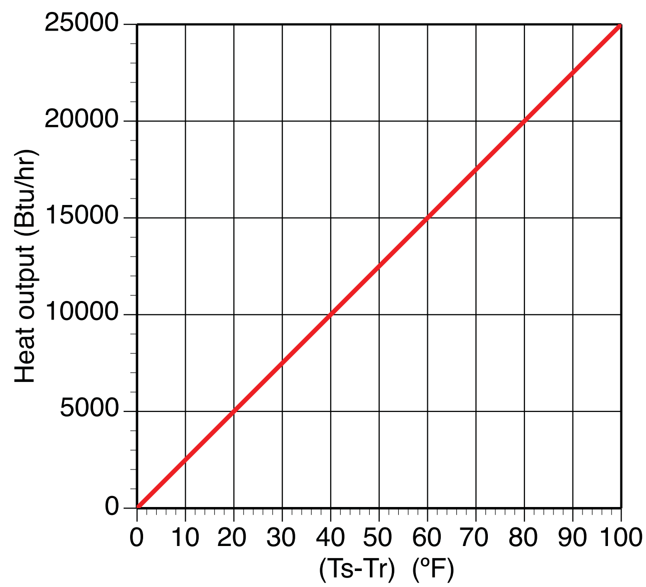
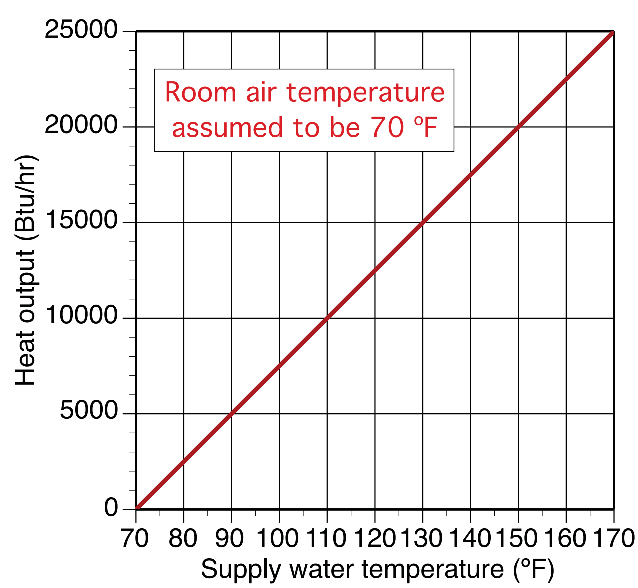


Figure 5-2



The slope of the line in such a graph depends on the characteristics of the heat emitter. The greater the ability of the heat emitter to release heat at a given supply water temperature, the steeper the slope of the line.

If the desired room air temperature is assumed to be 70ºF, the graph in Figure 5-1 can be modified as shown in Figure 5-2.

The only difference is that the horizontal axis now shows supply water temperature. This proportional relationship between supply water temperature and heat output holds true as a reasonable approximation for most hydronic heat emitters. It is an important characteristic in the context of another control technique called outdoor reset control.

OUTDOOR RESET CONTROL:

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

Outdoor reset control is based on the previously discussed proportionality between the heat output of a heat emitter and the water temperature supplied to that heat emitter. It is also based on the proportional relationship between the heat loss of a building and the temperature difference between the inside and outside air temperatures.

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

Outdoor reset controllers use Formula 5-2 to calculate the target water temperature that should be supplied to a given hydronic distribution system at any given time.

Formula 5-2

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

Where:

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

The reset ratio (RR) is determined as follows:

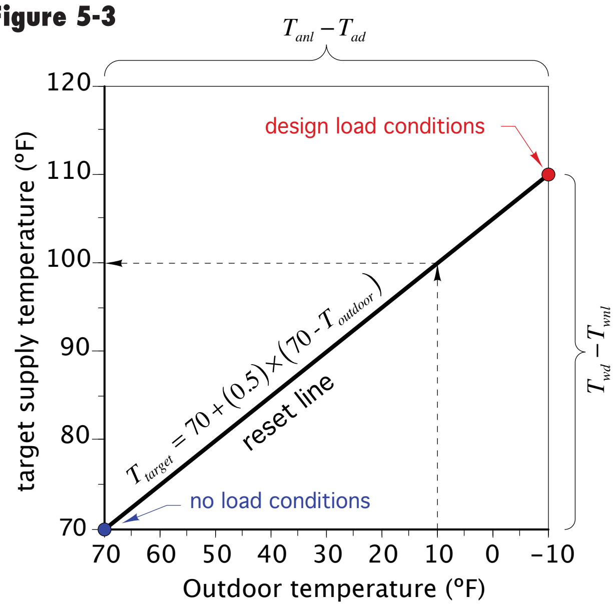
Formula 5-3

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

Where:

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

Figure 5-3



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

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

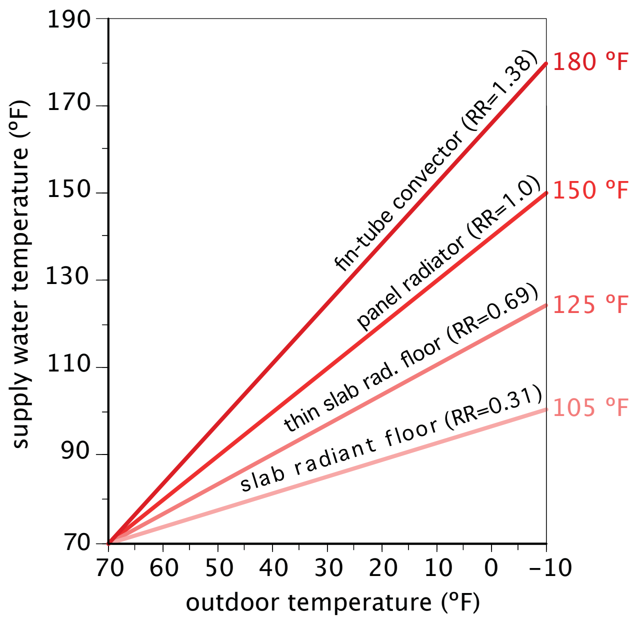
The graph in Figure 5-3 is a good way to visualize these relationships.

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

The reset ratio (RR) is the slope of the reset line. It is found by dividing the vertical temperature difference between the red dot and blue dot by the horizontal temperature difference between these dots. For the case represented in Figure 5-3, the reset ratio is:

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

Figure 5-4



The graph of a reset line can be used to find the target supply temperature for any outdoor temperature. First, locate the outdoor temperature on the horizontal axis. Next, draw a vertical line up to intersect the reset line. Finally, draw a horizontal line from this intersection to the vertical axis and read the required target supply temperature. For example, when the outdoor temperature is 10ºF, the reset line in Figure 5-3 indicates the target supply temperature is 100ºF.

The target supply temperature can also be determined by entering the outdoor temperature, indoor temperature and reset ratio into Formula 5-2. For the reset line shown in Figure 5-3, the target supply temperature when the outdoor temperature is 10ºF would be:

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

The reset ratio will change depending on the type of heat emitters used in the system and how they are piped. Low temperature systems such as heated slab-on-grade floors typically have low reset ratios, and thus shallow sloping reset lines. Higher temperature distribution systems such as traditional fin-tube baseboard usually have higher reset ratios, and thus steeper reset lines. Figure 5-4 shows some examples. Keep in mind that the lines and reset ratios shown are representative, but not necessarily the exact requirement for any given system.

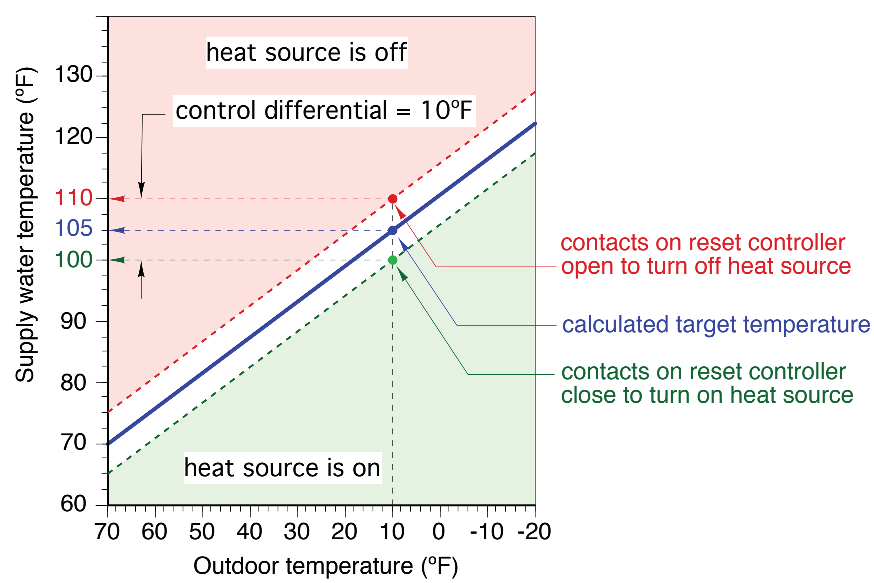
IMPLEMENTING OUTDOOR RESET CONTROL:
There are three ways to implement outdoor reset control in hydronic systems:

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

These techniques can be used individually or together.

HEAT SOURCE RESET (FOR ON/OFF HEAT SOURCES):
The temperature of water supplied to a distribution system can be controlled by turning a heat source on and off.

Figure 5-5



The graph in Figure 5-5 illustrates the logic used by a reset controller that controls an on/off heat source. The sloping blue reset line represents the "target temperature" (e.g., the ideal supply water temperature for a particular distribution system over a range of outdoor temperatures). For example, if the outdoor temperature is 10ºF, the blue line in Figure 5-5 indicates a target supply temperature of 105ºF (as indicated by the blue dot).

When the reset controller is powered on, it measures both outdoor temperature and the current supply temperature. It then uses the measured outdoor temperature, along with its settings, to calculate the target supply temperature. Then it compares the calculated target supply temperature to the measured supply temperature.

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

The settings represented in Figure 5-5 would result in the following control actions when the outdoor temperature is 10ºF:

• If the water temperature supplied to the distribution system is above 100ºF (e.g., 105 less half the differential of 10ºF), the contacts in the reset controller remain open and the heat source remains off.

• If the water temperature supplied to the distribution system is below 100ºF, the contacts in the reset controller close to turn on the heat source. Once turned on, the heat source would remain on until the water supplied to the distribution system reaches 110ºF (e.g., 105ºF plus half the differential) or higher.

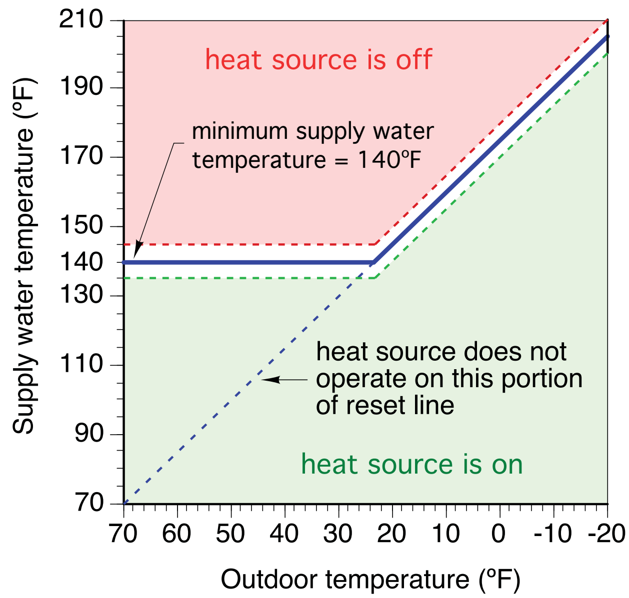
The 10ºF differential between the temperatures at which the heat source is turned on and off helps prevent short cycling. The value of the differential can be adjusted on most outdoor reset controllers. Smaller differentials reduce the variation in supply water temperature both above and below the target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

MINIMUM SUPPLY TEMPERATURE:
Heat source reset control is somewhat limited when used with a conventional gas- or oil-fired boiler. If the temperature of water returning to the boiler is allowed to drop too low, flue gases will condense within the boiler or its venting system. To prevent this, most heat source reset controllers have an adjustable minimum supply temperature. With this feature, the controller does not allow the boiler to operate below a specified minimum temperature, regardless of outdoor temperature. Such an operating strategy is called partial reset control and is illustrated in Figure 5-6.

Notice how the lower portion of the reset line is not accessed due to the minimum supply temperature setting.

Although partial reset control protects a conventional boiler from operating with sustained flue gas condensation, it also prevents the distribution system from operating at theoretically ideal lower water temperatures during low-load conditions. Because the supply water temperature to the distribution system is higher than necessary during these times, some means of preventing the building from overheating is required. In most systems, this is accomplished by turning off a circulator or closing a zone valve whenever the indoor thermostat senses the room is at or above setpoint temperature.

Figure 5-6



HEAT SOURCE RESET (FOR MODULATING BOILERS):
Many modern boilers, and even some heat pumps, can modulate their heat output over a relatively wide range. This allows the heat source to better match the heating load. Modulation reduces issues such as short cycling and temperature variations that are more common in systems using on/off heat sources.

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

MIXING RESET:
Outdoor reset control can also be implemented by a mixing assembly such as 3-way and 4-way mixing valves, or a variable-speed injection mixing pump. The logic used for mixing reset is similar to that already described for modulating heat sources. The outdoor temperature is measured, the target supply temperature is calculated and the two are compared. Any deviation between these temperatures determines the output signal from the reset controller to the mixing assembly. The goal is the same: to keep the water temperature supplied to the distribution system at, or very close to, the target temperature.

CONTROLLING HEAT OUTPUT USING FLOW RATE:
The flow rate through any heat emitter affects its heat output. The following principle always applies:

The faster a heated fluid passes through a heat emitter, the greater the rate of heat transfer, all other conditions being equal.

It might seem intuitive to assume that heat transfer from a heat emitter increases *in proportion* to flow rate through it (i.e. doubling the flow rate through the heat emitter would double its heat output). However, this is not true. The rate of change of heat output from any hydronic heat emitter is a very non-linear function of flow rate. At low flow rates, heat output rises rapidly with increasing flow, but the greater the flow rate becomes, the slower the rate of increase in heat output.

To illustrate this, consider the situation in Figure 5-7, which shows the heat output of a radiant floor circuit

Figure 5-7

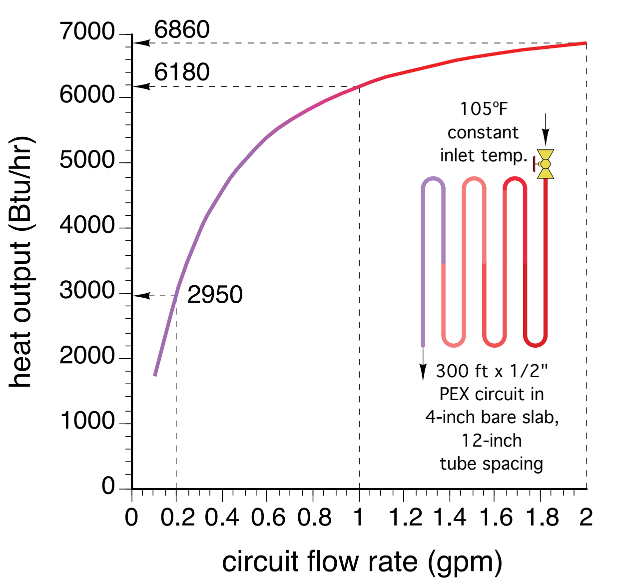
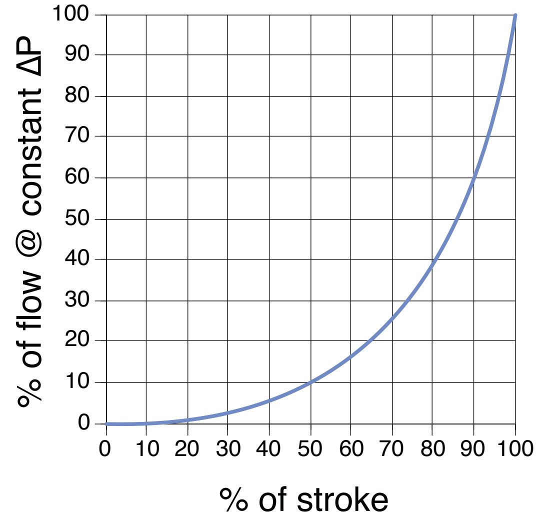


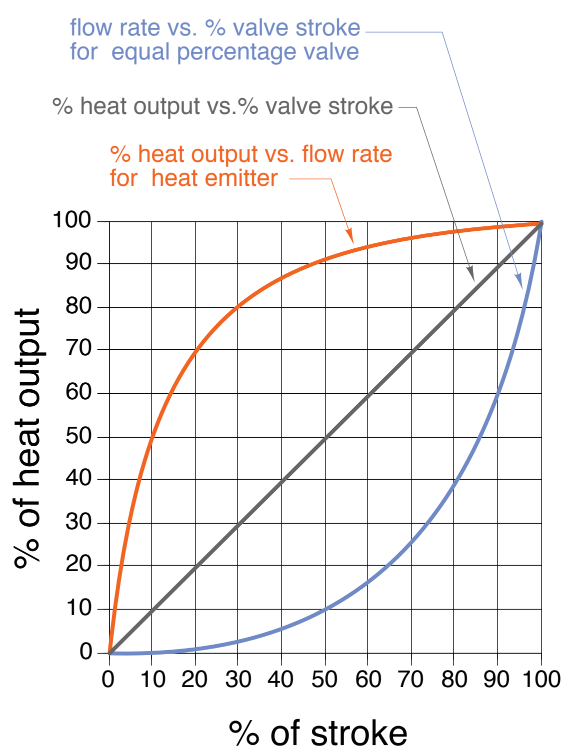
Figure 5-8



versus the flow rate through it. The circuit consists of ½-inch PEX tubing, spaced 12 inches apart in a bare, 4-inch thick concrete slab floor. This circuit is supplied with water at a constant temperature of 105ºF.

The circuit's maximum heat output of 6,860 Btu/hr occurs at the highest flow rate shown, 2.0 gpm. Decreasing the

Figure 5-9



circuit's flow rate by 50% (e.g., to 1.0 gpm) decreases its heat output to 6,180 Btu/hr, a drop of only about 10%. Reducing the flow rate to 10% of the highest value (e.g., to 0.2 gpm) still allows the circuit to release 2,950 Btu/hr, about 43% of its highest output.

This non-linear relationship between heat output and flow is typical of *all* hydronic heat emitters. It tends to make adjusting heat output with a valve more complicated than what one might assume. For example, as a technician first begins *closing* a balancing valve, there is relatively little change on the heat output of the circuit. However, when the balancing valve is only 10–25% open, small adjustments yield large variations in heat output.

Special types of valves with "equal percentage characteristics" have been developed to compensate for the rapid rise in heat output low flow rates. These valves allow flow rate to rise very slowly as they first begin to open. The farther the valve stem is opened, the faster flow through the valve develops, as shown in Figure 5-8.

When a valve with an equal percentage characteristic regulates flow through a heat emitter with the previously discussed non-linear heat output versus flow rate characteristic, the *net effect* is an approximately proportional relationship between the percentage the valve is open and the rate of heat output from the heat emitter. This relationship is shown in Figure 5-9.

The very slow increase in flow rate as the valve begins to open compensates for the rapid rise in heat output from the heat emitter at low flow rates. Likewise, the rapid increase in flow at higher flow rates compensates for the relatively slow rise in heat output at high flow rates. As a general design rule, *valves with an equal percentage characteristic should be used in any situation where heat output is regulated by varying flow through a heat emitter.*

The straight line showing a proportional relationship between heat output and valve stem position assumes that a constant differential pressure is maintained across the valve as it opens. Some pressure-independent balancing valves (PIBVs) are designed to maintain this constant differential pressure across the valve under a wide range of conditions.

6. SWITCHES, RELAYS AND LADDER DIAGRAMS

Every heating system that operates with electricity uses one or more electrical switching devices to regulate its operation. A working knowledge of these devices is essential in designing, installing or troubleshooting hydronic systems. This section presents an overview of basic switching devices and the terminology associated with them. It also introduces ladder diagrams as a graphical tool for documenting control system wiring and operating logic.

SWITCHES:

The operating modes of most heating and cooling systems are determined by a specific arrangement of electrical switch contacts. These contacts must be either open or closed. An open contact prevents an electrical signal (e.g., voltage) from passing a given point in the circuit. A closed contact allows the voltage signal to pass through. These contacts can be part of a manually operated switch, an electrically operated switch called a relay or contactor, or contained within specialized controllers. If all the contacts in a circuit containing a voltage source and a load are closed simultaneously, an electrical current will flow through the circuit, and some control action will take place.

POLES & THROWS:

Switches and relays are classified based on their poles and throws. The number of poles is the number of independent and simultaneous electrical paths through the switch. Most of the switches used in heating control systems have one, two or three poles. They are often designated as single pole (SP), double pole (DP) or triple pole (3P).

The number of throws is the number of position settings where a current can pass through the switch. Most switches and relays used in heating systems have either one or two throws and are called single throw (ST) or double throw (DT) switches.

Figure 6-1 shows a typical double pole/double throw (DPDT) toggle switch. The printing on the side of the switch indicates that it is rated for a maximum of 10 amps of current at 250 volts (AC), or 15 amps of current at 125 VAC. When selecting a switch for a given application, be sure its current and voltage ratings equal or exceed the current and voltage at which it will operate.

The double pole, double throw switch shown in Figure 6-1 can be represented schematically by the symbol in Figure 6-2.

Figure 6-1

Figure 6-2

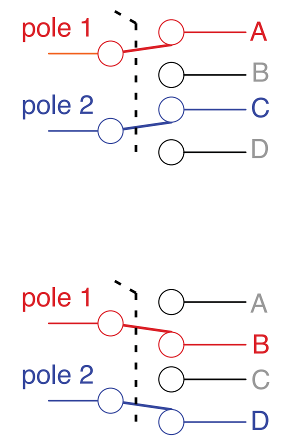


Figure 6-3

The two lines on the left represent the independent electrical paths entering the switch (e.g., the poles). The two sloping lines connecting the circles on the left to the circles on the right represent the blades of the switch. These are internal conducting mechanisms that move when the handle of the switch is moved. The dashed vertical line represents a non-conducting internal linkage that makes both blades move at the same time, but does not allow any electrical interaction between the blades. The circles all represent terminals to which external wires can be connected.

In the upper portion of Figure 6-2, the lever of the switch is set so that pole 1 on the left side conducts to terminal A on the right side. Similarly, pole 2 conducts to terminal C. Notice that the sloping lines representing the blades make contact from the center of the pole terminals to the edges of terminals A and C. Think of these blade lines as "pivoting" on the pole terminals and making contact with the periphery of terminals A and C. When the switch is in this position, terminals B and D are "floating." As such, they cannot pass any electrical signal through the switch.

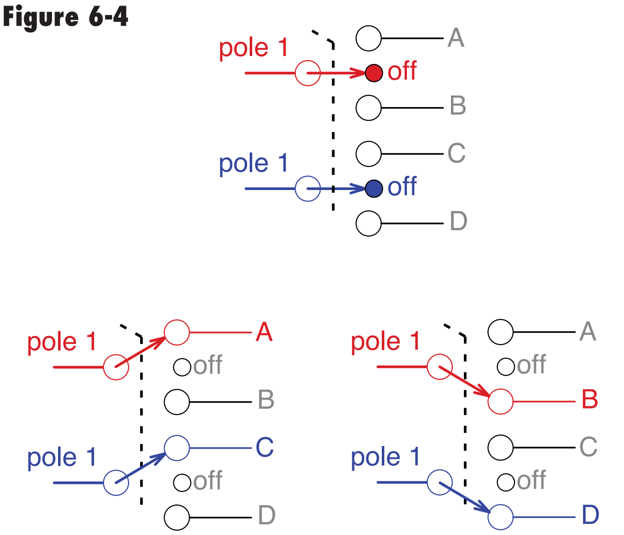
When the lever of the switch is moved to its other position, pole 1 conducts to terminal B, and pole 2 conducts to terminal D. Terminals A and C are now floating.

These two illustrations show the only two possible states of the DPDT switch. There is no other position in which the lever can be set to create a third possible state. Because the two terminals labeled poles are active in both states of the switch, they are often referred to as the "common" terminals.

Figure 6-3 shows two manually operated toggle switches. The switch in the upper right is a double pole, double throw switch with a "center off" setting (DPDT c/o). Notice that the switch lever is straight up from the switch body, and that the bezel plate reads "off" in this position. This setting allows the middle switch contact to remain electrically isolated from either of the end contacts. A typical application for this switch allows a control system to operate in either heating, cooling or off. The latter occurs when the switch is in the center off position. The switch in the lower left is a single pole, double throw with a center off setting (SPDT c/o).

Figure 6-4 shows schematic representations for the DPDT c/o switch. Notice that the blade of the switch can park at two isolated terminals labeled "off." These terminals do not connect to external wiring. They simply represent a position for the blades in which no electrical signal is allowed through the switch.

Figure 6-4



The switches in Figures 6-1 and 6-3 have screw terminal connections. Similar switches are available with quick-connect terminals. Switches of this type are also available with a wide range of current ratings and voltage ratings to suit different applications. Designers need to specify switches with ratings that meet or exceed the maximum electrical current within the circuit the switch will be part of. In some cases, there will be two current ratings—one for *resistive* loads and another for *inductive* loads. Typically, the current rating for an inductive load such as a motor or transformer is lower than (often half) the current rating for a resistive load, such as an incandescent light or heating element.

Switches are also rated for a maximum voltage. This is the maximum allowed voltage between any electrified portion of the switch and electrical ground. In most switches, the lever and any other metal portion of the body that contacts surrounding objects represent electrical ground. Applying a switch at voltages higher than its rating creates the possibility of dielectric breakdown and a ground fault current.

RELAYS:

Relays are electrically operated switches. They can be operated from a remote location by a low voltage and low current electrical signal. They consist of two basic subassemblies: The coil and the contacts. Other parts include a spring, pendulum, and terminals. These components and basic operation of a relay are illustrated in Figure 6-5.

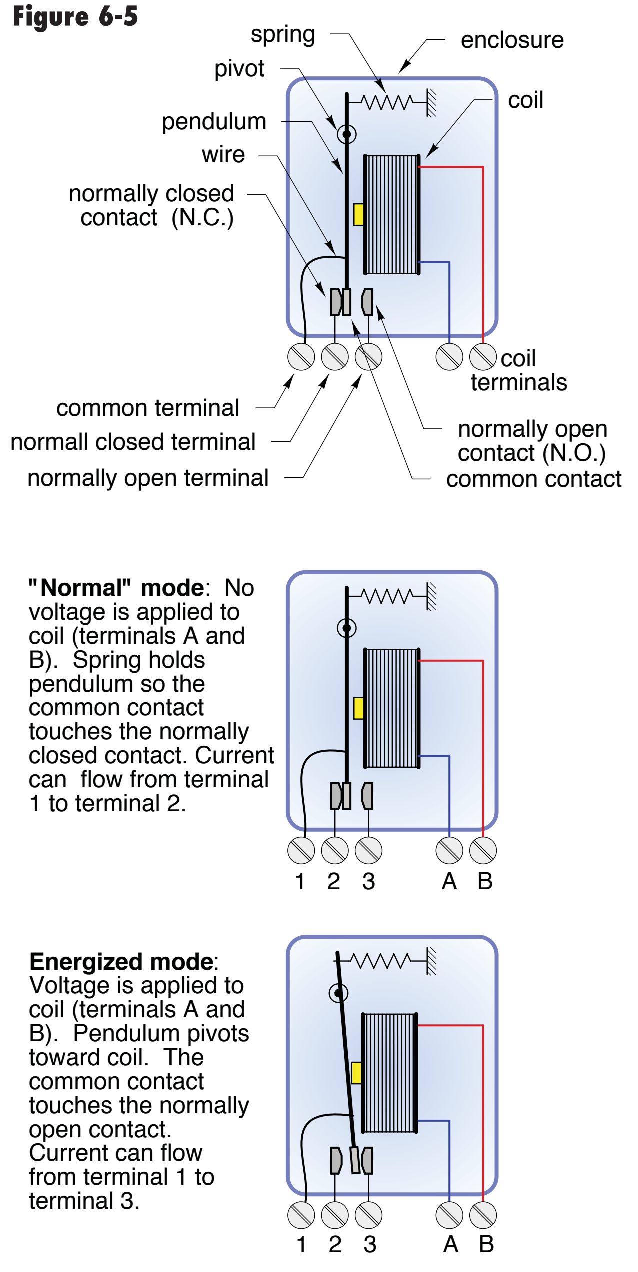
The spring holds the contacts in their “normal” position. When the proper voltage is applied to the coil, and a current flow through it, it creates an electromagnetic field. This magnetic field creates a force that pulls the common contact, which is attached to the pendulum, from its “normal” position, to its other possible position. This movement slightly extends the spring inside the relay. In most relays, this action takes only a few milliseconds. A click can be heard as the contacts move from one position to the other. When voltage is removed from the coil, the magnetic field collapses, and the spring pulls the contacts back to their deenergized (e.g., normal) position.

Relay contacts are designated as normally open (N.O.), or normally closed (N.C.). In this context, the word “normally” means when the coil of the relay is *not* energized. A normally open contact will not allow an electrical signal to pass through while the coil of the relay is off. A normally closed contact *will* allow the signal to pass when the coil is off. Like switches, relays are also classified according to their poles and throws.

The coil is rated to operate at a specific voltage. In heating systems, the most common coil voltage is 24 VAC. Relays with coil voltages of 12, 120, and 240 VAC are also available when needed. Relays with coils designed to operate on DC voltages are also available, although less frequently used in heating control systems.

Figure 6-6 shows the schematic symbols for both switches and relays. On the double and triple pole switches, a dashed line indicates a nonconducting mechanical coupling between the metal blades of the switch. This coupling ensures that all contacts open or

Figure 6-5



close at the same time. Note the similarity between the schematic symbols for switches and relays having the same number of poles and throws.

Some control systems require one or more relays to be installed to perform various switching or isolation functions. The type of relay often used is called a general-purpose relay. They are built as plug-in modules with clear plastic enclosures. Their external terminals are designed to plug into a relay socket. These sockets have either screw terminal or quick-connect tabs for connecting to external wires. Relay sockets allow relays to be removed or replaced without having to disturb the wiring connected to the terminals of the socket. Each terminal on the socket is numbered the same as the connecting pin on the relay that connects to that terminal. This numbering is very important because it allows the sockets to be wired into the control system without the relay being present. Relay manufacturers provide wiring diagrams that indicate which terminal numbers correspond to the normally closed, normally open, common, and coil terminals. In some cases, the wiring diagram is printed onto the relay enclosure.

Figure 6-6

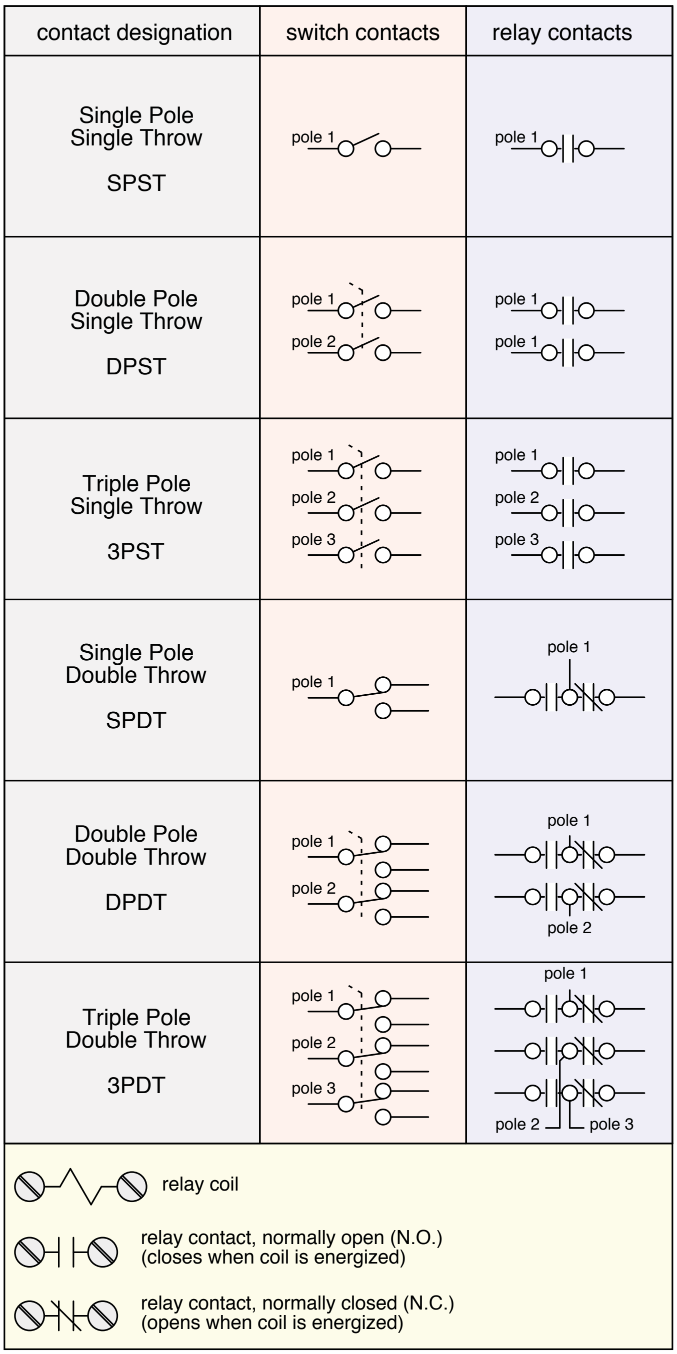
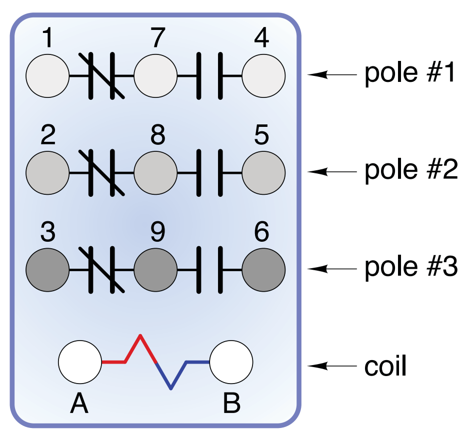


Figure 6-7 shows a general-purpose triple pole, double throw, (3PDT), relay along with the socket it mounts into.

Figure 6-8 shows the wiring schematic for the relay

Figure 6-7

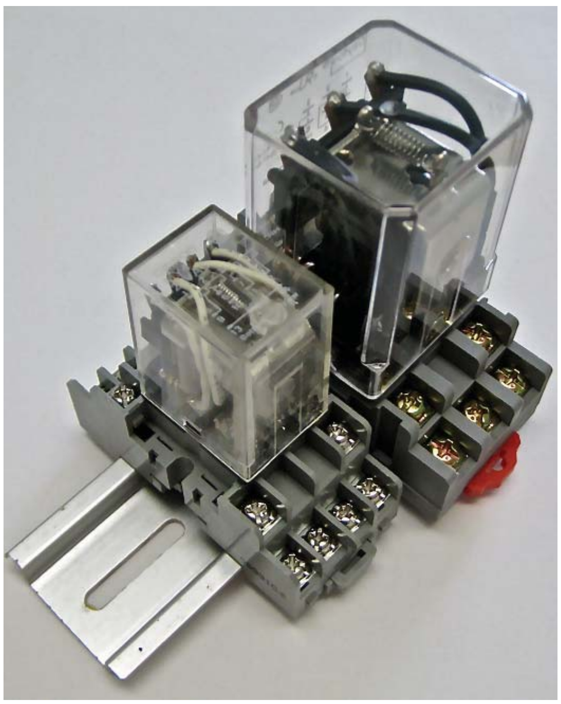
Figure 6-8



shown in Figure 6-7. It identifies the normally open and normally closed contacts, their corresponding terminal numbers, and the coil terminals.

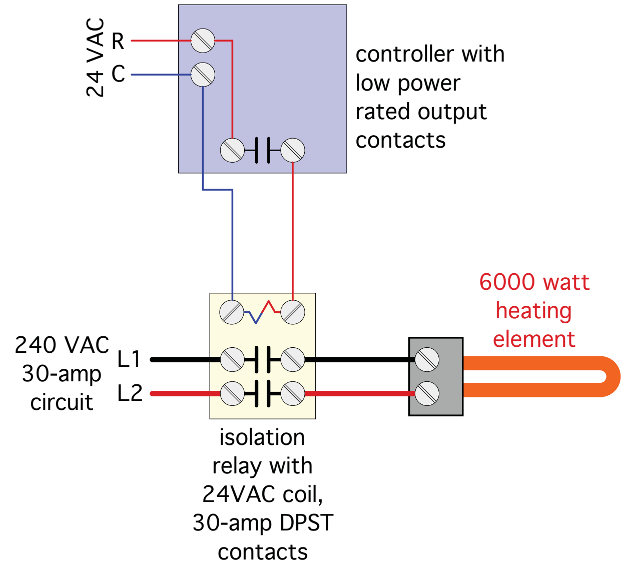
Many relay sockets are designed to be snapped into an aluminum DIN rail as shown in Figure 6-9. This rail allows relay sockets to be added or removed quickly, and without fasteners. The DIN rail is a standard modular mounting system used in many types of control systems. Many small control devices are designed to be mounted to DIN rails. By mounting a generous length of DIN rail in a control cabinet, relays and other components can be easily added, removed, or moved to a different location.

Figure 6-9



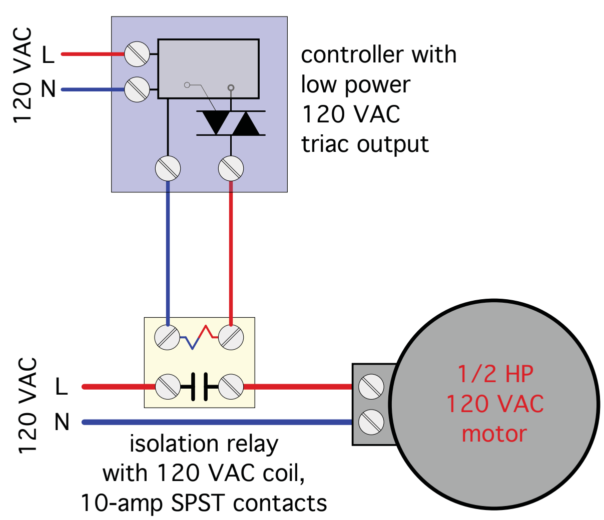
ISOLATION RELAYS:
Sometimes it is necessary for a controller to operate an electrical load that requires substantially more electrical current than can safely flow through the output contacts of the controller. One example would be turning on a 6,000-watt electrical heating element from a low voltage controller having an output relay that is only rated for up to 1 amp of current in a 24 VAC circuit. Assuming the heating element is supplied with 240 VAC, the current requirement is 6,000/240 = 25 amps. With a safety margin factored in, this type of load requires a switch device rated for at least 30 amps. The schematic in Figure 6-10 shows how such a load could be switched using a properly sized isolation relay.

Figure 6-10



Another example uses a controller such as the Caleffi iSolar differential temperature controller to turn on a ½ horsepower circulator motor with a full-load current rating of 7 amps. The output on the iSolar controller uses a solid-state AC switch called a triac rather than mechanical relay contacts. This triac is rated to switch up to 1 amp in a 120 VAC circuit. If connected directly to the motor, the triac would be instantly and irreversibly damaged by the higher current. Figure 6-11 shows how an isolation relay would be wired to handle this situation.

Figure 6-11



An isolation relay can be a general purpose relay or a specialized relay that includes features such as selectable coil voltage, an indicator light to show when the load is energized and a switch to manually operate the load if necessary. Figure 6-12 shows an example of one such relay.

This relay is designed to mount directly into the knockout of a standard junction box. It has wiring that allows the relay's coil to be operated by either 120 VAC or 24 VAC. In this situation, the installer would connect the 120 VAC coil lead to the triac output on the iSolar controller and route the common lead of the coil back to the other output terminal on the iSolar controller, as shown in Figure 6-13.

Figure 6-12

Courtesy of Function Devices, Inc.

The leads connected to the normally open contact of the relay would be wired to switch the higher current 120 VAC to the motor. The 24 VAC lead of the coil and normally closed output lead from the relay would be capped. All connections would be housed in a junction box, or as otherwise required by code.

It is also possible to use a special type of "isolation relay" between a variable voltage/variable frequency triac output on a controller and a higher amperage-requirement motor that is to be controlled at variable-speeds. This type of relay is called a solid-state relay. An example of such a device that can supply up to 5 amps of output current is shown in Figure 6-14.

The solid-state relay contains a high current-rated triac compared to those in some controllers with triac outputs. The triac in a solid-state relay "amplifies" the signal sent to it from the controller's triac. This preserves the information contained in the variable voltage/variable frequency signal, but at the higher current amplitude needed to drive a more powerful motor.

Figure 6-13

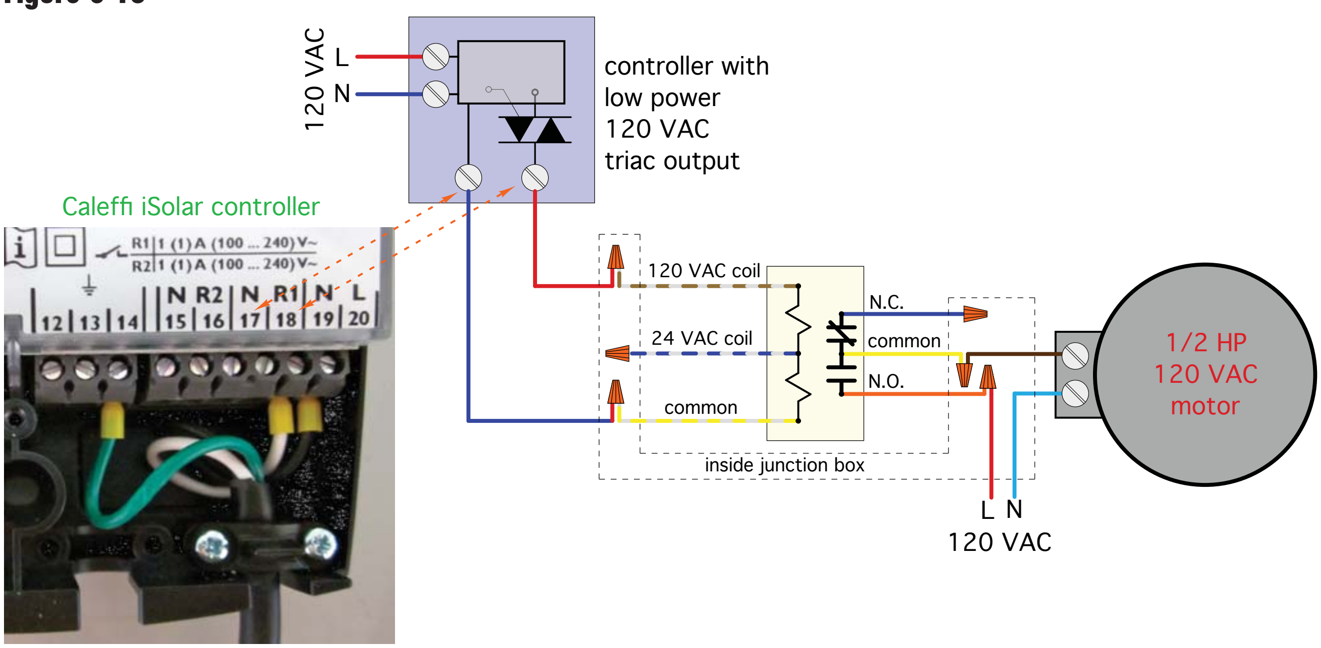


Figure 6-14

Figure 6-15

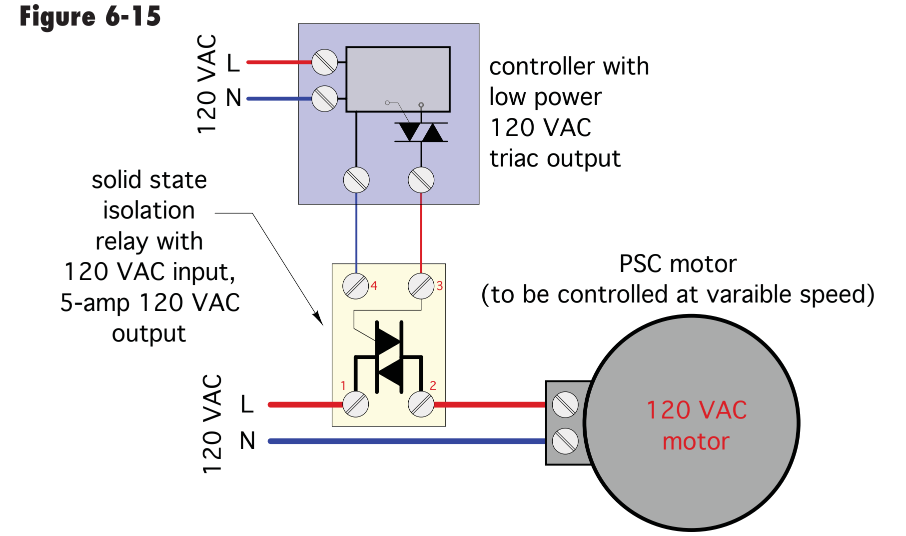
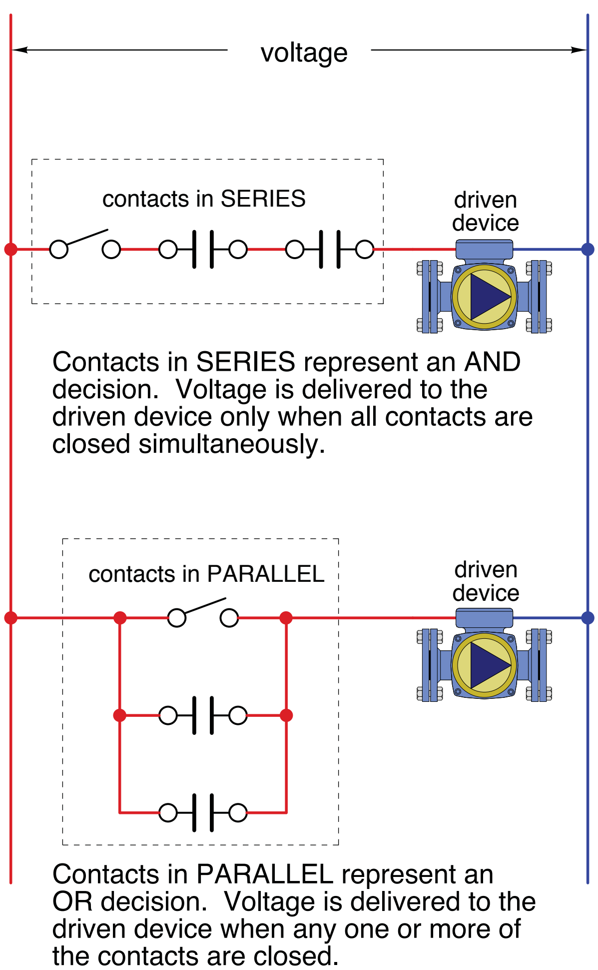


Figure 6-16



A typical application is to boost the power of the variable-speed triac output on a Caleffi iSolar controller, allowing it to drive PSC motors with up to 5-amp full-speed current demands. The wiring for this application is shown in Figure 6-15

HARD WIRED LOGIC:

One of the ways of creating operating logic for a control system is by connecting switch contacts, or relay contacts, in series, parallel, or combinations of series and parallel. Figure 6-16 shows basic series and parallel arrangements.

Contacts in series represent an “AND” decision. For an electrical signal to reach a driven device, all series-connected contacts must be closed simultaneously.

Contacts in parallel represent an “OR” decision. If any one or more of the contacts are closed, the electrical signal passes across the group of parallel switches to operate the driven device.

When switch contacts, relay contacts, or contacts that are part of specialized hydronic controllers are physically wired together in a given manner, they create hard-wired logic. Such logic determines exactly how the control system functions in each of its operating modes. Some operating modes are planned occurrences, while others may be fail-safe modes in the event a given component does not respond properly.

LADDER DIAGRAMS:

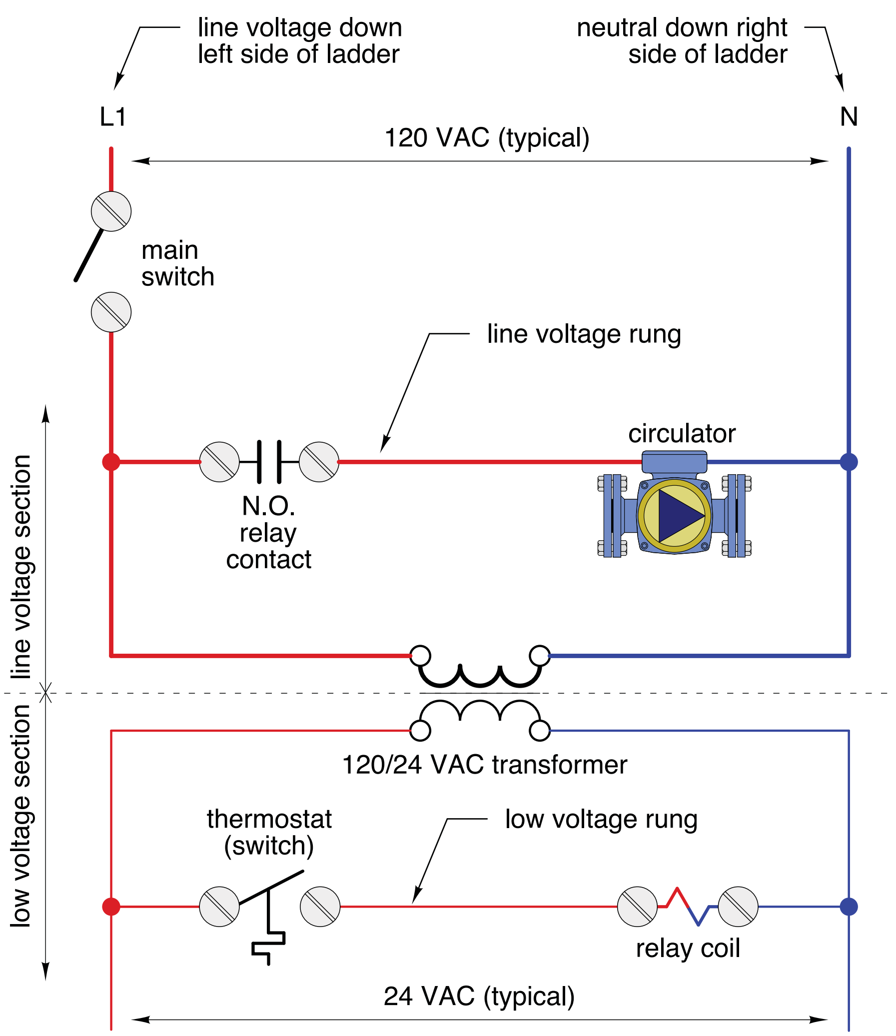
It is often necessary to combine several control components to build an overall control system. The way these components are connected to each other, and to driven devices such as circulators, zone valves and boilers, determines how the system operates.

A ladder diagram is a standard method for developing and documenting the electrical interconnections necessary to build a control system. The finished diagram can then be used for installation and troubleshooting. Such a diagram should always be part of the documentation of a customized hydronic heating or cooling system.

Ladder diagrams have two sections: the line voltage section at the top of the ladder, and the low voltage section at the bottom of the ladder. A voltage step down transformer separates the two sections. The primary side of the transformer is connected to the line voltage. The secondary side of the transformer powers the low voltage section. In North America, most heating and cooling systems operate with a secondary voltage of 24 VAC.

An example of a simple ladder diagram is shown in Figure 6-17. The vertical lines can be thought of as the sides of an imaginary ladder. Any horizontal line connected between the two sides is called a rung. A rung connected across the line voltage section is exposed to 120 VAC. A rung connected across the low voltage section is usually exposed to 24 VAC. The overall ladder diagram is constructed by adding the rungs necessary to create the desired operating modes of the system. The vertical lines of the ladder can be extended as necessary to accommodate all required rungs.

Figure 6-17



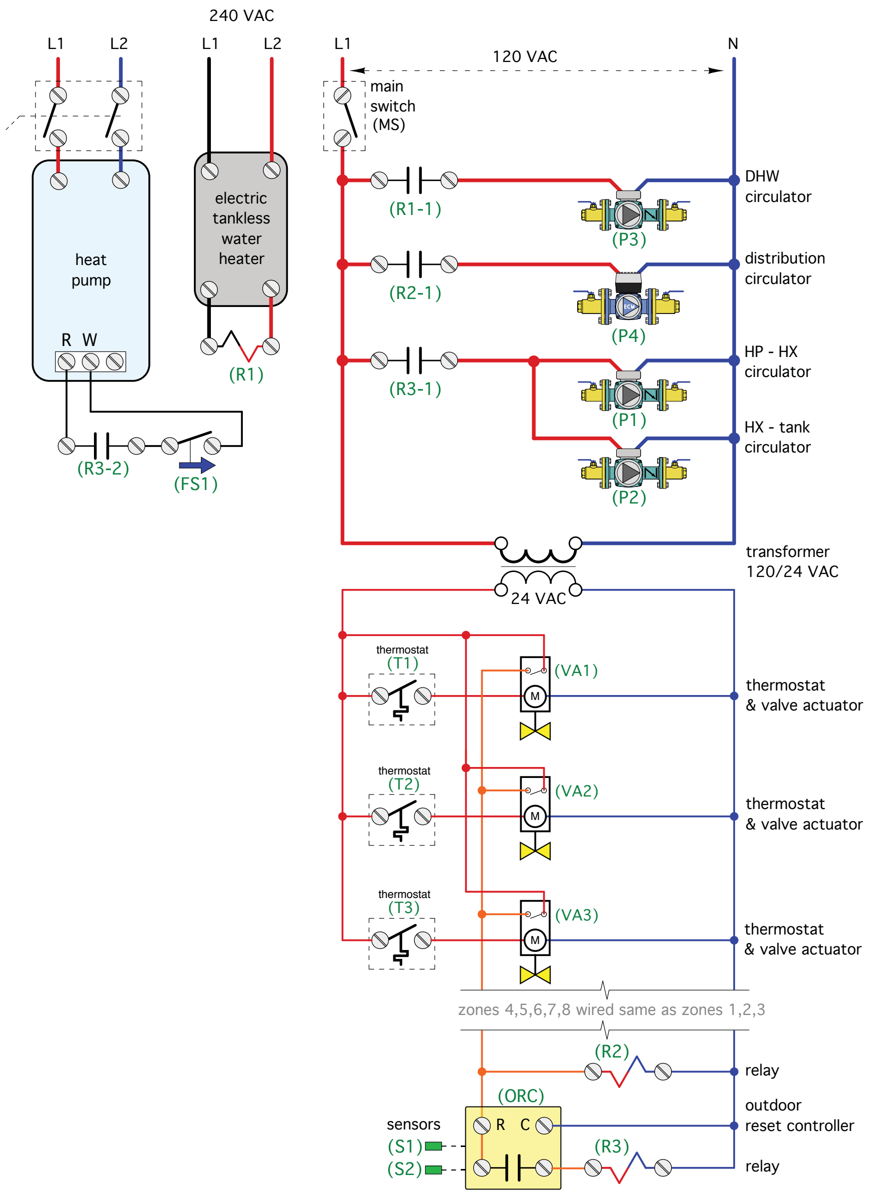
Relays are often used to operate line voltage devices such as circulators, oil burners or blowers based on a “call” for operation from a low voltage device such as a thermostat. Ladder diagrams show how this is accomplished. When a circuit path is completed through a relay coil in the low voltage section of the ladder, one or more contacts of that relay, located in the upper portion of the ladder, close to supply line voltage to driven devices such as a circulator or blower. Note that the coil and contacts of the same relay often appear in different sections of the ladder diagram. When more than one relay is present in the diagram, it’s important to use consistent labeling to know which relay contacts are associated with a given relay coil.

It is also common to show a main switch at the top of the ladder. When open, the main switch prevents any electrical signal from passing downward into the ladder diagram, and thus would totally prevent any electrical components shown in the ladder diagram from operating. For systems powered by 120 VAC, the main switch would be installed in the live lead (e.g., the left vertical line of the ladder). For systems supplied by 240 VAC, a double pole main switch would be used to open both live leads to the ladder.

Consider a situation in which a line voltage circulator is to be operated by a low voltage thermostat. Since the circulator requires line voltage to operate, it is connected across the line voltage section of the ladder diagram, as shown in Figure 6-17. A normally open relay contact is wired in series with the circulator. When this contact is open, the 120 VAC voltage present on the left side of the ladder cannot pass to the circulator, and thus it remains off. To close this contact, the coil of the relay must be energized. This requires a completed circuit path across the low voltage section of the ladder. By wiring the relay coil in series with the thermostat, the coil is energized when the thermostat contacts are closed, and off when they are open. The overall operating sequence is as follows: the thermostat contacts close, low voltage is applied across the relay coil, the energized coil pulls the normally open relay contacts shown in the line voltage rung together and line voltage is applied across the circulator to operate it.

Although this example is relatively simple, it illustrates the basic use of both the line voltage and low voltage sections of the ladder diagram. More complex ladder diagrams are developed by placing schematic symbols for additional components into the diagram. Some of these components might be simple switches or relays. Others might be special purpose controllers that operate according to how the manufacturer designed them and how their adjustable parameters are set. When shown in a ladder diagram, such controllers are called "embedded controllers," since they are part of a ladder diagram that documents the overall control system. An example of a ladder diagram with several rungs and an embedded outdoor reset controller (ORC) is shown in Figure 6-18.

Figure 6-18



Although most of the electrical components in the system, such as circulators, zone valves, outdoor reset controllers and thermostats, are shown within the main ladder, some other devices are shown outside the ladder. These include an electric tankless water heaters and an air-to-water heat pump. Both of these devices require their own dedicated electrical power circuits, and thus do not draw power from the circuit supplying the ladder diagram.

Notice that all the devices are labeled (shown in green). A typical relay coil is labeled as (R2) or (R3), and its associated contacts are labeled as (R2-1) or (R3-2). These designations associate specific contacts with the relay coil that operates them. For example, relay coil (R2) operates relay contact (R2-1). The number after the dash indicates the pole number of the relay contact. For example, (R2-1) designates pole #1 on relay (R2), and (R2-2) designates pole #2 on the same relay. Such designations are critically important when interpreting the operating logic associated with the ladder diagram. Since all the relay coil symbols and contact symbols look the same, these designations are the only way to know which contacts are associated with a given relay coil.

Figure 6-19 shows the piping schematic of the system associated with the ladder diagram shown in Figure 6-18.

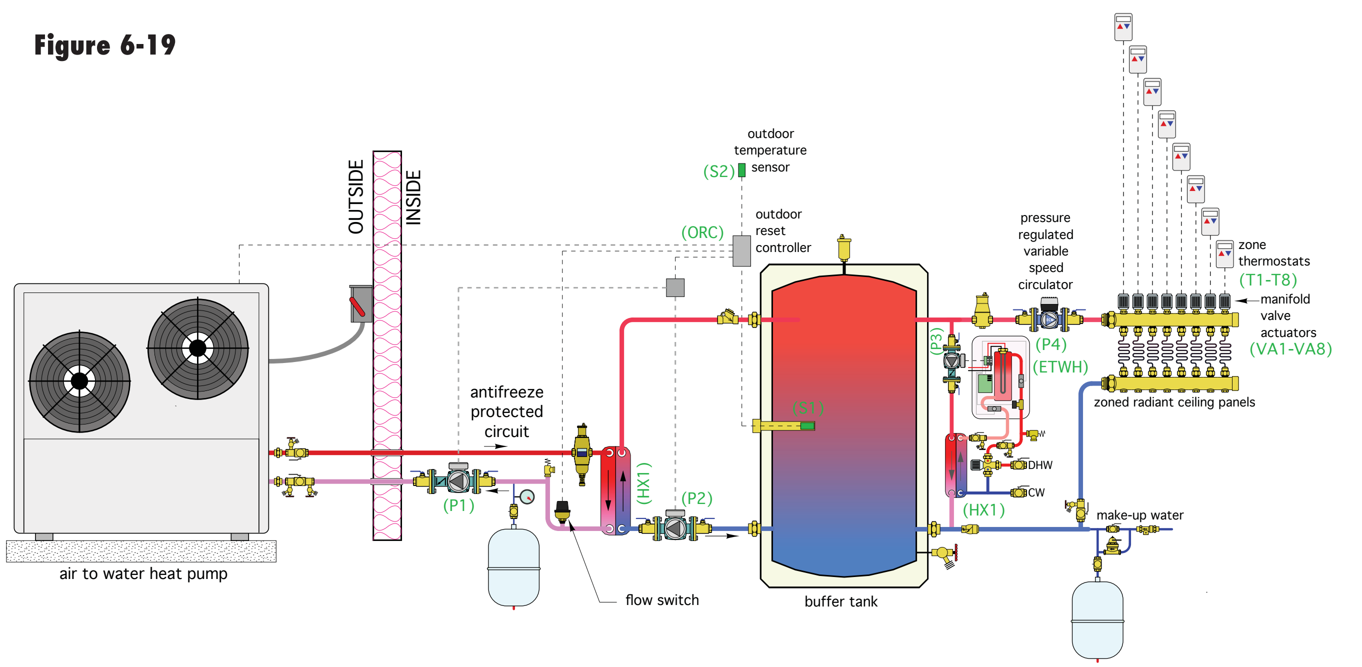
Notice that the electrically driven components on the piping schematic have corresponding designations on the ladder diagram. This makes it easy to cross-reference between the two diagrams when examining the operating logic or troubleshooting the installed system.

Another important aspect of properly documenting a control system is to create a description of operation. This is a text-based description that narrates the sequence of events that must take place in each operating mode of the system. It is created by describing each component in the operating sequence, beginning with the component that "calls" for a specific mode of operation. Each operating mode should be described independently, while making frequent reference to the component designations in the ladder diagram. An example of a complete description of operation for the system shown in Figures 6-12 and 6-13 is as follows:

DESCRIPTION OF OPERATION:

1. Space-heating mode: *The distribution system has several zones, each equipped with a 24 VAC thermostat (T1, T2, T3, etc.). Upon a demand for heat from one or more of these thermostats, the associated 24 VAC manifold valve actuators (VA1, VA2, VA3, etc.) are powered on. When a valve actuator is fully open, its end switch closes. This supplies 24 VAC to the coil of relay (R2). This closes the normally open contacts (R2-1) that supply 120 VAC to circulator (P4). Circulator (P4) operates in constant differential pressure mode to supply the flow required by the distribution system. A call for heat also supplies 24 VAC to the outdoor reset controller (ORC). This controller measures outdoor temperature from sensor (S2). It uses this temperature, in combination with its settings, to calculate the target supply water temperature that needs to be maintained in the buffer tank. If the tank requires heating, the normally open relay contacts within the (ORC) close. This energizes the coil of relay (R3). One set of normally open contacts (R3-1) close to turn on circulators (P1) and (P2). This establishes flow through the heat pump and between the heat exchanger (HX1) and the buffer tank. Another normally open relay contact (R3-2) is wired in series with the contacts from the flow switch (FS1). When both of these contacts are closed, a 24 VAC circuit is completed between the R and Y terminals. This turns on the heat pump in heating mode and delivers heat to the buffer tank. The heat pump continues to run until: 1. The buffer tank reaches the target temperature of the outdoor reset controller (ORC) plus half of its differential setting, or 2. All zone thermostats are satisfied.*

Figure 6-19



***2. Domestic water heating mode:** Whenever there is a requirement for domestic hot water flow of 0.6 gpm or higher, the flow switch inside the tankless electric water heater closes. This closure applies 240 VAC to the coil of relay (R1). The normally open contacts (R1-1) close to turn on circulator (P3), which circulates heated water from the upper portion of the buffer tank through the primary side of the domestic water heat exchanger (HX2). The domestic water leaving (HX2) is preheated to a temperature a few degrees less than the buffer tank temperature. This water passes into the thermostatically controlled electric tankless water heater, which measures its inlet temperature. The electronics within this heater regulate current flow to the heating elements so that water leaving the heater is at the desired temperature. All heated water leaving the tankless heater flows into an ASSE 1017-rated mixing valve to ensure a safe delivery temperature to the fixtures. Whenever the demand for domestic hot water drops below 0.5 gpm, circulator (P3) and the tankless electric water heater are turned off.*

7. HYDRONIC ZONING CONTROLS

One of the most sought after benefits of hydronic heating and cooling is the ability to easily divide a building into multiple zones. A zone is any area of a building in which the 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. Readers are encouraged to review *idronics* #5, available at www.caleffi.us, for a more detailed discussion of zone planning.

In residential and light commercial hydronic systems, there are four common methods of controlling heat flow to individual zone circuits:

1. Zoning with on/off zone valves
2. Zoning with on/off manifold valve actuators
3. Zoning with on/off zone circulators
4. Zoning with wireless thermostatic radiator valves

This section discusses all four methods and shows how specific controllers are configured for each of them.

ZONING WITH ON/OFF ZONE VALVES:
One of the most common methods for zoning hydronic systems uses 2-way electrically operated zone valves, an example of which is shown in Figure 7-1.

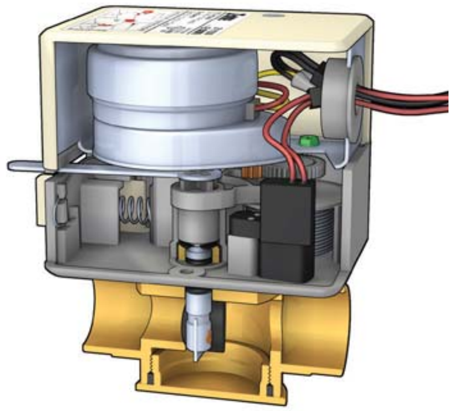
Most zone valves have brass bodies. Within that body is a high-temperature elastomer disc secured to a rotating shaft. As the shaft is rotated through its full range of motion, the disc moves from a position where it completely covers the orifice through the valve to a position where maximum flow can easily pass through the valve.

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 have actuators that use a small AC synchronous motor coupled to a gear assembly to rotate the valve's shaft. These valves are usually fully open within one minute after electrical power is applied. Most zone valves of this type also have an internal torsion

Figure 7-1a

Figure 7-1b



spring that is wound as the valve is powered open. 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 should be equal to or greater than the maximum differential pressure the valve could experience in a given system.

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

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.

Zone valves are intended to operate in either their fully open or fully closed position. This distinguishes them from modulating valves, which can operate fully open, fully closed or anywhere in between. 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 used to close the valve when power is applied.

PIPING FOR 2-WAY ZONE VALVES:
A piping schematic of a typical hydronic heating system using 2-way normally closed zone valves is shown in Figure 7-2.

In this example, 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.

Notice that purging valves are installed 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. Flow-balancing valves can also be installed on either the supply or return side of each circuit. Figure 7-3 shows all of these valves installed within an insulated piping system.

Figure 7-2

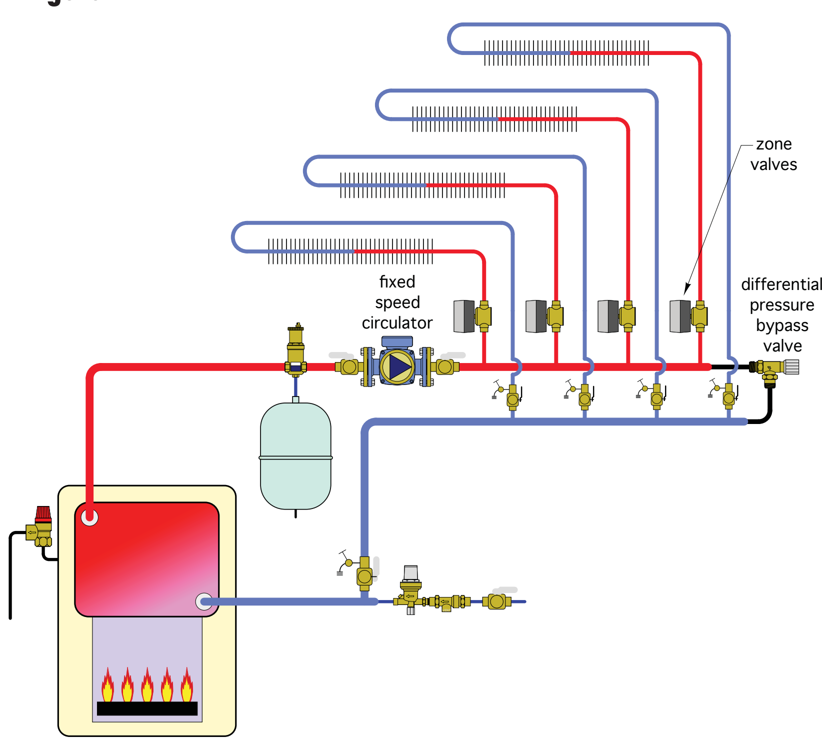
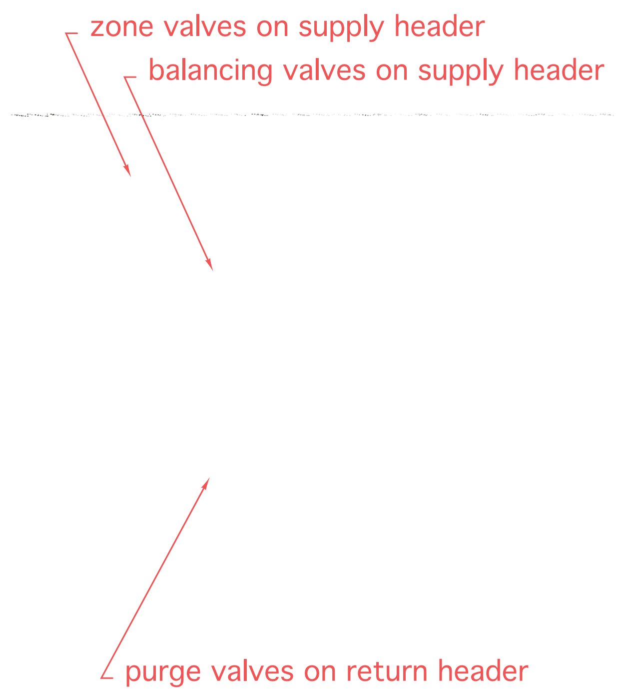
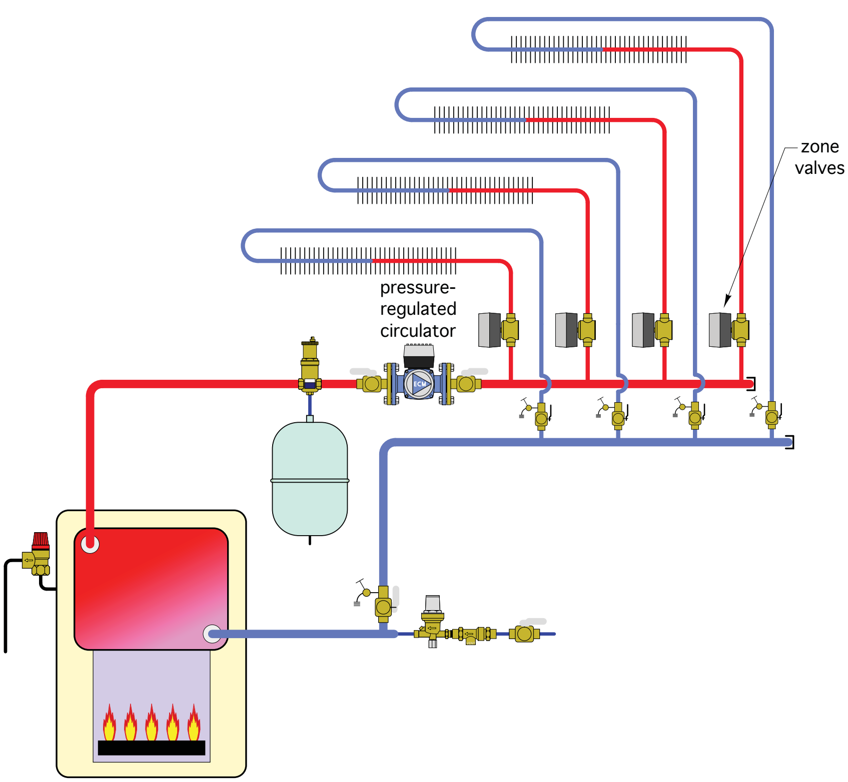


Figure 7-3



Courtesy of Tim Cutler

Figure 7-4



The system shown in Figure 7-2 uses a fixed-speed circulator. This circulator and the heat source operates whenever any zone valve is powered on by its associated thermostat. Heated water is circulated through any circuit with an open zone valve. This circulation continues until the thermostat for the zone is satisfied. At that point, electrical power is removed from the zone valve, and it closes. When no zones require heat, the circulator and heat source are also turned off.

The system in Figure 7-2 also 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.

An alternative piping system using the same 2-way normally closed zone valves is shown in Figure 7-4.

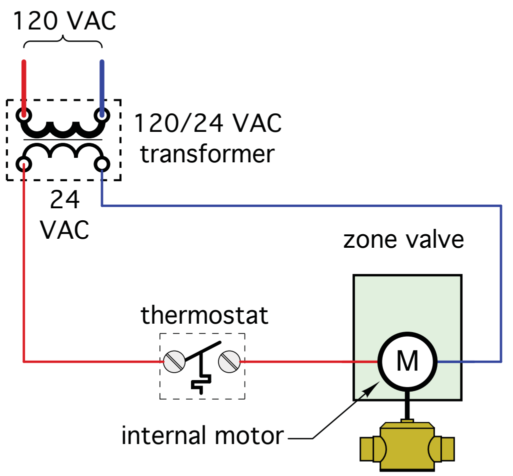
This system uses a variable-speed pressure-regulated circulator in place of the fixed-speed circulator shown in Figure 7-2. This circulator contains electronics that automatically adjust its speed as the number of active zone circuits increases or decreases. By controlling its speed, this circulator can maintain a nearly constant differential pressure between 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.

ELECTRICAL CONFIGURATIONS FOR ZONE VALVES:
Zone valves can be equipped with actuators that operate at different voltages. The most common operating voltage in hydronic heating systems is 24 VAC supplied by a step down transformer. This low voltage 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, which 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, as well as 208 VAC or 277 VAC in commercial installations. Actuators that operate at these voltages are available. All wiring at these line voltages has to be protected based on both the NEC and any local electrical codes.

Zone valves are usually controlled by a low voltage thermostat. The most common configuration is one zone valve with one associated thermostat. The thermostat acts as a temperature-operated switch. When the thermostat determines that the zone requires heat, it closes its internal electrical contacts. 24 VAC passes through these contacts and on to the motor in the zone valve. A second wire from the zone valve's motor connects to the common side of the transformer, as shown in Figure 7-5.

Figure 7-5

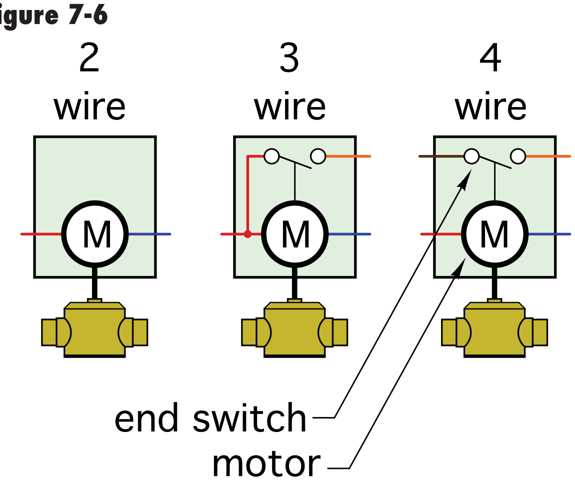


There are three internal wiring configurations for 24-volt zone valves. They are named based on the number of wires coming from the valve:

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

Figure 7-6 illustrates the differences in internal wiring.

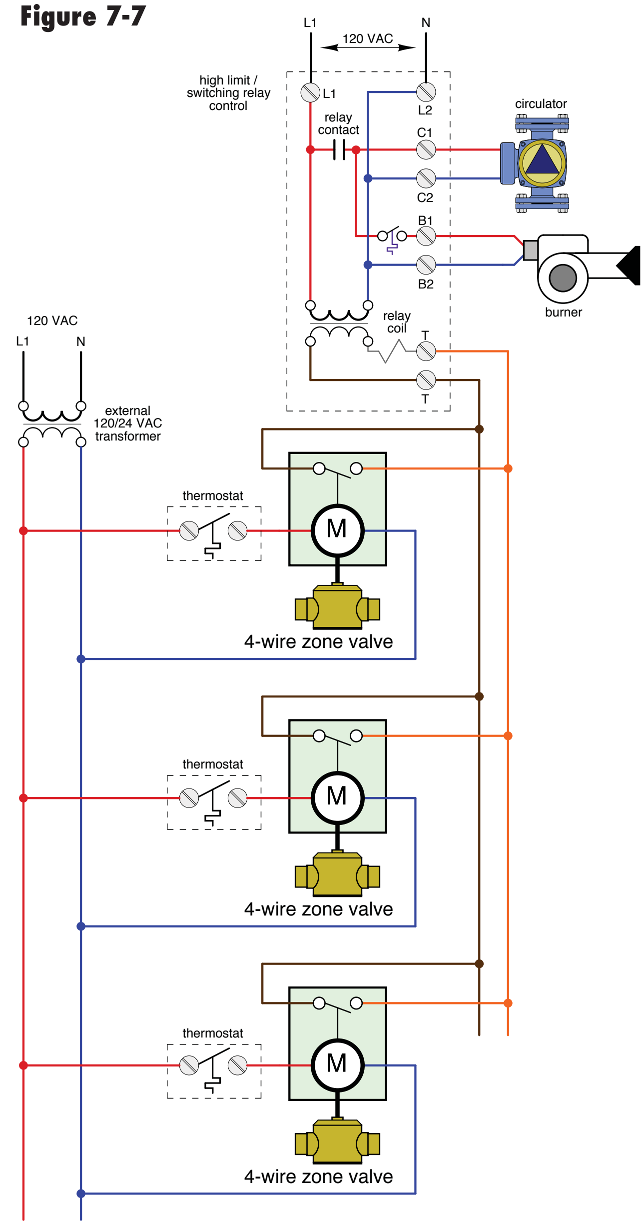
Figure 7-6



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

A 3-wire zone valve adds an end switch to the actuator. This switch 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 or a mixing device. End switches that are fully sealed from atmospheric conditions provide the longest service life.

Figure 7-7



A four-wire zone valve also contains an end switch. However, this switch is *electrically isolated* from the wiring used to operate the valve's 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 7-7.

The electrical power required to operate the zone valve's motor 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 its actuating motor. 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 2–7 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 5 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 zone valve's motor.

When using zone valves with end switches, the end switches should only connect to low voltage (24 VAC) circuits. *Never wire line voltage through the end switch of any zone valve.*

Later portions of this section describe multi-zone relay centers that allow all the functionality of these wiring diagrams, along with additional features, to be achieved within a prewired controller.

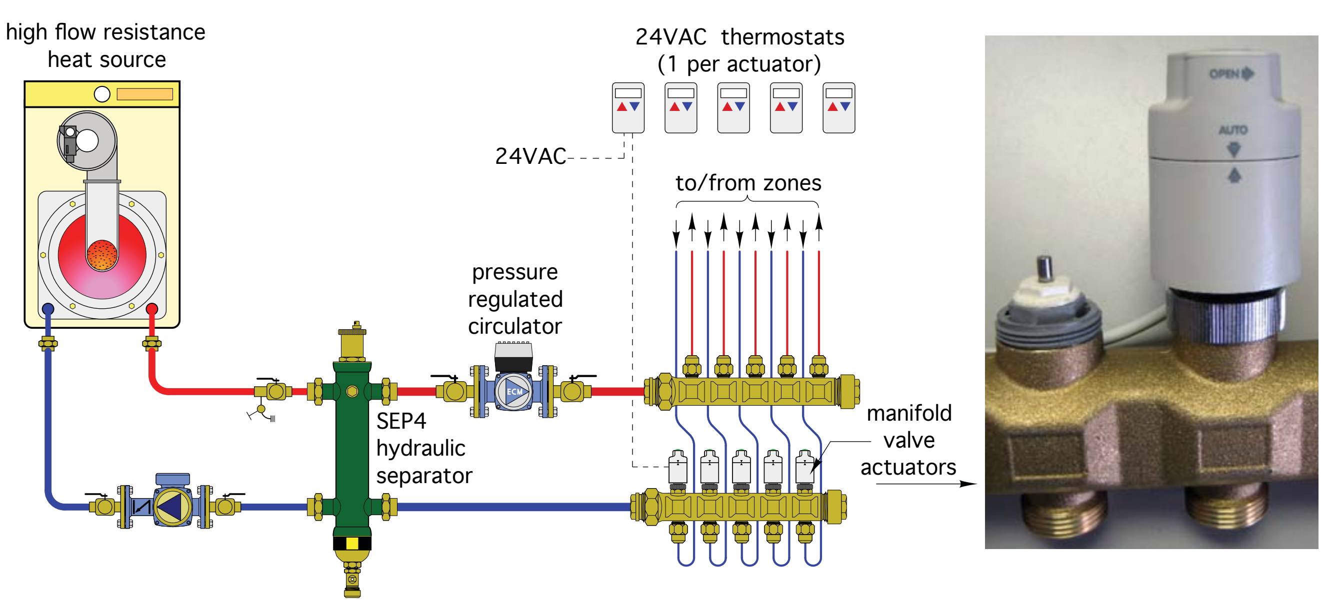
ZONING WITH ON/OFF VALVE ACTUATORS:

The availability of PEX and PEX-AL-PEX tubing was essential to the growth of the radiant panel heating market in North America. Fortunately, the temperature and pressure ratings of these tubing materials, along with their flexibility, allow them to be used for much more than radiant panel circuits. They can be combined with several manifold systems to create "homerun" distribution systems that supply a variety of heat emitters, including fin-tube baseboard, panel radiators and fan coils. An example of such a system is shown in Figure 7-8.

Water from the heat source passes through the hydraulic separator and enters the supply manifold. Each branch circuit from the supply manifold leads to a single heat emitter. Another tube connects the outlet of each heat emitter back to the return manifold.

In this system, each manifold circuit is equipped with a 24 VAC valve actuator. When this actuator is attached to a manifold valve, it forces the stem of that valve to its

Figure 7-8

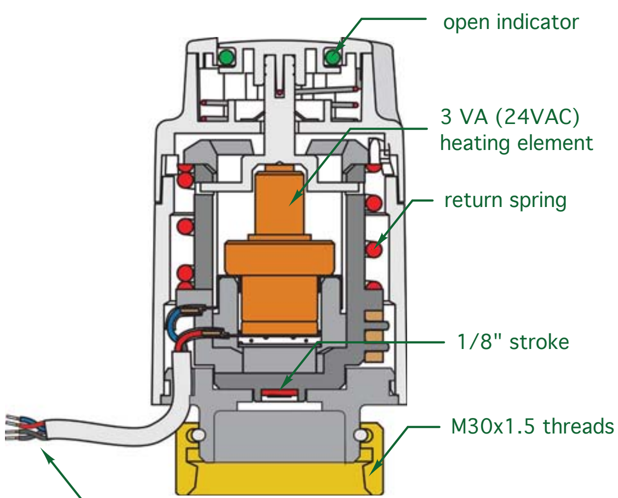


closed position, thus blocking flow through the associated circuit. When 24 VAC is applied to the valve actuator, it retracts its stem, allowing the spring-load manifold valve to open. This configuration allows independent flow control through any circuit supplied from the manifold station with the same type of 24 VAC wiring used with zone valves.

Manifold valve actuators are available in either 2-wire or 4-wire configurations. The 4-wire version includes an isolated end switch that closes when the actuator reaches its fully open position. Like the end switch in a 4-wire zone valve, this switch can provide a heat demand indication to the remainder of the control system.

Figure 7-9 shows the internal components of a manifold valve actuator.

Figure 7-9

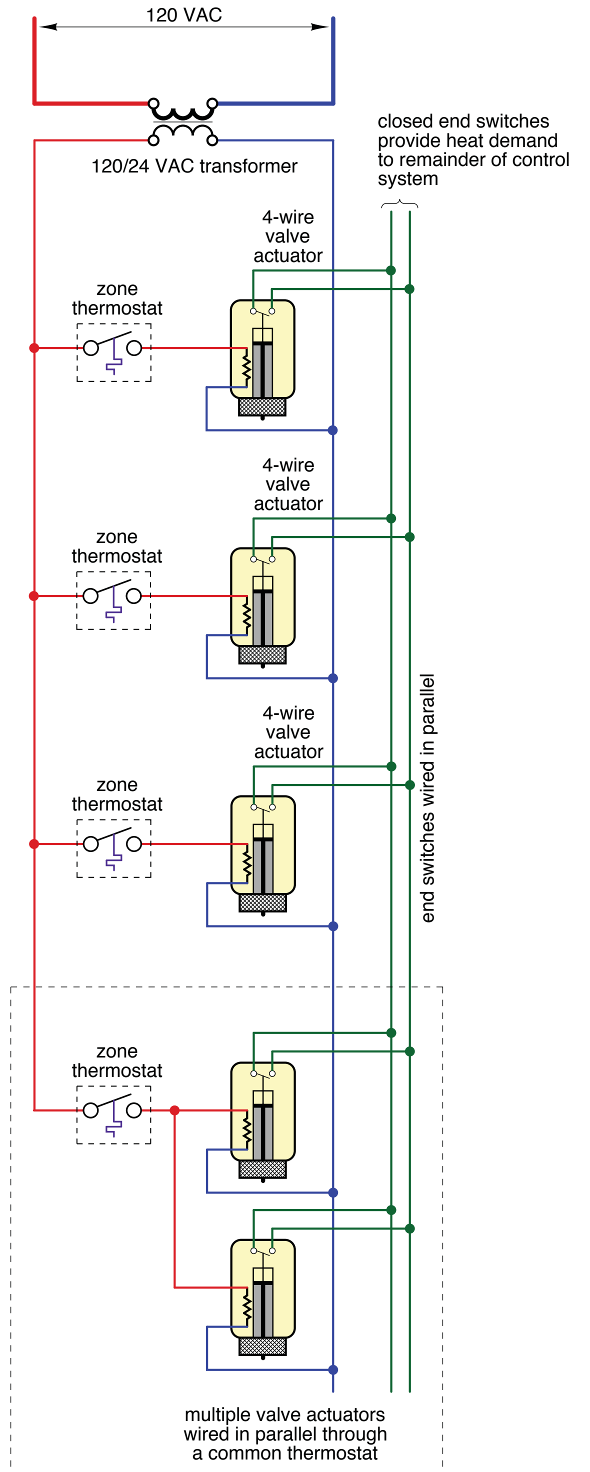


When 24 VAC power is applied to a manifold valve actuator, the "thermal motor" inside it is activated. This motor contains a special wax that expands within a sealed chamber due to electrical heating. This causes the actuator's stem to retract over a period of 2–3 minutes, depending on the initial temperature of the actuator. The stem movement allows the spring-loaded manifold valve to which the actuator is attached to open. When the actuator reaches its fully open position, the electrically isolated end switch within the actuator closes.

Figure 7-10 shows how 4-wire valve actuators can be wired based on a ladder diagram structure. Note the similarity of this wiring to that used with 4-wire zone valves in Figure 7-7.

Each actuator receives a 24 VAC signal when its associated thermostat calls for heat. The actuator opens its associated manifold valve and closes its end switch. The closed end switch provides a "heat demand" signal to the remainder of the control system, which turns on other

Figure 7-10



devices such as the heat source, circulators or a mixing device. When multiple zones are supplied from a common manifold, the end switches of all valve actuators are usually wired in parallel, as shown in Figure 7-10. Thus, any actuator can provide the heat demand signal. In some cases, multiple valve actuators are wired in parallel, and operate from a common thermostat. This technique is used in situations where two or more circuits are required within the same zone.

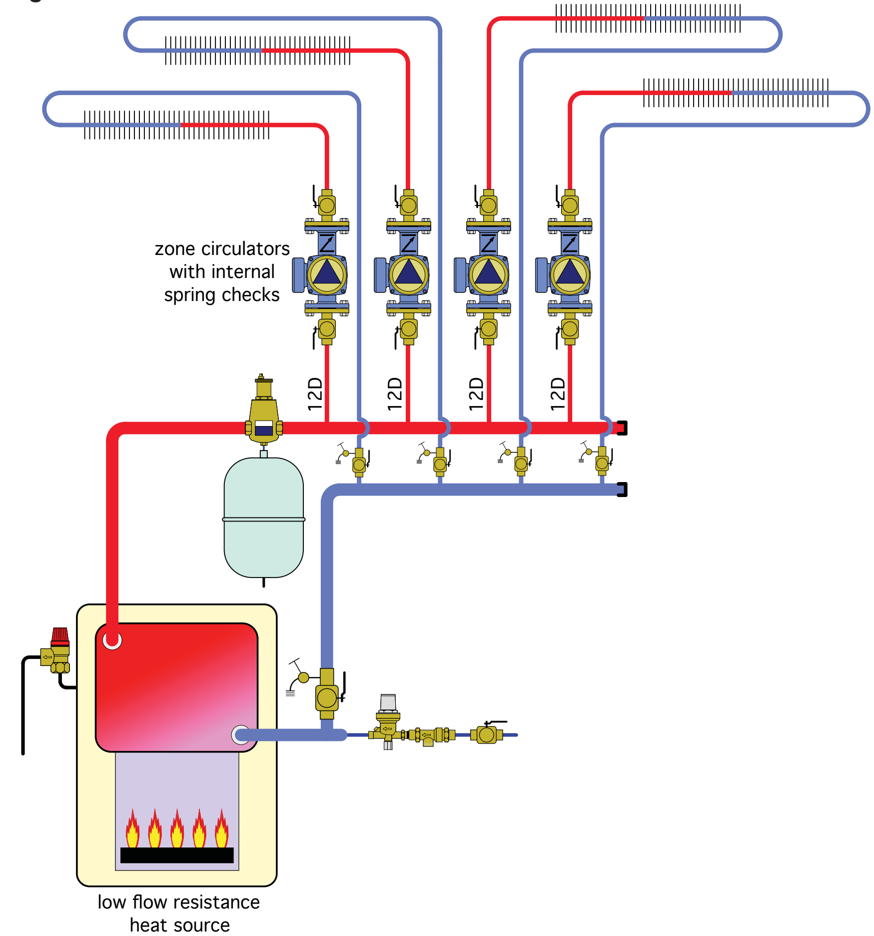
The transformer that powers a group of manifold valve actuators must have a volt-amp (VA) rating high enough to handle the initial current draw of all valve actuators capable of operating simultaneously. Although this is not a common occurrence, it can happen when all zones are turned on at the same time following a setback period. It can also occur when all zone thermostats demand heat simultaneous after a prolonged power outage in cold weather.

The VA demand of a valve actuator or a zone valve is often listed in the manufacturer's specification. Alternatively, the inrush current draw of the actuator of a zone valve may be listed. For example, a given valve actuator may have a specified inrush current demand of 250 milliamps (250 mA). It's inrush VA draw can be estimated from this based on a nominal 24 VAC supplied from the transformer: VA = 24 volts x 0.25 amp = 6 VA.

The transformer can now be conservatively selected by totaling the inrush VA requirement of all valve actuators, zone valves or other low voltage devices powered by the transformer and adding 5 VA as a safety factor. For example, if 8 valve actuators, each requiring an inrush demand of 6 VA, will be powered from a transformer, its minimum VA rating should be 8 x 6 + 5 = 53 VA. This is a conservative selection criteria because the steady-state VA demand of most valve actuators and zone valves using heat motors is lower than their inrush VA demand.

When using manifold valve actuators with end switches, the end switches should only connect to low voltage (24 VAC) circuits. *Never wire line voltage through the end switch of any manifold valve actuator.*

Figure 7-11



ZONING WITH ON/OFF ZONE CIRCULATORS:

Another traditional North American method of hydronic zoning is the use of a separate circulator for each zone. A piping schematic showing this approach is given in Figure 7-11.

When the thermostat in a given zone "calls" for heat, the associated zone circulator and heat source are turned on. When a zone thermostat is satisfied, its associated zone circulator is turned off. All zone circuits begin and end at headers. These headers should be generously sized to keep head loss to a minimum. This, in combination with a low head loss heat source, provides adequate hydraulic separation between the individual circulators, preventing any significant interference between them.

Each zone circulator in Figure 7-11 contains an internal spring-loaded check valve. These valves prevent reverse flow through inactive zone circuits while other zones are operating. They also prevent buoyancy-driven hot water flow through inactive zone circuits.

Figure 7-12

Courtesy of Bell & Gossett

The notation “12D” below each circulator is a reminder to install a straight section of piping that has a length of at least 12 times the nominal diameter of the pipe on the inlet side of each circulator. This reduces turbulence in the flow entering the circulator, and helps minimize its operating noise. It is appropriate for zone circulators as well as any other circulators in hydronic systems.

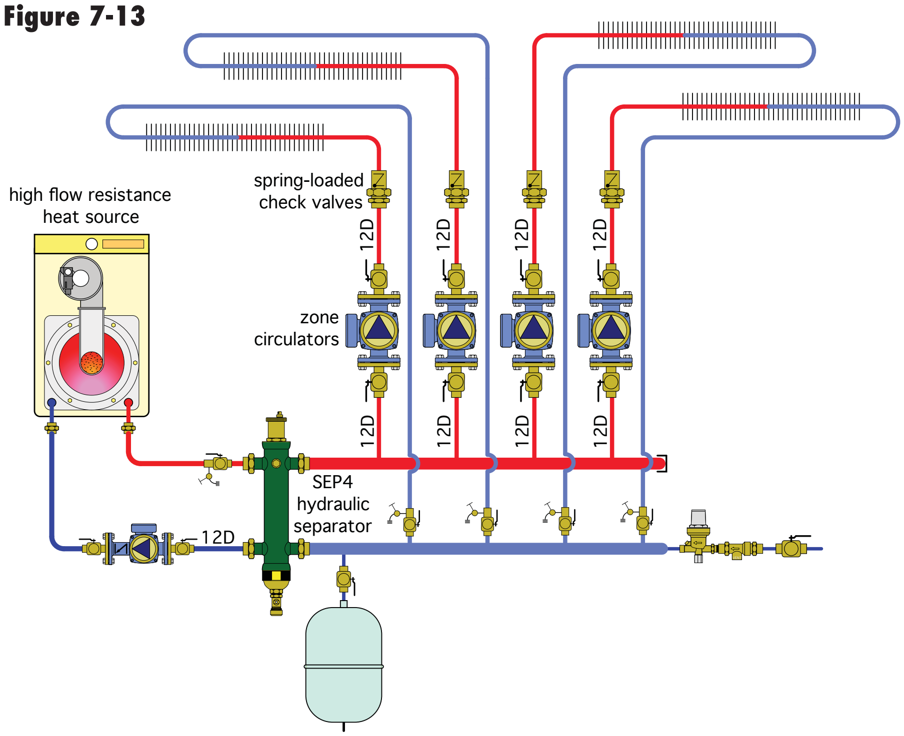
Each zone circulator is also equipped with isolation flanges. They allow each circulator to be isolated from the remainder of the system and serviced or replaced when necessary, with minimal spillage of fluid. Figure 7-12 shows several zone circulators, each equipped with isolation flanges that contain internal check valves.

If the heat source has significant flow resistance, it’s best to install a means of hydraulic separation between that heat source and the distribution headers, as shown in Figure 7-13.

This system uses a Caleffi SEP4 hydraulic separator between the high flow resistance boiler and the distribution system. Along with preventing interference between the boiler circulator and the distribution circulators, this hydraulic separator provides high efficiency air separation, and thus replaces the need for an air separator. It also provides high efficiency magnetic dirt separation.

On systems with many small zone circuits, it is also possible to use a Caleffi ThermoCon buffer tank in place of the hydraulic separator. This tank adds thermal mass to stabilize the heat source against short cycling. It also provides hydraulic separation when piped as shown in Figure 7-14. A high efficiency air separator should also be included in the system.

Figure 7-13



Again, each zone circuit contains a spring-loaded check valve to prevent heat migration and reverse flow. In this system, those check valves are external valves mounted downstream of the circulator outlet. Each zone circuit should also be equipped with its own purging valve to expedite air removal at startup.

Also notice the temperature sensor located within a well inserted into the mid-height connection of the buffer tank. The boiler monitors the temperature of this sensor, and fires as necessary to maintain the upper portion of the buffer tank at a suitable temperature to supply the distribution system.

Be sure to install a minimum of 12 pipe diameters of straight pipe on the inlet side of all check valves. This reduces turbulence and reduces operating sound.

Figure 7-14

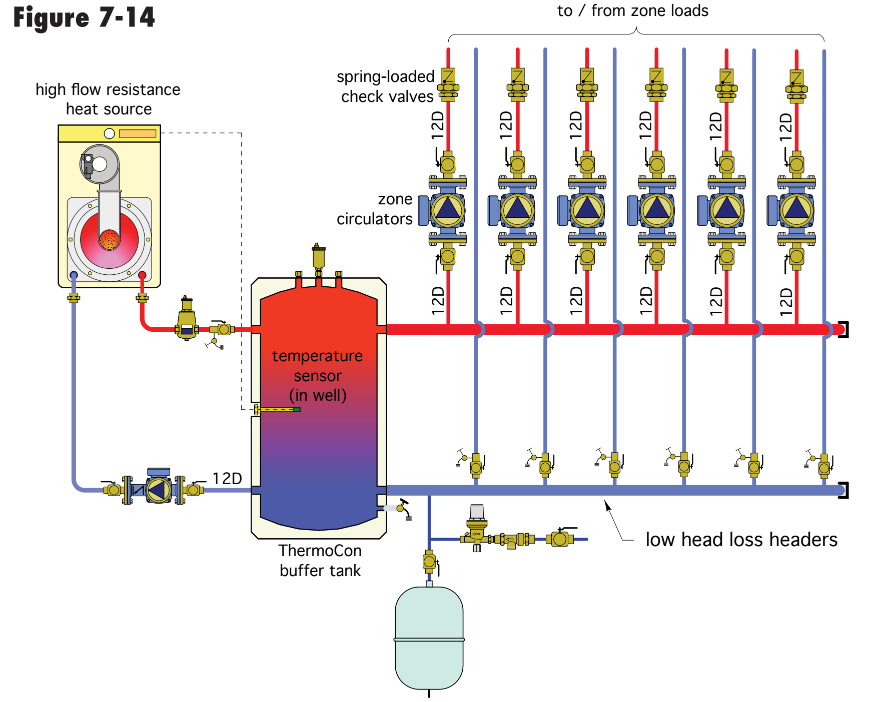
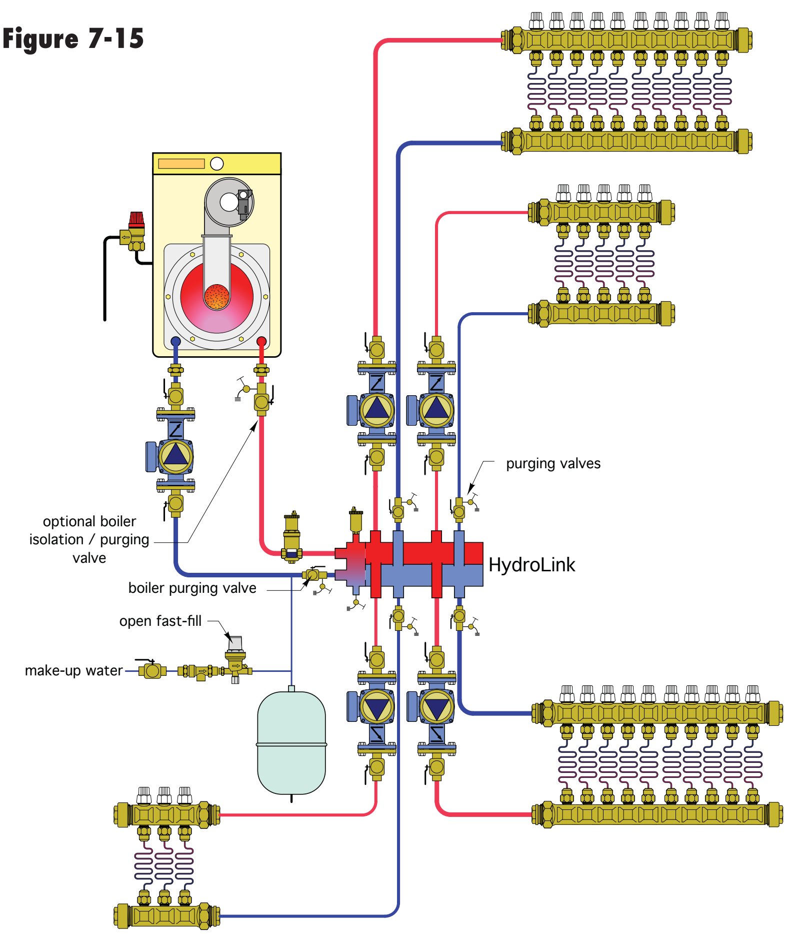


Figure 7-15



Another approach to circulator-based zoning is shown in Figure 7-15.

This system uses a Caleffi HydroLink to provide hydraulic separation between all the circulators mounted to it, as well as with the boiler circulator.

The total electrical energy use of a system using circulator zoning tends to be higher than that of systems using valve-based zoning. Designers should carefully scrutinize circulator selection and speed settings to minimize "over-pumping" and needless power consumption. Small zone circuits can often be handled using ECM-based high efficiency circulators set for appropriately low speed settings. In small zone circuits, each of these circulators may provide adequate flow using only 10–40 watts of input power.

ELECTRICAL CONFIGURATIONS FOR ZONE CIRCULATORS:
Figure 7-16 shows one way to wire four zone circulators using a ladder diagram approach. Each zone thermostat provides 24 VAC to the coil of its associated zone relay. One contact in the associated relay closes to provide 120 VAC to the associated zone circulator, located in the upper section of the diagram. Another contact (e.g., another pole) within the same relay closes to provide a "dry contact" heat demand signal to the remainder of the control system. Notice how all relay contacts that provide the heat demand signal are wired in parallel, and thus represent "OR" logic. Any one of them can supply the heat demand signal. The electrical signal passing through these contacts is supplied from a different power source within the overall control system.

MULTI-ZONE RELAY CENTERS:
Although it's possible to manually wire zone valves or zone circulators in combination with relays to create zoning control, that process can be tedious, especially for systems with many zones. Furthermore, the results can look intimidating to a service technician who is not familiar with the system they are expected to work on, as shown in Figure 7-17.

Figure 7-16

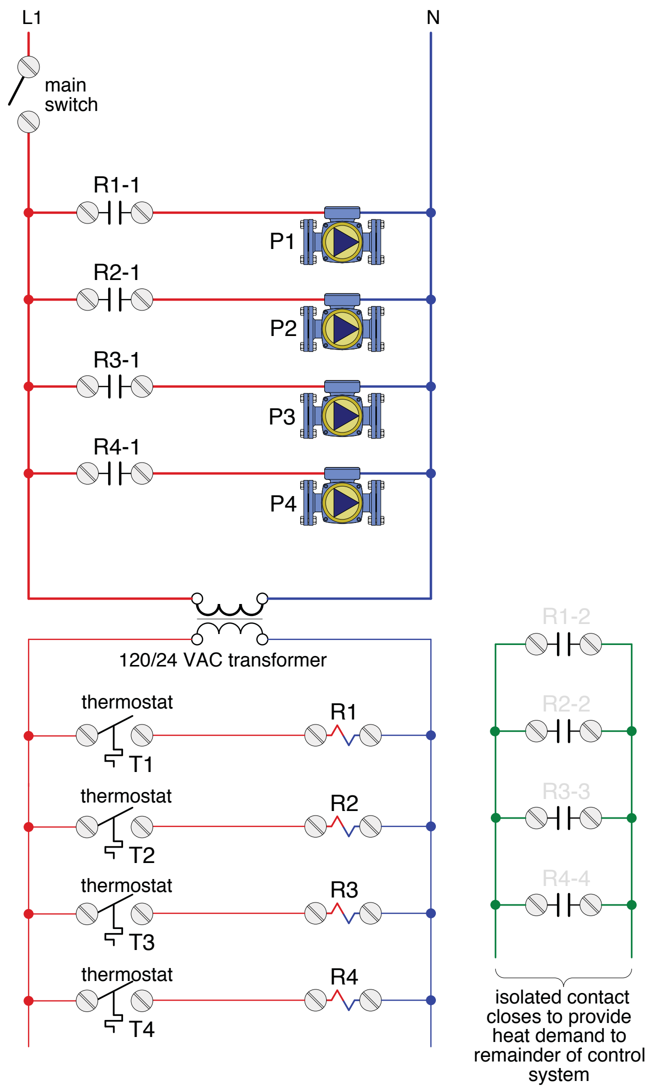
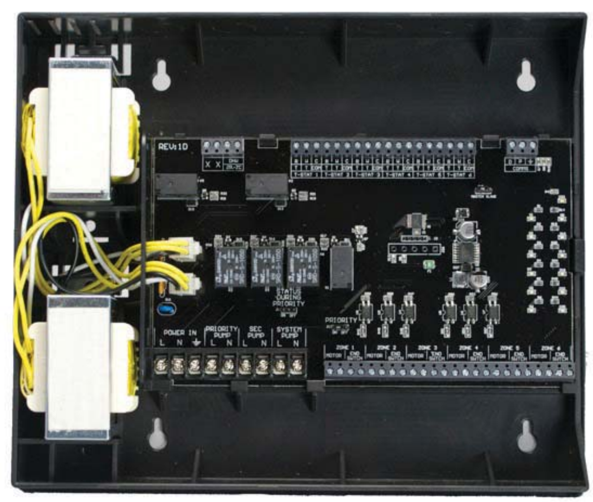


Figure 7-17

Figure 7-18

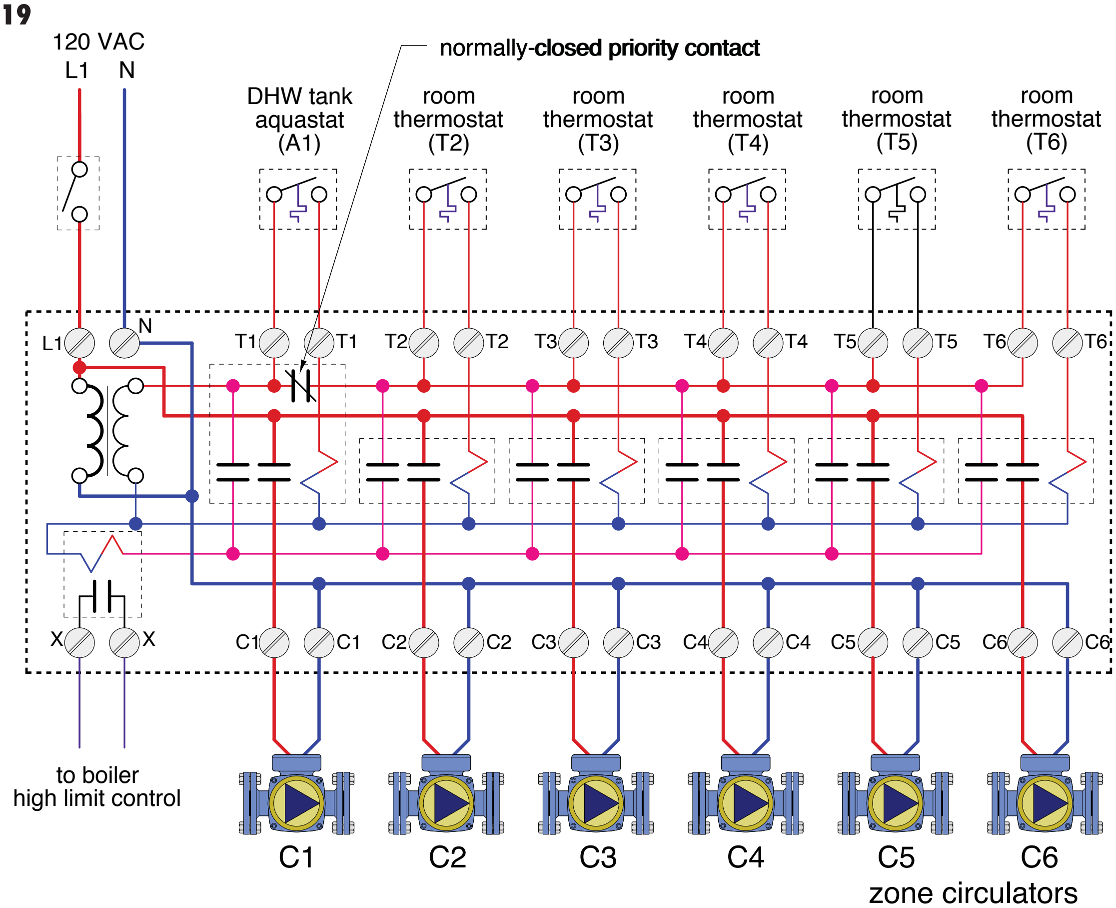


A multi-zone relay center (MZRC) is a modern solution to hydronic zone control that minimizes field wiring, avoids clutter and provides all the necessary zone control functions. MZRCs are available for systems using zone valves or zone circulators, in configurations ranging from 3 to 6 zones. Some models can be electrically linked for systems that require more than 6 zones.

Figure 7-18 shows an interior view of a multi-zone relay center designed for up to 6 zone valves.

The terminals at the top center of the printed circuit board are for thermostat connections. Some MZRCs provide two terminals for each thermostat. They are usually marked “R” and “W.” Other MZRCs provide *three* terminals for each thermostat. They are usually marked “R,” “W” and “C.” The “C” terminal connects to the common side of the 24 VAC transformer within the MZRC. This terminal allows thermostats that require an external 24 VAC power source to be powered from the MZRC. Many modern thermostats using microprocessor circuits require this external power supply. Thermostats with internal batteries usually do not require external power. If the thermostat used only requires two wires, it would connect to the “R” and “W” terminals, and the “C” terminal would remain unconnected.

Figure 7-19



When a zone thermostat calls for heat, a relay within the MZRC is turned on. In systems using zone circulators, this relay provides a line voltage output to operate the associated zone circulator. In systems using zone valves, a 24 VAC output is turned on to operate the associated zone valve. The line voltage connections for zone circulators, or 24 VAC connections for zone valves, are typically located along the lower edge of the controller.

Another relay within a MZRC provides an electrically isolated contact closure that can signal other equipment that a heat demand is present. The connections for this isolated contact are usually designated “X X.” This contact closes *whenever any one or more of the zone thermostats call for heat.* In most systems, this contact is used to turn on the heat source. It can also be wired to turn on a mixing controller, outdoor reset controller or other component(s) in the system.

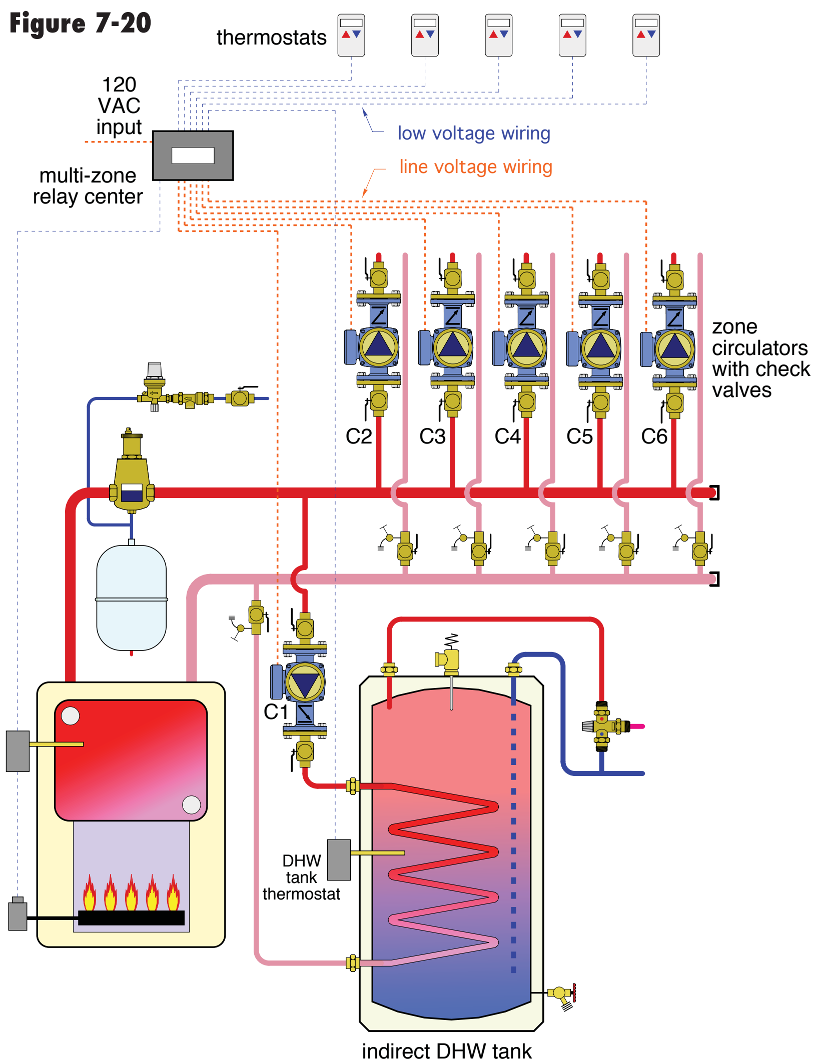
Figure 7-19 shows the conceptual wiring of a six-zone relay center for use with zone circulators. Five of the zones provide space heating, while the remaining zone provides domestic water heating through an indirect storage water heater. This basic schematic does not include some of the additional features available in many currently available MZRCs.

Figure 7-20 shows the piping schematic of the system represented in Figure 7-19. Notice that wiring from all the space-heating thermostats, along with that from the aquastat for domestic water heating, is routed to the MZRC. All the line voltage wiring to operate the six circulators is also routed to the MZRC.

PRIORITY ZONES:

One of the zone outputs in modern multi-zone relay centers can be configured as a priority zone. When this configuration is selected, all other “non-priority” zones are temporarily turned off whenever the priority zone is operating. This allows the full output of the heat source to be available to the load connected to the priority zone. The most common application for a priority zone is domestic water heating. Since the full boiler capacity can be directed to domestic water heating, hot water is produced quickly.

Figure 7-20



This is very desirable in applications that have large demands for domestic hot water.

Most currently available multi-zone relay centers also have a priority override feature. This allows the priority zone to be the only active zone for up to some maximum allowed time, such as one hour. If the priority zone is still active after this allowed time, any other zones that are calling for heat at the time are turned back on. This feature prevents a possible freeze up of an inactive zone circuit should the priority zone fail in the active mode (and thus prevent the other zones from operating).

CALEFFI MULTI-ZONE RELAY CENTERS:

Figure 7-21 shows a typically residential or light commercial hydronic system that provides space heating and domestic hot water, and uses four zone valves for zoning. Domestic water is heated using an indirect water heater supplied from the boiler by a separate circulator. Flow to the space-heating distribution system is provided by a variable-speed pressure-regulated circulator.

Figure 7-22 shows how the Caleffi ZVR106 multi-zone relay center would be wired for this system.

Figure 7-21

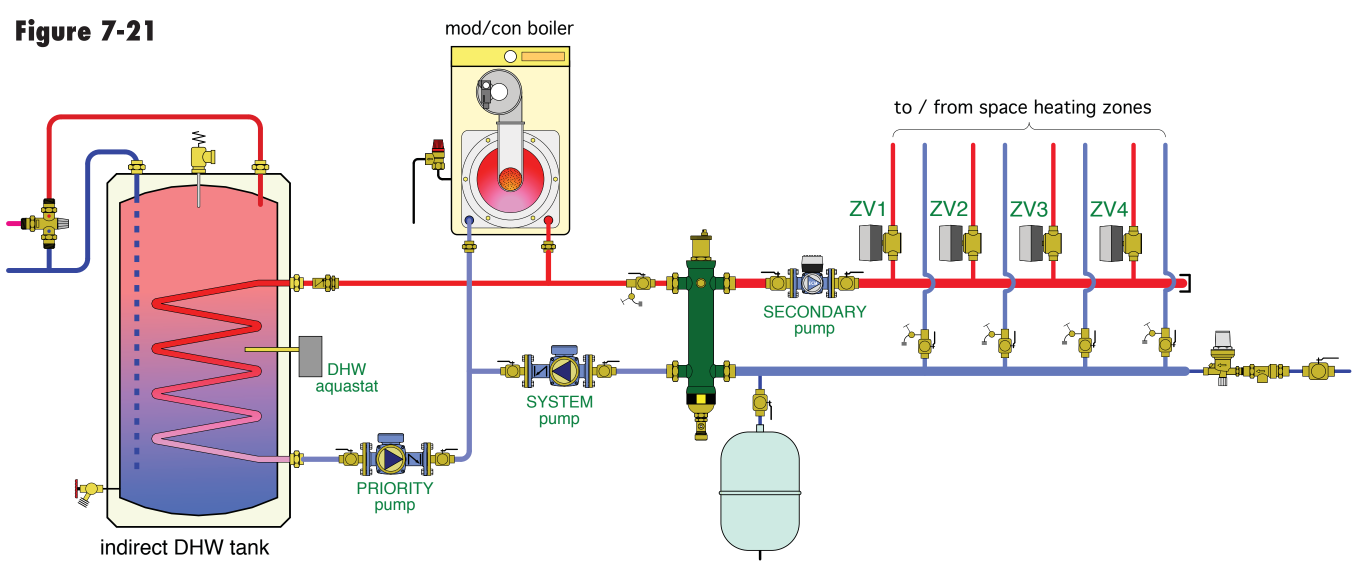
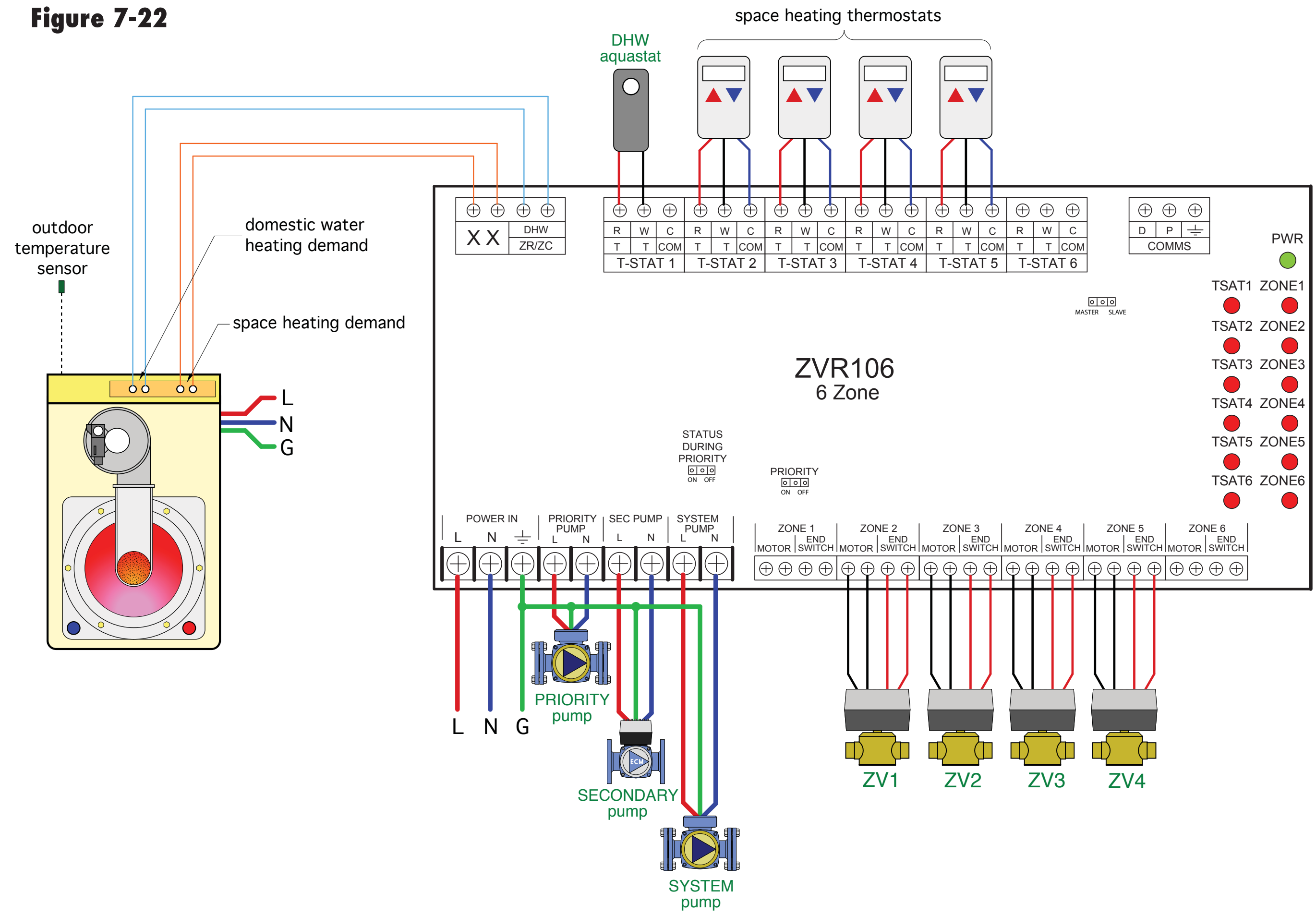


Figure 7-22



The DHW aquastat, which is a thermostat that measures water temperature inside the storage tank, determines when the indirect water heater requires heat. It is connected to the T-STAT terminals on the ZVR106. This aquastat provides a dry contact closure when the DHW tank requires heating. The ZVR106 responds in two ways: 1. It turns on the “priority circulator” to create flow between the boiler and indirect water heater. 2. A dry contact within the ZVR106 closes between the ZR and ZC terminals. This closure is interpreted by the boiler as a “DHW demand.” In its DHW heating mode, the boiler fires and targets a leaving water temperature set on its internal controls for this mode of operation. This temperature is usually higher than the boiler outlet temperature during space heating. Typical values would be 150–180ºF.

If the jumper on the ZVR106 is set so that zone 1 operates as the priority zone, any active space-heating zone valves are temporarily turned off, as are the system pump and secondary pump. If priority mode is *not* selected, any space-heating zones that were active when zone 1 is turned on will remain active, as would the system pump and secondary pump.

Upon a call for space heating from any thermostat, the ZVR106 multi-zone relay center provides three actions: 1. It supplies 24 VAC to turn on the associated zone valve. 2. A dry contact closes between the (X X) terminals. 3. 120 VAC is supplied to turn on the system pump and secondary pump.

The dry contact closure between the (X X) terminals signals the boiler that a space heating demand is present. This allows the boiler to operate in space-heating mode, where supply water temperature is usually based on outdoor reset control.

The system pump creates flow between the boiler and hydraulic separator. The secondary pump creates flow from the hydraulic separator through all the active zone circuits. In the system shown in Figure 7-21, the secondary pump is a variable-speed pressure-regulated circulator, which automatically adjusts flow based on the status of the zone valves. As more zone valves open, the circulator speed increases to maintain a stable differential pressure between the supply and return headers. This stabilizes the flow rate in the active zone circuits, regardless of how many zones are active.

The status lights on the right side of the ZVR turn green to indicate a call from any of the thermostats or the DHW aquastat. They also turn green to indicate an active status on any of the zone valves.

Figure 7-23

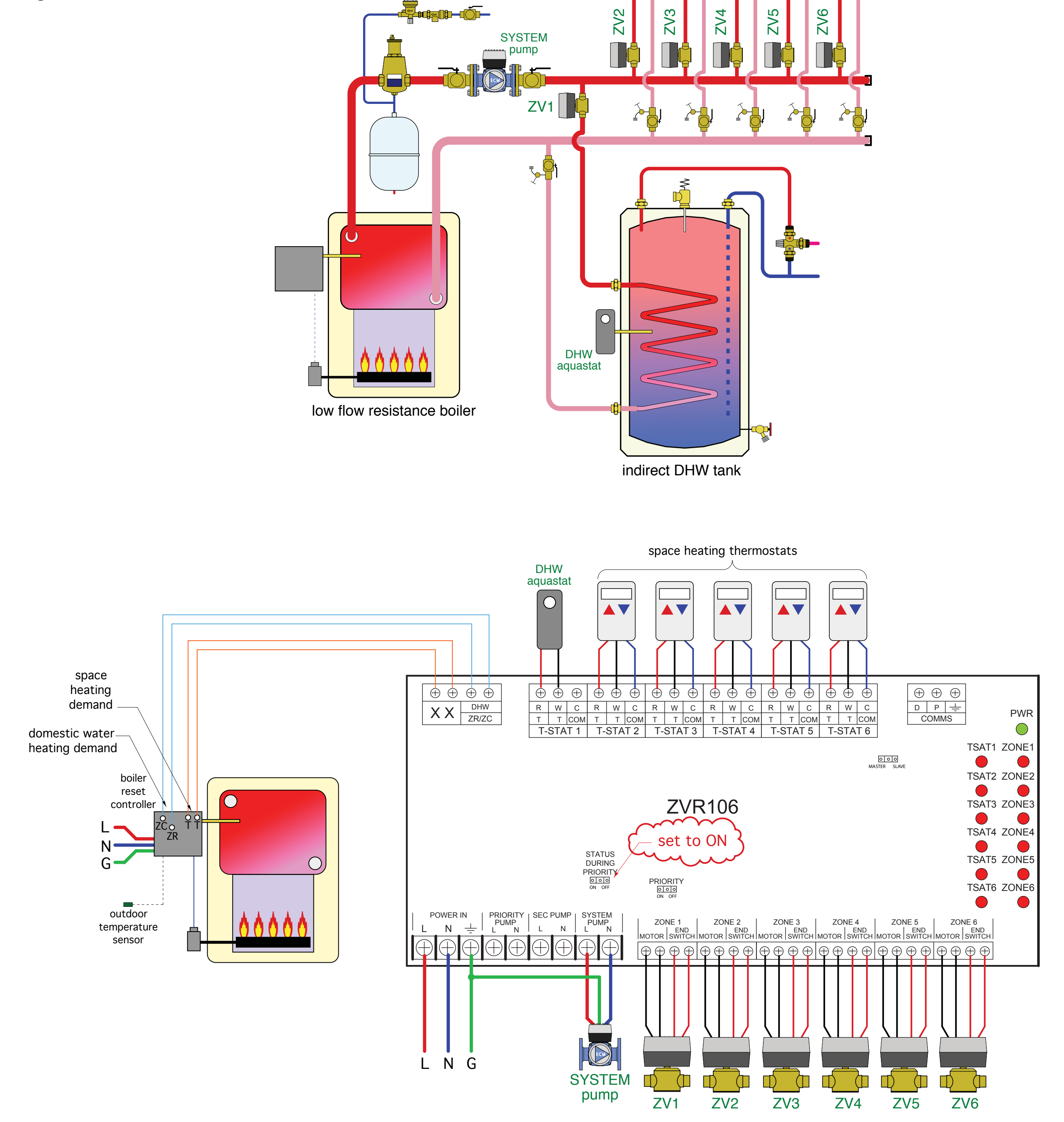
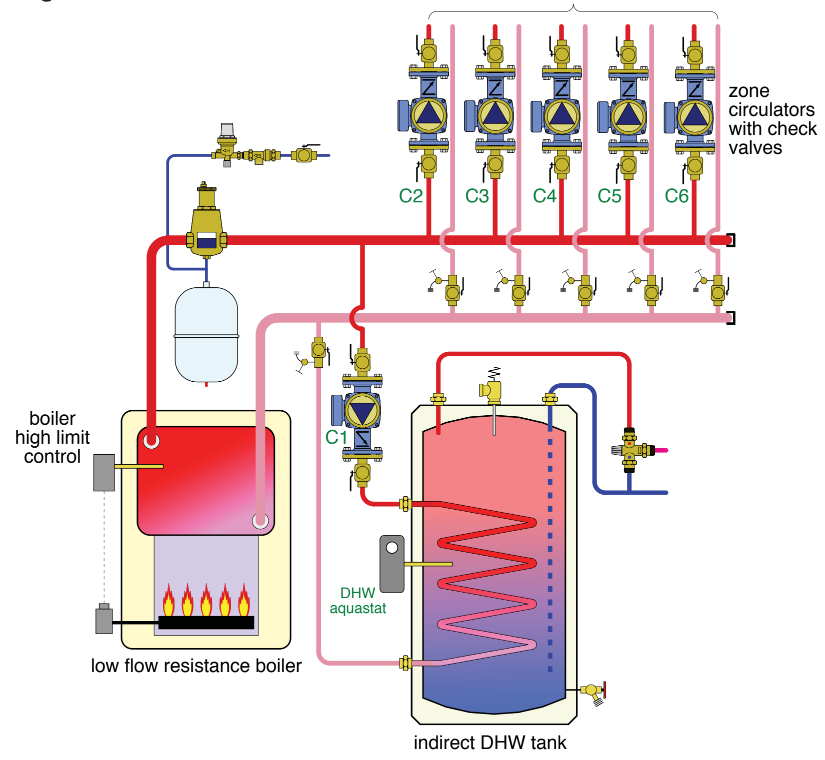


Figure 7-24



Some modern boilers contain internal controls that can operate the circulator between the boiler and the indirect water heater (e.g., the "priority pump"), as well as the circulator between the boiler and means of hydraulic separation (e.g., the "system pump") and the distribution circulator (e.g., the "secondary pump'). In such cases, it is not necessary to wire these circulators to the multi-zone relay center.

It is also possible to use a Caleffi ZVR multi-zone relay center to operate a priority load, such as domestic water heating. Figure 7-23 shows a configuration with a conventional (low flow resistance) boiler and a single circulator. The indirect water heater is the priority load. When the aquastat in the water heater calls for heat, the system circulator is turned on, zone valve (ZV1) opens, and an isolated contact between the ZR and ZC terminal in the ZVR multi-zone relay center closes. The latter tells the boiler to operate in domestic water mode, during which it ignores outdoor temperature and targets a fixed upper temperature limit.

Once activated, the priority zone is allowed to be the only zone operating for up to 60 minutes. If, at the end of that period, the priority load is still active, the Caleffi ZVR checks to see if any of the other zones are calling for heat. If they are, those zones are turned back on. If none of the other zones are calling for heat, the priority zone is allowed to remain active, as the only load, for another 60 minutes. This cycle repeats based on the same logic.

Figure 7-24 shows a multi-zone hydronic system using zone circulators. Zone 1 supplies an indirect water heater. Zones 2 through 6 are for space heating. The boiler uses a standard high limit controller (e.g., the boiler controller does not have outdoor reset control capabilities). This type of controller is very common on older gas-fired and oil-fired boilers.

Figure 7-25 shows how a Caleffi ZSR106 multi-zone relay center would be wired for this system.

As in the previous system, the DHW aquastat determines when the indirect water heater requires heat. It is connected to the T-STAT 1 terminals on the ZSR106. This aquastat provides a dry contact closure when the DHW tank requires heating. The ZSR106 responds in two ways: 1. It turns on circulator (C1). 2. A dry contact within the ZSR106 closes between the (X X) terminals, which enables the boiler to fire. If the current boiler temperature is lower than its setpoint temperature minus a differential, the burner fires and remains on until either the boiler reaches the temperature setting of its high limit controllers or the heat demand is removed.

If the DIP switch on the ZSR106 is set for priority operation of zone 1, any active space-heating circulators are temporarily turned off. If priority mode is not selected, any space-heating circulators that were active when zone 1 turned on will remain on.

Notice that the ZR/ZC terminals on the ZSR106 multi-zone relay center are not used in this application. This is because a standard boiler high limit controller does not distinguish between a call for space-heating operation versus one for domestic heating. Instead, it simply enables the boiler to fire when any type of heat demand is detected.

In the United States, federal regulations now require all new boilers, both conventional and those designed for condensing mode operation, to be equipped with a *means of control that ensures that any change in "inferred load" creates a corresponding change in supply water*

Figure 7-25

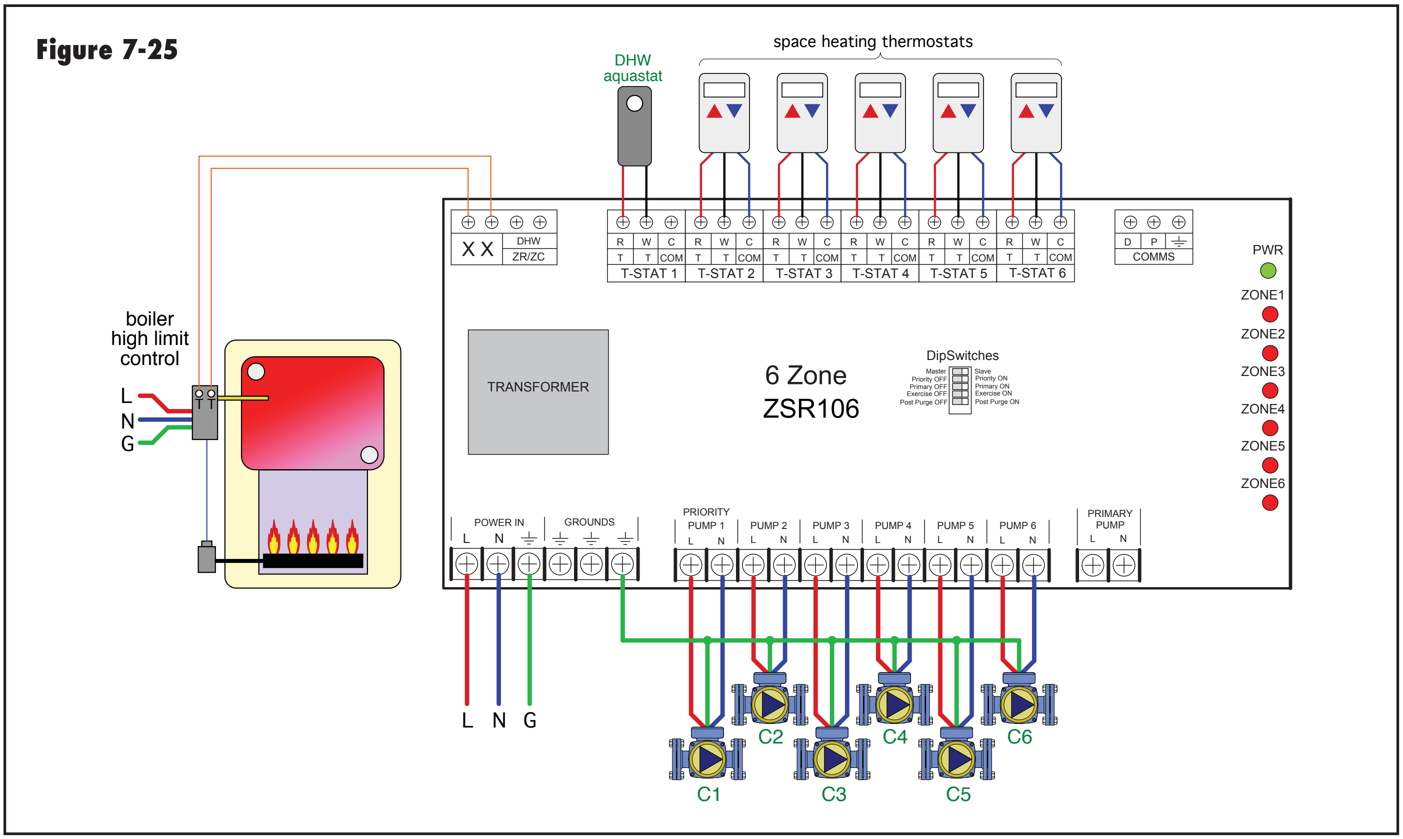
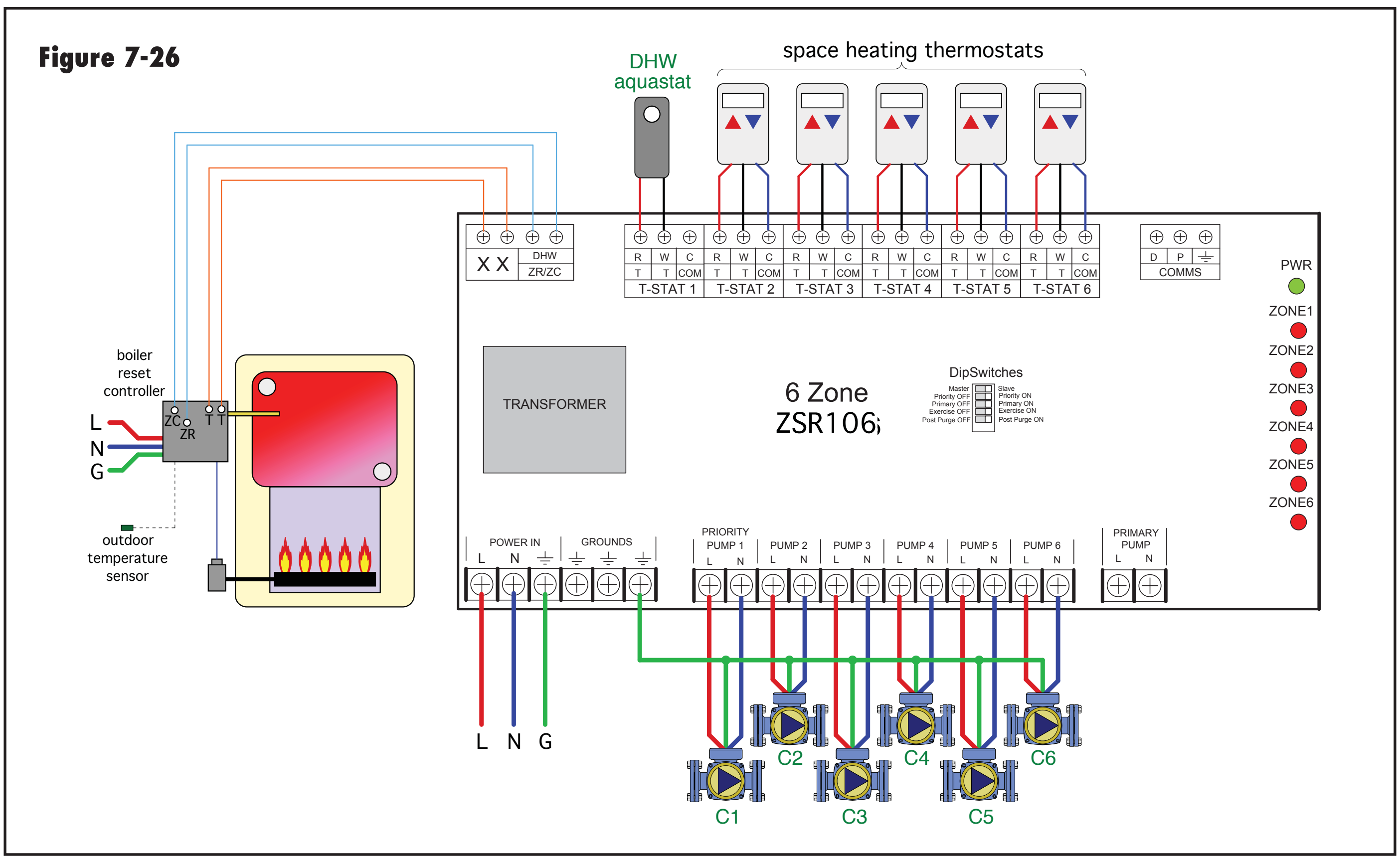


Figure 7-26



temperature. Furthermore, the boiler's burner is not allowed to fire until the means of control confirms that the inferred load cannot be met using residual heat in the boiler. In most cases, these requirements are met by incorporating an outdoor reset controller into the boiler. However, during a call for domestic water heating, the boiler's controller will ignore the outdoor temperature, and instead target a higher setpoint temperature that allows for high rates of heat transfer through the heat exchanger in the indirect water heater. Thus, new boiler controllers must distinguish between a call for space heating and a call for domestic water heating.

The Caleffi multi-zone relay centers can accommodate these differences. If the boiler has its own reset controller or other type of controller that distinguishes between a call for space heating and a call for domestic water heating, the following terminals would be used: 1. A dry contact within the multi-zone relay center closes between the (X X) terminals to indicate a *space-heating demand*. 2. A dry contact within the multi-zone relay center closes between the ZR and ZC terminal to indicate a *domestic water-heating demand*. The contact closure between ZR and ZC can also be used to signal a heat demand for other loads for which the boiler should operate at a fixed setpoint rather than under outdoor reset control. Snowmelting and pool heating are two examples of such loads. They are typically supplied through heat exchangers, and those heat exchangers are usually sized based on a fixed supply water temperature from the boiler. If necessary, the contact between the ZR and ZC terminals of the Caleffi multi-zone relay centers can switch a 120 VAC circuit passing up to 2 amps.

Figure 7-26 shows how the wiring of Figure 7-25 would be modified to accommodate this type of boiler controller.

Caleffi multi-zone relay centers also provide an option to "exercise" the system's circulators if desired. Circulator exercising is intended to prevent circulators from "ceasing," and thus not starting, if they have remained inactive for long periods of time. If the exercise mode is enabled, each circulator is turned on for 30 seconds following 72 hours of inactivity. This feature is automatically enabled on the Caleffi ZSR multi-zone relay center for circulators and is selectable on the ZVR multi-zone relay center for zone valves.

The Caleffi ZSR multi-zone relay center for zone circulators also provides an option that allows the priority circulator to continue operating for 2 minutes after the aquastat calling for the priority zone to operate has opened its contacts. This "post purge" feature allows some of the residual heat in the boiler to be captured and transferred to the water in an indirect water heater.

ZONING WITH 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 TRVs). Such valves require no wired electrical power or batteries, and provide silent operation.

Thermostatic radiator valves consist of a valve body and non-electric thermostatic operator, as shown in Figure 7-27.

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 the operator. In others, it's generated by the thermal expansion of a liquid within a sealed bellows. In either case, the force generated pushes inward on the valve's spring-loaded shaft. This brings the valve's disc closer to the seat, and thus reduces flow. If necessary, the operator can completely close the valve to prevent any flow through its associated heat emitter.

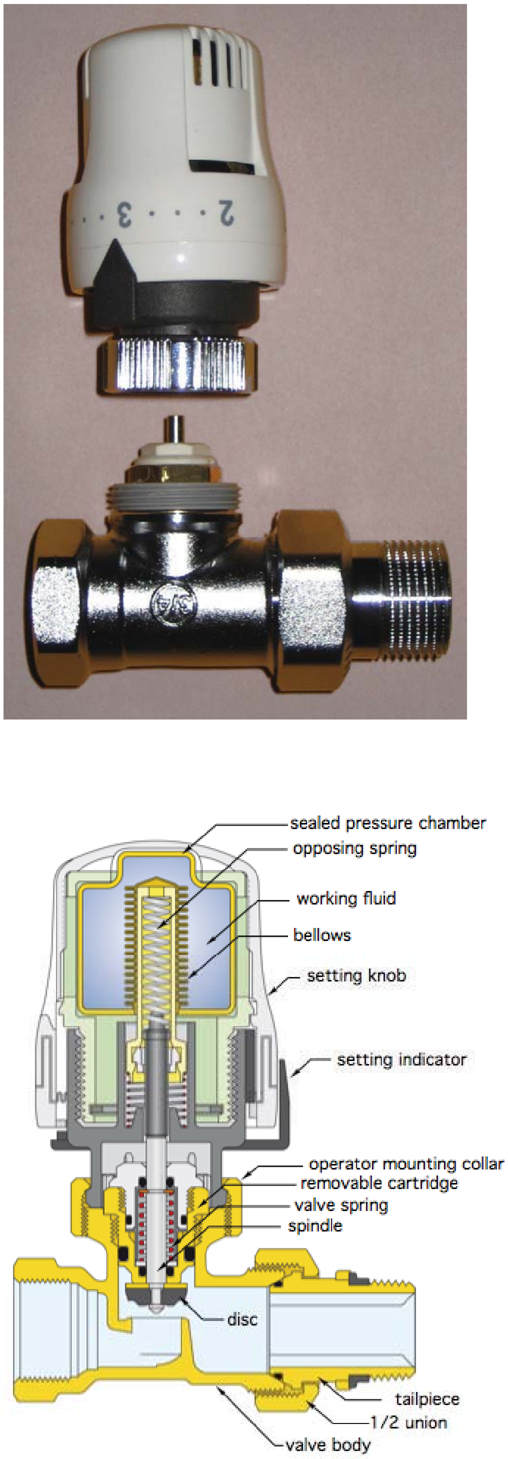
Thermostatic radiator valves are adjusted similarly to knob-type room thermostats. The outer portion of the operator is a knob. It can be manually rotated to select the desired comfort level for the zone. Rather than temperature settings, the knob has numbers from 1 to 5 as relative indicators of comfort. 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's 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 electric manifold valve actuators, thermostatic radiator valves are *modulating* devices. They adjust 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.

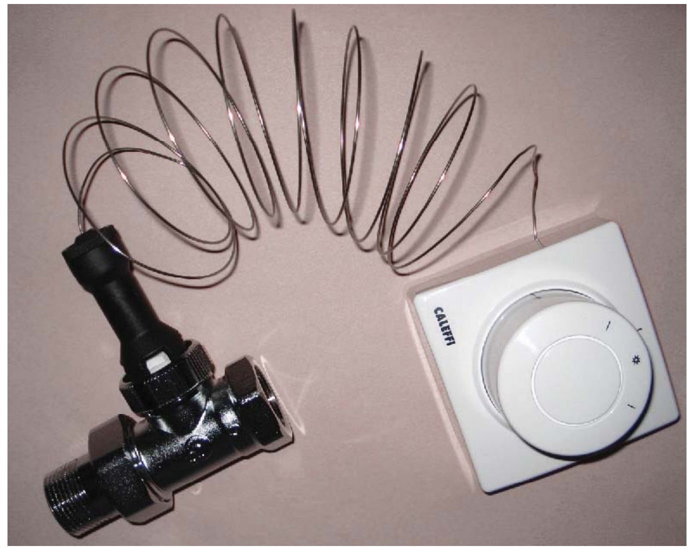
There are many different types of radiator valves and thermostatic operators. One of the most common is a manually adjusted knob/operator assembly that fastens

Figure 7-27



directly to a 2-way spring-loaded valve, as shown in Figure 7-27. 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 above the heat emitter goes

Figure 7-28



directlypast the operator. This would 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.

Thermostatically operated valves are also available with a remote setting dial that connects to the operator with a capillary tube, as shown in Figure 7-28.

The capillary tube conveys fluid between the remote setting dial and the operator to effect movement of the valve's shaft. This type of operator allows adjustments of room temperature from the same nominal wall height as would be typical for an electric thermostat. Assemblies with capillary tubes up to 6.5 feet long are available. It is important not to cut or severely kink the capillary tube when this type of thermostatic operator is installed.

Thermostatic operators can also be directly attached to panel radiators that have internal flow regulating valves, as shown in Figure 7-29.

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 radiator's vertical flow 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 7-29

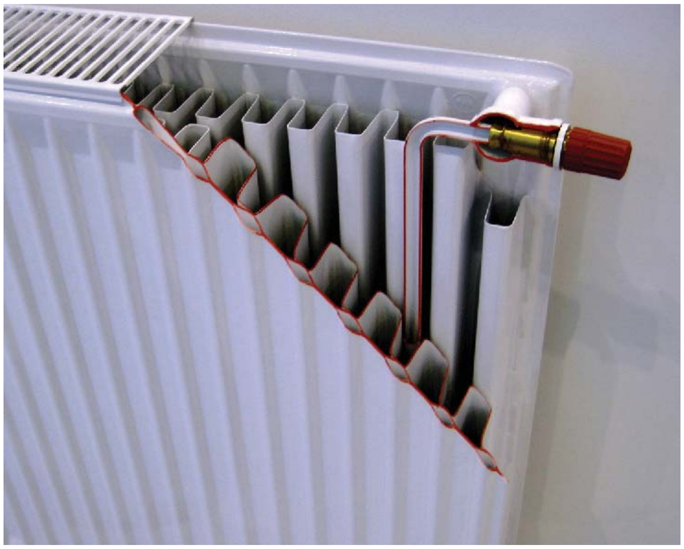


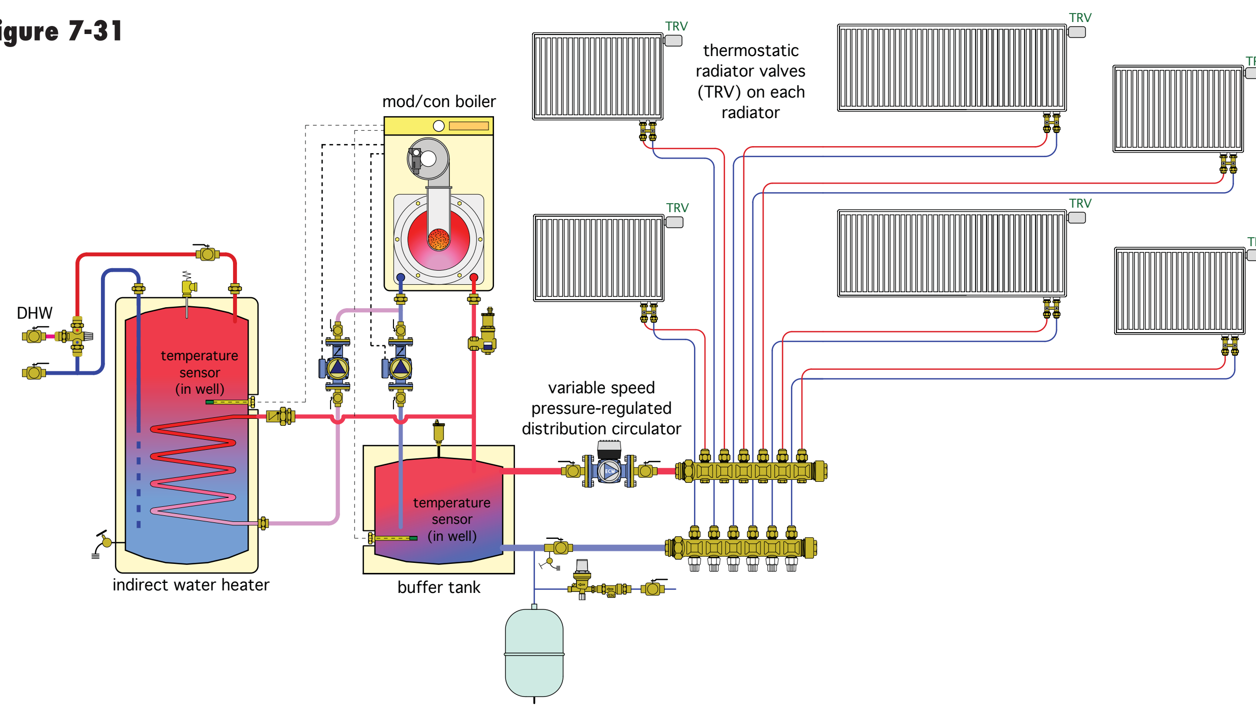
Figure 7-30

This type of radiator is usually supplied with a simple knob that can be used to manually adjust the internal valve. To convert the radiator to thermostatic operation, the original knob is unscrewed and replaced with a thermostatic operator, as shown in Figure 7-30. With this configuration, the radiator's heat output will continually respond to variations in room temperature. It is a simple method for creating room-by-room comfort control.

Figure 7-31 shows a system that includes several panel radiators, each equipped with thermostatic operators. All panel radiators are supplied using a homerun distribution system supplied from a single manifold. Domestic water is supplied by an indirect water heater. The low mass boiler supplies the space-heating circuits through a small (25-gallon) buffer tank. The latter prevents the boiler from short cycling when the load imposed by the distribution system is very small. This buffer tank also provides hydraulic separation between the boiler circulator and variable-speed pressure-regulated distribution circulator.

This system takes advantage of the control functions built into several current generation mod/con boilers. These include the ability to:

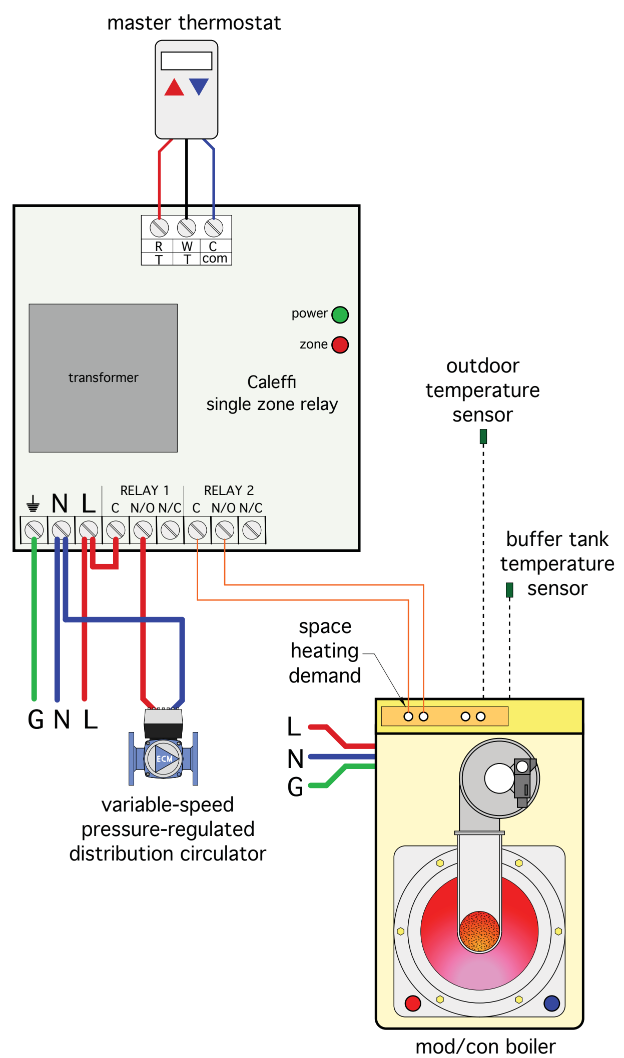
Figure 7-31



1. Power both the domestic hot water circulator and the boiler circulator.
2. Directly sense and control the temperature of the domestic hot water tank.
3. Directly sense and control the temperature of the buffer tank.
4. Provide priority control for domestic water heating.

The remaining control function is to supply line voltage to the pressure-regulated distribution circulator and "tell" the boiler to operate in space-heating mode whenever the building requires heat. In addtion to the functions listed above, some modern boilers can provide a line voltage output to operate the distribution circulator whenever the outdoor temperature drops below some minimum value.

Figure 7-32



For boilers that don't include this function, the Caleffi single zone relay, in combination with an interior master thermostat, can provide this control action, as shown in Figure 7-32.

The single zone relay is operated by a low voltage master thermostat. This thermostat should be located at a central location within the building and away from interior heat sources or areas subject to solar heat gain. It is typically set 1° or 2°F above the normal desired interior air temperature. When the contacts in the master thermostat close, the single zone relay supplies power to the distribution circulator. It starts up and adjusts its speed to maintain a constant differential pressure, regardless of how many thermostat radiator valves are open or partially open. Another set of isolated contacts in the single zone relay close to provide a space-heating demand signal to the boiler. The boiler fires and operates to maintain an acceptable supply water temperature within the buffer tank. That temperature is based on the settings of the boiler's internal outdoor reset controller.

If a demand for domestic water heating occurs, and the boiler's internal controls are set for DHW priority, the circulator between the boiler and buffer tank is turned off, and the circulator to the indirect water heater is turned on. The boiler targets a temperature based on how its internal controls are set for the domestic water-heating mode. The space-heating circulator can continue to operate during this mode, dispersing the heated water in the buffer tank to the distribution system.

8. OTHER ELECTRICALLY BASED CONTROLLERS

This section discusses several electrically based controllers that are commonly used in residential and light commercial hydronic systems. Some of these devices are mandated into the system by code. Others are selected for specific control requirements. All hydronic system designers and technicians should be familiar with these devices.

HIGH LIMIT SWITCHING RELAY:

Because many smaller hydronic systems use a single boiler, single circulator and single room thermostat, they have virtually identical control requirements. The similarity of these systems allows manufacturers to design a specialized controller that coordinates the operation of all these components. That device is called a high limit switching relay controller, or sometimes just a "high limit controller." Manufacturers of packaged boilers often equip those boilers with this type of controller, and usually prewire it to both the burner and circulator. Figure 8-1 shows an example of a high limit switching relay controller mounted to the top of a boiler. Figure 8-2 shows the internal components of this controller. Figure 8-3 shows the schematic representation of a high limit/switching relay.

Figure 8-1

This controller integrates a 120/24 VAC transformer, relay and capillary-type thermal switch into a small case that mounts directly to the boiler. The temperature-sensing bulb extends from the rear of the controller. It is inserted into an immersion well that is threaded into the top or side of the boiler, as illustrated in Figure 8-4.

The immersion well allows the sensing bulb to "feel" a temperature that is very close to that of the fluid surrounding the well. The well is usually made of copper for good thermal conductivity. The sensing bulb must be coated with a special thermal grease before it is inserted into the well. This reduces the thermal resistance caused by air gaps between the outside of the sensing bulb and the inside of the well. The lower this resistance, the lower the difference between the temperature of the fluid outside the well and the temperature felt by the sensor bulb.

Figure 8-2

Courtesy of Honeywell

Figure 8-3

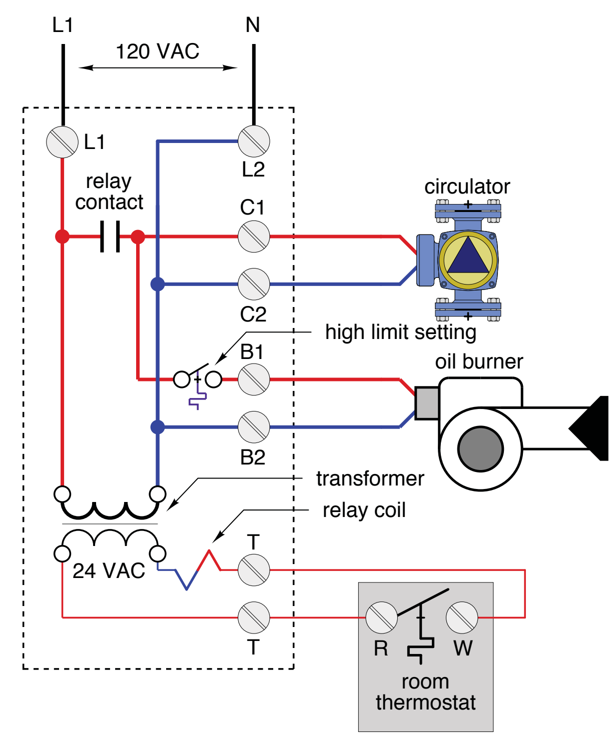
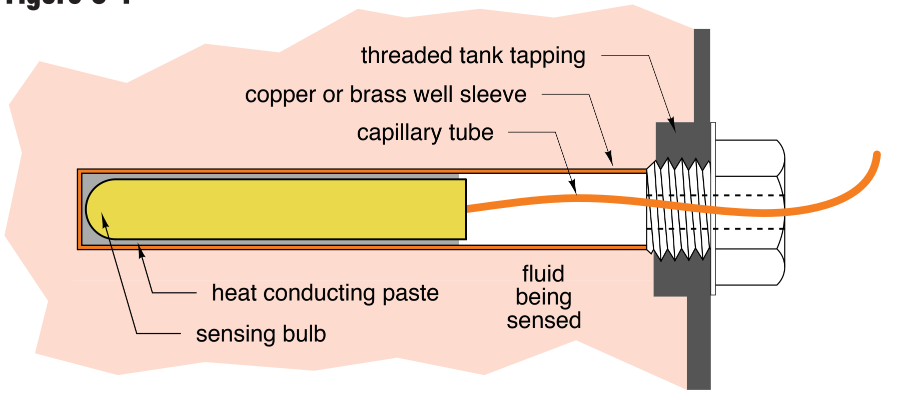


Figure 8-4



A high limit switching relay controller operates as follows:

1. Whenever line voltage is supplied to the controller, its internal transformer is activated. 24 VAC is present at one of the two terminals marked T in Figure 8-3. That terminal is connected to the (R) terminal of the room thermostat.

2. When the room thermostat calls for heat, its contacts closes, passing 24 VAC through the thermostat and back to the controller. This energizes the relay within the controller.

3. The relay contacts close to supply line voltage to the system circulator.

4. If the boiler is cool, the thermostatic assembly in the high limit controller will have the contacts that operate the burner in the closed position, and the burner will fire. If the boiler temperature is already at, or close to, the high limit setting of the controller, the burner contacts will be open, and the burner remains off.

5. *If and when* the boiler temperature climbs to the high limit setting, the thermostatic element opens the burner relay contacts, turning off the burner. The circulator continues to operate, provided that the room thermostat is still calling for heat.

6. Assuming the demand from the room thermostat continues, the water temperature within the boiler will cool as heat is dissipated by the heat emitters. When the boiler temperature decreases by a specific differential below the high limit setting (usually about 8°F), the burner is turned back on. This cycling of the burner will continue as long as the room thermostat is calling for heat.

7. When the room thermostat is satisfied, its contacts open and the 24 VAC circuit through the relay coil in the controller is interrupted. The burner and circulator are both turned off.

MANUAL RESET HIGH LIMIT:
Many mechanical codes, especially those applicable to public buildings, require a redundant temperature-limiting controller on all boilers. This controller must be capable of turning off the boiler if the primary operating controller fails in the on mode. Most codes also require that the redundant high limit controller cannot automatically close its contacts once they have opened. The controller designed for this purpose is called a manual reset high limit (MRHL). An example is shown in Figure 8-5.

Figure 8-5

Like a high limit controller, a MRHL controller uses a capillary-type sensing bulb that projects from the rear of its enclosure. The sensing bulb slides into a well that is usually threaded into a tee near the hot water outlet of the boiler. Thus, the MRHL controller senses the water temperature directly downstream from the boiler. Some boilers may also have threaded tapping that allows the sensor well to be mounted directly into the boiler block.

A MRHL controller is typically adjusted so that it will open its normally closed contacts only if the boiler outlet temperature is substantially higher than it would be under normal operation. For example, if the boiler's high limit controller, or outdoor reset controller, might allow the water temperature leaving the boiler to be as high as 180°F under design load conditions, the MRHL might be set to open at 200°F. The objective is to turn off the boiler if a high temperature malfunction occurs, but not create "nuisance trips" if the boiler temperature temporarily drifts a few degrees above normal. Once the contacts in the MRHL open, they must be manually closed by pressing the red button on the front of the controller.

LOW WATER CUTOFF:
Another safety device required on boilers by many codes is a low water cutoff (LWCO). This device detects the presence of water at the end of its probe, which is usually teed into the system's piping. If water is *not* detected, the LWCO opens its electrical contacts to turn off the boiler. The objective is to prevent the burner from operating if the boiler does not contain water within its heat exchanger. Such a situation is extremely dangerous and has resulted in boiler explosions before LWCO controllers were widely required; hence the code-mandated use of a LWCO device in modern systems.

Some boilers use an external LWCO, such as shown in Figure 8-6.

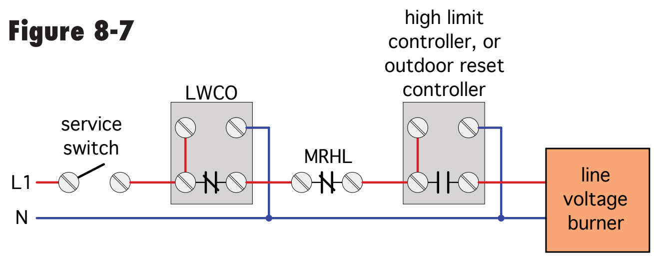
Figure 8-6

This type of LWCO is usually located close to the boiler's hot water outlet. The water-detecting probe is mounted into a tee. The electronics within the LWCO are powered by either 120 VAC or 24 VAC. The LWCO passes a very low electrical current through the water between the two electrodes on its probe. If water is *not* detected over an elapsed time of a few seconds, the LWCO opens a set of contacts to turn off the boiler. The slight time delay allows for momentary passage of an air bubble past the probe without tripping off the burner.

Some modern boilers come equipped with internal LWCO devices. Some work based on detecting the presence of water, others by detecting low system pressures. Designers should always verify that the type of LWCO used in the system is accepted by local mechanical codes.

As a general guideline (but subject to specific code requirements), the main operating controller of the boiler (i.e., the high limit switching relay or a boiler reset controller) would be wired in series with both the MRHL and LWCO safety devices. A service switch that controls all electrical power supplied to the boiler would also be wired in series with these safety devices and the main operating controller, as shown in Figure 8-7. This configuration allows any of the controllers or safety devices to stop the burner if an abnormal condition occurs.

Figure 8-7



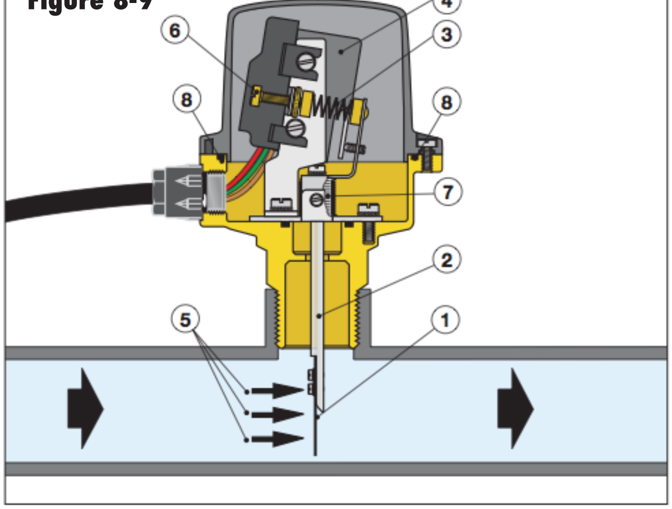
FLOW SWITCHES:
Some equipment used in hydronic systems can be damaged if heat is generated within the system, but there is no water flow to carry that heat away from the equipment. For example, the finned-copper tube heat exchanger used in some boilers can be highly stressed if no water is flowing through the boiler when its burner is firing. In hydronic cooling systems, flat plate refrigerant-to-water heat exchangers that serve as the evaporator for a refrigeration cycle can quickly freeze and potentially burst if there is insufficient flow through the water side of the heat exchanger as refrigerant is evaporating on the other side.

Figure 8-8

One method of protecting "flow-sensitive" hardware is to install a flow switch and wire it so that an insufficient flow rate causes the switch to turn off the heating or cooling source before any equipment could be damaged. Figure 8-8 shows an example of a flow switch. Figure 8-9 shows its internal construction.

The flow switch is composed of a blade (1) fastened to a control rod (2) connected at the top to an adjustable counter spring (3). This assembly pivots when the

Figure 8-9

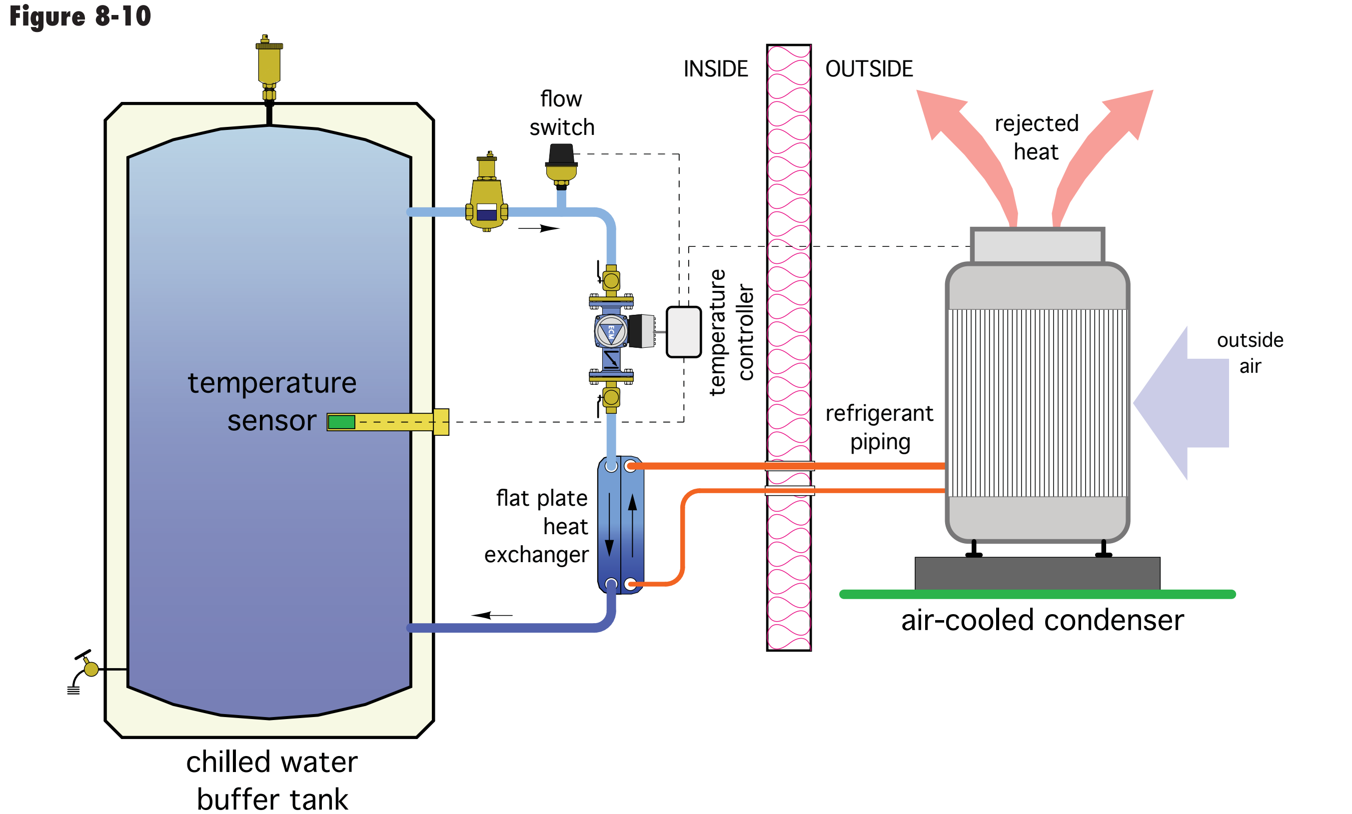


flow rate past the blade reaches or exceeds the set closing value. The pivoting action operates a microswitch contained in a protective casing (4). At rest, the counter spring keeps the microswitch contact open. When flow decreases to the adjustable opening value, the internal spring force overcomes the fluid thrust against the blade and the microswitch contacts open. The flow rates for closing (increasing flow) and opening (decreasing flow) can be modified by means of the adjusting screw (6). A stainless steel bellows (7) separates the electric and the hydraulic parts, preventing any contact between the fluid and the electric components. The blade of the Caleffi flow switch shown in Figures 8-8 and 8-9 can be changed to accommodate pipe sizes ranging from 1 to 8 inches.

Figure 8-10 shows how a flow switch should be located between a chilled-water buffer tank and water-to-refrigerant heat exchanger serving as the evaporator.

The flow switch should be adjusted to detect a minimum acceptable water flow rate through the heat exchanger. A typical control sequence for this system would be as follows: 1. A temperature setpoint controller determines when the chilled-water buffer tank requires cooling and closes its electrical contacts in response. 2. A low voltage control signal passes through these contacts to a relay that turns on the circulator to create water flow through the evaporator. 3. The electrical contacts within the flow switch close when a sufficient flow rate is established through the flat plate heat exchanger. 4. The closed contacts in the flow switch complete a low voltage control circuit that allows the refrigeration system to operate. If the flow rate falls below a minimum value, the refrigeration system is immediately turned off.

Figure 8-10



MOTORIZED BALL VALVES:
Several types of motor-operated valves have already been discussed in this issue of idronics. These include mixing valves, diverter valves, zone valves, and manifold valve actuators. Another type of electrically operated valve that can be used in hydronic systems is called a motorized ball valve. Examples of 2-way and 3-way motorized ball valves are shown in Figure 8-11.

Figure 8-11

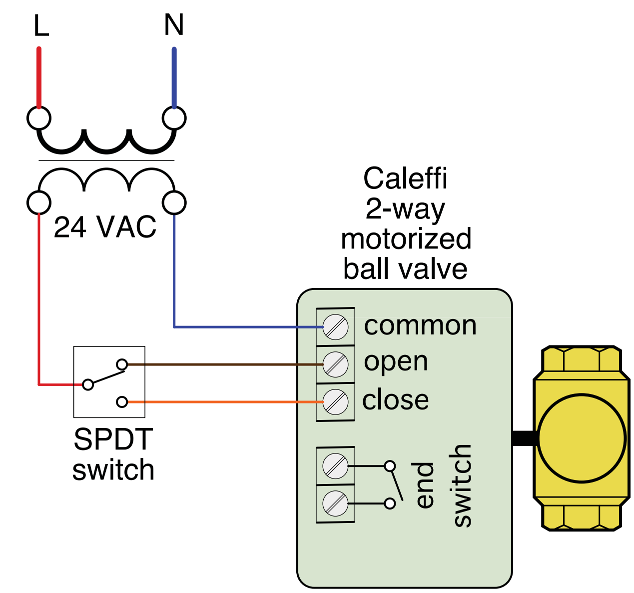
In their fully open position, ball valves create relatively low flow resistance in comparison to other valves of similar size. Thus, motorized ball valves have the advantage of higher flow coefficients (e.g., higher Cv values) in comparison to zone valves of similar size.

Another advantage is that the rotating ball design allows the valve to experience lower differential pressure as it closes compared to a plug & seat type valve. This allows motorized ball valves to close against higher differential pressure relative to other types of valves.

The actuators used on motorized ball valves combine a 24 VAC synchronous motor with a gear train. The latter reduces the rotational speed of the motor so that the shaft of the ball valve turns very slowly, requiring about 40 seconds for 90 degrees of rotation. The gear train also greatly increases the mechanical torque applied to the valve's shaft.

Unlike most zone valves, which are powered open but rely on a spring to close, some motorized ball valves must be powered open and powered close. A typically wiring diagram for such a valve is shown in Figure 8-12.

Figure 8-12

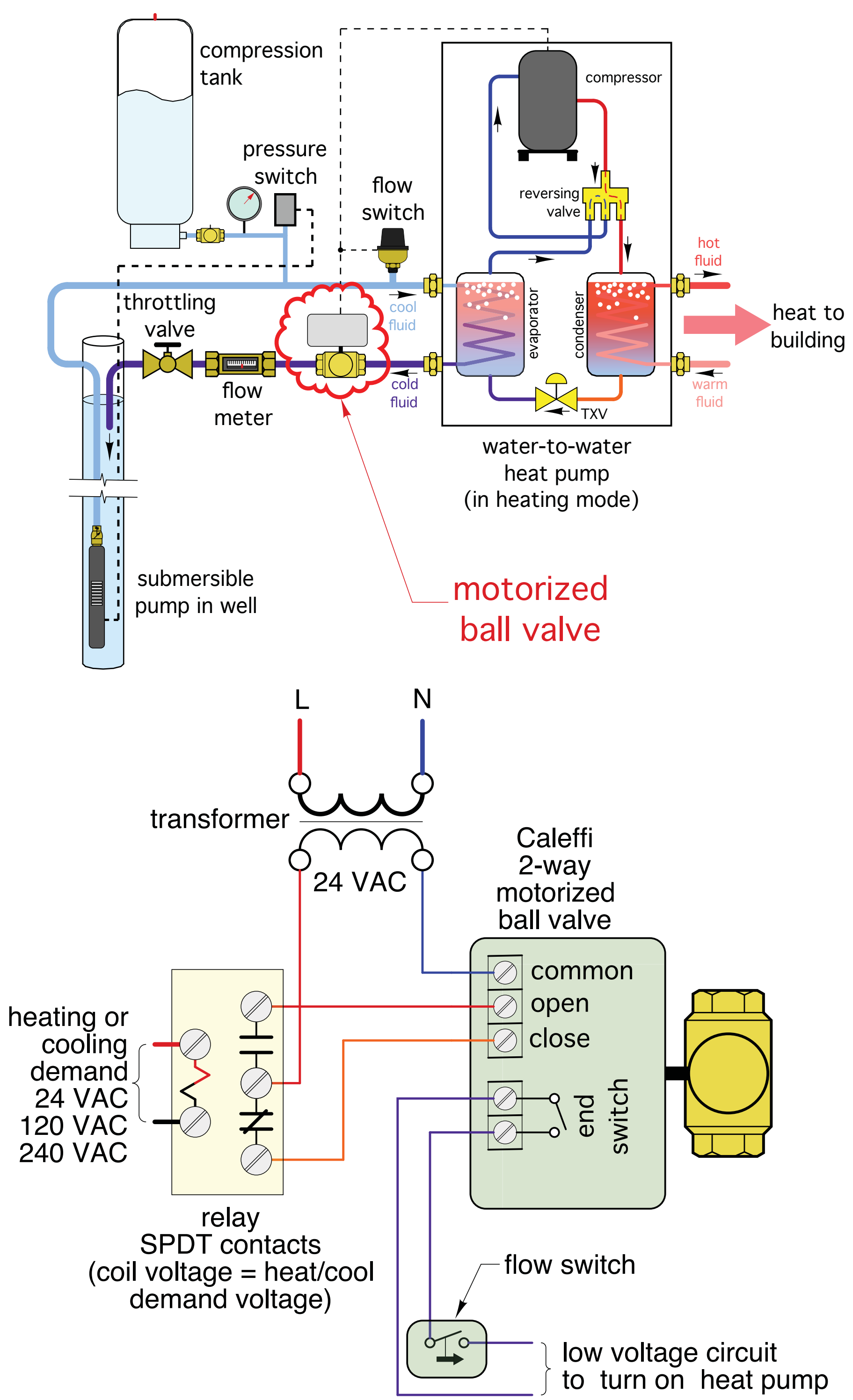


When 24 VAC is applied between a common lead (blue in Figure 8-12), and the open lead (brown in Figure 8-12), the motor operates to open the valve. When the valve reaches about 80% open, an internal microswitch closes. This switch is similar to the end switch in a zone valve. It can be used to signal for operation of other devices in the system. When the valve is fully open, the motor stops turning, even though power is still applied on the open lead. This does not damage the impedance-protected actuator motor.

When 24 VAC power is applied to the close lead (orange in figure 8-12), the actuator motor closes the valve. External controls must be configured so that power cannot be applied to both the open and close terminals at the same time.

Two-way motorized ball valves are used to turn flow on or off. One application that takes advantage of the

Figure 8-13



low flow resistance of the ball valve, along with its ability to close against a potentially high differential pressure, is shown in Figure 8-13.

This open-loop heat pump system uses a 2-way motorized ball valve to start and stop flow of well water through the heat pump. The valve opens when there is a "demand" for heat pump operation in either heating or cooling mode. This demand may be from low voltage circuitry or line voltage circuitry. A relay with a coil voltage that matches the heating or cooling demand voltage connects 24 VAC from a transformer to the open terminal on the ball valve's actuator. As the valve opens, its end switch closes. The end switch is wired in series with the flow switch. This creates hardwired "AND" logic that requires both the end switch and the flow switch to be closed as a prerequisite to turning the heat pump. When the load is satisfied, the relay coil is turned off. Its normally closed contact passes 24 VAC from the transformer to the close terminal on the ball valve's actuator. The valve closes and its end switch opens.

Three-way motorized ball valves can be used for either diverting or bypass applications.

In diverting applications, flow enters the center port (marked as AB) of the 3-way valve shown in Figure 8-14. When the open lead is energized, the ball rotates so that all entering flow leaves through the left side port (marked as A). When the close lead is energized, all entering flow leaves through the right side port (marked as B).

Figure 8-14

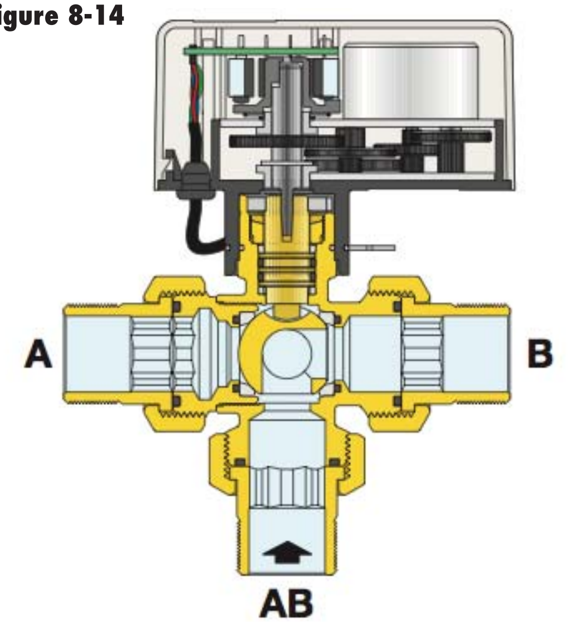


Figure 8-16a

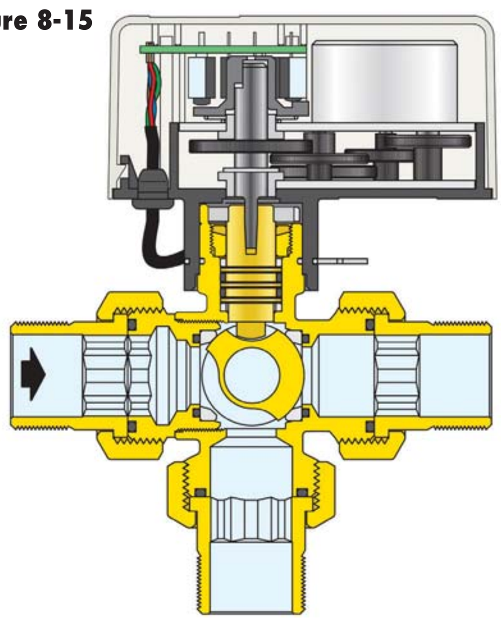
Figure 8-16b

Courtesy of Honeywell

In bypass applications, flow enters the left side port of the 3-way valve, as seen in Figure 8-15. When the open lead is energized, the ball rotates so that all entering flow leaves through the right side port. When the close lead is energized, all entering flow leaves through the bottom port.

TEMPERATURE SETPOINT CONTROLLERS:
Every hydronic system that uses electrical controls has need of devices that can turn a process on or off based on the fluid temperature at some location in the system. One "classic" device for this type of control action is called an aquastat, an example of which is shown in Figure 8-16.

Figure 8-15



Aquastats may contain a single pole, single throw (SPST) switch, or a single pole, double throw (SPDT) switch. If intended for heating applications, the SPST contacts typically open upon a temperature rise at the sensor bulb. The contacts are moved by a bellows type actuator, as illustrated in Figure 8-17.

The sensor bulb and capillary tube that connects this bulb it to the bellows are filled with a fluid that expands when heated. The pressure created by the expanding fluid distorts a thin metal bellows sufficiently to move the electrical contacts together.

Aquastats usually have an adjustable differential ranging from 5–30ºF. On heating aquastats, the differential is typically acting *below* the setpoint temperature. For example, if a heating aquastat is set for 150ºF with a 15ºF differential, the contacts open when the sensor bulb reaches or exceeds 150ºF and close when the sensor bulb temperature drops to 135ºF or less.

The electrical contacts in aquastats are usually rated to carry several amps of current at line voltage. This allows the aquastat to be directly wired to fractional horsepower motors or other line voltage devices. The enclosures of most aquastats provide electrical knockouts for direct connection of line voltage electrical conduit. These contacts can also be used to switch lower voltages.

Figure 8-17

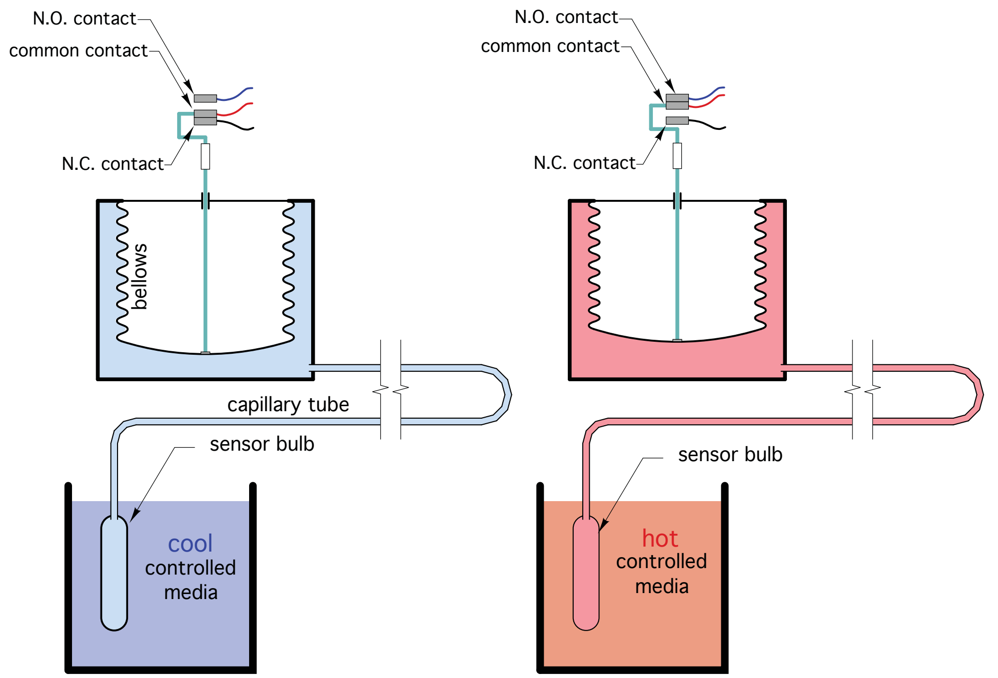


Figure 8-18

Courtesy of White Rogers

Aquastats can be ordered with different length capillary tubes. In some cases, the aquastat is designed to be strapped directly to a pipe, with its sensor bulb sandwiched between the pipe surface and the aquastat enclosure. This type of device is appropriately called a "strap on" aquastat. Other variations include a capillary tube long enough for the sensor bulb to be mounted in an immersion well threaded into piping directly behind the aquastat's enclosure, such as shown in Figure 8-16. Other models are available with capillary tubes up to 12 feet long, as shown in Figure 8-18. These devices are often called "remote bulb" aquastats.

During installation, it's important that the capillary tube is not cut or severely kinked. Remember, it's a tube, not a wire. If cut or severely kinked, the controller is rendered useless.

Figure 8-19

Courtesy of Dwyer Instruments

For the best accuracy, the sensor bulb should be mounted into an immersion well that is threaded into the tank, pipe or heat source for which the fluid temperature is being controlled. If this is not possible, the sensor bulb should be firmly strapped to the outside of a pipe and wrapped with a sleeve of insulation several inches longer than the sensor bulb.

Capillary bulb aquastats have been used for several decades. Some are still used for specific hydronic system applications, such as turning on the fan motor in a unit heater. However, capillary tube aquastats now compete with a wide range of electronic temperature setpoint controllers. The latter usually offer several more features, often at comparable prices. Figure 8-19 shows an example of such a controller.

This controller uses a thermistor temperature sensor and can work over a wide range of temperatures from -58–230ºF. It has an adjustable differential ranging from 1–20ºF. This differential can be set above or below the setpoint, enabling the controller to be used in both heating and cooling applications. The output is a single pole, double throw (SPDT) relay rated for several amps at line voltage.

One advantage of electronic setpoint controllers is that the temperature sensor can be located a long distance—in some cases, several hundred feet—from the controller, if necessary. However, designers should always verify this maximum distance and use the type and size of sensor wiring required for long-distance runs. Modern electronic setpoint controllers also provide a wider range of setpoint temperatures and a wide range of differentials compared to aquastats. Most have a digital display of the current sensor temperature, as well as other information such as the status of the output relay. Most can also show fault codes if a sensor is malfunctioning or disconnected. Some can also be configured to operate in either Fahrenheit or Celsius temperature scales.

Setpoint controllers are also available for 2-stage control. One output relay closes for stage 1 and another for stage two. This allows two devices to be operated from a single controller. One example is where the first stage contacts operate a geothermal heat pump to add heat to a buffer tank, and the second stage contacts operate an auxiliary boiler that also adds heat to the tank if the heat pump cannot maintain the desired temperature within the tank.

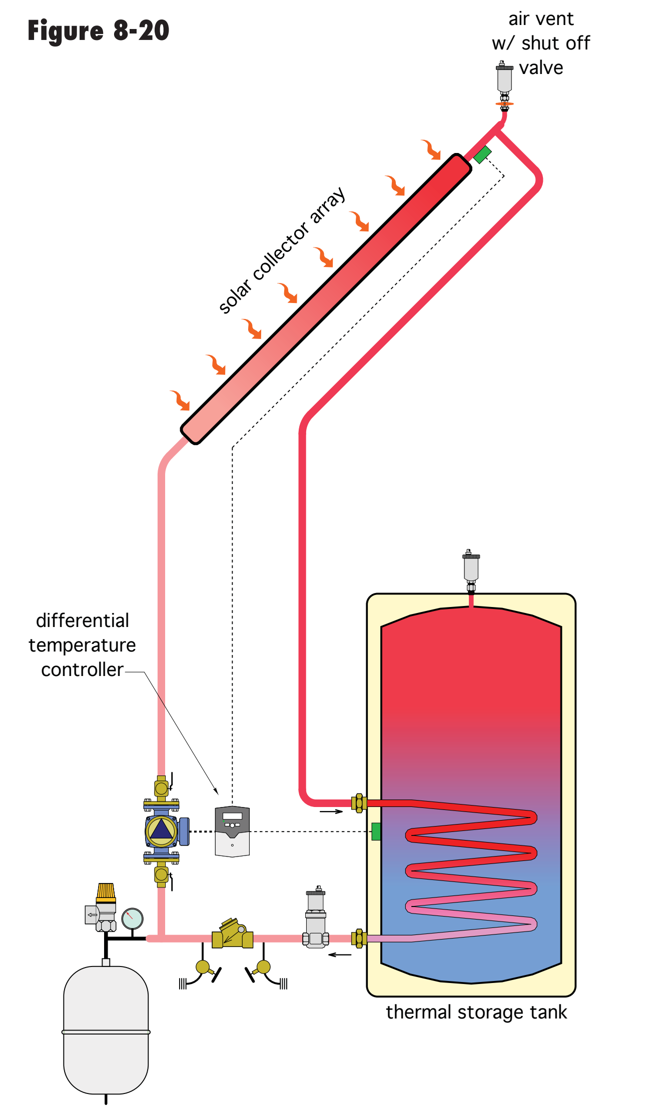
DIFFERENTIAL TEMPERATURE CONTROLLERS:
There are applications where a control action must be based on the *difference* between two temperatures, rather than the value of either temperature. This is especially true in systems using renewable energy heat sources, or those performing heat recovery actions. A differential temperature controller (abbreviated as DTC) is available for such applications.

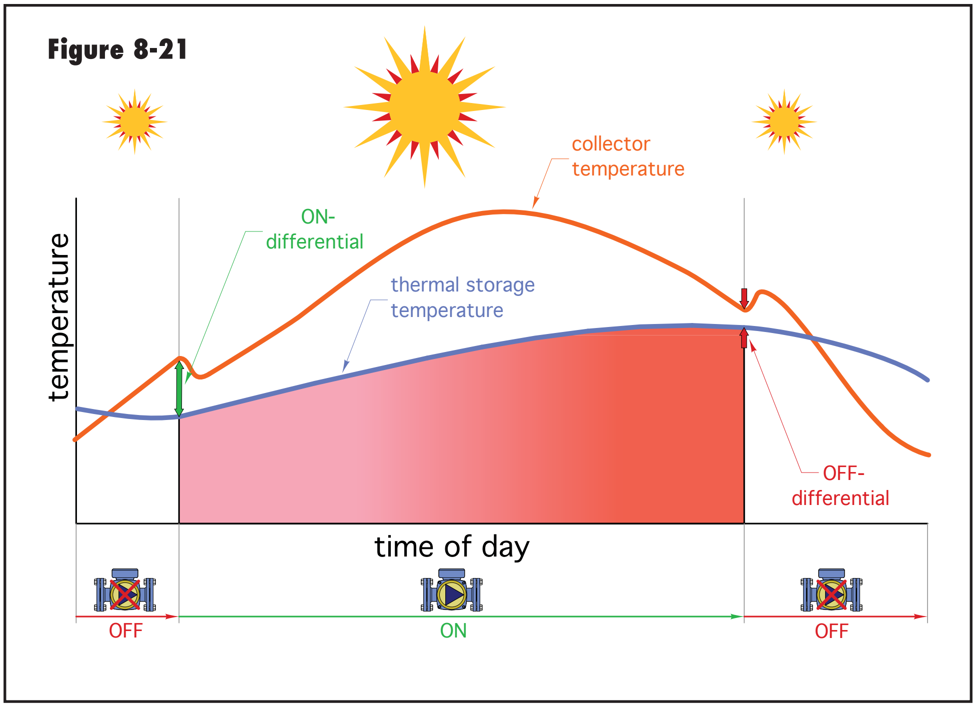
A basic DTC has two temperature sensors. One is called the *source* temperature sensor, and the other is called the *storage* temperature sensor. The word "source" refers to any potential source of heat. Examples include a solar collector, a wood-fired boiler, or a tank containing heated water. The word "storage" refers to any potential destination for the heat from the source. The most common example is a thermal storage tank. However, "storage" could also be a swimming pool, a concrete slab or any other media that could potentially accept heat from the source.

All DTCs also have two temperature differentials. One is called the *on-differential*, and the other the *off-differential*. In the context of DTCs, "differential" means the difference in temperature between the source temperature sensor and the storage temperature sensor. The DTC closes its normally open relay contacts whenever the temperature at the source sensor is greater than or equal to the temperature at the storage sensor plus the *on-differential*. Once the relay contacts close, the controller continues to monitor the temperature at both sensors. If the temperature at the source sensor drops to, or below, the storage temperature plus the *off-differential*, the relay contacts open.

The on-differential and off-differential of most modern differential temperature controllers are adjustable. Typical on-differentials for solar thermal applications are in the range of 9–15ºF. Typical off-differentials are in the range of 4–6ºF. In solar thermal applications, the differential settings should factor in the thermal mass of the collector, the heat loss of the collector return piping and the flow rate through the collector. The goal is to allow energy collection whenever possible, but avoid situations where the fluid may loose more heat than it gains as it passes through the collector circuit.

Figure 8-20





after the circulator turns off since no fluid is flowing through the absorber plate to extract the diminished, but still present, solar heat gains. In some cases, the collector circulator may restart for a short time. As the collector temperature drops later in the afternoon, the collector circulator will finally stop and remain off until the next time the sun sufficiently heats the collector.

Some DTC controllers use solid-state devices called triacs rather than on/off relays to operate circulators between a heat source and storage. Triacs, in combination with microprocessor control, can alter the frequency and voltage signal sent to the circulator controlling flow through the heat source. This variable flow capability reduces the potential for cycling at the beginning and end of heat collection periods. It also reduces the electrical energy used by the circulator at times of marginal energy transfer, where full flow is not required.

One of the most common applications for a DTC is operating the circulator that creates flow between an array of solar collectors and a thermal storage tank containing domestic water, as illustrated in Figure 8-20.

Figure 8-21 illustrates how the on-differential and off-differential relate to temperature changes in the solar collector and thermal storage tank during a sunny day.

Assuming clear sky conditions, the collector temperature steadily climbs during the morning and eventually reaches a value that equals the temperature of the storage tank sensor plus the on-differential. At that point, the DTC turns on the collector circulator. Notice how the collector temperature dips immediately after the collector circulator turns on. This is caused by the rapid cooling effect of fluid in the piping leading to the collector array as it first moves into the collectors. The setting for the on-differential and off-differential should be such that this dip doesn't cause the circulator to quickly turn off. If several short cycles are observed during a clear morning startup, the on-differential should be slightly increased and the off-differential slightly decreased.

Figure 8-21 shows a steady increase in thermal storage temperature during the mid-day period. This gain tends to level out as the afternoon continues. As solar intensity diminishes, the collector temperature eventually drops to the off-differential of the DTC, and the collector circulator turns off. The collector temperature will typical rise slightly

Figure 8-22

Figure 8-22 shows an example of a modern differential temperature controller.

This controller provides the basic differential temperature control operating just discussed, along with several other functions such as temperature limiting, and heat dump activation when necessary.

9. EXAMPLE SYSTEMS

This section presents three complete hydronic systems and their associated controls. These systems cover a range of applications, including systems with both conventional and renewable heat sources. Several types of distribution systems and heat emitters are also included, as are different methods of domestic water heating.

Each system begins with a piping schematic and explanation of the concepts used in the system. A complete wiring diagram for the system is then presented. A full description of operation narrates how the various control devices work for each of the system's operating modes.

Designers should keep in mind that many of the sub-assemblies shown in these examples can be applied in other systems using different heat sources, numbers of zones or mixing methods.

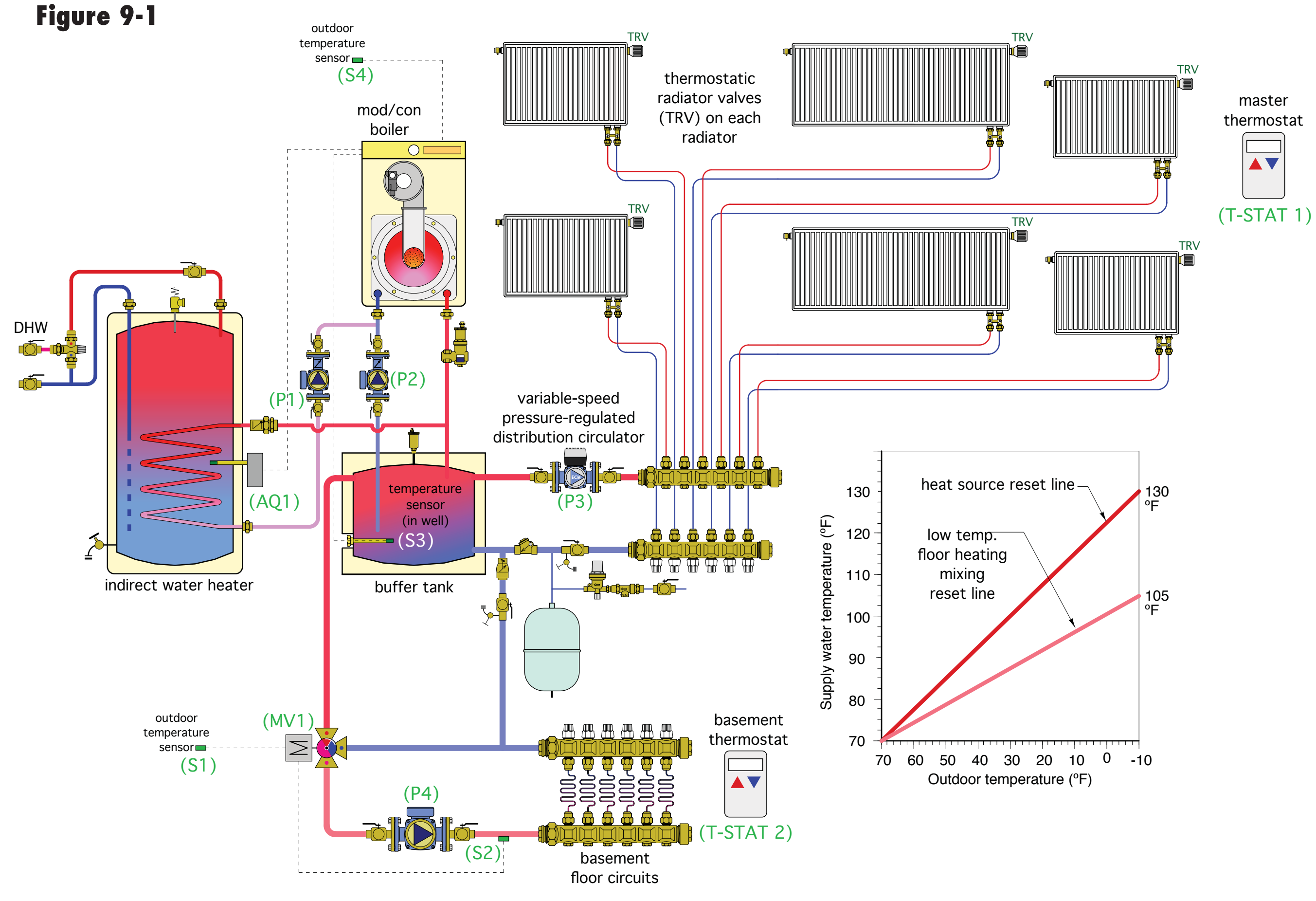
SYSTEM #1: Mod/con boiler supplying floor heating and panel radiators.

Figure 9-1 shows the piping for a system that supplies a single zone of radiant floor heating to a basement slab, along with several panel radiators on the main floor of a house.

Each panel radiator is equipped with a thermostatic radiator valve to allow room-by-room zoning. During space heating mode, the mod/con boiler operates on its internal outdoor reset control, which has been set to produce a supply water temperature of 130ºF when the outdoor temperature is -10ºF. The low temperature water for floor heating is produced by mixing down water from the buffer tank using a 3-way motorized mixing valve. This valve operates on 24 VAC and has its own outdoor reset logic. It is set to supply 105ºF water to the floor when the outdoor temperature is -10ºF. The reset lines for the radiant floor and panel radiators are shown on the piping schematic.

A small 25-gallon buffer tank provides thermal mass to stabilize the boiler against short cycling due to the small room-by-room heating loads represented by the independently controlled panel radiators.

Figure 9-1



Domestic hot water is produced by an indirect water heater, which is supplied as a priority load from the boiler. The boiler temporarily goes to a higher setpoint temperature during this mode of operation.

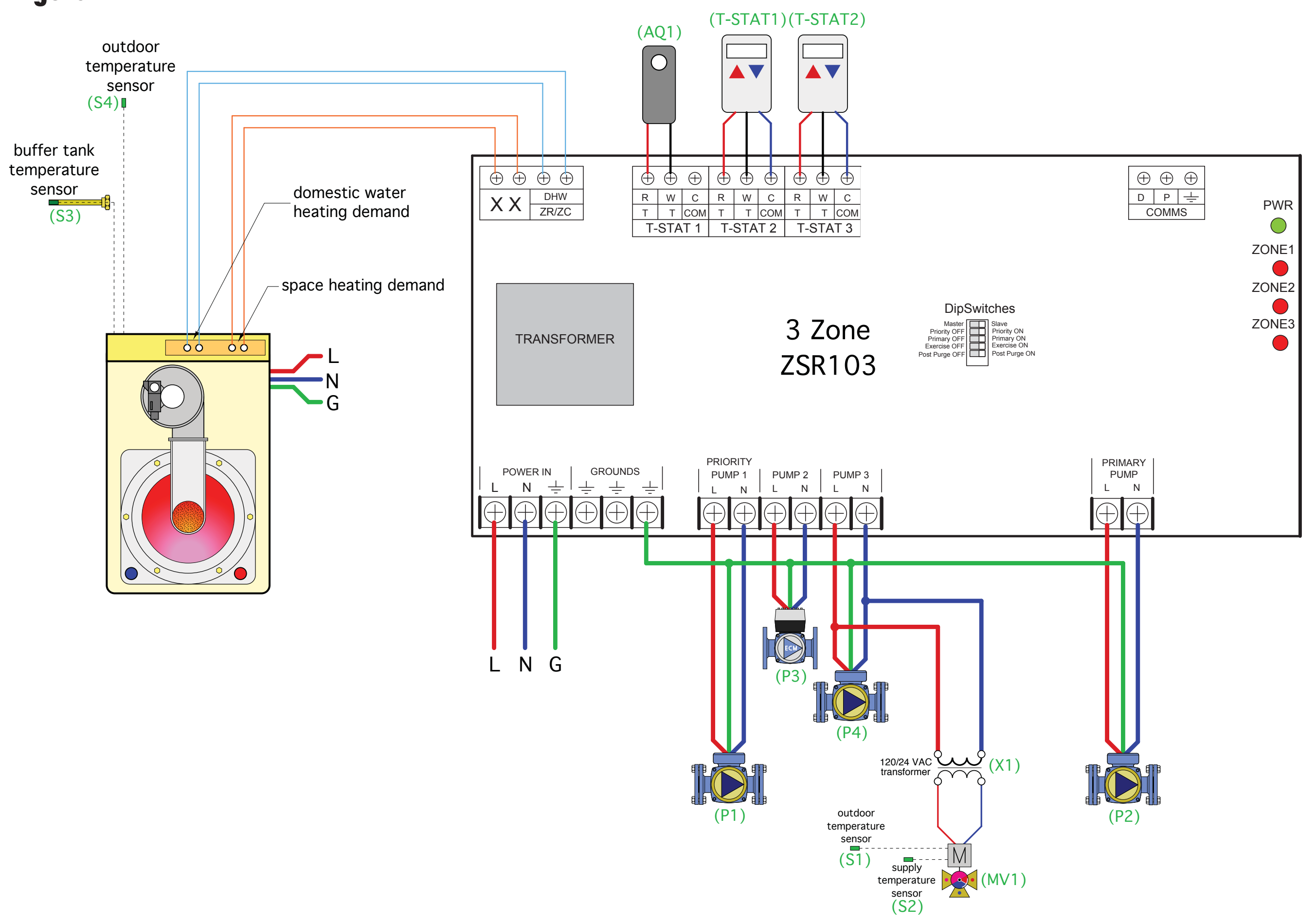
Figure 9-2 shows how the electrical controls for this system are implemented using a Caleffi ZSR103 multi-zone relay center as the primary control device.

The DIP switch on the ZSR103 has been set for priority operation of zone 1 (e.g., domestic water heating). Other DIP switches on the ZSR103 controller have also been set so the “primary pump” (P2) is temporarily turned off during priority mode operation. Circulator (P3) for the panel radiator circuits is turned on whenever there is a call from the main floor master thermostat (T-STAT 1). Circulator (P4) for the radiant floor circuits is turned on whenever there is a call from the basement thermostat (T-STAT 2). A 120/24 VAC transformer is wired in parallel with circulator (P4). It supplies 24 VAC power to operate the motorized mixing valve whenever the basement zone is active.

The following is a description of operation of system #1:

1. Domestic Water Heating: *The temperature of the domestic hot water storage tank is monitored by aquastat (AQ1), which has been adjusted to close its contacts when the water temperature in the tank drops to 110ºF and open its contacts when the tank temperature reaches 125ºF. When aquastat (AQ1) calls for heat, it turns on the priority zone 1 of the multi-zone relay center (ZSR103). Circulator (P1) is turned on. A dry contact closes across the (ZR ZC) terminals in the (ZSR103) to provide a domestic water heating demand to the mod/con boiler. The boiler fires and operates based on its own internal setpoint for the domestic water-heating mode. Any space-heating loads that were on are temporarily turned off during the priority domestic water-heating mode. When aquastat (AQ1) is satisfied, its contacts open. This turns off zone 1 circulator (P1) and opens the (ZR ZC) contact, which turns off the DHW demand to the boiler.*

Figure 9-2



2. Basement Floor Heating: *Upon a call for heating from thermostat (T-STAT 2), the multi-zone relay center (ZSR103) turns on circulator (P4) to provide flow through the basement floor circuits. A 120/24 VAC transformer (X1) is also turned on to supply 24 VAC to the motorized mixing valve controller (MV1). When powered on, the mixing valve controller (MV1) operates on outdoor reset control based on its internal settings and modulates to control the supply water temperature to the floor circuits. The (X X) terminals in the (ZSR103) close to provide a space-heating demand to the boiler. The boiler checks the temperature of sensor (S3) within the buffer tank. When necessary, it fires to maintain this temperature based on its own outdoor reset control settings. When thermostat (T-STAT 2) is satisfied, circulator (P4), motorized mixing valve (MV1) and the boiler are turned off.*

3. Panel Radiator Heating: *The master thermostat (THM1) on the main floor is set to a temperature 2ºF above the normal comfort temperature. It is used to initiate a call for heating for all areas served by panel radiators. Upon a call for heating from (T-STAT 1), the multi-zone relay center (ZSR103) turns on circulator (P3) to provide flow through the manifold station supplying the circuits to each panel radiator. Flow to each radiator is determined by the setting of its thermostatic radiator valve. Circulator (P3) is a variable-speed pressure-regulated circulator set for constant differential pressure mode. The (X X) terminals in the (ZSR103) close to provide a space-heating demand to the boiler. The boiler monitors the temperature of sensor (S3) within the buffer tank. When necessary it fires to maintain this temperature based on its own outdoor reset control settings. When master thermostat (T-STAT 1) is satisfied, circulator (P3) and the boiler are turned off.*

SYSTEM #2: Wood gasification boiler supplies space heating and domestic hot water.
The system shown in Figure 9-3 uses a high efficiency wood gasification boiler as the sole heat source for space heating and the primary means of domestic water heating.

Nearly all wood gasification boilers require substantial thermal storage. In this system, thermal storage is provided by a 500-gallon unpressurized tank. Because the tank represents an "open" component, the boiler, which must operate in a pressurized closed loop, is linked to the tank using a brazed plate heat exchanger (HX1). Similarly, the closed-loop distribution system is linked to the storage tank through another heat exchanger (HX3). Several independently operated zones of low temperature panel heating are supplied from heat exchanger (HX3).

The boiler circuit includes a 3-way thermostatic anti-condensation valve that raises the boiler's inlet temperature above 130ºF to prevent sustained flue gas condensation.

The near-boiler piping also contains a heat dump. Upon a power failure, a *normally open* zone valve, which would otherwise be closed when power is available, opens. This allows thermosiphon flow to develop from the boiler through an array of finned copper tubes suspended above the boiler. The latter dissipate residual heat from the boiler to prevent it from overheating and possibly opening its pressure relief valve.

Figure 9-3

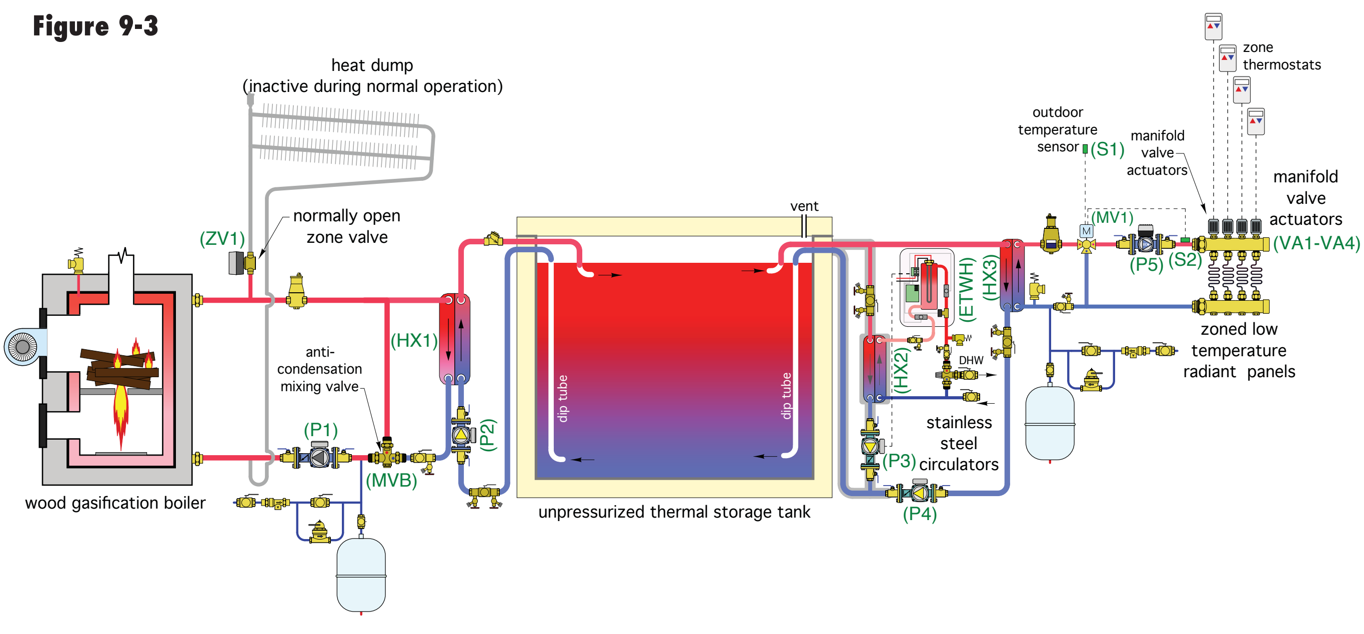
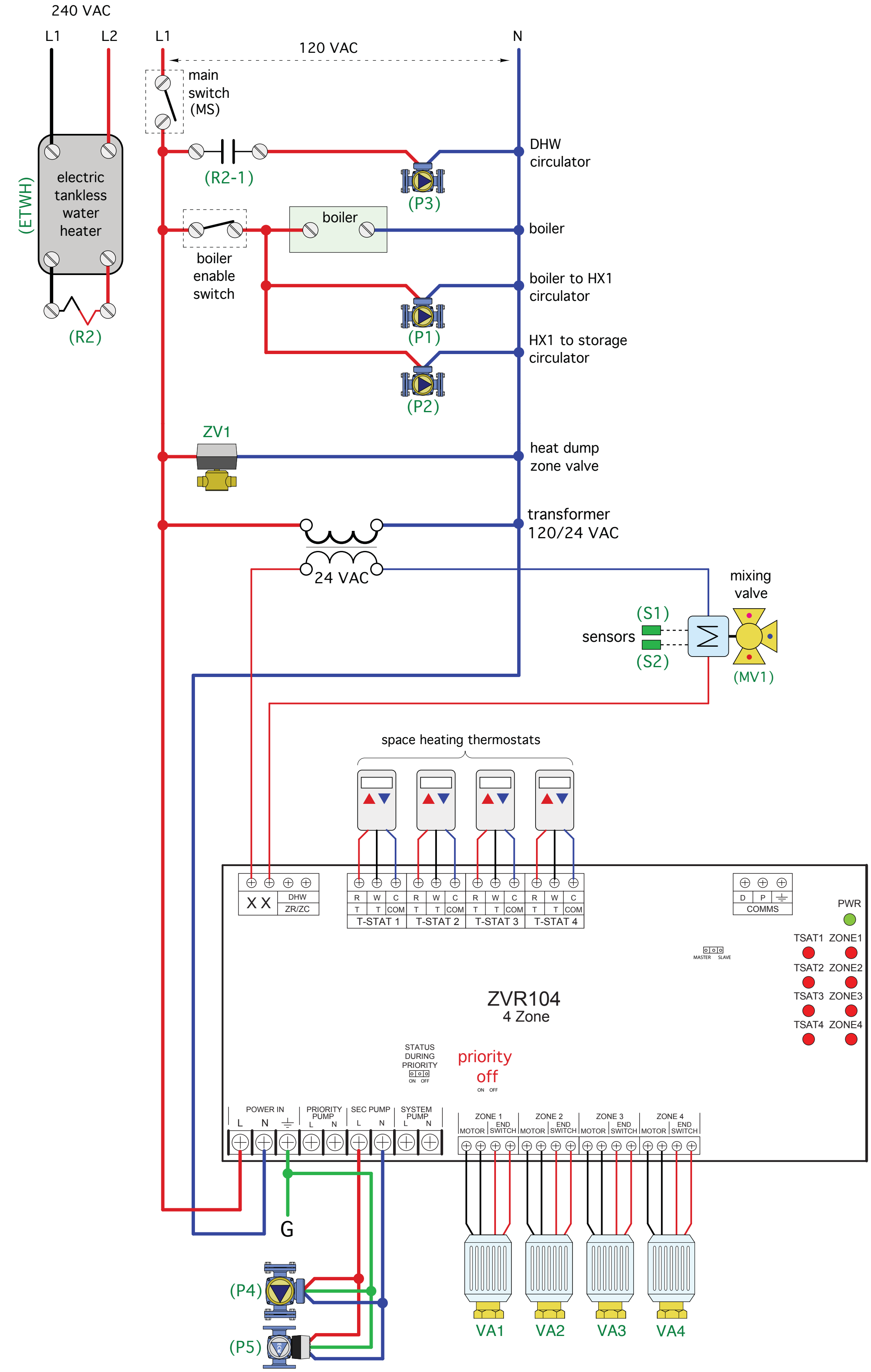


Figure 9-4



240 VAC
L1
L2
L1
N
120 VAC
main switch (MS)
electric tankless water heater
(ETWH)
(R2)
(R2-1)
DHW circulator
(P3)
boiler
boiler
boiler enable switch
boiler to HX1 circulator
(P1)
HX1 to storage circulator
(P2)
ZV1
heat dump zone valve
transformer 120/24 VAC
24 VAC
mixing valve
(S1)
sensors
(S2)
(MV1)
space heating thermostats
X X
DHW
ZR/ZC
R W C
T T COM
T-STAT 1
T-STAT 2
T-STAT 3
T-STAT 4
D P
COMMS
PWR
TSAT1 ZONE1
TSAT2 ZONE2
TSAT3 ZONE3
TSAT4 ZONE4
ZVR104
4 Zone
STATUS DURING PRIORITY
priority off
POWER IN
PRIORITY PUMP
SEC PUMP
SYSTEM PUMP
ZONE 1
ZONE 2
ZONE 3
ZONE 4
MOTOR
END SWITCH
G
(P4)
(P5)
VA1
VA2
VA3
VA4

A stainless steel circulator (P2) operates simultaneously with (P1) to convey heat from heat exchanger (HX1) to the storage tank. Circulator (P2) is located low within the system to maximize static pressure at its inlet. A bidirectional purging valve in the circuit between (HX1) and the thermal storage tank ensures air displacement from the "gooseneck" piping above the water level in the tank. A swing check is installed to stop reverse thermosiphoning from the tank through the heat exchanger piping.

The piping within the tank uses 90° elbows oriented to create horizontal flows that help preserve temperature stratification. The hottest water in the upper portion of the tank is drawn out to either heat exchanger (HX2) for domestic water heating, or to heat exchanger (HX3) for space heating. The coolest water remains at the bottom of the thermal storage tank.

Domestic water is heated on-demand using an external stainless steel brazed plate heat exchanger (HX2). Whenever there is a flow demand for domestic hot water of 0.6 gpm or higher, the flow switch inside the electric tankless water heater closes. This closure is used in combination with a relay to turn on circulator (P3), which routes water from the upper portion of the thermal storage tank through the primary side of heat exchanger (HX2). Closure of the flow switch also energizes an electrical contactor within the tankless heater to supply 240 VAC to triacs, which regulate current flow through the heating elements. The power delivered to the heating elements is regulated by electronics within the tankless heater that measure incoming and outgoing water temperature. The power delivered to the elements is limited to that required to provide the desired delivery water temperature. All heated water leaving the tankless heater flows into an ASSE 1017-rated mixing valve to ensure a safe delivery temperature to the fixtures.

Space heating is provided by a four-zone low temperature distribution system. The heat emitters are sized to provide design heating load with a supply temperature not higher than 120ºF. The water temperature supplied to the distribution system is controlled by a motorized 3-way motorized mixing valve. This valve is powered by 24 VAC and operates based on its own outdoor reset programming.

Figure 9-4 shows how the electrical controls for this system are implemented using a Caleffi ZVR104 multi-zone relay center in combination with a ladder diagram that embodies the remainder of the control logic.

The following is a description of operation for system #2.

Description of Operation:

1. Boiler Operation: *When the wood gasification boiler is fired, the operator closes a switch, typically on the boiler, that enables 120 VAC to be supplied to the boiler. This switch closure also supplies 120 VAC to circulators (P1) and (P2). Thus, flow between the boiler and heat exchanger (HX1), as well as between (HX1) and the thermal storage tank, is enabled. As the temperature at the boiler outlet climbs, the 3-way thermostat valve (MVB) modulates to allow heat flow to heat exchanger (HX1) and onward to thermal storage, while also maintaining the boiler's inlet temperature above 130ºF to prevent sustained flue gas condensation within the boiler.*

2. Boiler Overheat Protection: *If a power failure occurs, the normally open zone* valve (ZV1), which would otherwise be closed when power is available, opens. This allows thermosiphon flow to develop between the boiler and an array of finned copper tubes suspended above the boiler. The fin tube array dissipates residual heat from the boiler.

3. Space-Heating Mode: *All zoning is coordinated through the multi-zone relay center (ZVR104). Upon a call from any of the space-heating thermostats (T1...T4), 24 VAC is passed to the associated manifold valve actuators (VA1... VA4). When any valve actuator reaches its fully open position, an end switch within the valve actuator closes, signaling that the zone is open. The multi-zone relay center responds by turning on circulators (P4) and (P5). Circulator (P4) creates flow between the thermal storage tank, and heat exchanger (HX3). Circulator (P5) is a variable-speed pressure-regulated circulator that adjusts its speed to maintain a constant differential pressure across the distribution manifold as the manifold valve actuators open and close. When any zone calls for heat, the motorized mixing valve (MV1) is turned on by a 24 VAC signal passed through the (X X) terminals on the (ZVR104). When powered on, mixing valve (MV1) measures the outdoor temperature at sensor (S1) and uses this temperature, along with its settings, to calculate the necessary target supply water temperature to the distribution system. It compares the target supply temperature to the actual supply temperature measured by sensor (S2) and adjusts the hot water and return water flow proportions into the valve to maintain the temperature at sensor (S2) as close to the target temperature as possible.*

4. Domestic Water-Heating Mode: *Whenever there is a flow demand for domestic hot water of 0.6 gpm or higher, a flow switch within the electric tankless water heater (ETWH) closes. This closure supplies 240 VAC to the coil of relay (R2). The normally open contacts (R2-1) close to turn on circulator (P3), which circulates heated water from* *the upper portion of the thermal storage tank through the primary side of the domestic water heat exchanger (HX2). The domestic water leaving (HX2) is either preheated or fully heated, depending on the temperature in the upper portion of the thermal storage tank. This water passes into the thermostatically controlled tankless water heater (ETWH), which measures its inlet temperature. The electronics within this heater control electrical current flow to its heating elements based on the necessary temperature rise (if any) to achieve the desired domestic hot water temperature. If the water entering the tankless heater is already at or above the setpoint temperature, the elements are not turned on. All heated water leaving the tankless heater flows into an ASSE 1017-rated mixing valve to ensure a safe delivery temperature to the fixtures. Whenever the demand for domestic hot water drops below 0.5 gpm, circulator (P3) and the tankless electric water heater are turned off.*

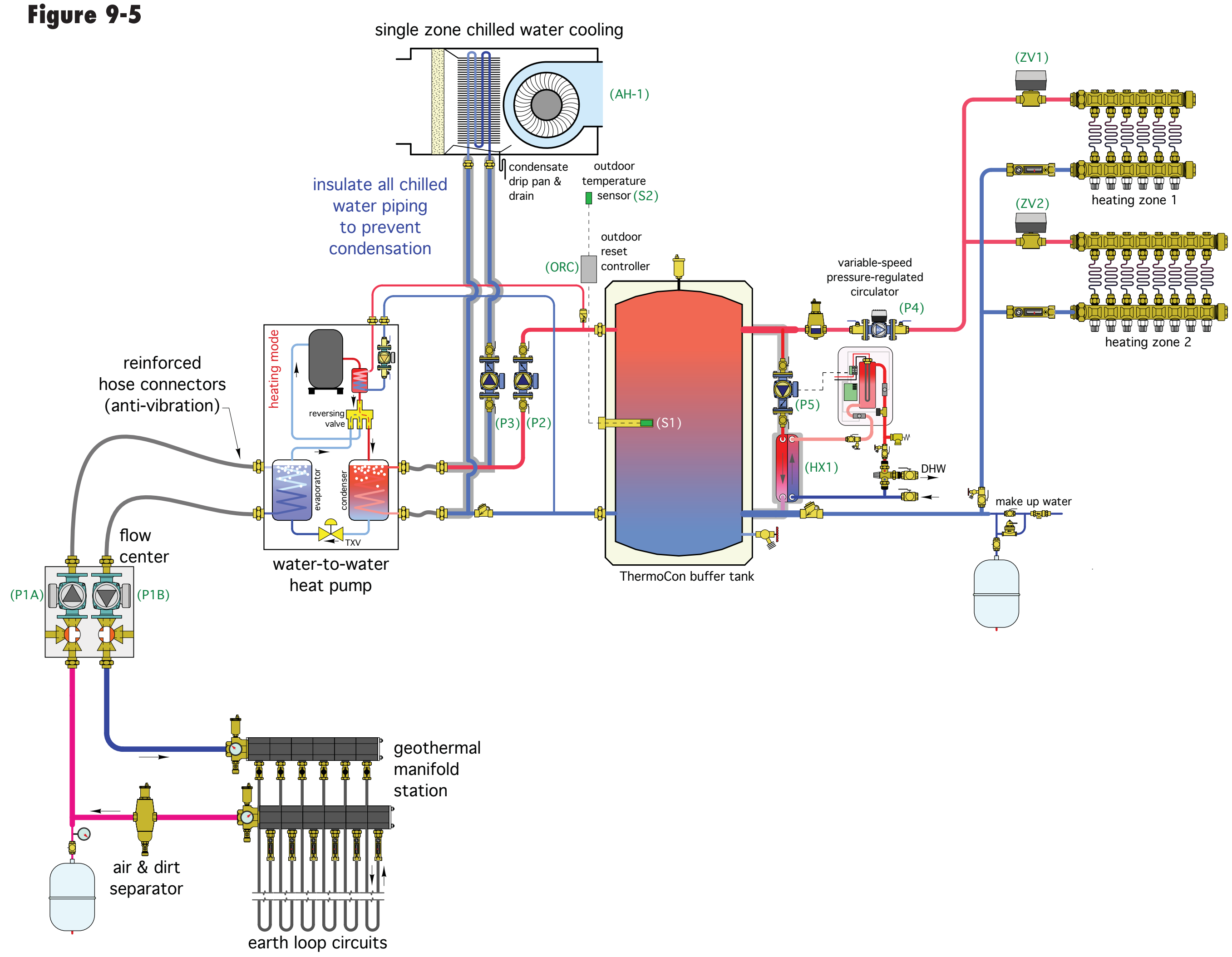
SYSTEM #3: Geothermal water-to-water heat pump provides heating and cooling.

The system in Figure 9-5 provides two zones of radiant panel heating in combination with a single zone of cooling. An on/off water-to-water geothermal heat pump, equipped with a desuperheater, is the sole heat source of space heating and the sole source of chilled water for space cooling.

Because an on/off heat pump is used with multiple zones of heating, a buffer tank is used to prevent the heat pump from short cycling under partial load conditions.

Flow in the earth loop is provided by two series-arranged circulators within the flow center. The earth loop is filled and purged using the two 3-way valves contained within the flow center. The earth loop is equipped with an expansion tank, as well as a combined air & dirt separator.

Figure 9-5



Flexible, reinforced hoses are used to connect the flow center to the heat pump while minimizing vibration transfer.

During heating mode, the heat pump is turned on and off by an outdoor reset controller that measures the outdoor temperature, and uses this temperature, along with its settings, to determine the appropriate target temperature for the buffer tank. The outdoor reset controller operates the heat pump as necessary to maintain the buffer tank within a narrow range of this target temperature. Figure 9-6 shows how the outdoor reset controller is configured so that the target supply water temperature to the distribution system is 110ºF at design load conditions, which correspond to an outdoor temperature of 10ºF.

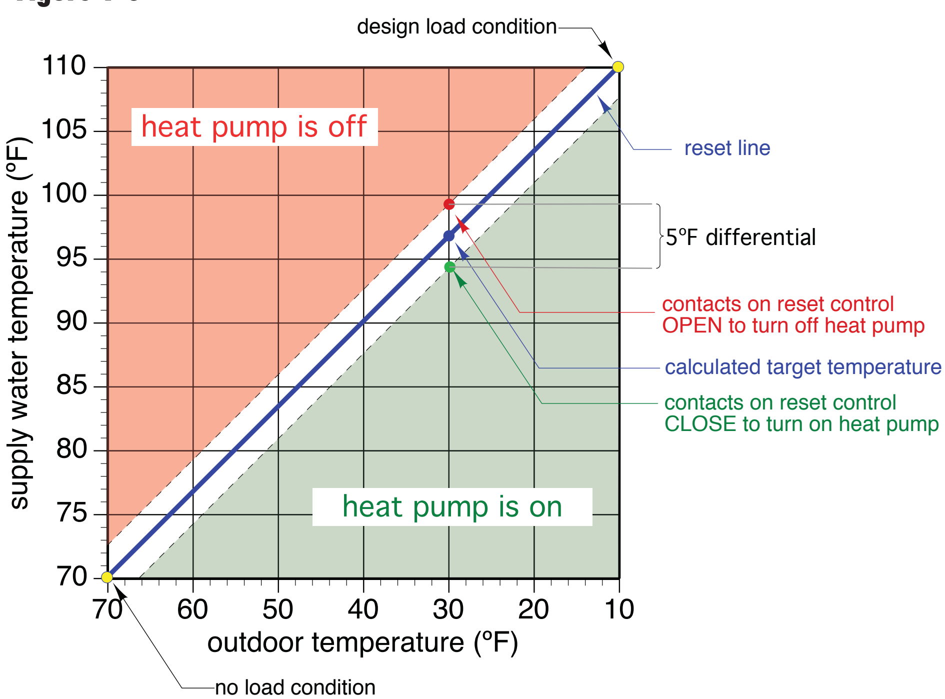
The two space-heating zones are controlled by zone valves that respond to their associated thermostats. When either of the heating zones are active, the variable-speed pressure-regulated circulator (P4) operates in constant differential pressure mode.

Domestic water is heated “on-demand” using an external stainless steel brazed plate heat exchanger. Whenever there is a flow demand for domestic hot water of 0.6 gpm or higher, the flow switch inside the tankless electric water heater closes. This closure is used, in combination with a relay, to turn on circulator (P5) that routes water from the upper portion of the buffer tank through the primary side of this heat exchanger. Closure of the flow switch also energizes an electrical contactor within the tankless heater. Triacs within the tankless water heater regulate electrical current flow through the heating elements. The power delivered to the heating elements is limited to that required to provide the desired outgoing domestic hot water temperature. All heated water leaving the tankless heater flows into an ASSE 1017-rated mixing valve to ensure a safe delivery temperature to the fixtures.

Cooling is provided by a single chilled-water air handler that has been selected to match the cooling capacity of the heat pump. *This eliminates the need for a buffer tank in cooling mode operation.* Circulator (P3) operates in combination with the blower in the air handler, and the heat pump whenever cooling is required.

The desuperheater within the heat pump absorbs heat from the hot refrigerant gas exiting the compressor. This heat is transferred to the buffer tank, where it can be used by the on-demand domestic water-heating sub-system. When the heat pump is operating in cooling mode, the heat transferred to the buffer tank by the desuperheater is “free heat” that would otherwise be dissipated to the earth loop. When the heat pump operates in heating mode, the combined heat transfer from the refrigerant to system water through both the desuperheater and the condenser slightly increases the COP of the heat pump.

Figure 9-6



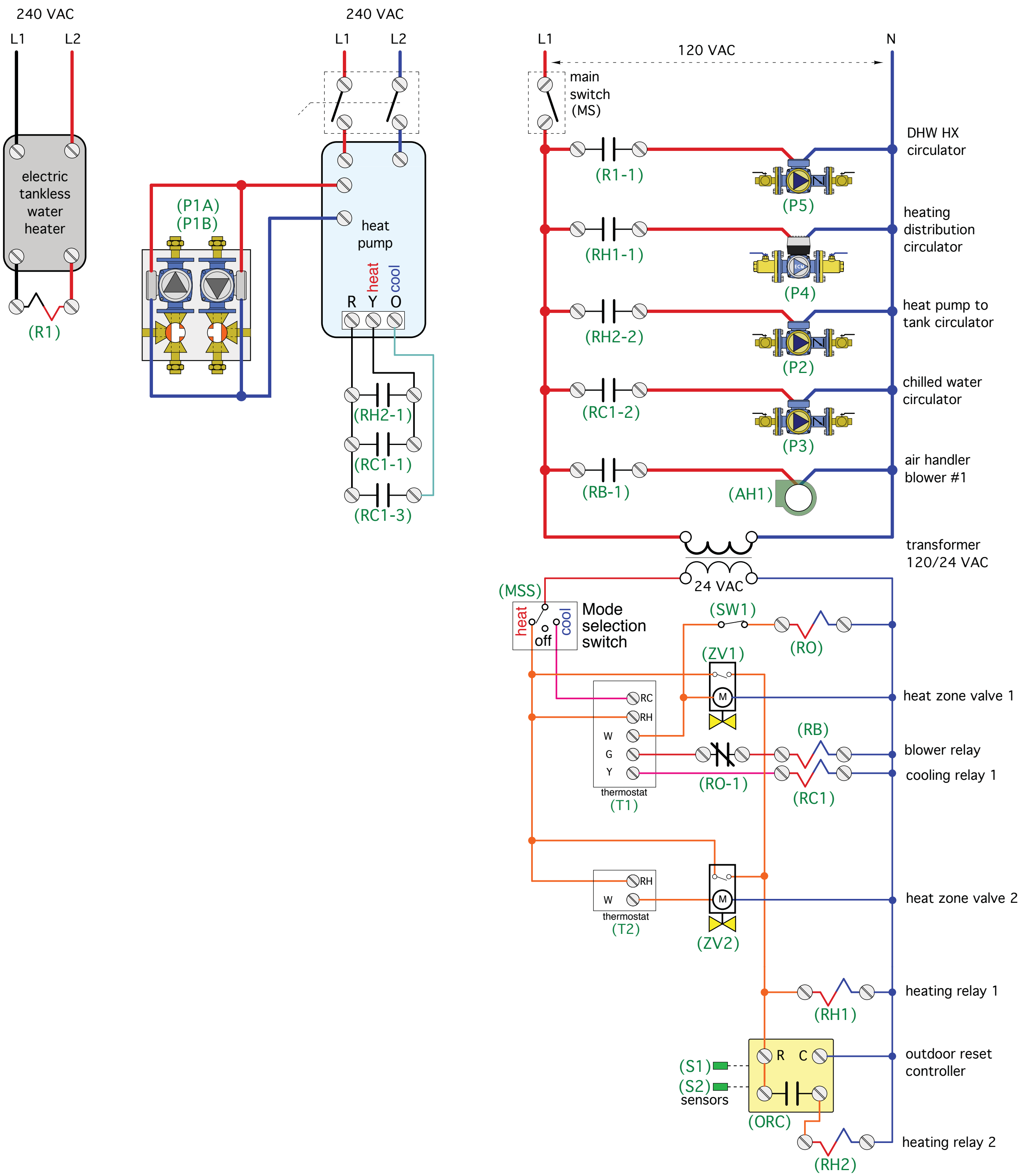
The electrical wiring for system #3 is shown in Figure 9-7. This wiring is shown in ladder diagram format to demonstrate the ability to create detailed “hard-wired” operating logic and document it in a form that is easily followed by installers and service technicians.

The following is a description of operation for system #3.

Description of Operation:

1. Space Heating: *The mode selection switch (MSS) must be set for heating. This supplies 24 VAC to both space-heating thermostats. Thermostat (T1) controls heating in zone 1 and cooling for the entire building. Thermostat (T2) is a heating-only thermostat. If either thermostat calls for heating,*

Figure 9-7



240 VAC
L1
L2
electric
tankless
water
heater
(R1)
(P1A)
(P1B)
240 VAC
L1
L2
heat
pump
heat
cool
R
Y
O
(RH2-1)
(RC1-1)
(RC1-3)
L1
120 VAC
N
main
switch
(MS)
(R1-1)
(P5)
DHW HX
circulator
(RH1-1)
(P4)
heating
distribution
circulator
(RH2-2)
(P2)
heat pump to
tank circulator
(RC1-2)
(P3)
chilled water
circulator
(RB-1)
(AH1)
air handler
blower #1
transformer
120/24 VAC
24 VAC
(MSS)
heat
off
cool
Mode
selection
switch
(SW1)
(RO)
(ZV1)
heat zone valve 1
RC
RH
W
G
Y
thermostat
(T1)
(RB)
blower relay
(RO-1)
(RC1)
cooling relay 1
RH
W
thermostat
(T2)
(ZV2)
heat zone valve 2
(RH1)
heating relay 1
(S1)
(S2)
sensors
R
C
(ORC)
outdoor reset
controller
(RH2)
heating relay 2

24 VAC is passed to the associated zone valve, causing it to open. When the valve is fully open, its end switch closes. This passes 24 VAC to heating relay (RH1) and powers-on the outdoor reset controller (ORC). One relay contact (RH1-1) closes to supply line voltage to heating distribution circulator (P4). The outdoor reset controller (ORC) measures the outdoor temperature at sensor (S2). It uses this temperature, in combination with its settings, to calculate the target temperature for the buffer tank. It also measures the current temperature of the buffer tank at sensor (S1). If that temperature is more than half the set differential below the target temperature, 24 VAC is passed to the coil of relay (RH2). One contact (RH2-1) closes across the (R) and (Y) terminals of the heat pump, turning it on in the heating mode. The earth loop circulators (P1A) and (P1B) are turned on by an internal relay within the heat pump. A second contact (RH2-2) closes to apply line voltage to circulator (P2), which creates flow between the heat pump and the buffer tank. The heat pump continues to run, assuming a heat demand continues, until the temperature at sensor (S1) reaches half the differential of the (ORC) above the target temperature. When all thermostats are satisfied, relay coil (RH1) and the outdoor reset controller (ORC) are turned off.

2. Space Cooling: *The mode selection switch (MSS) must be set for cooling. This supplies 24 VAC to the (RC) terminals of thermostat (T1). When the mode selection switch is set for cooling, 24 VAC is interrupted to thermostat (T2). If thermostat (T1) calls for cooling, 24 VAC is switched to the thermostat's (Y) terminal, as well as its (G) terminal. This energizes the coil of relay (RC1). One contact (RC1-1) closes to connect the heat pump's (R) terminal to its (Y) terminal, which turns on the heat pump's compressor. Another contact (RC1-3) closes to connect the heat pump's (R) terminal to its (O) terminal. This turns on the heat pump's reversing valve so that the heat pump operates in cooling mode. Another contact (RC1-2) closes to supply line voltage to cooling distribution circulator (P3). The earth loop circulators (P1A) and (P1B) are turned on by an internal relay in the heat pump. The 24 VAC applied to the thermostat's (G) terminal energizes the coil of relay (RB). Contact (RB-1) closes to supply line voltage to the blower in the air handler.*

3. Blower Operation: *The blower in the air handler will always operate in cooling mode. It can also be set for continuous operation in either heating or cooling mode by setting the fan switch on thermostat (T1) to "on." If the blower is not to run in heating mode, switch (SW1) should be closed. This will allow 24 VAC to energize the coil of relay (RO) when thermostat (T1) calls for heat. A normally closed contact (RO-1) opens, interrupting 24 VAC to the blower relay (RB), and thus preventing the blower from operating. If switch (SW1) is left open, the blower in the air handler will operate whenever thermostat (T1) calls for heating.*

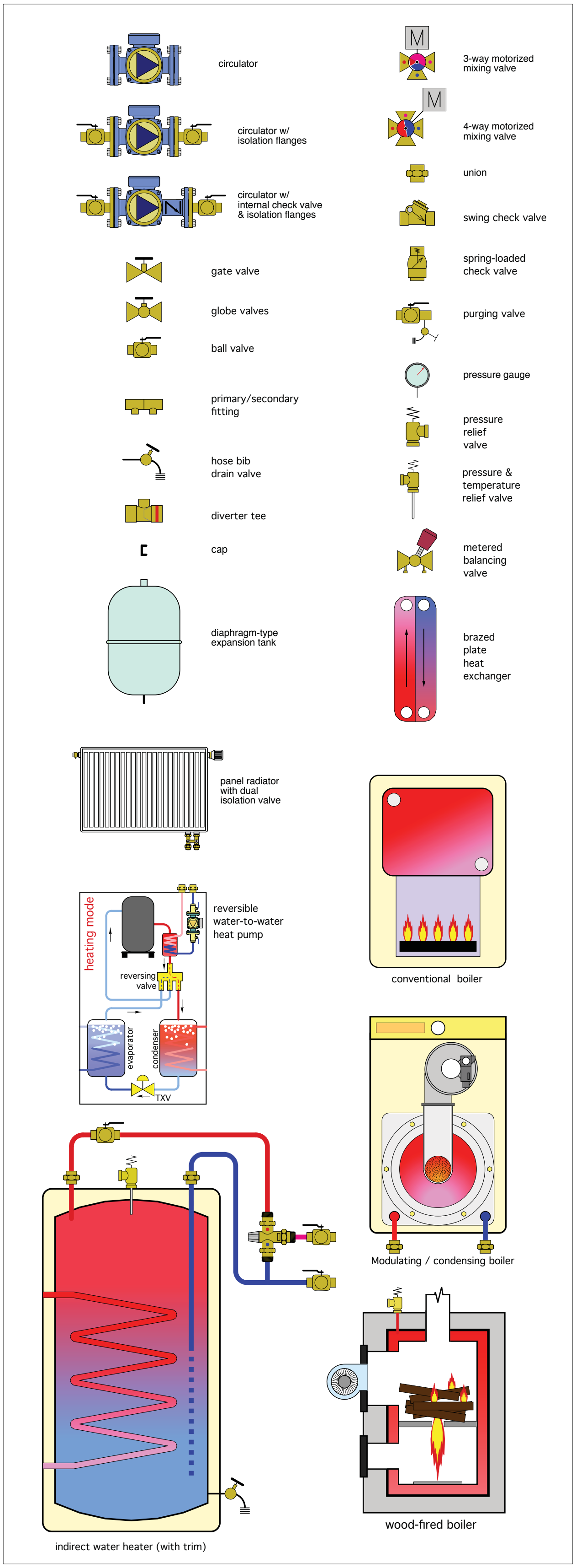
4. Domestic Water Heating: *Whenever there is a flow demand for domestic hot water of 0.6 gpm or higher, the flow switch inside the tankless electric water heater closes. This closure applies 240 VAC to the coil of relay (R1). The normally open contacts (R1-1) close to turn on circulator (P5), which circulates heated water from the upper portion of the buffer tank through the primary side of the domestic water heat exchanger (HX1). The domestic water leaving (HX1) is preheated to a temperature a few degrees less than the buffer tank temperature. This water passes into the thermostatically controlled tankless water heater, which measures its inlet temperature. The electronics within this heater regulate current flow to the heating elements so that water leaving the heater is at the desired temperature. All heated water leaving the tankless heater flows into an ASSE 1017-rated mixing valve to ensure a safe delivery temperature to the fixtures. Whenever the flow demand for domestic hot water drops below 0.5 gpm, circulator (P5) and the tankless electric water heater are turned off.*

SUMMARY

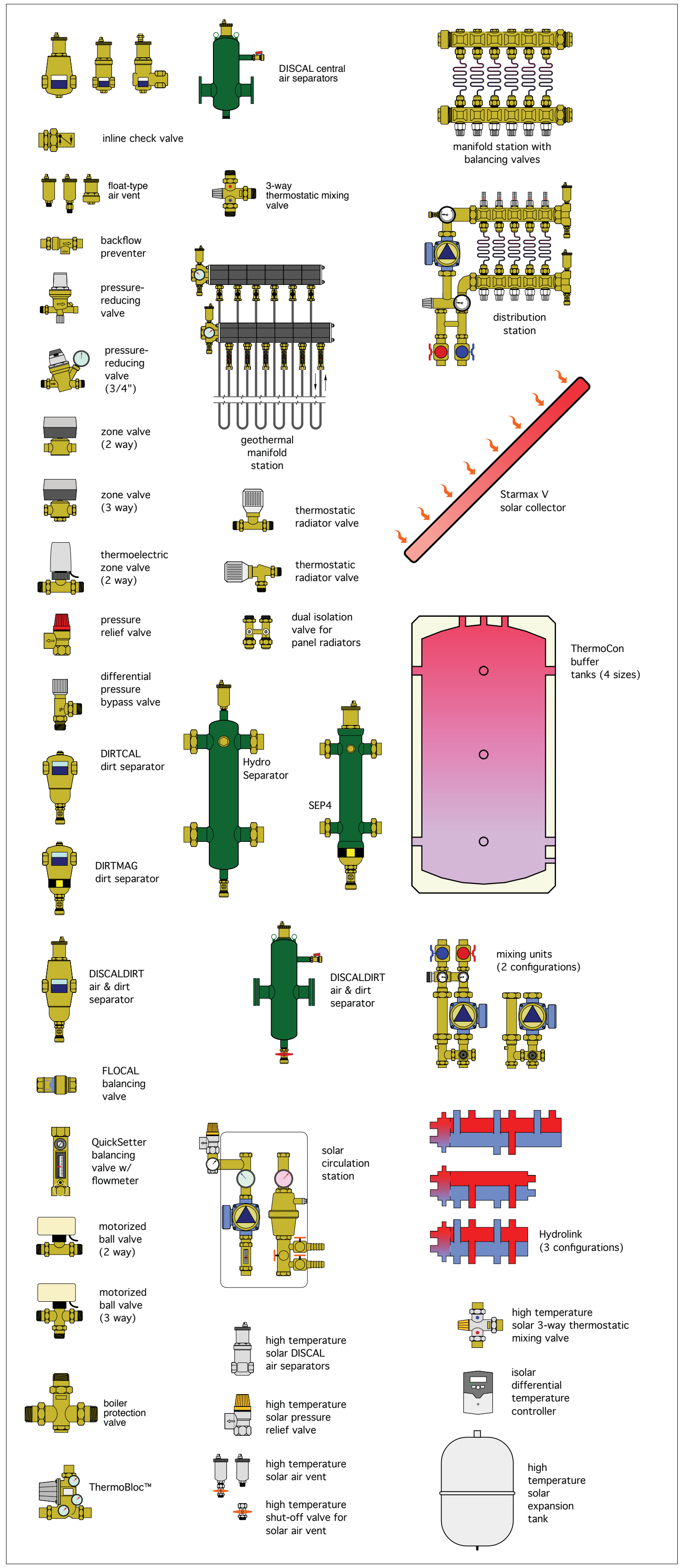
This issue of *idronics* has discussed many of the basic control concepts and associated hardware used in hydronic systems. It has provided an introduction to a very broad topic. It has also demonstrated how basic control devices can be used to operate state-of-the-art hydronic heating and cooling systems. Readers are encouraged to access documents on specific controllers from their manufacturers to learn the details of how they operate.

APPENDIX A: PIPING SYMBOL LEGEND

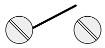
GENERIC COMPONENTS

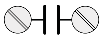


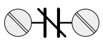
CALEFFI COMPONENTS



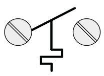
APPENDIX B: ELECTRICAL COMPONENT SYMBOL LEGEND

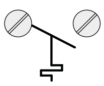

single pole switch

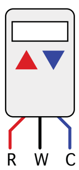

normally open relay contact


normally closed relay contact

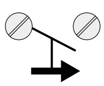

relay coil

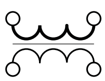

heating thermostat

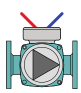

cooling thermostat

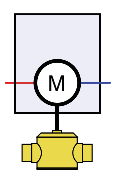


3-wire electronic heating thermostat

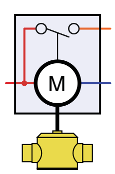

flow switch


transformer

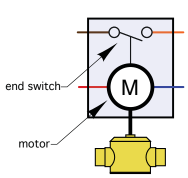

circulator



2-wire zone valve

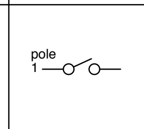
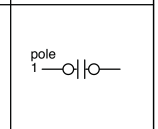
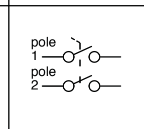
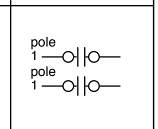
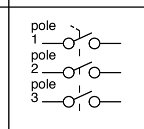
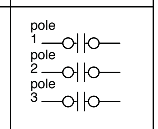
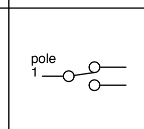
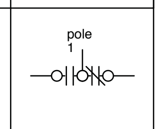
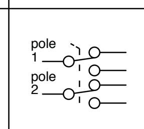
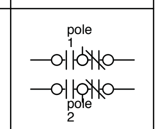
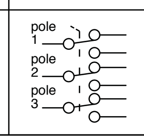
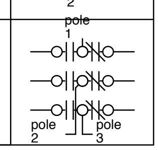


3-wire zone valve

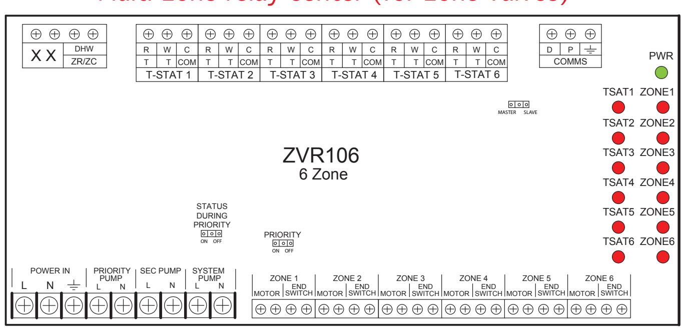


4-wire zone valve

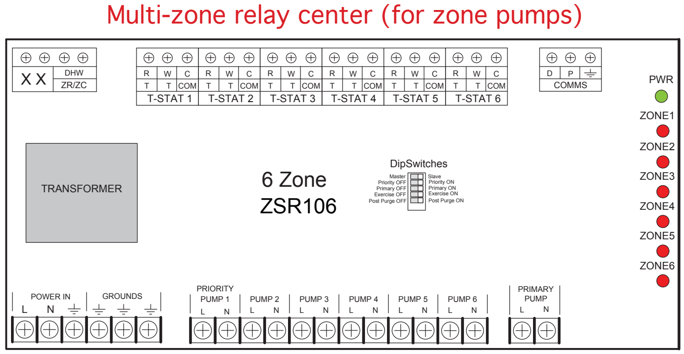
Poles & Throws for switches and relays

contact designation	switch contacts	relay contacts
Single Pole Single Throw SPST		
Double Pole Single Throw DPST		
Triple Pole Single Throw 3PST		
Single Pole Double Throw SPDT		
Double Pole Double Throw DPDT		
Triple Pole Double Throw 3PDT		

Multi-zone relay center (for zone valves)



Multi-zone relay center (for zone pumps)



Z-one Relay
single zone switching relay

ZSR101

CALEFFI

Intertek 4009064 Conforms to UL 873

Function

The ZSR101 single zone switching relay is operated by low voltage thermostats. The ZSR101 single zone switching relay incorporates Power In, Relay 1 and Relay 2 connection terminals to provide a convenient and cost effective way to control a circulator and a boiler operating control in a single zone hydronic heating system. The ZSR101 single zone switching relay saves hours in installation time and provide a clean and professional installation.

Features

- Compatible with low voltage 2, 3, or 4 wire thermostat
- R, W, C and TT Comm dual labeling at thermostat terminals
- 120 VAC pump outputs
- High capacity transformer
- Large screw terminal connections
- Simplified wiring with pre-installed jumper
- Heavy duty sealed relay
- Relay 1 and Relay 2 connection terminals
- Fuse protected relays (with spare fuse)
- Easy to read PC board layout
- Compact modern design
- Front LED Lights
- 100% Factory tested with 3 year warranty
- ETL Approved

Product range

Code **ZSR**101 Z-one™ Relay switching relay ....single zone

Technical specifications

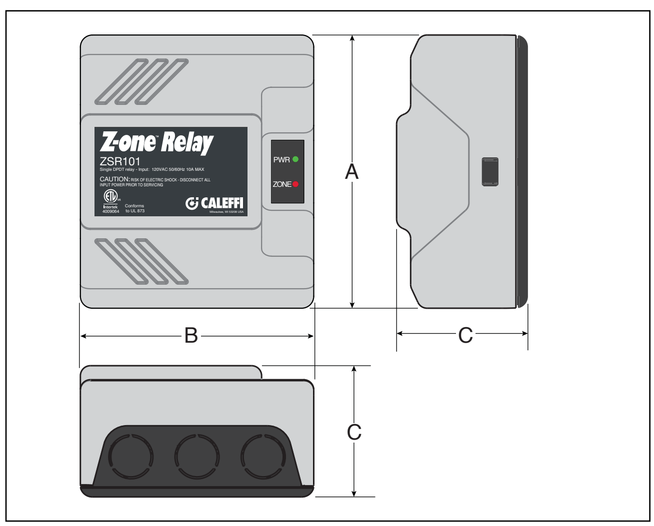
Materials

Housing plastic:	ABS
Front display lights:	LED
Electrical Knockouts	(6) 1/2" size

Performance

Power Supply:	120 VAC, 50/60 Hz
Transformer Voltage:	24 VAC
Maximum transformer load:	12 VA
Temperature limits for:	
Shipping and storage max:	110°F (43°C)
Maximum Operating:	110°F (43°C)
Maximum Humidity:	90% non-condensing
Electrical Switch Rating:	10A Max Combined
Replaceable Fuses:	Type 2AG, 5A Slow Blow
Approvals:	Conforms to UL873 listed by ETL

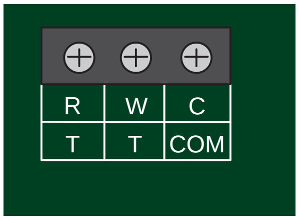
Dimensions



Code	Zones	A	B	C	Wgt. (lbs)
ZSR101	1	5 3/8"	4 5/8"	2 5/8"	1.1

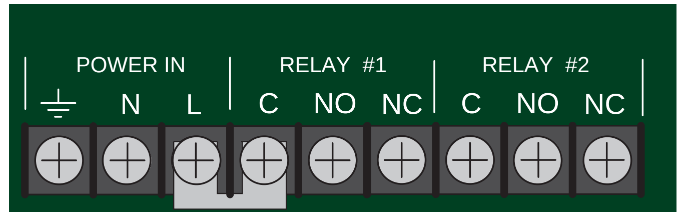
Operating principles

When a zone has a demand from a thermostat (T T or R W) the relay will close sending 120 VAC to Relay 1 NO terminal switching ON the pump, Relay 2 closes C to NO dry contact, signaling the boiler of a heating demand.

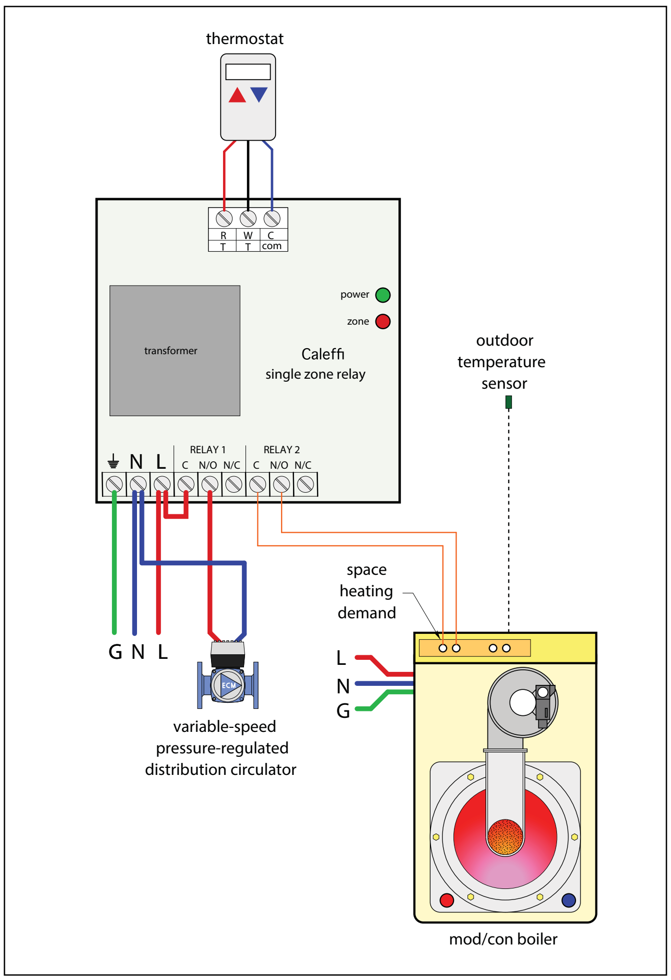


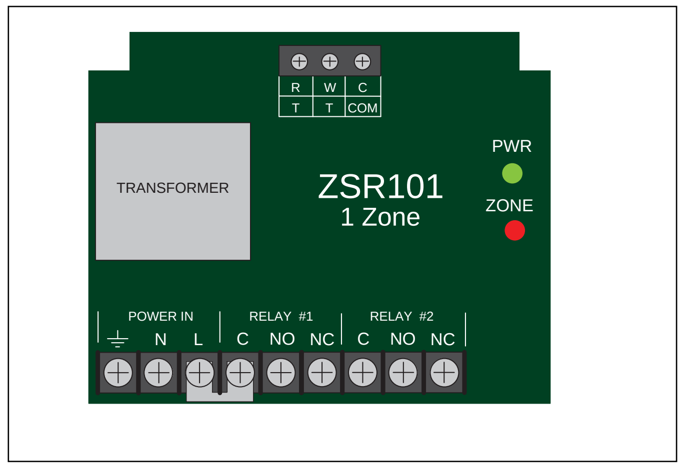
R, W, C and T T Comm dual labeling at thermostat terminals. Compatible with low voltage 2, 3, or 4 wire thermostats or any other low voltage devices having a switching action..

Large screw terminal connections makes wiring easy. Power IN 120V AC to N and L screw terminals with a factory installed jumper from L terminal to the C terminal of Relay 1 for simplified pump connection.



Wiring diagram (illustrative example)





Z-one™ Relay
Multi-zone switching relays

ZSR series

Intertek 4009064 Conforms to UL 873

Function

The ZSR series is multi-zone pump and boiler operating control for multiple zone hydronic heating or cooling systems. The ZSR series interfaces with low voltage thermostats, or any other low voltage controllers having a switching action. The ZSR series controls up to 3, 4, 5 or 6 heating circulator pumps, depending on model selected, a primary pump and has LED indicators to provide functional status and easy system troubleshooting. In addition, a primary pump system circulator is switched on whenever any zone calls for heat.

Features

- Compatible with low voltage 2, 3, or 4 wire thermostat
- R, W, C and TT Comm dual labeling at thermostat terminals
- Z-oneLink unlimited zone expansion
- 120 VAC pump outputs
- Selectable Priority with 1 hour time-out feature
- Selectable Post Purge
- Selectable Exercise
- Dry contacts for DHW (ZR/ZC), capable of switching line voltage
- High capacity transformer
- Large terminal connections
- Simplified wiring with extra ground terminals
- Heavy duty sealed relays
- Fuse protected (with spare fuse)
- Front LED Lights
- 100% Factory tested with 3 year warranty
- ETL Approved

Product range

Code **ZSR**103 Z-one™ Relay switching relays ......three zone
Code **ZSR**104 Z-one™ Relay switching relays ......four zone
Code **ZSR**106 Z-one™ Relay switching relays ......six zone

Technical specifications

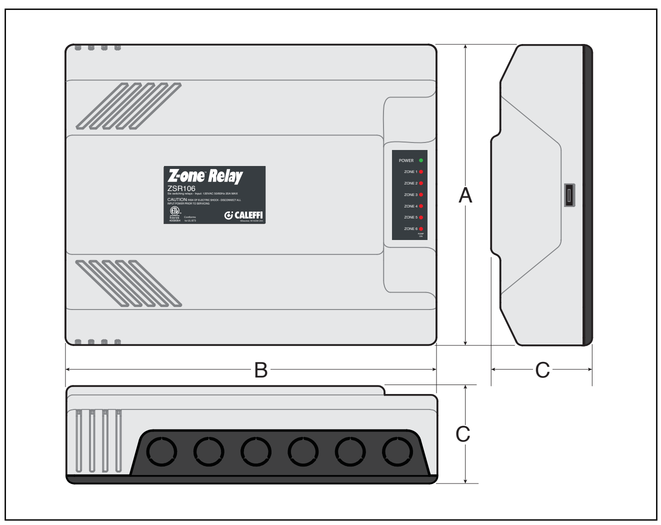
Materials

Housing plastic:	ABS
Front display lights:	LED
Electrical knockouts	(12) 1/2" size

Performance

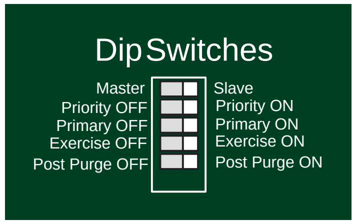
Power supply:	120 VAC, 50/60 Hz
Transformer voltage:	24 VAC
Maximum transformer load:	12 VA (ZSR103/4), 20 VA (ZSR106)
Electrical switch rating:	20A max combined
Electrical switch rating pump output:	120 VAC, 5A each
Dry contact rating, ZR/ZC, DHW, XX:	120 VAC max, 2A each
Replaceable fuses:	Type 2AG, 5A slow blow
Temperature limits for:	
Shipping and storage max:	110°F (43°C)
Maximum Operating:	110°F (43°C)
Maximum Humidity:	90% non-condensing
Approvals:	Conforms to UL873 listed by ETL

Dimensions



Code	Zones	A	B	C	Wgt. (lbs)
ZSR103	3	9 1/4"	11"	3"	3.2
ZSR104	4	9 1/4"	11"	3"	3.2
ZSR106	6	9 1/4"	11"	3"	3.2

Operating principles



The DIP Switches on the ZSR series can be positioned for the following operations.

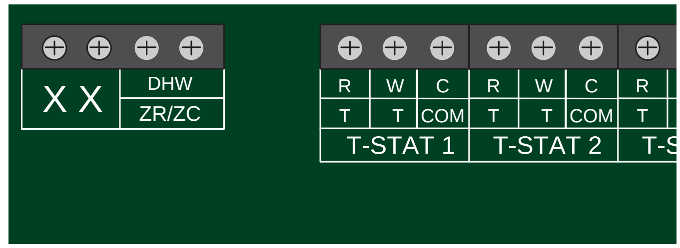
Master / Slave: allows for unlimited expansion to additional ZSR relays.

Priority OFF / Priority ON: When priority mode is ON, upon demand, zone 1 will operate as priority and all other zones are temporarily switched off (with 1 hour time-out). When priority mode is OFF, all zones remain active.

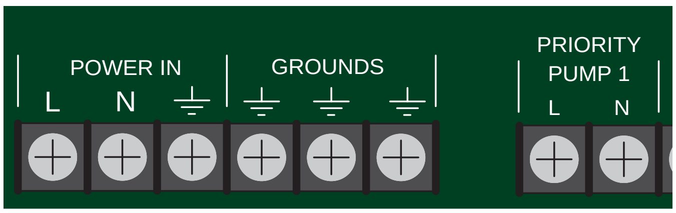
Primary OFF / Primary ON: When primary mode is ON, the primary pump will continue to operate during priority.

Exercise OFF / Exercise ON: When exercise mode is ON, each circulator is switched on for 30 seconds following 72 hours of inactivity.

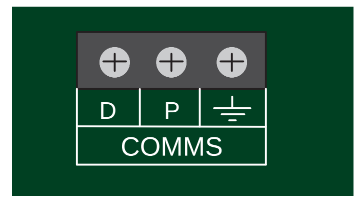
Post Purge OFF / Post Purge ON: When post purge is ON, the priority pump continues operating for 2 minutes after the priority zone is switched off.



When a zone has a demand from a thermostat (T T or R W) the relay will close sending 120 VAC to the corresponding zone pump, primary pump and closes (X X) dry contacts signaling the boiler of a heating demand. Zone 1 can be used for priority by positioning the Priority dip switch to ON, a demand from T-Stat 1 will activate priority pump 1 and all other zone pumps will be switched OFF, plus DHW (ZR/ZC dry contact rated to switch max 120 VAC, 2A) will close during priority. Depending on Primary pump dip switch position, the primary pump will remain either ON or OFF.

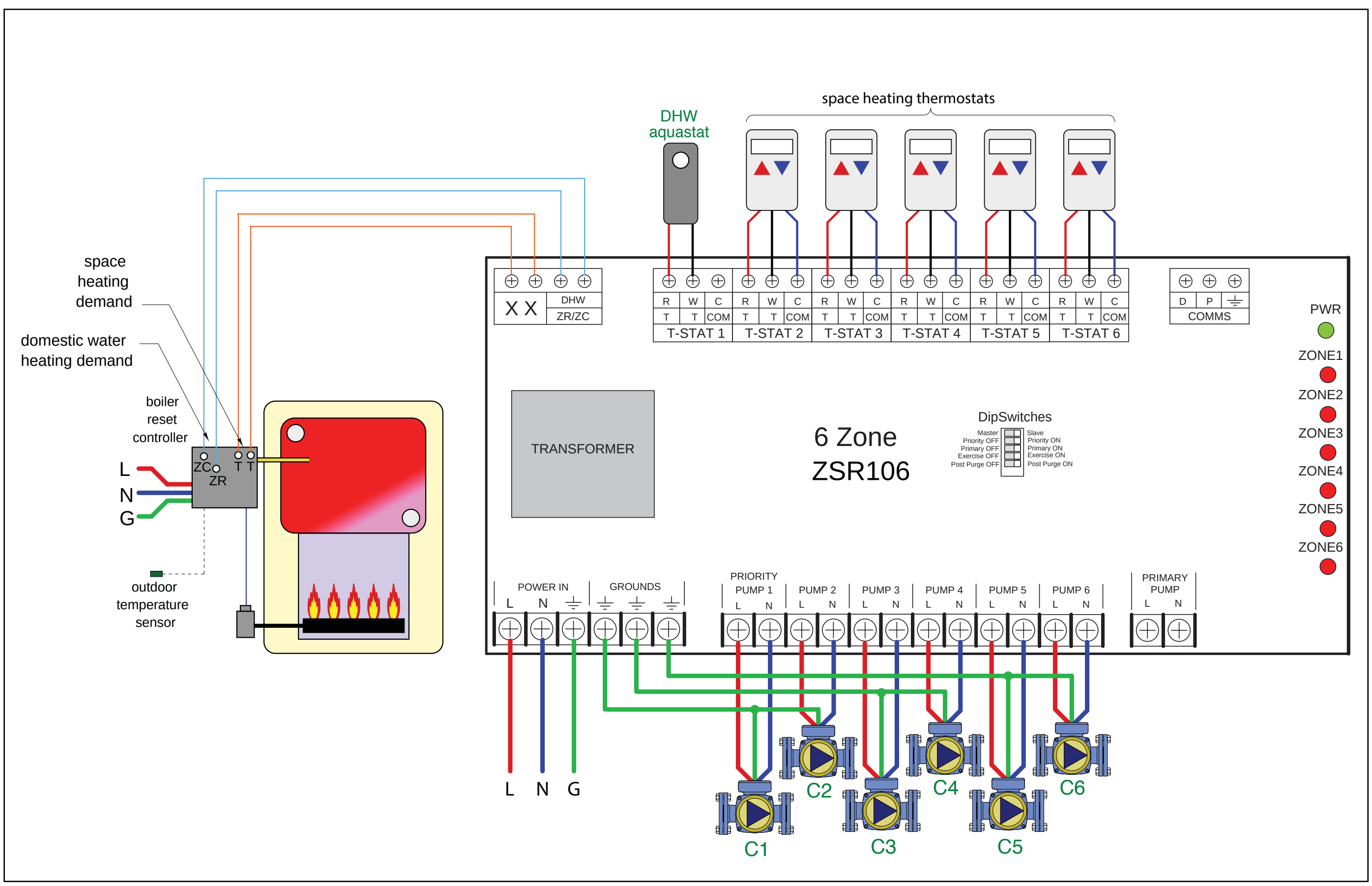


Large screw terminal connections makes wiring easy. Three extra ground screw terminals connection allows fast grounding of pumps. Pump terminals have 120 VAC outputs for simplified pump connection.



Z-oneLink unlimited expansion allows adding addition ZSR series relay controls to a Master ZSR. Communication is accomplished by connecting three wires (bell or thermostat wire) to the communication terminals located in the upper right hand corner. The dip switch is positioned to Master / Slave position. A demand for heat from any zone will fire the boiler and start the pump.

Wiring diagram (illustrative example)



Z-one™ Relay
Multi-zone valve switching

ZVR series

Intertek 4009064 Conforms to UL 873

Function

The ZVR series is a multi-zone valve relay and boiler operating control ior multiple zone hydronic heating or cooling systems. The ZVR series interfaces with low voltage thermostats, or any other low voltage controllers having a switching action. The ZVR series controls up to 3, 4, 5 or 6 zones, depending on model selected. In addition, a system circulator pump and secondary pump is turned on whenever any zone calls for heat. LED indicators provide functional status and easy system troubleshooting. The ZVR series is a perfect match with Caleffi's Z-one™ motorized zone valves.

Features

- Compatible with low voltage 2, 3, or 4 wire thermostat
- R, W, C and TT Comm dual labeling at thermostat terminals
- Z-oneLink unlimited zone expansion
- Selectable priority with 1 hour time-out feature
- System pump status selectable during priority
- Circulator will start only after the zone valve end switch is closed
- Dry contacts for DHW (ZR/ZC), capable of switching line voltage
- Large terminal connections
- High Capacity 40 VA Transformer standard for 3 and 4 zone models-expandable to 80 VA, and 80 VA for the 6 zone model
- Automatic resettable fuse
- Controls system pump, secondary pump, and priority pump
- Front LED Lights
- 100% Factory tested with 3 year warranty
- ETL Approved

Product range

Code **ZVR**103 Z-one™ Relay switching relays ....three zone
Code **ZVR**104 Z-one™ Relay switching relays ....four zone
Code **ZVR**106 Z-one™ Relay switching relays .... six zone

Technical specifications

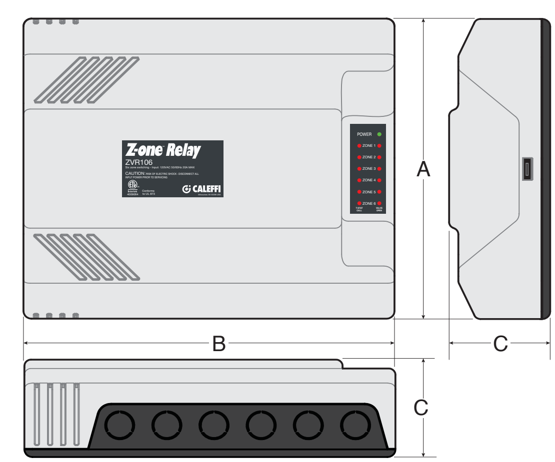
Materials

Housing plastic:	ABS
Front display lights:	LCD
Electrical Knockouts	(12) 1/2" size

Performance

Power supply:	120 VAC, 50/60 Hz
Transformer voltage:	24 VAC
Maximum transformer load:	40 VA (ZVR103/4), 80 VA (ZVR106)
Electrical switch rating:	20A Max Combined
Electrical switch rating, ZR/ZC, DHW, XX:	120 VAC, 2A each
Electrical switch rating pumps:	120 VAC, 5A each
Resettable Fuse:	automatic
Temperature limits for:	
Shipping and storage max:	110°F (43°C)
Maximum operating:	110°F (43°C)
Maximum humidity:	90% non-condensing
Approvals:	Conforms to UL873 listed by ETL

Dimensions



Code	Zones	A	B	C	Wgt. (lbs)
ZVR103	3	9 1/4"	11"	3"	3.2
ZVR104	4	9 1/4"	11"	3"	3.2
ZVR106	6	9 1/4"	11"	3"	3.2

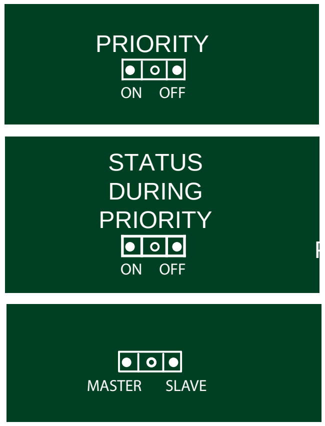
Operating principles

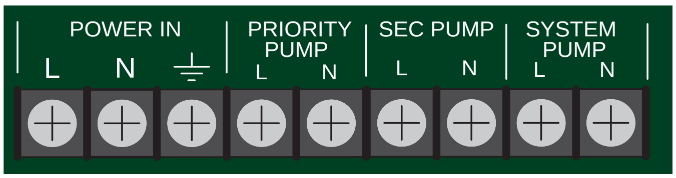
The jumpers on the ZVR series can be positioned for the following operations.

Priority ON / Priority OFF: When priority jumper is ON, upon demand, zone 1 will operate as priority and all other zones are temporarily switched off (with 1 hour time-out). When priority mode is OFF, any zones that were active when zone 1 was switched on will remain on.

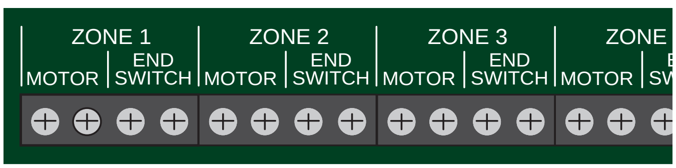
Status During Priority ON / Status During Priority OFF: When status jumper is ON, the system pump will continue to operate during priority.

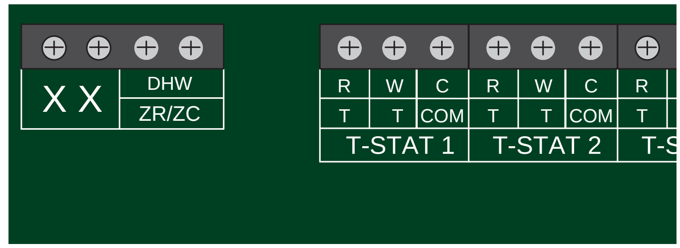
Master / Slave: allows for unlimited expansion to additional ZVR relays.





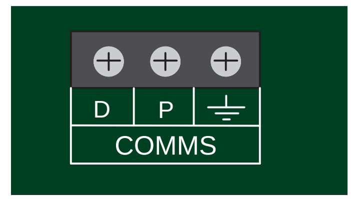
Larger screw terminals connections makes wiring easy with three pump screw terminal connections. Pump terminals connection have 120 VAC outputs for simplified pump connections. Zone valve connections can be 2, 3 or 4 wire.



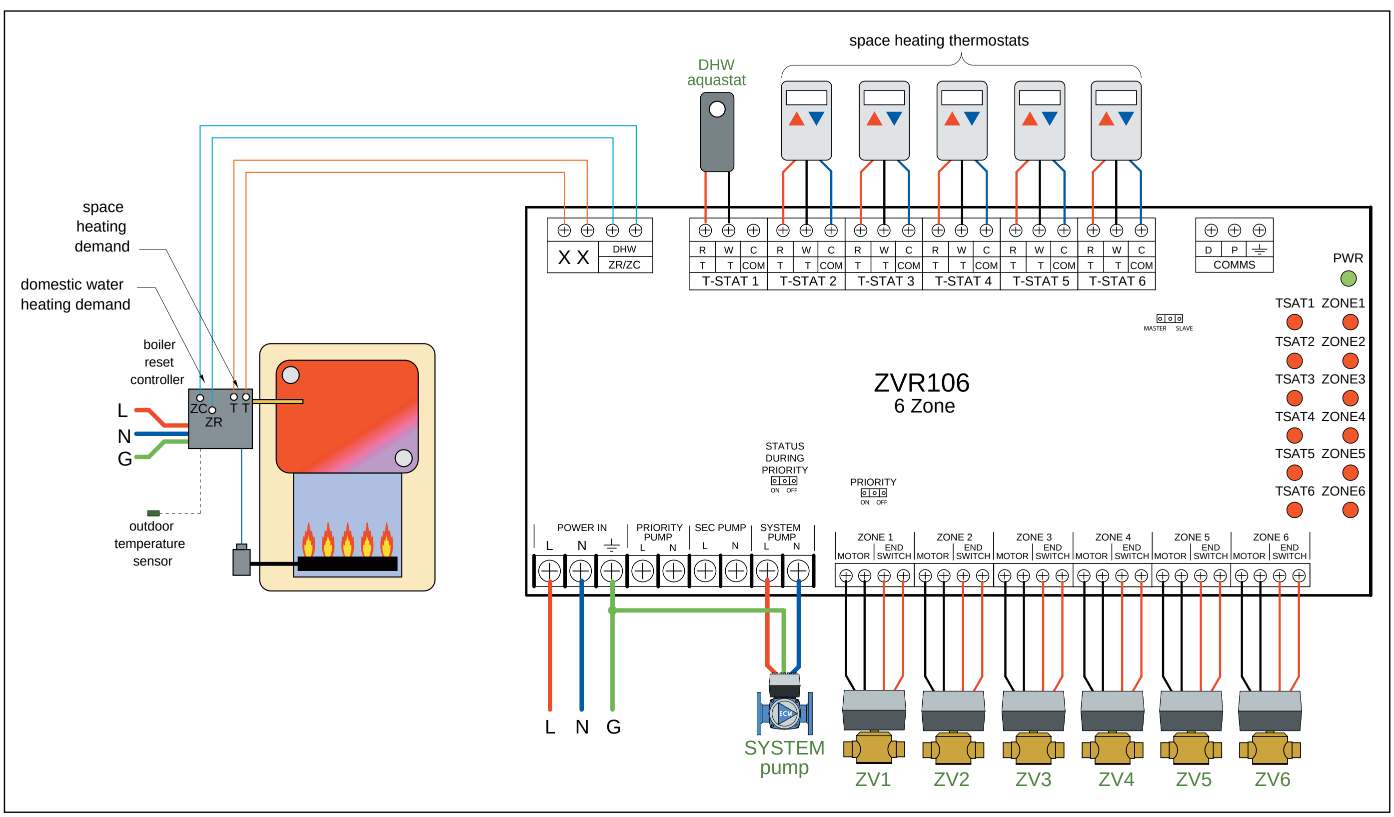


When a zone has a demand from a thermostat (T T or R W) the control will send 24 VAC to the corresponding zone valve. When the zone valve end switch closes, the primary pump will switch on and the (X X) dry contacts will close to signal the boiler of a heating demand. Zone 1 can be used for priority (either a priority pump or valve). When the priority jumper is ON, a demand from T-Stat1 will activate 24VAC to valve 1 and the priority pump will switch on after the end switch closes (requires a jumper if a valve is not used). The DHW (ZR/ZC) dry contact will also close. Depending upon "Status During Priority" jumper, the system pump will either be ON or OFF.

Z-oneLink unlimited expansion allows adding addition ZVR series relay controls to a Master ZVR. Communication is accomplished by connecting three wires (bell or thermostat wire) to the communication terminals located in the upper right hand corner. The jumper is positioned to Master / Slave position. A demand for heat from any zone will fire the boiler and start the pump.



Wiring diagram (illustrative example)



Z-one™ zone valve

Z series

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 an 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 leads or terminal connections UL listed for plenum installations UL listed for plenum installations.

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.

E239721 US LISTED 86BP

• US Patent 7,048,251.

Product range

Code **Z40** 24VAC normally closed with auxiliary switch, 18" wire leads with 2-way brass flare body................inverted
Code **Z40F** 24VAC normally closed with auxiliary switch, 18" wire leads with 2-way brass flare body ....¾"
Code **Z44** 24VAC normally closed with auxiliary switch, 18" wire leads with 2-way brass sweat body ....½"
Code **Z45** 24VAC normally closed with auxiliary switch, 18" wire leads with 2-way brass sweat body ....¾"
Code **Z45P** 24VAC normally closed with auxiliary switch, 18" wire leads with 2-way brass press-connect body ....¾"
Code **Z46** 24VAC normally closed with auxiliary switch, 18" wire leads with 2-way brass sweat body ....1"
Code **Z47** 24VAC normally closed with auxiliary switch, 18" wire leads with 2-way brass sweat body ....1¼"

Code **Z50** 24VAC normally closed with auxiliary switch, screw terminals with 2-way brass flare body ....Inverted
Code **Z50F** 24VAC normally closed with auxiliary switch, screw terminals with 2-way brass flare body ....¾"
Code **Z54** 24VAC normally closed with auxiliary switch, screw terminals with 2-way brass sweat body ....½"
Code **Z55** 24VAC normally closed with auxiliary switch, screw terminals with 2-way brass sweat body ....¾"
Code **Z55P** 24VAC normally closed with auxiliary switch, screw terminals with 2-way brass press-connect body................¾"
Code **Z56** 24VAC normally closed with auxiliary switch, screw terminals with 2-way brass sweat body ....1"
Code **Z57** 24VAC normally closed with auxiliary switch, screw terminals with 2-way brass sweat body ....1¼"

Code **NA10**005 Inverted flare nut with attached copper sweat tail piece................ ½"
Code **NA10**006 Inverted flare nut with attached copper sweat tail piece................¾"
Code **NA10**007 Inverted flare nut with attached copper sweat tail piece................1"
Code **NA16**265 Pressco™ copper press-connect union nut tail piece................¾"

Technical specifications

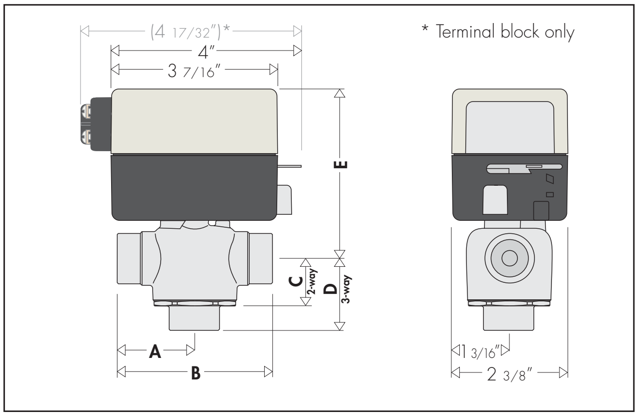
Valve body

Materials: - body:	forged brass
- seat:	machined brass
- stem:	stainless steel
- o-ring seals and paddle	EPDM
Flow:	1 to 7.5 Cv
Suitable fluids::	water and glycol solutions
Max. percentage of glycol:	50%
Fluid temperature range:	32 – 240°F
Max. static pressure:	15 psi low pressure steam 300 psi
Max. close-off Δ pressure:	20 to 75 psi
Connections: - sweat:	½", ¾", 1" & 1¼"
- NPT female:	½", ¾" & 1"
- inverted flare:	½", ¾" & 1"
- Press connect:	¾"
Approvals:	some bodies lead-free brass. Lead plumbing law certified by IAPMO R&T

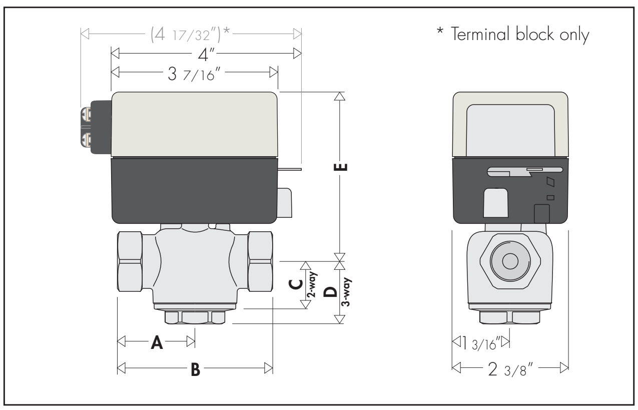
Actuator

Materials: - base & cover:	self-extinguishing poly-carbonate
- base plate:	aluminum
Motor: - standard AC voltage:	24 V ; 50/60 Hz
Power requirements:	5.0 W, 7 VA
Power connections: - Terminal screws with auxiliary switch:	24 V only
- Wire lead length:	18", 24 V only
Auxiliary switch load:	0.0 A min, 0.4 A max, 24 V (24V only)
Ambient temperature range:	32 to 104°F for 24, 120 V
Humidity:	95% non-condensing
Full Stroke Time: - On:	<60 seconds
- Off:	6 seconds
Approvals:	UL873, cUL Listed & CE UL 1995 sec. 18 approved for air plenums and ducts

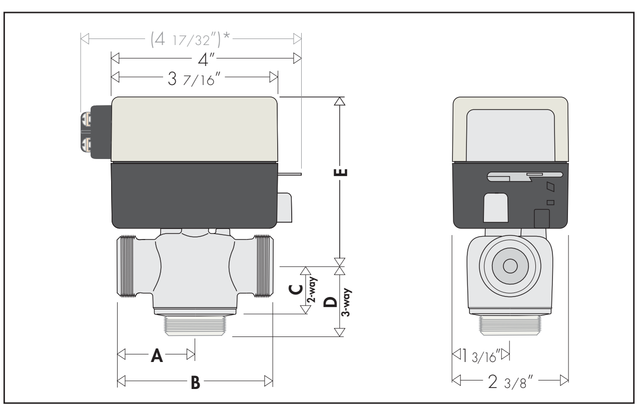
Dimensions



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	E
2-way 1" male union	1 7/16"	2 7/8"	15/16"	1 1/4"	3 1/2"
3-way 1" male union	1 7/16"	2 7/8"	15/16"	1 5/8"	3 1/2"

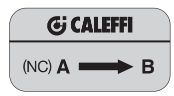
Operating principle

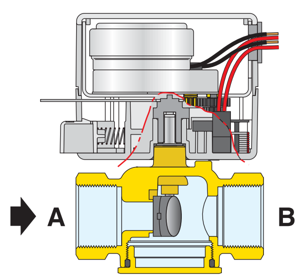
The Z-one™ actuator has a synchronous motor that winds the return spring and moves the valve paddle to the desired position. When power is removed the actuator spring returns the valve paddle. The Z-one™ actuator is equipped with or without auxiliary switch.

Operation of normally closed valve

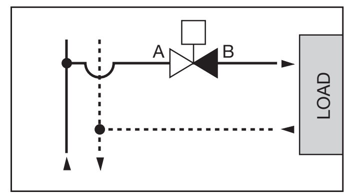
	2-way	3-way
N.C. without power	Port "A" closed	Port "A" closed Port "B" open Port "AB" open
N.C. opened with power	Port "A" opened	Port "A" opened Port "B" closed Port "AB" open
N.C. manually opened	Port "A" open	Port "A" opened Port "B" opened Port "AB" opened

2-way
(with the power off, passage A is closed)

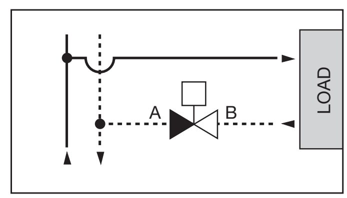




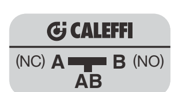
2-way installed on the flow side

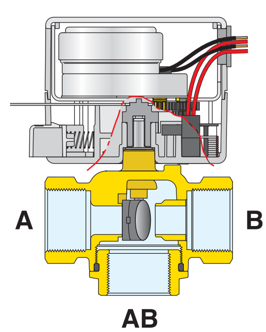


2-way installed on the return side

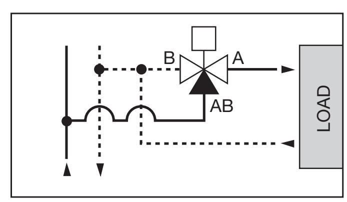


3-way
(with the power off, passage A is closed)

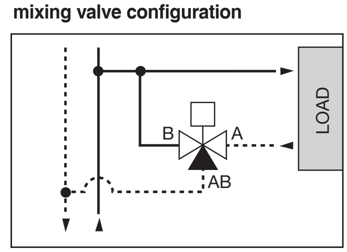




3-way installed on the flow side as a diverting valve configuration



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



Flow Switch

626 series

Function

The flow switch detects whether there is any flow in the piping and opens or closes an electrical contact. It is normally used in heating, air-conditioning, refrigeration, water treatment, additive pumping and process systems in general. The flow switch can control devices such as pumps, burners, compressors, refrigerators, motorized valves; to turn on indicator and alarm devices and regulate equipment for dosing water additives.

In heating systems, the flow switch will switch the burner off in case of a lack of fluid circulation in heating circuit. A lack of fluid circulation would otherwise impair the operation of the temperature-sensitive safety and protection devices

c UL us LISTED 30V9 Industrial Controls Equipment

Product range

Code 626600A Flow switch..1" NPT male
Code 626009 Replacement stainless steel paddle assembly........................ for pipe diameters from 1" to 8"

Technical specifications

Materials

Body:	brass
Cover:	Class UL94V-0 self-extinguishing poly-carbonate
Micro-switch protection casing:	self-extinguishing poly-carbonate
Bellows rod and bellows:	stainless steel
Paddle for pipes:	stainless steel
Micro-switch spring:	stainless steel
O-Ring seals:	EPDM

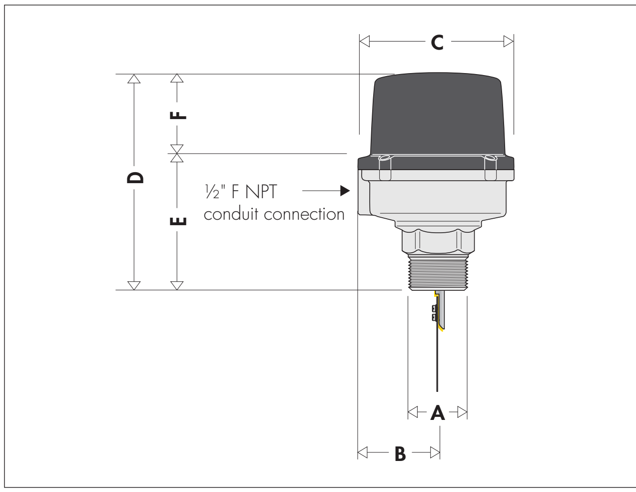
Performance

Suitable fluids::	water and glycol solutions
Max. percentage of glycol:	50%
Max. working pressure:	150 psi
Fluid temperature range:	-20 – 250°F
Minimum flow:	5.7 gpm
Connection:	1" NPT male
Pipe sizes:	from 1" to 8"

Electric specifications

Voltage:	250 VAC
Current:	15 (5) A
Protection class:	NEMA 5
Electrical connection:	½" NPT female
Approvals:	cULus, CE

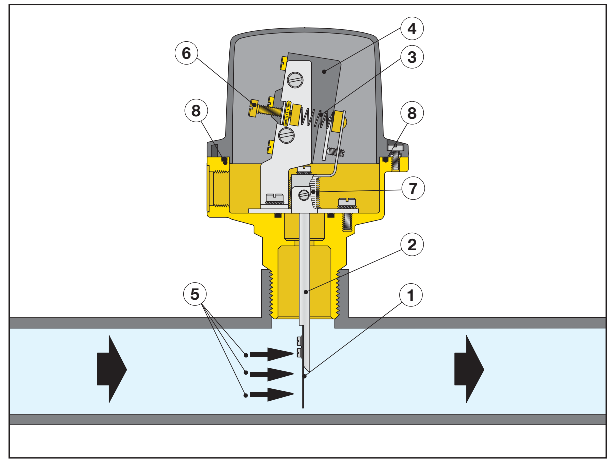
Dimensions



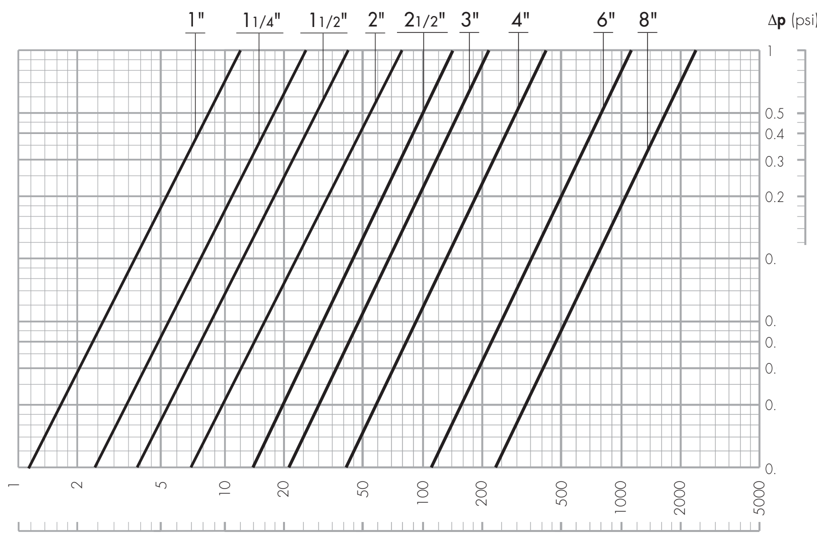
Code	A	B	C	D	E	F	Wgt (Lbs)
626600A	1" NPT	1 ¾"	3 ¼"	5 ¼"	3 ¼"	2"	2

Operating principle

The flow switch is composed of a paddle (1) integral with a control rod (2) connected, at the top, to an adjustable counter spring (3). The assembly, by turning around a pin under the action of the fluid flow, operates a micro-switch contained in a protective casing (4). At rest, the counter spring keeps the micro-switch contact open. When the increasing flow rate of the fluid within the piping becomes equal or greater than the trip flow rate, the thrust (5) on the paddle applied (1) by the flow overcomes the opposing force applied by the adjustable spring (3) thus making the micro-switch contact close. With a decreasing flow rate, on reaching the trip flow rate values, the flow thrust on the paddle is not enough to overcome the opposing force applied by the adjustable spring, so the paddle returns to the rest position and the micro-switch contact opens.
The trip values for closing (increasing flow) and opening (decreasing flow) the micro-switch contact can be modified with the adjusting screw (6).



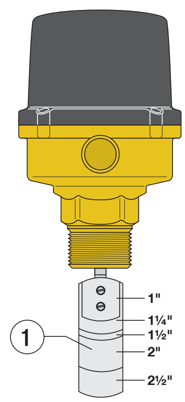
Hydraulic Characteristics

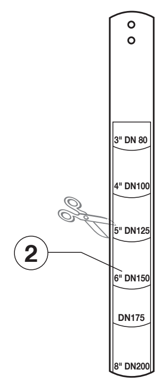


Size	1"	1 1/4"	1 1/2"	2"	2 1/2"	3"	4"	6"	8"
Cv	11.5	24.3	37.6	67	139	208	405	1098	2255

Installation

The unit is equipped with a set of paddles (1), to be used for different pipe diameters, particularly sized to allow easy installation and minimal head losses.
For diameters equal to or greater than 3", it is necessary to add to the pre-assembled paddle in increasing order the long paddle (2) (supplied in the package), just cutting it to the size corresponding to the desired diameter. Replacement paddle assemblies are available, order part number 626009.



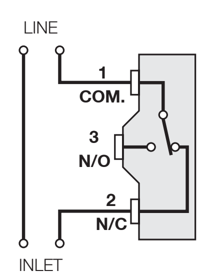


Operating flow rates: gpm

Diameter of pipe	1"	1 1/4"	1 1/2"	2"	2 1/2"	3"	4"	5"	6"	8"
Minimum calibration Operating trip flow rate **with increasing flow**	5.7	7.5	11.4	13.2	22.0	29,9	44.0	61.1	72.6	162
Minimum calibration Operating trip flow rate **with decreasing flow**	4.0	5.5	8.4	9.7	16.3	22.9	37.4	51.5	63.8	145
Maximum calibration Operating trip flow rate **with increasing flow**	12.3	16.7	26.0	29.5	51.5	69.5	94.6	136	189	334
Maximum calibration Operating trip flow rate **with decreasing flow**	11.9	16.3	25.5	29.0	50.6	68.6	92.4	127	158	308

Micro-switch connections

Flow switch is used to activate a device when flow starts. When flow starts and the increasing operating trip flow is reached or exceeded, the common (1) and normally open (3) contacts are closed, while the common (1) and the normally closed (2) are open.



INNOVATIVE ZONING

Z-one™ Relay

MULTI-ZONING RELAYS

- Single zone switching relay
- Multi-zone 3, 4, 5 and 6 pump switching relays
- Multi-zone 3, 4, 5 and 6 zone valve switching
- Z-oneLink unlimited zone expansion standard
- Selectable priority, post purge and exercise
- Dry contacts for DHW (ZR/ZC), capable of switching line voltage
- Large screw terminals with extra ground screw terminals
- Front bright LED function lights
- Heavy duty sealed relays, fuse protected
- 100% Factory tested with 3 year warranty
- Conforms to UL873 listed by ETL

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