Block F: Hydronic Heating and Cooling Systems

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Plumbing Apprenticeship Program Level 3

Industry Training Authority BC

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VICTORIA, B.C.

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Introduction

In this training block you will look at hydronic heating and cooling systems. Fundamentals of hydronics will be introduced, followed by determining system loads, and examining different radiant systems. You will also be introduced to electrical components and controls specifically used in the installation of hydronic systems.

Competency F1: Determine Hydronic System Loads

The intent of this section of learning resources is to familiarize the learner in the methods used to estimate heat losses for buildings of residential construction. The information presented has been based on literature provided by TECA (Thermal Environmental Comfort Association of BC). TECA are an amalgamation of two volunteer, not-for-profit trade associations of contractors, manufacturers, wholesalers and agents of heating and cooling equipment. They operated in British Columbia independently as RHWHA (Residential Hot Water Heating Association of BC) and HVCI (Heating, Ventilating and Cooling Industry Association of BC) until May of 2006 when they amalgamated to form TECA. It is important to point out that all local codes and standards are to be consulted when applying the information taken from this text, specifically in the requirement for conformance to the document CSA-F280 “Determining the Required Capacity of Residential Space Heating and Cooling Appliances”.

Learning Objectives

After completing the learning tasks in this Competency, you will be able to:

- Size piping and components for hydronic systems
- Design a residential hot water radiant floor heating system

Learning Task 1

Purpose of a Heating System

Comfort

The main purpose of a building's heating system is to provide comfort for its inhabitants. By definition, comfort is a condition whereby a person feels neither too cold nor too hot. The human body achieves comfort when it can "dump" the heat created by bodily functions at the same rate as by which it gains heat from its immediate environment. A person undergoing light activity will generate, and have to get rid of, approximately 400 btus (422 kJ) per hour in order to feel comfortable. If there is too little heat supplied to that person from the building's interior spaces, that person will feel cold; too much and they will feel hot. If they increase their activity level, they'll need to get rid of more heat, and a cooler surrounding air temperature would be required in order for them to not feel overheated. As you can guess, a building's heating or cooling system does not have the ability to anticipate the comfort levels of every person within it, as we all have differing metabolisms and levels of activity. The best we can do, as heating professionals, is to provide a constant, uniform temperature within the building so that each individual may tailor their activities and attire to meet their own needs.

The manner by which a person receives the external heat it requires is also a major contributor to the level of comfort expected. The human body loses heat by five means: radiation, convection, evaporation, conduction and respiration.

A body loses the majority (approximately 48%) of the heat it generates by way of thermal radiation. Radiation is the transfer of heat via infra-red waves through the air from a warm object to a colder object. In the winter, if a person sits close to an outside wall, they will feel colder than if they were sitting nearer to the middle of the room, even though the air temperature in the two locations is the same. This phenomenon has been labeled "cold 70".

Heat lost by convection (air currents) accounts for approximately 30% of the body's total heat loss, and approximately 22% is lost through evaporation (sweating). If a person is clothed and wearing slippers or shoes, conduction losses are very minimal, such as would occur through bare feet on a cold floor. As well, respiration (breathing) losses are so small that they are not considered when designing heating systems.

Radiant Heating vs Convection Heating

Because radiation losses from a body are the highest of all the methods of heat transfer mentioned, it makes sense that, by putting heat back to that person in the same manner, they should feel most comfortable. The "ideal heat curve" of the human body would see the floor temperature at approximately 80°F (approximate skin temperature), to approximately 68°F at a point 5 feet above the floor (average head height), and to much less near the ceiling, where heat is generally not needed. A radiantly-heated floor panel system matches almost perfectly those heat layers which the human body needs for most comfort.

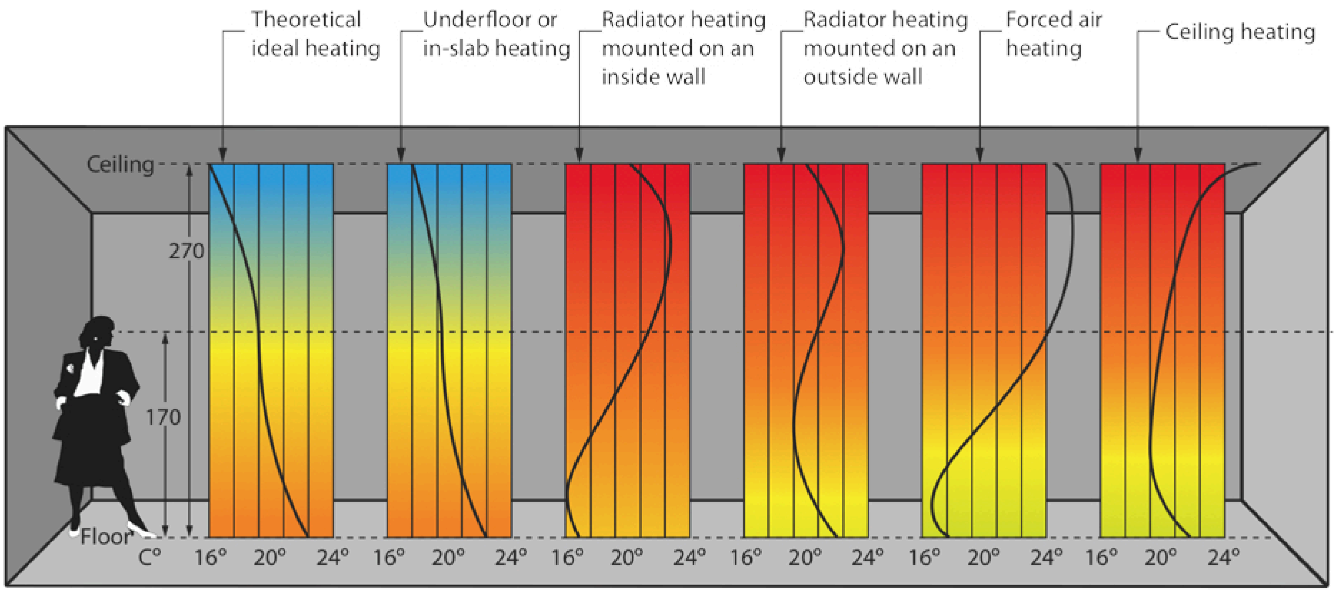

Figure 1 Theoretical ideal heating curve comparisons

On the other hand, forced warm air furnaces supply hot air to a room through grilles in the floor. This hot air rises and collects near the ceiling, which intensifies the heat loss high up in the room. The floor is cold to the touch, while the air temperature at face level may be close to the desired setpoint of the thermostat. Coupled with the fact that forced air systems try to achieve their results by adding heat to an insulator (air) and distributing it, forced air systems typically operate as one big zone, with a thermostat located in a hallway or central part of the house. While the hallway may be comfortable, nobody typically spends time there and the living areas of the house suffer the consequences. The rooms at the south end of the building are overheated while the rooms on the north side are generally colder. There are far more advantages than disadvantages to the use of hydronics, in particular hydronic radiant systems, over the use of forced air systems.

Btus

Heat is described and measured by its *intensity* and *quantity*. Most people know that they are experiencing heat when they touch a metal object whose other end is embedded in a flame and it feels hot to the touch. In actual fact a *quantity of heat* is being applied to the end of the metal piece within the flame, and this results in a change in *intensity of heat* (temperature) in degrees Fahrenheit or Celsius between the molecules of the metal in the two opposite ends of the metal. This is evidence of heat transfer via conduction.

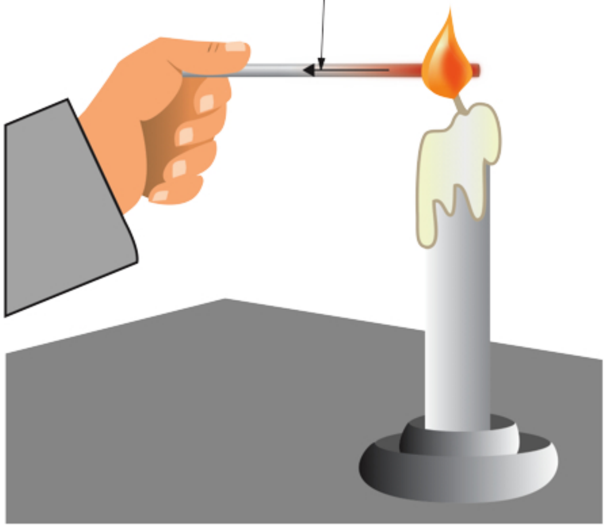

Figure 2 Heat transfer via conduction

If the end of the metal farthest from the flame gets hot to the touch, the person is experiencing the intensity of heat within the metal object. It is the quantity of heat that we are most concerned with when we design a building's heating system. That quantity is measured in btus or, more specifically to our heating industry, in btus per hour (btuh).

The language of heat within the heating industry in North America is predominantly in Imperial terms. Therefore, for the purposes of the information within this learning guide, quantities of heat will be referred to in Imperial terms as btuh, and intensities of heat will be referenced in degrees Fahrenheit (°F). It should be noted that some building departments or jurisdictions in Canada may require heat loss estimates to be in kilojoules (kJ) and degrees Celsius (°C). In those instances, heat loss calculations can be done in Imperial terms first and then converted into the desired outcomes.

One kilojoule (1 kJ) = 0.95 btus, or conversely 1.055 kJ = 1 btu.

For heat's intensity, 1.8 °F = 1°C, or conversely 0.555 °C = 1°F.

To convert heat's intensity to a temperature scale (thermometer), the formula to use is:

$$(°C \times 1.8) + 32 = °F, \text{ or conversely } (°F \div 1.8) - 32 = °C.$$

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Learning Task 2

The Concept of Heat and Heat Transfer

Heat Loss ("Load") Calculations

A btu (British Thermal Unit) is the *quantity* of heat required to raise the temperature of one pound of water by one degree Fahrenheit. Therefore, it would require adding 2 btus to 2 pounds of water in order to raise its temperature by 1°F, 3 btus for 3 pounds of water through 1°F and so on. The quantity of heat in btus needed for any process that involves the sensible heat that changes the temperature of an amount of water can be calculated by using this formula:

$$\textbf{BTUs} = \textbf{mass} \times \Delta\textbf{T} \times \textbf{S.H.}$$

Mass will be the weight of water in pounds, ΔT will be the desired change in temperature in °F, and S.H. (specific heat) of water is 1 (see the previous paragraph).

Example 1

Calculate the required btus to take 40 Imp. gallons of water from 50°F to 140°F, such as would be occurring when initially filling and heating the water in a standard electric water heater.

Mass will be 40 Imperial gallons × 10 pounds/Imperial gallon = 400 pounds of water

ΔT will be (140°F − 50°F) = 90°F

S.H. (specific heat) of water = 1

Therefore, the heat quantity required for that job would be:

400 × 90 × 1 = 36,000 btus.

If the expectation is that this job needed to be done in an hour, then we would have to add 36,000 btuh to the water. If the job were to be compressed to within ½ hour, then we would have to double the heat quantity to meet that time frame, so we would have to apply 36,000 × 2 = 72,000 btuh.

Example 2

Calculate the heat load on a boiler that contains 20 Imperial gallons of water, if the water temperature has to be increased from 170°F to 190°F.

Mass = 20 Imp. Gallons × 10 lbs/Imp gal = 200 lbs

ΔT = (190 − 170) = 20°F

S.H. of water = 1

200 × 20 × 1 = 4,000 BTUs

Boilers used in residential hydronic (hot water) heating systems typically operate on a temperature differential (ΔT) of 20°F, unlike a storage-type water heater that normally operates on a ΔT of approximately 90 to 100°F. Traditional non-condensing boilers must keep the temperature of the water returning back into the boiler at a minimum of 140°F so as to keep condensation from forming on the external surfaces of the heat exchanger. Condensation is caused when the large amounts of water vapour produced by the burning of hydrocarbon gases, such as natural gas and propane, come in contact with a heat exchanger that, although considered hot, has a temperature below atmospheric dewpoint (approximately 129°F). Condensation would create many problems including corrosion, sooting, cooling of the flame, plugged heat exchangers and premature failure.

In the heating industry, the heat quantities required are predominantly expressed within a 1-hour time frame. Thus, our heat loads are always referenced as “BTUH”. We will look at the losses from a building and the heat we intend to put back into it in order to offset those losses, and we’ll specify those requirements in terms of BTUH.

Water vs Air as a Heating Medium

It has long been known that the use of water for heating buildings has many advantages over the use of air for the same purposes. This is covered within the Level 2 learning guide and should be revisited to get the most knowledge from this learning package. Aside from other factors discussed, the single most-utilized advantage is water’s ability to hold more heat than can air. One US gallon of water (the industry standard) would contain approximately 167 btus if it were to be heated from 170°F to 190°F. (8.33 pounds × 20°FΔT × 1). By comparison, the volume of air required to hold the same amount of heat would be staggering. The specific heat of one cubic foot of air is 0.018 btu. In other words, it would take 0.018 btus to raise the temperature of one cubic foot of air by one degree Fahrenheit. If Q represents the amount of air in ft^3 needed to hold 167 btus, and we were trying to increase temperature by 20°F, then we would apply the formula:

$$Q \times 0.018 \times 20 = 167$$

Working the formula through, we would calculate Q to be approximately 464 ft^3.

What this means is that, in order to deliver a 20°F increase in temperature to a hot water heating system, we would only have to send out 1 US gallon of water into it, whereas we would have to deliver 464 ft^3 of air to a forced air heating system in order to get the same result. A single ¾″ diameter pipe could easily and noiselessly achieve this. A warm air duct, having a great internal area and contributing far more noise to the building (along with other associated down-sides) could also deliver this same amount of heat. Ducts, however, are much harder to conceal within a structure without compromising the structure’s integrity. Also, “zoning”, which is the strategy of applying heat to only certain areas of a building as needed, is much easier to accomplish with water rather than with air. With zoning, the correct amount of heat is delivered to each area based upon that area's identified heat losses. Although ducted air systems can be "zoned", it is far more involved and expensive than when using water. Again, it has long been known that hydronic systems are preferred over air systems for heating purposes for just those reasons. The one downside to a hydronic system when compared to an air system was always the relative complexity of controls and heat transfer units needed when trying to provide cooling to a building using water. The same ductwork that heats a house in the winter can cool the house in the summer simply by the use of an outdoor condensing unit coupled to a cooling coil mounted within the supply air duct (plenum) connected to a forced warm air furnace.

Heat Transfer

As mentioned earlier, the human body transfers heat in 5 ways, which are radiation, convection, perspiration, conduction and respiration. Seeing as a building doesn't have lungs or sweat glands, a building's heat is lost via radiation, conduction and convection. Ever since man discovered fire, it has been known that some materials allow heat to move through them better than others. These materials are known as thermal conductors or simply conductors. Conductors such as glass, metal and concrete have their molecules bound together fairly tightly and although the robust qualities of both metal and concrete make them well suited as construction materials, those same qualities are undesirable when trying to maintain a comfortable indoor environment. Other materials, such as fiberglass and polystyrene ("styrofoam"), don't have such tight molecular bonds, and as such won't conduct heat through them as readily. These materials are known as insulators, and are used in cavities between structural members in buildings to reduce the movement of heat. Fiberglass batts, polystyrene board and, more recently, sprayed-in foam are the most common materials used to insulate buildings.

Figure 1 Fiberglass batt insulation

Air is also considered an insulator, as long as it can't move freely in or out of a confined space, such as between two sealed panes of glass. For many decades now, window manufacturers have utilized the practise of creating a "dead-air space" between sealed glass panes in order to increase the insulative value of windows. Reflective coatings and the use of argon and similar inert gases increase the insulation values even further.

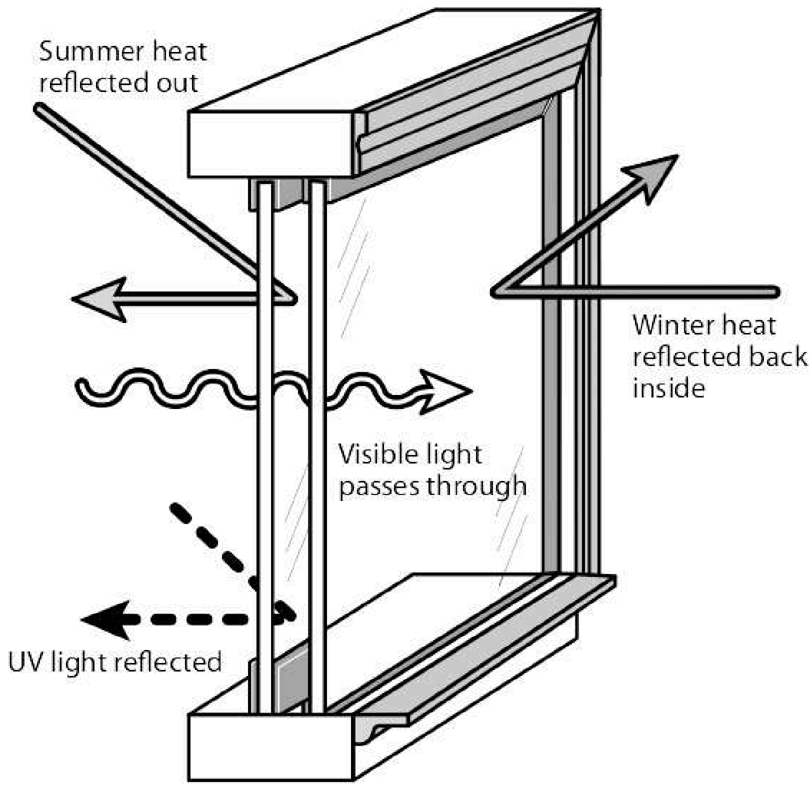

Figure 2 Modern double-pane sealed "low-E" window

DTD (Design Temperature Difference or Differential)

The "R", "K" and "U" values for materials are expressions of thermal resistance or conductivity for materials or assemblies when there is a 1°F differential, or "ΔT", between the two sides or faces of that material or assembly. As mentioned earlier, if the ΔT is doubled, then the rate of heat transfer will also double. If the ΔT is halved, then so will be the rate of transfer and so on. The ΔT that is used in heat loss calculations for buildings will the temperature difference between what is desired indoors, known as "Indoor Design Temperature" or "IDT", and the outdoor design temperature or "ODT".

Part 9 of the BC Building Code ("BCBC") identifies the indoor design temperature to be used in three areas of buildings.

Specifically, 9.33.3.1 (1) contains:

- subclause (a) which requires a minimum IDT of 22°C (72°F) for indoor living spaces,
- subclause (b) which requires a minimum IDT of 18°C (64°F) for unfinished basements, and
- subclause (d) which requires a minimum IDT of 15°C (59°F) for heated crawl spaces.

For ease of calculations, most designers will use **72°F** for all heated areas of a residential building, however there could be cases where this may lead to the selection of a heat plant (eg. boiler) that is oversized for that application. There can be 25,000 to 50,000 btuh or more of input separating boiler models. If the heat required for the building is just above what a certain desired boiler's output can deliver, the designer has the ability to re-evaluate or "fine tune" the heat loss in areas such as unfinished basements and heated crawlspaces, using their specific IDTs. This could possibly lower the heat loss estimate to a point which would allow a heat plant with smaller input to be selected while still delivering the minimum amount of heat needed for the application.

In addition, TECA's Hydronics System Guidelines suggests that an IDT of 68°F (20°C) may be used in occupied areas where hydronic radiant heating is the primary source of heat. This is due to the fact that a room heated to 68°F through radiant means can offer the same level of comfort as one that is heated via convection to 72°F.

The BCBC specifies that the "Outdoor Design Temperature" ("ODT") will be taken from Appendix 2 Climatic Design Data for Selected Locations in British Columbia. The value to be used is known as the "January 2.5% Value".

Design Temperature Chart for selected BC Locations									
	Design					Design			
Location	Temp. [F]	Adjustment	(calc)	(calc)	Location	Temp.[F]	Adjustment	(calc)	(calc)
Abbotsford	13	1.07	0	0	Mcleod Lake	-32	1.89	0	0
Agassiz	7	1.18	0	0	Masset	18	0.98	0	0
Alberni	22	0.91	0	0	Merritt	-15	1.58	0	0
Ashcroft	-14	1.56	0	0	Mission City	14	1.05	0	0
Beaton River	-36	1.96	0	0	Montrose	0	1.31	0	0
Burns Lake	-24	1.75	0	0	Nakusp	-11	1.51	0	0
Cache Creek	-14	1.56	0	0	Nanaimo	20	0.95	0	0
Campbell River	18	0.98	0	0	Nelson	-5	1.4	0	0
Carmi	-11	1.51	0	0	New Westminster	19	0.96	0	0
Castlegar	-2	1.35	0	0	North Vancouver	19	0.96	0	0
Chetwynd	-33	1.9	0	0	Ocean Falls	9	1.15	0	0
Chilliwack	10	1.13	0	0	100 Mile House	-20	1.67	0	0
Cloverdale	17	1	0	0	Osoyoos	3	1.25	0	0
Comox	18	0.98	0	0	Penticton	3	1.25	0	0
Courtenay	18	0.98	0	0	Port Alberni	22	0.91	0	0
Cranbrook	-17	1.62	0	0	Port Hardy	21	0.93	0	0
Crescesnt Valley	-5	1.4	0	0	Port McNeill	21	0.93	0	0
Crofton	21	0.93	0	0	Powell River	15	1.04	0	0
Dawson Creek	-35	1.95	0	0	Prince George	-31	1.87	0	0
Dog Creek	-20	1.67	0	0	Prince Ruppert	15	1.04	0	0
Duncan	21	0.93	0	0	Princeton	-16	1.6	0	0
Elko	-20	1.67	0	0	Qualicum Beach	19	0.96	0	0
Fernie	-21	1.69	0	0	Quesnel	-29	1.84	0	0
Fort Nelson	-41	2.05	0	0	Revelstoke	-16	1.6	0	0
Fort St.John	-34	1.93	0	0	Richmond	19	0.96	0	0
Glacier	-17	1.62	0	0	Salmon Arm	-10	1.49	0	0
Golden	-17	1.65	0	0	Sandspit	20	0.95	0	0
Grand Forks	-4	1.38	0	0	Sidney	21	0.93	0	0
Greenwood	-5	1.4	0	0	Smithers	-22	1.71	0	0
Haney	15	1.04	0	0	Smith River	-51	2.24	0	0
Hope	2	1.35	0	0	Squamish	12	1.09	0	0
Kamloops	-10	1.49	0	0	Stewart	-10	1.49	0	0
Kaslo	-9	1.47	0	0	Surrey	17	1	0	0
Kelowna	0	1.31	1.31	0	Taylor	-34	1.93	0	0
Kimberley	-16	1.6	0	0	Terrace	-5	1.4	0	0
Kitimat Plant	2	1.35	0	0	Tofino	27	0.81	0	0
Kitimat Townsite	2	1.35	0	0	Trail	3	1.25	0	0
Langley	17	1	0	0	Ucluelet	27	0.81	0	0
Lillooet	-10	1.49	0	0	Vancouver	19	0.96	0	0
Lytton	-3	1.36	0	0	Vernon	-5	1.4	0	0
Mackenzie	-33	1.9	0	0	Victoria	23	0.89	0	0
McBride	-31	1.87	0	0	Williams Lake	-23	1.73	0	0
					Youbou	22	0.91	0	0

Figure 3 Outdoor Design Temperature Chart

This is not the lowest recorded temperature for that location, but is the lowest expected temperature for all but 2.5%, or approximately 18 hours, of what is considered the coldest month of the year. The rationale for the 2.5% value is that buildings tend to retain their heat well enough to withstand a short period where the outdoor temperature drops below the 2.5% temperature value without dire consequences. If needed, extra layers of clothing and supplemental heat can assist building occupants in “weathering” these rare occasions.

“Design temperature difference” (DTD), or the calculated difference between the IDT and ODT, must be determined because it is used in each formula in estimating building heat loss. According to Table C-2 of the BCBC, a heat loss design estimate for a building in Penticton, BC would use 5°F (−15°C) as the ODT and 72°F (22°C) as the IDT. This means that each formula would have 67°F used as the DTD (ΔT).

Heat Gain

Buildings will gain heat in the same manner as they lose it. Some areas of the province, in particular those in the Okanagan valley, rely heavily upon air conditioning for summer comfort. In those cases, a heat gain estimation would be calculated much in the same way as for a heat loss, using the indoor design temperature and the outdoor “dry bulb” (ambient air) temperature to calculate a design temperature difference. Appendix “C” of the BCBC lists the July 2.5% dry bulb values for most locations within BC.

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Learning Task 3

Heat Loss and Heating Requirements

Transmission Loss

In the heating season, we want to prevent the heat that we've put into the building from passing through building materials to the great outdoors. Heat that is lost via conduction through the molecules of the building structure's materials is known as *transmission loss.*

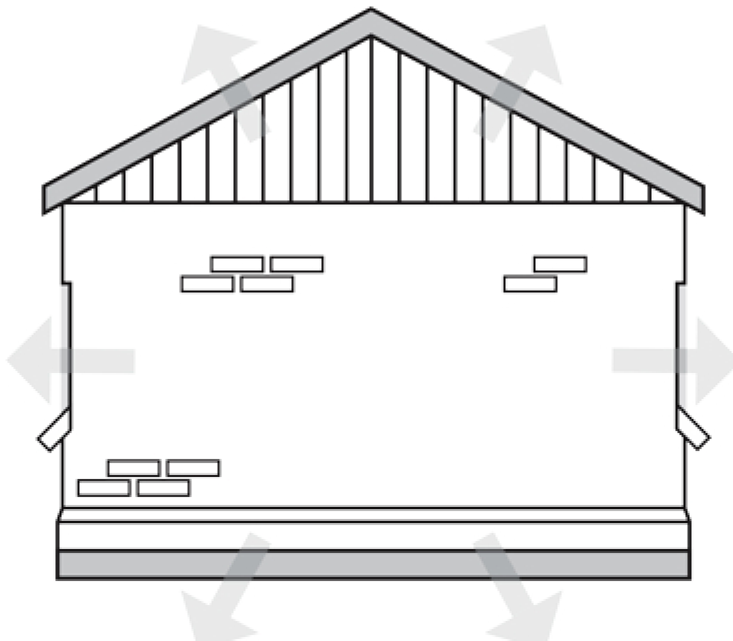

Figure 1 Transmission losses through the materials of the building envelope via conduction

Through many decades now, manufacturers and industry associations have tested and certified the materials commonly used in construction as to their ability to resist the flow of heat through them, and have applied a recognized identifier to them. This identifier is known as an "R" value, with "R" signifying "thermal resistance". Here's a common example of a material with its "R" value clearly shown on its packaging.

Figure 2 R14 Batt Insulation

"R" values are indicative of the number of hours it would take for 1 BTU to pass through 1 ft^2 of this material when the ΔT between the two sides of the material is 1°F. This is sometimes written as:

$$R = 12 \text{ hrs/btu/ft}^2/°F$$

R12 fiberglass insulation is commonly used in 2 × 4 outer wall construction typical of the 1960's to 1980's. R14 fiberglass batts can also be found in 2 × 4 construction, but the material is slightly more dense than the R12 and therefore has a better insulating quality to it. Today's construction, typically using 2 × 6 exterior wall studs, uses R20 to R28 batt insulation or, better yet, spray foam between the studs. In essence, the higher the "R" value, the better the insulator.

An "R" value is an expression of how long, in hours, it would take for 1 BTU to pass through 1 ft^2 of material when there is a 1°ΔT between the two sides. In the heating industry, however, this expression is exactly backwards to what we need to know. Our industry is based on information expressed in BTUs per hour, not in hours per BTU. To be able to do any of the calculations necessary in building, we must turn an "R" value into what is known as a "K" value. This is done by simply dividing the single material's "R" value into 1. As an example, if we want to calculate how many BTUs per hour will pass through R14 insulation, we would divide 1 by 14 to get a "K" value of 0.07. This means that 0.07 BTUH will pass through 1 ft^2 of this material when the ΔT between the two faces is 1°F. If we double the thickness of the material, it will take twice as long for heat to pass through it. And, if we double the ΔT between sides, it will take ½ the time for the heat to pass through.

So, just like our previous calculations regarding BTU calculations and water, there is a formula to use when trying to estimate the transmission losses through a material. The formula is:

$$\text{Transmission loss} = \text{Area (ft}^2) \times \text{“K” value} \times \Delta T \text{ (design temperature difference)}$$

Let's use the R12 material in an example. Suppose we have a 2 × 4 wall that is 15 feet long by 8 feet high, and we're trying to maintain a temperature on one side of 72°F while the temperature on the other side could be as cold as –10°F. We would have 120 ft² of material, the "K" value would be $\frac{1}{12}$ = 0.08 and the ΔT would be 82°F. The calculation would then be:

$$120 \times 0.08 \times 82 = 787.2 \text{ BTUH}$$

What this means is that, every hour, we could expect 787 BTUs to pass through this 120 ft² of material as a "transmission loss". We can adopt the widespread rationale within the industry that we don't use decimals of btus; instead we usually round them to the nearest whole number.

"U" Value

"K" values are not normally involved in calculating heat losses in building construction due to the fact that they are representative of a single material only. Walls are an assembly in the form of drywall, studs, fiberglass batts, wood sheathing, vapour barriers, air films and outside wall coverings such as wood siding or stucco.

When we need to calculate the estimated heat lost through an assembly that is made up of many different materials, we have to come up with an aggregate or summary "R" value. As mentioned previously, every material used in construction will have an "R" value attached to it. In making a list of exterior wall construction from one face to the other, it might look like this, as an example:

Inside air film on ½" gypsum wall board on vapour barrier on 2 × 6 wood studs with fiberglass batts on $\frac{3}{8}$*" plywood sheathing on lapped, bevelled wood siding on outside air film.*

Each of these components has an identified "R" value that can be found in numerous tables in industry publications as well as on the internet. If any values differ between tables, the difference will be very minimal. Here are examples of "R" values that include those in the wall construction listed above.

Material	**R per inch thickness**	**R for given thickness**
Interior air film		0.68
Exterior air film		0.17
Gypsum wallboard ½″		0.45
Vapour barrier		Negligible
Fiberglass batt	4.0	
Polyurethane (spray-in foam)	5.9	
Concrete block 8″		1.11
Brick, common	0.20	
Plywood	1.25	
Polystyrene	5.00	

Bevelled, lapped siding		1.05
Single pane glass		1.13

As you can see, depending on the type of material, the "R" value can be expressed either by the inch of thickness and then adjusted, or by a given thickness. Many materials such as plywood and polystyrene come in many thicknesses so a per-inch value is usually listed once. Other materials such as concrete block and brick are found as certain standard sizes and are listed accordingly.

To assign an aggregate "R" value to the wall listed above, simply identify the "R" value for each material and add them together.

The air that clings to a material's surface by adhesion has actually been assigned an "R" value. For the wall's exterior surface, it's listed as 0.17 and for the interior surface it's 0.68. Working from inside-to-outside through the wall, the numbers to add together would be:

0.68 (inside air film) + 0.45 (½″ gypsum wallboard) + 0 (vapour barrier) + 22.00 (fiberglass batts) + 0.47 ($\frac{3}{8}$″ plywood sheathing) + 1.05 (bevelled lapped siding) + 0.17 (outside air film) = "R" 24.82

The inside air film, outside air film, ½″ drywall and lapped siding are all unit values, whereas the values for the fiberglass batts and plywood sheathing must be calculated according to thickness. For the fiberglass batts, the "R" value is 4.0 per inch of thickness. Thus, "R" of 4.0 per inch thickness × 5.5″ = "R" of 22.00.

The process is the same for the plywood sheathing; "R" of 1.25 per inch thickness × $\frac{3}{8}$″ = "R" of 0.47

For reasons that are unclear, the plastic vapour barrier that is sandwiched between the drywall and studs is considered to have a "negligible" resistance to the flow of heat and is therefore omitted from heat loss calculations.

Now that we've established an aggregate "R" value for a wall assembly, we can come up with a "U" value just as we did for establishing the "K" value for a single material. In our case, we would divide 24.82 into 1 to get "U" of 0.04 (round "R". "K" and "U" values to two decimals). Remember that a "U" or "K" value is an expression of a material or assembly's ability to *conduct* heat through it in BTU/HR, whereas an "R" value is an expression of a material or assembly's *resistance* to the flow of heat through it in HOURS/BTU. It should be clear, then, that we are always interested in coming up with the "U" value so it can be used in a multiplication formula to give us a BTUH heat loss. The lower the "U" value, the better the insulator.

It's important to note that there isn't much difference between the thermal conductivity of a 2 × 4 wall assembly with wood siding and one with stucco or brick siding. Where the greatest difference lies is in the insulation within the stud space. Exterior walls have been mandated to be at least 2 × 6 construction for many decades now due to the fact that, with an extra 2 inches of insulation in the walls, they are much more energy efficient. The move to 2 × 6 exterior walls versus 2 × 4 was mainly energy-based and not particularly based on strength of the wall.

TECA as well as other associations involved in the heating industry have come up with abbreviated lists of “U” factors. The TECA “U” values are shown in Figure 3 below.

Heat Loss *U-Factors* Table for Standard Construction
See Appendix, page 8-6, for Factors other than listed

WINDOWS	
Single glazed	
No storm sash	1.13
With storm sash	.56
Double glazed (metal frame with thermal break)	
1/4" air space	.65
1/2" air space	.59
5/8" air space	.52
Low E—air filled	.38
Low E—argon filled	.34
Triple glazed	
Two 1/2" air spaces	.36

WALLS	
A: Frame—Above Grade	
NO INSULATION:	
Stucco with building paper, 1/2" wood sheathing, studs, 1/2" drywall	.50
Siding/brick veneer with building paper, 1/2" wood sheathing, studs, 1/2" drywall	.35
Siding, Stucco, or Brick veneer with building paper, 1/2" wood sheathing, studs, 1/2" drywall and:	
R7 INSULATION	.10
R12 INSULATION	.07
R14 INSULATION	.06
R20 INSULATION	.05
B: Concrete—2 ft. Below Grade	
8" poured concrete, NO INSULATION	.06
8" poured concrete, 2x4 studs, 1/2" drywall	
R5 INSULATION	.04
R14 INSULATION	.03
R20 INSULATION	.03

CEILINGS	
A: Roof with Attic Space	
5/8" drywall, 3/8" sheathing and shingles	
R12 INSULATION	.07
R20 INSULATION	.05
R28 INSULATION	.03
R40 INSULATION	.03
B: **Built-up Roof, No Attic Space**	
5/8" drywall and 3/8" wood sheathing	
R12 INSULATION	.06
R20 INSULATION	.04
R28 INSULATION	.03
R40 INSULATION	.03

FLOORS	
A: Wood over unheated enclosed space	
Finished floor, sub-floor on joists	
NO INSULATION	.15
R12 INSULATION	.04
R20 INSULATION	.03
B: **Wood over Exposed space**	
Finished floor, sub-floor on joists	
R12 INSULATION	.06
R20 INSULATION	.05
C: **Concrete**	
Slab on grade:	
1" edge insulation—per LINEAR Feet	.69
2" edge insulation—per LINEAR Feet	.53
Slab below grade:	
Per square feet of area	.04

Figure 3 Heat Loss “U-Factors” table

Rather than having to go through the process of identifying all the components of a wall assembly, adding together their “R” values and dividing that into 1 to get a “U” value, one simply has to identify a wall assembly by its general makeup. There is not a lot of variation in wall assemblies used in residential construction, so these “U” values listed are particularly helpful in more quickly obtaining a heat loss while still applying a reasonable degree of accuracy.

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- Figure 2 R14 Batt Insulation by ITA is licensed under a CC BY-NC-SA licence.
- Figure 3 Heat Loss "U-Factors" table is courtesy of TECA BC.

Learning Task 4

Calculating Transmission Loss

Rooms have ceilings, floors, and walls with doors and windows. Transmission losses must be calculated for each surface that has unconditioned space on the other side of it. This means that a floor with a heated room below it would be considered to not have any downward heat loss. The same is said for a ceiling with a heated room above it or a wall that abuts a heated room. In short, only surfaces that separate a heated space from the outdoors need to have heat losses calculated for them.

Transmission Losses through Windows and Doors (Openings)

The "U" values used for doors are the same as for windows. A "U" value, based on parameters such as single, double or triple glazed with or without special coatings and fillers, is selected from a table, and multiplied by area in ft^2 and by the DTD. As an example, 48 ft^2 of doors and windows with a "U" value of 0.59 in Penticton would calculate to be $48 \times 0.59 \times 67 = 1,897$ BTUH.

Walls and Openings

Walls that separate heated (conditioned) spaces from the outdoors are called "exposed walls", and they will have an area that includes windows and doors. The losses through windows and doors ("openings") must be calculated separately, as they will have different "U" factors than will the walls themselves (see above). The easiest way to perform an exposed wall calculation is to do a takeoff of the area of the openings first. If a room has a total of 108 ft^2 of openings in its exposed walls, that area would be subtracted from the total area (length × height) of the exposed wall. So, an exposed wall that measures 28 feet long by 8 feet high would have a gross area of 224 ft^2. When the openings are subtracted from that gross area, the net area of exposed wall becomes $224 – 108 = 116$ ft^2. The heat loss formulas can now be applied to the net wall area. Table 2 lists the "U" values for framed walls whose exterior finishes are lumped together into one category. In other words, it doesn't matter what the exterior wall finish is – the "U" value depends upon the "R" value of the insulation in the wall cavities. So, for our exterior wall in Penticton, with a net area of 116 ft^2, using R20 insulation in the walls, the calculation would be $116 \times 0.05 \times 67 = 389$ BTUH

Ceiling and Floor Losses

Ceiling losses will only be counted for rooms on a top floor, and are listed as either "roof with attic space" (normal residential construction using trusses) or "built up roof, no attic space" (typically flat or vaulted roofs) with an insulation value attached to them. Floor losses (other than basements) will only be counted if they are located over unheated space such as an open carport ("wood over exposed space") or a garage ("wood over enclosed space"). The insulation values will determine the "U" value chosen from the table, and their transmission losses are calculated in the same manner as with openings and exposed walls.

Thermal Bridging

Our previous example did not make mention at all of a thermal resistance for the 2 × 6 studs themselves. This is because they are spaced at either 16″ or 24″ centres along the wall and are difficult to allow for. Some heat load designers will include a small allowance for the studs when coming up with the "U" value for an assembly but this is a matter of designer preference.

The studs that form the support system for walls will have a heat loss through them which is higher than that of the insulation between them. This occurrence is known as "thermal bridging". By definition, thermal bridging, also known as cold bridging or thermal bypass, is an area or component of an object which has a higher thermal conductivity than the surrounding materials, creating a path of least resistance for heat transfer. Overlooked for a great period of time, thermal bridging has recently come to the forefront of heat load calculations as designers strive to be as accurate and comprehensive as possible in their estimates. Thermal bridging not only causes a loss of heat within the space, it can also cause the warm air inside the space to cool down. When heat attempts to escape a room, it follows the path of least resistance. Likewise, the same process occurs during the summer, only in reverse, allowing heat to enter your otherwise cool building, called heat gain. Thermal bridging happens when a more conductive material allows an easy pathway for heat flow, usually where there is a break in (or penetration of) the insulation. Some common locations include:

- The junctions between the wall and the floor, roof, or doors and windows.
- The junction between the building and the deck or patio
- Penetrations in the building envelope to include pipes or cables
- Wood, steel, or concrete envelope components such as foundations, studs, and joists
- Recessed lighting
- Window and door frames
- Areas with gaps in insulation

In short, any area where there isn't a continuous, unbroken layer of insulative material can be considered a thermal break. These areas should be addressed in both the design and construction phase, as studies have show that in an otherwise airtight and insulated home, thermal bridges can account for a heat loss of up to 30%. Whether you're building a new home or retrofitting an existing structure, care should be taken to avoid unnecessary breaks or penetrations in the building envelope so that the possibility of thermal bridging decreases.

Slab Edge Loss

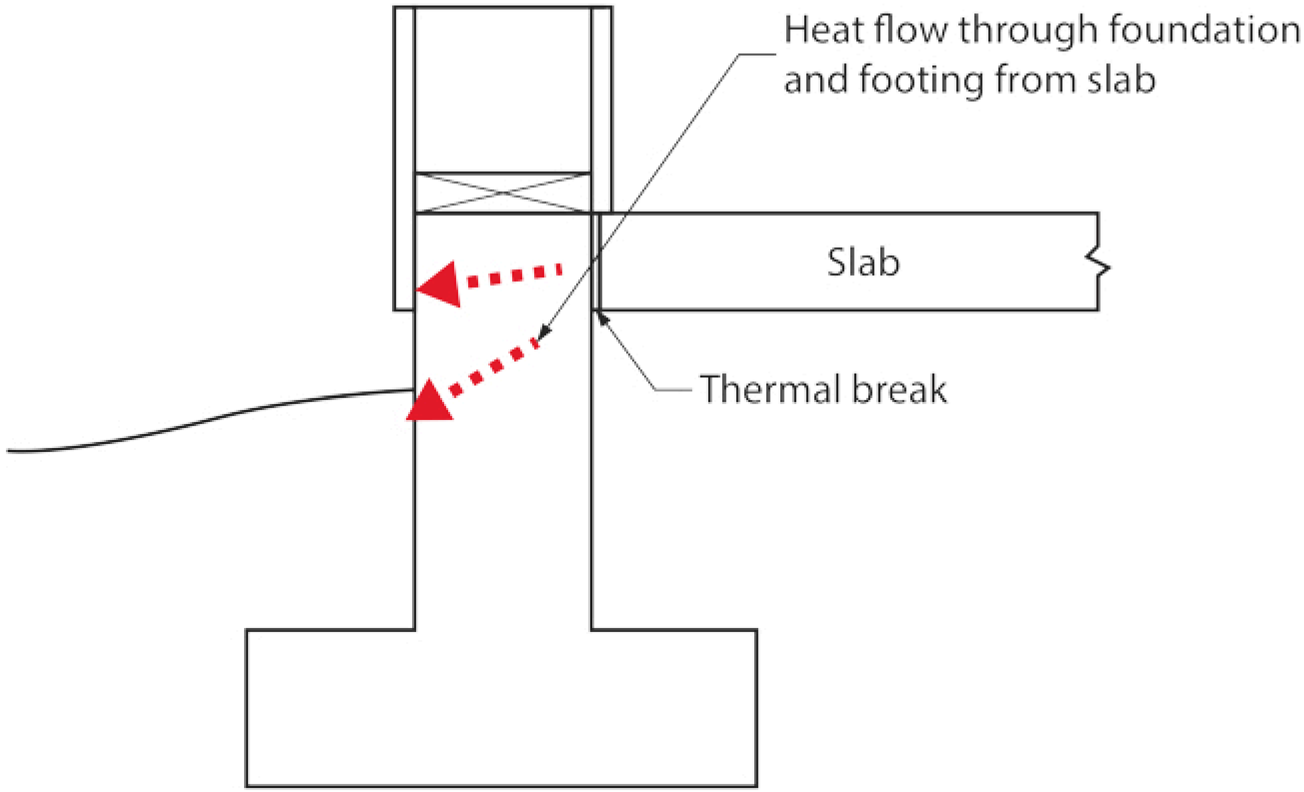


Figure 1 Slab edge loss

The thermal bridging that occurs at the point where the indoor concrete slab meets the concrete foundation wall is almost inevitable. Concrete has a low "R" value and there is little that can be done to mitigate the transmission of large amounts of heat between the two masses. Therefore, there will be a category of heat loss called "slab edge loss" that is calculated when using slab-on-grade construction. The formula is written as:

$$\text{Slab edge length (ft)} \times \text{“U” value} \times \Delta T = \text{BTUH.}$$

The slab edge "U" factor, from the table above, is either 0.69 when using 1" insulation, or 0.53 when 2" insulation is used.

As an example, if a room with slab-on-grade construction had 32 lineal feet of exposed slab edge with 2" insulation and the DTD was 67°F, the calculated slab edge loss would be 32 × 0.53 × 67 = 1,136 BTUH. This would be added to the transmission and infiltration losses for that room.

With radiant floor heating, slab edge insulation is a must. A strip of rigid insulating material such as polystyrene is sandwiched between the two concrete masses to try to reduce the thermal bridging effect. As well, rigid polystyrene (XPS) is commonly attached to the outside of the foundation wall, with a protective sheet of galvanized sheet metal covering it, to further reduce the heat loss through the concrete to the soil and outside air.

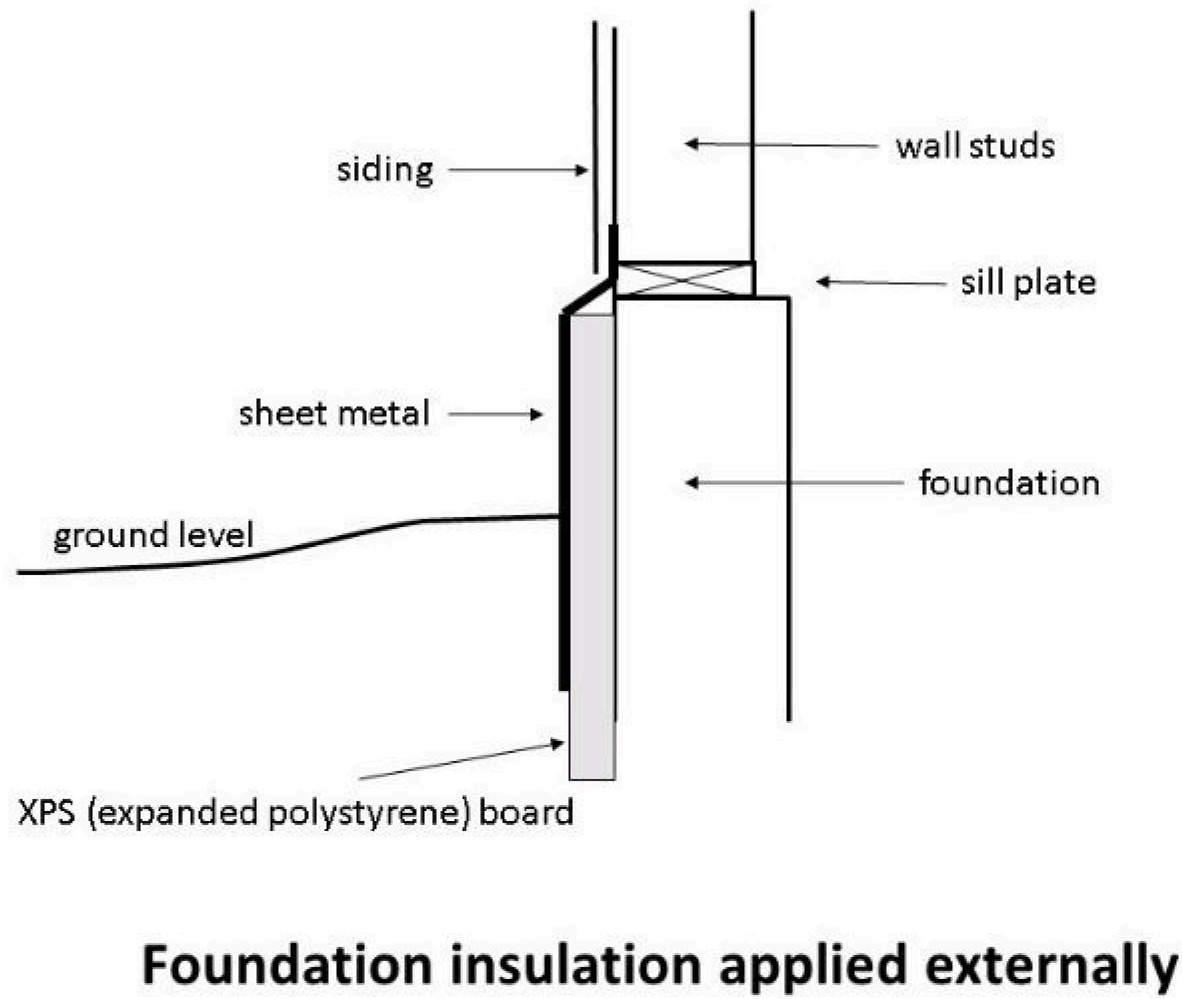


Figure 2 Slab edge insulation

Basement Concrete Slab Loss

If a basement concrete floor is more than 2 feet below finish grade, a downward loss should be calculated. The formula is similar to that for walls, except that the IDT can be lower if desired. Using 65°F (18°C) as an allowable value for an unfinished basement, the calculation would be:

Area (ft^2) × DTD (65 − ODT) × 0.04 ("slab below grade" from "U" values table above) = BTUH

If the slab is being heated through radiant means, then the slab temperature is used as the IDT.

Infiltration/Exfiltration Loss

Today's structures are far more airtight than were their counterparts of 50 years ago. Old wood frame double-hung, single pane windows have long ago given way to double or triple glazed gas-filled reflective windows mounted in vinyl frames. Caulking, weatherstripping and energy-conserving measures make today's structures far less drafty than ever before. That said, there are still imperfections in building envelopes that will allow heated interior air to escape to the outdoors, or cold outside air to be forced into the living space. These heat losses, which can be classified as due to convection, are simply referred to as "infiltration losses".

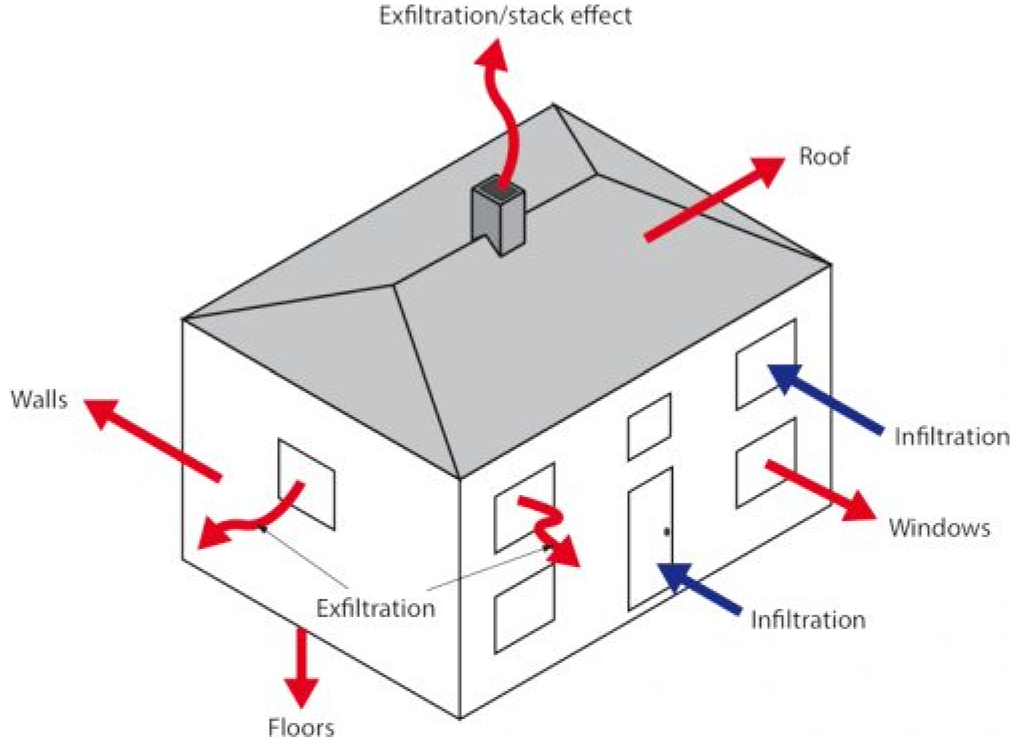


Figure 3 Heat loss via conduction and infiltration/exfiltration

Heat loss from infiltration (inward flow) and exfiltration (outward flow) is uncontrolled air leakage through joints in the construction and cracks around windows and doors. In the winter, the cold air that infiltrates the building is equal to the amount of hot air that escapes. Conversely, in the summer, the cooler air inside escapes and hot exterior air infiltrates. Infiltration is caused by wind and stack-driven pressure differentials, which prompt air movement within the building envelope. In British Columbia the BC Building Code sets out requirements that are meant to both offset infiltration losses while also delivering fresh air for the health of occupants. The infiltration rate varies greatly depending on climate and the tightness of construction. In general, ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers) recommends for small buildings with low infiltration rates (<0.5 air changes per hour, known as "tight" or "airtight" construction) to use mechanical ventilation to ensure good indoor air quality (IAQ). We'll confine our focus to the determination of the heat lost through infiltration rather than the requirements for mechanical air exchange.

Calculating Infiltration Loss

Just as in the calculation of transmission loss, there is a formula used for calculating losses of heat through infiltration, and it is based upon the fact that air has a specific heat, by volume, of 0.018 as mentioned earlier in the heading "water vs air as a heating medium". So, the formula is written as:

Infiltration loss = ACH (# of air changes per hour) × 0.018 (specific heat of air) × DTD (design temperature difference) × room volume (ft^3).

The determination of an air change rate for a room is somewhat arbitrary, in that there are many factors at play. For our purposes within this learning guide, we will use the Air Change Table found in TECA's literature below as our benchmark.

Air Change Table (courtesy of TECA BC)

Description	**Infiltration Rate**	**AC Factor***
R2000 Dwellings ONLY w/fully distributed ventilation systems (HRV's)	$\frac{1}{3}$ ACH (air change/hr)	.005
Rooms w/windows on 1 side only	$\frac{1}{2}$ ACH	.009
Rooms w/windows on 2 sides	$\frac{2}{3}$ ACH	.012
Rooms w/windows on 3 sides	1 ACH	.018
Entrance Halls	1 ACH	.018
Sum rooms w/windows or doors on three sides	$1\frac{1}{2}$ ACH	.027
Rooms w/fireplace (except sealed combustion units_	1 – $1\frac{1}{2}$ ACH	.018 – .027

$$\text{*Air Change Factor} = \frac{\text{Infiltration Rate}}{60} \times 1.08$$

$$\text{For Example:} \frac{\frac{1}{2}\text{ACH}}{60} \times 1.08 = .009$$

As shown in the air change table above, air change rates vary from $\frac{1}{3}$ air changes per hour (ACH) to 1 ½ ACH. The choice of which one to use for a room comes down to determining how many exterior walls in that room have openings (doors or windows) and the type of room it is. For example, if a corner bedroom has two exterior walls but only one of them has windows, it would be classified as having ½ ACH. If the bedroom were 8 ft × 10 ft × 8 ft high, its volume would be 640 ft^3. If ½ of the room's air volume needed to be reheated every hour, we would need to heat 320 ft^3 of that room's air. Rather than split a room's volume into $\frac{1}{3}$, ½, etc., we instead leave the room volume alone and adjust the specific heat value for air which is shown in the far-right column. What would otherwise have been a calculation of (640 ft^3 × $\frac{1}{2}$) × 0.018 × DTD = BTUH infiltration loss, would then become 640 ft^3 × (0.018 × 0.5) × DTD = BTUH infiltration loss. The net result is the same, however the specific heat value is altered to be a multiplier instead of using only a portion of the room's volume. This also makes it easier for use in the formulas that are in use within the TECA heat loss software programs.

An entrance hall, which is a room with an outside door that is being used frequently, would have a higher rate of air exchange than, say, a bedroom. It is listed at 1 ACH. Solariums (sun rooms), with a lot of glass area, and rooms with wood-burning fireplaces, have an even greater expectation of exfiltration loss, so are listed as 1 ½ ACH.

As you can see from Table 3 above, the determination of which factor to use when performing an infiltration loss using the TECA guidelines is simply reduced to identifying how many exposed walls in that room have openings (doors or windows) and what type of space it is.

Additional Heat Losses

Hot water heating systems may be designed to provide heat for other services or equipment such as:

- domestic hot water
- swimming pool
- hot tub
- outdoor radiant panels for melting snow

The heat loss for these services and equipment must be determined in an appropriate manner, and in some but not all cases added to the total. A swimming pool is a good example of not having its heat load added to that of the building because, in most cases, swimming pools are shut down and not used in the heating season. The energy needed for heating of the domestic hot water can be prioritized over the heat needed for the building, using the rationale that for the period of time that the heating plant is directing energy to the domestic water, the building can "coast" on its retained heat. In this way, the domestic water can be heated instead of the building, so that there is no additional heat needed.

A hot tub's heat load would certainly be added to that of the building because they are often used and enjoyed more in the heating season, and the need to add a snow melting system's load onto that of the building is also obvious.

Calculation of the loads for swimming pools, hot tubs and snow melt will not be part of this learning package.

Oversizing the Heating System

There are many conflicting thoughts on determining the size of the heating plant and components. Some heating professionals will add 15 to 30% to the heat load to compensate for other losses within the system, such as heat loss through the piping ("piping tax") and additional capacity required for start-up of a cold system ("warm-up allowance" or "pickup allowance"). The extra capacity also guarantees sufficient heat if the outdoor temperature drops below the ODT, if use patterns cause additional heat losses, and if the residents prefer a temperature above the IDT.

Other professionals claim that these extra losses are minimal and that the heating system rarely runs at design conditions, so it is already in fact oversized. This rationale results in a lower installation cost. Those professionals would allow for 100% of the calculated heat load for the building and no more when selecting a heat plant. Also keep in mind that, no matter which sizing rationale is used, boiler inputs normally increase in increments of 25,000 to 50,000 Btuh, so slightly oversizing the boiler is almost inevitable.

Now complete the self test below.

Self-Test 1

Self-Test 1

1. Which one of the following is *not* a method of heat loss found in building heating systems?
    a. Conduction
    b. Respiration
    c. Radiation
    d. Convection
2. What is the approximate percentage of heat that a human body loses by radiation?
    a. 48
    b. 30
    c. 22
    d. 12
3. What is the phenomenon known as, whereby a person can feel cold because they are sitting too close to a window or exterior door, when the temperature setting in the room is normal?
    a. "Warm 98.6"
    b. "Cold 98.6"
    c. "Warm 70"
    d. "Cold 70"
4. What is the name given to the set of interior room temperature conditions where the human body feels the most comfort?
    a. The desired setpoint
    b. The ideal heat curve
    c. The desired heat curve

   d. The ideal setpoint

5. What is the temperature that is read on a thermometer indicating?
   a. The quantity of heat present
   b. The latent heat present
   c. The intensity of heat present
   d. The BTUs that are present
6. Which one of the following formulas would be used to calculate the number of BTUS involved in the heating of water within a heating plant, such as a boiler?
   a. BTUS = Mass × ΔT × S.H.
   b. BTUS = Mass × latent heat × ΔT
   c. BTUS = Latent heat × ΔT × area
   d. BTUS = Area × ΔT × S.H.
7. What is the ΔT used in the design of most hot water heating systems that are fed from a boiler?
   a. 140°F
   b. 90°F
   c. 20°F
   d. 5°F
8. What is the minimum return water temperature that should be maintained when using a non-condensing boiler?
   a. 20°F
   b. 90°F
   c. 120°F
   d. 140°F
9. What is the term known as whereby heat is able to be applied to only the areas of a building where it is needed, rather than to the whole building?
   a. Zoning
   b. Priority
   c. Area selection
   d. Heat propagation
10. What would be the “K” value for a material that has an insulating value of “R” = 22?
    a. 23
    b. 22
    c. 11
    d. 0.045

11. How many BTUs would be involved in the transfer of heat through 150 ft² of a material that has an “R” value of 14 if the temperatures on either side of the material are 72°F and 5°F?
    a. 704
    b. 809
    c. 140,700
    d. 161,700
12. When designing a heating system, what is the “January 2.5%” value for that geographical area known as?
    a. The required temperature
    b. The estimated temperature
    c. The indoor design temperature
    d. The outdoor design temperature
13. According to the TECA Hydronic System Guidelines, what is an allowable IDT that can be used residentially when performing a heat loss estimate if hydronic radiant panels are intended as the primary source of heat?
    a. 140°F
    b. 80°F
    c. 72°F
    d. 68°F
14. According to Part 9 of the BCBC, what is the allowable IDT for an unfinished basement?
    a. 15°C (59°F)
    b. 18°C (64°F)
    c. 20°C (68°F)
    d. 22°C (72°F)
15. In heat loss language, what is the term for heat that is lost from a building through conduction?
    a. Radiation
    b. Infiltration
    c. Convection
    d. Transmission
16. What is the term for heat that is lost when cold air makes its way into the building through cracks and imperfections in the building’s envelope?
    a. Radiation
    b. Infiltration
    c. Conduction
    d. Transmission

17. Using Table 1, calculate the "U" value for an exterior wall made up of outside air film on 4″ brick on ½″ plywood sheathing on 2 × 6 wood studs with fiberglass batt insulation on vapour barrier on ½″ gypsum wall board on inside air film (use average value for fiberglass batt insulation).

    a. 0.04
    b. 0.16
    c. 0.52
    d. 22.83

18. According to Table 2 (Heat Loss U-Factors Table), which one of the following double-glazed windows would have the best insulation rating?

    a. $\frac{1}{4}$″ air space
    b. $\frac{1}{2}$″ air space
    c. $\frac{5}{8}$″ air space
    d. Low "E" – argon filled

19. What is the term given to the situation where, for instance, a heated slab-on-grade butts up to the exterior foundation wall, allowing heat to transfer between the two materials more easily than through the surrounding structure?

    a. Infiltration
    b. Convection
    c. Thermal bridging
    d. Thermal connectivity

20. What would be the infiltration loss for a corner bedroom that measures 20 ft × 15 ft × 8 ft, has openings on both exterior walls, with an ODT of 5°F and an IDT of 72°F?

    a. 1,447 BTUH
    b. 1,930 BTUH
    c. 2,894 BTUH
    d. 4,342 BTUH

21. What would be the expected outcome of the rate of heat transfer if the ΔT between two sides of a wall or ceiling were doubled?

    a. The rate would be halved
    b. The rate would stay the same
    c. The rate would double

22. What would be the expected outcome of the rate of heat transfer if the "R" value of a material were doubled?

a. The rate would be halved
b. The rate would stay the same
c. The rate would double

23. A contractor plans to build two identical houses, one in Inuvik and the other in Vancouver. Which one of the following statements would be true?

    a. The Vancouver house's heat loss will be the greater of the two.
    b. The Inuvik house's heat loss will be the lesser of the two.
    c. The IDT for the two houses will be different.
    d. The ODT for the two houses will be different.

24. How many air changes per hour (ACH) would a room with openings on 3 sides undergo?

    a. $\frac{1}{3}$
    b. $\frac{1}{2}$
    c. 1
    d. $1\frac{1}{2}$

25. What is the "U" value to be used for a framed above-grade wall with stucco veneer with building paper, ½″ wood sheathing, studs, ½″ drywall and R14 insulation?

    a. 0.05
    b. 0.06
    c. 0.07
    d. 0.50

26. What is the "R" value of 3 inches of extruded polystyrene?

    a. 15.0
    b. 10.0
    c. 5.0
    d. 4.0

27. What is the air change factor to be used for an R2000 dwelling with a fully distributed ventilation system (HRV)?

    a. $\frac{1}{3}$ ACH
    b. $\frac{1}{2}$ ACH
    c. $\frac{2}{3}$ ACH

   d. 1 ACH

28. What is the ODT to be used when designing a building in Youbou, BC?
   a. 22°C
   b. 15°C
   c. 22°F
   d. 15°F

29. Calculate the heat loss (transmission and infiltration) for a bedroom above a carport if:
   - the room is 12 feet long × 11 feet wide × 8 feet high
   - there is a 3′ × 5′ window with double pane glazing with $\frac{1}{2}$″ air space mounted in each of the two exterior walls
   - walls are stucco with R20 insulation
   - the floor beneath the bedroom has R20 insulation
   - the attic space has R40 insulation
   - the home is being built in Kimberly, BC.

30. What would be the downward loss through a concrete floor that is 8 feet below finish grade if the house is in Powell River and the slab measures 17′ – 6″ wide by 33′ – 3″ long? (Assume an IDT of 65°F).
   a. 1,164 BTUH
   b. 1,327 BTUH
   c. 1,732 BTUH
   d. 1,614 BTUH

Check your answers using the Self-Test Answer Keys in Appendix 1.

Media Attributions

- Figure 1 Slab edge loss by ITA is licensed under a CC BY-NC-SA licence.
- Figure 2 Slab edge insulation by ITA is licensed under a CC BY-NC-SA licence.
- Figure 3 Heat loss via conduction and infiltration/exfiltration by ITA is licensed under a CC BY-NC-SA licence.

Competency F2: Radiant Systems

For at least the last three decades, radiant floor panel systems have replaced baseboard wallfin convectors as the hydronic system of choice in residential construction. Prior to the advent of polybutylene and PeX tubing, radiant floor panels using copper and steel were much more expensive to install, and the science behind the design of these systems was still very much in the development stage. Today, there are a number of resources that can be tapped into for hydronic heat loss and radiant panel design. Methods have been proven and software is readily available that makes the whole process of design much easier than ever before. In this section we will identify the different types of radiant systems, their design considerations and the components within them.

Learning Objectives

After completing the learning tasks in this Competency, you will be able to:

- Size piping and components for hydronic systems
- Design a residential hot water radiant floor heating system

Learning Task 1

It is important to note here that there are 3 types of PeX tubing manufactured, and although they may look the same, there are distinct advantages to the use of one of them when used in hydronic systems.

PeX "A" is manufactured by the Engel method, which gives it a "memory". The tube always wants to revert back to the condition it was in when manufactured, so it can be used with expansion-type fittings as well as crimp and compression varieties. Probably its best trait is its ability to be kinked and repaired 100% just by heating to a minimum temperature. The "B" and "C" varieties cannot be used with expansion fittings, and any kinks must be cut out and replaced.

When PeX tubing is used for radiant panels, it must be of the type that has an oxygen-barrier coating for heating. This coating minimizes the rate of oxygen diffusion to a point where its effects on the ferrous components that the water comes into contact with are negligible. Additives to the system water, such as rust inhibitors, also help to keep the levels of free oxygen in the water almost non-existent, which prolongs the life of the system components. Early radiant systems using polybutylene were plagued by early system rust-outs from within, which gave this part of the heating industry a lot of bad publicity. Once the oxygen diffusion issue was identified and rectified, consumer and contractor confidence in radiant systems was restored.

Consult the levels 1 and 2 learning guides for more information on PeX tubing and oxygen diffusion.

"Wet" Systems

Cross-linked polyethylene (PeX) tubing embedded within a concrete mass, known as a "wet" system, has been proven to be the best option for radiant heat transfer within a house. The concrete has a high thermal mass which aids in heat transfer, so water temperatures can be fairly low as the concrete only needs to be warm to do its job.

Basement Slabs

Typically, basement floor construction has always been a concrete slab poured over a vapour barrier placed on top of compacted granular fill; in other words, a perfect vehicle for supplying radiant heat to the basement. The slabs have varied from 2 inches to 4 inches in thickness depending on the codes of the day and builder preference. Welded wire fabric (wire mesh abbreviated as "WWF") is usually embedded within the slab for reinforcement, which makes the attachment of tubing, and maintaining proper tube spacing, a beneficial spinoff of its inclusion. The WWF is normally heavy gauge round wire, welded at all junctions, and with 6" spacing between wires. Plastic "zip" ties or malleable wire (rebar wire) can be used to attach the tubing to the WWF, usually with no more than 24" between ties to keep the tube from floating in the concrete slurry. The WWF is propped up so that the WWF and attached tubing are near the middle of the slab depth-wise.

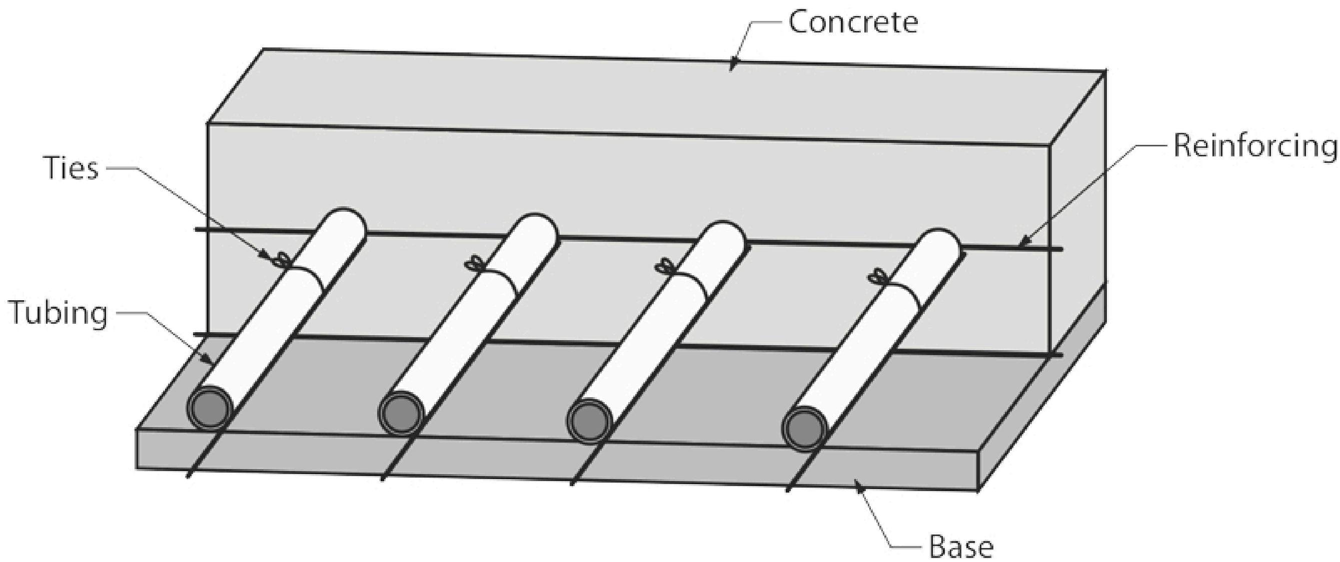


Figure 1 Slab-on-grade radiant panel

Wherever the tubing makes a turn or return bend, more ties are needed in order to maintain the tube's shape without kinking. It is important to note here that, if tubing of PeX "B" or "C" is used, any kink in tubing will damage it, and the tube must be replaced. PeX "A" however can be repaired if kinked, simply by heating it with a heat gun (never an open flame!). Even though manufacturers of PeX "A" may have a different opinion when their expansion-type fittings are used, most AHJs (Authorities Having Jurisdiction)will not allow any joints in tubing that is embedded in concrete. That means that any kinks in PeX "B" or "C" will result in the replacement of entire loops unless the damaged portion of the loop is re-routed to a nearby wall where it is brought up out of the slab, repaired and then returned into the slab to continue with regular layout. In order to minimize downward heat loss, and to help drive the heat upward, heated basement slabs should have a minimum of 2 ½" of rigid polystyrene foam between the vapour barrier and the slab bottom. This is especially necessary if there is a heat sink beneath the slab, such as a high water table. Depending on the type of fill under the slab and the presence or absence of a heat sink, many designers and installers will only use under-slab insulation for the outer 2 feet of slab where it contacts the foundation wall. The theory here is that, not long after initial operation, the ground temperature will stabilize and the downward heat loss will be negligible.

Concrete Over Wood Subfloors

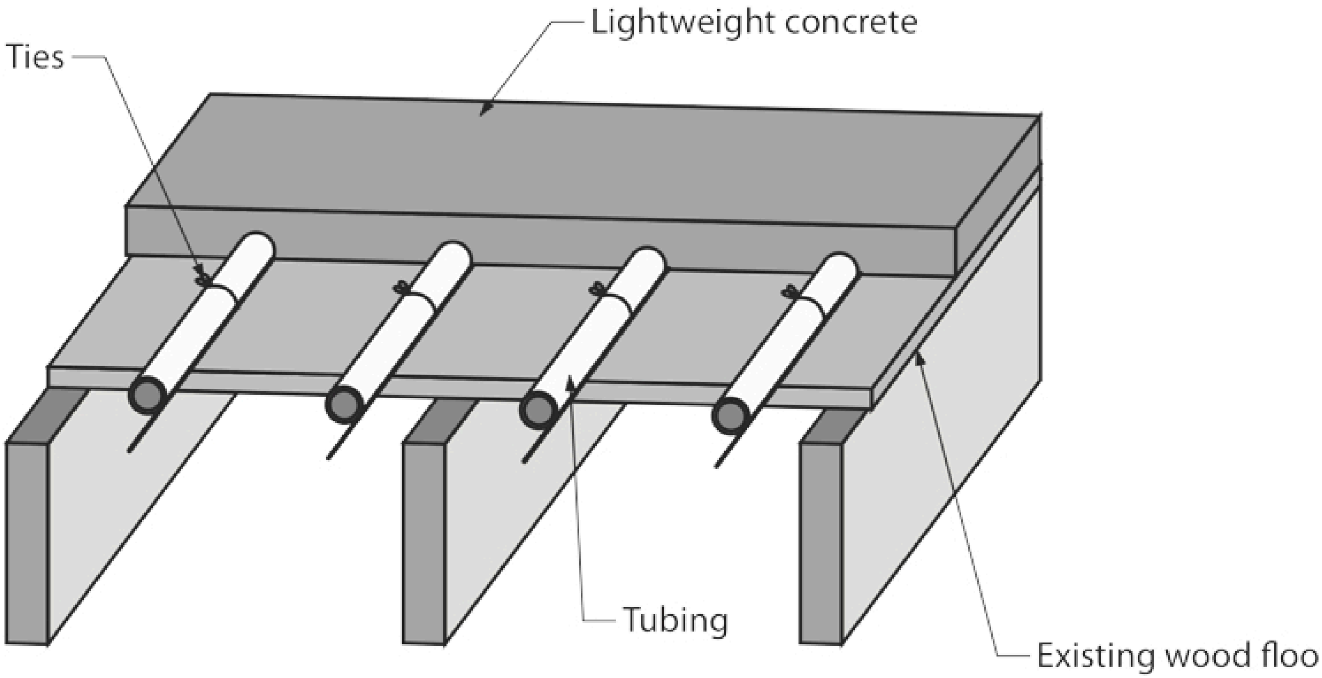


Figure 2 Wet system on plywood subfloor

For floors above grade, a lightweight, 1 ½″ thick concrete/gypsum mixture is poured in two “lifts” over ½” tubing stapled to the plywood subfloor (most common) or pressed into channels in pre-formed plastic mats (less common). Just as in the basement slabs, care must be taken to not kink the tube. In that event, a narrow channel can be cut in the wood subfloor immediately below the tube. The damaged portion is routed through the channel into the ceiling below where the damaged portion is repaired and is considered “accessible’ by cutting into the drywalled ceiling if the repair should ever fail. When concrete-over-wooden-subfloor systems are installed, there is an extra bottom plate installed under all the exterior and interior walls that is wider than the regular bottom plate. There are three reasons for this extra plate.

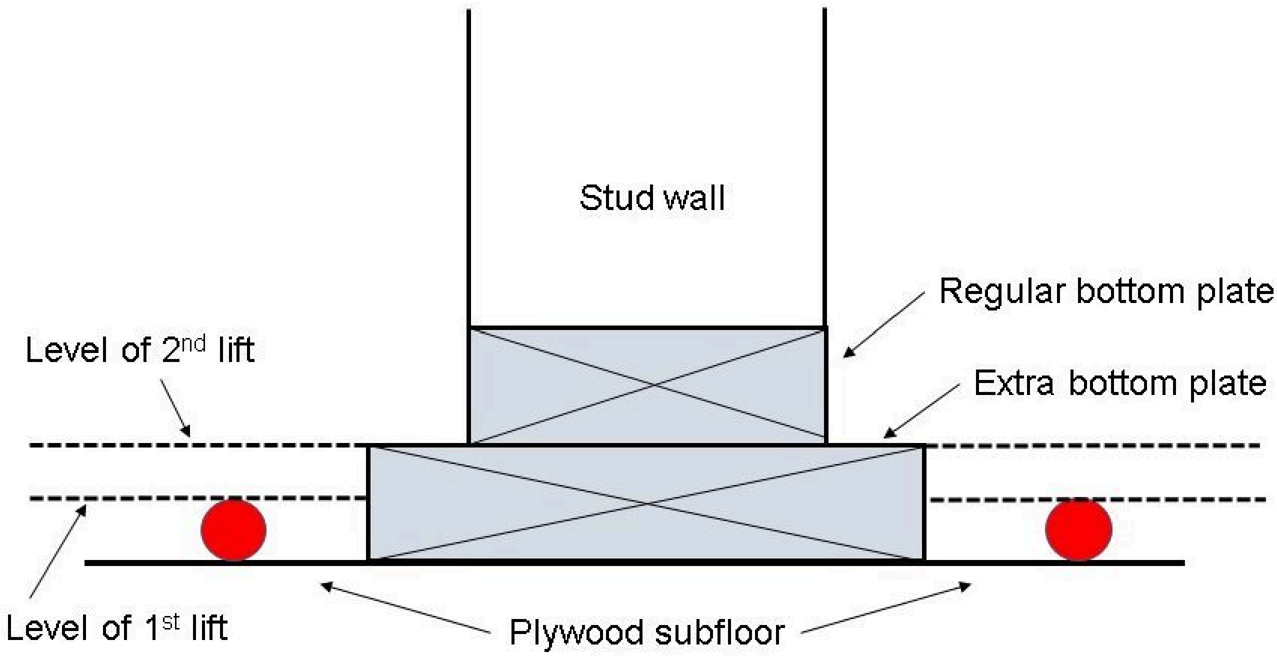


Figure 3 Profile at interior wall of wet slab-on-wood-subfloor system

The first is to act as a "screed" for the final height of the second lift of concrete. The first lift is only ¾″ thick which takes it to the top of the tubing. The second lift completes the 1 ½" thick profile and the wider bottom plate acts as a screed for leveling the 2nd lift. The second reason is to be an area where the "smooth-edge" (carpet tack strip) is nailed to, if carpet floor covering is being installed. The third reason is to regain the lost 1 ½″ of ceiling height that is taken up by the concrete.

The other variety of wet system is found outdoors as a snow melt system. PeX tubing is embedded in the concrete of sidewalks and driveways, so as to keep snow and ice from accumulating by circulating an antifreeze or brine solution through the tubing. As such, these systems are usually separated from the building heating system by the use of a heat exchanger.

Figure 4 Brazed plate heat exchanger

The heat exchanger would be this system's "boiler", and would require the use of its own expansion tank, circulator and makeup water. A heightened level of backflow preventer is usually needed for any system that has any chemicals, including salt, that are mixed with water.

Because of the high thermal mass of a wet system, they take time to heat up and cool down. Due to this fact, an indoor wet system is expected to operate at a constant temperature. Night setback thermostats are never a good option for a wet indoor radiant system. Snow melt systems, on the other hand, would be very costly to operate if left to run constantly at a set temperature, so they are normally only brought on when needed. Control systems and sensors can be installed outdoors and embedded in the slab to monitor the slab's temperature and the presence of snow and ice, thereby limiting the amount of time that the system needs to operate in order to do its job.

"Dry" Systems

If the style of construction can't accommodate a wet installation, there are a few different ways in which radiant heat may still be utilized.

One method is to use the joist space below the floor as a heated channel. A minimum of two PeX tubing runs are either attached to the sides of the joist space about 3 inches below the soffit of the floor (most common), or they are suspended below the floor on special hangers (less common). The tubing heats the joist space and this heat is transferred through the floor to the room above.

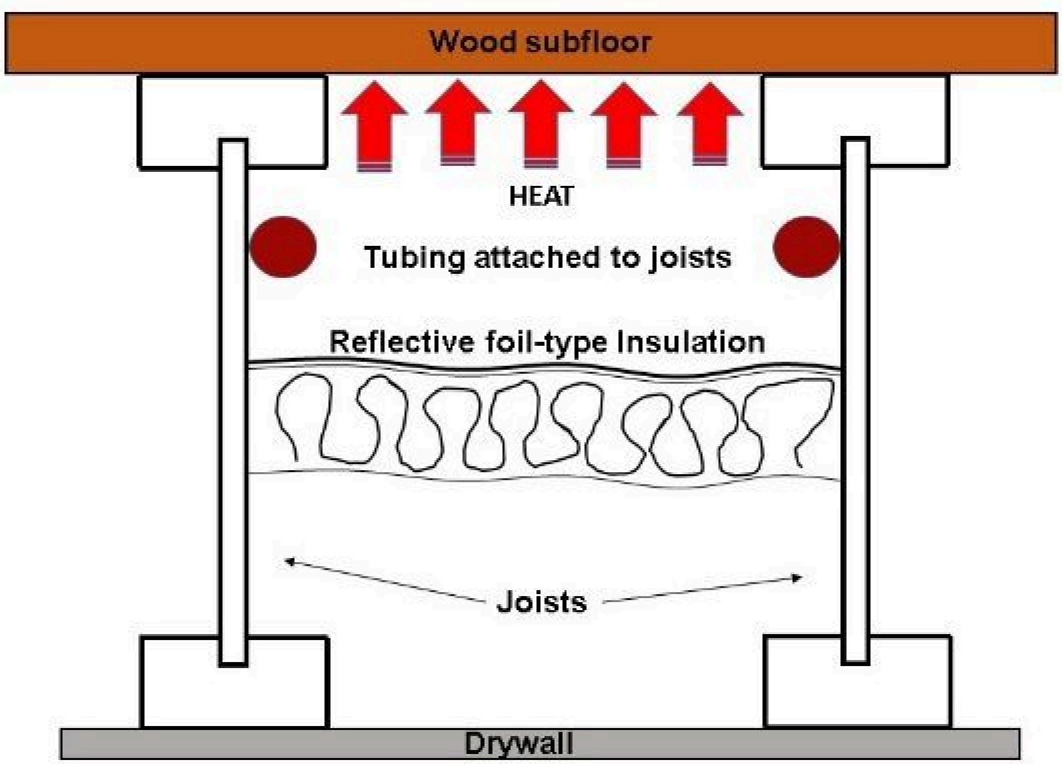


Figure 5 Dry staple-up system

A major down-side to this style of heating is that the air that is trapped in the joist space must act as the heating medium, and air is more of an insulator than a conductor. A better way of applying heat is to run the tubing through grooves in aluminum plates and staple the plates to the underside of the floor. The heat transfer rate is better because of the direct contact between the tubing, the plates and the flooring.

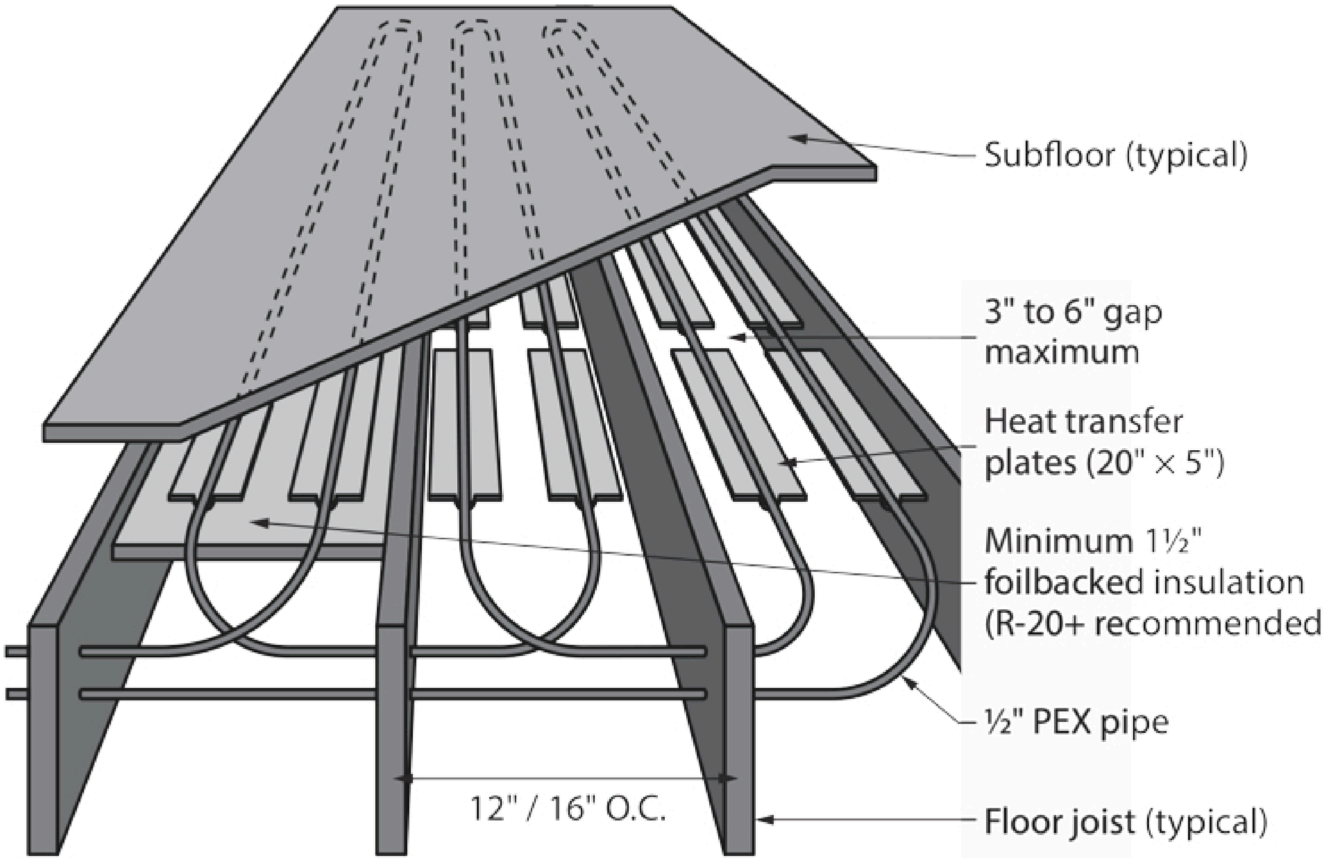


Figure 6 Typical in-joist dry system using aluminum plates

For either of these dry systems, the water temperature has to be much higher than with the wet systems. The bottom of the joist cavity must be insulated when using either type of system. Fiberglass batt insulation can be used and as long as the "R" value of the batts is higher than the "R" value of the subfloor and floor covering above, the heat will be driven upward. A better option would be to use foil-backed insulation in the joist cavity, with the foil facing upward. This helps to reflect any downward radiation from the tubing or plates back toward the soffit.

Figure 7 Reflective foil insulation

Aluminum coils that resemble radiators have been developed for dry systems that assist the heat in getting out of the tubing and into the joist space. Although available, they don't seem to be as popular an option as the aforementioned types and their use is very limited.

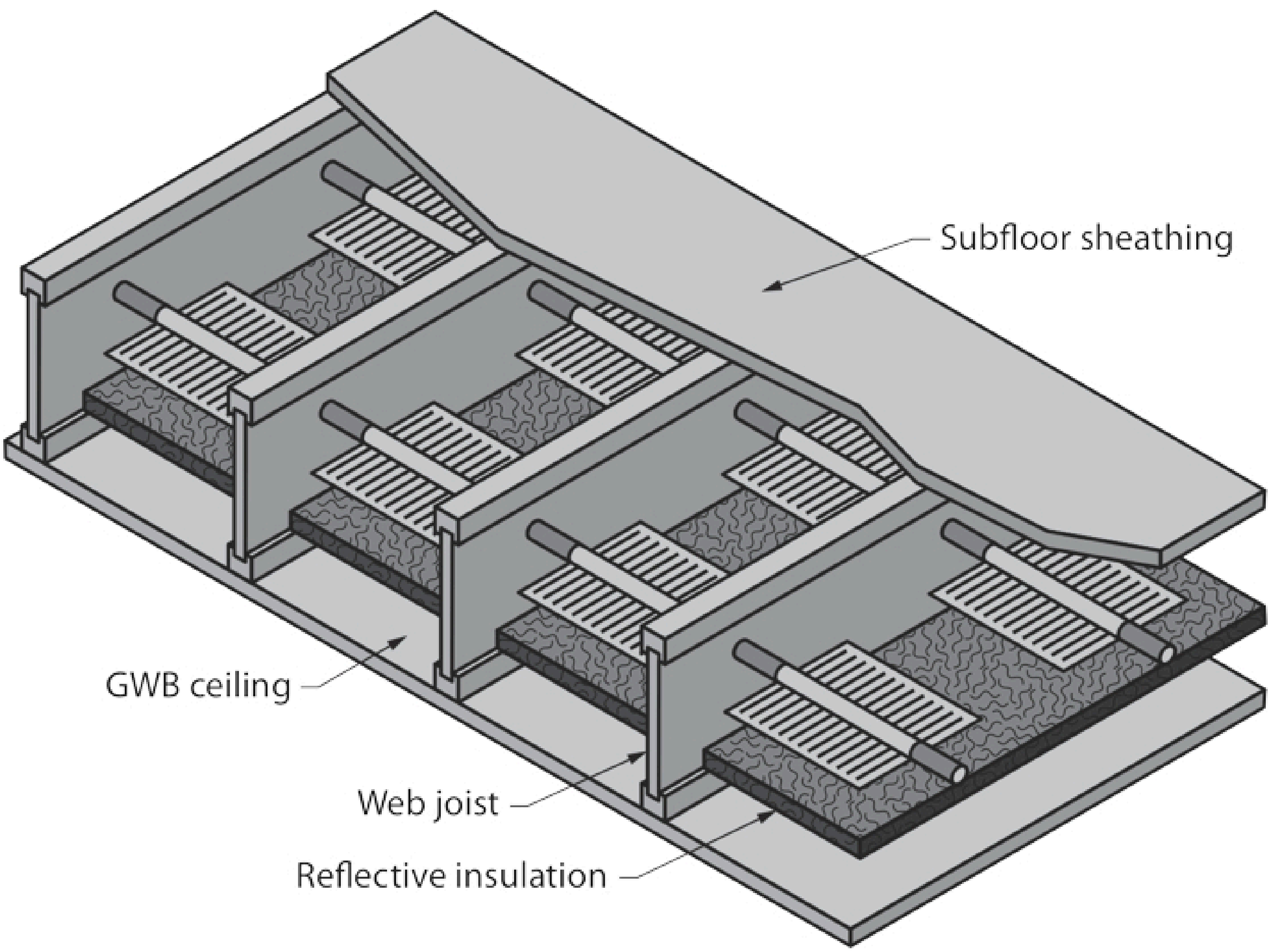


Figure 8 Finned plates in a dry system

Another style of radiant panel should be mentioned here, although usually only found in institutions such as hospitals and schools. Radiant ceiling panels are manufactured to be installed in ceilings directly above windows in hospital rooms and classrooms. Like the other dry-type systems, they have to operate at high temperatures but because they are out of the normal reach of most people, the danger of scalding is avoided. They also have minimal impact on the aesthetics of the room because there is nothing to block the infra-red rays from projecting downward. Furniture placement can't block the heat flow as it can with forced air or baseboard wall-fin installations.

In some rare cases, such as in a penthouse with a lot of glass, tubing is attached to walls and covered over with plaster. In those installations, anything meant to be hung on the wall would need to be specifically located, to avoid damaging the tubing.

Media Attributions

Learning Task 2

Select and Size Piping

Tubing Layout Patterns

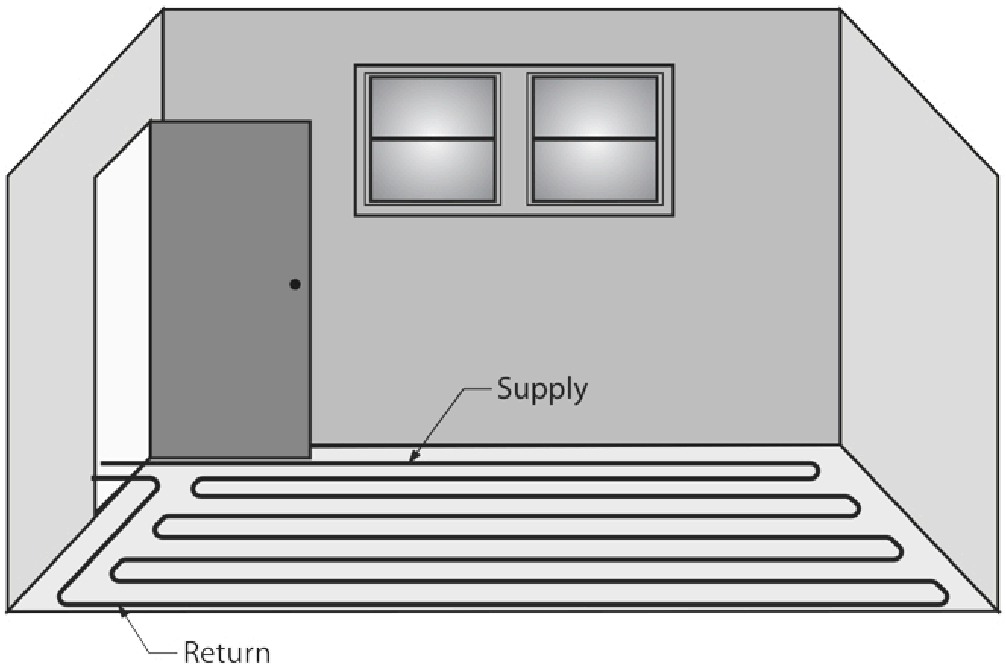


Figure 1 Tubing pattern for rooms with one outside wall

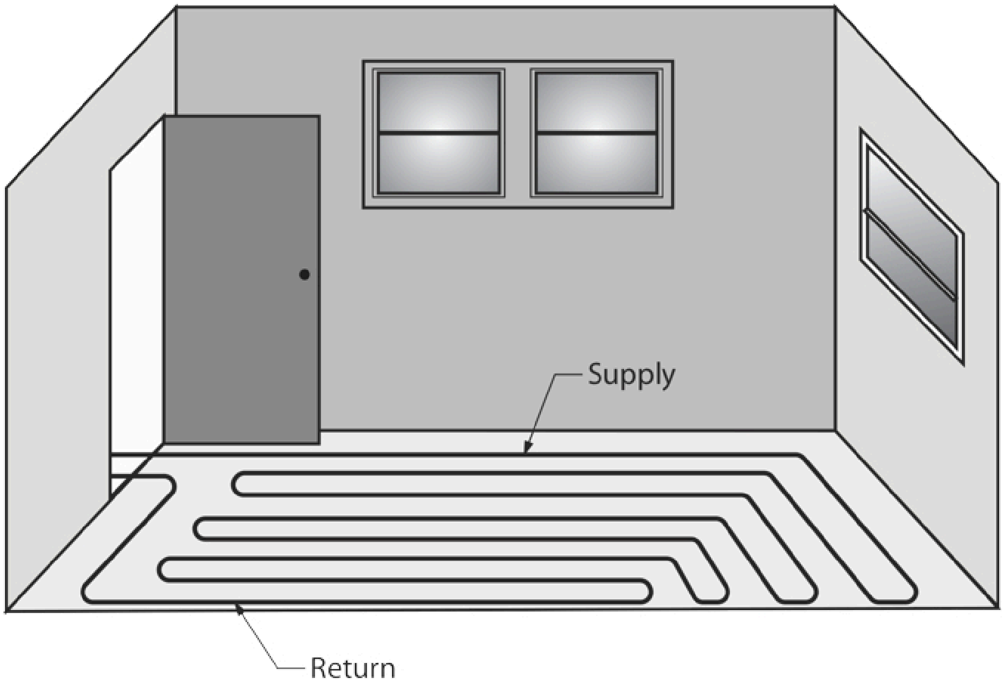


Figure 2 Tubing pattern for rooms with two outside walls

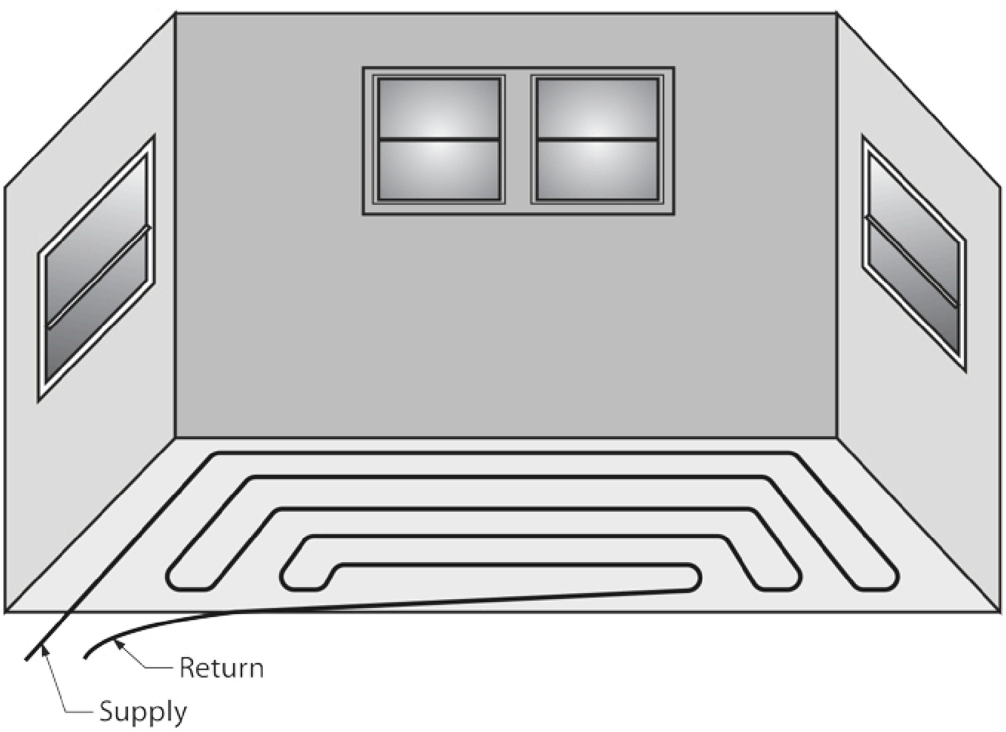


Figure 3 Tubing pattern for rooms with three outside walls

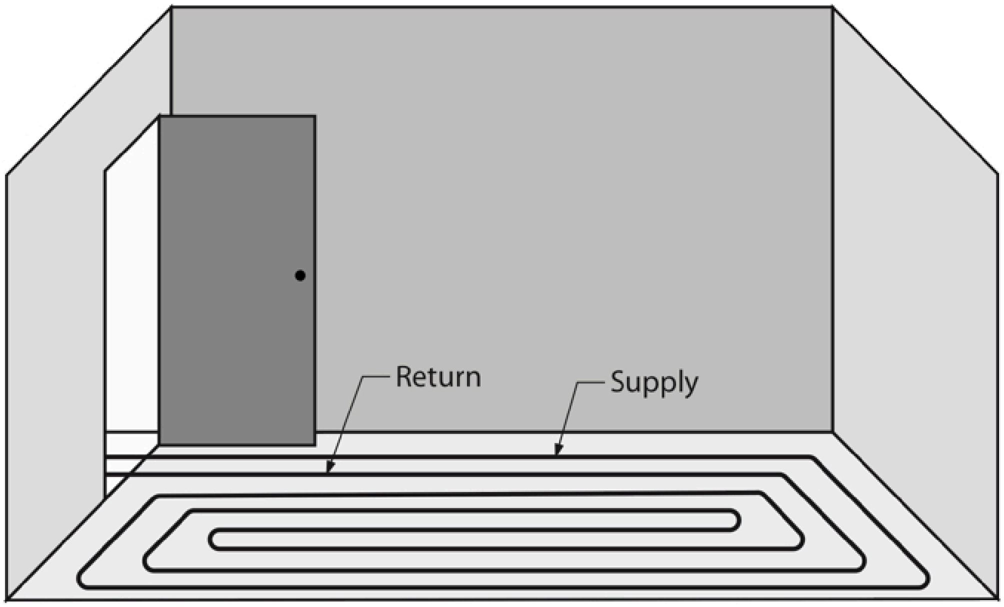


Figure 4 Tubing pattern for rooms with four or no outside walls (“counterflow”)

The graphics above show the common floor panel tubing layouts used. The layout chosen will primarily depend upon the room itself, which could have up to six unheated environments butting up to it. For instance, if a room has an unheated carport below or an unheated attic space above, a counterflow pattern is a good choice in that it spreads the heat out evenly across the floor. Serpentine layouts are common for rooms with 1 or 2 outside walls.

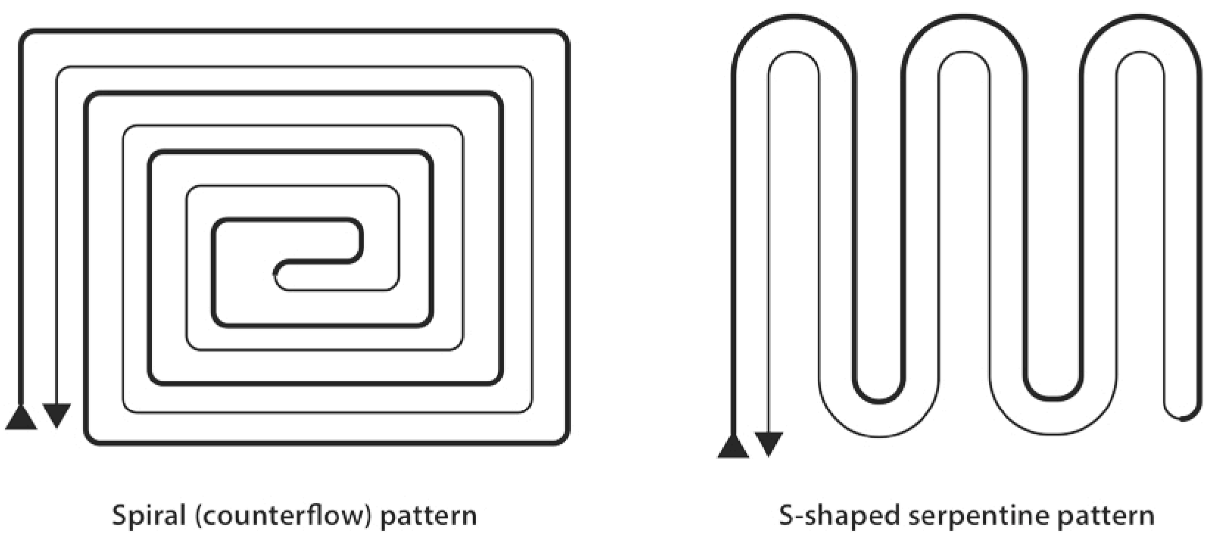


Figure 5 Radiant tubing layout patterns

The main consideration in the loop layouts is that the warmest water should always be delivered to the areas of greatest heat loss first, so the tubing should enter a room through the doorway and make one pass along the outside wall or walls, about 6 inches from them. Then, the tubing turns 180° and parallels the first run at a distance of 6 inches away from the first pass. After the initial 2 passes, the installer then resumes with the layout pattern chosen.

Tube Size and Loop Spacing

A loop is a run of tubing that starts at the supply manifold and ends at the return manifold. Loop centre spacing is determined by the size of the tube and the required floor output in BTUH/ft² of available area. Excluding the spacings at outside walls, spacing for residential systems can vary between 12″, 9″, 6″ and in a few cases even as narrow as 4″ on centre. Commercial systems can be greater than 12″ o.c. where tubing of $\frac{5}{8}$″ NPS and larger is used. Although tubing of $\frac{1}{4}$″ NPS and $\frac{3}{8}$″ NPS has special applications, tubing of $\frac{1}{2}$″ NPS is the standard size for residential systems. Table 2.1 below shows the relationship between tube diameter and spacing.

Table 2.1 Tube Centre Spacing (inches) (courtesy of TECA BC)

Floor Output Required	**Tube Diameter (Nominal I.D.)**			
BTUH/sq ft	$\frac{3}{8}$″	$\frac{1}{2}$″	$\frac{5}{8}$″	$\frac{3}{4}$″
0 – 10	12	12	12	12
10 – 20	9	12	12	12
20 – 25	9	12	12	12
25 – 30	6	9	12	12
30 – 40	4	6	9	9

As you can see, residential ½″ tubing is installed at 12″ on centre for heat outputs up to and including 25 btuh/ft². For heat outputs between 25 and 30 btuh/ft² the spacing decreases to 9″ on centre, and then to 6″ on centre for heat outputs over 30 btuh/ft² to a maximum of 40 btuh/ft². If heat output required exceeds 40 btuh/ft² in areas where people tend to spend time, the floor temperature needed to achieve this would be too uncomfortable for occupants, and supplemental heat such as provided through baseboard wall-fin must be used.

The maximum recommended length of a radiant tubing loop is dependent upon the loop's ΔT as well as its size, with 300 feet being the maximum length of a ½″ loop using a ΔT of 20°F. If these lengths are exceeded, the frictional resistance will no doubt increase to more than has been allowed for in the circulator (pump) design, and the water flow rate will be less than expected. Larger tube sizes will allow longer loop lengths and a greater heat output, with less head loss against the circulator.

If ¾″ tongue-and-groove hardwood is contemplated for flooring over a wet system on a wooden subfloor, "sleepers" of 2 × 2 lumber are fastened to the plywood subfloor in between the loops so that the hardwood can be nailed to it. This means that the lie of the hardwood boards must be predetermined so that the sleepers are perpendicular to the boards. This will also affect the loop layout pattern. When designing, always check with the specific tubing manufacturer to ensure any of their important characteristics are identified and allowed for. With radiant design, the choice of floor coverings cannot be left to the last minute or to change, as they factor greatly in loop layout and spacing.

Floor Output Required

As mentioned above, the tube spacing will be determined according to the tube size and floor output needed. Once a total heat loss estimate is performed, each room's heat loss will be known. One simply has to take the heat output in btuh and divide it by the available square footage in the room where tubing can be laid. Some rooms will have areas where tubing shouldn't be installed. Under cabinets in kitchens and bathrooms are two such areas where tubing would either be ineffective or would be detrimental to the room's use. In a kitchen, laying tubing under cabinets should be avoided because the heat is trapped by the cabinets, can't make its way out into the room and consequently food stored within the cabinet will spoil more quickly. Another area to avoid laying tubing is under stoves and refrigerators. These appliances are heat generators and as such are already adding heat to the kitchen.

When calculating the available area for tubing installed in a kitchen, subtract the areas of the cabinets, refrigerator and stove from the total kitchen area to arrive at the net area for the kitchen tubing layout. Divide that into the heat loss for the kitchen, to get the floor output required.

As an example, let's say the kitchen's gross area is 165 ft^2. If the cabinets, stove and fridge take up 55 ft^2 of that area, then the area left for the tubing installation is 110 ft^2. If the kitchen's heat loss was estimated to be 3,726 btuh, then the floor's output would be 3,726 ÷ 110 = 33.87 btuh/ft^2. Looking at Table 2.2 above, we would see that the tube would have to be laid at 6″ o.c. within the available area. This also means that, for every square foot of floor where tubing is to be laid, there will be 2 feet of tubing. Knowing this will help to determine the total footage of tube required for the kitchen, so 110 ft^2 of kitchen floor will have 220 feet of tube in it.

Other areas where tubing should not be placed are within 6 – 12″ of a toilet bowl, so as to not melt the wax seal. Most plumbers will mount the floor flange on a pair of 2 × 8's or 2 × 10's, laid side-by-side, to set the correct height for the flange as well as to physically maintain clearance between the heated concrete and the tubing. As well, a foam toilet bowl gasket is always a good choice for use with heated floors. Laying tubing beneath bathtubs is questionable, in that the heat from the tubing wouldn't get out from under the tub easily, but the tub itself would be kept warmer when someone is having a bath. The location of any appliance or equipment that needs to be anchored to the floor has to be planned carefully when locating loop runs. If loops are already installed and operational, an infra-red thermometer or camera is a good tool to use to help pinpoint the location of the embedded tubing, minimizing any "hit-and-miss" exploration that could have serious consequences.
There are four multipliers, representing ratios, that are used to help determine total length of tubing in each room. These are based upon the room's available area and tube spacing, and they are **1:1, 1.3:1, 2:1 and 3:1**. For rooms with 12″ spacing, there will be 1 lineal foot of tube for every square foot of floor area covered by tubing; rooms with 9″ spacings will require 1.3 lineal feet of tube per square foot; 6″ spacings will need 2 lineal feet of tube per square foot; and 4″ spacings will require 3 lineal feet of tube per square foot. If all the rooms' tubing lengths and tail lengths (the distance for each loop from the supply manifold out to the room and back to the return manifold) are added together, the sum will be the total length of tubing for the entire house. Just as in most other supply/install situations, it is customary to assume that we would order 10% more tube than is minimally required, to allow for waste

as well as for loop lengths without joints needed per room. Depending on the manufacturer, ½″ tube comes in rolls of 100’, 150’, 250’, 300’, 400’, 500’, 1000’, 1200’ and 2000’.

Installation Guidelines

The following are general guidelines to be followed when installing tubing.

- Take care to not damage the tubing either in installation or during the pouring of the concrete.
- Always run to an outside wall, and return at 6″ o.c. for the first two passes within a room.
- Maintain continuous loop lengths; do not embed a joint or connection in concrete unless approved by both manufacturer and AHJ.
- Use a minimum bend radius of 10x the outside diameter of the tubing.

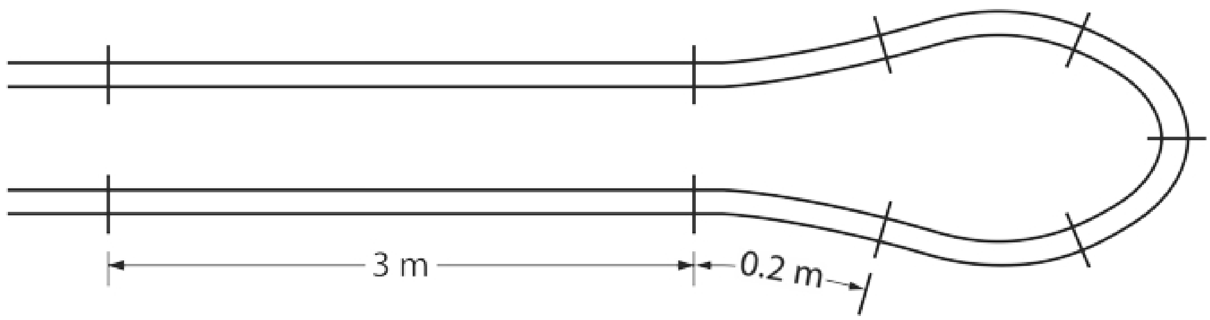


Figure 6 Suggested loop fastening

- Replace any damaged loops entirely, or repair only if approved by the manufacturer.
- Maintain at least ¾″ of concrete over the top of tubing.
- Encase tubing that passes through an expansion joint inside a pipe sleeves that is one tube size larger.
- Pipe entering or exiting a concrete slab, or passing through an expansion joint, must do so through a sleeve.
- Tie tubing directly to WWF using twist ties or plastic straps. Make sure to cut off any ends that might protrude up through the top of the slab.
- Use enough ties to ensure the tubing won’t float upward during the pouring process. Maximum of 3m (10’) spacing between ties on a straight run, and 0.2m (8”) between ties on bends.
- Fill the system to 700 kPa (100 psi) for at least 30 minutes and inspect for leaks. Maintain water under pressure in the tubing while pouring concrete, to keep the tubes from floating.
- Once concrete pouring is finished, water pressure can be released from tubing. Blow out tubing using clean, dry air if freeze-up is possible.
- Do not re-pressurize tubing until concrete is up to its maximum pressure, in order to prevent the concrete from cracking.

Another important point to remember is to not store tubing in direct sunlight. UV rays are harmful to all plastics. Make sure that the tubing stays protected from the sun as long as possible before being installed.

Sizing the Heat Plant

Typically, boilers are the heat plant most commonly associated with hydronic heating, although with the increasing focus on green energy by the reduction of the use of fossil fuels, heat pumps are gaining in popularity. Regardless of the choice of heat plant used, the bottom line is that the heat plant's output, not input, is the determining factor for sizing purposes. For example, if an estimate of a house's heat loss were 37,841 btuh, then a boiler with an output of at least that amount would be needed. Also, one common rule of thumb is that the boiler's output should be at least 10% greater than the estimated heat needed. However, there are others who maintain that a heat loss estimate is based on design conditions that aren't very often encountered, and therefore the extra 10% output doesn't necessarily need to be allowed for. In most cases, as long as a boiler's output is greater than the heat load, there will likely be enough of a "buffer" there to deliver the heat needed even at the coldest times of the year.

Sizing the Circulator(s)

Sizing a circulator is not a straightforward task, and therefore many circulators in use are likely to have been chosen incorrectly for their application.

Firstly, the choice of piping strategy dictates how many circulators are needed and where they are to be located. Take for instance an old high-mass cast iron boiler feeding heat out through ¾″ copper tubing to baseboard convectors in a house. In most cases, a single circulator and multiple zone valves were used, and this "low head" system didn't require the pump to produce much pressure, although it may have required a substantial flow rate in USGPM depending on the number of zones served. The pump should be installed downstream of the "point of no pressure change". This is the point in the piping system where the expansion tank attaches to the supply main. The pump was chosen for its ability to move all the water in the system if all the zones were calling for heat, as well as to produce the pressure needed to overcome frictional losses through the piping, valves, fittings and any other component in the circuit with the highest head loss that the pump supplies.
*It's important to note that the head loss that a pump has to overcome is **not** the sum of the head losses through **all** the circuits that the pump supplies; it is **only** the single circuit with the most frictional resistance which includes the head loss through the longest loop that it supplies.*

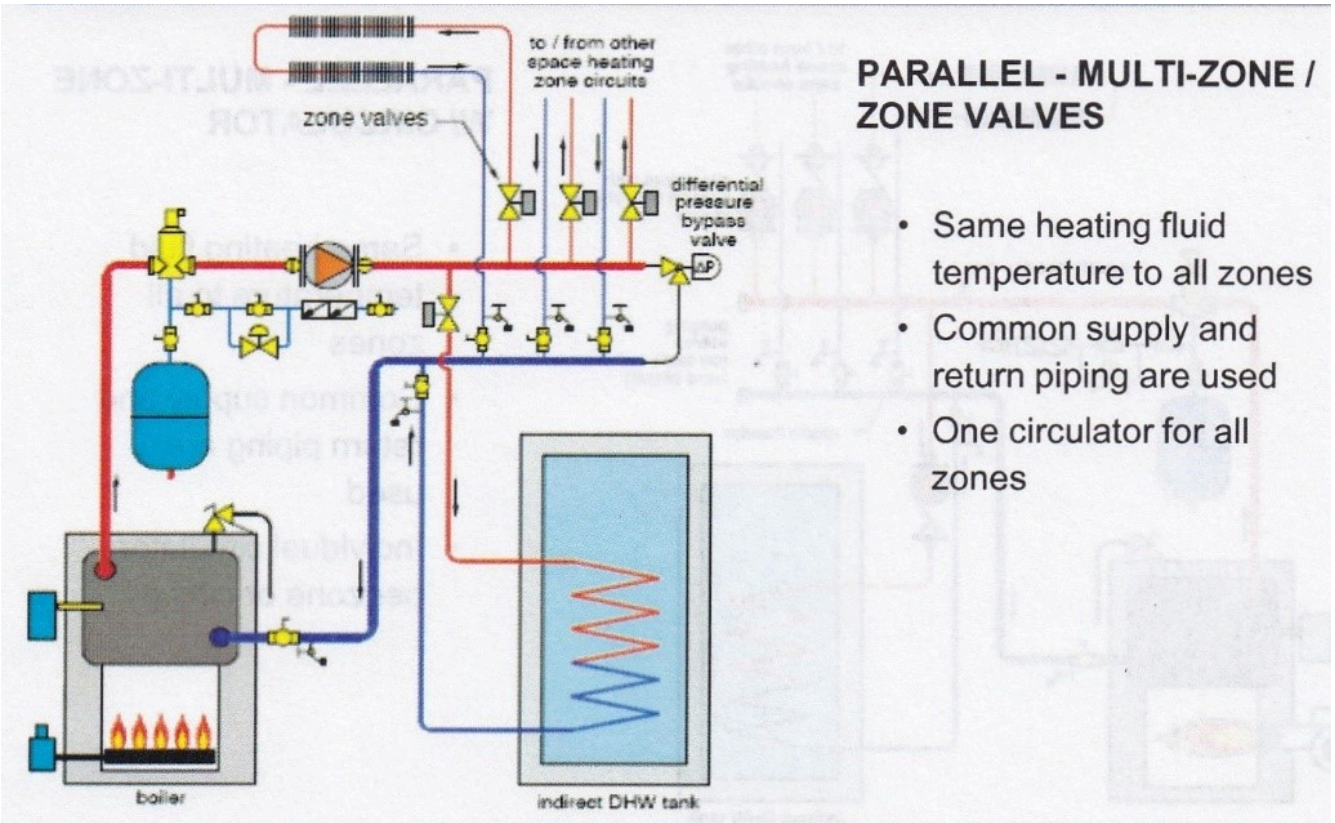


Figure 7 Multiple Zone Valves with Single Circulator

The illustration below is an example of lengths that must be considered when calculating the head against a pump.

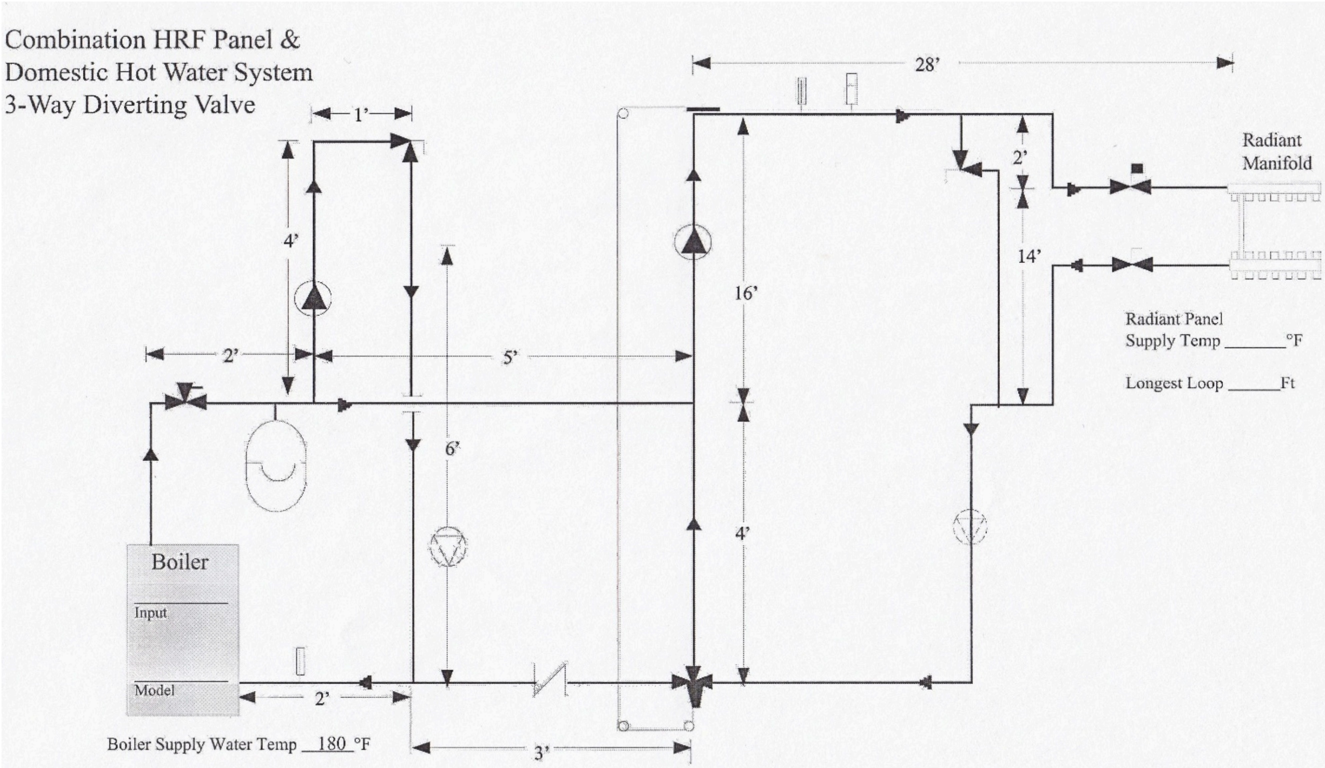


Figure 8 Measuring circuit length

The distance from the pump's outlet to the most remote manifold or heat emitter and back to the pump's inlet is measured, and an additional 50% of the measured length is added to reflect the extra frictional resistance caused by fittings and valves. This "equivalent" length is then converted into a head loss by using a table such as Table A on one of the pages that follow.

Secondly, today's hydronic systems, with equipment such as heat exchangers and small diameter tubing, tend to have more head loss through their circuits than their "older" counterparts, which in turn requires a pump that produces more pressure. As well, if multiple pumps are used in place of zone valves, each one will have less water to move, and less frictional resistance that it has to overcome. So, the characteristics and requirements of circulators have changed with the times. Multiple small, high head, low flow rate pumps have largely replaced the single low head, high flow rate pumps found in the older, less sophisticated systems.

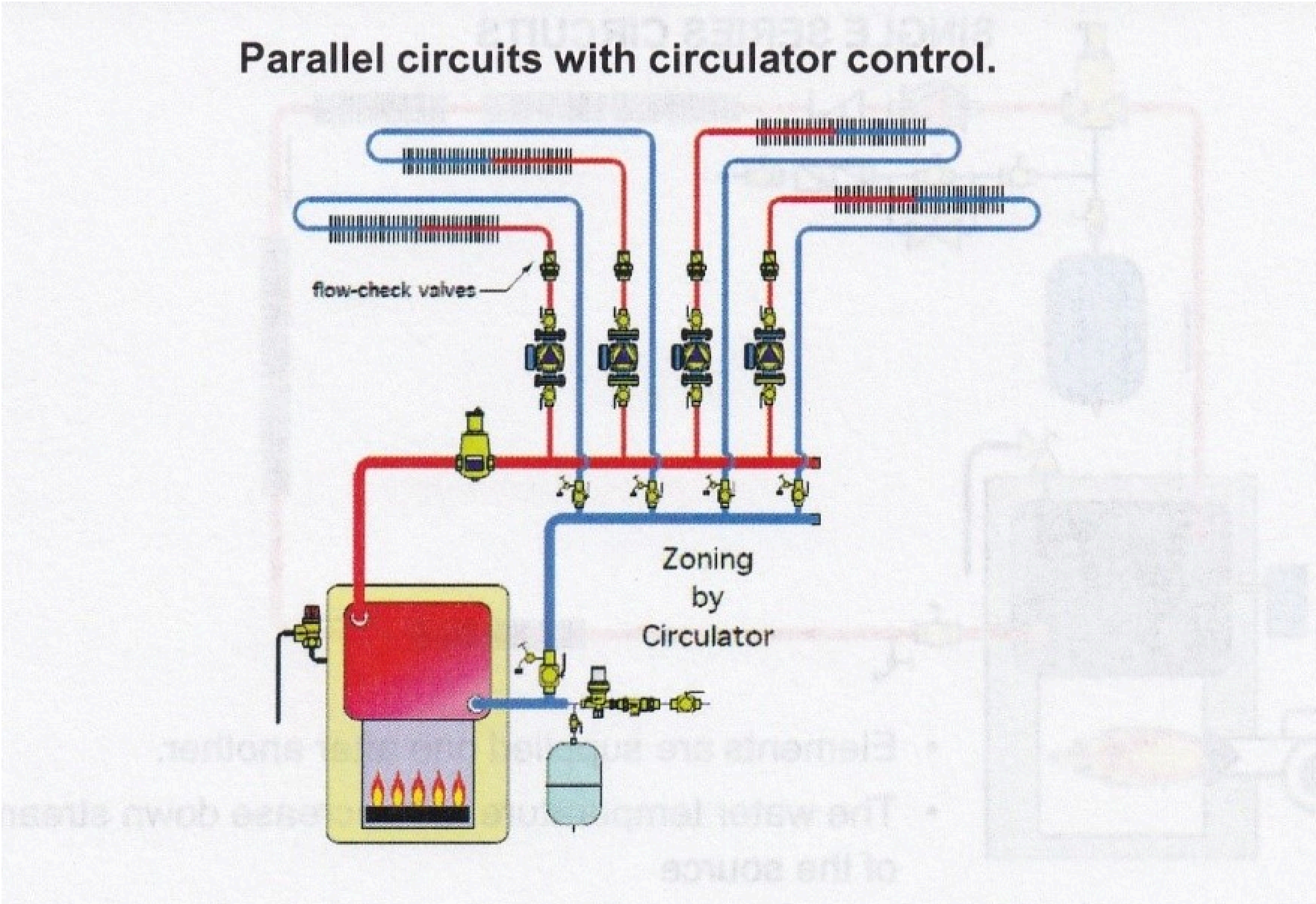


Figure 9 Multiple Circulators for Zone Control

Pumps are chosen based on the two factors mentioned above, which are flow rate required (in USGPM) and resistance to flow that the pump must overcome (in feet of head). These two variables are able to be calculated and identified on a pump graph commonly known as a “pump curve”. The graphic below shows the performance curves for two pumps; one that produces a lot of pressure but not a lot of flow (high head) and the other that produces a lot of flow but not a lot of pressure (low head).

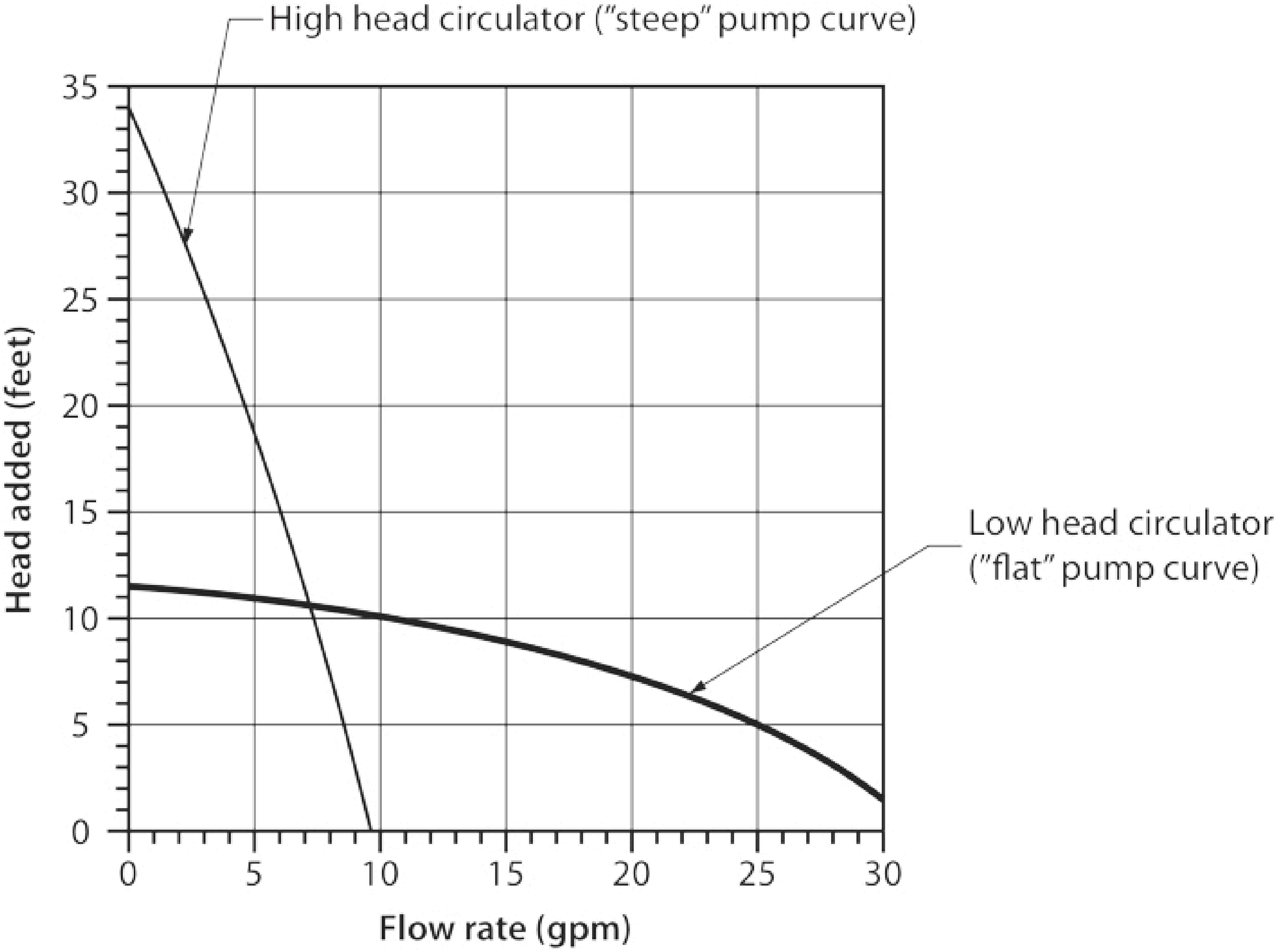


Figure 10 High head vs low head curves

A pump will always deliver a certain flow based on the pressure it is offsetting. In the graph above, if the desired flow rate were to be 7 USGPM, or for simplicity from this point forward simply GPM, the low-head pump would be able to produce approximately 11 feet of head or about 4.8 psi. On the other hand, the high head pump, at 7 GPM flow rate, would produce approximately 15 feet of head or 6.5 psi. The system's requirements therefore must be known before a pump can be selected. Just like a pump, the heating system has a "curve" which is a result of plotting the system requirements on a graph at varied flow rates. This is an involved process, so for ease of description we'll be strictly dealing with a system's maximum flow and head loss requirements so we can plot that single point on a pump graph.

The two widely accepted key points to remember when selecting a pump are:

- to avoid excessive pressure causing noise, choose the pump that has the "flattest" curve, and
- a pump's curve must be "above" the system's maximum requirements when plotted on the graph, in order to overcome the system's head losses and still move enough water

Remember that the height of a closed system has no effect on a pump's operation because it is a balanced system. Wherever the pump is located, the instant that the impeller starts to turn, water will want to move through the system to re-enter the pump's intake port. So, if a pump doesn't have to overcome pressure created by a system's height, the only thing it has to overcome is the frictional resistance of the system components. In order to be able to correctly identify those friction losses, we have to first know the flow rates.

Calculating Flow Rates

The heat that we're trying to supply is expressed in BTUH, but to deliver that within a hydronic system using a pump, we need to turn BTUH (herat loss language) into GPM (pump language). The formula to use is:

BTUH ÷ 10,000 = GPM

This divisor of 10,000 is arrived at by multiplying 20°ΔT (industry-standard temperature differential) × 60 (minutes per hour) × 8.33 (pounds per USG)

The number is actually 9,996 BTUH per USGPM, but for the sake of 4 BTUH we can use 10,000 so that the calculation can usually be performed in one's head. So, if a pump had to deliver 64,325 BTUH at a ΔT of 20°F it would have to move at least 6.4 GPM. Some designers may choose to use a different ΔT for their systems. The flow rate divisor used would then be calculated as ΔT × 60 × 8.33. A ΔT of 15°F would use a divisor of 7,497 (7,500) BTUH per USGPM. For a 15°FΔT our heat requirement example above would need a flow rate of 64,325 BTUH ÷ 7,500 = 8.4 USGPM. A 10°ΔT would use a divisor of 5,000 BTUH per USGPM and so on. Because the industry has used a 20°FΔT for decades, we will always assume a divisor of 10,000.

Calculating Friction Losses

In order to calculate friction loss for any given piping circuit, designers not only have to know the expected flow rate through it (see above), they also need to know the components that the water will have to go through within that circuit. We know by now that frictional losses will increase if the flow rate increases – Bernoulli told us so. High flow rates in GPM will cause high frictional losses. In hot water heating systems, the idea is to keep flow rates low, somewhere between 1 and 4 feet per second, so that frictional losses can be held to a minimum. If water were moved very quickly through a system, not only would there be increased noise and erosion but there would be less time to let the heat that it contains be transferred to the heat transfer units. Tables have been created for hydronics designers that corelate a desired limit of frictional resistance with an equivalent length of piping. In domestic potable water systems where water moves very fast and at high pressures, friction loss is expressed as PSI/foot or feet of head/foot. For hydronic heating systems, the frictional resistance expression needs smaller units known as **millinches** per foot. A foot contains 12 inches and, instead of eighths, sixteenths or sixty-fourths, each inch is split into 1,000 parts called millinches. Translated into frictional losses of PSI per foot, 1 millinch/foot would be equivalent to 0.000083 psi per foot. The norm for designers is to move water through a system so that the frictional losses are kept to somewhere between 100 and 500 millinches per foot, with ***400 millinches/foot*** being the design norm.

The table shown below equates an equivalent length of pipe to a frictional loss for that length, at head losses between 200 and 500 millinches per foot.

Table 2.2 Total Equivalent Length of Pipe in Feet vs Head Loss (courtesy of TECA BC)

Pressure Head of Feet	**Piping Friction Loss — Millinches per Ft of pipe**					
	500	**400**	**350**	**300**	**250**	**200**
2	48	60	69	80	96	120
2.5	60	75	84	100	120	150
3	72	90	102	120	144	180
3.5	84	105	120	140	168	210
4	96	120	137	160	192	240
4.5	108	135	154	180	216	270
5	120	150	171	200	240	300
5.5	132	165	188	220	264	330
6	144	180	206	240	288	360
6.5	156	195	223	260	312	390
7	168	210	240	280	336	420
7.5	180	225	256	300	360	450
8	192	240	274	320	384	480
8.5	204	255	292	340	408	510
9	216	270	309	360	432	540
9.5	228	285	326	380	456	570
10	240	300	343	400	480	600
10.5	252	315	360	420	504	630
11	264	330	376	440	528	660
11.5	276	345	395	460	552	690
12	288	360	410	480	576	720
15	360	450	515	600	720	900
20	480	600	686	800	960	1200
25	600	750	857	1000	1200	1500
30	720	900	1030	1200	1440	1800
35	840	1050	1200	1400	1680	2100
40	960	1200	1370	1600	1920	2400

50	1200	1500	1725	2000	2400	3000

Equivalent length means taking the actual measured length and adding 50% to it to simulate extra losses through fittings. For example, a measured length of 70 feet, from outlet of the pump around through the circuit it serves and back to the inlet, would be considered to be 70 × 1.5 = 105 equivalent feet. As you can see, the shaded area on the table represents 400 millinches/ft. (the desired limit). Reading down that shaded column, we see that an equivalent length of pipe of 105 feet would be considered to have a head loss of 3.5 feet of head pressure against the pump. 150 feet of pipe at 400 millinches/ft would be given a total head loss of 5 feet, and so on. The units of measure can always be translated back and forth between feet of head and psi by using the .433 multiplier or its inverse of 2.31, but pump language for pressure is in feet of head.

Loop Losses

The table shown above is meant to assign a head loss to the supply and return piping near the boiler and out to the manifolds. Additionally, the head loss through the longest loop supplied by a manifold will have to be determined so it can be added to the other heads that the pump must overcome. Manufacturers of PeX tubing publish the head losses for their various types and sizes of tube, at different flow rates and temperatures and with different glycol mixtures. Because the tubing from various manufacturers is consistent in its inside diameter, tables from different manufacturers will be all but identical and their results are similar enough to be relied upon. Below is a table for the head loss through 100 feet of ½″ PeX “A” tubing using 100% water (no glycol).

Table 2.3 Head (feet of water) per 100 feet of tubing – Table for 100 feet of PeX “A” tubing at various temperatures and flow rates (from industry literature)

gpm	**Velocity (ft/s)**	**40°F 4°C**	**60°F 16°C**	**80°F 27°C**	**100°F 38°C**	**120°F 49°C**	**140°F 60°C**	**160°F 71°C**	**180°F 82°C**
0.1	0.18	0.06	0.05	0.05	0.05	0.05	0.05	0.04	0.04
0.2	0.36	0.21	0.19	0.18	0.18	0.17	0.16	0.16	0.16
0.3	0.54	0.44	0.41	0.39	0.37	0.36	0.35	0.34	0.33
0.4	0.72	0.75	0.70	0.66	0.64	0.61	0.59	0.58	0.57
0.5	0.91	1.14	1.05	1.00	0.96	0.92	0.89	0.88	0.86
0.6	1.09	1.59	1.47	1.40	1.35	1.29	1.25	1.23	1.20
0.7	1.27	2.12	1.96	1.86	1.79	1.71	1.66	1.63	1.60
0.8	1.45	2.72	2.51	2.38	2.30	2.19	2.13	2.09	2.05
0.9	1.63	3.38	3.12	2.96	2.86	2.73	2.65	2.60	2.55
1.0	1.81	4.10	3.79	3.60	3.47	3.31	3.22	3.16	3.09

To arrive at a head loss for a loop, simply find the closest temperature and flow rate for the desired loop, and adjust the table's head loss to reflect the actual loop length. For instance, for a loop that operates at 118°F and .65 GPM, enter the table by choosing 100°F and 0.7 GPM, which would be 1.79 feet of head per 100 feet of tubing. The rationale here is that colder water will have more frictional resistance than hot water, and 0.70 GPM will be more restrictive than 0.60 GPM. This approach will ensure that the pump will be able to move the water at the actual temperatures and flow rates. Once the head loss is identified from the table, multiply that number by the actual length of the loop. For the example above, if the loop's actual length was 240 feet, then the head loss through it would be 2.4 × 1.79 = 4.3 feet of head.

The Effects of Glycol

Winters in Canada can be very cold, depending on location, and in rural areas a constant electrical power supply can be hit-and-miss, so an antifreeze solution, rather than 100% water, may be a good choice for a hydronic system. However, there are effects that must be considered.

Firstly, there must be an acceptable backflow prevention device installed on the cold water makeup to the system. Where a "dual check with atmospheric port" (DCAP) device is the norm as a backflow preventer for residential systems that are not more than 250,000 btuh of input and have no chemicals added, a reduced pressure backflow assembly (RPBA) will be needed once any chemicals of any kind are added.

Secondly, the appropriate type of glycol to be used is polypropylene glycol, which is known as food-grade antifreeze. It is non-toxic but expensive. It's counterpart, ethylene glycol, is used in the automotive industry, and although less expensive than polypropylene glycol, it is *extremely* toxic, and its use in a hydronic system that is directly connected to a potable water supply is strongly discouraged, with or without backflow prevention.

Thirdly, glycol will have an effect on pumps and expansion tanks. The chart below illustrates the increase in effort that will be put on pumps that are trying to move a thicker-than-water solution. Depending on the temperature (hot water is "thinner" than cold water), a 50% glycol/water solution will be anywhere from 14% to 22% harder to move, and will create more head pressure as well, up to 2.14 times that which 100% water would create at 40°F

Table 2.4a Adjustment for 50% Glycol in Heating System – Flow Rate Adjustment

Fluid Temperature °F	**% Adjustment Factor**
40°F	1.22
100°F	1.16
140°F	1.15
180°F	1.14
220°F	1.14

Table 2.4b Adjustment for 50% Glycol in Heating System – System Pressure Adjustment

Fluid Temperature °F	**% Adjustment Factor**
40°F	2.14
100°F	1.49
140°F	1.32
180°F	1.23
220°F	1.18

Lastly, any glycol will have a detrimental effect on any rubber components in the system, mainly the rubber ball inside a zone valve. Over time, the rubber will erode and eventually disintegrate.

In summary, the use of glycol should be avoided if at all possible.

Another variable that must be known will be the use of any specialty components on a pump's circuit. These are circuit balancing valves (known as "circuit setters"), mixing valves and heat exchangers.

Circuit Balancing Valves ("Circuit Setters")

A pump will move water at a certain flow rate depending on the head losses that it is pumping against. If the flow rate through a circuit needs to be as accurate as possible, a balancing valve may have to be installed. They are a low-loss type of globe valve, and will have ports known as "Pete's Plugs" on the upstream and downstream sides of the valve seat. "Pete" is a twist of the expression "PT" which stands for pressure/temperature.

Figure 11 Circuit setter with PT plugs

Flow rate is measured by attaching a differential pressure gauge to the Pete's plugs and reading the ΔP across the valve. This reading is applied to a table for that particular valve which will indicate the GPM through the it at that setting. Adjusting the valve will alter the ΔP across it and thereby the flow rate.

Tempering Valves

If a system requires water temperatures that differ greatly, such as when a non-condensing boiler has to feed a radiant floor panel, the water to the panel must be tempered, and there are different valves available that can be used. They come in various types, configurations and sizes, and as such may be located in different points in the system.

Mixing Valves

A mixing valve can have either 2, 3 or 4 ports and is located at the point where high temperature water from the boiler and some of the low temperature return water converge, known as the "mixing point", with the tempered water going out to the system and the remainder of the return water going back to the boiler. Some examples of 3-way and 4-way mixing valves are shown below.

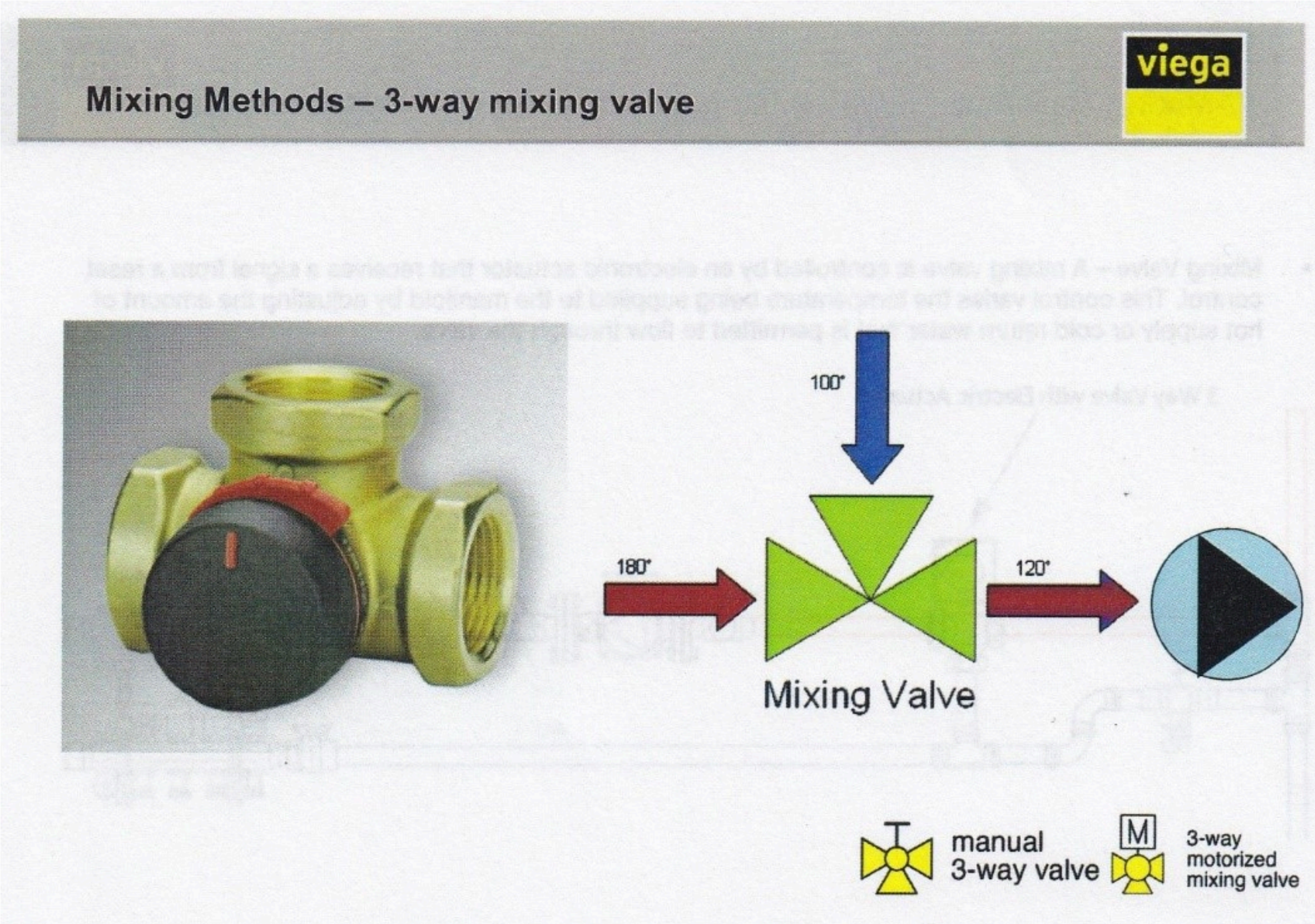


Figure 12 3-way mixing valve

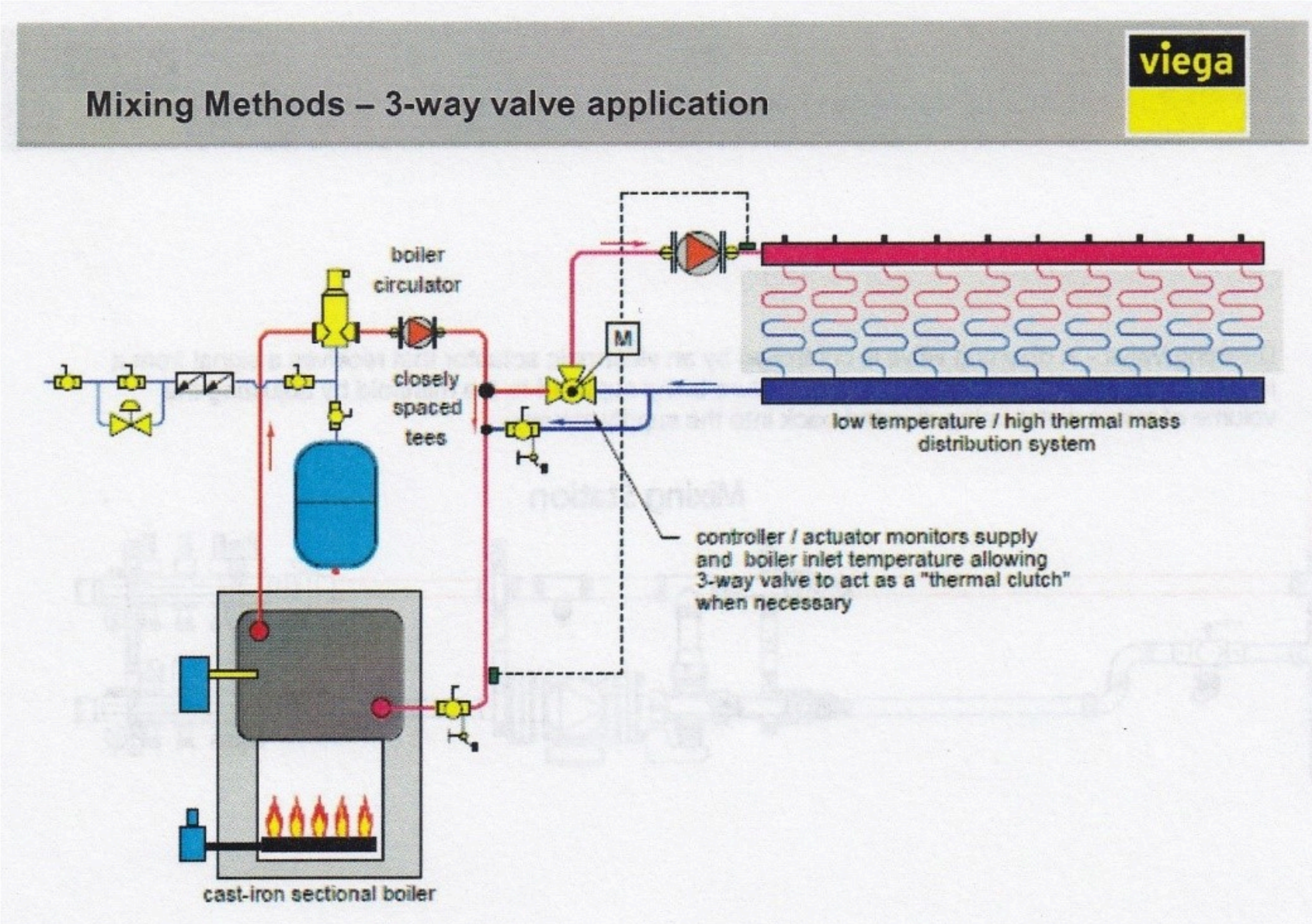


Figure 13 3-way valve in a primary-secondary system

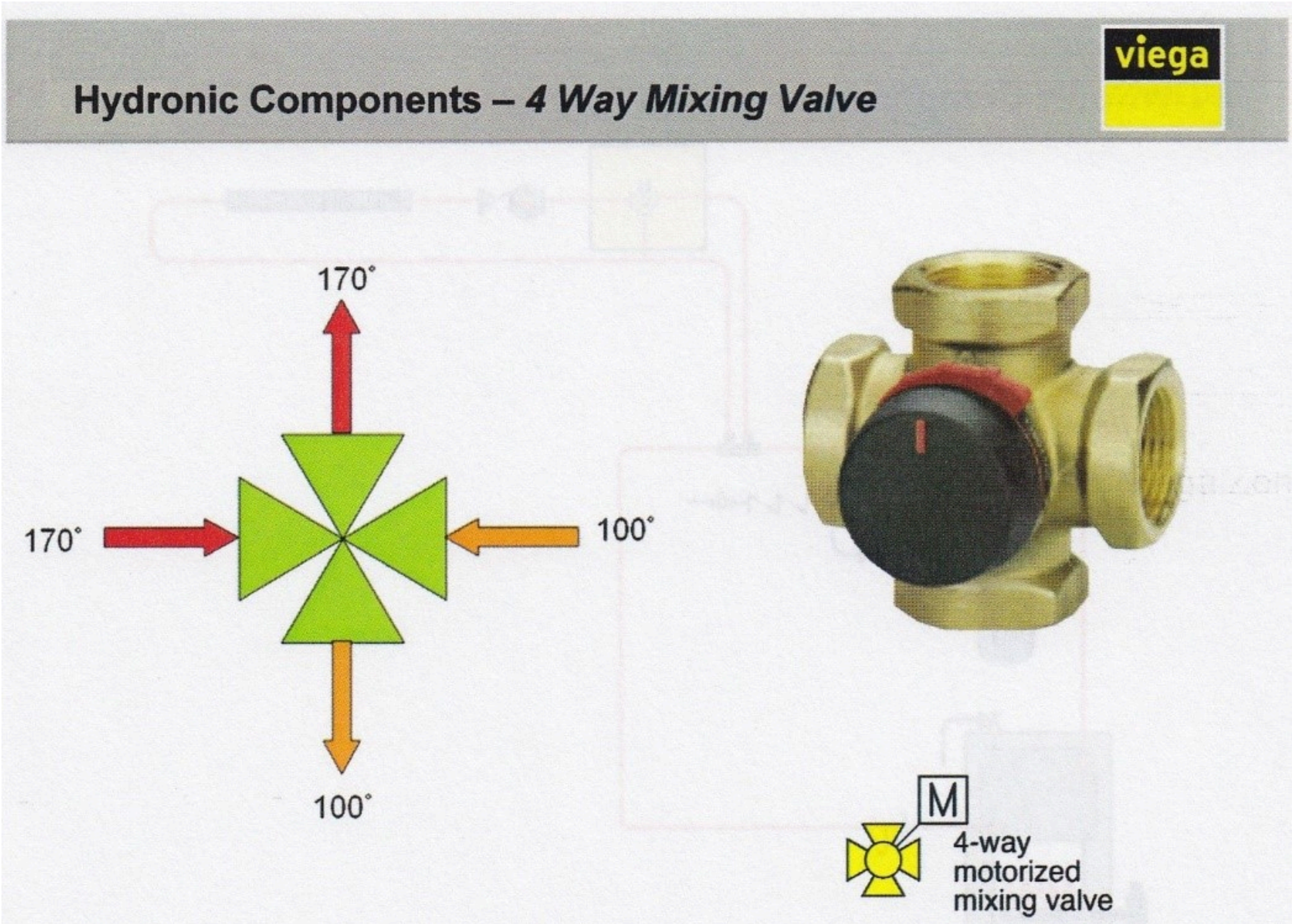


Figure 14 4-way mixing valve

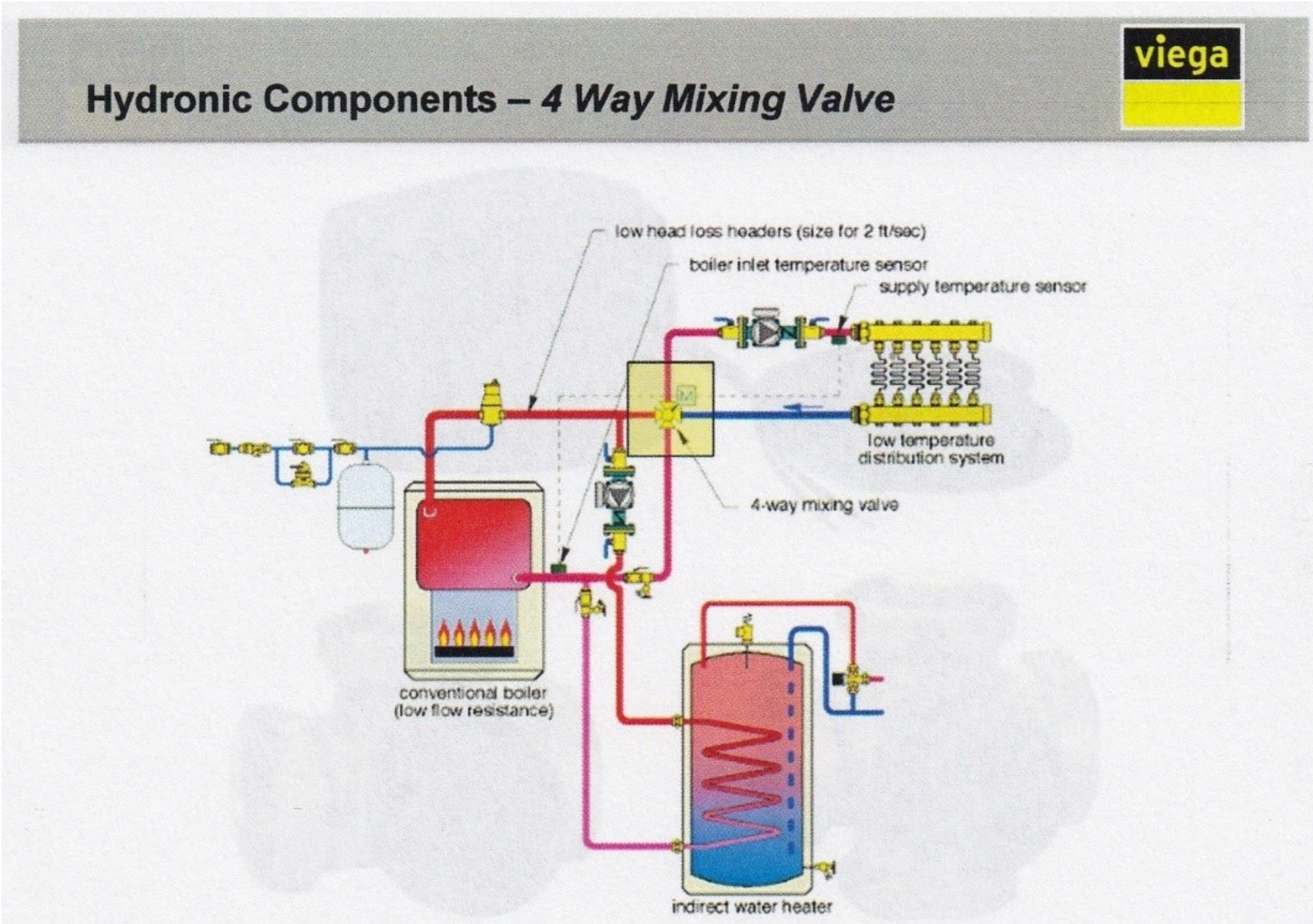


Figure 15 4-way mixing valve with radiant and high temperature DHW

The mixing valves can either be manually pre-set to supply a constant temperature (known as thermostatic) or can have a motorized actuator and controller added which is capable of modulating the temperatures as thermal conditions change (known as reset control).

Figure 16 Mixing valve actuator for modulating temperature control

Diverting Valves

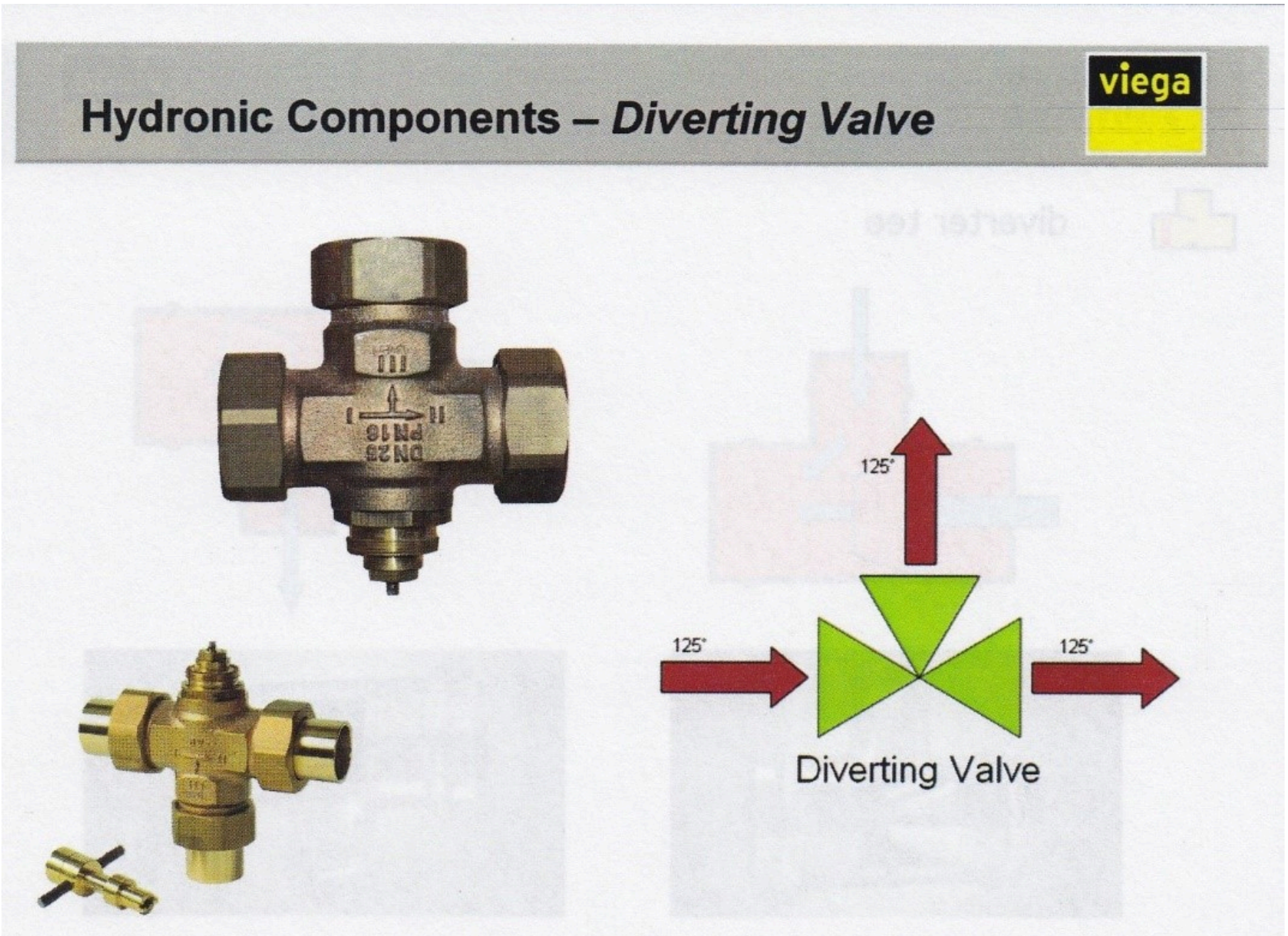


Figure 17 Diverting valve

There are a few differences between a diverting valve and a mixing valve. Diverting valves have the same entering and leaving water temperatures, and so are not located at the mixing point; rather it is located on the return piping, as seen in the diagram below.

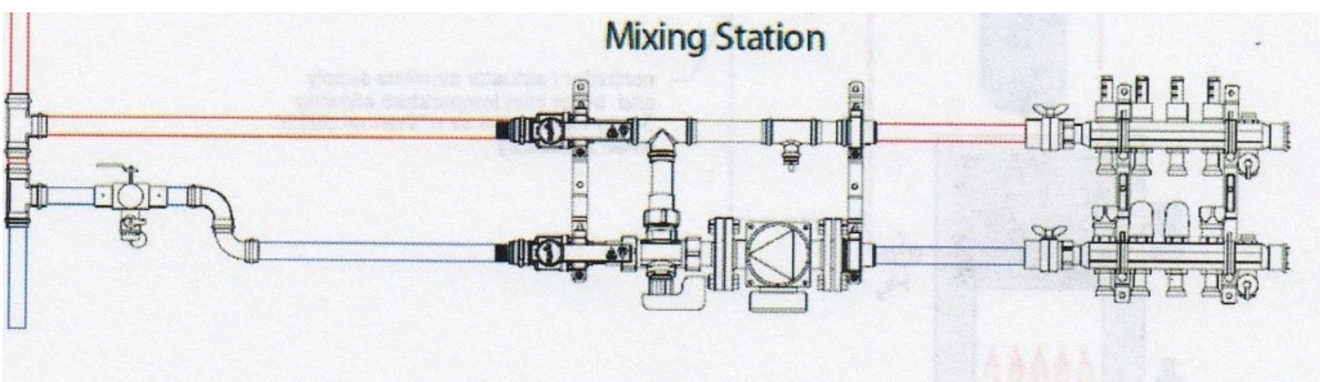


Figure 18 Diverting valve location

There is more explanation of these valves in a later module.

Injection Mixing

Another popular strategy for adjusting mixed water temperatures to manifolds is through the use of a pump to “inject” an amount of hot water into the supply side of a manifold, appropriately called “injection mixing”. Injection pumps are commonly used in conjunction with primary-secondary piping systems. A temperature controller reacts to a sensor’s output and sends a signal to a pump that the supply loop needs heat. The variable-speed pump sets itself to the speed required in order to maintain a desired temperature.

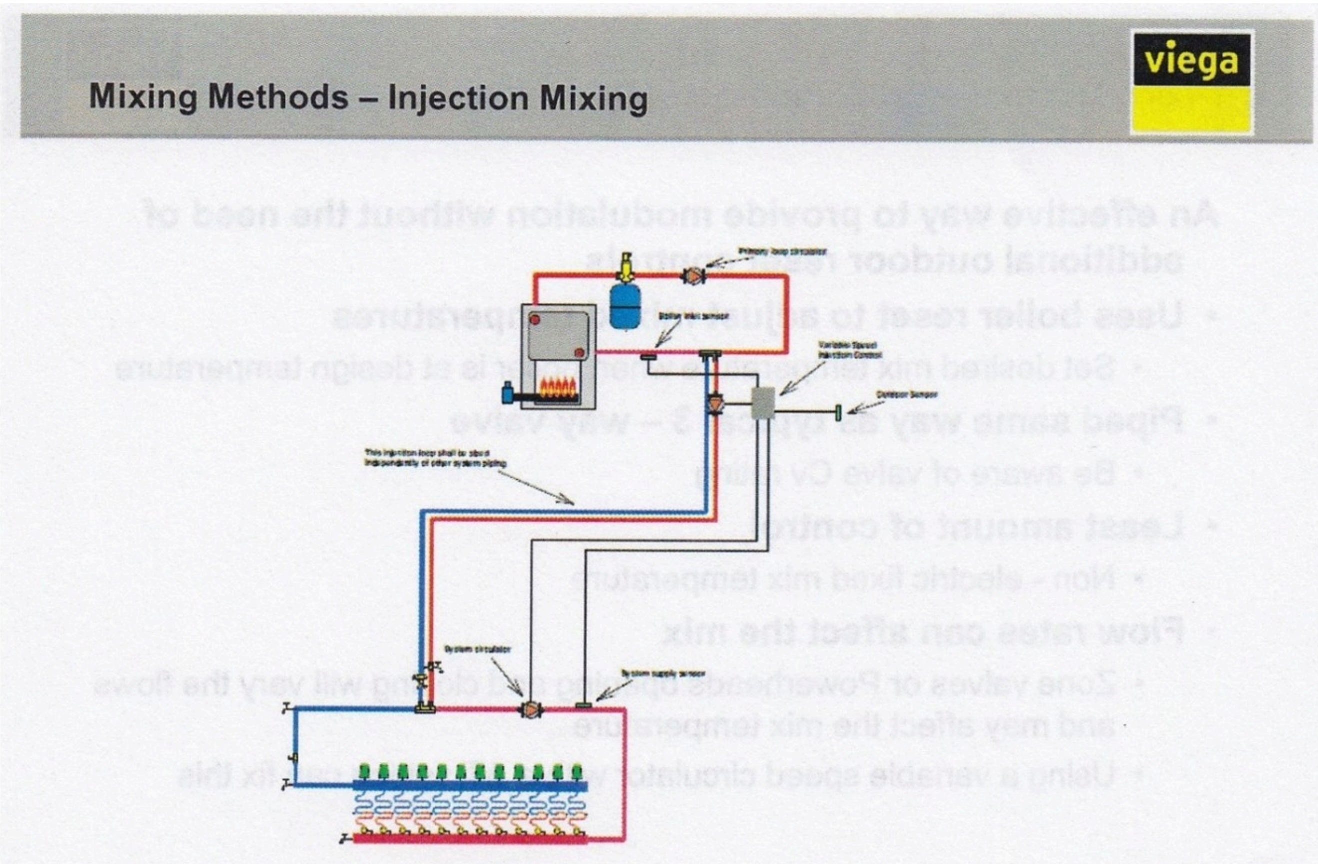


Figure 19 Mixing methods – injection mixing

Hydraulic Separation

Multiple pumps which share piping must be hydraulically separated from each other to ensure that the operation of one pump can’t affect the operation of the other. This can be accomplished by using a “hydraulic separator”, which can be as simple as a tank or large vessel that has very low head loss through it.

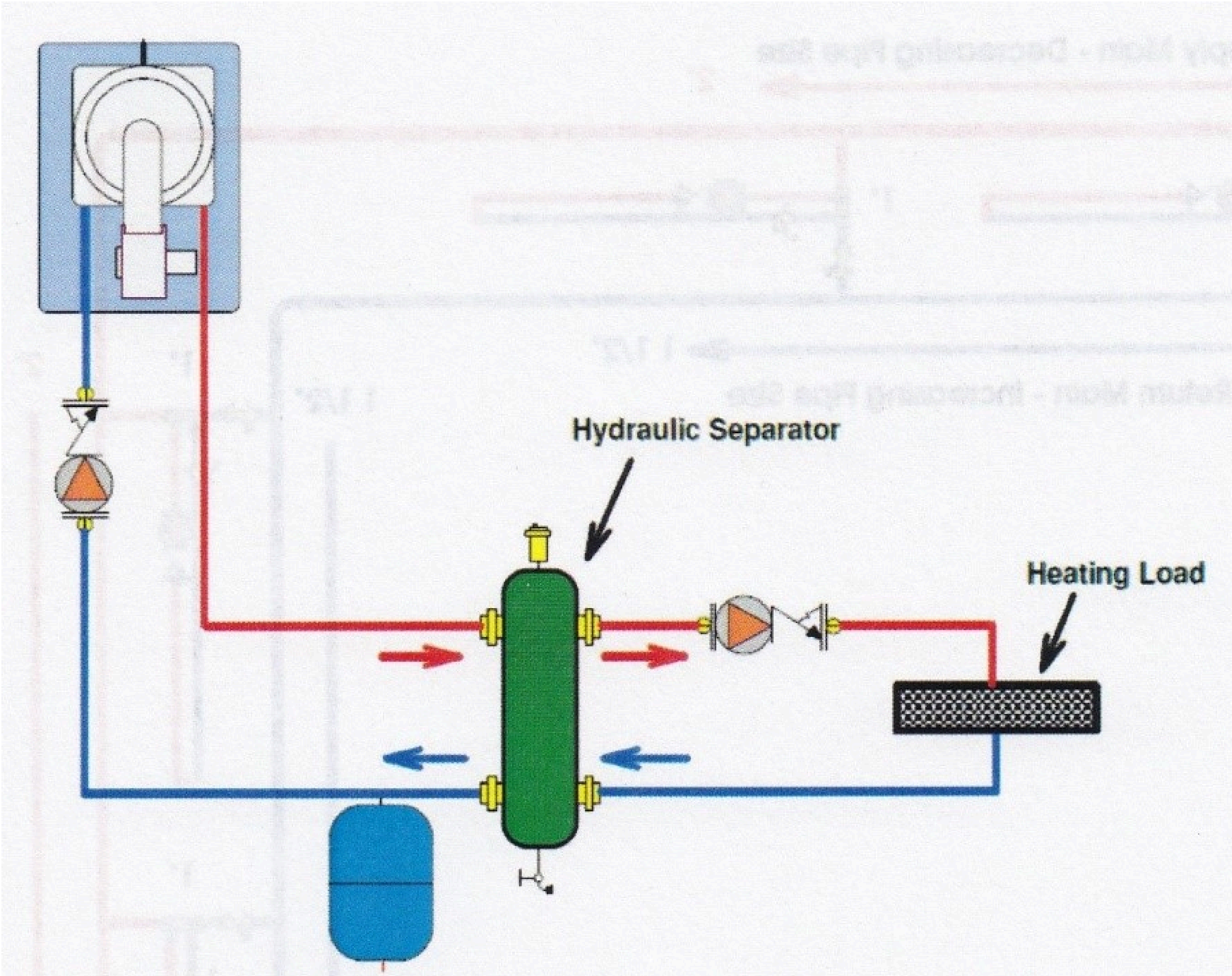


Figure 20 Hydraulic separator

This separation can also be through the use of tees located very close to one another as in the graphic below.

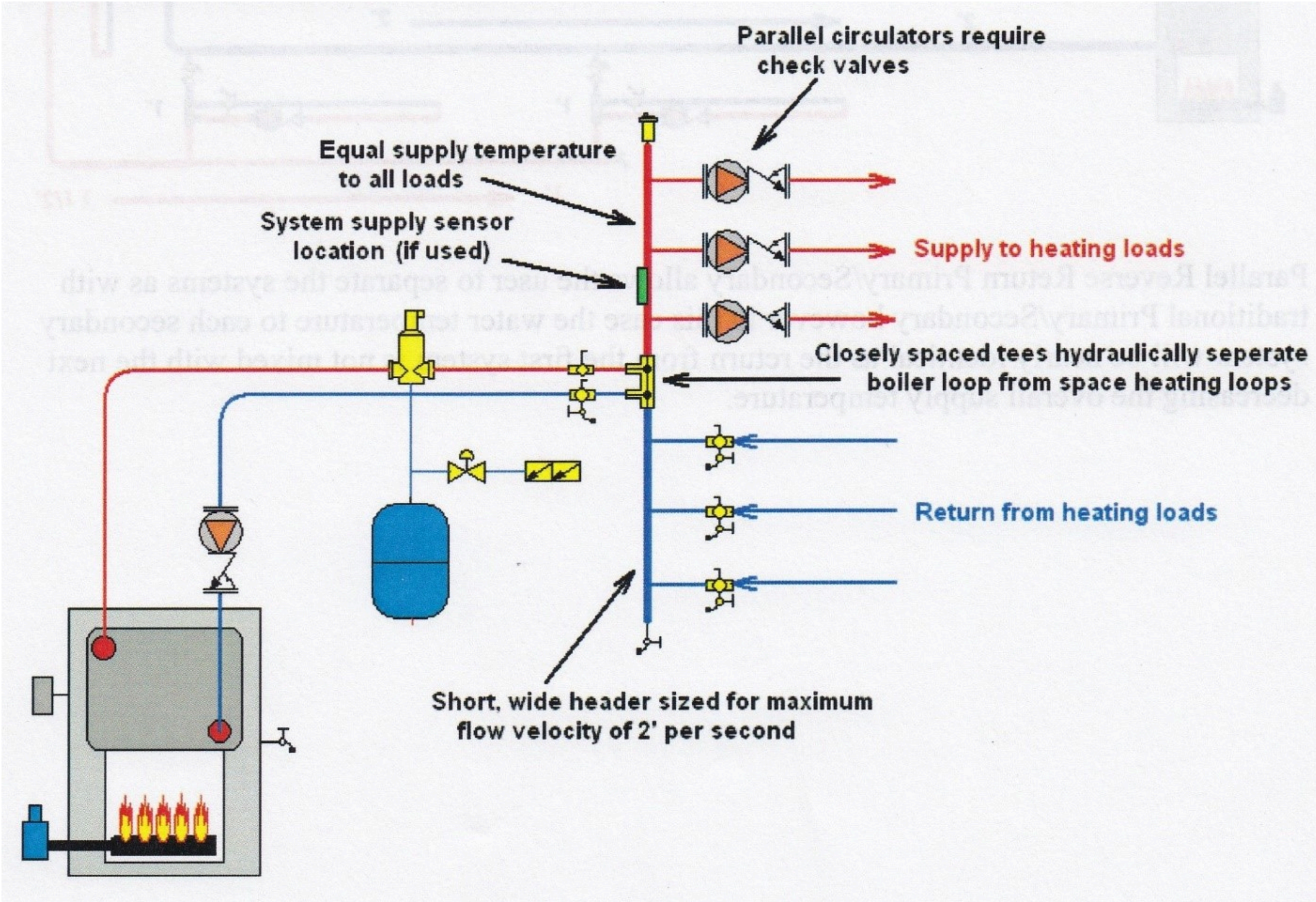


Figure 21 Hydraulic separation using closely-spaced tees

Heat Exchangers

Brazed plate heat exchangers used in residential and small commercial systems are very compact but have enormous heat exchange capacities. This is because the small spaces between the stainless-steel plates inside them have a huge surface area. Consequently, pumps have to work harder than normal to push water through them.

Figure 22 Brazed plate heat exchanger

CV Value

The manufacturers of high head loss components, such as mixing valves and heat exchangers, assign numbers to them for use in head loss calculations, known as “CV” (control valve) values. A CV value is the flow rate in GPM through the valve that would result in a 1 psi pressure drop across it. The same valve used in two different piping systems will have differing head losses through it because of the existence of differing flow rates. To calculate the pressure drop through a valve at a specific flow rate, use the following formula$\Delta P = (Q \div CV)^2$ where Q = desired flow rate and ΔP is the pressure drop in PSI.

As an example, let’s say that we are intending to use a valve that has a CV rating of 2.5. This means at a flow rate of 2.5 GPM, the pressure drop across the valve will be 1 psi. If we need to know what the pressure drop across the valve will be at a flow rate of 3.2 GPM, we would calculate it as follows:

$\Delta P = (3.2 \div 2.5)^2 = 1.64$ PSI which translates to 3.79 feet of head.

To correctly size a pump, the total head losses for the piping and devices that it must push water through are applied to the vertical axis (left side) of a pump graph. Draw a horizontal line across the graph from that point, then find the desired flow rate in GPM that it must supply along the horizontal axis at the bottom of the page and draw a vertical line upward through the graph from that point. The intersection of the horizontal and vertical lines would be the maximum needs of the system in head loss and flow rate, called the “system operating point”. For a pump to be effective, its curve has to fall above the system operating point. If it isn’t, it won’t put out enough pressure at the required flow rate to offset the frictional losses.

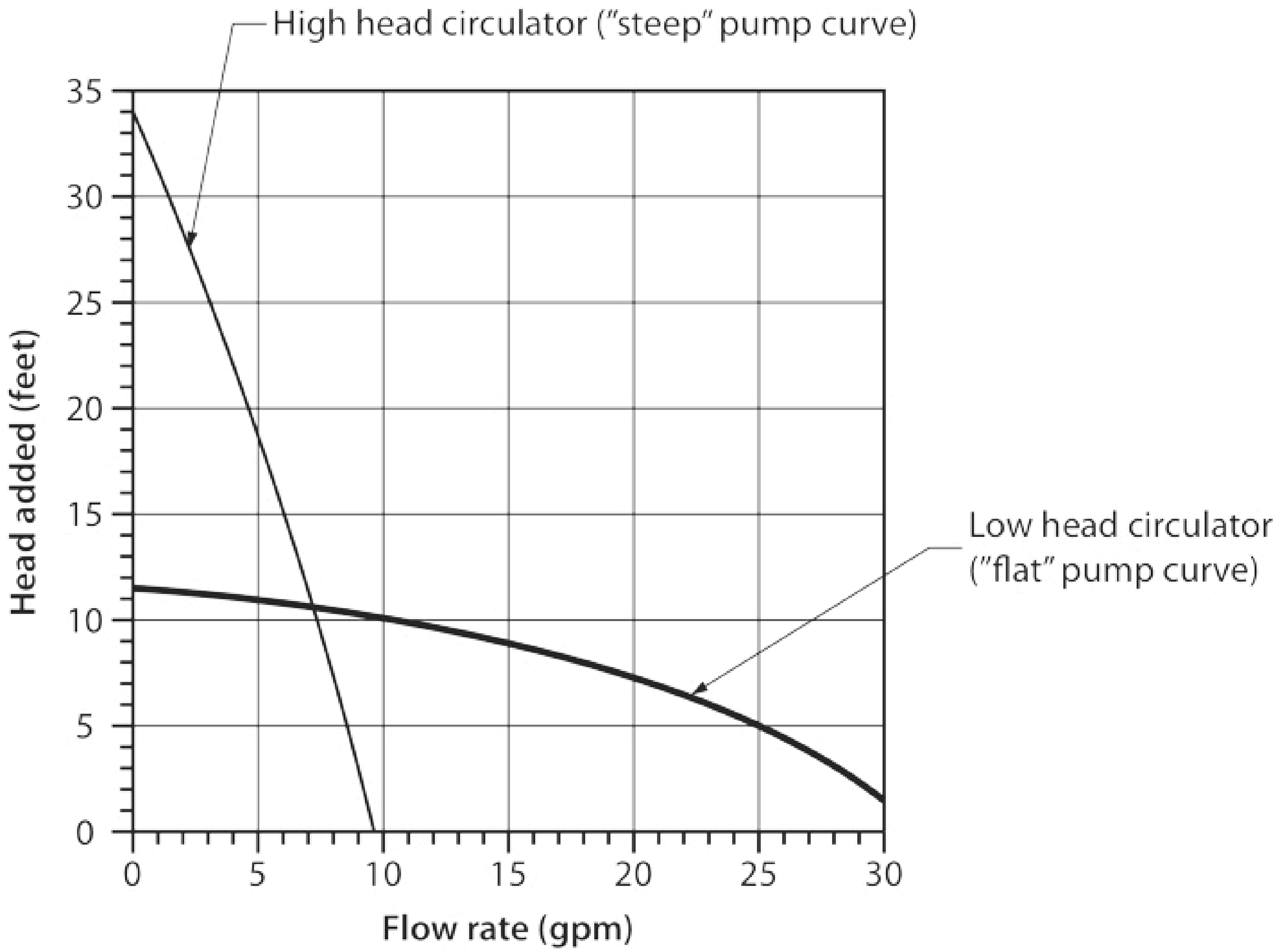


Figure 23 Pump chart

Looking at the chart above, if a system's operating point was 15 feet of head @ 5 GPM, the pump with the flat curve would only create 11 feet of head pressure at 5 GPM, and so would not do the job. The pump with the steep curve would put out approximately 18 feet of head pressure while moving 5 GPM and would work for that application. The ideal pump chosen would be one with a "flat" curve so as to avoid excessive pressure which creates noisy systems. As well, whenever possible, select circulators so that the operating point of the system falls within the middle third of their pump curve. This is the region where the circulator's efficiency is relatively high.

Some points to remember when installing pumps are:

- Many modern pumps are capable of operating at three different speeds. When using this variety of pump, always select the lowest speed that will deliver the head and flow rate required.
- Always locate circulators so that the connecting point of the system's expansion tank ("point of no pressure change") is as near the inlet of the circulator(s) as possible. This allows the circulator to "pump away" from the point of no pressure change and thereby increase the pressure in the circuit.
- Always provide hydraulic separation between any circulators in a system that could operate

simultaneously. This prevents interference between the circulators, especially when they have very different flow/head ratings.

For systems using a single pump and multiple zone valves, a differential pressure valve (DPV) is usually installed to avoid over-pressurizing the system in situations where there are only one or two zones calling for heat. A DPV will open to bypass water from the supply main to the return main when excessive pressure is sensed.

Figure 24 Differential pressure valve

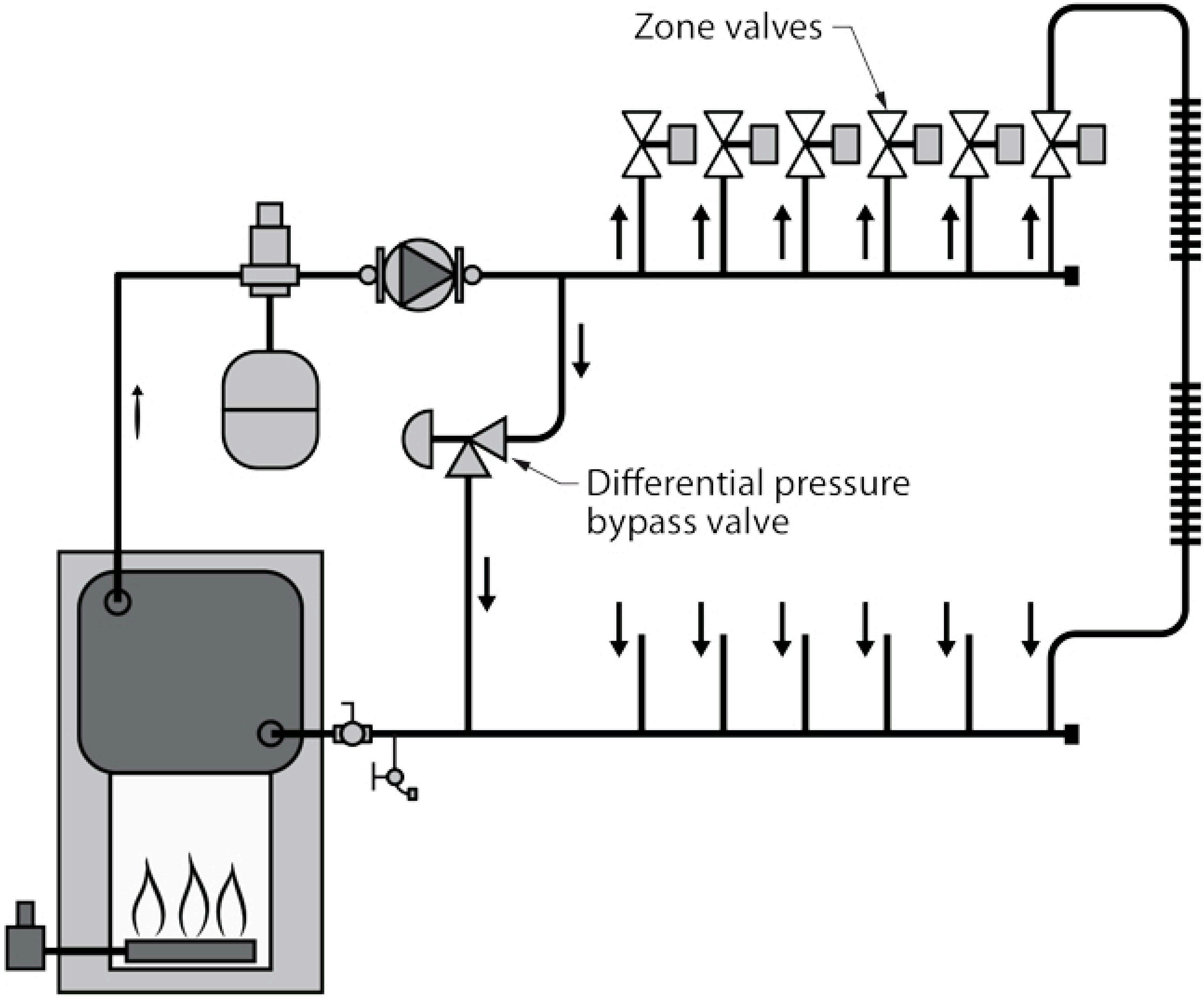


Figure 25 Multiple zones with single pump and DPV

Another way of regulating differential pressure in hydronic systems is through use of variable-speed circulators. This method has been used in larger hydronic systems for several years. It is accomplished through the use of electronic pressure transducers that communicate to a variable frequency drive (VFD) to electrically adjust the speed of an AC circulator motor. The more recent availability of smaller circulators with electronically commutated motors (ECM) now makes similar control techniques available in smaller residential hydronic heating and cooling systems. These “pressure-regulated” ECM circulators are ideal for systems using valve-based zoning. They eliminate the need for a differential pressure bypass valve. They also eliminate the need of pressure transducers and variable frequency drives.

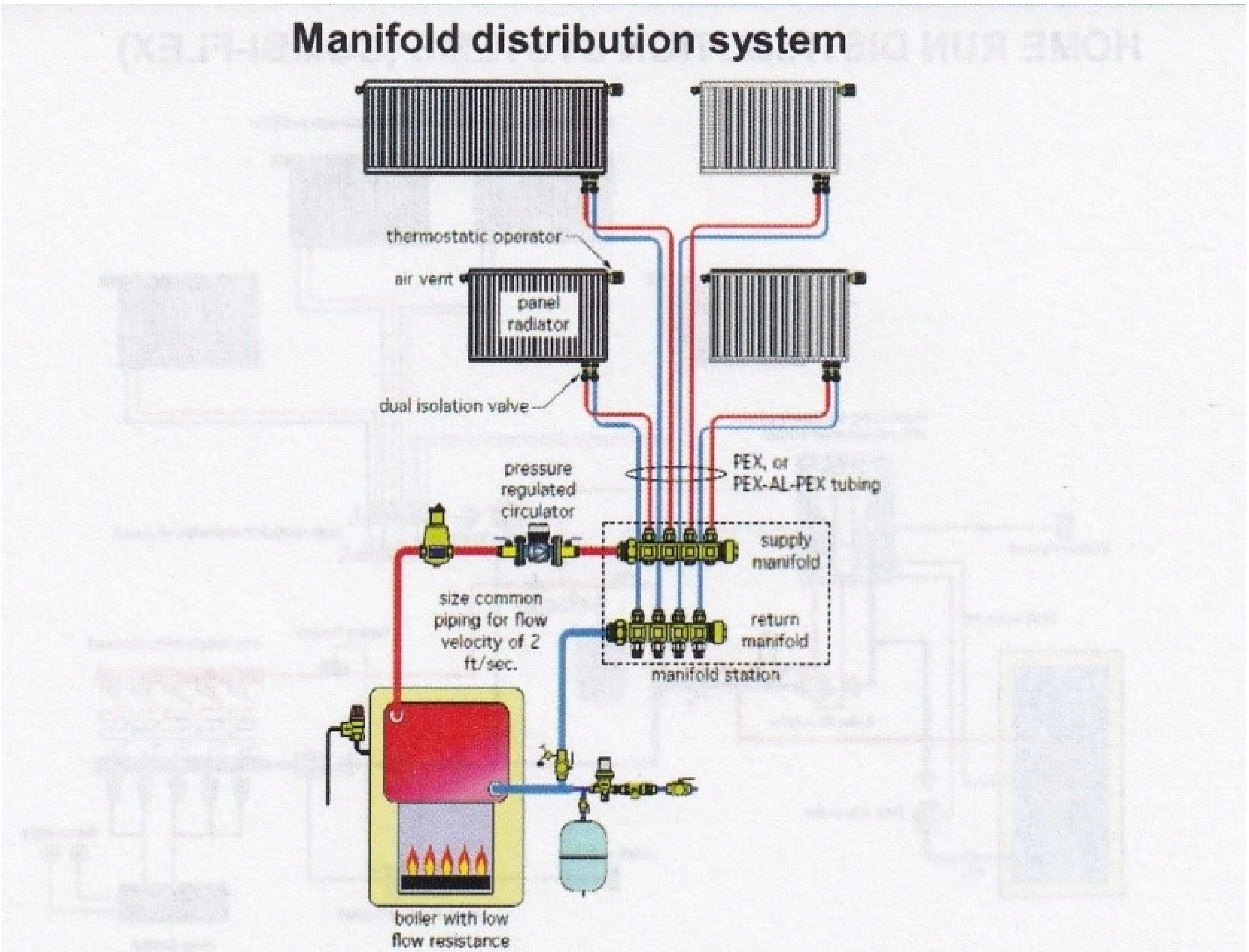


Figure 26 Valved system using pressure-regulated ECM circulator

Designers will sometimes specify circulators installed in series or in parallel with each other in the same piping circuit. Two pumps in series with each other will roughly double the pressure output while the flow rate will roughly remain unchanged, while two circulators in parallel will roughly double the flow rate while not appreciably affecting the output pressure.

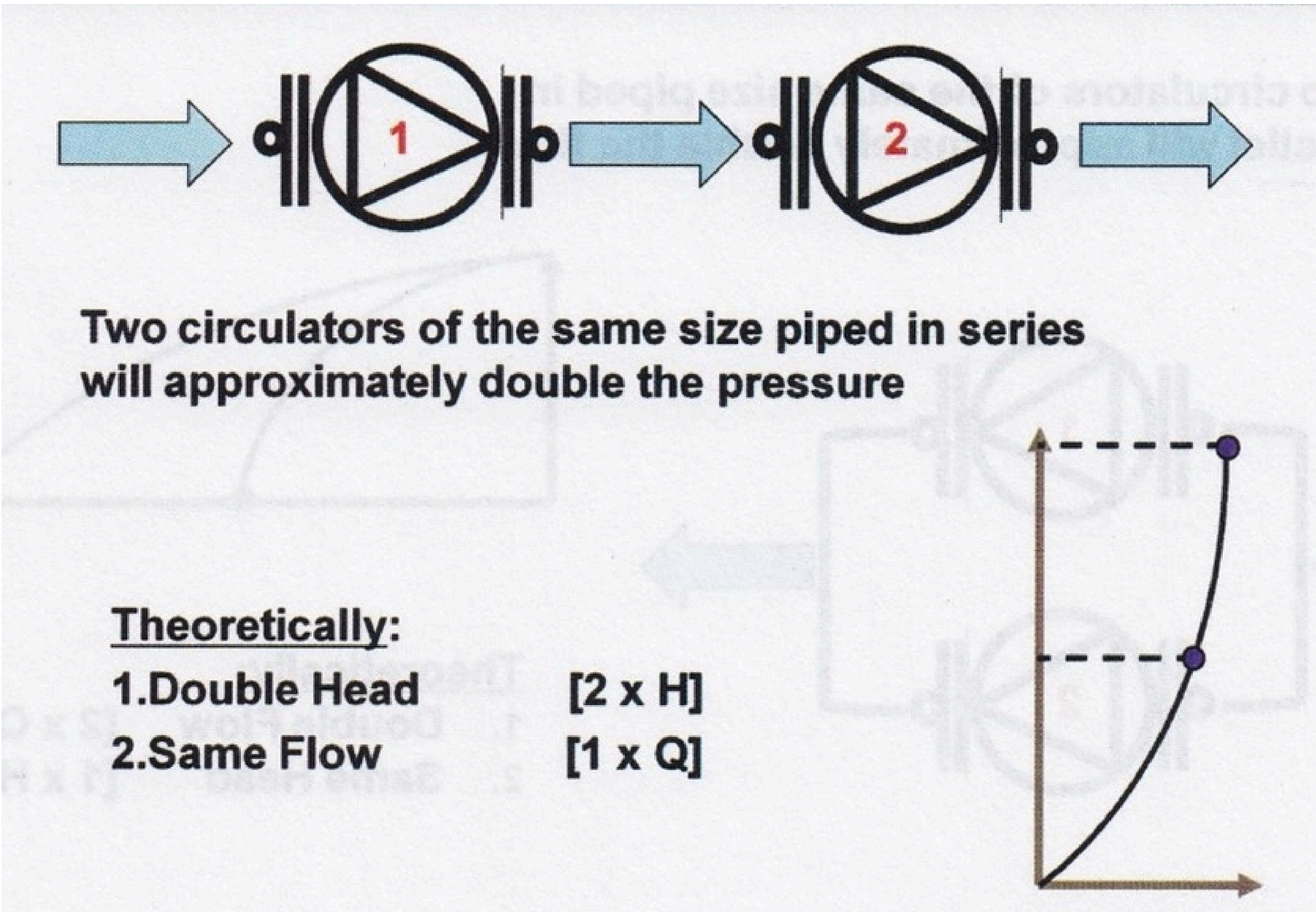


Figure 27 Two pumps in series will double the pressure, with unchanged flow rate

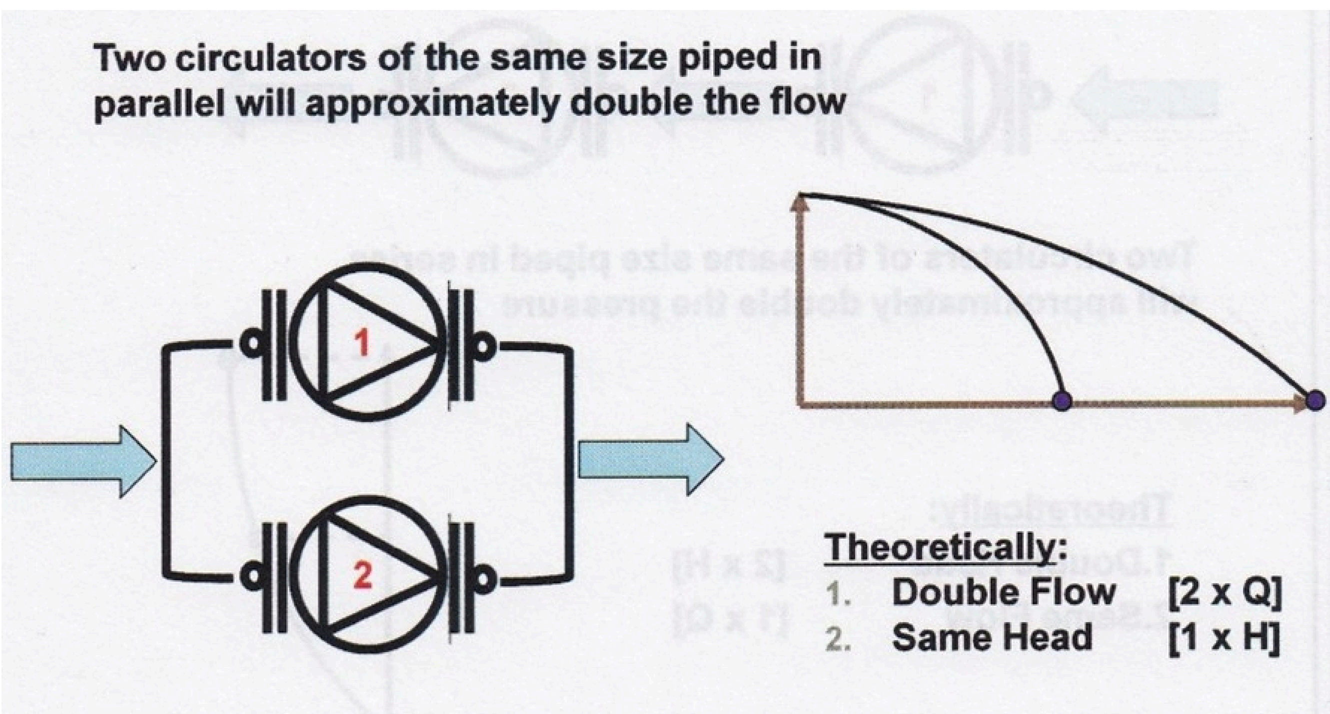


Figure 28 Two pumps in parallel will double the flow rate, with unchanged pressure

Installing two small circulators, rather than one large one, has proven cost-effective. For more in-depth information on circulators, visit websites such as caleffi.com, tacocomfort.com and Grundfos.com among others.

Sizing Expansion Tanks

Expansion tanks, also known as cushion or compression tanks, keep the system pressure from fluctuating widely when the system water heats up and cools down. Without one, the pressure buildup caused by thermal expansion would trip the pressure relief valve and discharge enough system water to keep the pressure at that maximum level. Once the boiler shuts off and the system water cools, the pressure will now drop below the fill valve’s setpoint and enough water will be added to hold the desired setpoint pressure. This sequence will repeat every time the boiler cycles on and off. The constant addition of fresh water to the system will eventually lead to rusting of ferrous components such as circulators and boilers, and leaks in these components would indicate that the system is in dire need of repair or replacement. Expansion tanks that are properly sized and maintained prevent all this from occurring.

Correctly sizing an expansion tank involves knowing:

- the minimum and maximum operating pressures
- the system volume in gallons
- the minimum and maximum operating temperatures, and
- the percentage mixture of glycol (if applicable)

Just as in pump sizing, manufacturers of expansion tanks publish sizing literature and tables to assist in the process. These are based on formulas that, for non-engineers, are much too complex and time consuming for most to deal with.

The old “conventional” expansion tanks were simply closed tanks where water and air were in direct contact with each other. Over time, air is re-absorbed into the water, which reduces the air volume until the tank has so little air that it is, for all intents and purposes, non-existent. The tank at this point is called “waterlogged” and will cause the aforementioned cycle of discharging/adding water.

Diaphragm-type tanks are the norm today.

Figure 29 Diaphragm-style expansion tank cutaway

As long as there is a butyl rubber or EPDM membrane separating the water and air, the waterlogging issues are largely a thing of the past. These newer styles of tanks can be smaller because of the pre-set air charge within them, and because system water isn't in direct contact with the steel of the tank, corrosion of the tank is greatly reduced. A diaphragm tank that shows water leaking from pinholes in the shell is an indicator that the rubber membrane has failed and that fresh water being repeatedly admitted into the system is causing corrosion. Fortunately, the thinnest steel in the entire system is in the shell of the diaphragm expansion tank, and corrosion problems within the system, evidenced by these pinholes, can usually be caught early enough to avoid a lot of damage to the major components.

A properly-sized diaphragm-type expansion tank should reach a maximum pressure about 5 psi lower than the relief valve setting when the system pressure reaches its maximum operating temperature. This prevents the relief valve from leaking at pressures just below its rated opening pressure.

The first step in sizing a diaphragm-type expansion tank is to determine the proper air-side pressurization of the tank using the following equation;

Pa = **(H × .433) + 5** where;

- "Pa" is the air-side pressurization of the tank in psi
- "H" is the height from the inlet of the expansion tank to the top of the system in feet
- ".433" is the density of water at its unheated temperature per foot of height, and
- "5" is the desired pressure to maintain at the top of the system in PSI.

For example, if the top of the piping circuit was 25 feet above the expansion tank connection and assuming the system is filled with water, the correct air side pressure in the tank would be calculated as:

$$Pa = (25 \times .433) + 5Pa = (25 \times .433) + 5Pa = 10.83 + 5Pa = 15.83 \text{ psi}$$

As you can see from the equation above, the correct set pressure for both the system fill valve and the air fill pressure for the tank is not simply 12 or 15 psi as is most commonly thought. The height of the system has to be factored in to be able to set these pressures correctly.

The pressure on the air-side of the diaphragm should be adjusted to this value *before* fluid is added to the system. Proper air-side pressure adjustment ensures the diaphragm will be fully expanded against the shell of the tank when the system is filled with fluid, but before it is heated. Failure to make this adjustment can result in the diaphragm being partially compressed *before* any heating occurs, and the full expansion volume of the tank would not be available as the fluid heats up. An underpressurized tank will act as if undersized, and possibly cause the relief valve to open each time the system heats up. This situation must be avoided. Use a low-pressure type of tire gauge with a scale of 0-30 psi and a bicycle pump or small air compressor to set the calculated air side pressure *before* filling the system with fluid.

The next step is to determine the volume of water in the system. This is also a fairly drawn-out endeavour if attempting to do long-hand, which involves measuring and calculating the volume of all the different piping by size and length, as well as the volume within the boiler and heat transfer units. Instead, various expansion tank manufacturers and hydronics partners have come up with shortcut methods that are very accurate when used in residential systems. One such method is given in TECA’s “Hydronic System Design” manual, which uses a combination of heat emitter types and heat load from a table (shown below) and applies these values to a step-by-step process in the worksheet also shown below. This results in an “acceptance volume” which is the volume, in gallons, that an expansion tank has to be able to allow to come into it when the system water heats up and expands in volume.

Table 2.5 Acceptance Volume[1] (courtesy of TECA BC)

Gal	**Litre**	**Base Board Heater** 6 l/kW 4.65 USG/ 1000 BTU 195°F (90°C)	**Panel Radiator** 8.33 l/kW 6.45 USG/ 1000 BTU 195°F (90°C)	**Cast Iron Radiator** 12 l/kW 9.3 USG/ 1000 BTU 195°F (90°C)	**Steel Radiator** 15 l/kW 11.6 USG/ 1000 BTU 195°F (90°C)	**Floor Htg** 18.5 l/kW ¾″ ID Tube 122°F (50°C)	**Floor Htg** 9.29 USG/ 1000 BTU ½″ ID Tube 122°F (50°C)
0.5	2	16,036	11,600	7,847	6,482	14,625	22,420
1	4	32,072	23,201	16,036	12,965	29,245	45,817
2	8	64,145	46,062	32,072	25,590	59,500	91,634

1. Acceptance Volume at Static Pressure of 7.4 psi.

3	12	96,263	69,263	48,109	38,555	88,710	137,450
4.8	18	144,327	103,724	71,993	57,622	133,550	205,700
6.6	25	200,284	144,327	99,971	80,182	185,200	285,600
9	35	280,466	201,990	140,233	112,254	260,000	400,000
13	50	399,204	288,314	200,284	160,022	371,400	572,240
21	80	641,456	460,620	318,680	256,241	590,000	910,500
29	110	880,296	634,632	440,148	351,436	816,000	1,257,500
37	140	1,122,548	808,644	559,569	446,972	1,043,000	1,598,700

Heat Capacity in BTUH with a max. operating pressure of 30 psi.

Note: To Calculate Acceptance Volume of BTUH not listed on Table 2.5:

$$\frac{\text{Unlisted BTUH}}{\text{next Listed BTUH}} = \underline{\quad\quad} \times \text{Acc. Volume for next listed BTUH} = \text{Acceptance Volume for unlisted BTUH}$$

Example: For an unlisted BTUH OF 24,054

$$24,054 \div 32,072 = \underline{.75} \times 1 \text{ gal} = .75 \text{ Gallon Acceptance Volume for 24,054 BTUH}$$

Quick Method – Expansion Tank Sizing by Heat Capacity[2]

This method is based on standard residential heating systems and piping capacities. It is very accurate for typical residential installations and may be used with confidence for sizing such systems.

- **Step 1: Type of heating system (or combination):** Record BTUH from Heat Loss Worksheet.
- **Step 2: Acceptance Volume: Use Table 2.5.** If BTUH value other than listed, calculate acceptance volume as shown in Table Note.
- **Step 3: Acceptance Volume Adjustment for temperature:** If temperature other than listed in Table 2.5, enter Factor from Table 2.6a or 2.6b.
- **Step 4: Total System Acceptance Volume.** Record adjusted Acceptance Volume(s) and total in Box G.

2. Courtesy of TECA BC

	Step 1 BTUH	Step 2 Acc Volume		Step3 Temp Factor		Step 4 Adj Acc Volume
1.Base Board	____BTU	____	×	____	=	____Gal(L)**A**
2.Panel Radiator	____BTU	____	×	____	=	____Gal(L)**B**
3.Cast Iron Radiator	____BTU	____	×	____	=	____Gal(L)**C**
4.Steel Radiator	____BTU	____	×	____	=	____Gal(L)**D**
5.Floor Heating ¾″	____BTU	____	×	____	=	____Gal(L)**E**
6.Floor Heating ½″	____BTU	____	×	____	=	____Gal(L)**F**

Total Acceptance Volume (Add Value A through F as required) = ____GalL**G**

- **Step 5: If Glycol is added to the system use Table 2.7.**

$$\frac{}{\text{Value G}} \times \frac{}{\text{Corr. Factor}} = \text{Acceptance value adjusted for Glycol in system} = \_\_\_\_ \; \mathbf{H}$$

Table 2.5 above has an assumed temperature of 195°F for four of the listed systems, and 122°F for the other two. If the system's temperature is otherwise, an adjustment is made by the use of a temperature adjustment factor, shown in Table 2.6a and 2.6b below, that is used as a multiplier in the worksheet.

Table 2.6a Temp Conversion Factors: 195°F – Use for for columns 1 thru 4 (courtesy of TECA BC)

Temp	Factor
140°F/60°C	0.47
158°F/70°C	0.61
176°F/80°C	0.81
212°F/100°C	1.21

Table 2.6b Temp Conversion Factors: 122°F – Use for for columns 5 & 6 (courtesy of TECA BC)

Temp	Factor
104°F/40°C	0.77
122°F/50°C	1.00
140°F/60°C	1.34
158°F/70°C	1.74

Lastly, an extra allowance must be made if the system will have glycol for freeze protection. The table below lists factors to be applied and sets out recommended water/glycol percentage mixtures dependent upon outdoor temperatures.

Table 2.7 Correction Factors for Percent of Glycol in the System (courtesy of TECA BC)

Outdoor Temp	% Glycol to be added to heating water	Water Glycol Mix expansion from freeze temperature up to 194°F (90°C)	Expansion more than water in %	Correction Factor
32°F/0°C	0%	3.7%	0%	1.00
14°F/−10°C	20%	4.4%	19%	1.19
−4°F/−20°C	34%	5.4%	46%	1.46
−22°F/−30°C	44%	6.4%	73%	1.73
−40°F/−40°C	52%	7.2%	95%	1.95

Glycol has an effect on the rate of expansion depending on the percentage of glycol in the system. Correction factors to compensate for this effect when calculating expansion tank size are give in Table 2.7.

The use of propylene glycol, while effective for freeze protection, will cause problems with pump capacities, rubber components and expansion tank sizing if not properly allowed for. As well, backflow protection awareness must be heightened due to the presence of chemicals added to the system.

Pipe Sizing

There are really only two locations within a hydronic radiant floor system where there are choices to be made as to the size of pipe. The first is the radiant tubing intended to be used in either a wet or a dry system. In a residential installation, the use of ½″ nominal tubing is the norm, and there would have to be special circumstances present to mandate the use of any other diameter. The second is the piping in the mains and branches between the boiler and the manifolds.

The tables below illustrate how engineers have simplified the sizing process for us.

Table 2.8 BTU Carrying Capacity of Pipe. In Thousands of BTU's. Based on 20°ΔT(temperature drop) (courtesy TECA BC)

Nominal Pipe Size (Inches)	Piping Friction Loss (Millinches per feet of pipe)					
	500 ft	400	350	300	250	200
$\frac{1}{4}$	4.4	3.9	3.6	3.3	3.0	2.7
$\frac{3}{8}$	10	8.7	8.1	7.5	6.8	6
$\frac{1}{2}$	17	16	15	13	12	11

$\frac{3}{4}$	39	35	31	30	27	23.9
1	71	64	59	53	48	42
$1\frac{1}{4}$	160	140	130	118	102	90
$1\frac{1}{2}$	240	210	185	175	156	140
2	450	410	360	322	294	261
$2\frac{1}{2}$	750	670	610	551	523	460
3	1400	1300	1150	1000	900	800

Table 2.9 BTUH Carrying Capacities for various pipe sizes at different ΔT's – Based on 400 millinch Friction Loss per feet (courtesy of TECA BC)

Pipe Size inches	**Flow Rate US GPM**	**°FΔT**	**°FΔT**	**°FΔT**	**°FΔT**	**°FΔT**
½″	1.6	8000	12000	16000	20000	24000
¾″	3.5	17500	26250	35000	43750	52500
1″	6.4	32000	48000	64000	80000	96000
1¼″	14	70000	105000	140000	175000	210000
1½″	21	105000	157500	210000	262500	315000
2″	41	205000	307500	410000	512500	615000

Formula: BTUH = USGPM × 500 × ΔT

Once again, we see that 400 millinches per foot is the preferred range of friction loss for hydronic systems, as evidenced by the shaded column in the first table and the fact that the second table is based on 400 millinches per foot at various ΔTs. The sizes we would be most concerned with are for ½″ through 1½″, as these would be considered the pipe size and heat capacity range of most residential systems. In a primary/secondary system as seen in the graphic below, the boiler and primary loops would be sized according to the output of the boiler. Piping in any secondary loops would be sized according to the heat load of that particular loop.

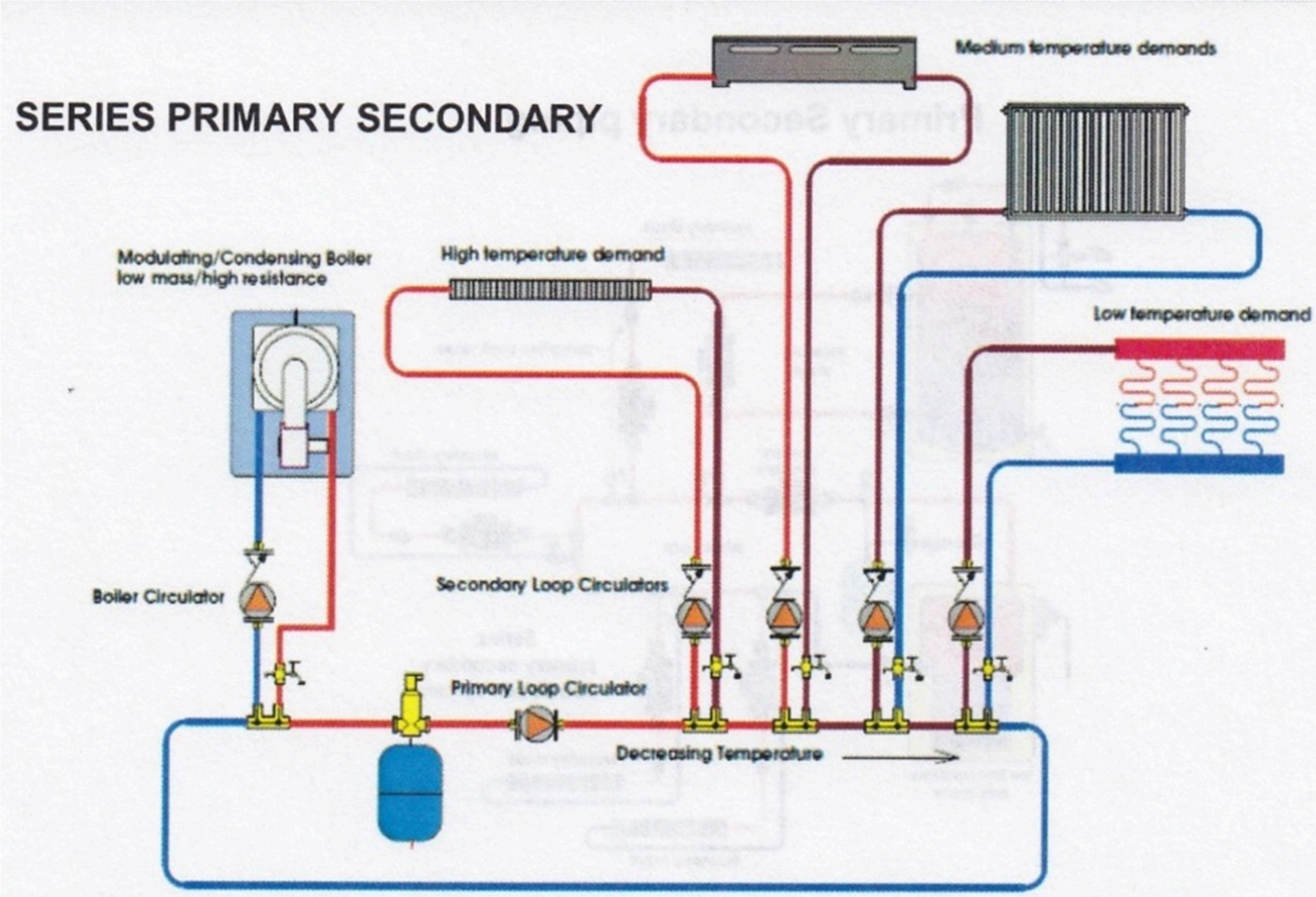


Figure 30 Primary/secondary system with secondary branch circuits

Now complete the self-test questions.

Self-Test 2

Self-Test 2

1. Which variety of PeX tubing is manufactured by the Engel method, and has a memory?
    a. PeX A
    b. PeX B
    c. PeX C
    d. PeX D
2. Which variety of PeX tubing requires an oxygen-diffusion barrier when used in radiant floor panels?

   a. PeX A
   b. PeX B
   c. PeX C
   d. All of them

3. What minimum thickness of rigid polystyrene foam should be placed under a basement concrete slab that is heated by radiant means?
   a. 1 inch
   b. 1 ½ inches
   c. 2 ½ inches
   d. 3 inches
4. If a repair connection must be installed in a loop in a concrete-over-wood subfloor panel, where should the joint be located?
   a. In the ceiling below
   b. In the concrete first lift
   c. In the concrete second lift
   d. Somewhere above the concrete
5. Which of the following is***not*** a purpose of the wide, extra bottom plate in above-grade walls of a radiant floor panel system?
   a. To give the wall more stability
   b. To allow for carpet nailing strips
   c. To act as a screed for the second concrete lift
   d. To make up the 1 ½″ of ceiling height that the concrete takes from the room
6. What would normally take place of a boiler in a snow melt system and effectively separates it from the building's heating system, to prevent the entire system from having to be freeze protected?
   a. A pot feeder
   b. A water heater
   c. A heat exchanger
   d. A hydraulic separator
7. What are radiant floor systems known as that heat the joist space below a floor?
   a. Wet systems
   b. Dry systems
   c. Air systems
   d. Hot systems
8. What is installed along with batt insulation between joists that causes heat to be driven upward

instead of downward?

a. Reflective foil
b. "Thermopan"
c. Aluminum coils
d. Absorption mats

9. Which one of the following would be a false statement in regards to the installation of radiant ceiling panels?

a. They operate at high temperatures
b. They operate at low temperatures
c. They don't interfere with furniture placement
d. They are out of reach of most people, for safety's sake

10. Which one of the following would be correct when laying radiant tubing loops in rooms that have one or two outside walls?

a. Make a pass about 3 inches in along the outside walls and then right away go to a counterflow pattern
b. Make two passes about 3 inches apart along the outside walls, then return back to the manifold
c. Make a first pass about 6 inches from the outside walls, then turn 180° with another 6-inch pass, then resume normal loop layout
d. Make two passes along the outside walls, then use a spiral loop layout for the rest of the room

11. According to the tube centre spacing table, what is the suggested spacing for ½″ tubing if the floor output required were to be 27 BTUH/ft²?

a. 12″ o.c.
b. 9″ o.c.
c. 6″ o.c.
d. 4″ o.c.

12. What is the maximum floor output from a radiant panel, in areas where people spend much time, over which supplemental heat will be necessary?

a. 20 btuh/ft²
b. 30 btuh/ft²
c. 40 btuh/ft²
d. 50 btuh/ft²

13. What is generally the longest suggested loop length for ½″ radiant tubing at a 20°ΔT?

a. 100 feet
b. 300 feet

c. 500 feet
d. 1,000 feet

14. What would be the tube spacing, floor output and total length of ½″ tube required in a kitchen if it had a gross area of 200 ft² and there were 42 ft² of lower wall cabinets, a range and fridge of 6.25 ft² each and an island of 30 ft²? The kitchen's heat loss is estimated to be 3,050 btuh.

    a. Floor output = 21.75 btuh/ft²; tube spacing = 12″ o.c.; total length of tube = 115.5 ft
    b. Floor output = 18.30 btuh/ft²; tube spacing = 6″ o.c.; total length of tube = 150 ft
    c. Floor output = 12.91 btuh/ft²; tube spacing = 12″ o.c.; total length of tube = 200 ft
    d. Floor output = 26.41 btuh/ft²; tube spacing = 9″ o.c.; total length of tube = 150 ft

15. What is normally used to locate tubing operating and embedded in a *residential* concrete floor?

    a. X-ray equipment
    b. An infra-red thermometer
    c. A metal detector
    d. A Polaroid camera

16. Which multiplier would be used when determining the total tube required for a room with tubing laid at 6″ o.c. spacing?

    a. 1:1
    b. 1.3:1
    c. 2:1
    d. 3:1

17. To what pressure, and for how long, should tubing be tested before being poured into a concrete mass?

    a. 100 psi for 10 minutes
    b. 100 psi for 30 minutes
    c. 50 psi for 10 minutes
    d. 50 psi for 30 minutes

18. What main characteristic of a boiler is used when choosing it?

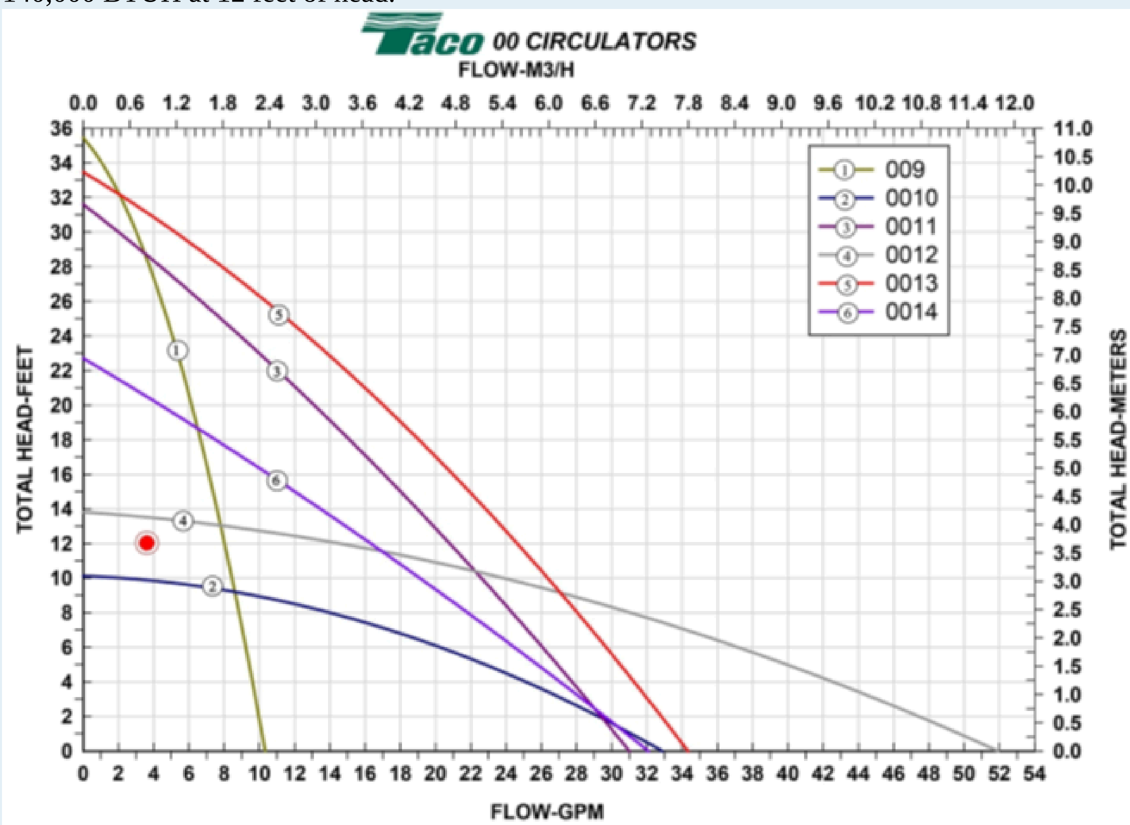
    a. Its input
    b. Its output
    c. Its fuel source
    d. Its efficiency

19. When assigning a head loss to a circulator, what is used as the head loss for the piping?

    a. The single circuit with the highest head loss served by the pump
    b. The sum of all the head losses from all the circuits served by the pump

c. The shortest measured single circuit served by the pump
d. The sum of the two longest circuits served by the pump

20. What are the two variables that are used in choosing a circulator?
    a. Psi and feet of head
    b. USGPM and flow rate
    c. Flow rate and feet of head
    d. Boiler output and size of piping
21. From the pump graph shown below, without oversizing, pick the circulator that would deliver 140,000 BTUH at 12 feet of head.



    a. #3
    b. #4
    c. #5
    d. #6
22. What should the GPM flow rate be for a pump that is operating at a 5°FΔT and is supplying 48,000 BTUH?
    a. 19.2 GPM
    b. 9.6 GPM
    c. 6.4 GPM

d. 4.8 GPM

23. How many millinches are there in one foot?

    a. 12
    b. 64
    c. 1,000
    d. 12,000

24. Using Table (A?) from the text, what is the head loss through 180 ***measured*** feet of pipe if friction losses are to be kept to within 400 millinches per foot?

    a. 4.5 feet
    b. 6 feet
    c. 7 feet
    d. 9 feet

25. What variety of valve is a circuit setter?

    a. Gate
    b. Relief
    c. Globe
    d. Butterfly

26. What is the name given to the strategy that uses a motorized mixing valve to automatically adjust its temperature setting in reaction to changing outdoor or system thermal conditions?

    a. Reset control
    b. Thermal mixing
    c. Thermostatic
    d. System monitor

27. What is the term given to the practise of ensuring that the operation of one pump doesn’t affect the operation of another, if they share common piping?

    a. No-share strategy
    b. Hydraulic principle
    c. Hydraulic separation
    d. Point of no pressure change

28. What characteristic of a brazed plate heat exchanger accounts for its high rate of heat transfer?

    a. Its number of ports
    b. Its inner plate surface area
    c. Its stainless-steel construction
    d. Its orientation (vertical vs horizontal)

29. If a mixing valve has a CV of 3.2, what will be the pressure loss across it, in feet of head, if there needs to be enough flow to supply 37,000 btuh at a ΔT of 20°F?

    a. 1.35
    b. 1.60
    c. 3.09
    d. 3.70

30. What type of valve can be installed between the supply and return mains that will open when the pressure in the supply main gets too high, as might happen when only one or two zone valves are open and there is only one system pump?

    a. An angle globe valve
    b. A backflow preventer
    c. A differential bypass valve
    d. An angle pressure relief valve

31. If two pumps are installed in parallel with each other, the approximate ________ will double.

    a. Flow rate
    b. Pressure
    c. Friction loss
    d. Temperature

32. What should the proper air-side pressure be of a diaphragm-type expansion tank where the top of the system is 29 feet above the point of no pressure change and there is to be 5 psi at that point?

    a. 17.56 psi
    b. 15 psi
    c. 12.55 psi
    d. 5 psi

33. Using the "Quick Method – Expansion Tank Sizing by Heat Capacity" and Table 2.5 Acceptance Volume and Table 2.6 Temp Conversion Factors, calculate the acceptance volume for a floor heating system using ½″ tubing that has a heat requirement of 45,000 BTUH and operates at 140°F if there is no glycol added?

    a. 1.00 USG
    b. 1.51 USG
    c. 2.02 USG
    d. 3.00 USG

34. Which one of the following would ***not*** be a consideration of adding glycol to a heating system?

    a. Boiler operation
    b. Pump performance

c. Expansion tank sizing

d. Increased focus on backflow prevention

35. According to Table 2.8 BTU Carrying Capacity of Pipe, in Thousands of BTU's, based on 20°ΔT(temperature drop), what size would the boiler and primary loops be for a system whose boiler output was 65,000 BTUH?

a. ¾″

b. 1″

c. 1 ¼″

d. 1 ½″

Check your answers using the Self-Test Answer Keys in Appendix 1.

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Competency F3: Switches and Relays

Learning Objectives

After completing the learning tasks in this Competency, you will be able to:

- Describe switches
- Describe relays

Learning Task 1

Describe Switches

Although the control systems of today are far more complex and involved than they were a few decades ago, switches and relays are still the heart of the operational systems. They come in many types, shapes, sizes, configurations and electrical designations. It is imperative that the tradesperson who is tasked with installing, maintaining and diagnosing hydronic systems has a basic understanding of how switches and relays work.

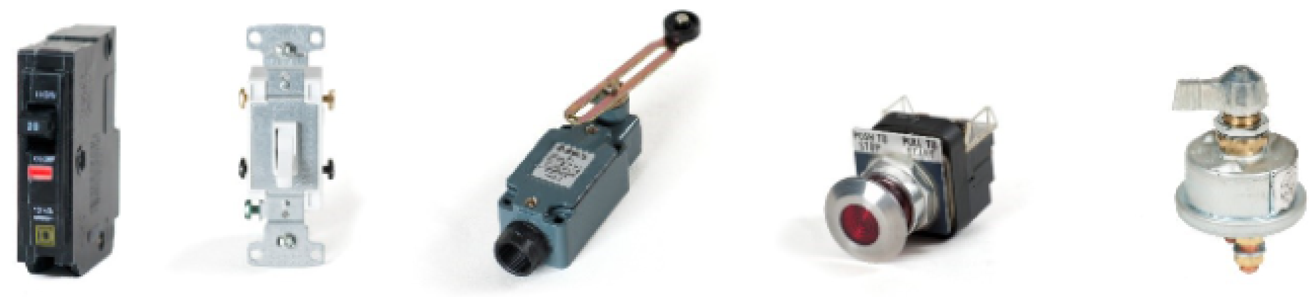


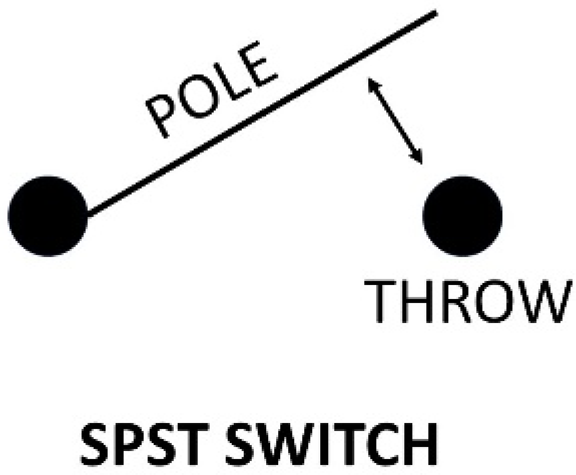
Figure 1 Switches

What is a Switch?

A switch is a device that makes or breaks (closes or opens) a path in an electrical circuit to allow loads, which are electrical components that perform work, to operate safely and in the manner that is intended.

Manual Switches

The best and simplest example of a manual switch is a light switch for a room. When the switch is manually moved or "thrown", the position of the moving part, called the "pole", changes. If it was in the "off' position to start with (the pole not touching the contact point called the "throw"), the contacts will close when the switch is thrown and the light will come on. Switches are referred to by the number of poles and throws they have. A bathroom light switch would normally be a single-pole, single-throw switch, as seen in the graphic below.

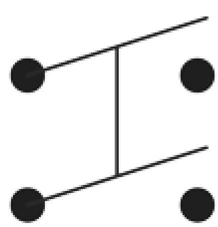


Five varieties of manual switches are shown below.

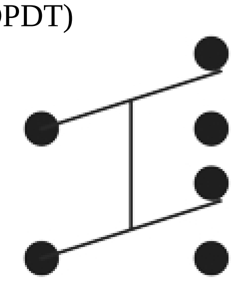
- Single pole, single throw switch (SPST)

- Single pole, double throw (SPDT)

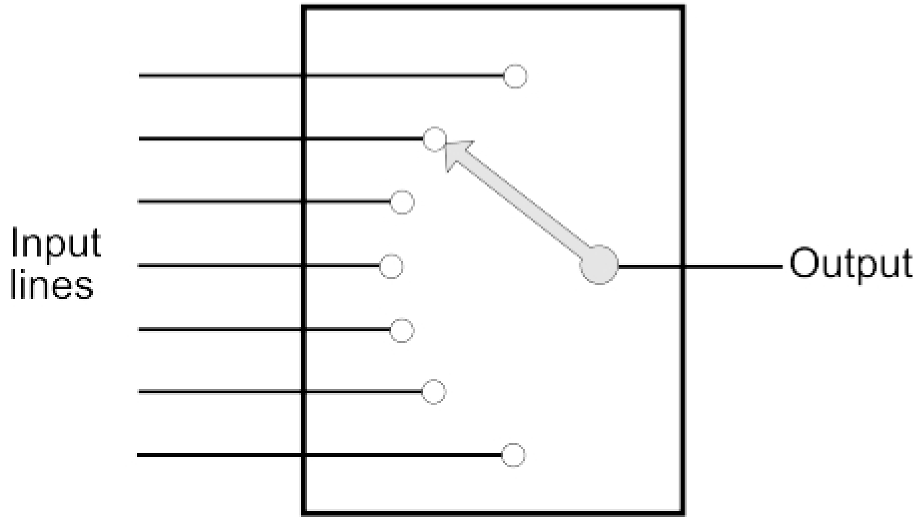
- Double pole, single throw (DPDT)



- Double pole, double throw switch (DPDT)



- 7 throw (1P7T or rotary switch)



Another variety of manually-operated switch is known as a momentary switch. These must be pushed or turned and held in order for the contacts inside them to close. They are spring-loaded and will snap back to their open position when the button is released.

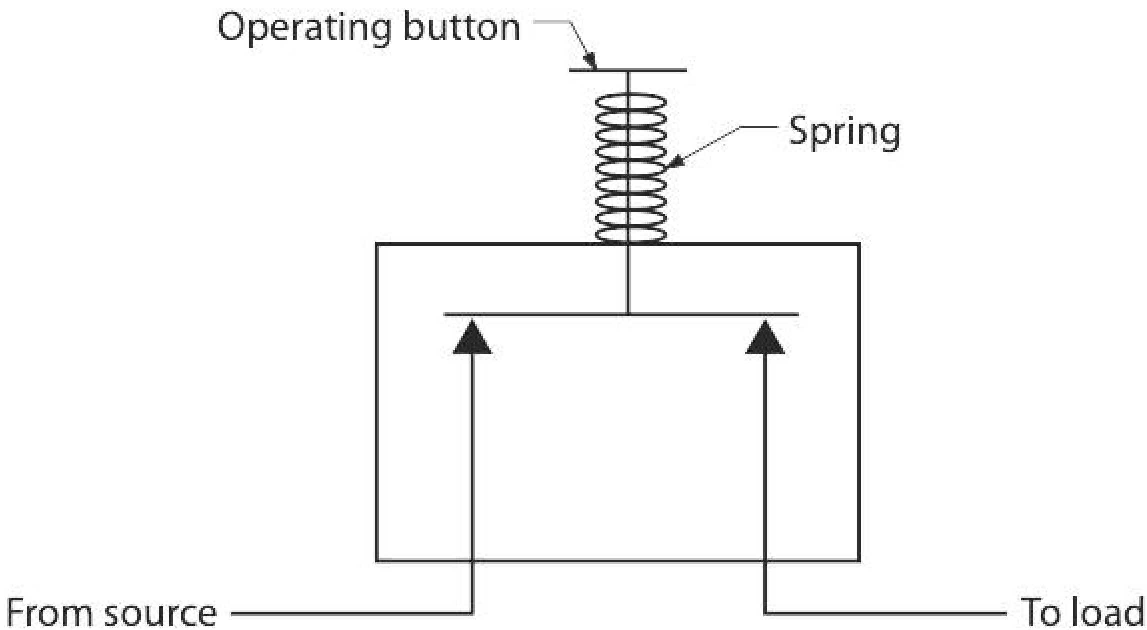


Figure 2 Momentary switch

Automatic switches are used to sense, measure and react to conditions such as, but not limited to, temperature, pressure, flow, liquid level and position. They are classified by what they measure and by the condition that causes them to react. For instance, a thermostat used for a heating system will open when the temperature rises to its desired level. This would be classified as “open on rise”. We want the thermostat to open its contacts, in other words shut the heating system off, when the heat it’s measuring reaches its setpoint temperature. When heated enough, the thermal element attached to the pole will rotate or lengthen, depending upon its design, and in doing so will move the pole off of the throw.

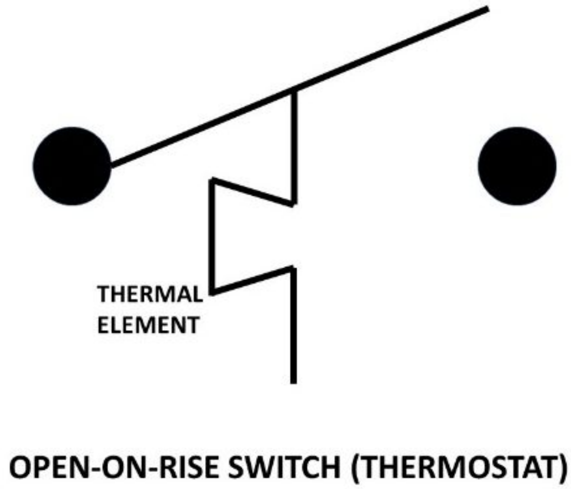


Figure 3 Heating thermostat

A cooling thermostat, shown below, would be classified as a “close on rise” switch, in that, as the temperature rises, the thermal element that the heat is exposed to will expand and close its contacts to bring on the cooling system. When the temperature surrounding the thermostat drops to the setpoint, the pole is pulled away from the throw and the system is de-energized.

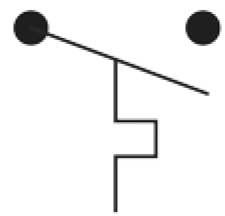


Figure 4 Close on rise switch (cooling thermostat)

An aquastat is a switch that does for water what a thermostat does for air. Aquastats typically consist of a liquid-filled bulb that is connected to a bellows within the housing of the switch, via a capillary that can be many feet in length. When the liquid expands due to heat being applied to the bulb, the pressure caused by the expansion of the liquid is transferred to the bellows and causes a mechanism to move. This mechanical interaction could cause a valve to snap open or closed, or to open or close slowly (modulate) depending on the style of the aquastat.

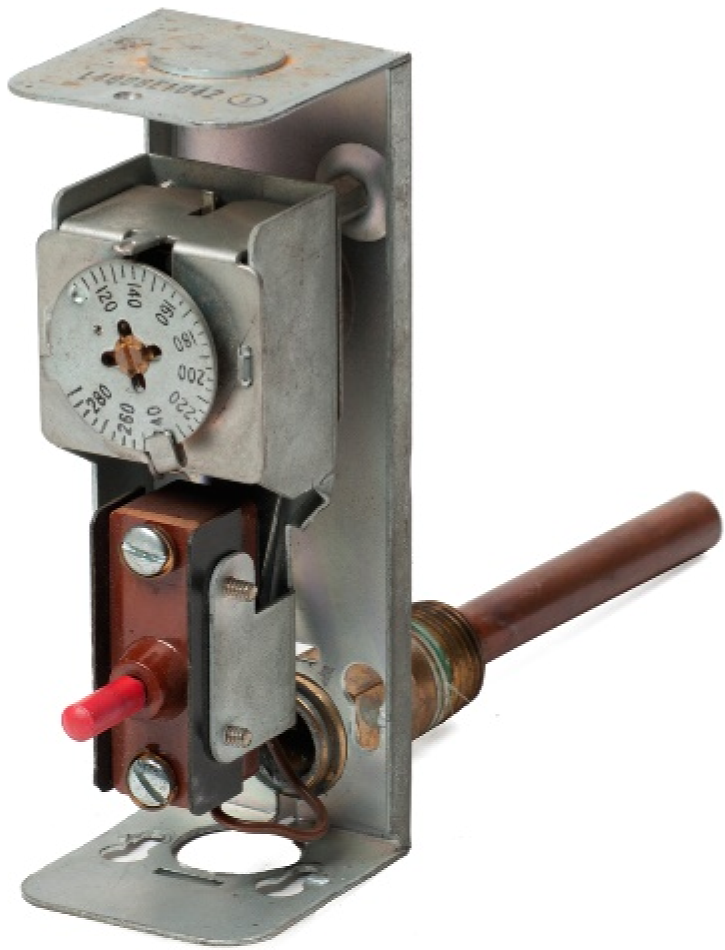


Figure 5 Manual-reset high limit aquastat

The aquastat shown above has a “thermowell” on the rear, attached to it by a clip. It is the well that actually is inserted into an opening in the piping system. The bulb fits fairly snugly inside the thermowell. A small amount of thermal-conductive grease is applied to the end of the bulb to ensure a more accurate heat transfer via conduction. The use of thermowells allows the aquastat to be replaced without losing any system water.

Many switches have a bit of variance between their open and closed positions. This is known as “differential”, and can either be fixed or adjustable. Many aquastats for hydronic systems have a fixed differential of 15°F (8.33°C). Pressure switches used on well pump systems have differentials pre-set at 20 psi and are adjustable to values a little above or below 20 psi.

In technical terms, the suffix “stat” is meant to signify a switch. The prefix “aqua” indicates water, “thermo” indicates air, a flow switch is known as a “flowstat”, a pressure switch as a “pressurestat” and so on.

A flow switch has a paddle that is inserted into the branch of a tee in the pipe that it is monitoring. When there is flow, the paddle is moved and the pole of the switch is both pushed onto a throw as well as pulled away from another throw. This is a single pole, double throw type of switch. It can be used to either energize or de-energize a circuit depending on the control strategy required. For instance, a low-mass boiler always needs to have flow through it when the burner is firing. A pump is meant to move water through the boiler, and to prove that the water is actually moving, the flow switch is installed in the piping. The boiler's burner circuit is wired through the common and "N.O." (normally open) contacts of the switch. When the paddle is moved by the flow, it closes the normally open contacts and allows power to complete the burner circuit. If the flow stops, the contacts attached to the spring-loaded paddle open, shutting off electricity to the burner circuit. In this case there would be no wire attached to the "N.C." terminal. This is a single pole, double throw switch as seen below.

Figure 6 Flow switch

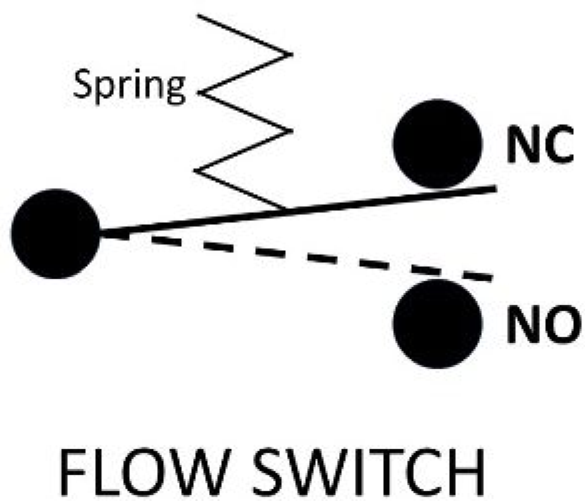


Figure 7 SPDT Switch

A pressure switch is used on mid-and-high efficiency gas equipment to prove that a venter fan is running and providing the correct amount of air movement before allowing the burner to fire. It can be either a SPDT type, just like the flow switch, or it can simply have one set of "N.O." contacts. In either case, the contacts close when the correct pressure is sensed. It has its own symbol that is meant to look like a cup that would move if air pushed its way into it, as seen below.

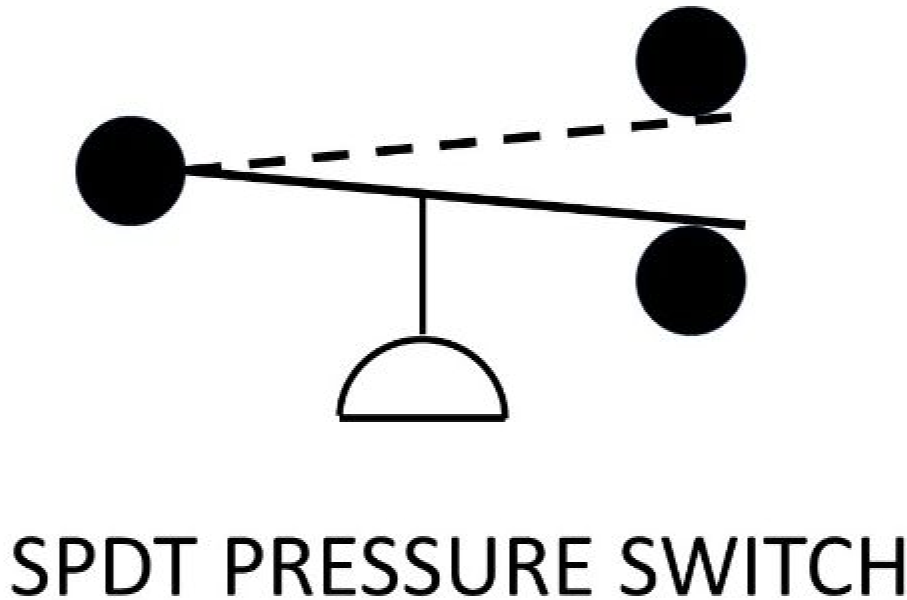


Figure 8 SPDT Pressure Switch

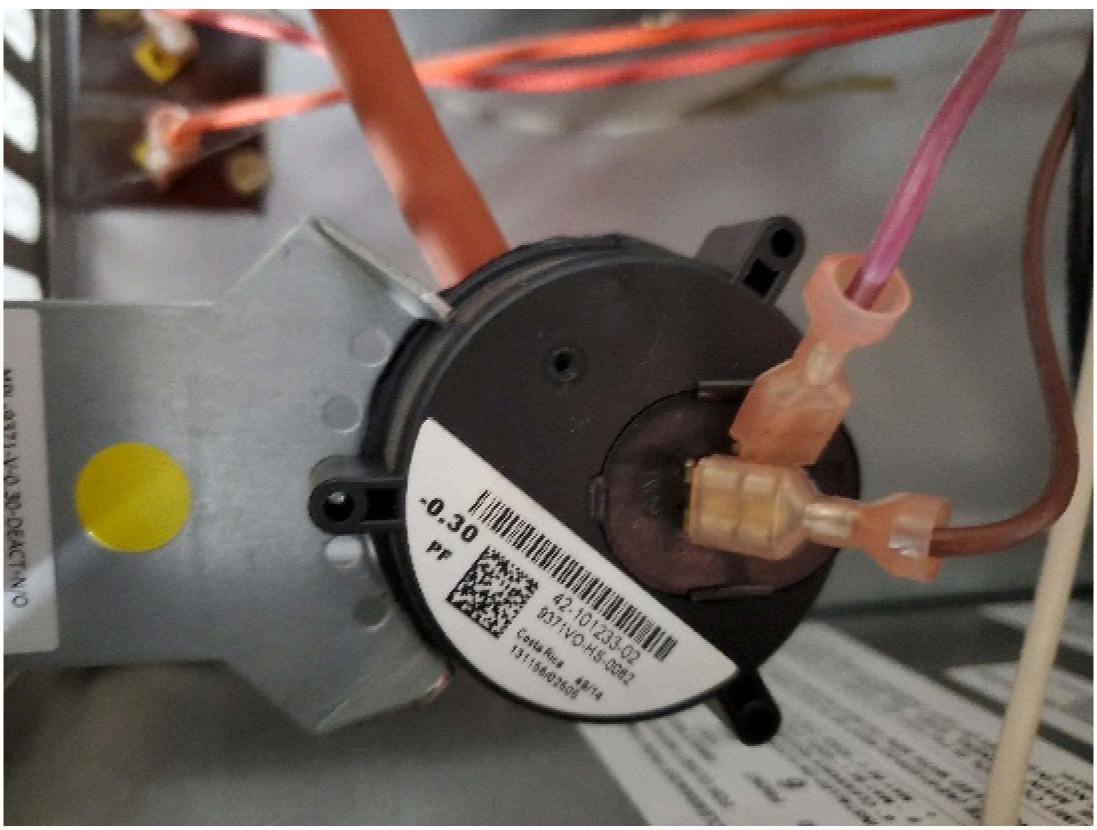


Figure 9 SPST pressure switch (NO)

The symbol above would represent the device pictured to its right. This is a pressure switch for a forced air furnace. The orange tube behind the switch is connected to the back of the switch housing and to the outlet side of the venter fan. When pressure is created by the fan, it is relayed to a diaphragm inside the housing. The diaphragm moves an armature, closing the contacts to signify that the fan is not only working but is putting out at least the amount of pressure, in inches water column, that is shown on the switch's tag (0.3 inches w.c.). When replacing a pressure switch, always use one that has the same pressure setting.

As with the other varieties of switches, they can either be single throw or double throw, and open on rise or close on rise.

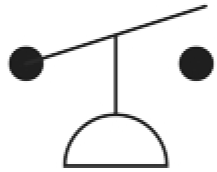


Figure 10 SPST open on rise

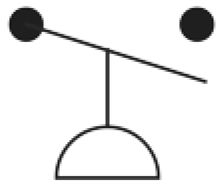


Figure 11 SPST close on rise

Float switches can be used to monitor the level of liquids in a vessel and will either open or close to control a pump supplying water to a cooling tower sump, or to shut off the burner in a steam or hot water boiler whose water level has dropped to an unacceptable point. This device is known as a low water cutoff. It and the symbol for a float switch are shown below.

Figure 12 Low water cutoff

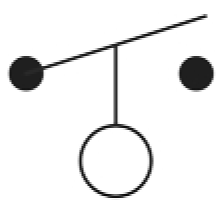


Figure 13 Float switch

End switches can be used if the position of a piece of mechanical equipment has to be proven before the next step in a sequence of operation can take place. In hydronics, a zone valve has to be proven to be open before the pump tries to move water through it. This prevents the pump from "dead-heading" which must be avoided. A 4-wire zone valve has an end switch wired across two of the wires which typically have red insulation. When 24 volts is applied across the two yellow-coloured wires, the motor of the control head is powered. The rubber ball on the end of the arm connected to the motor swings away from the port that it was covering, allowing the valve to open. When the arm reaches the end of its travel path, it contacts a micro-switch. The switch contacts close to allow 24 volts through the red wires to energize the coil of a relay, which connects to the pump, allowing the pump to start.

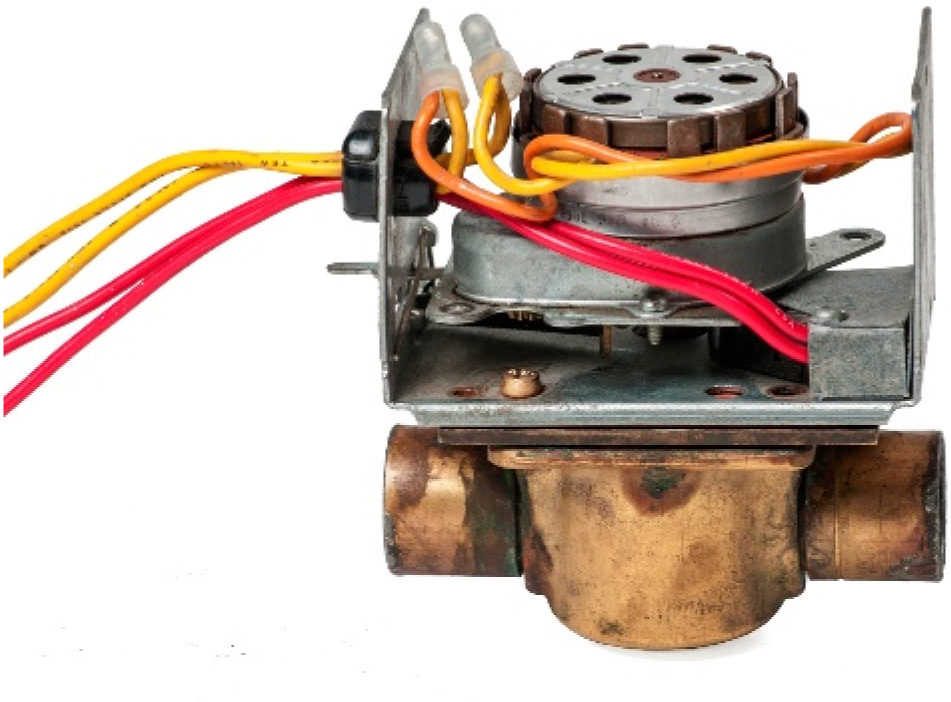


Figure 14 Zone valve with end switch

Another example of the use of an end switch is in the operation of the dampers on the inlet to a direct-fired makeup air unit (DFMA). These fan-driven units are used to supply tempered air to commercial kitchens while large volumes of air are simultaneously pulled from the space through a separate exhaust system. Before the fans can start, the dampers on the DFMA must be proven to be open. Just like in the motorized zone valve, an end switch is contacted by the damper arm at the end of its run, and power can then be allowed to energize the fans.

Figure 15 End switch for damper arm

A dimmer switch functions as an on/off switch with the addition of a variable resistor built into it. By turning the dial and increasing resistance, less current flows to the bulb which results in less light output. Although dimmer switches are common in building lighting, they don't see much use in heating systems.

Switches work by opening or closing electrical circuits, and as such, they will do their job no matter where they are located within the circuit. For safety's sake, they should always be located in the "hot" leg of a circuit. This means that they should be positioned between the source (power supply) and the load (the device that turns electrical energy into work). If switches are installed between the load and its ground connection, the load will still be able to be turned on and off, but the load will still be energized even when the switch is in the open ("off") position. This is very dangerous, in that electrocution hazards exist if someone were to touch any wiring contacts on the upstream side of the switch. By installing switches in the hot leg of the circuit, no power exists downstream of the switch, so loads can be safely worked on as long as the switch is locked out.

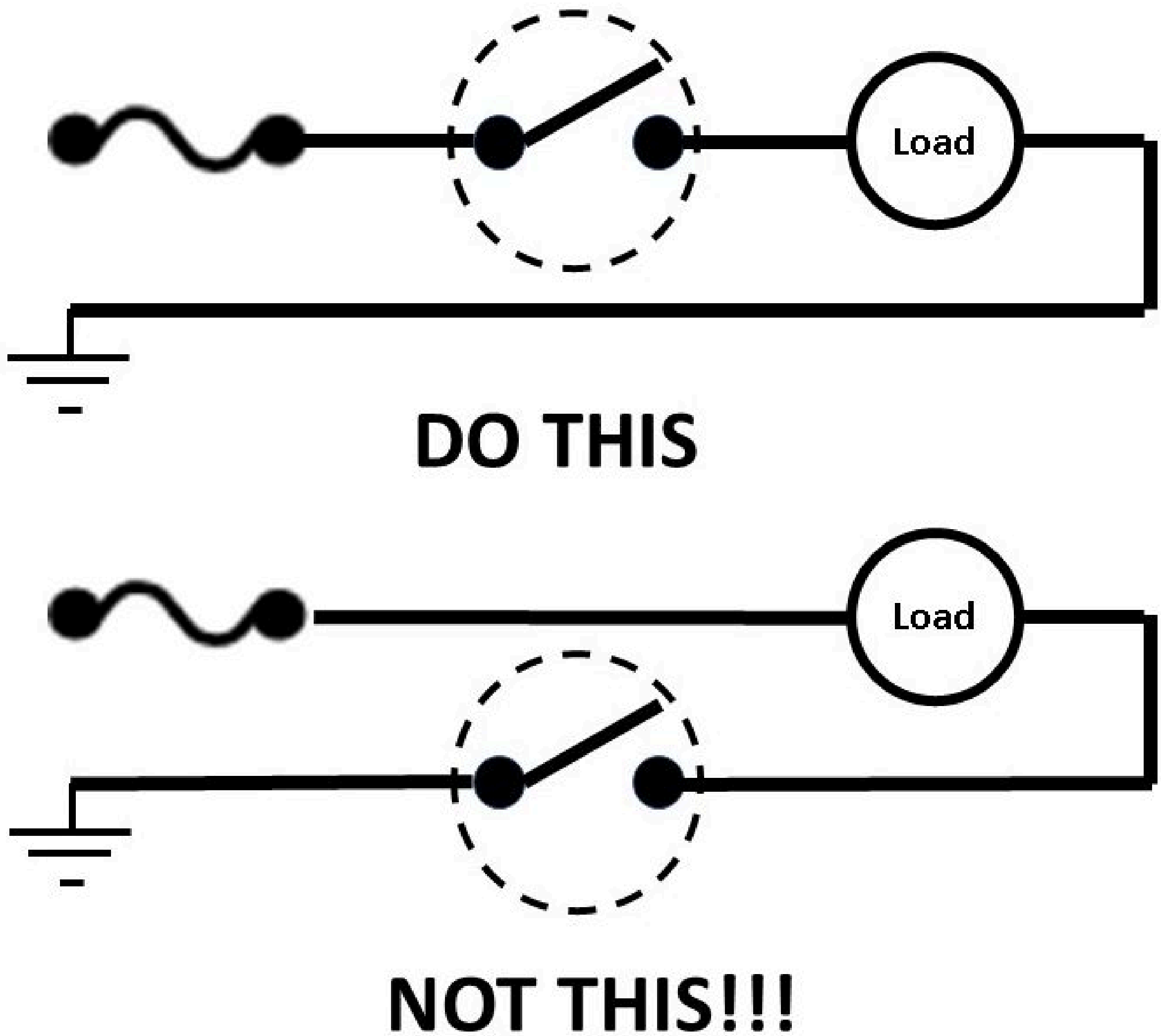


Figure 16 Correct position for a switch in a circuit

When installing a switch, make sure that its voltage and amperage ratings are at least as high as those it will be exposed to.

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- Figure 3 Heating thermostat by ITA is licensed under a CC BY-NC-SA licence.
- Figure 4 Close on rise switch (cooling thermostat) by ITA is licensed under a CC BY-NC-SA licence.
- Figure 5 Close on rise switch (cooling thermostat) by ITA is licensed under a CC BY-NC-SA licence.

Learning Task 2

Describe Relays

What is a Relay?

Our electrical circuits in a residential hydronic heating system typically have two different voltage values. Motors for pumps, fans and hot surface igniters are usually powered with 120 volts of alternating current (120VAC). These devices need this amount of voltage to be able to operate efficiently. On the other hand, for the sake of safety and sensitivity, our control circuits are powered with 24 volts of alternating current (24VAC). One of the jobs that our 24VAC hydronic control systems have is to turn 120VAC pumps, igniters and fans on and off, and as such, creates a dilemma – if we connect a 24VAC control system directly to a 120VAC component, the higher voltage will overpower and wreak havoc on the lower voltage circuits and equipment. This is where and why relays are used. In a relay race, the contact between runners is made via a baton. It is passed from one runner to the other without the runners actually touching each other. Our electrical relays do much the same job. Low voltage can operate high voltage equipment, without the two touching each other, thanks to relays.

"EMR"s and "SSR"s

There are two varieties of relays: electromagnetic relays (EMRs) and solid-state relays (SSRs). They both do the same job, which is to use a circuit with low power to operate equipment that uses a higher-voltage power source. An SSR is silent in operation and has no moving parts within it, so there is no arcing across contacts that are opening and closing. Wear and tear isn't an issue either and therefore an SSR has a lifespan of over 100 million cycles. EMRs, on the other hand, have a moving armature and moving contacts, and they will have a lifespan of roughly only 1 million cycles. Due to the arcing within them, EMRs can't be used in a volatile environment whereas SSRs can. Although there are distinct advantages to SSRs, they tend to be limited to operating one circuit only, whereas an EMR can have multiple sets of contacts within it. SSRs are found on furnace and boiler modules, in solid state fuse and relay panels in vehicles, and PCBs (printed circuit boards) among other places.

Figure 1 SSRs in a vehicle's fuse panel

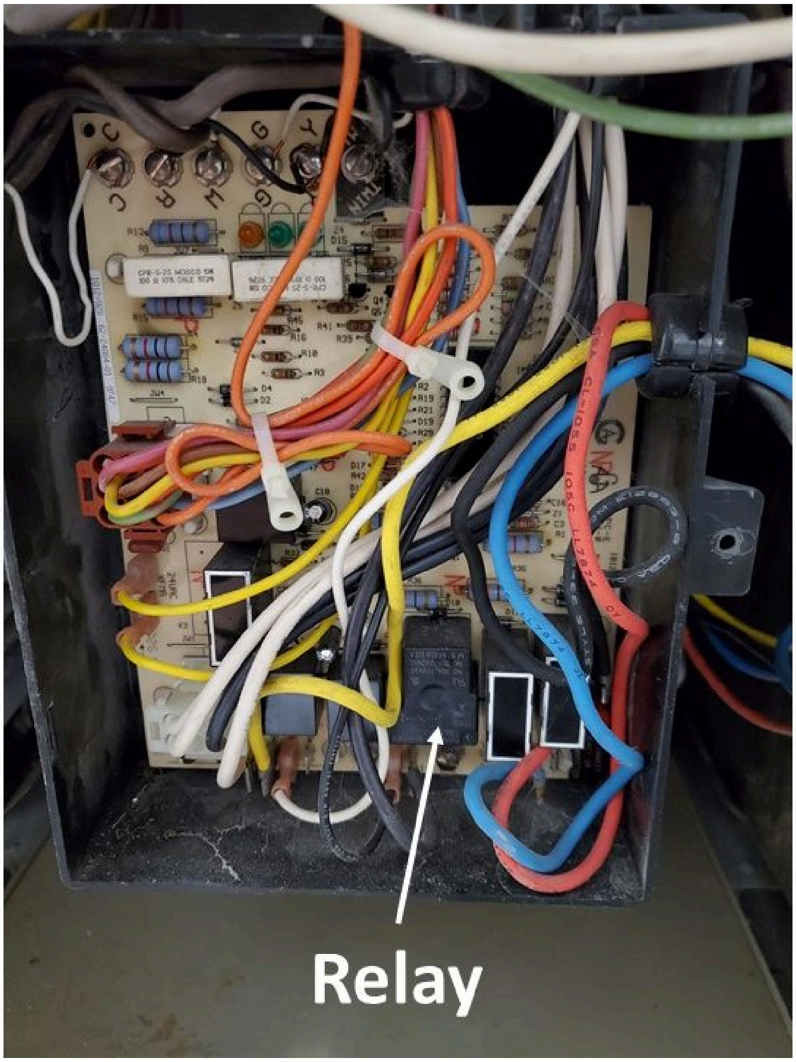


Figure 2 SSR on an integrated furnace control board

Most of the relays that are used in hydronic systems, that aren't a component of a PCB or solid-state control module, will be of the EMR type, so we will limit our study to EMRs.

Electromagnetic Relay Coils

Relays consist of a temporary electomagnet known as a "coil" and a single or multiple sets of spring-loaded electrical contacts. Coils in electromagnetic relays are rated for the voltage that is to be supplied to them. In a hydronic heating control system that operates at 24VAC, the coil would also have to be rated for 24VAC. A coil is simply a soft iron bar that has a coil of wire wrapped around it, similar to the way in which a solenoid is built. The difference between them is that, unlike the coil of a solenoid, the soft iron core of the relay coil doesn't move when it is energized. It becomes a temporary electromagnetic and is meant to attract an armature toward it.

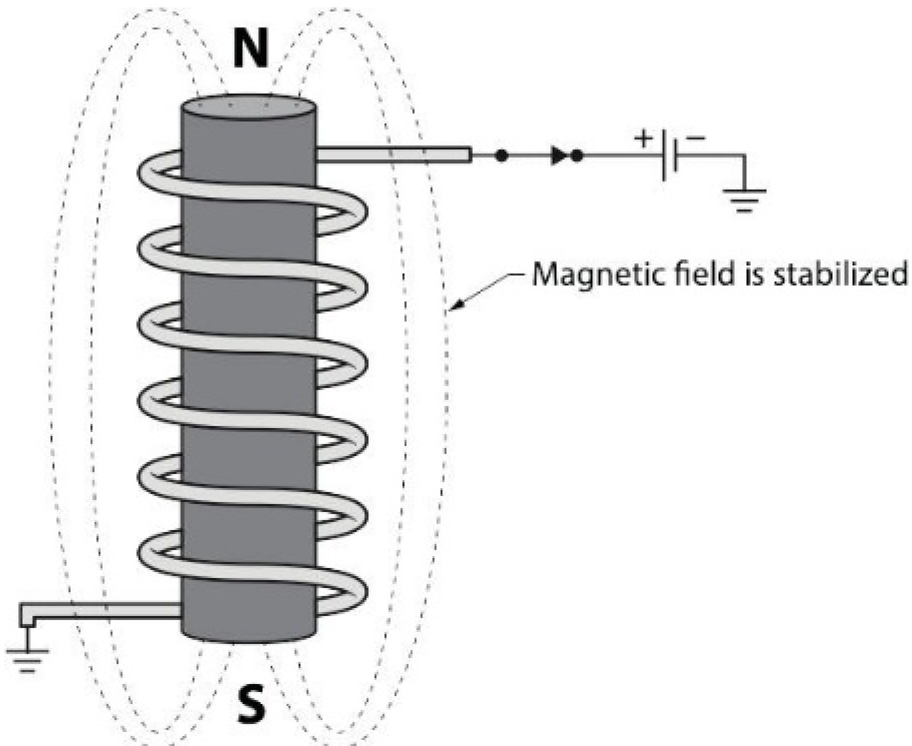


Figure 3 Temporary electromagnet (coil)

Attached to the armature is a ferrous component that will be attracted to the electromagnet, making it move. The armature itself doesn't conduct any electricity but attached to it are contacts that do. If the relay contacts are N.O. they will close when the coil is energized. Any contacts that are N.C. will open at the same time. In short, when a relay coil is energized, an audible "click" can usually be heard, and the normal or "at rest" positions of any contacts it controls will reverse. When the coil is de-energized, an audible "click" will be heard as a spring pulls the armature back to its original position and the contacts are once again as they were before the coil was powered up. The diagram below illustrates the different ways that the armatures work.

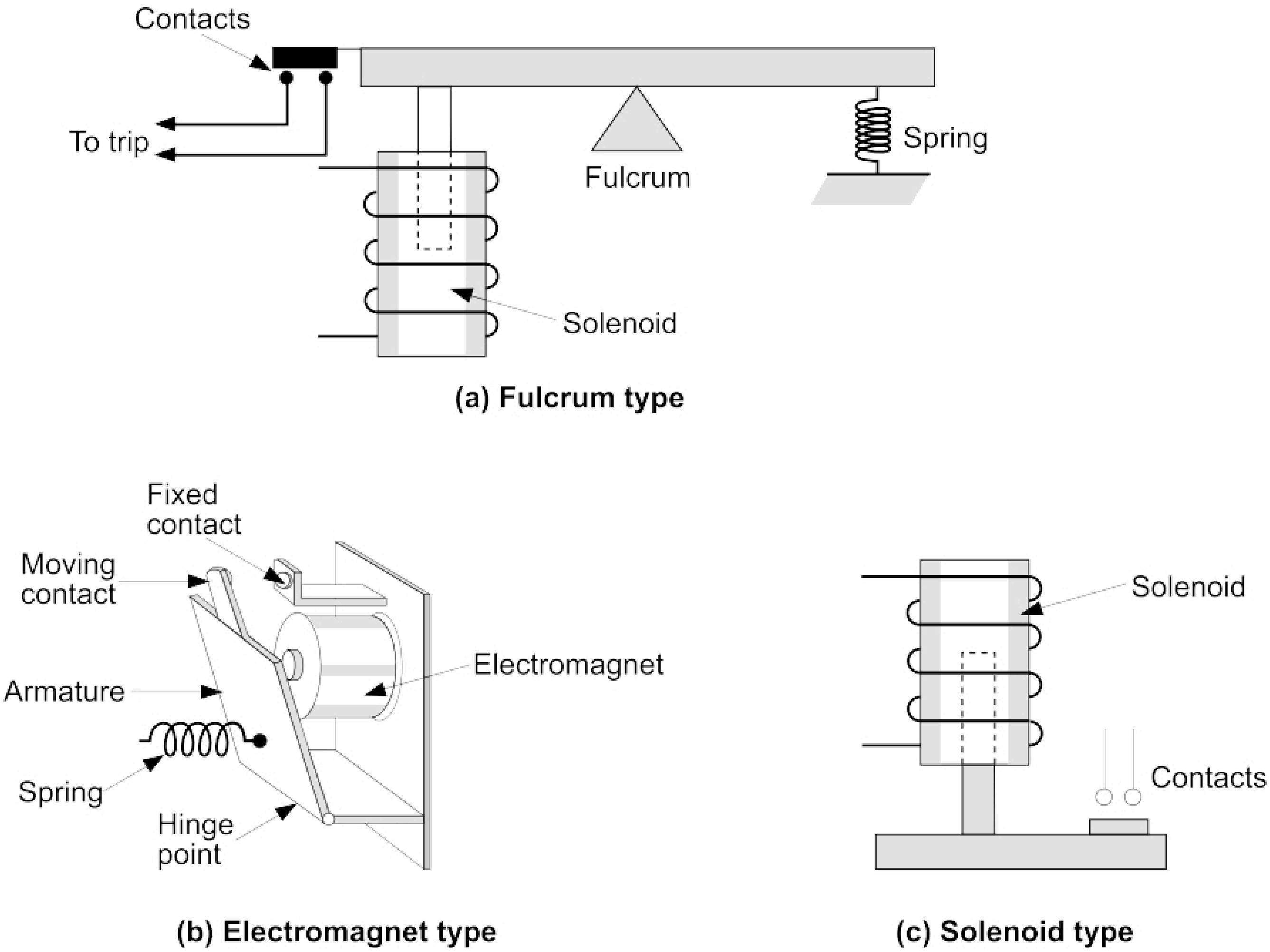


Figure 4 Relay coils and armatures

The Contacts

On the schematic for the relay shown below, the dark black rectangles represent ¼" male spade terminals that poke through the housing of the relay and are points of connection to wires, while the light lines indicate how the terminals are connected to each other within the device. The terminals that connect to the coil are usually indicated by a symbol for the coil shown between them. The symbols that indicate whether a set of relay contacts are N.O. or N.C. are as indicated on the schematic. The relay contacts can be capable of voltage values of up to 600V or as indicated on that particular relay. As well, the contacts are capable of conducting either alternating current (AC) or direct current (DC) through them at the maximum amperages that are also indicated on the relay, usually on a printed tag affixed to the relay.

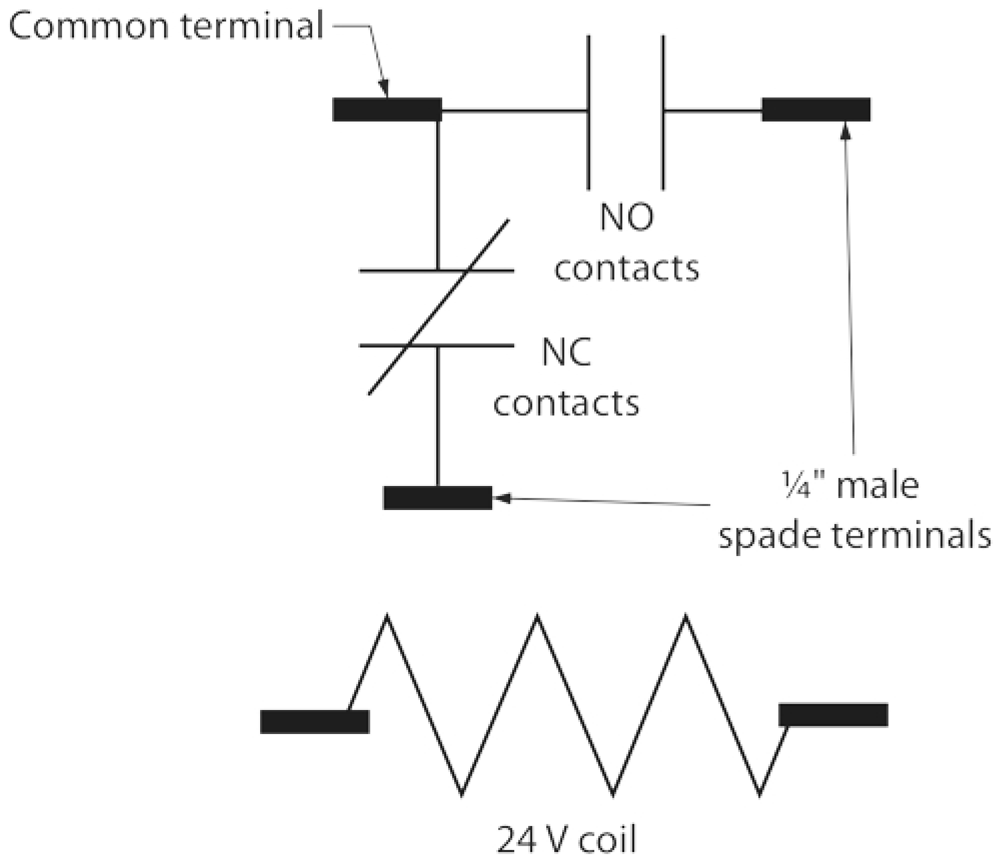


Figure 5 Honeywell SPDT 24VAC relay

Below is a picture of a Honeywell DPDT relay that is very common to the heating industry. It is the type that the schematic above references, with the exception that the schematic is of a SPDT relay. The DPDT variety, as shown below, can control two circuits when the coil is energized whereas the SPDT only controls one.

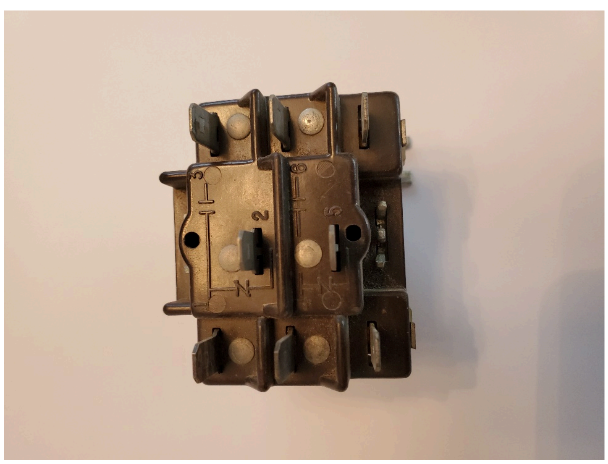


Figure 6 Honeywell DPDT relay with 24VAC coil

The relay pictured above has the wiring connections within its frame printed or cast into the plastic face as can be seen in the photo. The “common” terminal is #1 at the top left. This is where 120VAC would be connected if operating a 120VAC motor using the relay. The 120VAC output to the motor would be connected to terminal #3 at the top right (you should be able to see that there is a N.O. contact between them). When the coil is energized with 24VAC, the 120 volts, which was to this point present at terminal #2 (N.C.) is now directed to terminal #3 and the motor would be powered. Terminal #2 would be de-energized at this point.

Although not clearly marked on the face of the relay, the 24VAC coil is within the body of the relay, connected between the two bottom terminals shown.

The relay pictured below would work in the same manner as the Honeywell relay above in that it has a 24VAC coil between terminals #1 and #3 at the bottom. The common terminal is #6 which is externally connected ("jumpered") to #4 so any voltage applied to #6 would also exist at #4. Terminal #5 on the left has a N.C. connection between it and #6 as seen in the diagram below. This diagram is sometimes difficult to understand unless you are familiar with the concept of a relay. Terminal #2 on the top left has a N.O. connection between it and terminal #4. At rest, if there were voltage applied to terminal #6, it would also be present at terminal #5. When the coil across terminals #1 and #3 is energized with 24VAC, any voltage present at #5 would be interrupted and instead be diverted to terminal #2. This is where the hot line to a 120VAC motor would be connected.

Figure 7 White-Rodgers 24VAC SPDT relay

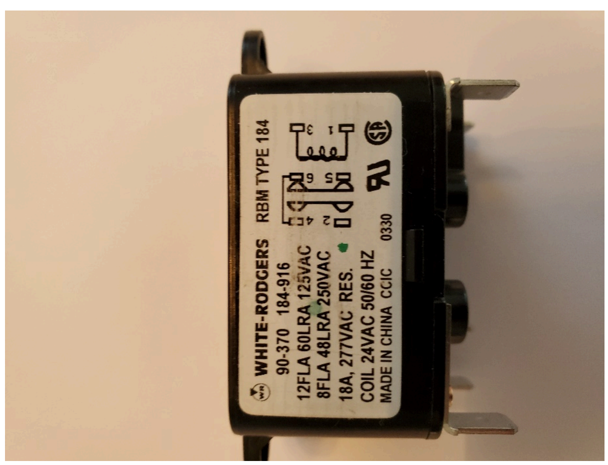


Figure 8 Schematic on side of White-Rodgers relay

In a 24VAC hydronic heating system, the relay allows a control voltage of 24VAC to turn on a 120VAC pump without the two voltages coming in contact with each other. A relay, therefore, is a magnetic switch, with electromagnetism being the force that operates the switching mechanism.

Many pieces of heating equipment have more than one relay, or multiple sets of relay contacts, and it may be necessary to identify and corelate the coils with the contacts they control. An industry standard is to number relay coils as 1K, 2K, 3K and so on. If relay 1K had 3 sets of contacts, then they would be labeled as 1K1, 1K2 and 1K3. Contacts for relay 3K would be labeled 3K1, 3K2, 3K3 etc. In that way, a wiring diagram with many relays and contacts should be easier to read and interpret, especially where diagnostics are concerned. The illustration below is of a supervisory control for gas equipment. It has a safe-start-check feature and can be followed by recognizing that there are 2 relay coils marked as “R” and “Q”. Relay coil “Q” only operates one set of contacts, being Q1 which is normally open (NO). Relay coil “R” has 3 sets of contacts, labeled as R1 (NC), R2 (NO) and R3 (NC). The drawing shows the system at rest, not yet operating. Leaving aside the sequence of operation, what we know is that when either coil is energized the contacts that it operates will reverse position. R1 and R3 will open when coil “R” is energized while R2 will close, and when coil “Q” is energized, contacts Q1 will close. Current flow will be stopped by any open contacts, and will flow across any contacts that are closed. Once the coils are de-energized they will snap back to their original position.

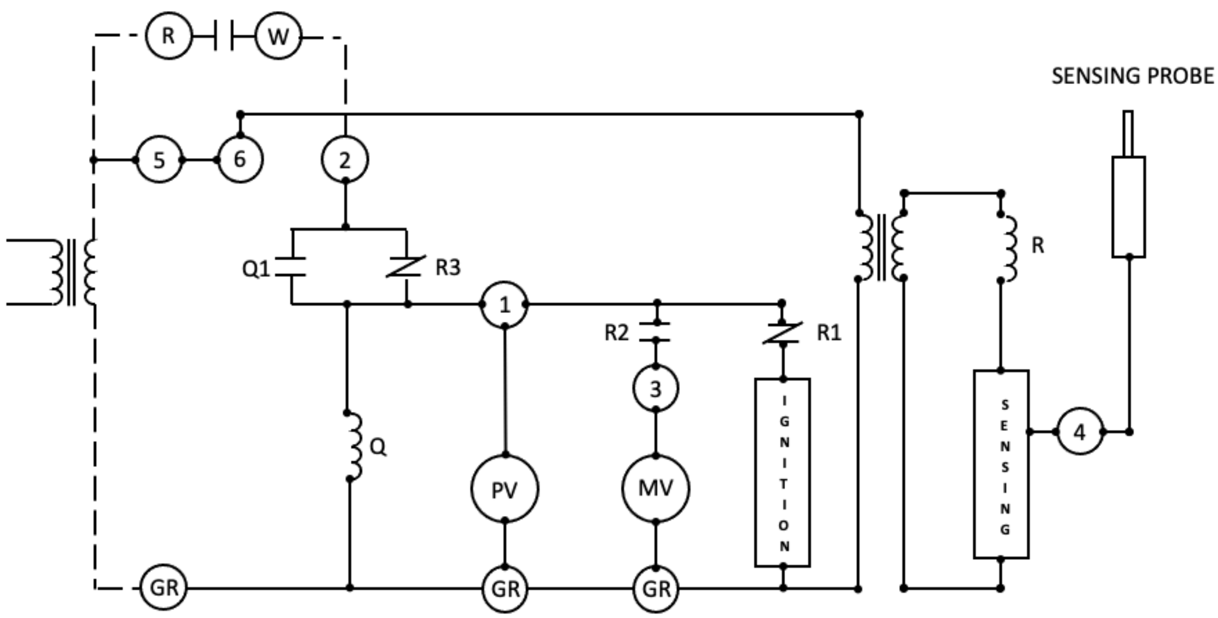


Figure 9 Wiring schematic diagram showing relay coils and their contacts

Now complete the Self-Test 3.

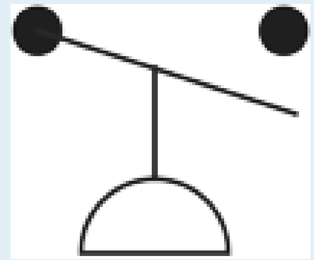
Self-Test 3

Self-Test 3

1. What is the moving part of a switch known as?
    a. A contact
    b. A switch
    c. A throw
    d. A pole
2. What is the stationary part of a switch known as?
    a. A contact
    b. A switch
    c. A throw
    d. A pole
3. How are switches designated?
    a. By their numbers of poles and throws
    b. By their number of contacts and switches
    c. By their number of poles and moving parts
    d. By their number of moving parts and amperages
4. What type of switch only "makes" while a person is pushing or twisting it?
    a. A time delay switch
    b. A short-term switch
    c. A momentary switch
    d. An instantaneous switch
5. Which one of the flowing choices would most accurately describe a heating thermostat?
    a. A pressurestat
    b. Open on rise
    c. Close on rise
    d. A relay
6. What are switches called that react to water temperature?
    a. Pressurestats

b. Thermostats
c. Flowstats
d. Aquastats

7. What does this symbol represent?



a. A flow switch
b. A level switch
c. A pressure switch
d. A temperature switch

8. What is the name of the switch that is used in a zone valve to prove that the valve is open?

a. A limit switch
b. A proving switch
c. A low water cutoff
d. An end switch

9. What voltage value is applied to the two yellow wires of most zone valves?

a. 24V DC
b. 24V AC
c. 120V DC
d. 120V AC

10. What voltage value is applied to the two red wires of most zone valves?

a. 24V DC
b. 24V AC
c. 120V DC
d. 120V AC

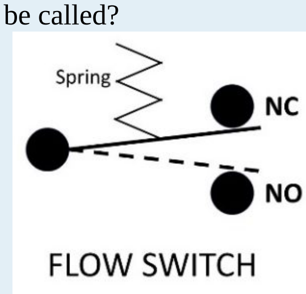
11. In which leg of a circuit should switches be located?

a. The neutral leg
b. The hot leg
c. The cold leg
d. The grounded leg

12. What type of relay is most often found in use in hydronic heating systems?

a. SSR
b. ECM
c. MMA
d. EMR

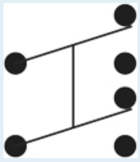
13. What is the voltage value of the coil in most relays used in hydronic heating control circuits?
    a. 24V DC
    b. 24V AC
    c. 120V DC
    d. 120V AC
14. What voltage value do most pumps in hydronic systems use?
    a. 24V DC
    b. 24V AC
    c. 120V DC
    d. 120V AC
15. Which one of the following statements regarding EMRs would be correct?
    a. When the coil is energized, only the NO contacts will open
    b. When the coil is energized, only the NC contacts will close
    c. When the coil is energized, the contact positions will reverse
    d. When the coil is energized, it will transform 120VAC into 24VAC
16. What would the device to the right be called?



    a. A relay coil
    b. A DPDT switch
    c. A relay contact
    d. A SPDT switch
17. What would the device below be called?

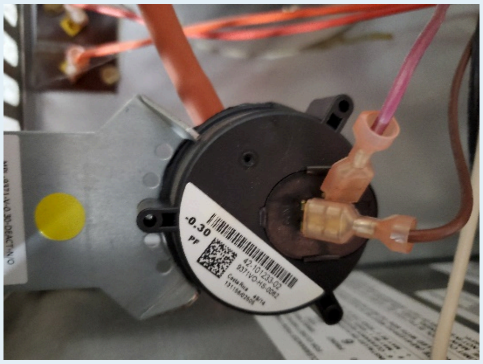
a. A pressure switch
b. A low water cutoff
c. A momentary switch
d. A pressure relief valve

18. What is the device shown below?



a. A SPDT switch
b. A DPST switch
c. A DPDT switch
d. A momentary switch

19. What is the device pictured?



a. A low water cutoff
b. A flow switch
c. A pressure switch
d. An aquastat

20. Which variety of relay has no moving parts but usually only controls one device?

a. An EMR
b. An MMA
c. An ECM
d. An SSR

Check your answers using the Self-Test Answer Keys in Appendix 1.

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Competency F4: Design Hydronic System Controls

Today's hydronic systems can be fine-tuned marvels of comfort. It was recognized long ago that heating our buildings with water afforded the people who lived and worked within them the greatest comfort level over all other types of distribution systems available, and the act of heating using an insulator (air) as the transfer medium should be seen as a compromise. Leaving the costs of the system aside, the fact of that matter is that forced air systems for houses are fairly simple to understand, and many homeowners and tradespeople who may be wary of sophisticated hydronic control systems will choose forced air over hydronics because that's what they are familiar with. Some of the fault with that outlook lies with hydronic installers. In the past, installers rarely left a "roadmap" with the owner or contractor, outlining just how the system's controls were supposed to work. This may have been strategic in its intent, in that the installer would be the likely recipient of the first call made if and when the system needed attention. More likely was the probability that the installer didn't have the ability to draw a simple, understandable ladder diagram to reflect the operational characteristics of the system.

Learning Objectives

After completing the learning tasks in this Competency, you will be able to:

- Describe the principles of electrical controls
- Describe control systems for hydronic systems
- Interpret electrical control circuits

Learning Task 1

Describe the Principles of Electrical Controls

The advent of the internet has quite possibly been the biggest boon to hydronics professionals, in that there is a mountain of information available at our fingertips to help guide us through any problems or questions we encounter. Online tutorials, virtual assistants and countless drawings and schematics offer help that once could only be obtained through phone calls to suppliers and by reading through volumes of technical manuals. Installation guides and FAQs take much of the mystery out of our control systems, so that we can make informed choices centred on the function and reliability of a product, rather than sticking with the status quo because of fear of the unknown. This learning module will attempt to help de-mystify some of the aspects of today's "whole-house" hydronic controls and set learners on the path of understanding the systems they are installing.

Although solid state controls have been around for a number of decades, it has only been within the last thirty or so years that they have been incorporated into residential design. Large commercial buildings usually have on-site professionals whose only job is to oversee the operation of the building's mechanical systems, which are constantly monitored and displayed through software programs. That job description/person doesn't exist in a residential home, so control systems for dwellings have to be proven, reliable and very much self-diagnostic as much as possible if a homeowner is to have confidence that they won't have to routinely call in an expensive tradesperson to troubleshoot their system.

The "Old"

Before PeX and radiant floor panels took over the residential hydronic heating world, systems were very simple. There were only a few choices of types of "conventional" non-condensing boilers (cast iron, copper fin tube and steel) and some basic piping strategies for high temperature systems (series loop, Monoflo© tee and the two 2-pipe systems) that fed baseboard wall-fin emitters. One pump pushed water everywhere and hydronics were simple.

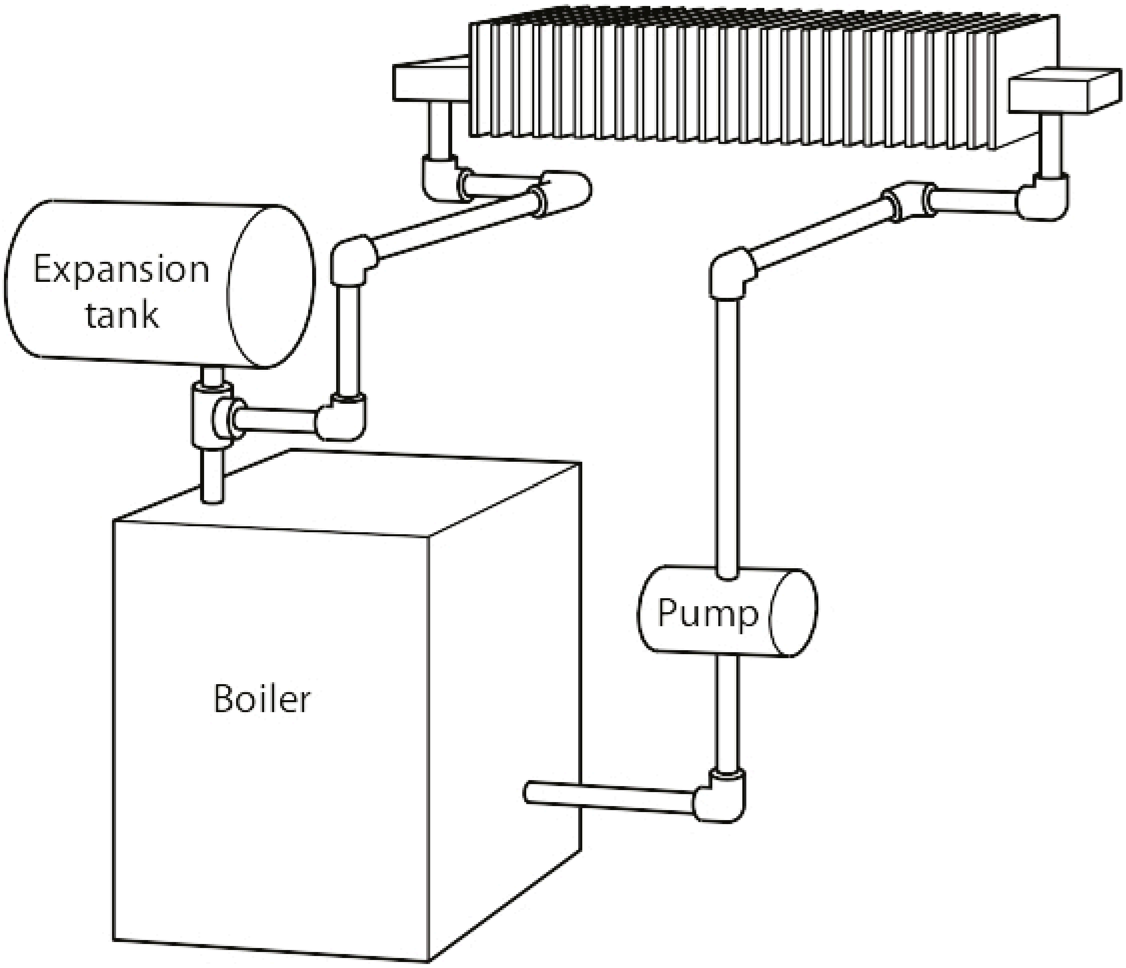

Figure 1 Non-condensing boiler and wall fin

Hydronic radiant floors changed all that.

Non-condensing boilers need high return water temperatures which are too hot for radiant floors. Radiant floors have low-temperature water circulating through them, so the need for multiple temperature piping systems was born. Installers at first attempted to simply turn down the operating setpoint temperature on the boilers, but they soon found out the effects of low temperature return water constantly entering the boiler. This low temperature return water was often below the atmospheric dew point temperature. Consequently, boilers rusted out on the outside and their heat exchangers plugged from the constant sooting caused by condensation dripping onto the burners below them. It was clear that things had to be done differently.

The "New"

If a boiler must run hot, and floors need only to be warm, then there has to be means to have two water temperatures exist within the same system. The use of mixing valves, diverting valves and variable speed injection pumps allows that to be achieved. To enable this to happen, today's hot water heating systems are now considered "high tech". More efficiency and comfort can be realized by the use of controls that measure and automatically adjust outdoor, indoor and system water temperatures. A spinoff to the use of high-tech controls is that hydronic cooling is now a viable option where in the past, without sophisticated controls, it wasn't.

The Heat Plant

The use of stainless steel and other corrosion-resistant alloys in boiler design has progressed. A secondary heat exchanger "scrubs" the latent heat from the flue gases, which increases their "AFUE" (Annual Fuel Utilization Efficiency) and also allows them to operate at lower temperatures. Thus, the condensation they produce won't cause corrosion problems.

Figure 2 Small residential condensing boiler

Further to that, air-to-water and water-to-water heat pumps are replacing hydrocarbon-fuelled boilers more and more, so dependency on fossil fuels is greatly reduced, thereby decreasing our carbon footprint.

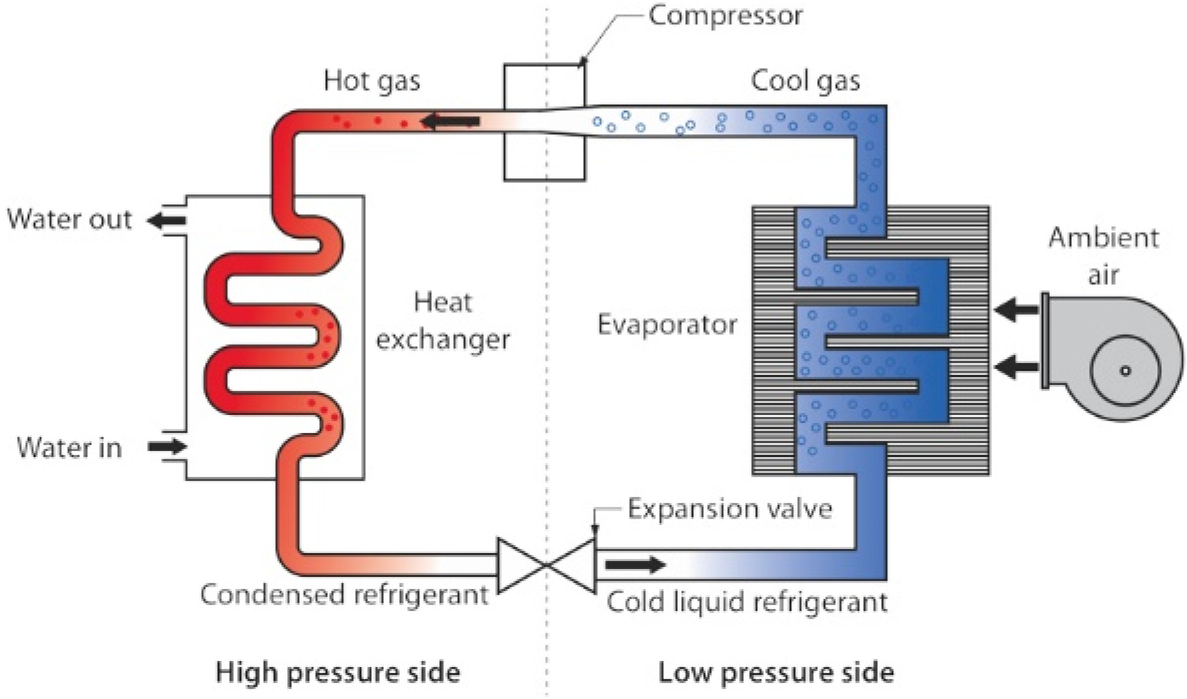

Figure 3 Air-to-water pumps

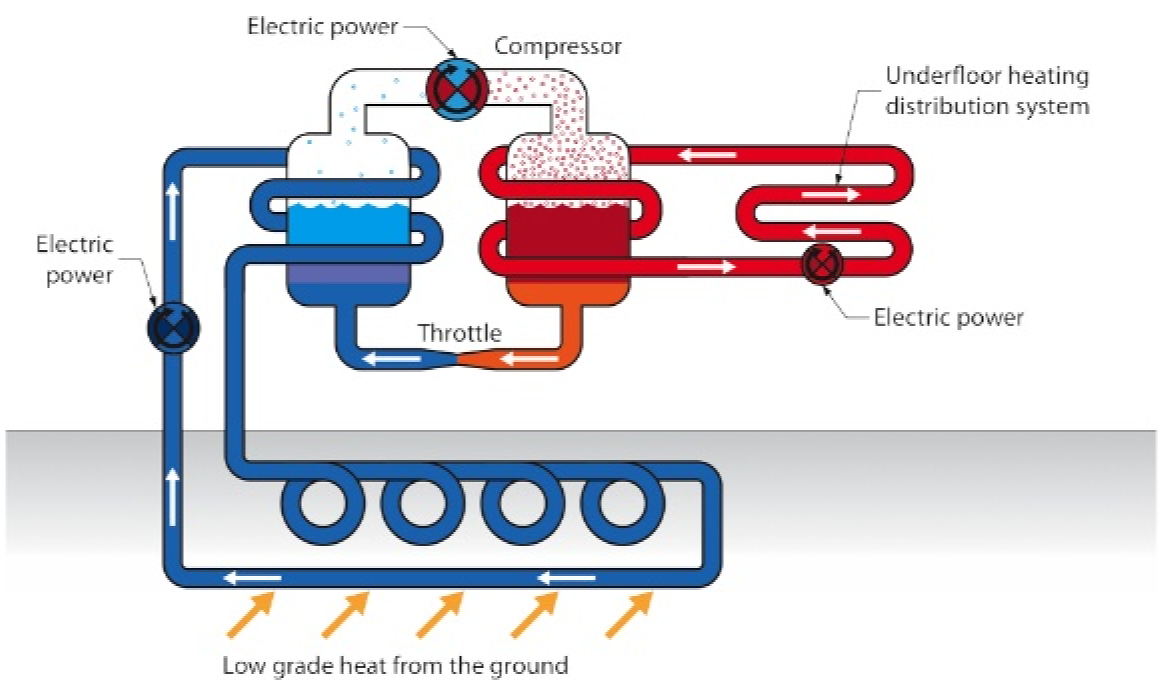

Figure 4 Water-to-water heat pump

The Piping

Primary/secondary piping strategies have largely replaced the standard series loop, Monoflo© tee and 2-pipe direct and reverse return piping that hydronics have grown up with.

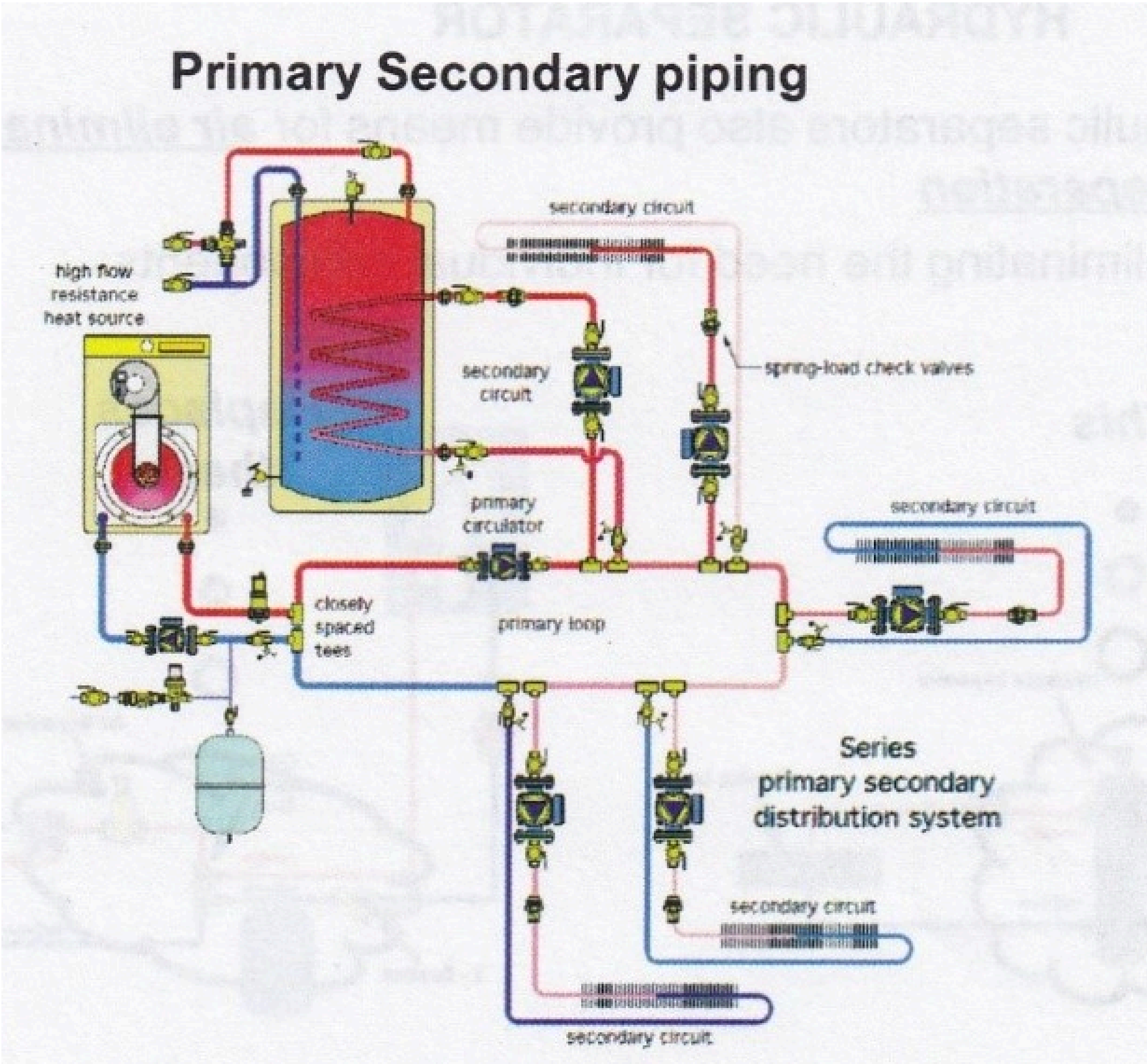

Figure 5 Primary/secondary piping

Primary/secondary piping systems rely on the principle of hydraulic separation for proper flow rates. Closely-spaced tees and hydraulic separators are used so that pumps that are connected to the same water system won't have an effect on each other. Placing tees no farther than 4 pipe diameters from each other ensures that there is minimal pressure drop between the tees. Large containers called "hydraulic separators" perform the same function, often with less room taken up and less connections overall.

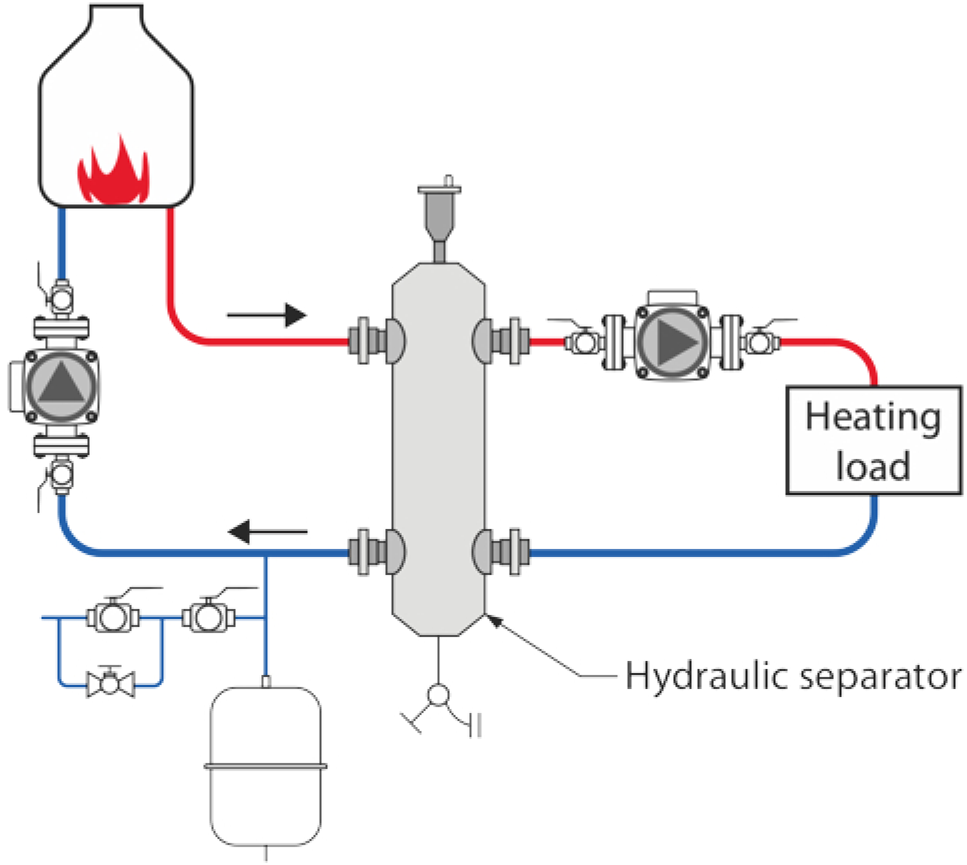

Figure 6 Hydraulic separator

Media Attributions

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- Figure 5 Primary/secondary piping © Viega. Used with permission.
- Figure 6 Hydraulic separatorby ITA is licensed under a CC BY-NC-SA licence.

Learning Task 2

Describe Control Systems for Hydronic Systems

The Controls

The term "controls" has a very broad scope. Within it are piping strategies and devices that are ultimately governed by "controllers", and there are many variations and combinations of the above. Viega© is recognized in the industry as one company that produces equipment and literature for different control strategies. They are probably best known worldwide for their innovations in press-type piping fitting technology, but they are also a dominant force in hydronics control. The diagrams below are just a few of the many offered by Viega © that show possible options for system control.

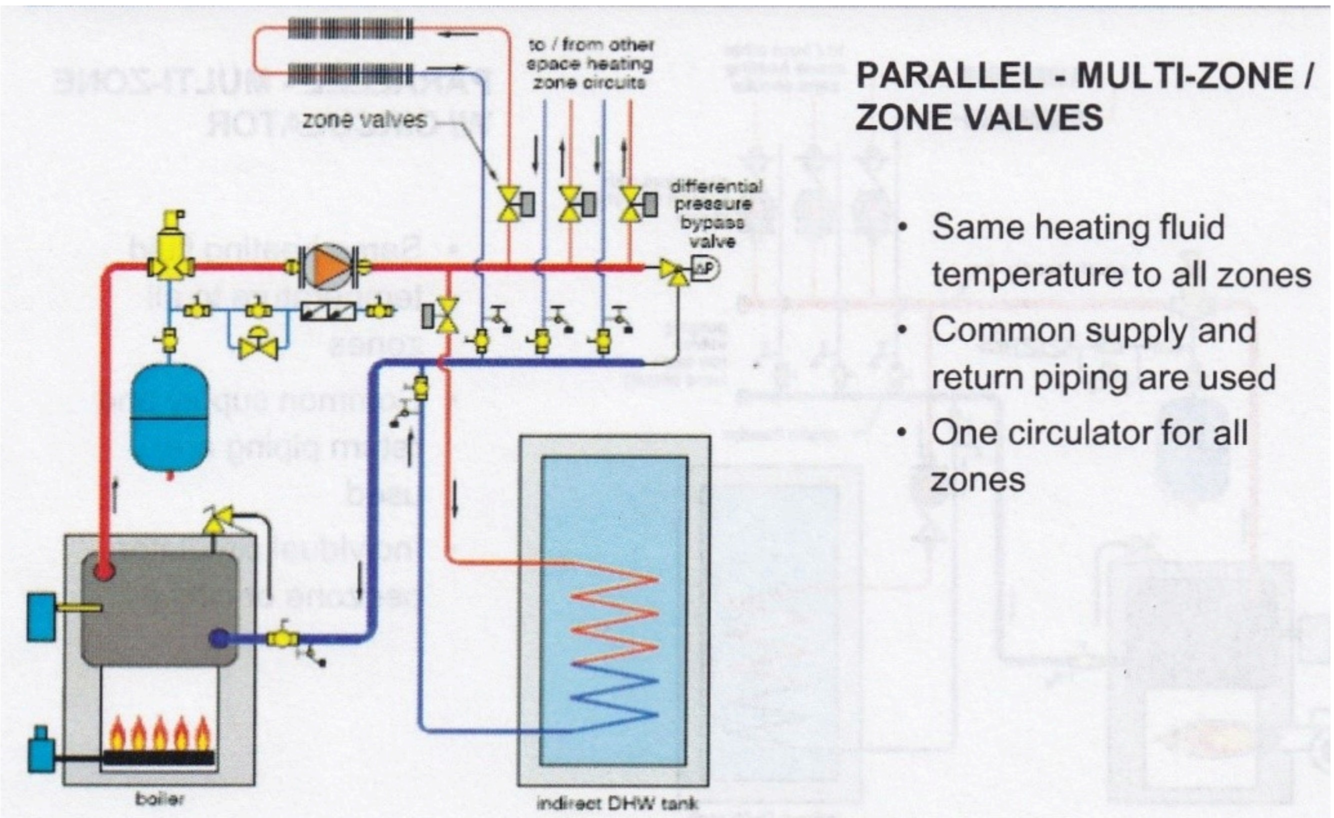

Figure 1 Multiple temperature demands using on-demand modulating boiler

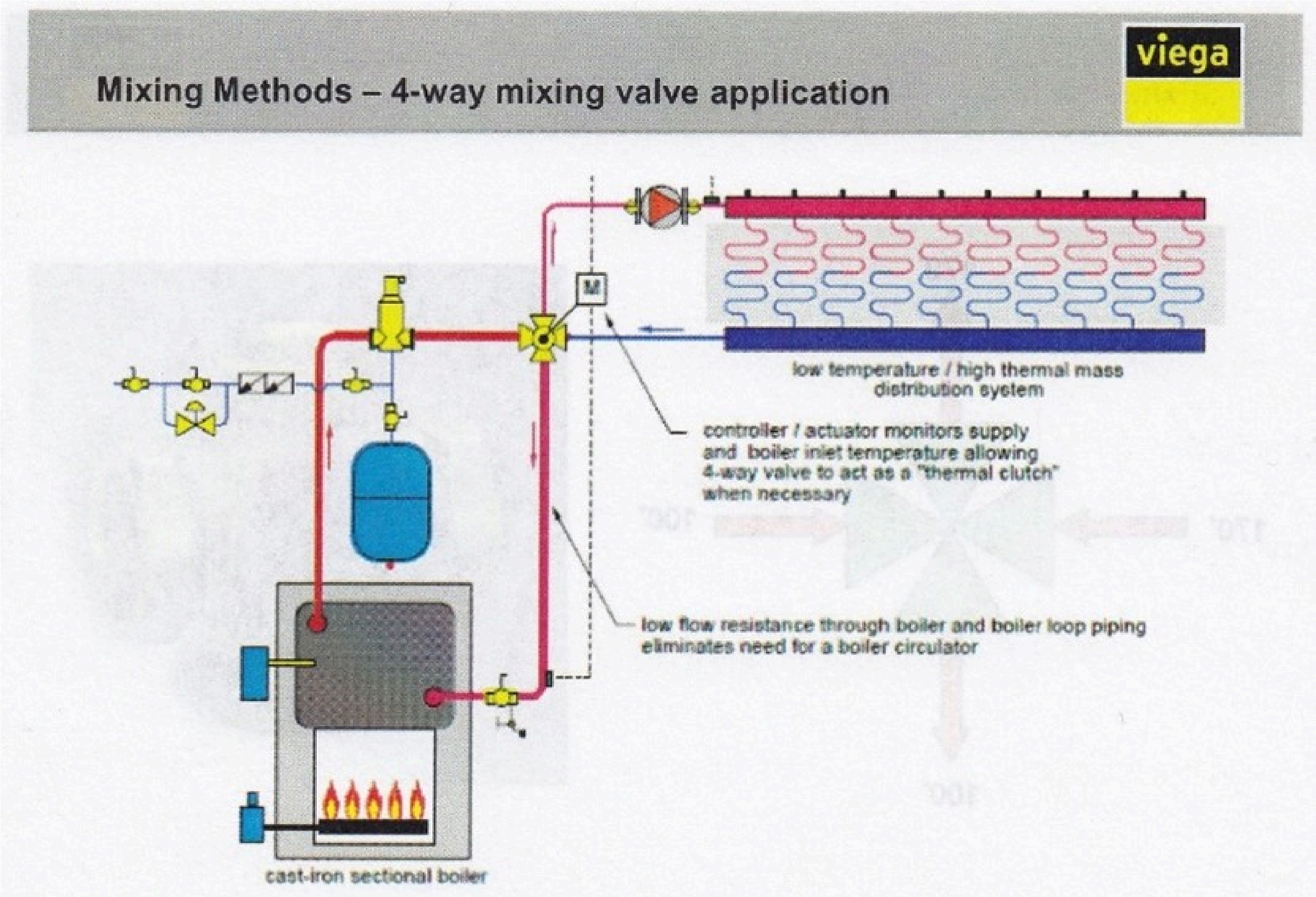

Figure 2 Temperature control using 4-way mixing for boiler protection

We will be using some of their drawings in this learning module but to be clear, there are far too many variations of piping and control strategies to be able to cover them all. We will pick out some that would most likely apply to today's residential systems and we'll endeavour to explain their design characteristics and operation.

With that in mind, let's first look at an "old-school" system using 2-pipe direct-return layout.

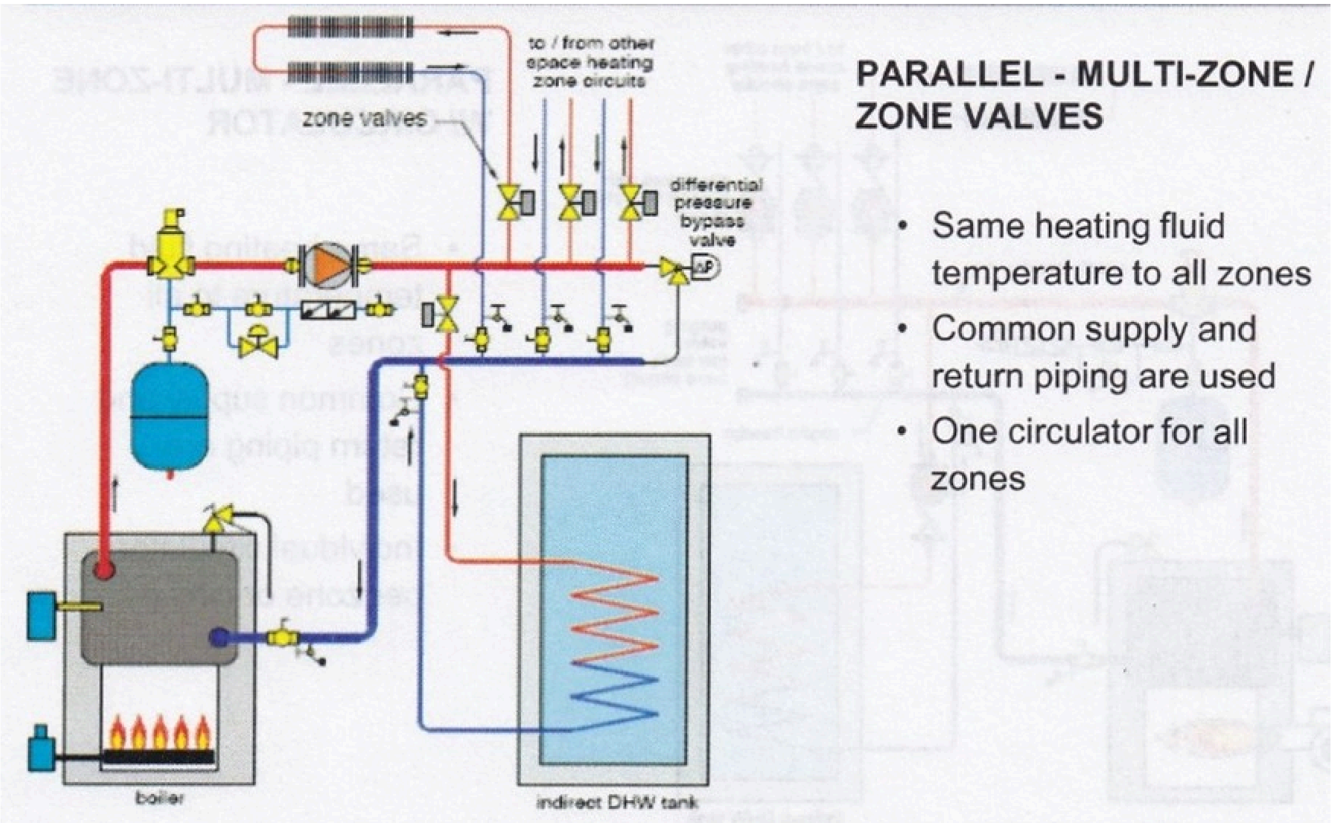

Figure 3 High temperature direct-return with indirect domestic water

This system used one pump to push water everywhere. The pump would be sized to produce enough head pressure to overcome the losses through the boiler, out through the circuit that had the most frictional resistance and back to the boiler, while being able to push water through all of the circuits if they were all calling for heat simultaneously. In other words, using the industry standard ΔT of 20°F, it would supply a flow of 1 GPM for every 10,000 BTUH of heat needed for the building.

Based upon a 20°FΔT, if the non-condensing boiler's operating aquastat was set at 180°F, then the system's average operating temperature would be 170°F. This would be the temperature used to size the baseboard wall-fin and the coil in the domestic hot water tank. The boiler burner circuit would get its 24VAC power supplied to it whenever an end switch on a zone valve closed. This was so that, theoretically, the burner couldn't fire unless a zone was open and water was flowing. If water flow had to truly be proven and not just assumed, the 24VAC would also have to pass through a flow switch to get to the burner.

The zone valves would be controlled by thermostats and the domestic hot water would be sensed by an aquastat.

If the boiler was of the low-mass variety, the pump and boiler burner circuit should only be energized if a zone valve proved open. If the boiler was high-mass, it could be operated without flow through it and so the burner circuit could always be energized to keep the boiler hot at all times if desired.

Because all aspects of these systems operated at high temperature, they required no mixing valves. The electrical schematic and ladder diagrams for them are similar to these below for a low-mass boiler, which is often referred to as “cold start” because it can’t fire to keep itself hot unless there is a call for heat from the system.

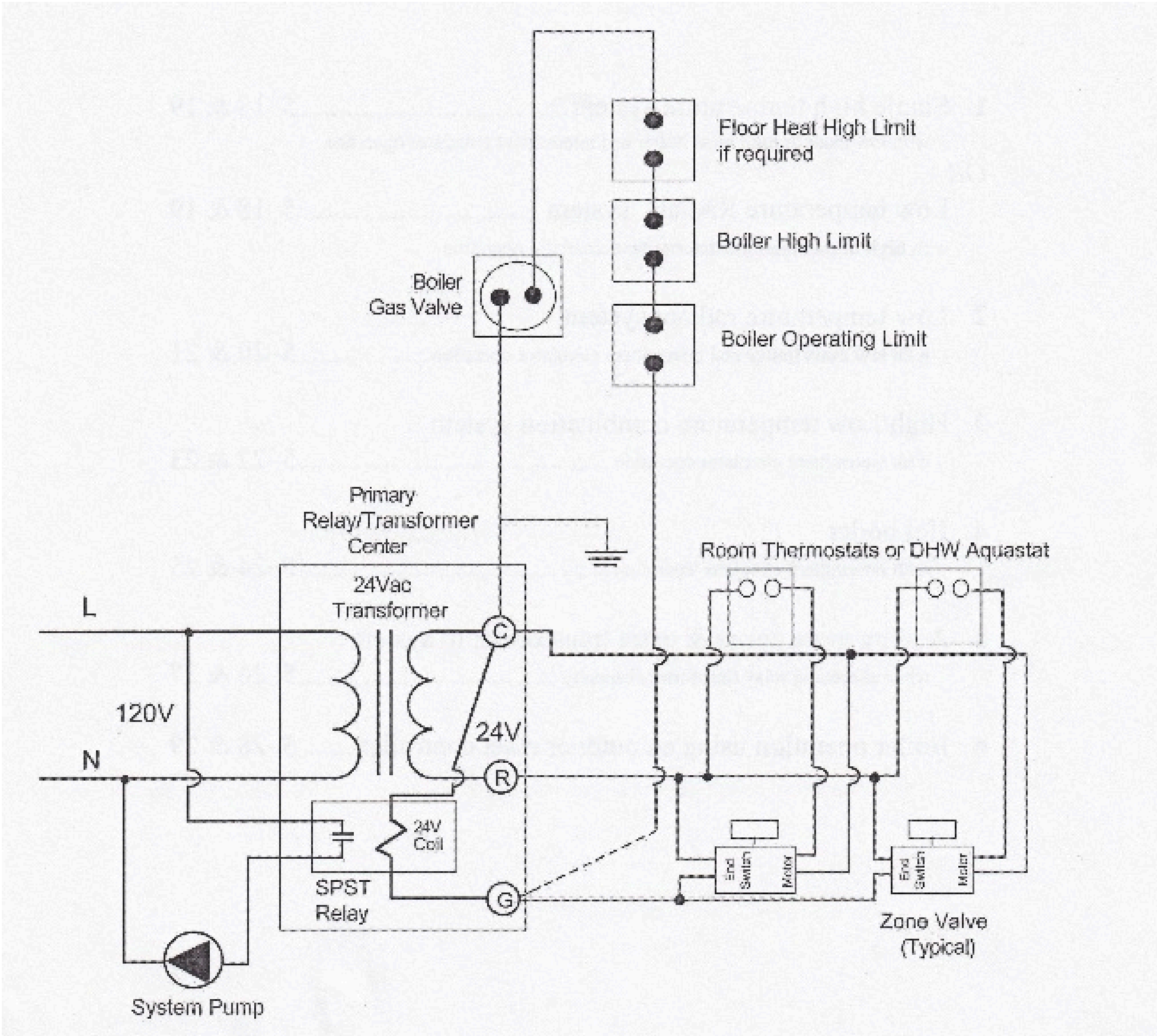

Figure 4 Schematic diagram

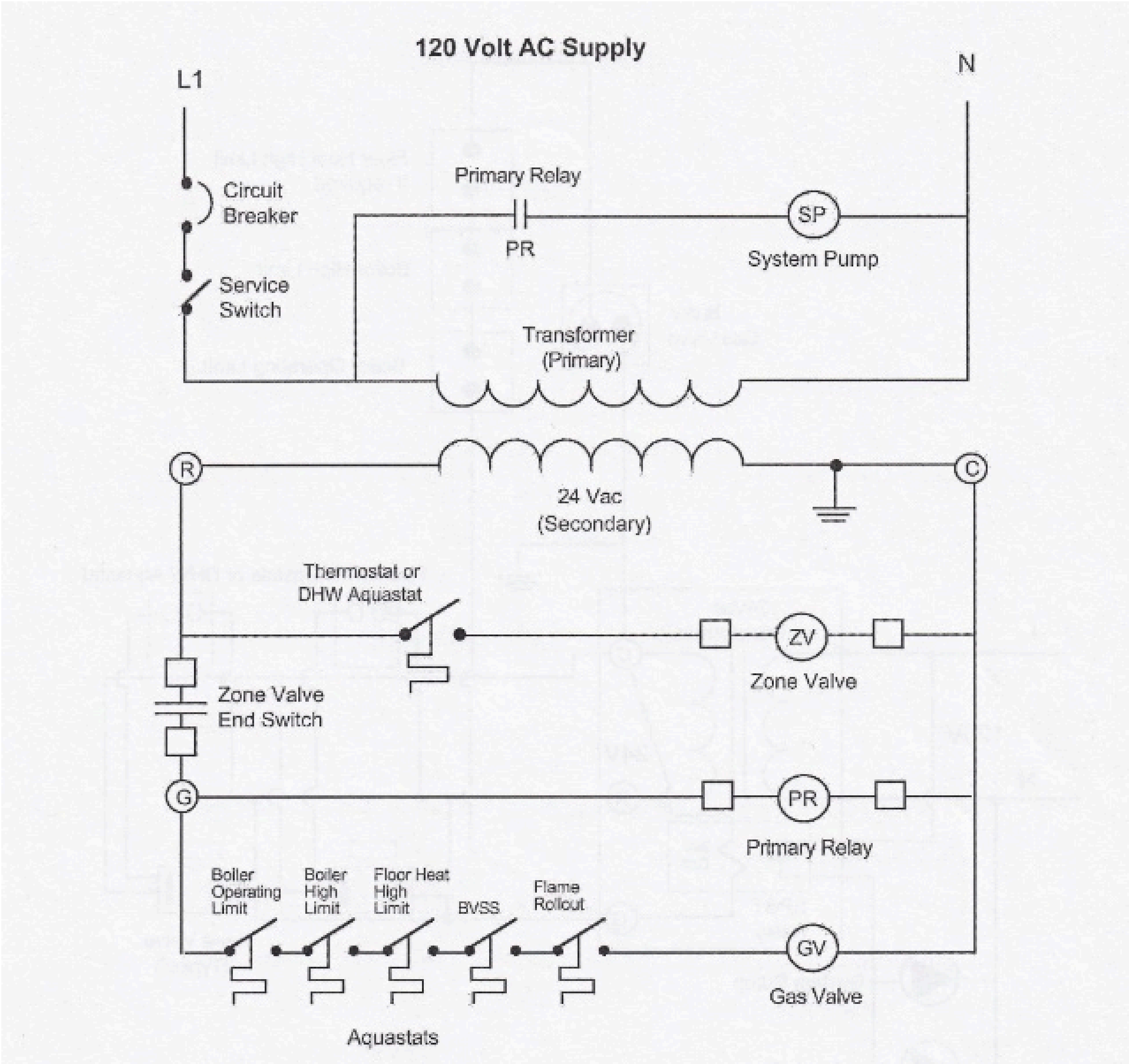

Figure 5 Ladder diagram

It is important to note that the schematic diagram tries to show the components as they might appear physically, whereas the ladder diagram shows only electrical symbols for the components. The schematic will have lines that cross each other on the page, and it may be hard to determine whether they are meant to connect or not. No wires in a ladder diagram will cross, so this diagram is sometimes easier to follow.

The transformer and relay for the diagrams above are shown contained within an enclosure known as a "furnace fan center" or "relay/transformer center". Its original main use was to add control of air conditioning to an old furnace system that didn't have a printed circuit board, but it also had use in hot water heating. It's simply an electrical box with a cover plate that has fixed to it a transformer and a relay base that a specific relay plugs into. 120VAC is fed into the box where line voltage connections to the transformer and relay base are made. The 24VAC terminals are mounted on the face of the transformer as seen in the pictures below, and that is where all the low voltage connections are made.

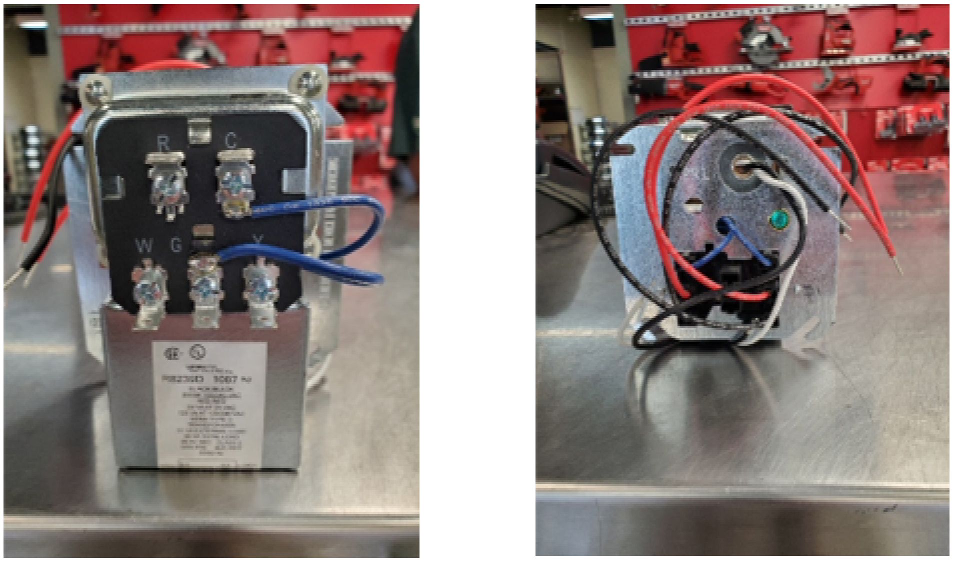

Figure 6 Relay/transformer centre

As seen in the diagrams and picture above, the “R” terminal is the external power supply to the thermostats and end switches. The “C” terminal is connected internally to the neutral side of the 24VAC transformer and is also the external ground connection for the burner and zone valve circuits. The outlet side of the end switches are connected to the “G” terminal which feeds the internal relay coil and externally feeds power to the burner circuit.

If a relay/transformer center has “W” and “Y” terminals, as in the picture above, it is because it has another internal relay for control of other devices such as an air conditioning condenser and the furnace fan which would be set to high speed for cooling.

Today’s new residential hydronic systems are rarely single-temperature systems. Any RFPs (radiant floor panels) will be fed with water that is somewhere between 90°F and 140°F, depending on the BTUH/ft² required and the “R” value of floor coverings. Any non-condensing boiler used with RFPs will still be operated at 180°F – 200°F to prevent condensation caused by low return water temperatures, so a mixing means must be employed. Let’s look at 3-way mixing valves as an example of a popular way of achieving this result.

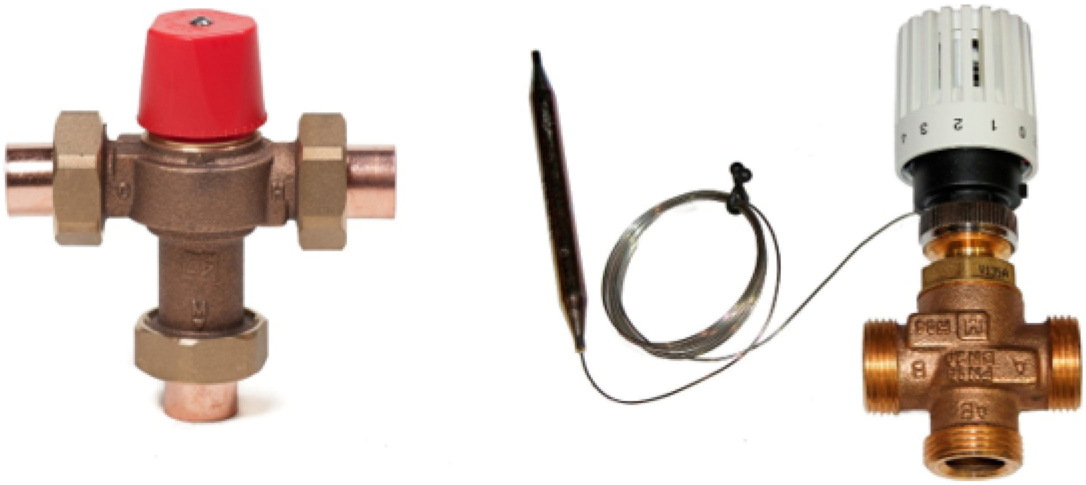

Figure 7 Three-way mixing valves

The position of the mixing stem in the valve on the left above is preset by hand and won't therefore react to any change in temperature at the ports. The one on the right will find its position depending on the heat in the piping that the bulb is immersed in or strapped to and the heat setting on the dial. A motor and motor controller can also be used on 3-way valves if desired. The 3-way valve's place in the piping system is shown below. Note that a mixing valve is located at the mixing point (the point in the piping system where the water is tempered), so it can have its sensor internally mounted.

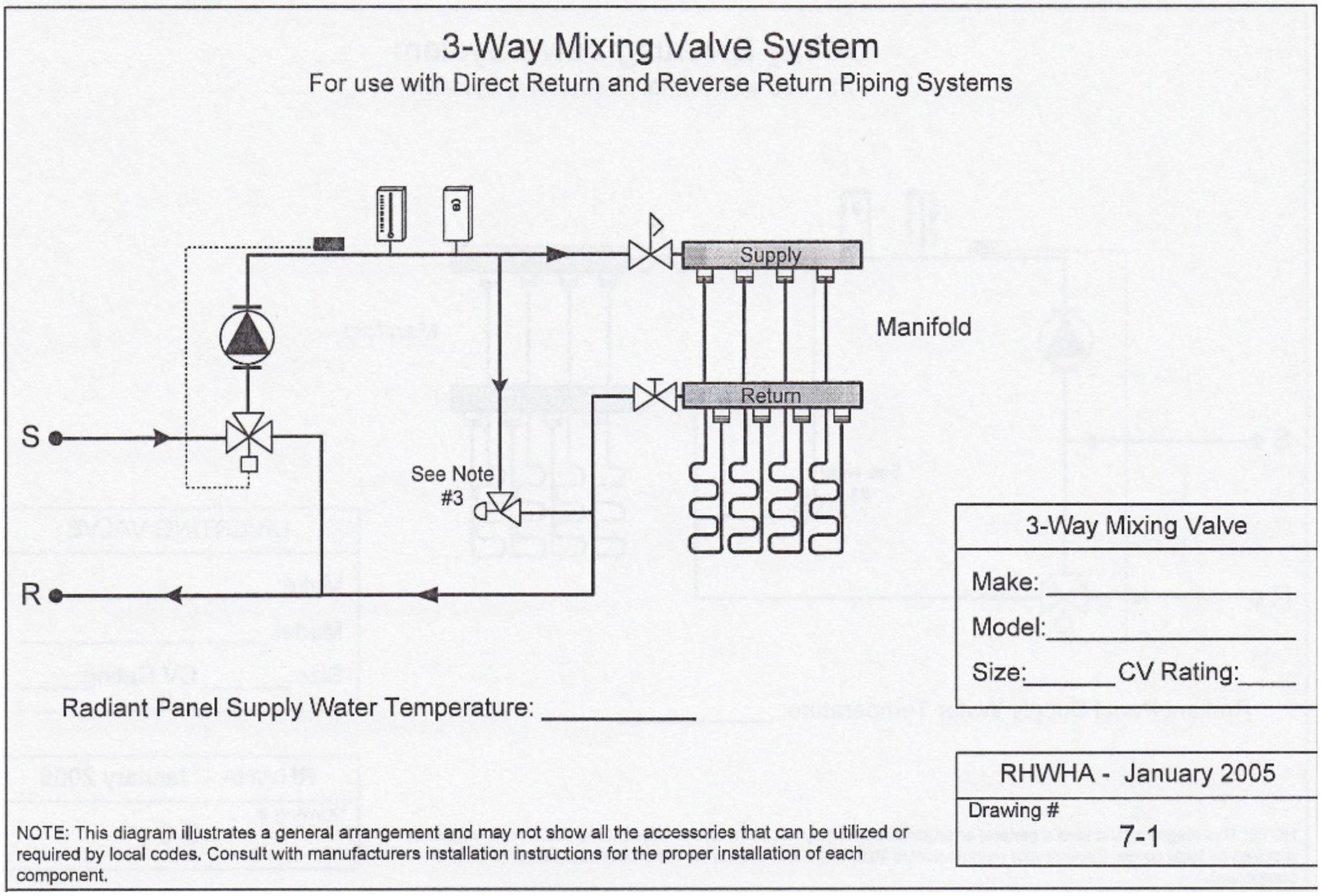

Figure 8 3-way mixing valve placement

The term "mixing valve" is used in a general context within the industry to denote the tempering of water through it.

Diverting valves are also used for 3-way tempering, and are not installed in the same location as the mixing valves. See the diagram below.

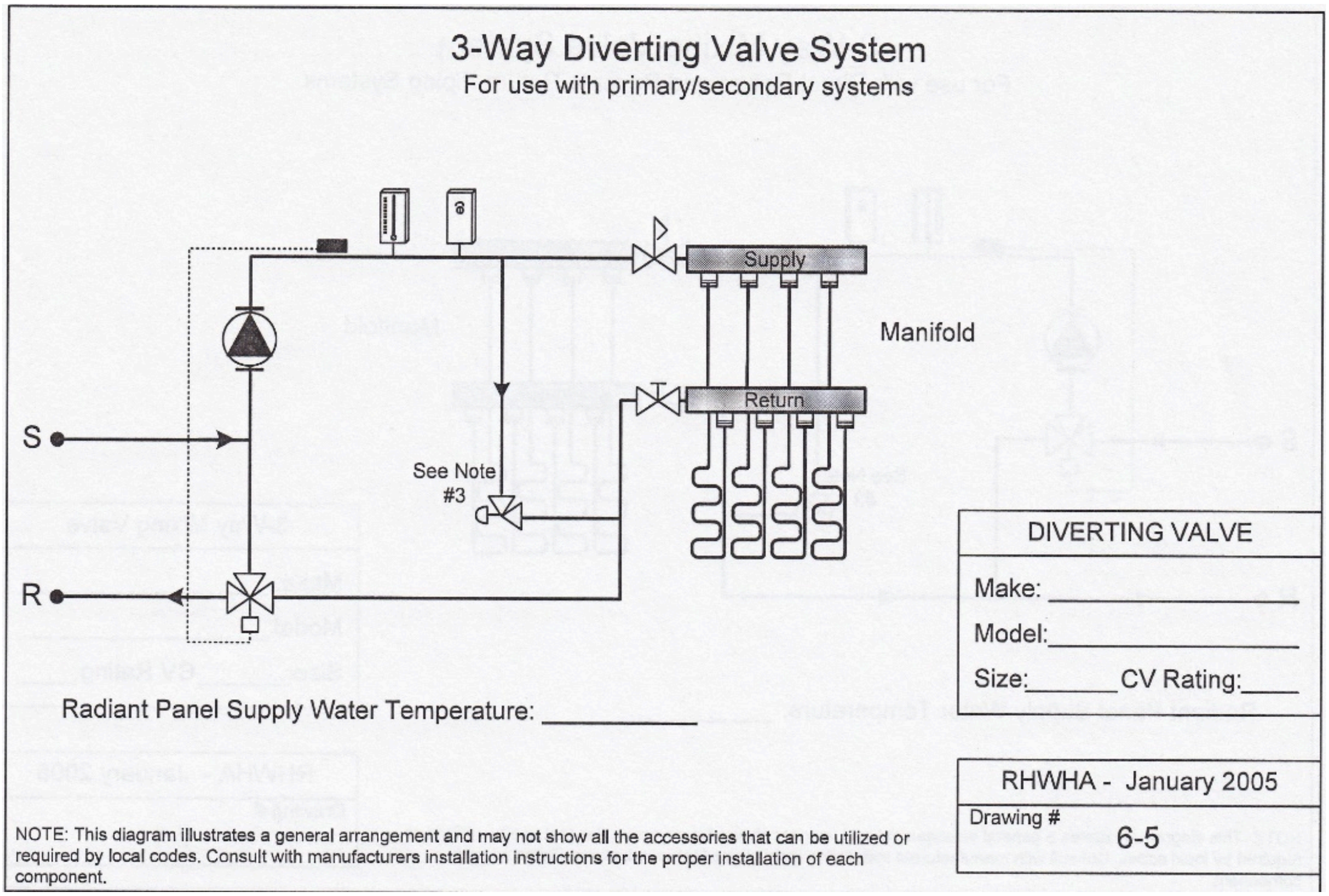

Figure 9 3-way diverting valve placement

Diverting valves are mounted on the return piping, so they are not located at the mixing point; as such, they must have a remote means of measuring temperature. A bulb, strapped to the supply piping, must be used in order to make the diverting valve react to a change in temperature on a pipe that may be metres away from it.

It is important to note that mixing and diverting valves are different, in that a mixing valve has two inlets and one outlet, whereas a diverting valve has one inlet and two outlets. Therefore, their use and positioning in a system is critical. Diverting valves are sometimes preferred because they have less head loss through them than mixing valves do.

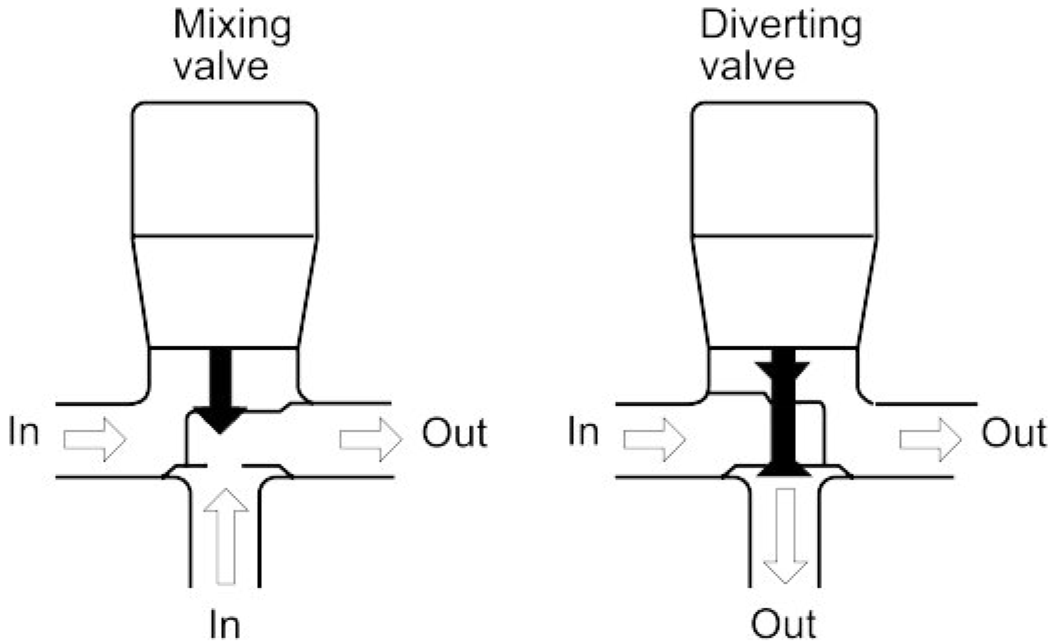

Figure 10 3-way mixing and diverting valves

A lesser-used component for tempering water in a circuit is by the use of a 2-way valve, as shown below.

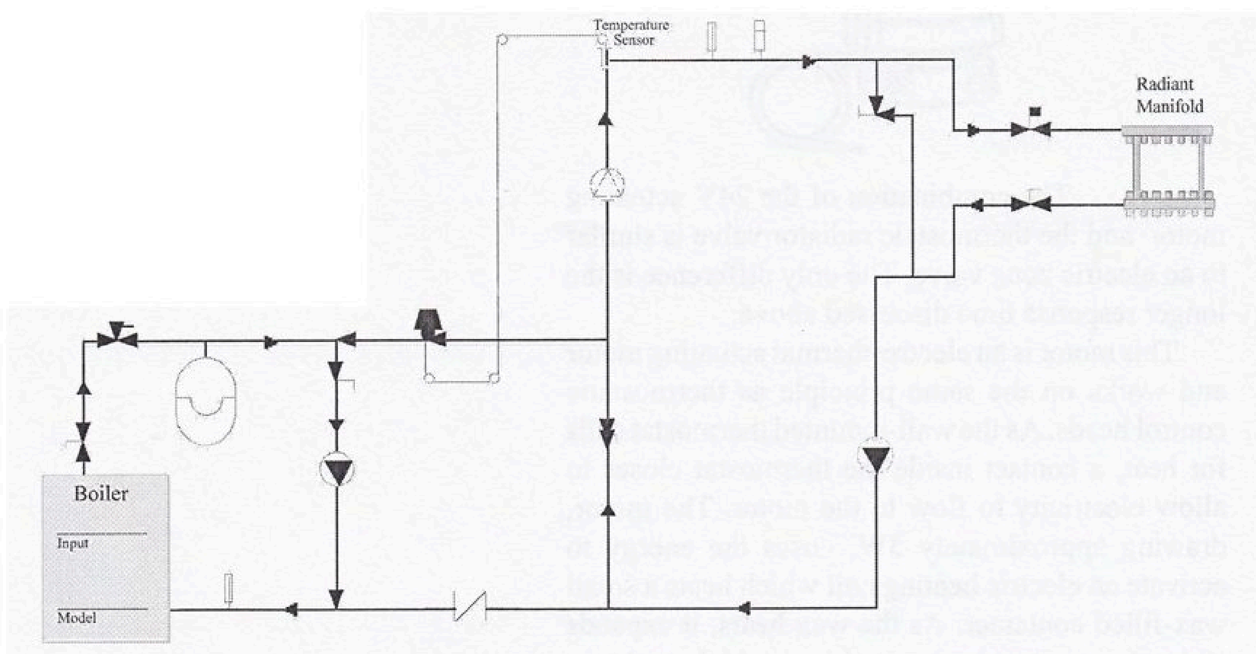

Figure 11 2-way injection valve placement

The 2-way valve is simply a throttling valve with a low head loss that is controlled by a capillary tube connected to a bulb. The bulb is positioned to sense the temperature in the radiant circuit. These systems are very similar to primary/secondary piping in that hot system water is throttled through the 2-way valve from the main loop to adjust the temperature in the floor system. There is no hydraulic separation between the pumps, so much care must be exercised in their selection. 3-way and 4-way mixing systems are therefore seen to be a better choice.

4-way mixing valves have very low head losses through them and as such, are considered the superior choice for tempering water.

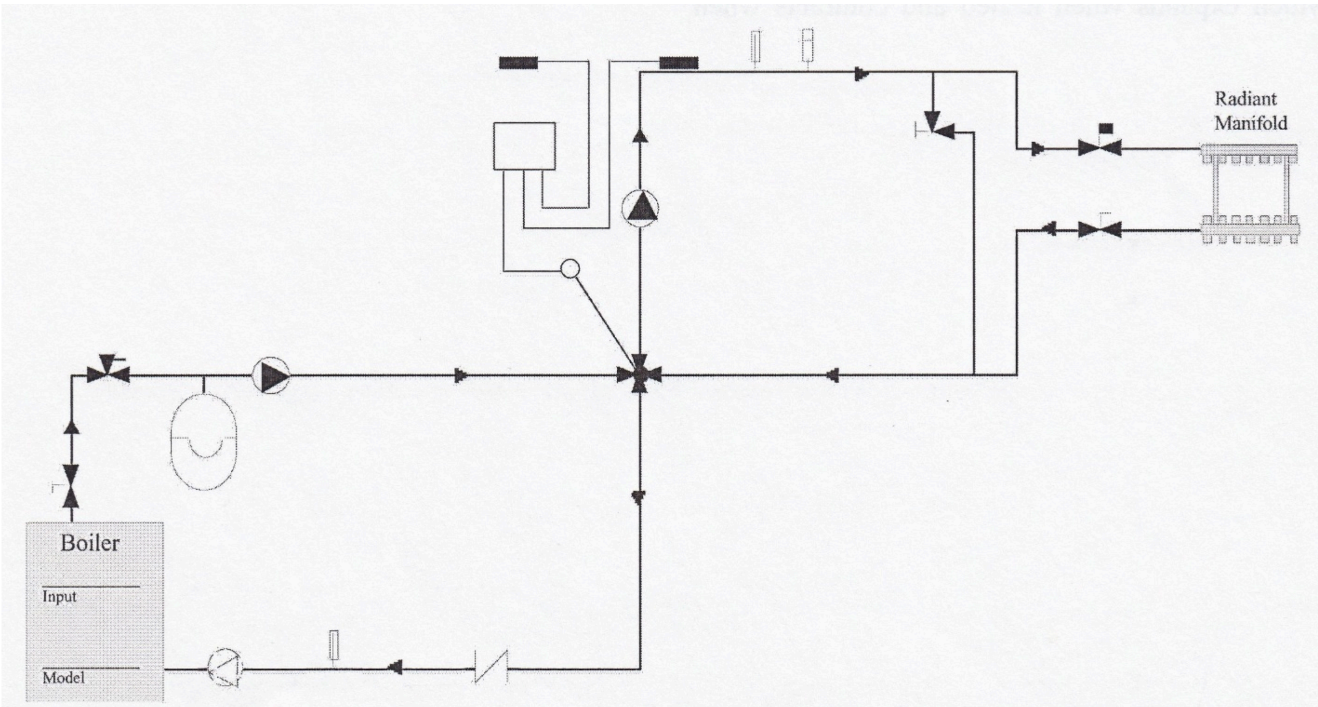

Figure 12 4-way mixing system using outdoor reset control

Just like the 3-way mixing and tempering valves, the 4-way valve can either be manually set to try to deliver one desired temperature or can be fitted with a motorized head which can automatically operate the mixing valve's stem in reaction to both system water and outdoor air temperatures. This is known as "outdoor reset control". As outdoor temperatures become colder, heat losses from a building increase. An outdoor reset control measures the outdoor temperature and as the indoor temperature drops, it balances the extra heat loss by making the system supply water hotter. A "heating curve" is used to calculate exactly how much hotter the supply water will need to be as outdoor temperature drops. The curve represents the number of degrees the supply water is raised for every degree the outdoor temperature falls. To calculate the correct heating curve, the following calculation is used.

Heating curve = (design supply temp − room temp) ÷ (room temp − outdoor design temp).

For example, if the ODT = 5°F, the desired room temperature = 70°F, and the desired design supply water temperature = 140°F, the calculation would be:

$$(140°F - 70°F) \div (70°F - 5°F) = 70°F \div 65°F = 1.08\ (1.1)$$

This means that, for every 1°F drop in outdoor temperature, the system water temperature will increase by 1.1°F. Conversely, when the outdoor temperature rises to 70°F, the system will have reached a "thermal equilibrium" where indoor and outdoor temperatures are equal. The reset control will have reached its “warm weather shutdown point” (WWSD) and the heating system operation will not be necessary.

Outdoor reset control can also be applied to the boiler primary loop to allow a lower boiler supply temperature in all but the design times of the year, although in no case should the return water temperature be dropped below the atmospheric dew point if the boiler is of the non-condensing type.

The sensor for outdoor reset controllers should be mounted outside on the north face of the building where it doesn’t receive direct sunlight or is exposed to any heat/cold sources such as the discharge from a dryer vent.

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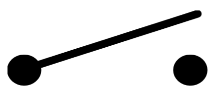
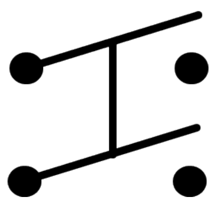
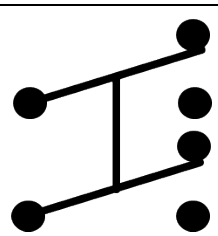
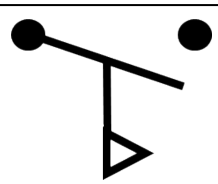
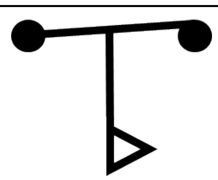
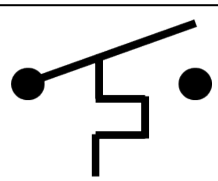
- Figure 11 2-way injection valve placement is courtesy of TECA BC.
- Figure 12 4-way mixing system using outdoor reset control is courtesy of TECA BC.

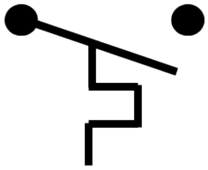
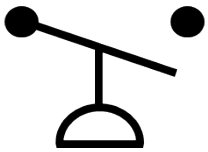
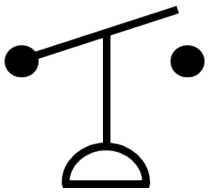
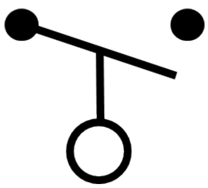
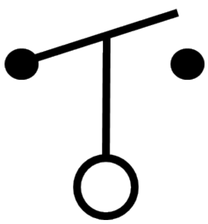
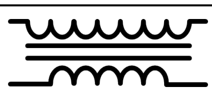
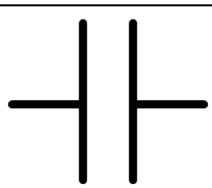
Learning Task 3

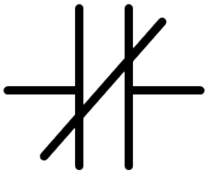
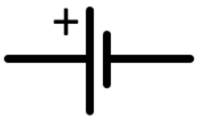
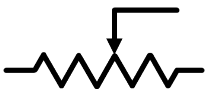
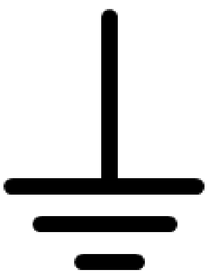
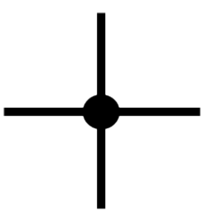
Interpret Electrical Control Circuit Diagrams

Electrical Symbols

By now, you should be familiar with the common symbols used in electrical circuits. Here is a recap of the common symbols used in electrical diagrams and a brief description of their meanings.

Symbol	Name	Description
	Single Pole Single Throw Switch (SPST)	Opens and closes one circuit
	Single Pole Double Throw Switch (SPDT)	Opens and closes alternate circuits
	Double Pole Single Throw Switch (DPST)	Opens and closes two separate circuits simultaneously
	Double Pole Double Throw Switch (DPDT)	Opens and closes two alternate circuits simultaneously
	Flow Switch	Closes on flow
	Flow switch	Opens on flow
	Temperature switch	Opens a circuit on a rise in temperature

	Temperature switch	Closes a circuit on a rise in temperature
	Pressure switch	Closes a circuit on a rise in pressure
	Pressure switch	Opens a circuit on a rise in pressure
	Float Switch	Closes a circuit on a rise in liquid level
	Float switch	Opens a circuit on a rise in liquid level
	Load	Generally, represents a wire winding or coil in a gas valve, light, motor, etc.
	Relay	Typically represents a coil in a relay
	Wire winding/coil	Similar to “load” above
	Transformer	Transformers increase or decrease voltage between primary and secondary circuits
	Normally open relay contact	Disallows current flow unless relay coil is energized

	Normally closed relay contacts	Allows current flow while coil is not energized
	Voltage source for direct current	Indicates a battery or other source of DC
	Resistor	Indicates a constant resistance in a circuit
	Variable Resistor	Indicates a resistance that can be changed in a circuit
	Pump	The point of the shaded triangle indicates the direction of flow
	Fuse	Opens a circuit when too much current flows
	Fuse	Same as above
	Ground (Earth)	A connection to the earth that has no voltage potential
	Wire connection	The dot indicates that there is a connection between wires

Wiring Diagrams

Let's look at wiring diagrams that represent a 2-temperature system with high and low temperature loads within it. A low mass non-condensing boiler is feeding an indirectly-fired hot water tank as well as a circuit of baseboard wall-fin emitters. The low temperature system will consist of two independantly-operating manifolds supplying RFPs. The schematic diagram is shown below.

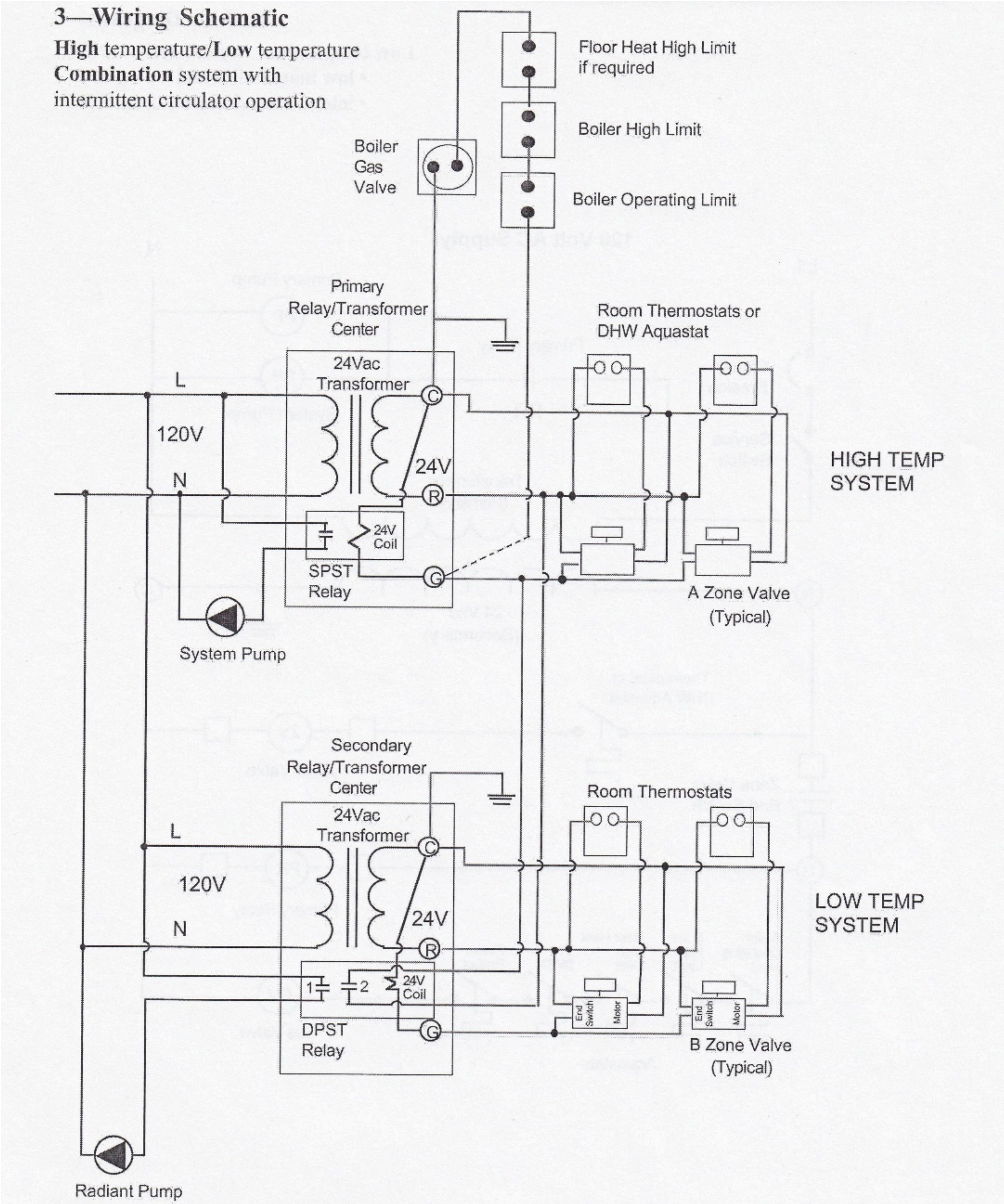


Figure 1 Schematic diagram of 2-pump, 2-temp system

The ladder diagram for this same system is shown below. You can refer to either diagram to follow the commentary on its sequence of operation.

If the DHW aquastat closes on a call for heat, 24VAC from the “R” terminal on the transformer/relay centre is fed to the zone valve motor for the DHW piping system. The motor drives open and the end switch contacts close. This allows 24VAC to power the “G” terminal on the primary relay, and two things will happen simultaneously.

Firstly, the coil on the relay is energized, which closes the N.O. set of contacts of the SPST relay. The 120VAC that were present at the common terminal of the relay will now power the pump, which operates to push water through the boiler and the open DHW zone.

Secondly, the external wiring that is connected at the “G” terminal of the relay allows 24VAC to the burner circuit. This is the circuit that contains all the limit switches for the boiler’s operation. As long as there aren’t any unsfae conditions being sensed, all the switches will be closed and the burner will fire until one of the switches opens. This is normally the aquastat for the boiler itself. It is the control that is commonly set to 180°F. If this temperature is reached, the burner will shut off until the temperature drops to its lower setpoint at which time it will once again make and bring the burner back on, all the while not interfering with the operation of the pump.

When the DHW tank comes up to its setpoint temperature (normally 140°F) the aquastat contacts will open and cut power to the zone valve. The spring on the zone valve motor will return the valve to its closed position, and as soon as the end switch opens, power is also cut to the relay’s “G” terminal, which de-energizes the relay coil to stop the pump and interrupt 24VAC to the burner circuit.

One thing to note on both diagrams is the relationship between **all** of the end switches and the primary relay. If only a high temperature zone calls for heat, it is only the primary pump that needs to operate. However, if **any** low temperature zone calls for heat, both pumps must be energized. The key to understanding this operation is through the recognition that the “G” terminal of the primary relay is also connected to a N.O. contact from the secondary relay/transformer center, fed by 24VAC from the primary transformer. This secondary centre has a DPST relay attached to it. In other words, when its 24VAC relay coil is energized, two sets of N.O. contacts will close. One set has 120VAC wired to it and will allow 120VAC to the secondary pump when it closes. The other set has 24VAC wired to it from the “R” terminal of the primary transformer , which allows that power to get back to the “G” terminal on the primary relay so that the other (main) pump will come on. The secondary pump will be the one that is driving water through whatever mixing device is being used, and for it to be able to do its job the primary pump must also be operating. For the high temperature circuits, only the primary pump has to operate.

You should also be able to follow the paths for power through the ladder diagram. One by one, trace the paths through the schematic and ladder diagrams at the same time. Close a thermostat on the high temperature system first, and then do the same for a thermostat on the low temperature system. This will help in understanding the paths that current must follow in order for the system to do what it is supposed to do.

You may also see that there aren’t as many circuits shown on the ladder diagram as there are on the schematic. Sometimes only one circuit is shown if it is the same as other circuits on that system. As well, the components of the relay (coil and contacts) aren’t shown side-by-side like they are on the schematic, so they must be marked to be better understood. The two N.O. contacts that operate the two pumps are shown in parallel to each other on the 120VAC side of the drawing but the actual contacts are contained in two separate pieces of equipment. Also the 120VAC side of the secondary transformer isn't shown because it is not needed to be; it is shown once only in relation to the primary relay/transformer center. Note too that the secondary relay contact 2, which is the one that will turn on the primary pump when a low temp thermostat calls for heat, is wired to the "R" terminal of the primary transformer, as was described above.

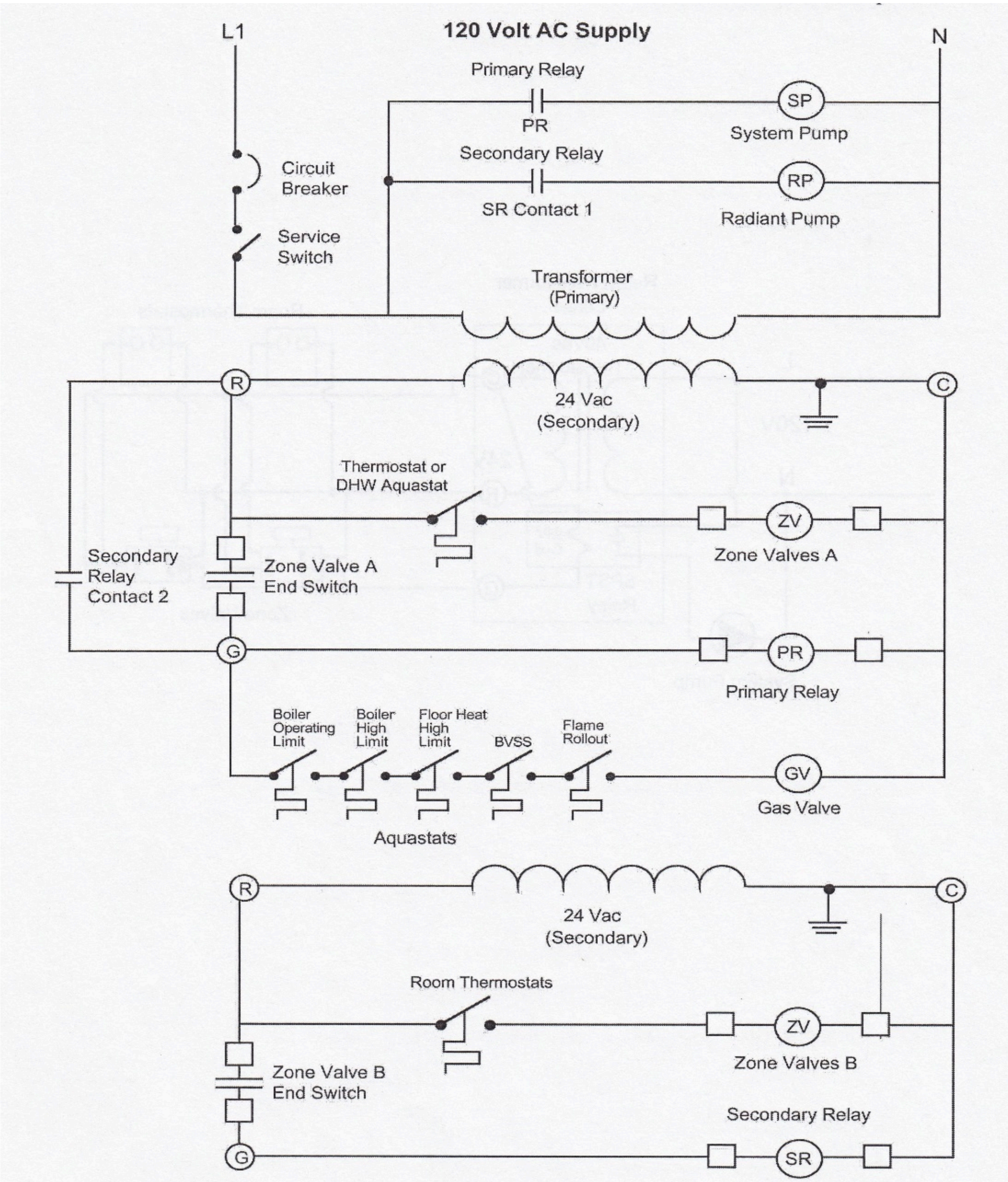


Figure 2 Ladder diagram of 2-pump, 2-temp system

The burner circuit in the diagram above shows 5 limit switches in series. There may be more or there may be less, depending on how many conditions need to be monitored. The boiler operating limit would be the operating aquastat which opens and closes to try to keep the boiler water at its setpoint temperature. The boiler high limit would be N.C. and would only open if for some reason the operating aquastat didn't open when its setpoint was reached. Any RFP system must have a N.C. high limit on the piping feeding it. This is so that 24VAC to the burner is interrupted if the manifold temperature reaches 20°F above its design temperature, or if the temperature exceeds the manufacturer's maximum for the PeX tubing fed by the manifold (from TECA BC Hydronic Guidelines). B-vented boilers will have a blocked vent safety switch (BVSS) at the boiler's draft hood so that the switch will overheat and open if the boiler is spilling its products of combustion instead of allowing them to get safely to the atmosphere through the venting system. The areas around the gas valve and burner inlets will usually have at least one or more SPST switches that will open if exposed to too much heat in that area, caused by conditions such as a plugged heat exchanger, among others. Any safety switches that are meant to sense unsafe conditions are usually located in series with each other in the burner circuit so that, if any switch opens, power to the burner is cut off.

The two diagrams above, with two load centers, are very similar to wiring that would be necessary when there are too many loads for the manufacturer-installed transformer to power. Installers at some point in time will come up against a situation where there are many zones, and zone valves, on their system. Most boiler manufacturers are still producing product whose origin was in the "old days" where there were only two to four zones in the house. In that era, each of the three floors that were typical of a larger house was controlled as a zone, with a fourth possibly being an indirectly-fired domestic hot water tank. One such manufacturer of low-mass, high-temp, low-cost boilers recognized the 4-zone scenario and installed a "zone control board" within their boiler's controls area. The board had a 40VA transformer built into it as well as connection terminals for four thermostats, and four zone valves with their associated wires for the motors and end switches they contained. This meant that the installer didn't need to make any 24VAC wiring connections other than from the thermostats and zone valves to the zone boards. The boilers also came with the circulator mounted on the return inlet to the boiler and pre-wired to the controls, making it even easier to wire the system.

Transformer Overload

Honeywell©, White-Rodgers© and similar manufacturers of zone valves will publish the amperage draw of their zone valve motors (remember that the end switch inside these units draws no power). For a typical Honeywell© 2 or 4-wire zone valve, the current draw is 0.32 amps.

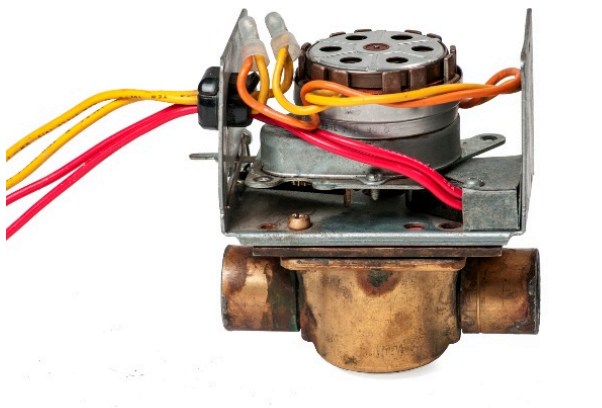


Figure 3 Honeywell © 4-wire zone valve

When looking at either the schematic or the ladder diagram, trace the wires back from the “C” terminal of the transformer. The first item encountered on any of those paths will be a load, as loads are connected to the “C” terminal in order to work, and it is the load that consumes the amperage.

Looking at the previous 2-temperature wiring diagrams, the loads fed by the primary transformer are the high temp zone valve motors, the primary relay coil and the gas valve. Each of these loads have a typical current draw of somewhere in the neighbourhood of 0.3 amps (in the field, the actual draw must be determined). For our diagrams, this means that, if we have two high-temp zone valves, a primary relay coil and a gas valve to power with 24VAC, the current being pushed out by the primary transformer will have to be **1.2 amps** (0.3 × 4). The primary transformer is normally already mounted to the boiler, as the burner circuit will be pre-wired. If the transformer is rated for 40VA (40 Watts), it will be capable of a maximum amperage of 1.67 amps, remembering from Ohm’s Law that VA ÷ V (volts) = A (amps), or VA ÷ A = V. We could therefore power one more zone valve (another 0.3A) from this transformer without exceeding its maximum rated output. If any more than 1 extra zone valve are added, the amperage draw will exceed the transformer’s limit, and although nothing immediate would likely happen, if all the zones were open the transformer would be overloaded and would heat up to the point where it would burn out. A burnt transformer is a sign that here are too many loads being powered and that somebody hasn’t done their math correctly.

Below are a schematic and ladder diagram showing the wiring needed when an extra transformer is added to power more zones. Note the similarity between these diagrams and the previous 2-temperature diagrams.

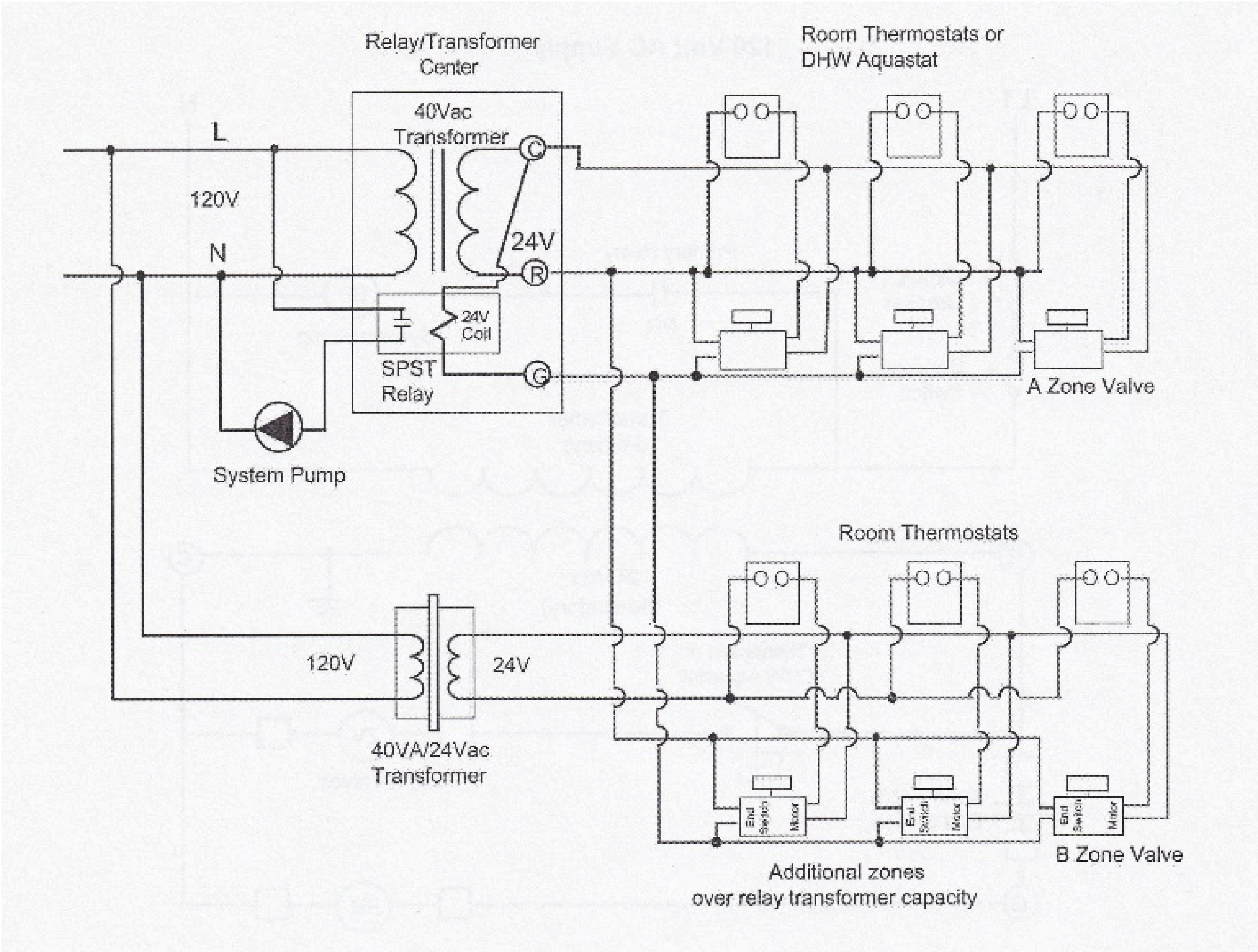


Figure 4 Schematic diagram for adding a transformer and zone valves

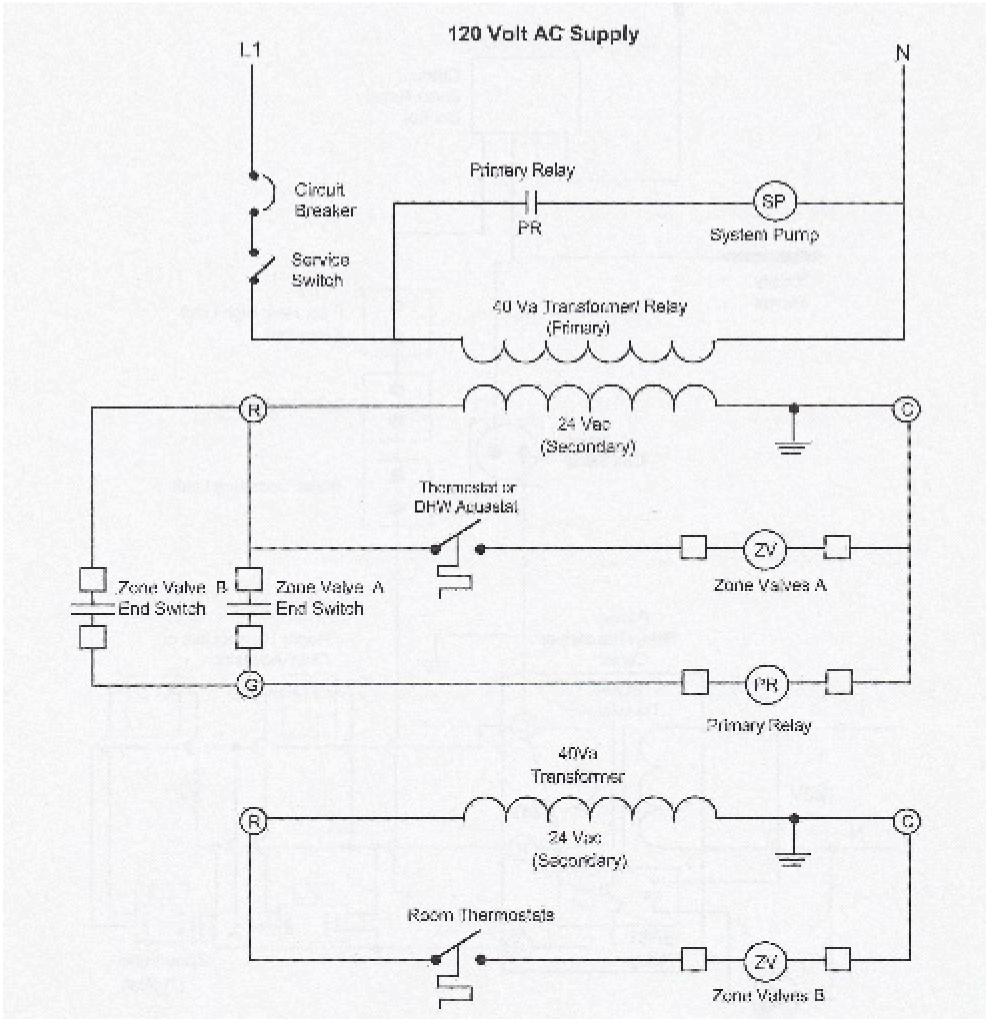


Figure 5 Ladder diagram for adding a transformer and zone valves

As in the 2-temp diagrams, note that the addition of the extra transformer is only for the extra zone valve motors, as they are the reasons for the extra current draws. They and the thermostats that control them are powered from the added transformer; the end switches of the new zone valves aren't loads and don't consume amperage, so they are connected to the same terminal that powers the original end switches. The closure of *any* end switch will power the relay coil and the burner circuit.

"Zone control boards" are great boons to the process of adding zones to systems. They are available from various manufacturers such as Taco©, tekmar© and Viega© among others. These boards are remotely mounted on an electrical device box near the boiler and are powered with 120VAC to supply the pumps that are controlled by the board. They contain either one or two 40VA transformers depending on the number of zone valves they will operate. Typically, a module for up to 4 zone valves will have a single 40VA transformer mounted within it, and an 8 zone module will contain (2) – 40VA transformers. Most of these types of controllers will be equipped with a "priority" zone. This is usually the zone that feeds an indirect domestic water heater. With priority control, when the DHW heater calls for heat, any other zones will be shut off until the call for heat at the water heater is satisfied. If the priority call lasts longer than 1 hour, the priority is cancelled for a short time so that the rest of the building can regain some heat, and if still needed the DHW priority is once again initiated which again shuts off the building heat. The zone controller shown below is a Viega© 18060 4-zone controller with priority. The wiring diagramfor it shows the connection points on the module. Zone 4 is the priority zone where the zone valve for the indirect domestic water would be connected. If it calls for heat, the other zones are temporarily de-energized.

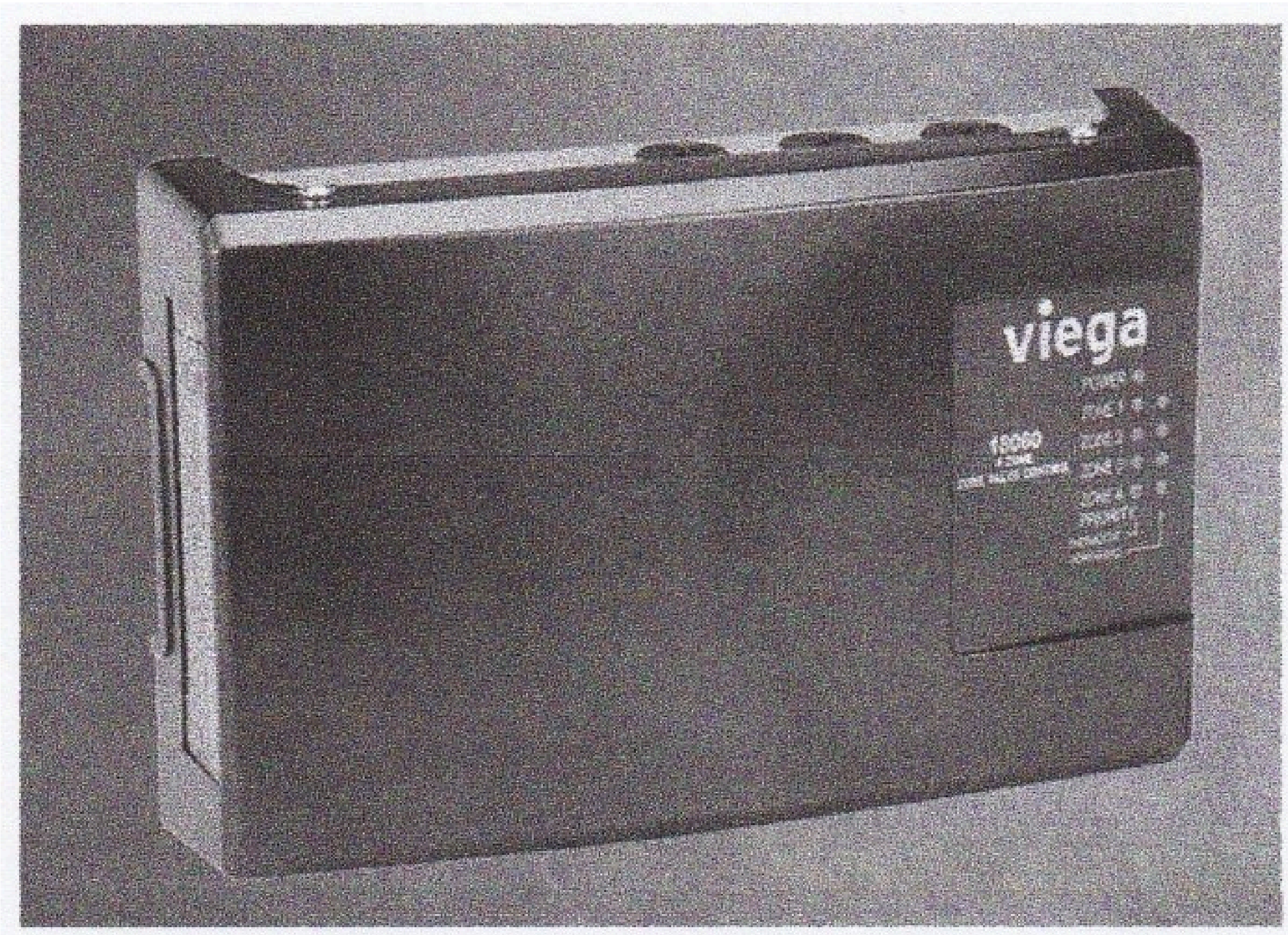


Figure 6 Viega © 18060 4-zone controller with priority

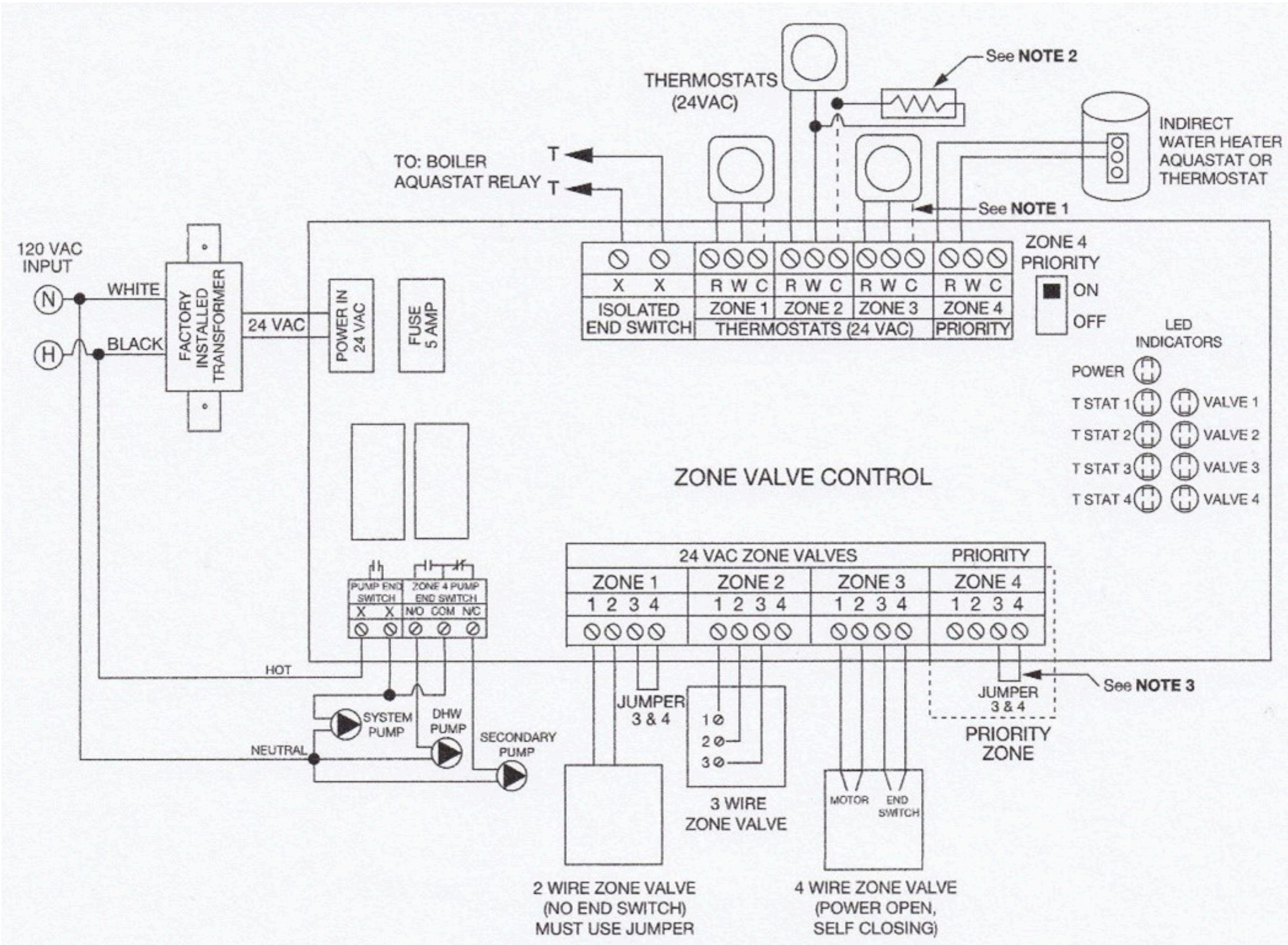


Figure 7 Wiring diagram for Viega © 18060

There are distinct advantages in using any of the zone control modules mentioned above. They set out the number of zone valves that they can accommodate, are furnished with a road map of the wiring connections, and as long as the installer can understand a wiring diagram, success is unavoidable.

Analyzing Circuit Operation

When an electrical circuit won't operate as it should, diagnostic steps need to be followed in order to pinpoint the problem. The first priority is to understand the sequence of operation. If a technician isn't familiar with the equipment, the ladder diagram can be used in lieu of a published troubleshooting flow chart.

Measuring Voltage

Any diagnostics of electrical circuits will require the use of a multi-meter, in particular the voltmeter function within it. A voltmeter contained within a "VOM" (volt-ohmmeter) will tell you where voltage is or isn't present and its value. One such use of a meter is shown below. With the meter set to measure AC voltage, a check across the points in the diagram as shown below would read:

1 = 0 volts; 2 = 0 volts; 3 = 24 volts; 4 = 0 volts and 5 = 0 volts.

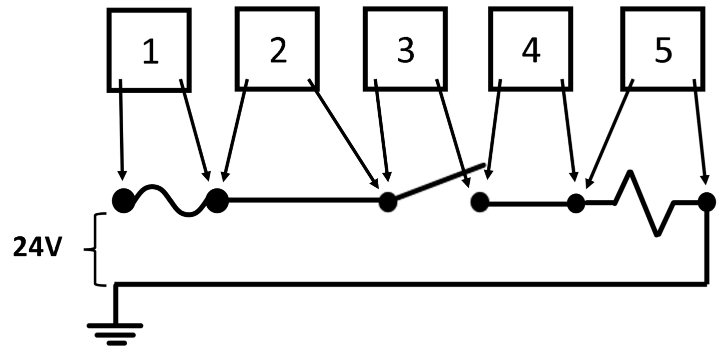


Figure 8 Open circuit readings using a voltmeter, method #1

Remember that a voltmeter will always tell you the *difference* in volts between the two meter leads. If a voltmeter reads "0", it could be because either:

- there is no voltage present at all at either of the leads, or
- the two leads are being exposed to the same voltage, or
- the meter isn't working properly

DON'T BE FOOLED BY A "0" READING!!!! Assuming that there is no voltage present could be life-threatening! Firstly, always check a known live circuit to ensure that the meter is functioning properly. Secondly, it may be a better idea to ground one of the leads and use the other to determine exactly where voltage is or isn't present. Looking at the same circuit but using the meter in a different way, as shown below, these readings should be present if the switch is in the open position.

1 = 24 volts; 2 = 24 volts; 3 = 0 volts; 4 = 0 volts and 5 = 0 volts

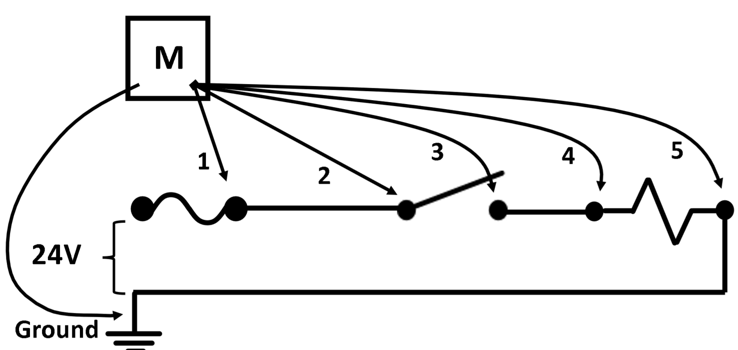


Figure 9 Open circuit readings using a voltmeter, method #2

This would tell us that the circuit is live up to the switch. If there is no voltage present beyond the switch, the switch is either in the open position or is closed and faulty.

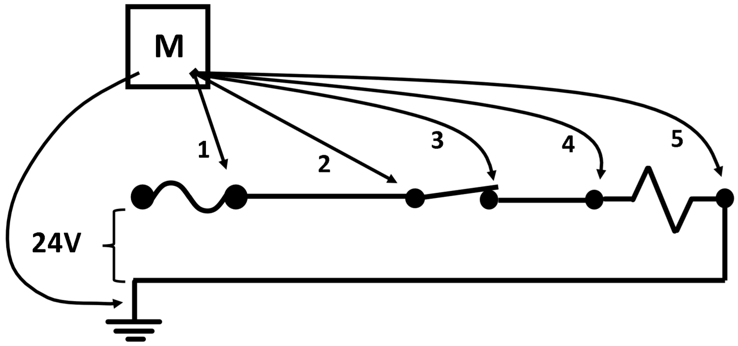


Figure 10 Closed circuit readings using a voltmeter, method #1

In the diagram above, the expected readings at the meter positions shown, with the switch in the closed position, would be 24 volts at points 1 through 4, and “0” volts at position 5, and the load should be operating. If the load isn’t operating and the readings at positions 1 through 4 are all 24 volts, then either:

- there is a faulty wiring connection between the load and the ground, or
- the load is receiving voltage but is faulty

So, if a circuit isn’t operating, the safest way to test the circuit is by using a multimeter set to measure volts. With the circuit powered, ground one of the leads and use the other lead to check to see where the voltage isn’t present in the circuit. That would be the place where there is an opening, which would either be an open switch, a loose wiring connection or a faulty component.

If using a digital multimeter, as shown below, polarizing the leads isn’t necessary when checking DC voltage. If the leads are reversed in polarity, a “minus” sign appears in front of the voltage measured, and no action is necessary as the meter isn’t being harmed.

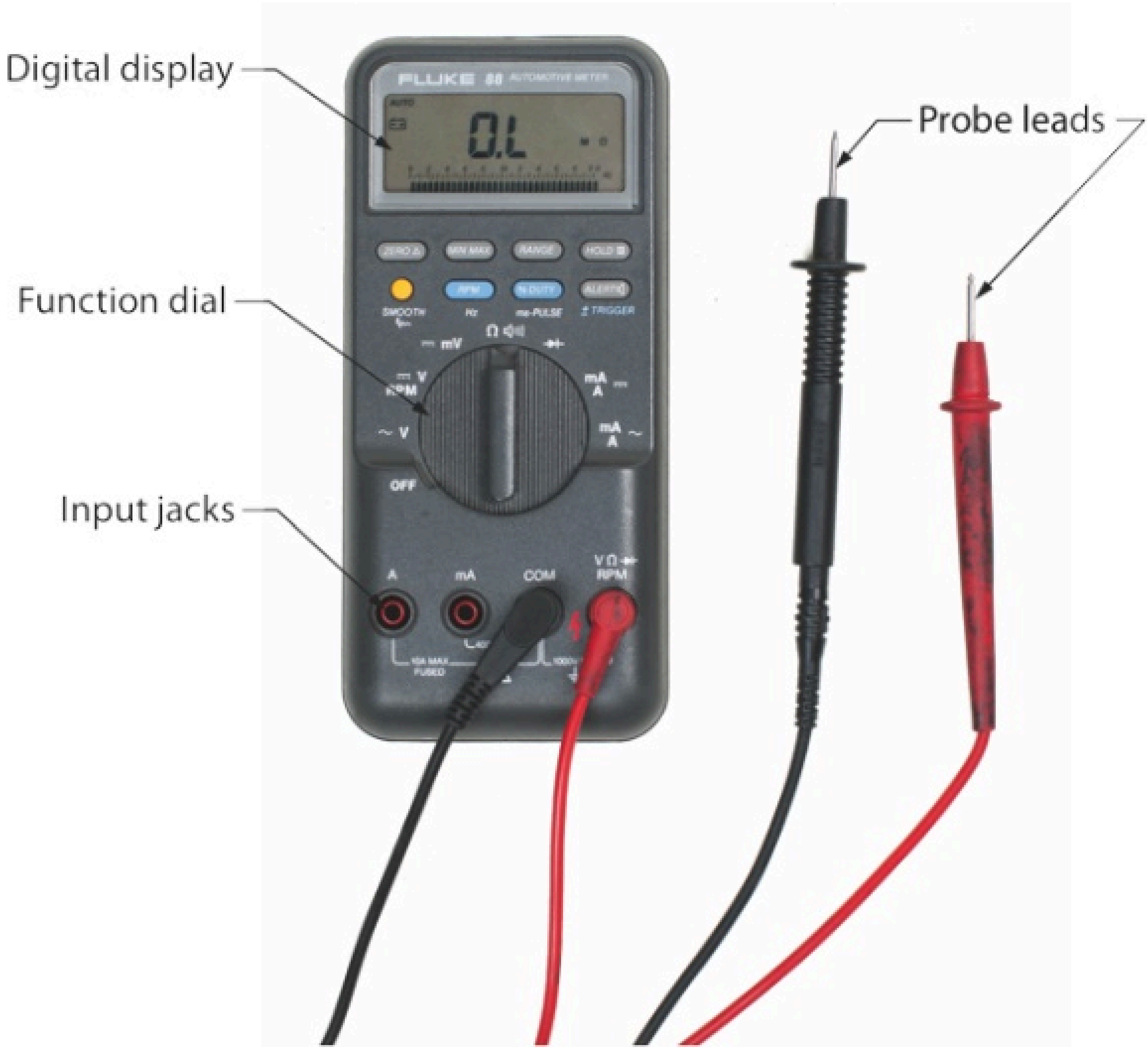


Figure 11 Digital multimeter

However, if using an analog meter to measure DC voltage, as shown below, the meter leads must be polarized to avoid damage to the meter. A "tap" test will ensure the polarity is correct. Simply attach one lead to one of the points being measured and tap the other lead on the other measurement point. If the meter's pointer moves in the right direction, polarity is correct; if it deflects in the wrong direction, polarity is incorrect, the meter could suffer damage and the meter leads must be reversed. Digital meters automatically correct for improper polarity to avoid meter damage.

Figure 12 Analog multimeter

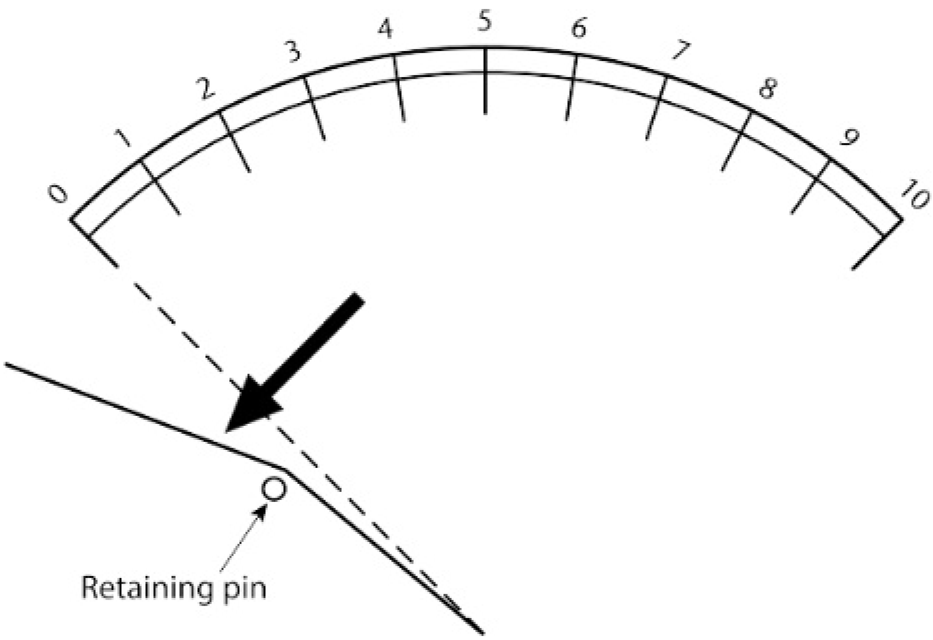


Figure 13 Analog meter measuring DC voltage with wrong polarity

Measuring Amperage

It is sometimes necessary to check current flow through a circuit. This is harder to accomplish than a voltage check. When voltage is being measured, there is no need to disconnect wires because the voltmeter is used in parallel with the circuit being tested. Ammeters, on the other hand, must be installed in series with the circuit or components being checked. This would require that a wire is removed and the meter leads are connected between the wire and the point that the wire is removed from. As well, the meter leads must be at least as heavy in wire gauge as the wiring in the circuit being checked, and this usually is not the case for multimeters. The easiest way to check for amperage (current flow) in a circuit is to use a clamp-on ammeter as shown below.

Figure 14 Clamp-on ammeter

To use the meter, set the range indicator to measure the type of amperage in the circuit (AC or DC), open the jaws by pressing the lever on the side of the meter and capture the single wire being measured within the "circle" of the jaws. Close the circuit so that it is energized and the load is operating. Any current flow through a conductor will create a magnetic field around it, and the meter will measure the strength of the field and translate it into amperage. If the current flow is very small, it may be difficult to measure. If there is enough slack in the wire, wrap it into a coil, counting how many wraps are in the coil. Insert one side of the jaws into the coil, take the measurement and then divide by the number of wraps to get the true current flow.

It is important to make sure that it is only a single wire inside the jaws and not a cable of 2 or more wires. The magnetic fields created in a 2-wire cable will be in reverse polarity to each other and will cancel each other out, resulting in a "0" reading.

Measuring Resistance

A VOM contains a battery, usually 9VDC. If the VOM is of the digital variety, the battery not only powers the solid state board for the display but also provides a power source for the ohmmeter function. An analog meter uses the battery strictly for the ohmmeter within it and both types of meters will have a fuse in them as well. If the Ohms function won't work, it is likely because the battery is depleted, in which case the digital meter will usually have a "low battery" notice pop up. There is no such notice on an analog meter. Check that the fuse is intact in either case.

Am Ohmmeter pushes current from the on-board battery out through one lead, through the device or circuit being tested and back and will measure the resistance it encounters. Depending on the selector switch position, the reading will then have to be multiplied by the selected factor (Ohms × 1K; Ohms × 100K, etc). Before using the ohmmeter it must be "zeroed". Set the selector switch to any of the positions that have the "Omega" sign (Ω) and touch the meter leads together. The reading should be "0" ohms (all the way to the right end on an analog meter). If the needle is off "0" at all, it can be adjusted by using the thumbwheel as seen in the image below. On the analog meter, the Ohms scale is the one at the very top of the scales. It's a non-linear scale, meaning that a pointer position halfway between the left and right extremeties is not ½ of a full reading such as it is when using either the amperage or voltage functions, as there is no "halfway" measurement between fully connected with no resistance and an infinite amount of resistance such as would result froma missing or broken wire. If the circuit being tested has continuity (isn't broken) and no resistance, the needle will move all the way to the right and hover directly over the "0" mark.

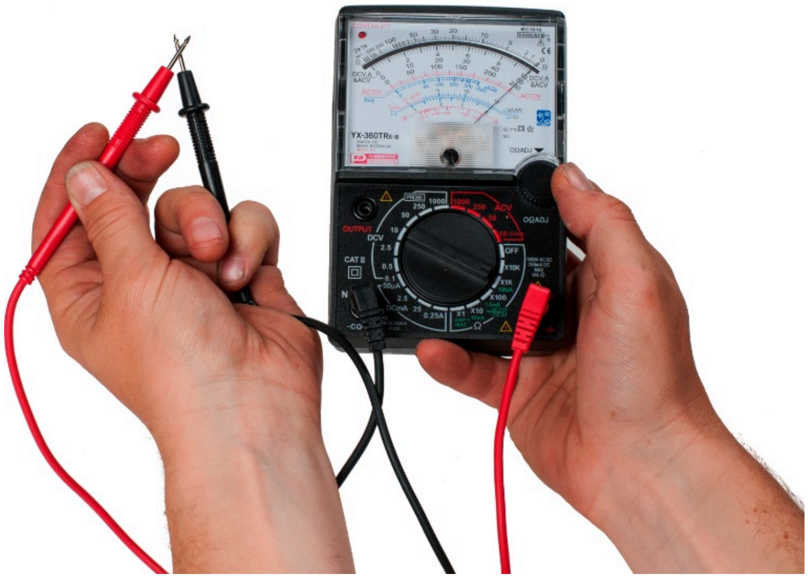


Figure 15 "Zeroing" an analog Ohmmeter

The thing to always remember when using either the digital or analog meters for Ohms measurement is that the circuit must *not* be powered. If it is, the best outcome would be that the fuse inside the meter trips; the worst would be damage to the meter. Use the voltmeter to check for power before checking for resistance.

Safety

Whenever a circuit or piece of equipment is opened for inspection, it should be powered off and locked out unless power is needed for readings. If that is the case, use extreme caution, especially around 120VAC, and use the meter to verify that any points that you may come into contact with are live or dead. Have manufacturer's literature handy, not only for expected readings but for troubleshooting tips. Manufacturers include troubleshooting flow charts in their literature and these are sometimes the best and easiest way to track down problems and determine solutions. Most boiler manufacturers' flow charts involve meter checks and will lead you through the process. This is a good example of why our gas codes specify that the literature for gas equipment be left with the homeowner. Fortunately, the internet is there for us when onsite manuals aren't present.

Remember that being shocked by live equipment is a possibility, so make sure that there is a plan in place in the event that it occurs. Have someone nearby if assistance is needed, with access to 911 calls and possibly an Automated External Defibrillator (AED). Exposure to even mild electric shock can knock a heart out of its natural rhythm, so being alone when testing electricity is not a good idea.

Now complete the self-test below.

Self-Test 4

Self-Test 4

1. Which one of the following would *not* be a means of providing low temperature water for a hydronic system?
    a. The use of a mixing valve
    b. The use of a diverting valve
    c. The use of a variable speed injection pump
    d. Lowering the aquastat setting on a non-condensing boiler
2. What is used to “scrub” latent heat from a condensing boiler?
    a. A primary heat exchanger
    b. A secondary heat exchanger
    c. A tertiary heat exchanger
    d. A direct vent heat exchanger
3. What is the principle behind the use of multiple pumps for proper flow rates in a primary/secondary piping system?
    a. The use of direct return piping layout
    b. The use of Monoflo © tees
    c. Hydraulic separation
    d. AFUE
4. Tees in a primary/secondary system should be placed no farther than a maximum of ________ diameters apart.
    a. 2
    b. 3
    c. 4
    d. 5
5. One USGPM will deliver _______BTUH if the ΔT is 20°F.
    a. 5,000
    b. 7,500
    c. 10,000
    d. 20,000

6. What device, contained within a 4-wire zone valve, ensures that the pump won't start and the burner won't fire unless the zone valve is open?
    a. An end switch
    b. A thermostat
    c. An aquastat
    d. A relay
7. What is term is sometimes given to a low-mass boiler?
    a. Hot start
    b. Cold start
    c. Warm start
    d. Tempered start
8. What is a main feature of a ladder diagram that makes it easy to follow?
    a. The components are shown to scale
    b. The components are shown as they might be seen
    c. The lines that represent wires will cross each other
    d. The lines that represent wires won't cross each other
9. Where are the low voltage terminals located on a relay/transformer centre?
    a. Inside the transformer
    b. Inside the junction box
    c. On the face of the transformer
    d. On the back of the junction box
10. Which terminal on a relay/transformer center is the 24VAC neutral?
    a. "C"
    b. "R"
    c. "Y"
    d. "G"
11. Which terminal on a relay/transformer center powers all the thermostats and end switches?
    a. "C"
    b. "R"
    c. "Y"
    d. "G"
12. Which terminal(s) on a relay/transformer center would be wired to an A/C system?
    a. "C" and "N"

b. “R” and “G”
c. “G” and “N”
d. “Y” and “W”

13. Where in the piping would a 3-way mixing valve be located?
    a. At the mixing point
    b. In the boiler return piping
    c. In the piping to the expansion tank
    d. At the highest point in the system
14. Where in the piping would a 3-way diverting valve be located?
    a. At the mixing point
    b. In the boiler return piping
    c. In the piping to the expansion tank
    d. At the highest point in the system
15. What is the main advantage for using a 3-way diverting valve rather than a 3-way mixing valve?
    a. The diverting valve is located at the mixing point
    b. A mixing valve has less head loss than a diverting valve
    c. A diverting valve has less head loss than a mixing valve
    d. The mixing valve needs a motorized controller in order to work properly
16. What is one main disadvantage of using a 3-way diverting valve rather than a 3-way mixing valve?
    a. It needs a remote sensor
    b. It needs a motor controller
    c. It needs an outdoor reset control
    d. It has a higher head loss through it
17. How many inlets and outlets does a 3-way diverting valve have?
    a. 2 inlets and 1 outlet
    b. 1 inlet and 2 outlets
    c. 3 outlets
    d. 3 inlets
18. Which one of the choices below is considered to be the best option for tempering water to a low temp system due to its very low head loss?
    a. A 2-way injection valve
    b. A 3-way mixing valve
    c. A 3-way diverting valve

d. A 4-way mixing valve

19. What is the term given to a controller than automatically adjusts system water temperature when the temperature outside rises or falls?

    a. Outdoor sensing
    b. Indoor sensing
    c. Outdoor reset
    d. Indoor reset

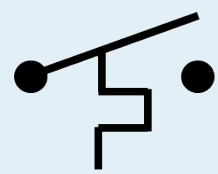
20. What is the equation used to calculate the curve for an outdoor reset control?

    a. (room temp − outdoor temp) × (design supply temp + outdoor tem)
    b. (outdoor temp − room temp) ÷ (outdoor temp − design supply temp)
    c. (design supply temp − room temp) ÷ (room temp − outdoor design temp)
    d. (design supply temp × room temp) ÷ (room temp × outdoor design temp)

21. What is the setting known as where, on an outdoor reset control, the indoor and outdoor temperatures are equal, causing the system to shut itself off?

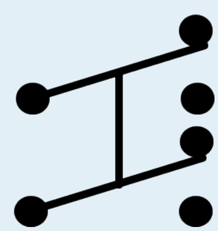
    a. Warm weather shutdown point (WWSD)
    b. System design temperature shutoff (SDTS)
    c. Outdoor shutdown point (OSP)
    d. Indoor heat shutdown (HIS)

22. What is the meaning of the symbol shown to the right?



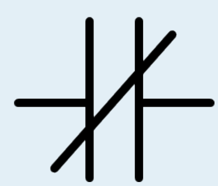
    a. A flow switch
    b. A pressure switch
    c. A heating thermostat
    d. A cooling thermostat

23. What is the meaning of the symbol shown to the right?



    a. A DPDT switch
    b. A DPST switch
    c. A SPST switch
    d. A SPDT switch

24. What is the meaning of the symbol shown to the right?



    a. A normal closed relay contact
    b. A pressure switch
    c. A transformer
    d. A coil

25. What is the next event that occurs after a zone thermostat closes?

    a. The pump starts
    b. The burner fires
    c. The zone valve opens
    d. The end switch opens

26. What happens when 24VAC is sent to the “G” terminal on a primary relay/transformer centre that is controlling a non-condensing boiler using a single pump?

    a. The burner fires and the pump shuts off
    b. The pump turns on and the end switch opens
    c. The pump turns on and the burner fires
    d. The boiler aquastat and thermostat open

27. What is the normal temperature setting for an indirectly-fired domestic water heater?

    a. 140°F
    b. 160°F
    c. 180°F
    d. 200°F

28. How many contacts are needed on a secondary relay/transformer centre to make the primary and secondary pumps start in a 2-temperature system?

    a. One N.C. contact
    b. Two N.C. contacts
    c. One N.O. contact
    d. Two N.O. contacts

29. Looking at a ladder diagram, if you follow a path from the “C” terminal of a transformer backwards through the diagram, you will find the _______.

    a. Loads
    b. Sources
    c. Switches
    d. Main disconnect

30. In what arrangement and into which circuit are all the limit switches wired for a hydronic system that uses a gas boiler?

    a. In series, in the burner circuit
    b. In parallel, in the burner circuit
    c. In series, in the circulator circuit
    d. In parallel, in the circulator circuit

31. According to the TECA BC Hydronic Guidelines, an RFP must have a N.C. high limit on the piping feeding it that must shut off the burner if the temperature there reaches ____°F above its design temperature.
    a. 5
    b. 10
    c. 15
    d. 20
32. If needed, where would a "BVSS" be located on a boiler?
    a. Near the burners
    b. Near the draft hood
    c. Near the boiler circulator
    d. Near the manifold furthest from the boiler
33. If an old three storey house had one thermostat and zone valve per floor, yet there were four zone valves on the boiler supply piping, what would normally have been supplied with water through the fourth zone valve?
    a. A snow melt system
    b. A swimming pool
    c. A hot water tank
    d. A hot tub
34. If a transformer was rated at 24VAC and 60VA (Watts), how many amps of current would it be capable of safely supplying?
    a. 0.40
    b. 1.67
    c. 2.50
    d. 960
35. If a secondary transformer is necessary because of too much load, what will it provide power for?
    a. All the extra equipment including thermostats, zone valve motors and end switches
    b. Only the extra thermostats and zone valve motors
    c. Only the extra thermostats and end switches
    d. Only the gas burner circuit
36. What component of a hydronic heating system is wired to the "priority" terminals of a zone control board?
    a. The pump relay
    b. The burner circuit
    c. The DHW zone valve

   d. The warm weather shutdown control

37. When the priority zone calls for heat, which other zones will still operate?
    a. Only the ones with the highest heat load
    b. Only one zone on the bottom floor
    c. Three zones maximum
    d. None
38. A voltmeter will be connected _______with the circuit or component being tested.
    a. In series
    b. In parallel
    c. Permanently
    d. Via a bare wire
39. An ammeter that *isn't* a clamp-on style will be connected _______with the circuit or component being tested.
    a. In series
    b. In parallel
    c. Permanently
    d. Via a bare wire
40. When checking amperage on a 4-wire cable, using a clamp-on style ammeter, how many wires can be encircled by the meter's jaws?
    a. 1
    b. 2
    c. 3
    d. 4
41. What is the single most important point listed below when using an ohmmeter?
    a. Make sure the circuit is low voltage
    b. Make sure the circuit isn't powered
    c. Make sure the leads are soldered to the component being tested
    d. Make sure to have one hand free to be able to make adjustments
42. What would be the next step involved after touching the leads together when "zeroing" an ohmmeter?
    a. Remove the fuse
    b. Set the selector switch for DC Ohms
    c. Turn power on the circuit being checked
    d. Turn the adjusting screw so that the pointer is directly over "0"

Check your answers using the Self-Test Answer Keys in Appendix 1.

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- Figure 3 Honeywell © 4-wire zone valve by ITA is licensed under a CC BY-NC-SA licence.
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- Figure 15 “Zeroing” an analog Ohmmeter by ITA is licensed under a CC BY-NC-SA licence.

Competency F5: Install Hydronic Control Systems

Once the hydronic system has been designed, it is time to install it. The major piping components are placed and installed according to the design specifications and manufacturers' literature. Care must be taken to follow all design considerations to the letter; to not do so could mean violating code requirements and nullifying warranties, among other consequences.

By this point in time, most installers within our piping industry have been well-schooled in the techniques and considerations involved in the installation of the pipes, valves and fittings that make our hydronic systems work. As long as the designers have produced a piping schematic that entails the manner that all the major components, such as the boilers, pumps, mixing valves and heat emitters, should be sequenced, the installer should have few problems.

Learning Objectives

After completing the learning tasks in this Competency, you will be able to:

- Describe wiring components
- Describe conductor installation
- Describe wire termination

Learning Task 1

Describe Wiring Components

If the designer has also produced a schematic or a ladder diagram for the wiring and controls, all that is left is the physical installation of the electrical components. This is where installers have had, and continue to have, issues. Those issues revolve around the parts, pieces and installation techniques required by the installer to ensure that this part of the system is completed properly. We'll look at some of the things that come into play when wiring hydronic systems.

"Field Wiring"

The wiring that we, the installers, are responsible for is commonly shown on manufacturers' literature and labeled as "field wiring". This is any wiring that is not pre-installed on the equipment at the factory. In a forced air furnace installation, the field wiring is usually limited to the wiring for the thermostat and the connection of the line voltage power supply. There is much more field wiring needed for hot water heating systems. The legal ability for pipe trades personnel to perform any field wiring of a hydronic heating system, regardless of voltage, falls under a Gasfitter "A" or "B" Certificate of Qualification, as long as the fitter is working under a gas contractor's license, an installation permit has been obtained and the heat source is gas-fired. Most in the hydronics industry would agree that a plumber/gasfitter, rather than an electrician, should logically be the person to perform this work due to the knowledge and understanding of the components involved in hydronics and the "sequence of operation" for our gas systems. That having been stated, let's turn our attention to the physical aspects of the wiring installation for our systems.

Wire Versus Cable

The terms "conductor" and "wire" are synonymous, meaning they are referred to as the same when describing the actual component that will carry current between two points in a circuit. Wire is made of either copper or aluminum, with copper being the material of choice. Solid wire is used in permanent installations that won't be subjected to much movement or vibration in their life. Stranded wire is used in extension cords for portable equipment where there will be much movement and portability in use. In either case, the wire insulation on each conductor keeps the wires from unwanted contact with each other or the equipment around it.

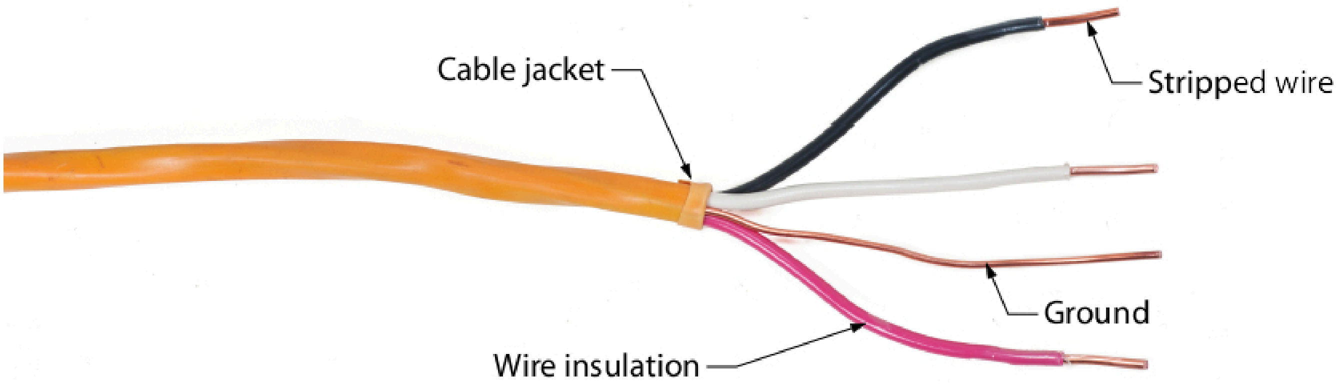

Figure 1 Solid-wire non-metallic sheathed cable

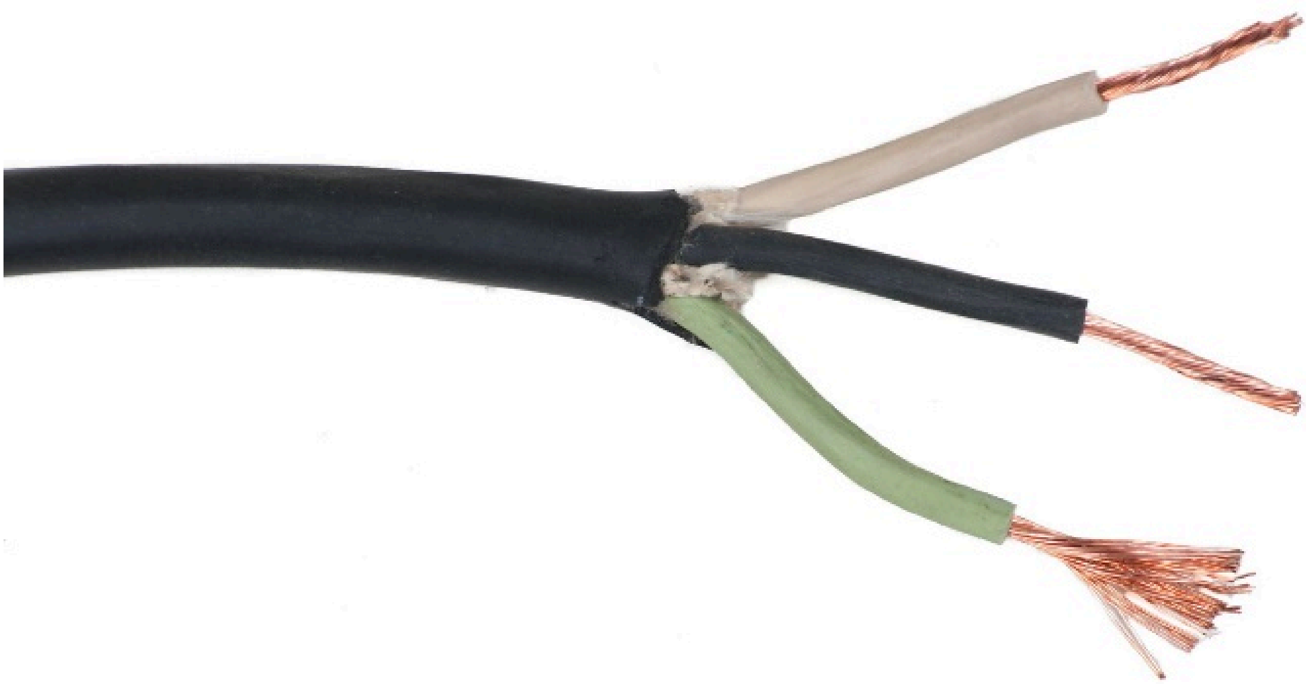

Figure 2 Stranded-wire extension cord

While extension cord can be allowable for limited use in situations where equipment must be moved often for cleaning or routine maintenance, it is not acceptable for use in permanent installations of fixed equipment.

Cables consist of individual insulated conductors, contained within a jacket or sheath. The wire insulation is normally either rubber or some variety of plastic. The sheath could be a vinyl material, such as in an NMD90 cable, as seen below, or could be more robust so as to protect the wire from damage, as in the armoured cable also shown below.

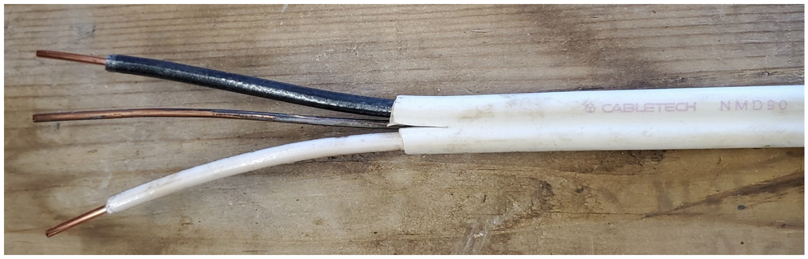

Figure 3 2-conductor non-metallic sheathed cable (NMD90)

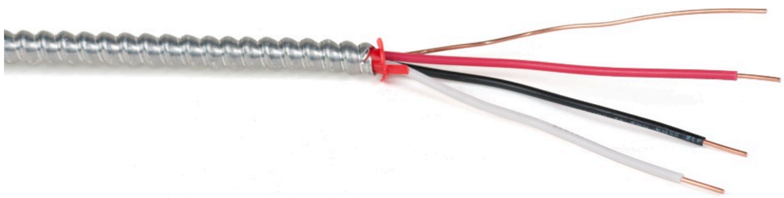

Figure 4 3-conductor armoured cable

Some of the metal sheath of armoured cable must be removed when making wire connections. To do so, first bend the cable until the armour begins to pop open. Next take a saw blade or side cutters and cut through the remaining armour avoiding coming into contact with the conductors. Once the armor is cut through, remove the armor sheath to expose the conductors. A split plastic bushing should be pushed into the end of the metal sheath to protect the issuing conductors from abrasion.

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- Figure 3 2-conductor non-metallic sheathed cable (NMD90) by ITA is licensed under a CC BY-NC-SA licence.
- Figure 4 3-conductor armoured cable by ITA is licensed under a CC BY-NC-SA licence.

Learning Task 2

Describe Conductor Installation

Boxes and Enclosures

The Canadian Electrical Code (CEC) dictates that no wiring splices are allowed outside of an approved enclosure. Any standard outlet box, switch box, or light fixture box (known as device boxes) can serve as an approved enclosure, but where a wiring splice needs to occur in other locations along the circuit, the approved enclosure is usually called a junction box. A junction box is simply a standard electrical box that is mounted securely to framing or the structure, and containing the connection (splice) of two or more conductors.

Cables are secured to the box with cable clamps (or conduit connectors if the circuit includes conduit) and the box must have a removable cover to create a complete enclosure. Junction box covers must remain accessible; they cannot be covered with drywall or other surface material.

Examples of common device boxes are shown below.

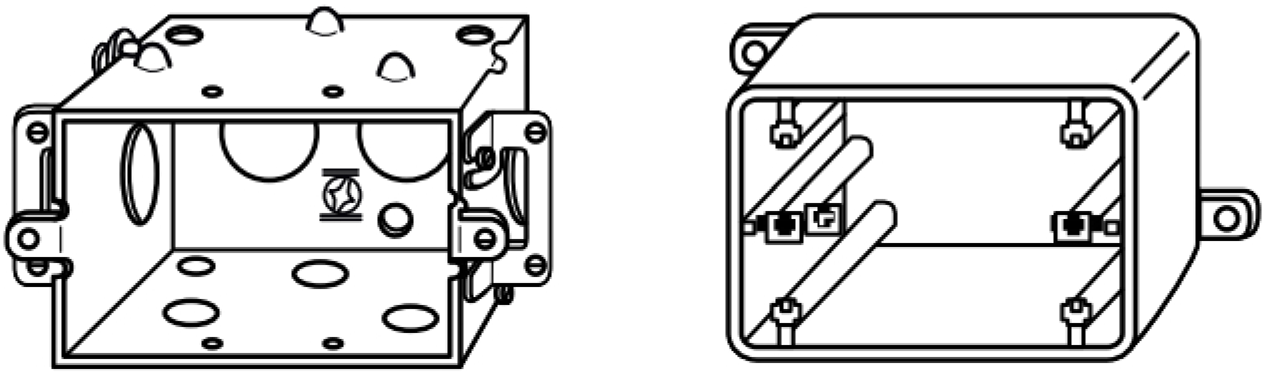

Figure 1 Metal (left) and plastic (right) device boxes

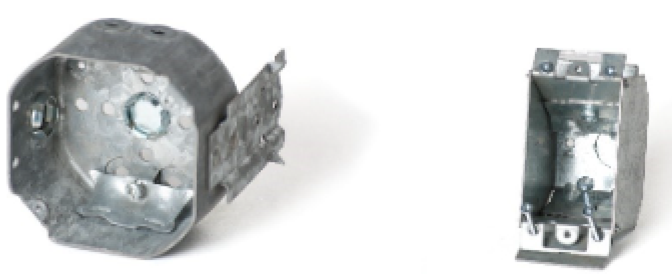

Figure 2 Device and junction boxes

If using metal conduit to run wiring to the electrical box, then a metal box is required, firstly to anchor the conduit and secondly because the conduit and metal box system itself may be used to ground the system. If using non-metallic sheathed cable (NMSC), such as “Loomex” NMD-90, then you can use either plastic boxes or metal boxes, as long as the cable is secured to the box with an appropriate cable clamp.

Single light fixture switches and outlet receptacles typically fit into standard rectangular boxes, also known as “single-gang” or “one-gang” boxes. They are generally 2 x 3 inches in size, with depths ranging from 1 1/2 inches to 3 1/2 inches. Some boxes are “gang-able”—with detachable sides that can be removed so the boxes can be linked together to form larger boxes for holding two, three or more devices side-by-side.

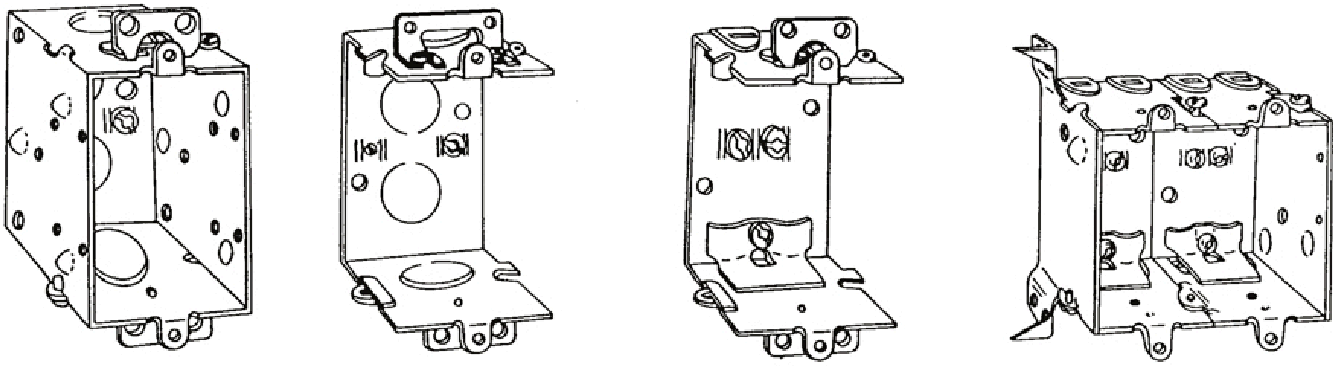

Figure 3 “Gang-able” boxes

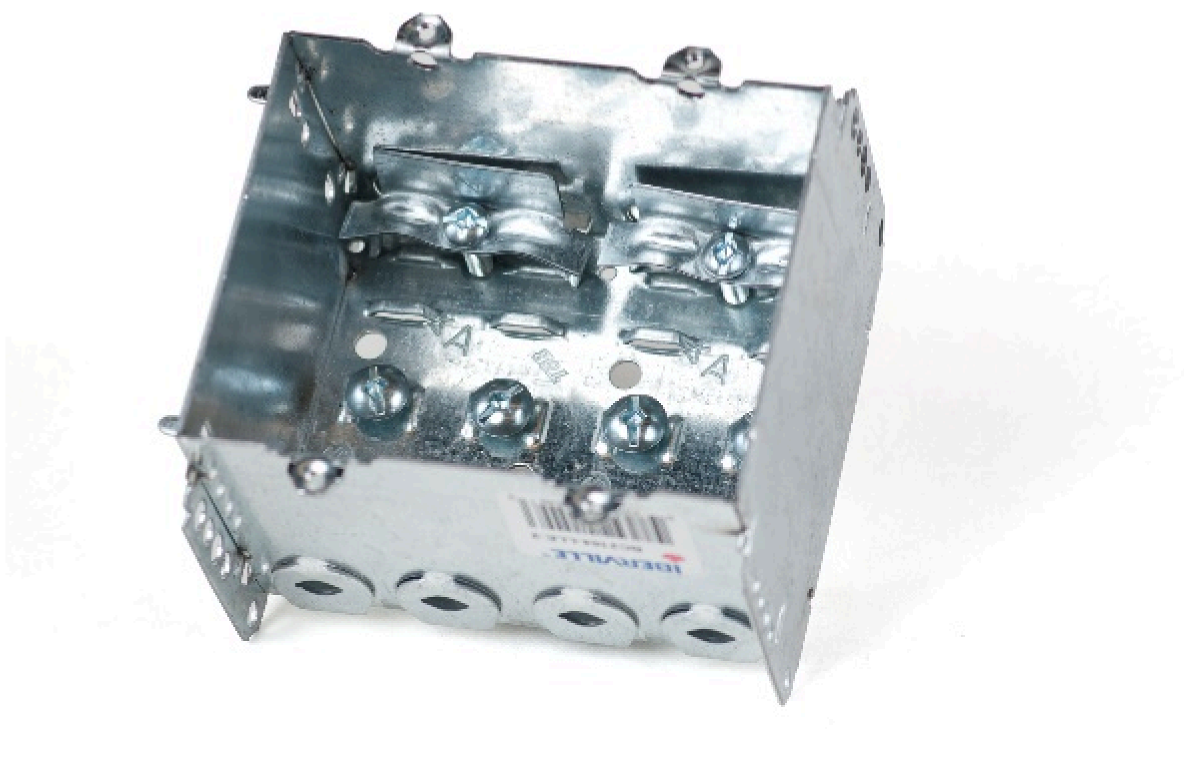

Figure 4 2-gang device box with integral cable clamps

If the box doesn’t have an internally-installed means of securing the cable to the box, as shown in the image of the 2-gang box above, the box will need to have a “box entry fitting” or cable connector attached through a knockout on the box wall.

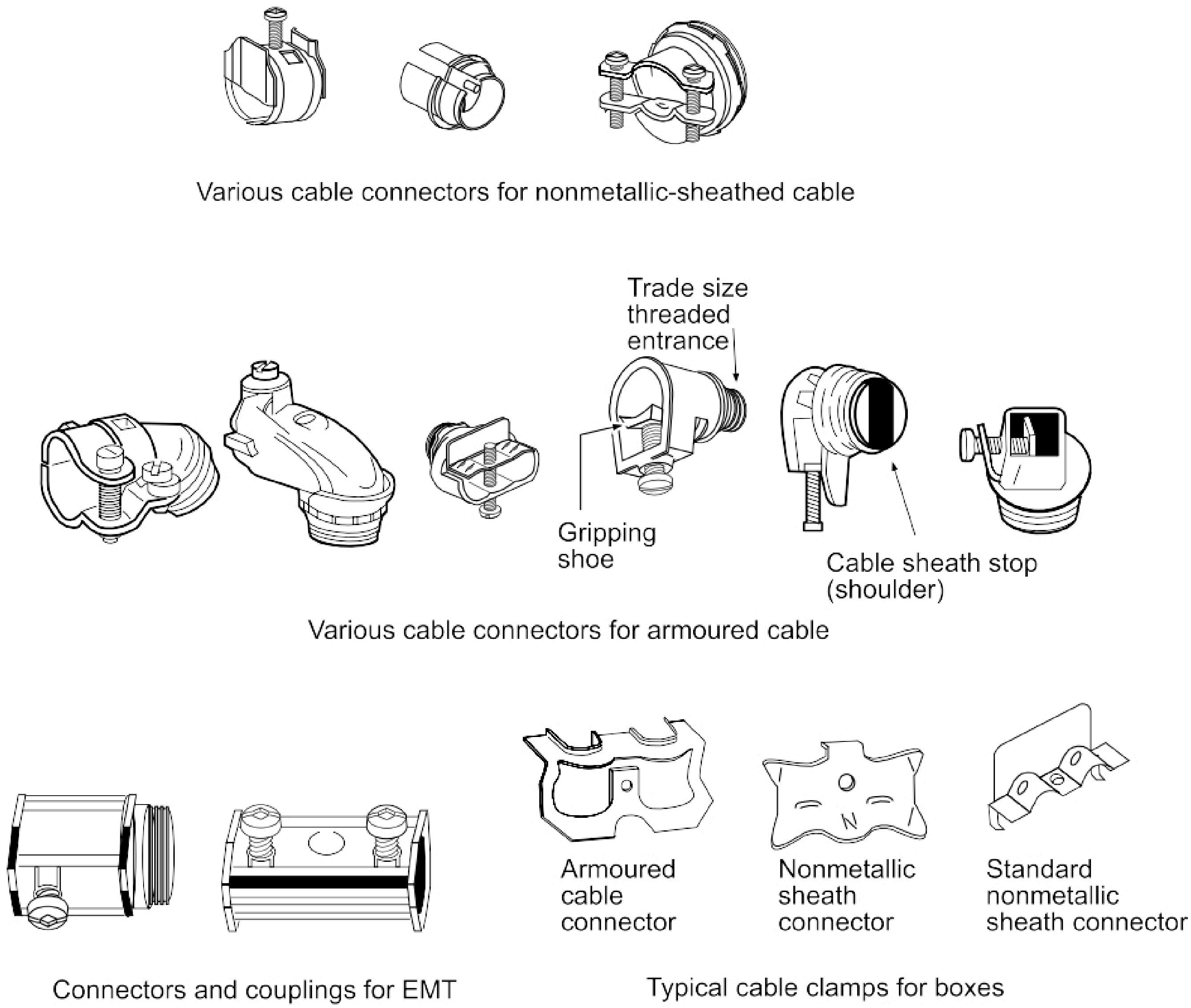

Figure 5 Various cable-to-box fittings

This entry fitting is normally secured to the box by a threaded connection, and the cable is held to it by a clamp with screws, as seen in some of the images above. If armoured cable is used, box entry fittings appropriate for that cable must be used.

Wire and Protection

There are many varieties of electrical wire available. Section 4 of the CEC states that any exposed wiring that is within 1.5m (5 feet) of the floor has to be protected from damage. This can be done in a few different ways, one of which is by using armoured cable, sometimes referred to as “BX” or “Tech” cable. Teck cable has more layers of material inside it than does BX, as well as a waterproof vinyl coating and so is able to be used in more areas than BX can. BX is simply a hollow flexible helix of metal with insulated conductors and a bare bonding wire supplied inside it.

Figure 6 "BX" armoured cables (repository images)

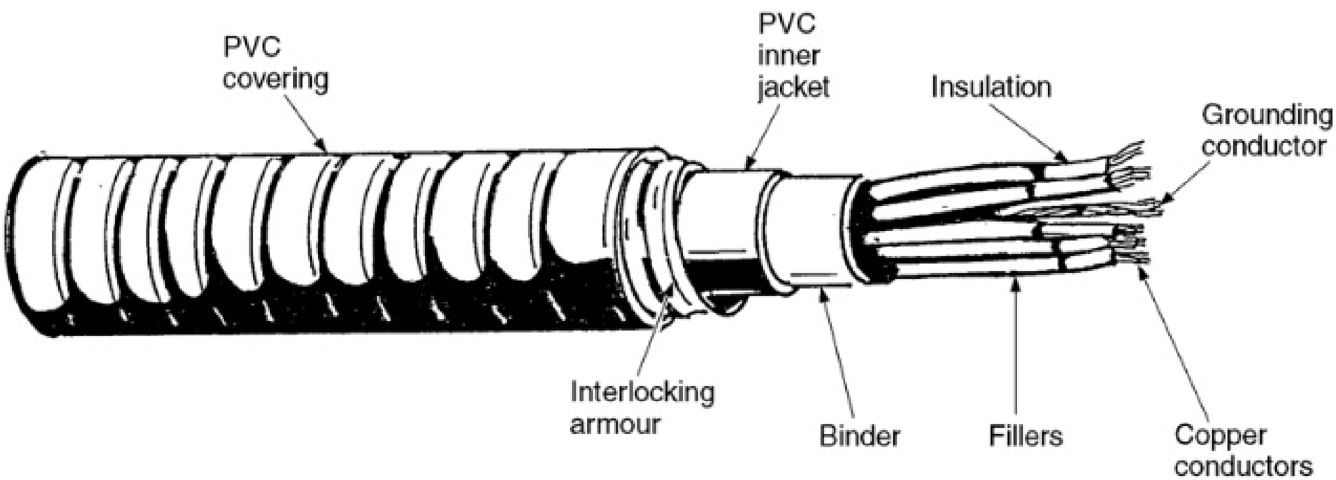

Figure 7 "Teck" armoured cables

Cables and insulated wires can also be protected by being run through tubing made of plastic or metal or through Schedule 40 pipe. All these are generally referred to as conduit, although the term only correctly applies to the Sch 40 material which uses threaded connections.

PVC conduit is solvent-welded together, and drastic changes in direction are made through the use of an elbow sometimes called a "sweep". These are long-radius 90° elbows that allow wires to be pulled through them more easily than if they are of the short-turn variety. Threaded PVC adapters are used for attaching PVC conduit to boxes.

Figure 8 PVC conduit and 90-degree elbow or "sweep"

PVC conduit also comes in lengths or rolls of flexible tube which can save the installer time and money by not requiring elbows for changes of direction. Couplings facilitate tube-to-tube connections and threaded adapters connect tube-to-boxes.

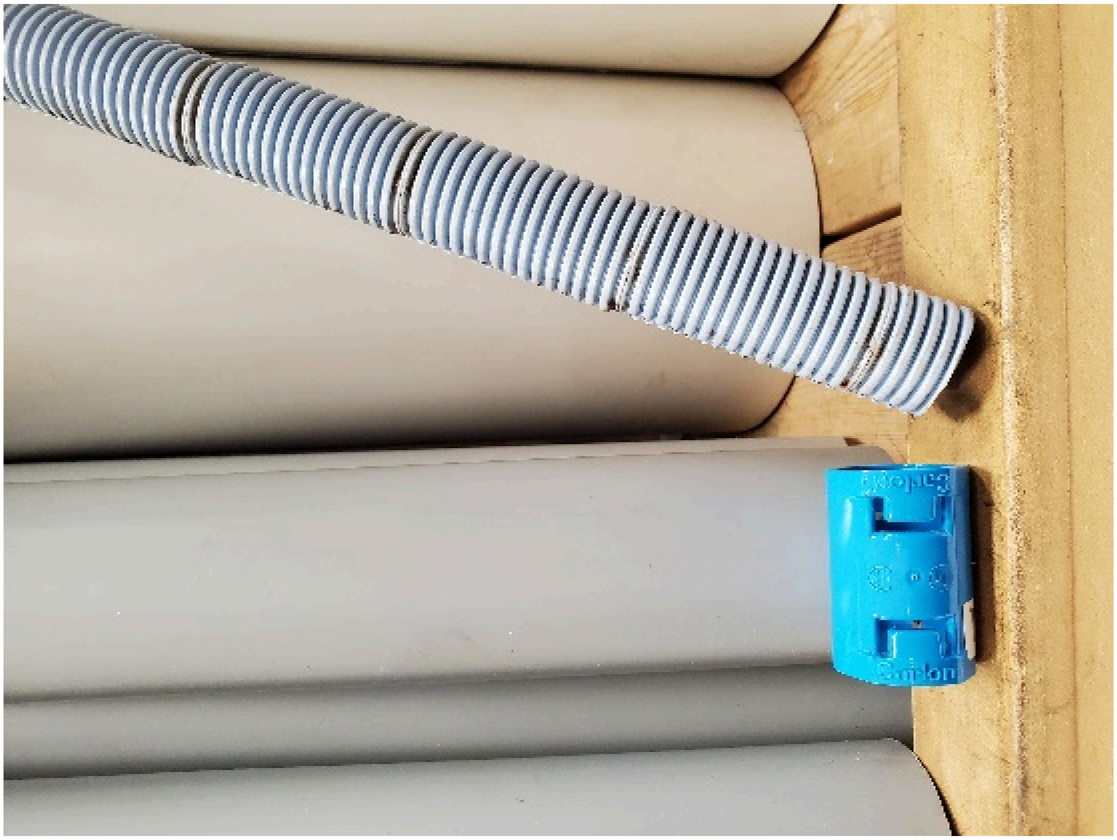

Figure 9 Flexible PVC conduit and coupling

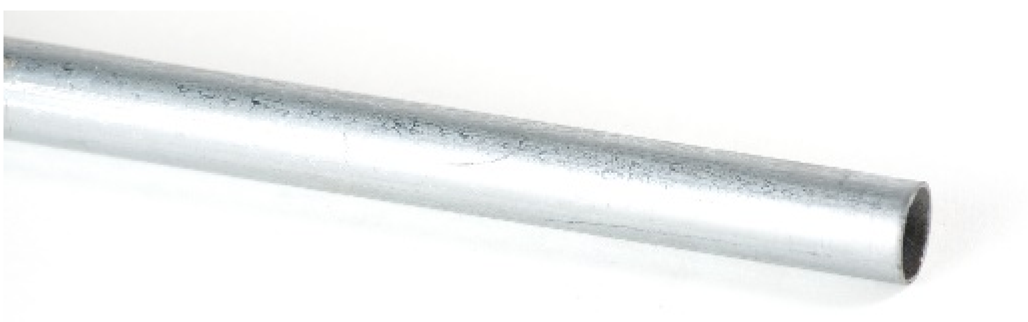

Figure 10 Thin-walled electrical metallic tubing (EMT)

EMT is joined using fittings with set screws as seen below. Bends in EMT can be made with tubing benders or through the use of metal conduit elbows and set-screw couplings.

Figure 11 EMT box entry fitting

Figure 12 Coupling

Rigid metal conduit is galvanized Schedule 40 pipe and is joined using galvanized threaded fittings.

Figure 13 Rigid metal conduit

Flexible metal conduit is similar to BX but without the wires placed inside it by the manufacturer. Like the flexible plastic conduit, wires are pulled into it after it is installed between boxes (“pull points”). The image below shows a flexible gas line installed within flexible metal conduit.

Figure 14 Flexible metal conduit protecting a CSST gas line

In the electrical world, a “raceway” is essentially any rigid enclosed or semi-enclosed channel that protects, routes and hides cables and wires. A surface raceway is an excellent choice for concealing and protecting wires between components in a mechanical room. A plastic track is attached to a horizontal or vertical surface, into which wires and cables can be laid or fastened. A plastic cover snaps over the assembly, creating a neat, finished product while also allowing for future wires to be installed.

Figure 15 Surface-mounted plastic channel

Separation of Circuits

Sections 12 and 16 of the CEC impose restrictions on the installation of Class I and Class II circuits (limited power circuits) within the same raceway with those supplying circuits of unlimited power. Hydronics controls circuits are predominantly Class II circuits, with power output limited to 100 VA (Watts). To avoid issues of voltage and current transference via electromagnetic induction, as well as to satisfy Code requirements, it is always best to keep line voltage wiring separated from low voltage (24VAC) wiring, even if they are to be connected to the same piece of equipment. Avoid pulling low voltage wire or cable through any holes in structural members that have line voltage wires or cables in them. A good rule of thumb is to keep at least 2 inches of separation between low and line voltage wiring.

Box and Conduit Fill Limits

The physical size of boxes and conduit has to be appropriate for the number and type of conductors within them. Rules found in 12-3034 and 12-3036 of the CEC impose limits on the number of conductors that can be installed in boxes and conduit. The determining factors are many, and include internal volume of the box, the number of conductors, conductor gauge, number of wire connectors, and number and size of devices installed within the box. As such, the interpretations of those rules involve much study. Before attempting to install a circuit, consult the applicable Code rules and solicit the opinion and expertise of a qualified electrician if unsure.

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- Figure 13 Rigid metal conduit by ITA is licensed under a CC BY-NC-SA licence.
- Figure 14 Flexible metal conduit protecting a CSST gas line by ITA is licensed under a CC BY-NC-SA licence.
- Figure 15 Surface-mounted plastic channel by ITA is licensed under a CC BY-NC-SA licence.

Learning Task 3

Describe Wire Termination

Twist-on Connections

Conductors can be joined together by a number of means, the most common being via solderless wire connectors, also known as “wire nuts” or “twist-on” connectors as shown below.

Figure 1 Solderless twist-on connectors

The devices shown above are most commonly referred to as “marrettes”, again reflecting our industry’s tendency to name tools or components based on their inventor or original patent holder, such as we do with “Channellock” pliers or a “Crescent” wrench.

To properly join two or more wires using a wire nut, the ends of the conductors must first be stripped of the insulation covering them, using wire strippers.

Figure 2 Wire strippers

There should be approximately ¾″ to 1″ of bare wire exposed. Next, grip the two or more wires into a cluster, with the ends of the insulation, rather than the bare wire ends, lined up together. Using a pair of lineman pliers or a specialty tool for the purpose, twist the bare wires together into a tightly-wound assembly.

Figure 3 Lineman pliers

Using the cutting jaws of the pliers or a pair of side cutters, cut the wound end of the wires off so that there is approximately $\frac{5}{8}$″ – ¾″ of bare wires left showing. Next, select a twist-on connector that is appropriate for the number and gauge of wires being joined within it. Manufacturers sometimes publish such information on the packaging for the connectors.

Figure 4 Wires readied for the twist-on connector

Figure 5 Twist-on connector installed

Twist the wire nut clockwise onto the wire cluster until hand-tight. Then, using pliers, give the wire nut another ¼ to ½ turn. This ensures that the connector is appropriately tight.

Another type of wire connector uses what looks to be a marrette-type of housing over a set-screw connector, as shown below. The wires are inserted into the brass barrel and the set screw is tightened down onto them. The cap is then screwed onto the barrel snugly to complete the connection.

Figure 6 Set-screw connector

If wires are smaller in diameter (higher in gauge number) than #14AWG, they should be joined by lug-type connections. Even a slight scoring from a knife when stripping the insulation on 18AWG solid copper conductors can result in the small-diameter wire breaking when being twisted together under a marrette. The image below shows a terminal strip that can be helpful for connecting smaller-gauge wires. The end of the wire is bared and either hooked under a terminal screw, as shown, or pushed into a slot that has a set screw to hold it there.

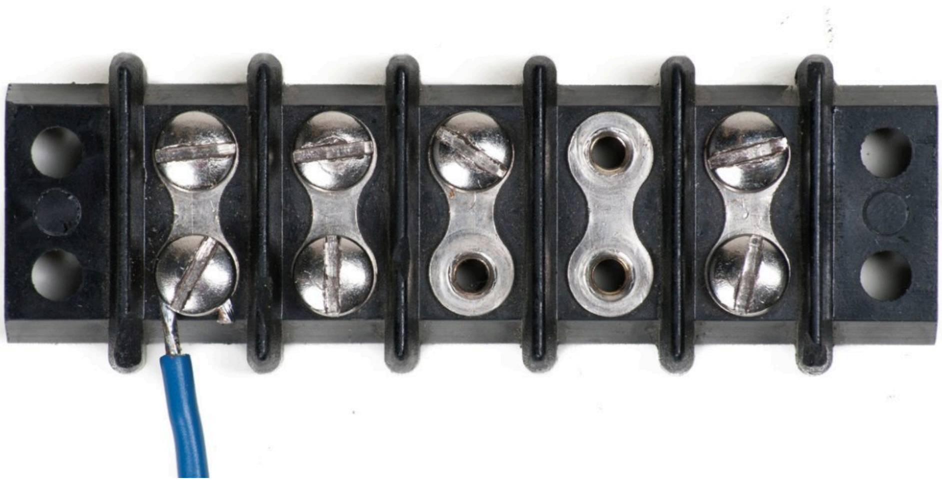

Figure 7 Terminal strip

Terminal strips come in various lengths, are often gang-able and are also available within a junction box where there are threaded posts on which to make multiple connections, as seen in the image below.

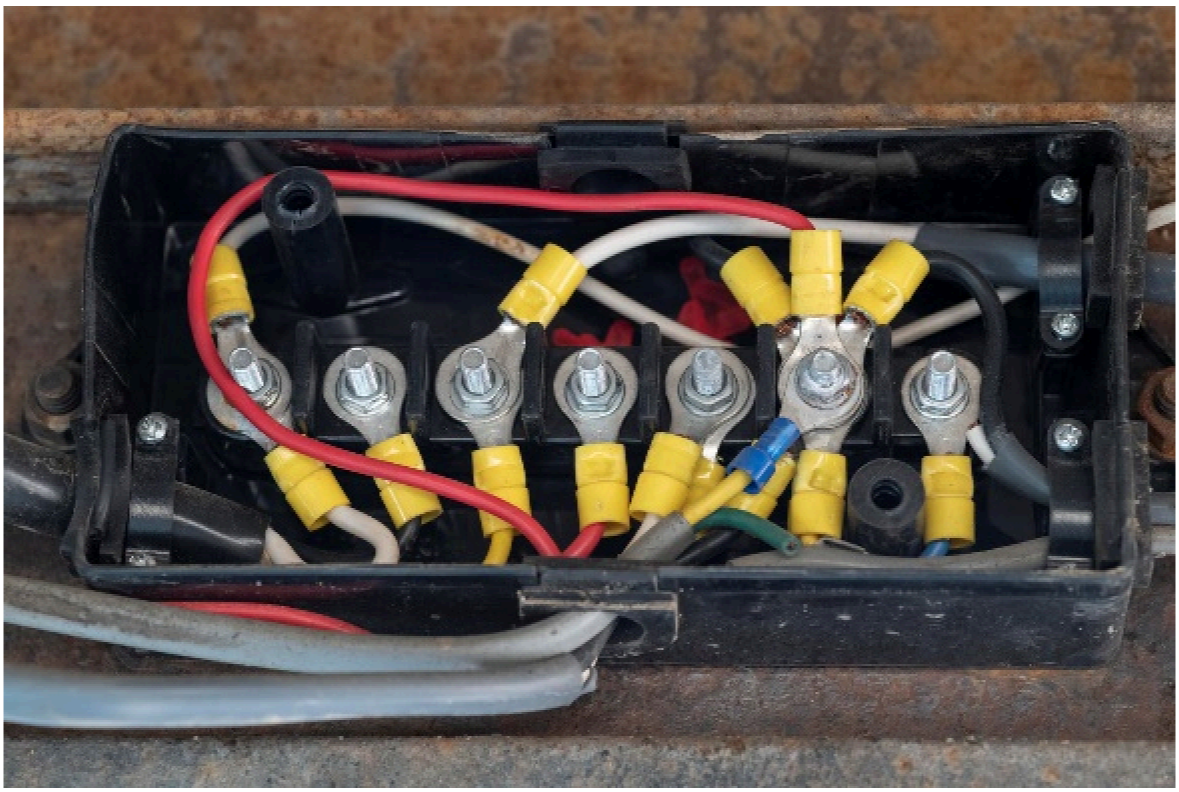

Figure 8 Sealed junction box using terminal posts (studs)

Wires can also be connected together by crimping. The shoulders of crimp fittings can either be insulated or bare and they come in a wide variety of sizes and configurations. A dedicated crimping tool or a combination stripper/crimper is used to secure the terminal fitting to the wire end.

Figure 9 Crimping tool

Figure 10 Combination crimper/stripper

The image below shows crimped wire terminals (ends). Only about $\frac{1}{4}''$ to $\frac{3}{8}''$ of the conductor has to be bared when using crimp connectors. The bared wire end is pushed into the opening so that the insulation butts up against the shoulder of the connector. If the connector is too large for the wire gauge, the wire can be pushed too far into the terminal, resulting in a situation where the insulation is sandwiched between the wire and the inside of the connector, with little or no contact between wire and connector. Crimp fittings are colour coded to indicate the size wire they are meant to be used with.

Figure 11 Insulated and uninsulated forked and ring terminal crimp connectors

Heat shrink sleeves can be used to insulate and protect a crimped connection. Some heat shrinks have the ability to seal the connection from water, such as in a well pump installation.

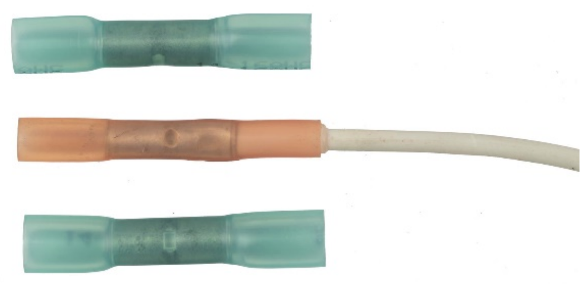

Figure 12 Heat shrinks over crimped butt connectors

The CEC also allows soldered wire connections for power conductors (hots and neutrals) but not for bonding conductors. A bonding conductor is usually bare or covered with green insulation if in an extension cord. Bonding conductors tie together all the metal components of a circuit that are never meant to be live so that, in the event of a “short” between a hot wire and a metal component of the circuit, the breaker will trip and any electrocution hazard is nullified. If too much current passes through a soldered “hot” connection without tripping the overcurrent device (breaker or fuse), the solder will melt and the wires will likely become disconnected, which in turn should deaden the circuit. If that were to happen to a soldered bonding conductor, the ground connection would be lost, the breaker or fuse could be unaffected and an electrocution hazard could still exist.

Any soldered connection must be made over with a heat shrink or electrician’s tape so that it has at least the same level of insulation as the wire.

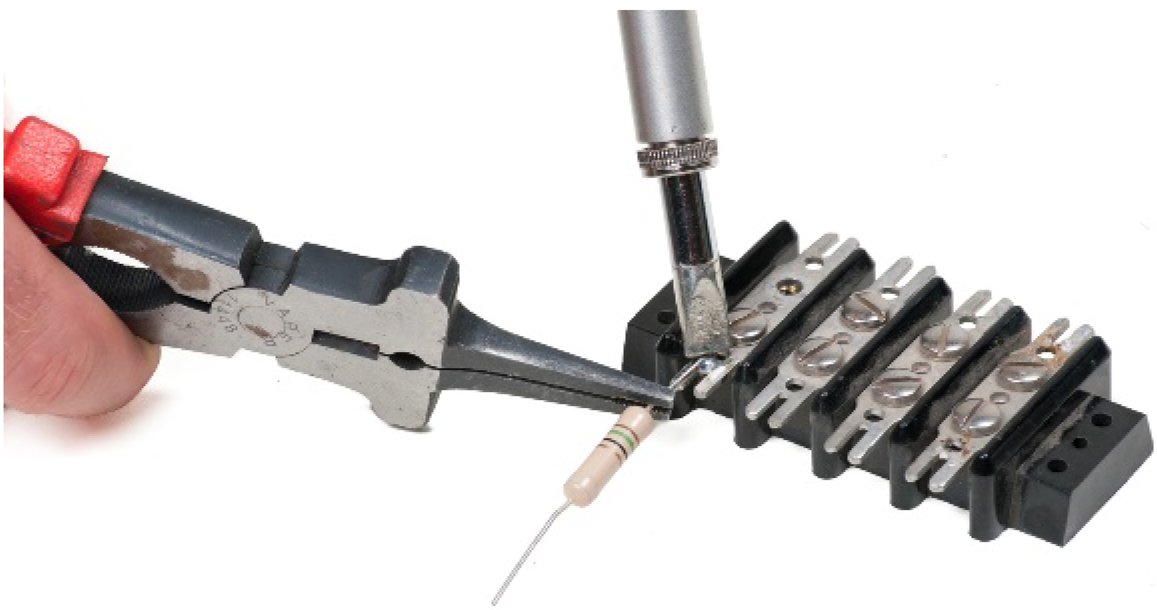

Figure 13 Soldering using a heat sink

When making soldered wire connections, make sure to not overheat any of the components. Using a heat sink, such as a pair of pliers to hold the wire very near the soldering point, as shown in the image above, helps to dissipate unwanted heat.

Now complete the Self-Test 5.

Self-Test 5

Self-Test 5

1. Complete the following statement: “Field wiring is _________.”
    a. Wiring done on a rural property
    b. Wiring that is not factory installed
    c. Wiring associated with a magnetic field
    d. Wiring provided by Field and Associates
2. What is the difference between “wire” and “cable”?
    a. Cable is constructed of steel
    b. Wire is constructed of aluminum
    c. Cable consists of individual wires
    d. Wire consists of individual cables
3. What is the purpose of a split plastic bushing when used with armoured cable?
    a. To prevent abrasion of the wire insulation
    b. To change between two cable diameters
    c. To help build up insulation thickness
    d. To change from steel to plastic
4. Within the context of the explanations in this guide, what does “CEC” stand for?
    a. Canadian Energy Conglomerates
    b. Cable Energizing Configuration
    c. Constant Energy Connection
    d. Canadian Electrical Code
5. What type of box must be used with metal conduit?
    a. Metal
    b. Plastic
    c. Concealed
    d. Either metal or plastic
6. If a device box can be dismantled and made larger, it is said to be _________.

a. Gang-able
b. Adaptable
c. Versatile
d. Useable

7. How are box entry fittings attached to boxes?
   a. By spot welding
   b. Through the cover plate
   c. Through the rear of the box
   d. Through knockouts on the box wall
8. According to the CEC, exposed conductors must be protected from damage if within ______ of the floor.
   a. 1.5 m
   b. 2.6 m
   c. 3.0 m
   d. 5.0 m
9. What is the difference between “BX” and “Teck” cable?
   a. “BX” is waterproof; “Teck” isn’t
   b. “Teck” is waterproof; “BX” isn’t
   c. “BX” has flexible armour; “Teck” doesn’t
   d. “Teck” has flexible armour; “BX” doesn’t
10. What is used to connect PVC conduit to a box?
    a. A sweep
    b. A threaded adapter
    c. A swaged-end connector
    d. A solvent-welded coupling
11. What type of material is rigid metal conduit?
    a. PVC plastic
    b. Copper tubing
    c. Thin-walled metal tubing
    d. Galvanized Schedule 40 pipe
12. What is any rigid enclosed or semi-enclosed channel that protects, routes and hides cables and wires known as?
    a. A conduit
    b. A pathway

c. A raceway

d. A rigid channel

13. What is the power output limitation for a Class II circuit?

    a. 100 Amps
    b. 100 Ohms
    c. 100 Volts
    d. 100 Watts

14. What is the general rule regarding separation distance between low voltage and line voltage conductors that are in close proximity to each other?

    a. Maintain at least 2 inches physical distance between them
    b. They cannot be in the same room together
    c. There is no minimum separation required
    d. Maintain at least 2 meters of separation

15. A "marrette" is an example of a _________ of wire connector.

    a. Soldered type
    b. Solderless type
    c. Set-screw type
    d. Threaded adapter type

16. How much length of tightly-twisted bare wire ends should there be under a wire nut connection?

    a. $\frac{1}{8}'' - \frac{1}{4}''$
    b. $\frac{1}{4}'' - \frac{1}{2}''$
    c. $\frac{5}{8}'' - \frac{3}{4}''$
    d. $\frac{3}{4}'' - 1$

17. What device is suggested for use when connecting small-diameter wires, to prevent them from breaking if twisted together?

    a. A marrette
    b. A raceway
    c. A junction box
    d. A terminal strip

18. How much wire must be stripped for a crimped connection?

a. $\frac{1}{8}'' - \frac{1}{4}''$
b. $\frac{1}{4}'' - \frac{3}{8}''$
c. $\frac{3}{8}'' - \frac{3}{4}''$
d. 1″ – 2″

19. According to the CEC, which one of the following must *not* be joined using a soldered connection?

    a. Two hot wires
    b. Three hot wires
    c. Two neutral wires
    d. Two bonding wires

20. What is suggested to be used whenever making a soldered wire connection, to avoid melting the wire insulation?

    a. A heat tap
    b. A heat sink
    c. A heat scrubber
    d. A heat-resistant wire

Check your answers using the Self-Test Answer Keys in Appendix 1.

Media Attributions

Appendix 1: Self-Test Answer Keys

Competency F1

Self Test 1

1. b. Respiration
2. a. 48
3. d. “Cold 70”
4. b. The ideal heat curve
5. c. The intensity of heat present
6. a. Mass (weight in pounds) × ΔT (in degrees F) × S.H. (specific heat)
7. c. 20°F
8. d. 140°F
9. a. Zoning
10. d. 0.045 (1 ÷ 22)
11. a. 704150 ft² × (1 ÷ 14) × (72 – 5) = 150 × 0.07 × 67 = 703.5 (round to 704)
12. d. The outdoor design temperature
13. d. 68°F
14. b. 18°C (64°F)
15. d. Transmission
16. b. Infiltration
17. a. 0.04
    Outside air film = 0.17;
    4″ brick = 0.44; ½″ plywood sheathing = 0.63;
    FG insulation = 3.72 × 5.5″ = 20.46;
    vapour barrier = 0; ½″ GWB = 0.45;
    inside air film = 0.68
    Aggregate “R” value = 22.83 “U” value = 1 ÷ 22.83 = 0.04
18. d. Low “E” – argon-filled
19. c. Thermal bridging
20. b. 1,930 BTUH(20 × 15 × 8) ft³ × (2/3 ACH × 0.018) × (72 – 5) = 2400 × 0.012 × 67 = 1,930 BTUH
21. c. The rate would double

22. a. The rate would be halved
23. d. The ODT for the two houses will be different.
24. c. 1 ACH
25. b. 0.06
26. a. 15.0(3 × 5.0/inch)
27. a. 1/3 ACH
28. c. 22°F
29. Windows: (2) × 3′ × 5′ × 0.59 × (72 – -16) = 1,558 BTUH
    Net walls: ((11 × 8) + (12 × 8)) – 30 = 154 ft^2
    154 × 0.05 × 88 = 678 BTUH
    Ceiling: (12′ × 11′) × 0.03 × 88 = 348 BTUH
    Floor: (12′ × 11′) × 0.05 × 88 = 581 BTUH
    Infiltration: (12′ × 11′ × 8′) × (2/3 × 0.018) × 88 = 1,115 BTUH
    Total heat loss: 4,280 BTUH
30. a. 1,164 BTUH(17.5′ × 33.25′) × 0.04 × (65 – 15) = 1,164 BTUH

Competency F2

Self Test 2

1. a. PeX "A"
2. d. all varieties need oxygen-barrier, whether in wet or dry systems
3. c. 2 ½″ polystyrene
4. a. in the ceiling below
5. a. to give the wall more stability
6. c. a heat exchanger
7. b. dry systems
8. a. reflective foil
9. b. they operate at low temperatures is a false statement
10. c. make a first pass 6 inches from the outside walls, then turn 180° with another 6-inch pass, then resume normal loop layout
11. b. 9″ o.c. from Table (2.2A?)
12. c. 40 btuh/ft^2
13. b. 300 feet is the norm although there may be some manufacturers who differ
14. d. 200 ft^2 – 84.5 ft^2 = 115.5 ft^2 of available area. 3050 btuh ÷ 115.5 ft^2 = 26.41 btuh/ft^2 of floor output. From Table (2.2A?), this is 9″ o.c. tube spacing. 115.5 × 1.3 (tube spacing factor for 9″ o.c.) = 150 feet of tubing

15. b. infra-red thermometer
16. c. 2:1
17. b. 100 psi for 30 minutes
18. b. its output
19. a. the single circuit with the highest head loss served by the pump
20. c. flow rate and feet of head
21. b. #4
22. a. 19.2 GPM 48,000 ÷ (5 × 60 × 8.33)
23. d. 12,000 12 inches × 1,000 millinches/inch
24. d. 9 feet of head 180 measured feet × 1.5 (fitting allowance) = 270 equivalent feet. Under the 400 millinch column, 270 equivalent feet = 9 ft. head
25. c. globe
26. a. reset control
27. c. hydraulic separation
28. b. its inner plate surface area
29. c. 3.12 feet of head 37,000 btuh ÷ 10,000 btuh/USGPM = 3.7 GPM
    $(3.7 \div 3.2)^2 = 1.156$ $1.156^2 = 1.3369$ psi
    1.3369 psi × 2.31 ft hd/psi = 3.088 (3.09) feet head
30. c. a differential bypass valve
31. a. flow rate
32. a. 17.56 29 feet × .433 psi/ft = 12.56 12.56 + 5 = 17.56 psi
33. c. 2.02 USG (45,000 ÷ 59,500) × 2 gal = 1.51 USG 1.51 × 1.34 (temp. adj.) = 2.02
34. a. boiler operation
35. c. 1 ¼″ 65,000 BTUH on Table 2.8 = 1 ¼″ pipe

Competency F3

Self Test 3

1. d. a pole
2. c. a throw
3. a. by their number of poles and throws
4. c. a momentary switch
5. b. open on rise

6. d. aquastats
7. c. a pressure switch
8. d. an end switch
9. b. 24V AC
10. b. 24V AC
11. b. the hot leg
12. d. EMR
13. b. 24V AC
14. d. 120V AC
15. c. when the coil is energized, the contact positions will reverse
16. d. a SPDT switch
17. b. a low water cutoff
18. c. a DPDT switch
19. c. a pressure switch
20. d. an SSR

Competency F4

Self Test 4

1. d. lowering the aquastat setting on a non-condensing boiler
2. b. a secondary heat exchanger
3. c. hydraulic separation
4. c. 4 diameters apart
5. c. 10,000 8.33 lbs/USG x 60 min/hr x 20°FΔT
6. a. an end switch
7. b. cold start
8. d. the lines that represent wires won't cross each other
9. c. on the face of the transformer
10. a. "C"
11. b. "R"
12. d. "Y" and "W"
13. a. at the mixing point
14. b. in the boiler return piping

15. c. a diverting valve has less head loss than a mixing valve
16. a. it needs a remote sensor
17. b. 1 inlet and 2 outlets
18. d. a 4-way mixing valve
19. c. outdoor reset
20. c (design supply temp – room temp) ÷ (room temp – outdoor design temp)
21. a. warm weather shutdown point (WWSD)
22. d. a cooling thermostat
23. a. a DPDT switch
24. a. a normally closed relay contact
25. c. the zone valve opens
26. c. the pump turns on and the burner fires
27. a. 140°F
28. d. 2 N.O. contacts
29. a. loads
30. a. in series, in the burner circuit
31. d. 20
32. b. near the draft hood
33. c. a hot water tank
34. c. 2.50 60VA ÷ 24VAC = 2.50A
35. b. only the extra thermostats and zone valve motors
36. c. the DHW zone valve
37. d. none
38. b. in parallel
39. a. in series
40. a. 1
41. b. make sure the circuit isn’t powered
42. d. turn the adjusting screw so that the pointer is directly over “0”

Competency F5

Self Test 5

1. b. wiring that is not factory installed

2. c. cable consists of individual wires
3. a. to prevent abrasion of the wire insulation
4. d. Canadian Electrical Code
5. a. metal
6. a. gang-able
7. d. through knockouts on the box wall
8. a. 1.5 m
9. b. “Teck” is waterproof; “BX” isn’t
10. b. a threaded adapter
11. d. galvanized Schedule 40 pipe
12. c. a raceway
13. d. 100 Watts
14. a. maintain at least 2 inches physical distance between them
15. b. solderless-type
16. c. $\frac{5}{8}$″ – ¾″
17. d. a terminal strip
18. b. ¼″ – $\frac{3}{8}$″
19. d. two bonding wires
20. b. a heat sink

Appendix 2: Climatic Design Data for Selected Locations in British Columbia

Design Temperature Chart for selected BC Locations – Part 1

Location	Temp. [F]	Adjustment	(calc)	(calc)
Abbotsford	13	1.07	0	0
Agassiz	7	1.18	0	0
Alberni	22	0.91	0	0
Ashcroft	−14	1.56	0	0
Beaton River	−36	1.96	0	0
Burns Lake	−24	1.75	0	0
Cache Creek	−14	1.56	0	0
Campbell River	18	0.98	0	0
Carmi	−11	1.51	0	0
Castlegar	−2	1.35	0	0
Chetwynd	−33	1.9	0	0
Chilliwack	10	1.13	0	0
Cloverdale	17	1	0	0
Comox	18	0.98	0	0
Courtenay	18	0.98	0	0
Cranbrook	−17	1.62	0	0
Crescent Valley	−5	1.4	0	0
Crofton	21	0.93	0	0
Dawson Creek	−35	1.95	0	0
Dog Creek	−20	1.67	0	0
Duncan	21	0.93	0	0
Elko	−20	1.67	0	0
Fernie	−21	1.69	0	0

Design Temperature Chart for selected BC Locations – Part 2

Location	Temp. [F]	Adjustment	(calc)	(calc)
Fort Nelson	−41	2.05	0	0
Fort St. John	−34	1.93	0	0
Glacier	−17	1.62	0	0
Golden	−17	1.65	0	0
Grand Forks	−4	1.38	0	0
Greenwood	−5	1.4	0	0
Haney	15	1.04	0	0
Hope	2	1.35	0	0
Kamloops	−10	1.49	0	0
Kaslo	−9	1.47	0	0
Kelowna	0	1.31	1.31	0
Kimberley	−16	1.6	0	0
Kitimat Plant	2	1.35	0	0
Kitimat Townsite	2	1.35	0	0
Langley	17	1	0	0
Lillooet	−10	1.49	0	0
Lytton	−3	1.36	0	0
Mackenzie	−33	1.9	0	0
McBride	−31	1.87	0	0
Mcleod Lake	−32	1.89	0	0
Masset	18	0.98	0	0
Merritt	−15	1.58	0	0
Mission City	14	1.05	0	0

Design Temperature Chart for selected BC Locations – Part 3

Location	**Temp. [F]**	**Adjustment**	**(calc)**	**(calc)**
Montrose	0	1.31	0	0
Nakusp	−11	1.51	0	0
Nanaimo	20	0.95	0	0
Nelson	−5	1.4	0	0
New Westminster	19	0.96	0	0
North Vancouver	19	0.96	0	0
Ocean Falls	9	1.15	0	0
100 Mile House	−20	1.67	0	0
Osoyoos	3	1.25	0	0
Penticton	3	1.25	0	0
Port Alberni	22	0.91	0	0
Port Hardy	21	0.93	0	0
Port McNeill	21	0.93	0	0
Powell River	15	1.04	0	0
Prince George	−31	1.87	0	0
Prince Rupert	15	1.04	0	0
Princeton	−16	1.6	0	0
Qualicum Beach	19	0.96	0	0
Quesnel	−29	1.84	0	0
Revelstoke	−16	1.6	0	0
Richmond	19	0.96	0	0
Salmon Arm	−10	1.49	0	0
Sandspit	20	0.95	0	0

Design Temperature Chart for selected BC Locations – Part 4

Location	**Temp. [F]**	**Adjustment**	**(calc)**	**(calc)**
Sidney	21	0.93	0	0
Smithers	−22	1.71	0	0
Smith River	−51	2.24	0	0
Squamish	12	1.09	0	0
Stewart	−10	1.49	0	0
Surrey	17	1	0	0
Taylor	−34	1.93	0	0
Terrace	−5	1.4	0	0
Tofino	27	0.81	0	0
Trail	3	1.25	0	0
Ucluelet	27	0.81	0	0
Vancouver	19	0.96	0	0
Vernon	−5	1.4	0	0
Victoria	23	0.89	0	0
Williams Lake	−23	1.73	0	0
Youbou	22	0.91	0	0

Versioning History

This page provides a record of edits and changes made to this book since its initial publication. Whenever edits or updates are made in the text, we provide a record and description of those changes here. If the change is minor, the version number increases by 0.01. If the edits involve substantial updates, the version number increases to the next full number.

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