Block B: Heating & Cooling Systems

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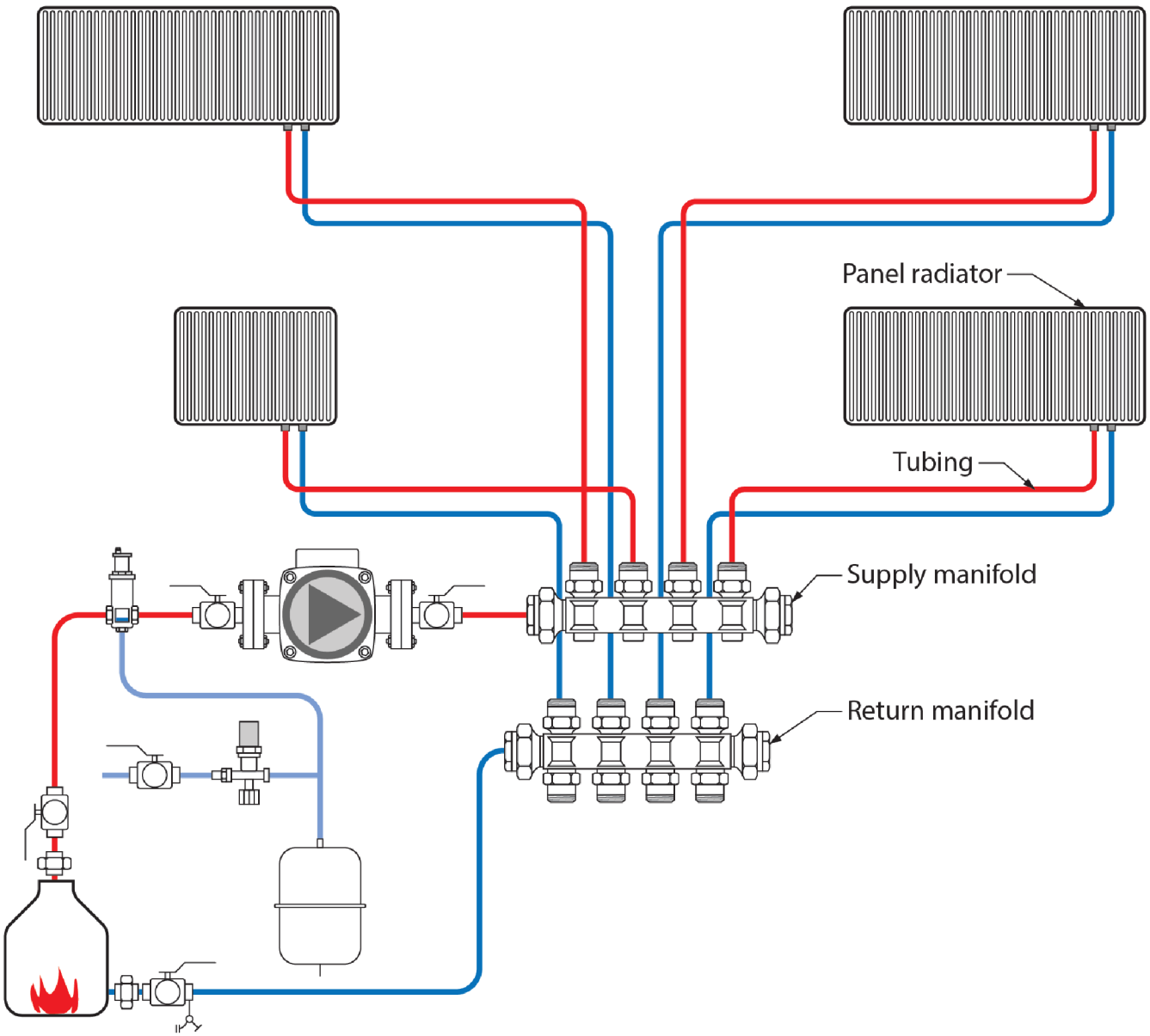

Plumbing Apprenticeship Program Level 2 Series

Block B: Heating & Cooling Systems

BC Plumbing Apprenticeship, Level 2

SKILLED TRADES BC

BC PIPING ARTICULATION AND CURRICULUM SUBCOMMITTEE; ROD LIDSTONE; AUDREY CURRAN; AND PAUL SIMPSON

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Block B: Heating & Cooling Introduction

In the field, there are many similarities or overlaps with the work of plumbers and gas fitters. Many plumbing and heating contractors employ both plumbers and gas fitters as well as tradespeople with dual certifications.

Upon completion of a Plumbing Apprenticeship, a plumber can receive cross-program credit for a portion of the Gas fitter apprenticeship. As such, training in fuel gas has been incorporated into all levels of the Plumbing Apprenticeship.

Block B of the **Plumbing Apprenticeship Program Level 2 Series** focuses on the fundamentals of heating and cooling systems, providing apprentices with a thorough understanding of various system types and their components. This section is designed to equip apprentices with the knowledge needed to install, maintain, and troubleshoot complex heating and cooling systems, with an emphasis on hydronic technology.

Plumbing Apprenticeship Program Level 2 Series

The *Plumbing Apprenticeship Program Level 2 Series* offers comprehensive training materials designed to build on foundational skills and knowledge. The series is divided into four main blocks, each focusing on critical areas of plumbing systems and installations.

Block A: Fuel Gas Systems (https://a-fuelgas-bcplumbingapprl2.pressbooks.tru.ca/)

A-1: Gas Fired Appliances
A-2: Gas Codes Regulations and Standards
A-3: Gas Appliance and Building Air Requirements
A-4: Technical Instruments and Testers

Block B: Heating and Cooling Systems (https://b-heating-bcplumbingapprl2.pressbooks.tru.ca/)

B-1: Types of Heating and Cooling Systems
B-2: Hydronic Heating and Cooling Generating Equipment
B-3: Hydronic Heat Transfer Units
B-4: Hydronic Heating Piping and Components

Block C: Install Fixtures and Appliances (https://c-plumbfixappliance-bcplumbingapprl2.pressbooks.tru.ca/)

C-1: Plumbing Fixtures and Trim
C-2: Plumbing Appliances

Block D: Drainage Systems (https://d-drainagesystems-bcplumbingapprl2.pressbooks.tru.ca/)

D-1: Sanitary Drain, Waste and Vent Systems
D-2: Planning and Installation of DWV Systems
D-3: Storm Drainage Systems
D-4: Test and Drainage Systems
D-5: Drainage System Maintenance and Repairs

Plumbing Apprenticeship Program Overview and Upcoming Resources

- **Plumbing Apprenticeship Program Level 1 Series** is coming soon to TRU Open Press in 2025–2026!
- **Plumbing Apprenticeship Program Level 3 Series (https://collection.bccampus.ca/search/?q=%22pl3%22)** can be found in the BCCampus Open Collection (https://collection.bccampus.ca/).
- **Plumbing Apprenticeship Program Level 4 Series** (https://bccampus.ca/projects/archives/zed-cred-z-degrees/ztc-open-educational-resources-for-trades/) can be found in the BCCampus Open Collection. (https://collection.bccampus.ca/) (Block F: Commission and Service will be available soon.)

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Safety Advisory

The current Standards and Regulation in BC can be obtained at the WorkSafeBC (http://www.worksafebc.com) website: http://www.worksafebc.com

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Symbol Legend

Important Information

Potentially Toxic/ Poisonous Situation

Required or Optional Resources

Potentially Flammable Situation

Complete a Self-Test

Possibly Explosive Situation

Use Protective Equipment

Potential Electric Shock

Acknowledgments

The development of the *Piping Trades Learning Guides* was a collaborative effort driven by a commitment to excellence in trades education. These guides were created to support apprentices and journeypersons in mastering the skills and knowledge essential to the piping trades. This achievement would not have been possible without the dedication and expertise of *Skilled Trades BC* and the *Piping Trades Articulation Committee*, whose leadership and guidance have been instrumental in shaping high-quality training resources. We extend our sincere gratitude for their contributions and ongoing stewardship in advancing the piping trades.

The Open Press

The Open Press combines TRU's open platforms and expertise in learning design and open resource development to support the creation and reuse of open educational resources, while encouraging open scholarship and research.

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References

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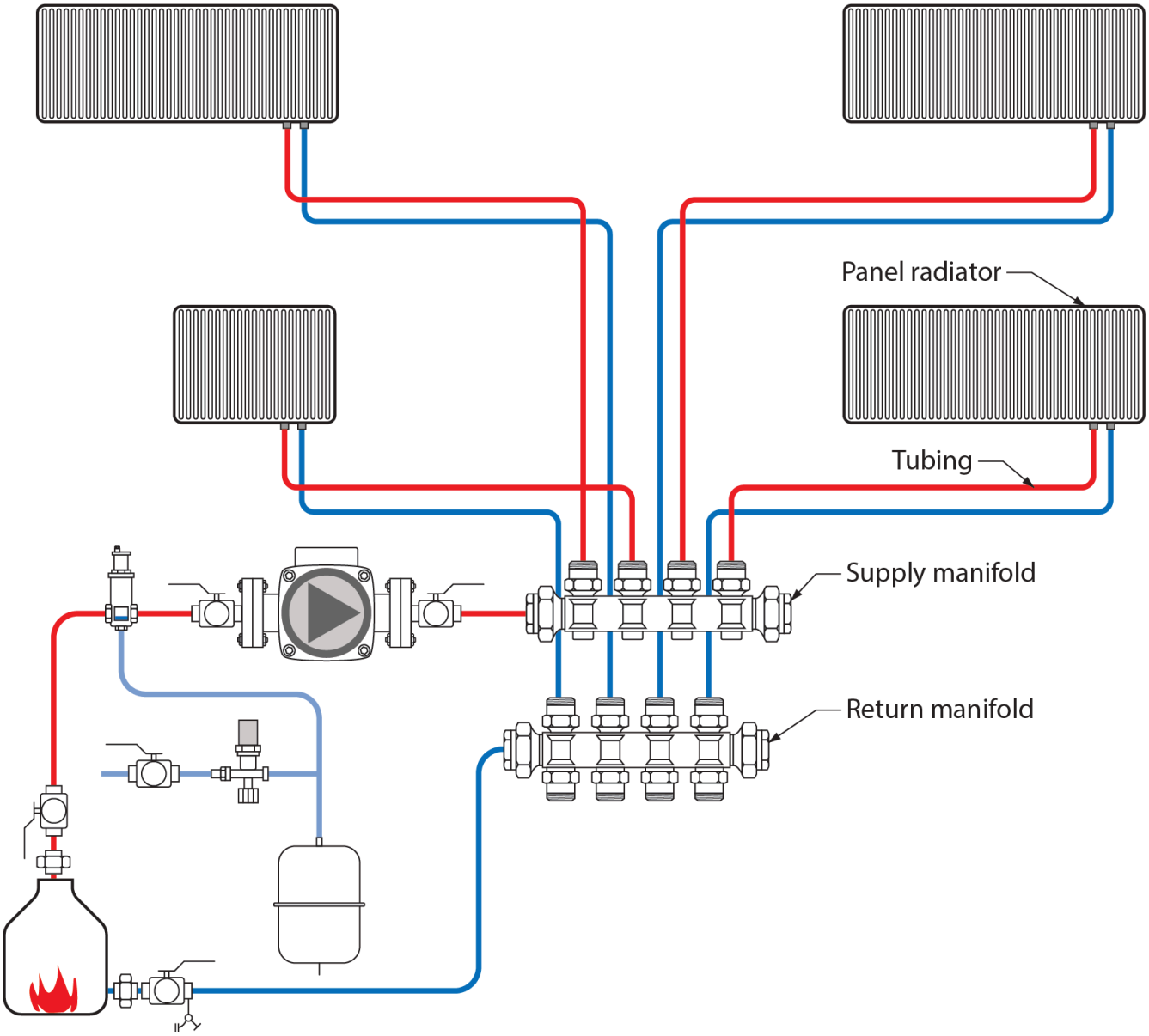
B-1 TYPES OF HEATING AND COOLING SYSTEMS

Plumber Apprenticeship Program – Level 2



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B-1 Types of Heating and Cooling Systems Introduction

The purpose of a building's heating or cooling system is not necessarily to raise or lower the temperature of the building but rather to offset or balance the amount of a heat lost or gained in order to maintain a constant temperature within the building. A building's heating system is said to be in thermal equilibrium when the heat input is in balance with the heat lost. In an ideal system, the occupants would not be conscious of either warm or cold sensations. This thermal equilibrium situation would be the goal of the heating ventilation and air-conditioning (HVAC) system designer/installer.

Learning Objectives

After completing the chapters in this section, you should be able to:

- Describe the concepts of heat and heat transfer.
- Describe low-pressure steam heating systems.
- Describe residential forced-air systems.
- Describe hydronic heating and cooling systems.

Terminology

The following terms will be used throughout this section. A complete list of terms for this section can be found in the **Glossary**.

- **air vents:** Steam cannot circulate, nor can radiators emit heat until air has been vented from the system. Thermostatic air vents are installed on each radiator and at the end of each steam main. Thermostatic steam traps also act as air vents. (Section B-1.1)
- **dry return:** The portion of the return main located above the boiler water level. (Section B-1.2)
- **equalizer line:** The vertical piping at the end of the header going back to the boiler return connection. Its job is to return any water that slips out of the boiler with the steam and to balance the pressure between the supply and the return sides of the boiler. Without a properly sized equalizer, water can back out of the boiler. (Section B-1.2)
- **gauge glass:** Used to identify the water level in the boiler. Expect to see some minor movement in the water line when the boiler is operating. When the boiler is off, the "normal" water line is the centre of the gauge glass. When the system is running, the "normal" water line is near the bottom of the gauge glass. (Section B-1.2)
- **Hartford loop:** A piping arrangement designed to prevent complete drainage of the boiler if a leak

develops in the wet return. The wet return is connected to an equalizing line between the supply and return opening of the boiler. This connection is made about 2 in. below the normal water level of the boiler. This connection between the loop and the equalizer must be made with a close nipple to prevent water hammer. (Section B-1.2)

- **header:** Boilers, depending upon their size, have one or more outlet tappings. The vertical steam piping from the tapped outlet joins a horizontal pipe called a "header." The steam supply mains are connected to this header. If the boiler has more than one outlet, it's important to remember to pipe the headers with swing joints. This will help alleviate any stress on the boiler when the header heats up and expands. (Section B-1.2)
- **heat emitters (units):** Steam heating systems use convectors, cast-iron radiators, wall fin tubes, and similar heat-emitting units. (Section B-1.4)
- **low-water cutoff:** Shuts off the burner should the water level fall to an unsafe level. The boiler manufacturer determines this level, but it's usually within one-half inch of the bottom of the gauge glass.
- **radiator valve:** Controls the steam supply to the system radiators. Each radiator is equipped with an angle pattern radiator supply valve. (Section B-1.2)
- **relief valve:** Protects the boiler against a runaway fire. On space-heating steam boilers, the relief valve is set to pop open and relieve pressure at 15 psi. This is the limit for any low-pressure boiler. (Section B-1.2)
- **risers:** The vertical pipe carrying steam to the radiator from the supply main. (Section B-1.2)
- **steam boiler:** A steam boiler is a device that heats water until it turns into steam. This steam is then used to provide heat or power. It works by burning fuel like coal, oil, or gas, or by using electricity to generate heat. The steam produced can be used for various purposes, such as heating buildings, running engines, or powering machines. (Section B-1.2)
- **steam supply main:** Carries steam from the header to the radiators connected along its length. (Section B-1.2)
- **steam traps:** Prevent steam from getting into the condensate returns because they close in the presence of steam, creating a separation from the return piping of the system. The steam trap has three jobs — to let air pass through the radiators, to close when steam reaches it, and to open when condensate accumulates. (Section B-1.2)
- **wet return:** The portion of the return main located below the boiler water level. It is always completely filled with water and does not carry air or steam in the same way that the dry return does. (Section B-1.2)

B-1.1 Heat and Heat Transfer

Heat is a form of energy. In North America, heating is commonly discussed using imperial units. Heat can be measured by its quantity and intensity. Before any heating system can be designed, it is necessary to understand what heat is, how it is transferred, and how that heat movement can be measured.

Quantifying Heat Energy

Heat quantity is described in British thermal units (BTU). One BTU is defined as the amount of energy it takes to raise one pound of water by one degree Fahrenheit. This is the approximate amount of energy released by burning one wooden match.

The metric unit of energy is the joule (J) or kilojoules (kJ). 1 BTU equals 1.054 kJ. The metric equivalent of the BTU is the kilowatt (kW). Note that the kilowatt incorporates one hour of time within its definition. Sometimes kilowatts are described as kilowatt hours.

Power is the rate at which energy is generated, converted, or used. The power ratings of heating and cooling equipment are expressed in BTU's per hour (BTU/h) or kilowatts (kW). One kilowatt is equivalent to 3,412 BTU/h.

Temperature is the measure of heat intensity and is expressed in degrees Fahrenheit (°F) or degrees Celsius (°C). Fahrenheit and Celsius are often associated with imperial and metric scales, but that is not the case. Rather, they are parts of scales that have their baseline at the point where all heat is absent. This point is known as absolute zero.

The scale that shares degrees with the Fahrenheit scale is the Rankine scale. It has 460 of its degrees below 0°F — so 32°F would be expressed as 492°R (Rankine):

$$32^{\circ}\mathrm{F} + 460 = 492^{\circ}\mathrm{R}$$

The other scale that corresponds to degrees Celsius is the Kelvin scale. There are 273 degrees Kelvin between 0°C and absolute zero — so 100°C would be expressed as 373°K (Kelvin):

$$100^{\circ}\mathrm{C} + 273 = 373^{\circ}\mathrm{K}$$

Figure 1 compares the various temperature scales.

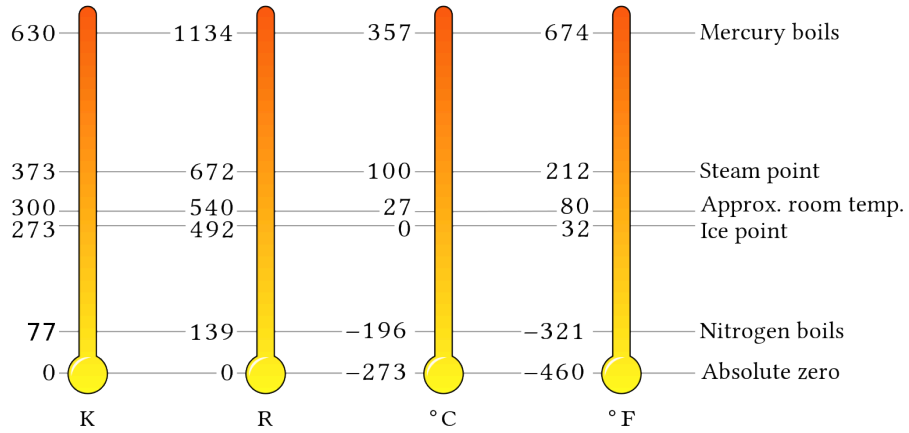

Figure 1 *Comparison of the Various Temperature Scales (Steven Baltakatei Sandoval/Wikimedia Commons) CC BY-SA 4.0 (https://creativecommons.org/licenses/by-sa/4.0/deed.en)* ***(Long description*** *(#Fig1_longdesc))*

All matter is composed of atoms. All atoms vibrate, and this vibration is caused by the presence of heat. Even matter that is at temperatures below 0°C will vibrate because they contain heat. At absolute zero, all vibration stops, and no heat is present. The higher the intensity of atomic vibrations within a material, the greater the temperature of the material and the greater its heat content. Any material above absolute zero contains some measurable amount of heat energy. So, you could say that adding 10 BTU (a unit of heat) to a pound of water will increase the water's temperature by 10°F (which measures the intensity of heat). Heat's intensity is measurable with a thermometer, while the heat content of a material is the result of applying its temperature to a formula. A material's heat intensity is a result of its heat content.

Heat Transfer

Heat always moves from an area of increased atomic activity (higher temperature) to an area of decreased atomic activity (lower temperature). Heat is transferred from one material to another by three main processes:

- **Conduction**
- **Convection**
- **Thermal radiation**

In a hot water heating system, heat transfer units or emitters use the processes of conduction, convection, and radiation to transfer heat to rooms or zones. The rate of heat transfer, known as heat flow, depends on the temperature difference between materials. Heat energy will continue to transfer from warm material to cool material until both are the same temperature.

Conduction

Conduction is the transfer of heat by contact. Molecules vibrate in response to their level of heat energy. When two

molecules bump into each other, the vibration of one affects the other, and heat energy is transferred. When materials that have different temperatures are in contact, heat from the warm material is conducted to the cool material (Figure 2).

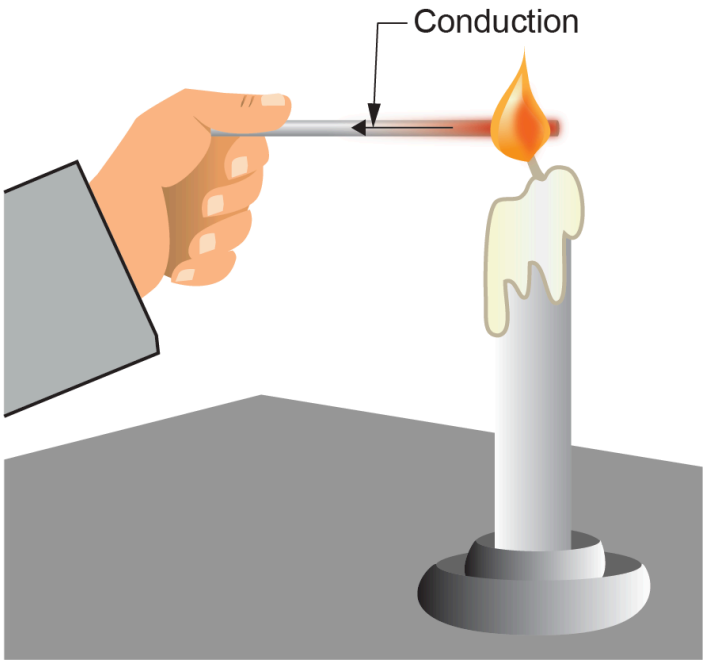

Figure 2 *Heat transfer. (Skilled Trades BC, 2021) Used with permission.*

Effects of Conduction

Hot water loses heat through the walls of containing vessels and piping. Water in piping has molecular contact with the piping walls. This contact causes heat to conduct through the piping walls to outside air.

The speed at which heat energy transfers through conduction depends on the difference in temperature between the two materials. If the temperature difference is doubled, the heat flow rate also doubles.

The amount of heat transferred is also affected by the amount of surface area in contact. If the surface area in contact is doubled, the amount of heat transferred also doubles.

All materials allow some movement of heat. Some materials, such as metals, allow heat to conduct very rapidly. Other materials, like air, allow heat to conduct slowly. Heat conductivity (or thermal conductivity) is the speed at which a material is able to transfer heat. A material with low heat conductivity is called an insulator. The lower the heat conductivity, the greater the insulation value. Table 1 lists the heat conductivity of several common substances with a thickness of 1 in., a surface area of 1 sqft, and a temperature difference across the material of 1°F.

Table 1: Heat Conductivity of Common Substances

Substance	Conductivity
Copper	2660 BTU/h
Steel	320 BTU/h
Concrete	12 BTU/h
Water	4.1 BTU/h
Plastic	1.2 BTU/h
Air	0.15 BTU/h

Copper conducts heat more quickly than steel, and steel conducts heat more quickly than plastic. Plastic conducts so little heat that it is classed as an insulator. Plastic's low conductivity and high corrosion resistance make it an ideal material for moving water within a heating or cooling system.

Convection

Convection is the transfer of heat in a fluid (a gas or a liquid) caused by a difference in densities. It is sometimes called gravity circulation. When heat is applied to a fluid, the temperature of the fluid increases, causing it to expand and become less dense than the surrounding fluid. It is then pushed upward as cooler, denser fluid flows downward to take its place. This upward push by cooler, denser fluid is known as buoyancy. Early hydronic heating systems depended on gravity circulation to move heat from the heat source (boiler) through piping to the heat transfer units (cast-iron radiators) in the heated areas.

Air in contact with the radiators was heated by conduction, which in turn created movement of heated air in the room through convection (Figure 3). This process of heating the air is still used by modern convectors, although the circulation of water is accomplished through the use of pumps.

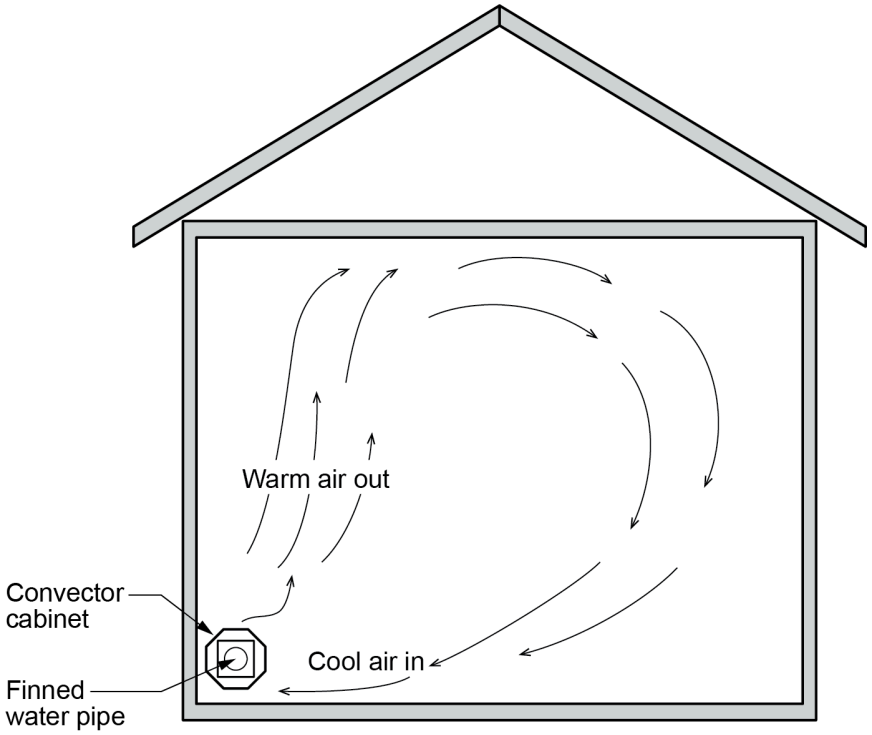

Figure 3 *Convection currents in a room or zone. (Skilled Trades BC, 2021) Used with permission.*

Radiation

Radiation is the transfer of heat by electromagnetic heat rays emitted directly from a heat source to a receiving material. Heat rays travel through space in the same way that light rays travel. It is important to note that radiant heat does not raise the temperature of the air between the source and the material. Heat rays are rarely impeded or absorbed by intervening air due to air's lack of mass or density. When the heat rays reach a material other than air, that material absorbs them and becomes warmer.

A good example of a radiant heat source is the sun (Figure 4). Imagine you are outside on a very cold yet sunny day. If you stand facing the sun, you will feel warmth on your face, but not on your back. On the other hand, if you turn away from the sun, your back warms up, but your face will feel cold. The sun's rays are heating you directly, rather than heating the air between it and you.

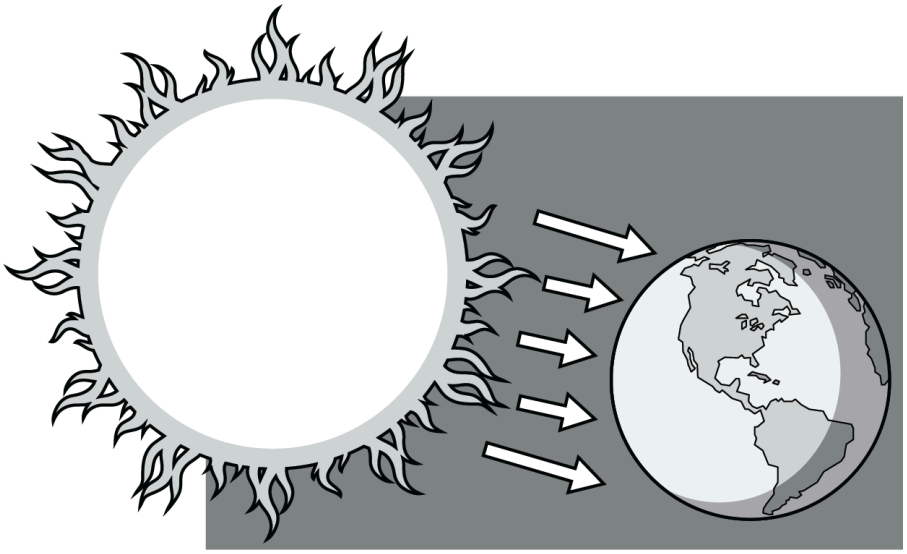

Figure 4 *The Sun's radiation reaches the Earth through space. (Skilled Trades BC, 2021) Used with permission.*

Radiant Heat

The amount of heat transmitted by a radiator is proportional to its surface area and temperature. The best radiators of heat are rough and black, such as cast-iron stoves. Light-coloured, smooth, and shiny materials, such as toasters and kettles, tend to reflect heat. As the temperature of the radiating material increases, the amount of radiation increases.

Self-Test B-1.1: Heat and Heat Transfer

Complete Self-Test B-1.1 and check your answers.

If you are using a printed copy, please find Self-Test B-1.1 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://b-heating-bcplumbingapprl2.pressbooks.tru.ca/?p=37#h5p-1 (https://b-heating-bcplumbingapprl2.pressbooks.tru.ca/?p=37#h5p-1)

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- **Figure 1** Comparison of the various temperature scales (https://commons.wikimedia.org/wiki/File:Temperature_scales_comparison_(K,R,C,F).svg) is by Stephen Baltakatei Sandoval (2023) via Wikimedia and is used under a CC BY-SA 4.0 (https://creativecommons.org/licenses/by-sa/4.0/deed.en) licence.

Long Description: Figure 1 Comparison of the Various Temperature Scales

The following table shows a comparison of the various temperature scales: Rankine, Fahrenheit, Celsius, Kelvin.

Comparison of the Various Temperature Scales

Rankine (°R)	Fahrenheit (°F)	Description	Celsius (°C)	Kelvin (°K)
1134	674	**Mercury boils**	357	630
672	212	**Water boils; steam point**	100	373
492	32	**Water freezes**	0	273
460	0	**—**	-18	256
139	-321	**Nitrogen boils**	-196	77
0	-460	**Absolute zero**	-273	0

Back to Figure 1 (#Fig1)

B-1.2 Low-Pressure Steam Heating Systems

A steam heating system takes advantage of the high latent heat given off when steam condenses to water. Although residential steam heating systems were very common in the late 19th and early 20th centuries, they are rarely installed in new single-family residential construction. Compared to other heating methods, it is more difficult to control the output of a steam system.

However, steam can be sent to places (e.g., between buildings on a college or university campus), which allows an efficient central boiler and low-cost fuel to be used. Tall buildings take advantage of steam's low density to avoid the excessive pressure required to circulate hot water from a basement-mounted boiler. In industrial systems, process steam used for power generation or other purposes can also be tapped for space heating. Steam for heating systems may also be obtained from heat-recovery boilers using otherwise wasted heat from industrial processes.

In a steam heating system, each room is equipped with a radiator, which is connected by piping to a **steam boiler**. Steam entering the radiator condenses and gives up its latent heat, and the radiator, in turn, heats the room or zone. The condensate water (or condensate) returns to the boiler either by gravity or with the assistance of a pump. Some systems only use a single pipe for combined steam and condensate return. Since trapped air prevents proper circulation, such systems have vent valves to allow air to be purged. Pipes must be carefully sloped to prevent trapped condensate blockage. In domestic and small commercial buildings, the steam is generated at relatively low pressure, less than 15 psig (200 kPa).

Latent heat, not steam pressure, does the actual heating work in a residential steam heating system. Remember that steam gives up 970 BTU of usable heat for every pound that condenses back to water. The job of steam pressure is strictly to overcome the friction that steam meets as it works its way around the system. A steam heating system requires only enough pressure back at the boiler to overcome the system piping's friction; that pressure is very low because the pipe is sized to offer very little resistance to steam flow. Therefore, house steam heating systems should not operate at pressures higher than two psig.

Steam heating piping systems are classified by how they handle the steam and condensate. One-pipe systems use common piping for both the steam and condensate, whereas two-pipe systems use separate piping for each.

System Components

The following is a list of some more common components found in low-pressure steam heating systems, some of which are shown in Figure 1.

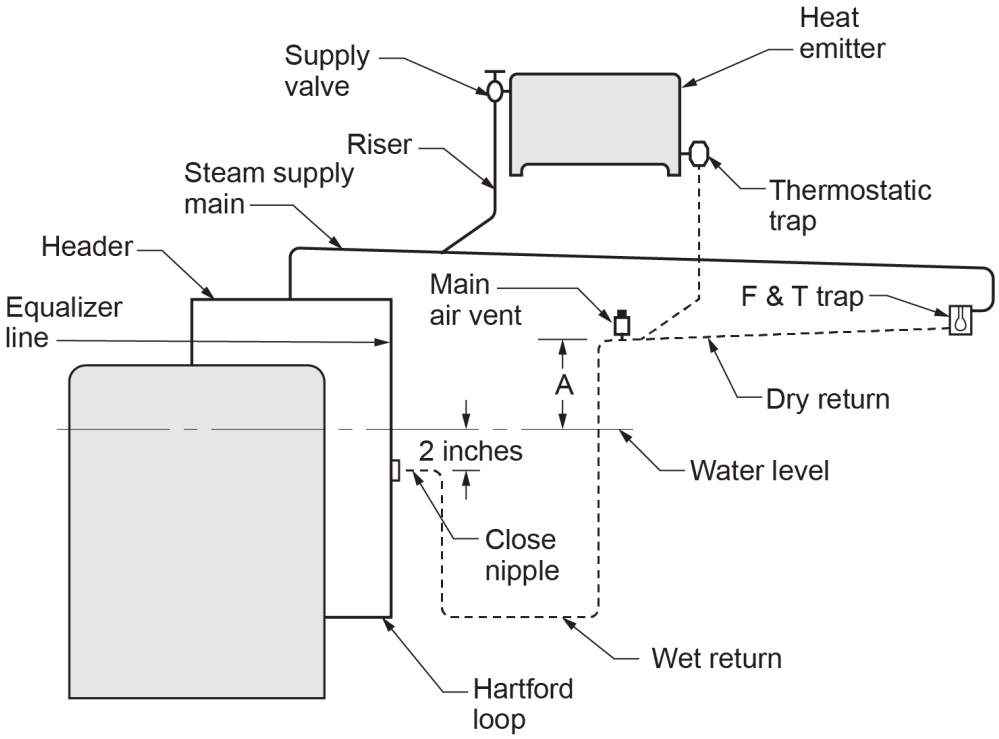

Figure 1 *Steam heating components. (Skilled Trades BC, 2021) Used with permission.*

Steam boiler: Steam boilers differ from hot water boilers in that they are only partially filled with water. A sight glass is provided for visual observation of the boiler water level. A relief valve protects the boiler from damage should excessive pressures occur. The burner is operated from a steam pressure switch, called a pressuretrol, which determines the operating pressure range of the boiler. During a call for heat, the boiler will cycle up to the cut-out setting of the pressuretrol. At that point, the pressuretrol will shut off the burner. Commercial boilers also require a manual-reset high-limit pressuretrol to shut off the burner should the pressure rise too high.

Header: Boilers, depending upon their size, have one or more **outlet tappings**. The vertical steam piping from the tapped outlet joins a horizontal pipe called a header. The steam supply mains are connected to this header. If the boiler has more than one outlet, it is important to remember to pipe the headers with swing joints. This will help alleviate any stress on the boiler when the header heats up and expands.

Equalizer line: The equalizer line is the vertical piping at the end of the header going back to the boiler return connection. Its job is to return any water that slips out of the boiler with the steam and to balance the pressure between the supply and the return sides of the boiler. Without a properly sized equalizer, water can back out of the boiler.

Steam supply main: The steam supply main carries steam from the header to the radiators connected along its length.

Risers: The vertical pipe carrying steam to the radiator from the supply main is called a riser.

Heat emitters (units): Steam heating systems use convectors, cast-iron radiators, wall fin tube, and similar heat-emitting units.

Dry return: The dry return is the portion of the return main located above the boiler water level.

Wet return: The wet return is the portion of the return main located below the boiler water level. It is always completely filled with water and does not carry air or steam in the same way that the dry return does.

Hartford loop: The Hartford loop is a piping arrangement designed to prevent complete drainage of the boiler should a

leak develop in the wet return. The wet return is connected to an equalizing line between the supply and return opening of the boiler. This connection is made about 2 in. below the normal water level of the boiler. This connection between the loop and the equalizer must be made with a close nipple to prevent water hammer.

Gauge glass: The gauge glass is used to identify the water level in the boiler. Expect to see some minor movement in the water line when the boiler is operating. When the boiler is off, the "normal" water line is the centre of the gauge glass. When the system is running, the "normal" water line is near the bottom of the gauge glass.

Air vents: Steam cannot circulate, nor can radiators emit heat until air has been vented from the system. Thermostatic air vents are installed on each radiator and at the end of each steam main. Thermostatic steam traps also act as air vents.

Radiator valves: Radiator valves control the steam supply to the system radiators. Each radiator is equipped with an angle pattern radiator supply valve.

Steam traps: Steam traps prevent steam from getting into the condensate returns because they close in the presence of steam creating a separation from the return piping of the system. The steam trap has three jobs — to let air pass through the radiators, to close when steam reaches it, and to open when condensate accumulates.

Relief valve: The relief valve protects the boiler against a runaway fire. On space-heating steam boilers, the relief valve is set to pop open and relieve pressure at 15 psi. This is the limit for any low-pressure boiler.

Low-water cut-off: The job of the low-water cut-off is to shut off the burner should the water level fall to an unsafe level. The boiler manufacturer determines this level, but it is usually within one-half inch of the bottom of the gauge glass.

One-Pipe Steam Systems

One-pipe systems take their names from the single pipe that connects each radiator to the steam main. Both steam and condensate travel in this pipe but in opposite directions.

Counterflow System

In **counterflow** systems (Figure 2), the steam and condensate travel in opposite directions in the steam main piping. When there is counterflow, the pitch must be at least 1 in. in 10 ft. The steam main must be one size larger than one used for other types of one-pipe systems.

Dimension A (Figure 2) must be of sufficient height to provide enough gravity head pressure to return condensate to the boiler. The head provided by the height of this column consists of the steam system pressure drop and the static head needed to overcome the pressure drop in the condensate return lines. It is standard practice for a system based on $\frac{1}{2}$ psi pressure drop to make the minimum distance for Dimension A not less than 28 in.

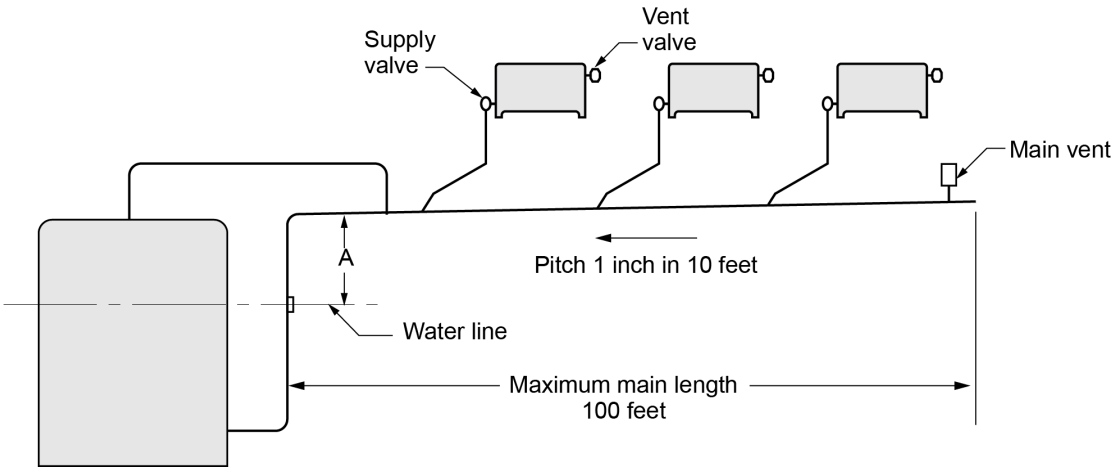

Figure 2 *Counterflow system. (Skilled Trades BC, 2021) Used with permission.*

Parallel Flow System

In **parallel** flow systems, the steam and condensate move in the same direction in the horizontal steam and return mains. The pitch on the mains should be at least 1 in. in 20 ft. Figure 3 shows a parallel flow system with a **wet return** from the end of the steam main, and Figure 4 shows a **dry return**.

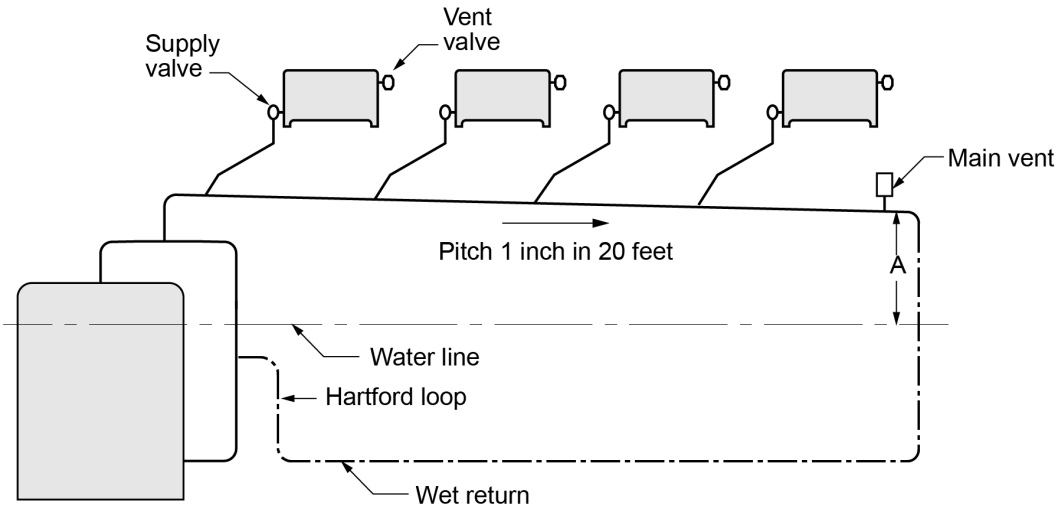

Figure 3 *One-pipe parallel flow system, with wet return. (Skilled Trades BC, 2021) Used with permission.*

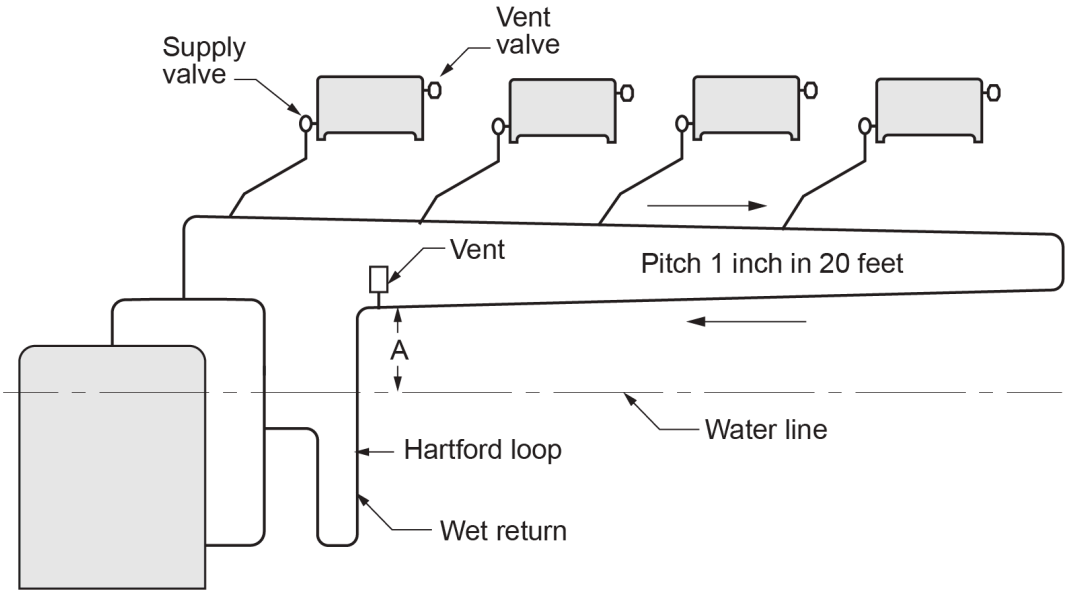

Figure 4 *One-pipe parallel flow system, with dry return. (Skilled Trades BC, 2021) Used with permission.*

Two-Pipe Steam Systems

Two-pipe systems (Figure 5) differ from one-pipe systems in that the former carries steam and condensate to and from the radiators using separate lines. The steam lines supply steam to the radiators, which discharge their air and condensate to the return lines. Traps are used at each radiator and at the end of each supply main to prevent the entry of steam into the return lines.

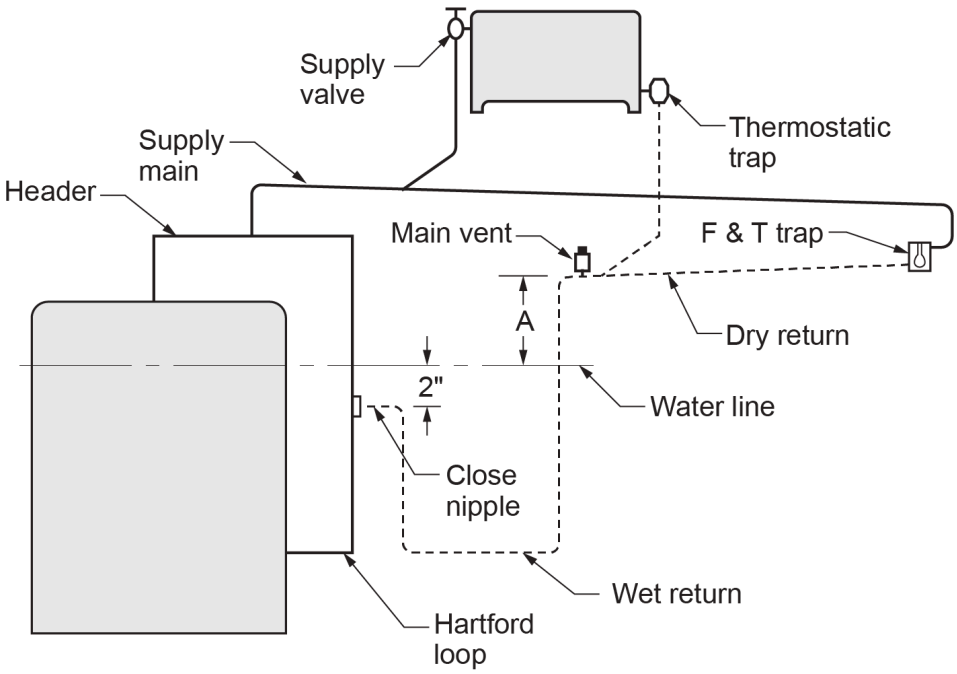

Figure 5 *Two-pipe gravity return system. (Skilled Trades BC, 2021) Used with permission.*

Steam traps also have a curious effect on the system's returns. Because they close off the steam, traps prevent steam pressure from getting into the returns. In a one-pipe system, the water returns to the boiler because of the static weight of the water in Dimension A and the "leftover" steam pressure at the end of the main.

Two-pipe systems do not have any leftover steam pressure to help move the condensate back into the the boiler. This is because of the traps. This means that with two-pipe steam systems, Dimension A must be at least 30 in. for every pound of pressure in the boiler. In other words, if a boiler fires at 2 psig, it will need 60 in. of height between the centre of the **gauge glass** and the bottom of the lowest steam main.

This is why condensate pumps are often used in two-pipe steam systems.

Pumped Condensate Return Systems

Installations with their dry return at an insufficient elevation over the boiler water line to provide gravity condensate return must be equipped with condensate return pumps (Figure 6). A condensate pump is the low point in the system. Everything must flow downhill to it. A condensate pump has a receiver tank for collecting returning condensate; the tank is vented to the atmosphere.

Inside the receiver is an electrical float switch. This switch turns the pump on when the water level inside the receiver rises and off when it falls. On the discharge side of the pump is a check valve (to keep the boiler water in the boiler) and a throttling valve. The throttling valve is used to slow the pump down because most pumps discharge at too high a rate and pressure for most residential heating applications. The throttling valve will stop the check valve from chattering by adding resistance to the pump's pressure.

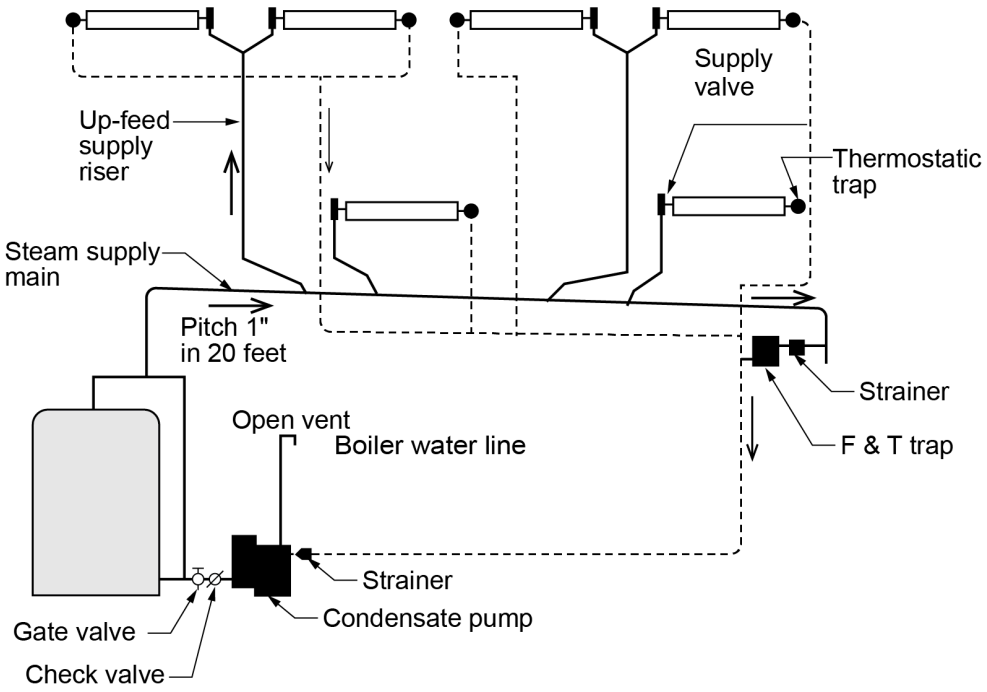

Figure 6 *Steam heating system with condensate pump. (Skilled Trades BC, 2021) Used with permission.*

One problem with condensate pumps is that they are only designed to fill and dump. They have no way of detecting if the boilers they serve need water or not, which can be a problem for low-water-content boilers. Because of this, boiler-feed pumps are sometimes used in place of condensate pumps.

A boiler-feed pump is different from a condensate pump because the float switch that controls the pump is located on the boiler itself rather than in the pump's receiver. With a boiler-feed pump, the pump can come on only if the boiler needs water.

The receiver in the boiler-feed pump is also much larger than the condensate pump's receiver. This oversized receiver gives the condensate a place to wait until the boiler needs it.

Self-Test B-1.2: Low-Pressure Steam Heating Systems

Complete Self-Test B-1.2 and check your answers.

If you are using a printed copy, please find Self-Test B-1.2 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

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B-1.3 Residential Forced Air Heating and Cooling Systems

In Canada, forced-air heating is the most common type of heating system used for residential and commercial buildings.

Pros and Cons of Forced Air Heating

One advantage forced-air systems have over other heating systems is the movement of the return air through a filter that constantly removes dust and other airborne particles from the air stream as the system works.

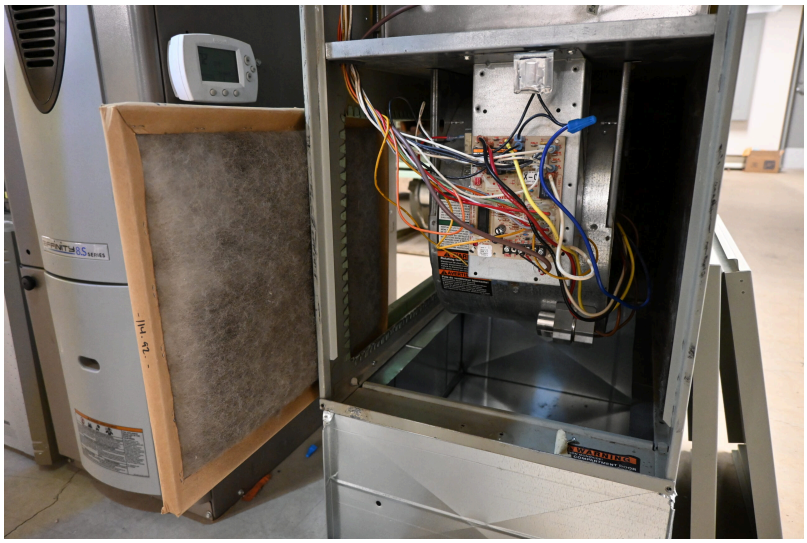

Figure 1 *Forced air furnace media filter installation. (TRU Open Press) CC BY-NC-SA (https://creativecommons.org/licenses/by-nc-sa/4.0/deed.en)*

Air filtration is a feature that neither electric baseboard nor hot water (hydronic) heating systems contain. Filtering the air lessens the amount of dust and debris that settles on furniture or is breathed in by occupants and keeps debris from plugging heating and cooling coils.

Another reason for the popularity of forced air heating systems is the ability to add an evaporator coil (Figure 2) into the ductwork so that the system can be used to cool the house in the summer months. This is another feature that neither electric baseboard nor hydronic systems can offer.

Forced-air systems are often chosen over hydronic heating systems because of the cost of installation. The cost of a ducted forced-air heating system is generally lower than a hydronic heating system.

Figure 2 *Evaporator (A) coil. (Skilled Trades BC, 2021) Used with permission.*

The downside of forced-air heating is the difficulty in maintaining a comfort level in all areas of the home. Typically, a single thermostat is located central to the structure, so it is not affected by cold transfer from outside walls and windows. The thermostat controls the on/off operation of the system. Airflow regulators, known as dampers, are installed in the individual supply duct runouts and/or the grilles and registers (Figure 3) to throttle airflow to a specific area. To maintain a consistent comfort level everywhere, the system must be balanced by adjusting each damper and measuring airflow at the outlets. Every adjustment has a direct effect on the airflow at other outlets, and any miscalculated movement of a damper's setting will throw the entire system out of balance.

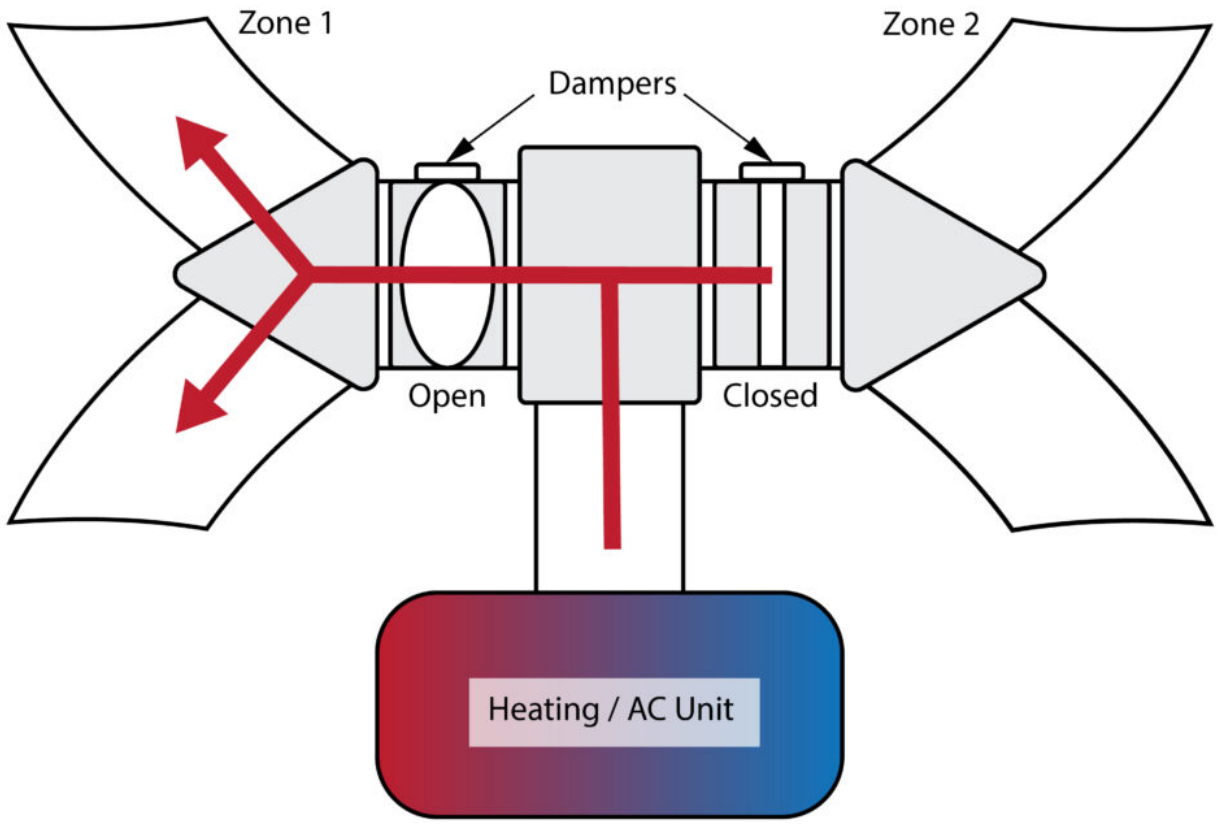

Figure 3 *Supply duct dampers. (TRU Open Press; [modified] Angi, 2024) CC BY-NC-SA (https://creativecommons.org/licenses/by-nc-sa/4.0/deed.en)*

The air flow in individual rooms can be restricted by dampers in the floor grilles.

Figure 4 *Floor grille with damper. (Skilled Trades BC, 2021) Used with permission.*

Furnace Types

Regardless of type, all furnaces consist of an air filter, a blower, a heat exchanger/element/coil, various operating and limit controls, and two main air plenums (supply and return) for ductwork connections.

Efficiency Types

As of January 1, 2010, Canadian federal efficiency guidelines have determined that all new installations of residential furnaces must have a minimum annual fuel utilization efficiency (AFUE) of 90%. This means that new gas furnace installations must be of the condensing type. When more heat energy is taken out of the products of combustion to meet this new requirement, the water vapour within those products condenses back into water, which forms carbonic

acid when mixed with the carbon dioxide in the flue gases. Depending on the drainage system and its overall dilution capabilities, this fluid may need to be drained directly (Figure 5) into an acid neutralizer.

Older (1980s–1990s) furnaces were considered mid-efficient, due to the design of the heat exchanger. These furnaces were capable of 80–83% efficiency. Very old furnaces (pre–1980) were known as standard efficiency, rarely breaking 78% efficiency.

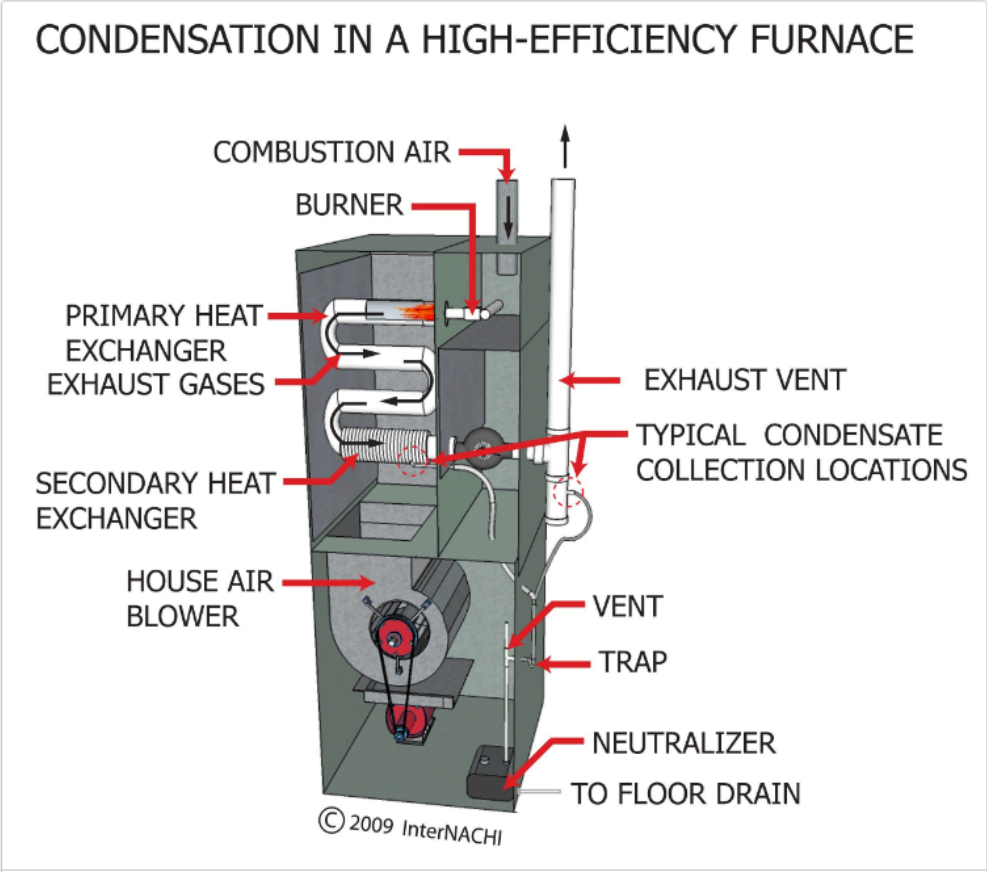

Figure 5 *High efficiency gas furnace with condensate drain going to an acid neutralizer.*
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Gas-fired furnaces are also split into categories based on their vent pressures and efficiencies (flue losses). Mid-efficiency furnaces are known as Category I and vented using metal Type B venting materials, whereas high-efficiency furnaces are Category IV and commonly use pressure sealed plastic Type BH venting materials.

Air Flow Configurations

Because of their in-shot burner orientation, most mid- and high-efficiency furnaces can be installed as upflow (most common for multi-level homes) (Figure 6), downflow (for rancher-style construction with a crawl space) (Figure 7), or horizontal flow (for mounting in a crawl space or attic) (Figure 8). These are known as convertible or multi-position furnaces (Figure 9). A convertible gas furnace may require special vent and drainage modifications to accommodate the various configurations.

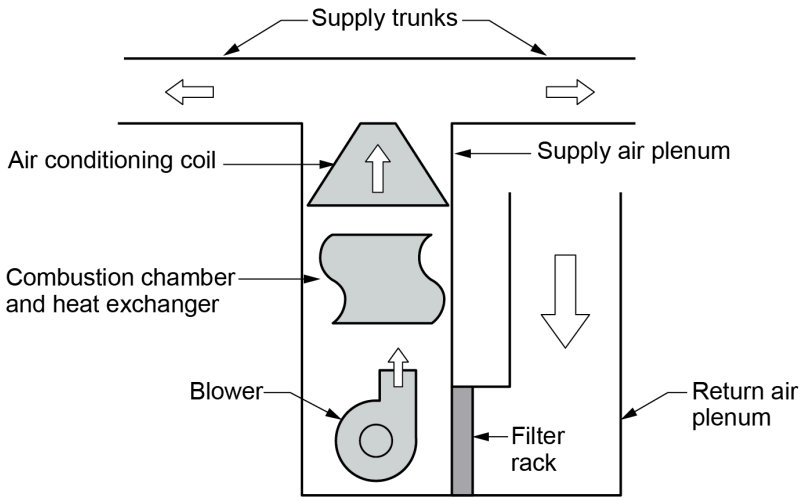

Figure 6 *Upflow furnace. (Skilled Trades BC, 2021) Used with permission.*

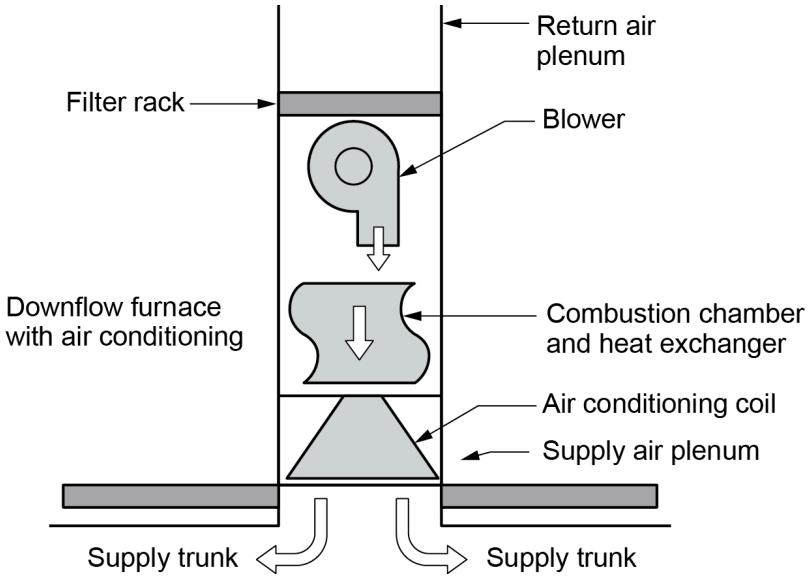

Figure 7 *Downflow furnace. (Skilled Trades BC, 2021) Used with permission.*

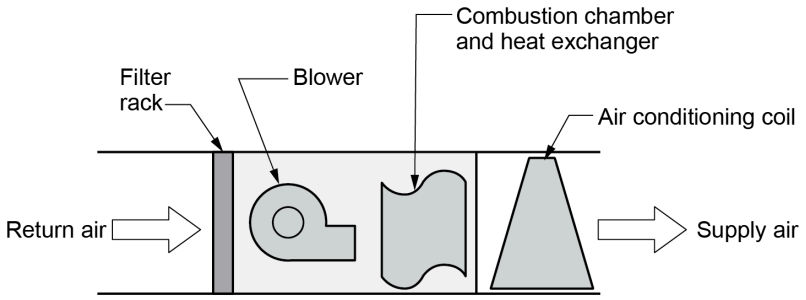

Figure 8 *Horizontal flow furnace. (Skilled Trades BC, 2021) Used with permission.*

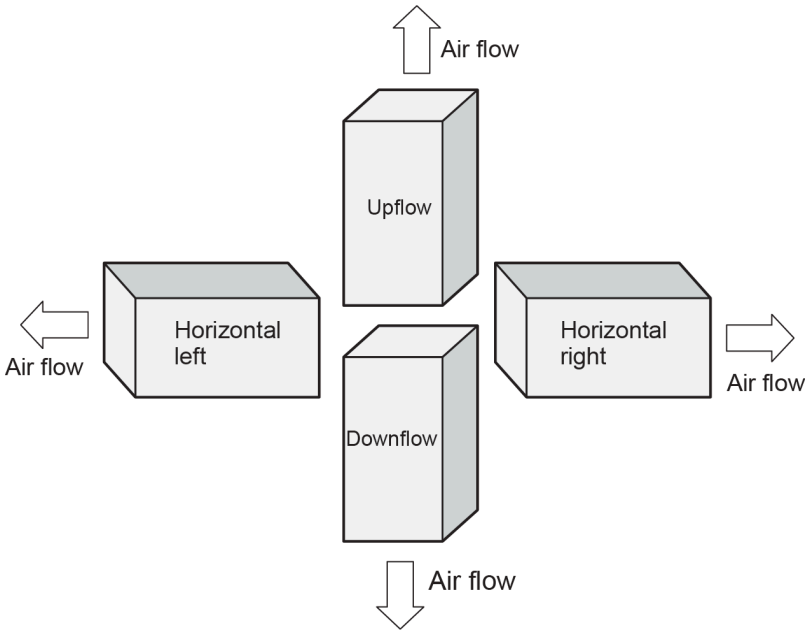

Figure 9 *Convertible furnace positions. (Skilled Trades BC, 2021) Used with permission.*

Air Filters

All forced-air furnaces require air filtration to operate safely and efficiently. Some furnaces are intended for use with specific types of filters, but in many cases, the filter is an add-on component, so the appropriate filter must be chosen.

Airborne particles can include dust created by activities both inside and outside the house, hair and skin flakes from pets and humans, tobacco smoke, spores, bacteria, and viruses. Some filters will easily remove the larger particles, such as visible dust, but smaller particles that can enter the lungs, such as bacteria and viruses, are the most problematic. For these particles, the chosen filter must have the ability to remove such small particles.

The minimum efficiency reporting value (MERV) is a numerical value given to filters to identify their filtering ability. This industry standard operates on a numerical value between one and 16 microns, with higher numbers indicating greater filtering capacity.

High-efficiency particulate arrestance (HEPA) filters, which remove a very high percentage of airborne contaminants, are often specified for various commercial, industrial, and institutional applications.

The tighter the filter media's fabrication, the harder it will be for airflow to pass through it. The blower fan's power and volume capabilities will need to be assessed for compatibility with each filter type.

Filter Types

The three basic types of air filters are media, electrostatic, and electronic.

Media filters (Figure 10) are the least complicated and, therefore, the least costly and most-used type. Made from paper, fibreglass, or cloth, they are positioned in the return air stream, where air is pulled through them toward the blower. They have a hammock, slab, or pleated design; can be reusable or disposable; and are available as low-, medium-, and high-efficiency types.

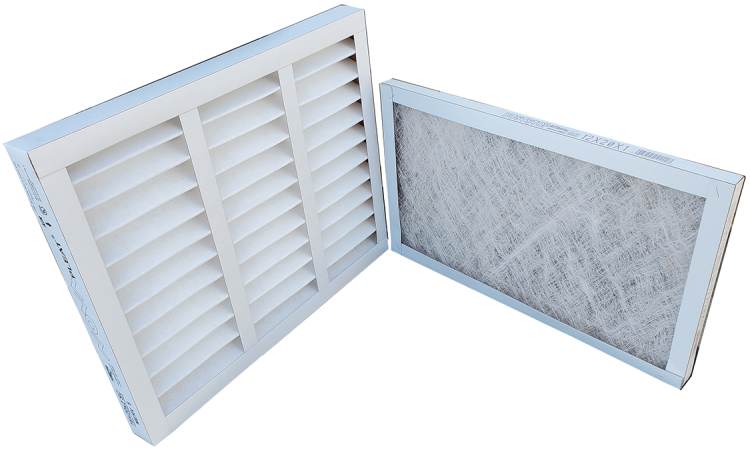

Figure 10 *Media-type filters. (Skilled Trades BC, 2021) Used with permission.*

Electrostatic filters (Figure 11) are media-type filters made from a material that generates a static charge when air flows through it. This static charge attracts and holds more particles to the medium than regular media filters.

Figure 11 *Electrostatic filters. (Skilled Trades BC, 2021) Used with permission.*

Electronic air cleaners (EAC) use an electronic charge to remove and collect particulate from the circulated air (Figure 12). They use an external power source rather than the airflow itself to generate the charge that attracts the particles. A charged plate collects the particles and requires manual cleaning.

Figure 12 *Electronic air cleaners. (Skilled Trades BC, 2021) Used with permission.*

Blowers

The blower is a squirrel-cage-type fan positioned between the filter and the heat exchanger. Air is pulled through the filter and pushed across the heat exchanger into the main supply plenum. Older models were driven by a belt connected by pulleys or sheaves to an alternating current (AC) single-speed electric motor (Figure 13). The speed of the blower could be increased or decreased by altering the position of the belt within an adjustable pulley mounted on the motor's shaft. Blowers can still be found today in appliances, such as rooftop heating and cooling units, which can be built larger to accommodate the extra room needed for the fan and motor.

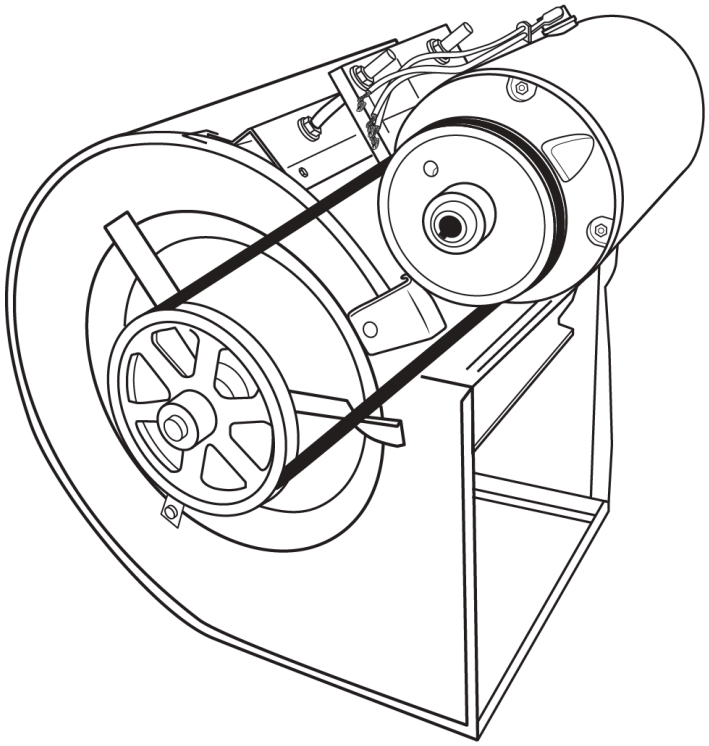

Figure 13 *Belt-driven blower. (Skilled Trades BC, 2021) Used with permission.*

Modern blowers (Figure 14) do not use pulleys and belts. The motor is mounted within the fan housing and connected directly to the fan's drive shaft direct drive. The speed of the fan is adjusted by connecting one of the wires from the motor's speed taps to the power supply.

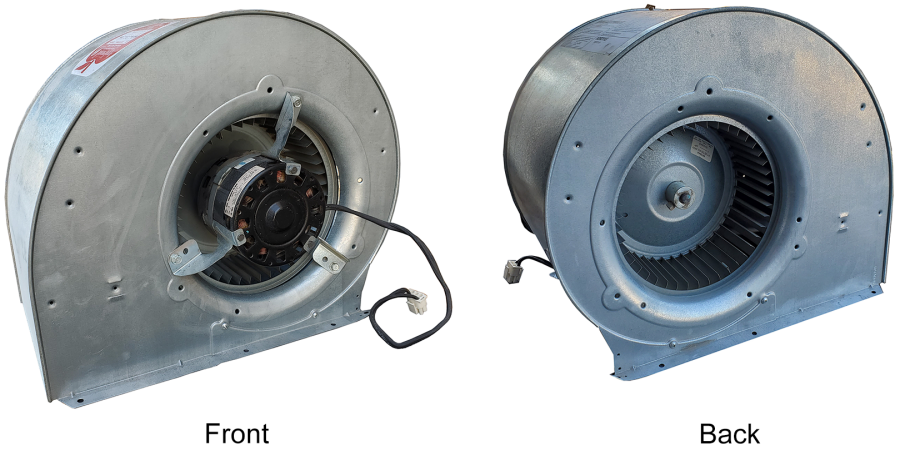

Figure 14 *Direct-drive blower (front and back). (Skilled Trades BC, 2021) Used with permission.*

Some high-efficiency blower models use direct current (DC) direct-drive motors capable of automatically adjusting their speed in relation to the filter's airflow. As the filter starts to collect dust, air flow through it is restricted, and the blower ramps up its speed to maintain the required air flow.

Heat Exchangers

Forced-air furnace energy sources are gas (natural or propane), fuel oil, electricity, heat pump, or hydronic (hot water) coil.

Gas or Fuel Oil Furnace

- Heat is produced by combustion of fuel gas through a burner or oil-type burner located in a combustion chamber.
- A heat exchanger keeps the products of combustion separated from the supply air stream.
- Ignition is provided by an electric spark, standing pilot, or hot surface igniter.
- There is a delay between the burner ignition and blower operation so that cold air is not blown into heating spaces before the heat exchanger has reached temperature.
- High-efficiency gas furnaces have a secondary heat exchanger to absorb as much heat as possible from the products of combustion and, thus, release flue gas condensate that must be drained to a safe location (Figure 15).
- Safety devices ensure that combustion gases and unburned fuel do not accumulate in the event of an ignition or venting failure.

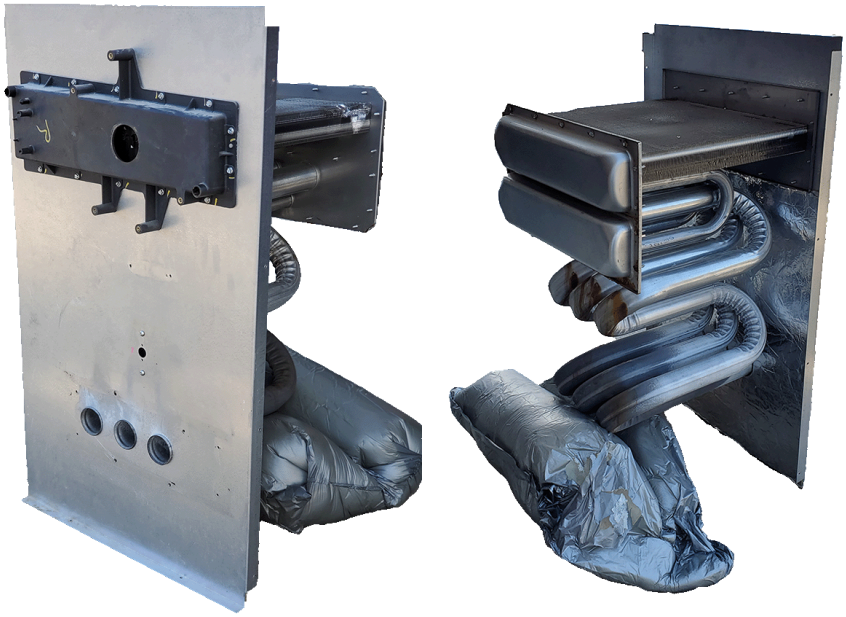

Figure 15 *High-efficiency heat exchanger (front and back). (Adapted from Skilled Trades BC, 2021) Used with permission.*

Electric Furnace

- Heating elements installed in the air stream are used to heat the supply air.
- When the thermostat calls for heat, the blower and electric element(s) come on at the same time.

- When the thermostat is “satisfied,” the blower and element(s) shut off.
- It has no heat exchanger, minimal moving parts, and requires very little maintenance.
- It is usually more expensive to operate than a natural gas furnace.

Heat Pump

- A heat pump extracts heat from the environment, using either the ground or outside air as the source, via the refrigeration cycle.
- It requires less energy than electric heat and is normally more efficient than fossil-fuel-fired furnaces (gas/oil).
- Air-source types may not be suitable for cold climates unless used with a backup (secondary) source of heat. Newer models may still provide heat when installed in temperatures below 0°C (32°F).
- A refrigerant coil is installed in place of the burner/heat exchanger. The system can also be used for cooling in a central air-conditioning system.

Figure 16 *Air source outdoor unit (left) and indoor A-coil (right). (Adapted from Skilled Trades BC, 2021) Used with permission.*

Hydronic Coil

- A hydronic coil combines a hydronic (hot water) heat source with forced-air delivery.
- Heat is produced by the combustion of fuel (natural gas, propane, wood) or electric heating elements in a hot water boiler.
- A heat exchanger, in the form of a hydronic coil, is placed in the air stream of the air handler. Copper is often used in the construction of supply and return manifolds and tube coils.
- Heated water is pumped through the heat exchanger then back to the boiler to be reheated. The air stream picks up the heat from the hot water coil and distributes it through the duct system.
- With a wood-fired boiler, a buffer tank is used between the hydronic coil and the boiler to store the energy. This

enables the wood boiler to fire continuously while loaded with wood and the hot water to circulate intermittently as space heating is required.

Duct Systems

Ducting is normally made of galvanized sheet metal or aluminum. It can be formed into square or rectangular ducts with machines or purchased in two L-shaped pieces and snapped together on site. Round ducts are also available in the same configuration and material and can be purchased in snap-together pieces or continuously formed lengths known as "spiral."

Warm air is moved by the blower through the supply air plenum into the trunk duct and distributed into the branches connected to the supply grilles or registers.

The plenum is the duct that connects directly to the furnace. There is a supply plenum and a return plenum on each forced-air furnace. The air filter is always mounted either inside the blower compartment or onto the return air plenum, where it attaches to the furnace.

If the plenum directs air into a trunk that runs in one direction only, away from the furnace, it is a one-way trunk and branch system (Figure 17). Such a system might result from the furnace being located near one side of a structure. A furnace located near the middle of the structure has two or more trunks running in each direction and is therefore called a two-way trunk and branch system (Figure 18).

Branches are ducts connected to the trunk main and terminating at the boot, which holds the heat grille or register in the floor, wall, or ceiling.

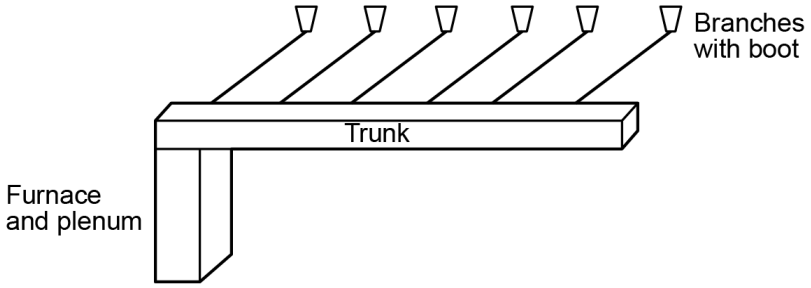

Figure 17 *Trunk and branch (one-way system). (Skilled Trades BC, 2021) Used with permission.*

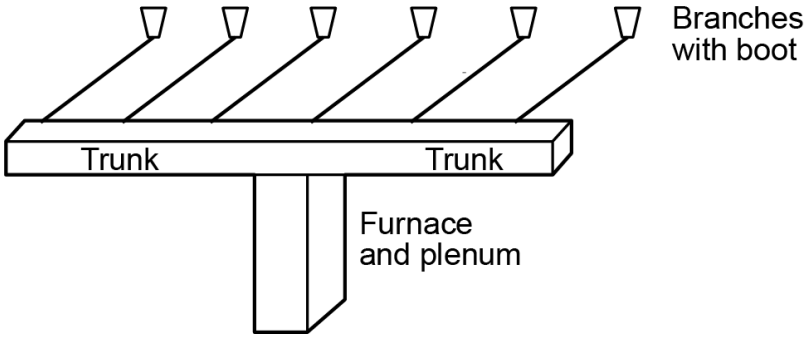

Figure 18 *Trunk and branch (two-way system). (Skilled Trades BC, 2021) Used with permission.*

In addition to the trunk and branch layout, branches can be installed in a spider, radial, or perimeter loop configuration (Figure 19).

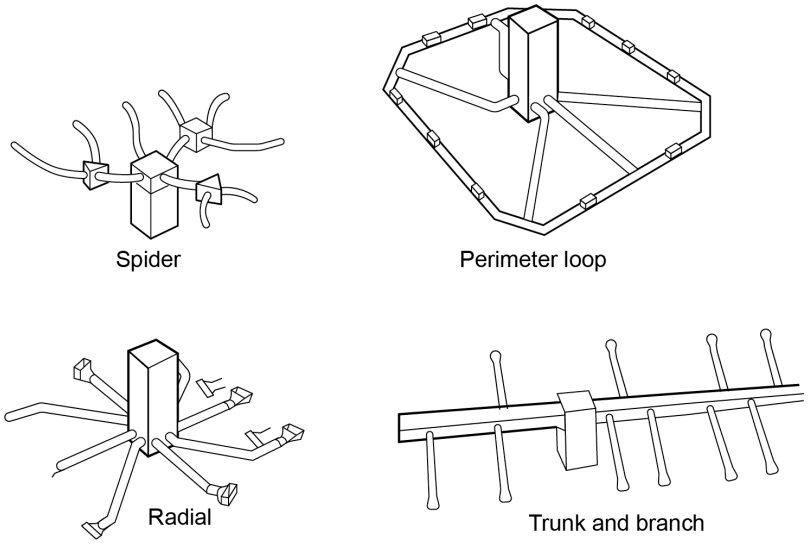

Figure 19 *Duct system configurations. (Skilled Trades BC, 2021) Used with permission.*

A branch that connects to a terminal fitting on an exterior wall will allow outside air to be drawn into the return air system whenever the blower operates. This is installed so that fresh air for the ventilation of the building and health of its occupants can be heated and distributed throughout the building.

Airflow Controls

Most duct systems in residential applications have manually adjusted dampers to control the airflow to the heat registers. The initial commissioning balancing process sets and locks these dampers into place. When the heating system operates, warm air is delivered evenly to all areas of the structure. If a demand for heat exists in selected areas only, a more sophisticated system of control is required, known as “zoning.” This involves installing motorized dampers on either the trunk or branches that open or close in response to an electric circuit being energized. For instance, in a two-storey home with a suite in the basement, one dedicated trunk could supply heat to the basement branches only

while the other supplies the upstairs branches. A large motorized damper on each trunk would allow someone to control the heat supply to either the upstairs or the basement independently or simultaneously. Motorized dampers are not normally found in residential buildings.

Figure 20 *Motorized zone damper (TRU Open Press) CC BY-NC-SA (https://creativecommons.org/licenses/by-nc-sa/4.0/deed.en)*

Forced-Air Add-On Devices

Outdoor air in the winter can become very dry. Moisture levels are reduced with a drop in temperature. A humidifier maintains indoor relative humidity to around 40%. Moist air helps maintain comfort. Excessively dry air can make occupants feel colder than normal.

Benefits of Humidifiers

- Assists in minimizing the presence of static electricity.
- Helps keep nasal membranes from drying out (dry nasal membranes reduce occupants' susceptibility to fight colds and other airborne viruses).
- Prevents certain building materials from drying out, such as hardwood floors.

There are many types of humidifiers available, with each type introducing water vapour into the supply air stream in various ways. A control called a humidistat measures indoor humidity and activates an atomizing or steam type humidifier installed onto or inside the supply air plenum.

Controls

The main comfort control for a forced-air system is the thermostat. It is mounted on an interior wall, usually central to the floor area on the main living floor. It is installed around 1.5 m (5 ft) above the finished floor level in an area where it will not be exposed to stray heating or cooling effects. Older-style thermostats contain an internal bimetal coil that, when exposed to a change in temperature, rotate and make or break a set of electrical contacts to activate or deactivate a heating system. Newer-style thermostats use thermistors to sense the temperature in the structure. Most thermostats, as well as the other controls on a heating system, operate on a 24-volt AC-control voltage.

Thermostats can be heat-only, heat/cool, analogue, digital, digital/programmable, or Wi-Fi–enabled ("smart"). Programmable thermostats are increasingly popular with forced-air heating due to the air's low thermal mass. This means the temperature settings on a thermostat serving a building heated with forced air can be set to a lower temperature in the evening or anytime the building is unoccupied, then raised quickly during occupied hours. "Smart" thermostats communicate through the customer's Wi-Fi system and can be adjusted remotely for even more control options.

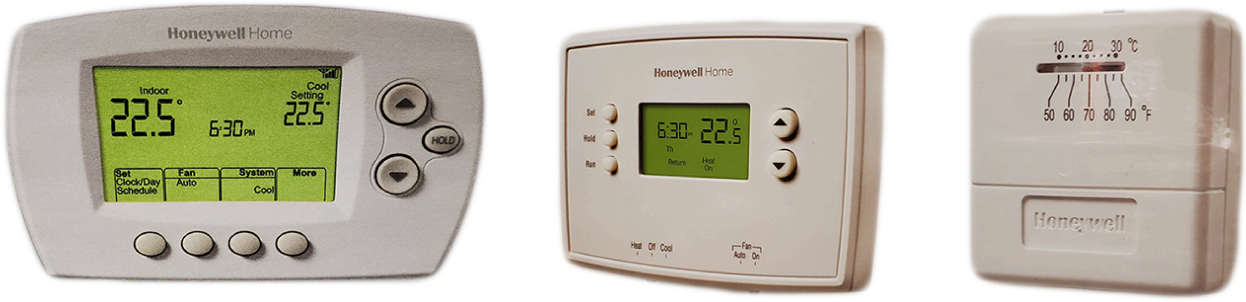

Figure 21 *"Smart," digital-programmable, and non-programmable analogue thermostats. (Adapted from Skilled Trades BC, 2021) Used with permission.*

Other controls found on gas-fired furnaces include:

- High temperature limit switches that open an electrical circuit and shut off the gas valve when it senses excessive temperature inside the heat exchanger.

Figure 22 *High-limit thermal switch. (Adapted from Skilled Trades BC, 2021) Used with permission.*

- Flame rollout switches that open an electrical circuit to shut off the gas supply if the flame rolls off the burners and into the appliance's controls compartment.
- Air pressure switches (Figure 23) that are set to sense designed pressures within the combustion chamber, vent piping, or combustion air intake piping and that open or close electrical contacts when it senses pressures above or below the required designed pressure.

Figure 23 *Pressure switch. (Skilled Trades BC, 2021) Used with permission.*

- Blocked vent safety switches located on the draft hood of older appliances that sense the heat from a blocked venting system above the draft hood and open electrical contacts to shut off the burner.

- Gas pressure regulators that control the pressure of gas supplied to the burner and in the piping that feeds heating equipment.
- A furnace control module that controls the operation of the gas delivery system. Newer modules, called integrated furnace controls, also control the blower.

Self-Test B-1.3: Residential Forced Air Heating and Cooling Systems

Complete Self-Test B-1.3 and check your answers.

If you are using a printed copy, please find Self-Test B-1.3 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://b-heating-bcplumbingapprl2.pressbooks.tru.ca/?p=41#h5p-3 (https://b-heating-bcplumbingapprl2.pressbooks.tru.ca/?p=41#h5p-3)

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Retrieved February 27, 2025, from https://www.angi.com/articles/how-to-find-dampers-in-ducts.htm (https://www.angi.com/articles/how-to-find-dampers-in-ducts.htm)

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- **Figure 1** Force air furnace media filter installation is by TRU Open Press.
- **Figure 3** Supply duct dampers is by TRU Open Press, modified from original image by Angi (2024) for educational purposes.
- **Figure 5** High efficiency gas furnace with condensate drain going to an acid neutralizer (https://www.nachi.org/gallery/heating/condensation-in-a-high-efficiency-furnace-2) is ©InterNACHI® and is used with Permission.

B-1.4 Hydronic Heating and Cooling Systems

Hydronics is the concept of using water as a vehicle to move thermal energy between two points. Installers must understand that both hydronic heating and cooling involve the transfer of heat. Heating and cooling systems for buildings either add or remove heat from a space to keep its occupants comfortable. In some cases, heating or cooling is used for process purposes, as with refrigerators, freezers, and kilns.

The study of hydronics here will focus on providing an environment within buildings that allows people to be comfortable during their daily activities. This section will concentrate primarily on using hydronics for heating because this practice is widespread and occurs in both residential and commercial environments, whereas hydronic cooling is not as common in homes and residential buildings.

Hydronic Systems

In hydronic heating systems, water can be thought of as the transportation medium for heat. Thermal energy is absorbed by the water at the heat source (most commonly a boiler), carried by the water through the piping, and released into a space by a **heat emitter**. Hydronic cooling systems use the same principle, except the water carried by the piping absorbs unwanted heat from a space, such as a room or zone, and takes it back to the equipment that removes the heat (most commonly a cooling tower and chiller). It then sends this chilled water back to the space again. In many of today's sophisticated building energy systems, the heat absorbed by the chilled water can be used to transfer heat to other parts of the building or to preheat domestic water. This creates greater efficiency within the heating and cooling systems.

Water has many characteristics that make it ideal for heating and cooling. It is nontoxic, non-flammable, and readily available and has one of the highest heat-storage capabilities of any material.

The earliest hydronic heating systems, known as gravity systems, operated on the principle of buoyancy (Figure 1). Water becomes less dense when heated, and this density differential between water in the boiler supply and return mains causes convection currents that carry the hot water out and up through piping to the heat transfer units (HTU). At the HTUs, the water releases its heat and regains density, falling back down through the return piping to the boiler. Because of the absence of electricity and pumps, these systems needed larger diameter piping to create enough circulation to carry heat to the far reaches of a building. With the advent of compact electricity pumps came forced circulation systems to move the water between the heat source and emitters (Figure 1). This resulted in many improvements, such as better control and smaller-diameter piping.

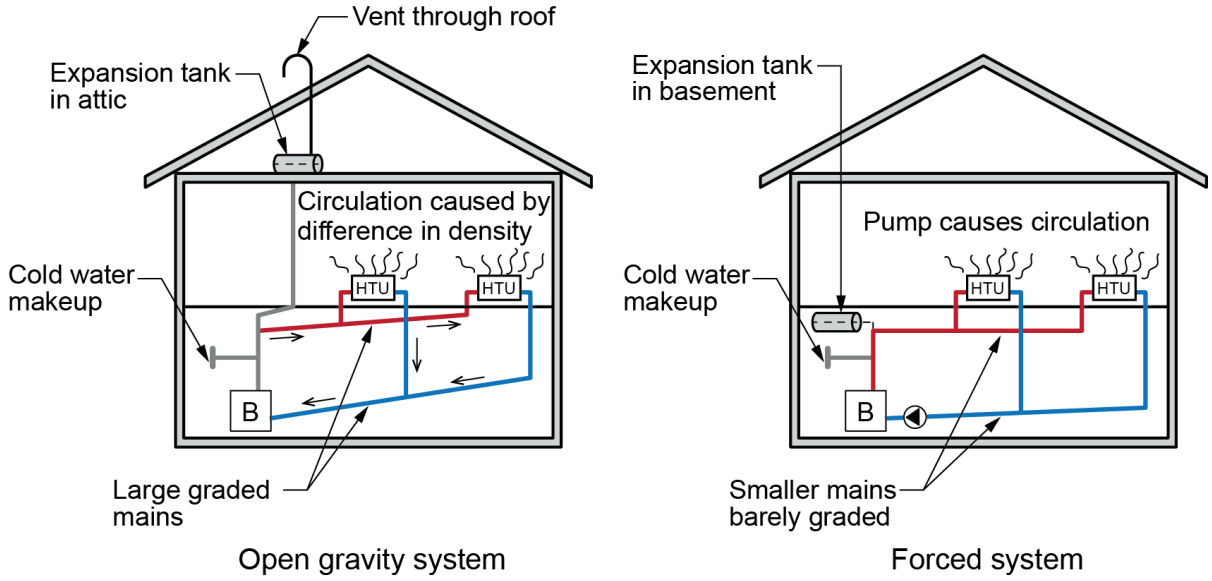

Figure 1 *Water circulation systems. (Skilled Trades BC, 2021) Used with permission.*

Comfort is the Goal

Comfort can best be described as the absence of discomfort, for example, when a person feels neither too hot nor too cold. It is rare that someone will comment on how comfortable a room feels, but they certainly know when they feel uncomfortable. Maintaining comfort is not a matter of supplying heat to the body but of controlling the manner and rate at which the body loses heat.

Heat is a byproduct of our bodies' functions, and a normal adult engaged in light activity generates heat at a rate of approximately 400 British thermal units per hour (BTU/h) or 422 kiloJoules per hour (kJ/hr). Comfort is achieved when the interior environment allows heat to leave the body at the same rate as it is produced. As the activity level increases so does the need for the immediate environment to transfer the extra heat away at the same rate that it is being generated. Failing to do so fast enough will cause the person to feel overheated and uncomfortable. When interior conditions allow heat to leave a person's body at the same rate that it is generated, that person feels comfortable.

In a typical indoor environment, approximately 48% of a person's body heat is released by thermal radiation to colder surfaces (e.g., standing by a window), 30% is released by convection to surrounding air (e.g., sitting in a drafty room), and 22% is released by evaporation from the skin (sweating). A small amount may also be released by conduction from skin or clothing surfaces in contact with cooler objects (e.g., bare feet on a cold floor and also through respiration (breathing out warm air)). Because the human body is affected mostly by radiant heat loss, people feel the effects of proximity to cold surfaces such as windows and supermarket refrigerators and freezers more easily. The greater the temperature differential (ΔT) between body temperature and ambient or surface temperature, the faster the rate of departing body temperature. Sometimes people notice that they feel cold while standing beside cold surfaces when the ambient temperature is actually at the comfortable level of 22°C. This is the reason that radiant heating systems are widely accepted as being the most comfortable of all (Figure 2).

The advantage of heating through radiation is that surfaces in rooms tend to become warmer. This reduces the effect of radiant heat loss from the body and increases comfort. Later sections will cover radiant systems in greater detail.

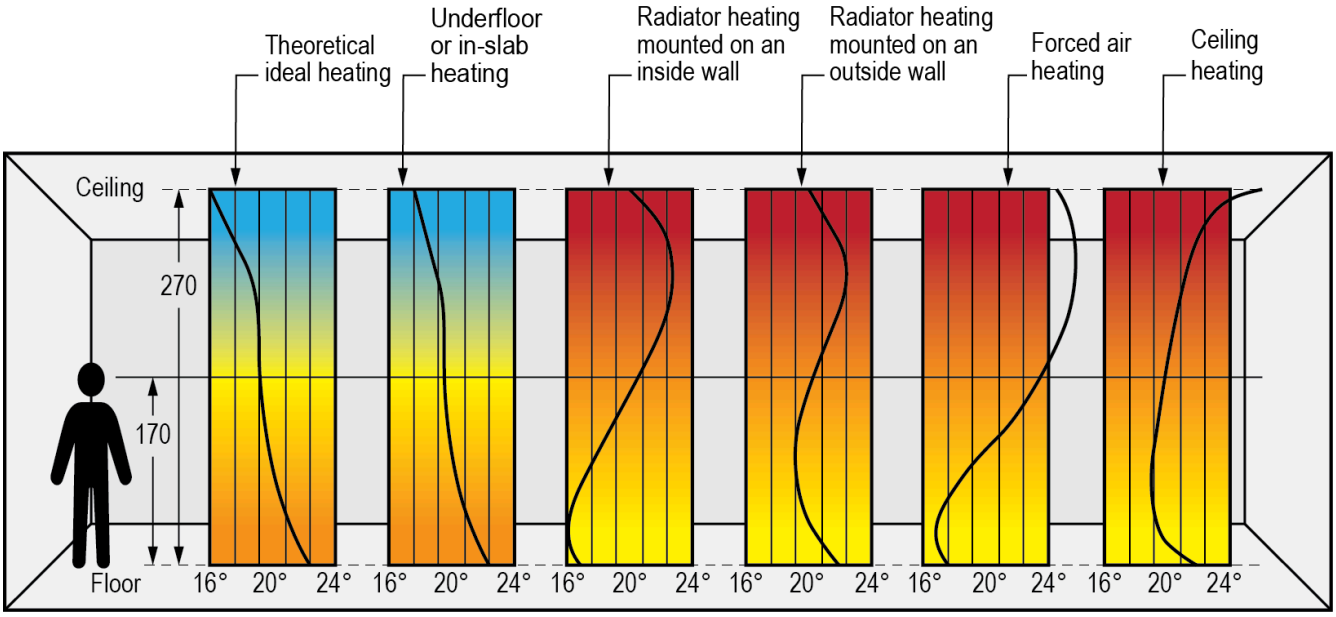

Figure 2 *This graph shows ideal heat and temperature; blue is cold, red is hot. (Skilled Trades BC, 2021) Used with permission.*

Advantages and Disadvantages of Hydronic Heating and Forced-Air Heating

Water has long been known to be a good heat transportation medium, particularly in Europe, where houses and buildings have been heated by water for decades, even centuries.

The practice of using air for heating is a North American development. Houses here do not tend to stay with one family for generations, as is common in Europe. Many studies have indicated that North Americans stay in one house for an average of seven years and, consequently, the extra cost of a hot water heating system over that of a forced warm air system may not be recovered by the time a person sells their house. Short-term economics are at play here, and comfort is collateral damage.

There are many advantages, and some disadvantages, of heating with hot water rather than with forced air.

Main Advantages

- **Energy savings:** many studies have consistently shown that hot-water heating systems use less energy than forced-air heating systems in similar structures.
- **Control:** a hydronic system can have as many areas of control (zones) as the occupants desire. A forced-air system typically has one thermostat location and can only hope to achieve comfort in all areas of a building according to that thermostat's set point.
- **Design flexibility:** hydronic heating offers almost unlimited possibilities to accommodate, such as space heating, domestic water heating, snow melting, and pool heating.
- **Clean and quiet operation:** a hydronic system operating properly is silent, whereas airflow through ducts and outlets generates noise.
- **Fewer germs and contaminants:** hydronic systems do not circulate as much dust and pollen through the air as forced-air systems. Also, people who are ill can be isolated in bedrooms and their germs are not as readily spread

throughout the rest of the building.

- **Less air stratification:** stratification is the tendency of warm air to rise and accumulate at the ceiling, as shown in Figure 2, while cold air falls and gathers at the floor. The heat losses through the walls near the ceiling are much higher with these "bands" of stratification.
- **Non-invasive installation:** a $\frac{3}{4}$ in. copper tube can carry the same amount of heat energy in water out to a house as can an 8 in. by 14 in. rectangular duct carrying heated air. Piping can be hidden by running through floor joists, whereas heating ducts must be installed below the joists, creating unnecessary drops in ceiling height.

Main Disadvantages

- **Installation cost:** when comparing the installation costs between of a hydronic heating system and a forced-air system, the forced-air system is on average less costly to install.
- **Reaction time:** a forced-air system is quicker to respond to temperature demands in a room due to its lower thermal mass than a hydronic system using convectors or radiant panels; of these two, convectors respond more quickly than radiant panels.
- **Heat emitter intrusion:** aside from radiant floor and ceiling panels, the heat emission units or heat transfer units used in hydronic heating tend to interfere with the aesthetics of a room. Radiators and convectors can affect the placement of furniture and drapes, among other things.

The advantages of hot water heating over forced air are many and contribute toward the general acceptance of hydronic heating as being the system of choice.

Self-Test B-1.4: Hydronic Heating and Cooling Systems

Complete Self-Test B-1.4 and check your answers.

If you are using a printed copy, please find Self-Test B-1.4 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

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Self-Test B-1.1: Heat and Heat Transfer

Complete Self-Test B-1.1 and check your answers.

1. Besides conduction and convection, in what way does most heat travel?
    a. Radiation
    b. Insulation
    c. Gravity
    d. Centrifugal force

2. Which one of the following items does heat travel through most quickly?
    a. Conductor
    b. Radiator
    c. Insulator
    d. Convector

3. What kind of heat moves through air without actually heating the air?
    a. Conduction
    b. Convection
    c. Radiation
    d. Insulation

4. What is the gravity circulation of water between a boiler and a heat transfer unit called?
    a. Convection
    b. Conduction
    c. Radiation
    d. Insulation

5. What is circulation in a gravity system caused by?
    a. The boiler being higher than the emitter
    b. The emitters being above the boiler piping
    c. The difference in the water densities in the system
    d. A pump

6. The density of a liquid or gas is usually increased as its temperature increases.
    a. True
    b. False

7. There is a gradual density loss as water is heated.
    a. True

b. False

8. How does water lose heat through the walls of pipe?
   a. Convection
   b. Conduction
   c. Insulation
   d. Radiation

9. By what process is heat transferred between the Sun and Earth?
   a. Convection
   b. Conduction
   c. Insulation
   d. Radiation

10. What is the heat conductivity of air in BTU/hr per ft^2 per °F per inch of thickness?
    a. 320
    b. 12
    c. 4.1
    d. 0.15

11. A BTU is the measurement of what?
    a. Heat's intensity
    b. Heat's quantity
    c. Heat's conductivity
    d. Heat's reactivity

12. A degree Fahrenheit is the measurement of what?
    a. Heat's intensity
    b. Heat's quantity
    c. Heat's conductivity
    d. Heat's reactivity

13. One kilowatt equals how many BTU/h?
    a. 1,000
    b. 2,520
    c. 3,412
    d. 5,214

14. "The quantity of heat required to raise or lower the temperature of one pound of water by one degree Fahrenheit" is a description of what?
    a. One joule

b. One calorie
c. One watt
d. One BTU

Answer Key: Self-Test B-1.1 (#chapter-answer-key-self-test-b-1-1) is on the next page.

Answer Key: Self-Test B-1.1

1. a. Radiation
2. a. Conductor
3. c. Radiation
4. a. Convection
5. c. The difference in the water densities in the system
6. b. False
7. a. True
8. b. Conduction
9. d. Radiation
10. d. 0.15
11. b. Heat's quantity
12. a. Heat's intensity
13. c. 3412
14. d. BTU

Self-Test B-1.2: Low-Pressure Steam Heating Systems

Complete Self-Test B-1.2 and check your answers.

1. What is the maximum steam pressure that a residential steam heating system should operate at?
    a. 2 psig
    b. 15 psig
    c. 30 psig
    d. 100 psig

2. Latent heat rather than steam pressure does the actual heating work in a residential steam heating system.
    a. True
    b. False

3. What is the name of the control that operates the boiler's burner?
    a. Thermostat
    b. Pressuretrol
    c. Boiler reset
    d. Operating aquastat

4. What is the name of the horizontal steam pipe that joins together the boiler outlets?
    a. Header
    b. Equalizer
    c. Supply main
    d. Hartford loop

5. What is the name of the vertical pipe that balances the pressure between the supply and return side of the boiler?
    a. Riser
    b. Header
    c. Equalizer
    d. Supply main

6. What is the name of the type of system in which steam and condensate travel in opposite directions in the steam main piping?
    a. Two pipe
    b. Wet return
    c. Counterflow
    d. Parallel flow

7. On a gravity return two-pipe steam heating system, what is the minimum height required between the centre of

the gauge glass and the bottom of the lowest steam per psi of boiler pressure?

a. 10 cm
b. 0.433 ft
c. 30 in.
d. 2.31 in.

8. How does the boiler-feed pump activate (not condensate pump)?

a. The pump is activated by the boiler pressuretrol.
b. The pump is activated by a reverse-acting aquastat.
c. A float switch turns the pump on when water level inside the boiler drops.
d. A float switch turns the pump on when water level inside the receiver rises.

Answer Key: Self-Test B-1.2 (#chapter-answer-key-self-test-b-1-2) is on the next page.

Answer Key: Self-Test B-1.2

1. a. 2 psig
2. a. True
3. b. Pressuretrol
4. a. Header
5. c. Equalizer
6. c. Counterflow
7. c. 30 inches
8. c. A float switch turns the pump on when water level inside the boiler drops.

Self-Test B-1.3 Residential Forced Air Heating and Cooling Systems

Complete Self-Test B-1.3 and check your answers.

1. What is the most common reason that forced-air heating systems are installed rather than electric baseboard or hydronic?
    a. The least costly to install.
    b. Filters the air being heated.
    c. Provides the most comfort.
    d. Operates without any noise.

2. What is the term for when the airflow through the system is adjusted in an attempt to deliver an even heat throughout the building?
    a. Air throttling
    b. Equalization
    c. Balancing
    d. Evening out

3. What is another term for airflow regulators?
    a. Valves
    b. Regulators
    c. Air stops
    d. Dampers

4. What is the current minimum required efficiency for new furnaces?
    a. 100%
    b. 90%
    c. 80%
    d. 78%

5. New furnace installations must be of which type?
    a. Evaporating
    b. Condensing
    c. Convecting
    d. Conducting

6. What is produced when carbon dioxide is allowed to mix with water in the flue of a gas-fired appliance?
    a. Carbon black
    b. Carbohydrates

c. Carbonic acid
d. Carbon tetrachloride

7. What category do high-efficiency furnaces fall under?
    a. I
    b. II
    c. III
    d. IV

8. What is the term for the style of burners used by mid- and high-efficiency furnaces?
    a. In-shot
    b. Up-shot
    c. Side-shot
    d. Buck-shot

9. What type of forced-air furnace would be used in a rancher-style house where the furnace sits on the main floor and the warm air ductwork is below the floor in the crawl space
    a. Up flow
    b. Top flow
    c. Down flow
    d. Horizontal flow

10. Which one of the following is not a type of furnace filter?
    a. Media
    b. Electronic
    c. Electrostatic
    d. Electromagnetic

11. Which one of the filters below generates a static charge when air flows through it?
    a. Media
    b. Electronic
    c. Electrostatic
    d. Electromagnetic

12. Where is the furnace blower located?
    a. Between the filter and heat exchanger
    b. Between the heat exchanger and the supply plenum
    c. Upstream of the return air plenum connection to the furnace
    d. Downstream of the supply air connection to the heat exchanger

13. How do you adjust the speeds of a belt-driven blower?

a. Plug in different wires from speed taps on the motor
b. Adjust a pulley attached to the blower wheel
c. Adjust a pulley attached to the motor
d. Replace the pulley on the blower

14. Which one of the following would not contain a heat exchanger of some variety?

a. Gas furnace
b. Oil furnace
c. Heat pump
d. Electric furnace

15. Which one of the following gains its heat by extracting it from the ground or outside air and transferring it to a refrigerant coil?

a. Heat pump
b. Gas furnace
c. Hydronic coil
d. Fuel oil furnace

16. What is the sequence of heated airflow in a trunk and branch duct system?

a. Trunk, plenum, register, branch
b. Plenum, trunk, branch, register
c. Branch, plenum, trunk, register
d. Register, plenum, trunk, branch

17. If zoning is desired in a forced-air system, what components must be installed?

a. Heat exchangers
b. Electronic air cleaners
c. Motorized automatic dampers
d. Condensers and evaporators

18. What is the main comfort control for a forced-air heating system?

a. Thermostat
b. High-limit switch
c. Direct-drive motor
d. Motorized damper

19. What component oversees the operation of the entire furnace and is found on most newer furnaces?

a. Gas pressure regulator
b. Blocked vent safety switch
c. Motorized automatic damper
d. Integrated furnace control

Answer Key: Self-Test B-1.3 (#chapter-answer-key-self-test-b-1-3) is on the next page.

Answer Key: Self-Test B-1.3

1. a. The least costly to install.
2. c. Balancing
3. d. Dampers
4. b. 90%
5. b. Condensing
6. c. Carbonic acid
7. d. IV
8. a. In-shot
9. c. Down flow
10. d. Electromagnetic
11. c. Electrostatic
12. a. Between the filter and heat exchanger
13. c. Adjust a pulley attached to the motor
14. d. Electric furnace
15. a. Heat pump
16. b. Plenum, trunk, branch, register
17. c. Motorized automatic dampers
18. a. Thermostat
19. d. Integrated furnace control

Self-Test B-1.4 Hydronic Heating and Cooling Systems

Complete Self-Test B-1.4 and check your answers.

1. Why is water a good medium for transporting thermal energy?
    a. It can exist in all three states.
    b. It can only exist as a liquid.
    c. It has a low heat-storage ability.
    d. It has a high heat-storage ability.

2. With the ideal heating or cooling system, the occupants would not be conscious of either warm or cold sensations.
    a. True
    b. False

3. The purpose of a building's heating system is to raise the temperature of the building.
    a. True
    b. False

4. What is the best definition of "comfort"?
    a. The absence of discomfort
    b. When your feet are warm
    c. When your face is cool
    d. It is too vague to define.

5. Approximately how many British thermal units (BTU) will an adult generate every hour through normal indoor activity?
    a. 200
    b. 400
    c. 600
    d. 1,000

6. What are the three main ways that a person loses heat?
    a. Convection, conduction, and respiration
    b. Conduction, respiration, and perspiration
    c. Radiation, convection, and evaporation
    d. Radiation, perspiration, and respiration

7. Where was the expansion tank located in the old gravity hot water heating systems?

a. In the basement
b. In the attic
c. Below the boiler
d. Beside the boiler

8. What addition to hydronic systems, brought about by the supply of electricity, allowed the use of smaller piping than that used in gravity systems?

a. Copper tube
b. Natural gas
c. City water
d. Pumps

9. Approximately what percentage of a person's heat is lost through convection?

a. 22%
b. 30%
c. 48%
d. 55%

10. A $\frac{3}{4}$ in. copper pipe can carry as much heat out into the building as what size hot air duct?

a. 3 in. round
b. 6 in. by 6 in.
c. 8 in. by 14 in.
d. 16 in. round

11. What is the term given to the bands of temperature in a room caused by warm air rising and collecting at the ceiling and cold air falling to the floor?

a. Stratification
b. Ramification
c. Collection
d. Conduction

12. What feature of a forced-air system allows it to have a quicker response time than a hydronic heating system?

a. High-velocity airflow
b. High thermal mass
c. Low-velocity airflow
d. Low thermal mass

13. What is an area of control known as?

a. Zone
b. Pass
c. Section

d. Wing

Answer Key: Self-Test B-1.4 (#chapter-answer-key-self-test-b-1-4) is on the next page.

Answer Key: Self-Test B-1.4

1. d. It has a high heat storage ability
2. a. True
3. b. False
4. a. The absence of discomfort.
5. b. 400
6. c. Radiation, convection, and evaporation
7. b. In the attic
8. d. Pumps
9. b. 30
10. c. 8 in. by 14 in.
11. a. Stratification
12. d. Low thermal mass
13. a. Zone

Plumbing Apprenticeship & Trade Resources in BC

A successful career in plumbing requires a strong foundation of skills, knowledge, and workplace safety awareness. Below are key resources to support plumbing apprentices in BC, including educational pathways, trade certifications, workplace safety guidelines, and mental health and wellness support.

Plumbing Apprenticeship & Certification Resources

- **SkilledTradesBC – Plumbing Apprenticeship (https://skilledtradesbc.ca/plumber)** — Overview of plumbing training, certification requirements, and apprenticeship pathways in British Columbia.
- **Red Seal Program – Plumber (https://www.red-seal.ca/eng/trades/plumbers/overview.shtml)** — National certification program with exam prep guides and trade mobility information.
- **BC Building Codes & Standards (https://www.bccodes.ca/)** — Official building and plumbing codes for British Columbia.

Workplace Safety & Regulations

- **WorkSafeBC (https://www.worksafebc.com/en)** — Essential safety resources for plumbers, including:
  - Health & Safety – WorkSafeBC (https://www.worksafebc.com/en/health-safety)
  - Report Unsafe Working Conditions (https://www.worksafebc.com/en/contact-us/departments-and-services/health-safety-prevention)
  - Report a Workplace Injury or Disease (https://www.worksafebc.com/en/claims/report-workplace-injury-illness)
  - Submit a Notice of Project Form (https://www.worksafebc.com/en/for-employers/just-for-you/submit-notice-project)
  - Get Health and Safety Resources (Videos, Posters, Publications, and More) (https://www.worksafebc.com/en/resources-health-safety)
  - Search the OHS Regulations (and Related Materials) (https://www.worksafebc.com/en/law-policy/occupational-health-safety/searchable-ohs-regulation)
  - Conduct an Incident Investigation (https://www.worksafebc.com/en/health-safety/create-manage/incident-investigations/conducting-employer-investigation)
- **CCOHS: OHS Answers Fact Sheets – Plumber (https://www.ccohs.ca/oshanswers/occup_workplace/plumber.html)** — Safety guidelines and best practices for plumbers in various work environments.

Financial Supports

- **Financial Support (SkilledTradesBC)** (https://skilledtradesbc.ca/financial-support) — Information about grants, tax credits, Canada apprentice loans, employment insurance, and the Indigenous Skills and Employment Training

(ISET) program.
- **StudentAidBC (https://studentaidbc.ca/)** — Complete post-secondary education through student loans, grants, and scholarships. There is also programs that help with loan repayment.
- **WorkBC (Government of BC)** (https://www.workbc.ca/find-loans-and-grants/students-and-adult-learners/services-apprentices-and-employers) — Services for apprentices and employers.

Mental Health & Wellness Support

- **HealthLink BC – Mental Health and Substance Use** (https://www.healthlinkbc.ca/mental-health-and-substance-use) — HealthLink BC resources for mental health and wellness support.
- **Here2Talk** (https://here2talk.ca/) — Free and confidential counseling services available to all post-secondary students registered at a BC school.
- **Help Starts Here** (https://helpstartshere.gov.bc.ca/) — A database with over 2,500 listings of services related to mental health and substance use supports.
- **Hope for Wellness Helpline** (https://www.hopeforwellness.ca/) — 24/7 online chat and phone line with experienced and culturally competent counselors available to all Indigenous people in Canada.
    - First Nations Health Authority Mental Health Supports Info Sheet [PDF] (https://www.fnha.ca/Documents/FNHA-mental-health-and-wellness-supports-for-indigenous-people.pdf) by First Nations health Authority — List of culturally safe services for Indigenous people.
- **HeretoHelp – BC** (https://www.heretohelp.bc.ca/) — Mental health resources, including videos, articles, and support services in BC.
- **BC Construction Industry Rehabilitation Plan** (https://www.constructionrehabplan.com/) — Mental health and substance use services for CLRA and BCBT members and their families.
- **Virtual Mental Health Supports (Government of BC)** (https://www2.gov.bc.ca/gov/content/health/managing-your-health/mental-health-substance-use/virtual-mental-health-supports) — Virtual services are available for British Columbians who are experiencing anxiety, depression, or other mental health challenges.

Crisis Support

- **Interior Crisis Line Network** — Call 1-888-353-2273 (tel:+1-888-353-2273) for 24/7 emotional support, crisis intervention, and community resource information.
- **Talk Suicide Chat Service** (https://talksuicide.ca/) — An alternative if calling is difficult; available for crisis intervention.
- **310Mental Health Support** — Call 250-310-6789 (tel:+1-250-310-6789) for emotional support, information, and resources specific to mental health.
- **1-800-SUICIDE** — Call 1-800-784-2433 (tel:+1-800-784-2433) if you are experiencing feelings of distress or despair, including thoughts of suicide.
- **Opioid Treatment Access Line** — Call 1-833-804-8111 (tel:+1-833-804-8111) between 9 am and 4 pm to connect with a doctor, nurse, or healthcare worker who can prescribe opioid treatment medication that same day.
- **KUU-US Crisis Response Service** — Call 1-800-588-8717 (tel:+1-800-588-8717) for culturally-aware crisis support for Indigenous peoples in BC.
- **Alcohol and Drug Information and Referral Service** — Call 1-800-663-1441 (tel:+1-800-663-1441) to find resources and support.

Emergency Services — For life-threatening situations, call 911 or visit your nearest emergency department.

Version History

This page provides a record of changes made to this learning resource, Plumbing Apprenticeship Level 2, Block B (https://b-heating-bcplumbingapprl2.pressbooks.tru.ca/). Each update increases the version number by 0.1. The most recent version is reflected in the exported files for this resource.

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Version	Date	Change	Details
1.0	September, 2025	Plumbing Apprenticeship Level 2 Block B learning resource from STBC content converted to open and freely accessible digital platform and published at TRU.	