

●●● POWER ENGINEERING

Fourth Class

Edition 3.5

Building Environmental Systems and Control

Part B

Unit B-11



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BUILDING ENVIRONMENTAL SYSTEMS AND CONTROL

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UNIT INTRODUCTION

In today's environment, energy costs are high, and technological choices are increasing. Building owners, tenants, and occupants demand a high level of comfort, a healthy environment, and higher energy efficiency. New building materials, sophisticated infrastructure requirements, and the increasing economic impact all expand the duties of the facility operator, and make the role more demanding.

Operating and controlling the indoor climate in a facility involves managing both the heating and cooling systems. To manage these systems effectively, the operator must have an understanding of the processes and equipment in the facility.

Qualified Power Engineers, who are also facility operators, often operate the HVAC systems. As such, it is important to have a basic knowledge of how these systems are designed, and how to control a HVAC system to achieve an optimal balance between efficiency and comfort.

UNIT RATIONALE

As a qualified facility operator, the Power Engineer needs to be skilled in the safe and efficient operation of refrigeration HVAC and thermal processes. These processes typically involve generating and using steam, and other thermal fluids. The Power Engineer also needs to be able to manage the indoor climate of the facility, to ensure that both the occupants and equipment can operate comfortably.

This unit will provide a basic understanding of the equipment, processes, and control systems that the Power Engineer will encounter while maintaining human comfort levels in a facility.





CHAPTER 1

Steam Heating

LEARNING OUTCOME

When you complete this chapter you should be able to:

Describe the components, operating principles, and maintenance procedures of steam heating systems.

LEARNING OBJECTIVES

Here is what you should be able to do when you complete each objective:

- 1. Describe the construction and operation of steam heating system devices used to transfer heat from steam to a heated space.*
- 2. Describe the auxiliary equipment used in a steam heating system, including air vents, radiator valves and traps, and condensate return equipment.*
- 3. Describe standard types of piping and equipment layout for steam heating systems.*
- 4. Describe the general operation and maintenance of steam heating systems.*
- 5. Apply a steam heating system troubleshooting guide.*



CHAPTER INTRODUCTION

Power Engineers must be familiar with the equipment in all facility areas for which they are responsible. They must trace lines, familiarize themselves with system layouts, and become adept at troubleshooting. Every facility has some type of HVAC system. These systems often use steam as a heat source. Power Engineers must understand how steam heating supports facilities operation.

This chapter addresses equipment design, function, and purpose. It also identifies typical system configurations. This baseline knowledge is necessary for efficient system operation.

This chapter discusses how buildings are heated using steam. It emphasizes how steam is distributed, and how condensate is returned to the boilers. As well, it covers the equipment needed to transfer heat from steam to air. The final objective discusses how to troubleshoot problems in a steam heating system.

OBJECTIVE 1

Describe the construction and operation of steam heating system devices used to transfer heat from steam to a heated space.

HEATING EQUIPMENT

Heating equipment is comprised of all parts of a heating system, except the boiler and its fittings. These parts can include:

- [Radiators](#)
- [Convectors](#)
- [Unit heaters](#)
- Fin coils
- Steam traps
- [Air vents](#)
- Pumps

Radiators

Heat transfer may be radiant, conductive, or convective.

Radiation refers to the transmission of energy via electromagnetic waves. The higher a body's temperature is, the greater the electromagnetic radiation. Electromagnetic waves travel in straight lines. When the waves reach a body, the body will absorb, reflect, or transmit the waves. If the waves are absorbed, they are converted into heat.

Conduction involves the transfer of heat energy from molecule to molecule within an individual substance, or from the molecules of one body to those of another body in direct contact with the first body.

Convection involves the movement of matter, and the heat contained within that matter. Convection takes place only in fluids (liquids or gases). Convection can be either natural or forced.

- **Natural Convection** occurs due to fluid density differences resulting from temperature differences. The convection currents that develop transfer heat without the need for mechanical devices.
- **Forced Convection** involves the use of pumps (in the case of liquids) or fans (in the case of gases) to move hot fluid. Forced convection provides more vigorous fluid movement, and therefore greater heat transfer rates.

Radiators use both radiant and convective heat transfer. A hot radiator provides heat by radiation. The air near a hot radiator heats up, expands in volume, decreases in density, and then rises. Cool dense air, near the floor, replaces the rising hot air. This cool dense air then also heats up and rises. This cycle of air movement (called a convection current) continues as long as there is a temperature difference between the radiator and the air. In radiators, convection currents eliminate the need for fans.

Radiators have a large surface area. This facilitates radiation of heat from the steam in the radiator to the surrounding air.



Radiators types have three classifications:

Floor radiators: have legs so they can stand on the floor.

Window radiators: have low headroom types for locations such as under windows.

Wall-hung radiators: have no legs and are mounted to the wall.

Older radiators were made of cast iron sections, connected with screws or push nipples. Modern radiators are made of pressed light steel panels, which are welded together. The use of steel allows designers to save space. As well, steel radiators may be stylish in design and more efficient than cast iron radiators.

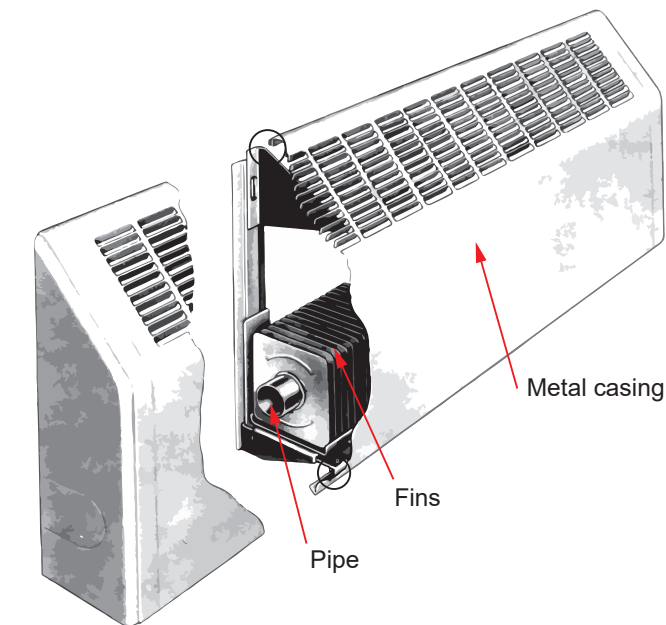
Convection Radiators (Convectors)

Convectors have largely replaced cast-iron radiators. Unlike a traditional radiator, a convector transfers heat mostly through convection. In a convector, steam or hot water flows through a copper or steel tube that has metal fins attached to it. The fins increase heat transfer from the tube to the air circulating through the convector. The piping is enclosed in a metal cabinet cover with grill-type openings at the top and an open bottom.

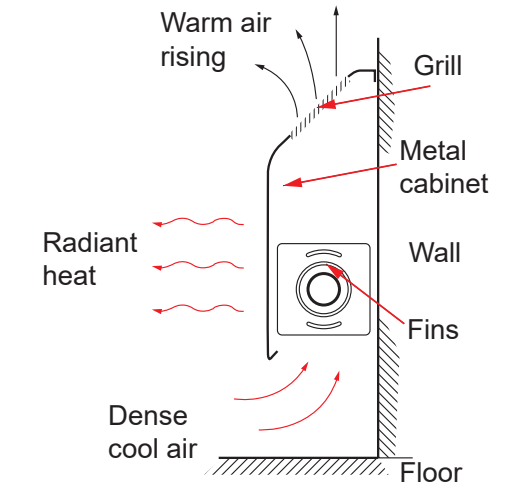
Figure 1 shows the basic construction of a convector. Figure 2 illustrates how convection currents circulate the air naturally, without the aid of a fan. Cool air enters at the bottom of the unit. The finned tube heats up the air on contact. The air rises upward, and flows out of the top grill. Some heat also radiates from the surface of the warm cabinet.

Radiators and convectors should be placed against outside walls, especially under windows. This placement allows the warm air rising from these units to mix with the cold air descending from the cooler surfaces above. This helps prevent cold drafts on the floors, and provides more even temperatures throughout the rooms.

Figure 1 – Convector (Cutaway View)



(Courtesy of Dunham-Bush)


Figure 2 – Convector Air Circulation


Note: A wall convector will not circulate the heated air if the cabinet cover rests on the floor. There must be room below the cabinet cover for cooler air to enter and replace the rising heated air.

The wall convector piping must be graded down, in the direction of flow, for the condensate to drain and collect at the steam trap.

Unit Heaters

A unit heater is a convector heater that uses a blower or fan to force the air through the heating coil, instead of using natural circulation. The result is a large output of heat from a relatively small unit.

Unit heaters are supplied in many configurations including:

- Cabinet units
- Floor mounted units
- Surface or recessed wall mounted units
- Ceiling suspended units, which discharge air horizontally or vertically



Figure 3 shows a cabinet unit heater with its front panel removed. This internal view shows the twin blower and heating element. This type of unit is often used in corridors, lobbies, and other hard to heat areas.

Figure 3 – Cabinet Unit Heater

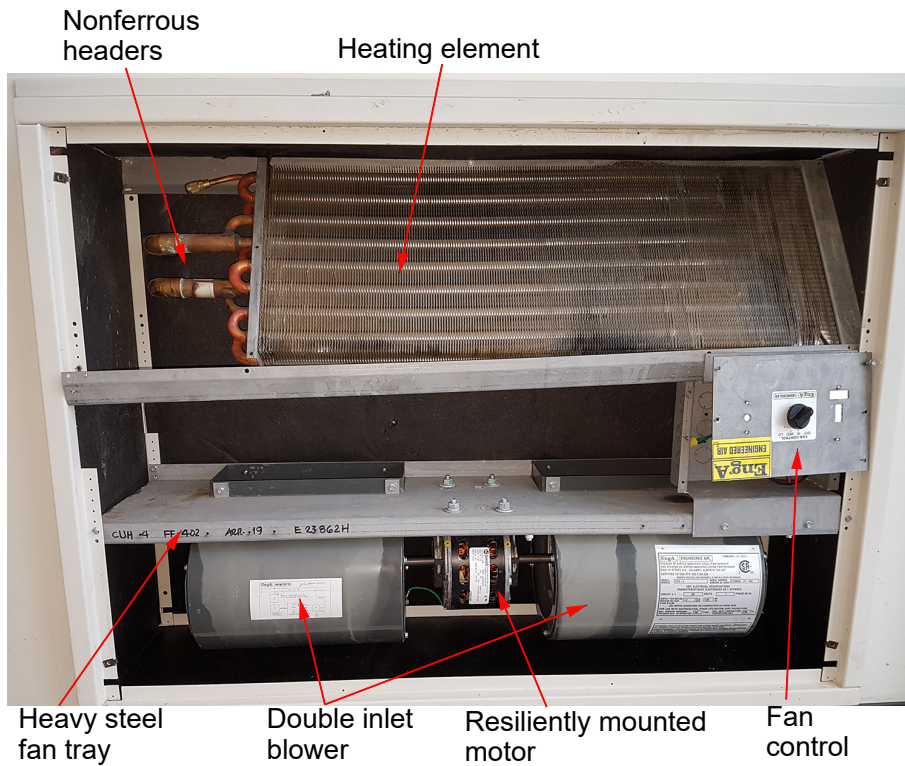
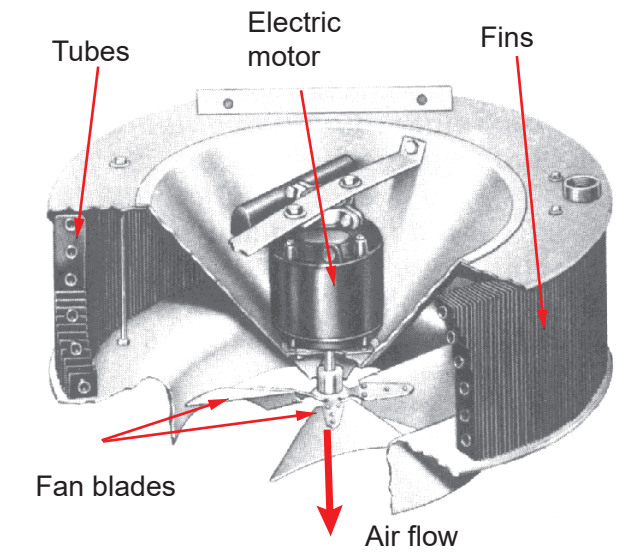


Figure 4 shows a sectional view of a ceiling mounted unit heater, with vertical air discharge.

Figure 4 – Vertical Discharge Unit Heater

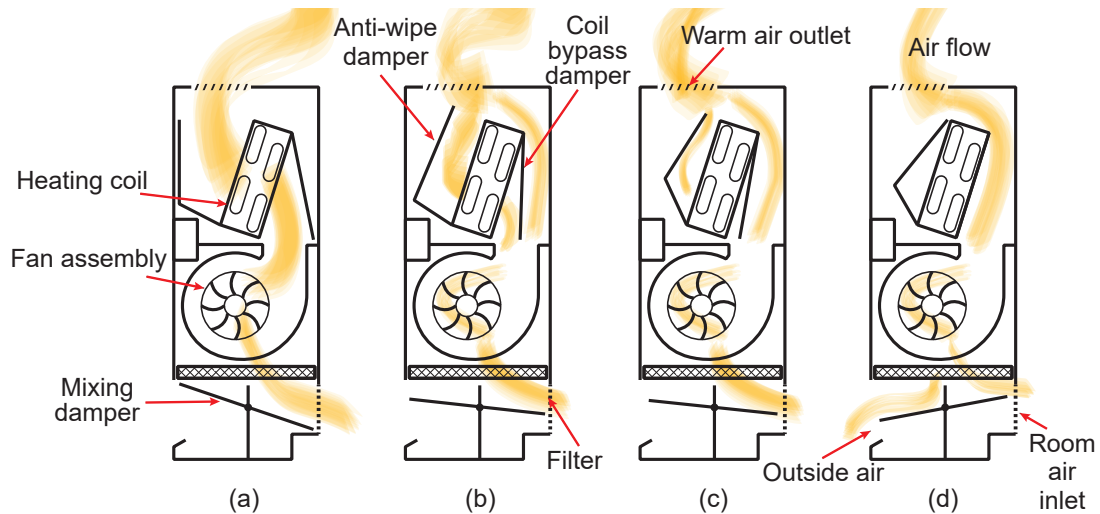


Unit Ventilators

Unit ventilators, also called univents, are cabinet type unit heaters. In addition to the standard heating coil and blower or fan, the univents are also equipped with an air filter, several dampers, and an outside air inlet to admit fresh air for ventilation.

Figure 5 illustrates cross-sectional views of a blow-through type of unit ventilator with the dampers shown in various positions.

Figure 5 – Unit Ventilator Cross-Sectional View



The action of the thermostatically controlled unit shown in Figure 5 automatically adjusts as the temperature of the room changes:

- When room temperature is below the setting of the thermostat, the mixing damper prevents outside air from entering, while keeping the room air inlet wide open. The coil bypass and anti-wipe dampers are wide open. This forces all the air discharged by the fan to pass through the heating coil.
- As room temperature approaches the thermostat setting, the mixing damper opens the outside air intake slightly. This reduces the amount of room air entering the unit. The coil bypass damper closes in, and allows part of the air mixture to bypass the heating coil. The anti-wipe damper also closes in, which forces the heated air to mix with the unheated bypassed air.
- When room temperature is near the thermostat setting, the mixing damper and bypass damper control the temperature. The mixing damper controls the amount of outside air that enters the unit for ventilation. The bypass damper regulates the amount of air that passes through the heating coil.
- When room temperature exceeds the thermostat setting, as is often the case during warm weather, the mixing damper admits a maximum amount of outside air, and a minimum amount of room air. Bypass and anti-wipe dampers close the heating coil off completely.

Unit ventilators are often equipped with three-speed fan switches, to regulate the airflow through the unit.



OBJECTIVE 2

Describe the auxiliary equipment used in a steam heating system, including air vents, radiator valves and traps, and condensate return equipment.

AUXILIARY EQUIPMENT

The auxiliary equipment often included in a steam heating system includes:

- Air vents
- Radiator valves
- Radiator traps
- Condensate receivers and pumps
- Vacuum pumps

Air Vents

When a steam heating system initially starts up, all piping, radiators, and convectors are filled with air. This air must be removed from the system to make way for the steam. Under certain conditions, air may enter the system while it is operating.

The presence of air is undesirable since it will:

- Block the steam from flowing freely.
- Reduce heat transfer from the convectors and other heat exchange equipment.
- Promote corrosion in the system, especially in the condensate return piping.

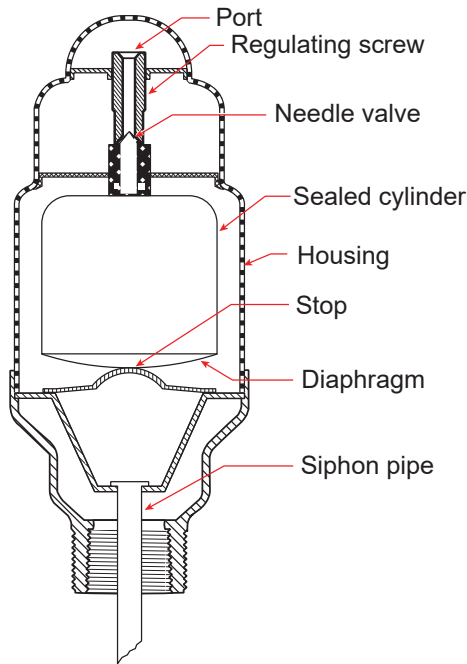
Older steam heating systems had manually operated vent valves (usually small petcocks) placed on high points in the piping, where air would tend to collect. During startup, and occasionally during operation, these valves were opened to allow accumulated air to vent.

Modern systems vent automatically. Figure 6 illustrates an automatic air vent used to expel the air from the risers and main headers of the heating system. The valve permits air to leave the system, but closes tightly when the system is completely filled with steam.

The air vent consists of a small housing that contains a sealed cylinder. The cylinder is partially filled with a volatile liquid, and has an attached needle valve. The bottom of the cylinder consists of a flexible diaphragm, which rests on a stop.

When cool air (relative to the steam temperature) surrounds the cylinder, the needle valve opens and allows the air to escape. When most of the air is expelled and hot steam starts to surround the cylinder, the increased temperature causes the volatile liquid to evaporate. The pressure inside the cylinder increases, which increases its height. The increased height forces the needle valve up against its seat, and effectively prevents the escape of steam.

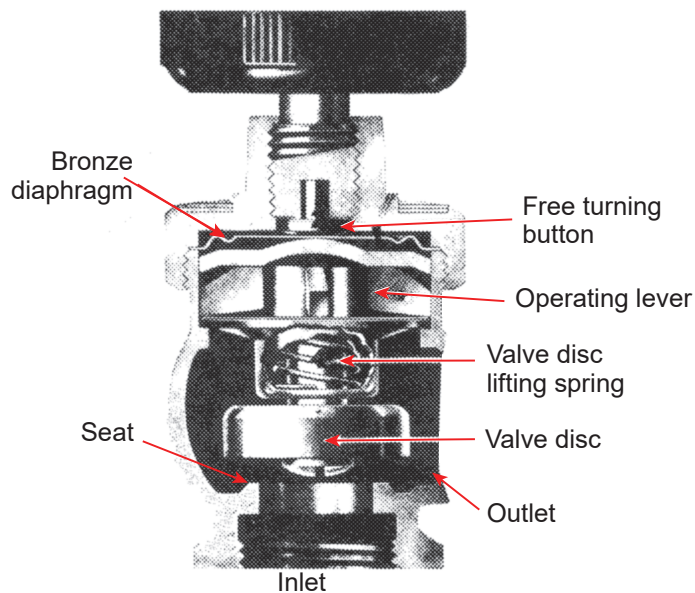
The temperature around the sealed cylinder drops when the valve housing again collects sufficient air. The vapour in the cylinder condenses, and its internal pressure drops. This allows the cylinder to contract, which re-opens the needle valve.

Figure 6 – Air Vent


Radiator Valves

Manually operated radiator valves are special globe valves used to control the flow of steam to radiators. They are either a straight through design or an angle design. Some of these valves are packless, which prevents steam from leaking around the valve stem. The packless valves also eliminate the need for repacking.

A packless radiator valve is shown in Figure 7. It has a bronze diaphragm that completely seals off the valve body. The diaphragm prevents steam from leaking out around the valve stem. When the valve stem is turned, the button pushes down against the diaphragm, which in turn pushes down the operating lever. The lever forces the valve disc against its seat and closes the valve. When the stem backs off, the spring lifts the disc from its seat and opens the valve.

Figure 7 – Packless Radiator Valve


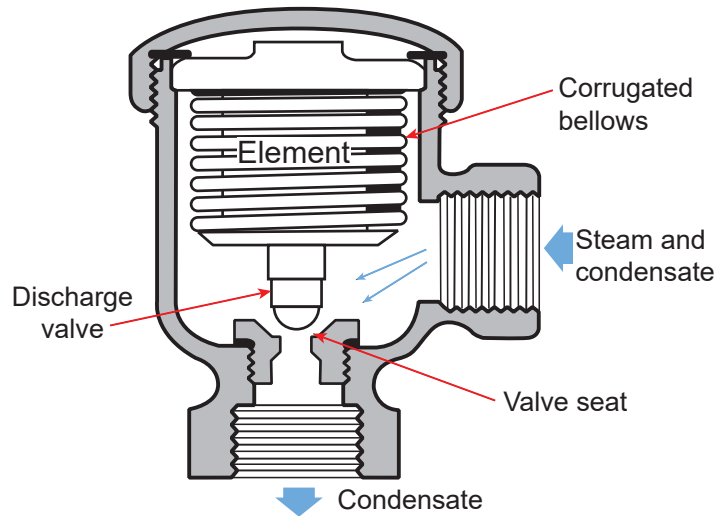


Radiator Traps

The steam in the radiator condenses to water as it gives up its heat to the room. Water accumulating in the radiator will disrupt heat transfer; therefore, it is necessary to remove the water as fast as it forms.

The radiator trap allows the condensed steam or water to discharge from the radiator, but prevents steam from escaping. The thermostatic radiator trap is commonly used for this purpose, with either a corrugated bellows or disc. Figure 8 shows a corrugated bellows type radiator trap.

Figure 8 – Thermostatic Radiator Trap



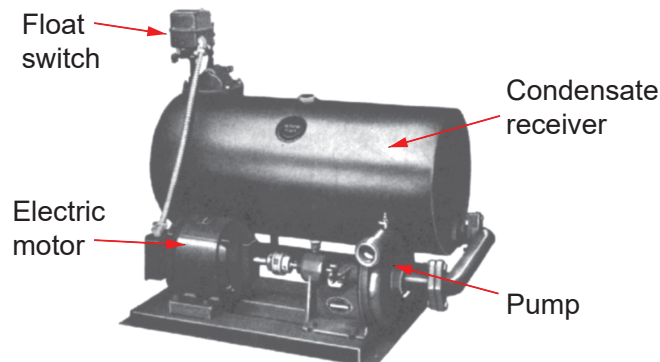
If the radiator trap is cold or full of condensate, the fluid inside the bellows remains in a liquid state. This liquid causes the bellows to contract, and raises the valve away from its seat. The condensate then flows out of the trap, and steam flows into it. The steam causes the fluid in the bellows to evaporate, and the bellows expands from the increased pressure. The valve then seats itself to prevent the loss of steam.

Condensate Receivers and Pumps

In many steam heating systems, the condensate discharged from the steam traps drains, by gravity, through the return piping to a condensate receiver. A condensate pump then delivers the water from the receiver to the steam boiler, as needed.

Figure 9 shows a condensate receiver with a horizontal condensate pump. On this unit, a float switch on the receiver controls the pump. The condensate receiver is vented to atmosphere so that the pressure in the receiver and return piping is at atmospheric pressure.

Figure 9 – Condensate Receiver with Horizontal Condensate Pump



Vacuum Pumps

In buildings that cover large areas, such as shopping centres, schools, and factories, the resistance to flow of the condensate in the return piping of steam heating systems is quite high. In such systems, vacuum pumps are sometimes used to draw the condensate away from heat exchangers and through the condensate piping.

The vacuum pump performs two major functions:

1. It creates and maintains a vacuum in the return piping. This reduces the backpressure, and allows the condensate to flow more easily to the condensate tank.
2. It returns the condensate back to the boiler.

Figure 10 shows a common type of vacuum pump with condensate tanks and piping arrangement. Condensate flows to the accumulator tank. When the water in this tank reaches a predetermined level, the float switch starts the vacuum pump. However, the suction of this pump does not draw the water from the accumulator tank; the pump draws the water from the air-separating tank, as shown in Figure 11. The pump discharges the water, via the exhauster, to the top of the air-separating tank, and pushes a portion of the water to the boiler. In Figure 11, the valves have been removed to show the flows.

Figure 10 – Vacuum Pump

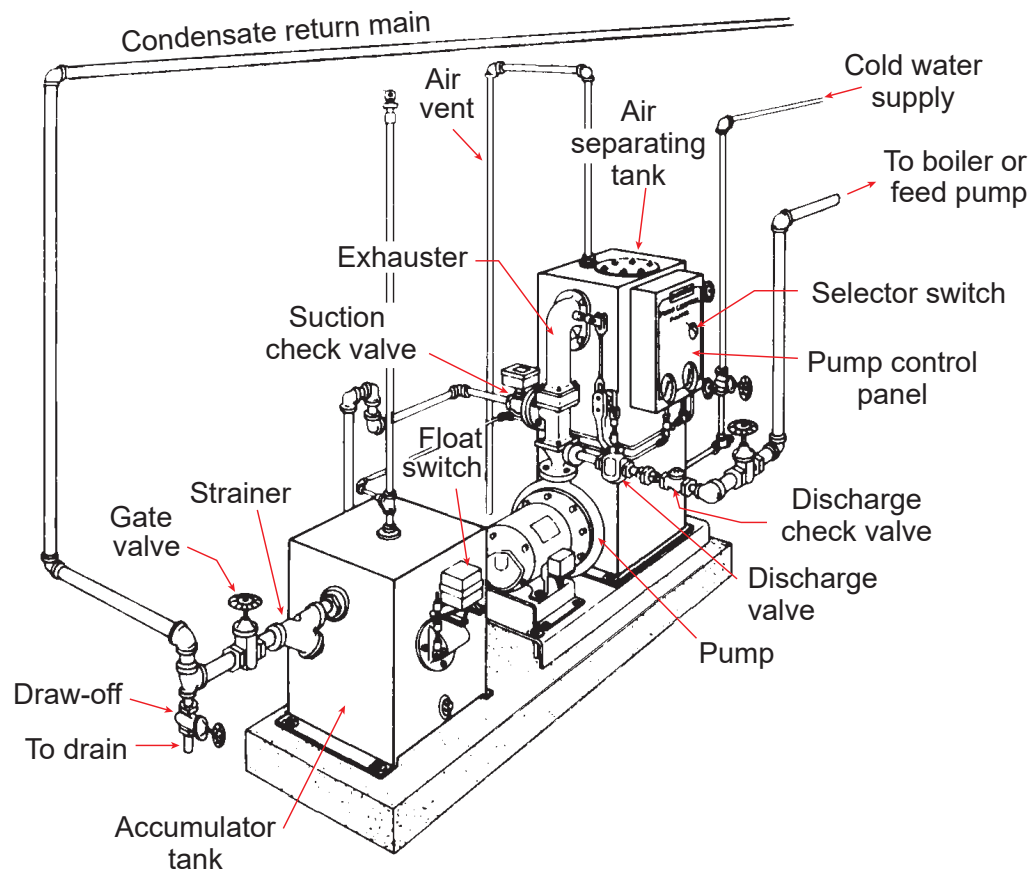
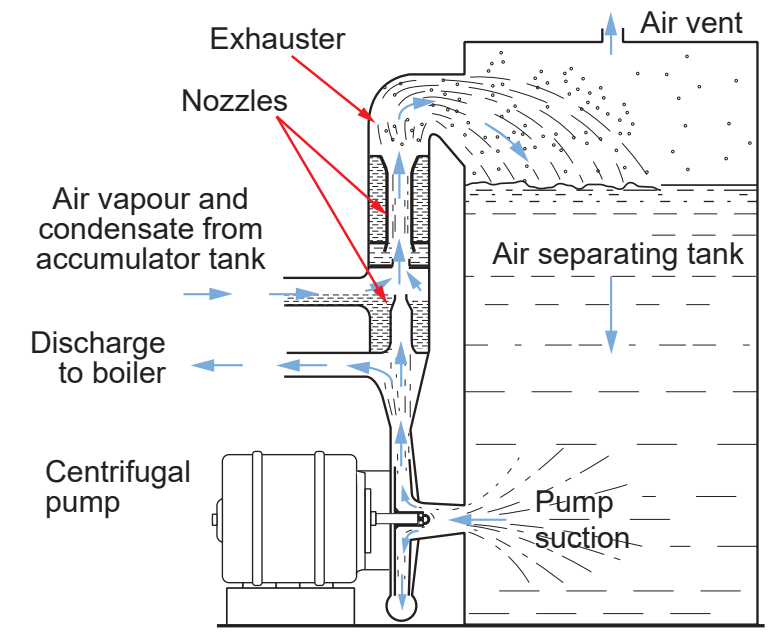



Figure 11 – Pump Schematic Diagram


The exhauster consists of a series of nozzles, and the pump forces water through them. The water leaves the first nozzle at a very high velocity. This action draws air, water, and water vapour from the accumulator tank, and creates a vacuum in the tank and return lines. The water vapour condenses as it combines with the water that passes through the nozzles. This increases the vacuum. The water-air mixture then passes through the remaining nozzles, and discharges into the air-separating tank.

Once in the separating tank, the air exits to atmosphere through a vent on the top of the tank, and the water collects below. When the level of the water in the tank rises, a float causes the discharge valve in the boiler feedline to open. When this occurs, water pumps back to the boiler.

OBJECTIVE 3

Describe standard types of piping and equipment layout for steam heating systems.

PIPING AND EQUIPMENT LAYOUT FOR STEAM HEATING SYSTEMS

There are many types of steam heating system configurations used historically and in the present day. These include:

- a) One-pipe gravity return system
- b) Two-pipe gravity return system
- c) Two-pipe gravity steam system with steam traps
- d) Two-pipe return trap system
- e) Two-pipe with variable vacuum system
- f) Two-pipe condensate pump system
- g) Two-pipe vacuum return system

The two most common systems in use today are f) and g). These two systems are discussed in further detail below.

Two-Pipe Condensate Pump System

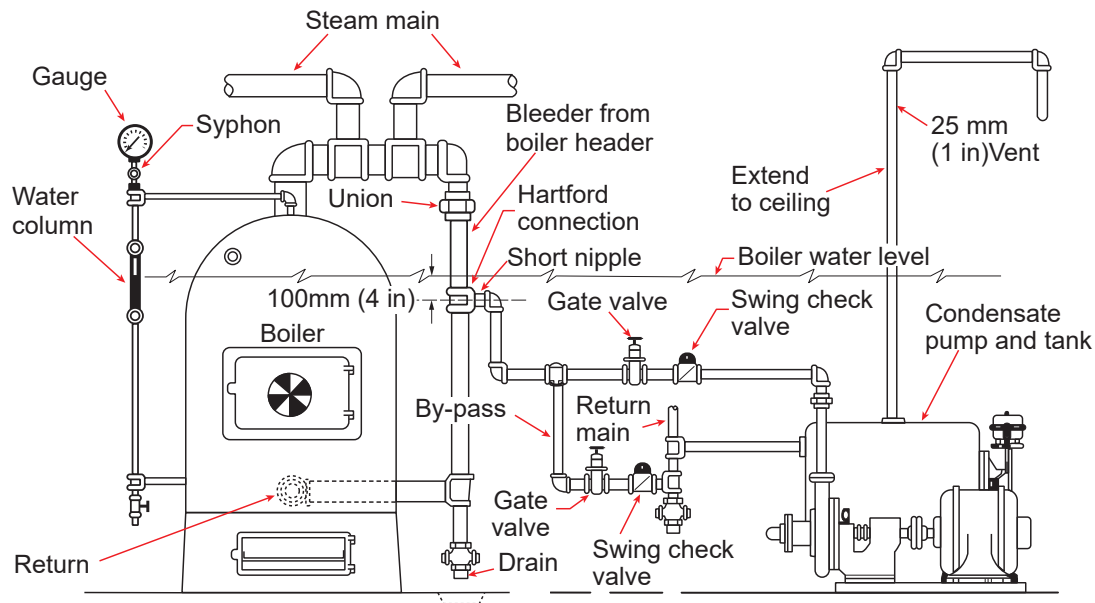
In larger systems, all the condensate returns to a common condensate receiver or tank. A boiler feed pump then feeds condensate into the boiler.

In many heating systems, it is not possible to return the condensate directly to the boiler by gravity. This may be due to one of the following:

- Available static head in the return line is insufficient.
- It is not possible to use a return trap.

In these situations, the condensate pump system is used. All the condensate flows by gravity to a condensate tank, which may be located well below the boiler water level. A condensate pump then returns the water from the tank through a Hartford loop connection, into the boiler (Figure 12).

This system must be balanced in order to return the condensate to the boiler at the same rate as the steam is being produced. A float control in the receiver tank operates the pump.


Figure 12 – Condensate Pump System


Two-Pipe Vacuum Return System

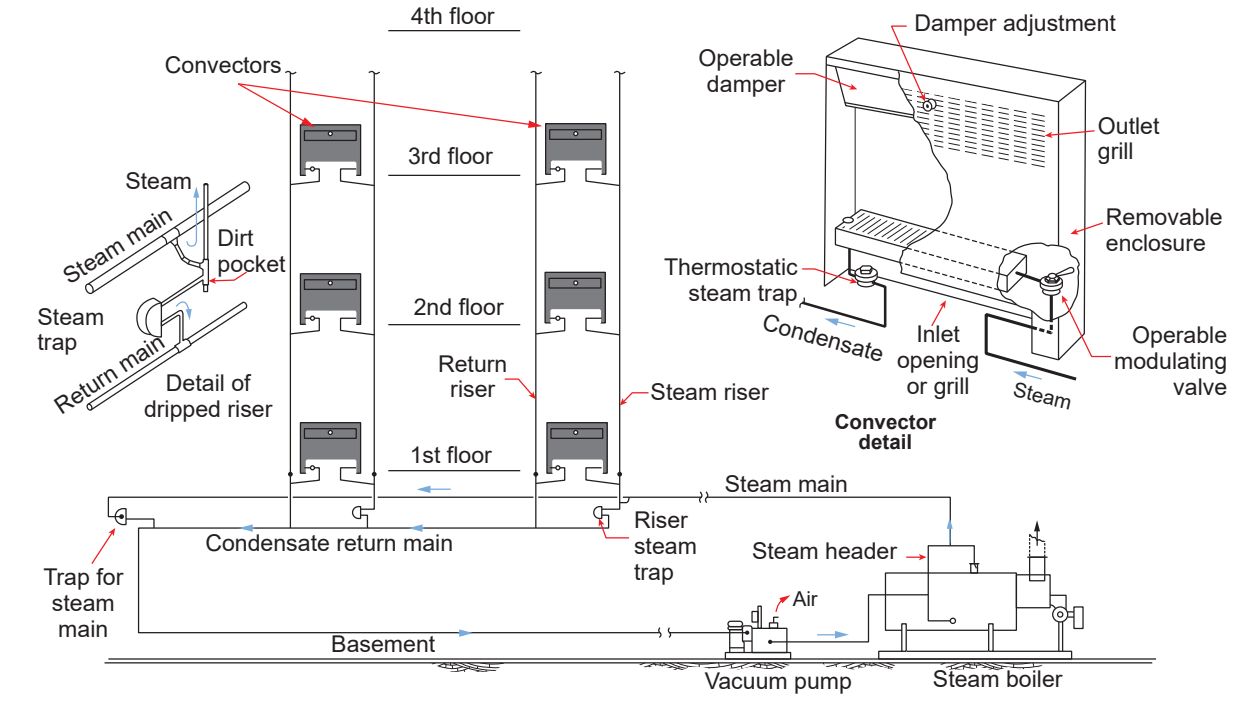
In all the steam heating systems described above, the condensate flows back to the boiler, return trap, or condensate receiver by gravity. In larger buildings, however, proper gravity flow is difficult to achieve due to the resistance in long runs of return piping.

In the two-pipe vacuum return system, the steam is supplied to radiators or convectors equipped with modulating valves and thermostatic steam traps, at pressures up to 103 kPa. The following is a description of how this system works:

1. The vacuum pump draws the condensate and air discharged from radiators or convectors through the return line to an accumulator tank. This creates a partial vacuum in the line and tank, which results in a more positive flow in the line. Special air vents that prevent the re-entry of air into the system must be used on a vacuum return system.
2. The vacuum pump then draws the air and condensate from the accumulator tank, and discharges them into an air-separator tank. There, the air vents to atmosphere, and the condensate returns to the boiler.

Figure 13 is a diagram of a vacuum return system. Note that all supply mains, return mains, and convector connections are pitched to promote condensate drainage. Drip lines equipped with steam traps are installed on the steam risers and at the end of the steam main, to remove condensate that forms in these lines.

Figure 13 – Vacuum Return System





OBJECTIVE 4

Describe the general operation and maintenance of steam heating systems.

SYSTEM OPERATION AND MAINTENANCE

Steam heating systems require daily and seasonal maintenance to operate safely and efficiently. Operation of a steam heating system begins with starting up the system. Once the system is running, preventative maintenance must be performed to ensure the system operates smoothly.

Steam System Startup

A brand new heating system should be tested and commissioned by the heating contractor and, in many jurisdictions, a boiler inspector. The following remarks and steps mainly apply to a system that has already been commissioned and accepted by the boiler inspector, and has already been in operation.

Assuming that the operator has just taken charge of the building, the heating system should be given a thorough inspection before firing it up.

Typical pre-startup inspection includes:

1. Ensure the boiler has a valid inspection certificate.
2. Carefully examine the boiler. Make sure it is clean inside and out, and that fittings and dampers are in good working order.
3. Inspect all accessible pipelines. Check for:
 - a) Broken fittings.
 - b) Signs of leaks.
 - c) Broken hangers that cause pipelines to sag.
 - d) Pipes with restricted ability to expand.
4. Test all valves on mains or branches to ensure that they open and close easily.
5. Check all strainers for obstructions and clean them if necessary.
6. Inspect all the heating units, control valves, air vents, steam traps, and exposed piping in rooms to ensure they are in good working order.

If everything is in order:

7. Fill the boiler so the level is above the low water cut-off, but is still low enough to allow the water to expand in the boiler. Then start the fire.
8. When the steam gauge begins to show pressure, leave a certified Power Engineer in charge of the boiler, and make another tour of the entire system. Note whether there are any leaks, and check all sections of the piping and heating units to ensure they are warming up. If some sections remain cold, either they are not receiving steam, or they are air bound. The causes may include a closed valve, a broken valve spindle that makes it impossible to lift the disc or gate, or a defective air vent or steam trap. Locate the defective part, and repair or replace it.



9. Return to the boiler and verify that the returns are coming back freely to the boiler, receiver, or vacuum pump. Keep a close eye on the water level in the boiler. If the water is being held up in the system, or the traps or pumps are not working properly, the water level in the boiler will fall rapidly. If the water level threatens to fall too low, shut down the boiler, and locate the trouble. For the plant to operate correctly and safely, the condensate must return to the boiler promptly.
10. Using approved procedures, test the safety valve by raising the steam pressure to the blowoff point.
11. Try the blowoff valve, and test the water column and gauge glass. Make sure that all the passages are clear.

Radiator, Convector, and Univent Maintenance

In the case of radiators and convectors, the main sources of trouble are the valves and traps. If the radiator valve is not the packless type, repack it periodically to prevent leakage around the valve spindle. Replace any valves that do not shut off tightly.

A leaking steam trap will allow steam to blow from the radiator into the return lines. Besides interfering with the normal flow of condensate in the returns, the steam will also escape to atmosphere through the condensate receiver vent. This escaping steam wastes both water and heat energy.

Air vents may become plugged with deposits, and should be cleaned regularly. Replace them if they constantly leak steam or water. Replace the nipples connecting radiator sections if the nipples corrode and start to leak. Keep radiators and convectors, especially finned convectors, free of dust.

Keep the univent filters, heating coils, dampers, and fan blades free of dust and gummy deposits. Lubricate the motor and fan bearings according to the manufacturer recommendations.

It is common practice to arrange for the overhaul of each item during the summer (off) season. Preventive maintenance of this type will reduce the possibility of heating problems occurring when the system is in service.



OBJECTIVE 5

Apply a steam heating system troubleshooting guide.

TROUBLESHOOTING STEAM HEATING SYSTEMS

Table 1 is a checklist that can help to locate the cause of many problems that may develop in a steam heating system. This list assumes that the systems were properly designed, installed, and had operated satisfactorily before the trouble developed.

Some of these corrective actions should only be performed by qualified tradespeople. Unqualified persons could make problems worse, or even unsafe, by tinkering. As well, regulations may be in place to prevent unqualified personnel from performing certain tasks. Do not play with balancing valves and cocks. Balancing the heating system is a delicate operation. Only knowledgeable persons, equipped with the proper tools and measuring instruments, can successfully balance these systems.

Table 1 – Troubleshooting Guide – Steam and Vapour Heating Systems

POSSIBLE CAUSE	CHECK	CURE
COMPLAINT: Slow or insufficient heat throughout the building.		
Firing rate too low	It should take 20-30 minutes for the average boiler operating above atmospheric pressure to raise steam pressure 7 kPa, with all heating units on. It should take 15 minutes for a vacuum system.	Increase fuel supply to burner.
Insufficient radiator or convector surface	Calculate heat loss of a building and the heating unit capacity required; Compare with actual capacity installed.	Increase firing rate to raise steam or vapour pressure, or install extra heating unit capacity.
Insufficient steam supply to heating units	Piping undersized, flow of steam and condensate restricted; Piping improperly pitched for proper drainage of condensate. Possible bypassing of steam to return line. Valves and nipples clogged; Valves on mains partly closed; Improper types of valves. Air openings on air vents clogged; Vents passing steam. Return trap and air eliminator on vapour system not working.	Correct the pipe size and pitch. Eliminate bypassing. Clean the valves, clean or replace nipples; Replace improper valves. Clean the vent openings; Replace corroded air vents. Clean or repair poorly operating return trap air eliminator.



POSSIBLE CAUSE	CHECK	CURE
Excessive make-up water to condensate return tank	Manual make-up valve open, or automatic make-up valve sticking open, and hot condensate is overflowing to sewer; Colder boiler feedwater is reducing the steaming capacity of the boiler.	Close the manual make-up valve; Repair automatic make-up valve.
Water leaves boiler with steam	Water level too high, causing carry-over; Water in the piping obstructs steam flow, overloads steam traps, and causes heating units to fill with water. Foaming boiler, water level unstable.	Adjust or repair the water level control. Blow off the boiler several times to remove impurities; or clean the boiler.
Vacuum equipment defective	Condensate not returning properly, air not being removed, vacuum drop.	Clean or repair the equipment.
Insufficient steam supply to heating unit	Size of supply and return piping, connections, and valves. Improper pitch. Clogging of connections and valve. Defective radiator valve.	Install the correct piping and valve. Correct the pitch. Clean or replace the connections. Repair the valve.

POSSIBLE CAUSE	CHECK	CURE
COMPLAINT: Slow or insufficient heat in one or more rooms.		
Poor air venting	Air vent clogged, defective, or improperly sized.	Clean or replace the vent.
Radiator or convector improperly pitched	Condensate will not drain out readily, and is restricting steam flow.	Pitch unit in the proper direction.
Faulty steam trap	Heating unit cold; Air and condensate trapped.	Repair or replace the trap.
Convector fins clogged with dirt, lint, etc.	Airflow through unit restricted.	Clean the fins.
Supply main and heating unit on lower floor flooded	Insufficient static head for removal of condensate; steam flow blocked.	Install condensate return tank below level of lowest heating.



CHAPTER SUMMARY

This chapter introduced a variety of equipment used in steam heating systems. These systems are complex, and challenging to operate and troubleshoot.

Operators must understand how air can negatively affect heat transfer, when trapped in a steam heating system. As well, operators must understand the systems for distributing steam and returning condensate.

Power Engineers that understand the fundamentals of steam heating systems can successfully operate them and troubleshoot their related problems.





Hot Water Heating

LEARNING OUTCOME

When you complete this chapter you should be able to:

Describe the various designs, equipment, and operation of hot water heating systems.

LEARNING OBJECTIVES

Here is what you should be able to do when you complete each objective:

- 1. Describe the standard piping and circulation layouts of hot water heating systems.*
- 2. Compare the advantages and disadvantages of hot water and steam heating systems.*
- 3. Describe various types of special hot water heating systems.*
- 4. Describe the purpose and function of standard hot water heating system accessories.*
- 5. Explain how the location of the hot water circulating pump and the expansion tank are determined.*
- 6. Describe the routine operation of hot water heating systems, including cleaning, filling, starting, and the use of glycol/antifreeze.*
- 7. Explain typical problems and resolutions in the operation of steam heating systems.*



CHAPTER INTRODUCTION

In many respects, a hot water heating system (also known as a hydronic heating system) is similar to a steam heating system. It uses a boiler to transfer heat, generated from the combustion of a fuel in a furnace, to the water. In the space that is heated, the same heat transfer devices, such as radiators, convectors, and unit heaters, are used in addition to baseboard wall fins, reheat coils, and in-floor heating panels. These heating units are connected by a piping system to the boiler.

A hot water heating system differs from a steam heating system in that the temperature of the water in the boiler is not raised to its boiling point. Therefore, no steam is produced. Also, the entire system – boiler, piping, and heating units – is completely filled with water or a glycol/water mixture except for some air space in a conventional expansion tank.

The hot water heating cycle starts with the liquid being heated in the boiler. It then circulates through the supply piping to the heating units, where it gives up part of its heat, which lowers its temperature. The cooler water is returned to the boiler through the return piping and is heated again. The hot water heating system temperature difference from the boiler outlet through the system piping and back to the boiler return connection is typically 11°C (20°F).

This chapter covers a number of standard configurations and the major accessories used in a typical hot water heating system.

OBJECTIVE 1

Describe the standard piping and circulation layouts of hot water heating systems.

Two types of hot water heating systems will be discussed in this section:

- Gravity circulation
- Forced circulation

GRAVITY CIRCULATION SYSTEMS

In traditional hot water heating systems, the water was circulated by gravity acting on the difference in density (buoyancy) of the hot water in the supply main and the cooler water in the return main. This means circulation was by natural convection. These systems used open expansion tanks to accommodate changes in water volume as the water temperature changed. Some of these systems still operate very well today, in small residential applications.

The advantages of the gravity hot water system were its simple operation and low maintenance. However, these systems are no longer installed because of the following disadvantages:

- Large pipe sizes are necessary in order to keep flow resistance to a minimum, since flow depends only upon gravity.
- Circulation to radiators is difficult to maintain on the same elevation as the boiler.
- Response to changes in heat demand is slow.
- Maximum water temperature is limited to approximately 77°C (171°F).

FORCED CIRCULATION SYSTEMS

The disadvantages of a gravity system can be overcome by using a closed expansion tank, and a pump to force the water through the system.

With forced circulation, smaller pipes may be used, and positive circulation can be established to all heating units. In addition, the response to changes in heating load is quicker than with gravity systems. The use of a pump, however, means noisier operation, increased power costs, and increased maintenance.

Besides allowing for expansion and contraction of the water, the closed expansion tank also provides a cushion of air above the water level in the tank. This allows the system to operate at pressures well above that of the atmosphere. For domestic and commercial applications, the working pressure of most hydronic systems is between 85 kPa and 140 kPa (12 psi and 20 psi). The temperature of the water in the system may vary from 70°C to 120°C (158°F and 250°F).

Forced circulation hot water systems are classified according to the arrangement of piping. There are two general types of systems: upfeed and downfeed.

Upfeed System: The upfeed system has its supply main installed at a low level; this provides an upward feed to the various risers. The risers then feed the heating units on the floors above. The return main is installed at the level of the supply main. The returning water goes through the return risers and into the return main.

Downfeed System: The downfeed system has its supply main installed overhead, in the mechanical room or pipe space. This system provides a downward feed to the risers. The risers then feed the heating units on the floors below. The return main is installed at a low level. The return risers usually feed downward to the return main, which then returns the water to the boilers.



These systems may be further classified into the following types:

- Series loop system
- One-pipe system
- Two-pipe direct return system
- Two-pipe reverse return system
- Multi-zone system

Today, piping systems used for heating are variations or combinations of the above listed types. The first two systems are rarely used these days because of the disadvantages listed below.

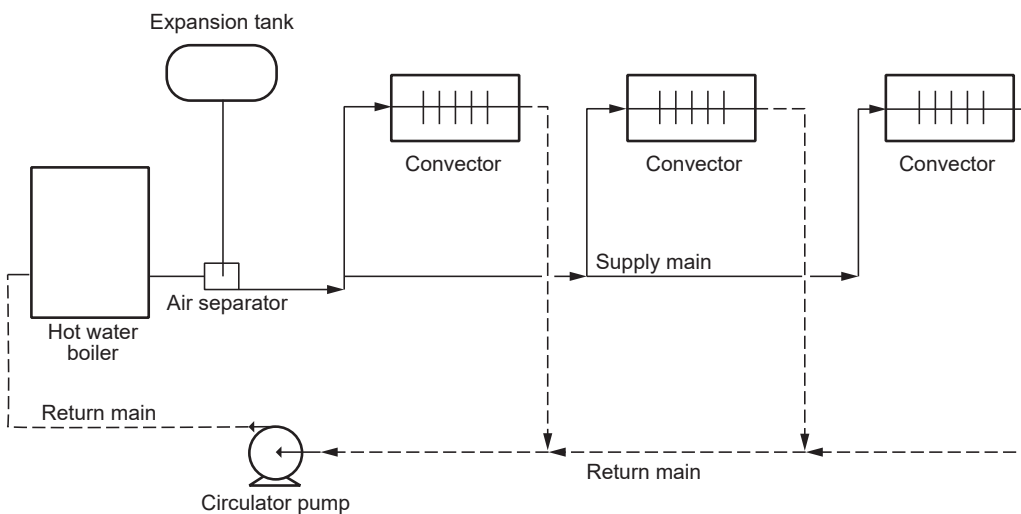
A **series loop system** has low heat capacity. The water progressively cools as it passes through the heating loop. This cooling effect decreases the heat emitted from each consecutive radiator or convector.

A **one-pipe system** can control zone temperatures. However, the water entering each consecutive convector is somewhat cooler. This cooling effect makes it necessary to increase the size of the convectors towards the end of the system.

Two-Pipe Direct Return System

Figure 1 shows a two-pipe direct return system that uses a supply main and a return main. Each convector is directly connected to both of these mains. The temperature of the water entering each convector is the same. This system is referred to as a direct return system because the return from each convector flows back to the boiler by the shortest and most direct route. In this system, the first radiator fed is the first to return to the boiler, and the last radiator fed is the last to return to the boiler.

Figure 1 – Two-Pipe Direct Return System



A pump circulates the water through the boiler and around the system. The expansion tank is connected to the air separator installed in the supply main near the boiler. The piping is sloped upward (pitched) in a certain direction to facilitate air removal.

It is difficult to balance the volume of water in the direct return system because of the different circuit lengths going to each convector. For example, the water circuit from the boiler through convector number one and back to the boiler again is much shorter than the circuits to the other convectors. Similarly, the number two convector circuit is shorter than numbers three, four, five, and so on. Though the temperature of each convector may be the same, the flow through the furthest convector is sluggish. It is therefore necessary to size the system piping carefully in order to obtain equal flow through each convector.

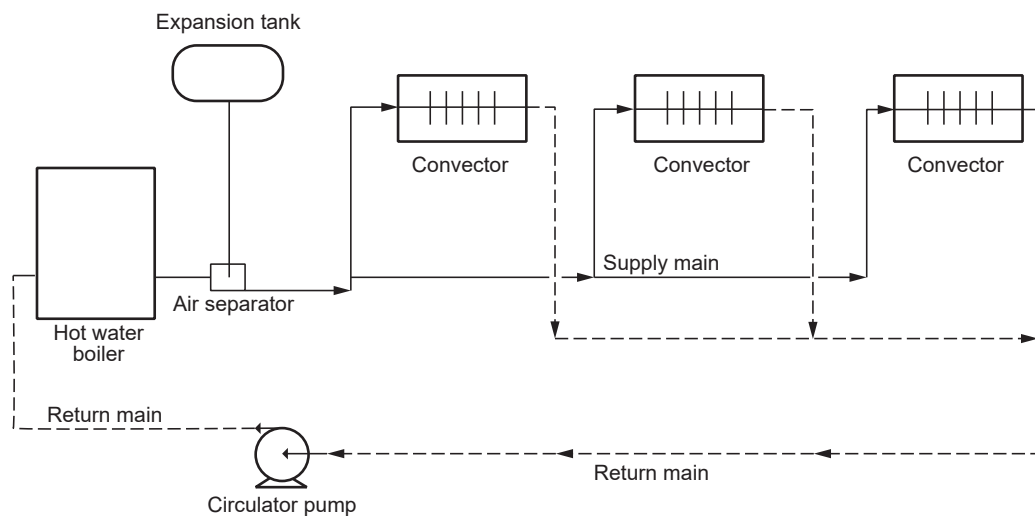
The direct return system is seldom used unless other factors, such as the cost of installation, play a more important role. In this system, balancing will help to maintain a constant air temperature across the entire floor or room.

Two-Pipe Reverse Return System

Figure 2 shows a reverse return system that uses a supply main and a return main, same as the direct return system. However, in the reverse system, the return from each convector takes the long way around to return to the boiler. The advantage of this method is that all the circuits are the same length.

This means the water travels the same total distance from the boiler and back again, regardless of which convector it goes through. This feature causes the system to be self-balancing. All convectors receive the same flow of water, at the same temperature. Also, pipe sizing in the reverse return system is less critical than in the direct return system.

Figure 2 – Reverse Return System

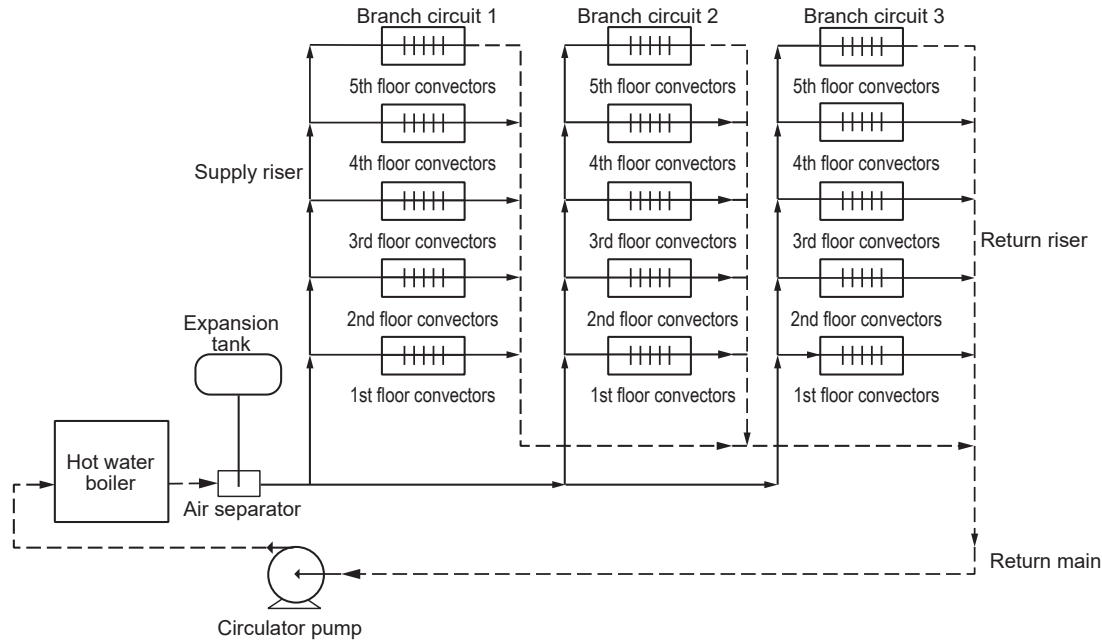
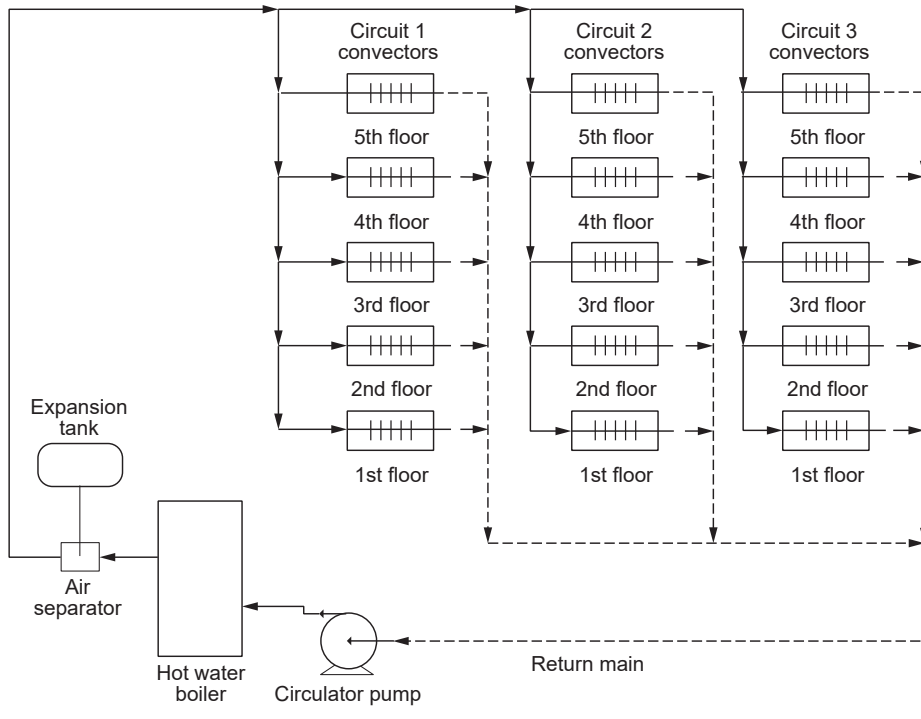


As with other forced systems described thus far, the pump is located in the return line, and discharges into the boiler. The expansion tank is the closed type, and has with an air separator. The piping pitches upward to provide air ventilation.

The reverse return system is suitable for heating systems in multi-storey buildings. Figures 3 and 4 show both an upfeed and downfeed piping arrangement.

In the upfeed system shown in Figure 3, the supply main and return main are located in the basement. The supply main feeds upward to the risers.

In the downfeed system shown in Figure 4, the supply main is overhead. The supply main feeds downward into the risers.


Figure 3 – Multi-Storey Upfeed Reverse Return System

Figure 4 – Multi-Storey Downfeed Reverse Return System


In both of the systems above, the circulating pump is located near the boiler; this allows the pump to provide maximum pressure in the supply main.

Single convectors connected between supply and return risers illustrate the branch circuits in both diagrams. In reality, each branch circuit may contain several heating units that serve a number of rooms in a suite or office. When a branch circuit contains only a small number of heating units, the circuit is usually arranged as a series loop system. For a branch circuit that has a larger number of heating units, the circuit should be arranged as a reverse return system.

Multi-Zone Systems

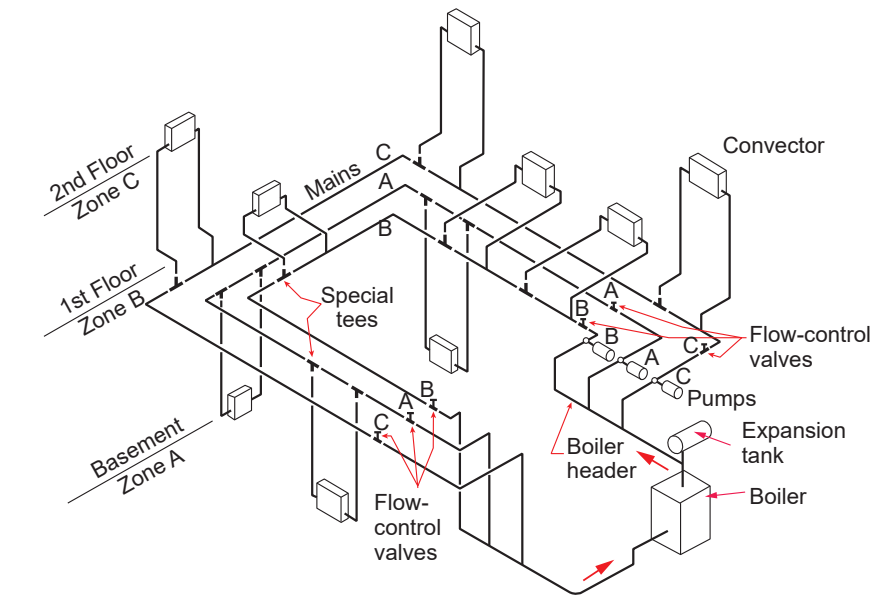
In many buildings, the hot water heating system is divided into several separate circuits. Each circuit supplies heat to a different section or zone of the building.

The flow of water through each zone is then controlled in one of the following ways:

- Each zone circuit is equipped with its own circulating pump. A zone thermostat controls the operation of the pump.
- A single circulator is used for the entire system. A thermostatically controlled motorized valve controls the flow through each circuit.
- A primary pump circulates the hot water through the main headers continuously. Each zone draws the water off the main, when needed, by means of a secondary or zone pump controlled by the zone thermostat.

Figure 5 shows a three-zone heating system for a three-storey building. Each floor has its own one-pipe system. This multi-zone system is common in smaller buildings that require relatively short circuits for each zone, which reduces the need for larger convectors later in the loop.

Figure 5 – Three-Zone, Multi-Circuit, One-Pipe System



(Courtesy of Dunham-Bush)

A zone thermostat controls the hot water supply of each circuit. The thermostat starts and stops the circulating pump for that particular zone. Thus, the supply to each zone is completely independent from the other zones. Any or all of the zones may be operating at one time. The boiler maintains the water temperature at the required setting. Each circuit also contains flow control valves, which close when the pump is not running. When closed, the valves will prevent natural circulation, which could cause overheating of that zone.



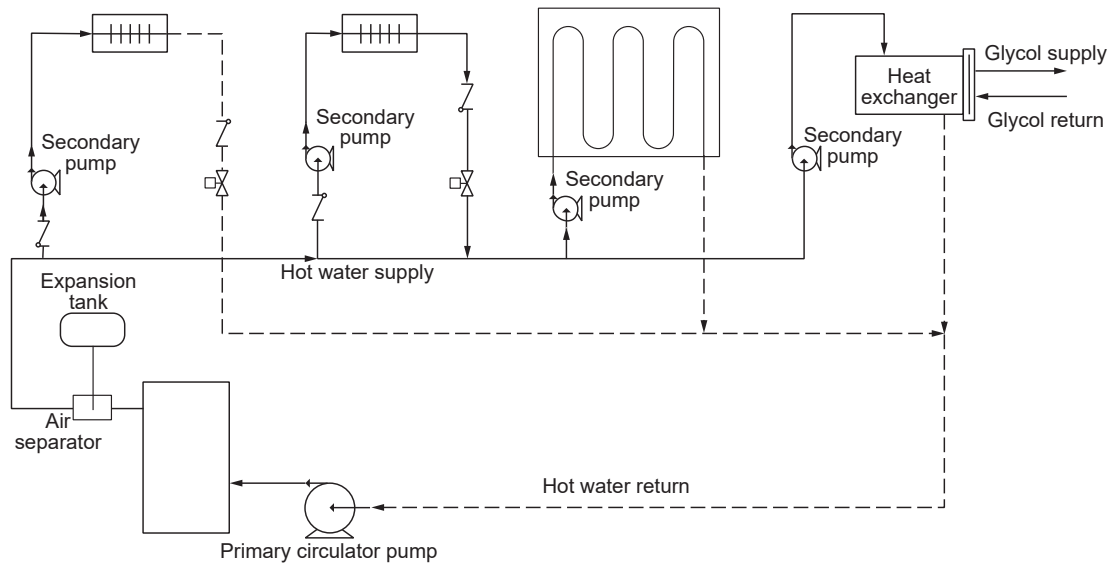
The advantage of such a multi-zone system is that each zone can be heated to a different temperature, depending on the occupancy requirements. A system like that shown in Figure 5 may be used in a building where:

- The basement is used for storage.
- The first floor is office space occupied five days a week, but only during the day.
- The second floor contains a medical lab that provides services 24 hours a day, 7 days a week.

From this example, it is obvious that the heating requirements for each floor are very different.

Figure 6 shows a basic diagram of a complex multi-zone system. This system has primary and secondary pumping circuits that serve the many secondary zones.

Figure 6 – Multi-Zone Hot Water System, with Primary and Secondary Pumping Circuits



OBJECTIVE 2

Compare the advantages and disadvantages of hot water and steam heating systems.

HOT WATER HEATING COMPARED TO STEAM HEATING

The two main types of heating systems are hot water systems and steam systems. They both have their disadvantages and recommended places of use. Listed below are some the advantages and disadvantages of using a hot water heating system instead of a steam heating system.

Advantages of a Hot Water Heating System

- a) The temperature of the supply hot water can vary in relation to the changing outdoor temperature more readily than the steam temperature can be varied. This allows for variations in load without adjusting the flow of hot water to the radiators.
- b) A hot water boiler is smaller and more compact than a steam boiler of the same output, since no boiler steam space is required. Also, in the hot water system, pipe sizes are usually smaller, and the system uses fewer and less expensive fittings.
- c) The piping pitch or slope is not as critical in a forced circulation hot water system as in a steam system, where proper drainage of condensate is required.
- d) Maintenance costs are usually less in a hot water system. This system does not require traps, condensate return systems, or condensate piping, and there is less corrosion.
- e) Water treatment for a closed loop hot water system is simpler and less costly than for a steam system.
- f) Since make-up water is minimal, fewer water treatment chemicals are used.

Disadvantages of a Hot Water Heating System

- a) In a multi-storey building, a hot water system is located in the basement. The boiler must be designed to withstand high pressure, due to the high head of water in the system.
- b) In a large hot water system, considerable power is required to circulate the water.
- c) A hot water system is in greater danger of damage due to freezing. To reduce the risk of freezing, the system should contain an approved glycol/water mix.
- d) If a leak occurs, it will do more damage in a hot water system than in a steam system due to the volume of water released.
- e) The piping in a hot water heating system must be designed in a manner that will prevent air pockets from developing in the piping. Mains and branches are graded to system high points, where air vents are located. If a pocket of air grows into an air lock, it will block the circulation.



OBJECTIVE 3

Describe various types of special hot water heating systems.

SPECIAL HEATING SYSTEMS

Hot water heating systems are easily adapted to special situations. Two types of special hot water heating systems are the **radiant panel heating system** and the **snow melting system**.

Radiant Panel Heating System

A radiant panel heating system will warm sections of ceilings, walls, or floors. Steam and hot water heating systems supply heat mainly by convection. The radiant panels supply most of the heat by radiation and only a small volume by convection.

Several methods can be used to warm these sections or panels:

- a) Unit heaters warm up air, which then passes through hollow floor tiles, or through the space above hung ceilings.
- b) Electrical heating cables embedded in the panels.
- c) Hot water that circulates through piping or tubing embedded in the panels.

Method C is the most frequently used, and will be the only one discussed in this text.

To prevent occupant discomfort and cracking of plaster walls and ceilings, temperatures used in panel heating are limited. Surface temperatures need to stay within certain limits:

- Ceilings should be lower than 46°C (115°F).
- Walls should be lower than 38°C (100°F).
- Floors should be lower than 30°C (86°F).

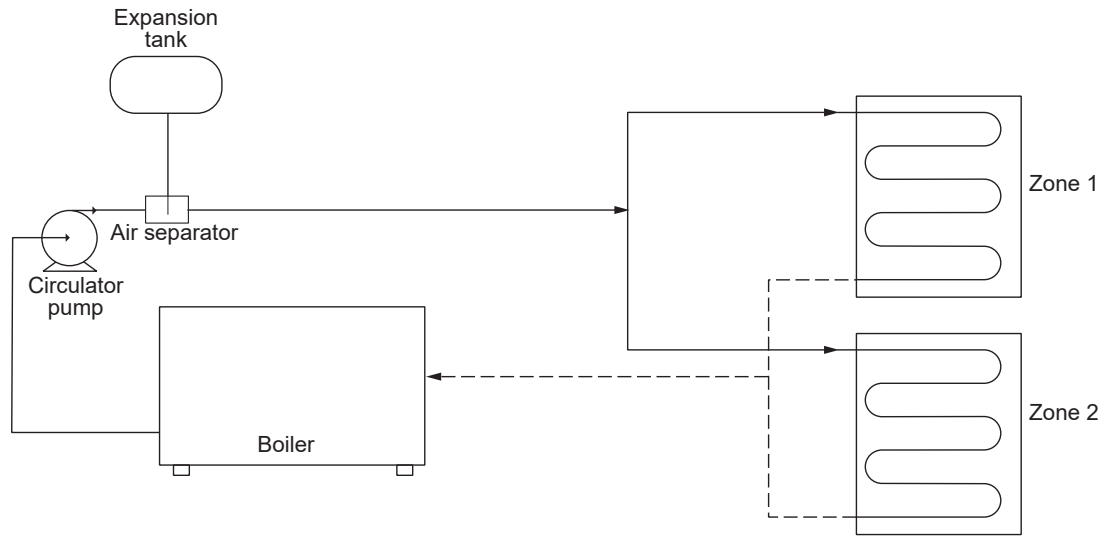
Continuous serpentine coils, made of plastic or thin copper tubing, usually heat the panels. In the past, steel piping laid out in a grid pattern was used when greater strength was required, as in concrete floor slabs. Today special plastic tubing (PEX) is used in most residential, commercial, and industrial in-floor heating installations.

The temperature of the water in the coils is generally lower than that used in a conventional hot water heating system. The water temperature needs to stay within certain limits:

- In ceilings, the water temperature should be lower than 80°C (176°F).
- In floors, the water temperature should be lower than 60°C (140°F).

Figure 7 is a basic diagram of a two-zone panel heating system.

Figure 7 – Two-Zone Panel Heating System



Note: The supply and return piping for each zone uses the reverse return system. All panels are equipped with a balancing fitting to obtain even heat distribution.

Boiler water temperature is typically above 66°C. A mixing valve or heat exchanger tempers the water before it circulates through the panel.

Advantages of Radiant Panel Heating

- a) More even heat distribution throughout the rooms.
- b) More comfort for buildings built on concrete slabs without a crawl space or cellar, when using heated floor panels.
- c) Heating elements are completely out of sight and do not interfere with furniture or building layout.

Disadvantages of Radiant Panel Heating

- a) Due to their large heat storage capacity, the panels are slow to heat up and cool down. This process makes it difficult to maintain a steady room temperature when the outside temperature changes quickly.
- b) Any leakage in the panels or in-floor tubes is costly to repair.
- c) Changes in the heating system are difficult to make.

Snow Melting System

The use of snow melting systems to clear driveways, sidewalks, or parkade ramps is becoming more and more popular. This type of system melts snow and ice, which makes it safer for pedestrians and vehicles, and eliminates the need for snow removal.

There are several types of snow melting systems. Here is a list of the more commonly used types:

- a) Hydronic snow melting systems use a heat transfer solution heated in a converter by either steam or hot water supplied by the boiler of the building heating system. A circulator then pumps the heat through coils in the sidewalk. The heat transfers to the sidewalk and melts the snow and ice.
- b) Electric systems use electric resistance heating cables buried in concrete ramps or sidewalks.
- c) Radiant heat systems use infrared radiant lamps mounted above ramps or sidewalks.



Snow melting systems use large amounts of energy. These systems should only run when necessary.

Figure 8 shows an example of the coil layout for a sidewalk snow and ice melting system. The coils are embedded at least 5 cm below the surface of the concrete. Note the balancing valves in the return piping of the coils.

Figure 8 – Sidewalk Snow and Ice Melt System

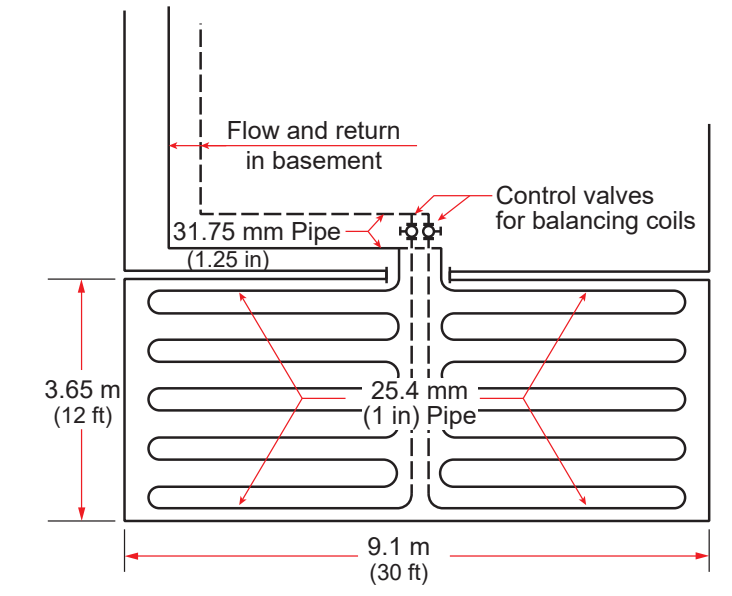
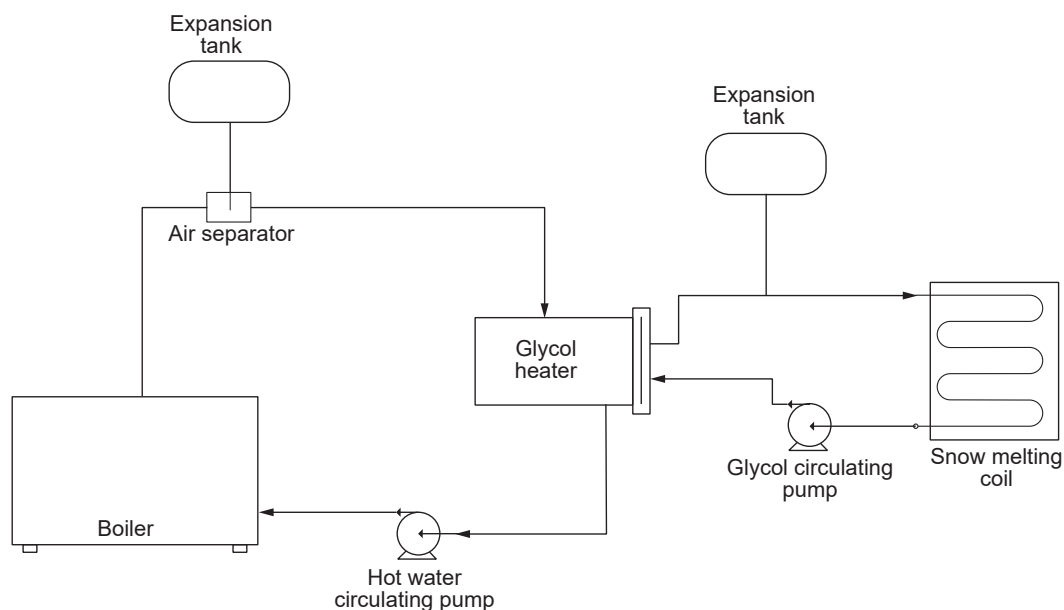


Figure 9 shows a basic diagram of a snow melting system and also details the heating equipment. These systems are usually filled with an antifreeze solution (ethylene or propylene glycol). In this case, there is a glycol heater connected to the boiler. When the outside temperature is below freezing and the system is not operating, the antifreeze prevents the system from freezing.

Figure 9 – Piping Detail for a Snow Melting System



OBJECTIVE 4

Describe the purpose and function of standard hot water heating system accessories.

ACCESSORIES

A hot water heating system uses various accessories. This objective discusses the devices listed below:

- Air vents
- Air separators
- Flow control valves
- Balancing valves and fittings
- Riser stop valves
- Pressure reducing valves
- Circulating pumps
- Expansion tanks
- Backflow devices
- Steam to hot water converters

Air Vents

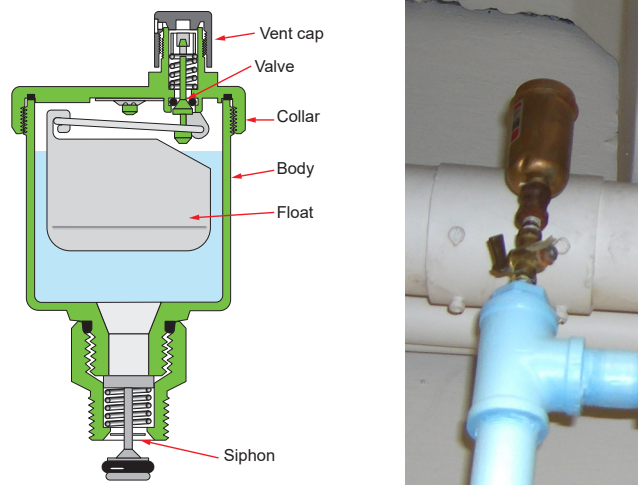
In a hot water heating system, air collects in the high spots of the piping and heating units. This air forms air pockets that can restrict or even block the flow of water. Without proper water flow heat transfer is inconsistent and there is insufficient heating. Improper water flow can also cause noisy operation of the heating system.

When filling a hot water system for the first time, it is important to vent all the air out of the system. Air tends to collect at the high points of the system, such as the upper parts of the risers, and in radiators and convectors. Before starting the system, remove the air from these points. At startup, the system should be air-free, except for the air trapped in the expansion tank.

Cold water contains a certain amount of dissolved air which is freed when the water is heated. Therefore, air removal is necessary during the warm-up and regular operation of the heating system.

In older systems, venting was done manually. Manual venting involved opening small petcocks on radiators and convectors, and larger vent valves on the risers.

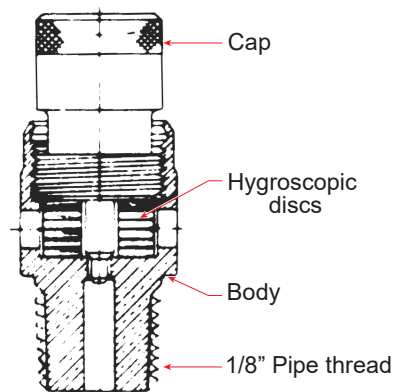
On newer systems, automatic air vents are used. Figure 10 shows a float-operated air vent commonly installed on the highest part of mains and risers. As long as water is present in the vent body, the float holds the vent valve shut. When air collects in the air vent, the float drops down and opens the vent valve.


Figure 10 – Float Type Air Vent


A common practice is to install a small valve below this type of air vent. When the heating system is in operation, the valve allows the air vent to be isolated and serviced.

The float type air vent is available in a shorter body style to fit baseboard and wall fin enclosures, if required. An automatic float type air vent is normally installed on piping points where the vent may not be easy to access.

Figure 11 shows an automatic vent used on radiators and convectors. This vent uses composition discs, which are hygroscopic (they readily absorb water). When in contact with water, the discs swell or expand to seal off the vent opening. Any air trapped at the vent will dry the discs and cause them to contract, which will open the vent port. The vent can also be opened manually by turning the cap about 3/4 turn, so that the discs do not pack together.

Figure 11 – Hygroscopic Automatic Air Vent


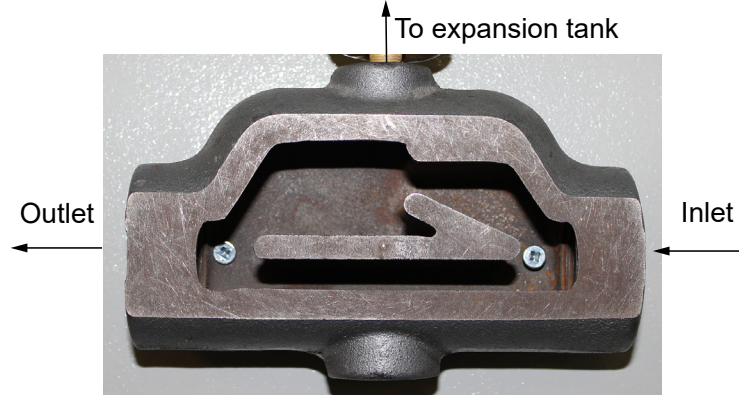
Air Separators

When the water in the boiler heats up, the air released should not be allowed to travel to the rest of the heating system. This air needs to be trapped, and either directed to the expansion tank, or vented to the atmosphere. Two methods are available to remove this air from the water.

The first method allows the air to leave the boiler with the heated water. Air is lighter than water, and will tend to travel along the upper portion of a horizontal pipe. The first horizontal stretch of the supply piping, after the water leaves the boiler, will have an air separator or air scoop installed in it.

A cutaway view of one type of air separator is shown in Figure 12. This air separator or scoop contains a baffle that causes the air bubbles to rise and accumulate in the upper part of the housing. The bubbles then pass upwards to the expansion tank, which is connected directly to the separator. In the expansion tank, the air helps to maintain the air cushion. If a diaphragm (bladder) type expansion tank is used, the bubbles vent to atmosphere through an air vent.

Figure 12 – Air Separator



In the second method, the hot water leaves the boiler through a dip tube, which extends several centimeters below the top of the boiler. The dip tube prevents the air that collects at the top of the boiler from leaving with the water. Instead, the air passes up to the expansion tank, which is either directly connected to the top of the boiler (Figure 13), or to a special fitting which combines the hot water outlet and tank connection (Figure 14).

Figure 13 – Air Separation in a Boiler

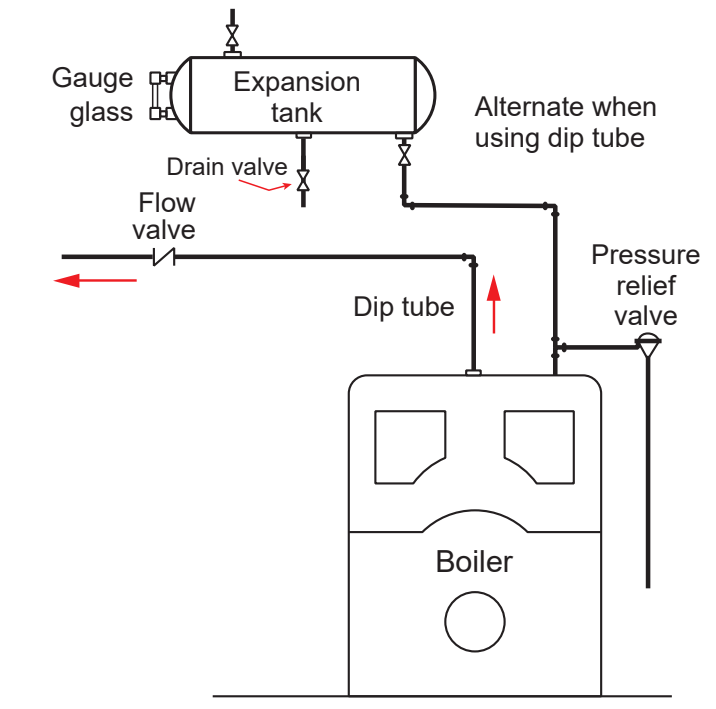
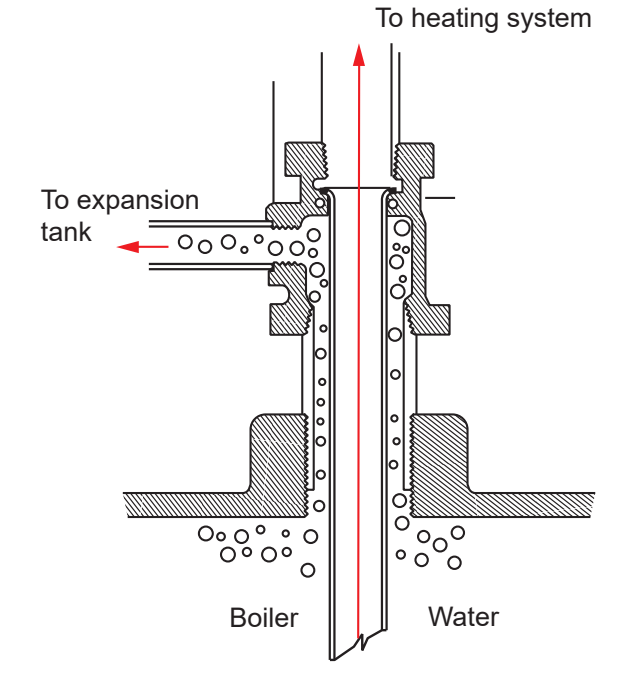



Figure 14 – Airtrol Boiler Fitting


Flow Control Valves

A flow control valve is necessary in each circuit of a multi-zone pump system. These valves prevent the hot water from circulating after the zone control has stopped the circulator. If the water continues to circulate, it may cause a zone to overheat. The water continuing to circulate in the system has two possible causes:

1. Water is still circulating in the other circuits connected to the same supply and return mains.
2. Water is circulating by natural convection currents caused by the temperature differences of the water in various parts of the circuit (gravity circulation).

Balancing Valves and Fittings

Zone circuits in multi-zone systems do not always have the same flow resistance, due to the difference in piping length, and the number of connected heating units. As a result, the flow of hot water through each zone may not always be the correct amount needed to satisfy the heating requirement of the zone. This is called hydraulic imbalance.

To correct this condition, a balancing valve is installed in each zone circuit. By adjusting these valves, it is possible to regulate the flow of water so that each circuit receives the proper amount of water. The balancing valves commonly used are either plug valves, or globe valves with a plug type disc. Some balancing valves use a “lockshield” design, which prevents anyone from tampering with the position of the valve after the balancing has been completed.

Water balancing eliminates the unequal flow of water through the zone circuits. Only a qualified contractor should perform this balancing.

Flow imbalance between convectors on the same heating circuit can be corrected by installing and adjusting small plug valves, or cocks, on the outlet of each convector. These valves form part of the connecting fittings between the convector and return pipe, so they are called balancing fittings.

Riser Stop Valves

A gate or ball valve should be installed at the start of each supply riser, and at the end of each return riser. This allows each section to be shut off individually for servicing, without interrupting the operation of the remainder of the heating system.

Pressure-Reducing Valves/Auto Fill Valves

The auto fill valve is simply a pressure-reducing valve. It keeps the system filled with water, and maintains a minimum set pressure in the system. If some water is lost due to leakage, the system pressure drops. The automatic fill valve will open to feed either municipal water, or water from another source, into the system. The pressure setting of a typical pressure-reducing valve is 103 kPa to 124 kPa (15 to 18 psi). Taller buildings need to be set at a higher pressure, so there will be enough water pressure on the highest floor.

If the pressure-reducing valve is set too high, then the pressure relief valve will discharge.

Circulating Pumps

The circulating pump forces water to circulate through the heating system. Larger commercial installations use the centrifugal pump, normally installed on the boiler piping, downstream of the expansion tank. Pump design can be in-line or base mounted.

Isolation valves, bypass valves, check valves, strainers, and pressure gauges are commonly installed with circulating pumps. Flexible piping connections can be used on the pump to prevent excessive noise and vibration from being transmitted to the building. The pumps must be capable of operating quietly and reliably for long periods, without shutdown.

In small installations, the in-line circulator type is favoured. These low head pumps may be as small as 375 watts (1/2 hp). These pumps are installed in the system piping, which also supports the pumps. The small pumps are driven by an electric motor through flexible couplings; often, the pump and motor are close-coupled. Larger systems use a high head pump and motor that are usually base-mounted.

Expansion Tanks

In hydronic systems, the expansion tank is a piece of equipment for water to expand in when heated. Since all hot water heating systems heat water, they all require expansion tanks.

Hot water heating systems are closed systems. Initially, they are filled with water to a minimum of 83 kPa. As soon as the boiler fires, the water begins to expand. Water is incompressible, which means it creates more water pressure as it expands. Without room for expansion, the water pressure would increase in a matter of minutes to the boiler pressure relief valve setting at 207 kPa.

Hot water heating systems must be equipped with expansion tanks for the following reasons:

- a) As the water in the boiler and system heats up, it expands. To prevent excessive pressure buildup, the hot water expands into the expansion tank.
- b) As the water in the boiler and system cools down, it contracts. To keep the system properly filled, the water stored in the expansion tank returns to the system. This reduces the need for make-up water.

Expansion Tank Designs

In the past, open expansion tanks were installed above the highest radiator in the system. They were used on gravity systems, and to provide static head pressure. The open expansion tank had a vent line open to atmosphere, a gauge glass to show the water level, and an overflow from the upper portion of the tank to a drain. The use of the open tank was usually limited to systems with a maximum water temperature of 80°C. These tanks were mainly used on older, small capacity residential hot water heating systems.



Modern hot water systems have closed expansion tanks. A cushion of air is trapped in the tank, and is compressed when water enters the tank (due to a temperature rise in the system). This action increases the system air and water pressure.

A pressure increase in the system may be beneficial, since it allows for higher operating temperatures without running the risk of reaching the boiling point of the water. However, pressures must not exceed the maximum allowable working pressure of the weakest system component.

The expansion tank should be large enough to:

- a) Accommodate the excess water volume when the water temperature increases.
- b) Contain a large volume of air to prevent an excessive pressure increase.

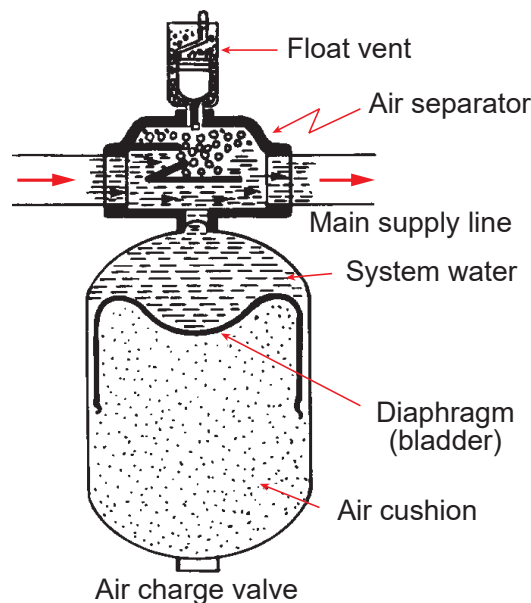
With a larger volume of air in a closed tank, there is less variation in the system pressure as the water temperature changes.

A conventional expansion tank has an air cushion on top of the water. The air and water are in direct contact with each other, and the water absorbs some of the air. When the temperature of the water in the system drops, the water leaves the tank along with the air it absorbed. As the temperature of the water increases, the air is free once again. The freed air must be vented; otherwise, it may interfere with the proper flow of water through the system, and it will also cause corrosion in the steel piping and heating units.

Bladder expansion tanks have a flexible diaphragm that separates the system water from the air. The diaphragm provides a permanent air cushion, and helps to avoid problems caused by air escaping into the system.

In Figure 15, the expansion tank has a diaphragm attached to the bottom of the air separator. In this case, the tank is installed in the main supply line to the system. This type of tank may also be installed into a tee, or any suitable tapping in the supply line.

Figure 15 – Diaphragm Type Expansion Tank



An expansion tank with a bladder cannot vent the air trapped in the system. Therefore, air that separates from the water in the separator, or from the top of the boiler, needs to have a means of exiting the system. With the use of an automatic air vent, the air can directly vent to atmosphere.

Large heating systems often have expansion tanks that use nitrogen gas as an air cushion. As an inert gas, nitrogen is less soluble in water than air, and it does not cause corrosion. A nitrogen-filled pressure cylinder, connected to the top of the tank with a pressure-reducing valve, will maintain a pressurized gas cushion in the tank.

Backflow Devices

A backflow prevention device protects the potable water of the building from the contaminated boiler water. This mandatory device is installed on the potable cold water feed line that goes to the boiler. To ensure its safe operation, qualified personnel must test this device regularly.

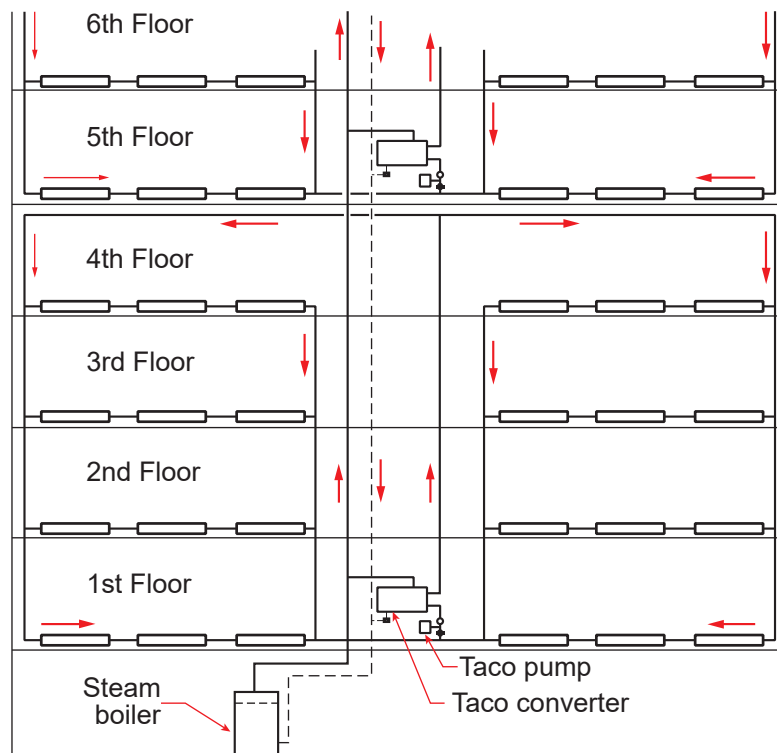
Steam to Hot Water Converters

In a hot water heating system, it is sometimes preferable to heat the water with steam from a steam boiler. A steam to hot water converter supplies the steam. This converter is usually a shell-and-tube heat exchanger. The water in the exchanger flows through tubes and heats up. The steam created from the heated water then enters the shell surrounding the tubes.

The following are two applications where a steam to hot water converter may be used.

- In multi-storey buildings where there is excessive head on the hot water boiler in the basement. A steam boiler can supply steam to a number of converters located at four or five floor intervals (see Figure 16).
- In buildings where steam is required for kitchen, laundry, sterilizers, or air conditioning equipment, but hot water is preferred to heat the building.

Figure 16 – Multi-Storey Building Heating by Converters



(Courtesy of Taco Inc.)

OBJECTIVE 5

Explain how the location of the hot water circulating pump and the expansion tank are determined.

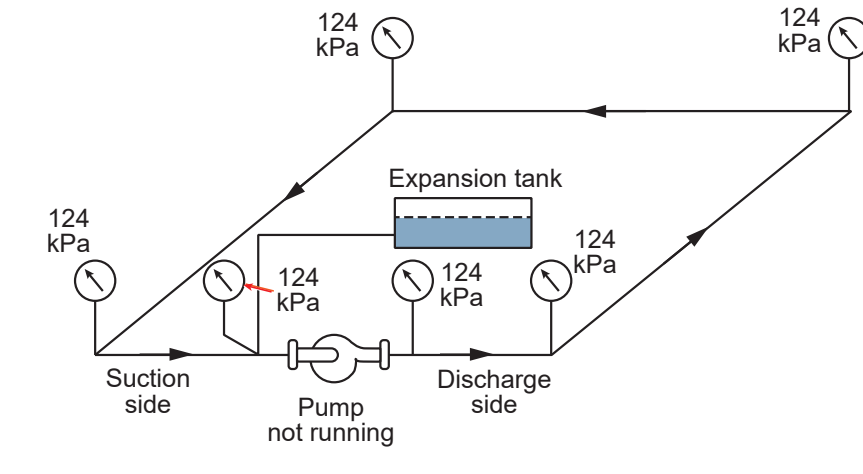
LOCATION OF PUMP AND EXPANSION TANK

Troubleshooting issues with a hot water heating system can be facilitated by understanding how the equipment is arranged. The system pressure within a closed loop heating system is predictable and is based on the pump supply pressure, elevation of each component, and system temperature and pressure.

Point of No Pressure Change

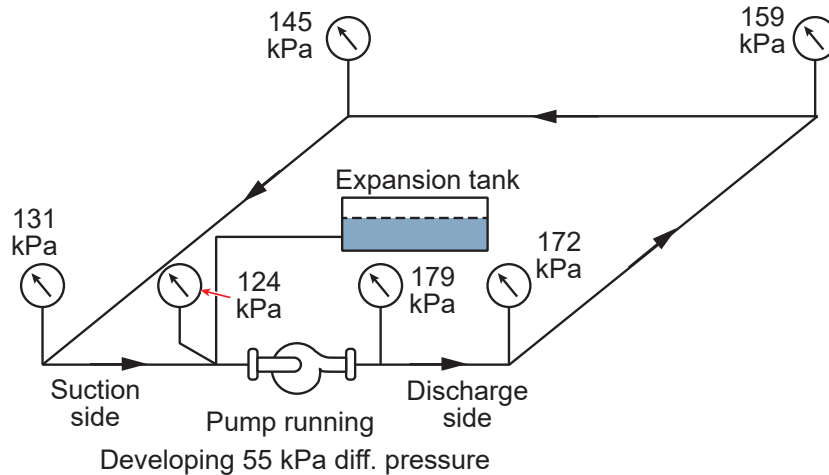
Figure 18 shows a simplified diagram of the main circuit of a closed hot water system laid out as a horizontal loop. The expansion tank is partially filled with air, which is compressible. The remainder is filled with water, which is non-compressible. Except for the air space in the expansion tank, the entire system is filled with water. In this diagram, there is no way to add or remove water. Therefore, when the pump is not running, the pressure in the system is uniform. For simplicity, the boiler is not shown in Figures 18, 19, and 20.

Figure 18 – Closed Loop Hot Water System: Pump Off

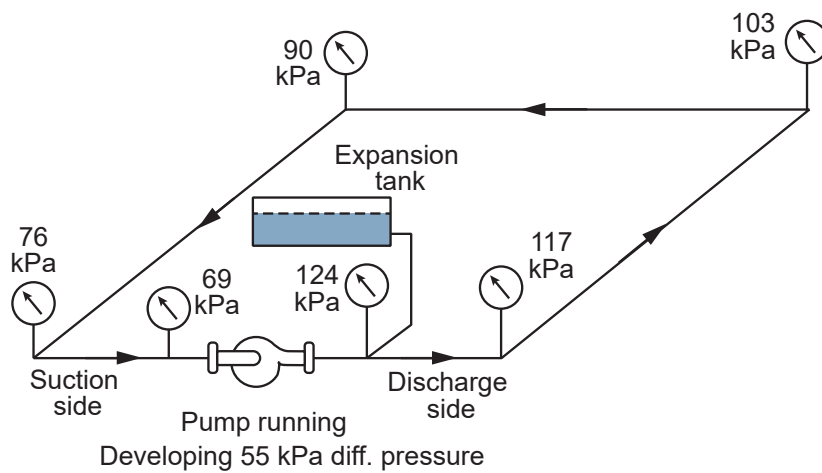


When the pump is running, there is a pressure differential (the pump head) between the suction side of the pump and the discharge side. This differential causes a pressure change throughout the system. Therefore, the system is not at a uniform pressure when the pump is running. Due to the location of the expansion tank and the air volume in the tank, when the pump starts, the suction pressure remains the same as if the pump was not running (Figure 19). This statement is true as long as the temperature of the water and the volume of the water remain unchanged.

The pressure in the expansion tank does not change because of the air that is in the tank. When the pump is turned on and it begins to draw water from the suction side of the system, there is a slight drop in pressure at the pump inlet. This drop in pressure causes the air to expand, and pushes some water back into the system to maintain the pressure. This action then causes the pressure on the suction side to remain the same as when the pump is not running. The discharge pressure from the pump increases as the pump is running.


Figure 19 – Closed Loop Hot Water System: Pump Running


If this same expansion tank is on the discharge side of the pump (see Figure 20), a similar effect occurs on the discharge side. The pressure increases on the discharge side, and it transmits to the air inside the tank. When the water pushes into the tank, it causes the air to compress. The reduction in air volume compensates for the change in discharge pressure. Because the pump can compress the air, the pressure on the discharge side remains unchanged. However, the pressure drops on the suction side.

Figure 20 – Closed Loop Hot Water System with Expansion Tank at the Pump Discharge


The pressure at the point where the expansion tank is connected to the system is practically the same as the pressure in the tank. Therefore, this connection point is referred to as the point of no pressure change.

In a hot water system, the boiler pressure should not be affected when the circulating pump is operating. To facilitate this, the point of no pressure change is almost always located at or near the boiler.

The heating system pressure must be kept above the saturation pressure that corresponds to the hot water temperature. Otherwise, some water will flash to steam. This action may cause the circulating pump to cavitate or become vapour bound. When flash steam collapses, water hammer may also occur.



Minimum Pressure in a Hot Water System

To prevent the pump from cavitating, a positive pressure should be maintained in the system at all times. The pressure at the highest point of the system should be at least 12 kPa, which is equivalent to a head of water of 1.2 m.

As a rule, the minimum reading on the altitude gauge of a boiler in a large hot water system can be determined as follows:

1. Measure the distance from the top of the boiler, to the highest point in the system.
2. Add 1.2 m to the result in step 1.

Recall that 1 m of water height is equivalent to 9.81 kPa.

If the highest point of the heating system is 19.8 m above the top of the boiler, the altitude gauge on the boiler should indicate at least 21 m of water head. Since 1 m of water head is equivalent to a pressure of 9.81 kPa, a pressure gauge on the boiler should indicate at least $21 \times 9.81 = 206$ kPa.

In high-rise buildings, it is common to place the boiler and circulator on the top floor. In this situation, the water head may have to be increased in order to supply sufficient suction head for the circulator to prevent cavitation or vapour binding. Always make sure that the pressure is high enough to give the pump the required net positive suction head.

Although the expansion tank will compensate for changes in pressure occurring in the hot water system, it cannot compensate for leaks. An automatic fill valve (a pressure-reducing valve) helps the system to maintain proper pressure.



OBJECTIVE 6

Describe the routine operation of hot water heating systems, including cleaning, filling, starting, and the use of glycol/antifreeze.

CLEANING NEW HOT WATER SYSTEMS

All new systems contain many types of foreign material. During construction, these materials will inadvertently find their way into the system. Some of these materials include:

- Pipe dope
- Thread cutting oils
- Soldering flux
- Rust preventives or slushing compounds (greasy or oily surface coatings)
- Core sand
- Welding slag
- Dirt, sand, or clays from the job site

Fortunately, these impurities are usually in small amounts, and they do not cause too much trouble. However, some substances break down chemically during the operation of the system. If these substances are present in sufficient quantities, they may cause the water to become acidic. This will lower the pH to below 7, which can result in corrosion.

When piping is welded in place, care should be taken to prevent the welding slag from collecting in valves, elbows, pump impellers, and so on. Welding slag in fittings will interfere with circulation. If the slag gets caught in a pump impeller, it will cause serious pump trouble, such as burned out motors, excessive noise, and reduced circulation. Slag, metal shavings, and debris can affect the operation of control valves. Manufacturers cannot be expected to guarantee their products against damage from welding slag, or other foreign material.

It is common practice to install a temporary strainer in the suction line. The strainer prevents larger particles from reaching the circulating pump.

It is easy and inexpensive to clean out a new hot water system to remove any substances that may break down and cause corrosion. An alkaline solution circulated through the system for several hours will remove these substances from the system.

The chemicals used for this purpose are (in order of preference):

1. Trisodium phosphate
2. Sodium carbonate (soda ash)
3. Sodium hydroxide (caustic soda)

Use only a single chemical for the cleaning. A water treatment professional can help to select the right chemical and in the correct proportions to clean the system. Use the recommended solution to fill the system. Ensure all air is vented before circulating the solution. If possible, allow the solution to reach design or operating temperatures. After the solution circulates for a few hours, drain the system completely and refill it with fresh water. Usually enough of the cleaner will adhere to the piping to give an alkaline solution satisfactory for operation.

Note: Make sure to follow the recommended cleaning procedures given by the water treatment professional.

A clean hot water system should never be drained, except for an emergency, or the necessary servicing of equipment. Antifreeze solutions in systems should be tested from year to year as recommended by the manufacturer of the antifreeze used.

Filling and Starting Systems

When filling a hot water system prior to putting it into service, it is most important to vent all the air from the system. The following steps cover the general procedure for filling and starting a system.

1. Open all vents, and close all drains.
2. Admit water to the system, with the automatic fill valve set to supply adequate pressure to the highest point of the system.
3. Vent each radiator and convector unit, and all the high points of the system. Leave the automatic air vent caps loose for automatic venting in the future.
4. Check the altitude gauge on the boiler when the system is completely filled and vented. If necessary, readjust the automatic fill valve, to obtain the proper system pressure.
5. Check the water level in the expansion tank. The level should just be showing at approximately $\frac{1}{2}$ full or less on the gauge glass.
6. Switch on the power supply to the boiler and circulator, and start up the boiler.
7. Warm up the boiler, and circulate the water through the entire system; this will remove any air bubbles clinging to the inside walls of piping and the boiler. The bubbles will either vent, or they will enter the expansion tank. The boiler warm up will also free and remove the air dissolved in the cold water.
8. Check the entire system for proper operation. Correct any irregularities or leaks.
9. When the boiler temperature reaches the maximum setting, shut off the burner, stop the circulator, and vent all parts of the system once again.
10. Set the controls to start normal operation.

Use of Antifreeze

When the heating system is exposed to freezing temperatures, an antifreeze solution may be used instead of water. If this is the case, the following points should be taken into account:

- a) Make sure the antifreeze used is not corrosive to the piping or other parts of the system. Many manufacturers of antifreeze solutions include a corrosion inhibitor in their products.
- b) Since antifreeze expands more than water, a larger expansion tank is required.
- c) Antifreeze is denser than water; therefore, more power is required for the circulating pump.
- d) Antifreeze does not carry as much heat as water; therefore, antifreeze must be kept at a higher temperature.
- e) Where possible, do not circulate the antifreeze solution through the boiler. Glycol breaks down at boiler temperatures. Use a heat exchanger so the high heat in the boiler does not heat the glycol mixture.
- f) Before using antifreeze in an old system, thoroughly flush out and clean the system. Circulate a solution of chemicals, at the right proportions, as recommended by a water treatment professional.
- g) Antifreeze mixtures are harmful if swallowed. Keep them out of the reach of children.
- h) If there is a potable water heat exchanger installed on the heating system, use only a food grade glycol solution (e.g. propylene glycol). Check with the local authority to determine if this type of system is allowed.



ROUTINE OPERATION AND MAINTENANCE

Hot water boilers may vary from large units used in large buildings or complexes to very small boilers used in small buildings and strip malls. Hot water heating systems should be carefully maintained on a regular basis to ensure reliability for when they are needed most. A structured program should include some of the following recommendations.

Hot Water Boilers

Boilers used in smaller buildings only require minimal supervision and maintenance. However, several points should be strictly observed.

1. Follow the manufacturer instructions for routine operation of the boiler.
2. Test the pressure relief (safety) valve and controls regularly. Mark the tests on the log sheet.
3. Observe the operation of the burner regularly. Make sure that the air supply to the boiler room is open.
4. Keep the boiler and boiler room clean. Keep covers on all controls since they are very sensitive to dust and dirt.
5. Determine the required boiler operating procedures of the local authority.

Circulating Pump

Check the operation of the circulating pump regularly. If the pump has a stuffing box, make sure it does not drip excessively. Lubricate the pump and motor, as needed. Modern residential and commercial circulating pumps do not use oil for lubrication. Instead, they have a wet rotor sealed inside the pump casing. These pumps are very efficient, extremely quiet, and require little maintenance. Always follow the manufacturer maintenance instructions.

Expansion Tank

Check the water level in the expansion tank regularly. Make sure the air cushion in the tank is maintained. If the tank becomes waterlogged, check for leaks on the tank and gauge glass connections. Make the required repairs, and then recharge the tank with air.

Piping and Valves

Inspect the piping and valves periodically. Make repairs at the first sign of leakage. Otherwise, property damage may occur.

When possible, open and close valves to check their operation.

Baseboard, Wall Fin, Radiators, Convectors and Unit Ventilators

Keep baseboard heaters, wall fins, radiators, convectors, unit ventilators, and unit heaters clean and free from blockage. Make sure furniture does not obstruct the flow of air around these units.

**OBJECTIVE 7**

Explain typical problems and resolutions in the operation of steam heating systems.

TROUBLESHOOTING GUIDE FOR HOT WATER HEATING SYSTEMS

Table 1 is a troubleshooting guide for hot water heating systems. An operator may use a similar guide to figure out the cause of many issues that can develop in these systems. The guide in Table 1 assumes that the systems were properly designed, installed, and had operated properly before trouble developed.

Some of the corrective actions listed should only be performed by qualified tradespeople. Unqualified persons could make problems worse, or even unsafe, by tinkering. As well, regulations may be in place to prevent unqualified personnel from performing certain tasks.

Do not adjust balancing valves and cocks. Balancing a heating system is a finicky operation. Only knowledgeable persons, equipped with the proper tools and measuring instruments, can successfully balance systems.

Table 1 – Troubleshooting Guide - Hot Water Heating Systems

TROUBLE	POSSIBLE CAUSE	CORRECTION
COMPLAINT: Slow or insufficient heat throughout the building		
Boiler water temperature too low	Burner not lit <ul style="list-style-type: none"> No power Setting controls too low or defective Defective safety shut-off valve Flame failure device shuts burner down Flow switch failure Low water condition 	<ul style="list-style-type: none"> Check power supply to boiler and various control circuits. Raise the setting of temperature operating control and/or outdoor reset the control. Replace defective controls. Replace valve. Find reason for flame failure, correct trouble. Check circuit and switch operation; replace if necessary. Circulating pump is off. Start pump. Investigate cause of low water. This may be a sizeable water leak, possibly from a frozen pipe or heating coil.
	Burner input too low due to insufficient fuel supply <ul style="list-style-type: none"> Main test firing valve not fully open Automatic fuel control valve does not open sufficiently Fuel filter is plugging Fuel pressure is too low 	<ul style="list-style-type: none"> Open valve wide. Inspect valve; repair or replace. Clean or replace filter. Increase pressure.



TROUBLE	POSSIBLE CAUSE	CORRECTION
Boiler water temperature too low (continued...)	Burner input too low due to poor combustion <ul style="list-style-type: none"> • Burner nozzle plugging • Restricted air supply to boiler room • Air dampers closed in • Fan belts slipping • Too much excess air 	<ul style="list-style-type: none"> • Clean nozzle. • Remove any obstruction from air supply openings or ducts. • Adjust dampers to give required amount of air. • Adjust belt tension. • Reduce air supply by adjusting dampers.
	Heating surfaces of boiler dirty. Stack temperatures are higher than normal.	<ul style="list-style-type: none"> • Shut boiler down and inspect heating surface on fire and waterside. Clean when necessary, to prevent reoccurrence. • Improve water treatment. • Check combustion.
Main supply header temperature too low	Boiler water temperature too low	See above
	3-way mixing valve allows too much cool return water into supply main	Check operation of 3-way mixing valve.
	Controls improperly adjusted or inoperative	Raise setting of space or medium thermostat and/or outdoor reset control.
Insufficient water circulation	Circulator not operating <ul style="list-style-type: none"> • Power off 	<ul style="list-style-type: none"> • Check power supply to pump and controls; power may have been switched off by mistake. If breaker tripped, check for electrical trouble in motor, or mechanical trouble in pump.
	Thermostat or aquastat controlling pump operation not working properly.	<ul style="list-style-type: none"> • Check setting of controls, replace if defective.
	Control valve malfunctioning	Replace defective control valve
	Screen in pump section plugging	Clean screen.
	Stop valves in supply and return headers not fully open.	Check and open valves wide.



TROUBLE	POSSIBLE CAUSE	CORRECTION
COMPLAINT: Insufficient heat in one zone		
Supply water temperature too low	Temperature of water in main supply line too low	See above
	Zone mixing valve malfunctioning	Check operation of valve by manipulating space thermostat.
	Control setting too low or control inoperative	Check setting of thermostat and outdoor reset control. Replace defective controls.
Insufficient water circulation	Zone circulator not operating	See above procedure for main circulator.
	Stop valves in zone supply and return headers not fully open	Check and open valves fully.
	Balancing valves closed in too much	Open valves more.
	Zone control valve malfunctioning	Check operation of valve; replace if defective.
	Air lock in piping after repairs have been made on the system	Check air vent operation.
COMPLAINT: Insufficient heat in one or more rooms		
Insufficient water circulation	Balancing valve in branch line, or balancing cocks on connectors closed in too much.	Adjust valve or cocks.
	Air pockets in piping or heating units	Manually vent air. If equipped with automatic air vents, check operation of these vents.
	Convactor valve does not open fully	Repair or replace valve.
	Room thermostat malfunctioning	Replace thermostat.
	Sensing bulb of thermal control valve covered	Make sure airflow over sensing bulb is not restricted.
	Piping or convactor frozen	Defrost, watch for leaks, and find cause of freezing trouble.
Restricted air flow through heating unit	Unit heater or ventilator <ul style="list-style-type: none"> • Fan not working • Filter plugged • Dampers misadjusted 	<ul style="list-style-type: none"> • Check power supply to fan. Check 3-speed switch. • Clean filter. • Check operation damper control.
	Air passages clogged with dust	Clean fin coils.
	Damper plates not fully open	Adjust dampers.
	Carpeting restricts air flow	Lower or cut back carpeting.
	Curtains restrict air flow	Shorten curtains.



TROUBLE	POSSIBLE CAUSE	CORRECTION
COMPLAINT: Heating system noisy		
Noisy circulator	Faulty bearings	Replace bearings and check alignment of pump and motor.
	Impeller unbalanced	Inspect impeller for damage or plugging.
	Cavitation in pump <ul style="list-style-type: none"> • Suction restricted • Suction pressure too low • Water temperature too high 	<ul style="list-style-type: none"> • Check that size of pump suction complies with that recommended for the pump. • Raise system pressure. • Lower water temperature.
Piping	Cannot freely expand, rubs holes through walls and floor	Enlarge holes to give proper clearance.
	Pipe guides binding around expansion joints	Re-align and lubricate as necessary.
	Air in system	Make sure air vents are in operation. Manually vent air from high points.
Convectors	Heating element rubs against wall and casing when expanding and contracting	Provide proper clearance.
	Casing vibrates	Strengthen vibrating parts.
Unit heaters and ventilators	Motor or fan bearings rough	Renew bearings.

CHAPTER SUMMARY

Hot water heating systems are similar to steam heating systems, they both have boilers that transfer heat to a fluid that circulates and gives off heat. Hot water systems have several advantages over steam systems:

- a) Simpler maintenance requirements
- b) Less complexity
- c) Ease of temperature control

Hot water systems use similar heat exchanger designs for space heat, such as radiators, convectors, and unit heaters. However, in addition to these devices, baseboard wall fins, reheat coils, wall panels, ceiling panels, and in-floor heating panels may also be used in hydronic heating systems.

This chapter covered several common piping configurations for hot water heating system. Common layouts were included for the following types of systems:

- Upfeed
- Downfeed
- Direct return
- Reverse return
- Multi-zone
- Multi-story

Each system has advantages and disadvantages.

Special heating systems, such as radiant panel and snow melting systems are unique hydronic heating applications. Hydronic systems have unique fittings not found on steam heating systems. Some of the fittings covered in this chapter included air vents, air separators, flow control valves, automatic fill valves, expansion tanks, and balancing valves.

Steam heating systems may also provide hot water for heating. For this purpose, steam to hot water convertors are used. These heat exchangers are like boilers in hot water heating systems, and have many of the same fittings, including safety relief valves.

Except for a few small residential systems, all hydronic systems use circulating pumps to distribute hot water through the terminal units. Some systems employ several pumps. These may provide hot water to individual zones, to allow for different temperature set points in different locations. If a single primary circulating pump is used, the expansion tank is often located on the suction side of the pump, to prevent cavitation.

New hot water systems require cleaning to remove debris that may damage pumps or interfere with control valves. If a system is designed, installed, and cleaned correctly, it should operate with little trouble. When problems arise, troubleshooting guides can help provide solutions.



Other Heating Systems

LEARNING OUTCOME

When you complete this chapter you should be able to:

Describe common heating systems encountered by Power Engineers.

LEARNING OBJECTIVES

Here is what you should be able to do when you complete each objective:

1. *Describe natural gas fueled warm air heating systems.*
2. *Describe the recommended maintenance procedures for warm air heating and ventilating systems.*
3. *Discuss the concept and application of infrared heating.*
4. *Describe the different methods of electric heating, and their advantages and disadvantages compared to other types of systems.*



CHAPTER INTRODUCTION

Power Engineers may be required to operate many different heating systems. The heat supply may be required to meet:

- a) A general need
- b) A very specific heating requirement
- c) Specific heating challenges

There are no one-size fits all heating systems. Power Engineers must understand the different designs, operational challenges, and limitations of each system. Some of the limitations may include:

- The type of fuel source available
- The type of area heated
- Specific safety requirements

Operators need to understand the various methods used to operate and maintain heating equipment safely and efficiently, while minimizing affects to the environment.

This chapter covers the design and operation of several different types of electric, infrared, and forced air systems. The maintenance needs of forced air systems will also be addressed.

OBJECTIVE 1

Describe natural gas fueled warm air heating systems.

FORCED WARM AIR HEATING SYSTEMS

In residences and small commercial buildings, forced warm air heating systems usually supply all the heat required.

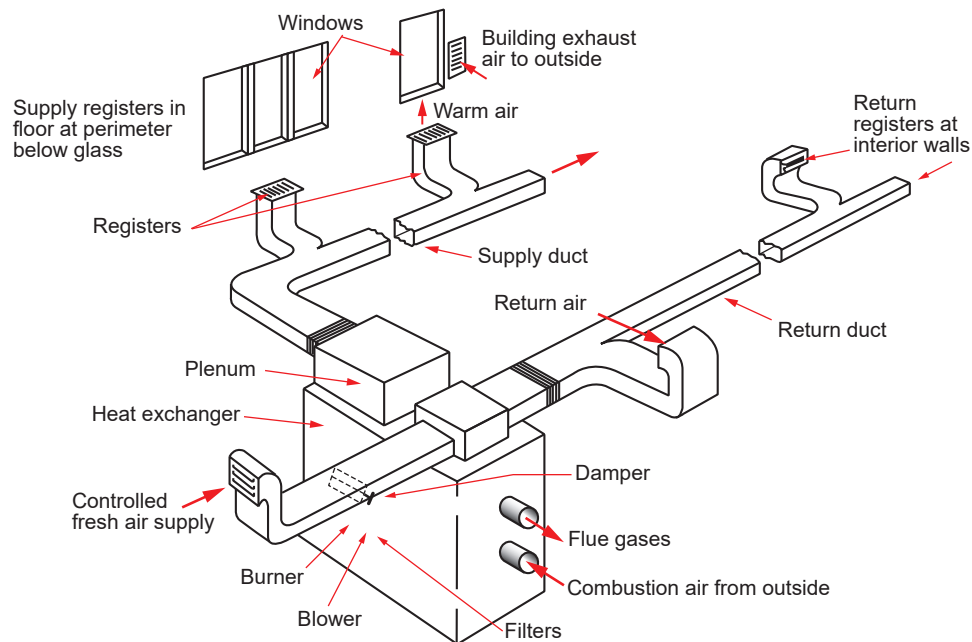
In larger buildings, the primary heat requirement is often supplied by a steam or hot water heating system. A secondary warm air heating system is used to supply the remainder of the heat required. The secondary system also provides fresh, filtered, heated, and humidified outside air for ventilation and humidification purposes.

Figure 1 is a basic diagram of a forced warm air heating system. The baseboard return registers, located at the interior walls, draw the cooler air out of the rooms and into the return duct. The cooler air goes through the return duct and filters, and flows into the blower compartment of the furnace.

The blower forces the air through a heat exchanger, where it is warmed, and then into the supply duct. This duct branches off into supply risers, which carry the warm air to the various rooms. The warm air enters the rooms through registers.

A fresh air supply duct allows a controlled amount of outside air to enter the system for ventilation purposes. This air mixes with the return air before it passes through the filters.

Figure 1 – Forced Warm Air Heating System





Heating Sources

Various types of heat sources are used in warm air heating systems. This objective discusses natural gas fired furnaces; however, there are other heating sources. These sources can be divided into the following classes:

Fired Heater: The furnace is a self-enclosed appliance. A motor driven blower circulates air through a heat exchanger, where it receives heat produced from the combustion of oil or gas. However, the circulating air does not come into direct contact with the products of combustion.

Electric Resistance Coil: The circulating air is heated by passing through electric resistance coils. Due to the high cost of electricity, the electric furnace has not found widespread use in larger warm air heating systems. It is mainly restricted to use in residences, or areas where electricity is readily available and other fuel sources are not.

Fin-Coil Heat Exchanger: When steam or hot water is used for the primary heating system, part of the steam or hot water produced by the boiler is supplied to fin-coils installed in the air ducts. This heats the air in the secondary warm air heating system.

Forced Air Furnaces

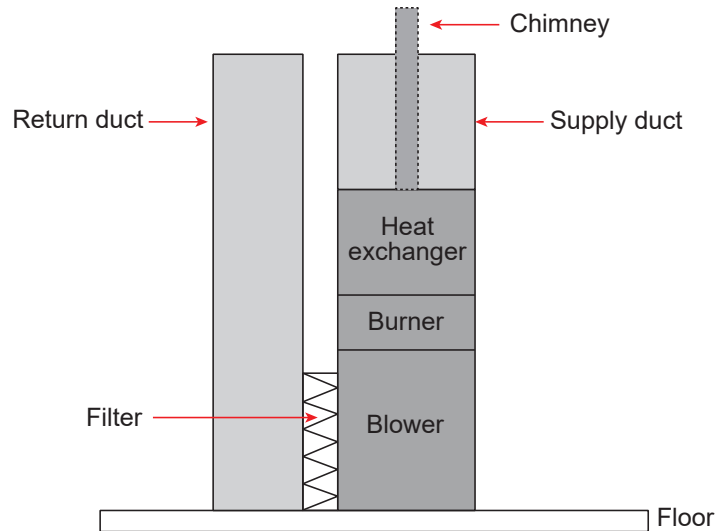
Forced air furnaces are designed in various shapes and sizes to fit installation requirements. They are classified by:

- a) Direction of airflow (horizontal, upflow, or downflow)
- b) Height (lowboy or highboy)
- c) Type of fuel burned (gas- or oil-fired)
- d) Heating capacities in kilojoules per hour
- e) Efficiency (high, low, or mid)

A short description of some of these furnaces follows.

As shown in Figure 2, the blower of a highboy upflow furnace is located beneath the heat exchanger, and it discharges vertically upward. This type of furnace saves floor space. Air enters through the bottom or from the side of the lower compartment, via the filter. The air leaves the furnace at the top.

In buildings without basements, this furnace is usually installed on the first floor, in the utility room or a closet. In such installations, a return duct is often not required. However, the return airflow back to the furnace must be unrestricted. When installed in a basement, the return air is ducted down to the blower compartment. This type of furnace is commonly used in residences or small buildings.


Figure 2 – Highboy Upflow Furnace


The downflow furnace is similar in construction and design as the upflow furnace; except the air flows downward, and the equipment must be arranged to match this flow. In this unit, the blower is located above the heat exchanger, and it discharges downward. The air enters at the top, and exits from the bottom.

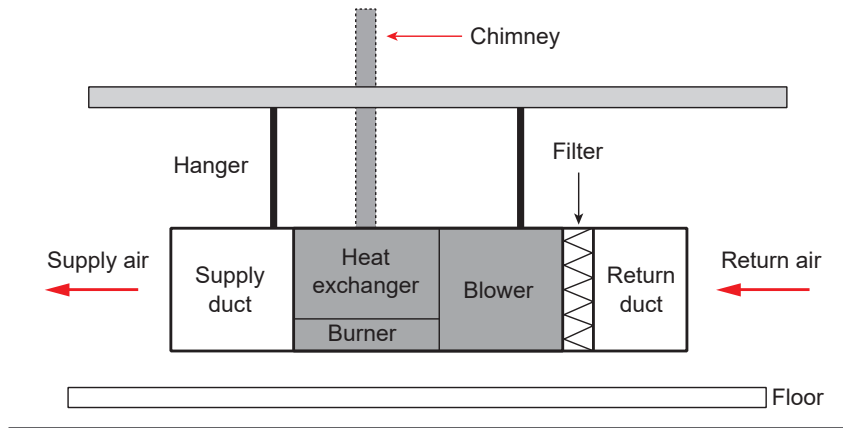
The downflow units are used in buildings without basements that have the warm air supply ducts set in the concrete floor slab, or in a crawl space beneath the floor. These furnaces can also be found in manufactured homes.

The lowboy furnace is used where headroom is limited. The blower is located beside the heat exchanger section of the furnace. The cool return air is drawn in from the top of the furnace, goes through the filter, and enters the blower. The air is forced past the heat exchanger, and warm air discharges through the top of the furnace.

The lowboy furnace may be upflow or downflow. These furnaces are a little over 1.2 m high, and provide easy installation in basements of residences and commercial buildings.

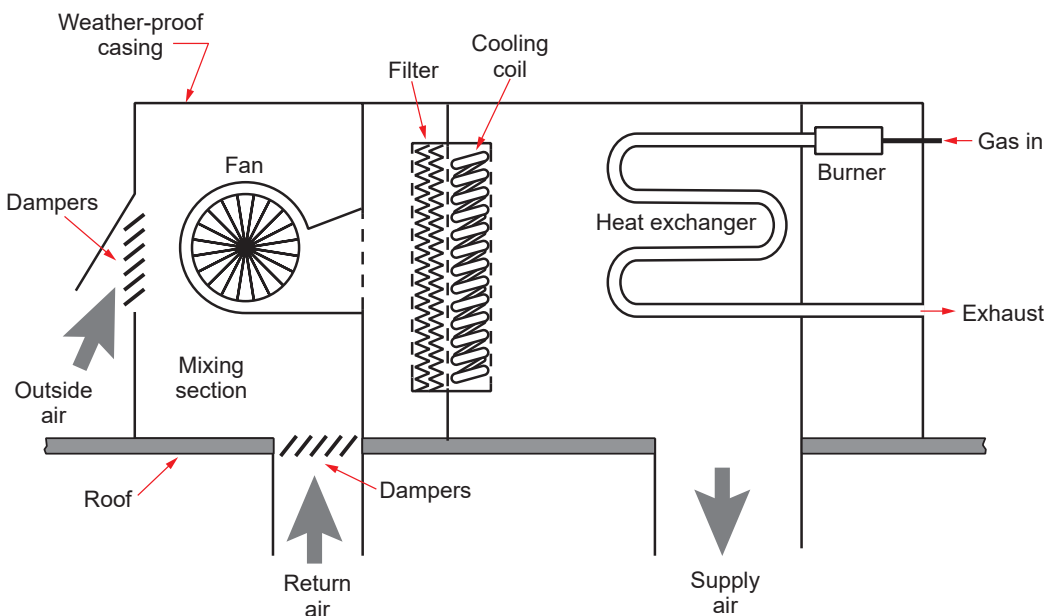
The horizontal furnace has the blower located behind the heat exchanger. The air enters at one end of the furnace, and proceeds through the filter and blower. The filtered air passes over the heat exchanger, and warm air leaves at the opposite end of the furnace. Figure 3 shows a horizontal furnace.

The horizontal units are usually only about 0.6 m high. They are used in areas with limited headroom, such as attics and crawl spaces below floors. Alternatively, they may be suspended from the ceiling.


Figure 3 – Horizontal Furnace


The warm air duct furnace is mounted directly into the supply duct of a make-up air system, a ventilating system, or an air-conditioning system. This furnace consists of the heat exchanger burner equipment section of a forced warm air furnace. This unit can have its own blower or fan, or it can use the fan of the ventilation system. Warm air duct furnaces are commonly used in shops and warehouses.

The rooftop heating unit (Figure 4) has a weatherproof casing that protects it from the elements. Usually a rooftop heater incorporates more than just a heat exchanger, furnace, and a fan; it may also include a filter and a cooling coil.

Figure 4 – Rooftop Heating Unit


Fresh air is drawn from outside and mixes with the supply air in the mixing section. A fan then pushes the air through a filter and past the heat exchanger, where it is warmed. The air is pushed downwards, into the space to be treated, or into a supply air duct. Gas mixes with the air, and burns at the burner. The flue gases travel through the inside of the exchanger, and exhaust to outside.

The rooftop heating unit is often equipped with dampers to control the fresh air make-up, and the return air to regulate and mix the fresh and supply airflows. Placing the unit on the roof can save considerable space inside the building, and may simplify the design of the duct system. This type of unit is commonly found in commercial buildings.



Fired Space Heaters

The term space heater generally applies to a fired heater installed in the space to be heated, which heats the air directly, without the use of any ducting. A common application of unit heaters is in underground parking garages or automotive repair garages.

Because vehicles operate in these enclosed areas, there is a high likelihood of CO, NO_x, and other emissions in this space. Therefore, it is critical to constantly replace this toxic air with fresher air. In these applications, it is important to achieve a minimum number of air changes per hour, as required by municipal regulations. An air change is the volume of air required to occupy the space in question. Essentially the amount of fresh air made available each hour must be greater than the volume of the space to be conditioned.

In this case, it is not practical to use a centrally located warm air furnace with a duct system. Heating of each area by one or more space heaters is often preferred. A commonly used heater is a unit heater.

Unit Heater

The fired unit heater is similar in construction to the duct furnace. However, the heat exchanger and burner equipment of the fired unit are mounted in a cabinet suspended from the ceiling.

In low-capacity unit heaters, a propeller type fan forces the air through the heat exchanger. Then, adjustable louvres distribute the warm air throughout the area. These heaters are not equipped with a filter.

Large unit heaters have one or more centrifugal fans to move the air. These heaters are equipped with filters.

High Efficiency Furnaces and Heaters

Almost all new furnaces designed today are heated with fuel oil, propane, or natural gas. These new furnaces typically have a high **Annual Fuel Utilization Efficiency (AFUE)**. Because all installations are different, there are several AFUE numbers for gas and oil fired furnaces.

The higher the AFUE number, the higher the energy efficiency of the furnace. This means that the furnace removes much of the heat from the flue gas before it vents to the atmosphere. Furnaces with a higher AFUE achieve greater than 90% efficiency.

Older furnaces allowed the flue gas to escape at 230°C or higher. Newer high AFUE furnaces are designed to have the flue gas exit below 100°C. This means less energy is required to maintain the desired temperature in the building.

A furnace with an AFUE range of 60% to 70% converts 60% to 70% of every fuel dollar into heat. The remaining 30% to 40% goes up the stack as wasted heat.

Low AFUE furnace designs were improved by installing automatic vent dampers, electronic ignition, improved heat exchangers, and draft inducers. These improved furnaces were termed mid-efficiency.

The vent damper minimizes heat loss up the stack. As soon as the demand for heat is met, the burners shut off. The damper then closes and traps the residual heat in the heat exchanger. The closed damper prevents the warm air from escaping the building, up the stack via the furnace. When there is a demand for more heat, the damper opens before the burners are lit.

Electronic ignition eliminates the need for a standing pilot. Which means, there is no wasted heat when the furnace is off.

Increased heat recovery produces larger increases in efficiency. There are two ways to increase heat recovery:

- a) Install a specially designed heat exchanger.
- b) Add a secondary heat exchanger.



With both of these methods, the flue gases remain in the furnace for longer. More heat can be scrubbed from the flue gases by increasing the length of time the gases remain in the furnace. This is similar to going from a 2-pass firetube boiler to a 4-pass firetube boiler. However, the addition of a heat exchanger in the system produces a pressure drop, which is overcome by the installation of an induced draft fan.

High AFUE (high efficiency) furnaces have additional secondary and tertiary heat exchangers to lower the flue gas temperature even further. As in a conventional furnace, the flue gases leave the primary heat exchanger at a temperature of about 230°C to 250°C. When the flue gases pass through the secondary exchanger, more heat transfers to the air, so the temperature of the flue gases drop to about 65°C.

Since the temperature of the flue gases drops below the dew point in the secondary or tertiary exchanger, the water vapour in the flue gas condenses. If there is any sulfur in the fuel, the SO₂ (sulfur dioxide) in the flue gases may combine with this condensate to form sulfuric acid. This acid may corrode the exchanger, blower, and the venting. Therefore, these parts are made of corrosion resistant material. A plastic drainpipe, which goes to the sewer, removes condensate that collects in the lower part of the secondary exchanger.

Solar Air Heating

Solar energy technology is becoming an economical option to preheat air before it enters a commercial or industrial facility. There are two ways to use this solar heated air:

- a) Directly, to supplement the existing heating or process air systems in the facility
- b) As a pre-warmed source of feed air for industrial furnaces

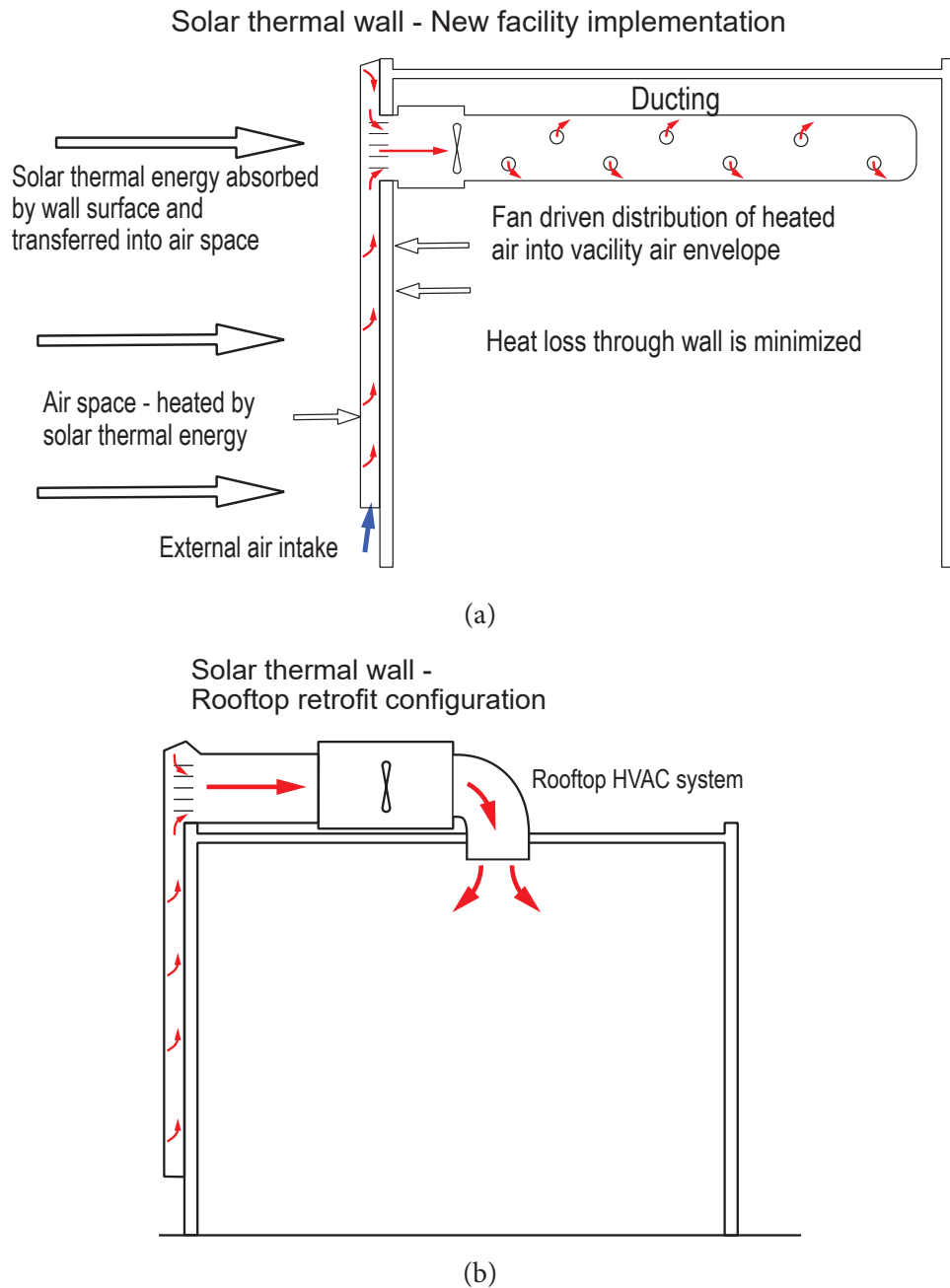
Facilities that use solar energy include:

- Government buildings
- Warehouses
- Multi-storey residential buildings
- Central heating plants
- Grain dryers

The most widely used application of solar thermal air heating uses cladding on south facing walls that absorb solar energy. Figure 5 shows two common configurations.

Figure 5(a) is a simple energy flow of a solar wall configuration, integrated directly into the building HVAC system. The wall cladding absorbs the external solar thermal energy. Then, the energy transfers into an air space between the cladding and the wall. Outside fresh air (blue arrow) is drawn into the airspace, and it rises up as it is heated by the thermal energy. The heated air enters the building. A fan drives the air, through ducting, into the internal airspace.

Figure 5(b) is a rooftop HVAC system that directs the air into the building. This second configuration is more common for building retrofits.

Figure 5 – Solar Thermal Air Heating Wall Configurations

ADVANTAGES AND DISADVANTAGES OF A FORCED WARM AIR SYSTEM

In a forced warm air heating system, an electric motor drives a fan or blower to circulate the air. This system has several advantages over other types of heating systems, especially gravity warm air, which uses differences in air density alone to create circulation.



Advantages of a Forced Warm Air System

Some of the advantages of using a forced warm air system include:

- a) The air circulation is positive, which allows for a more uniform temperature distribution.
- b) The ducts are much smaller than in a gravity system, and can be enclosed within walls and ceilings.
- c) The furnace can be located in any part of the building.
- d) The air may be cleaned by filters.
- e) The air can be humidified by installing a humidifier in the warm air supply.
- f) Controlled quantities of external ventilation air may be drawn into the system.

The last three items give the forced warm air system a definite advantage over steam and hot water heating systems. These other systems use radiators and convectors to supply the heat and do not provide for filtration, humidification, or ventilation.

Disadvantages of a Forced Warm Air System

Forced warm air systems have certain disadvantages:

- a) The air ducts are larger, and are more difficult to enclose than steam or hot water piping.
- b) The system can be quite noisy if not properly designed. Air flowing through the ducts at too high a speed can create an unpleasant noise level in the building. Fan, motor, and combustion equipment sounds may transmit through the entire building by the ducts.

FURNACE COMPONENTS

A forced warm air furnace consists of several components enclosed in a single casing. These components are discussed below.

Heat Exchangers

The heat exchange section of an oil-fired furnace is usually cylindrical in shape, and mounted above the combustion chamber. The hot combustion gases travel through this chamber, and give off heat to the air circulating around the chamber.

A gas-fired furnace is equipped with heat exchangers with a number of flat, hollow channels made of steel plate. The hot combustion gases travel upward, through the channels, to the flue. This gives off heat to the air circulating around the channels. The sides of the channels are usually corrugated, for added strength and greater heat transfer.

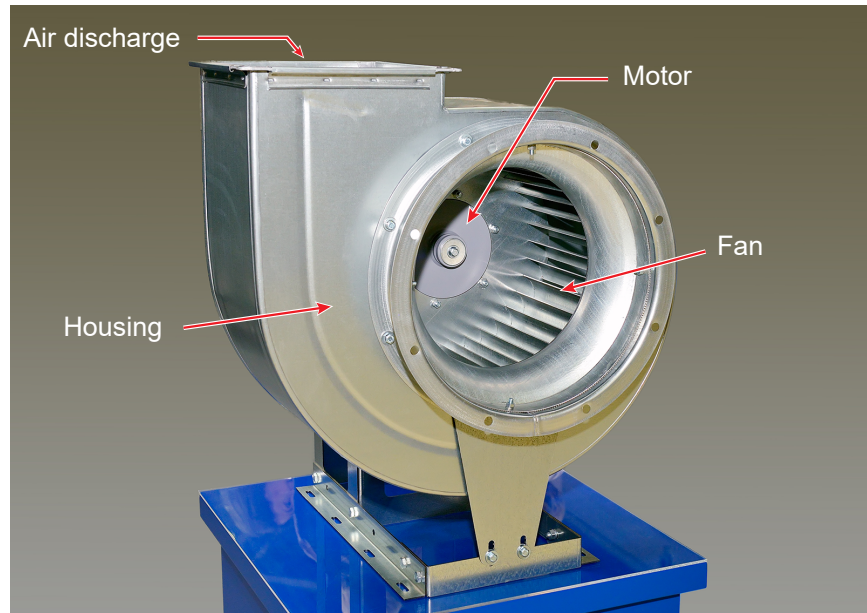
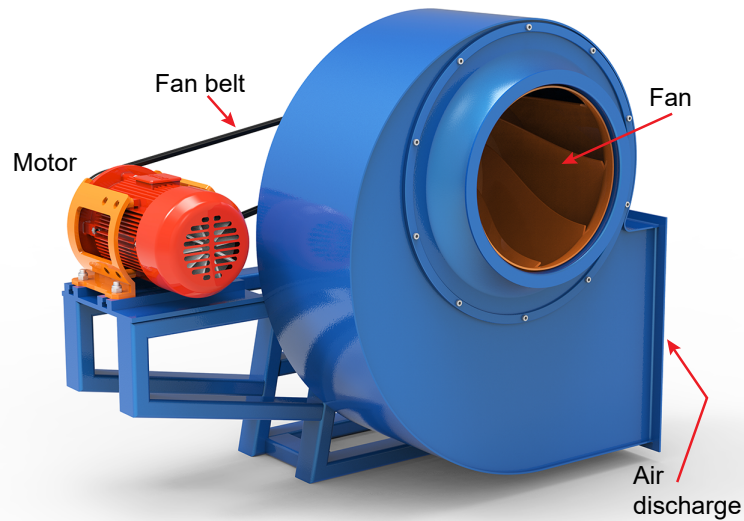
Combustion Equipment

Most oil and gas burners used in warm air furnaces are similar to those used in low-pressure steam and hot water heating boilers, such as atmospheric gas burners and high-pressure spray atomizing oil burners.

Blowers and Motors

A centrifugal blower or fan, driven by an electric motor, draws air through the return ducts and filter, and forces it through the heat exchanger and supply ducts. The blower is a double inlet type (air enters the rotor on both sides). The rotor usually has forward curved vanes or blades. The operating principle of the blower is similar to that of a centrifugal pump.

The blower rotor is often mounted directly on the motor shaft, so it runs at the same speed as the motor (see Figure 6). However, it can also be driven by a V-belt, as shown in Figure 7. In the V-belt style, a fixed pulley is mounted on the blower shaft, and an adjustable pulley is mounted on the motor shaft. The motor is then mounted on an adjustable bracket outside the blower housing. Belt-driven blowers run at considerably lower speed than the motor.

Figure 6 – Directly Driven Blower

Figure 7 – V-Belt Driven Blower


Cushion mounts support the motor and rotor; this isolates them from the blower housing and furnace. Isolating this equipment also prevents noise and vibration from transferring to the furnace and duct system.

Humidifiers

Most warm air heating furnaces are also equipped with a humidifier, which supplies moisture to the air. This humidifier maintains the relative humidity in the heated spaces at the required level. The humidifier is usually installed in the warm air plenum of the furnace, or in the supply duct.



OBJECTIVE 2

Describe the recommended maintenance procedures for warm air heating and ventilating systems.

MAINTENANCE OF WARM AIR HEATING AND VENTILATING SYSTEMS

Warm air heating and ventilating systems will give satisfactory and dependable service provided they are maintained properly. The small amount of maintenance required by these systems is vital for trouble-free operation. The following items should be checked at prescribed intervals, and tested before the start of the heating season.

Fan and Blowers

If kept clean and properly lubricated, fans and blowers usually give little trouble. Wipe off the fine dust that collects on the blades or vanes at least once a year. Check the condition of the blades at the same time. Immediately investigate any unusual sounds, such as rubbing. Any obstruction to the free rotation of the blades may destroy the unit.

Motor

Electric motors are rugged and simple machines. They will give little or no trouble if given reasonable care. Make sure that the bearings are always properly lubricated. Do not allow dirt, dust, and oil to accumulate on the coils or windings. Vacuum the air openings to the motor or blow them clear.

Lubrication

Smaller capacity blowers and motors are usually equipped with either sealed ball bearings, or sleeve type bearings. The sealed ball bearings require no lubrication. Sleeve bearings need a few drops of oil about twice a year, or as often as recommended by the manufacturer.

Always follow the manufacturer recommendations for the type of grease or oil to use in the bearings, and how often to lubricate them. Do not over lubricate motor bearings. Oil soaked surfaces cause dust to accumulate, which is a fire hazard. The excess oil may:

- Work into the coils and windings
- Attack the insulation
- Cause short-circuiting
- Burn the motor

Blower V-Belt Drive

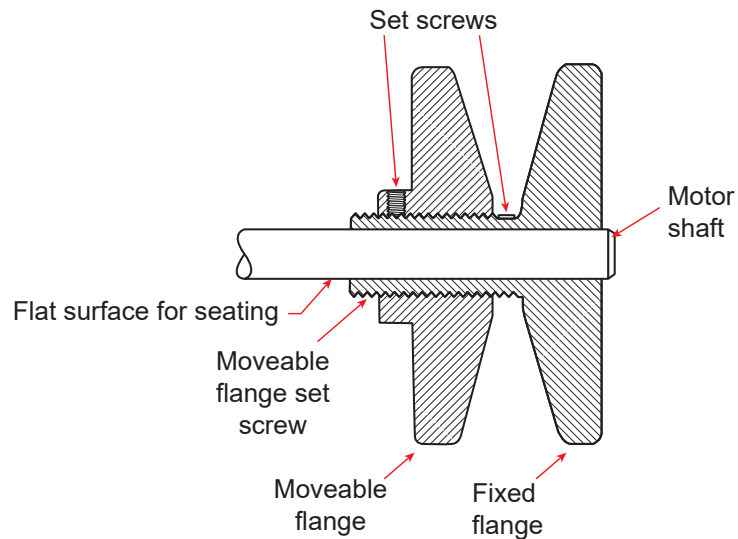
In a large warm air furnace, the blower is usually driven by an electric motor using a V-belt, which is fitted on pulleys mounted on the motor and blower shaft. Since the blower is to run at a lower speed than the motor, the speed is reduced by mounting a smaller pulley on the motor shaft and a larger pulley on the blower shaft. The motor shaft has to make several turns in order to turn the blower shaft once.

The blower motor is usually equipped with an adjustable pulley (also called a sheave), as shown in Figure 8. Adjusting this pulley varies the blower speed, and changes the volume of air that moves through the heating system. An increase in blower speed results in more airflow delivery, and an increase in motor amperage. The motor nameplate indicates the maximum current the motor can handle; this determines the maximum speed and volume the blower can deliver.

The pulley consists of a fixed flange, held in place on the motor shaft by a set screw and a movable flange, which is threaded on the hub of the fixed flange. The movable flange is also held in place by a set screw seated on the flat surface of the threaded hub. The V-belt runs in the groove between the two flanges. Bringing the flanges of the pulley closer together makes the V-belt ride higher in the groove and increases the blower speed. Conversely, moving the flanges apart makes the belt ride deeper in the groove, and reduces the blower speed.

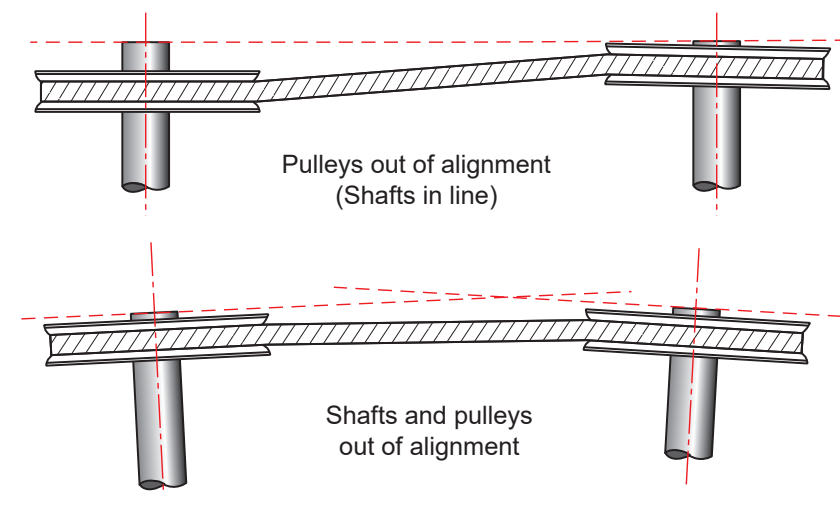
Check V-belts regularly. Replace them when they show signs of fraying, cracking, and wear. Make sure equipment is completely isolated before proceeding with repairs.

Figure 8 – Adjustable Pulley



Pay attention to the alignment of the pulleys. The grooves of the pulleys should be in a straight line. The motor and blower shaft should be parallel. Otherwise, the V-belt will quickly fray and wear. Figure 9 shows two ways in which the pulleys may be misaligned.

Figure 9 – Pulley Misalignment





Common ways to check the alignment are with a:

- Laser light
- Straight edge (a perfectly straight steel bar)
- Thin wire or string placed against the upper and lower side of the two pulleys

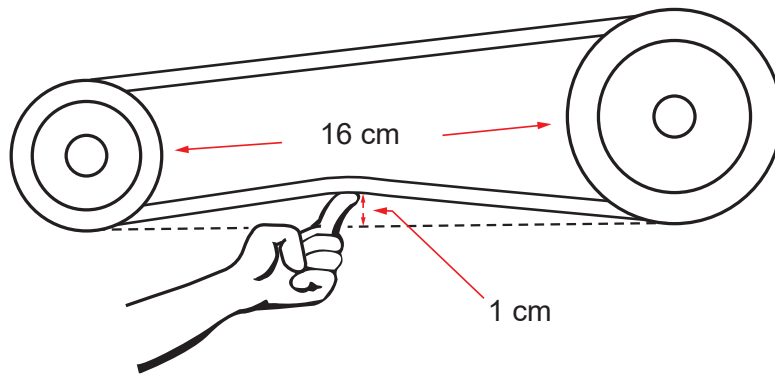
When the pulleys are in perfect alignment, the two rim edges of each pulley will touch the straight edge, wire, or the laser light at the same time.

Also, pay attention to the tension of the V-belt. It should be snug in the pulley grooves, but not tight. If the tension is too tight, it will put excessive force on the bearings and V-belt, and cause early failure. On the other hand, when the V-belt is too slack, it will lose its grip and start to slip. A squealing sound coming from the blower compartment on startup is an indication that the V-belt is too slack.

A simple rule for determining the proper V-belt tension for blowers less than 1 kW is that for every 16 cm of distance between the pulley rims, the belt should have about 1 cm of vertical movement, when pushed halfway between the pulleys, with a 45 N of force. This is shown in Figure 10.

For drive units greater than 1 kW, more accurate methods of belt tensioning should be used. Different types of belts have different tension requirements. The belt supplier will be able to give specific instructions for the application.

Figure 10 – Checking Belt Tension



When there are two or more belts driving a blower or fan, replace the belts as a matched set. Belts stretch during normal service. When a new belt is put on a pulley drive with an old belt, the tighter new belt will take most of the load. This will cause it to wear more quickly, and prematurely break.

On Track

Never try to install a V-belt without loosening the motor. Trying to roll or force a belt on the pulleys will overstress the belt, resulting in early failure.



Filters

Clean filters at least four times a year, or more often if dust conditions are high. Failure to do so will result in loading or clogging the filters, which limits the airflow. The limited airflow will cause insufficient heating and will waste fuel.

Clean washable filters according to manufacturer recommendations. Replace disposable or throwaway filters.



Burner

Observe the operation of the burner at regular intervals. Gas burners generally require little maintenance. The oil burner nozzle may require occasional cleaning to remove carbon deposits. Clean the burner fuel filter at the same time. On a gas burner, keep the pilot light free from dust accumulation.

Heat Exchanger

After long service, some heat exchangers develop corrosion holes or cracks in the welded joints. Careful examination should reveal any deterioration. If the heat exchanger has failed, carbon monoxide from the flame could enter the warm air stream, which puts the building occupants in danger.

Controls

Controls require little maintenance, except that room thermostats may occasionally require a gentle blowing, to remove dust deposits. However, check the operation of the controls when servicing the items that do require maintenance.

Humidifier

Most warm air furnaces are equipped with a humidifier. The operation and servicing of humidifiers is discussed under the topic of humidifiers.

Ducts and Outlets

Keep ducts as airtight as possible. Leaks may develop at the section joints. Since these are not quite as apparent as leaks in steam or hot water lines, they are often neglected. This may result in insufficient warm air supply to certain areas, and in wasted heat. Repair leaks promptly. Keep outlets clean and unobstructed.

Manual Dampers

In the duct system, manual dampers are used to control airflow. Adjust these dampers according to an air balance test, to ensure that the dampers move freely.



OBJECTIVE 3

Discuss the concept and application of infrared heating.

INFRARED HEATING

Infrared radiant heating has found widespread use in comfort heating. This type of heating is used in areas that are difficult, or costly, to heat with other types of systems.

Infrared heaters send out radiant energy in the form of invisible infrared waves. These waves travel in straight lines through the air, without warming it. However, when the waves strike a solid, opaque object, the radiant energy converts into heat.

When used for comfort heating, the infrared heater is usually mounted overhead. The radiant energy is directed downward to the floor, and to any persons or objects on the floor. If the amount of radiant heat received by a person standing on the floor is sufficient to replace body heat losses, this person will be quite comfortable, even when the surrounding air temperature is low.

With the infrared radiant energy directed toward the floor, equipment and people at working level are heated, while the upper levels remain cooler. Leaving the upper areas unheated provides savings on heating costs.

Radiant area heating can be found in ice arenas and curling rinks. To prevent damage to the ice surface, the air temperature in these buildings needs to be kept sufficiently low. However, in order to keep the spectators on the bleachers warm, heat needs to be provided. To solve this problem, radiant heaters are installed above the bleachers.

Spot heating covers only a very small area. It is typically used on loading docks, open work sheds, and bus shelters, to name a few. These areas are open to the outside atmosphere, and occupants may be subjected to very low air temperatures. The radiant heater should have sufficient capacity to make up for the increased body heat losses of the occupants. Spot heating is also used for snow melting at building entrances, on parking garage ramps, and other hard to heat areas.

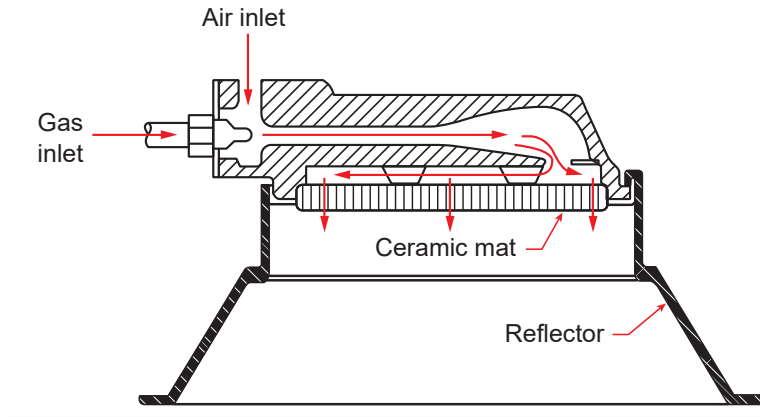
Gas-Fired Infrared Heaters

Gas-fired infrared heaters fall under four categories:

1. Surface Combustion
2. Directly Fired Refractory
3. Internally Fired or Vented
4. Low-Temperature Catalytic

Surface Combustion Heater

A type of surface combustion heater is shown in Figure 11. This heater uses either a porous or drilled ceramic mat, a metal screen, or a wire mesh as an emitting surface. The gas and combustion air are mixed in the upper chamber at a pressure slightly above atmospheric. This mixture flows through the mat and burns on the surface in a thin layer. The surface of the mat heats to a temperature range of 760°C to 900°C, causing it to emit infrared radiant energy. A metal reflector surrounding the mat directs the energy waves onto a specific area.

Figure 11 – Unvented Ceramic Gas-Fired Radiant Heater


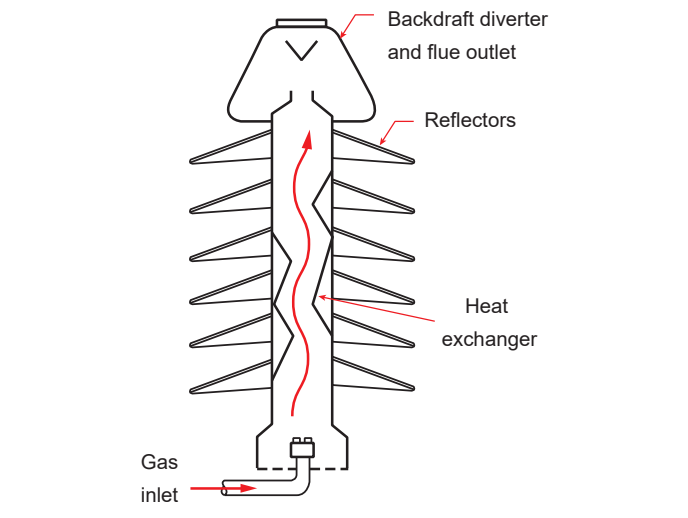
This type of heater is not vented. Sufficient ventilation must be provided to remove these gases, and to prevent excessive moisture buildup.

Directly Fired Refractory Heater

The directly fired refractory heater has a radiating surface made of a block of refractory. A burner flame impinging on its surface heats the block. The result is surface temperatures ranging from 980°C to 1260°C. This heater is unvented and has a reflector.

Internally Fired or Vented Heater

The internally fired, or vented heater, consists of a heat exchanger that is either metallic or ceramic. The gas-air mixture burns inside the exchanger. Most of the heat produced transmits to the emitting surface, which reaches a temperature of 400°C and over, depending on design. The flue gases carry off the remaining heat, and vent to the outside of the building. A number of reflectors direct the infrared energy radiated by the emitting surface in a specific pattern. Figure 12 shows a basic diagram of a vertical, vented radiant heater.

Figure 12 – Vented Metallic Gas-Fired Radiant Heater




Low-Temperature Catalytic Heater

The low-temperature catalytic heater contains a layer of glass wool. This glass wool is impregnated with a catalyst, such as a metallic salt, backed with a layer of porous refractory, and covered by a metal screen. The catalyst promotes oxidation. The gas-air mixture passes through the refractory into the layer of glass wool and catalyst, where oxidation of the gas takes place. This causes the fuel to burn slowly, without flame. The resulting temperature is considerably lower than in the normal combustion process. The metal screen absorbs the heat, and becomes the radiating surface. Emission temperatures vary from 315°C to 455°C.

These heaters are common in the oil and gas industry. Some smaller remote buildings require heating. Due to the possibility of a hydrocarbon leak, normal heaters could be an ignition source in these remote buildings. Catalytic heaters, though, are intrinsically safe.

OBJECTIVE 4

Describe the different methods of electric heating, and their advantages and disadvantages compared to other types of systems.

PRINCIPLES, METHODS, AND EQUIPMENT FOR ELECTRIC HEATING

Electricity can be directly converted into heat energy in an electric resistance heating element. When connected to an electric circuit, a certain current flows through the heating element and causes it to heat. This heat can be used for various purposes.

Many different methods are available to use electricity for comfort heating. These methods are divided into two general groups:

1. Direct heating
2. Indirect heating

The following section describes the various methods and equipment used for electric heating in buildings. Most of the heat exchange equipment used for electric heating is quite similar in design and operation to the equipment used in steam, hot water, and warm air heating systems.

Direct Heating

The electric direct heating equipment is installed in the areas to be heated. The heat transfers directly from the source of heat to the air, and persons and objects in these areas.

Baseboard and Wall Heaters

The electric resistance baseboard heater is a popular natural convection type heater. Its design is quite similar to that of a steam or hot water convector. It consists of one or two tubular heating elements, fitted with aluminum fins. The baseboard heater is mounted against the wall in a sheet metal casing, near floor level.

Wall heaters are usually recessed in the wall. They are commonly used in the vestibules of stores, restaurants, and buildings. The heating element of a forced convection heater is similar to that of a baseboard heater. A fan draws the cooler air from the room, along the heating element, and then blows the heated air back into the room. A thermostat mounted on the unit senses the temperature of the air and controls the heating element and fan.

Other types of direct heaters include unit heaters, unit ventilators, radiant panel heaters, and snow melters. The applications for these heaters are similar to those for hot water and steam heating systems; however, they use electricity as the source of heat.

Indirect Heating

The heat supplied by the electric indirect energy transfers to a medium that carries the heat to the areas to be heated.

Electric Boilers

In steam and hydronic heating systems, electric boilers can be used to supply the heat. Steam and hot water then function as carriers of the heat supplied by the electric energy. Thus, electric energy is used in an indirect way to heat the various areas. The electric energy is converted into heat energy with the use of either electrodes or resistance type heaters immersed in the boiler water.



Central Warm Air Furnaces, In-Duct, and Make-Up Heaters

Open wire electric resistance heating elements are commonly used to heat the air in warm air heating and ventilating systems. The heat supplied by the elements is transferred to the air, which then carries it to the areas to be heated. Therefore, these are considered to be indirect methods of heating.

ADVANTAGES AND DISADVANTAGES OF ELECTRIC HEATING

Electricity is an ideal source of heat for homes, stores, and apartments. It has many advantages over other heat sources:

- a) Electric heating devices produce no toxic gases. They require no combustion air, no chimney, and no fuel storage. These devices are quite safe, since they operate at lower temperatures, and have no flame.
- b) The equipment normally requires less space. A central system is usually not required, as each room can be equipped with a separate heating unit.
- c) Individual room temperature control is easy to obtain.
- d) Operation of the device is clean and silent.
- e) Installation costs are usually lower.
- f) Maintenance costs are lower.

However, electric heating has some disadvantages:

- a) Operating costs are generally higher than that of systems burning fossil fuels.
- b) An electrician is required to repair the system.



CHAPTER SUMMARY

This chapter covered several methods of heating that do not specifically use hot water or steam. Three types of heat delivery were introduced:

1. Warm air
2. Infrared
3. Electric heat

Discussed in this chapter were fuel-fired warm air and infrared heating systems.

Systems used in conjunction with the main heat supply will vary from plant to plant. Power Engineers must know how to operate, maintain, and troubleshoot issues with these systems.



Cooling Systems and Combination Systems

LEARNING OUTCOME

When you complete this chapter you should be able to:

Describe central, unitary, and combined HVAC systems.

LEARNING OBJECTIVES

Here is what you should be able to do when you complete each objective:

- 1. Describe the general layout and operation of unitary air conditioning systems.*
- 2. Describe the general layout and operation of central air conditioning systems.*
- 3. Describe the general layout and operation of combined air conditioning systems.*
- 4. Discuss how HVAC systems should be operated under different situations.*



CHAPTER INTRODUCTION

There is a variety of HVAC systems. The Power Engineer is expected to operate the system installed in the facility. An understanding of basic layout design and operation will assist the Power Engineer to operate, troubleshoot, and maintain the system.

It is important to have a basic knowledge of the various designs of air conditioning systems that are in use.

This chapter introduces unitary, central, and combined air conditioning systems. It discusses the operation and basic layouts of the various systems. It provides the Power Engineer with the tools to operate the system, based on predefined criteria.

OBJECTIVE 1

Describe the general layout and operation of unitary air conditioning systems.

UNITARY AIR CONDITIONING SYSTEMS

A unitary system utilizes self-contained packaged equipment installed in, or adjacent to, a zone that provides air conditioning only for that area. The system is usually fully assembled in the factory, with all of the components required for the application. The complete package is then shipped to the site for installation. The units are usually installed with little or no ductwork; therefore, they are located in the area best served economically.

These units are single zone in operation, and normally controlled by a space thermostat, or a thermostat mounted on the unit, with a sensing bulb in the return airflow. These systems are easy to install, relatively low in initial cost, and utilized in residential and commercial buildings. They normally do not satisfy all of the requirements for environmental control, but are sufficient for selected applications.

Window Air Conditioner

This packaged unit uses a direct expansion refrigeration system to cool and dehumidify a local area. Normally installed in a window or exterior wall opening, it supplies conditioned air directly to the space, without ductwork. It requires no piping connections, and it can usually plug into a standard wall outlet for electrical power supply.

The unit has two compartments:

1. One for the supply air
2. One for the condenser

In the supply air compartment, room air is drawn through a low efficiency air filter and evaporator coil to provide cooling. A fan then delivers the air back into the room at a lower temperature through adjustable directional louvres.

The condenser compartment is exposed to outdoor air. This compartment houses the compressor, an air-cooled condensing coil, and a condenser fan. The heat absorbed in the evaporator coil and the heat of compression dissipate to the outdoor air in the condensing coil. Condensate from the evaporator coil drains back to a pan located below the condenser fan. It evaporates when a “slinger ring” on the fan throws the condensate against the condensing coil. A thermostat, with its sensing bulb located in the return airflow to the evaporator coil, starts and stops the compressor to maintain room temperature. A manually controlled damper allows a minimum flow of outdoor air into the room for ventilation, if desired.

These units are noisy in operation, and result in wide swings in room temperature due to the on-off control of cooling. Also, they provide no direct control of the amount of dehumidification, as the latter occurs only when the cooling coil is in operation to satisfy room temperature requirements. However, window air conditioners have a relatively low initial cost, and they are well suited to provide local cooling in residential and commercial installations. Capacities typically range from 0.3 to 1.8 tonnes of refrigeration.



Packaged Air Conditioner

Packaged air conditioners are normally mounted on the floor, in a vertical position; however, they may also be mounted on the floor horizontally, or suspended in false ceiling spaces. The unit consists of a supply fan, low-efficiency air filter, and direct expansion cooling coil.

This type of air conditioner usually delivers conditioned air directly to the space, through a discharge plenum, but it may be connected to a limited amount of ductwork. The heat of refrigeration may either be dissipated in a city water-cooled condenser, or by a remote outdoor air-cooled condensing unit located on the roof. Auxiliary water or steam heating coils, steam humidifiers, and a minimum outdoor air duct connection may also be included.

These units are normally available in a 2.7 to 13.6 tonne range. They are single zone in operation, but can handle much larger areas than window air conditioners. Temperature may be controlled by a space thermostat, or by a sensing bulb located in the return air stream. Stepped capacity control is available in larger units with dual compressors. Dehumidification is provided, but is not directly controlled.

Packaged air conditioners satisfy more of the basic environmental requirements, and are quieter than window air conditioners. However, they are still noisy in operation due to the compressor located in the conditioned space. They are well suited for use in:

- Restaurants
- Commercial or retail areas
- In rooms such as laboratories, where supplemental cooling may be required due to heat released from equipment in the room

A variation of these air conditioners is seen in process cooling units for computer rooms. These units are designed to handle the substantial heat released from computer equipment. They maintain fine control of environmental conditions in the computer room. They are more complex in design and operation than standard units.

- Fans are sized to handle higher air volumes.
- Air filters are a high efficiency type.
- Dual refrigeration circuits are used to provide backup operation.
- Higher capacity humidifiers are included to maintain close control of room humidity.
- Cooling coils are designed to provide dehumidification when required.
- Sophisticated electronic controls are utilized, including display panels to indicate room conditions and alarms.

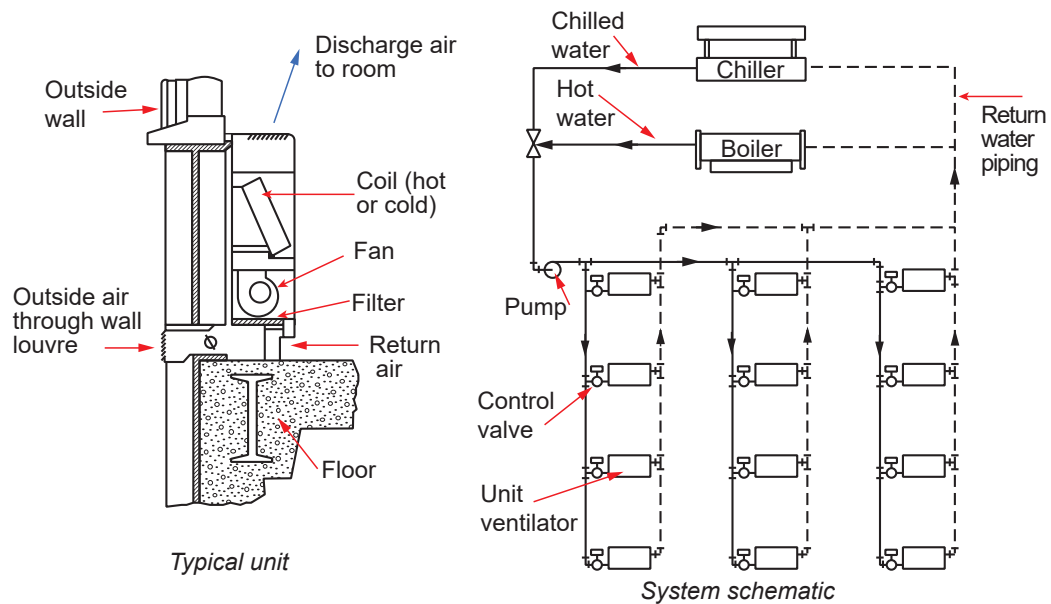
These units provide excellent control of environmental conditions, but are very costly. They are specifically designed for applications where room conditions must be maintained within a limited range at all times.

Unit Ventilator

This system was developed to provide individual room temperature control in buildings, such as hotels, that have many zones, but limited available floor space. The units, as shown in Figure 1, are mounted on the exterior walls of the building. This unit comes equipped with a:

- Low-efficiency filter
- Fan
- Heating and/or cooling coil
- Manually adjustable duct connection to the outdoors, to provide a minimum amount of outdoor air

Figure 1 – Unit Ventilator System



Room air is drawn into the bottom of the unit. It mixes with a fixed amount of outdoor air. The mixed air is then filtered, and a fan blows it through the coils, back into the room. The coils are connected to a piping system, which provides chilled water from refrigeration machines for summer cooling and hot water from boilers for winter heating.

The room temperature can be controlled by either a space or return air thermostat, which operates a control valve in the water supply to the coil. This system provides acceptable room temperature control, particularly if a modulating valve is used in the water supply to the coil. Installation requires minimal space in the room; however, condensate drain piping is required for each cooling coil, and may be difficult to install. No humidification is provided, and the outdoor air intake may be subject to freezing during winter in colder climates. Also, the location of these air intakes must be carefully considered, particularly at ground level, where vehicle exhaust fumes may be present.



Rooftop Unit

These self-contained rooftop air handling units are used for larger applications, from 2.7 to 68 tonnes or more, of cooling. The units are manufactured in sections on a modular basis, and are designed with a weatherproof casing enclosure for exposed installations on roofs.

A unit may consist of a:

- Plenum section with motorized dampers for mixing outdoor and return air
- Filter section
- Supply fan
- Heating section
- Cooling coils
- Humidifier

There is great flexibility in the selection of components, since filters of varying efficiencies can be used. Natural gas burners, or hot water or steam coils, can provide heating and chilled water, or direct expansion coils can be used for cooling. For the direct expansion option, an air-cooled condensing section can be added to the package.

The units are usually mounted on a roof, adjacent to the area served. Supply air can be directly delivered to the space, or ducted to provide more even distribution throughout the area. Controls range from simple space or return air thermostats, to sophisticated electronic packaged controls with energy management features. Note the mixing section of this system is usually capable of **free cooling** and operation on 100% outside air.

Rooftop units are commonly used for single zone commercial buildings, such as:

- Department stores
- Restaurants
- Food stores
- Shopping centers
- Warehouses
- Light manufacturing plants
- Recreational facilities
- Gymnasiums
- Other single-storey buildings with large floor areas

In addition, these units are used for office buildings and schools, but must be carefully designed to prevent noise transmission from the units into occupied spaces located directly below. They may not be well suited to multi-zone controls.

The rooftop unit is a very flexible design. It can provide only the basic heating and ventilation requirements, or full environmental control. The initial cost for these units is very competitive, since they are factory assembly, and they do not require floor space or a building enclosure for installation. However, they may be more difficult to maintain due to their exposed location on rooftops.

OBJECTIVE 2

Describe the general layout and operation of central air conditioning systems.

CENTRAL AIR CONDITIONING SYSTEMS

In a central air conditioning system, all the major components, such as boilers, chillers, and air handling units, are located in a central mechanical room in the building. This mechanical room is where the air is conditioned. The air is then distributed by ductwork throughout the building, to satisfy the heating and cooling requirements in each zone. Central systems are commonly used in larger buildings. These systems have the following advantages in comparison to unitary systems.

- a) The system is easier to operate and maintain since the major components are in a mechanical room. This system can be inspected without disrupting occupied areas in the building.
- b) The equipment is not located immediately adjacent to occupied areas; therefore, it is easier to control the noise and vibration generated by the major components.
- c) For buildings with high load requirements, large central equipment components with higher operating efficiencies and a lower initial cost per unit output can be utilized.

The main drawbacks of central systems are the:

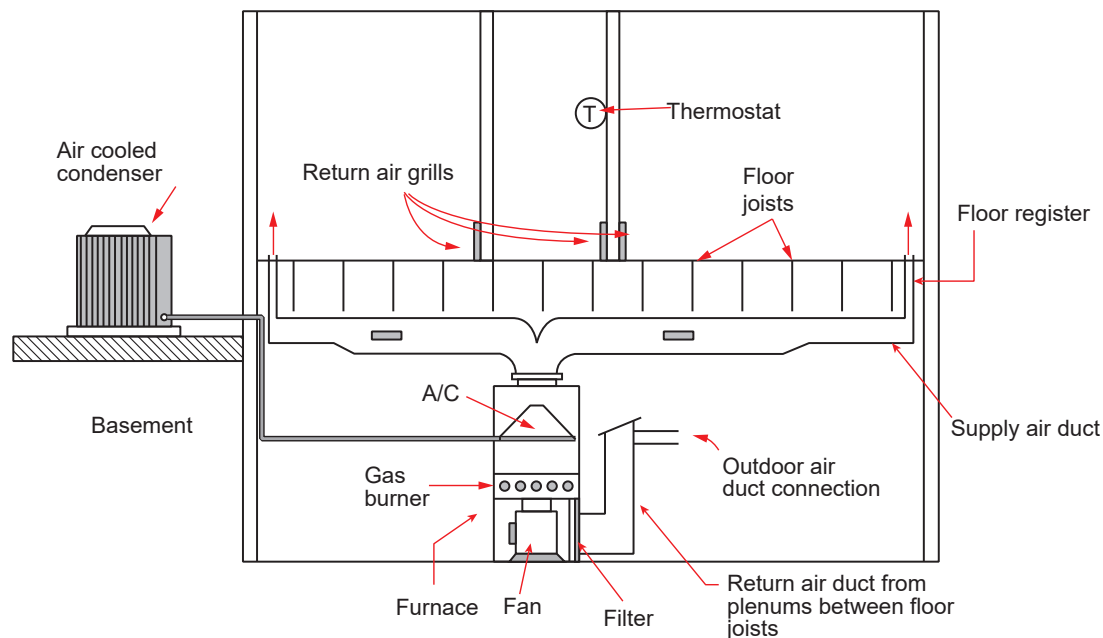
- a) Amount of building space required to accommodate mechanical rooms.
- b) Need for distribution ductwork and the cost to install it.
- c) Larger equipment components may be more difficult to maintain. A breakdown of one key component may result in a shutdown of the air conditioning system for the entire building.

Forced Air System

The most common central system is the forced air furnace installed in many residences. Normally located in the basement, the furnace provides heated air to each room in the house through ductwork. The basic furnace has:

- A low efficiency filter
- A direct drive or belt driven fan
- An indirect natural gas-fired heating section, as shown in Figure 2

An outdoor air duct is normally connected to the return air ductwork to provide a fixed amount of outside air into the system. Other components may also be added to the furnace to provide satisfactory environmental conditions on a year-round basis. These components can include a high-efficiency electronic air filter, a water humidifier, or a direct expansion cooling coil with a remote air-cooled condensing unit.


Figure 2 – Forced Air System with Natural Gas Heating


The forced air system is single zone in operation. A wall-mounted thermostat, located in a hallway on the main floor, controls the heating and cooling cycles, and the fan. If constant air circulation within the space is desired, a manual override switch permits continuous operation of the fan.

This system is effective in operation, and can provide all of the basic requirements for residential installations. It is particularly well suited for buildings of wood frame construction, where spaces between floor joists are used for return airflow. It is also used in retail buildings, such as food stores, restaurants, and offices. It is typically installed in a small room adjacent to the conditioned space. Drawbacks to this system include:

- a) It is relatively noisy to operate.
- b) It is limited to a single zone temperature control.

Supply air registers are normally installed at floor level, below windows, for heating purposes. However, they must also supply cool air during the summer. This may cause discomfort due to drafts at floor level.

Single Zone, Constant Air Volume System

As the name implies, a constant air volume system provides a constant volume of air to the space. The temperature of the air is adjusted directly. This is similar to the rooftop unit system, except the air handling unit is located in a mechanical room within the building. The unit may include heating, cooling, filtration, and humidification elements to condition the air. The ductwork in the building then distributes the air.

Space conditions are maintained by adjusting the supply air temperature with return air, or a room thermostat. This system is suitable for use in single zone applications, such as gymnasiums and retail spaces, but is not effective for multi-zone layouts. This type of system is normally easier to maintain than an equivalent rooftop system, because the unit is located indoors; however, the mechanical room must be sized to provide sufficient clearance for access to the unit.

High Velocity Terminal Reheat System

Compared to a low velocity system, the size of the supply ductwork is reduced in the high velocity terminal reheat system. The high velocity system uses higher air velocities for distribution throughout the building. This reduces ductwork costs and building space requirements to accommodate the ducts. However, more powerful supply fans, with larger motors, are required to develop higher supply air pressures.

A terminal reheat box is required in the branch duct to each zone. These boxes reduce the airflow and maintain a constant supply air volume, in spite of air pressure fluctuations in the high velocity ducts. The box consists of a volume regulator, a reheat coil, and an acoustic insulation. Each box is rated for a maximum capacity, but actual airflow can be set by manually adjusting a volume controller on the exterior of the box.

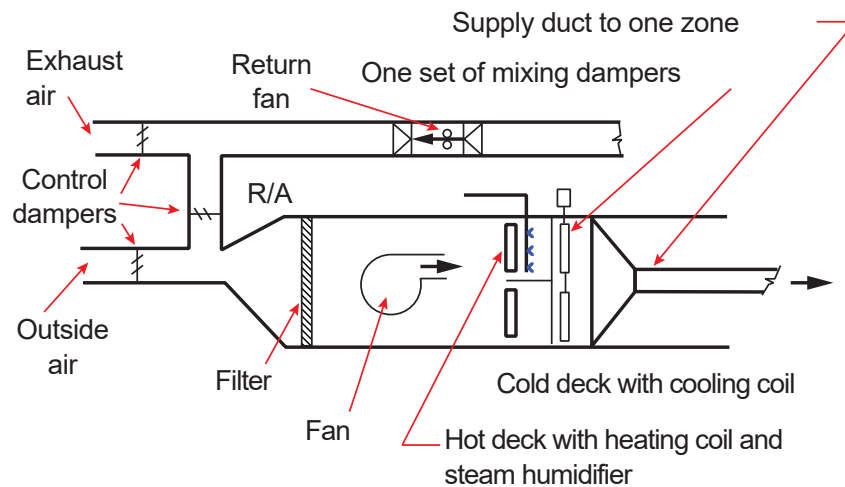
The high velocity system provides effective control of room conditions. This system is used in large buildings where the added cost of the high velocity components and terminal boxes is offset by the savings due to reduced space requirements. This system is also well suited for retrofit projects where an air conditioning system is required in a building that has limited available space for ductwork.

A high velocity system may be more difficult to maintain. System operation is noisier, has more vibration, and there are additional pressure regulating controls in the boxes. Note that the boxes are best located above corridors, adjacent to the conditioned space, so that occupants are not disturbed when access to the boxes is required.

Multi-Zone System

A multi-zone system is a constant volume system; however, the discharge of the air handling unit is modified to provide multi-zone control, as illustrated in Figure 3. The unit includes the typical arrangement of mixed air dampers, filters, humidifier, and fan. The cooling coils and heating coils are located downstream from the fan, and are offset rather than installed in-line. Therefore, supply air may flow into two separate discharge compartments: a **hot deck** and a **cold deck**.

Figure 3 – Multi-Zone Unit



Anywhere from 2 to 12 pairs (or more) of zone mixing dampers can be located at the discharge of the unit. A separate duct connects each pair to each zone. A space thermostat in the zone acts through an operator to modulate the dampers and adjust the mixture of hot and cold air. This satisfies the space conditions by varying the supply air temperature. The dampers are linked together, but are 90° out of phase, which means that when the cold deck is fully open, the hot deck is fully closed. Therefore, each zone is supplied with a constant volume of air, and the supply fan handles a constant total volume of air.



The cold deck normally supplies air at 12.5°C (54°F) on a year round basis, and utilizes free cooling whenever possible. The output of the hot deck varies in accordance with heating requirements. When hot water coils are used, water temperature is normally reset on an outdoor air temperature schedule, as an energy saving measure. A preheat coil may be included in colder climates for heating of mixed air to 12.5°C, if required. A supplementary humidifier can be installed in the hot deck for winter humidification.

This system provides good control of room temperature conditions on a year round basis. However, humidity control is reduced under certain operating conditions, such as when large portions of air bypass the hot deck humidifier during winter, or escape dehumidification in the cooling coils during summer. This system is well suited for use in smaller buildings with multi-zone layouts, such as schools. However, its application is limited by the:

- a) Number of zones available on the air handling unit.
- b) Space requirements.
- c) Complexity of the separate supply ducts to each zone.

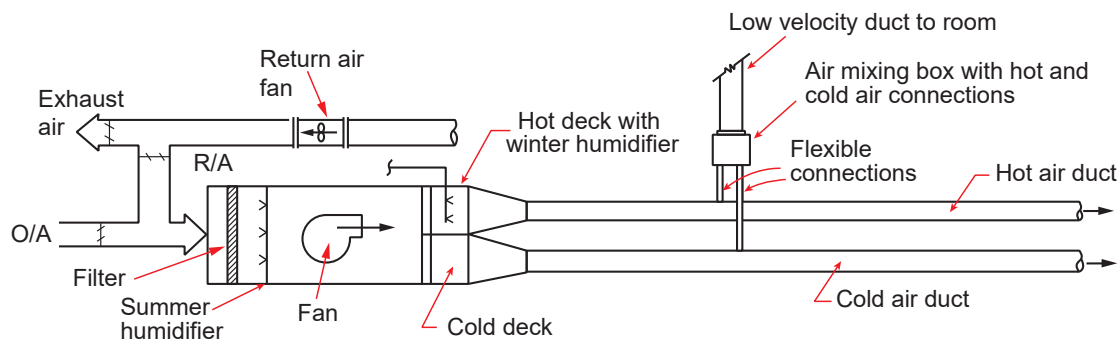
Dual Duct System

The dual duct system (see Figure 4) is similar in concept to the multi-zone system, hot and cold air are mixed to vary the supply air temperature to each zone in order to satisfy room conditions. However, rather than mixing at the discharge of the air handling unit, the cold and hot air are ducted separately throughout the building, then blended in a mixing box located in each zone. The air handling unit includes:

- Filters
- Humidifier
- Fan
- Hot deck
- Mixed air section
- Cold deck discharge compartments

Each zone has a thermostat to control the temperature of the air that enters the zone. The thermostat controls how the hot air and cold air will mix in the mixing boxes. Dampers are used to mix the two streams of air together.

Figure 4 – Dual Duct System



The cold deck air is supplied at approximately 12.5°C on a year round basis. It utilizes free cooling, with supplementary mechanical cooling, when required. Hot deck heating can be provided by steam or hot water coils. The latter is preferred since its output can be reset in accordance with outdoor air temperature. A separate humidifier in the hot deck may be installed for winter humidification.



Each main supply duct is sized to handle full airflow, and is of medium or high velocity design to minimize building space requirements. This design results in significant variations in duct static pressures. The mixing boxes have pressure regulators to adjust for these fluctuations, and maintain a constant volume of airflow to each zone. As in most large systems, a separate return air fan ensures controlled return airflow from each area.

Dual duct systems are widely used for larger office, commercial, institutional, and medical buildings. This type of system provides a constant air circulation rate in each zone, and good control of space conditions. This system can handle many more zones than a multi-zone system. Additional zones can be created by simply adding boxes. Due to the high velocity design of dual duct systems, special attention must be given during design to minimize noise transmission into occupied areas. Therefore, acoustic insulation is a standard feature of mixing boxes. Silencers may also be installed in each duct main.



OBJECTIVE 3

Describe the general layout and operation of combined air conditioning systems.

COMBINED SYSTEMS

Combined systems maintain space conditions by combining a central air system with supplementary equipment in each zone. The air system includes an air handling unit located in a mechanical room, and distribution ductwork throughout the building. The unit provides cooling, ventilation, humidity control, and air circulation. Supplementary units, located in each zone, provide heating or additional cooling, as required, to handle zone load conditions.

This type of system is used in a wide variety of multi-zone buildings that require fine control of individual room temperatures. The air system is smaller in these systems, due to the additional capacity of the supplementary units in each zone. Therefore, this system needs less space in the building for mechanical rooms and ductwork than required for an equivalent central system. This system also allows more flexibility for energy saving measures. For example:

- a) The air system can be shut down during unoccupied periods.
- b) Building space conditions can be maintained by only operating the heating units in each zone.

Constant Air Volume System with Perimeter Heating

This constant air volume system combines a central air system with perimeter heating elements, such as wall fin radiators, located along exterior walls in each zone, as shown in Figure 5. The air handling unit is located in a central mechanical room. The unit includes:

- An air mixing section
- Filters
- Cooling coils
- Humidifier

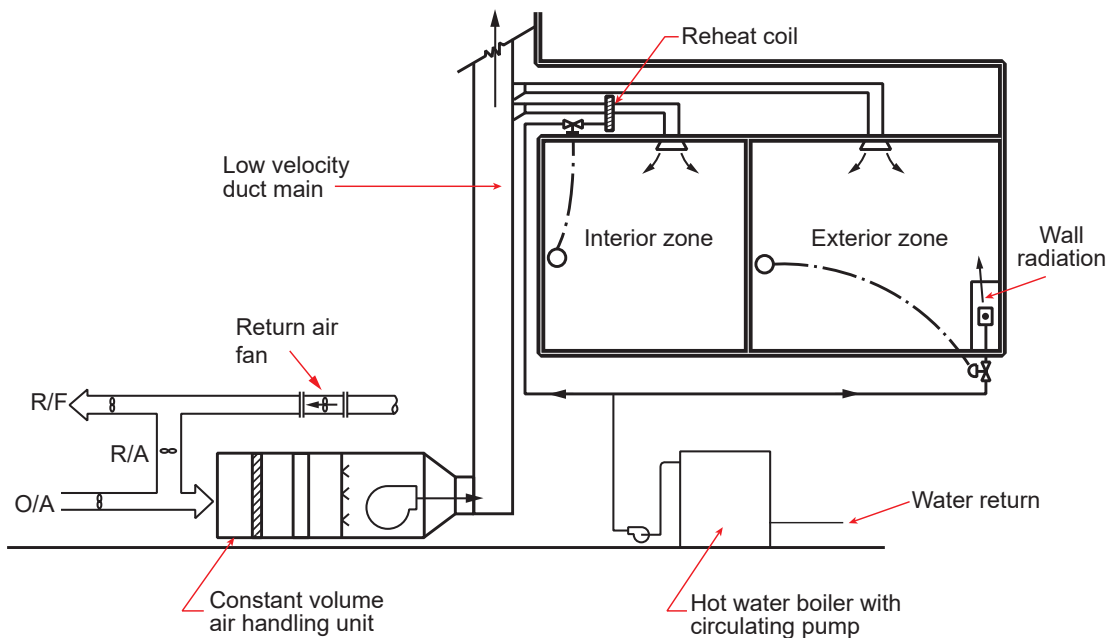
The air handling unit operates at a constant volume. The unit supplies air at approximately 12.5°C, through low velocity ductwork, to all areas of the building. Perimeter heating is installed below windows to offset heat loss and prevent cold down drafts. A boiler, located in a central mechanical room, supplies the hot water. This water is piped throughout the building in a system designed to support the required temperature control zones.

This type of system is typically used for multi-zone buildings, such as schools. The advantages of this system are:

- a) It provides effective control of room conditions.
- b) It is relatively easy to operate and maintain.
- c) The shutdown of the air system during lengthy unoccupied periods reduces energy consumption.

However, there are several disadvantages including:

- a) It is not well suited for larger buildings due to the space requirements for the low velocity ductwork.
- b) The cooling and reheating of supply air is not energy efficient when rooms are at less than maximum cooling load.

Figure 5 – Constant Volume System with Perimeter Heating

Fan Coil Units with Make-Up Air System

Fan coil units (FCU) with make-up air systems are used extensively in motels and hotels due to:

- Minimal space requirements
- Low initial cost
- High degree of individual zone control

A fan coil unit is installed in each room to provide the heating, cooling, and air circulation requirements. This unit is located on an exterior wall, or in the false ceiling space above the entrance to the room. The unit includes a:

- Disposable filter
- Fan
- Heating and cooling coil
- Condensate drain piping from the cooling coil

In addition, a 100% outside air system is installed to provide ventilation and humidity control. The air handling unit is located in a central mechanical room and includes:

- Filters
- Heating coil
- Cooling coil
- Humidifier
- Supply fan

Low velocity ductwork distributes the conditioned air. The air enters each room through a wall grille.

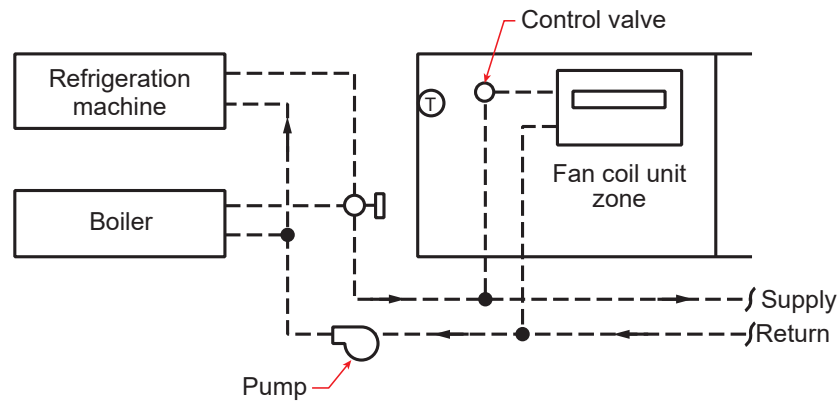
A wall thermostat controls the temperature in each room. The thermostat cycles the unit on and off as required. The make-up air system provides supplementary treated air for heating and cooling, to increase human comfort.



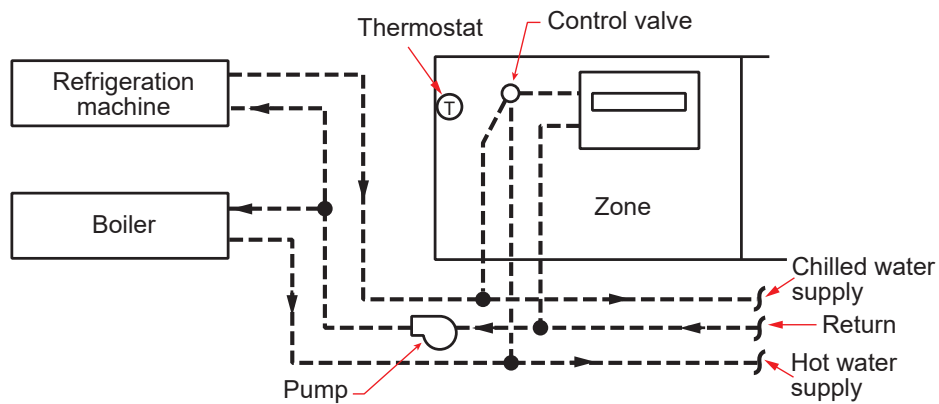
Boilers and chillers located in the central mechanical room provide hot water heating and chilled water supply to the coils in each room. Piping may be connected to the coils in a two-, three-, or four-pipe system (Figure 6), depending on the degree of control required and initial cost limitations.

The two-pipe arrangement (Figure 6(a)) is the least costly. It is made up of a supply and return connection to a single coil in each unit. Piping is connected to the boiler, for winter heating, and to the chiller, for summer cooling; however, it cannot provide both functions at the same time. This system provides adequate control during the peak heating and cooling seasons, but performs poorly during intermediate seasons when room loads may change from heating to cooling during the course of a day.

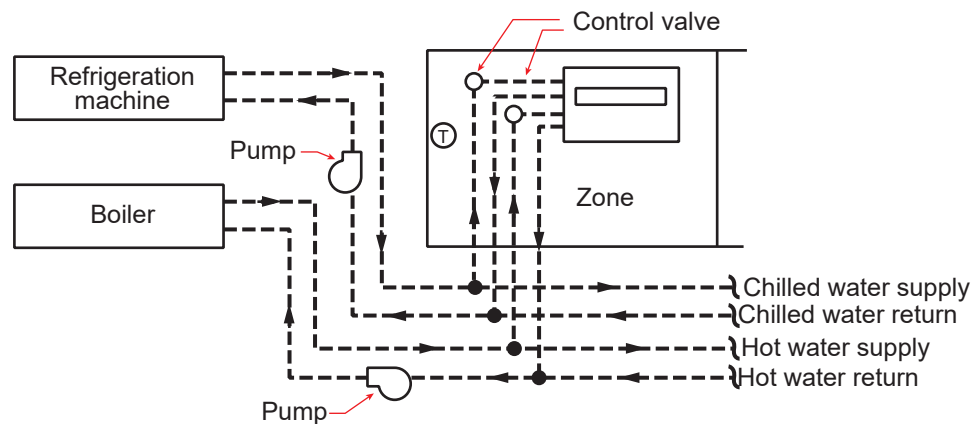
A three-pipe system (Figure 6(b)) includes separate hot water and chilled water supply pipes, and has a common return pipe. Therefore, the boiler and chiller may operate simultaneously. The room thermostat maintains conditions in the room by adjusting a three-way valve to provide the required blend of hot and chilled water to the fan coil unit. This system provides superior control of room conditions, but has a higher initial cost. Also, it is not energy efficient during intermediate seasons, because the common return water pipe results in false loading of the boiler and chiller, which increases operating requirements.

Figure 6 – Fan Coil System Piping Arrangements

(a) Two-Pipe Arrangement



(b) Three-Pipe Arrangement



(c) Four-Pipe Arrangement

The four-pipe system (Figure 6(c)) provides the best control of room conditions on a year round basis. In this arrangement, two separate supply and return piping systems are connected to separate coils in each unit. Each coil has separate hot water and chilled water control valves, which are sequentially controlled by the room thermostat. This arrangement has the highest initial cost, but provides maximum comfort, and improved energy efficiency.



The individual fan coil unit in each room provides rapid response to a change in thermostat setting, thus set points may be lowered to reduce energy consumption when the room is unoccupied. However, a common complaint is the noise generated by the fan.

Hydronic Heat Pump System

The hydronic heat pump system combines a packaged heat pump unit with a central make-up air system.

Heat Pump

As applied to a year-round air conditioning system, a heat pump is a system that uses refrigeration equipment to remove and discharge heat from a space. This system also heats the same space during colder weather; it picks up heat from a low-level heat source and discharges it indoors.

A refrigerator is a classic example of a heat pump. Heat moves from a high source, hot item, to a low source, cool item. Heat moves from the food inside the fridge, to outside the fridge. In winter, this is a source of heat for a home or building. In summer, this is an added heat load to the air conditioning system.

Air-to-Air Heat Pump

In principle, the construction of the air-to-air heat pump is similar to that of a refrigeration system used for air conditioning purposes. The cooling operation cycle is identical. However, with certain modifications, the function of the indoor (evaporator) and outdoor (condenser) heat exchangers can be reversed during cooler weather.

When reversed, the outdoor coil (the cooling cycle condenser) acts as the evaporator to extract heat from the outdoor air, even though the temperature may be quite low. The indoor coil (the cooling cycle evaporator) then becomes the condenser, and discharges this heat to the indoor space.

Adding a reversing valve will reverse the flow of refrigerant. This valve makes the evaporator and condenser switch duties. Adding a second, or special, expansion valve that allows the valve to operate in both directions creates a reversible refrigeration system.

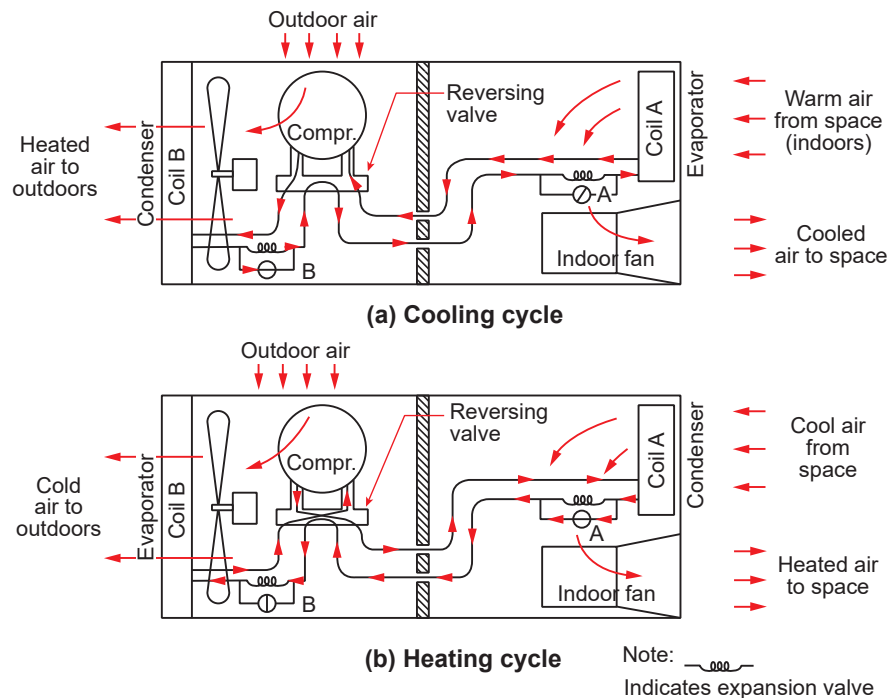
A schematic diagram of the operation of a wall or window-mounted packaged heat pump is shown in Figure 7. The following describes how the cooling and heating cycles operate in this unit.

Cooling Cycle

During the cooling cycle, the air-to-air heat pump operates similar to an air conditioning unit. Expansion valve A supplies liquid refrigerant to indoor coil A (see Figure 7). Check valve A is closed. In this coil, the refrigerant absorbs heat from the warm space air circulated through the coil by the indoor fan, which causes the refrigerant to evaporate. The reversing valve draws this vapour into the compressor. The compressor discharges the hot compressed vapour via the reversing valve to outdoor coil B, where the vapour gives up its heat to the circulating outdoor air, and returns to its liquid state. This liquid then flows via check valve B, and the reversing valve, to expansion valve A, and completes the cycle.

When the indoor temperature drops to the point where heat is required, the reversing valve switches the heat pump over to the heating cycle.

Figure 7 – Operation of a Packaged Heat Pump



Heating Cycle

Expansion valve B supplies liquid refrigerant to indoor coil B (see Figure 7). Check valve B is closed. The refrigerant absorbs heat from the outdoor air and evaporates. The reversing valve draws this vapour into the compressor. The compressor moves the hot compressed vapour to the indoor coil, where the heat transfers to the circulating space air, which causes the vapour to condense. Liquid refrigerant now flows back to expansion valve B, via check valve A and the reversing valve, to complete the cycle.

Using fin tube type heat exchangers, the heat pump described above is classified as an air-to-air pump. This type is most common for smaller capacities up to 23 tonnes (25 tons). This heat exchanger is used for residences and small commercial buildings, although it is available for larger capacities as well.

Alternative Equipment for Heat Pumps

Efficiencies may be gained by replacing the finned air coils that contain refrigerant with water heat exchangers (plate, shell and tube, or any other heat exchanger). The water heat exchangers also offer the flexibility of utilizing the waste heat for a number of uses. The heated/cooled water can be used to heat a space, preheat domestic hot water, heat a swimming pool, or any other heating application.

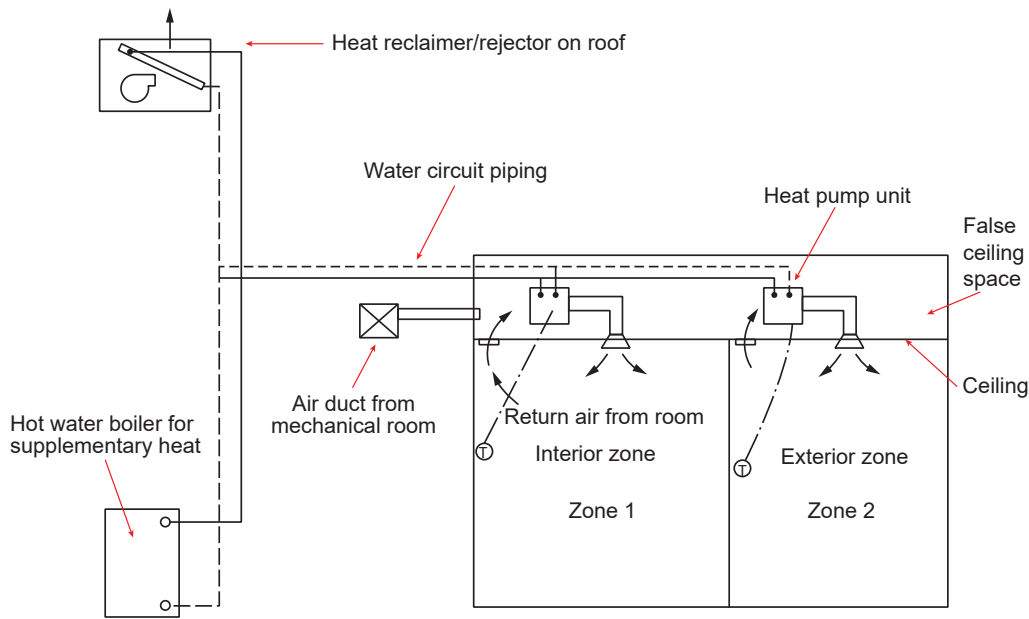


It can also be more efficient to obtain low-grade heat by using water (or water glycol mix if freezing is a concern) from a lake or pond, ground wells, or coils placed under the ground surface, below frost level. Another option is to use a pair of water wells. The water is pumped out of one well, the heat is extracted, and the water is pumped back down the other well. With the reversing valve, either side can be cold or hot, depending on the season and application.

Heat pumps can be combined with a hydronic system and a central make-up air system. Each zone has a heat pump to heat or cool the zones independently of each other. The water circuit provides a source of heat or condenser cooling, depending on the operating mode of the heat pump. When the cooling load is high, the heat from the loop is rejected through a rooftop heat exchanger. When the heating load is high, additional heat is added with a supplemental hot water boiler.

Conditioned air from the heat pump is delivered to the zone through low velocity ductwork.

Figure 8 – Hydronic Heat Pump System



A make-up air system provides outside air for ventilation and humidity control. The supply air is cooled to 12.5°C during summer, and is heated in accordance with an outdoor air reset schedule during winter. The conditioned air is ducted throughout the building. The air is normally released into the false ceiling space near the intakes of the heat pump units for circulation into the room.

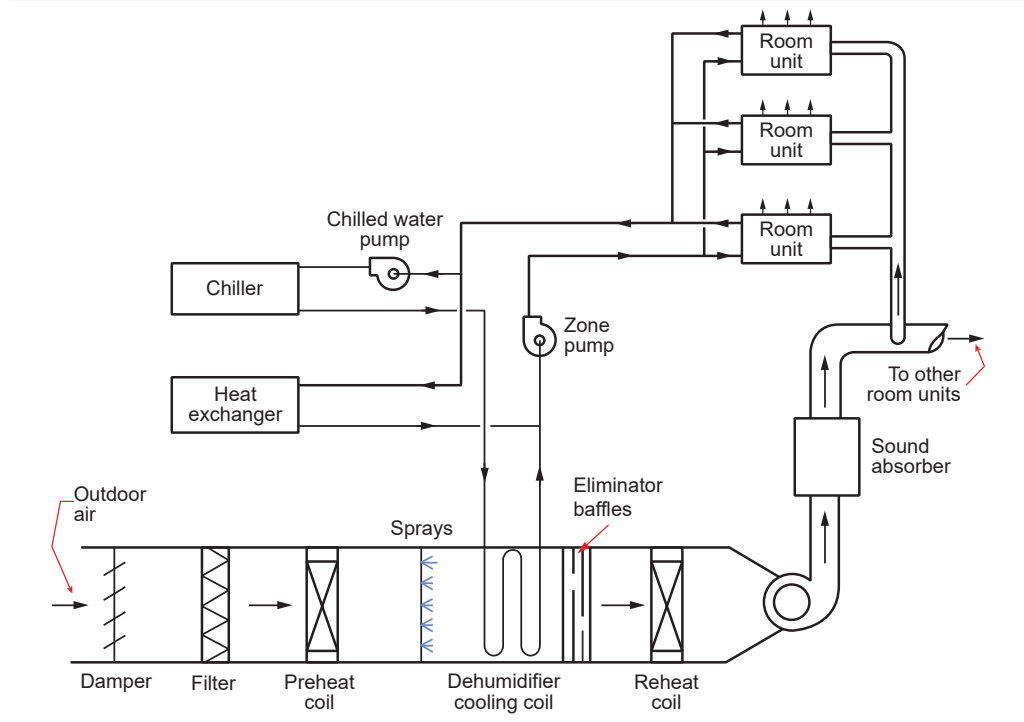
The hydronic heat pump system provides multi-zone control capability. Since part of the equipment is located in the zone, the system requires less mechanical space. This system is used in hotels, retail areas, shopping malls, and office buildings. The system has relatively low energy consumption; however, a large portion of its energy input is electrical, which may be very costly in certain areas.

Induction System

An induction air conditioning system distributes conditioned air from a central make-up unit to the various rooms through ductwork. This air travels at high velocity, and passes through the room units, which contain additional heating and cooling coils. The high velocity “primary” air induces a flow of “secondary” room air through the coils. This mixture discharges back into the room at the correct temperature. The unit operates on 100% outside air. It provides ventilation and humidity control, as well as, supplementary heating and cooling. The ratio of secondary to primary airflow is typically 4 to 1.

Referring to Figure 9, outdoor air is drawn into the central make-up unit. It passes through a filter and then a preheat coil. This prevents freezing air from reaching the dehumidifier section. The dehumidifier section consists of a set of spray nozzles and a cooling coil, which removes moisture from the air by controlling the dew point temperature. The sprays may also be used to provide moisture to the air if humidification is desired. The air then passes through eliminator baffles, which remove any entrained water droplets from the air stream. The final temperature of the air is now adjusted as it passes through the reheat coil.

Figure 9 – Induction System Schematic



A room thermostat controls the temperature in each zone. It modulates a control valve to vary the flow of chilled water or hot water to the induction unit coil. The induction units are selected so the chilled water to the coil satisfies the summer cooling load, and hot water to the coil handles the winter heating load.

The main difficulty in operating this system with a two-pipe installation is maintaining satisfactory room conditions during the intermediate seasons, particularly in rooms with large solar loads on the east, south, and west building exposures. As with fan-coil systems, controllability can be improved by using three- or four-pipe connections for the induction units. The four-pipe connection provides the best control, since the room thermostat can obtain heating or cooling from the induction unit coil at any time as required. However, both the initial and operating costs are higher than for a two-pipe system.

Building space requirements for ductwork are minimized. Therefore, this system is well suited for use in very large buildings with multiple zones, such as hospitals.



Variable Air Volume (VAV) with Perimeter Heating

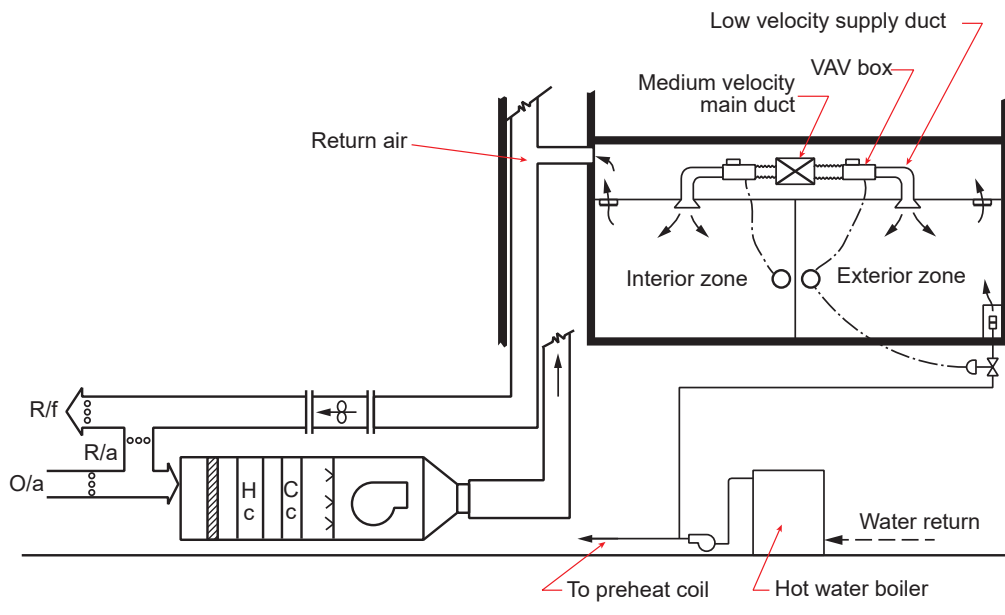
The **variable air volume (VAV)** system is similar to the constant volume system with perimeter heating. It differs in the manner in which room temperatures are controlled in the cooling mode. In the constant volume system, air is supplied at a constant temperature, and it is reheated by perimeter radiation, or by reheat coils, to maintain space conditions. In the VAV system, air is supplied at a temperature of approximately 12.5°C. Space conditions are maintained by modulating the volume of air supplied to each room.

The system combines a central air handling system with perimeter heating in exterior zones. The air handling unit is located in a mechanical room. The unit includes:

- An air mixing section
- Filters
- Cooling coils
- A pre-heat coil
- Humidifiers
- A fan

As shown in Figure 10, a VAV box is located in each branch duct, and modulates the airflow to the zone. Each box includes a damper and operator to control air quantity, acoustic attenuation, and a pressure regulator compensates for the varying inlet air pressure in the main duct.

Figure 10 – Variable Air Volume with Perimeter Heating System



The central fans have variable inlet vanes, or other volume control devices, which automatically adjust their output in accordance with total system requirements. The output of the supply fan is normally controlled to maintain a set discharge static pressure in the main supply duct, downstream of the fan. The return fan is controlled to maintain the desired building pressurization, or the fan is “slaved” to the supply fan volume control.

Due to the VAV, operation of this system allows the system design to be flexible enough to compensate for the heat added to the sides of a building that are receiving the radiant heat from the sun. Because the system can vary itself, the result can be a reduction of 20 to 30% in air capacity. This reduces system sizing requirements and operating costs.

The VAV with perimeter heating has gained popularity due to its energy efficient operation. This system is used for all types of buildings, with diversity of cooling loads and multiple zones. The VAV is energy efficient; it provides only the amount of heating and/or cooling actually required; and the air system can be shut down during unoccupied periods. However, the controls are more complicated and are difficult to maintain.

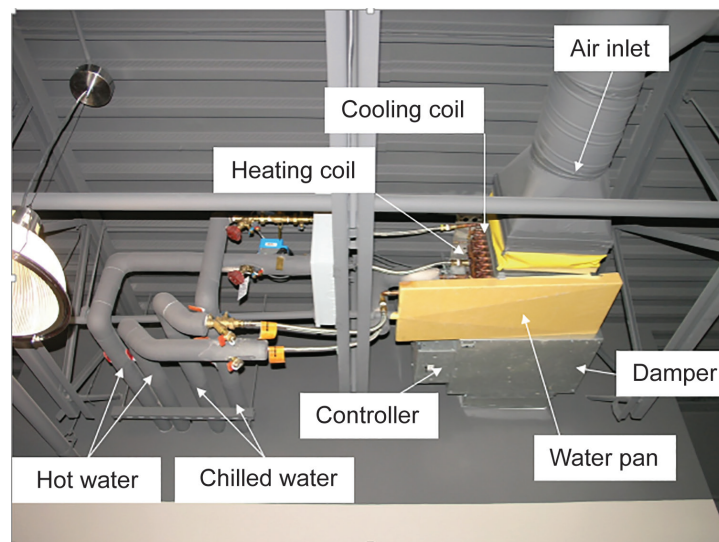
Variable Air Volume (VAV) Box

In a VAV system, a VAV box is installed in each zone, and there will be several boxes in a building. As mentioned previously, a disadvantage of this system is increased maintenance costs, and more time spent by the operators inspecting the system. VAV boxes may consist of any of the following pieces of equipment:

- Heating coil
- Cooling coil
- Fan
- Filter
- Damper with controls

To take advantage of the energy efficiencies of the VAV system, a four-pipe system is used; this provides two coils for separate cooling and heating functions. Each coil has its own supply and return waterlines. In Figure 11, the cooling coil is upstream, beside the heating coil. A water pan is located below the coils to catch any condensed water from the cooling process. A controller adjusts the damper to vary the airflow into the zone. The water pan collects any condensate after the air has passed through the chiller.

Figure 11 – Variable Air Volume Box





OBJECTIVE 4

Discuss how HVAC systems should be operated under different situations.

OPERATION OF SYSTEMS

Many factors must be considered in the design and operation of air conditioning systems. The system must be able support the following:

- Geographic location
- Building layout
- Building function
- Capital costs
- Seasonal changes
- Operating costs
- Maintenance requirements
- Operating integrity
- System upgrades

Many of the above considerations focus on system design, which the Power Engineer may have no control over. However, the Power Engineer does have operational control for operating cost efficiency; integrity of the equipment; and has significant input into maintenance requirements, which must follow the appropriate codes and regulations.

Geographical Location

Climatic conditions are of prime importance since they influence the heating and cooling loads on a building. As the seasons change, it is up to the operator to start preparing one system for startup, and another for shutdown and layup. For example, repairs, maintenance, and updates to the chiller system must be completed before the summer cooling season begins.

As the colder months approach, the chiller must be prepared for a long layup. This must include a schedule to complete inspections, maintenance, repairs, and system updates.

Building Layout

The physical size and overall layout of the building must be considered when operating a system. Any of the areas of the building that are south facing will have a higher degree of temperature fluctuation, due to the radiating heat from the sun. It is important for the operator to verify the operation of each zone, and to ensure it performs according to its design.

Let the occupants know how the changing outdoor environment, such as sunlight or wind, may affect their side of the building. This will allow the occupants to understand that the system will need some time to respond to these changes.

Building Function

The function of the building will obviously affect system operations. Normal occupancy periods, and the need to operate certain areas during off-hours are important factors. The amount of zoning required, and the degree of control due to environmental conditions in each zone must be clearly defined.

Capital Costs

The Power Engineer does not usually determine capital costs. However, a well-trained Power Engineer, who is competent with the equipment, building, and vendors, may be able to influence the implementation of those capital costs. From experience, the operator may be able to determine more cost effective ways to install or implement equipment; or to find ways to reduce the operational costs of the building by spending the capital money appropriately. The capital cost is normally a one-time, up-front cost.

Seasonal Changes

The building air conditioning system can easily handle the outdoor temperatures when they are unusually high or low during winter and summer. However, seasonal changes that occur during the spring and fall are the most challenging for the system.

The transition from the cooler days to warmer days, or vice versa, causes the system to add or remove heat equivalent to the outdoor air temperatures. The operator may have to fine-tune the system to respond to these changes to maintain human comfort.

Operating Costs

The Power Engineer must strive to reduce the operational costs of the building by determining which systems may be shut off, or placed into service. The following are typical ways to reduce costs:

- a) Remove systems, such as ice melters, from service during the warmer months, when there is no need for this function.
- b) Install timers for electrical circuits that only need to be on for certain periods of time.
- c) Determine if a VFD for high-energy consumption motors will have a pay back after installation.
- d) Find ways to save on water consumption to reduce energy requirements.

The operator is the first line of defense when it comes to reducing energy requirements and the environmental impact of the building.

Maintenance Requirements

The operator is expected to follow the preventative maintenance (PM) schedule, if one exists, or to develop a PM program, if one does not exist. It is essential to have the equipment inspected and maintained. Plan and schedule with vendors to carry out the PM program. This helps to plan the budget. Having a clear PM program can help to establish a better budget for maintenance costs when the contractor knows what the expectations are.

Operational Integrity

Operators and owners are expected to follow the regulations of the jurisdiction where the building is located. Operational integrity includes:

- Boiler and pressure vessel inspections
- Safety valve inspections
- Certifications

Standard operating procedures, along with other related documents, must be updated to support the integrity of the facility.

System Upgrades

Many older buildings have been going through upgrades to increase efficiency, safety, and environmental requirements. The operator needs to work on scheduling these upgrades so they have the least amount of impact to the building and its clients.



CHAPTER SUMMARY

This chapter introduced the unitary, central, and combined air conditioning systems. This included the basic layout and operation of the various systems. The criteria that may affect how an operator handles and plans out the calendar year for operations and maintenance were also discussed.

It is critical for the operator to learn the system and have an understanding of how it operates. Having smart operating skills and knowledge also helps to find ways to overcome or compensate for design flaws.





Heat Gains and Losses, and Heat Recovery Methods

LEARNING OUTCOME

When you complete this chapter you should be able to:

Describe heat gains and losses, and common methods for energy recovery.

LEARNING OBJECTIVES

Here is what you should be able to do when you complete each objective:

- 1. Define heat transmission terminology.*
- 2. Describe heat gain and heat loss analysis in a building or plant.*
- 3. Describe the general principles of HVAC heat recovery.*



CHAPTER INTRODUCTION

Buildings gain and lose heat in many ways. It is important for building operators to know the various ways these gains and losses occur, in order to manage the operating costs of the building.

The Power Engineer in control of the building's atmospheric environment works to minimize any excess heat gains or losses. The emphasis changes from season to season. For example:

- Too much heat gain means the air conditioning equipment has to work longer to maintain a comfortable temperature during summer.
- Too much heat loss means the heating system equipment has to work longer to maintain a comfortable temperature during winter.

Overworked equipment will lead to increased fuel and electrical costs. Increased maintenance requirements often have a negative impact on equipment lifecycles.

This chapter will discuss the most commonly used heat recovery systems, such as the thermal wheel, heat pipe, and the runaround systems. It will also cover terminology, and the various sources of heat gains and losses.

OBJECTIVE 1

Define heat transmission terminology.

DEFINITIONS, SYMBOLS, AND RELATIONSHIPS

Thermal Transmission (W) or **Rate of Heat Flow** is the quantity of heat flow from all mechanisms, per time unit, under the conditions prevailing at that time. Heat energy always moves from a warmer source to a cooler source. The base unit for thermal transmission is the Watt.

Thermal Conductivity (λ) is the thermal heat flow, by conduction only, through a unit thickness of a single uniform type of material.

Relation to W

$$\lambda = W/LT \text{ (Watts per metre (thickness) – kelvin (temperature difference))}$$

Where λ = Thermal Conductivity

Thermal Resistivity (Ru) is the reciprocal of thermal conductivity.

Relation to W

$$R_u = LT/W \text{ (metres – kelvin per Watt)}$$

Relation to λ

$$R_u = 1/\lambda \text{ (metres – kelvin per Watt)}$$

Thermal Conductance (C) is the thermal heat flow through a unit area of a non-uniform, composite material when a unit average temperature difference is established between the surfaces. The value of the thermal conductance can be calculated by dividing the thermal conductivity with the thickness of the material.

Relation to W

$$C = W/L^2T \text{ (Watts per metre}^2 \text{ – kelvin)}$$

Relation to λ

$$C = \lambda/L \text{ (Watts per metre}^2 \text{ – kelvin)}$$

A related and commonly used term is the **U-Factor**, which is the thermal conductance for each degree change in temperature.

Thermal Resistance (R) is the reciprocal of thermal conductance. In other words, it is the value of a given material's ability to resist heat transfer or flow. Simply stated, the higher the R value, the greater the insulating value or resistance to heat flow.

Relation to W

$$R = \lambda L^2/W$$

Relation to C

$$R = 1/C$$



OBJECTIVE 2

Describe heat gain and heat loss analysis in a building or plant.

HEAT GAINS IN A FACILITY

Unplanned heat can get into an air-conditioned space in many different ways, all of which must be considered when the HVAC system is designed. They can include:

- Sensible transmission through glass
- Solar gain through glass
- Internal heat gains
- Heat gain through walls
- Heat gain through roof
- Heat gain through ventilation and/or infiltration

The amount of heat gained from each area must be calculated before the total heat gain, or its equivalent cooling load, can be estimated. The major types of heat gains may be divided into two groups:

1. External heat gains
2. Internal heat gains

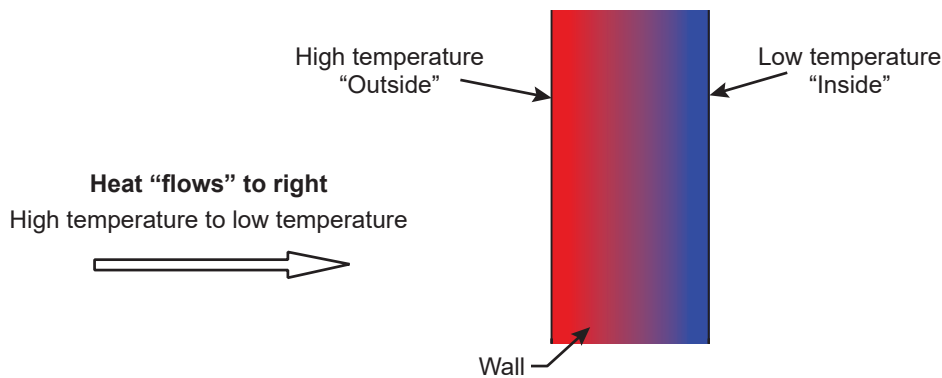
External Heat Gains

External heat gains include those by conduction, infiltration, ventilation, and solar radiation.

Conduction Heat Gains

Heat always conducts from a hot surface to a cooler surface, whether it involves two objects that are touching, or a single object with differing temperatures on one side versus the other side. Figure 1 illustrates this process. In summer, the analogy is how the hotter outer wall surface conducts heat energy to the cooler inner wall surface on the right.

Figure 1 – Heat Conduction Process in Solid Object



Conduction heat gains are based on the assumption that the temperature of the outer surface of the building is the same as the outdoor design condition. That is, they do not include the additional heat that will flow through the wall, roof, and glass areas when the sun's rays fall directly upon these surfaces. Solar heat gains change from hour to hour, according to the position of the sun. These heat gains will be discussed later.

When calculating conduction heat gains, because of the difference in the U-factor value of each component, it is important to know the:

- Construction details of the walls
- Construction details of the roof
- Types of windows and doors that are used

The amount of heat that flows through a square metre of shaded window, wall, roof, or floor depends upon the overall resistance, or thermal conductivity, of the materials used in construction, and the difference in the temperatures of their inner and outer surfaces. In other words, the more resistance the insulation in the construction offers against the conductance of heat, the smaller the total amount of heat flowing through the material during a unit length of time, for each degree of temperature difference.

The transmittance to heat flow is known as the **overall coefficient of heat transmission**, which is commonly called the **U-factor**. Standard U-factors for common types of walls, floors, roofs, windows, ceilings, and partitions can be found in tables published in the **ASHRAE Handbook - Fundamentals**.

Infiltration

The leakage of outdoor air into a building through cracks and openings is called **infiltration**. When outdoor air infiltrates into an air-conditioned space during summer, it carries with it the higher sensible and latent heat of the hot, and often more humid, outdoor air. Heat must be removed from this outside air, to cool it to the indoor design temperature. This imposes an additional load on the air conditioning equipment, called the infiltration load.

In order to estimate this load, the amount of air involved must be determined. There are two methods of estimating the quantity of air entering by means of infiltration:

1. Crack method of measuring infiltration
2. Air change method of measuring infiltration

Crack Method of Measuring Infiltration

The **crack method of measuring infiltration** into a building is based on the average quantities of air known to enter through doors, and cracks of various widths, from around windows and doors when the wind velocity is constant.

To calculate heat gain (or loss) by air infiltration for this method:

1. Determine the types of wall openings (windows and doors) that are creating the infiltration through the wall.
 - a) Find the circumference of all wall openings (the lineal crack) (L).
 - b) Find the air leakage through these openings, given the expected external wind velocity. (Q) – normally from ASHRAE data).
2. Determine the outside and inside design temperatures. These are the normally expected average temperatures during the time the calculation is determined for.
 - t_1 – inside temperature
 - t_0 – outside temperature



The terms are related in the following manner:

$$H = C \times Q(t_1 - t_0) \times L$$

Where:

H = Heat gain, or heat required, to raise the temperature of air leaking into the structure to the level of the indoor temperature (t_1)

C = A constant relating to the specific heat of air times the density of the outdoor air

Q = Volume of air entering the structure

t_1 = Indoor temperature

t_0 = Outdoor temperature

L = Length of crack around the circumference of all openings

The heat gained through infiltration is determined individually for each opening, and then collectively through the entire wall.

Air Change Method of Measuring Infiltration

The **air change method of measuring infiltration** is a way to quickly approximate a source of heat loss. This method recognizes that more heat should be placed in a room that has multiple openings, than the same room without openings. Unfortunately, it does not consider any of the following:

- The nature of the opening
- How the opening is sealed
- The effect of external wind velocity

The air change method is quicker but less accurate than the crack method. The air change method involves the use of tables from any number of sources, including ASHRAE, that show the recommended number of air changes per hour expected in rooms with various exposures. For example:

- a) Rooms with windows or doors in one wall may be recommended to have 1.0 room volume air changes per hour.
- b) Rooms with windows or doors in two walls may be recommended to have 1.5 air changes per hour.
- c) Rooms with exposures in three or more walls, or have a drive-through opening, may be recommended to have 2.0 – 3.0 air changes per hour.

Solar Heat Gains

Solar heat is the result of the radiant rays of the sun. These rays do not heat the air space directly, but heat the object or surface on which they fall. The object or surface will in turn transmit this heat by conduction, radiation, and convection to the air space or other objects.

Radiant solar rays can be reflected by a bright surface, the same as light rays. Transparent materials reflect or absorb a small percentage of the radiant or solar rays. Therefore, a portion of the solar energy which passes through glass results in heat gain by convection and radiation.

Solar heat gains are variable. These gains change depending on latitude, season of the year, and time of day. Each one of these affects the angle of the sun's rays, which determines the amount of reflected and absorbed energy.

One of the most difficult problems is determining the peak load time. Because of the varying types of heat gains, great care must be taken to establish when the peak load will occur. The time of the maximum solar heat gain should not always be assumed to be the time of the overall maximum load. In calculating solar heat gains, the occupancy load, orientation of the building, and the type of shading all affect the solar gain.

Various methods are used to reduce summer solar heat gains. Windows may be furnished with reflective glass, heat absorbing glass, awnings, shades, or blinds. Each of these is effective in reducing solar gains. A new building should be designed with the reduction of summer cooling load as a prime consideration.

Adequate insulation is essential. Light coloured roofing also reduces the cooling load considerably.

When making a cooling load survey of an existing building, it is important to remember how the overall cooling load may be reduced by using any, or all, of the means above.

Internal Heat Gains

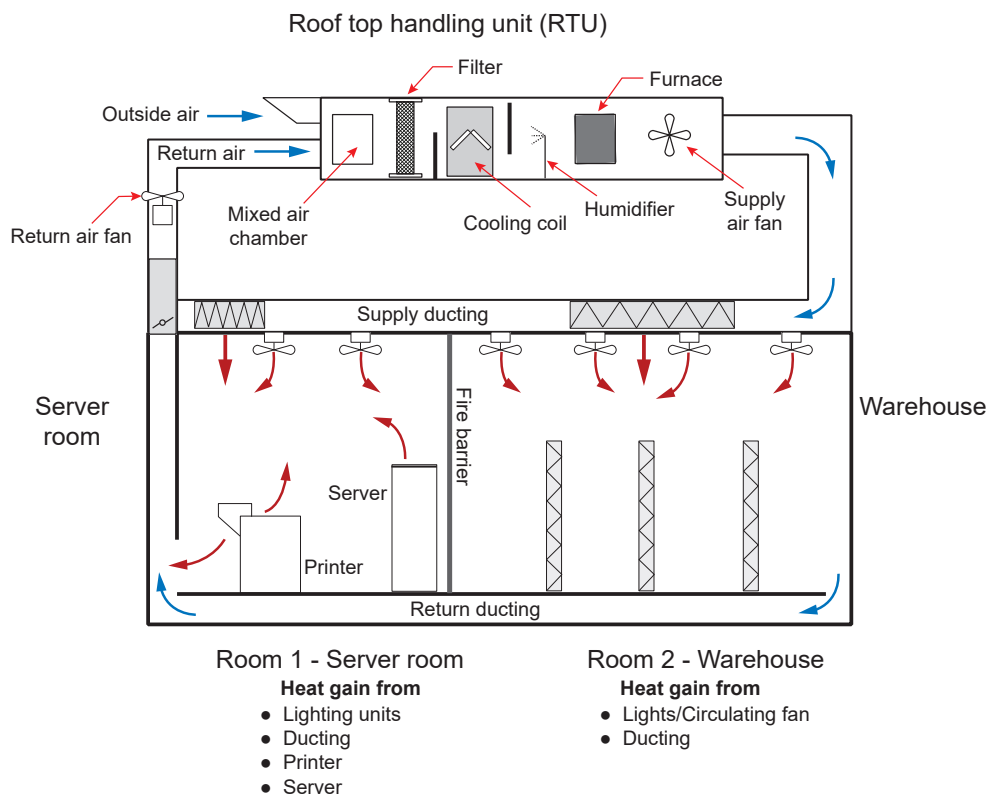
Internal heat gains in facilities can include gains from:

- People
- Lighting
- Motors
- Equipment
- Food
- Other processing applications

Figure 2 provides a simple example of two rooms in a facility.

In Room 1, which is unoccupied in the diagram, heat gain comes from the supply ducting via the air vents (green), two light fixtures, a server, and a printer.

In Room 2, heat gain comes from the supply ducting/air vents, and four combination light/fan fixtures. The HVAC supply in this example comes from the rooftop air handling unit. Each room returns air through the common return ducting.


Figure 2 – Internal Heat Gain Example


Heat Gains from Building Occupants

The heat load generated by the occupants will depend on the activity of the people in the building. The load will be in the form of both sensible and latent heat. The latent heat is contained in the water vapour, liberated from a person's body in the form of respiration and perspiration. This latent heat must be removed from the water vapour in the air; otherwise, it will cause the water vapour to condense on the coil of the cooling equipment.

Heat Gains from Lighting

The heat given off by light fixtures is not greatly affected by the room temperature. It depends mainly upon the power rating.

The heat gain from incandescent lighting fixtures is calculated by adding the power rating of each fixture. The resulting sum represents the heat gain, in watts.

Heat gains from lighting can be reduced by recessing the fixtures to keep some of the heat from entering the room. Fixture manufacturers issue data books showing correction factors to use for the various arrangements and types of fixtures.

Heat gains should be reviewed for older buildings that have been retrofitted with low heat producing LED lighting.

Heat Gains from Electric Motors

Electric motors give off sensible heat while they are running. The cooling equipment must remove the heat that is equivalent to the motor load. This is true whether the motor load is in the conditioned room or in the air stream.



Heat Gained from Hospital and Laboratory Equipment

Hospitals and laboratories have very stringent air conditioning criteria. These facilities are subject to significant heat gains because of the type of equipment they use. Equipment can vary significantly from space to space inside the building envelope. This makes it difficult to calculate generalized heat gain.

Heat Gained from Office Equipment

Offices generally have standard equipment that produces heat gains into the building envelope. This equipment includes computers, monitors, printers or copiers, and other office machines that use power.

Heat Gained from Cooking and Food Preparation Appliances

Cooking equipment installed in a conditioned space without a hood and exhaust fan is estimated (ASHRAE) as a heat gain of 50%. On average, this heat gain is 66% sensible heat and 34% latent heat. The balance of the heat is transferred to the dining space by the meals.

Food preparation equipment installed in air-conditioned areas includes both hooded (broiler, grill) and unhooded (blender, oven) equipment. Steam based equipment can include items such as a compartment steamer, sanitizing dishwasher, and steam kettle.

HEAT LOSSES IN A FACILITY

When the outdoor temperature is below the temperature inside a building, heat will escape from the building. The lower the outdoor temperature, the more heat will escape. The heating system must replace any heat loss in order to maintain comfortable indoor conditions. To keep the cost of heating as low as possible, it is necessary to keep heat losses to a minimum. Loss of heat from a building occurs by conduction, convection, and radiation.

Conduction, Convection, and Radiation

Heat conducts through building walls, ceilings, and floors, from the warmer inner surfaces to the cooler outer surfaces. For example:

- a) Warm room air gives up some of its heat near the cooler outside walls and ceiling. As the air cools, it becomes heavier, falls toward the floor, and is replaced by warmer air which, in turn, gives up heat. Convection currents are set up and heat is lost.
- b) Warmer objects and surfaces in the room radiate heat to the colder outside walls.

Adding layers of insulation, such as fibreglass or Styrofoam, to wall surfaces, and extra panes of glass to windows will reduce these heat losses. For example, heat losses through single pane windows are significantly higher than double pane windows, which usually have argon gas filled into the space between the two panes.

A single pane window with an outside temperature of -18°C and inside temperature of 21°C has a glass temperature of -9°C . A double pane window with argon gas has an inside glass temperature of 13°C , which is 22°C warmer.

Infiltration

Heat is also lost by the leakage of air into, and out of, the building through infiltration. Most of this leakage takes place around windows and doors. If the building was poorly constructed, leakage will also occur through the building walls. Cold air which leaks into a building must be heated by the heating system, which increases fuel consumption.

Infiltration can be reduced by thoroughly caulking around frames, and by weather stripping doors and windows. As with heat gains, the wind velocity directly affects how much heat loss occurs by conduction, convection, radiation, and infiltration. The stronger the wind, the more heat is lost.

Most buildings are set to run at a slightly positive pressure during heating periods. Infiltration will usually be from inside to outside, which means loss of treated air, including energy.



Ventilation

Although infiltration should be kept to a minimum, a certain amount of fresh air is required to provide ventilation and prevent excessive moisture buildup within a building. In smaller buildings, fresh air is provided by opening windows. In larger buildings, the fresh air comes from mechanical ventilating systems.

Since the heat of the stale warm air vented to the outside is lost and the cold fresh air has to be warmed again, ventilation puts an extra load on the heating system. Therefore, ventilation should be limited to what is necessary to maintain comfortable conditions in the building.

Most local codes specify that a minimum amount of outdoor air must be supplied for buildings of various occupancy types and activities. The **ASHRAE (2009 Fundamentals)** guidelines for minimum air ventilation in residential buildings are 3.5 L/s per person or 0.15 L/s per m² of floor space, for normal occupancy of one person per 25 m².

Infiltration is not an effective way to provide necessary ventilation, as on still days infiltration is minimal. Infiltrated air carries dust and other contaminants, which are not pre filtered, as is supply or ventilation air through an HVAC system.

The introduction of a controlled amount of ventilation air into a building offers the following advantages:

- a) Ventilation air is introduced through the air conditioning equipment in a constant quantity to maintain a positive pressure within the building. This positive pressure will cause an outward escape of air through cracks, windows, and doors, which controls or eliminates infiltration.
- b) Ventilation air can easily be filtered, which reduces the labour and expense involved in cleaning.

The amount of ventilation air required to adequately pressurize a space is seldom less than one air change per hour. In all cases, it must be greater than the total infiltration rate, plus the positive exhaust rate created by exhaust fans used for rest rooms and kitchens. It must also meet the L/s per person ventilation requirements.

To summarize, the ventilation rate is based on the larger of the following two requirements:

- a) Infiltration rate, plus exhaust rate, plus a small additional rate to maintain a positive pressure.
- b) The L/s requirements per person.

CAUTION

After 1973, the drive for energy conservation became so intense that ventilation almost became a bad word. It was an easy target for energy conservation; a few changes in control settings, and the building energy consumption could be reduced. However, this is a dangerous procedure. By decreasing the rate of ventilation, there is a risk of affecting comfort, and potentially public health, as well.



The arbitrary reduction of ventilation rates to save energy is a poor practice. Losses in employee efficiency and increased sick time may more than offset the savings.

It is also important to remember that changes in the use and occupancy of buildings may necessitate changes in the ventilation rate. The original rate set by the designer should be reviewed periodically, and reset to suit the actual occupancy and use.

Once the volume of outdoor air required for ventilation is established, the heat gain load can be calculated.



For spaces that are occupied sporadically, such as schools, universities, and office buildings, a CO₂ sensor is included in the control scheme. The more people in the area, the higher the CO₂ levels will be. The ventilation system adds more fresh air to reduce the CO₂ levels, and adds more oxygen to the occupied space. When the space is unoccupied, the ventilation rate decreases, which saves energy.



OBJECTIVE 3

Describe the general principles of HVAC heat recovery.

AIR CONDITIONING HEAT RECOVERY

Odours and bacteria can spread with recirculated air; therefore, in certain air-conditioned buildings, such as hospitals, recirculating the air is not permitted.

In a hospital, for areas such as operating rooms, emergency rooms and isolation wards, recirculating the air within each individual room, or between rooms, could spread infection or disease. Therefore, these areas have separate air conditioning systems.

The separate air conditioning system draws in 100% outdoor air and conditions it. The conditioned air then moves through the individual rooms and maintains specific conditions. The air discharges outside the building, away from any air intakes. The air does not recirculate in the room or in the system. This is known as a once through air conditioning system.

Exhausting warm humidified air in winter, or cool dry air in summer, is thermodynamically wasteful, and it also affects fuel and power costs. In addition, the ventilation rate of many of these areas is usually considerably higher than that required in ordinary comfort systems. However, a heat recovery system can recover a considerable amount of heat, and may also reduce operational costs.

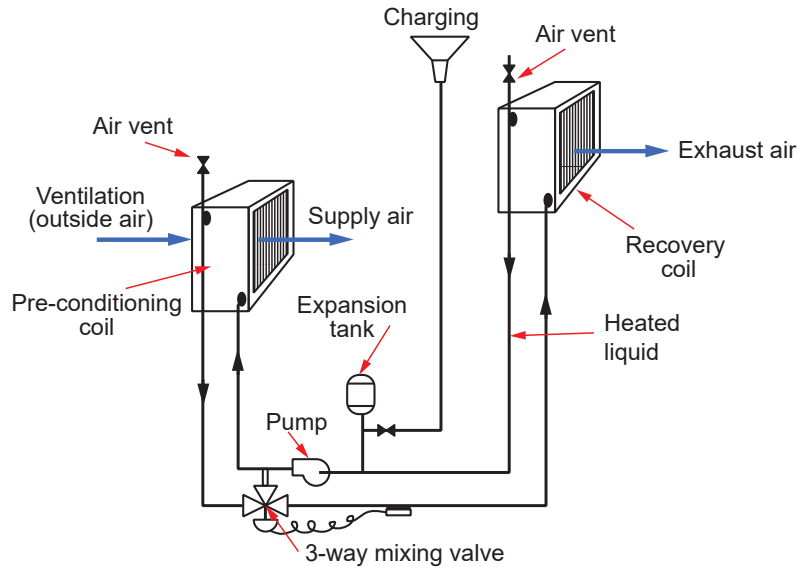
Various heat recovery methods are in use today. This section discusses the three methods listed below in further detail.

- Runaround System
- Thermal Wheel
- Heat Pipe

Runaround System

The runaround system, as shown in Figure 3, consists of two fin-tube heat exchangers that are connected by a circulation system. Liquid pumps through the system and moves heat from one coil to the other.

One coil, called the recovery coil, is installed in the ductwork handling the exhaust air. The other, called the pre-conditioning coil, is installed in the ductwork that introduces ventilation (make-up air) into a building or a process.

Figure 3 – Runaround Coil Heat Recovery System

The recovery coil extracts heat from the warm exhaust air, before it discharges to the outdoors. The circulating liquid absorbs the heat and carries it to the pre-conditioning coil, where it transfers to the cold ventilation air.

The operating temperature range of the system will determine what type of liquid to use. When freezing is possible, ethylene glycol is used.

The following additional features are illustrated in Figure 3:

- The coils are piped for a counterflow arrangement, to optimize heat transfer efficiency.
- The glycol supply to each coil is piped to the bottom connections, to ensure better air venting.
- The charging station is at a higher elevation than both coils. This makes it possible for gravity to charge the system slowly, while the system vents gradually. Where it is physically impossible to have a high elevation charging station, the alternative is to charge the system with a hand pump.
- The location of the expansion tank, as illustrated, ensures “the point of no pressure change” is at the inlet of the pump. This minimizes the problems of cavitation and air infiltration into the system due to negative pressure.

Advantages of the Runaround System

The advantages of the runaround system include:

- The exhaust and ventilation streams can be remote; they need not be side by side.
- Many exhausts can be grouped on the same system. The coils for washrooms, boardrooms, and office exhausts can all be connected to the same glycol circuit.
- No contamination occurs between exhaust and ventilation streams.
- This system is readily adaptable to retrofit applications.
- Less space is needed compared to other recovery systems, and the installation cost is comparatively low.
- Maintenance is relatively simple, except in cases where the exhaust is highly polluted, such as exhaust air expelled from a factory. In such instances, filtering of the exhaust air may be required.
- The energy expended by the pump is added to the glycol, and it is recovered when preheating the ventilation air.



Disadvantages of the Runaround System

The disadvantages of the runaround system include:

- a) The recovery range (45% to 55%) is relatively low for HVAC applications, because frost formation is the governing factor.
- b) The temperature difference between the exhaust and ventilation must be high enough (25°C) for good efficiency. Consequently, its effectiveness is reduced during mild weather.
- c) During the cold season, the full recovery rate cannot be used (when it is needed the most), because frost may form on the recovery coil.

Thermal Wheel

The **thermal wheel**, shown in Figure 4, is known by several different names including:

- a) Rotary regenerative heat exchanger
- b) Heat wheel
- c) Energy transfer wheel
- d) Ljungstrom wheel (derived from the name of the Danish inventor who patented the device in 1907)

Originally, the thermal wheel was used mainly to recover heat from boiler flue gas, to preheat combustion air. Since the early 1960s, this device has been adapted for commercial and industrial applications.

In contrast with the runaround system, the thermal wheel uses a single exchange unit, in which the mass of the material of the rotor carries the heat.

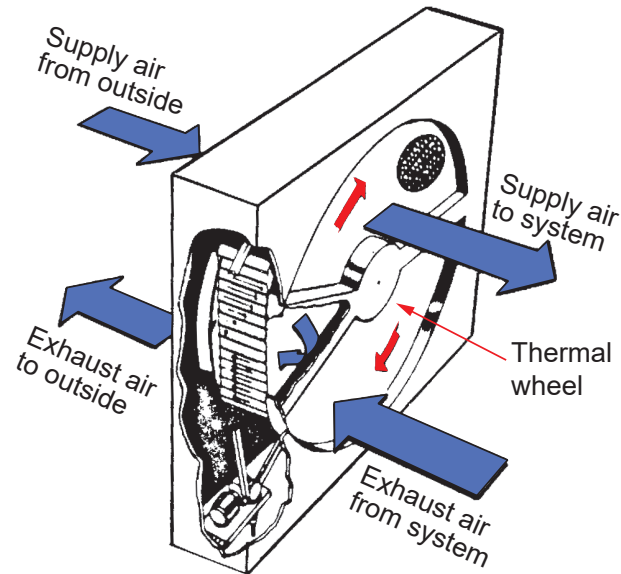
The design of the thermal wheel consists of a casing split into two sections, and a rotating wheel approximately 300 mm thick and 1 to 3.7 m in diameter.

Spoke-like divider plates divide the wheel into segments. These segments are filled with suitable metallic heat transfer media, such as corrugated knitted aluminum, stainless steel, or aluminized steel wires. In some instances, the segments are filled with non-metallic, desiccant-impregnated material, which forms narrow air passages. Such a wheel is called a hygroscopic recovery wheel, and is used where transfer of both sensible and latent heat is desired.

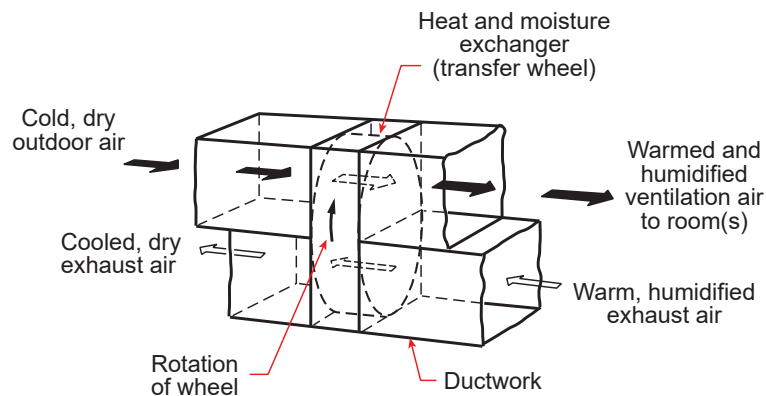
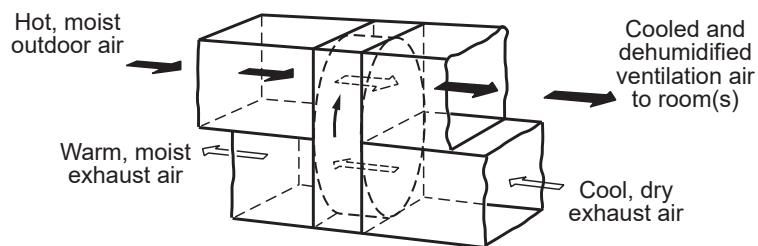
As illustrated in Figure 5, the ductwork feeding the two streams of air must be adjacent and parallel in order to permit the installation of the thermal wheel.

Often this requirement necessitates expensive ductwork modifications, which can be a major disadvantage.

Since the wheel rotates slowly, the medium is alternately exposed to the outdoor make-up air stream and to the exhaust air stream. If the wheel in question is a hygroscopic recovery wheel, it will pick up heat and moisture from one airflow and transfer it to the other. In order to optimize the heat transfer efficiency, the two air streams must flow in opposite directions (a counterflow arrangement).

Figure 4 – Rotary Regenerative Heat Exchanger (Thermal Wheel)

As indicated in Figure 5, the direction of the exchange depends on the season. During a heating cycle, Figure 5(a), the incoming low temperature make-up air is heated and humidified by heat transferred from the warm, moist exhaust air. During summer months, Figure 5(b), cooling and dehumidifying of the hot humid outdoor air is accomplished in a similar manner, by giving up heat to the cooler exhaust air stream.

Figure 5 – Operation of Rotary Regenerative Heat Exchanger (Thermal Wheel)**(A) Winter operation****(B) Summer operation**



Advantages of the Thermal Wheel

- Piping, pump, and circulating heat transfer liquids are not required.
- Only a small motor is required to rotate the wheel via a speed reducer (Optimum efficiency is achieved at 18 to 20 r/min).
- Both sensible and latent heat recovery is possible.
- Recovery over a wide range of temperatures is possible due to the extensive variety of wheel media.
- Good heat recovery. For sensible heat, thermal recovery of 60 to 70% is possible. For latent heat, the thermal recovery can be 20 to 50%.

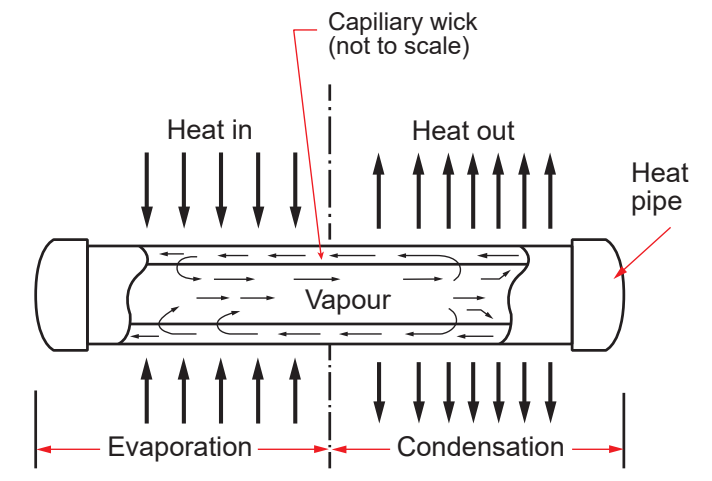
Disadvantages of the Thermal Wheel

- Side-by-side duct arrangement is required, which may be very costly, especially for retrofits.
- A large space is required to accommodate the size of the wheel, and to allow for the counterflow of air streams.
- Cross-contamination is possible, and requires regular monitoring.
- When using a purge section, the exhaust fan must be oversized by about 10% of the rated air volume, so a larger motor is required.
- A perfect sealing arrangement is impossible.
- Frost may form on the wheel during the cold season, but this problem is less severe than with the runaround cycle.

Heat Pipe

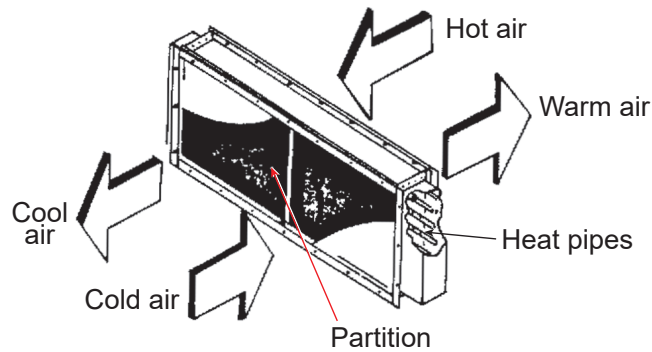
As illustrated in Figure 6, a **heat pipe** is a tube with a capillary wick structure. The internal surface of the tube is machined with fine circumferential striations. The tube is permanently sealed at each end, evacuated, and then partially filled with a volatile liquid, usually a refrigerant. Warm or hot air flows over one end of the heat pipe; this transfers heat and causes the refrigerant to vaporize. The refrigerant vapour then flows to the cold end of the pipe, where it condenses back into a liquid. The capillary or pumping action of the wick entrains the condensed liquid, which travels back to the hot end of the tube to be re-evaporated, thus completing the cycle.

Figure 6 – Heat Pipe



A heat pipe recovery unit is a counterflow air-to-air heat exchanger, as shown in Figure 7. Even though the appearance is quite similar to that of an ordinary fin-and-tube water coil, it is obviously quite different. In this unit, there are no return bends or headers to interconnect the tubes. Consequently, each individual tube is a heat pipe which operates independently, and spans the full length of the unit.

Figure 7 – Heat Pipe Recovery Unit



(Courtesy of Engineered Air)

Applications

The heat pipe recovery unit has been used successfully in industrial, commercial, and institutional air movement systems.

There are three main types of applications:

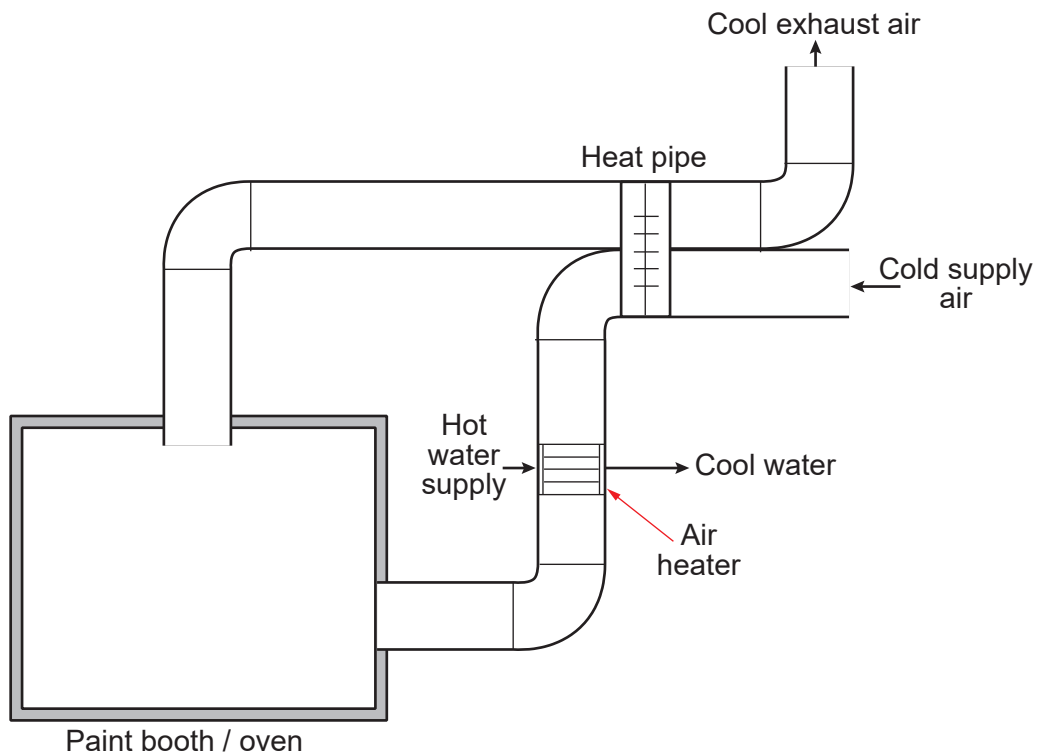
1. Process-to-process
2. Process-to-comfort
3. Comfort-to-comfort



Process-to-Process

The process-to-process method recovers heat from a process and feeds it back into the same process. As indicated in Figure 8, the recovered energy is utilized whenever the process is in operation. Typical process-to-process applications are paint drying ovens, spray dryers, and brick kilns.

Figure 8 – Process-to-Process Heat Pipe

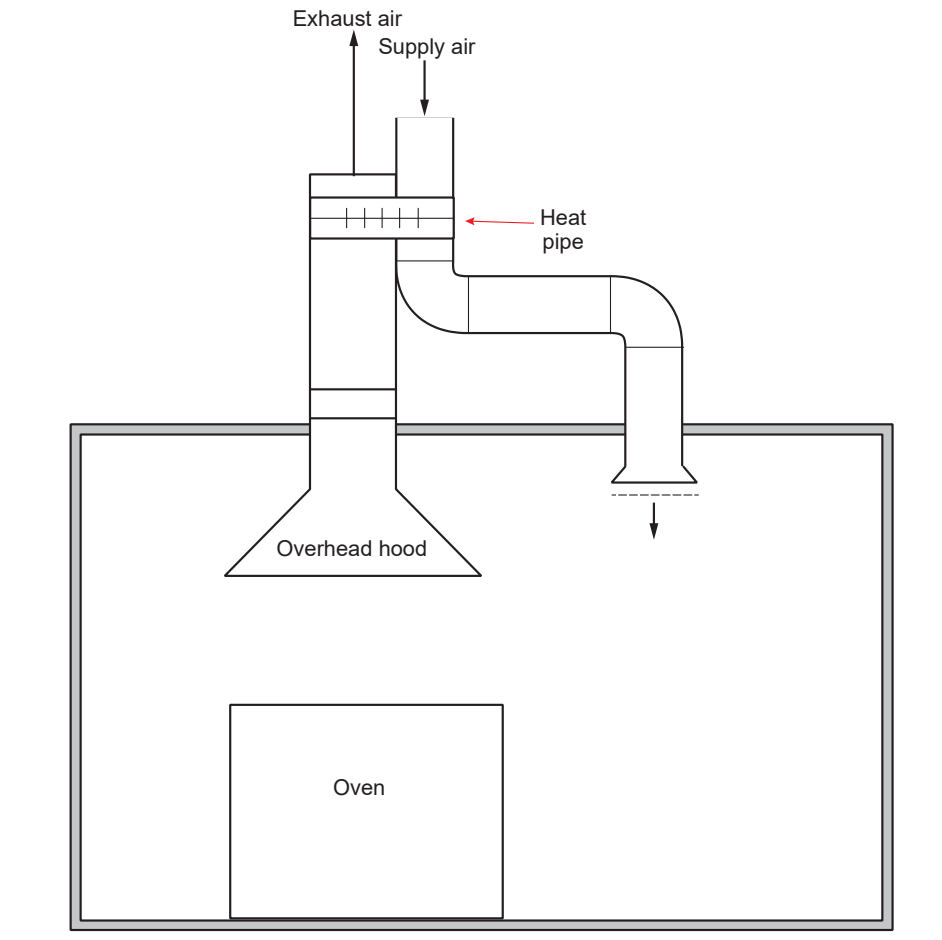


Process-to-Comfort

The process-to-comfort method recovers heat from a process and uses it to heat make-up air or ventilation air.

Figure 9 shows a process-to-comfort application. In winter, the heat recovered from the drying oven is used to heat the make-up air that is necessary to meet the ventilation code requirements. Examples of process to comfort applications are heat treatment furnaces, waste steam reclaimers, and laboratory or kitchen hood exhausts.

Figure 9 – Process-to-Comfort



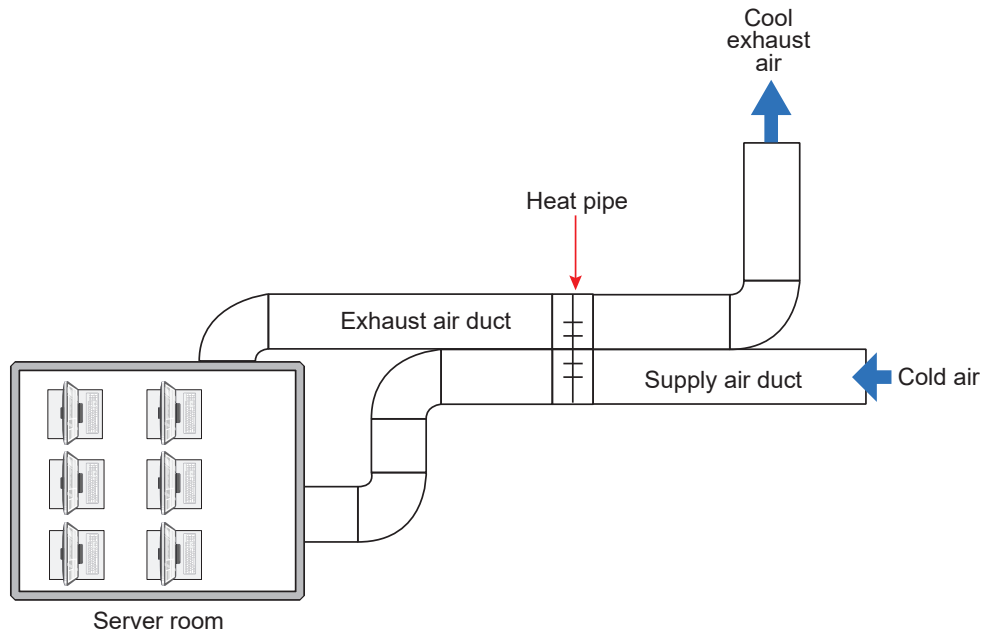


Comfort-to-Comfort

As indicated in Figure 10, the comfort-to-comfort method recovers the heat of the exhaust air stream and uses it to preheat the ventilation air during winter.

Because the heat pipe recovery unit can transfer heat in either direction, the process shown in Figure 10 can be reversed during the summer season. In summer, the ventilation air is precooled by transferring heat to the exhaust air stream. The summer process can take place whenever the outdoor air temperature is higher than the exhaust air.

Figure 10 – Comfort-to-Comfort



Heat Pipe with Preheat Coil

This method uses a preheat coil in the ventilation air stream, on the inlet side of the recovery unit. A temperature-sensing element, installed on the side where the air leaves the exhaust stream, modulates the capacity of the preheat coil. Heat energy is gradually added to the cold air stream, to prevent frost formation on the exhaust section.

Advantages of Heat Pipe Recovery Units

- Piping and pumps are not required.
- There are no continuously moving parts.
- Recovery is practical for a wide range of temperatures, from -50°C to approximately 700°C .
- There is no cross-contamination.
- No external power is required.
- It can be treated to resist corrosion.
- It comes in a wide variety of sizes, which makes it adaptable to the space available.
- It is simple to maintain by brushing, air blowing, or spray washing (manual or automatic).
- It has good recovery: 60% to 70%. Transfer of heat within the heat pipe is highly efficient, and is almost instantaneous with uniform temperatures over the length of the unit.



Disadvantages of Heat Pipe Recovery Units

- a) A side-by-side duct arrangement is needed, which is costly. It requires a large space, and is difficult to retrofit.
- b) Recovery is limited when there is a possibility of frost forming on the exhaust section.
- c) It is more expensive than the runaround system.



CHAPTER SUMMARY

Finding ways to increase overall efficiencies helps to reduce energy costs, and lowers the environmental footprint of the facility. Investing in newer materials and technologies can improve efficiencies and lower operating costs.

This chapter introduced some common terminology, as well as, how buildings gain and lose heat. Basic knowledge about how the characteristics of a building's atmospheric envelope can be managed and optimized was discussed. This allows the qualified operator to reduce fuel and maintenance costs, and improve the human comfort level for the occupants of the facility.

The available technology used for heat recovery over time can be improved. The operator must understand how each system works, and needs to find ways to improve the operation. Basic recovery systems, such as the thermal wheel, heat pipe, and runaround system are commonly used. The Power Engineer will encounter these systems in industry.





HVAC Control Strategy

LEARNING OUTCOME

When you complete this chapter you should be able to:

Describe the control systems strategies used in HVAC systems.

LEARNING OBJECTIVES

Here is what you should be able to do when you complete each objective:

- 1. Describe a basic ventilation control strategy for HVAC systems.*
- 2. Describe heating control strategies for HVAC systems.*
- 3. Describe humidification, dehumidification, and cooling control strategies for HVAC systems.*
- 4. Describe volume control with static pressure regulation for HVAC systems.*



CHAPTER INTRODUCTION

There are many different ways to control an HVAC system. Previous chapters introduced different designs and equipment for managing various HVAC system parameters. This chapter provides a fundamental understanding of how to control these various designs to meet the ever-changing environment within a building.

This chapter examines the control strategies for each HVAC subsystem separately. Mastering these individual strategies will help the Power Engineer to develop a more integrated understanding of HVAC systems.

Documents that describe the engineering design of control systems are referred to as control narratives. These documents help the operator to troubleshoot many of the different issues that arise.

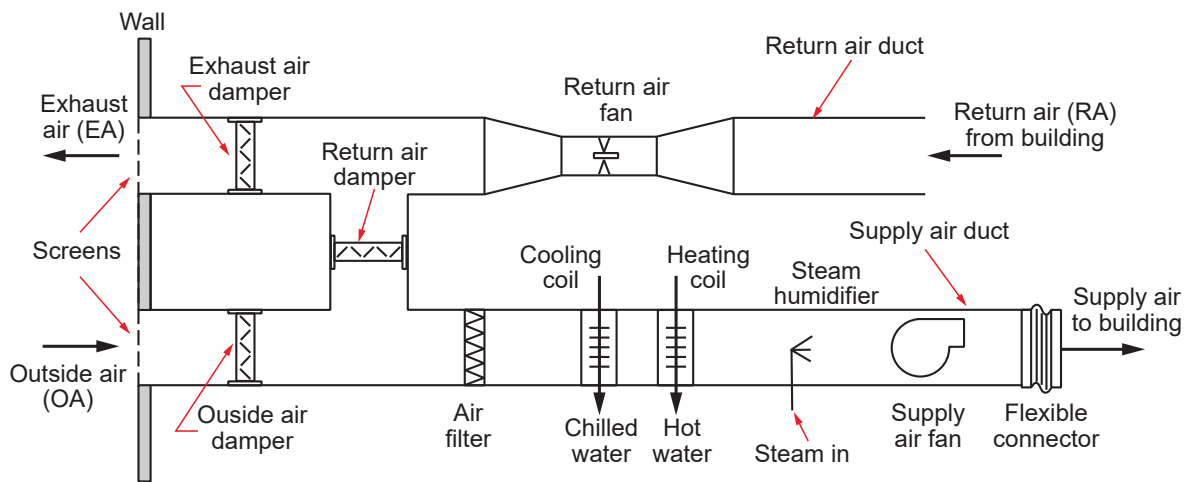
A control strategy is a method of linking mechanical equipment to the instrumentation systems that control them. In HVAC systems, the control strategies are designed to control the various parameters used to maintain human comfort. These control strategies are also designed to increase operational efficiencies and reduce operating costs. A third function of control strategies is to protect equipment from failures.

OBJECTIVE 1

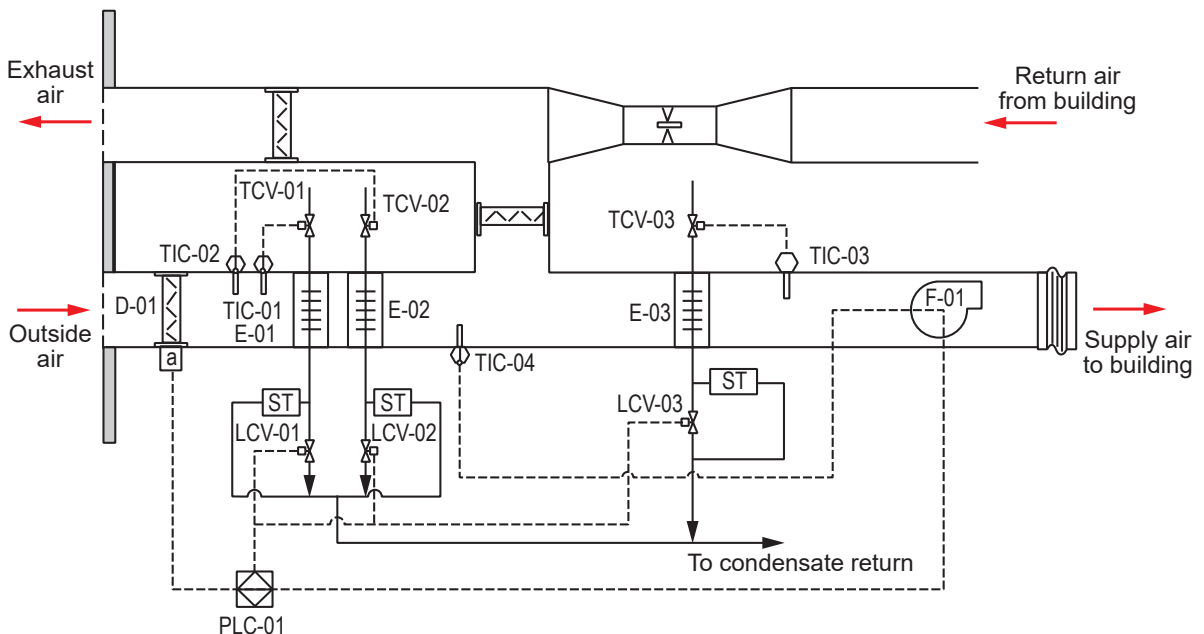
Describe a basic ventilation control strategy for HVAC systems.

BASIC OPERATION OF AN HVAC SYSTEM

The drawings shown in Figure 1 are of a basic HVAC system. Figure 1(a) shows the mechanical layout of the system. Figure 1(b) shows the instrumentation control loops that govern the mechanical elements of the system.

Figure 1 – HVAC Mechanical Drawing

(a) Mechanical Systems Only



(b) Controls Indicated



Many of the diagrams used in this chapter will not show all of the equipment in Figure 1. The equipment in each figure will focus on a specific control loop and its operating strategy.

The purpose of ventilation is to remove contaminants from the building air; these include dust, CO, CO₂, odours, and high humidity. A properly designed ventilation system removes these contaminants and conditions the air. The conditioned air usually includes make-up air, which is also called **outside air (OA)**.

The ventilation system blends the OA with the return air (RA) from the building. This mixture is called supply air (SA), and it is supplied to the building. The ventilation control strategy also includes the **exhaust air (EA)** which is the air that returns from the building, but it is not recirculated.

Most systems blend the OA and RA in a predetermined ratio. Some buildings, such as hospitals, or individual rooms in a building may require 100% OA. This requirement will not be discussed here. A generally accepted value of 15% minimum OA provides enough fresh air to maintain human comfort and meet regulatory requirements. This value may change daily or seasonally, based on factors such as the activities occurring inside the building, the number of people occupying the building, seasonal temperatures, and time of day.

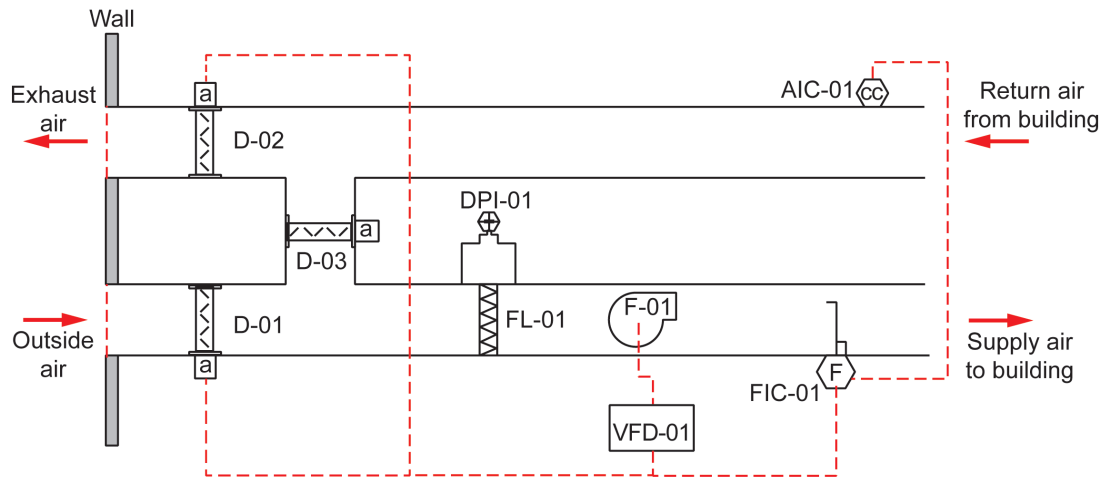
The primary concern of the building operator is to:

- a) Maintain human comfort.
- b) Ensure that contaminant levels are not above recommended levels.
- c) Minimize the operating costs of the building.

It is imperative for the ventilation system to meet the minimum “air changes per hour.” This is defined by how many times per hour the total volume of air in the building is changed out (replaced by SA). If this value is two air changes per hour, then the HVAC system supplies and removes the total air volume times two over a one hour time period.

The ventilation system in Figure 2 uses a combination of multi position dampers (D-01, D-02, and D-03), and a variable frequency drive (VFD-01) for supply air fan (F-01). In order to achieve proper airflow control, the EA damper D-02 must be synchronized with the OA damper D-01 and with the RA damper D-03. Synchronizing the three dampers helps maintain the proper ratio of RA to OA. A flow controller (FIC-01) measures the airflow in the supply air duct, and makes adjustments according to the set point entered into this controller.

In general, the OA dampers and the EA dampers will be open the same percentage, while the RA damper will be closed by the same percentage. For each quantity of fresh air brought into the HVAC unit, the same quantity will be exhausted to maintain constant building static pressure. As well, when the OA and EA dampers are closed, the RA dampers will be open to recirculate the air, without adding or exhausting air.

Figure 2 – Basic Ventilation Control in an HVAC System


If the airflow drops below set point, the controller modifies the control output signal to the supply air fan. VFD-01 increases the fan speed to increase the volume of air circulated.

An air analyzer, installed on the RA duct, maintains proper air quality in the building. The analyzer measures CO and CO₂ concentrations in the air. As the pollutants increase, AIC-01 sends a new set point to FIC-01, which increases the supply air fan speed and the OA/RA ratio as well. The ratio changes when the OA and EA dampers are more open and the RA dampers are closed; this allows more fresh air to flow through the building.

Table 1 lists the identifiers used in Figure 2.

Table 1 – Control Instrumentation Identifiers and Descriptions in Figure 2

Identifier	Description
AIC-01	Air Analyzer (CO, CO ₂)
D-01, D-02, and D-03	Outside Air, Return Air, and Exhaust Air Dampers
DPI-01	Differential Pressure Indicator
F-01	Supply Air Fan
FIC-01	Flow Indicator Controller
FL-01	Air Filter
VFD-01	Variable Frequency Drive for F-01



Operating Costs

The following strategies may optimize the HVAC system and also reduce operating costs.

- a) Put the building into off-hours mode when not occupied. In off-hours, the fan shuts down, the OA and EA dampers close, and the RA dampers open. This control strategy is used in Figure 3. The programmable logic control (PLC-01) utilizes an internal timer to enable the supply air fan, and to allow the dampers to modulate when the fan is on.
- b) Use a VFD drive for the supply air fan. If the horsepower requirements for the fan are large enough, the power savings will be worth the initial investment for the VFD.
- c) Monitor the return air quality. By reducing the outside air requirements to a minimum, the operator can optimize the system. The HVAC system then needs to treat less air, which reduces costs.
- d) Check the air filters for quality and cleanliness. It takes a lot of power for the fan to draw or force air through plugged filters. Measuring the differential pressure across filters will determine how plugged the filters are. In Figure 2 a differential switch (DPI 01) performs this measurement. When the differential pressure is too high, this switch indicates that the filters need to be replaced. Although changing the filters more frequently adds savings by lowering power consumption, changing them too frequently means additional costs in filters.

OBJECTIVE 2

Describe heating control strategies for HVAC systems.

HEATING PROCESS

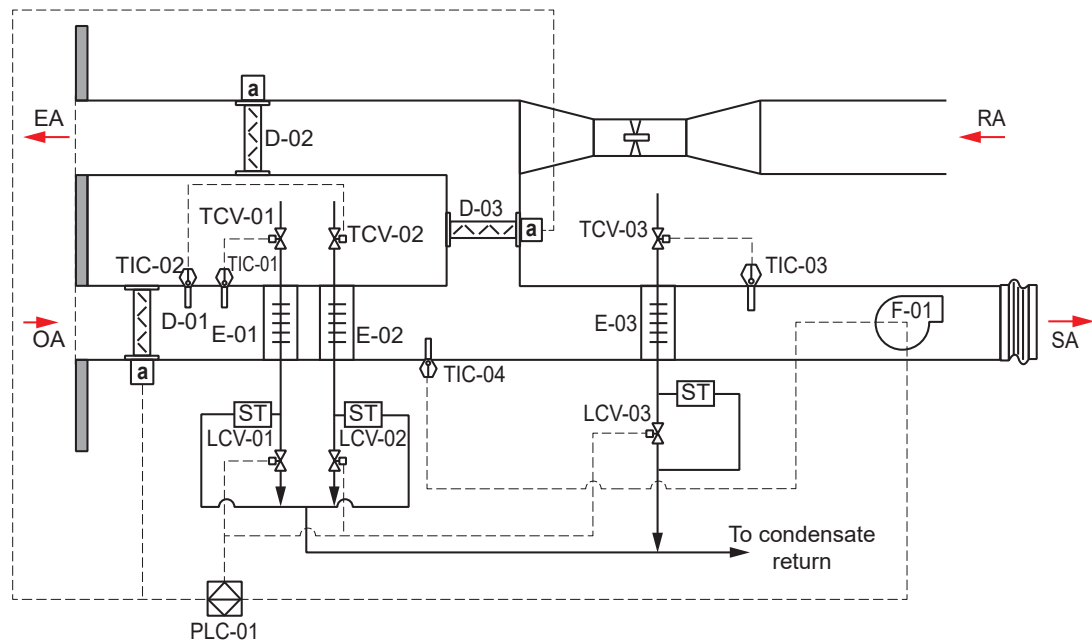
The “H” in HVAC stands for “heating.” Incoming air may require additional heat to keep the building comfortable, depending on the season. Heating system controls ensure that the correct amount of heat is added to ensure occupant comfort, and to protect against freezing. A properly designed control strategy meets these requirements.

HVAC systems may use preheat and heating coils to warm the air. Preheat coils are used to preheat the fresh outside air (OA) prior to mixing with return air. Heating coils are used to heat the mixture of return air (RA) and OA prior to distributing this supply air (SA) to the building. The operator must understand how the control strategy manipulates the system components to meet heating objectives.

The heating and preheat coils in Figure 3 (E-01, E-02, E-03) are steam heat exchangers. Air travels through the steam coils and absorbs heat. The steam condenses. Steam traps then discharge the steam to the condensate line. As the OA and RA temperature vary, the amount of steam supplied to the coils varies to maintain the desired SA temperature.

The system shown in Figure 3 uses three heat exchangers to warm up the air. The heating control strategy must be designed in such a way that the coils work independently and optimally as the load demand changes.

Figure 3 – HVAC Unit Basic Heating Control



For example, if the desired SA temperature is 14°C and the OA temperature is slightly below this temperature, the heating coil (E-03) adds heat to the OA and RA. When the OA temperature drops below 14°C, the temperature indicating controller (TIC-03) manipulates the temperature control valve (TCV-03) to allow steam flow into E-03. When the OA temperature drops to 3.5°C, TIC-01 manipulates TCV-01, allowing steam flow into preheat coil E-01.



By using both preheat and heating coils, the air supplied to the building can be easily maintained at the desired air temperature. Preheating coils are usually limited to about 18°C in air temperature rise across the coil. When a temperature rise of more than 18°C is required, multiple preheat coils are used.

In Figure 3, the two preheat coils are controlled independently from each other. The control system maintains the desired air temperature using both coils. When the air temperature begins to drop near freezing (around 1.5°C), TIC-02 starts to open TCV-02, and allows steam to enter E-02. By the time the temperature reaches 1.5°C, TCV-01 will be about 50% open.

In combination, these three heating coils can maintain the desired air temperature, even during severe temperatures. The heating coils operate efficiently as long as the condensate drainage system is designed to handle the volumes of condensate produced. It is essential that properly sized steam traps are installed, to ensure that the condensate that forms inside the coils drains reliably.

Table 2 lists the identifiers used in Figure 3.

Table 2 – Control Instrumentation Identifiers and Descriptions in Figure 3

Identifier	Description
D-01, D-02, and D-03	Outside Air, Exhaust Air, and Return Air Dampers
E-01	Preheat Coil #1
E-02	Preheat Coil #2
E-03	Heating Coil
F-01	Supply Air Fan
LCV-01, LCV-02, and LCV-03	Steam Condensate Dump Valves for heat exchangers E-01, E-02, and E-03 respectively
PLC-01	Programmable Logic Control
ST	Steam Trap
TCV-01, TCV-02, and TCV-03	Temperature Control Valves for heat exchangers E-01, E-02, and E-03 respectively
TIC-01	Temperature Indicator/Controller for E-01
TIC-02	Temperature Indicator/Controller for E-02
TIC-03	Temperature Indicator/Controller for E-03
TIC-04	Temperature Safety Control Device for F-01

Safety Control Systems

Control strategies must be in place to protect the coils. When steam is the heating medium and the outside air is near freezing, condensate may not drain well. If this occurs, the condensate may freeze inside the coil, which can damage the heat exchanger. During normal operations, the condensate drains back to the condensate receiver without interruption. During adverse conditions, the coil may suddenly need to dump the condensate to prevent freezing. Referring to Figure 3, the dump valve (LCV-01) facilitates this operation. The dump valve control strategy is described below.

The chance of freezing increases when the air temperature drops from 1°C to subfreezing. The preheat coils receive steam when the OA temperature falls to 3.5°C. When the steam condenses in the coil, a slight vacuum forms. As long as enough steam is supplied to the coil, a vacuum does not form. However, at low heating loads, the steam added to the coil may be insufficient, and a vacuum may form. This vacuum will keep the condensate from draining out of the coil. If the OA temperature drops below freezing, coil freeze-up will occur.



Therefore, TCV-01 has a minimum opening of 50% when the OA temperature drops below 0°C. When TCV-01 is open 50%, there is sufficient steam flow to prevent a vacuum from forming in the coil (E-01). The condensate is then able to flow freely to the condensate receiver, thus eliminating freezing concerns. During these conditions, there is enough airflow to keep the coil from overheating.

Refer to Figure 3. As long as the supply air fan (F-01) continues to operate, the outside air dampers (D-01, D-02, and D-03) will remain open. If for any reason F-01 is off, PLC-01 generates a control signal to close D-01 and D-02, and to fully open D-03. Both D-01 and D-02 must be closed to prevent the cold air from infiltrating the HVAC system. This will protect the preheat coils and heating coils from freezing when the fan is not running.

When shutting down the system in cold weather, it is necessary to drain the coils of all condensate to protect them from freezing. The dump valves (LCV-01, LCV-02, and LCV-03) ensure that the condensate fully drains from each coil. When the supply air fan shuts down, PLC-01 generates a signal to open the dump valves.

The same operating and control strategies for heating and freezing protection apply to E-02 as well.

There are numerous other ways of controlling steam HVAC systems. The source of heat (electric, hot water, glycol, or steam) and the mechanical design determine the best control strategy to use. The systems discussed here are only examples of what to consider when designing control strategies to operate and protect the system.



OBJECTIVE 3

Describe humidification, dehumidification, and cooling control strategies for HVAC systems.

HUMIDITY CONTROL

The purpose of humidity control is to maintain proper humidity levels within the building, to provide human comfort. In Figure 4, a humidistat (HIC 01) monitors the humidity a certain distance downstream of the humidifier. In areas with low humidity, humidifiers add water vapour to the air to achieve the required humidity set point.

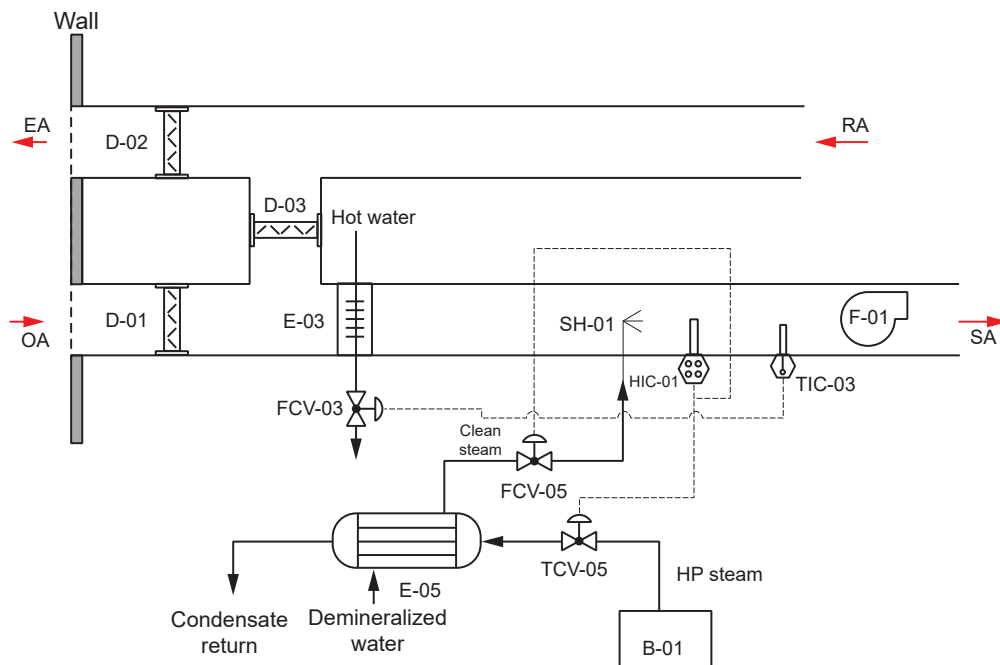
The control loop normally operates in automatic mode. However, a manual mode can be used during upsets, startup, and shutdown.

Boiler steam may carry toxic elements, such as filming and neutralizing amines. This steam cannot be used for direct humidification. In a **clean steam** humidification system, high-pressure boiler steam, or some other heat source, boils pure water to use for humidification.

In Figure 4, a heat exchanger (E-05) uses high-pressure steam from the heating system to boil pure demineralized or reverse osmosis water. HIC-01 measures the humidity in the supply air duct and generates a control output signal based on the deviation from the humidity set point. The control output signal is used to position the steam control valve TCV-05 and clean steam flow valve FCV-05.

A low air humidity causes the steam control valve (TCV-05) and the clean steam flow valve (FCV 05) to open. This increases both the steam flow to E-05 and the flow of clean steam for humidification. High humidity causes TCV-05 and FCV-05 to close. This decreases both the steam flow to E-05 and the flow of clean steam.

Figure 4 – HVAC Unit Humidification Control



In this humidification system, steam is added to the air, which increases the sensible heat and latent heat of the air. A temperature indicating controller, located downstream of the humidifier, makes small adjustments to the heating system. This controller allows the system to compensate for the heat added by the steam from the humidifier. If more clean steam is added, TIC-03 measures a temperature increase in the air, and makes small changes to FCV-03 to adjust the amount of heat added to the air through E-03.

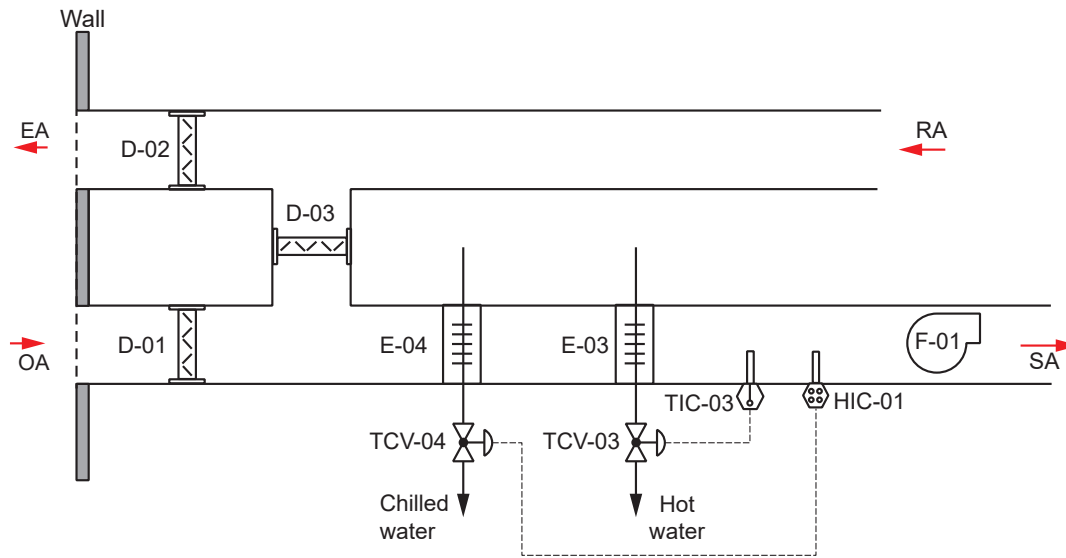
Even though two different control loops may not directly interconnect, the changes made by one control loop can affect the operation the other one. When operating a facility, study the control strategies and determine how each control loop is tied directly or indirectly to others. This will help the operator to develop troubleshooting and problem solving skills.

Table 3 lists the identifiers used in Figure 4.

Identifier	Description
B-01	Boiler – generates heat for E-05
D-01, D-02, and D-03	Outside Air, Exhaust Air, and Return Air Dampers
E-03	Heating Coil
E-05	Clean Steam Generator – exchanges heat between steam and demineralized water
F-01	Supply Air Fan
FCV-03	Flow Control Valve – controls hot water flow
FCV-05	Flow Control Valve, 2 position valve (Open or Closed)
HIC-01	Humidistat (Humidity Indicator Controller)
SH-01	Steam Humidifier
TCV-05	Temperature Control Valve – controls steam flow
TIC-03	Temperature Indicating Controller

DEHUMIDIFICATION AND COOLING CONTROL

The dehumidification process removes excess water vapour from the air. In some systems this function is combined with the conditioning system for cooling air. The example in Figure 5 combines dehumidification and cooling strategies. Chilled water is used in the cooling coil (E 04), and hot water is used in the heating coil (E-03). Changing the temperature of the air by changing its sensible heat affects how much water vapour the air can hold. When the air temperature drops, the mass of water that air can hold also drops. If lowered enough, the air temperature can lower the dew point of the air.


Figure 5 – HVAC Unit Dehumidification and Cooling Control


E-03 and E-04 only change the sensible heat of the air. To dehumidify, the air enters E-04, which lowers the air temperature enough to bring the air to its dew point. The water vapour in the air condenses and falls out of the air stream. The relative humidity of the air downstream of E-04 will be 100% at a temperature of about 12°C. A tray installed below E-04 catches the condensed water, and drains it away from the HVAC system.

The air then flows through E-03, to lower the relative humidity and raise the air temperature. Here, the air temperature increases to approximately 18°C. This lowers the relative humidity to within the desirable range of 40% to 60% for human comfort.

The humidity indicating controller (HIC-01) measures the humidity in the supply air duct. If the humidity deviates from the set point, HIC-01 sends a proportional control output signal to TCV-04.

If the humidity is too high, the cooling coil (E-04) temperature must decrease. Therefore, TCV-04 must be more open to increase the chilled water flow through E-04. The increased water flow removes more sensible heat from the air. The lowered air temperature decreases the dew point, which causes more water to condense.

The air temperature rises and allows the air to hold more water.

If the air temperature leaving E-04 is too low for human comfort, the heating coil raises the air temperature. The temperature indicating controller (TIC-03) measures the air temperature of the air leaving E-03. When the air temperature drops below the set point, TIC-03 sends a control output signal to TCV-03, which increases the flow of hot water to the heating coil. If the air temperature increases above the set point, TIC-03 sends a signal to close TCV-03 more, which reduces the flow of hot water into E-03.



Table 4 lists the identifiers used in Figure 5.

Table 4 – Control Instrumentation Identifiers and Descriptions in Figure 5	
Identifier	Description
D-01, D-02, and D-03	Outside Air, Exhaust Air, and Return Air Dampers
E-03	Heating Coil
E-04	Cooling Coil
F-01	Supply Air Fan
HIC-01	Humidistat (Humidity Indicator Controller)
TCV-03	Temperature Control Valve – hot water
TCV-04	Temperature Control Valve – chilled water
TIC-03	Temperature Indicating Controller



OBJECTIVE 4

Describe volume control with static pressure regulation for HVAC systems.

VOLUME CONTROL

The purpose of pressure regulation in a building is to maintain the proper static air pressure within the building. Buildings normally run slightly above atmospheric pressure to minimize the uncontrolled infiltration of untreated air into the building. Commonly, the system pressure is measured in the supply air duct. The static pressure is usually from 40 to 50 kPa. When the static pressure rises above 50 kPa, the air velocity in the duct may generate too much noise and may cause excessive airflow from the air registers. When the static pressure drops below 40 kPa, the system may have operational issues; possibly, the system has reached maximum capacity. The air pressure must be controlled to deal with these two issues.

Often, a single duct system supplies air to the various conditioned spaces, at a constant temperature. The heating or cooling load in each zone may vary considerably due to sun and wind exposure. Regulating the amount of conditioned air entering each zone keeps the temperature at comfortable levels. This conditioned air is supplied by thermostatically controlled variable air volume boxes (VAV) in the zone air supply duct.

As the VAVs modulate their individual airflows, the total volume of air flowing through the system varies considerably. As a result, the system static pressure changes. Therefore, a system of controls and a control strategy must be utilized to keep the static pressure within the desired range.

In order to maintain a positive building pressure, the static pressure is measured in the supply air duct, and the volume of air supplied to the building is then manipulated. Buildings have kitchen and washroom exhaust fans that remove stale air. The HVAC system must replace this stale air with fresh outside air. During summer, when temperatures are above a comfortable range, the HVAC system has an added load. The controls in the system must compensate for this load. In summer operation, the supply air becomes the cooling medium for the building, and the system will call for an increase in air volume to keep the building cool.

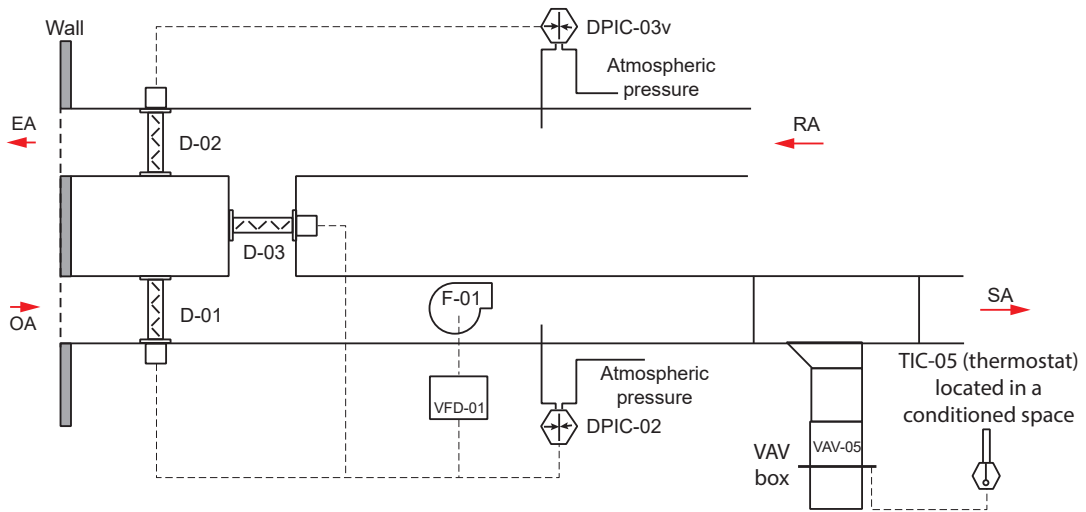
Refer to Figure 6. When the thermostat (TIC-05) detects an increase in room temperature, it requests more cooling. This causes the variable air volume box (VAV-05) to become more open, and allows more cool air to enter the space. The extra air volume leaving the supply air (SA) duct causes a slight drop in pressure in the SA duct.

The differential pressure transmitter (DPIC-02) measures the SA pressure and compares it to the building static air pressure. The controller responds to the change in differential pressure by manipulating the fan speed and damper positions to adjust the airflow to the SA duct, which changes the SA duct pressure.

When duct static pressure drops below set point, the fan (F-01) speed increases and the OA damper (D-01) opens further. These changes cause an increase in air volume flow, restoring SA duct static pressure to set point.

When duct static pressure rises above set point, the fan (F-01) speed decreases and the OA damper (D-01) closes further. These changes cause a decrease in air volume flow, again restoring SA duct static pressure to set point.

Figure 6 – HVAC Unit Dehumidification and Cooling Control



On the hottest days of the year, the load placed on the HVAC system may be so great that the system reaches its maximum capacity. The operator can recognize this by observing the supply air pressure, the fan speed, and the damper positions. If the supply air pressure is below 40 kPa, the fan speed is at maximum, and D-01 and D-02 are at 100% open positions, the system is at maximum capacity. At this point, there is little the operator can do other than to take advantage of any free cooling that may be available. If the overnight or early morning outside air temperature is low enough, the operator can set the air handling unit to start earlier in the day. This will allow the system to draw in cooler outside air, to get a head start on the increased daytime load.

If the various zone temperatures drop too low, then the system thermostats call for less cooling. As the VAVs close off, the SA duct static pressure increases. The controls slow the fan and adjust the damper positions to maintain the duct static pressure set point. During the heating season, the system control strategy operates in a similar manner to maintain the correct pressure while supporting the correct air temperature in the building.

In the RA duct, a DP transmitter (DPIC-03) measures the RA duct pressure and compares it to the building atmospheric pressure. If the pressure inside the RA duct increases, DPIC-03 will adjust D-02 slightly more open to allow more air to exhaust from the building.

A couple of air volume issues include:

- Hot and cold locations in the building
- Air imbalances

Hot and cold areas in the building and air imbalances are associated with improper balancing of air throughout the system. Air imbalances are evident when people struggle to open or close doors, due to excessive air pressure differential.

In order for the controls to operate the HVAC equipment efficiently, the mechanics must be properly set up. Throughout air distribution systems, there are several mechanical air dampers that are manually adjustable. These dampers must be set properly throughout the building to eliminate hot and cold areas and air imbalances.

If there are significant issues with air volume and distribution, it may be necessary to call in a contractor to balance the air in the system. Balancing the air will ensure an even distribution and correct volume of air for each space. The air balance testing will determine if the fan is capable of supplying the required amount of air based on the engineering design. After the air balancing is completed, the facility operator will be able to support the needs of the building.



Table 5 lists the identifiers used in Figure 6.

Table 5 – Control Instrumentation Identifiers and Descriptions in Figure 6	
Identifier	Description
D-01, D-02, and D-03	Outside Air, Exhaust Air, and Return Air Dampers
DPIC-02	Differential Pressure Indicating Controller
DPIC-03	Differential Pressure Indicating Controller
F-01	Supply air Fan
TIC-05	Temperature Indicating Controller (Thermostat)
VAV-05	Variable Air Volume Box
VFD-01	Variable Frequency Drive



CHAPTER SUMMARY

This chapter introduced some possible control strategies for an HVAC system. One way to consider a building is to think of it as a living, breathing entity. Throughout the day, the building heats up and cools off, and the humidity levels change due to a large influx of people into the building. The HVAC system must compensate for all of these changes.

Various strategies control the many different operating parameters to ensure the highest quality of comfort within the building. The control strategies also take advantage of efficiencies, such as free cooling, and protect the HVAC system from freezing.

Although there are many different ways to control each one of the described parameters, operators must have a basic understanding of how and why control strategies are used. This basic knowledge will make it easier for operators to understand and operate HVAC systems. The operator will be able to increase the building efficiencies and help with troubleshooting.



UNIT SUMMARY

This concludes the unit on Building Environmental Systems and Control. This unit covered:

- a) Descriptions of a range of heating systems including steam, hot water, and natural gas.
- b) Descriptions of a variety of cooling and combination systems.
- c) How the indoor climate of a building gains and loses heat.
- d) A basic discussion of how these HVAC systems are controlled.

This unit focused on providing a broader perspective of the responsibilities of the Power Engineer as a qualified operator in a facility. This goes beyond the jurisdictionally mandated and regulated responsibilities.

Managing and operating all systems related to the generation and use of steam and thermal fluids is as important as the regulated pressurized processes. Managing the systems that support work environments and the human comfort of all building occupants is also essential.

A self-assessment tool is available on MyPower LMS. Login using the unique user ID and password found on the inside front cover of Unit 1.



4th Class Edition 3.5 • Part B
UNIT B-11

KNOWLEDGE EXERCISES AND UNIT GLOSSARY

Chapter 1	Steam Heating	U11-9
Chapter 2	Hot Water Heating	U11-11
Chapter 3	Other Heating Systems	U11-17
Chapter 4	Cooling Systems and Combination Systems	U11-19
Chapter 5	Heat Gains and Losses, and Heat Recovery Methods	U11-21
Chapter 6	HVAC Control Strategy	U11-23
Unit B-11	Unit Glossary	U11-27



KNOWLEDGE EXERCISES – CHAPTER 1

Name: _____ Date: _____

Instructor: _____ Course: _____

Objective 1

1. Explain why placing things in front of a convector will affect its ability to transfer heat.

2. Explain the heat transfer advantages of unit heaters over convectors.

Objective 2

3. Explain how air trapped inside steam heating systems and steam heating coils impedes heat transfer.

4. Explain why it is important to drain condensate from the radiator.

5. Describe two major functions of a vacuum pump.



Chapter 1 (Cont.)

Objective 3

- 6. Explain the primary functions of the piping systems used in steam heating plants.

Objective 4

- 7. After the boiler shows signs of increasing pressure, what are the key indicators to ensure the heating system is functioning properly.

- 8. List the parts of convectors, radiators, and univents that require regular maintenance.

Objective 5

- 9. Fill in the blanks for troubleshooting if there is insufficient heat in one or more rooms.

POSSIBLE CAUSE	CHECK	CURE
Poor air venting		
Radiator or convector improperly pitched		Pitch unit in the proper direction.
	Heating unit cold; Air and condensate trapped.	Repair or replace the trap.
Convector fins clogged with dirt, lint, etc.		
	Insufficient static head for removal of condensate; steam flow blocked.	Install condensate return tank below level of lowest heating.



Chapter 2 (Cont.)

7. Sketch a simple snow melt system.

Objective 4

8. Explain how a dip tube prevents the air in the boiler from leaving with the water that is exiting the boiler.

9. Why are hot water heating systems equipped with expansion tanks?



Chapter 2 (Cont.)

10. Sketch an air separator fitting, showing its internal parts. Then, explain how it removes entrained air from hot water heating systems.

Objective 5

11. Explain why the pressure will not change at the point where an expansion tank is connected.

12. Discuss how the hot water system pressure can have an impact on the circulator pump.



Chapter 2 (Cont.)

13. A boiler is installed in the basement of a 10-storey building. There are 11 storeys above the boiler. Each storey is 3 m high. What should the boiler pressure gauge read, in kPa, when the system is full and properly pressurized?

Objective 6

14. Explain the disadvantages of using glycol instead of water in a heating system.

15. When glycol heat exchangers may come in contact with potable water, _____ glycol is used, because it is non-toxic.

16. When a hot water heating system is in operation, what is the normal expansion tank water level?

Objective 7

17. A room is too cold. Identify two main trouble areas that require investigation.

18. Name three causes of hot water circulating pump noise.

19. A piping system is making gurgling and sloshing noises. What is the cause? How is this condition corrected?





KNOWLEDGE EXERCISES – CHAPTER 3

Name: _____ Date: _____

Instructor: _____ Course: _____

Objective 1

1. Inside a house, where are the supply air registers and the return air registers located? Why does the location make a difference?

2. List six considerations to best match a warm air furnace to the installation.

3. What are key considerations when selecting a furnace?



Chapter 3 (Cont.)

Objective 2

4. On an indirectly driven blower and motor system, which piece of equipment has a large pulley and why? What happens to the speed when an adjustable pulley is brought closer together?

Objective 3

5. Explain how infrared heat is transferred.

6. When using a non-vented infrared heater, what must the building HVAC system compensate for?

Objective 4

7. Explain why electric heating is safer than using a fossil fuel heating system.

8. Discuss the differences between direct and indirect electric heating.



KNOWLEDGE EXERCISES – CHAPTER 4

Name: _____ Date: _____

Instructor: _____ Course: _____

Objective 1

1. Explain the source of heat that dissipates in the condenser, and explain where the heat will go.

2. Compare the similarities and differences between a window mounted air conditioner and the unit ventilator.

Objective 2

3. Explain why mixing boxes are installed in the dual duct system.

4. Constant air volume systems are controlled by adjusting what operating parameter?



Chapter 4 (Cont.)

Objective 3

5. Describe the advantage and disadvantage of a four-pipe fan coil with make-up air.

6. Define a combined air conditioning system.

Objective 4

7. Explain the difference between capital costs and operational costs.

8. Give an example of the relationship of capital cost versus operating costs.



Chapter 5 (Cont.)

Objective 3

5. Explain the advantage of installing a runaround system over a thermal wheel.

6. Provide an example where a heat pipe could be used for heat recovery.



KNOWLEDGE EXERCISES – CHAPTER 6

Name: _____ Date: _____

Instructor: _____ Course: _____

Objective 1

1. List four ways that a ventilation control strategy can help reduce operating costs.

2. Referring to air changes per hour, explain how ventilation controls regulate the amount of air entering the building.

Objective 2

3. What is the primary concern when operating a steam or hot water heating system in subfreezing temperatures?

4. Explain why multiple preheat coils may be used.

5. Explain how a control strategy can prevent a vacuum from forming within steam coils.



Chapter 6 (Cont.)

Objective 3

6. How is the output of a clean steam generator adjusted to control humidity?

7. How does the addition of steam to air for humidification affect the control of the heating system?

8. Explain what happens during summer operation when the humidity in the supply air drops.

Objective 4

9. Explain how the operator can modify the pressure control strategy to take advantage of the available free cooling.



Chapter 6 (Cont.)

10. Explain what problems may occur if the supply air duct pressure is above or below the desired pressure range of 40 kPa to 50 kPa.

Northern Lights over Alberta Skies



(Courtesy of Daniel Dawson Fotografie)



UNIT B-11 GLOSSARY

Term	Definition
AFUE	See <i>annual fuel utilization efficiency (AFUE)</i> .
Air change method of measuring infiltration	A method of determining the rate of air infiltration into a building, using tables that show the expected number of air changes per hour in rooms with various exposures.
Air vent	An automatic or manual valve that removes air from the highest point of a coil or piping system.
Annual fuel utilization efficiency (AFUE)	A measure of thermal efficiency for fired heating equipment that measures the useful energy output as a percentage of energy input.
Clean steam	Steam generated with mineral and chemical free water to meet regulatory requirements for use in food, drug, medical, or HVAC humidification processes.
Cold deck	In a multi-zone, constant air volume HVAC system, a chilled water or direct expansion coil that provides cool air and dehumidification.
Convactor	A heating device comprised of a copper or steel finned tube, through which steam or hot water flows. Convectors transfer heat through radiation and natural convection.
Crack method of measuring infiltration	A method of determining the rate of air infiltration into a building, based on the average quantities of air known to enter through doors, and cracks around windows and doors, when wind velocity is constant.
Downfeed system (HVAC)	A hot water heating system installed above the system main, which feeds vertical lengths of piping from above.
Electric resistance coil	A heating coil comprised of metal wires that heat up when electric current passes through them. They are used in baseboard heaters and electric water heaters.
Exhaust air (EA)	Air returning from a building that is exhausted directly to the outside instead of being reconditioned.
Fin-coil heat exchanger	A heat exchanger with fins attached along the coil to increase the heat transfer surface area.
Free cooling	A method of cooling a building using low temperature outside air, rather than mechanical refrigeration.
Heat pipe	A heat exchanger that transfers heat between two surfaces, by means of the phase change of a volatile fluid. The liquid phase absorbs heat, and is converted to the vapour phase, at the first surface. At the second surface, the fluid condenses and rejects the heat.
Hot deck	In a multi-zone, constant air volume HVAC system, a hot water or steam coil that provides hot supply air.
Infiltration	Outdoor air that leaks into a building through cracks and openings.
Once-through air conditioning system	A specialized air-conditioning system often used in hospital operating rooms. It supplies only outside air, and exhausts all the return air.
Outside air (OA)	Unconditioned air brought into an HVAC system directly from the outdoors.
Radiator	A device, often made of cast iron, and used to radiate heat to the surrounding air.
Rate of heat flow	See <i>thermal transmission</i> .



Term	Definition
Runaround system	A heat exchange recovery system consisting of two fin-tube heat exchangers coupled by a circulation system, through which a heat transfer fluid is pumped. When used in an HVAC system, the fluid accepts heat from exhaust air and rejects heat to outside air.
Thermal conductance (C)	The thermal heat flow through a unit area of a non-uniform, composite material when a unit average temperature difference is established between the surfaces.
Thermal conductivity (λ)	The thermal heat flow, by conduction only, through a unit thickness of a single uniform material.
Thermal resistance (R)	The inverse (reciprocal) of thermal conductance.
Thermal resistivity (R)	The reciprocal of thermal conductivity.
Thermal transmission (W) (Rate of heat flow)	The quantity of heat flow from all mechanisms, per unit time, under the conditions prevailing at that time.
Thermal wheel	A circular honeycomb matrix of heat-absorbing material that slowly rotates within the supply and exhaust air streams of an air-handling system. As the thermal wheel rotates, heat is picked up from the exhaust air stream in one half of the rotation, and released to the supply stream in the other half of the rotation.
U-factor	The inverse or reciprocal of thermal transmittance.
Unit heater	A heater with electric resistance, steam, or hot water heating elements that heat air using forced convection.
Upfeed system (HVAC)	A hot water heating system installed below the system main, which feeds vertical lengths of piping from below.
Variable air volume (VAV)	An HVAC system that varies the flow of constant temperature air to achieve set point.
VAV	See <i>variable air volume (VAV)</i> .

