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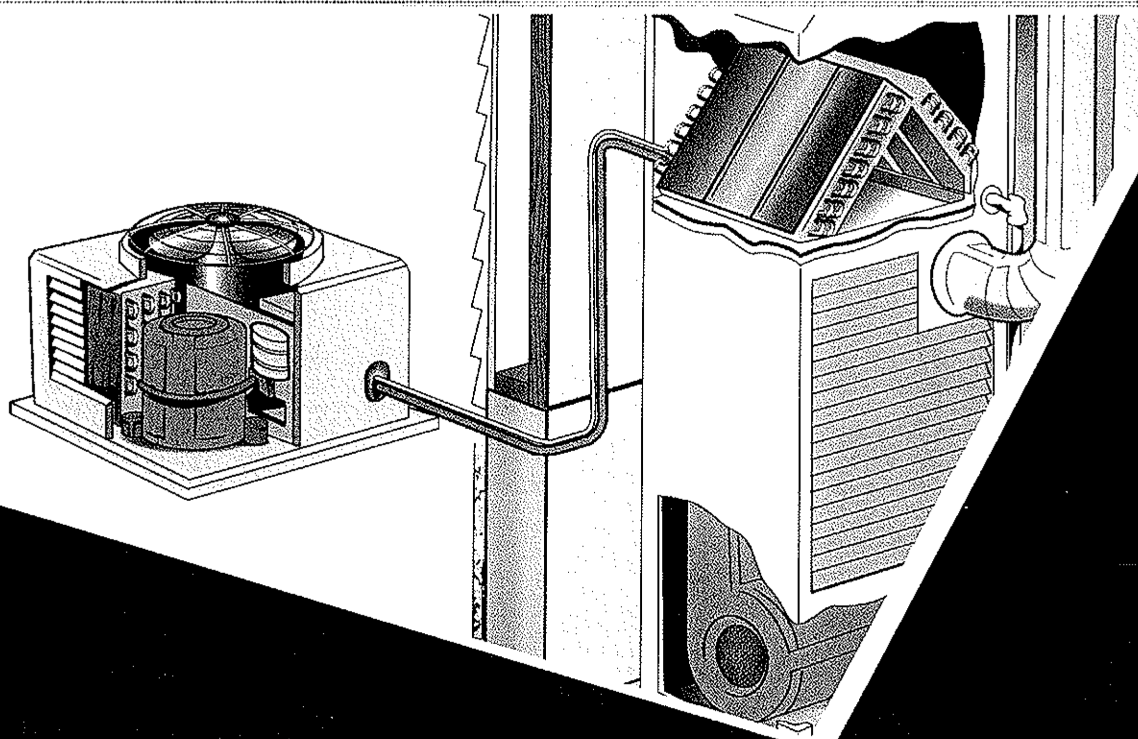
Specialty Products

Introduction to HVACR©



BOOK #10

CERTIFICATE COURSE

FIRST EDITION

ProductPro®

The Standard in Product Knowledge Solutions

Specialty Products

Introduction to HVACR©

from the

American Supply Association Education Foundation

Introduction to HVACR© provides warehouse, counter, and sales personnel with an overview of the operation and components of residential and small commercial HVACR systems. It is ***NOT*** *intended to provide the kind of complex, technical data, which would enable employees to plan or install HVACR systems. This course includes definitions of common industry terms, descriptions of the components and functions of residential and small commercial systems, and other information that will help employees serve their customers more effectively when they come to purchase HVACR products.*

THIS COURSE INCLUDES AN ONLINE FINAL EXAM
This course is limited to a single user. When you are ready to take the final exam to earn your Certificate of Completion, please contact ASA at info@asa.net. ASA staff will contact you about how to register for the final exam.

ProductPro®

The Standard in Product Knowledge Solutions

 FIRST EDITION.

HEADQUARTERS

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Welcome to the *ProductPro® Product Knowledge Training* series!

The Plumbing-Heating-Cooling-Piping (PHCP) and Industrial Pipe, Valves, and Fittings (PVF) industry is an important business channel. The products we sell keep people healthy, comfortable, and productive. However, very few people understand the products we distribute and how much they contribute to our nation's health and economic welfare. Although many people seldom think about industrial pipe, valves, and fittings, they play an important part in the quality of people's lives. Without modern industrial systems, our lives would be far less comfortable than they are today. Consider for a moment that plumbing systems protect health, industrial PVF systems keep cities and industries working, heating and cooling systems increase productivity, and refrigeration promotes health, safety, and enjoyment.

In the United States, there are thousands PHCP/ Industrial PVF wholesaler-distributor locations that generate billions of dollars in wholesale sales. It is an exciting and very competitive industry, and managing a successful company requires cooperative efforts from educated and motivated employees. To sell products in a highly competitive atmosphere, it is crucial that all employees understand the products their company sells. Employees must be knowledgeable enough to provide customers with the products they need to keep their operations running smoothly.

Your company may also expect you to be familiar with heating, ventilation, air conditioning, and refrigeration (HVACR) systems, which handle air quality, temperature control, humidity regulation, heating, refrigeration, and other aspects of climate control within buildings. Like plumbing systems, the manufacturing, installation, and operation of these heating, ventilating, and cooling systems are based on codes, engineering, and science. All the parts needed for these systems must be organized and collected by highly professional wholesale distributors so they can be made available to installation professionals on demand and installed as needed. The wholesaler-distributor plays a critical role in making sure that the components from many manufacturers are available in one place, on demand for a complete and flawless installation.

What you will learn from this training

This *ProductPro®* course is designed to give you an overview of the HVACR industry and its products. HVACR systems comprise a complex network of mechanical and electronic parts such as fans, ducts, pipes, thermostats, and switches. These systems handle air quality, temperature control, humidity regulation, heating, refrigeration, and other aspects of climate control within buildings. Without this climate control, life would be very difficult. Skilled professionals, called HVACR technicians, install and maintain the HVACR systems found in a variety of structures such as residences, commercial and office buildings, schools, and hospitals.

When you look around your company's warehouse, you see heating, ventilation, air conditioning, and refrigeration parts that contractors and others assemble into comfort systems—systems that keep us warm in the winter and cool in the summer. Some of the products discussed in this course may not be part of your company's current inventory, and some of your company's products may not be discussed in this course. To do your job well, it is important that you also learn the details about specific items stocked by your company. Be certain to spend time studying manufacturers' catalogs and materials in addition to completing this course.

How the course is organized

This *ProductPro®* course is divided into five separate chapters, each with instructional text and a review quiz that you will correct yourself using the key provided at the end of the chapter. Advanced information is included in the Digging Deeper sections for students who want more information. The material in the Digging Deeper sections will not be tested. A glossary of common HVACR terms is included so you can look up terms that are unfamiliar to you. Understanding these terms will help you to develop the vocabulary needed to enhance your ability to communicate well with your customers and colleagues. The glossary terms are also highlighted in the text.

After you understand the basic concepts presented, know the important facts, and can confidently answer the questions correctly on all the quizzes, you are ready to take the final exam.

This course is limited to a single user and includes an online final exam.

The exam has 50 multiple-choice questions, which are graded automatically. When taking the final exam, keep in mind that there is only one correct answer per question.

When you are ready to take the final exam to earn your Certificate of Completion, please email ASA at info@asa.net. ASA staff will contact you with information about how to register for and take the final exam.

Seven simple hints for successful course completion

1. **Read the learning objectives**
   Read the learning objectives at the beginning of each chapter. They will tell you what you should know when you complete the chapter. Go back after you read the chapter and ask yourself whether you are confident in your command of the material. If you are not, re-read anything that you did not understand.
2. **Search for the important ideas**
   Use a highlighter or a pen to highlight or underline the most important points as you read. Think about how each idea relates to the rest of the chapter. Write notes in the book margins about points you don't understand or about how the material you read applies to your own company.
3. **Ask questions**
   Ask your supervisor or mentor about any point you do not understand. Particular questions you'll want to ask include whether the products you are studying are carried by your company, how well they sell, and how important they are in your company's overall inventory.
4. **Apply what you are learning to your job**
   Always think about what you have just read or learned. Compare your company's products to the products you have read about in the book.
5. **Pace yourself in your studying**
   Don't try to complete the course all at once. You will remember what you learn more effectively if you make sure you understand each chapter thoroughly before you more on to the next. Take some time to "plug in" what you have just studied before acquiring more new information.
6. **Be proud of what you have accomplished**
   When you successfully complete the course, be sure to download, print, and proudly display your Certificate of Completion. You earned it!
7. **Commit to learning something new every day**
   This course is just one step in developing your professional knowledge and your career skills. Read industry trade journals, study the manufacturers' literature, and attend any training the manufacturers offer. Listen to what company and industry experts say. Enthusiastically take any additional training your company offers!

Visit the ASA Education Foundation website at www.asa.net regularly to find out about other learning opportunities to advance your career.

Acknowledgements

Developing new editions of the *ProductPro®* product knowledge training courses is an ambitious undertaking. During the creation and revision of this course, many individuals shared their expertise, input, and resources to significantly improve the interest and energy in the *ProductPro®* courses.

We are grateful to Mike Feutz, Associate Professor at Ferris State University and HVACR Department Chair, who acted as the primary author of this course and created a course that is accurate, relevant, and consistent with the *ProductPro®* brand. Professor Feutz was named the 2008 and 2010 Mechanical Contractors Association of America, Inc. Educator of the Year.

Special thanks to the reviewers from APR Supply, Coburn Supply Company, Inc., The Gemaire Group, Nord Consulting, and Southern Pipe & Supply Company, Inc. who thoroughly and diligently reviewed the course text, quizzes, illustrations, and final exam to ensure accurate and highly readable information. Their expertise and experience ensure that the content demonstrates a high level of real world application that immediately can be put to use in employees' day-to-day duties.

The ASA Education Foundation expresses its very special gratitude to the visionaries who established and led the charge to develop the Karl E. Neupert Endowment Fund. Contributions that established the Fund were provided by hundreds of manufacturers, wholesalers, and individuals who recognized the need for a permanent endowment fund that would ensure the ASA Education Foundation's ability to provide programs needed by the industry in perpetuity. Their generous contributions continue to make a major impact on the education and training opportunities available to the industry. We are deeply grateful for their commitment.

Good Luck. Good Learning. Have Fun.

– The ASA Education Foundation

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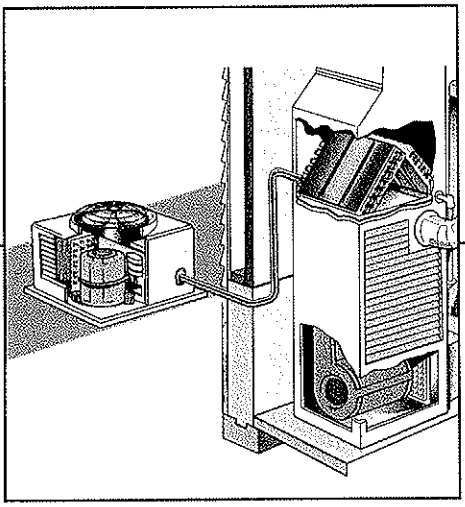
1 OVERVIEW OF HVACR

LEARNING OBJECTIVES

After successfully completing this chapter, you will be able to:

1. Define common HVACR terms.
2. Compare and contrast heat transfer by conduction, convection, and radiation.
3. Explain how power, energy, and heat are related.
4. Discuss the importance of HVAC load calculations, including factors that influence HVAC load.
5. Explain how temperature differs from heat.
6. Compare and contrast specific heat, sensible heat, and latent heat.
7. Explain how temperature and pressure affect heating and cooling applications.



HVACR Systems

In this course, you will learn some basic information about heating, ventilating, air conditioning, and refrigeration systems (commonly referred to by the acronym **HVACR**), which handle air quality, temperature control, humidity regulation, heating, refrigeration, and other aspects of climate control within buildings in a repetitive cycle. Secondary responsibilities are to provide clean, filtered air through these systems and exhaust contaminated air to maintain the quality of the indoor environment. Like plumbing systems, the manufacturing, installation, and operation of heating, ventilating, and cooling systems are based on codes, engineering, and science.

Heating, ventilation, and air conditioning functions—the "HVAC" part of the acronym—are responsible for human comfort inside buildings. In modern homes and other buildings, these functions are often combined into one system. HVAC systems provide thermal comfort during cold winter months. Warmed or cooled or dehumidified air flows through a series of tubes—called **DUCTS**—distributed throughout a building. Fresh air brought in by ventilation systems provides acceptable indoor air quality and minimizes adverse health effects. Air conditioning provides cooling during hot summer months by using refrigeration to chill indoor air. Air conditioners use a fixed supply of refrigerant in closed coils continuously circulating, evaporating, and condensing. Then a fan is used to move the warm interior air over these cold, refrigerant-filled coils to chill the indoor air. Refrigeration (the "R" part of the acronym) uses a technology similar to air conditioning to keep our food and some manufacturing processes cool. Together, HVACR systems are what keep people warm in the winter and cool in the summer, provides fresh air for them to breath, and allows them to store food and beverages for long periods.

Before we discuss HVACR systems and components, let's review a few basic concepts. These concepts are the fundamental building blocks for understanding of HVACR systems. You will see these terms and concepts used throughout this course.

Comfort Heating Principles

The **LAW OF CONSERVATION OF ENERGY** is one of the basic laws of nature. It is a technical way to say that we cannot create or destroy energy. However, we can *move* it from one place to another and we can *change* it from one form to another. Another law of nature is that heat always flows from a warmer body to a cooler one. The reverse is **NEVER** true. Comfort heating began when cave dwellers discovered that they felt more comfortable if they slept close to a fire on a cool night. A **COMFORT HEATING SYSTEM** is a system designed to maintain indoor living area temperatures at levels that allow the heat loss from the human body to occur at comfortable rates.

The human body is a warm body, a heat source. The food we eat turns into the energy to keep our bodies operating and the heat to keep our bodies warm. Our "normal" body temperature is assumed to be 98.6° Fahrenheit (98.6°F), although your own body's normal temperature may vary slightly from that figure. A body temperature significantly above or below the normal 98.6° may indicate abnormal conditions in your body. Through the centuries, human beings have learned to use clothing and various heat sources to help us keep our body temperature stable and in the normal range. However, our bodies are subject to the same laws of nature as all other objects. Our bodies lose heat to our cooler surroundings. This is normal and necessary so that our bodies do not overheat. If we lose heat faster than our bodies produce the heat, we "feel cold" and uncomfortable. Our bodies tell us we are getting too cold to operate properly.

Conversely, if our surroundings are warmer than our bodies, we do not give off enough heat, and we feel too warm. Humidity in the air and air movement also determine how we feel. Under normal conditions, when our bodies become too warm, they perspire: they give off heat. If the perspiration evaporates off the skin quickly, the perspiration is not visible. This may occur, for example, in hot, dry climates.

But if the surrounding humidity is too high, perspiration will evaporate too slowly, or not at all, and we feel hot, sweaty, and uncomfortable. If there is excessive movement of air ("wind" or a "draft") around our bodies, the perspiration will evaporate too quickly, and we will feel cold. Human beings have learned how to create a living environment that allows us to lose body heat gradually, at a rate that we don't notice, so we don't "feel cold."

HVACR Systems Transform, Transfer, and Transport Energy

HVACR systems are designed to transform energy from one form to another, transfer it from one substance to another, and transport it from one place to another.

In a heating system, energy stored in natural gas (chemical potential energy) is transformed to heat (thermal energy) during combustion (a chemical process) and transferred through the walls of the combustion chamber to the air flowing through the furnace. The thermal energy in the warm air is then transported through the duct system to be distributed throughout the house, where the energy is once again transferred from the warm air to the cooler room.

In a cooling system, electrical energy is transformed into mechanical energy needed to drive the compressor and move refrigerant through an air conditioning system. In the cooling coil, heat energy is transferred from the warm house to the cool refrigerant through the walls of the copper tubing in the coil. That heat energy is transported to the compressor through the refrigerant lines. When the refrigerant gets to the compressor, it gets heated when the compressor's mechanical energy is transformed to thermal energy through the heat of compression. After the compressor heats the refrigerant, the hot refrigerant is transported through the refrigerant lines to another coil called the condenser. This coil sits outside the home, where heat from the hot refrigerant is transferred through the walls of the copper to the outside air.

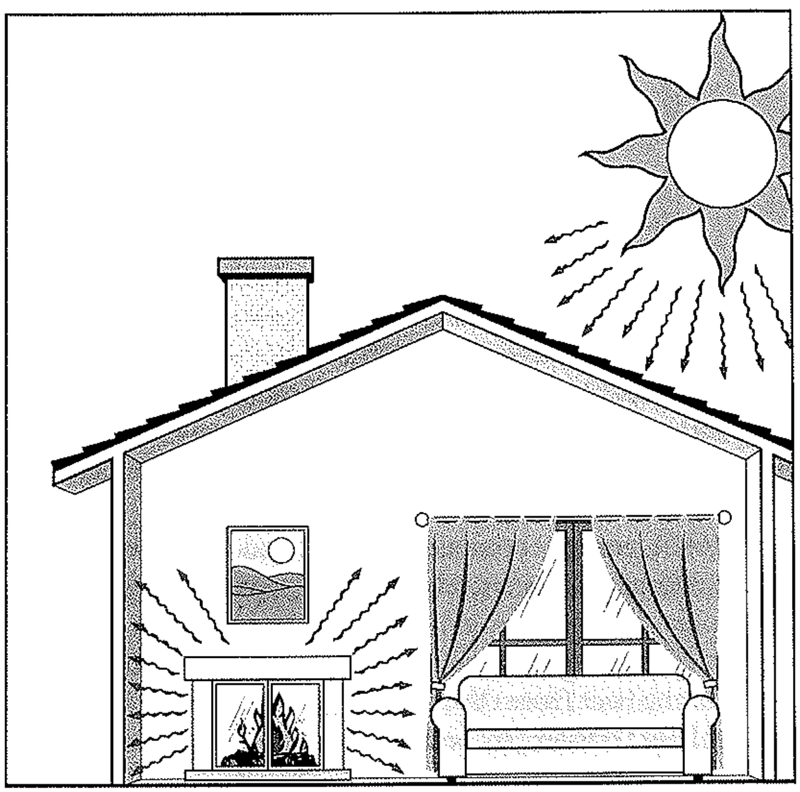
Sources of Heat Transfer

The Kinetic Molecular Theory of Matter provides an explanation of many characteristics of matter, including how heat works and why materials change from solid to liquid to gas. This theory states that all matter (solid, liquid, and gas) consists of tiny particles called atoms that are joined to form **MOLECULES**. These particles are constantly moving and bouncing off each other like billiard balls. The motion of molecules is responsible for the phenomenon of heat.

The term "heat" can have a number of meanings, including temperature. According to the *American Heritage Dictionary®*, when used as a physics term, **HEAT** is "a form of energy associated with the motion of atoms or molecules and capable of being transmitted through solid and fluid media by conduction, through fluid media by convection, and through empty space by radiation." In other words, the faster the molecules are moving, the higher the temperature.

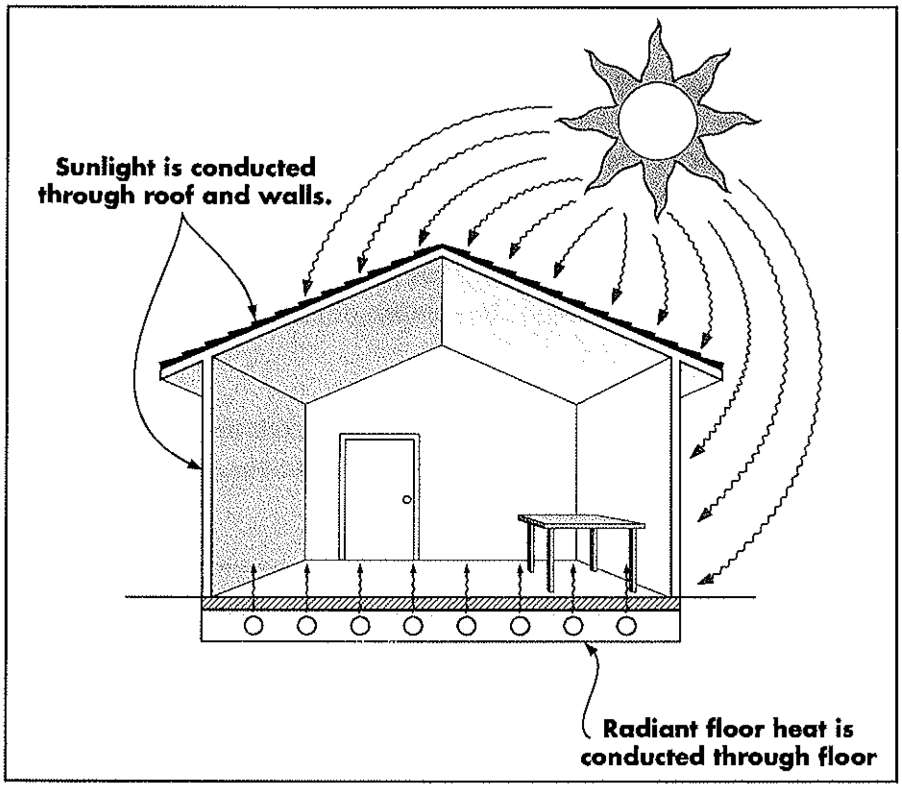
Cave dwellers learned to use both the sun and fire as sources of heat and comfort. By creating holes in the ceiling of their caves, they created a very primitive type of comfort heating system.

HOUSE HEATED BY RADIATION



Fire transfers heat by means of heat rays (or heat waves) through a process called **RADIATION**, which is heat transfer without the use of molecules. Energy from the sun reaches earth by radiation; there are no molecules in space to transfer energy by conduction or convection. Any warm object will radiate energy to cooler objects. In HVACR, energy is transferred by radiation using radiators, radiant heaters, and in-floor radiant heating. Radiant cooling is also possible.

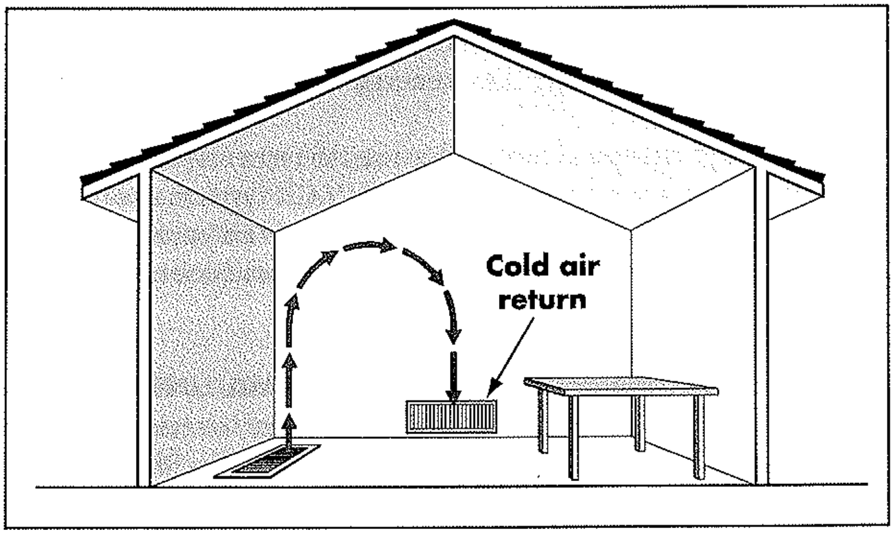
HOUSE HEATED BY CONDUCTION



CONDUCTION is heat transfer from molecule to molecule. Conduction takes place in anything that has molecules. Remember that molecules are constantly moving. You might think of them as bumper cars. When they touch each other, heat is transferred: the closer the molecules, the better the conduction. Molecules are closest to each other in solids, so conduction works best in solids. Molecules are not as close in liquids, so conduction does not work as well. Molecules in gasses are spaced far apart, and conduction works poorly.

In HVACR, energy is transferred by conduction through the walls of heat exchangers and buildings. Conducted heat is not transferred instantly. It takes some time for each molecule to be heated and to transfer the heat to adjoining molecules. The roof and the walls of a house will conduct the heat of the sun into the house in the summer or will conduct the heat from the inside to the outside in the winter. We insulate our houses to control heat transfer by conduction and convection.

HOUSE HEATED BY CONVECTION



CONVECTION is the transfer of heat by circulation of the molecules in the material that is heated. Rather than molecules passing heat energy from one another, energy is carried along with the molecule. It may help to think that energy is "hitching a ride" on a molecule as it moves from one place to another. In HVACR, energy is transferred by convection when air is heated or cooled by furnaces and air conditioners and distributed throughout a building by a duct system. Boilers that circulate steam or hot water, and chillers that circulate chilled water also transfer energy by convection.

Understanding Power and Energy

The terms "power" and "energy" are often confused. Perhaps the simplest method to tell the difference between the two terms is to think of power as a *rate* and energy as a *quantity*. In physics, **POWER** is the rate at which energy is transferred, used, or transformed. **ENERGY** is the capacity of a physical system to perform **WORK**. In plumbing systems, power is measured in **POUNDS PER SQUARE INCH (psi)** while energy is measured in **GALLONS PER MINUTE (gpm)**.

Energy has many forms. **POTENTIAL ENERGY** is energy at rest, while **KINETIC ENERGY** is energy in motion. When you stretch a rubber band, the rubber band has potential energy. If you were to shoot the rubber band into the air, the potential energy is converted to kinetic energy. In another example, the water in a closed faucet has potential energy, and when the faucet is opened, the water has kinetic energy.

When energy is used to physically move something, we say that *work* has been done. How much is moved and how fast it is moved defines *power*. For example, one horsepower is the power required to move 550 pounds one foot in one second. If we want to move something, we must transfer energy. This is energy transfer due to mechanical work.

Another type of energy transfer is heat and we use the term *heat* to describe thermal energy. We'll compare heat to temperature later. HVACR systems use both types of energy transfer, though the focus is mainly on heat. Fans and pumps do mechanical work to move air and water, while furnaces, boilers, and air conditioners heat and cool by transferring thermal energy.

HVACR systems measure energy using **BRITISH THERMAL UNITS (Btu)**, a standard unit of energy, which is the exact amount of heat necessary to raise the temperature of one pound (1 lb) of water by one degree Fahrenheit (1°F). One Btu is approximately the amount of heat created when a kitchen match is burned. It takes one Btu to raise the temperature of 1 lb water from 71° to 72°F.

The Btu is a unit of energy. It is a *quantity*. By itself, a quantity of energy doesn't mean much in HVACR. But when we add the factor of time, we have a measurement of power that means something. For example, during the winter, energy leaks out through the walls of a home. A furnace or boiler adds energy back into the home to match the rate of heat loss. If we said that a home has a heat loss of 100,000 Btu, that is like saying a boat leaks ten gallons of water. Both are meaningless unless we say how quickly they are leaking.

Does the house lose 100,000 Btu every minute or every winter? In HVACR, the *rate* of heat is used to describe how much heat is lost in a building during the winter, and how much heat is gained during the summer. When a home has a heat loss of 100,000 Btu *per hour*, a furnace can be specified to provide 100,000 Btu of heat *per hour* to make up for it. So it makes much more sense to use **BRITISH THERMAL UNITS PER HOUR (Btu/h)**, which is a measurement for the number of Btu delivered by the equipment in one hour. Btu/h is also used for sizing the capacity of a piece of heating or cooling equipment,

For electrical energy, the kWh is a measure of kilowatts (kW) used times the hours of use. Here is an example. Say we turned on ten 100 watt light bulbs and left them on for 20 hours. Our *rate* of using electricity would be:

Ten light bulbs x 100 watts per light bulb = 1000 watts. (1000 watts = 1 kW)

The *quantity* of electricity used would be:

20 hours x 1 kW = 20 kWh

In HVACR, a Btu/h is different from a kWh. Where kWh is kilowatt (kW) *times* hours, a Btu/h measures Btu *per* hour. Just as miles per hour (mph) tells how fast a car is going, Btu/h tells us how fast we are transferring thermal energy.

The following table provides a comparison between power and energy measurements in plumbing, electrical, and HVACR systems.

POWER AND ENERGY

Unit Comparison		
	Energy (Quantity)	Power (Rate)
Plumbing	psi	gpm
Electrical	kW	kWh
HVAC	Btu	Btu/h

HVAC Load Calculations

In both commercial and residential HVAC systems, the capacity of the system must be equal to a building's total heat loss (in winter) or gain (in summer) in order to maintain a comfortable environment inside. The design of an HVAC system begins with calculating heating and cooling **LOADS**, or the rate of heat transfer, which is typically accomplished by designers with software programs. A specific amount of heat must be constantly removed or added in order to maintain the desired indoor temperature. During the hot summer, the **PEAK COOLING LOAD** is the amount of heat that must be removed in an hour to maintain a comfortable room temperature. The cooling load unit is either Btu/h or watts. During the winter, the **PEAK HEATING LOAD** is the amount of heat that must be added over an hour's time to keep the space warm. The heating load is measured in Btu/h.

DESIGN LOAD in an HVAC system is calculated for the maximum heat loss that a building will experience in the winter and the maximum heat gain that a building will experience in the summer.

Design load uses weather information provided by the National Weather Service as one of many factors that influence HVAC load. The National Weather Service has been measuring weather conditions at airports and cities throughout the United States for more than 50 years. With this information, we have a good idea how cold it will get on the coldest day of the year in any part of the country. And we have a good idea how hot and humid it will get during the summer.

For heating, the term "design load" expresses the total predicted heat loss on the coldest day of the year for a particular building design in a particular climate. For cooling, design load must account for more than the outside temperature. It must also account for heat from the sun. In most parts of the country, cooling systems must also remove humidity from the air. Getting rid of the humidity (or dehumidifying) adds significantly to the load of an air conditioning system. And there are many sources of heat and humidity inside the building that air conditioning systems must eliminate as well. Because of all these factors, the design load for cooling *may or may not* occur on the hottest day of the year.

In the table below, you can see how heating loads are reduced by many of the factors that increase the load on a cooling system.

FACTORS THAT INFLUENCE HVAC LOAD

FACTORS	HEATING		COOLING	
	Increases Load	Decreases Load	Increases Load	Decreases Load
External Loads (from outside the building)				
Outside Temperature	X		X	
Infiltration	X		X	
Ventilation	X		X	
Solar Gain		X	X	
Internal Loads (from inside the building)				
Radiant Heat Gain		X	X	
Heat from Occupants		X	X	
Heat from Lighting		X	X	
Heat from Equipment		X	X	
Heat from Process		X	X	
Humidity from People		X	X	
Humidity from Process		X	X	
Atmospheric Humidity		X	X	

In order to determine design load, designers perform load calculations on buildings to determine how much heat is gained or lost due to conduction, convection, and radiation. For cooling loads, additional heat gain due to internal loads must also be calculated.

In the *Factors that Influence HVAC Load* above, you probably noticed that every factor increases cooling loads, but only three increase heating load. Only the factors that increase load are included in load calculations. This is because, for heating, the internal loads *help* the heating system by adding heat to the building. Remember, equipment is selected for the worst-case scenario, so in the middle of the night when no one is in a commercial building and all the lights and equipment are turned off, the heating equipment has to be large enough to offset the entire heating load by itself. On the other hand, when you consider cooling equipment, it must be sized to handle the load during the day when the sun shining, when it is hot and humid outside, and when the building has its maximum occupancy with all the lights and equipment turned on.

Before an HVAC system can be designed, the conductive, convective, radiant, and internal loads must be calculated. Let's briefly look at each of these loads.

Conduction is heat transferred through the **BUILDING ENVELOPE**, which consists of everything that separates the inside of the building from the outside: walls, doors, windows, roof, and slab. The term for heat gained or lost through the building envelope is **CONDUCTIVE LOAD**. How much heat is lost or gained depends on several conditions.

1. The greater the temperature difference (or "TD") between the inside of the building and outdoors, the greater the heat gain or loss. In engineering circles, a difference is referred to as a "delta." It is also common to call temperature difference "Delta T," for difference in temperature. The Greek letter for our letter "d" is called "Delta" and is symbolized with a small triangle (Δ). You will often see Delta T written as "Δt."
2. The materials used in the construction of the building, including insulation, and the R-value of those materials affect heat gain and loss. **R-VALUE** is a measure of insulation's ability to resist heat traveling through it. The higher the R-value, the less heat will be gained or lost.
3. In general, the **SURFACE AREA** is the sum of all the areas of all the shapes that cover the surface of the object. The greater the surface area exposed to the outdoors, the greater the heat gain or loss will be.
4. Finally, the higher the **WIND SPEED**, which is the rate of motion of air, the more heat gain or loss will be.

When air leaks into or out of a building it is referred to as **INFILTRATION**. When we bring in fresh air using a fan, we call that **VENTILATION**. When air enters or leaves a building by either ventilation or infiltration, energy is carried along with it. We call this heat gain or loss the **CONVECTIVE LOAD**.

When the sun heats buildings, we say that the building experiences **SOLAR GAIN**. Energy from the sun arrives by radiation, and this energy must be accounted for with a **RADIATION LOAD CALCULATION**.

INTERNAL LOADS are sources of heat (and humidity) inside the building. People are an internal load. An average adult in a resting position adds about 350 Btu/h. Each light bulb, coffee pot, computer, motor, and any other device that consumes electricity adds heat to a building.

Once conductive, convective, radiant, and internal loads have all been added up, the designer selects heating and cooling equipment that matches or slightly exceeds the total. As you might suspect, load calculations are very complex. This course will not teach you to conduct load calculations, but you need to know about them so you can understand why a particular sized unit is ordered.

Heat and Temperature Relationship

Remember that the motion of molecules is responsible for the phenomenon of heat. The hotter it becomes, the faster the particles move; the colder it is, the slower they move. In fact, at absolute zero (-460°F), particle motion stops. At absolute zero, there is no temperature and there is no heat. Higher temperature is caused by adding energy (heat), while lower temperature is caused by removing heat. It is not possible to cool below absolute zero.

TEMPERATURE is a measure of hot and cold. It is a measurement of *heat intensity*, not *heat quantity*. For example, if you leave a glass of water in a room long enough for it to reach room temperature, both the water in the glass and the air in the room will have the same heat intensity (temperature). But they will not have the same heat *quantity*. Later in this chapter, you will learn that different substances (such as water and air) require different amounts of heat to change their temperature.

When you heat a solid, its molecular particles move faster and faster until they reach melting point and becomes a liquid. The speed of particles in a liquid is higher than in a solid, and of course, the temperature of a liquid is higher than a solid. Because additional heat is needed to melt the solid, the liquid has both a higher temperature and more energy (heat). If you continue to add heat to the liquid, its molecular particles will move faster and faster and faster until it reaches the point where it will boil (vaporize) and become a gas. Particle speed (temperature) and energy content (heat) is higher in a vapor than in a liquid.

The speed of atomic particles may not mean much to you, but temperature scales do, and you can measure temperature using a thermometer. Higher thermometer readings indicate more energy, but they don't tell us how much. Remember the glass of water we discussed earlier? Both the water and the room reached the same temperature, but each had a different amount of heat quantity. If we needed to heat or cool both the room and the water, we would need a scale to tell us how much energy must be added or subtracted to do so. Heat is a measure of that energy.

Measurement of HVAC Efficiency

ENTHALPY is a term used to describe the total energy in a system or substance. In HVACR, enthalpy is measured in **BRITISH THERMAL UNITS PER POUND (Btu/lb)**, the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit. With that knowledge, you can calculate how much energy you would need to heat or cool any quantity of water by any number of degrees.

Specific Heat

Because each substance has unique physical properties, it follows that each substance requires a different amount of energy to be heated or cooled. **SPECIFIC HEAT** is a measure of the amount of energy required to warm or cool one pound of a material one degree Fahrenheit. In the United States, this energy is measured Btu. Because one Btu is the amount of energy required to heat one pound of water one degree Fahrenheit, the specific heat of water is one (1) Btu/lb. Each material has its own unique specific heat. For example, ice requires only about 0.5 Btu/lb, while air requires 0.24 Btu/lb.

Digging Deeper

You probably won't need to do these calculations in your job, but we want to show you how easy these calculations really are. If you wanted to know how much energy (in Btu) is needed to heat or cool any substance from one temperature to another you can use this equation:

Energy Needed = lb × temperature difference × specific heat

Let's work through this to raise a 10 lb glass of water 1°F. Just remember that it takes 1 Btu for 1 lb of water and to change 1°F. To start we need to know what the specific heat of the item is. For this example water has a specific heat of 1 Btu, so the equation for the specific heat of water would be:

Energy Needed = lb × temperature difference × 1 Btu

Now let's add the 1°F temperature difference to the equation:

Energy Needed = lb × 1°F temperature difference × 1 Btu

Finally we will add the 10 lb glass of water to the equation:

Energy Needed = 10 lb × temperature difference × 1 Btu

Now calculating the above equation will tell us that it takes 10 Btu to raise the temperature of 10 lb of water 1 degree:

Energy Needed = 10 lb × 1°F temperature difference × 1 Btu = 10 Btu

But what if we had a 12 lb glass of water, and wanted to raise it 10°F, from 60°F to 70°F? First we would change the equation by changing the temperature difference to 10°F.

Energy Needed = 10 lb × 10°F temperature difference × 1 Btu

Then we would change the 10 lb to 12 lb, representing the size difference in the glass of water.

$$Energy\ Needed = 12\ lb \times 10°F\ temperature\ difference \times 1\ Btu$$

This equation would tell us it would take 120 Btu to heat 12 lb of water 10°F.

$$Energy\ Needed = 12\ lb \times 10°F\ temperature\ difference \times 1\ Btu = 120\ Btu$$

Now let's say that both a glass of water and the air are at 82°F, and we needed to cool the room to 72°F. Since we have two objects we will have to do two separate calculations, one for the water and one for the room, and then add the two totals together.

As you will recall the specific heat of water is 1 Btu. So we can start the water calculation like this:

$$Energy\ Needed = lb \times temperature\ difference \times 1\ Btu$$

Now the temperature difference will be 10°F for both the water and the air (82°F - 72°F = 10°F.)

$$Energy\ Needed = lb \times 10°F\ temperature\ difference \times 1\ Btu$$

Assume the glass of water weighs 1 lb, this will make the math easy.

$$Energy\ Needed = 1\ lb \times 10°F\ temperature\ difference \times 1\ Btu$$

After solving, this would give us 10 Btu to lower the temperature of the water 10°F.

$$Energy\ Needed = 1\ lb \times 10°F\ temperature\ difference \times 1\ Btu\ specific\ heat = 10\ Btu$$

Now let's look at how many Btu it would take to lower the air temperature 10°F. It takes one Btu to cool one pound of water one degree Fahrenheit, but it only takes 0.24 Btu to cool one pound of air one degree Fahrenheit. So we would say the specific heat of the air is 0.24 Btu:

$$Energy\ Needed = lb \times temperature\ difference \times 0.24\ Btu\ specific\ heat$$

Remember the temperature difference will be 10°F for both the water and the air (82°F - 72°F = 10°F.)

$$Energy\ Needed = lb \times 10°F\ temperature\ difference \times 0.24\ Btu\ specific\ heat$$

Finally, assume the air in the room weighs 10 lb, so the calculation would be:

$$Energy\ Needed = 10\ lb\ air \times 10°F\ temperature\ difference \times 0.24\ Btu\ specific\ heat$$

The energy we would have to remove from the air would be 24 Btu, calculated as:

Energy Needed = 10 *lb air* × 10°F *temperature difference* × 0.24 *Btu specific heat* = 24 *Btu*

To calculate the total Btu we need to add the amount of energy for the water and the air.

10 *Btu (water)*+24 *Btu (air)* = 34 *Btu (total)*

So the total amount of energy we would have to remove would be 34 Btu.

Sensible and Latent Heat

The term **SENSIBLE HEAT** describes energy that is used to raise or lower temperature. For example, all the energy required to heat a home during the winter is sensible heat. The amount needed depends on how many degrees the home is to be warmed, the specific heat of all the contents in the home (including the air), and the building materials that make up the home. When sensible heat is added or removed, the resulting difference in temperature can be "sensed" using a thermometer.

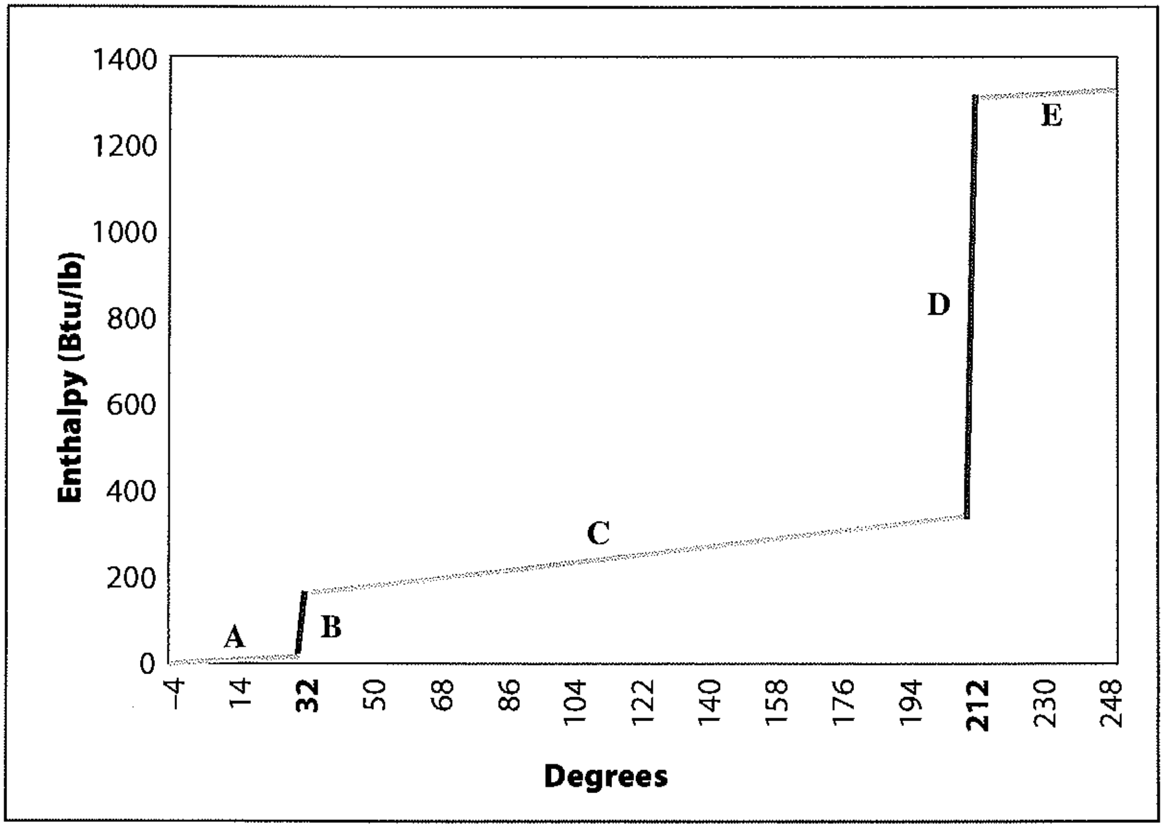
The term **LATENT HEAT** is used to describe energy that is used to change a material's state of matter. The word "latent" is Latin for "hidden," and so latent heat means "hidden heat." We can't sense that heat is being added by using a thermometer because temperature remains the same during a phase change. In terms of using a thermometer, the addition of heat is "hidden" from us. For example, melting ice changes water from a solid to a liquid. Boiling water in a pan changes its state from liquid to vapor. Melting ice and boiling water are both example of latent heat. When water evaporates from a puddle, the energy required to transform it from water to water vapor is another example of latent heat. Where did that water go? It was absorbed by the surrounding air. When that air cools to dew point, that water vapor will condense on the grass as dew. The energy released when the water vapor transformed to liquid as dew is also latent heat.

Consider a pan of water on a stove filled with tap water. When you turn the burner on, the temperature of the water will increase until it reaches boiling temperature. This increase in temperature can be measured (or "sensed") on a thermometer, and so we call that *sensible* heat. Once the water reaches boiling point the temperature no longer changes. It is "locked" on the boiling temperature. As the burner continues to burn, the energy from the flame is used to change water from liquid to vapor (steam). If you were to read a thermometer in a pot of boiling water at sea level, you would read 212°F from the minute the water began to boil until it all boiled away. This is *latent* heat, which is significantly greater than sensible heat for any material. For example, water requires one Btu to raise its temperature 1°F (specific heat of water). That same pound of water requires 144 Btu to be melted from a pound of ice. To boil that same pound of water requires 970 Btu.

Enthalpy of Water

To help you fully understand how sensible heat, latent heat, and specific heat work, look at the following table that describes the enthalpy (total energy) of water.

ENTHALPY OF WATER



A. Specific heat of ice is approximately 0.5 Btu.
B. Latent heat of fusion = 144 Btu
C. Specific heat of water is 1 Btu
D. Latent heat of vaporization = 970 Btu
E. Specific heat of water vapor (steam) is approximately 0.5 Btu

Here's what the graph illustrates.

- ***Lower left corner of the graph: one pound of ice at -4°F.*** The specific heat of ice is approximately 0.5 Btu.
- ***Line A: Sensible heat added to ice.*** For every 0.5 Btu added, the temperature will increase by one degree Fahrenheit. Line "A" ends at 32°F because the ice will melt at 32°F; it cannot be heated above 32°F. (The difference between 32°F and -4°F is 36°F.) At 0.5 Btu per degree, 18 Btu's have been added to heat the ice from -4°F to 32°F.

- *Line B: Latent heat melts ice:* Line "B" illustrates the latent heat of fusion, the energy added to melt one pound of ice. For water, the latent heat of fusion amounts to 144 Btu per pound of water or ice. Remember that latent heat is required whenever there is a change in state. To melt ice, the state is changed from solid to liquid. Once 32°F is reached, the ice will no longer warm. If we add more heat, it will begin to melt. If we add more energy, more ice will melt. If we remove energy, some of the water will freeze again. As long as the temperature is 32°F and there is some water and some ice, the temperature remains at 32°F.
- *Line C: Sensible heat added to water:* Line "C" graphs the energy added to heat water from freezing (32°F) to boiling (212°F). Remember that the specific heat of water is one Btu per pound. (The difference between 212°F and 32°F is 180°F.) We would need to add 180 Btu to heat one pound of water from freezing to boiling.
- *Line D: Latent heat boils water:* Line "D" graphs the energy required to vaporize (boil) one pound of water. Again, this involves a change of state (liquid to vapor), so Line D shows latent heat. For water, 970 Btu/lb is required to boil a single pound. As long as there is a water and steam mixture at 212°F, there can be no change in temperature as energy is added or subtracted. Adding energy will boil more water, while subtracting energy will condense some steam.
- *Line E: Sensible heat added to steam:* Line "E" graphs what happens when energy is added to water vapor (steam) after all water has been boiled. The specific heat of steam is about 0.5 Btu per pound, and so any energy added after boiling will heat the steam above 212°F.

Pressure and Temperature Relationship

In HVACR systems, pressure significantly affects systems in a number of ways. The relationship between temperature and **PRESSURE** plays a factor in both heating and cooling applications. Boiling temperature varies with pressure. For example, water boils at 212°F at sea level (0 psig). **PSIG**, which stands for pounds per square inch gauge, expresses pressure in relation to atmospheric pressure. A tire gauge reads in psig, meaning that pressure inside the tire is compared to the pressure outside of the tire. Pressure cookers cook faster because a lid is placed over a pan of boiling water, causing the pressure inside to rise above atmospheric pressure. There are three common pressures and corresponding boiling temperatures used in pressure cookers. At a pressure of 5 psig, water boils at 220°F; at 10 psig, the boiling point rises to 235°F; and at 15 psig, the boiling point becomes 250°F. In high elevations where the atmospheric pressure is lower, water boils at a lower temperature. For example, water in Denver, which is approximately one mile above sea level, boils at about 202°F.

In boiler systems, pressure determines how much energy water or steam can carry. In a hot water boiler, higher pressure will allow water to reach a temperature above 212°F without boiling. This allows more energy to be added to the water at the boiler for transportation throughout the building. In turn, this enables pipe sizes to be smaller. For the same reason, higher pressures in steam systems require the water to be heated to a higher temperature before it converts to steam. The added energy required to reach a higher boiling point allows each pound of steam to carry more energy. Further, steam compresses with high pressure. This means that one pound of steam takes up less space. When higher pressures are used, smaller pipes can be used because each pound of steam carries more energy and occupies less space.

In air conditioning and refrigeration systems, pressure affects the boiling point of refrigerant. As you will learn in the section on air conditioning and refrigeration, temperatures in refrigerators, freezers, and air conditioners are dependent on pressure. Just like with water and steam, higher pressures in refrigeration systems cause higher boiling points, while lower pressures cause lower boiling points. In basic terms, pressure is adjusted to the point where refrigerant will boil or condense at a temperature sufficient to perform the task it was designed to do.

Refrigeration and air-conditioning equipment is rated in Btu/h or in **TONS**, a unit of measure in the United States equal to 907 kg or 2,000 lb. A ton of cooling is based on the cooling effect due to melting one ton of ice in a 24-hour period. Each pound of ice requires 144 Btu to melt (latent heat of fusion). For a ton, that would be 2000 lb x 144 Btu per lb = 288,000 Btu. In other words, melting one ton of ice in one day would provide 288,000 Btu per day worth of cooling. Equipment is rated by the hour rather than by the day, so when 288,000 Btu per day is divided by 24 hours per day, the result is 12,000 Btu/h. Thus, one ton of cooling is equivalent to 12,000 Btu/h.

Pressure in Duct and Piping Systems

PRESSURE LOSSES occur whenever there is friction or turbulence. In the ducting and piping systems, pressure losses impact fans and pumps, which are designed to not only provide the proper amount of air or water, but to overcome the frictional and turbulent losses caused by the ducting and piping systems. Many components can cause turbulent pressure drops. For example, whenever an elbow is added to change direction, there is a pressure drop. Pressure drops occur whenever there is a change in size caused by transitions and reducers. Dampers and valves are designed to create restrictions to control flow, and this causes pressure drops. Heating and cooling coils add resistance to flow, as do filters, especially dirty ones.

Fans and pumps supply the energy that causes flow in HVACR systems. In a straight run of pipe or duct, the water or air tends to flow nice and straight, but when components are added to the system, the water or air acts just like water in a river and becomes turbulent. Energy that could have been used to move the flow along is now used to push through restrictions and make turns. As a result, either the rate of flow will be reduced or a larger fan or pump will be needed.

Even if the piping or ducting system is straight as an arrow, there will still be pressure losses. Pressure also drops due to friction. The longer a piping or ducting system and the rougher the inside surface, the more frictional losses will occur. If you have ever connected several garden hoses together, you have experienced frictional losses. Even though the water pressure at the faucet is the same, the longer the garden hose, the less water you get.

Velocity, Static, and Total Pressure

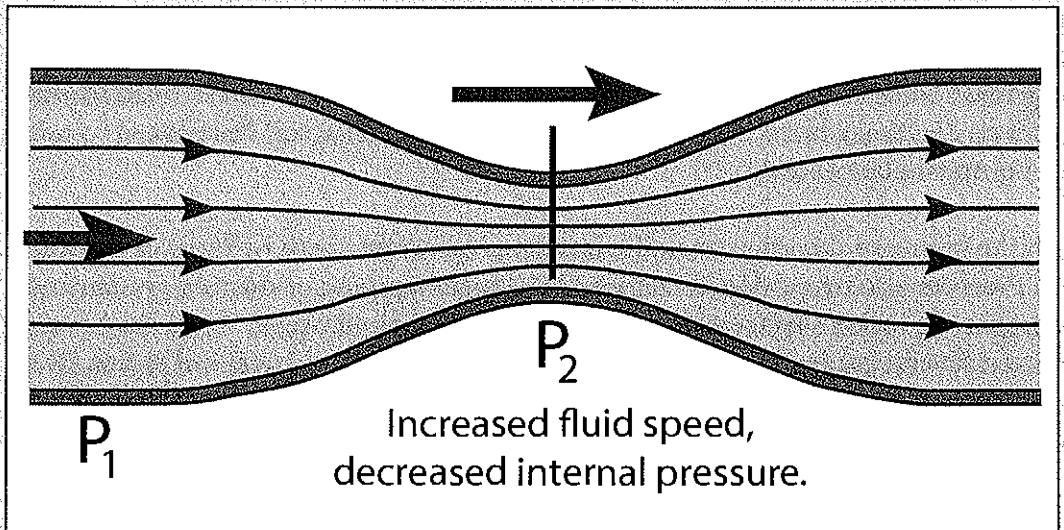
When the wind blows, you can feel **VELOCITY PRESSURE**, which is pressure resulting from some medium in motion, such as the air following the shock front of a blast wave. Air in a balloon has **STATIC PRESSURE**, pressure exerted by a liquid or gas while at rest. The air is under higher pressure than the room around it. Atmospheric pressure and water pressure in a lake or ocean are other examples of static pressure. You can feel the pressure change when your ears pop as you drive up a mountain, fly in an airplane, or dive in the ocean.

You have likely experienced static pressure when you entered or exited a building. When you open a door and air whooshes in or out, that movement is caused by static pressure in the building. If it is higher than atmospheric pressure, air will whoosh out; lower and it will whoosh in. Just as air in a balloon will leak out if you poke a hole in the balloon, air will "leak out" of a building when an opening is created if the pressure inside is higher than outside. In a duct system, there is both static and velocity pressure. Velocity pressure is caused by the air moving through the duct, and static pressure is caused by the frictional and turbulent losses of the system. The sum of static and velocity pressure is **TOTAL PRESSURE**. You won't be asked to size ducting or piping systems in your job, but understanding how pressure acts in these systems can help your communication with your customers.

Digging Deeper

Again, you probably won't need to know the information in this Digging Deeper section to do your job, but we have included the information for those who are interested. Let's take a look at a device called a **VENTURI** to explore velocity, static, and total pressure. You can see a pipe squashed down at the center. We'll make up some numbers to show some pressure relationships in a system like this.

VENTURI



At P1 let's assume a velocity pressure of 2 pounds per square inch (psi) and a static pressure of 0.5 psi. Total pressure would be 2 psi + 0.5 psi = 2.5 psi. Next, let's assume that the area at P2 is exactly half the area at P1. This means that fluid flowing through the venturi would have to flow twice as fast through P2 as P1. Logically, velocity pressure would also double, from 2 psi to 4 psi. Total pressure will gradually drop throughout any system, but the change in total pressure between P1 and P2 would be so small that we'll ignore it for this example. We'll assume that total pressure at both P1 and P2 is the same, and we found that to be 2.5 psi. Since total pressure is the sum of velocity and static pressure, with the total pressure at P2 at 2.5 psi and the velocity pressure at 5 psi, static pressure actually drops below atmospheric pressure (2.5 psi – 4 psi = -1.5 psi). Although this seems odd, a leak in the system at P2 would cause a leak *into* the system because of the negative static pressure.

You can prove this law of physics to yourself with a simple experiment. Take two sheets of paper and hold them close to each other, with one hanging from each hand. Now blow down between them. You would think that the papers would blow apart, but they actually draw together. This is because the higher velocity of the air you are blowing through the paper causes the static pressure to drop, and the room pressure on the other side of the papers pushes them together.

In the next chapter, we will review some basic types of comfort heating systems for residential and small commercial buildings. You will learn about fuels and combustion, ignition devices, control and safety devices commonly used in heating systems.

REVIEW QUIZ OF OVERVIEW TO HVACR

Answers appear on page 26

Quiz Questions:

1. In which direction does heat always move?
   a. From a cooler body to a warmer body
   b. From a warmer body to a cooler body
   c. From the center of a body to the outside of another body
   d. From the outside of one body to the center of another body

2. Typically, most people feel cold when
   a. the temperature falls below 80 degrees.
   b. the inside temperature is more than 30 degrees lower than the outside temperature.
   c. they perspire more than is necessary to cool their body surface.
   d. they lose heat faster than their body can develop it.

3. A heating system which maintains living area temperatures at levels which allow body heat loss at a comfortable rate is called a
   a. comfort heating system.
   b. radiant heating system.
   c. convection heating system.
   d. conduction heating system.

4. Heat transfer by circulation of the molecules in the material (air) being heated is called
   a. radiation.
   b. convection.
   c. conduction.
   d. hydronic.

5. When a warm object touches a cold object, heat is transferred from one molecule to another in the substance being heated. What is this process called?
   a. Radiation
   b. Convection
   c. Conduction
   d. Transmission

REVIEW QUIZ OF OVERVIEW TO HVACR

Answers appear on page 26

6. Heat transfer can occur in all of the following ways EXCEPT
   a. Radiation
   b. Compression
   c. Conduction
   d. Convection

7. Which of the following terms **BEST** describes the rate at which energy is transferred, used, or transformed?
   a. Horsepower
   b. Power
   c. Heat flow
   d. Convection

8. In plumbing systems, how is power measured?
   a. Pounds per square inch (psi)
   b. Gallons per minute (gpm)
   c. Miles per gallon (MPG)
   d. British thermal units per hour (Btu/h)

9. What is the term for the maximum amount of heat a system is designed to handle or the maximum amount of cooling that the system can produce?
   a. Peak cooling load
   b. Design load
   c. Peak heating load
   d. Conductive load

10. All of the following factors decrease HVAC load EXCEPT
    a. Outside temperature
    b. Humidity from people
    c. Heat from equipment
    d. Heat from process

11. All of the following are part of the "building envelope" EXCEPT
    a. Doors
    b. Windows
    c. Roof
    d. Carpet

REVIEW QUIZ OF OVERVIEW TO HVACR

Answers appear on page 26

12. When you are solving a problem in thermodynamics, which of the following terms means "a change in temperature"?
    a. R-value
    b. Delta T
    c. Conductive load
    d. Latent

13. Which of the following terms is used to describe the total energy in a system or substance?
    a. Enthalpy
    b. Specific heat
    c. Sensible heat
    d. Latent heat

14. Specific heat is a measure of the amount of energy required to warm or cool one pound of a material 1 degree Fahrenheit.
    a. True
    b. False

15. Why is it important to understand the enthalpy of a substance such as water?
    a. Too little heat energy may be unsuitable and too much may cause failure.
    b. When water reaches a boiling point, the temperature no longer changes.
    c. Latent heat is significantly lower than sensible heat for any material.
    d. The amount of heat needed depends on how many degrees the water is to be warmed.

16. Which of the following **BEST** describes velocity pressure?
    a. Pressure resulting from some medium in motion, such as the air following the shock front of a blast wave
    b. Pressure exerted by a liquid or gas while at rest
    c. Pressure greater than atmospheric pressure that are measured relative to atmospheric pressure
    d. Pressure less than atmospheric pressure that are measured relative to atmospheric pressure

REVIEW QUIZ OF OVERVIEW TO HVACR

Answers appear on page 26

17. Which of the following terms is pressure resulting from some medium in motion, such as the air following the shock front of a blast wave?
    a. Velocity Pressure
    b. Static Pressure
    c. Total Pressure
    d. Convection Pressure

18. Which of the following is a unit of measurement for HVAC energy?
    a. kW
    b. psi
    c. kWh
    d. Btu

19. In HVACR, which of the following items is used to transfer heat by radiation?
    a. Heat exchangers
    b. Radiant heaters
    c. Chillers
    d. Duct system

20. What is the difference between the terms "power" and "energy"?
    a. Power is the capacity of a physical system to do work; energy is the rate at which work is performed.
    b. Power moves air and water; energy is how that movement is measured.
    c. Power is a rate; energy is a quantity.
    d. Power is a quantity; energy is a rate.

ANSWERS TO REVIEW QUIZ

CHAPTER 1

OVERVIEW OF HVACR

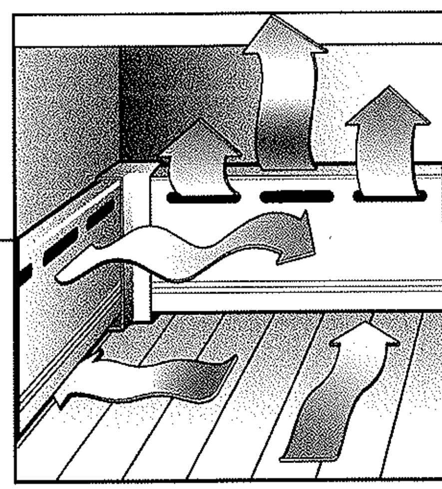
1. b. From a warmer body to a cooler body
2. d. They lose heat faster than their body can develop it.
3. a. comfort heating system
4. b. convection
5. c. Conduction
6. b. Compression
7. b. Power
8. b. Gallons per minute (gpm)
9. a. Peak cooling load
10. a. Outside temperature
11. d. Carpet
12. b. Delta T
13. a. Enthalpy
14. a. True
15. a. Too little heat energy may be unsuitable and too much may cause failure.
16. a. Pressure resulting from some medium in motion, such as the air following the shock front of a blast wave
17. a. Velocity Pressure
18. d. Btu
19. b. Radiant heaters
20. c. Power is a rate; energy is a quantity.

2 INTRODUCTION TO HEATING

LEARNING OBJECTIVES

After successfully completing this chapter, you will be able to:

1. Compare hydronic heating systems to hot air heating systems.
2. Discuss the Annual Fuel Utilization Efficiency (AFUE) and distinguish between standard-efficiency, mid-efficiency, and high-efficiency furnaces.
3. Describe several furnace control and safety devices.
4. Explain how the various types of boilers are used to heat water.
5. Discuss the Department of Energy (DOE) rating program and analyze the DOE's three kinds of ratings: the input rating, the DOE heating capacity, and the net rating.
6. Discuss the four common types of piping systems used in hot water heating systems.



Overview of Heating

You'll recall from Chapter 1 that a *comfort heating system* is a system designed to maintain indoor living area temperatures at levels that allow the heat loss from the human body to occur at comfortable rates. In the later part of the 20th century, we began to think in terms of two basic kinds of comfort heating systems: (1) hydronic heating systems and (2) hot air heating systems.

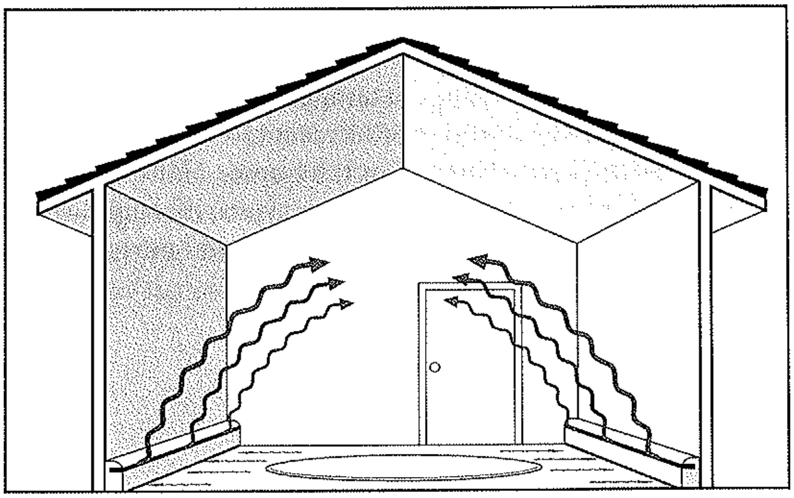
A **HYDRONIC HEATING SYSTEM** is a comfort heating system that uses a fluid (generally water) to transfer the heat to points of use. A traditional hydronic system transfers heat by means of circulating hot water, by use of a pump, through piping systems to points of use and then heats the desired areas by radiation and convection. This is the most commonly used method of transferring heat in residential or commercial buildings.

A **HOT AIR HEATING SYSTEM**, also called a forced air heating system, transfers heat by moving hot air, by use of a blower, through ducts to points of use and then heats the desired areas by convection or by movement of hot air through areas to be heated. There are, however, hybrid approaches that use hot water coils to heat the water but use blowers and ducts to circulate hot air derived from the hot water coils. These hot water-coil/blower systems are not as common as either traditional hot water systems or traditional forced hot air systems but are sometimes used. This course will discuss **ONLY** residential and small commercial systems.

Circle of Warmth

One design principle of residential/small commercial systems is the principle called the "circle of warmth." The circle is created by placing the heat emitters, which actually radiate the heat from the warm water, around the outside of a room or building. This circle of warmth helps to replace the heat lost through the walls, floors, ceilings, doors, and windows.

HOUSE HEATED BY CIRCLE OF WARMTH DESIGN



Advantages of Circle of Warmth Design

The circle of warmth design used in the hot water heating system offers several advantages to the homeowner. One advantage is that the outside walls of the room/building are kept warm, which helps keep the room temperature stable and comfortable, without hot spots or cold surfaces. Because hot water systems depend mostly upon the natural air currents, rather than fan-induced forced air currents, there are fewer drafts, and the heat is more evenly distributed. Because the natural convection currents are less intense than fan-generated forced air currents, the heat feels gentler. Without forced-air ducts to circulate air from room to room, there are no ducts or strong currents to carry dirt, allergens, odors, sounds, smoke or fire throughout the house.

In many cases, hydronic heating is more economical than forced air heat. The pipes that carry the hot water are smaller than air ducts and the hot water system is a closed system. This means that less heat is lost because there are no openings (such as duct seams) for heat to escape. This greater efficiency of delivery is particularly important if the heat source must be located at some distance from the areas to be heated. For this reason, hot water heating systems are very often used for apartment buildings and building complexes such as colleges and government buildings.

Another advantage of having a hot water system is that the system can be adapted to additional uses such as heating water for bathing and dishwashing, heating water for swimming pools, and using hot water coils (with a glycol additive) for melting snow on sidewalks and driveways. In areas where winters are not severe, hot water heating systems sometimes use specially-modified hot water heaters (instead of boilers) to provide hot water for both household use and heating.

With a hot water system, it is relatively easy to provide for the fact that not all the rooms in the house need to be at the same temperature at the same time. Also the temperature of the water can be rather easily raised or lowered to match outside conditions, making cost of heating more easily controlled.

Some buildings use **ZONING**, the practice of heating and cooling areas within a structure separately. By using zoning, the temperature can be varied from area to area according to use. This allows the homeowner to react to variables such as wind and sun to maintain an even comfort level throughout the home. Hot water pipes require less space than air ducts. Pipe can easily be run through closets, through walls, and under floors. When remodeling or adding space, it is easier to add new heat emitters (radiators, baseboard units, etc.) to a hot water system than to construct new ducts for a forced-air system.

Disadvantage of Circle of Warmth Design

One disadvantage of the traditional hot water heating system—which uses piping to carry the water to heat emitters—is that the system is harder to adapt to conventional residential air conditioning because there are no ducts in place. There are ways, however, to use hot water heat with regular ductwork by passing air over hot water coils and using a blower to move the warm air from the coils throughout the house. Sometimes in large complexes or commercial buildings, chilled water is run through the pipes and used for cooling purposes. However, such systems are generally too expensive for residential use.

Overview of Furnaces

A **FURNACE** is a device that combines a hydrocarbon with oxygen from the atmosphere and has some sort of heat source to start combustion. It contains the combustion within a combustion chamber and exchanges most of the heat of combustion with air that flows through the furnace. It vents the harmful exhaust gasses to the outside and keeps them separate from the air flowing through the furnace. A furnace must be capable of repeating this process over many years in a safe and efficient manner.

Fuel oil furnaces (and boilers) are becoming more rare as customers switch to propane or natural gas. The Energy Information Administration of the DOE estimates that only 7.5% of the residential market heats with fuel oil, with nearly 6.5% in the northeast alone. In other words, it is insignificant in the overall heating market and regionalized. Most supply houses will sell products related mostly to natural gas, with liquid petroleum gas second. Therefore, we will not be covering fuel oil furnaces in this course.

Gas furnaces are the predominant heating source in the United States. In warmer climates, you will often see electric furnaces and heat pumps, but the gas furnace is more common nationwide. In this section, you will learn about the fuels used in these devices and how the combustion process releases the heat we need for our homes. You will also learn about the different types of gas furnaces and various components commonly used in them.

Fuels and Combustion

NATURAL GAS and **LIQUID PETROLEUM (LP GAS)** are the two fuels used the most for gas furnaces. Customers with access to a natural gas source will almost surely use natural gas for heating. Since it is supplied to the building in an underground pipe, natural gas is the most convenient fuel available. Customers never have to "fill the tank."

If natural gas is not available, the remaining heat source choices include electricity, fuel oil, or liquid petroleum (LP gas), which is the same thing as propane or bottled gas. Because of its expense compared to other choices, electricity is used seldom in cold climates. Given the choice between fuel oil and propane, most customers choose propane.

Before we begin discussing individual fuels, let's discuss combustion. You will recall that combustion occurs when something burns. In technical terms, **COMBUSTION** is simply a chemical reaction between a fuel and oxygen that produces heat, carbon dioxide (CO2), and water vapor. Note that **CARBON MONOXIDE** is not a normal byproduct of combustion. It is produced when insufficient oxygen is present during the combustion process. Combustion needs only a fuel, oxygen, and heat. You will notice that an ignition source is not required. If fuel and oxygen are present in sufficient quantities and the temperature reaches a point where combustion can occur, a fire will start. We call this **SPONTANEOUS COMBUSTION**. Normally, we keep our fuel/oxygen mixtures at temperatures well below the spontaneous combustion temperatures, and so we have to provide some sort of **IGNITION** (a heat source) to get the fire going.

Digging Deeper

You will not need to know the following for your job, but has been included to help give you in depth knowledge. The fuels we burn are made of hydrogen and carbon, and so we call them **HYDROCARBONS**. Natural gas, propane, fuel oil, and gasoline are all hydrocarbons. Hydrocarbons are compounds made up of carbon and hydrogen atoms. Each hydrocarbon has a unique number of each. Natural gas (methane) has one carbon atom and 4 hydrogen atoms and is designated as CH_4. Propane has 3 carbon atoms and 8 hydrogen atoms. It is designated as C_3H_8.

The oxygen used for combustion in furnaces comes from the atmosphere. Our air is roughly 21% oxygen. Another 78% is nitrogen, and the remaining 1% consists of a number of other gasses.

Natural Gas

The U.S. Energy Information Administration (EIA) reports that 7,893,155,000,000 cubic feet of natural gas was consumed in 2011 for residential and commercial use. That is 7.8 *trillion cubic* feet, bigger than the size of 200 Empire State Buildings. It is the most common fuel in large cities and in many suburbs and even some rural areas. Most of that natural gas is used for space heating, which means it was consumed mostly in furnaces.

Natural gas is roughly 90% methane, which is a naturally occurring gas created from the decay of plants and animals. Often found near crude oil, natural gas is mined from the ground where it is trapped by layers of rock. It has a specific gravity of 0.554, which means that it is lighter than air. If a leak occurs, natural gas will float away if not contained. Natural gas has no color and no odor. A chemical called **METHANETHIOL** is added to give it its unique smell. So when we say we can smell natural gas, we actually smell an artificial odorant that was added so we could smell *something*.

One cubic foot of natural gas contains about 1050 Btu of heat energy. Impurities affect the actual heat content, so you will most often hear that a cubic foot of natural gas contains 1000 Btu. Natural gas is the most economical fuel for heating. It is clean burning, it is convenient, and it is safe because it is lighter than air. The United States has about one fifth of all the natural gas in the world, according to estimates. It is logical that it is the most used fuel for space heating.

LP Gas/Propane

LIQUEFIED PETROLEUM (LP) GAS, a flammable mixture of hydrocarbon gasses used as a fuel in heating appliances and vehicles, is a general term used to describe several liquid mixtures of propene, propane, and butane. Because LP gas used for space heating is mostly propane, the terms LP gas and propane are often used interchangeably. In fact, some suppliers call their product "propane" while others call theirs "LP gas." Still others label themselves as an "LP Gas" company, but call their product "propane."

Whatever you want to call it, propane is the second most common fuel used for space heating. Propane is sold by the gallon rather than the cubic foot, hence the name "liquid petroleum gas." In the atmosphere, propane boils at -44°F, which means it exists as a gas under normal circumstances. Unlike natural gas, propane is not delivered in a pipeline. It must be stored in tanks. When it is pressurized during the storage process, much of it condenses into a liquid. As long as the tank is held under pressure, a portion of the propane will remain liquid. However, the top portion of the tank will always have at least a little bit of gas in it. When the valve on the tank is opened, the pressure in the tank drops and more of the liquid propane converts to gas. Propane is purchased, shipped, and stored as a liquid. But when it is burned, it is burned as a gas. Like natural gas, propane has no color or odor, and includes an odorant so you can smell it.

With a specific gravity of 1.52, propane is about 1 ½ times heavier than air. This means propane will not float away like natural gas. Instead, it will settle to the floor, where it will pool unless it is vented. This creates a safety hazard. You could walk into a room filled with propane up to your knees and not know it because it is below your nose. Older furnaces have pilot lights that are located a couple of feet off the floor. Technicians have safely lit pilot lights with a match only to be badly injured or killed when they threw the burning match on the floor where propane from the extinguished pilot had pooled.

Propane is more expensive than natural gas. It is not as convenient because it must be shipped and stored in tanks and cylinders. This means the customer must keep an eye on the level of propane in the tank and arrange for delivery when the tank is nearing empty. Natural gas customers have an uninterrupted supply via a pipeline. Propane is also more dangerous, since it pools in low areas rather than floating away like natural gas. For these reasons, you will see propane used where there are no natural gas pipelines.

Compared to natural gas, propane has a higher heating value: 2500 Btu per cubic for propane compared to 1000 Btu per cubic foot for natural gas. However, it is more expensive than natural gas, and it is sold by the gallon rather than the cubic foot. One gallon of propane contains about 92,000 Btu of heat energy—roughly 92 times more energy than a cubic foot of natural gas (at 1,000 Btu per cubic foot). However, a gallon of propane cost $2.149 when this book was written in 2013, while 100 cubic feet (ccf) of natural gas cost $0.8049. Note that fuel prices vary greatly throughout the country and throughout the year. Contact your fuel supplier for the most current rates in your area.

At the time of this publication propane was almost three times more expensive than natural gas. Now let's look at how this was calculated. Because the two fuels are not sold using the same units (gallons or ccf), we can't do an apples to apples comparison. The best way to find which fuel is less expensive is to compare the cost per Btu. Unfortunately, this produces a very small number since a Btu is a very small amount of energy. So let's compare the purchase of a million Btus using both natural gas and propane.

One gallon of propane contains 92,000 Btu. To find out how many gallons to purchase to get a million Btu, we would divide one million by 92,000:

$$\frac{1{,}00{,}000\ Btu}{92{,}000,\ Btu\ per\ gallon} = 10.87\ gallons$$

At $2.149 per gallon, the propane would cost:

$$10.87\ gallons \times \$2.149\ per\ gallon = 423.26$$

One ccf of natural gas contains 100,000 Btu (1000 Btu per cubic foot times 100 cubic feet). To find out how many ccf we would need to purchase, we would divide one million by 100,000:

$$\frac{1{,}00{,}000\ Btu}{100{,}000,\ Btu\ per\ ccf} = 10\ ccf$$

At $0.8049 per ccf, the natural gas would cost:

$$10\ ccf \times \$0.8049 \text{ per ccf} = \$8.05$$

Propane, at $23.26 per million Btu, cost almost 3 times more than natural gas, at $8.05 per million Btu.

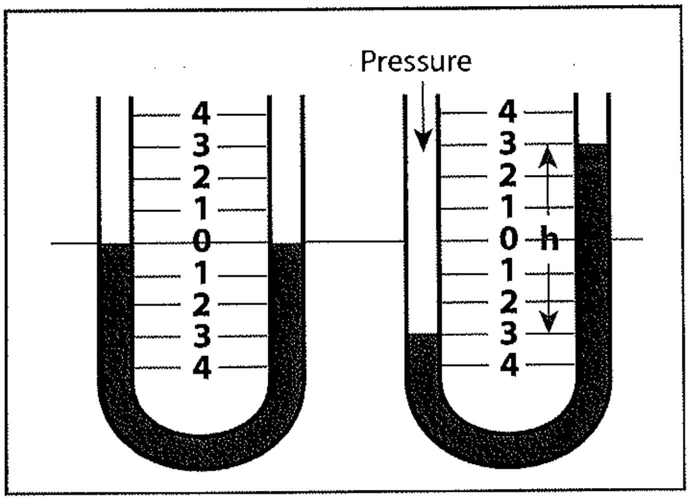
Converting Between Gasses

Gas furnaces are designed to burn either natural gas or propane. A furnace equipped to burn natural gas should not be connected to an LP gas fuel source, and a furnace equipped to burn LP gas should not be connected to a natural gas fuel source. It is important for the customer to purchase a furnace equipped to burn the type of fuel available in the area.

The process to convert furnaces from one gas to another is easy, but care must be taken to make sure it is done properly. An important step is to adjust the **GAS MANIFOLD** pressure for the gas that will be burned. The gas manifold is simply a pipe that is connected to the outlet of the gas valve with evenly spaced holes drilled and tapped for mounting the spuds, and will be discussed in detail later in this chapter. Gas pressure is very low compared to other pressures. For example, an air hose at a gas station is rated in pounds per square inch (psi). The pressure in a gas line is not even one psi and would be impossible to read on a tire gauge.

Gas pressure (and pressure in duct systems) is measured in inches of water column. A **MANOMETER** is an instrument used to measure pressure. In the illustration below, you will see two **U-TUBE MANOMETERS**, glass tubes bent into the shape of the letter "u." The manometer on the left has been partially filled with a liquid, typically with water, and is left open to the atmosphere on both ends. Because atmospheric pressure is equal on both columns of liquid, both columns will have the same height.

MANOMETERS



Look at the manometer on the right and imagine that you are blowing down into the tube where you see the word "pressure." Of course, you would see the column of liquid on the left drop while the column on the right would rise. The difference in height between the two columns, shown by the dimension "h" (at "0" in the manometer) can be measured and recorded. This dimension is called **WATER COLUMN PRESSURE**. If you blew harder, the difference between the columns would be greater. A more accurate digital version of the Manometer is also available and can provide a quicker cleaner measurement than the traditional U tube.

The pressure scale "inches of water column" literally measures the difference in water column heights in a u-tube manometer. The more pressure, the greater the inches of water column.

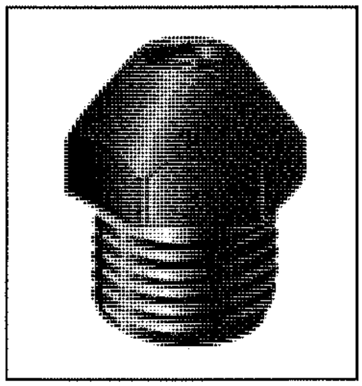
A pressure of one psi will cause the two columns to have a difference of 27.7 inches in height. In other words, one psi is equal to 27.7 **INCHES OF WATER COLUMN (inWC)**.

In a furnace, the **GAS REGULATOR** adjusts the pressure of the gas that feeds the gas valve. The most common setting for natural gas is 3.5 inWC for high fire, and 1.7 inWC for low fire, while the most common settings for propane (LP gas) range from 10 to 11 inWC. You can see that both pressures are well below 27.7 inWC (1 psi), and it begins to make sense why water column is used to measure gas pressure.

As you just learned, changing gas pressure is important when converting from one fuel to another. It is also important to change the **ORIFICES** in the gas manifold. The orifice size will be larger for natural gas than for propane because propane has a higher heat content per cubic foot of gas than natural gas. The pressure for propane is 10 to 11 in WC, which is quite a bit higher than the 3 ½ inWC used for natural gas.

The orifice is a precisely drilled hole in a small part called an *orifice spud*. The spud threads into the gas manifold and meters the fuel gas to the burners. Each burner has its own spud, and each spud must be changed when converting from one fuel to another.

ORIFICE SPUD



Kits are available for converting furnaces from one fuel gas to another. The kits will vary depending on the furnace. Every kit will include new spuds with the correct orifice for the new fuel. Often, the spuds are simply called *orifices*. Kits may also include: a gas regulator spring kit (may contain pressure regulator adjusting screw; "O" ring and regulator adjustment cap); tapped gas nipple; spoiler screw; diverter plate; low gas pressure switch; electrical components (wire harness); installation guide; and new labels with information about the conversion. It is very important that the proper kit is supplied because the improper kit could cause the furnace to overfire.

Furnace Efficiency

FURNACE EFFICIENCY is a measure of how much heat energy we get out of fuel compared to how much heat energy is actually in the fuel. For example, you learned that one cubic foot of natural gas contains about 1000 Btu. If a furnace that burned natural gas delivered 800 Btu of heat to the house for every cubic foot of gas it burned, it would be 80% efficient:

$$\frac{800\ Btu}{1000\ Btu} = 80\%$$

The **ANNUAL FUEL UTILIZATION EFFICIENCY (AFUE)** compares the amount of energy used over an entire heating season (input) to the amount of energy that the furnace actually delivers to the building during that same season (output). Furnace efficiencies are split into three categories:

1. **MOBILE HOME OR OLDER CONVENTIONAL FURNACES** are rated at about 56% to 78% AFUE. These furnaces use atmospheric burners and exhaust the combustion byproducts up the flue at 350°F to 400°F.
2. **MID-EFFICIENCY FURNACES** are rated 80% to 83% AFUE. These will typically use induced or forced-draft systems. You can tell these furnaces are more efficient because they exhaust the combustion byproducts at cooler temperatures (275°F to 300°F) than conventional furnaces. Cooler exhaust gasses tell us that the furnace used more of the heat of combustion to heat the house.
3. **HIGH-EFFICIENCY FURNACES** are rated from between 87% and 98.5%. Like mid-efficiency furnaces, high-efficiency furnaces use induced or forced-draft systems. Exhaust gasses from these furnaces have the coolest exhaust gasses of all furnaces, from only 110°F to 120°F. In fact, the exhaust gasses are cooled so much that the water vapor that is a byproduct of combustion is condensed out of the exhaust. These furnaces use PVC pipe for the flue to avoid corrosion from the water condensed out of the exhaust.

Gas Regulators and Valves

The **GAS REGULATOR** drops the pressure from the natural gas supply line or the propane storage tank to the proper pressure for the furnace burners. The manufacturer sets the pressure requirement. The gas regulator is typically part of the gas valve.

The **GAS VALVE** is located downstream from the gas regulator. The function of the gas valve is to open when the thermostat calls for heat, allowing gas to flow to the burners. When the thermostat is "satisfied" (building has warmed up to **SETPOINT**), the gas valve closes to shut off the burner. There are several types of gas valves that use different methods to open and close the gas valve. Many modern gas valves use a **SOLENOID VALVE**, while others use a diaphragm or heat motor-controlled valve. A solenoid valve is an automatic valve that is operated by an electromagnet that either opens or closes the valve.

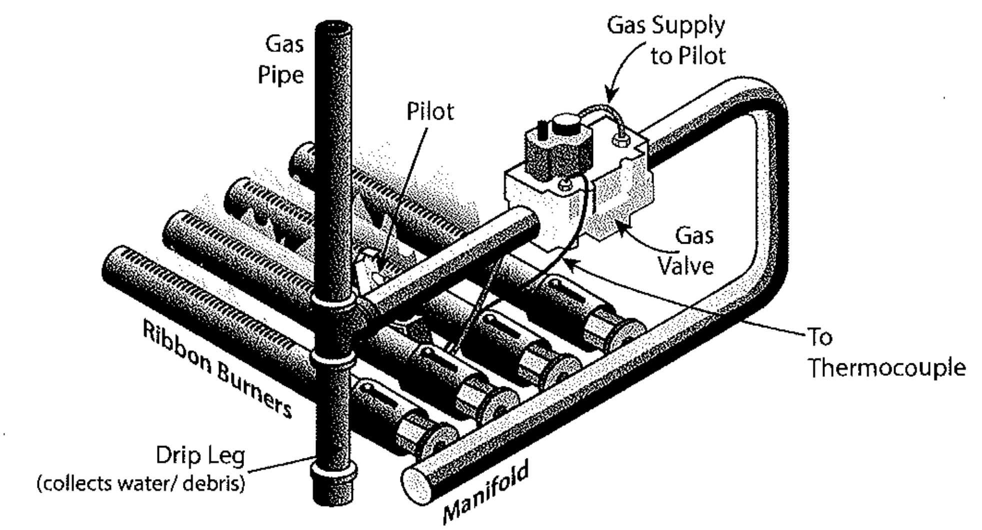
Gas valves that include a valve for the pilot are called **COMBINATION VALVES**. Many modern furnaces use a gas valve that combines the regulator, a manual shutoff, the gas supply and controls for the pilot, and the main gas valve and controls. These valves are called **AUTOMATIC COMBINATION GAS VALVES (ACGV)** or **REDUNDANT VALVES**. There are many gas valves on the market.

Gas Manifold and Burners

The **GAS MANIFOLD** is simply a pipe that is connected to the outlet of the gas valve with evenly spaced holes drilled and tapped for mounting the spuds. Older and lower efficiency furnaces use burners called **ATMOSPHERIC BURNERS** because the air they use for combustion is at atmospheric pressure.

The figure below shows a gas manifold connected to a gas valve, with four burners. The burners themselves are called **RIBBON BURNERS** when they are designed to deliver a solid flame from one end to the other. **SLOTTED-BURNERS** have a series of slots from one to the other. They may be made of cast iron or steel. These burners extend into the heat exchanger and are just shorter than the heat exchanger. The heat exchanger's job is to transfer energy from the flame and hot combustion products to the air circulated through the furnace by the main fan. Heat exchangers will be discussed in detail in the next section of this chapter.

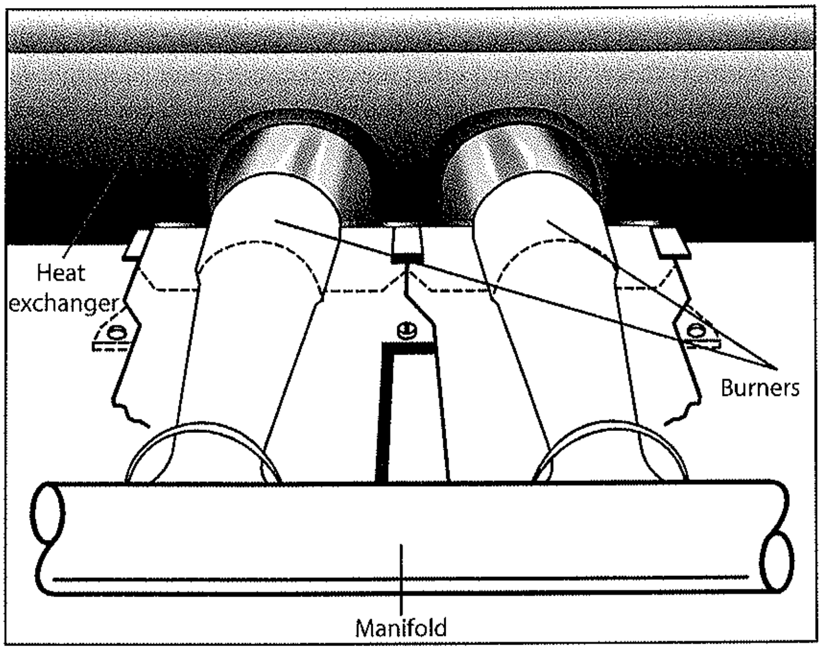
GAS SUPPLY TO BURNERS



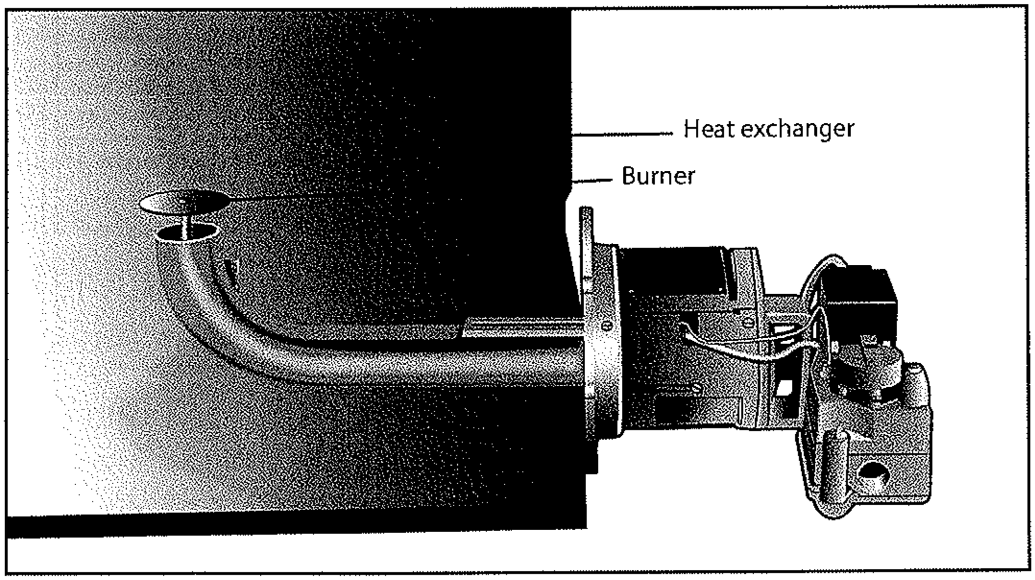
Note that the crossover igniters have been omitted for clarity.

Below are images of inshot and upshot burners, two kinds of **SINGLE-PORT BURNERS**. These burners are much shorter than ribbon burners and do not extend into the heat exchanger. Instead, they are mounted at the opening of the heat exchanger and the flame is pulled in using an induced-draft fan.

INSHOT BURNER



UPSHOT BURNER



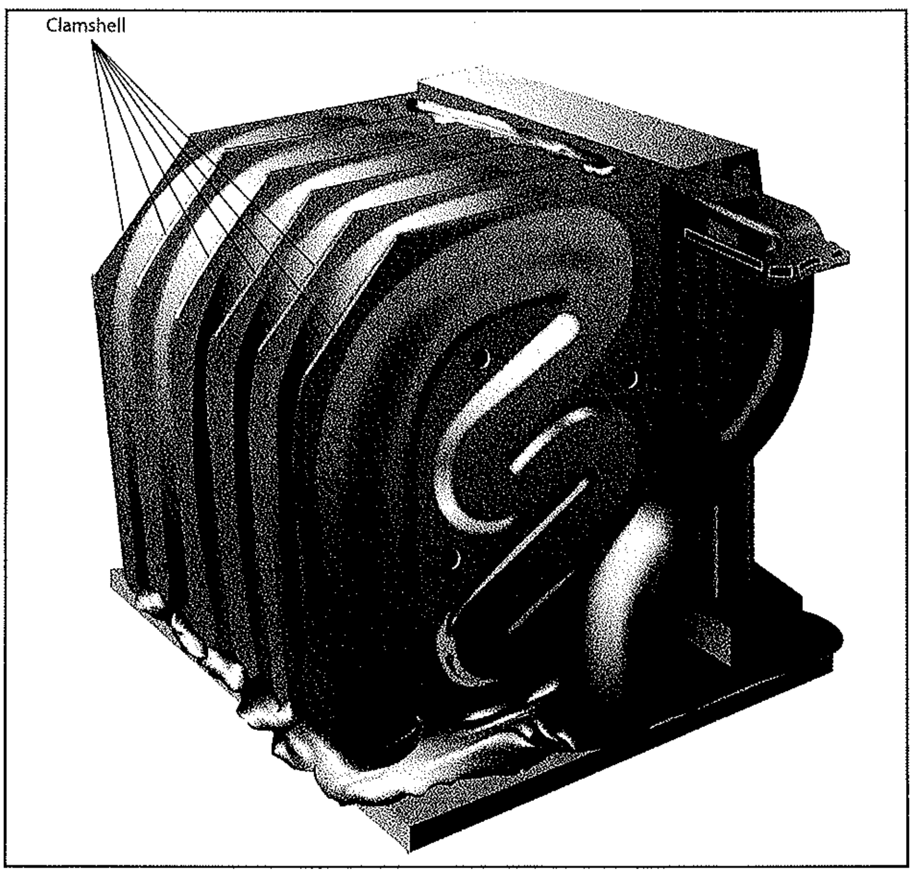
Heat Exchangers

The heat exchanger's job is to transfer energy from the flame and hot combustion products to the air circulated through the furnace by the main fan. The **HEAT EXCHANGER** is separated into sections, with one section for each burner. This provides greater heat transfer surface area.

There are many kinds of heat exchangers. They vary depending on the efficiency of the furnace and the manufacturer. Standard efficiency furnaces have a single heat exchanger and are naturally vented. That is, the heat of the combustion gasses causes them to rise up the flue using natural draft.

Medium efficiency furnaces extract more heat energy from the exhaust gasses. This cools the exhaust gasses so much that they no longer can rise up the flue due to natural draft. These furnaces used forced-draft or induced-draft blowers. Forced-draft systems have a blower that feed the heat exchanger with combustion air. The pressure of the combustion air forces the exhaust gasses out of the flue. Induced-draft systems use a blower to suck the combustion gasses through the heat exchanger. To help you remember, force-draft supplies air and induced-draft removes air.

CLAMSHELL HEAT EXCHANGER



CLAMSHELL HEAT EXCHANGERS feature two pieces of stamped metal that are seamed together to form an inner passage for hot combustion gasses. Air from the building is circulated over the outside surface of the heat exchanger to be warmed. Each burner is inserted into one "clamshell" and so the heat exchanger will have a section for each burner. Clamshell heat exchangers commonly use a ribbon or slotted atmospheric burners with natural or induced-draft furnaces. Burners are mounted at the bottom of the heat exchanger for natural draft systems, and can be mounted at the bottom or top with forced or induced-draft systems.

TUBULAR HEAT EXCHANGERS are simply bent pieces of pipe through which the hot combustion gasses flow. Clamshell heat exchangers have an inherent weak point at the seams. This weak point is eliminated with the tubular heat exchanger. Tubular heat exchangers are commonly used in conjunction with inshot burners and induced-draft blowers. There is one tube for each burner, and burners are typically located at the bottom of the heat exchanger.

SEALED HEAT EXCHANGERS have burners located at the top. Systems that use sealed heat exchangers cool the exhaust gasses so much that the water vapor condenses. This condensation must be allowed to drain from the furnace, and so the path of the exhaust gasses is downward. These systems are logically called condensing furnaces. They not only extract the sensible heat from the hot exhaust gasses, but they also extract some of the latent heat made available due to the condensation of the water vapor that is a byproduct of combustion.

Standard-efficiency (conventional) furnaces are equipped with a single heat exchanger. In these systems, the exhaust gas must be hot enough to rise up the flue due to natural draft. Medium efficiency furnaces have a single heat exchanger as well, but circulate more air than a standard-efficiency. This allows the furnace to extract more energy from the exhaust gasses. This cools the gasses so much that they must be helped out of the flue using forced or induced-draft blowers. High efficiency (condensing) furnaces may have up to three heat exchangers, with the third looking like a radiator. This is to cool the exhaust gasses as much as possible using the extensive heat transfer surface. These systems use PVC pipe for the flue because the exhaust gasses are so cool, and because the condensate is usually slightly acidic and can corrode metals.

Control and Safety Devices

Because combustion takes place within the furnace, a number of safety devices are used to reduce the risk of fire. In this section, you will learn about the common safety devices that are used on modern furnaces.

If fuel gas were allowed to flow when there is no flame, a dangerous condition would be created. The unburned natural gas or propane would flow into the room and building in which the furnace is installed, creating the potential for fire or explosion. **FLAME SENSING DEVICES** are designed to prevent this condition. They ensure that the flame has actually ignited and do not allow the main gas valve to open until a flame has been established.

In older style furnaces with **STANDING PILOTS** (a pilot light that always burns), a **THERMOCOUPLE** is used to sense the flame and prove it is burning. This is called "proving the flame." When a thermocouple is heated, it generates a very small voltage of about 15 millivolts (mV). One millivolt is one thousandth of a volt. The current generated by the thermocouple is used to hold the pilot gas valve open. If the flame goes out, the thermocouple cools. When it is cool, it does not generate the small voltage. The pilot gas valve closes and the pilot goes out. (Note: If you have ever lit a pilot light, you know that you have to hold a button down for a short time. This keeps the pilot gas valve open so that the flame can heat the thermocouple. Once the thermocouple is heated, you let go of the button and the current from the thermocouple keeps the valve open.) A **THERMOPILE** is simply several thermocouples wired together to increase voltage. It serves the same function as a thermocouple. It serves the same pilot function as a thermocouple, and it also provides voltage to the main valve. It produces about 750 milivolts.

A **LIQUID FLAME SENSOR** uses a bulb filled with a liquid. The bulb is connected to a diaphragm by a small tube, which is also filled with the liquid. When the bulb is placed in the flame, the liquid in the bulb is heated and expands. This pushes on the diaphragm at the other end of the small tube. The diaphragm pushes against electrical contacts, which energizes the circuit to open the gas valve. When the flame goes out, the liquid in the bulb cools and contracts, opening the contacts at the diaphragm, and the gas valve closes.

Another system uses a **BIMETALLIC STRIP**, which is simply two pieces of different metals bonded together. When the strip is heated, the metals expand at different rates and warp the strip. In a flame-sensing device, the bimetal strip is placed in the flame, and when the flame heats the strip, the strip warps and closes the electrical contacts that energize the gas valve circuit and open the valve. When the flame is extinguished, the strip cools and straightens out, opening the contacts and closing the gas valve.

FLAME RECTIFICATION is another way to sense flame. "Rectify" means to convert alternating current (AC) to direct current (DC). Flame rectification operates on the fact that a flame can conduct electricity. In other words, the flame acts as a switch. When the flame is lit, the switch is on, and when the flame is out, the switch is off. The system is designed to rectify the alternating current that flows through the flame to direct current. The electronics in the control module are designed to recognize only DC current.

Flame rectification systems have an advantage over other flame sensing systems because there is no time delay caused by elements heating up. The instant the flame ignites, the system detects the flame. This reduces the amount of time a main gas valve will be open during what is called "trial for ignition."

The **HIGH LIMIT SWITCH** is designed to shut the furnace down if it gets too hot. In modern furnaces, the limit is a small button-shaped device with a bimetal snap-action disc inside. The disc is designed to snap open when heated too much. This interrupts the power to the gas valve and shuts down the burners. In some systems, the button is mounted on a couple of arms so it can be extended into the furnace near the heat exchanger.

Some furnaces (older models in particular) use a **FAN LIMIT SWITCH**. This device is a combination switch that turns the main fan on and off based on the temperature of furnace. It also has a high limit switch that will turn the burners off in case the furnace gets too hot.

PRESSURE SWITCHES are used on furnaces that have forced or induced-draft systems. The pressure switch has a diaphragm inside that closes contacts when the fan is on. If the pressure switch does not "make" (turn on), then the furnace will not light. This safety feature makes sure not only that the inducer blower is running, but that air is actually flowing. Sometimes the flue gets clogged with snow, a bird's nest, or some other debris. When that happens, the fan runs, but not enough air moves through the flue and exhaust gasses cannot escape the house. The pressure switch is a vital device to help ensure proper furnace operation and to help prevent dangerous conditions that could lead to carbon monoxide poisoning.

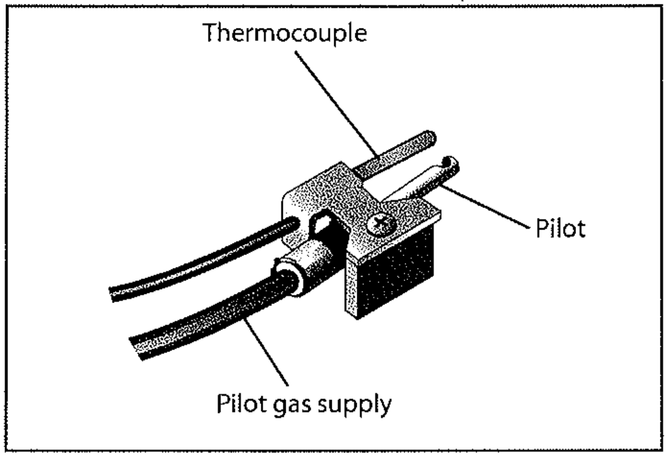
A **FLAME ROLLOUT SENSOR** looks and acts very much like a limit switch. It is designed to open if the flame rolls outside of the heat exchanger into the area where the gas valve and wiring are located. The heat of the flame causes the flame rollout switch to snap open and shut off the gas valve. The limit switch looks very similar to a flame rollout switch.

The **BLOWER DOOR SAFETY SWITCH** acts like a switch on the refrigerator door. If the furnace blower door panel is removed, the switch opens and prevents the furnace from firing.

Ignition Devices

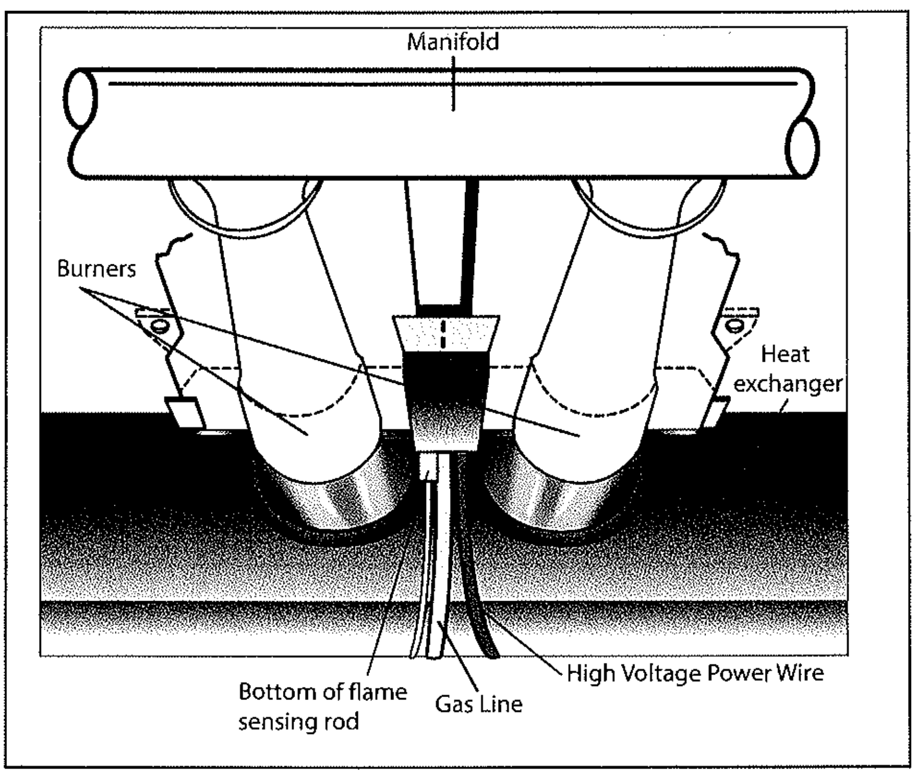
STANDING PILOTS are simply pilot lights that burn all the time. They work in conjunction with a thermocouple or thermopile used to prove the pilot is lit.

STANDING PILOT



When the main gas valve opens, the pilot provides the heat (ignition source) to ignite the main burners. **INTERMITTENT PILOT (IP) SYSTEMS** use a spark igniter to light a pilot, which is then used to light the main burner. These have the advantage over a standing pilot system of saving fuel, since the pilot is only lit when the main burner is on. These systems typically use flame rectification to prove the flame. You can see the small gas line feeding the pilot, the bottom of the flame sensing rod, the high voltage wire that feeds the intermittent pilot, the bottom of two inshot burners, the manifold, as well as the heat exchanger.

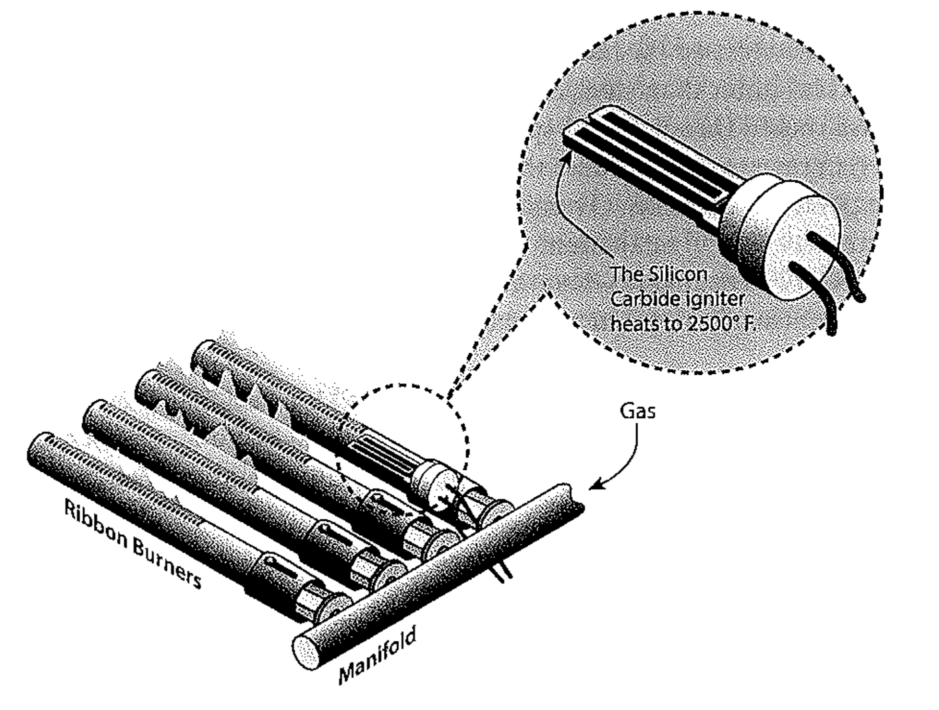
INTERMITTENT PILOT



The only difference between an intermittent pilot system and a **DIRECT-SPARK IGNITION (DSI)** is that a DSI ignites the main burner itself, rather than a pilot. Electronically, a DSI system will have a shorter "trial for ignition" time to prevent a lot of unburned gas from escaping, since main burner gas is flowing while ignition takes place.

HOT SURFACE IGNITION (HSI) SYSTEMS replace spark igniters on either intermittent pilot or direct ignition of the main burner. These systems energize the hot surface igniter for a short period of time before the gas valve is opened. Once gas begins to flow, it is ignited immediately. Like on spark-ignition systems, you will typically see flame rectification used to prove the flame on HSI systems.

HOT SURFACE IGNITION



Note that the crossover igniters have been omitted for clarity.

Popular Direct Ignition Styles

HSI and DSI systems are currently the most popular **DIRECT** ignition types used in residential and light commercial applications. Residential split systems will more often use the (HSI) to light the burners directly, and residential and light commercial package units will most likely use a (DSI) to spark directly to the burner for ignition.

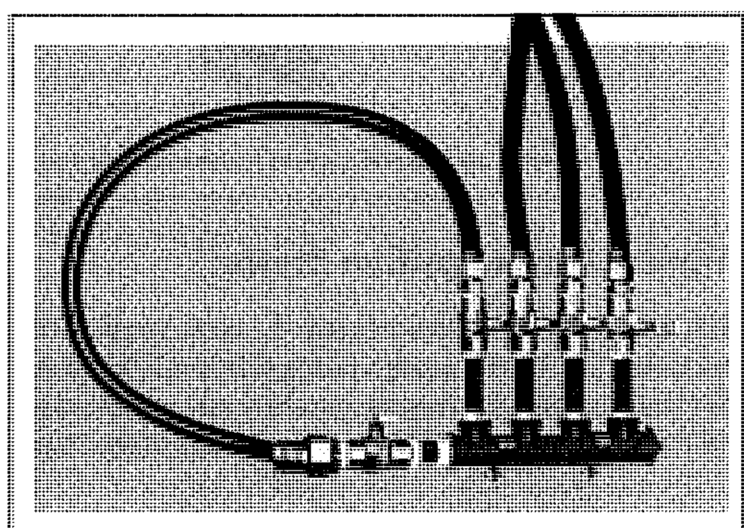
Piping

Gas piping is used to route the fuel gas (natural gas or LP gas) from the source to the furnace. Different piping materials can be used depending on the region of the country and the local code in force. **CARBON STEEL PIPE** (commonly called black iron pipe) was the predominant material used for fuel gas systems for many years. It is very durable and reliable, but it is heavy and relatively more labor intensive when compared to other piping material. For example, the joints are made with threaded connections. This means a cut piece of pipe must be threaded by hand, or by using a portable machine designed to cut threads. Steel pipe is available in lengths up to 21 feet, which means a joint must be made at least every 21 feet. In residential systems, this is not such a big deal, since long, straight runs of gas pipe are rare. However, every time a fitting is installed to join pipe, to change the direction of the pipe, reduce its size, or allow for a branch tee or valve, the pipe must be cut, threaded, and screwed together using pipe wrenches.

COPPER is commonly used for fuel gas systems and has been approved by major code organizations. It is lighter than steel, and when soft copper coils are used, the copper can be bent and routed through tight spaces. This greatly reduces the number of fittings needed, which in turn greatly reduces the number of joints required, and that reduces labor and the potential for leaks. Overall, the cost to install copper may be less than steel pipe because of the ease of installation. Copper tubing and wrought copper fittings can be joined by **BRAZING**. Brazing is when the pieces are soldered together, with a metal alloy. Flared fittings are also allowed, but an installer should not use them in hidden spaces.

CORRUGATED STAINLESS STEEL TUBING (CSST) is a relatively new material used for fuel gas. Like copper, CSST is available in coils and can be bent and routed through tight spaces. In addition, you can actually pull it through a building like you were pulling wire. Black iron pipe and copper tubing is typically installed so that all gas appliances are fed from the same main. As more appliances are connected, the main or trunk line gets bigger. CSST can be installed so that each appliance gets its own feed line from a main manifold. This allows smaller diameter gas lines to be routed through the building, and this makes installation easier.

CSST AND MANIFOLD



CSST requires special fittings for connections, but manufacturers claim that up to 75% fewer connections are needed when compared to black iron pipe. And like copper, CSST is much lighter to manipulate.

Venting

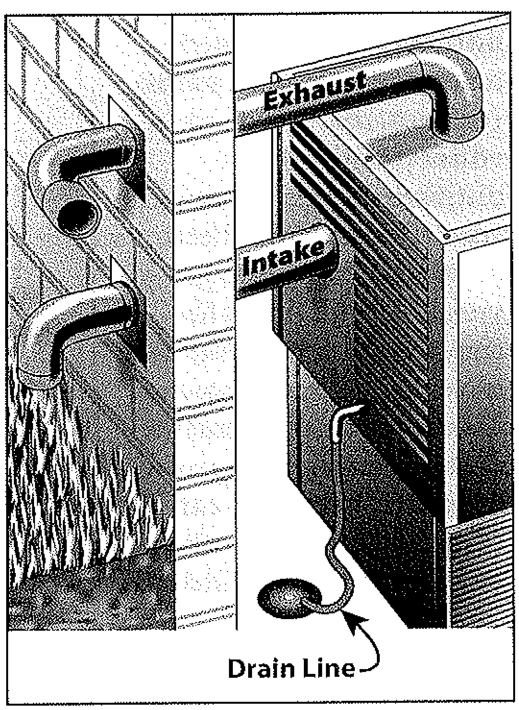
All furnaces must be vented to allow the combustion gasses to escape from the building. Conventional furnaces vent hot combustion gas, using the buoyancy of the gas to create what is called **STACK EFFECT**. "Stack effect" simply means that warm air rises because it is lighter than cooler air. The combustion gasses in a conventional furnace can reach up to 400°F and rise up the flue very quickly.

Conventional furnaces use either a masonry chimney or **TYPE B VENT**. Known simply as "B-vent," this product is a double-wall pipe made with an aluminum inner pipe and a galvanized or aluminum outer pipe separated by an air gap. It is available in round and oval and in a number of sizes. Fittings and accessories are manufactured for a complete venting system.

Masonry chimneys may require a **CHIMNEY LINER**. These are usually made of flexible stainless steel or aluminum pipe, but rigid systems are also available. Known as **Z-VENT**, these liners protect the mortar in masonry chimneys from damage caused by condensation and acid from flue gasses. Kits are available with all the parts needed to connect the furnace and the chimney.

High efficiency furnaces use two PVC pipes for venting. One pipe brings combustion air to the furnace from the outside, the other vents the combustion gasses. Remember that these furnaces cool the exhaust gasses below dew point, so the water vapor that is one of the products of combustion is condensed and must be drained. In the image to the right, you can see a furnace with two large PVC pipes and one smaller one. The two larger pipes are used for combustion air and venting, while the smaller one is routed to a drain in the floor to drain away the condensation. In the exterior view, you can see the two PVC pipes penetrating the exterior wall of the building.

DIRECT VENTED HIGH EFFICIENCY FURNACE WITH PVC VENT AND DRAIN PIPE



Overview of Boilers

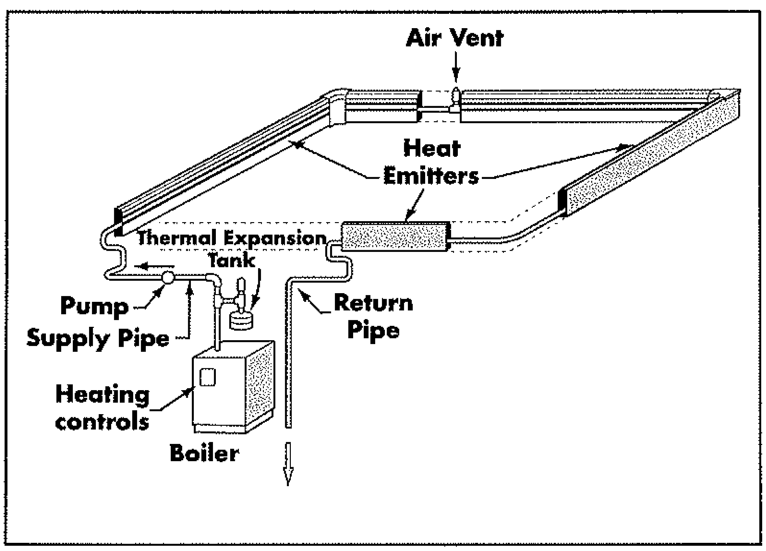
The parts that make up a hot water comfort heating system will be discussed in this section. How the system components are sized will be included. The building for which the heating system is designed will determine the specific kinds and sizes of the system components. But all systems must have certain basic components. Parts of a hot water heating system are:

- The boiler which heats the water
- The burner, if separate from the boiler
- The thermal expansion tank attached to boiler
- The booster pump(s) or circulator to circulate water
- The piping system through which the water moves
- The **RADIATION** (heat emitters in various forms such as radiators, radiant panels, and baseboard units) which transmit the heat from the water into the air of the rooms to be heated
- Various accessories, called **HYDRONIC SPECIALTIES**, to improve the performance of the system
- Heating controls to operate and regulate the system

Boiler Basics

The hot water from the boiler circulates through the distribution piping system to the radiation components (radiators, baseboard units, radiant panels) which distribute the heat to desired areas. The amount of heat provided by the heating system depends upon the temperature of the water as it leaves the boiler, the amount of water circulating, and the construction and design of the system itself. The part of the heating system which provides the heat is called the boiler.

HOT WATER HEATING SYSTEM



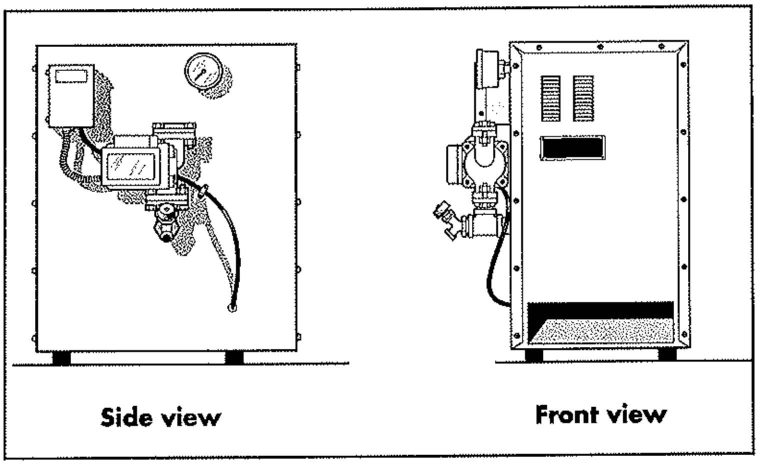
A **BOILER** is a closed pressurized container in which a liquid is heated. The operating parts of the boiler are generally enclosed in an attractive cabinet for a residential boiler.

The code regulating construction of boilers is the **AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME)** code. Local codes usually are modeled after the ASME code.

Residential boilers may be powered by gas, fuel oil, or electricity. Commercial or industrial boilers sometimes use wood or coal.

By ASME code, boilers must be made of cast iron, steel, or copper. Hot water boilers for most homes or small commercial buildings are designed to operate at a maximum pressure of 30 **POUNDS PER SQUARE INCH (PSI)** or 30 psi and at temperatures of no higher than 250° F.

BOILERS



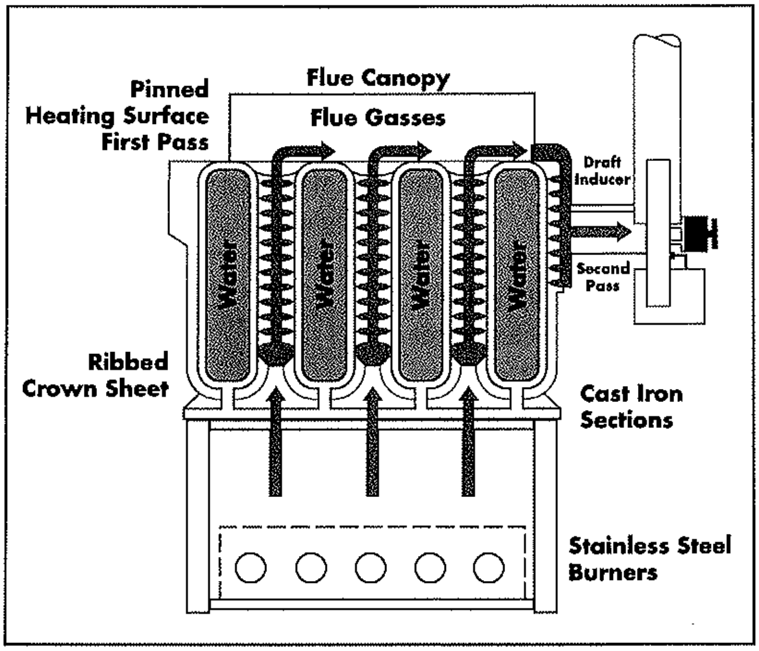
Types of Boilers

Boilers may heat the water in one of several different ways.

- A **WATER TUBE BOILER** is basically a steel shell with tubes inside. The water runs through these tubes, which are surrounded by hot flue gasses. The gasses heat the water.
- A **FIRE TUBE BOILER** reverses the process. The tubes contain the hot flue gasses and the water surrounds the hot tubes.
- An **ELECTRIC BOILER** uses electric heating elements (insulated to prevent short circuits) inside the water tank to heat the water.
- A **CAST IRON BOILER** is composed of several cast iron sections which contain the water. Hot gasses move vertically between these sections.
- A **FLASH BOILER** has a copper-finned heat exchanger mechanism containing some water. The heat exchanger is surrounded by hot flue gasses.
- A **CONDENSING BOILER** uses all the energy created by combustion by capturing the heat from the exhaust, through condensing the moisture in the exhaust gas. To work, the return water must be lower than the exhaust gas dew point (less than 136°F).

Boiler Ratings

CAST IRON BOILER



Boilers for residential use must conform to a rating program sponsored by the **DEPARTMENT OF ENERGY (DOE)**. Under this program, boilers are given three different kinds of ratings: the input rating, the DOE heating capacity, and the net rating.

The **INPUT RATING** indicates the amount of heat energy from fuel put into the boiler. This rating is generally given in thousands of Btus per hour using the abbreviation "Btu/h" or using the abbreviation "MBH."

ONE MBH = 1000 Btu/h

The "M" refers to the prefix "mil" which means "thousand" as in "millennium" meaning a thousand years; "B" refers to Btus; "h" refers to an hour.

To convert MBH to Btu/h: Multiply the MBH by 1000 by moving the decimal point 3 places to the right.

EXAMPLES: 25.5 MBH = 25,500 Btu/h
48.0 MBH = 48,000 Btu/h

To convert Btu/h to MBH:
Divide the MBH by 1000 by moving the decimal point 3 places to the left.

EXAMPLES: 25,500 Btu/h = 25.5 MBH
48,000 Btu/h = 48.0 MBH

If boiler burns 1 gallon of fuel oil, which provides 140,000 Btu/h of heat, then the input rating would be 140,000 Btu/h (140 MBH).

Rating charts will show this in one of three ways:

1 gph (gallon of oil per hour)
OR
140,000 Btu/h
OR
140 MBH

The second rating is the **DOE HEATING CAPACITY**. This rating refers to the actual amount of heat available for distribution through the piping system to heat the building. Technically, this figure is the amount of heat generated minus the amount of heat lost up the smoke stack/chimney. This rating is also measured in Btu/h or MBH. For larger boilers, this is called *output* or *gross output*.

The third rating is the **NET RATING**. This figure, also in Btu/h or MBH, indicates the amount of heat available at the radiation (baseboard heat emitters, radiant panels, radiators) after theoretical allowances for heat lost in piping and pickup from cold starts. A cold start is when the system is started at ambient temperature. This figure may be shown on the chart as "I=B=R net water rating" or "net water rating."

I=B=R stands for Institute of Boiler and Radiator Manufacturers, a function of the Hydronics Institute, which is the organization that tests and rates boilers and other hydronic equipment. All boilers rated by I=B=R have ASME approval. The net rating is more important than heating capacity when choosing a boiler. The net rating is the MOST important rating used when selecting the proper size boiler.

To properly select a boiler, the calculated heat loss of the building or area to be heated must be known. The net rating of the boiler chosen must be at least as great as the heat loss of the area to be heated. For example, if the building heat loss is figured at 35,000 Btu/h, the net rating of the boiler must be at least 35,000 Btu/h. Look at the sample boiler rating chart below.

MODEL A BOILER RATINGS

Boiler Model Number	Input (MBH)	DOE Heating Capacity (MBH)	I=B=R Net Rating (MBH)	AFUE% (Annual Fuel Utilization Efficiency)
A3	62	52	45	85%
A4	96	84	70	84%
A5	130	108	94	83%
A6	164	134	119	83%

In addition to the three ratings already mentioned, the U.S. Department of Energy requires that manufacturers provide consumers with efficiency ratings, much like the auto industry's Estimated Miles Per Gallon.

These boiler efficiency figures are calculated estimates called the **ANNUAL FUEL UTILIZATION EFFICIENCY (AFUE).** These figures may also be shown on charts with the heading "DOE Seasonal Efficiency." The AFUE figures are given in percentages (%) to help consumers determine which boilers are more efficient in fuel usage. Higher percentages indicate more efficient boilers.

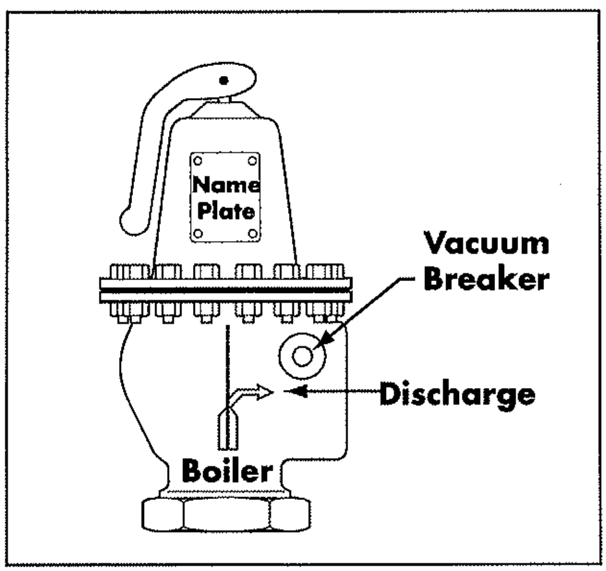
The Federal Trade Commission requires that a fact sheet showing comparative AFUEs must be available (upon request) from the wholesaler for every residential model sold.

Boiler Requirements

All hot water boilers must be fitted with a **SAFETY RELIEF VALVE** to relieve excess pressure. At a predetermined pressure, the valve opens and discharges water at a rate which will prevent further buildup of pressure. The safety relief valve is sometimes called a *pressure relief valve*. All safety relief valves must be rated and installed according to the ASME Boiler and Pressure Vessel Code.

ASME also requires that all hot water boilers have a combination temperature and pressure gauge called a **BOILER GAUGE**. The temperature reading tells the water temperature in the boiler. The pressure reading shows pressure in the boiler when the system is filled with **cold water**, and then it shows the higher pressure when the water is heated. The pressure in the boiler must be great enough for effective operations, but not greater than the maximum pressure for which the boiler is rated.

SAFETY RELIEF VALVE



A boiler may be purchased separately—without burner or controls—or as a packaged boiler. A **PACKAGED BOILER** is pre-assembled with burner, controls, and possibly the booster pump. The boiler is ready for hookup to piping system, fuel line, and wiring. Some of the boiler packages offered may vary what is included.

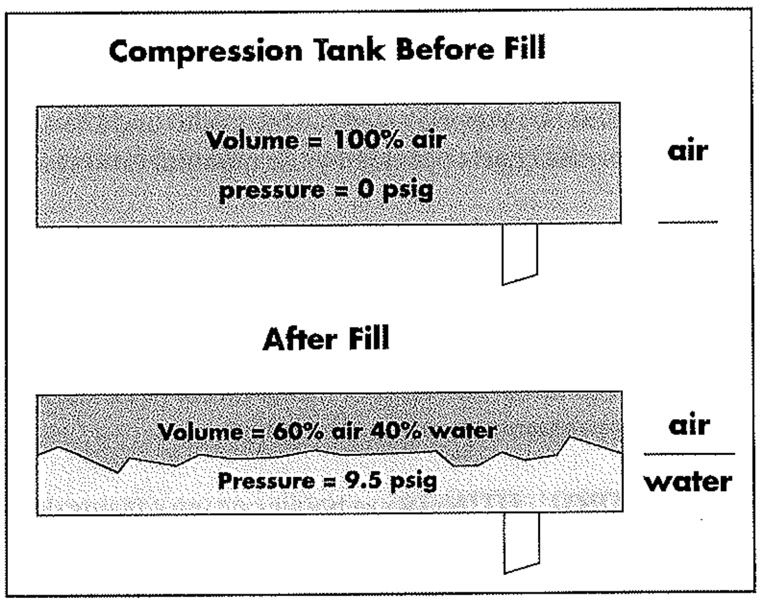
Overview of Tanks

The water in the system expands as it is heated. To allow for this expansion, some type of tank is used to hold the extra water. In the past an open expansion tank was used. Now it is more common to use a **THERMAL EXPANSION TANK**, also called a compression tank or a closed expansion tank.

As the water expands up into the tank, the cushion of air is compressed. This compression of the air also helps maintain proper pressure in the system.

Types of Thermal Expansion Tanks

THERMAL EXPANSION TANK CHART

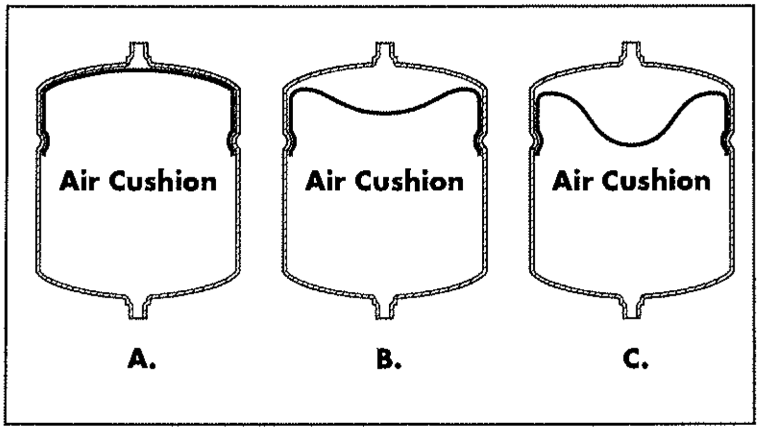


There are two types of thermal expansion tanks: the conventional tank and the diaphragm tank. The **CONVENTIONAL THERMAL EXPANSION TANK** is a tank containing a cushion of air which allows the water to expand into the tank from the system. As the heated water expands, the cushion of air is compressed.

The conventional tank has no separating device between the air and the water and eventually the water will absorb some of the air. If too much air is absorbed, the tank becomes waterlogged and must be recharged with air in order to maintain air space for the water to expand and to maintain proper working pressure. Waterlogging may also occur if air leaks out of the tank if the proper air control fittings are not properly installed. Various air control fittings are available for use with compression tanks. If your company sells conventional thermal expansion tanks, consult your manufacturer's catalogs regarding air control fittings.

The second type of thermal expansion tank is the **DIAPHRAGM** or **BLADDER EXPANSION TANK**, which has a flexible diaphragm separating the water from the air so that air cannot be absorbed by the water. This prevents waterlogging. The diaphragm thermal expansion tank comes from the factory precharged with air.

DIAPHRAGM TANK



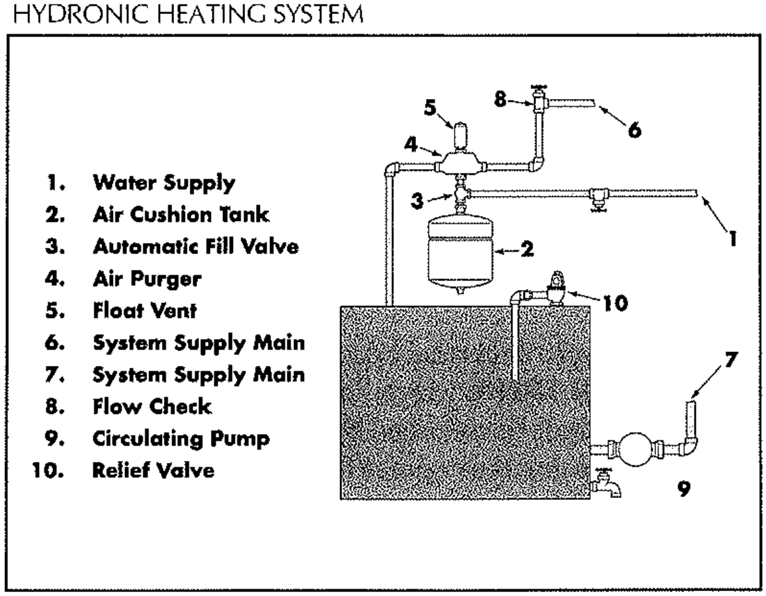
When the tank is first installed near the boiler, the air pressure keeps the diaphragm pushed against the inside of the tank (Position A). As the heating system is filled, some water flows into the air cushion tank (Position B). As the water becomes heated, it expands and presses against the diaphragm, which flexes and allows the expanding water to compress the air cushion to allow for the expansion of the water. The heated water in the system expands and some flows into the tank (Position C).

The tank must be properly sized for the boiler and the system. It is important to follow the instructions and charts provide by the manufacturers for sizing.

When the system is filled with fresh water, that water contains some air. As the water heats, some of this air is released. If the released air gets into the main piping system, it causes the system to make noise or gurgle. If too much air gets into the system, the flow of hot water can be slowed or stopped. The only place in the system where there **should be** air is in the tank. Therefore, various forms of air control fittings are available for attachment to the tank and/or the boiler.

AIR CONTROL FITTINGS are boiler or tank fittings designed to prevent the air from getting into the main piping system and to direct the air into the air cushion tank. Air control fittings frequently come as part of a package with a packaged boiler or an air cushion tank. Check your manufacturer's catalog to find the appropriate fittings.

HYDRONIC HEATING SYSTEM



Hydronic Specialties

Accessories which improve the performance of the major parts of the system (boiler, piping, heat emitters) are called **HYDRONIC SPECIALTIES**. Various manufacturers produce hydronic specialties under their own trade names. Some of the common specialties have been discussed earlier in connection with the parts of the system on which they are used. Some of the specialties are air control devices, valves, and pumps.

AIR CONTROL DEVICES are hydronic specialties used to eliminate air from the system. These include (1) air separating devices and air venting devices for the boiler and thermal expansion tank, and (2) air vents for emitters and pipes.

Other specialties are designed to control flow of water coming into the system, including:

- **PRESSURE REDUCING VALVES** used to reduce the pressure of water coming into the system if the incoming water is under greater pressure than the water in the system
- **FILL VALVES** to control the flow of water into the system as it is being filled. A manual bypass may allow for quick filling
- **BALANCING VALVES**, or balancing cocks, are usually installed at the end of each circuit and manually adjusted to equalize water distribution in multiple circuit systems
- **ZONE VALVES** and **ZONE PUMPS**, operated by thermostats, control water flow in individual zones of a zoned system
- **FLOW CHECK VALVES** prevent gravity circulation of water if the pump is shut off

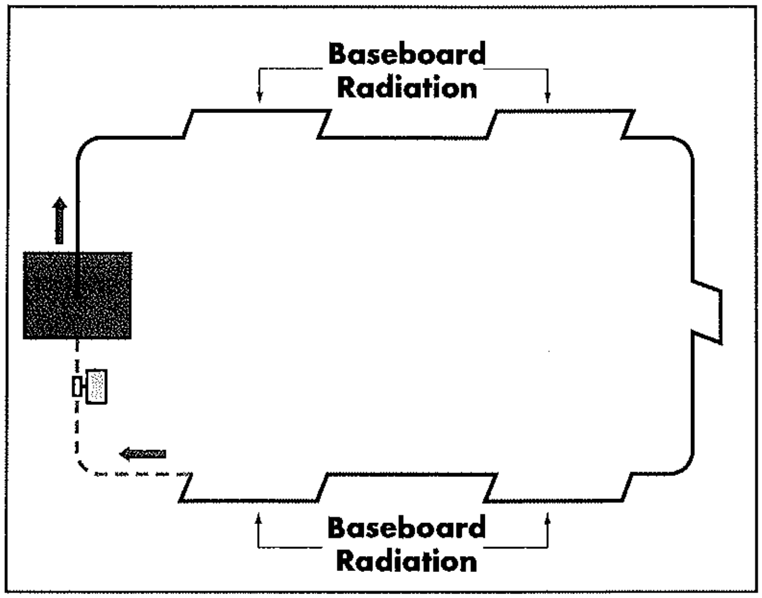
All these specialties are used for flow control of the water in the system. One-pipe fittings for connecting emitters to one-pipe systems are considered specialties. Sometimes circulator pumps, thermal expansion, boiler gauges and other accessories are considered specialties and are shown in specialty catalogs. From time to time your customers may ask for hydronic specialties. It is important that you become familiar with the various specialties produced by your manufacturers. You will also need to know the specialties by proprietary trade name.

Overview of Piping

After the heat loss has been determined for individual rooms and for the whole building, the system designer draws up a **PIPING LAYOUT**, to scale, showing the location of the boiler and all the heat emitters and the piping arrangement which will connect the boiler and the heat emitters. Pipe lengths can be measured accurately by referring to the piping layout.

In a piping layout, the **SUPPLY PIPE**, which supplies hot water to the emitters from the boiler, is often shown with a solid line. The **RETURN PIPE**, which returns cooled water to the boiler, is often shown by a broken line.

PIPING LAYOUT



There are four common types of piping systems used in hot water heating systems: (1) series loop systems, (2) one-pipe systems, (3) two-pipe systems, and (4) radiant panel systems.

Series Loop Piping System

The most common system in use in houses and small buildings is the series loop system. The **SERIES LOOP PIPING SYSTEM** uses one continuous loop with all the heat emitters (usually baseboard) making up parts of the loop. All the water flows from the boiler through the supply side of the pipe, then through each heat emitter in the series, and finally through the return side of the pipe to the boiler. Because there is no large main pipe with feeder pipes attached, the series loop system is sometimes called a **MAINLESS SYSTEM**.

The major advantage of the series loop piping system is that it is considerably less expensive than other types of systems because it requires less pipe, fewer fittings, and less labor to install it.

However, there are two possible drawbacks to the series loop system:

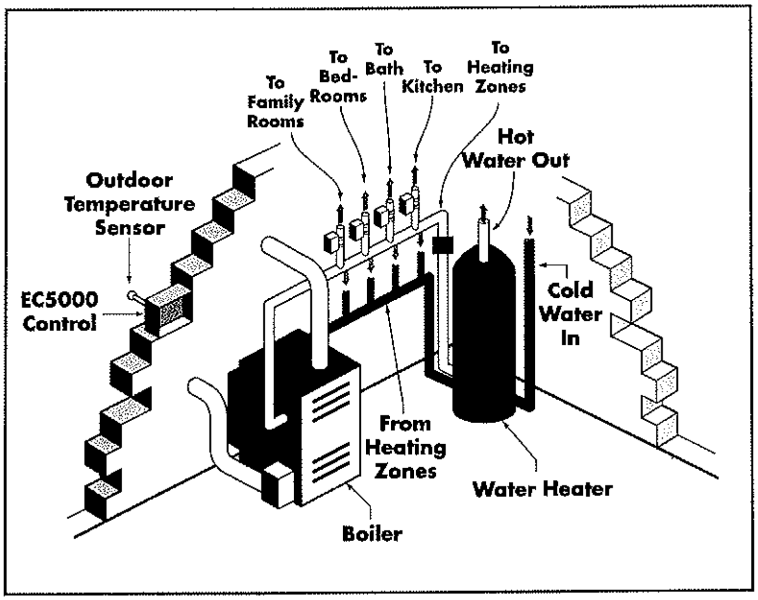
1. It is not possible to control the amount of, or the temperature of, water flow through one or a few emitters without affecting the whole system. For that reason, dampers are installed on the emitters to help in controlling the amount of heat given out.
2. The diameter of the water tubes in the baseboard heat emitters limits the amount of water that can flow through the whole system, since all of the water flows through all of the heat emitters. Therefore, the amount of heat available is limited because of the limits on water flow.

However, for small buildings, the lower cost of the series loop system outweighs the disadvantages. Also, the drawbacks of the series loop can be overcome somewhat by dividing the series loop into several separate circuits or zones for better control of water flow and temperature.

One complete pipe loop between the supply main and the return main of the boiler is called a **CIRCUIT**. A series loop may have several circuits. If a system uses more than one thermostat, each section which has its own thermostat is called a **ZONE**.

Using multiple circuits and/or multiple zones in a series loop system increases the ability to control the amount of heat available in each section and allows the system to carry more heat than a single loop of pipe.

BOILER AND WATER HEATER

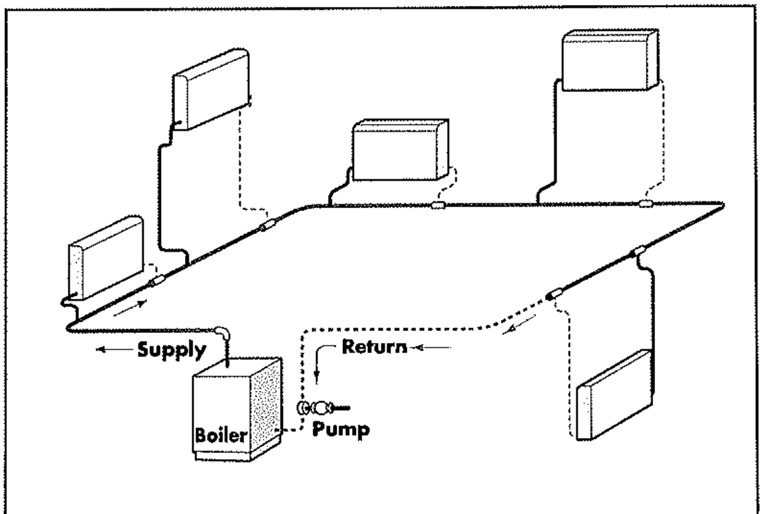


One-Pipe System

The second most common piping system in small buildings is the **ONE-PIPE SYSTEM**. A one-pipe system or monoflow system uses one continuous pipe, called a **MAIN**, making a loop from the supply side to the return side of the boiler. Each heat emitter is connected to the main by two branch pipes called **RISERS**.

One riser is the supply riser; the other is the return riser.

ONE-PIPE FORCED AIR HOT WATER HEATING SYSTEM



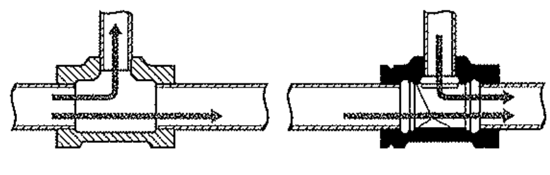
One Pipe Forced Air Hot Water Heating System (single circuit)

The risers must be connected to the main with special tees, called **ONE-PIPE FITTINGS**, which divert some of the water from the main into the heat emitters.

If the heat emitter units are above the main, called an **UPFEED SYSTEMS**, one of the special fittings is required.

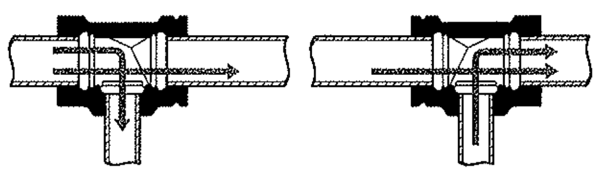
In a **DOWNFEED SYSTEM**, two one-pipe fittings are needed. Various manufacturers make one-pipe fittings, and they may vary regarding use and sizing of one-pipe fittings.

UPFEED SYSTEM



For radiators above the main - normal resistance

DOWNFEED SYSTEM

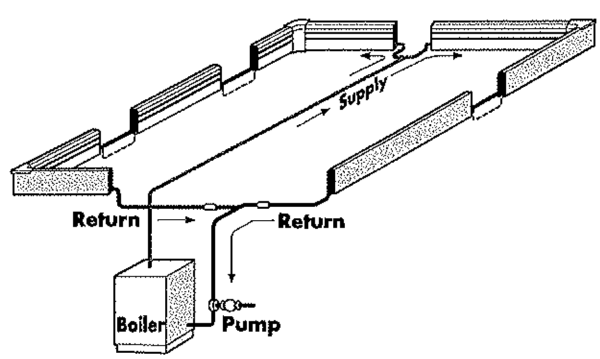


For radiators below the main

One-pipe systems have an advantage over series loop systems because the amount of heat to each room can be controlled by using a **BALANCING VALVE** on the riser to regulate hot water flow. However, the additional piping, pipe and installation costs may make the one-pipe system more expensive than the series loop.

Like a series loop system, the one-pipe system may use multiple circuits. A **MULTIPLE CIRCUIT SYSTEM** uses more than one complete loop of pipe to connect heat emitters and boiler. Multiple circuits may provide better control over the amount of heat delivered. Multiple circuits are necessary where a single long run of small diameter piping may develop more internal friction than the pump may overcome.

SERIES LOOP BASEBOARD SYSTEM



Series Loop Baseboard System
(multiple circuit)

Two-Pipe System

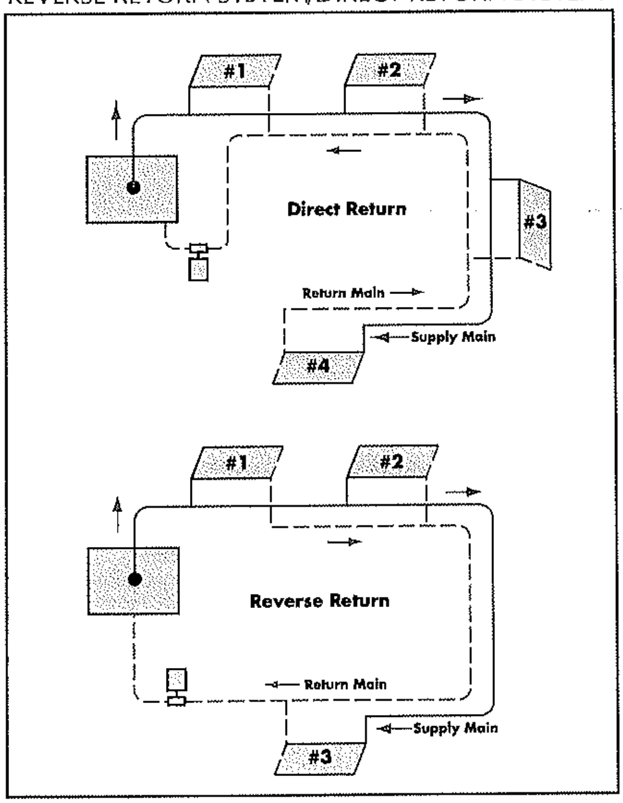
In commercial buildings and older homes, a two-pipe system may be used. In a **TWO-PIPE SYSTEM**, one main carries heated water from the boiler to the emitters but a second main carries cooled water from the emitters back to the boiler. There are two kinds of two-pipe systems: the **REVERSE RETURN SYSTEM** and the **DIRECT RETURN SYSTEM**.

In the reverse return system, the emitters are connected to the return main in the reverse order from the way they are connected to the supply main. That is, the heat emitter that is first on the supply main is the last connection on the return main. Because of the way this system is hooked up, the distance the water travels to each unit is approximately the same and this provides even flow to each heat emitter. It also makes it possible to control each heat emitter individually.

In a direct return system, the first heat emitter on the supply main is also the first heat emitter to return water. Direct return systems require more complicated balancing procedures than do reverse return systems.

The heat carried in the water in the piping system is released into the rooms to be heated through **RADIATION OUTLET DEVICES** or **TERMINAL DEVICES**. Radiation transfers the heat into the rooms, partly by radiation and partly by convection. Individual units such as baseboard units, which are used around the walls of a room to provide the circle of warmth referred to earlier, are often called heat emitters.

REVERSE RETURN SYSTEM/DIRECT RETURN SYSTEM



The other major kind of radiation is the **RADIANT PANEL SYSTEM**, which is usually radiant floor heating, in which hot water tubing is placed under the floor in such a way that the whole floor is warm and radiates heat into the room. Emitters should be placed so that a comfortable, uniform temperature is maintained everywhere in the room, without cold walls or cold drafts.

It is important for emitters to be installed under areas of glass. Installations under the glass make up for the high rate of heat loss from the glass and prevent cold downdrafts of air from the glassed area.

If it is not possible to place the emitters under the glass areas, the next best location is along the outside walls of the room, which do not have glass areas. It may be necessary to use both under-glass placement and around the wall placement. The basic idea is to provide a circle of warmth around the room.

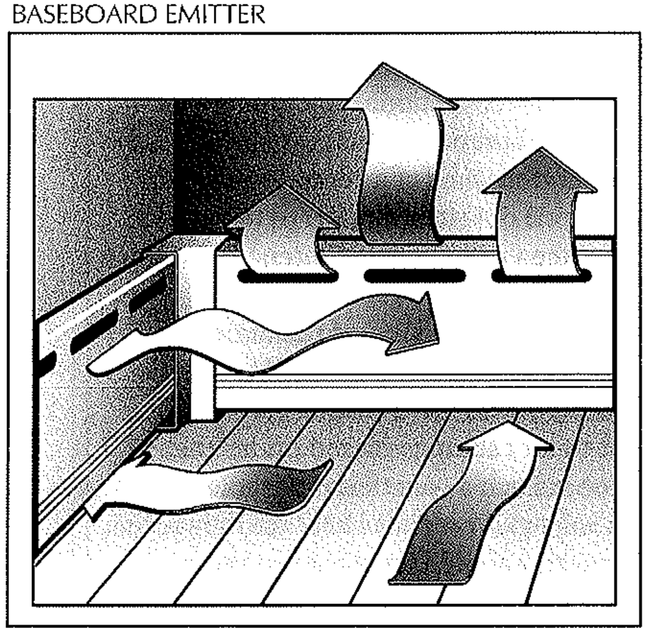
Types of Heat Emitters

The kinds of emitters now sold for residential and small commercial use are baseboard units, finned tube units, and convectors. Cast iron radiators, though still in use in many buildings, are rarely sold now for new homes.

Most of the radiation sold for residential use is baseboard. The **BASEBOARD EMITTER** unit replaces the conventional baseboard trim along the floor of the room to be heated. Baseboard is usually installed on a series loop piping system.

There are two kinds of baseboard emitters sold: (1) cast iron and (2) finned tube baseboard. Cast iron baseboard has hollow cast iron sections through which the hot water can circulate. Air inlet and outlet openings allow air to circulate around the hollow sections. Finned tube baseboard is a tube, generally made of copper, with attached fins (usually aluminum). The whole tube is surrounded by a metal cover with top and bottom openings for air circulation.

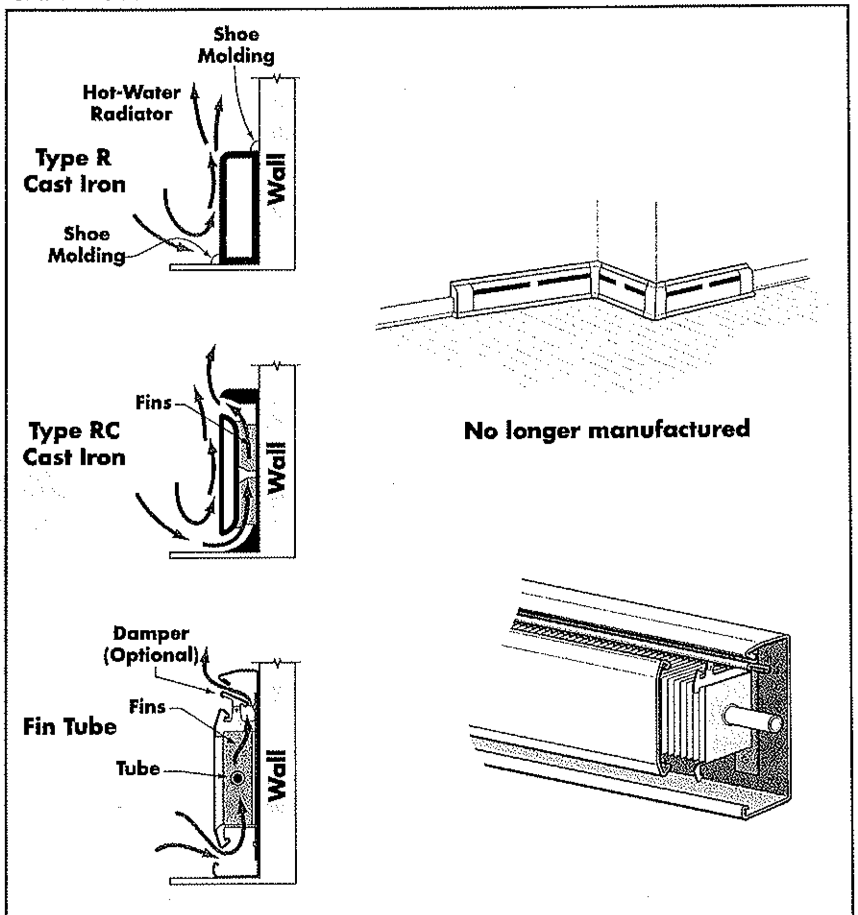
BASEBOARD EMITTER



Cast iron baseboard is manufactured in sections 12-inch, 18-inch, and 24-inch lengths. This allows for on-site assembly as needed. Baseboard is I=B=R rated in Btu/h output per linear foot of baseboard. Each rating is approved for a specific water temperature and water flow rate. Water flow rates are generally given at either one gpm (500 lb/hr) or four gpm (2000 lb/hr).

If the system flow rate is less than four gpm (2000 lb/hr), you must use the one gpm (500 lb/hr) rating. If the system flow rate is four gpm *OR ABOVE*, use the four gpm rating. If the flow rate is unknown, use the one gpm rating.

CAST IRON AND FINNED TUBE BASEBOARDS



Basic Classes of Residential Type Basebord Emitters.

Commercial buildings may use commercial **FINNED TUBE UNITS**, which are very much like finned tube baseboard except that the units are larger and they have considerably greater output than finned tube baseboard. Like baseboard, commercial finned units are rated in Btu/h per foot based upon system water temperature and flow rate. The size of the unit, the type of metal, the number of tiers of heating elements, and the number of fins per foot also determine output of the unit.

A **CONVECTOR** is an emitter consisting of a finned heating element enclosed in a casing or cabinet with top and bottom openings placed to promote circulation of room air without use of a fan. The convector recirculates the room air, passing it over the heating element. Convectors may be used in small commercial buildings or, occasionally, in homes. As the name suggests, a convector heats more by convection than by radiation.

Convectors cannot be installed on a series loop system. A one-pipe or a two-pipe system is needed.

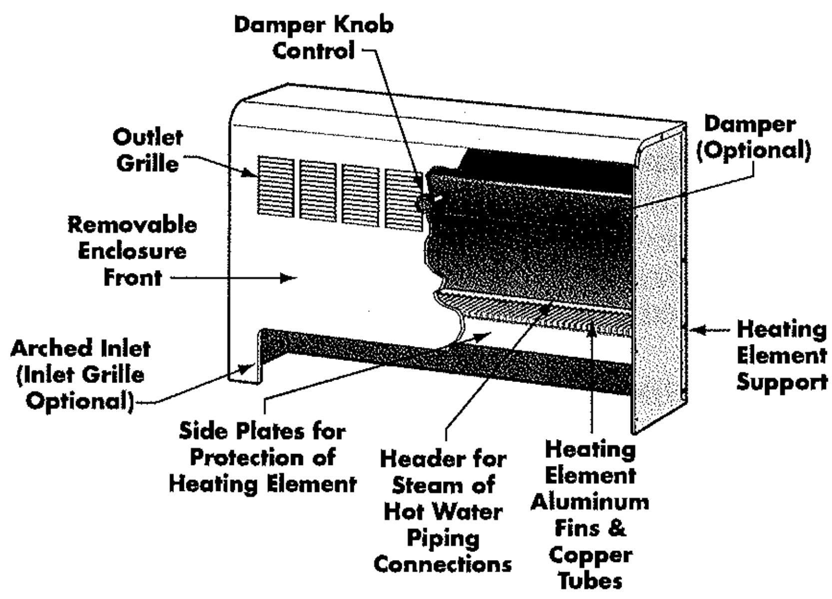
The convector cabinet may be free standing, wall hung, or partially or fully recessed in the wall, depending upon placement and use. The heating capacity of the convector is determined by the size of the heating element, the height and depth of the cabinet, and the placement of the air outlet. Generally larger units produce more output.

The room air enters at floor level, passes over the heating element, and leaves the cabinet through a grill at the top of, or top front of, the cabinet.

Ratings for convectors are usually expressed in MBH for specific water temperatures and water temperature drops.

ONE MBH = 1000 Btu/h

CONVECTOR CABINET



The chart below shows the output, in MBH, of several models at 210°F average water temperature with a 20° temperature drop. The physical dimensions of the cabinets are also shown, since the dimensions affect output and must also be considered in terms of space available in the room. In larger rooms it is better to install two convectors, for better distribution of warmth.

CONVECTOR RATINGS TABLE

Front Outlet Types Model & Height (in)	20° Temp Drop Depth (in)	Average Water Temp 210°		Length	65° Entering Air	
		20"	24"	28"	32"	36"
C-18	4	1.9	2.3	2.7	3.1	3.6
	6	2.6	3.3	3.9	4.6	5.3
	8	3.3	4.2	5.2	6.2	7.1
C-20	4	2.0	2.6	3.1	3.6	4.2
	6	3.0	3.7	4.5	5.3	6.0
	8	3.6	4.7	5.6	6.6	7.6
C-24	4	2.3	2.9	3.5	4.2	4.8
	6	3.5	4.4	5.3	6.2	7.1
	8	4.3	5.2	6.2	7.3	8.2
Models: Height & Depth		MBH (Thousands of Btu/h)				

Notice that model C-20 with a cabinet 24" long and 6" deep will produce 3.7 MBH at average water temperature of 210°F. with a 20° water temperature drop in the system. Multiply 3.7 MBH x 1000 to get Btu/h: 3.7 MBH = 3,700 Btu/h

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Evaluating Cast Iron Radiators

Cast iron radiators have been used in older buildings, but they are not often used in new construction. Your supply house may handle radiators for replacement in older systems.

The rating of a cast iron radiator is based on **EQUIVALENT DIRECT RADIATION (EDR)** per square foot of heating surface. The Btu/h output of this square foot rating will depend on the system water temperature. (See the Heat Emission Rates chart.) To learn to size radiators for a heating system, consult your manufacturer's catalogs and training materials.

According to the Heat Emissions Rates chart that follows, by how many degrees would you have to increase system water temperature to increase the E.D.R. output by 20 Btu/h? The system water temperature must be increased by 10°F.

HEAT EMISSIONS RATES FOR CAST IRON RADIATORS TABLE

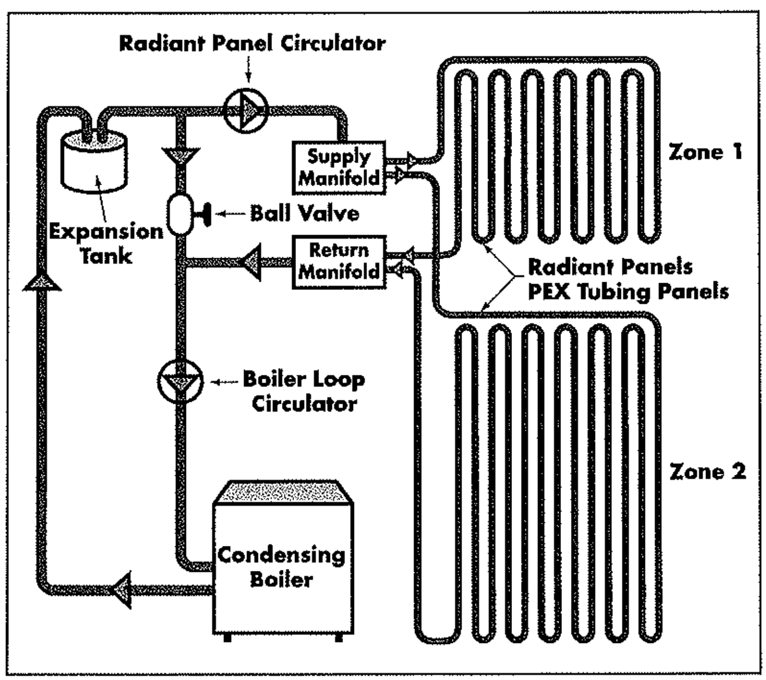
System Design or Average Water Temperature	Heat Emission (Output) Rates Btu/h per Square feet of Surface
170°F	150
175°F	160
180°F	170
185°F	180
190°F	190
195°F	200
200°F	210

Radiant Floor Heating

A **RADIANT PANEL SYSTEM** circulates the hot water through a series of coils embedded in the floor (or sometimes the ceiling). The floor acts as the heat emitter. **RADIANT FLOOR HEATING** makes use of hot water flowing through flexible tubing which is attached to or embedded in the floor. The surfaces in the room are warmed by radiated heat from the floor, and the air in the room is warmed by coming in contact with the room surfaces. One important reason for using radiant floor heating is that lower water temperatures can be used. If the system is properly designed, the floor surface temperature will be evenly warm but will be only a few degrees warmer than the temperature of the air in the room.

Another advantage is that the air near the floor—which would naturally be colder using a forced air heating system—is comfortably warm using radiant floor heat. The cooler air will be near the ceiling, which is farther away from the warm floor.

BOILER SYSTEM

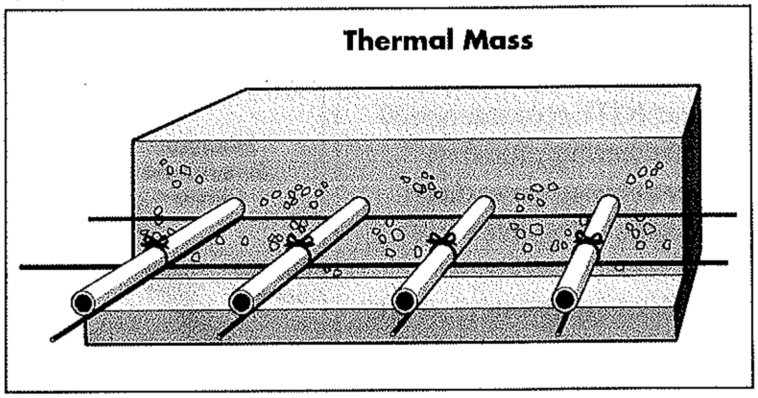


Radiant floor heating is especially appropriate for buildings built on concrete slabs, but it is also possible, with proper thermal mass materials, to use radiant heating with wood floors and suspended floors. Suspended floors are floors which have open spaces, such as crawl spaces or basements, beneath them. The pattern in which the tubing is laid depends upon the layout of the room and the use to which it is put.

The tubing is generally embedded in some kind of **THERMAL MASS**, which is usually a dense concrete-like material poured as a sub-floor or a finished floor. The thermal mass stores heat, distributes between the tubes, and transfers it to the surface of the floor. The thermal mass may be concrete, lightweight concrete (with bubbles in it caused by a foaming agent), or gypsum cement, which is lighter than concrete.

The tubing may be soft copper, rubber, plastic (**PE, PEX, PEX-AL-PEX,** or **PBB**), or a composite of plastic and metal. The type, size, and placement of tubing depend upon the overall system design and the temperature of the water. The tubing should be flexible enough to be laid in one continuous pattern with no joints. Tubing may be tied to wire mesh to keep it from floating to the top of the concrete thermal mass, or it may be stapled or otherwise fastened to the underneath of a floor or subfloor. To avoid heat buildup, hot water tubing should not be placed in areas which will be under low, heavy furniture such as appliances, large bookcases, and entertainment centers. For the same reason, tubing should not be laid under food storage cabinets, as heat can cause spoilage.

THERMAL MASS



Because the temperature of the floor is so important to the heating of the room, a very important variable which must be considered when planning a radiant floor heating system is the type of floor covering that will be used in the room. The owner of the building must be consulted on the matter of floor coverings.

Any covering placed upon the surface of the flooring could block some of the heat and require the water temperature to be raised. While ceramic tile and vinyl floor covering have only small effects on the radiation of the heat, carpeting and carpet pads can have a very significant effect on the design water temperature. The thicker the carpet, the hotter the water will have to be to make up for the blockage of heat.

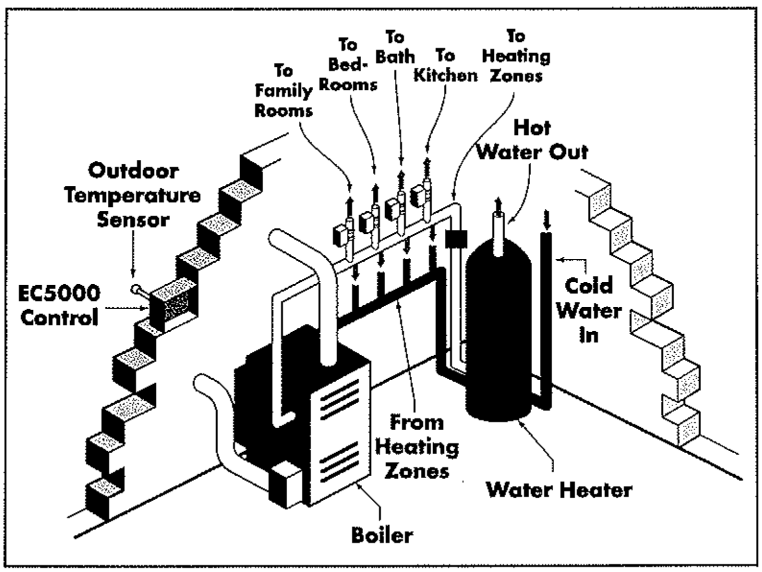
The insulative quality of floor coverings are measured according to their **R-VALUES**. The type of floor covering and the thickness both affect the R-value. The higher the R-value, the more likely the covering will require higher water temperatures.

There are many factors and considerations that go into designing a radiant floor heating system. A well planned system can provide years of comfort for the people using the room or building. To learn more about radiant floor heating systems, contact your company's manufacturers for assistance and take any training they offer.

Zoning

One of the advantages of hot water heat is the ability to provide different amounts of heat to several parts of the building by zoning. A **ZONED SYSTEM** allows the flow of heat to different parts of the building to be regulated by thermostat. The system may use either individual zone circulator pumps or a single system circulator and multiple **ZONE VALVES** (electric or non-electric). Do not confuse zones with multiple circuits. A zoned system may have one or more circuits.

ZONED SYSTEM



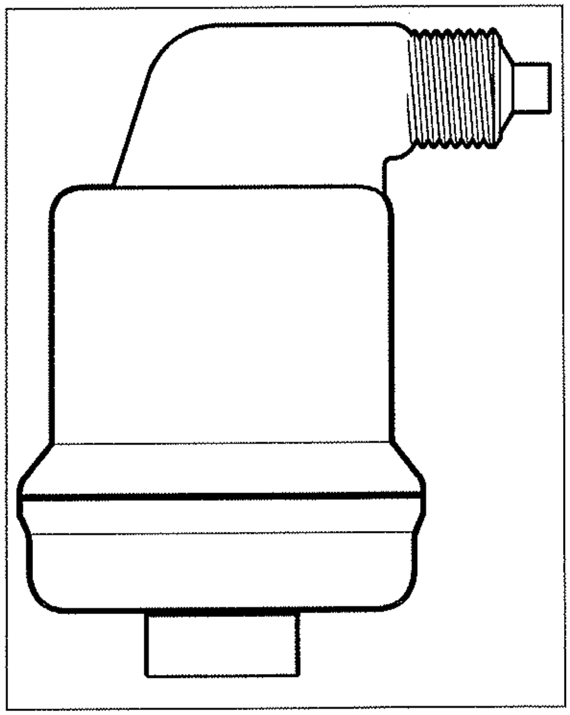
Steel pipe, copper tubing, or plastic tubing are commonly used in hot water comfort heating systems. Galvanized pipe is NOT recommended. For the heating industry, copper tubing is specified by nominal pipe size. This is different from the air conditioning industry, which specifies copper tubing by outside diameter, which is 1/8" more than the nominal size. If the radiation is radiant floor tubing, the tubing may be:

- Soft copper
- Rubber: ethylene propylene diene monomer (EPDM)
- Polyethylene (plastic): either high density polyethylene (HDPE) or cross-linked polyethylene, called **PEX TUBING**
- Composite: made of a thin aluminum (usually) layer sandwiched between two layers of plastic

Air Vents

Air vents should be used at the high points of any piping system to allow the air that is released by the hot water to rise to the top of the system to be vented out. Air in the pipes makes noise and can cause disruption of the heat delivery.

AIR VENT



REVIEW QUIZ OF INTRODUCTION TO HEATING

Answers appear on page 74

1. What are the two most common types of comfort heating systems in use today?
   a. Convection and conduction
   b. Hydronic and radiant
   c. Hydronic and hot air
   d. Forced air and radiant

2. What is one purpose for creating the "circle of warmth" with a hot water heating system?
   a. To replace the heat lost through the walls, floors, ceilings, doors, and windows
   b. To increase the overall heat in the residence
   c. To evenly distribute heat to every floor in the residence
   d. To ensure that the inside walls are warmer than the outside walls to reduce cost

3. The purpose of the Annual Fuel Utilization Index (AFUE) is to
   a. write the code for boiler construction.
   b. provide rating for various hydronic products.
   c. develop a system to test heat emission of boilers.
   d. help consumers estimate efficiency in fuel usage.

4. All of the following are part of a hot water comfort heating system EXCEPT
   a. Boiler
   b. Pump curve
   c. Booster pump
   d. Thermal expansion tank

5. All of the following are factors that determine how much heat is provided by the heating system EXCEPT
   a. the temperature of water leaving the boiler
   b. the amount of water circulating
   c. the design of the system
   d. the location of the boiler

REVIEW QUIZ OF INTRODUCTION TO HEATING

Answers appear on page 74

6. Residential boilers may use any of the following fuels to heat water **EXCEPT**
   a. Diesel oil
   b. Gas
   c. Fuel oil
   d. Electricity

7. The Department of Energy (DOE) rating refers to the amount of
   a. heat energy circulating in the system.
   b. heat available to heat a building.
   c. heat energy from fuel put into the boiler.
   d. heat available from radiation to heat the rooms.

8. Which type of boiler has a copper-finned heat exchanger containing some water surrounded by hot flue gasses?
   a. Water tube boiler
   b. Flash boiler
   c. Fire tube boiler
   d. Condensing boiler

9. What are the two purposes of air control fittings?
   a. To allow for the expansion of water as it heats and to maintain pressure in the system
   b. To keep air out of the main piping system and direct it into the air cushion tank
   c. To separate the water from the air and prevent the air from being absorbed by the water
   d. To allow for the expansion of the water and prevent the water from being absorbed

10. Which measurement does a boiler gauge show?
    a. Amount of air and water in the boiler
    b. Water temperature and pressure in the boiler
    c. Efficiency rating of the boiler
    d. Estimate amount of heat loss in the boiler

REVIEW QUIZ OF INTRODUCTION TO HEATING

Answers appear on page 74

11. Why does an expansion tank become waterlogged?
    a. The air may leak out of the tank or too much air is absorbed in the water.
    b. The diaphragm prevents the air from being absorbed by the water.
    c. The pressure in the boiler is greater than the maximum pressure for which the boiler is rated.
    d. The valve opens and discharges water at a rate which prevents further build up of pressure.

12. A scale drawing showing the location of the boiler and heat emitters and piping arrangement which will connect the boiler and heat emitters is called a
    a. two-pipe system.
    b. series loop system.
    c. piping layout.
    d. hydronic layout.

13. All of the following are common types of piping systems used in hot water heating systems **EXCEPT**
    a. Series loop systems
    b. One-pipe systems
    c. Radiant panel systems
    d. Combined panel systems

14. The major advantage of series loop systems over other piping systems is that they
    a. control the flow of water.
    b. last 30 percent longer.
    c. are easier to install.
    d. are less expensive.

15. Which of the following is a drawback of the series loop piping system?
    a. The size of the water tube in the heat emitter limits the amount of water flow and therefore the amount of available heat.
    b. It has one continuous pipe from the supply side to the return side of the boiler with heat emitters connected by rises to the main.
    c. The amount of heat to each room can be controlled by using a balancing valve in the riser.
    d. The system diverts some of the water from the main to the heat emitters.

REVIEW QUIZ OF INTRODUCTION TO HEATING

Answers appear on page 74

16. An advantage of using multiple zones and multiple circuits is that they
    a. reduce cost by circulating hot water through coils in the floor or ceiling.
    b. employ one continuous pipe from the supply side to the return side.
    c. allow for better control of heat delivered in each section.
    d. use a balancing valve in the rise to control the amount of heat to each room.

17. In which type of system is heat flow controlled to allow for differing amounts of heat in various parts of the building?
    a. Multiple circuit system
    b. Direct return system
    c. Radiant panel system
    d. Zoned system

18. All of the following materials are used for gas piping **EXCEPT**
    a. Copper
    b. Carbon steel
    c. Corrugated stainless steel tubing (CSST)
    d. Galvanized steel pipe

19. In a radiant panel system, heat emitters should be located
    a. above areas of glass and/or along the outside walls of the room.
    b. above areas of glass and/or along the inside walls of the room.
    c. under areas of glass and/or along the outside walls of the room.
    d. under areas of glass and/or along the inside walls of the room.

20. One advantage of using radiant floor heat is that
    a. lower water temperature can be used.
    b. higher water temperature can be used.
    c. it is less expensive than other systems.
    d. installation is easier than other system types.

ANSWERS TO REVIEW QUIZ

CHAPTER 2

INTRODUCTION TO HEATING

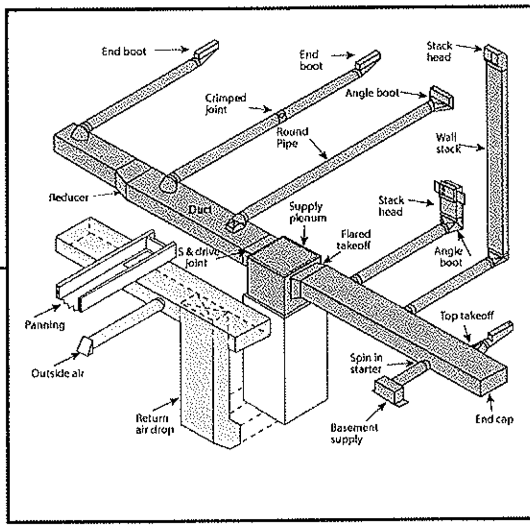
1. c. Hydronic and hot air
2. a. To replace the heat lost through the walls, floors, ceilings, doors, and windows
3. d. help consumers estimate efficiency in fuel usage.
4. b. Pump curve
5. d. the location of the boiler
6. a. Diesel oil
7. c. heat energy from fuel put into the boiler.
8. b. Flash boiler
9. b. To keep air out of the main piping system and direct it into the air cushion tank
10. b. Water temperature and pressure in the boiler
11. a. The air may leak out of the tank or too much air is absorbed in the water
12. c. piping layout
13. d. Combined panel systems
14. d. are less expensive
15. a. The size of the water tube in the heat emitter limits the amount of water flow and therefore the amount of available heat
16. c. allow for better control of heat delivered in each section
17. d. Zoned system
18. d. Galvanized steel pipe
19. c. under areas of glass and/or along the outside walls of the room.
20. a. lower water temperature can be used

3 INTRODUCTION TO VENTILATION / CIRCULATION

LEARNING OBJECTIVES

After successfully completing this chapter, you will be able to:

1. Discuss the purpose of air distribution systems.
2. Define the term "ductwork" and discuss the various materials that may be used in ductwork.
3. Compare and contrast Energy Recovery Ventilators (ERV) with Heat Recovery Ventilators (HRV).
4. Explain what the Minimum Efficiency Reporting Value (MERV) measures and discuss why this is important.
5. Describe the characteristics of the best filters.
6. Identify and evaluate various types of humidifiers.



Air Distribution Systems

AIR DISTRIBUTION SYSTEMS bring conditioned (heated or cooled) air to people occupying a building, and therefore directly affect occupant comfort. Over the last several decades, significant improvements have been made to the design of air distribution systems, as well as to the way in which these systems are controlled. These improved designs and controls can result in dramatic energy savings, yet many buildings continue to rely on obsolete, inefficient systems for this critical function.

You have seen many air distribution systems in houses and public buildings. They consist of **DUCTWORK**, which typically falls into one of three categories: galvanized metal, flexible duct, and ductboard. **GALVANIZED** means coated with zinc, so most of the ductwork you see is zinc-coated steel. In many cases, such as open-ceiling malls and restaurants, the ductwork is left exposed and painted to match the underside of the decking above it. In some cases, the ductwork is painted a contrasting color to add interest to the ceiling space. In most commercial buildings and many homes, the ductwork is hidden above the ceiling.

The **FLEXIBLE DUCT**, also known as flex, is usually a flexible material over a metal wire when used for HVAC. The flexible duct can be insulated, usually with a glass wool with a thin flexible cover over the insulation. It's normally used for short runs, because of greater pressure loss when compared to other types of material.

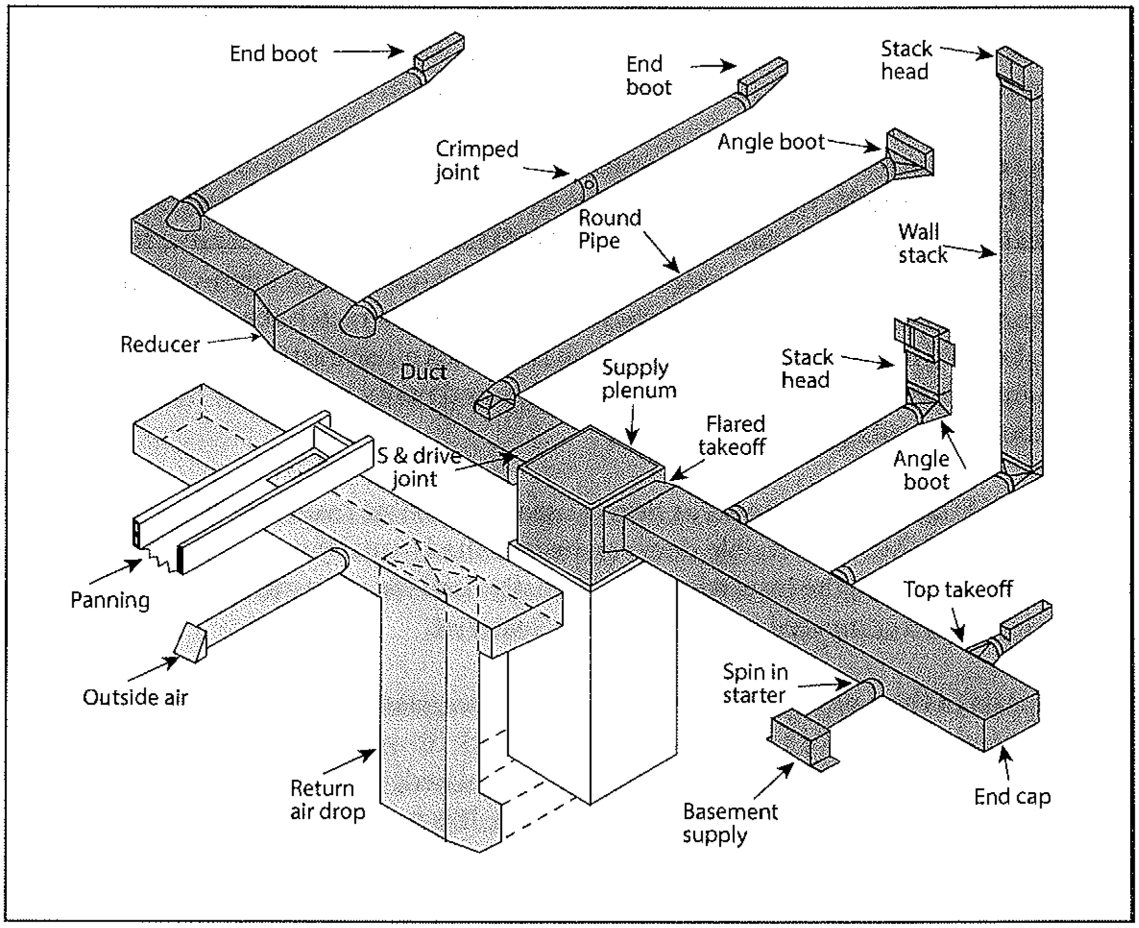
In some parts of the country, it is common to use fiberglass **DUCT BOARD**. This is a foil-faced product made of 1, 1 ½, or 2 inches of thick fiberglass. This material is very light compared to metal ductwork, is inherently insulated, cannot corrode, and does not condensate as much as cold metal surfaces can. It is very labor efficient as it can be designed and built on the jobsite.

Ductwork can also be made of aluminum, stainless steel, plastic, fabric, and even cement. Use of these materials is rare in residential and light commercial installations, although some older homes have aluminum ductwork because of the shortage of steel during WWII. In larger applications, materials other than galvanized are typically used where corrosion is an issue, such as in **NATATORIUMS** (indoor swimming pools) and manufacturing facilities that involve food or have caustic atmospheres.

Ductwork is commonly square, rectangular, or round, though you will see flat oval ductwork in some larger installations. The following graphic illustrates the many components needed to make a typical air distribution system.

Energy Recovery Ventilators (ERVs) and Heat Recovery Ventilators (HRVs)

TYPICAL AIR DISTRIBUTION SYSTEM



The word **VENTILATE** means to bring outdoor air into a building to provide fresh air for the occupants. Opening windows is one way to provide ventilation, but the amount or quality of the air is difficult to control. Most often, ventilation is accomplished using one or more fans located in the air distribution system. When air is brought into a building, the same amount of air must be exhausted. Otherwise, the building would become pressurized and the ventilation fan could no longer deliver fresh air.

During the heating season, the outdoor air brought in for ventilation is often very cold and must be heated before it can be distributed to occupied spaces. And during the cooling season, the outdoor air must be cooled, and if the climate is humid, it must also be dehumidified. This all takes a tremendous amount of energy.

During the heating season, **ENGERY RECOVERY VENTILATORS (ERVs)** and **HEAT RECOVERY VENTILATORS (HRVs)** are used to transfer heat energy from the warm exhaust airstream to the cold fresh airstream, so the fresh air is "preheated" before it is circulated through the air distribution system. This reduces the load on the heating system and saves energy. During the cooling season, ERVs and HRVs transfer heat energy from the fresh airstream to the exhaust airstream, so that the heat from the hot outdoor air is carried back outdoors with the exhaust air. In effect, this "precools" the hot outdoor air and reduces the load on the cooling system.

So, what's the difference between an Energy Recovery Ventilator (ERV) and a Heat Recovery Ventilator (HRV)? The HRV captures only sensible heat. As you learned earlier, sensible heat involves the transfer of energy that changes temperature. In other words, HRVs can transfer heat energy only.

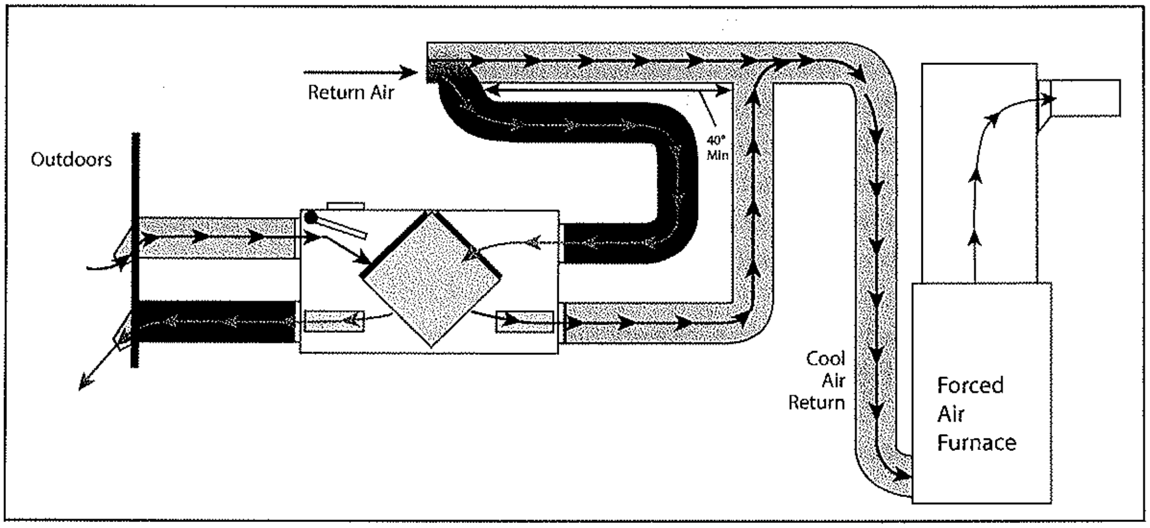
ERVs also transfer some of the water vapor from one airstream to another. You will remember that the energy used to vaporize or condense water is called "latent heat." So ERVs transfer both sensible and latent heat, while HRVs can only transfer sensible heat. You might hear an ERV called an *enthalpy recovery ventilator* because it captures total enthalpy and not just sensible heat.

You would use an HRV if you lived in a cold climate, because the cold outdoor air is very dry and you would be most interested in exchanging heat energy. But if you lived in a hot climate with a long cooling season, you would use an ERV because the outdoor air must be both cooled and dehumidified.

Both devices look very similar from the outside. The difference is found in the heat exchanger core. HRVs use numerous aluminum or plastic plates to separate the two airstreams. These plates can transfer up to 85% of the sensible heat from one airstream to the other.

ERVs use a plate in the heat exchanger that allows water vapor to pass through. Because the air on one side of the plate (exhaust air during the summer) is drier than the air on the other side of the plate (hot humid outside air), water vapor is drawing through the plate due to the difference in vapor pressure between the two surfaces. The plates are typically made of a special polymer membrane, some of which are washable to maintain efficiency. ERVs can transfer about 80% of the sensible heat and 40% of the latent heat between the two air streams.

TYPICAL HRV OR ERV INSTALLATION



Filters

Air cleaning is a critical step in maintaining the efficiency of any HVACR system. The key to efficient operation is efficient heat transfer through heat exchangers in furnaces and coils in air conditioners, condensing units, and air handling units. Dirt buildup on any heat exchange surface acts as an insulator and slows down the transfer of energy. This means that systems must work longer, and that increases wear and tear and uses more energy.

FILTERS are the key to keeping systems and equipment clean. Air filters are rated according to the **MINIMUM EFFICIENCY REPORTING VALUE (MERV)**. MERV ratings vary from 1 to 20, with higher numbers offering greater filtering. Greater filtering ability comes at a cost, however. Filters that do a better job also have a greater pressure drop across them. This means that the fan has to work harder to move air through the filter, and this costs more energy. Not all manufacturers use the MERV rating system. For example, 3M uses a system they call the **MICROPARTICLE PERFORMANCE RATING (MPR)**. This filter rating system only takes into account the tiny microscopic particles between 0.3 and 1 microns, which is actually based on one of the tests used to establish a MERV rating. Some of the particles that fall in this range are:

- All bacteria
- Droplet nuclei (sneeze)
- Cooking oil
- Most smoke
- Insecticide dust
- Most face powder
- Most paint pigments

These rating systems are a good gauge when comparing other filters that use the same rating system.

Digging Deeper

You will see many kinds of filters. As you would expect, those with low MERV ratings cost less. The Minimum Efficiency Reporting Value (MERV) Parameters Table, is provided by the Environmental Protection Agency (EPA) and provides a summary of various types of filters and their MERV ratings. You will see three columns under the label *Particle Size Removal Efficiency, Percent in Particle Size Range, µm*. These columns measure the size of dust particles in **microns (µm)**. A micron is the same thing as a micrometer, which is one millionth of a meter. There are 25,400 microns in one inch. To give you an idea of how big some things are in microns, a human hair is 40 to 300 microns in diameter, pollens range from 10 to 1000 microns, and typical atmospheric dust ranges from 0.001 to 30 microns.

To interpret the numbers you see in the three columns for particle sizes (0.3 to 1 µm, 1 to 3 µm, and 3 to 10 µm) are percentages of efficiency for capturing particles of dust in that size range. For example, the most efficient filters are **ULTRA LOW PENETRATION AIR (ULPA)** and **HIGH EFFICIENCY PARTICULATE AIR (HEPA)**. You will find them in the top rows of the table. They have MERV ratings ranging from 17 to 20 (which is above the normal rating scale) and they can catch up to 99.99% of particles ranging from 0.3 to 1 µm in size.

MINIMUM EFFICIENCY REPORTING VALUE (MERV) PARAMETERS TABLE

ASHRAE Standard 52.2				ASHRAE Standard 52.1	Application Guidelines		
MERV	Particle Size Removal Efficiency, Percent in Particle Size Range, µm: 0.3 to 1	1 to 3	3 to 10	Dust-Spot Efficiency Percent	Particle Size and Typical Controlled Contaminant	Typical Applications	Typical Air Filter/Cleaner Type
20	≥ 99.999	in 0.1 - 0.2 µm particle size		—	< 0.3 µm • Virus (un attached) • Carbon Dust • Sea Salt • All combustion smoke	• Electronics manufacturing • Pharmaceutical manufacturing • Carcinogenic materials	HEPA/ULPA Filters*
19	≥ 99.999	in 0.3 µm particle size		—			
18	≥ 99.99			—			
17	≥ 99.97			—			

16	> 95	> 95	> 95	—	**0.3-1 µm** • All bacteria • Droplet nuclei (sneeze) • Cooking oil • Most smoke • Insecticide dust • Most face powder • Most paint pigments	• Superior commercial buildings • Hospital inpatient care • General surgery	**Bag Filters** - Non supported (flexible) microfine fiberglass or synthetic media, 12 to 36 inches deep. **Box filters** - Rigid style cartridge, 6 to 12 inches deep.
15	85-95	> 90	> 90	> 95			
14	75-85	> 90	> 90	90-95			
13	< 75	> 90	> 90	80-90			
12	—	> 80	> 90	70-75	**1-3 µm** • Legionella • Humidifier dust • Lead dust • Milled Flour • Auto emission particles • Nebulizer drops	• Superior residential • Better commercial buildings • Hospital laboratories	**Pleated filters** - Extended surface with cotton or polyester media or both, 1 to 6 inches thick. **Box Filters** - Rigid style cartridge, 6 to 12 inches deep.
11	—	65-80	> 85	60-65			
10	—	50-65	> 85	50-55			
9	—	< 50	> 85	40-45			
8	—	—	> 70	30-35	**3-10 µm** • Mold Spores • Dust mite body parts and droppings • Cat and dog dander • Hair spray • Fabric protector • Dusting aids • Pudding mix	• Better residential • Commercial buildings • Industrial workspaces	**Pleated filters** - Extended surface with cotton or polyester media or both, 1 to 6 inches thick **Cartridge filters** - Viscous cube or pocket filters **Throwaway** - Synthetic media panel filters
7	—	—	50-70	25-30			
6**	—	—	35-50	< 20			
5	—	—	20-35	< 20			
4	—	—	< 20	< 20	**> 10 µm** • Pollen • Dust mites • Cockroach body parts and droppings • Spanish moss • Sanding dust • Spray paint dust • Textile fibers • Carpet fibers	• Minimum filtration • Residential window air conditioners	**Throwaway** - Fiberglass or synthetic media panel, 1 inch thick **Washable** - Aluminum mesh, foam rubber panel **Electrostatic** - Self-charging (passive) woven polycarbonate panel
3	—	—	< 20	< 20			
2	—	—	< 20	< 20			
1	—	—	< 20	< 20			

*This table extracted from EPA (*http://www.epa.gov/iaq/pdfs/residential_air_cleaners.pdf*) as adopted ANSI/ASHRAE Standard 52.2-2007.*

**The last four MERV values of 17 to 20 are not part of the official standard test, but have been added by ASHRAE for comparison purposes. Ultra Low Penetration Air filters (ULPA) have a minimum efficiency of 99.999 percent in removing 0.3 µm particles, based on the IEST test method. MERVs between 17 and 19 are rated for 0.3µm particles, whereas a MERV of 20 is rated for 0.1 to 0.2 µm particles.*

*** For residential applications, the ANSI/ASHRAE Standard 62.2-2007[16] requires a filter with a designated minimum efficiency of MERV 6 or better.*

Humidifiers

During periods of low humidity, typically during the heating season, when the air is especially dry, **HUMIDIFIERS** are used to add humidity to a building. When air is heated, its relative humidity drops and it feels even drier.

You will find most humidifiers are designed to be mounted in the air distribution system so they can humidify the entire building. Others are self-contained and can be used in buildings without an air distribution system.

Some humidifiers are called **EVAPORATIVE HUMIDIFIERS**. These devices use some sort of wetted media. Dry air is circulated through or around the media and water is evaporated into the air.

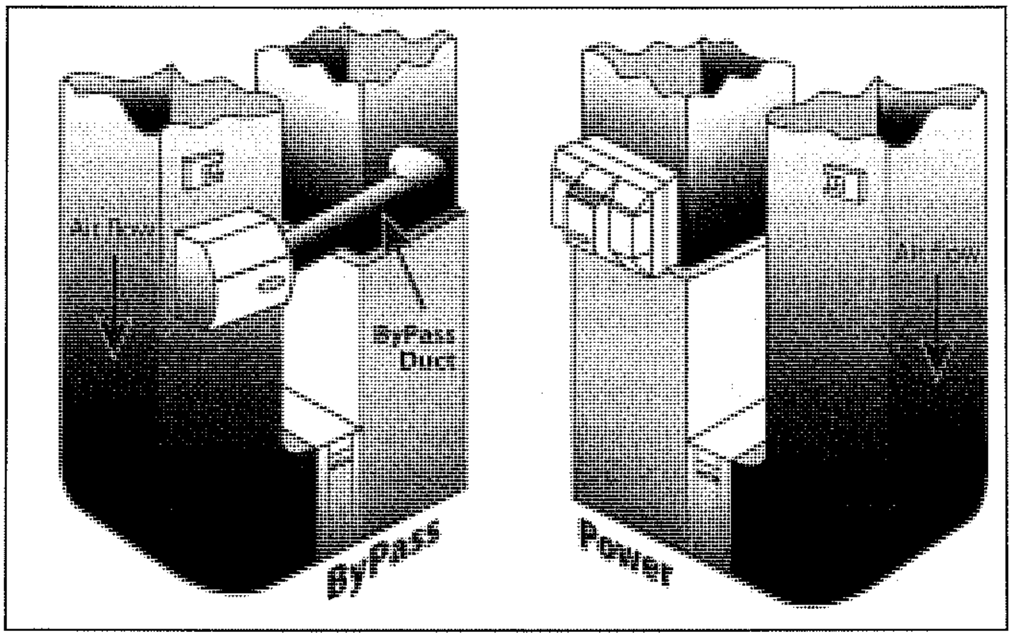
An **UNDER-DUCT HUMIDIFIER** can be found in two styles. As you would expect, a hole is cut into the bottom of the duct and these are mounted to the bottom of the duct so that the wetted media extends into the duct. One style is a **DRUM-TYPE** humidifier, which uses a drum that rotates using a small electric motor. The drum is covered with a sponge-type material and rotates into a reservoir of water that is evaporated when the sponge rotates through the warm air stream.

The other style is a **DRIP-TYPE** humidifier. It uses a pad instead of a drum. You can see a hose leading to the top of the pad. A solenoid valve opens when the blower starts to allow a small amount of water to dribble down through the pad. Air that circulates around the pad evaporates water from the pad.

PLENUM-MOUNT HUMIDIFIERS are designed to mount to the side of the **FURNACE PLENUM**. A furnace plenum is a metal box, attached to the furnace, which connects the furnace to the supply side or return side duct work. You can see a couple examples of plenum-mount humidifiers in the next figure. On the right is a **POWER HUMIDIFIER**. It has its own blower and fan to circulate and supply air to the air distribution system.

Below is a **BYPASS HUMIDIFIER** (also known as *flow-through humidifiers*). It is mounted to the return air duct. It can also be mounted to the supply air plenum. Because the supply air plenum is under positive pressure and the return air duct or plenum is under negative pressure, air is forced to flow through the humidifier from the supply air plenum, through the round duct, and into humidifier on the return air duct. As the air passes through the humidifier, it evaporates water from a drip pad in the humidifier. This humid air is then drawn into the return air duct. From there it is drawn into the main blower and circulated through the air distribution system to the entire building. Plenum-mount humidifiers can be the drum or pad (drip) type.

PLENUM-MOUNT HUMIDIFIERS



Although not nearly as common, steam humidifiers or atomizing humidifiers are sometimes used. **STEAM HUMIDIFIERS** inject steam directly into the airstream. These eliminate the need for the airstream to evaporate moisture from some media, but they require a device to make the steam. Cost makes these impractical for most residential and light commercial applications. The **ATOMIZING HUMIDIFIER** sprays very small droplets of water into the airstream, where they are quickly evaporated. One type of atomizing humidifier uses a spray nozzle to create the tiny droplets. Another, called the **CENTRIFUGAL ATOMIZING HUMIDIFIER** uses a wheel (slinger or impellor) to spin water and break it into tiny droplets. Like steam dehumidifiers, these devices are expensive and typically not seen in smaller applications. They also require very clean water.

All humidifiers have rather high maintenance requirements. Minerals in water are left behind when water evaporates, clogging the humidifier media. Pads, drums, and discs must be replaced like furnace filters when they become clogged.

Some humidifiers use floats to maintain water level in the reservoir. Others use solenoid valves that allow water to flow through the humidifier only when the circulating fan is running. Drum and disc-type humidifiers have small electric motors to turn the drum or disc. You will most commonly see humidifier media replaced. But the motors, transformers, solenoid valves, nozzles, float assemblies, relays, and water feed tubes are all susceptible to failure and could also need replacement.

Dehumidification

As more people become more conscious of energy and the environment, there is an increase in interest in lower-cost ways to dehumidify the air. A typical air conditioning system uses the cooling coil to wring moisture from the air. Keep in mind that any time air is cooled below its dew point, water vapor from the air will be condensed into water and the air will become drier. This is the most common method of drying air (*dehumidification*), but it is limited to a dew point of about 40°F. This limitation also limits the amount of moisture that can be removed.

Another way to dry air uses a desiccant. A **DESICCANT** is simply something that has an affinity for water, which means it attracts and holds water vapor. If you think about it, you realize that most materials are desiccants. For example, wood, soil, and fibers such as wool all hold water vapor. Commercial desiccants are used for their ability to hold a great deal of water – up to 1100% of their dry weight! Desiccants are also used for their ability to be regenerated or renewed.

Desiccants attract and hold moisture by either adsorption or absorption. In the **ADSORPTION** process, the desiccant does not change, other than adsorbing water. A sponge is a good example of something that adsorbs water without changing. With **ABSORPTION**, the water changes the desiccant. For example, when salt absorbs water, it changes from a solid to a liquid.

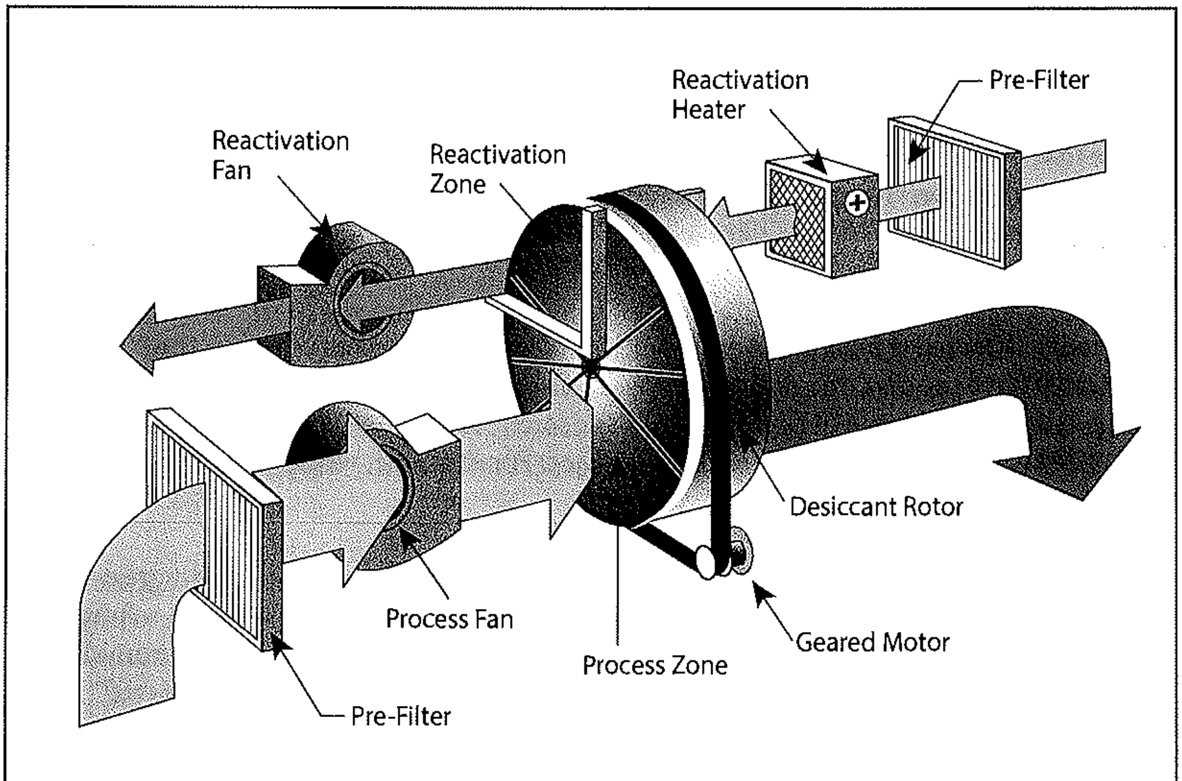
Let's compare a sponge to a desiccant. When the sponge is dry, it can adsorb a great deal of water. Once the sponge is **SATURATED** (or soaked up all it can), it must be wrung out so that it can adsorb more. Wringing out a sponge regenerates it. Desiccant dehumidifiers work in a similar manner. They adsorb water from the air, but must be "wrung out" (regenerated) so they can adsorb more.

A desiccant dehumidifier typically uses a wheel or rotor made of layers of pleated sheets impregnated with a desiccant material, such as silica gel. You have probably seen little bags of **SILICA GEL**, a granular, vitreous, porous form of silicon dioxide made synthetically from sodium silicate, in some products you buy. Silica gel packets are placed in the packing material to adsorb any moisture that may degrade the product. After you open your new product, you discard the packet. But, in a dehumidifier, the desiccant must be regenerated and reused.

With many dehumidifiers, heat is used to "dry out" the desiccant. When the desiccant is heated, the water that has been "soaked up" vaporizes and is carried away as water vapor by an airstream. This "dries out" the desiccant and readies it to adsorb more moisture. Thus, the desiccant in a dehumidifier is used over and over again.

The figure below represents a very common type of desiccant dehumidifier. You can see the wheel or rotor that we described earlier. Notice that the wheel is rotated using a belt driven by a small motor. It rotates through two airstreams that are separated from one another by ducting. **DAMP AIR**, also called *process air*, is air that has a high relative humidity. This air flows through one portion of the wheel. In the drawing, this area is shown as three quarters of the wheel's area. In other designs, the process air flows through only half of the wheel.

DESICCANT DEHUMIDIFIER



As the process air flows through the wheel, moisture from the air is transferred to the desiccant infused in the wheel. This dries the air. During the process, the desiccant becomes saturated and must be reactivated before it can adsorb any more moisture.

Eventually, the portion of the wheel that is saturated rotates through the reactivation zone. You can see this zone in the drawing as one-quarter of the wheel's area, and you can see that the air flowing through this zone is first heated. This does two things. It enables the air to hold more moisture, and it helps the water adsorbed in the desiccant to evaporate. This *reactivates* (or dries) the desiccant on the wheel before it rotates back into the process area so it can once again adsorb moisture from the process air.

The reactivation air becomes moist as it flows through the reactivation zone and is exhausted from the building. The process air becomes drier as it flows through the process zone and is circulated to the conditioned space of the building.

Like other HVACR equipment, there are many designs of desiccant dehumidifiers. In some models, the wheel revolves as slow as only three times every hour. Others revolve from 10 to 30 rotations per hour. Others spin as fast as 20 to 60 revolutions per *minute*.

The desiccant dehumidifiers we have discussed so far use an active desiccant wheel. This means that they use heat to regenerate the desiccant. Another kind of dehumidifier is known as a **TOTAL-ENERGY WHEEL** (often called an *enthalpy wheel*). This type of desiccant dehumidifier is used to transfer both heat and moisture from outdoor air brought into a building for ventilation, to an exhaust airstream that is vented to the outside.

What happens with a total-energy wheel is during the winter, heat and moisture from the warm moist exhaust air is transferred to the cold dry air that is brought into the building for ventilation. During the summer, heat and moisture from the hot humid outside air is transferred to the air exhausted from the building, which has already been cooled and dehumidified by the building's air conditioning system. This type of energy wheel does not heat an airstream to reactivate the desiccant. Instead, these devices rely on the warm air that is either leaving or entering the building to do the job.

REVIEW QUIZ OF VENTILATION / CIRCULATION

Answers appear on page 94

1. What is the purpose of an air distribution system?
   a. Cools the air in a residence or small commercial building
   b. Provides greater energy savings over other types of systems
   c. Brings conditioned air the to occupants of a building
   d. Reduces the amount of time needed to condition the air

2. Air distribution systems consist of ductwork which is most often made from
   a. concrete.
   b. fiberglass duct board.
   c. galvanized sheet metal.
   d. plastic.

3. The term "galvanized" means the material is coated with
   a. stainless steel.
   b. aluminium.
   c. zinc.
   d. copper.

4. All of the following are typical components of an air distribution system **EXCEPT**
   a. Supply plenum
   b. Humidifier
   c. Duct
   d. Reducer

5. What is the major difference between an Energy Recovery Ventilator (ERV) and a Heat Recovery Ventilator (HRV)?
   a. The ERV captures only sensible heat.
   b. The ERV captures only latent heat.
   c. The HRV captures only latent heat.
   d. The HRV captures only sensible heat.

6. Would you use an HRV or an ERV if you lived in hot climate?
   a. You would use an ERV because it cools and dehumidifies the outside air.
   b. You would use an HRV because it cools and humidifies the air.
   c. You would use both an HRV and an ERV because even in a hot climate, some days can be cool.
   d. You would use an ERV because it both heats and cools the inside air.

REVIEW QUIZ OF VENTILATION / CIRCULATION

Answers appear on page 94

7. If you have two filters, one with a MERV rating of 5 and the other with a MERV rating of 8, which is the better filter?
   a. The filter with a MERV rating of 8 is better because higher numbers translate to more effective air filtration.
   b. The filter with a MERV rating of 5 is better because lower numbers translate to more effective air filtration.
   c. The MERV rating between 5 and 8 is virtually the same so there is no real difference between these filters.
   d. The MERV rating does not measure "better" or "worse" because all filters are efficient when used properly.

8. Plenum-mount humidifiers are designed to mount to the side of which of the following?
   a. Furnace plenum
   b. Draft hood
   c. Blower chamber
   d. Heat exchanger

9. 3M developed a filter rating that only takes into account the tiny microscopic particles between 0.3 and 1 microns. What is 3M's rating system called?
   a. Minimum Efficiency Reporting Value (MERV)
   b. Ultra Low Penetration Air (ULPA)
   c. Microparticle Performance Rating (MPR)
   d. High Efficiency Particle Air (HEPA)

10. What is the term for the unit of length equal to one millionth of a meter?
    a. Nuclei
    b. Micron
    c. Kilometer
    d. Centimeter

11. What happens to dry air when it is heated?
    a. When dry air is heated, its relative humidity drops and it feels even drier.
    b. Heat caused the air to become more humid.
    c. When dry air is heated, the air becomes more moist.
    d. Dry air is circulated through the heater and condenses.

REVIEW QUIZ OF VENTILATION / CIRCULATION

Answers appear on page 94

12. Which of the following are the two types of under-duct humidifiers?
    a. Plenum-mount and power humidifiers
    b. Power and drum-type humidifiers
    c. Bypass and drip-type humidifiers
    d. Drum-type and drip-type humidifiers

13. What is another name for a bypass humidifier?
    a. Flow-through humidifier
    b. Steam humidifier
    c. Evaporative humidifier
    d. Atomizing humidifier

14. Centrifugal atomizing humidifiers not commonly used in smaller applications because they are
    a. too noisy.
    b. larger than most other types of humidifiers.
    c. too expensive.
    d. difficult to keep clean.

15. Which of the following elements in a typical humidifier is used to wring moisture from the air?
    a. Cooling coil
    b. Circulating fan
    c. Solenoid valves
    d. Relays

16. "Adsorption" is the process by which molecules of a substance collect on the surface of another substance. "Absorption" is the process by which one substance takes up another substance through minute pores or spaces between its molecules.
    a. True
    b. False

17. All of the following items are desiccants **EXCEPT**
    a. Wood
    b. Soil
    c. Fiber
    d. Plastic

REVIEW QUIZ OF VENTILATION / CIRCULATION

Answers appear on page 94

18. What is one characteristic of damp or process air?
    a. It dries out the desiccant.
    b. It has a high relative humidity.
    c. It has a low relative humidity.
    d. It lacks any humidity.

19. All of the following are components of a desiccant humidifier EXCEPT
    a. Process zone
    b. Reactivation zone
    c. Bypass duct
    d. Pre-filter

20. Which of the following is the most likely to reduce the efficiency of any HVACR system?
    a. Air cleaning
    b. Dirt buildup
    c. Filters
    d. Humidifiers

ANSWERS TO REVIEW QUIZ

CHAPTER 3

VENTILATION / CIRCULATION

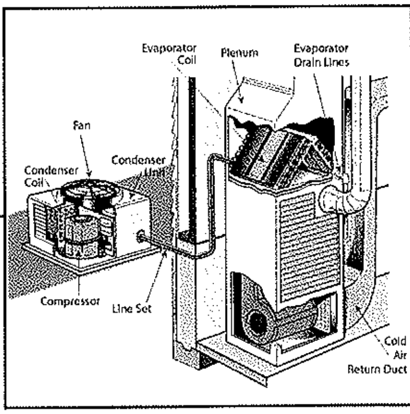
1. c. Brings conditioned air the to occupants of a building
2. c. galvanized sheet metal
3. c. zinc
4. b. Humidifier
5. d. The HRV captures only sensible heat
6. a. You would use an ERV because it cools and dehumidifies the outside air.
7. a. The filter with a MERV rating of 8 is better because higher numbers translate to more effective air filtration.
8. a. Furnace plenum
9. c. Microparticle Performance Rating (MPR)
10. b. Micron
11. a. When dry air is heated, its relative humidity drops and it feels even drier.
12. d. Drum-type and drip-type humidifiers
13. a. Flow-through humidifier
14. c. too expensive
15. a. Cooling coil
16. a. True
17. d. Plastic
18. b. It has a high relative humidity.
19. c. Bypass duct
20. b. Dirt buildup

4 INTRODUCTION TO AIR CONDITIONING AND REFRIGERATION

LEARNING OBJECTIVES

After successfully completing this chapter, you will be able to:

1. Compare the adsorption cycle to the vapor compression cycle.
2. Explain the air conditioning process and describe several types of unitary equipment used in residential and light commercial applications.
3. Compare high temperature, medium temperature, and low temperature refrigeration.
4. Calculate coefficient of performance (COP) and explain what it measures.
5. Discuss the purpose of compressors and compare hermetic, semithermetic, and open drive compressors.
6. Discuss the functions of an evaporator.
7. Compare thermostatic expansion valves to electronic expansion valves.
8. Describe the purpose of various service valves.
9. Describe and compare CFC refrigerants, HCFC refrigerants, HCF refrigerants, HC refrigerants, and refrigerant blends.



Overview of Air Conditioning and Refrigeration

Unlike the days when cooling took place with chucks of ice cut from lakes and rivers, modern cooling uses mechanical cooling systems. Mechanical cooling uses one of two refrigeration cycles: the absorption cycle or the vapor compression cycle. If you have seen a refrigerator that runs on propane in a recreational vehicle (RV), you have seen a system that uses an **ABSORPTION CYCLE**. While refrigerators used in RVs (and some large chillers) employ the absorption cycle, most air conditioning and refrigeration systems used today employ the **VAPOR COMPRESSION CYCLE**. Most supply houses stock components for vapor compression cycle machines and leave it up to the manufacturers to supply parts for absorption equipment.

Most of your customers work on vapor compression cycle equipment and will refer to vapor compression as the "refrigeration cycle." Very few of your customers will have even heard of an absorption cycle. Therefore, this chapter will focus on the vapor compression cycle only, and we will call it simply the "refrigeration cycle." Remember that it is impossible to "make cold." Instead, air conditioning and refrigeration systems act much like a sponge used to remove water from a surface. A sponge simply absorbs water and moves it to another place where it is wrung out. In simple terms, an air conditioner absorbs heat energy from inside a building and moves it outside. A refrigerator absorbs heat energy from inside the refrigerator and moves it to the kitchen. Both systems "pump" heat energy from one point to another. The point where the heat energy is absorbed gets cooler and the point where the heat energy is "wrung out" gets warmer.

The Refrigeration Cycle

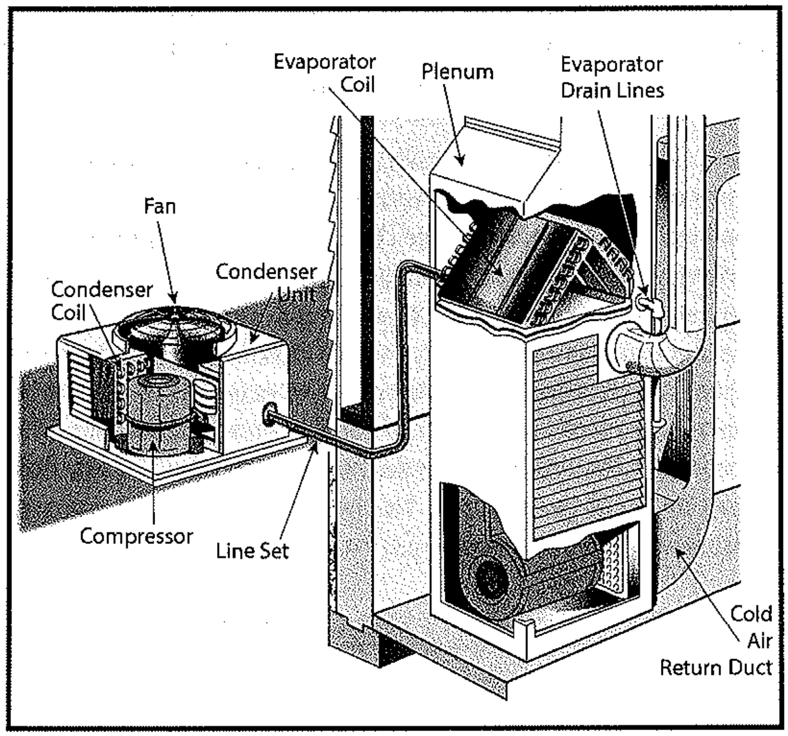
Refrigeration and air conditioning systems both use a **REFRIGERATION CYCLE**. During the cycle, a fixed supply of refrigerant in a closed system is continuously circulating, evaporating, and condensing. In air conditioning, the refrigeration cycle is used for human comfort, i.e., to cool people. In refrigeration, the refrigeration cycle cools products or processes. Restaurants, grocery stores, bars, and other businesses use walk-in coolers and freezers to keep products cold. We all shop at grocery stores where we get our eggs, dairy products, and frozen foods from display cases. Large fruit storage facilities use warehouse-sized refrigerated buildings to store and preserve products. These are all examples of commercial or industrial refrigeration applications.

These systems share similar components with residential refrigerators and freezers and air conditioners, but are designed for different purposes and use different temperatures. Even though all refrigeration systems are designed to cool, they are classified as high, medium, or low temperature applications. In the coming sections, we will discuss the components that enable equipment to keep people and products cool.

Air Conditioning

In reality, **AIR CONDITIONING** involves heating, humidifying, dehumidifying, and cleaning air. What we call an "air conditioner" is really a heat pump—it pumps energy from one place to another. In the process, the place that lost energy cools down, while the place that receives energy warms up. Because our society calls a refrigeration cycle used to cool people "air conditioners," we will use that term in this text.

SPLIT-SYSTEM

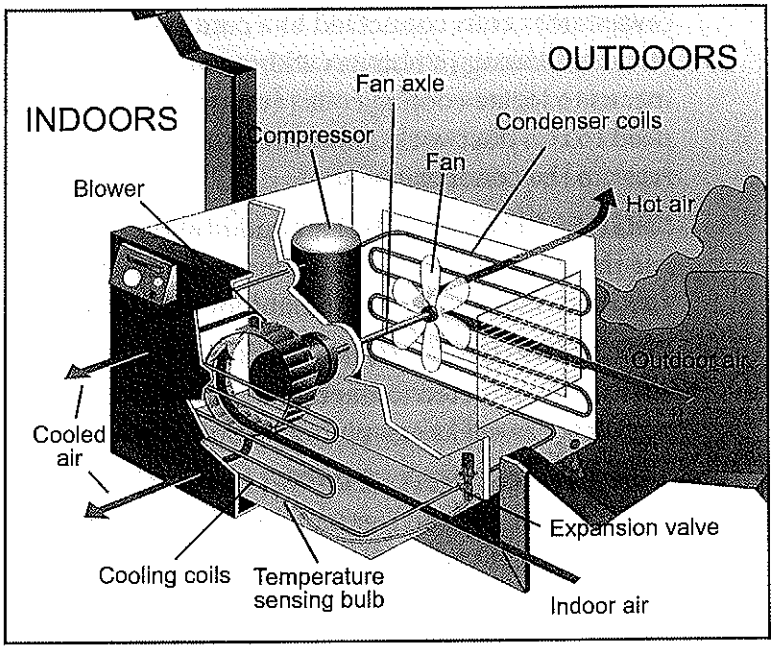


UNITARY AIR CONDITIONERS contain an evaporator (cooling coil), a compressor, and a condenser. Often, unitary equipment also provides heating using fossil-fuel burners (natural gas or propane) or electric resistance coils. **SPLIT-SYSTEMS** are unitary systems delivered in more than one factory-assembled component. A typical central air conditioning system for a home is an example of a split-system. Residential split-systems consist of two parts: the condensing unit, which houses the compressor and condenser, and the indoor unit, which includes the evaporator and metering device. A technician must connect these systems, usually with a **LINE SET**, which consists of two soft copper coils in standard lengths, typically ranging from 15 to 50 feet. A larger tube (usually 3/4, 7/8, or 1 1/8 inches in diameter), called the **SUCTION LINE**, carries refrigerant vapor from the evaporator (located inside) to the suction side of the compressor (located outside). The suction line is always insulated.

A smaller tube (the **LIQUID LINE**) is usually 3/8 inches in diameter and carries liquid refrigerant from the discharge side of the condenser to the metering device located inside next to the evaporator. Sometimes the liquid line is insulated. Some line sets come **PRECHARGED** with refrigerant, while others do not. The field connection required for split-systems can be a source of leaks and is a disadvantage of this equipment.

PACKAGED EQUIPMENT, such as window air conditioners and **ROOFTOP UNITS (RTUs)**, comes in one piece with a full charge of refrigerant and all connections made at the factory. Packaged units have the inherent advantage of being completely factory-built. This eliminates the chance of poor connections made in the field, as is the case with split-systems.

WINDOW AIR CONDITIONER



Air Conditioning Unit by Ryan Wilson
http://upload.wikimedia.org/wikipedia/commons/f/f2/Air_conditioning_unit-en.svg

The unitary market consists of three sectors: residential, light commercial, and commercial. **RESIDENTIAL SYSTEMS** use single-phase electricity (usually 220 volts for the condensing unit and 110 volts for the inside unit) and have cooling capacities of 65,000 Btu/h (about 5 ½ tons) or less. **LIGHT COMMERCIAL EQUIPMENT** serves small businesses and ranges from 65,000 Btu/h up to 135,000 Btu/h (11 ¼ tons) and can be either single-phase or three-phase, although three-phase is more common. **COMMERCIAL EQUIPMENT** provides capacities larger than 135,000 Btu/h and serves large commercial buildings.

Your company may stock unitary equipment in many configurations, some of which are listed below.

- **WINDOW AIR CONDITIONERS:** Designed to install through an open window, these units feature a partition that separates the inside unit from the outside unit. The inside unit contains the evaporator, while the condenser and compressor are housed outside the partition. Some provide heating as well, typically using electric resistance heat.
- **PACKAGED TERMINAL AIR CONDITIONERS (PTACs):** Also known as *room air conditioners* or *through-the-wall air conditioners*, these units are similar to a window air conditioner, except these are designed to be semi-permanently or permanently installed through the wall, typically through a sleeve. Capacities can be larger than window units.

- **DUCTLESS MINI-SPLIT:** These units feature one or more wall or ceiling mounted evaporator coils connected to a common condensing unit. Often used for retrofit air conditioning in homes without an existing duct system, mini-splits provide a means to locate cooling coils (evaporators) throughout the building without the need to run ductwork. However, refrigerant lines must be routed from each evaporator to the condensing unit.
- **SPLIT-SYSTEM:** Central air conditioning systems in most residential applications use the split-system, which features an indoor unit consisting of the evaporator and metering device and an outdoor unit with the condenser and compressor.
- **ROOFTOP UNITS (RTUs):** Self-contained packaged units are mounted to a roof curb and connected to ducting to distribute air. An electrical connection is also required, as well as gas-piping if equipped with burners for heating.
- **AIR-SOURCE HEAT PUMPS (ASHPs):** Reversible air conditioners can heat and cool by reversing refrigerant flow. During heating mode, the indoor coil receives hot refrigerant vapor from the compressor, while the outdoor coil is supplied with cold refrigerant, which adsorbs energy from the surrounding air. During cooling mode, the indoor coil is supplied with cold refrigerant that adsorbs energy from inside air, while the outdoor coil receives hot refrigerant vapor from the compressor and rejects energy to the surrounding air.
- **WATER-SOURCE HEAT PUMPS (WSHPs):** These operate like the air-source heat pump, except water is used as a heat source for heating and a heat sink for cooling. The water source can be a lake, stream, well, or close-loop arrangement coupled with the earth.
- **VARIABLE REFRIGERANT FLOW (VRF) HEAT PUMPS:** Relatively recent to the market, VRF heat pumps are similar to mini-split systems in that multiple indoor **DX COILS** are supplied by a single condensing unit. DX coils are finned coils which circulate refrigerant. VRF heat pumps and mini-split systems differ in the number of coils that can be connected. Where mini-splits are typically limited to a small number of zones, 30 or more indoor DX coils can be supplied with refrigerant from a single condensing unit. Furthermore, these systems can heat and cool simultaneously by using hot refrigerant gas in some coils while cold refrigerant circulates to others.

Refrigeration

At first, **HIGH TEMPERATURE REFRIGERATION** sounds like a contradictory term. However, it helps us differentiate between the different temperatures used in the refrigeration industry. High temperature applications cool to temperatures above approximately 45°F, such as a florist cooler or a wine cooler. Flowers keep best at a temperature of about 45°F, so florist coolers have temperature of 45°F. Wine keeps best at about 55°F, so wine coolers maintain at roughly 55°F to mimic a wine cellar, which naturally maintains the cool temperature of the earth below ground.

MEDIUM TEMPERATURE REFRIGERATION cools to temperatures from above the freezing point of water (32°F) to about 45°F. Most refrigerated foods are kept in medium temperature applications, such as a refrigerator, at temperatures ranging from just above freezing (34 - 35°F) to no more than about 38°F.

LOW TEMPERATURE REFRIGERATION cools to below the freezing temperature of water (32°F). Most low temperature systems operate at temperatures well below 32°F. In commercial applications, frozen food should not be stored above 0°F. Most food is stored commercially between -13°F and -4°F, though some foods require colder temperatures, for example ice cream keeps best between -24°F and -13°F. Residential freezers hold temperatures between about 0°F and 9°F.

Efficiency Ratings

The cooling industry has a number of ways to rate the efficiency of air conditioners. Unlike cars whose efficiency is in miles per gallon (mpg) the cooling industry's rating is not so simple. In this section, you will learn about the different efficiency ratings. None of the ratings are perfect because they are based on "standard" conditions rather than "real world" conditions. On one hand, this forces all manufacturers to test their equipment under the same conditions. On the other hand, actual performance may vary. In other words, no matter which rating you use, you can only use it to compare equipment efficiency. You cannot use the rating to predict actual operation.

The term **kW/ton** means kilowatt per ton (12,000 Btu/h) of cooling. Larger commercial and industrial cooling systems (chillers) are commonly rated in this way. This rating tells us how much power (kW) is required for the machine to produce a ton of cooling. The lower the kW/ton, the more efficient the system.

COEFFICIENT OF PERFORMANCE (COP) is the basic measure of refrigeration system efficiency. COP is a ratio of output divided by input. More specifically, it is the output power divided by the input power.

- For an air conditioner or a heat pump in cooling mode, COP is the ratio of the cooling capacity of the refrigeration system to the energy consumed by the system.
- For a heat pump in heating mode, COP is the ratio of heat added by the system to the energy consumed by the system.

Digging Deeper

Advanced information is included in the Digging Deeper sections for students who want more information. The material in these sections will not be tested.

When you calculate COP, you have to measure the units for output and input in watts.

$$COP = \frac{Watt\ Output}{Watt\ Input}$$

Electrical input power is already measured in watts, while heating and cooling output power is typically measured in Btu/h. So, you have to convert Btu/h to watts. 1 watt = 3.412 Btu/h, so to convert, you simply divide the cooling or heating Btu/h by 3.412.

$$Watts = \frac{Btu / h}{3.412}$$

In COP, the higher the rating, the better. Typical air conditioning and heat pump systems have a COP of between 2 and 4. *(**IMPORTANT!** A COP of 2 does not mean the equipment is 200% efficient! It is impossible to be greater than 100% efficient. A COP of 2 simply means that the system delivers 2 watts of heating or cooling for every watt of energy consumed.)* Because COP measures power, it can measure only instantaneous performance, since power has no element of time. That means that COP does not tell us how a piece of equipment operates over time.

ENERGY EFFICIENCY RATIO (EER) measures *energy* output divided by *energy* input. EER is the ratio of output cooling energy (Btu) to electrical input energy or watt-hour (Wh).

$$EER = \frac{Btu}{Wh}$$

Because energy can be measured only over time, EER gives us a better idea than of how a piece of equipment operates over a time than COP does. One difference: while COP can be used for heating or cooling, EER is used for cooling only.

You can accurately convert COP to EER using this equation.

$$EER = COP \times 3.412$$

So, let's recap. With COP, we get a measure of instantaneous efficiency. EER gives us the efficiency of a piece of equipment operating in a steady state for an hour. However, neither of these measurements are very real world.

The **SEASONAL ENERGY EFFICIENCY RATIO (SEER)** estimates how efficient a piece of equipment will operate over an entire cooling season. SEER is based on a formula defined by the U.S. Department of Energy for residential air conditioning systems of less than 65,000 Btu/h (5.42 tons). SEER compares the total cooling output (in Btu) of a system for a typical season to the total energy consumed during that season (in watt hours).

$$SEER = \frac{Btu\ (for\ a\ season)}{Wh\ (for\ the\ same\ season)}$$

A SEER rating of 10 means that you get 10 Btu of cooling for every Wh of energy used. Using this measure, you can actually estimate the cost to run your air conditioner for a year.

Digging Deeper

Advanced information is included in the Digging Deeper sections for students who want more information. The material in these sections will not be tested on. Let's say that you have a 2-ton air conditioner. Remember that a ton of cooling is equal to 12,000 Btu/h. So your system has a capacity of 24,000 Btu/h. If your system were to run for 10 hours a day and 50 days each season, the seasonal cooling output would be:

24,000 Btu/h x 10 hours per day x 50 days per season = 12,000,000 Btu per season

If you had a 10 SEER air conditioner, your estimated total seasonal energy usage would be:

$$12{,}000{,}000\ Btu\ per\ season \div 10\ Btu\ per\ Wh = 1{,}200{,}000\ Wh\ (1200\ kWh)\ per\ season$$

If you had a 15 SEER air conditioner, your estimated total seasonal energy usage would be:

$$12{,}000{,}000\ Btu\ per\ season \div 15\ Btu\ per\ watt\ hour = 800{,}000\ Wh\ (800\ kWh)\ per\ season$$

If you know how much you are charged for electricity, you can estimate the cost to run a system for an entire season. Let's say your electricity costs $0.12 per kilowatt hour (kWh).

The 10 SEER unit would cost approximately:

$$1200\ kWh \times \frac{\$0.12}{kWh} = \$144$$

The 15 SEER unit would cost approximately:

$$800\ kWh \times \frac{\$0.12}{kWh} = \$96$$

The SEER rating can be used also to estimate how much power your air conditioner will require.

$$Power\ (watts) = Btu\ /\ h \div SEER$$

With a 10 SEER rating, the estimated power required for a 2-ton (24,000 Btu/h) air conditioner would be:

$$24{,}000\ Btu\ /\ h \div 10 = 2{,}400\ watts$$

A 15 SEER 2-ton unit would require less power:

$$24{,}000\ Btu\ /\ h \div 15 = 1{,}600\ watts$$

You can see that for EER and SEER, just as with COP, the higher the rating, the better.

MINIMUM SEER STANDARDS FOR NEW RESIDENTIAL INSTALLATIONS

	1994 to 2006	After January 2006
Split Systems	10	13
Packaged Systems	9.7	13

The **HEATING SEASONAL PERFORMANCE FACTOR (HSPF)** is the Department of Energy's measure of seasonal heating efficiency for heat pumps during the heating season. A heat pump is a reversible air conditioner. That is, it can cool during the summer and heat during the winter. The SEER rating is used to measure the efficiency of an air conditioner or heat pump during the summer. HSPF is used to measure the heat pump's efficiency during the winter.

$$HSPF = \frac{Btu\ (for\ a\ season)}{Wh\ (for\ the\ same\ season)}$$

The U.S. Department of Energy minimum values for HSPF are shown in the table below.

MINIMUM HSPF STANDARDS FOR NEW RESIDENTIAL INSTALLATIONS

	1994 to 2006	After January 2006
Split Systems	6.8	7.7
Packaged Systems	6.6	7.7

The Environmental Protection Agency (EPA) developed the **ENERGY STAR PROGRAM** to help consumers find high efficiency products. Energy Star ratings are higher than the minimum required ratings for manufacturers.

ENERGY STAR RATINGS FOR CENTRAL AIR CONDITIONERS AND AIR-SOURCE HEAT PUMPS

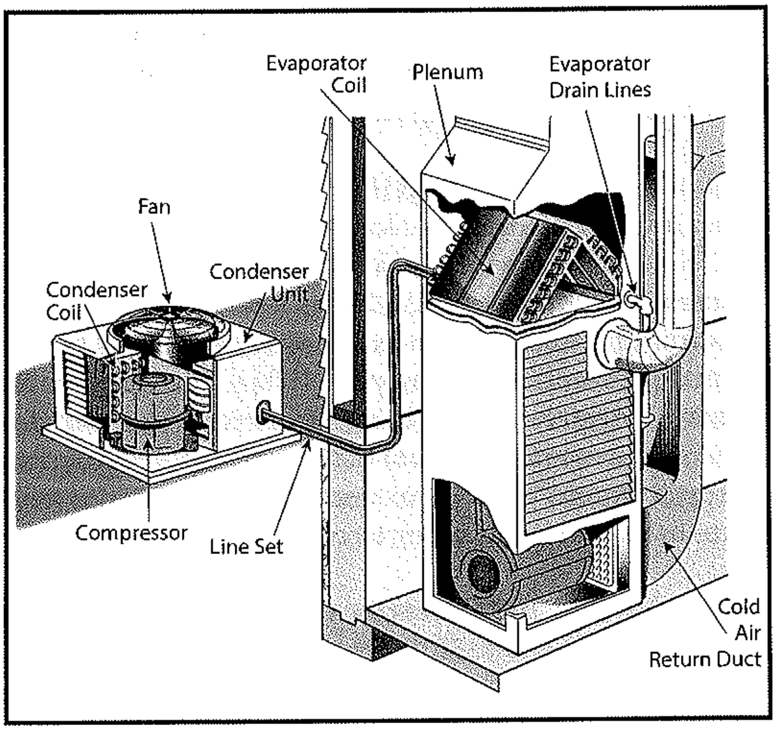
	EER	SEER	HSPF
Split Systems	12	14.5	8.2
Packaged Systems	11	14	8

Vapor Compression Cycle

The refrigeration cycle is based on physical properties of chemical compositions that we call refrigerants. **BOILING TEMPERATURE** is one of these properties. As you learned, boiling temperature varies with pressure—the higher the pressure, the higher the boiling temperature. With the **VAPOR COMPRESSION CYCLE**, we alter the pressure of a refrigerant so that we can get it to boil at a very cold (low pressure) temperature or a very high (high pressure) temperature.

To explain how these pressure changes enable an air conditioning system to cool a home, we will use a residential split system coupled with a furnace. You can see a cutaway of this system in the next figure. Assume we charge the system with a refrigerant called Refrigerant 22 (R-22). In the example we'll use within this section, you will see many references to boiling point temperatures. Each time, you will also see the corresponding pressure. Every refrigerant has its own unique pressure/temperature relationship, so it is important for you to understand that this example is for R-22 only. This is just one example of countless applications of the vapor compression refrigeration cycle.

CUTAWAY SPLIT AIR CONDITIONING SYSTEM



Any vapor compression cycle contains four main components: compressor, condenser, metering device, and evaporator. First, you'll learn briefly about each component according to the role it plays in the cycle. Next, each component is described in more detail. Finally, you'll learn about typical variations of the components to help you understand where and why they are used.

The **COMPRESSOR** lies outside the home, encased in a component called the **CONDENSING UNIT**. It works like an air compressor, except it compresses refrigerant vapor instead of air. It is important to note that the refrigerant must be in a vapor state rather than a liquid state when it enters the compressor. Liquid does not compress, and liquid entering the compressor can cause damage.

We will start our example with the R-22 refrigerant entering the compressor. It is drawn to the compressor by suction on the intake side of the compressor. We will explain how this works later. At this point in the system, the R-22 is in a vapor state. It is at a temperature of 60°F and a pressure of 70 psig. The compressor in our example raises the pressure of the refrigerant vapor by 227 psi. The result is a compressed vapor at a higher pressure (297 psig).

$$70\ psig + 227\ psig = 297\ psig$$

At the same time, the refrigerant vapor gets warmer. Why? Compressors work by drawing in a volume of vapor (gas), trapping that vapor, and then reducing the volume. This causes the molecules in the gas to squeeze closer together, and this causes both pressure temperatures to rise. This is called the "heat of compression." In our example, R-22 enters the compressor at 60°F (at 70 psig) and the heat of compression raises its temperature to 190°F (and its pressure to 297 psig).

At this 297 psig, R-22 boils at 130°F. However, the refrigerant leaving the compressor is at 190°F. This is already warmer than its boiling temperature. Remember that it was already a vapor when it entered the compressor, and so it and had already "boiled." The compressor simply warmed the vapor to a higher temperature by raising its pressure. When a gas has warmed above its boiling point, we call this **SUPERHEATED VAPOR**.

It may help to think of superheat in the same way you think about the temperature of water. If you add energy to ice, it would warm to 32°F. If you continue to add energy, the ice would change phase as it melts to water. Just when it melts into water, the temperature of the water is 32°F as well. If we add more energy, the water would begin to warm up. Vapor acts the same way. Once it has been boiled from a liquid, it will warm up beyond its boiling point. If it is 10°F warmer than its boiling point, it is said to have 10 degrees of superheat. If you remove energy from vapor with 10 degrees of superheat, it could only cool back down to its boiling point. If you continued to remove energy, it would "unboil," or condense. The next component in our example provides a place for superheated vapor to condense.

Let's review: The R-22 leaves the compressor at 190°F and its pressure is 297 psig. At that pressure, R-22 boils at 130°F. That means it has 60 degrees of superheat:

$$190°F - 130°F = 60°F$$

From the compressor, the R-22 refrigerant vapor flows a very short distance to the **CONDENSER COIL**. Although the term "coil" is used, the condenser's shape is not a coil at all. Rather, it is a series of copper tubes that allow refrigerant to flow back and forth in a serpentine path. The copper tubes are covered with numerous very thin aluminum fins. These fins increase the surface area of the tubes and provide for much more heat transfer. When you look at a condensing unit, you will see all the aluminum fins. You may have to look hard to see the copper lines because the fins are so tightly spaced.

The 190°F R-22 enters the copper tubes. Even though it may be a very hot day outside, perhaps as hot as 100°F, the 190°F refrigerant vapor is much hotter. It may be odd to think that 100°F air can be used for cooling, but that is what happens at the condenser. The 190°F refrigerant vapor is cooled by the 100°F air! Remember that the refrigerant entered the condenser at a pressure of 297 psig (190°F), and that the boiling point of R-22 at 297 psig is 130°F. At this pressure, R-22 above 130°F will be vapor. R-22 below 130°F will be liquid. At 130°F, the refrigerant will be in transition from liquid to vapor (boiling), or vapor to liquid (condensing).

Because the refrigerant vapor entered the condenser at a temperature above its boiling point, it can only cool until it reaches that point. We call this **DESUPERHEATING**, which simply means to cool a vapor. Desuperheating is a change in *sensible* heat because a temperature change takes place. When we cool the refrigerant vapor from 190°F to 130°F, we have removed all of the superheat. If we continue to remove energy, refrigerant vapor will begin to condense.

Remember that we are using an outside air temperature of 100°F, which is very hot but it is still cooler than the 130°F refrigerant. And because 130°F is still warmer than the surrounding outside air, energy will continue to leave the refrigerant. The refrigerant will begin to condense to a liquid. Once this begins to occur, the refrigerant is "locked" at 130°F until all the refrigerant has condensed to a liquid. During condensation, the refrigerant is releasing *latent heat*. It is undergoing a change of state from vapor to liquid, and it must release energy to do so. Note that the *latent heat* released to condense the refrigerant is absorbed as *sensible heat* by the outside air. In other words, the outside air is warmed by the energy released by the refrigerant. Though it is latent heat from the perspective of the refrigerant and sensible heat from the perspective of the outside air, it is the same energy.

If an air conditioning system is well-designed and functioning properly, all the refrigerant will condense to a liquid before it leaves the condenser. Remember, the condenser in our example is sitting outside, and the temperature outside is 100°F. Once the 130°F refrigerant has completely condensed to a liquid, it will begin to cool because the surrounding air is cooler than 130°F. This cooling takes place in the last part of the condensing coil, and in the copper line that leads to the next component in the system.

Cooling a liquid below its boiling point is called **SUBCOOLING**. Only about 5°F of subcooling typically takes place, and we will use that value in our example. Remember, the R-22 refrigerant condensed from a vapor to a liquid at 130°F. If we have 5°F of subcooling, the refrigerant will be 125°F when it enters the next device in the system; something called a "metering device." A **METERING DEVICE** (or *regulator*) measures and records the quantity or flow of the refrigerant. Think of a metering device as a valve designed to control the amount of liquid allowed through. Like any partially closed valve, the metering device causes pressure to drop from one side to the other. In our example, the metering device adds so much restriction that the pressure is reduced from 297 psig to 76 psig.

Remember how pressure affects boiling temperature? Higher pressures result in higher boiling temperatures, while lower pressures result in lower boiling temperatures. R-22 boils at 130°F when the pressure is 297 psig, but it has a boiling temperature of only 45°F when the pressure is 76 psig. Now, let's figure out what happens when pressure is dropped in a metering device. The liquid refrigerant enters the metering device at 125°F and 297 psig. At this point, it is below its 130°F boiling point. But the valve drops the pressure to 76 psig, and this drops the boiling point to 45°F. Liquid entering the valve at 125°F is *below* its 130°F boiling point, but when it leaves at 125°F it is now *above* its new 45°F boiling point. What happens? It immediately begins to boil!

If you have ever removed the radiator cap in your car when it was hot, you have seen this same thing happen. A radiator is a pressurized system. When water warms, it expands. The radiator cap serves as a pressure relief valve. That means that the cap will allow the radiator pressure to increase as the water expands because of the added engine heat, but will open if the water gets too warm to allow water to escape from the system. This water flows to the plastic overflow reservoir that you see next to your radiator. When the radiator cools down, a vacuum is created because the water contracts and the water in the overflow reservoir is drawn back into the system. A radiator cap rated for 15 psig will allow radiator water to warm up to about 250°F before it begins to boil. When you remove the cap, the pressure in the radiator drops to atmospheric pressure. At the same time, the boiling point of the water drops from 250°F to 212°F. What happens? Your radiator immediately begins to boil and blows scalding water all over you.

The pressure drop across the metering device causes the same thing to happen to refrigerant. When the pressure is dropped, the refrigerant begins to boil. It will continue to boil until it has either all boiled to a vapor, or until it has cooled to below its boiling point. And because its boiling point has dropped to 45°F, the refrigerant temperature drops to 45°F. When it begins to boil, it must absorb energy to do so. This again is the *latent heat* required to change its state from liquid to vapor. It gets some of this energy by absorbing it from the air surrounding the copper tube through which it flows. But it gets much of this energy from itself.

Consider a molecule of R-22 flowing along at 125°F under 297 psig with other molecules of R-22. Suddenly, the pressure is dropped through the metering device to 76 psig and the boiling point is now only 45°F. At 125°F, the molecule is way above its boiling point, and so it vaporizes. It needs energy to do so, and it grabs it from the molecules of R-22 surrounding it. This cools those remaining liquid R-22 molecules. As other molecules vaporize, remaining liquid molecules are cooled further. This process continues until all the liquid molecules have reached 45°F, at which point, any additional energy absorbed by the system vaporizes remaining liquid R-22 molecules. Liquid R-22 cooling takes place within a very short distance of the metering device. In fact, you can feel the copper lines entering and leaving the metering device. On the entering side, it will feel hot (125°F). On the leaving side, it will be very cold (45°F).

The 45°F R-22 is boiling when it leaves the metering device. From there, it immediately enters the last essential component of the vapor compression cycle—the **EVAPORATOR**. Like the condenser, the evaporator is another coil that does not look like a coil at all. It too consists of copper tubing surrounded by aluminum fins. Unlike the condenser, which is located outside the house, the evaporator coil is located inside the house. If the house is heated with a furnace, the evaporator will be inside a furnace plenum. Some systems position the evaporator inside a small air handling unit; others enclose the evaporator in a wall cabinet.

Our example system is coupled with a furnace and so the evaporator is located inside a furnace plenum. During cooling, the furnace fan blows air from the home past the evaporator coil. Air from the home is roughly room temperature, perhaps 75°F. The metering device has caused the refrigerant to begin boiling, and the temperature of the refrigerant is now 45°F. This cool refrigerant enters the copper tube evaporator. By the time it gets there, about 20% of the refrigerant has already vaporized (evaporated). That means that the remaining 80% is still liquid.

Air at 75°F from the house passes over the 45°F tubes of the evaporator. Energy from the warmer air is transferred to the cool refrigerant. Remember, the refrigerant at 76 psig is already boiling at 45°F, but there is 80% liquid yet to boil. The added heat from the 75°F air causes the remaining liquid refrigerant to boil. At the same time, the air is cooled because of the energy removed from it. Both sensible and latent heat are exchanged in the evaporator. The air is cooled (change of temperature) as *sensible* heat is absorbed from it and used as *latent* heat (change of state of matter) to boil the refrigerant. Though it is latent heat from the perspective of the refrigerant and sensible heat from the perspective of the room air, it is the same energy.

APPLYING WHAT YOU HAVE LEARNED:

Now take the time to think of how this will relate to your company. Use the space below to answer the following questions. If you are not sure of the answers ask your supervisor. These answers will vary for each company.

A. What type of air conditioning units does your company mostly sell? What manufacturers are carried?

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B. What are the three most energy efficient models carried by your company?

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Vapor Compression Cycle Components

As you learned, all vapor compression cycles contain at least four components. They are the compressor, the condenser, the evaporator, and the metering device. Often, specific applications call for the addition of other components and controls. In this section, you will learn basic information about common components, including different types of each. In some cases, you will also learn about some of the advantages and disadvantages of each.

Compressors

You learned earlier that the compressor acts as the heart of a refrigeration system. It provides the pumping power to move refrigerant throughout the entire system. It also performs the important function of raising the pressure and temperature of the refrigerant vapor. Remember that the compressor can be used only with refrigerant vapor. Refrigerant in liquid form cannot be compressed. If liquid refrigerant were to enter the compressor, either the compressor would simply stop running or damage would occur.

All compressors, regardless of type, lower pressure on the intake side and raise pressure at the outlet side. We call the intake side the "suction side," while the outlet is called the "discharge." Each compressor will have two openings called "ports." One is for suction, the other for discharge. A pipe carrying refrigerant vapor is connected to the suction opening (port). A second pipe is connected to the discharge opening (port). These pipes are called refrigerant "lines." They are usually made of copper tubing. For split systems, your company will stock line sets. When you start a refrigerator or air conditioner, the compressor draws refrigerant vapor from the evaporator into the suction side. Then the compressor compresses the refrigerant and sends it on its way to the condenser through the discharge line as a high-pressure, hot vapor. Refrigerant vapor always flows toward the compressor on the suction side (from the evaporator) and away from the compressor on the discharge side (to the condenser).

Compressor Types

Compressors can be *hermetic, semihermetic,* or *open drive compressors*. The term *hermetic* means "airtight." **HERMETIC COMPRESSORS** and their motors are mounted inside a steel shell housing and then the housing is welded tight. In this type of compressor, the motor and compressor are permanently connected to each other with a common shaft. Motors in hermetic compressors are surrounded by refrigerant vapor, which is how they are cooled. The motor adds heat to the refrigerant and heat generated by the motor is added to the work the compressor must do. You may hear hermetic compressors called "tin can" compressors because they are sealed like a can. And like a can, they must be cut open for any repair. For all practical purposes, hermetic compressors are usually considered to be disposable. Very few companies can service hermetic compressors, so when one fails, it is simply replaced. Your company may supply complete hermetic compressors, but will not supply parts for them.

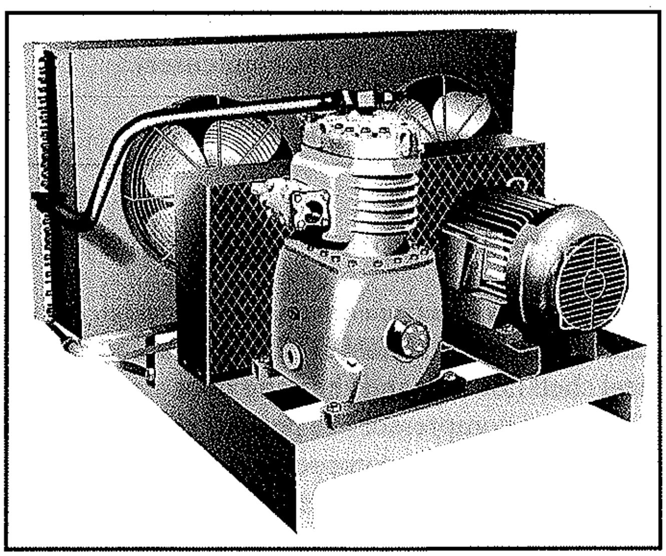
SEMIHERMETIC COMPRESSORS, sometimes called "serviceable" hermetic compressors, are bolted together rather than welded together. Like the fully hermetic compressor, both the motor and compressor are located inside the same housing and share a common shaft. Because the bolts can be removed, the compressor can be taken apart and serviced. As such, you may supply parts for these types of compressors.

With the **OPEN DRIVE CONFIGURATION**, the motor and compressor are separated and independent of each other. Both are fully serviceable, and one can be replaced without having to replace the other. Because the compressor is not connected to the motor with a common shaft line like the hermetic compressors, some other arrangement must be made to drive the compressor. You will see compressors that are either belt-drive or direct-drive. **BELT DRIVE** systems use belts and pulleys, similar to the belts and pulleys on an automotive engine. For this to work, both the motor and the compressor shafts have to be parallel to one another. That means the motor and compressor must sit side-by-side.

The shafts of both the motor and the compressor are fitted with pulleys with grooves in them. Many people call a pulley a **SHEAVE** (pronounced "shiv"). The belt fits in the groove and a large compressor may have more than one belt. If a belt fails on a multiple-belt system, all the belts must be replaced at the same time. They are provided in a matched set. Because the belts pull sideways on the shaft, the bearings experience more stress (called "load") than bearings in a hermetic, semihermetic, or direct drive systems. Because of this, belt-drive systems require heavier bearings. Belt and pulley alignment and belt tension is critical to prevent belt wear and premature failure. Shortly, we will discuss bearings more.

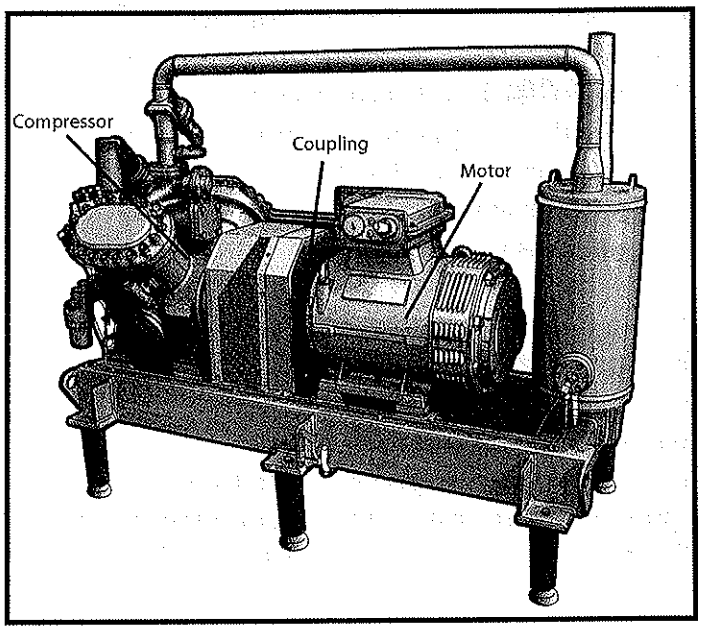
The following illustration shows a belt-drive compressor, motor, and condensing coil mounted on a steel frame. When these components are packaged together, it is called a **CONDENSING UNIT**. You will learn more about these later.

BELT DRIVE COMPRESSOR



A **DIRECT-DRIVE** system aligns the motor and compressor end-to-end and connect the shafts with a flexible coupling. The alignment of the motor and compressor is critical to prevent the coupling from wearing out. The illustration to the right shows a coupling and an assembly of a compressor and motor, connected by a coupling beneath a guard.

DIRECT DRIVE COMPRESSOR



The shaft on open-drive compressors passes through the casing so it can connect to a motor. A **SEAL** is a tight closure used where the shaft penetrates the casing to hold refrigerant inside the compressor while shaft spins. The seal has a surface that rubs against the shaft to prevent leaks into or out of the compressor. The rubbing surface is made of a material that will rub for years without wearing out. There are many types of seals. When replacing a seal for a customer, it is important to match the new seal to the old one.

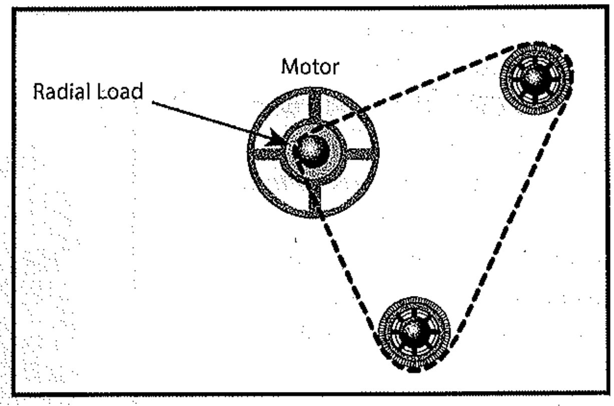
Load Types

BEARINGS are devices that support, guide, and reduce the friction of motion between fixed and moving machine parts. In a compressor, this is where the motor shaft is held in the motor casing, where the crankshaft spins inside of a hole in the compressor housing, and where the connecting rod spins on the crankshaft. The portion of the shaft that is machined to accept a bearing is called a *journal.*

Bearings have two kinds of loads, radial and thrust. A **THRUST LOAD** is the kind of load that tries to pull a bearing off a shaft or push it further onto the shaft. If you are sitting on a chair that swivels, your weight is putting a thrust load on the bearing used to support the chair when it swivels. An airplane propeller puts a large thrust load on bearings; it tries to pull the propeller shaft out of the airplane and the bearing has to withstand that pull.

A **RADIAL LOAD** is the kind of load that motors and pulleys put on bearings. It is a spinning load. As shown in the illustration, the belt that connects the motor to the pulleys is under tension. It is trying to pull the pulleys toward the center. The load put on the bearings by that pulling is a radial load.

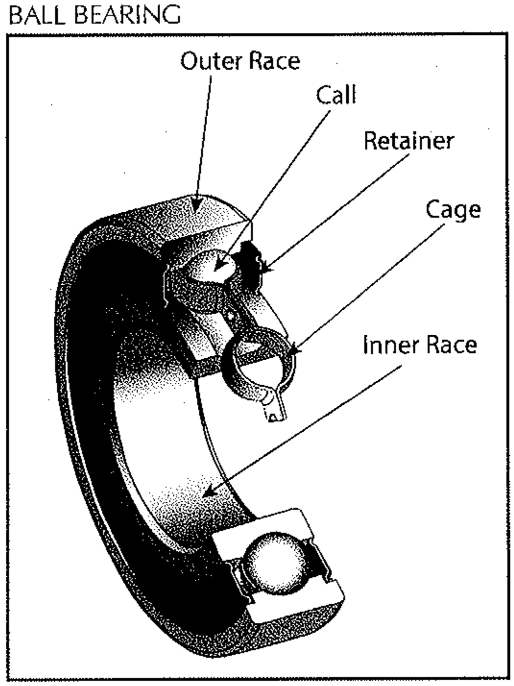
RADIAL LOAD



Bearings may be plain bearings or roller bearings. **PLAIN BEARINGS** have no spinning parts. They are the simplest type of bearing. Plain bearings are pressed into place to prevent them from spinning, or are provided with some other method to prevent spinning, such as small tabs that fit into small slots. With the bearing held fast, the shaft spins on the bearing surface. Plain bearings use a surface material that provides low friction, is long-lasting, and protects the shaft from wear. Ideally, a shaft is separated from a plain bearing by a thin film of oil. In effect, the shaft "rides" on the oil film. The lubrication properties of the oil provide low friction and prevent wear.

In actual use, the bearing surface and bearing journal on the shaft do come in contact, especially when the compressor is started and oil has not yet completely circulated. To prevent wear during these times, the bearing material is made of low-friction alloys. The material does not wear easily, but will wear more easily than the shaft does in order to protect the shaft. If wear occurs because of poor lubrication or high temperature, the bearing will be sacrificed so that the shaft can be preserved. In some cases, the wear is so bad that both the shaft and the bearing are damaged. The relative softness of the bearing material allows it to conform to minor imperfections and also allows small hard particles to embed themselves into the bearing material. This prevents scratches in the *journal* (the machined surface of the shaft).

BALL BEARING

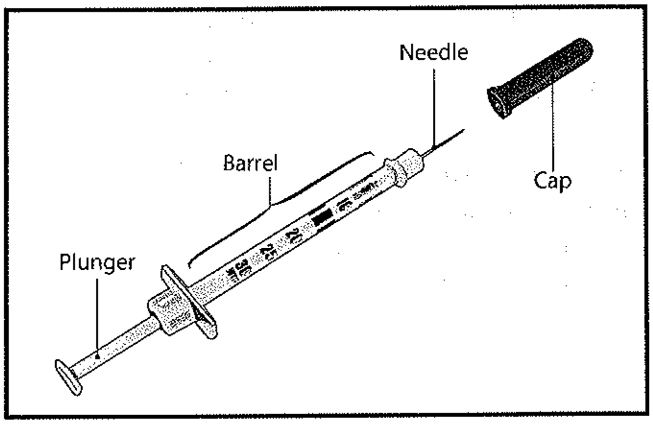


ROLLER BEARINGS use some sort of round shape between two loads. The most common and cheapest roller bearing is the *ball bearing*. The balls are held in place by inner and outer *races*, rings with a round groove in it. The groove contains the balls and provides a path for them to move. The outer race has the groove on its inside diameter. It is held in housing, usually with a press fit. This means that it must be pressed into place because the fit is very tight. The outer race does not spin. The inner race has the groove on its outside diameter. It fits tightly over the shaft. The inner race spins with the shaft. The inner and outer races are separated by steel balls. The balls roll in the grooves in the races, thus allowing the shaft to rotate with very little wear.

Classifications of Compressors

The three types of compressors—hermetic, semi-hermit, and open drive—are further classified as being either reciprocating, scroll, rotary, screw, or centrifugal compressors. We'll look at each of these compressors in this chapter. Much as gasoline engines use pistons moving within cylinders to compress fuel and air mixtures, **RECIPROCATING COMPRESSORS** use pistons and cylinders to compress refrigerant vapor. They do this by moving a piston back and forth. ("Reciprocate" means to move back and forth.) To help you understand how this works, imagine a syringe a nurse uses to give a shot. When the nurse inserts the needle into a vial of medicine and pulls back on the plunger, the syringe draws medicine into the barrel. When the nurse inserts the needle into your arm and pushes on the plunger, the medicine is forced out of the barrel.

SYRINGE



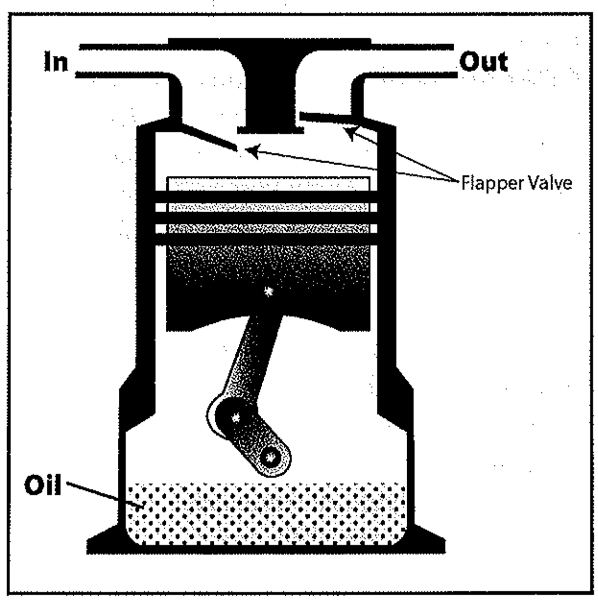
In a reciprocating compressor, the piston acts like the plunger and the cylinder acts like the barrel. When the piston is "pulled back," the volume of the cylinder increases and refrigerant vapor fills that volume. When the piston is "pushed forward," refrigerant vapor is forced out of the cylinder.

A syringe has only one opening at the top (where the needle is attached). The top of a compressor is called a "cylinder head," which has two openings. One is for suction and the other is for discharge. Each opening has a check valve. In a compressor, these valves are called **REED VALVES** (also called *ring valves* or *flapper valves*). The direction of refrigerant flow is controlled with little check valves. If you think about curtains hanging in an open window, you can imagine how these check valves work. When the wind blows into the window, the curtains blow out of the way and air enters the house. But when the wind changes direction and tries to blow air out of the house, the curtains get sucked against the window and prevent air from flowing. A check valves allows flow in only one direction. Whether the compressor uses ring valves or reed valves, one valve opens in and lets refrigerant vapor enter, while the other valves open out and lets refrigerant vapor escape.

When the piston is pulled away from the cylinder head, the suction reed valve, located on the inside of the valve plate, located just below the cylinder head, is pulled open. Refrigerant vapor is drawn from the suction line, past the suction reed valve, and into the cylinder. At the same time, the discharge reed valve, located on the outside of the valve plate, is kept shut by the suction of the piston. When the direction of the piston is reversed, it travels toward the cylinder head and valve plate. The suction reed valve is forced shut and prevents the refrigerant vapor from returning to the suction line. At the same time, the discharge reed valve is opened by the increasing pressure in the cylinder. The refrigerant vapor exits past the discharge reed valve through the discharge port and into the discharge line.

In this illustration, you can see how the flapper valve on the left opens to let vapor in, but will close to prevent vapor from leaving. On the right, you can see the flapper valve that lets vapor out, but will close to prevent vapor from coming in.

PISTON



RING VALVES work in a similar fashion. They are circular in shape and are held closed with a spring. When the pressure caused by the piston moving back and forth becomes greater than the spring pressure, the ring valve opens and allows refrigerant vapor to flow. Because intake valves are located on the valve plate inside of the cylinder, the piston cannot completely reduce the cylinder volume to zero; it must stop short of the top of the cylinder so that it does not hit the valves. A small amount of refrigerant vapor is trapped during discharge in the space taken up by the valves. This reduces the efficiency of reciprocating compressors because all the refrigerant that it had to draw in doesn't get discharged.

Reciprocating compressor designers look for ways to reduce the amount of room taken up by valves. The **DISCUS VALVE** arrangement allows the piston to travel closer to the cylinder head, thus reducing the amount of refrigerant vapor that remains during discharge and increasing efficiency. As long as the piston moves toward and away from the cylinder head, refrigerant vapor will be drawn into the compressor through the intake port and then forced back out through the discharge port. An electric motor usually drives the piston's back and forth motion; however, the motor may be powered by some sort of fuel, such as gasoline or natural gas.

Compressor Parts

In the following several sections, you will learn about many of the parts that make up a compressor. Some of these parts are unique to reciprocating compressors, but many are common to all compressors. Many of these parts can be replaced, and it is likely that your company will have them in stock or will be able to order them for your customers.

We'll begin with the compressor housing that holds the compressor components. Most small compressors use a steel housing and larger compressors use one made of cast iron. The compressor housing is similar to an engine block for an automotive engine. Both encase the internal components and protect them from the elements. The housing also keeps the fluids and pressures sealed inside.

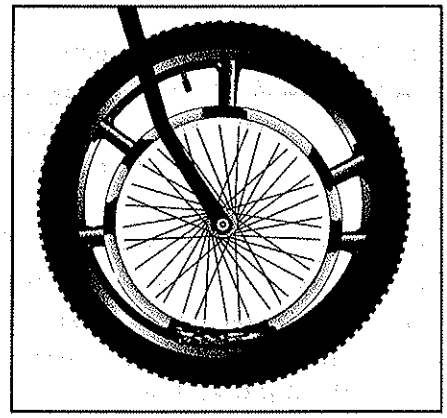
Just like automotive engines, compressors require lubrication. There are two principle lubrication systems: splash type and pressure type. **SPLASH-TYPE LUBRICATION SYSTEMS** house oil in the lower part of the compressor housing called the *crankcase*. As the compressor runs, the crankshaft splashes through the oil. Splash lubrication systems splash oil on every component that requires lubrication. **PRESSURE-TYPE LUBRICATION SYSTEMS** use an oil pump much like an automotive engine. Oil drains to the low point of the compressor where it is picked up and pumped throughout the compressor to lubricate all parts. Splash systems require oil levels high enough for the crankshaft to reach, while pressure systems require the extra components for pumping and distributing oil.

All compressors and their motors generate heat, and so they must be cooled. In hermetic compressors, both the motor and compressor are mounted in a welded steel shell. The refrigerant vapor on the suction side of the compressor is drawn from the system through a copper tube connected to the shell. It flows into the shell where it surrounds and cools the electric motor and compressor. The compressor then draws the refrigerant vapor from the surrounding shell, compresses it, and discharges it through the discharge port. Air-cooled compressors must be cooled by a surrounding airstream. Heat absorbed by the air is carried away by movement of the air. These compressors have fins cast into the compressor shell. The purpose of the fins is to increase surface area. The larger the surface area of the compressor shell, the better it can reject heat to surrounding air.

While pistons in reciprocating compressors move back and forth, motors run in a circular fashion. A **CRANKSHAFT** converts the motor's circular motion into the back and forth motion needed by the pistons. The crankshaft is fitted to the compressor housing at each end using a bearing. One end of the crankshaft is attached to the motor. The other end is held in place by a bearing. The bearings allow the crankshaft to spin without wobbling and without wear. The crankshaft is machined and polished to a very smooth surface where it fits into the bearings for a close fit.

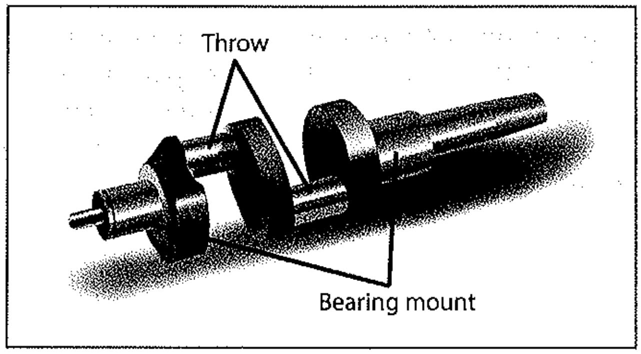
Imagine a clown bicycle designed for comedic visual effect or stunt riding. The axles are not centered on the wheel so, as the clown rides the bike, the off-center wheels cause an up and down motion. The further off-center the axle, the more up and down motion occurs. The spinning motion of the tire creates an up and down motion of the bike. This off-center axis is called an *eccentric.*

CLOWN BICYCLE WHEEL



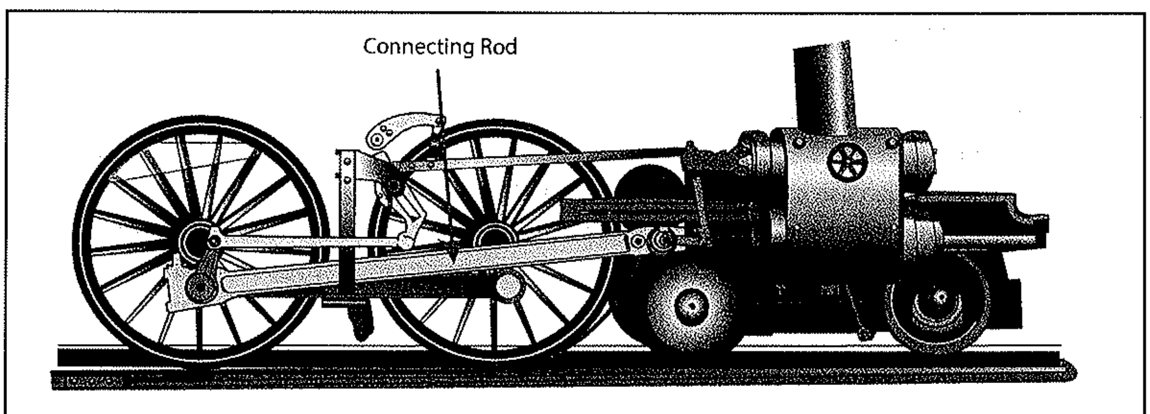
To convert the spinning motion to the back and forth motion needed by the pistons, the crankshaft has eccentric bearing surfaces machined into them where the piston connecting rod is attached. In a crankshaft, this eccentric is called a **THROW**. If there are more than one piston and cylinder in the compressor, the crankshaft will have more than one throw. The following image shows two throws. Notice that each end of the crankshaft is machined very smooth, as are the throws. This is where the bearings mount.

CRANKSHAFT



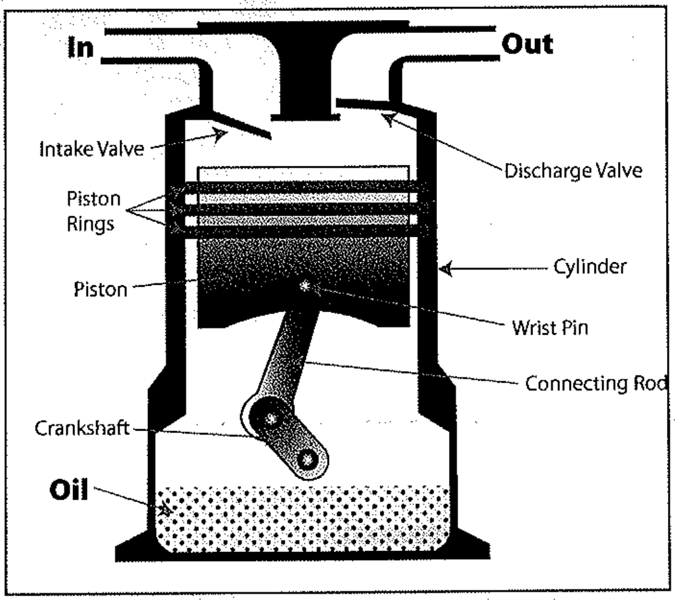
The **CONNECTING ROD** connects to the eccentric bearing surface (throw) of the crankshaft at one end. The other end connects to the piston using a *wrist pin*. The connection at the crankshaft spins. The connection at the piston goes back and forth (or up and down). The wrist pin allows the connecting rod to swivel at the piston so that the other end can spin on the crankshaft. In the following image, you can see a connecting rod that connects the back wheel to the steam cylinder mounted above the two smaller wheels in front.

CONNECTING ROD ON LOCOMOTIVE



A piston in the cylinder goes back and forth, driven by the steam engine. The connecting rod goes back and forth where it connects to the steam cylinder. The steam cylinder is the device mounted above and between the two small front wheels. Do you see how the back of the connecting rod is connected to the drive wheel off-center, just as on the clown bike? That end of the rod goes around in a circle because it is mounted to the wheel off-center. If you have a hard time imagining this, look at any movie or video that features a steam locomotive and you will see connecting rods. They convert the back and forth motion of the steam pistons to a circular motion to drive the wheels of the locomotive and move the train. The connecting rods in reciprocating compressors work exactly the same way, except they use the circular motion of the motor to drive the pistons up and down. However, unlike a locomotive engine, the connecting rods are not viable because they are housed inside a compressor.

PISTON

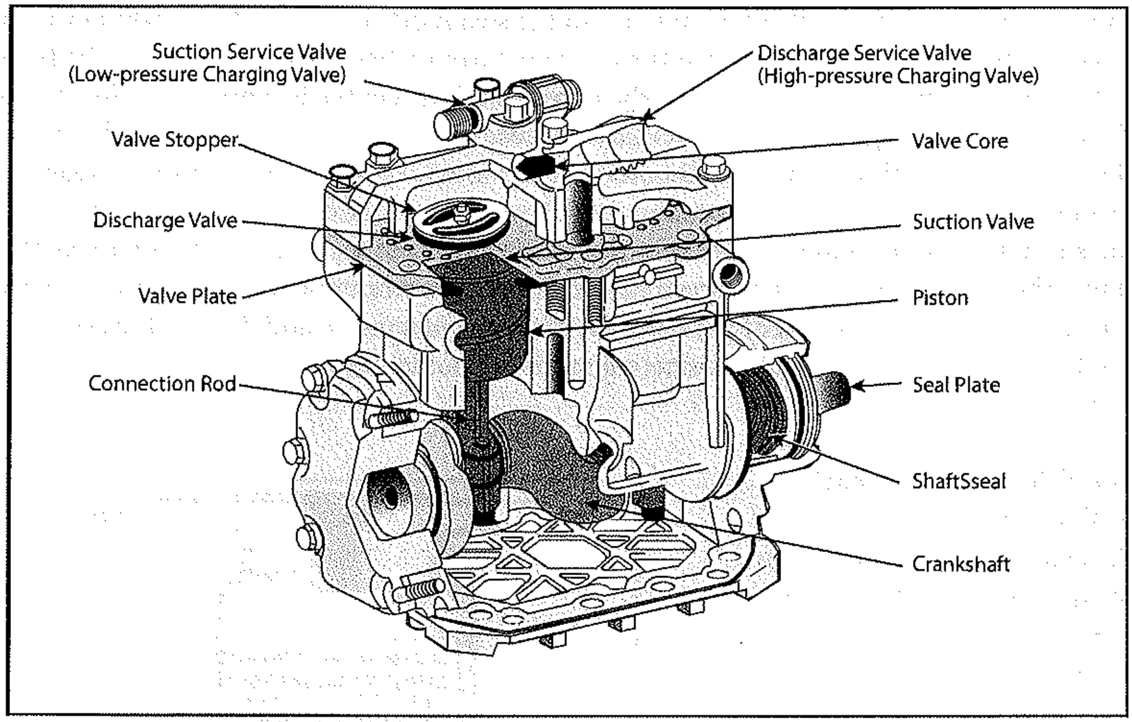


The **PISTON** moves back and forth (or up and down) inside the cylinders and draws in the refrigerant vapor through the suction port when the connecting rod pulls the piston down to expand the volume in the cylinder. When the rotation of the crankshaft causes the connecting rod to reverse the direction of the piston and reduce the volume in the cylinder, the refrigerant vapor is pushed back out of the cylinder through the discharge port. In compressors with small pistons, the fit between the piston and the cylinder it tight enough to prevent high refrigerant vapor from leaking past the piston. The thin film of oil actually acts as the seal. Larger cylinders use piston rings to prevent refrigerant vapor from leaking past the piston. Piston rings also prevent oil from leaking into the refrigerant.

The **VALVE PLATE** is located below the cylinder head and the compressor housing. It holds both the suction and discharge valves. Bolts passing from the head, through the valve plate and into the compressor housing hold everything in place. Gaskets on both sides of the valve plate seal the refrigerant vapor inside the compressor.

In the following cutaway of a reciprocating compressor, you can see where the parts we have just discussed mount in a reciprocating compressor. It is a relatively small, twin-cylinder compressor. But as you can see, there are many moving parts located inside that are prone to wear and failure. You will likely be selling replacement parts to your customers.

RECIPROCATING COMPRESSOR CUTAWAY



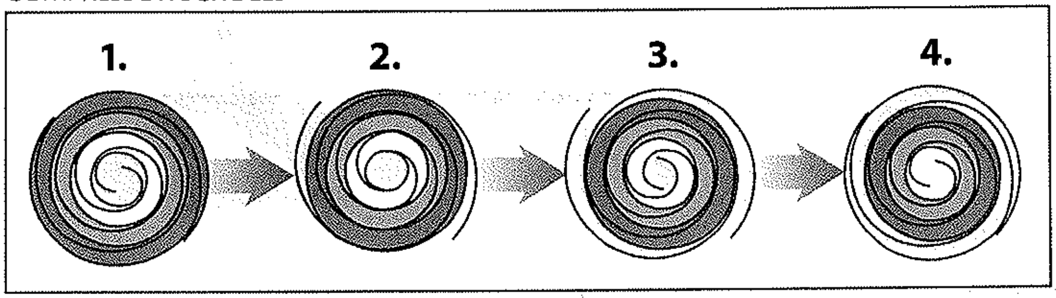
Reciprocating compressors operate at COPs ranging from approximately 3.52 to 2.70. As you will recall, Coefficient of Performance (COP) is the basic measure of refrigeration system efficiency.

Scroll Compressors

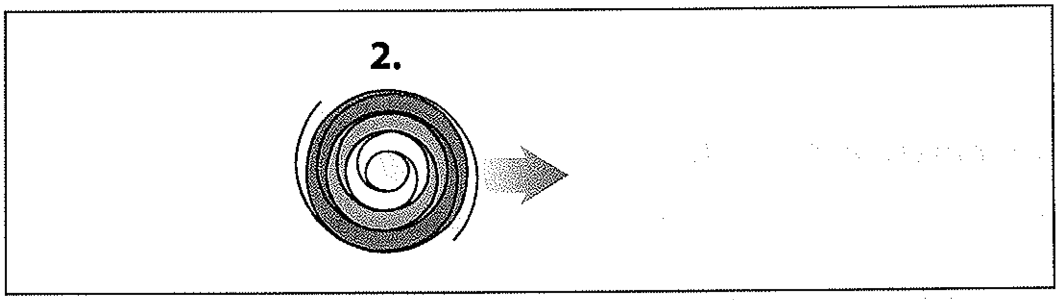
Reciprocating compressors are being largely replaced in the residential and commercial air-conditioning markets by the **SCROLL COMPRESSOR**, but are still widely used in the fractional horsepower (less than one horsepower) market in components such as refrigerators, freezers, window air-conditioners, and packaged terminal air conditioners (PTACs). "Recips" are also widely used in the commercial refrigeration industry, which includes foodservice and walk-in coolers and freezers.

Rather than using pistons and cylinders to compress refrigerant vapor, scroll compressors use two mating spiral-shaped scrolls. One scroll remains stationary, while the other scroll moves in an orbital motion (oscillates). Note that the motion of the moving scroll is not circular—it does not spin. Rather, it orbits within and around the stationary scroll. The following illustration shows four views of a scroll compressor as a blue arch, with the orbiting scroll as a red arch, shown in four different positions. If you can't find a video online, this is the next best thing. In all four views, the blue scroll remains stationary while the red scroll orbits in a counter-clockwise direction.

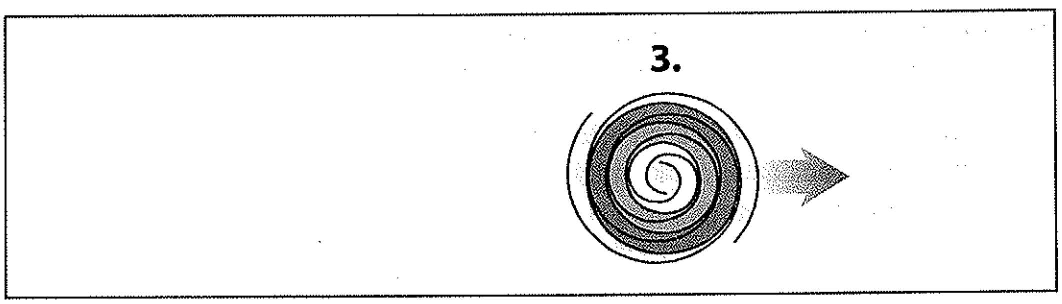
COMPRESSOR SCROLLS



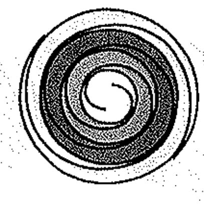
- At the first position shown, four separate charges of refrigerant vapor can be seen: pink, green, yellow, and blue. There are actually two charges of each color. Each charge has a somewhat crescent shape. Combined with its twin, each pair of charges forms a ring. The motion of the orbiting scroll forces each ring of refrigerant toward the center. As it moves toward the center, it becomes smaller. For the same amount of refrigerant vapor to occupy an ever-decreasing volume, compression takes place.



- In the second position, a new charge of refrigerant vapor is being drawn in. As the red scroll orbits counter-clockwise, an opening is created and refrigerant vapor rushes in to fill the void. You can see this as a new blue charge.



- In the third position, further orbiting of the red scroll pulls in more of the new blue charge. Meanwhile, the original blue charge has reached the center of the compressor and maximum compression. The suction of a scroll compressor is at the perimeter of the scrolls, while discharge of compressed refrigerant vapor takes place at the center of the scroll. The blue charge at the center is being discharged.



- In the fourth position, the red scroll has completed one orbit and seals off the new blue charge of refrigerant vapor. Further orbiting of the scroll will force the blue charge toward the center and compress it. As you view position 1 through 4 in sequence, you will notice that each colored charge gets progressively smaller. For example, yellow is shown in position 1 at approximately halfway between suction and discharge. Positions 2 and 3 show yellow moving toward the center, while position 4 shows yellow at maximum compression and ready to be discharged through the center.

Scroll Compressor Advantages

Scroll compressors have many advantages over reciprocating compressors.

1. *Simplicity of design:* Although an advanced manufacturing process is required to make scroll compressors, there are very few moving parts. Only the orbital scroll is needed for compression. As in any rotational device, bearings are required. In addition, a device can be used to prevent the orbital scroll from rotating. By comparison, a reciprocating compressor requires pistons, connecting rods (with bearings at each end), a crankshaft (with bearings at each end), cylinder heads, and valve plates (with both suction and discharge valves).

2. *Quiet operation:* Because a scroll simply moves in an orbital motion rather than a reciprocating (back and forth) motion and because there are no flapper (reed) valves opening and closing, there is less internal noise transmitted through the casing to the outside. Counterweights applied to balance the orbiting scroll reduce vibration and further reduce sound generation.

3. *Higher efficiency:* In a reciprocating compressor, the intake valves are mounted to the inside of the valve plate so they can be pulled open by the suction of the piston as it moves down the cylinder. Because of this, the piston must stop short of the top of the cylinder to prevent impact with the valves. This leaves a small amount of refrigerant vapor trapped at the top of the cylinder. The energy used to compress that vapor is wasted and efficiency is reduced. In a scroll compressor, there are no valves to get in the way. All the refrigerant that is drawn in during

each intake cycle is discharged once it reaches the center of the scroll. Reciprocating compressors have losses associated with the valves themselves. Scroll compressors have no valves, thus these losses are eliminated. Finally, reciprocating compressors have intake and discharge valves located very near each other. This allows the transfer of heat from hot discharge vapor to cooler suction vapor and that reduces efficiency. The intake and discharge on a scroll compressor are located far apart. This reduction in thermal loss increases efficiency. These factors give the scroll a higher efficiency than a reciprocating compressor.

4. ***Ability to handle liquid:*** Liquid cannot be compressed. In a reciprocating compressor, as the piston travels up in the cylinder, any liquid (called a **LIQUID SLUG**) that entered during intake has no place to go. Liquid trapped on top of the piston will cause damage when the volume in the cylinder is reduced to the volume of the liquid. Broken valves, connecting rods, and pistons can result from liquid slugging. If liquid enters a scroll compressor, the orbiting scroll will move slightly away from the stationary scroll, giving the liquid somewhere to go and preventing compressor damage.

5. ***Continuous refrigerant flow:*** A reciprocating compressor provides compression in distinct phases. During *intake*, refrigerant flows into the cylinder as the piston travels down and the increasing cylinder volume creates suction. Refrigerant vapor flows into the compressor at this time, but no refrigerant flows out. When the piston travels up, *compression* takes place as the volume of the cylinder decreases. During this phase, no refrigerant flows in or out of the compressor. During *discharge*, refrigerant flows out of the compressor each time the piston reaches the top of the cylinder and the discharge valve opens. The result is "puffs" of refrigerant flow. A scroll compressor provides intake, compression, and discharge all at the same time. Refrigerant vapor is always being drawn in, is always in various stages of compression, and is always being discharged.

According to research, scroll compressors operate at a COP than is on average 10% higher than reciprocating compressors. Scroll compressors are used commonly in the residential and commercial air conditioning markets where higher efficiencies are needed.

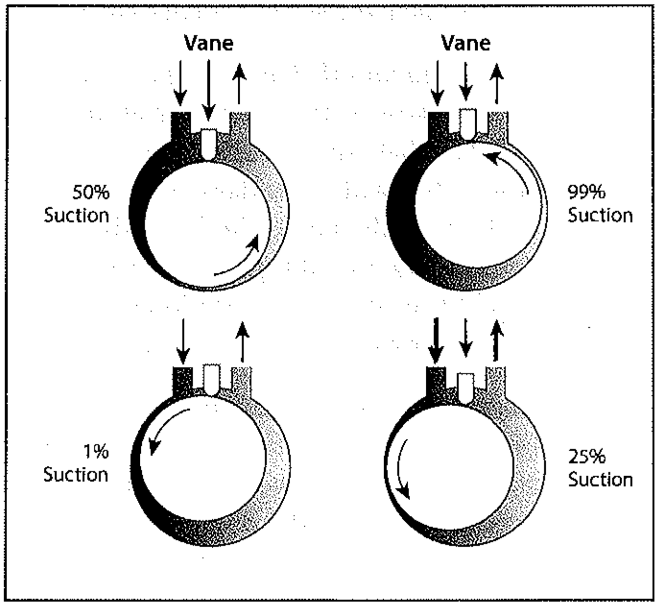
Rotary Compressors

There are a number of rotary compressors on the market. As you might guess from the name, **ROTARY COMPRESSORS** compress refrigerant using some type of rotating mechanism. They offer smoother operation than reciprocating compressors because they don't have parts going back and forth like reciprocating do.
Rotary compressors use a roller mounted to an eccentric shaft inside of a cylinder to

compress refrigerant vapor. In the illustration below, you can see how the rolling piston draws in refrigerant and compresses refrigerant at the same time. The **VANE** is spring loaded and moves up and down as the piston rotates to separate the suction gas from the compressed gas. A vane is a flat blade that moves in motion. A windmill sail is an example of a vane.

Compared to reciprocating compressors, rotary compressors have fewer moving parts. They are a low cost compressor to both purchase and maintain. They are efficient and spin at relatively low speeds, which helps to ensure long life. COP for these compressors can reach nearly 7.0, depending on temperature, making them a very efficient compressor. Fixed-vane, rolling-piston compressors and are good for applications that do not require large volumes of gas or high pressure. They are used in household refrigerators and air conditioning units ranging up to about 3 horsepower.

FIXED-VANE, ROLLING-PISTON ROTARY COMPRESSOR



Unlike the fixed-vane compressor, which has a single spring-loaded vane mounted to a non-rotating housing, **ROTARY-VANE COMPRESSORS** have a number of spring-loaded vanes mounted to the rotating piston. This provides multiple compression strokes per revolution. The fixed-vane compressor that we just discussed provides only one compression stroke per revolution. The rotary-vane can handle larger volumes of gas than the fixed-vane because of this.

ROTARY-VANE COMPRESSOR

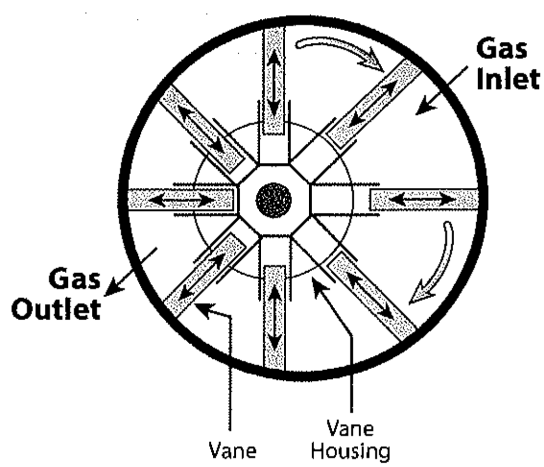


Plate Heat Exchanger
As the off-center drive shaft rotates, so does the vane housing. The vanes slide in and out to maintain contact with the cylindrical compressor wall. Gas enters at the largest opening and the compressed gas discharges from the smallest opening.

Efficiencies for rotary-vane compressors is not as high as the fixed-vane or scroll compressors. And, they have more parts than either the fixed-vane or scroll. Although you may still be asked to supply parts, these compressors have largely been replaced by other types.

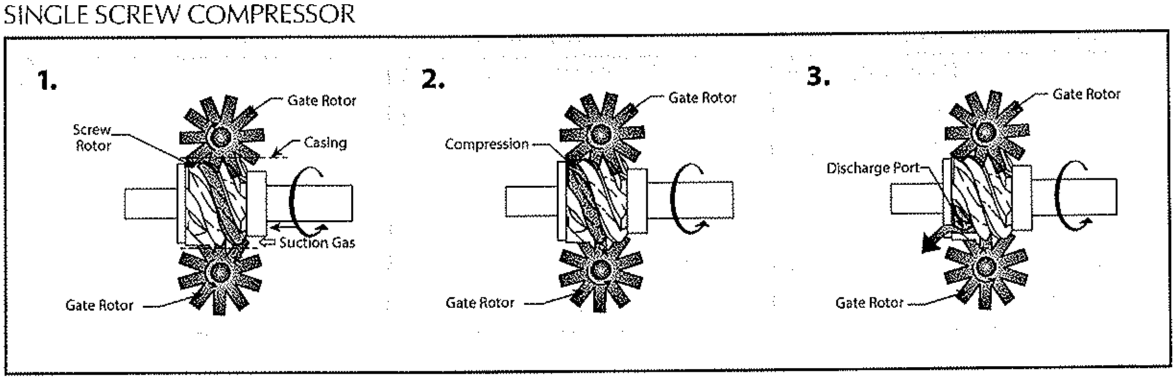
Fixed-vane compressors do offer an advantage of low weight-to-displacement ratio. This makes them appealing to the transport refrigeration applications, where low weight helps to increase fuel economy and reduces overall weight of the vehicle.

Screw Compressors

Like the reciprocating and scroll compressors, a **SCREW COMPRESSOR** is a positive-displacement machine. This means that a certain volume of refrigerant vapor will be compressed with each cycle of the compressor. Screw compressors (also known as *rotary screw compressors*) use single or twin-screw designs.

SINGLE SCREW COMPRESSORS use a main rotor with a helical (spiral) groove, similar to the thread of a wood screw, along with one or two "gate rotors." One end of the screw is open to the intake port, while the other is open to the discharge port. The gate rotor(s) are driven by the main rotor, and spin within the "threads" of the main rotor to prevent refrigerant vapor from leaking past (see illustration below).

SINGLE SCREW COMPRESSOR



As the main rotor spins, a portion of the "thread" passes the intake port. As the main rotor continues to spin, more and more of that particular "thread" passes the intake port. The rotation of the gate rotor(s) within the "thread" causes suction at the intake port, and the "thread" fills with refrigerant vapor. Eventually, the entire "thread" passes by the intake port and is closed off by the casing, trapping the refrigerant vapor between the gate rotor(s) and the casing.

Refrigerant vapor moves right to left because of the rotation of the main and gate rotors. As the volume of the "thread" decreases between the gate rotor(s) and the casing on the left (discharge side), the refrigerant vapor compresses. Eventually, the volume of the "thread" is reduced to zero, and the refrigerant vapor escapes through the discharge port on the left. Single screw compressors are widely used in both the refrigeration and air-conditioning industries. Sizes range from 40 to 500 tons.

TWIN-SCREW COMPRESSORS (also called *double helical rotary screw compressors* or *twin helical screws*) use two main rotors. The rotors are designed in "mating" pairs. One rotor is machined with helical (spiral) lobes (like a thread) and is called the *male rotor*. The other is machined with grooves or flutes (similar to a drill bit) and is called the *female rotor*. The pair is "mated" by machining the shape of lobes of the male rotor to fit exactly into shape of the grooves in the female rotor. The tolerance between the male and female rotors is tight enough that a film of oil provides a seal that prevents refrigerant vapor from leaking between the rotors.

The operation of the twin-screw compressor is similar to a single-screw compressor. As the rotors spin, spaces between the lobes and grooves fill with refrigerant vapor as they pass the intake port. Once past the intake port, they are sealed off the by fit between the rotors and the casing of the compressor. As rotation continues, the refrigerant vapor is compressed as the volume of the space between the lobes decreases. Eventually, the rotation of the rotors exposes the spaces to the discharge port and the refrigerant vapor is discharged to the system.

Similar to scroll compressors, both single and twin-screw compressor have few moving parts, and intake, compression, and discharge occur simultaneously. A typical reciprocating compressor running at 3450 revolutions per minute (rpm) provides 3450 "puffs" or discharges of refrigerant every minute. In comparison, twin-screw compressors can provide over 14,000 discharges every minute, more than four times greater, which results in a smoother and more continuous flow.

Typical screw chillers operate at a COP of approximately 5.0 to 7.0. Similar to the single screw compressors, twin screw compressors are found in refrigeration, air-conditioning, and heat pump applications. They are used most commonly in commercial and industrial application. Twin screw compressors used in the refrigeration and air-conditioning industry are similar in concept and design to some supercharges, such as the Lysholm supercharger, used in the automotive industry. Another common application is mobile air compressors used in road construction.

Centrifugal Compressors

Unlike other types of compressors, **CENTRIFUGAL COMPRESSORS** are not positive-displacement machines. Rather, centrifugal compressors use a rotating impeller to accelerate refrigerant vapor to a high velocity, and then convert the dynamic energy from the high velocity refrigerant vapor to pressure energy. Compared to positive-displacement compressors (recips, scrolls, screws, rotary), centrifugals offer little vibration or wear and higher volumetric capacities per size.

All positive-displacement machines provide flow in pulses. Though some provide a very high rate of discharges per minute (pulses), they are pulses none-the-less. Centrifugal compressors provide flow at a continuous rate and spin at a steady state, thus eliminating many of the vibrations associated with other positive-displacement compressor types. Centrifugal compressors have no contact between parts, such as pistons and cylinders or rotors, so wear is limited to bearings and vibrations caused by surface-to-surface contact is absent. Higher volumetric capacity is due to the continuous flow. There is no delay between discharges per minute inherent with positive-displacement compressors.

Some centrifugal compressors rotate at relatively low speeds, while others rotate at very high speeds. Compressors with very large impellers (up to seven feet in diameter) rotate slower because the large diameter of the impeller creates a high tip speed. To achieve a high tip speed with a smaller impeller, higher rotational speeds are required. Speeds vary from 1,800 to 90,000 rpm. For comparisons, a typical automobile engine is limited to around 6,000 rpm. A Formula 1™ race car engine rotates at up to 18,000 rpm. An automotive turbocharger is really just a small version of a centrifugal compressor (with a very small impeller by comparison). Some turbos spin at speeds up to 150,000 rpm.

TIP SPEED refers to the speed at the outer diameter of the impeller. The larger the impeller, the higher the tip speed for a given rotational speed. Tip speeds range from about 980 feet per second (fps), or about 670 miles per hour (mph) to a maximum of about 1400 fps (roughly 950 mph). At these speeds, the flow velocity of the refrigerant vapor is approximately Mach 1 (the speed of sound).

To convert this high velocity to high pressure, remember that as velocity pressure drops, static pressure increases. In the centrifugal compressor, the very high velocity refrigerant vapor slows down immediately after leaving the impeller, and as the velocity pressure drops, the static pressure increases. The increase in static pressure squeezes the refrigerant vapor and reduces its volume, thus compressing it. Centrifugal compressors can be single-stage or multiple-stage. In multiple-stage configurations, discharge gas from one stage enters the inlet of the next stage. Each stage increases the pressure of the refrigerant vapor. Up to 10 stages are possible.

Unlike positive displacement compressors, centrifugal compressors deliver constant flow of refrigerant. This results in higher volumetric capacity for a given size of compressor. Compared with the back and forth motion of reciprocating compressors, the orbital motion of scrolls, or the eccentric rotation of rotary compressors, centrifugals spin with a steady motion, resulting in less vibration. And without the need for seals between moving surfaces, such as piston rings against cylinder walls, mating surfaces of screw compressors, vane-to-rolling piston seals in rotary compressors, and tip seals on scroll compressors, the centrifugal impeller spins wear-free.

Centrifugal chillers operate in nearly the same COP range as screw chillers, approximately 5.0 to 7.0. This corresponds to a kW/ton requirement of 0.5 to 0.7. Centrifugal compressors are commonly used with chiller applications. A **CHILLER** is a machine designed to chill water rather than air. Large institutions, such as hospitals, or universities, use central chilled water plants to produce chilled water for the entire campus. Chilled water is then distributed to buildings located throughout campus, usually via underground tunnels. The chillers in the central chiller water plant must have sufficient capacity to cool all the buildings within the complex. While domestic refrigerators are rated in fractions of a ton of cooling and typical houses require approximately 2 to 5 tons of cooling, chiller sizes range into the thousands of tons.

These applications illustrate another advantage of the centrifugal compressor. When housed in a central chiller water plant, these machines are located remotely from occupied spaces and house the large mechanical equipment in one location. This also removes maintenance from occupied spaces and allows technicians to perform service without disrupting the operation of the other building onsite.

APPLYING WHAT YOU HAVE LEARNED:

Now take the time to think of how this will relate to your company. Use the space below to answer the following questions.. If you are not sure of the answers ask your supervisor. These answers will vary for each company.

A. Where are your compressors located? Which types do you stock?

B. What type of compressor does your company sell the most of?

Evaporators

Previously you learned that evaporators can have two functions. First, most evaporators are designed to absorb heat from whatever has to be cooled. In an air conditioning system, air is cooled. In a refrigerator or freezer, food and beverages are cooled. The second function of an evaporator may be to remove humidity from an airstream (dehumidify). Not all evaporators do this, but others have dehumidification as their principle duty.

In an air conditioning system, the evaporator absorbs heat (usually to remove humidity) from air. The cooler and drier air circulates throughout the building to cool it. In a refrigerator, the evaporator also absorbs heat (and removes humidity) from air, but the air is used to cool food rather than people. In both cases, the air is actually absorbing heat and humidity from either the building or the food in the refrigerator, and then the evaporator absorbs heat and removes humidity from the air. Remember that it is not possible to "make cold," but it is possible to absorb heat and move it to another location.

Let's use an air conditioning system for a quick review of the evaporator. In an air conditioning system, it is the evaporator that "soaks up" heat energy. This heat energy can be either sensible (change in temperature) or latent (change in state), and is usually both. Sensible heat is removed from the air as the air is cooled. Latent heat is removed when water vapor is condensed from the air on the surface of the evaporator. Water vapor releases heat when it is condensed.

Remember that the evaporator gets its name from the fact that refrigerant is boiling, or evaporating on the inside of the evaporator. Remember that the metering device lowered the pressure on the hot liquid refrigerant coming from the condensing unit, and that this drop in pressure caused the refrigerant to begin to boil immediately. And because it takes energy to boil something, the refrigerant that was boiling grabbed energy from the surrounding liquid refrigerant and this caused the liquid refrigerant to get very cold, i.e., 45°F.

So, when air cools as it hits an evaporator coil, the energy it loses is transferred through the walls of the evaporator to the 45°F refrigerant inside, and that sensible energy boils some of the liquid refrigerant. Remember that condensation occurs whenever the surface temperature of the evaporator is below the dew point of the air being cooled. With 45°F refrigerant inside the coil, the coil temperature is below the dew point of the air! When water vapor from that humid air condenses on the coil, it must give up energy to do so. Remember, a liquid has less energy than a vapor. The energy is transferred as the water vapor condenses on the coil, through the walls of the copper tube. That latent energy joins the sensible energy from the air being cooled and boils some more of the liquid refrigerant.

Evaporators that directly cool air are typically called "coils." When air is both cooled and dehumidified, the evaporator must have the capacity to remove both the sensible and latent heat called coil *loads*. The **TOTAL LOAD** of the coil is the sum of the sensible and latent heat load.

The term **SENSIBLE HEAT RATIO (SHR)** refers to the ratio of sensible load to total load. In other words, it tells us how much work the coil will have to do to cool the air as compared to the total work it will have to do. The SHR typically varies from 0.6 to 1.0 (60% - 100%). When the SHR is 100%, it means that all the coil is doing is cooling air—all its load is sensible. If the SHR is a low number, you know the air to be cooled is very humid. Air that is very humid will impose a higher latent load on the coil due to the amount of moisture that will be condensed on the surface of the evaporator.

Refrigerant in the evaporator adsorbs (soaks up) heat energy in the form of sensible and latent heat. The compressor then pumps refrigerant laden with that heat energy from the evaporator to the condenser, where the heat energy it is "wrung out." The condenser is situated in a place where the extra heat makes no difference. For a residential air conditioner, the condenser is outside where it rejects heat energy to the air. In a kitchen refrigerator, the condenser is on the outside of the refrigerator where the heat energy is rejected into the kitchen. You can't cool a kitchen by opening the door of the refrigerator. The refrigerator simply pumps heat from inside to outside. In the process, it picks up heat from the electric motor and from the heat of compressor. If you were to open the door, the refrigerator would actually add more heat to the kitchen than it removes. Rather than cooling the kitchen, you would be warming it! This helps explain why a refrigeration cycle is really a heat pump. It simply pumps heat from one place to another.

You learned that evaporators absorb heat by circulating refrigerant that is cooler than the medium to be cooled. And you know that for air conditioning, evaporator temperatures are typically around 40°F to 45°F. But for keeping food cool or frozen, that temperature is not cold enough to do the job. For refrigerator and freezer evaporators to work, refrigerant that is even colder must circulate. Remember that pressure sets the refrigerant temperature and that the refrigerant enters the evaporator as a boiling liquid. The pressure in the evaporator is set so the refrigerant boils (evaporates) at a temperature that is appropriate for the application. A rise in pressure will raise the refrigerant's boiling point, while a drop in pressure will lower it.

A Refrigerant Temperature—Pressure Chart is provided on the next page so you can see the relationship for temperature and pressure for six different refrigerants; R-12, R-22, R-134a, R-410A, R-502, and R-507.

REFRIGERANT TEMPERATURE—PRESSURE CHART

REFRIGERANT TEMPERATURE – PRESSURE						
°F	REFRIGERANT					
	12	22	134a	410A	502	507
	psig	psig	psig	psig	psig	psig
-40	*11*	0.6	*14.7*	10.1	4.1	5.5
-36.4	*9.1*	2	*13*	12.5	5.8	7.4
-32.8	*7.2*	3.6	*11.2*	15.1	7.7	9.4
-29.2	*5*	5.3	*9.3*	17.9	9.7	11.6
-25.6	*2.7*	7.1	*7.2*	20.8	11.8	13.9
-22	*0.3*	9.1	*4.9*	24	14	16.4
-18.4	1.1	11.1	*2.4*	27.4	16.4	19
-14.8	2.5	13.4	0.1	31	18.9	21.8
-11.2	4	15.7	1.5	34.8	21.6	24.8
-7.6	5.5	18.2	3	38.8	24.5	28
-4	7.2	20.9	4.6	43.1	27.5	31.3
-2.2	8	22.3	5.4	45.4	29.1	33
-0.4	8.9	23.7	6.3	47.7	30.7	34.8
1.4	9.8	25.2	7.2	50.1	32.4	36.7
3.2	10.8	26.7	8.1	52.5	34.1	38.5
5	11.8	28.3	9.1	55	35.9	40.5
6.8	12.8	29.9	10.1	57.6	37.7	42.5
8.6	13.8	31.5	11.1	60.2	39.5	44.5
10.4	14.8	33.2	12.2	62.9	41.4	46.6
12.2	15.9	35	13.3	65.7	43.4	48.8
14	17	36.8	14.4	68.6	45.4	51
15.8	18.2	38.6	15.6	71.5	47.5	53.3
17.6	19.4	40.5	16.8	74.6	49.6	55.6
19.4	20.6	42.5	18	77.6	51.7	58
21.2	21.8	44.4	19.3	80.8	53.9	60.4
23	23.1	46.5	20.6	84.1	56.2	62.9
24.8	24.4	48.6	22	87.4	58.5	65.5
26.6	25.8	50.8	23.4	90.8	60.9	68.1
28.4	27.1	53	24.8	94.3	63.4	70.8
30.2	28.6	55.2	26.3	97.9	65.9	73.6
32	30	57.5	27.8	101.6	68.4	76.4
33.8	31.5	59.9	29.3	105.3	71	79.3
35.6	33	62.4	30.9	109.2	73.7	82.3
37.4	34.6	64.9	32.6	113.1	76.5	85.3
39.2	36.2	67.4	34.3	117.1	79.3	88.4
41	37.8	70	36	121.2	82.1	91.6
42.8	39.5	72.7	37.8	125.4	85.1	94.8
44.6	41.2	75.5	39.6	129.8	88.1	98.1
46.4	43	78.3	41.5	134.2	91.1	101.5
48.2	44.8	81.2	43.4	138.7	94.2	105
50	46.6	84.1	45.4	143.3	97.4	108.6
51.8	48.5	87.1	47.5	148	100.7	112.2
53.6	50.4	90.2	49.5	152.8	104	115.9

REFRIGERANT TEMPERATURE – PRESSURE						
°F	REFRIGERANT					
	12	22	134a	410A	502	507
	psig	psig	psig	psig	psig	psig
55.4	52.4	93.3	51.7	157.7	107.4	119.7
57.2	54.4	96.5	53.9	162.7	110.9	123.6
59	56.5	99.8	56.1	167.8	114.4	127.5
60.8	58.6	103.2	58.4	173	118	131.6
62.6	60.7	106.6	60.8	178.4	121.7	135.7
64.4	62.9	110.1	63.2	183.8	125.5	139.9
66.2	65.2	113.7	65.7	189.4	129.3	144.2
68	67.5	117.3	68.2	195	133.2	148.6
69.8	69.8	121.1	70.8	200.8	137.2	153.1
71.6	72.2	124.9	73.5	206.7	141.2	157.7
73.4	74.6	128.8	76.2	212.8	145.4	162.3
75.2	77.1	132.7	78.9	218.9	149.6	167.1
77	79.7	136.8	81.8	225.2	153.9	172
78.8	82.3	140.9	84.7	231.6	158.3	176.9
80.6	84.9	145.1	87.7	238.1	162.7	182
82.4	87.6	149.4	90.7	244.8	167.3	187.2
84.2	90.4	153.8	93.8	251.5	171.9	192.5
86	93.2	158.2	97	258.5	176.6	197.8
87.8	96	162.8	100.2	265.5	181.4	203.3
89.6	98.9	167.4	103.6	272.7	186.3	208.9
91.4	101.9	172.1	106.9	280	191.2	214.6
93.2	104.9	177	110.4	287.5	196.3	220.5
95	108	181.9	113.9	295	201.4	226.4
96.8	111.2	186.9	117.5	302.8	206.7	232.5
98.6	114.4	192	121.2	310.7	212	238.6
100.4	117.7	197.1	125	318.7	217.4	244.9
102.2	121	202.4	128.8	326.9	222.9	251.4
104	124.4	207.8	132.7	335.2	228.5	257.9
105.8	127.8	213.3	136.7	343.7	234.2	264.6
107.6	131.3	218.9	140.8	352.4	240	271.4
109.4	134.9	224.5	144.9	361.2	245.9	278.3
111.2	138.5	230.3	149.2	370.1	251.9	285.4
113	142.2	236.2	153.5	379.3	258	292.6
114.8	146	242.2	157.9	388.6	264.2	299.9
116.6	149.8	248.3	162.4	398	270.5	307.4
118.4	153.7	254.5	167	407.6	276.9	315
120.2	157.7	260.8	171.7	417.5	283.4	322.8
122	161.7	267.2	176.4	427.4	290.1	330.7
125.6	170	280.3	186.2	447.9	303.6	347
129.2	178.6	293.9	196.4	469.2	317.7	364
132.8	187.4	307.9	206.9	491.2	332.2	381.5
136.4	196.6	322.5	217.8	514	347.1	399.8
140	206	337.5	229.2	537.6	362.6	418.7

Here is how the chart works. You look for the temperature you want in your evaporator in the left-hand column. Then you read across to the column for the refrigerant in your system. The number at the intersection of the row for your temperature and the column for your refrigerant is the pressure you will need in your evaporator. The left-hand column reads in temperature Fahrenheit. *IMPORTANT! These represent boiling temperatures. The numbers in the rest of the columns read in pressure, measured in pounds per square inch, gage (psig).*

Let's try an air conditioning example. Let's design our evaporator for a 41°F temperature. To find the evaporator pressure needed for a 41°F temperature, find the temperature in the second column (°F), then read across from 41°F to the psig column for the refrigerant used in the system. For example, if R-12 were used, the evaporator pressure would be set to 37.8 psig. For R-22, the evaporator pressure would need to be 70 psig; R-134a requires 36 psig; and R-410A would need 121.2 psig.

You can see that a number of refrigerants could be used. If you were designing a system, you would design it for the pressure required by whatever refrigerant you chose to use.

Evaporator Types

There are as many evaporator types as there are needs for cooling. Every device we use to keep something cool has an evaporator. When you think about all the things we need to cool, there are many of them! Many of them are specialized. For example, when you get a milkshake at a fast food restaurant, the machine that dispenses the shake has an evaporator especially designed to cool the shake mix to just the right temperature. Think of all of the different shapes you have seen for ice. Each machine that dispenses ice for soft drinks has an evaporator especially designed to freeze water into the shape of the ice used by that particular machine. Every vending machine that stores cold beverages must have an evaporator. If you happen to be a hockey fan, you could not enjoy your sport without the evaporators used to maintain the rink's frozen surface.

The list of applications that require cooling and need a specific evaporator is practically endless. We will discuss only the most common ones, that is, the ones your company will likely keep in stock.

Air Cooling

The most common type of evaporator is used for heat transfer between air and refrigerant. These evaporators are divided into two types: flooded and direct-expansion (DX). **FLOODED EVAPORATORS** are kept full of liquid refrigerant. As heat is absorbed, the refrigerant is boiled and the vapor is drawn off the top. Flooded evaporators work best when a small temperature difference exists between the air and the refrigerant and are used typically for low-temperature applications. These types are relatively rare and you will probably not be dealing with them.

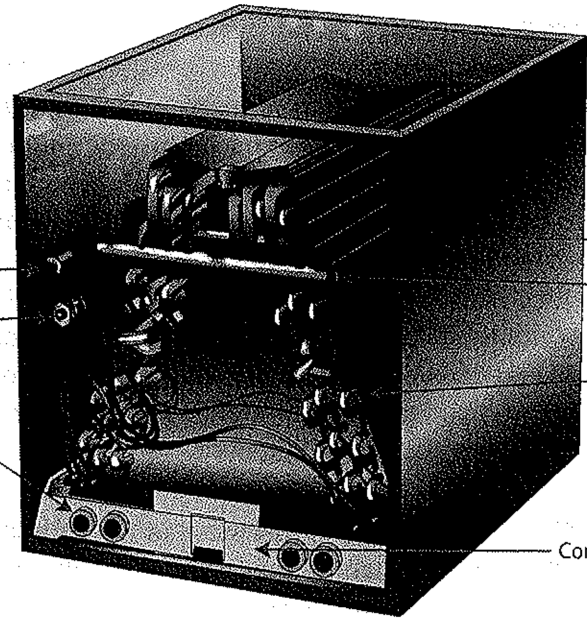
You will see many **DIRECT EXPANSION (DX) EVAPORATORS** (or *dry-type evaporators*), which get refrigerant from the metering device already boiling at the designed temperature. The evaporator is designed to completely boil all the refrigerant by the time it reaches the end of the coil. Remember that the refrigerant flows to the compressor from the evaporator, and it is critical that the refrigerant is vaporized completely by the time it leaves the evaporator. The most common DX coil is the **FINNED-TUBE TYPE**. These evaporators typically use aluminum fins over copper tubes. A typical manufacturing process punches holes in the aluminum fins to allow them to fit over the copper tube. Once the fins are in place, a **MANDREL** is rammed through the tube to enlarge it and lock the fins in place. This method of attaching aluminum fins to copper tubes provides a mechanical bond and facilitates excellent thermal conduction between the two materials.

The purpose of the aluminum fins is to increase the surface area of the copper tube significantly to enable better heat transfer between the air to be cooled and the refrigerant vapor within the copper tubes. The spacing of the fins is dependent on the temperature of the coil and the amount of moisture (or frost) that is expected on the coil surface. Coils that operate below freezing will frost up, and fins will be spaced further apart. Coils are commonly provided with copper tube ranging from 5/16 to 1 inch in diameter, with fins spaced from 4 to 18 **FINS-PER-INCH (FPI)**. The tubes can be spaced from roughly 5/8 to 3 inch apart.

The width and height of an evaporator coil is limited by the size of the equipment in which it will be installed. To extend surface area even more than placing fins over copper tubes allow, evaporator coils employ a technique that provides more than one row of tubes. Each additional row adds another evaporator to the system, which allows the system to do more cooling.

Residential systems take that concept a step further yet and arrange two multi-row coils in a slanted configuration within the same housing. Called an "A-coil" because of the resemblance to the letter "A," these coils provide greater coil surface area in a small plenum attached to a furnace or air handler. The following is a multi-circuit A-coil.

3-ROW, A-COIL



To provide good distribution of refrigerant to the coil, multiple circuits are supplied with liquid refrigerant. In the previous image, you can see where liquid refrigerant is fed to multiple circuits through the small copper tubes near the bottom of the coil. With the evaporator pressure set for the refrigerant to boil at 40°F, air from the home blows over and around the copper tubes and aluminum fins provides the heat energy required to boil the refrigerant.

After the refrigerant has evaporated, the refrigerant vapor collects near the top of the coil via the multiple tubes that are connected to the horizontal copper tube called a **SUCTION MANIFOLD**. On the left of the tube, there is an elbow with a short piece of tubing attached. When this evaporator is installed, that short piece of tubing is where the manifold will be connected to the suction line leading to the compressor. Just below that, there is a connection for the line to feed boiling liquid refrigerant to the evaporator. At the bottom of the coil is a plastic condensate pan. This collects water that was condensed on the cold coil surface from the warm humid air. This pan has four places to choose from to connect a drain to drain the water from the pan to a drain provided by a plumber.

Liquid Cooling

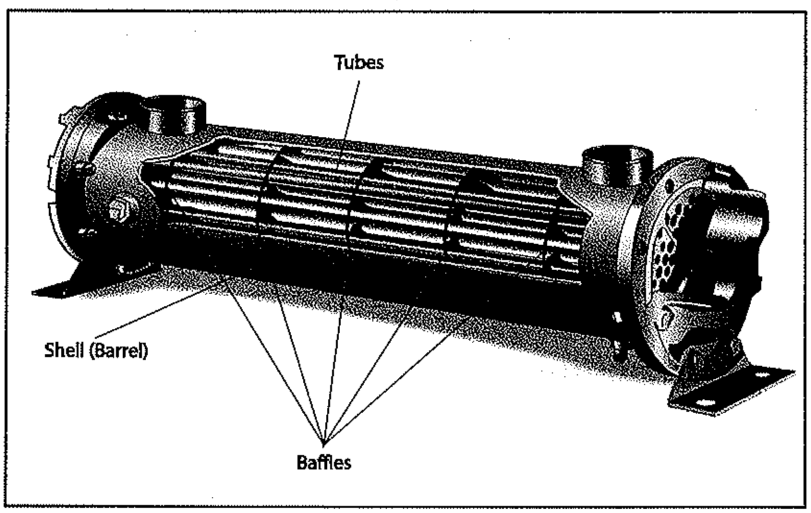
You'll recall that evaporators are the components that act like a sponge to "soak up" energy from a medium to be cooled. In air conditioning, that medium is air. But evaporators also cool liquids. Chillers are machines that use refrigeration to cool a liquid (usually water) and then the liquid is used to cool air. We sometimes mix the water with glycol (antifreeze) or salt (brine) for freeze protection.

At first, this double-step process may seem senseless. Why cool water with refrigerant only to cool air with the chilled water when you can directly cool the air with refrigerant? Water is much better for transporting energy than air. Remember that a pound of water can carry 1 Btu, while a pound of air can only carry 0.24 Btu. That means that a pound of water can carry more than four times energy than a pound of air. And a pound of air takes up roughly 13.3 cubic feet, while a pound of water takes up only 0.134 cubic feet. That means that air takes up about 100 times more space per pound than water. When you combine these two facts and consider the size of a pipe or duct you would need to move a given amount of energy, you can move over 400 times more energy per cubic foot of duct or pipe space with water than you can with air.

It is not practical to pump refrigerant great distances so DX systems are typically limited to about 50 feet. In long runs of refrigerant lines, too much energy leaks through the walls of the copper tubing even when the tubing is insulated, too much compressor energy is wasted pumping the refrigerant long distances, too much refrigerant oil gets stranded in the long lines, and too much money is wasted on refrigerant just to fill the long lines. And think of how much refrigerant would be have to be replaced in case there was a leak!

Chilled water systems chill water at a central plant and then that chilled water is pumped great distances. One or more chillers in a mechanical room of a commercial building, such as an office or hospital, chills water that provides cooling for several floors. Cooling a building with DX systems would require multiple systems throughout the building that would be noisy and take up a great deal of space. On a large campus, chillers are located in a separate building and pump chilled water through miles of tunnels to feed several buildings. Centrally locating chillers removes the noise and vibration from occupied buildings. It also allows maintenance personnel to work on the equipment without entering occupied spaces. Chillers also limit the circulation of refrigerant to the equipment room. If there were ever a leak, the refrigerant would be confined to the mechanical room. This offers a layer of safety for toxic or flammable refrigerants.

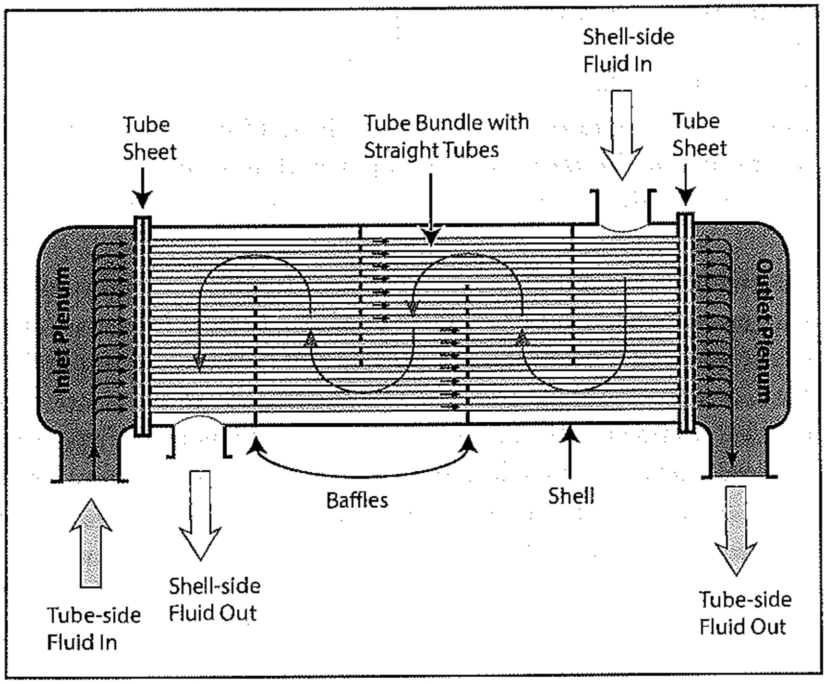
SHELL AND TUBE HEAT EXCHANGER



When an evaporator is used for cooling a liquid, it needs to be designed differently than one used for cooling air. Evaporators for chillers are typically of the shell-and-tube type. The following is a cutaway view of a typical shell and tube heat exchanger showing the shell, tubes, and inner baffles that support the tubes.

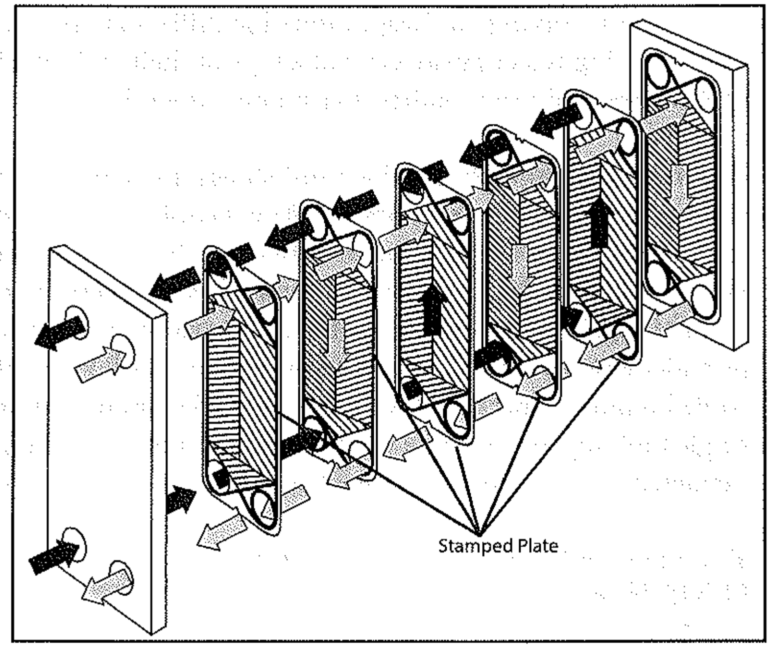
The following *schematic* (or diagram) shows the flow of refrigerant and water through a chiller's shell and tube evaporator. Many people call this the **CHILLER BARREL**. Liquid refrigerant enters through the bottom of the barrel and partially fills the shell (barrel). Water is pumped through a number of tubes that pass from one end of the shell to the other through the liquid refrigerant (left to right in the schematic). The warmer water provides energy, which causes the refrigerant to boil violently. In the process, the water is cooled (chilled) and exits the chiller barrel for circulation to cooling coils located within a single building, or through a distribution system to multiple buildings. Refrigerant vapor is extracted from the top of the shell and fed to the suction line of the compressor.

FLOW IN SHELL AND TUBE HEAT EXCHANGER



You might find some **PLATE HEAT EXCHANGERS** used as evaporators. The following image shows a plate heat exchanger in an exploded view with two flow paths represented by different colored arrows. In a plate and frame, one fluid flows between every other plate, while the other flows in the alternate spaces. Large surfaces for heat transfer exist on the plates, and a large number of plates can be positioned in a small area. The plates are *stamped* (embossed) into a corrugated pattern to increase surface area even more and to promote turbulent flow. Manufacturers design heat exchangers for turbulent flow because the more the fluid tumbles and turns, the better job it does transferring heat.

PLATE HEAT EXCHANGER



An evaporator is a heat exchanger. Its sole function is to adsorb heat from some medium to be cooled and usually dehumidified. In order to be efficient, a large surface area is required. Different kinds of heat exchangers accomplish this is different ways. Evaporators are constructed of materials that withstand corrosion such as copper, brass, stainless steel, aluminum, steel, or a combination of these materials. Because the purpose of anevaporator is to provide for the exchange of energy, evaporator materials are selected for good heat transfer properties. Copper and aluminum are better at conducting heat than stainless steel, so stainless steel is limited to applications that would corrode copper and aluminum.

Finned coils are usually made of copper tubing with shiny aluminum fins. The aluminum may have a baked-on or anodized coating to help prevent oxidation and improve the life expectancy of the coil. The tubing is usually round, although flattened tubes or hollow flat plate designs are also used. The inside surface can be smooth, but coils designed for higher efficiency and smaller size will have internal passages, fins, or grooves to increase surface area and promote turbulent flow. At the end of each tube, 180° elbows (*hairpin bend tubes*) are used to direct the flow to the next tube for another pass through the coil. In other coil designs, a header feeds tubes with refrigerant from one end of the coil, while another header collects the refrigerant at the other end. This type of evaporator coil is reflected in newer microchannel technology which will be discussed later in the condenser section.

Internally, evaporators are designed to provide turbulent flow. **LAMINAR FLOW** is flow in which molecules tend to stay in the same place in relation to other molecules. With laminar flow, there is little thermal interaction between molecules of a fluid. On the other hand, molecules in turbulent flow are constantly bumping into each other, which provides for good heat transfer within the fluid itself. You can imagine these two kinds of flow by picturing a river in your mind. A calm and placid river will have laminar flow. Water in the middle of the river tends to stay in the middle of the river and has little interaction with water along the shore. If there were a cold spot in the water, it would tend to say cold. In contrast, a white-water river has water that is constantly churning and mixing, and the temperature of the water is much better blended.

Now going back to the evaporators, to promote turbulent flow, the inside of tubing might be *rifled* (manufactured with spiral grooves) and the surfaces of plates might be stamped into a rough pattern. Shells are typically made of steel, while tubes are typically made of copper. Plate heat exchangers commonly utilize aluminum plates with gasket materials to separate the two flow patterns.

Most direct expansion evaporator coils both cool air and dehumidify it at the same time. Because these coils condense water vapor, the surface of the coil will be wet during operation. The condensate will drain from the coil and be collected in a drain pan. Most often, a small drain line will run from an opening provided in the drain pan to a floor drain located near the equipment. In cases where the evaporator is located below a convenient drain, the condensate must be pumped to a drain line with a small condensate pump.

Evaporator DX coils are typically sized by the ton, with each ton of cooling being equivalent to 12,000 Btu/h. The number of tons required depends on the cooling load of the building. In order to accurately determine the cooling load, a trained professional will perform a load calculation.

A standard coil rating is designed for 400 cubic feet per minute (cfm) of air to be circulated over the coil for each ton of cooling. For example, a 3-ton coil would require 1,200 cfm. This rating is based on a refrigerant temperature of 45°F. When selecting a coil, it is important for you to verify the circulation fan has sufficient capacity for the airflow requirements of the coil. If the air blowing over the coil blows too fast, water droplets from the water condensed from the humid air can be blown into the downstream ductwork. Water begins to get blown off coil surfaces at air velocities above 600 feet per minute (fpm). To prevent this condition, coils are designed for air velocities of 400 to 500 fpm.

Physical size is also a consideration. Common residential "A-coils" are designed to fit inside a plenum mounted at one end of a furnace or air handler. When you select an A-coil, you must check the manufactured and model of the furnace or air handler to verify that the coil will fit. You also must match the evaporator coil to the condensing unit. Condensing units are designed to reject the heat adsorbed by the evaporator coil, the heat generated by the compressor, and for hermetic compressors, the motor heat. If you select an evaporator coil that is too large for the condenser, the condenser will not be able to reject the heat absorbed by the evaporator.

In summary, you must match an evaporator coil to the building cooling load, circulating fan, furnace or air handler, and condensing unit. In retrofits, where cooling is being added to a building for the first time, the designer must pay attention to sizing requirements for good operation. Often, you can size a replacement coil based on the existing coil. For new installations, the installers typically install both the furnace and the air conditioner at the same time, and the units are matched by the factory for the application.

Condensers (Condensing Units)

Remember that the function of the condenser is to reject heat that has been adsorbed by refrigerant in the evaporator coil and refrigerant lines. And, the condenser must also get rid of the heat generated by the compressor and the motor. The refrigerant enters the condenser as a hot, high-pressure vapor after leaving the compressor. As you learned, the temperature of the refrigerant vapor must be higher than the surrounding temperature (**AMBIENT TEMPERATURE**). This makes sure that heat will flow from the hot refrigerant to the surrounding medium. For residential and light commercial applications, the surrounding medium is usually air. As the refrigerant vapor loses energy, it *condenses* to a liquid. That is how the condenser got its name: it condenses refrigerant.

Most condensers are air-cooled, though some are water-cooled and some use evaporative cooling. **AIR-COOLED CONDENSERS** are used most commonly in the residential and light commercial markets. They can be of finned tube, integral-fin, or microchannel construction. **FINNED-TUBE COILS** are the most common air-cooled condensers. You will see this type in most all residential and light commercial applications. Just like evaporator coils, condenser coils are typically made of copper tubing. You might see aluminum and steel tubing in the coil when ammonia is the refrigerant, but ammonia is not used in small applications. Tube diameters range from ¼ to ¾ inch. The inside of the tubes can be smooth or lined with tiny fins (microfin). The microfin design enhances heat transfer by increasing surface area and causing turbulent flow.

INTEGRAL-FIN CONDENSERS are made of copper or aluminum and have fins extruded as part of the tube itself. **MICROCHANNEL CONDENSERS** are used in automotive and aviation applications because they are very light. They are made of flattened aluminum tubes with aluminum fins zigzagging between tubes. The fins for condenser coils can be aluminum or copper. Most, if not all, of the equipment you sell will have aluminum fins. The fins themselves are very thin, averaging roughly 0.008 inches in thickness and are spaced between 8 and 20 fins per inch. The fins are razor sharp! You must be extremely careful when handling coils or you can get severely cut.

Central air conditioning systems in homes use what we call a "split-system" because the evaporator and metering device are located inside the house. This is the most common type of air conditioner. The condenser coil is typically mounted in a stamped-steel enclosure, which also houses the compressor and a condenser fan. The whole assembly is called a **CONDENSING UNIT**. When you see an "air conditioner" sitting outside a house, you are seeing just the condensing unit. If you look closely, you will see two refrigerant lines running through the wall of the house. They connect the condensing unit to the evaporator coil located inside the furnace plenum or air handler.

Remember that it is important to match condenser coils to evaporator coils. Condenser sizes range from about 110% to over 170% larger than evaporators because they must reject not only the heat adsorbed by the evaporator, but also the heat gained in the compressor and heat adsorbed in systems that use refrigerant to cool the electric motor. The actual size of the condenser depends on many factors, including the efficiency of the compressor and the evaporating and condensing temperatures. You will not be asked to size equipment, but you must make sure that the customer gets the equipment that is properly sized for they systems they are installing or servicing.

Metering (Expansion) Devices

Remember that the job of the metering device is to restrict (or meter) the flow of refrigerant. The metering device must allow just enough refrigerant to pass. Too much refrigerant will "flood" the evaporator coil. This literally means that the coil will get filled with liquid refrigerant. This would cause liquid to flow to the compressor, and that could damage or destroy the compressor. If the metering device restricts flow too much, the evaporator coil will be "starved" of refrigerant. It won't get enough refrigerant to do the cooling required. Restricted refrigerant flow can also cause the coil to frost up.

This might be a difficult concept for you to imagine, so let's take a break and think about a thick milkshake for a minute. Imaging sucking on a straw that is open on the other end. You would get a mouthful of air, but you wouldn't lower the pressure in the straw very much. Now, think of what happens when you put the straw in a thick milkshake. When you suck on the straw there is so much restriction that you get a mouthful of nothing and the straw collapses. You can see the pressure inside the straw drop as it collapses.

That same thing happens in an evaporator. Remember that the metering device is located on the suction side of the compressor, and the evaporator is located between the metering device and the compressor. You might think of the evaporator as your straw, the compressor as your mouth, and the metering device as the thick shake. A metering device that restricts too much flow acts like the thick milkshake. Meanwhile, the compressor continues to chug away, and so the pressure in the evaporator drops, just as the pressure does in the straw.

Remember how pressure affects boiling temperature? A lower pressure will cause liquid to boil at a lower temperature. If the metering device has too much restriction, the suction of the compressor will cause the pressure in the evaporator to drop. If the pressure drops low enough, whatever little refrigerant makes it through the metering device will boil at a temperature below 32°F, and any condensation on the evaporator coil will freeze.

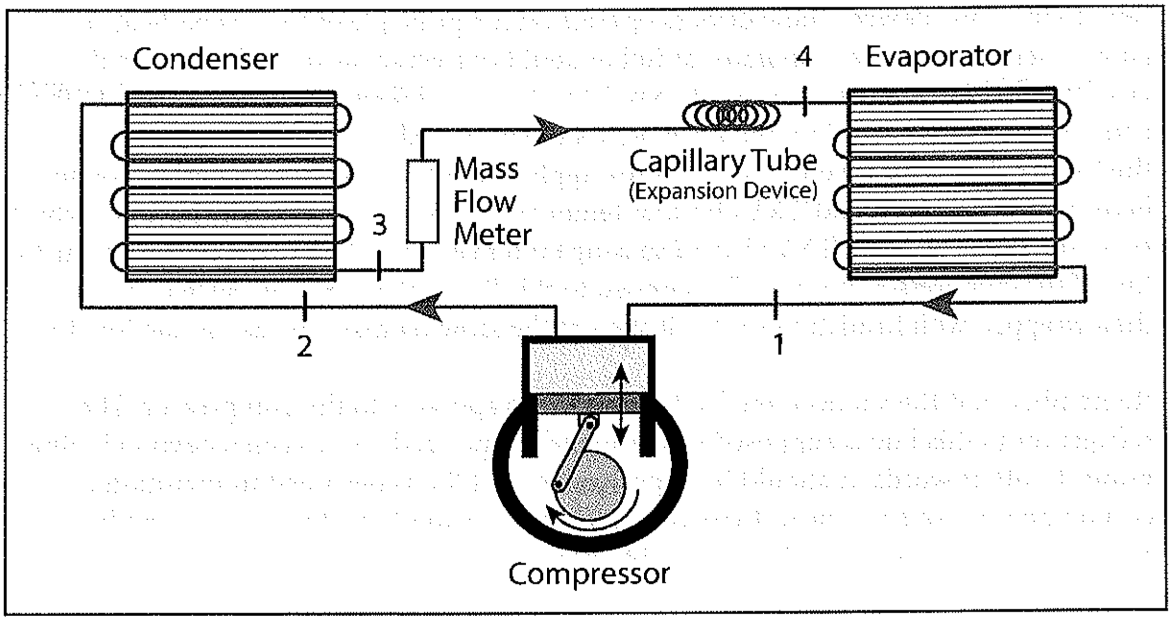
You will not be asked to troubleshoot problems with systems or metering devices, but it is critical for you to understand how important it is to provide the correct metering device. If you don't have the correct device in stock, you may be tempted to provide a similar device in its place. You may get lucky and the alternate device may work properly. But if the device works improperly, your customer may have to return to the service site and replace the new device.

A **CAPILLARY TUBE** (or *cap tube*) is a metering small-diameter tube designed to restrict the flow of refrigerant. The inner diameter, called the **BORE** is very small—only 0.020 to 0.09 inches. Like any metering device, the cap tube is installed between the liquid line coming from the condenser and the evaporator coil. It is installed as close to the evaporator as possible. Remember that the liquid line is typically 3/8 of an inch in diameter. When the refrigerant gets to a much smaller cap tube, the results are the same as when a four-lane highway suddenly drops to one lane. There becomes a restriction to flow. The longer the line, the more restriction there becomes.

The length and bore of a cap tube determines how much restriction will be added: the longer the tube and the smaller the bore, the more restriction. For new equipment, the capillary tube length is calculated and installed at the factory. Cap tubes are almost always coiled up because the tube itself is so long. Because the capillary tube is a fixed length, it is not suited for systems that must function over a wide range of operating conditions. You will see these installed on lower-cost systems that are designed to operate under more or less the same conditions all the time. Examples would be small systems such as window air conditioners, water coolers, and refrigerators. You might also see capillary tube metering devices used in lower-cost unitary air conditioning systems up to about 10 tons.

Now, take a minute to study the image of the capillary tube that follows on the next page. Study the relationship of compressor, condenser, capillary tube, and evaporator to one another. Also note where the capillary tube is coiled up and installed in front of the evaporator.

CAPILLARY TUBE



A simple way to meter refrigerant is to restrict the flow. **FIXED-ORIFICE METERING DEVICES** are very common in unitary residential air conditioning and heat pump systems. A fixed orifice is simply a small restriction of a fixed size located in the liquid line between the condenser and evaporator. Typically, you will see fixed-orifice metering devices used in systems with SEER ratings of 12 and below, and you will see thermostatic expansion valves (TEVs) used with systems with SEER ratings of 12 and above. The flow rate through these devices is purely a function of the pressure drop between the upstream and downstream side and the density of the refrigerant. Like capillary tubes, fixed-orifice metering devices cannot adjust themselves for varying operating conditions. They are designed for only for a specific condition.

You will hear these metering devices called *fixed-orifice, fixed-bore, accurators,* and *restrictors.* They will vary slightly from manufacturer to manufacturer, but they share the same design concept. Refrigerant is forced to flow through a very small opening and this restriction meters the amount that can pass. The size of the opening determines how much refrigerant will flow. To give you an idea of the size of these devices, one manufacturer lists an orifice with a bore of .047 inch for a one-ton system and another with a bore of 0.92 inch for a five-ton system. Some of these devices are designed with a bypass feature that allows them to be used in reversible-flow systems (heat pumps).

Capillary tubes and other fixed-orifice metering devices are designed for a single operating condition; however, **THERMOSTATIC EXPANSION VALVES** are a modulating type of metering device. This means that it can adjust itself to varying conditions, making it a superior metering device. It is also more expensive, which is why you will see so many cap tube and fixed-orifice systems.

You will see thermostatic expansion valves abbreviated as both **TXV** and **TEV**, but both refer to the same device. These devices operate on the principle of fixed superheat. This allows them to keep the evaporator as full of liquid refrigerant as possible, while still ensuring that the liquid is vaporized completely before it leaves the coil on its way to the compressor. For air conditioning systems, TXVs are typically set for 10°F superheat in the factory. TXVs for medium temperature applications typically have superheat set for between 5°F and 10°F, and TXVs for low-temperature applications usually have superheat set in the range of 2-5°F. TXVs have a sensing bulb that is attached to the outside of suction line of the compressor. It is usually clamped to this line with something such as zip ties, and then wrapped with insulation so that it stays at the same temperature as the suction line.

Remember that the suction line leads from the evaporator to the compressor. The refrigerant in this line is supposed be completely vaporized and warmed beyond boiling point. In other words, it should be superheated. A TXV is designed to maintain a certain amount of superheat. Remember, if there is superheat, there can be no liquid, and we want to make sure that no liquid enters the compressor.

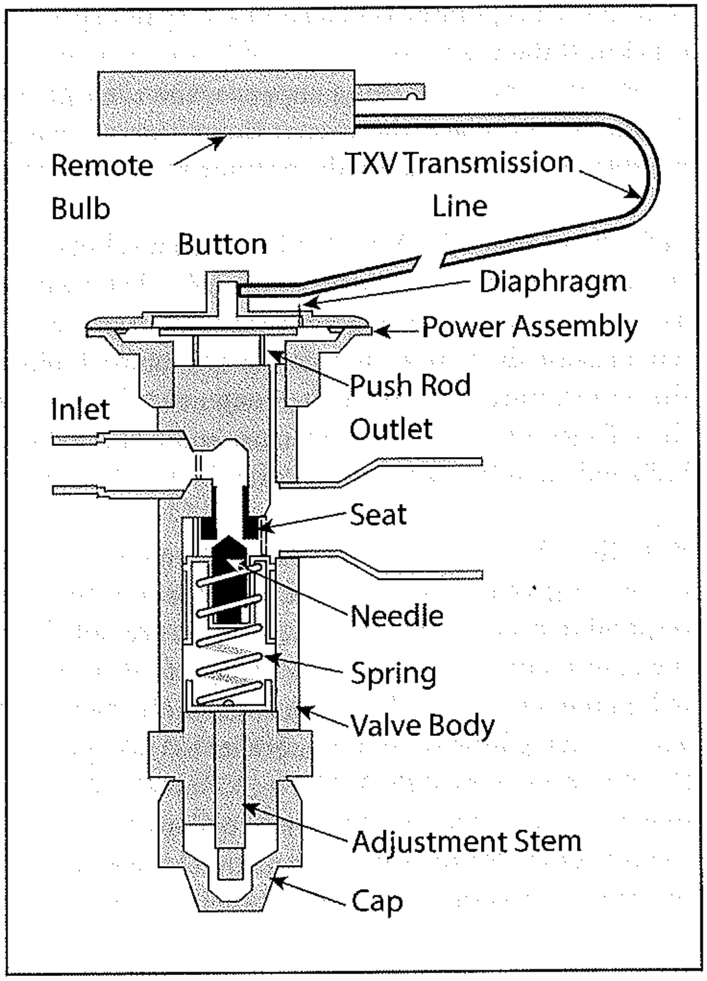
Different TXV designs feature sensing bulbs that are filled with either a liquid or a vapor. Some TXVs use a liquid with exactly the same temperature-pressure relationship as the refrigerant in the system. Often, the liquid is the same refrigerant as that used in the system. This is called a **LIQUID CHARGE BULB**. These bulbs are not completely full of liquid. Just as a tank of propane (liquid petroleum or LP gas) is liquid at the bottom of the tank and vapor at the top of the tank, a liquid-charged bulb will have some liquid and some vapor. As the bulb warms, more of the liquid is vaporized. And as the bulb cools, more of the vapor condenses to a liquid.

The fluid inside these bulbs is another place where the relationship between temperature and pressure comes into play in the HVACR industry. Let's say that a bulb is exactly half full of refrigerant liquid, and the space above the liquid is filled with refrigerant vapor. What happens when the bulb is heated? Of course, more of the liquid will vaporize. What happens to the pressure inside of the bulb? Because the bulb is sealed, there is no place for the refrigerant vapor to go. And since liquid greatly expands when it vaporized, the pressure inside the bulb will increase. The opposite will happen when the bulb cools. Some of the refrigerant vapor will condense, and this reduces the pressure inside the bulb.

A **CROSS LIQUID CHARGE** bulb is filled with a liquid with different properties than the refrigerant in the system. Any liquid-charged bulb will always have at least some liquid in them. A **VAPOR CHARGE** bulb has only a small amount of liquid refrigerant, so that at certain times during operation, all of the liquid will be vaporized. A **CROSS VAPOR CHARGE** bulb will have a small amount of liquid that is different than the refrigerant in the system. Any vapor-charged bulb will contain all vapor during certain operating conditions. For the purposes of this book, it is not important to know the reasons for these four different kinds of charges in the sensing bulb. But it is important for you to be aware that the differences exist, and it is important that your customers get the TXV they need for their particular application.

You may hear the sensing bulb called a *remote bulb* because it is attached to the actual valve by the **TXV TRANSMISSION LINE**. The valve itself gets mounted at the entrance to the evaporator, while the remote bulb is physically attached to the outside of the copper line leading from the evaporator to the compressor. The transmission line is nothing more than a capillary tube, i.e., a very small diameter copper tube that enables the remote bulb and the top of the valve to have the same pressure.

THERMOSTATIC EXPANSION VALVE



The top of the valve has a **DIAPHRAGM**, a thin metal disk, that seals the top of the valve from the bottom of the valve. The space on the top of the diaphragm is connected to the transmission line. When the pressure in the remote valve rises, that pressure travels through the transmission line and exerts pressure on the top of the diaphragm. When that happens, the diaphragm pushes against push rods, and the push rods open the valve a little bit. The higher the pressure gets in the remote bulb, the more the valve opens. When the pressure drops in the remote bulb, the pressure also drops above the diaphragm. When this happens, a spring pushes the diaphragm up, and this closes the valve a little bit. The lower the pressure gets in the remote bulb, the more the valve closes.

So, let's figure out what makes the pressure in the remote bulb rise and fall. We'll use a bulb charged with the same refrigerant as our system. Since the bulb is attached to the suction line, it will have the same temperature as the suction line. If the suction line gets warmer, the bulb will get warmer, and when the bulb gets warmer, the pressure inside the bulb goes up. If the suction line gets cooler, so will the remote bulb, and the pressure in the bulb will go down.

Next, let's think about what would make the evaporator get warmer or cooler. Remember, an evaporator is used to absorb heat. In order to do this, refrigerant boils inside the evaporator, absorbing the heat necessary to change from a liquid to a vapor. Let's assume that there is no flow in the evaporator, and that it has only a fixed amount of refrigerant in it. If the evaporator is placed in a very hot space, the refrigerant would boil very quickly. If the evaporator is placed in a cooler space, it would take longer to boil the refrigerant. The same thing happens when refrigerant is flowing through the evaporator. The hotter the space, the sooner the refrigerant will boil. After the refrigerant has completely vaporized, it will continue to heat up or become *superheated*.

Let's say we have a TXV set for 10°F, and it is hot enough in the space to boil all the refrigerant in the first quarter of the coil. That means the refrigerant will continue to heat as a vapor (superheat) as it flows through in the remaining three quarters of the coil. This would cause the temperature to rise way above boiling. We call this *excessive superheat*. As the temperature rises above the design of 10°F superheat, the excessive superheat will heat the refrigerant in the bulb and cause some of it to boil. This will raise the pressure in the bulb and open the valve more in the TXV. Like opening a water faucet, you get more flow.

With the TXV more open, more refrigerant flows to the evaporator. Because there is more refrigerant flowing, it will take more coil to get it to boil. The TXV will continue to respond to changes in pressure within the remote bulb until the amount of superheat in the evaporator drops back to the design of 10°F. At this point, nearly all the coil is needed to boil the refrigerant. This means that only the last little bit of the coil is full of refrigerant vapor, leaving little room for superheat to take place. In our example, there will be just enough room to heat the vapor by 10°F above its boiling point. If superheat drops too much, it means that the evaporator coil has too much liquid in it, and there wasn't enough room left over for the vapor refrigerant to heat up. The remote bulb will cool, some of the vapor refrigerant inside will condense, the pressure inside the remote bulb will drop, and the TXV will close a little bit. This will reduce the amount of refrigerant entering the evaporator, and the superheat will rise a little bit.

You can see that a TXV is much more complex than a capillary tube or fixed-orifice metering device. However, all metering devices must be selected carefully so just the right amount of refrigerant is allowed to flow. Even though a TXV can adjust itself to changing conditions, it is important to understand that it can only adjust itself accurately if it has been installed on a system matched to its performance. An oversized valve will allow too much refrigerant to flow, even though the valve was opened only a little. An undersized valve will not be able to allow enough refrigerant to flow, even when it is opened all the way.

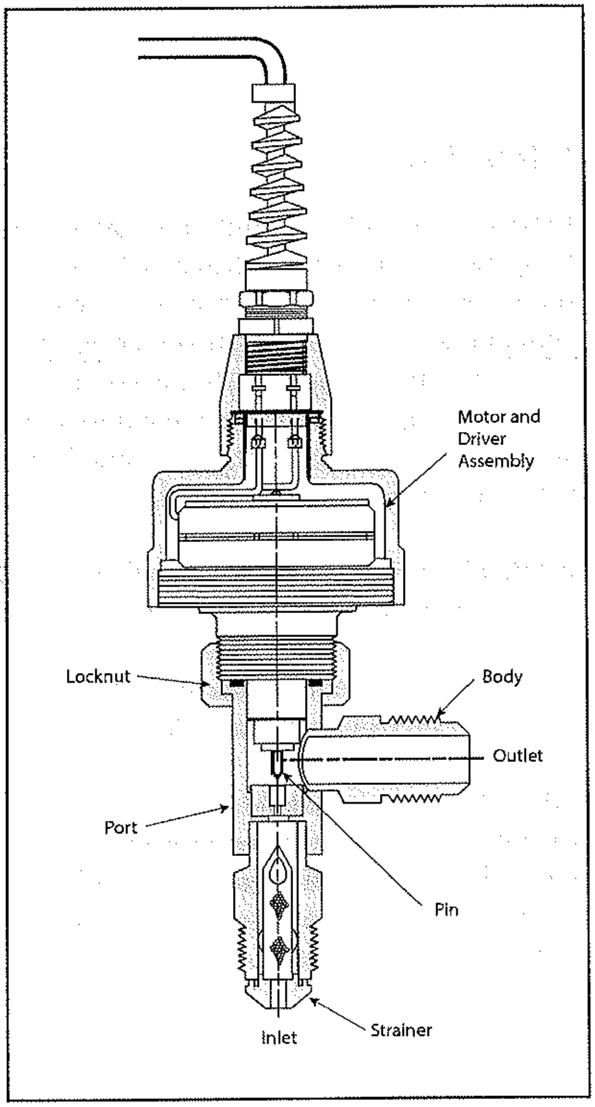
Some TXVs have an external equalizer to compensate for pressure drops from the inlet to the outlet of an evaporator. Such a TXV is needed when the pressure drop exceeds 3 psig for an air conditioner, 2 psig for commercial refrigeration applications, or 1 psig when the

TXV is used for low-temperature applications. For the systems serviced by your customers, it is important that you supply them with the correct TXV for their application. A basic understanding of the TXV operation will help you as you talk with your customers.

Automatic Expansion Valve (AXV)

The **AUTOMATIC EXPANSION VALVE (AXV)** maintains a constant pressure in the evaporator, unlike the thermostatic expansion valve, which maintains a constant evaporator superheat. Remember that boiling temperature is controlled by pressure and that refrigerant in an evaporator is boiling. By maintaining a constant pressure, the AXV will keep the refrigerant boiling at the same temperature. You will typically see AXVs on small equipment with a relatively constant load. Examples include ice cream freezers and drinking fountains.

ELECTRONIC EXPANSION VALVE



Electronic Expansion Valve (EEV)

ELECTRONIC EXPANSION VALVES (EEVs) provide even more precision than the thermostatic expansion valve (TXV). These valves use electronic controls to monitor the temperature and pressure of the evaporator constantly. With this technology, *superheat* (the phenomenon in which a liquid is heated to a temperature higher than its boiling point, without boiling) can be reduced to a minimum. The sooner refrigerant liquid boils in the evaporator, the longer the vapor has to heat up and the higher the superheat temperature will be.

In a refrigeration system, 100% of the evaporator coil should be used for cooling if possible. If less than 100% is used, coil area is wasted. Normally, some of the coil area is sacrificed to make sure that all of the refrigerant is vaporized before it gets to the compressor. This protects the compressor, but sacrifices efficiency. The EEV uses more of the coil, which produces less superheat and increases efficiency. This is possible because the EEF is very fast and very precise at metering refrigerant.

The electronic sensors used with the EEV are much quicker to respond than a remote sensing bulb in the TXV. Because they are very small and have little mass, electronic sensors respond to changes in temperature and pressure almost instantly.

The valve itself can also respond very quickly. The valve is moved using a **STEPPER MOTOR**. These stepper (or step) motors can operate at approximately 200 steps per second. They typically have over 1,500 steps between fully open and fully closed. With only about an eighth of an inch of travel between fully open and fully closed, you can see that each step moves the valves a very small amount. With the ability to make 200 very small changes per second, the EEV is very, very precise.

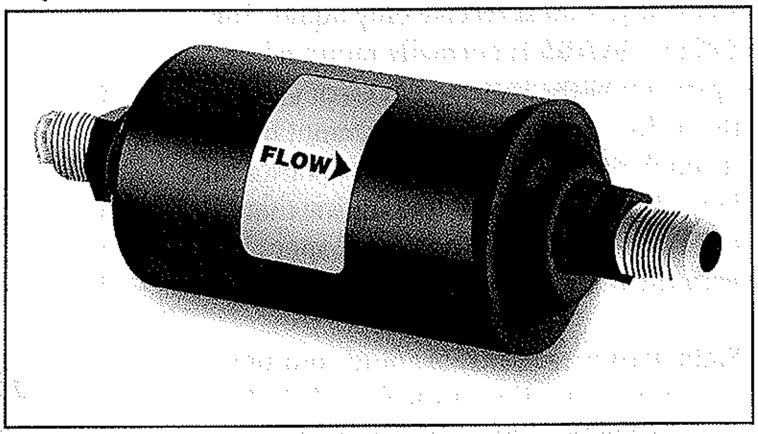
Filter-drier

Refrigeration and air conditioning systems must be clean and free from water and acids to operate properly and efficiently. However, some contaminants, including bits of tubing broken off after the tubing was cut, get into the system during installation. Other contaminants come from the soldering and/or brazing that takes place to connect tubing and components together. Some contaminants simply come from dirt and other foreign objects that get into the system before it is sealed up. Any water in a refrigeration system can react with refrigerant and heat to form acids. These acids can deteriorate motor windings, corrode metal, and form sludge in the system.

A **FILTER-DRIER** is a device installed in a refrigeration system that filters the refrigerant to trap small particles. It also includes a **DESICCANT** material to absorb any water that may be in the system. A desiccant is a material that is *hygroscopic*, which means that it can attract and hold water molecules. Those little bags of silica gel that you find in the box of some new products are examples of a desiccant.

Filter-driers are available in many sizes and sizes. Some are available for installation on the liquid line and some are for installation on the suction line. Most of the filter-driers you will supply are designed for smaller systems. These filter-driers are disposable and are replaced when they reach their capacity to hold dirt or water. You may also see some canister-type filter-driers, which are bolted together and have a desiccant core that can be replaced.

LIQUID LINE FILTER-DRIER WITH FLARE CONNECTIONS



LIQUID LINE FILTER-DRIERS should be installed on all new systems, and should be replaced whenever a system is opened up. These are typically located just upstream of the metering device to prevent particles from entering the metering device and clogging the very small opening inside. When liquid line filter-driers become clogged, technicians can detect a temperature drop from one side to the other. In effect, a dirty liquid line filter-drier acts just like a metering device.

SUCTION LINE FILTER-DRIERS are recommended any time a motor has to be replaced because of a burnout, or when any other major work has been performed. You can tell the difference between a liquid line and suction line filter-drier. For the same system, the suction line filter-drier will be bigger than a liquid line filter-drier, and it will be equipped with service ports on both the inlet and outlet sides. Because suction line filter-driers have refrigerant vapor instead of refrigerant liquid flowing through them, there will be no drop in temperature for the service technician to measure as there is when a liquid line filter-drier becomes clogged. The service ports on the suction line filter drier are so the service technician can measure pressure drop.

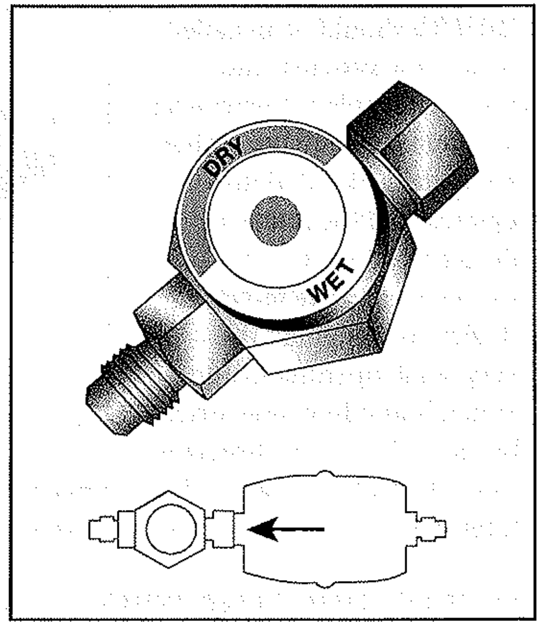
Filter-driers are available with solder, flare, or threaded connectors. Most are designed for flow in only one direction, which is indicated with an arrow. Some, used for heat pumps, are designed for flow in either direction and are called *bi-flow*.

Sight Glass

It can be challenging to tell what is going on inside a refrigeration system. The refrigerant is supposed to changing from liquid to vapor and back again, and the temperatures and pressures change throughout the system as well. Technicians can verify that the compressor is receiving only vapor refrigerant by measuring superheat. To verify superheat, the technician takes a temperature reading of the evaporator coil, then takes a temperature reading of the suction line just before it enters the compressor, and compares the two. If there is a difference, there is superheat, and the technician knows the compressor is getting only vapor.

For a metering device to work most efficiently, it must receive only liquid. The **SIGHT GLASS** is normally mounted just upstream of the metering device. It allows the technician to see the refrigerant flowing through the system, which should be a solid flow of liquid. Any bubbles indicate that the metering device is getting some vapor along with the liquid.

SIGHT GLASS WITH MOISTURE INDICATOR



Sight glasses are available (and common) with a moisture indicating disc. This disc is coated with a chemical compound that changes color when water is present. You can tell how much water is in the system by the color of the chemical. For example, if you see green, that commonly indicates a dry condition, which means all is well. A yellow/green color commonly means that some moisture is present. If you see yellow, that commonly indicates that the system is wet and there is a problem.

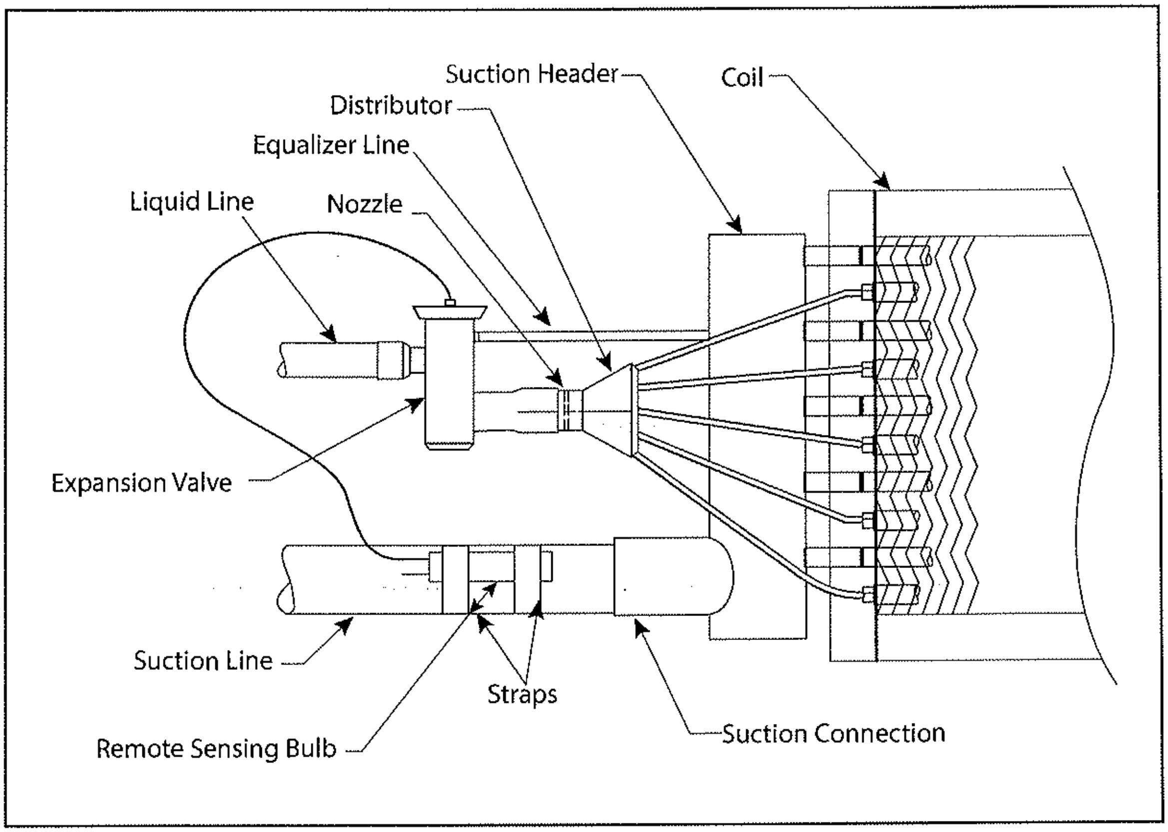
Distributor

Remember that when liquid refrigerant passes through a metering valve, part of the liquid immediately boils and turns to vapor. Even though most of the refrigerant leaving the metering device is liquid, the little bit of vapor takes up space. The liquid flows on the bottom of the line feeding the evaporator, while the vapor travels along the top.

Many evaporators have multiple circuits to make them more efficient. If a metering device is connected directly to a multiple-circuited evaporator, some of the circuits would be fed with liquid refrigerant and some would be fed the vapor. A distributor is used to prevent this from happening. A **DISTRIBUTOR** is a small device located at the outlet of an expansion device that distributes refrigerant evenly to numerous refrigeration circuits and blends the liquid/vapor mix so all circuits receive the same mix. Like other components, the distributor must be properly sized for it to work properly.

Some of a distributor's components are shown in the following schematic. Notice where the liquid line (from the condenser) feeds the expansion valve. The distributor is just downstream (to the right) of the expansion valve. This drawing also shows five circuits feeding the evaporator coil. The evaporator coil has five suction lines that feed the suction header and note where the suction header is connected to the suction line. The remote sensing bulb for the expansion valve is mounted properly to the suction line, where it can sense the superheat. The small curved line drawn from the remote sensing bulb to the expansion valve is the transmission line. This drawing also shows the external equalizer line used to compensate for the pressure drop through the distributor and evaporator coil.

DISTRIBUTOR



APPLYING WHAT YOU HAVE LEARNED:

Now take the time to think of how this will relate to your company. Use the space below to answer the following questions. If you are not sure of the answers ask your supervisor. These answers will vary for each company.

A. What type of condensers do your top three selling air conditioners use?

B. List the types of metering devices your company sells. Look at how they vary to each other.

Valves

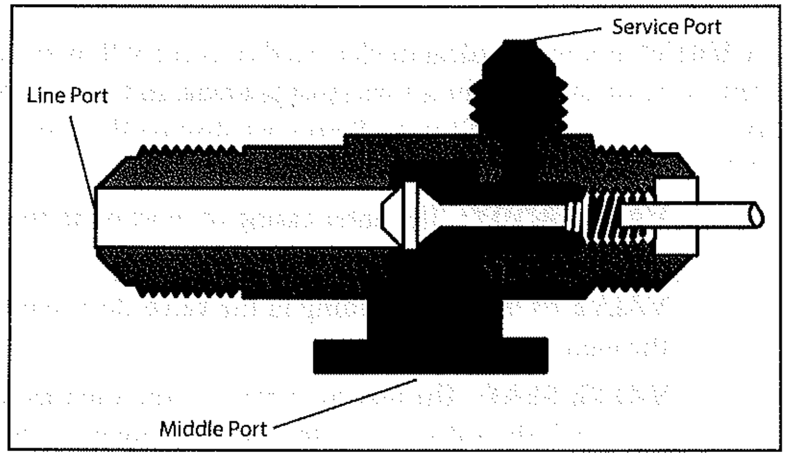
A **VALVE** is a mechanical device used to control flow media. Valves are used in refrigeration systems for a variety of reasons. In this section, you will learn about the types of valves and their uses. Before we discuss the types of valves available, we will define some of the common parts of a valve.

- **VALVE BODY:** The outer casing of most or all the valve that contains the internal parts or the "guts" of the valve.
- **VALVE PORT:** An opening in the valve closure member which permits flow through the valve.
- **VALVE SEAT:** The mating surface in the valve assembly that permits tight closure. If the valve seat or the valve is damaged, the valve will leak no matter how much it is tightened.
- **VALVE DISC:** The part of the valve that rests against the valve seat (sometimes referred to as *boss*). There are many valve designs, but service valves used in refrigeration systems use a valve disc and two valve seats to control flow, so we introduce you to that type of valve here. It may help you to think of the valve seat as a hole in a valve and a valve disc as the plug used to prevent flow through the hole.
- **VALVE STEM:** The rod or shaft transmitting motion from an operator (handwheel or gear operator) to the closure element of the valve. The valve disc is attached to the valve stem and moves up and down as you turn the valve stem.
- **PROTECTIVE CAP:** A removable cover that protects the sensitive valve internals from dust, dirt, and humidity. If valve caps are lost, they should be replaced immediately in order to avoid expensive damage later. A service technician has to unscrew the cap before the valve can be turned.
- **VALVE PACKING:** The deformable sealing material inserted into a valve stuffing box which, when compressed by the gland, provides a tight seal about the stem.
- **PACKING GLAND:** The space around a valve stem as it rises out of the top part of the valve, which is called the valve bonnet, that holds the packing in place.

Service Valves

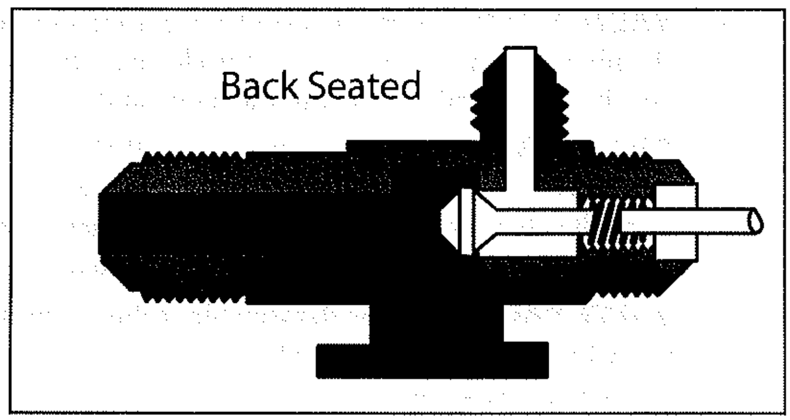
Technicians use **SERVICE VALVES** to access the inside of a refrigeration system. When a technician needs to add or remove refrigerant or oil, a service valve provides the spot to connect a gauge manifold. Service valves are located on the suction and discharge side of compressors mounted in the condensing units that you stock. You might see one on the liquid line as well. These valves have three valve ports and two valve seats.

SERVICE VALVE



The middle port (bottom port in the right figure) of the service valve is connected to the compressor or refrigeration system. The left port in the above figure is connected to one of the refrigeration lines. Logically, this port is called the **LINE PORT**. And the service port (top port in the right figure) is used for servicing the system. It is where the service technician will connect a gauge manifold.

Look at the above figure as we describe the different positions for the valve. Where you see the valve filled in black, is where the refrigerant can flow. You can see the valve disc at the left end of the valve stem, and you can see that it moves left and right between two valve seats. If you study where the refrigerant can flow in the three diagrams, you can see that the valve is never "open" or "closed." Instead it simply changes where the refrigerant is allowed to flow.

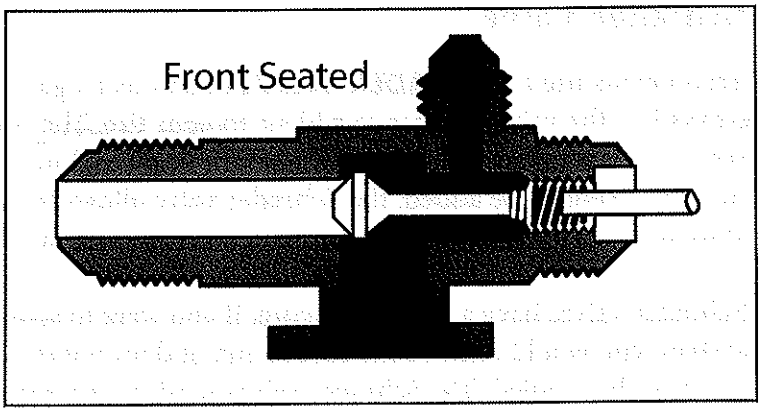


In the picture to the right, the valve has been turned all the way out. This would be like opening up a faucet for a garden hose all the way. In a service valve, some people will say the valve is open. It is more accurate to say the valve has been **BACK SEATED**.

This is the position for the valve during normal operation of the system. In other words, the valve will always be in this position except for the rare times when the system is under repair. In this position, refrigerant can flow between the compressor (bottom port) and the system (left port).

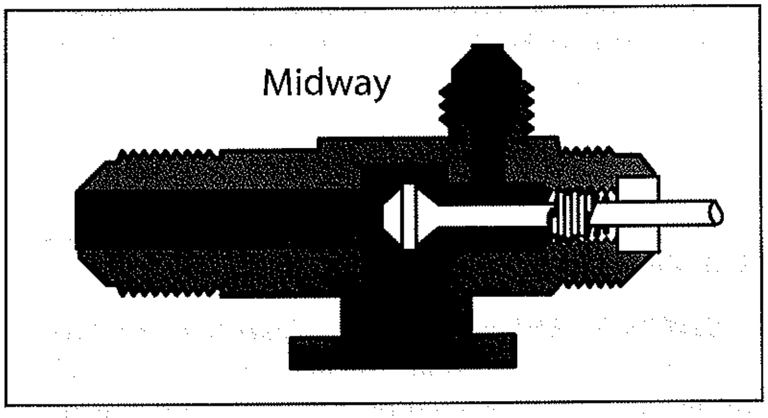
Can you see that if a technician connected a gauge manifold to the service (top) port when the valve is back seated, no pressure would be recorded and no refrigerant or oil could be added to the system?

The picture to the right shows the valve in a front-seated position. To **FRONT-SEAT** a service valve, you turn the stem clockwise all the way in. This would be like shutting off the faucet for a garden hose. Some technicians call this closing the valve, but it is more accurate to say the valve has been front seated.



In the front seat position, refrigerant can flow between the compressor and the service port, but it cannot flow between the compressor and the system. A gauge manifold connected to a front-seated valve will read whatever pressure the compressor has, and can be used to add or remove refrigerant or oil.

In the mid-seat position, the valve disc is halfway between the front seat and back seat and refrigerant can flow between all three ports. In this position, a gauge manifold will read the pressure of the system during normal operation and can be used to add or remove refrigerant or oil.



The valve stem on a service valve has a square end. Because there is no handle or handwheel to open or close the valve, a service wrench is used to turn the valve.

King Valve

A **KING VALVE** (also called a *liquid line service valve* or an *isolation valve*) is a service valve that is mounted on the outlet of a receiver and found downstream from a liquid line receiver. This valve is not as common as other valve types in residential units. It is called a "king valve" perhaps because it can be closed to permit the pump-down of a system in order to trap the refrigerant in the receiver and condenser; in that sense, it "rules" the system.

Schrader Valve

Technicians use a **SCHRADER VALVE** to connect a gauge manifold to the system. It works like the valve you use to add air to your tire. The core is depressed when the gauge manifold is connected to allow refrigerant or oil to flow into or out of the system. Even if nothing needs to be added, the Schrader valve allows technicians to read the pressure in a system, just as you read the pressure in your tire with a pressure gauge.

Schrader valves have a removable core. If you were to solder or braze a Schrader into a system, you would remove the core so that it does not overheat. You would reinstall it once the valve has cooled. The Schrader valves used in tires cannot be used in refrigeration systems because the material used to seal the valve is not compatible with refrigerant.

Your company will stock Schrader valves that can be soldered in the system. It will also have a version of the Schrader called the **LINE TAP VALVE** (also commonly called a **SADDLE VALVE** or **PIERCING VALVE**). A line tap valves comes in two halves, which are placed on either side of a refrigerant line and then clamped around the tubing using a couple of screws. Then a piercing pin is screwed into the tubing and retracted, which creates a sealed access port. Because the valve comes with a Schrader valve on one-half, a technician can hook a manifold gauge to the Schrader and perform whatever service needs to be done.

Check Valve

A **CHECK VALVE** is a valve that closes to prevent backward flow of liquid; it allows flow only in one direction. You may supply check valves for heat pump systems. When refrigerant flow reverses direction in a heat pump, the check valve will make sure the refrigerant flows to the correct metering device. (There are usually two metering devices in a heat pump.)

Solenoid Valve

A **SOLENOID VALVE** is an automatic valve operated by an electromagnet that either opens or closes the valve. The valve may be **NORMALLY OPEN (NO)** or **NORMALLY CLOSED (NC)**. A normally open valve is open until it is energized, and then it will close. A normally closed valve is closed until it is energized, and then it will open. Solenoid valves can control the flow of both vapor and liquid.

Solenoid valves are not used on residential or light commercial systems. They are used in systems that automatically pump the refrigerant to the receiver when the system is shut down. Rather than having a technician use service valves to manually pump down a system, solenoid valves perform this function automatically.

Receiver

Automatically adjustable metering devices, such as the TXV and the AXV, throttle to allow more or less refrigerant to flow. When less refrigerant is needed, the system needs a container, called a **RECEIVER**, to hold the excess liquid. The receiver, which can be horizontal or vertical, is installed between the condenser and the metering device. Any refrigerant not needed by the system stays in the receiver. When an automatically adjustable metering device calls for more refrigerant, pressure from the compressor forces liquid refrigerant to flow from the receiver to the metering device.

Receivers are used so that a system is never completely full of refrigerant. Imagine a tank with an inlet on the top and an outlet on the bottom. The inlet allows liquid to flow into the tank from the top and, because of gravity, the liquid flows to the bottom of the tank. With the top part of the tank full of refrigerant vapor, there is no way the inlet can pull liquid back out of the tank. The outlet at the bottom of the tank acts like a drain in a sink. The important thing to remember about a receiver is that it is a tank designed so that only liquid can leave the tank. Refrigerant vapor at the top of the tank cannot get out through the bottom because the liquid blocks it.

A receiver is simply a tank with the inlet arranged so that liquid enters at the top of the tank and the outlet must pick up liquid from the bottom of the tank. If the outlet connection needs to be at the top of the tank, the outlet is connected to a **DIP TUBE** (sometimes called a *pickup tube*). The dip tube runs to the bottom of the tank so that only liquid can enter. During normal operation, the receiver stores refrigerant that is not needed during low load conditions, and it acts as a source of extra refrigerant when more is needed during high load conditions.

A receiver can double as a tank to store refrigerant when the system needs servicing. The service technician will close (or front-seat) the king valve fitted to the outlet of the receiver. With the valve in this position, no refrigerant can leave the receiver. Next, the technician will start the compressor which pumps refrigerant from the evaporator, through the compressor, and into the condenser and receiver. Once the refrigerant has been pumped to the condenser and receiver, the service valve on the compressor is closed (or front-seated) to prevent refrigerant from flowing backward through the system. This process, which is called **PUMP DOWN**, effectively pumps all the refrigerant to the receiver and traps it there.

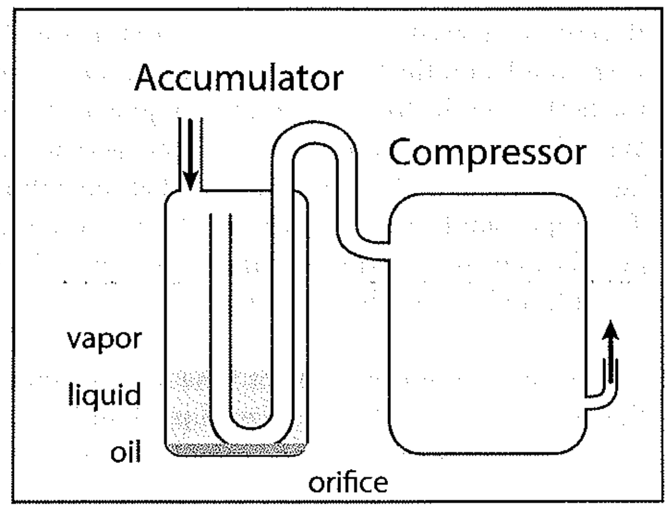
Accumulator

While a receiver is a tank that allows only liquid to leave, an **ACCUMULATOR** is a tank that allows only vapor to leave. Accumulators are installed between the evaporator and the compressor. Remember that no liquid should ever be allowed to enter the compressor because damage could occur. With an accumulator, small amounts of liquids *can* leave the evaporator and drains to the bottom of the accumulator. The accumulator's outlet is located at the top, so the liquid stays trapped at the bottom and only vapor can leave.

Any liquid in the accumulator will eventually vaporize and leave through the outlet at the top. Heaters wrapped around some accumulators speed up the vaporization of liquid refrigerant. Other accumulators run a loop from the liquid line coming off the condenser through them. The heat from the warm liquid helps to vaporize liquid in the accumulator. Most accumulators simply rely on the temperature of the surrounding air to vaporize any liquid refrigerant. Because of this, they are uninsulated.

Accumulators are built with some method of returning oil to the compressor. The image to the right shows a very common method. An inverted trap with a small hole in the bottom picks up oil at the bottom of the accumulator and returns it to the compressor.

SUCTION LINE ACCUMULATOR



Because heat pumps do not need as much refrigerant during the winter, accumulators are used as storage devices for excess refrigerant in heat pump systems during that time.

Dehumidifiers

As you've learned already, cooling coils in humid climates automatically dehumidify air as the air cools. This happens because the warm humid air that enters the cooling coil is cooled to dew point and below. When that happens, water vapor from the air is condensed on the coil and drained away.

The type of dehumidifiers used in small and medium-sized HVAC applications are air conditioners with both the evaporator and condensing coils located in the same cabinet. Dehumidifiers have a compressor, condenser, metering device (in this case, a capillary tube), and an evaporator. The fan draws moist air from the building through the evaporator coil. Because the coil is cold, the moist air hits dew point and water vapor is condensed out. The air leaves the evaporator cooler and dryer and immediately flows through the condenser. Heat from the condenser coils warms the air, but does not add any humidity. The result is air that is dryer and has a lower relative humidity.

Refrigerants and Refrigerant Oils

In this section, you will learn about the many kinds of refrigerants and oils used in refrigeration systems. We will begin with a brief history of refrigerants and then discuss common refrigerants, refrigerant oils, and refrigerant cylinder color codes. The history of refrigerants is included because you will hear technicians talk about refrigerants that are no longer used and about refrigerants that are still in use but no longer manufactured.

Scientists and entrepreneurs were learning about electricity and refrigeration during the same period in history, from the late 1800s through the early 1900s. In the early days of the refrigeration industry, people were experimenting with different chemical compounds to use as refrigerants. A **REFRIGERANT** is a body or substance that acts as a cooling medium by extracting heat from another body or substance. Early compounds had toxic-sounding names such as sulfur dioxide, methyl ether, methyl chloride, and ammonia. In fact, most of the compounds were toxic to humans, nearly all of them were flammable, and some were very corrosive. These facts led to efforts to find a refrigerant that was not toxic or flammable but has good thermodynamic properties.

Refrigerant Groups (Alphabet Soup)

The **NATIONAL REFRIGERATION SAFETY CODE** classifies refrigerants into three groups:

- Group I – safest of the refrigerants, such as R-12, R-22, and R-502
- Group II – toxic and somewhat flammable, such as R-40 (Methyl chloride) and R-764 (Sulfur dioxide)
- Group III – flammable refrigerants, such as R-170 (Ethane) and R-290 (Propane).

CFC Refrigerants

By the late 1920s, the search for safe alternatives to the earlier refrigerants resulted in CFC refrigerants. **CFC REFRIGERANTS** are made up of chlorine (the first C), fluorine (the F), and carbon (the last C). The abbreviation for chlorofluorocarbon (**CFC**) is used to describe these refrigerants. One of the earliest and most common CFC is R-12. (Note: The letters stand for chemicals used in the refrigerants. Later in this section, you'll learn about the numbering system used for refrigerants.) According to the Environmental Protection Agency (EPA), R-12 accounted for half of the 372 million pounds of refrigerants produced containing fluorine and carbon between 1930 and 1963. Not only was R-12 an excellent refrigerant, it was also used as a propellant in cans of spray deodorant. Those who used these deodorants remember them as being "cold" when sprayed.

R-12 and other CFCs such as R-11, R-113, R-114 and R-115 seemed to be the ideal refrigerants. They had the thermodynamic properties desired, were not harmful to humans, did not burn, and they were easy to manufacture. However, in the 1970s, scientists discovered that CFC molecules were very stable and remained in the atmosphere until they reached the stratosphere, where they were broken down by the sun's UV radiation. Once the CFC molecules are broken down by the sun, the chlorine atom is released and starts a chemical reaction that destroys ozone. Some publications report that a single chlorine atom can destroy up to 100,000 ozone molecules. In 1985, an "ozone hole" was discovered above Antarctica and CFC compounds were recognized as a contributing factor. As a result, all United Nation members ratified *The Montreal Protocol on Substances that Deplete the Ozone Layer*, which called for the phase-out of CFC refrigerants. By the end of 1995, it became illegal to produce or import CFC refrigerants.

HCFC Refrigerants

The **HCFCs**, which stands for hydrochlorofluorocarbons, are a second group of refrigerants. HCFC refrigerants include hydrogen (H) in addition to the chlorine (C), fluorine (F), and carbon (C) used in CFC compounds. *The Montreal Protocol* also called for the phase-out of HCFC refrigerants. HCFC refrigerants are being phased-out over a longer time span than CFCs because they have less potential to damage the ozone layer. Even though HCFCs contain a chlorine atom as CFCs do, HCFCs are less stable and break down in the troposphere. Because they break down below the ozone layer in the stratosphere, the chlorine atom is released where it cannot do damage. At the time of this publication, HCFCs are still allowed to be produced and used but in very limited quantities.

R-22 (HCFC-22) was the common refrigerant used in residential and many light commercial air conditioners and many existing systems still contain R-22. Because of anticipated leaks in the coming years, many of these systems will need additional replacement refrigerant so R-22 is still needed in the market. In 2010, it became illegal to produce new equipment that contained R-22. At this time, the phase-out calls for a gradual reduction of the production of the refrigerant itself. By 2020, it will be illegal to produce or import any HCFC-22, and by 2030 it will be illegal to produce or import any of the HCFC refrigerants.

HFC Refrigerants

The HCFs, which stands for hydrofluorocarbons, is a third group of refrigerants that contains no chlorine atoms. HFCs contain only hydrogen (H), fluorine (F), and carbon (C). Because HFCs have no chlorine atoms, they have zero **OZONE DEPLETION POTENTIAL (ODP)**. ODP is a measure of how badly a chemical compound can damage the earth's ozone layer located in the stratosphere. ODP is based on refrigerant CFC-11 (R-11). Because R-11 has three chlorine atoms, it has the maximum potential to damage the ozone layer of any of the refrigerants. R-11 has an ODP of 1.0, which is the highest number possible.

HFCs have been developed to replace ozone destroying CFCs. For example, R-134a (an HFC) has replaced R-12 (a CFC) in automotive air conditioners. Unfortunately, while HFCs have eliminated the threat to ozone, they have become known by some as "super greenhouse gases" because they have thousands of times the **GLOBAL WARMING POTENTIAL (GWP)** of carbon dioxide. **GWP** is a measure of how much heat a greenhouse gas can trap in the atmosphere. A greenhouse gas allows solar radiation to pass through the atmosphere and warm the earth. But greenhouse gasses also absorb heat energy that is radiated up from the warm surface of the earth, and then re-radiates some of that energy back down.

HC Refrigerants

A fourth group of refrigerants called hydrocarbon refrigerants, known as **HCs**, contain hydrogen and carbon. HCs have no fluorine or chlorine. You would know these refrigerants as fuels that include methane, ethane, propane, and butane, among others. These make excellent refrigerants. Because HCs have no chlorine atoms, they have zero ODP. However, they are flammable, which is their biggest drawback.

Refrigerant Blends

The refrigerant industry has been in a state of change since *The Montreal Protocol*. As old refrigerants are phased out, new refrigerants are developed to replace them. One method of development is to blend two or more refrigerants together to create **REFRIGERANT BLENDS**. Like blends before them, newer refrigerants are combined to provide the same properties of a refrigerant they are intended to replace.

A blend that has only one boiling point for a given pressure is known as an **AZEOTROPE** or **AZEOTROPIC MIXTURE**. As it boils, the liquid and vapor have the same mixture by percentage. In other words, if you mixed liquid 1 with liquid 2, the blend would have only one boiling temperature at any given pressure. As the mixture boiled, the boiling temperature would remain the same, just like it does with water.

Blends that have various boiling points for a given pressure are called **ZEOTROPES** or **ZEOTROPIC MIXTURES**. The range of boiling temperature in a zeotrope is called **TEMPERATURE GLIDE** which occurs when one or more of the refrigerants in the blend changes phase faster than the rest. In other words, you can separate zeotropes by normal distillation. When you **DISTILL** something, you are boiling a blend of at least two liquids, each with its own boiling point. The boiling point of the mix will be between the boiling points of the lowest and highest boiling points of the liquids. To illustrate this concept, assume that you have two liquids. Liquid A boils at 100°F while the liquid B boils at 200°F. When you mix the two liquids, the boiling point will be somewhere between 100°F and 200°F, according to the table below.

Liquid A (% of mix)	Liquid B (% of mix)	Boiling Point of Mix (°F)
100	0	100
75	25	125
50	50	150
25	75	175
0	100	200

Note that 75% of Liquid A mixed with 25% of Liquid B will boil at 125°F. As the mix begins to boil, Liquid A will boil at a faster rate than Liquid B because it is more volatile and has a lower boiling point. Because more of Liquid A is boiling than Liquid B, the liquid mix will become more concentrated with Liquid B. When the mix becomes 50/50, the boiling point will be 150°F. Soon the remaining liquid mixture will have only 25% of Liquid A and 75% of Liquid B. The table illustrates that the boiling point would rise to 175°F. This change in temperature during boiling is called *temperature glide in a zeotropic blend*.

Natural Refrigerants

NATURAL REFRIGERANTS are naturally occurring substances, which exist by nature and without artificial aid, such as hydrocarbons, carbon dioxide, ammonia, water, and air. These substances can be used as cooling agents in refrigerators and air conditioners, but do not harm the ozone layer and have no or negligible climate impact.

AMMONIA (R-717) does not belong to a group of refrigerants, but it is used as a refrigerant in large industrial and commercial applications. It has zero ODP and zero GWP, but it is very toxic. It is a very good refrigerant, but its toxicity limits its use to applications occupied by few people.

CARBON DIOXIDE (R-744) was a popular refrigerant before it was replaced with CFCs and HCFCs through the 1940s and 1950s. It is now being studied again because of its low cost and safety, as well as the phase-out of both CFCs and HCFCs.

You have probably heard and read about the level of carbon dioxide rising in the atmosphere and the political firestorm about whether its effect on the earth's climate is scientific fact or fiction. Carbon dioxide is the main character in these debates. It is such an important greenhouse gas that it is the baseline used to rate all other greenhouse gasses. Carbon dioxide has a GWP of 1. A higher number means that a gas is better at trapping the earth's heat than carbon dioxide.

Greenhouse gasses are important because they act like a blanket around the earth. But if the blanket gets too thin, the earth cools, and if the blanket gets too thick, the earth warms. Naturally occurring greenhouse gasses include carbon dioxide, water vapor, and ozone, among others.

Numbering System

DuPont is a dominant manufacturer of refrigerants, and its brand name for CFC and HCFC refrigerants is *Freon*. Because of DuPont's dominance, many people came to know all refrigerants as Freon, even though this is not accurate. It is common to designate a refrigerant with the letter "R," as in R-12. It is more accurate to designate the refrigerant as CFC-12, since that describes the chemistry of the compound regardless of who manufactured it. Thus, R-12, CFC-12, Freon-12, and dichlorodifluoromethane are all names for the same thing. In addition, manufacturers other than DuPont have their own brand names.

As you have seen, there are a number of refrigerants other than R-12. CFC, HCFC and HFC refrigerants are based on **ORGANIC FLUORIDES** or compounds containing fluoride and carbon. In 1956, DuPont developed a numbering system that was adopted by

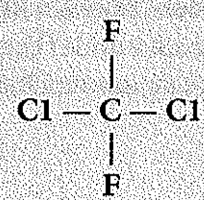
American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and became the standard of the industry. The numbers that you see today in CFC, HCFC, and HFC refrigerants are based on this standard.

Digging Deeper

Advanced information is included in the Digging Deeper sections for students who want more information. The material in these sections will not be tested.

1. The first digit on the right designates the number of fluorine atoms.
2. The second digit from the right designates the number of hydrogen atoms plus 1.
3. The third digit from the right designates the number of carbon atoms minus 1. The number is omitted if it is zero.
4. Each carbon atom can "connect" chemically with four other atoms. This is called a *bond*, or to be more accurate, a *covalent bond*. You can tell how many chlorine atoms there are by multiplying the number of carbon atoms (Step #3) by two and adding two. Next, you subtract the number of fluorine and hydrogen atoms you found in steps 1 and 2, and the remainder is the number of chlorine atoms.

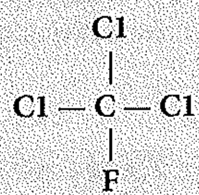
EXAMPLE 1: The molecule for CFC-12 is shown below. It has one carbon atom (C), two chlorine atoms (Cl) and two fluorine atoms (F). Note that the carbon (C) atom has four connections, or bonds.



CFC-12

1. The first digit on the right is a 2, so we know there are 2 fluorine atoms.
2. The second digit from the right designated the number of hydrogen atoms plus 1. Since the second digit from the right is a 1, when we subtract 1 we get 0. So, there are no hydrogen atoms in CFC-12.
3. The third digit from the right designates the number of carbon atoms minus 1. The number is omitted if it is zero. There is no third digit in CFC-12, so we know it is a zero. That tells us there is one carbon atom, since $0 + 1 = 1$.
4. The number of carbon atoms (1) x 2 + 2 = 4, so we know there are 4 connections to the single carbon atom. In step 1, we found that there are 2 fluorine atoms, and in step 2, we found that there are no hydrogen atoms. That leaves two connections open, and these are filled with chlorine atoms.

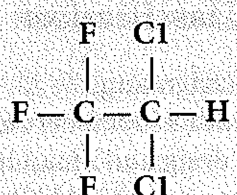
EXAMPLE 2: The molecule for CFC-11 is shown below. It has one carbon atom (C), three chlorine atoms (Cl) and one fluorine atoms (F). Like CFC-12, the carbon (C) atom has four connections, or bonds.



CFC-11

1. The first digit on the right is a 1, so we know there is only 1 fluorine atom.
2. The second digit from the right designate the number of hydrogen atoms plus 1. Since the second digit from the right is a 1, when we subtract 1 we get 0. So, there are no hydrogen atoms in CFC-11.
3. The third digit from the right designates the number of carbon atoms minus 1. The number is omitted if it is zero. There is no third digit in CFC-11, so we know it is a zero. That tells us there is one carbon atom, since 0 + 1 = 1.
4. The number of carbon atoms (1) x 2 + 2 = 4, so we know there are 4 connections to the single carbon atom. In step 1, we found that there is 1 fluorine atom, and in step 2, we found that there are no hydrogen atoms. That leaves three connections open, and these are filled with chlorine atoms.

EXAMPLE 3: HCFC-123 looks like this.



HCFC-123

1. The first digit on the right is a 1, so we know there are 3 fluorine atoms.
2. The second digit from the right designate the number of hydrogen atoms plus 1. Since the second digit from the right is a 2, when we subtract 1 we get 1. So, there is 1 hydrogen atom in HCFC-123.
3. The third digit from the right designates the number of carbon atoms minus 1. The third digit from the right in HCFC-123 is a 1. That tells us there are two carbon atoms, since 1 + 1 = 2.

4. The number of carbon atoms (2) x 2 + 2 = 6, so we know there are 6 connections to the two carbon atoms. (Note that each carbon atom has four connections, but each of the two carbon atoms used a connection to connect to each other.) In step 1, we found that there are 3 fluorine atoms, and in step 2, we found that there is 1 hydrogen atoms. That leaves two connections open and filled with chlorine atoms.

The "Rule of 90"

You may find the Rule of 90 to be a simpler way to determine the number of atoms in refrigerants.

1. Add 90 to the refrigerant number (using R-11 as an example):
   90 + 11 = 101
2. The three digits tell you respectively how many carbon, hydrogen and fluorine atoms are in each molecule
   1 carbon, 0 hydrogen, 1 fluorine.
3. The number of chlorine atoms is found exactly like the method described above. Subtract any non-carbon atom from 2 x number of carbon atoms + 2.
   1 carbon atom x 2 + 2 = 4. There is 1 fluorine atom and 0 hydrogen atoms, so there are 3 chlorine atoms.

Refrigerant Safety Group Classification

The American Society of Heating, Refrigerating & Air-Conditioning Engineers (ASHRAE) develops standards for both its members and others professionally concerned with refrigeration processes and the design and maintenance of indoor environments. Refrigerant safety group classifications are set by ANSI/ASHRAE Standard 34-2010. Standard 34 rates refrigerants by toxicity using the letters A and B, and flammability with numbers 1, 2, and 3. Class A refrigerants have a permissible exposure level (PEL) of 400 parts per million (ppm) or greater. Class B refrigerants have a PEL of less than 400 ppm.

Class 1 refrigerants are not flammable under normal circumstances. Class 2 and Class 3 refrigerant are flammable, with Class 3 being the most flammable refrigerants in the rating system.

REFRIGERANT SAFETY GROUP CLASSIFICATIONS

	Lower Toxicity	Higher Toxicity
Higher Flammability	A3	B3
Lower Flammability	A2 A2L*	B2 B2L*
No Flame Propagation	A1	B1
* A2L and B2L are lower flammability refrigerants with a maximum burning velocity of <10cm/s.		

Common Refrigerants

There are a mind-boggling number of refrigerants and it is difficult to keep them all straight. To assist you, review the following Popular Refrigerants Table, which describes some of the more popular refrigerants, more or less in order of their place in history. The Popular Refrigerants Table begins with CFCs, which have all been phased out. However, there are still a number of systems with CFC refrigerant and, until they are retrofitted or replaced, refrigerant will be needed in these systems.

The following table continues with HCFCs. Several are listed as retrofit or replacement refrigerants for CFCs. A **RETROFIT REFRIGERANT** is used to change out an existing system. The old refrigerant is recovered, the system is modified as needed, and then charged with the retrofit refrigerant. A **REPLACEMENT REFRIGERANT** is used in equipment in place of a refrigerant that has been phased out. Some HCFCs are used as retrofit or replacement refrigerants for CFCs, but due to be phased out and will soon need to be retrofitted and replaced themselves.

The following table concludes with HFC refrigerants. You will notice that there are many HFCs, all retrofit or replacement refrigerants. In reading through the list, you should begin to appreciate how versatile old refrigerants like R-12 were. Time will tell which of these HFC refrigerants survives in the market and which ones will be replaced by refrigerants yet to be developed.

Refrigerants are stored in cylinders painted with a designated color for each refrigerant. Your company probably has a chart of these colors on the wall where you work; this chart is provided for your reference during this course.

POPULAR REFRIGERANTS TABLE

Refrigerant	Cylinder Color	Safety Class	Chemical Name/ Components	Type
R-11	Orange	A-1	Trichlorofluoro-methane	CFC
R-12	White	A-1	Dichlorodifluoro-methane	CFC
R-502	Light purple	A-1	R-22 + R-115	CFC
R-22	Light green	A-1	Chlorodifuoro-methane	HCFC
R-123	Light gray	B-1	Dichlorotrifluoro-ethane	HCFC
R-401A	Coral red	A-1	R-22 + R-152a + R-124	HCFC
R-402A	Sand	A-1	R-22 + R-125 + R-290	HCFC
R-402B	Green-brown	A-1	R-22 + R-125 + R-290	HCFC
R-409A	[illegible]	A-1	R-22 + R-124 + R-142b	HCFC

Application	Notes	Status
Used for low-pressure, large centrifugal chillers. Provided inexpensive way to provide large quantities of chilled water for large air conditioning loads	Developed in 1932 and used extensively until phase-out in 1995.	Phased out
Most widely used refrigerant in nearly all applications, from small to large refrigeration and air conditioning systems, including low, medium, and high-temperature refrigeration systems.	Developed in 1931 and used extensively until phase-out in 1995.	Phased out
An azeotropic blend used for low-temperature systems.	Was a popular low-temperature refrigerant.	Phased out
Used as primary refrigerant in commercial and residential air conditioning systems. Also used in large centrifugal chillers and for industrial cooling.	Phased out for new equipment in 2010, total production must be phased out by 2020. Before switching to other refrigerants, check with manufacturer, doing so may void manufacturer's warranty.	Phased out
Replacement for R-11, until something better can be found. R-123 is toxic, so special precautions must be taken	Can be used as a retrofit for R-11, but guidelines must be followed. System my need new seals and other components.	Temporary replacement and retrofit
Near-azeotropic blend to retrofit R-12 or R-500 systems, especially for R-12 systems with evaporator temperatures between 10°F and 20°F.	Minor modifications needed when retrofitting R-12 or R-500 systems, though alkylbenzene oil is recommended when retrofitting an R-12 system.	Retrofit
Near-azeotropic blend to retrofit R-502 systems with little modifications needed.	Retrofit to alkylbenzene oil is recommended.	Retrofit
Near-azeotropic blend to retrofit ice machines using R-502.	Minimal system retrofit needed, but change to alkylbenzene oil is recommended.	Retrofit
Zeotropic blend to retrofit R-12 systems with evaporator temperatures between 10°F and 20°F. Also works in R-500 air conditioning systems	Mineral oil in system is OK down to 0°F, below which alkylbenzene lubricant should be used.	Retrofit

POPULAR REFRIGERANTS TABLE *(con't)*

R-507	Teal	A-1	R-125 + R-143a	HFC
R-134a	Light (sky) blue	A-1	Tetrafluoro-ethane	HFC
R-404A	Orange	A-1	R-125 + R-143a + R-134a	HFC
R-407A	Bright green	A-1	R-32 + R-125 + R-134a	HFC
R-407C	[illegible]	A-1	R-32 + R-125 + R-134a	HFC
R-410A	Rose	A-1	R-32 + R-125	HFC
R-417A	Green	A-1	R-125 + R-134a + R-600	HFC
R-422B	[illegible]	A-1	R-125 + R-134a + R-600a	HFC
R-422C	Mustard	A-1	R-125 + R-134a + R-600a	HFC
R-422D	Moss green	A-1	R-125 + R-134a + R-600a	HFC

Used in medium and low-temperature commercial refrigerant systems.	Replacement for R-502.	Replacement
Replacement for R-12 in medium and high-temperature refrigeration systems, air conditioning systems, and automotive systems. Also used as replacement for R-12 and R-500 in centrifugal chiller systems.	Not a direct drop in for R-12. Retrofit is possible, but guidelines must be followed carefully.	Replacement. Limited retrofit.
Retrofit near-azeotropic blend to replace R-502 in medium and low-temperature applications.	Not a direct drop in for R-502. Retrofit is required.	Replacement, limited retrofit
Zeotropic blend to retrofit R-22 medium and low-temperature commercial refrigeration systems.	Some TXV adjustments may be necessary. Only one oil change required with POE oil.	Retrofit
Zeotropic blend to replace R-22 in residential and light-commercial air conditioning, and in medium and high-temperature commercial refrigeration systems.	Some TXV adjustments may be necessary. Critical elastomeric seals must be changed. Only one oil change required with POE oil.	Replacement and retrofit
Near-azeotropic blend to replace R-22. Popular long term R-22 replacement in new residential and light commercial air conditioning systems.	Not recommended as a retrofit for existing R-22 systems.	Replacement
Retrofit zeotropic blend to replace R-22 in air conditioning	Direct drop in for R-22	Retrofit and replacement
Retrofit near-azeotropic blend to replace R-22 in air conditioning	Requires possible POE additions or replacement of mineral oil, and possible component changes.	Retrofit
Direct replacement for R-502, and a retrofit near-azeotropic blend to replace R-22 in commercial refrigeration systems	Requires possible POE additions or replacement of mineral oil, and required component changes.	Retrofit
Retrofit near-azeotropic blend to replace R-22 in air conditioning and commercial refrigeration systems	Requires possible POE additions or replacement of mineral oil, and possible component changes.	Retrofit

POPULAR REFRIGERANTS TABLE *(con't)*

R-427A	Green	A-1	R-32 + R-125 + R-143a + R-134a	HFC
R-438A		A-1	R-32 + R-125 + R-134a + R-600 + R-601a	HFC

Refrigerant Oils

As you would expect, refrigerant oils are chosen for their ability to lubricate moving parts in the refrigeration system. We normally think of a lubricant as something that functions to reduce friction and minimize wear. Those are certainly important functions of refrigerant lubricants, but there are other functions as well.

Refrigerant oil also acts as a barrier or seal between the suction and discharge sides of the compressor. Oil with higher viscosity creates a better seal and helps reduce noise better than oils with low viscosities. Of course, there is a tradeoff: higher viscosity oil has greater friction. Refrigerant oils also aid in sealing systems to help keep out contaminants and to maintain system pressures. They also help inhibit corrosion, and when wear does take place, the lubricant carries away the debris. The oil acts as a coolant as well, carrying heat away from bearings and other mechanism within the system.

In hermetic compressors, the oil must have electrical insulating properties because it is exposed to the motor and motor windings. Because some oil gets taken from the compressor by the refrigerant vapor, the oil must be compatible with the refrigerant and it must remain fluid even at the low temperatures it will experience in the evaporator. The oil that is carried away by refrigerant gas must be able to flow through the entire refrigeration circuit and return to the compressor in a reasonable amount of time. In a car, oil should be changed on a regular basis. In systems with hermetic compressors, the oil is added at the factory and expected to last the entire life of the compressor!

Finally, the chemical composition of the oil must remain stable when exposed to refrigerants, the various metals in the system, motor insulation, various other contaminants, and the temperature extremes seen between the high side and low side of the system. There is no perfect lubricant; the oil used by designers is selected based on a number of compromises. It is always best to use manufacturer recommended oil to be sure it will protect the system as designed.

Retrofit near-azeotropic blend to replace R-22 in both air conditioning and commercial refrigeration systems, but mainly commercial refrigeration systems	Requires partial POE replacement of mineral oil, but no component changes.	Retrofit
Retrofit zeotropic blend to replace R-22 in residential and commercial air conditioning and medium and low-temperature commercial refrigeration systems.	May require oil changes depending on system. Elastomeric seals must be changed. Requires minimal system changes and minimal TXV adjustments.	Retrofit

Refrigerant oils consist of two types: mineral oil and synthetic oil. **MINERAL OIL** includes any of various light hydrocarbon oils, especially a distillate of petroleum that has been used in systems with CFCs, HCFCs, and ammonia refrigerants for many years. Mineral oils are grouped into (1) paraffin, (2) naphthenes, (3) aromatics, and (4) nonhydrocarbons. Of these, the naphthenes are most commonly used in refrigeration systems. However, mineral oils have limited solubility with refrigerants such as R-22 and R-502 and lack solubility with R-134a. Solubility is needed so that the oil and refrigerant can mix and flow through the system together, which helps ensure that the oil will return to the compressor where it is needed. Mineral oils can contain wax, which can precipitate out as wax crystals in low temperature parts of the system. This will clog metering devices and screens, preventing refrigerant flow.

SYNTHETIC OILS were originally investigated to overcome the limited solubility of some refrigerants in mineral oils. You will see three synthetic oils commonly used in the refrigeration industry, (1) alkybenzenes, (2) glycols, and (3) esters. **ALKYBENZENE** is similar to mineral oil in many properties, but has better solubility with refrigerants such as R-22 and R-502. It also has high **MISCIBILITY** with CFC and HCFC refrigerants. This means that the refrigerant and the oil mix well and remain as one mixture over the range of temperatures and pressures in the system. Unlike mineral oils, alkybenzenes contain little or no wax, so the risk of clogging of the system is reduced. HCFC blends work best with alkybenzenes, though most CFC refrigerants also work well with this type of lubricant.

Commonly **POLYALKYLENE GLYCOLS (PAGS)** are used with R-134a in automotive systems. These lubricants have a high affinity for water, which means they will absorb water. Because of this, containers should be kept sealed tightly opened only when needed. **POLYOLESTERS (POES)** are lubricants used in systems containing HFCs. POEs contain no wax at all, so they have an advantage when used in very low temperature systems where wax will separate from other oils and clog systems. Like PAGs, they are **HYDROSCOPIC** (have an affinity for water), so you should be careful to minimize their exposure to the atmosphere.

System Retrofit

Because of concern over ozone destruction and global warming, there is a great deal of transition in the refrigeration and air conditioning industries. However, as systems change from one refrigerant to another, the lubricant used in the older systems cannot be forgotten. New systems and retrofitted systems must use oil that is compatible with new refrigerants.

For systems that are retrofitted from a CFC or a HCFC system with mineral oil to a HFC system that will use a POE or PAG lubricant, the technician must remove 95% to 99% of the mineral oil. Mixing lubricants can cause system problems because of incompatibility between the two oils. Most often, the technician must flush the system. Flushing the system is very similar to getting the cooling system in your car flushed. The technician must charge the system with some sort of solvent and then run the system for at least eight hours. The solvent might be a CFC refrigerant, a solvent made specifically for this purpose, or the new lubricant, depending on the system.

In the table below, you can see the types of oil used in retrofit systems. The table begins with HCFC refrigerants and shows which CFC refrigerant they replace. Next, you will see a list of HFC refrigerants that replace both CFC and HCFC refrigerants. In all cases, you can find which oil is recommended for the new refrigerant. Because of the required phase-out of HCFC refrigerants, all the HCFC refrigerants listed in the table will eventually be replaced as well.

REFRIGERANT OIL CROSS REFERENCE

Refrigerant	Replacement For	Type	MO	AB	POE	PAG
R-401A	R-12	HCFC	x	x		
R-409A	R-12	HCFC	x	x		
R-401B	R-500	HCFC	x	x		
R-408A	R-502	HCFC	x	x		
R-402A	R-502	HCFC	x	x		
R-402B	R-502	HCFC	x	x		
R-123	R-11	HCFC	x			
R-124	R-114	HCFC		x		
R-134a	R-12	HFC			x	x
R-404A	R-502	HFC			x	
R-507	R-502	HFC			x	
R-407C	R-22	HFC			x	
R-410A	R-22	HFC			x	
R-508B	R-13, R-23 & R-503	PFC			x	

AB = Alkybenzene
MO = Mineral oil
POE = Polyolester
PAG = Polyalkylene glycol
CFC = Chlorofluorocarbon
HCFC = Hydrochlorofluorocarbon
HVC = Hydrofluorocarbon
PFC = Perfluorocarbon

APPLYING WHAT YOU HAVE LEARNED:

Now take the time to think of how this will relate to your company. Use the space below to answer the following questions. If you are not sure of the answers ask your supervisor.

A. List the types of refrigerant that your company sells, also list their type of safety class.

B. List the types of refrigerant oil that your company sells.

Refrigeration and Air-conditioning Accessories

In this section, we'll discuss refrigeration and air-conditioning items that are nonessential (but desirable) that contribute to an overall result.

Valves

RELIEF VALVES in refrigeration systems are designed to relieve the pressure within system if the pressure or temperature gets too high. **SPRING-LOADED RELIEF VALVES** operate on pressure. When system pressure overcomes the tension of the spring, the valve opens to vent refrigerant until the spring pressure is stronger than the system pressure. These valves are installed where there is vapor in the condenser or receiver. The discharge port is threaded so pipe can be added to vent the refrigerant to the outside.

ONE-TIME RELIEF VALVES, which are actually fusible plugs, are temperature-operated. **A FUSIBLE PLUG** is simply a spot of solder with a specific melting temperature used to seal a hole drilled in the system.

Crankcase Heaters

CRANKCASE HEATERS may be internal or external. Internal heaters are inserted into the oil within the compressor, while external heaters are strapped to the compressor at the oil level. Crankcase heaters keep the *crankcase* (the metal casing that encloses the crankshaft in some engines) of the compressor warmer than other parts of the system when the system is turned off. This is necessary because some refrigerants, such as R-22, are drawn to oil like water to a sponge. The cooler the oil and the higher the pressure, the more refrigerant is absorbed. Here's what happens: Refrigerant vapor condenses in the cool oil just as water condenses out of the air (dew) when it gets cooler outside. When the air warms back up, the dew evaporates into the atmosphere. And when the oil warms up, liquid refrigerant evaporates into vapor refrigerant.

Pressure also affects how much refrigerant is absorbed in oil. To help explain this, you might picture a tank of propane sitting outside on an 85°F day. If you move the tank, you can hear liquid sloshing around. But propane boils at -44°F, so how can there be liquid when it is 85°F outside, when that is 129°F warmer than its boiling point? There is **VAPOR PRESSURE** in the tank.

Earlier, you learned how molecules in any substance are constantly moving, and the warmer it gets, the faster they move. In a liquid, occasionally a molecule will "jump" through the surface of the liquid and become a vapor. The warmer the liquid becomes, the faster the molecules move. This causes more of them to "jump" from a liquid to a vapor. This is what happens when something evaporates. If you were partially fill a container with a liquid and then seal it up, some of the liquid would evaporate. At the same time, some of the evaporated molecules would return to liquid. When more liquid molecules become vapor than vapor molecules return to liquid, the vapor molecules would begin to occupy the space above the liquid in the container. As this happens, the pressure in the container begins to rise because the vapor molecules are crowding themselves into the space above the liquid. This evaporation will take place until the pressure of the vapor molecules in the space above the liquid becomes so great that number of liquid molecules becoming vapor is equal to the number of vapor molecules becoming liquid. This is called **EQUILIBRIUM**.

If you heated the container, the liquid molecules would gain energy, and the rate of liquid molecules becoming vapor would exceed the number of vapor molecules returning to liquid. Of course, the pressure in the container would rise, and this would again continue until the pressure above the liquid became so great that the rate of transfer between liquid to vapor and back became equal again. The opposite would happen if you cooled the container. The vapor molecules would lose energy and "fall" back through the liquid surface to become liquid molecules at a greater rate than liquid molecules "jump" to vapor. This would lower the pressure in the container until the point of equilibrium was reached for the new, cooler temperature.

In the propane example, enough of the propane in the tank at 85°F has evaporated to reach equilibrium inside the tank. That is, the vapor propane above the liquid is pushing against the liquid with enough pressure to equalize the rate of transfer between liquid and vapor molecules. If you were to open the valve on the tank, some of that vapor would escape. That would cause the pressure to drop, and some more liquid molecules would immediately vaporize.

The same principle applies when liquid refrigerant is condensed in oil. As pressure goes up, more refrigerant vapor gets "pushed" into liquid, and when pressure drops, that liquid refrigerant in the oil evaporates and becomes a vapor again. While the system is operating, some refrigerant is absorbed in the oil, but most of it circulates throughout the system. When the system is in operation, the oil is warmer than when the system is off. This inhibits vapor refrigerant from condensing in the oil.

The crankcase of the compressor is on the suction side of the compressor, so when the compressor runs it reduces the pressure on the oil. As the pressure drops, liquid refrigerant in the oil evaporates. When the system is running, the warm oil and the low pressure of the oil reduce the ability of the oil to absorb refrigerant. But when the system is shut down, the oil cools and the pressure rises. The job of a crankcase heater is to keep the oil warm when the compressor is off. This keeps more of the refrigerant in a vapor state.

What happens if there is refrigerant in the oil? First, the more refrigerant in the oil, the more the oil becomes diluted and less able to lubricate. Second, when the oil is saturated with refrigerant, the sudden drop in pressure caused by the compressor starting causes the refrigerant to boil quickly. As a result, the oil foams and is pumped out of the compressor, which can cause damage to system components as the compressor operates with a lower amount of oil until the system becomes stabilized.

Discharge-Line Lubrication Separators (Oil Separators)

A small amount of oil leaves the compressor in most refrigeration systems, mixes with hot refrigerant gas, and travels as a fog. Without an **OIL SEPARATOR**, this oil would have to travel with the refrigerant throughout the entire system before it could return to the compressor where it is needed. Oil flows well through the condenser, but can become trapped in the evaporator, especially in systems with very low temperatures. Oil can become a gummy mass in the evaporator which interferes with the function of the system.

Not all systems use oil separators, but those that do use them to separate most of the oil from the refrigerant before it enters the system and return it to the compressor. Separators are installed immediately after the compressor in the discharge line. An oil separator is essentially a tank just downstream from the compressor. Because they are large compared to the refrigerant line, the refrigerant/oil mix that enters is directed through small screens, which cause the flow to change direction and slow down. The fogged droplets of oil mix with other droplets of oil to become larger and heavier drops, which fall to the bottom of the separator. A small float opens a needle valve when the oil level has reached a certain height, and the oil is returned to the compressor crankcase or oil reservoir through a small tube. Because the separator is under high pressure and the compressor crankcase is on the suction side, the oil flows readily with no pump needed.

Most oil separators have a magnet in the bottom to trap any metal particles. Because the oil falls to the bottom, the hot refrigerant gas is discharged from the top of the separator. In this way, the separator functions similar to a receiver in that only vapor is allowed to leave.

Pressure Switches

A **PRESSURE SWITCH** is a fail-safe device that prevents any number of incidents from occurring by either measuring the amount of pressure applied and reacting or simply by providing a way to decrease or increase different types of pressure. Any switch opens when it is turned off and closes when it is turned on. A **HIGH-PRESSURE SWITCH** turns the system off if the pressure rises too high, so it will open on a rise in pressure. A **LOW-PRESSURE SWITCH** turns a system off if the pressure drops too much, so it will open on a drop in pressure.

It may not seem readily apparent, but low-pressure switches protect systems from a low refrigerant charge as a means to control temperature, and as an automatic pump down control of the compressor. We'll explore each of these modes to give you a better understanding of this device.

A loss of refrigerant will cause the pressure in the evaporator to drop. The low-pressure switch is set to cut out between the normal expected operating pressure and atmospheric pressure. In the case of a loss of refrigerant, the evaporator pressure will drop. When the pressure drops to the cutoff point of the low-pressure switch, the compressor is shut off. This will prevent the compressor from lowering the pressure to below atmospheric pressure (a vacuum). A vacuum draws moisture into the system. In this mode, the low-pressure switch will cut back in at a pressure higher than normal expected operating pressure. This allows the system to continue in an off-and-on mode so the customer gets at least some cooling.

Some coolers use a low pressure switch as a thermostat. In this arrangement, the pressure of the refrigerant is used to start and stop the compressor. Because pressure changes with temperature, the technician simply needs to determine which pressure corresponds to the desired operating conditions and set the switch to cut out when the pressure drops to the corresponding desired low temperature, and cut back in when the pressure rises to the point where additional cooling is needed.

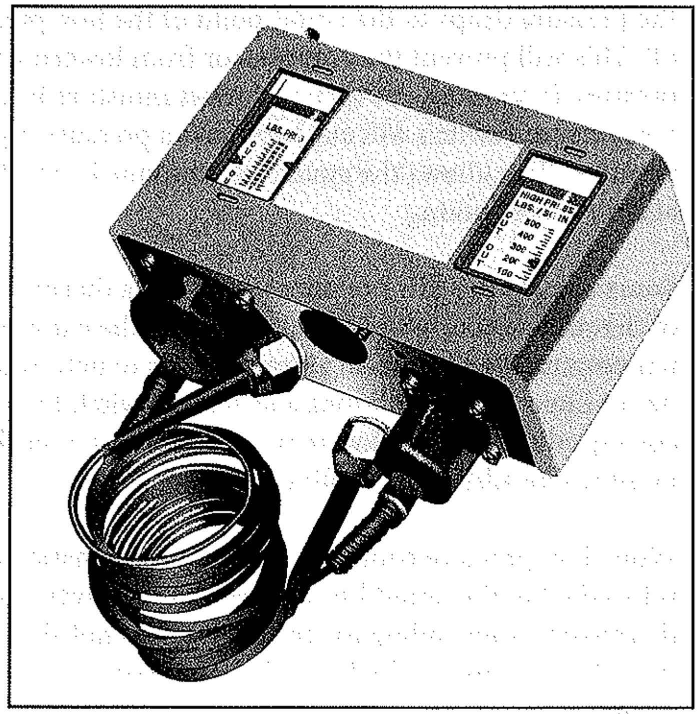
When low-pressure controls are used in automatic pump down systems, a solenoid valve is installed in the liquid line between the receiver and the metering device. When the thermostat stops calling for cooling, it does not shut off the compressor. Rather, it closes the solenoid valve in the liquid line. The compressor continues to run, and pumps the refrigerant from the portion of the system between the solenoid valve and the compressor into the condenser and receiver. This causes the pressure to drop in the evaporator.

The low-pressure switch shuts off the compressor when the desired pressure is reached in the evaporator. The compressor remains off until the low-pressure switch cuts back in. The low-pressure switch won't cut back in until the pressure in the evaporator rises, and this won't happen until refrigerant is allowed to flow through the solenoid valve from the receiver.

When the thermostat calls for more cooling, it opens the solenoid valve. That action allows refrigerant to flow from the receiver to the evaporator, which causes the pressure in the evaporator to rise. When the pressure reaches the cut in point, the compressor starts and continues to run until the thermostat once again closes the liquid line solenoid valve.

High-pressure controls protect the system against high head pressure. **HIGH HEAD PRESSURE** occurs when the flow of air or water used to cool the condenser is interrupted for some reason. Because the condenser will no longer be able to reject heat, it will not cool the refrigerant. Remember that pressure is linked to temperature, so if the condenser temperature goes up, pressure will go up as well. In a water-cooled system, a failed pump could stop the flow of water through the condenser, and this would cause the high-pressure switch to cut out and protect the compressor. In an air-cooled system, a failed condenser fan or a dirty condenser coil would cause the same problem. The figure below is an example of a combination low- and high-pressure control. Note the input for low pressure (left) and high pressure (right), as well as the dual scales.

DUAL-PRESSURE CONTROL (LOW- AND HIGH-PRESSURE)



The **LOW-AMBIENT FAN CONTROL** is another pressure switch used to start and stop the condenser fan motor depending on the pressure in the condenser. Again, because pressure and temperature rise and fall together, this pressure switch "senses" temperature when a technician sets the cut-in and cut-out points to pressures corresponding to desired fan start and stop temperatures.

The **OIL PRESSURE SAFETY CONTROL** is another type of pressure switch. This control senses the difference in pressure between the intake and discharge of the oil pump, and shuts the compressor off if the pressure differential falls below a set value, usually 10 psi. Because these switches have to sense pressure in two locations, they will have two pickups instead of one. They look very similar to the dual-pressure control seen in the previous figure, because it has two pickups. It lacks the scales included with the dual-pressure control.

APPLYING WHAT YOU HAVE LEARNED:

Now take the time to think of how this will relate to your company. Use the space below to answer the following questions. If you are not sure of the answers ask your supervisor.

A. What type of air conditioning and refrigeration valves does your company sell the most of? List them below.

B. Locate the pressure switches at your workplace. Compare a high pressure switch to a low pressure switch.

REVIEW QUIZ OF INTRODUCTION TO AIR CONDITIONING & REFRIGERATION

Answers appear on page 188

1. Which of the following BEST defines the term refrigeration cycle?
   a. A sequence of thermodynamic processes in which heat is withdrawn from a hot body and expelled to a cold body.
   b. A series of steps that involves heating, humidifying, dehumidifying, and cleaning air.
   c. A number of components in a refrigerator or refrigerated building used to cool or freeze food.
   d. A sequence of thermodynamic processes in which heat is withdrawn from a cold body and expelled to a hot body.

2. The unitary market consists of all the following sectors EXCEPT
   a. Residential
   b. Industrial
   c. Light commercial
   d. Commercial

3. The capacity of unitary air conditioners in the commercial sector is
   a. less than 135,000 Btu/h.
   b. 65,000 Btu/h or less.
   c. larger than 135,000 Btu/h.
   d. between 65,000 Btu/h and 135,000 Btu/h.

4. High temperature refrigeration usually cools to temperatures above approximately
   a. 45°F.
   b. 38°F.
   c. 35°F.
   d. 32°F.

5. How is the coefficient of performance (COP) calculated?
   a. Input power divided by output power
   b. Btu/h divided by watt output
   c. Output power divided by input power
   d. Btu/h divided by watt input

REVIEW QUIZ OF INTRODUCTION TO AIR CONDITIONING & REFRIGERATION

Answers appear on page 188

6. What does the Seasonal Energy Efficiency Ratio (SEER) measure?
   a. Basic measure of refrigeration system efficiency
   b. Measures how well a piece of equipment operates over time
   c. Estimates how efficiently a piece of equipment will operate over an entire cooling season
   d. Estimates how efficiently a piece of equipment will operate over an entire heating season

7. With a 10 SEER rating, what is the estimated power required for a 2-ton (24,000 Btu/h) air conditioner?
   a. 2,400 watts
   b. 1,600 watts
   c. 1,200 watts
   d. 800 watts

8. Which of the following is **TRUE** about the relationship between boiling temperature and pressure?
   a. The lower the pressure, the higher the boiling temperature will be.
   b. Pressure has no effect on boiling temperature.
   c. The higher the pressure, the higher the boiling temperature will be.
   d. Pressure and boiling temperature are inversely related.

9. Which of the following terms describes the process of cooling steam or gaseous refrigerant that is not at the saturation point or not ready to condense?
   a. Thermostatic expansion
   b. Desuperheating
   c. Vapor compression
   d. Cross vapor charge

10. All of the following are components of all vapor compression cycles **EXCEPT**
    a. Condenser
    b. Metering device
    c. Evaporator
    d. Diaphragm

REVIEW QUIZ OF INTRODUCTION TO AIR CONDITIONING & REFRIGERATION

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11. Which of the following is the simplest type of bearing?
    a. Ball bearings
    b. Plain bearings
    c. Roller bearings
    d. Roller thrust bearings

12. All of the following are ADVANTAGES of a scroll compressor EXCEPT
    a. Simple design
    b. High efficiency
    c. Ability to handle liquid
    d. Intermittent refrigerant flow

13. Centrifugal compressors differ from other types of compressors in that they
    a. have fewer moving parts.
    b. offer quiet operation.
    c. are not positive-displacement machines.
    d. use a main motor with a helical groove.

14. The function of an Automatic Expansion Valve (AXV) is to maintain
    a. a constant pressure in the evaporator.
    b. a constant evaporator superheat.
    c. the temperature and pressure of the evaporator.
    d. the flow of refrigerant in the system.

15. Which of the following valve parts is the mating surface in the valve assembly that permits tight closure?
    a. Valve port
    b. Valve disc
    c. Valve seat
    d. Valve stem

16. Which of the following valves allows flow in only one direction and closes to prevent backflow of liquid?
    a. King valve
    b. Schrader valve
    c. Solenoid valve
    d. Check valve

REVIEW QUIZ OF INTRODUCTION TO AIR CONDITIONING & REFRIGERATION

Answers appear on page 188

17. CFC refrigerants had the needed thermodynamic properties, were not harmful to humans, were not flammable, and were easy to manufacture. Why are they no longer produced?
    a. CFC refrigerant materials are no longer available.
    b. They are too expensive to manufacture in large quantities.
    c. When chlorine in CFC molecules is released, it destroys ozone.
    d. They were replaced by HCFC refrigerants, which are safer.

18. All of the following are natural refrigerants **EXCEPT**
    a. Ammonia
    b. Carbon dioxide
    c. Water
    d. Chlorine

19. Why are synthetic oils such as alkylbenzene used commonly in the refrigeration industry?
    a. Limited solubility with refrigerants such as R-22
    b. Contain little or no wax, which reduces system clogging
    c. High affinity for water
    d. Offer lower cost and more safety

20. Which of the following controls senses the difference in pressure between the intake and discharge of the oil pump, and shuts off the compressor if the pressure differential falls below a set value?
    a. Oil pressure safety control
    b. Low-ambient fan control
    c. High-pressure switch
    d. Low-pressure switch

ANSWERS TO REVIEW QUIZ

CHAPTER 4

INTRODUCTION TO AIR CONDITIONING AND REFRIGERATION

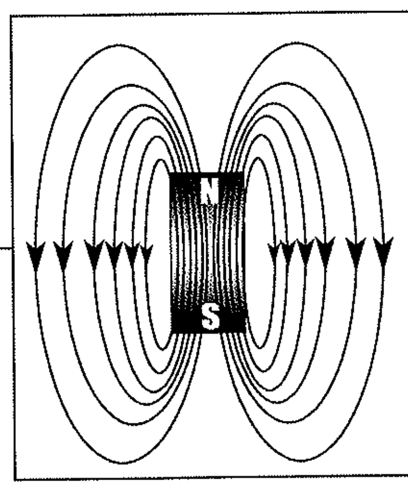
1. d. A sequence of thermodynamic processes in which heat is withdrawn from a cold body and expelled to a hot body.
2. b. Industrial
3. c. larger than 135,000 Btu/h.
4. a. 45°F
5. c. Output power divided by input power
6. c. Estimates how efficiently a piece of equipment will operate over an entire cooling season
7. a. 2,400 watts
8. c. The higher the pressure, the higher the boiling temperature will be.
9. b. Desuperheating
10. d. Diaphragm
11. b. Plain bearings
12. d. Intermittent refrigerant flow
13. c. are not positive-displacement machines.
14. a. a constant pressure in the evaporator.
15. c. Valve seat
16. d. Check valve
17. c. When chlorine in CFC molecules is released, it destroys ozone.
18. d. Chlorine
19. b. Contain little or no wax, which reduces system clogging
20. a. Oil pressure safety control

5 INTRODUCTION TO ELECTRIC MOTORS

LEARNING OBJECTIVES

After successfully completing this chapter, you will be able to:

1. Define the term "electrical current" and explain how it relates to electricity.
2. Explain why electricity and magnetism are inseparable by illustrating how a magnetic field operates.
3. Describe how an alternating current motor operates.
4. Identify and describe the purpose of items commonly included on a motor nameplate.
5. Compare and contrast these motors: single-phase; split-phase; capacitor-start, induction-run; and capacitor-start, capacitor-run.
6. Describe how the relay, the potential relay, and the current relay operate.



Introduction to Electric Motors

There are many kinds of electric motors, some very large and some very small. However, they all operate on the same principles. In this chapter, you will learn about basic electricity and electrical current. Next, you will learn what makes an electric motor work. Finally, you will learn about the different types of electric motors and their components.

Overview of Electricity and Electrical Current

Electricity is one of our most widely used forms of energy. **ELECTRICITY** is a type of energy that can build up in one place or flow from one place to another. When electricity gathers in one place it is known as *static electricity* (the word "static" means something that does not move); electricity that moves from one place to another is called *current electricity*. Electricity, which is a secondary energy source, comes from the conversion of other sources of energy, such as coal, natural gas, oil, nuclear power and other natural sources, which are called primary sources. Many cities and towns were originally built alongside waterfalls (a primary source of mechanical energy) that turned water wheels to perform work. Before electricity generation began slightly over 100 years ago, houses were lit with kerosene lamps, food was cooled in iceboxes, and rooms were warmed by wood-burning or coal-burning stoves.

The word "current" in the term **ELECTRICAL CURRENT** is used in the same way one would describe the movement of water in a river. When a river moves, it is said to have "flow" or "current." When electricity flows, we say that it has current. In a river, water flows. In electricity, electrons flow.

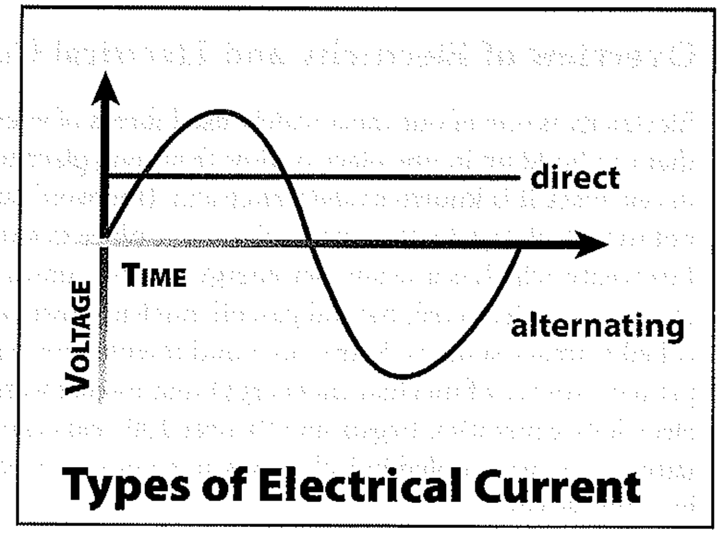
An **ELECTRON** is a stable negatively charged elementary particle with a small mass that is a fundamental constituent of matter and orbits the nucleus of an atom. In other words, an electron is a subatomic particle. Electrons spin around the center of an atom (the **NUCLEUS**) much as planets spin around the sun. Normally, the forces of nature hold electrons tight to an atom, but when an electrical force (**VOLTAGE**) is applied, the forces of nature are overcome and some electrons "jump" from atom to atom. This movement of atoms is called *current*, and measured in **AMPERES**, or simply as *amps*. The greater the voltage, the greater the quantity of electron flow.

Electrical current can be direct current (DC) or alternating current (AC). The term **DIRECT CURRENT (DC)** means that the current flows in only one direction. For example, batteries have direct current and have two terminals: one positive and one negative. Current always flows in the same direction between those two terminals. In electricity, direction of flow is designated as either **POSITIVE (+)** or **NEGATIVE (-)**.

The image below shows a **SINE WAVE**, a waveform with the shape of a **SINE CURVE**, representing a single frequency indefinitely repeated in time. The sine curve is a mathematical curve that describes a smooth repetitive oscillation or movement backward and forward. A spinning generator creates the sine wave. Direct current from a battery is illustrated as a straight line moving in one direction because the voltage never varies. For example, a car battery always puts out 12 volts. Direct current is shown as positive (+) voltage so it appears above **GROUND** in the graph.

ALTERNATING CURRENT (AC) means that the electron flow alternates between positive and negative. AC continually reverses direction. You can see from the image that alternating current looks like a wave. Half the time the current is above the center of the graph (*positive*); the other half, it is below the centerline (*negative*). That means that half the time it is flowing one way through a conductor, and the other half the time it is flowing the other way.

TYPES OF ELECTRICAL CURRENT



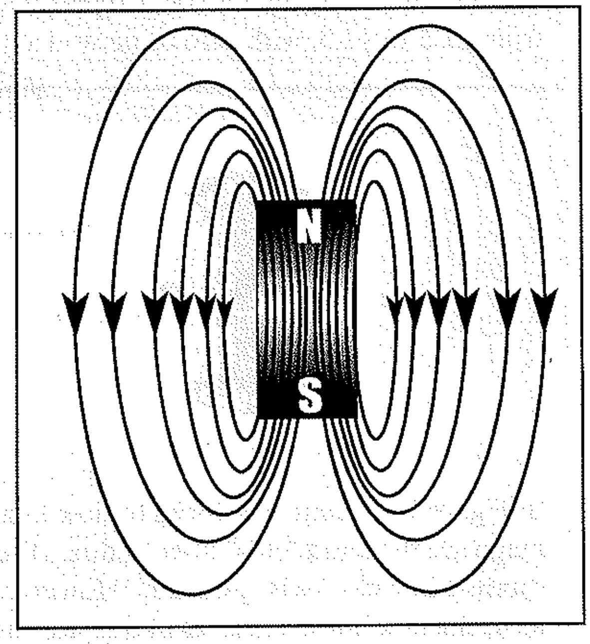
To illustrate this further, if a river could flow with alternating current, the water would constantly change directions. There would be no upstream or downstream, just back and forth. An individual molecule of water might never make it to the ocean. It might just go a couple of feet back and forth. Nevertheless, it is still moving and so there is still current flow.

Electrical Generation

Electricity can be generated by rotating a coil of wire through a magnetic field. As you know, magnets, which consist of a north and south pole, attract and repel each other depending on which poles are facing each other. Facing two like poles together creates a strong magnetic field and the poles repel each other. On the other hand, when opposite poles approach each other, the strong magnetic field pulls the magnets together. The closer the magnets, the stronger the field.

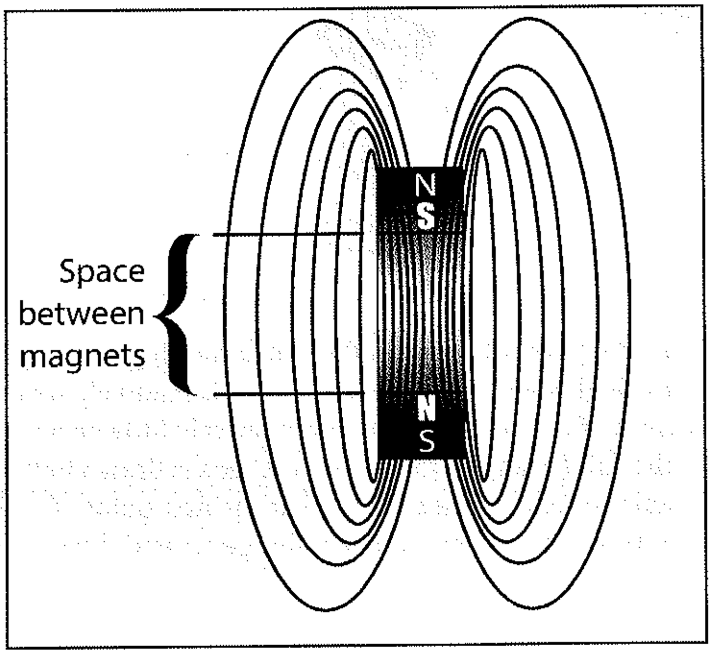
Electricity and magnetism are inseparable; one cannot exist without the other. You know that copper wire is not magnetic; you cannot stick a magnet to copper. However, when you send electric current through a copper wire, a **MAGNETIC FIELD**, the force that attracts or repels magnets, is created—the copper wire becomes a magnet. The electromagnets used to pick up cars at a scrap yard use this principle. The current's flowing through a coil of wire wound in the electromagnet, which allows the car to be lifted. When the car needs to be dropped, the current is shut off, and the electromagnet loses its magnetic field which is stronger in the center and becomes weaker as the distance from the magnets increase. Objects, such as a bar magnet or a current-carrying wire, can influence other magnetic materials without physically contacting them because of the magnetic field produced. Magnetic fields are usually represented by **MAGNETIC FLUX LINES**, which are the lines of force associated with a magnetic field.

MAGNETIC LINES OF FLUX



In a bar magnet, the flux lines emerge at one end of the magnet, and then curve around the other end. Think of the flux lines as being closed loops, with part of the loop inside the magnet, and part of the loop outside. The loops are parallel to one another, meaning that they never cross. At the ends of the magnet, where the flux lines are closest together, the magnetic field is strongest; toward the side of the magnet, where the flux lines are farther apart, the magnetic field is weaker.

MAGNETIC FIELD BETWEEN TWO MAGNETS

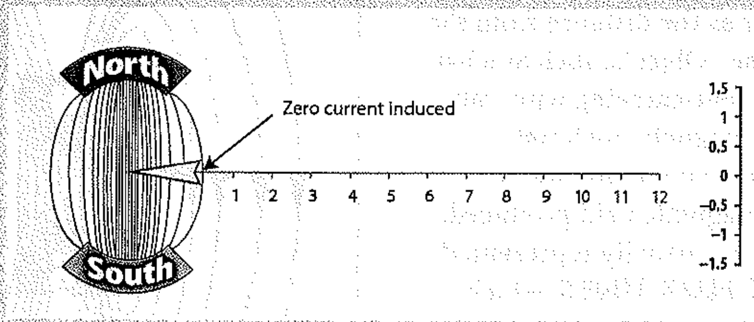


When two magnets are placed close to one another, the lines of flux extend between the magnets and concentrate in the center.

Digging Deeper

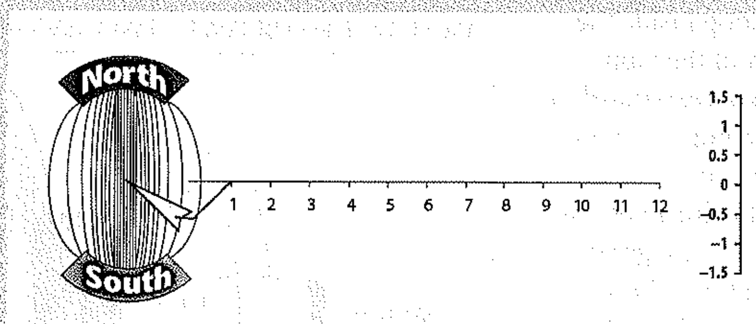
In the following series of figures, a magnet is represented by a north and south pole, with corresponding lines of flux in between. A coil of wire is represented by a light colored triangle and is advanced in a clockwise rotation 30° at a time. To the right is a scale on the x-axis, numbered from 1 to 12 representing the 12 points of rotation with another scale on the y-axis representing magnitude and numbered arbitrarily from –1.5 to +1.5, with zero or neutral at the midpoint.

Figure 1



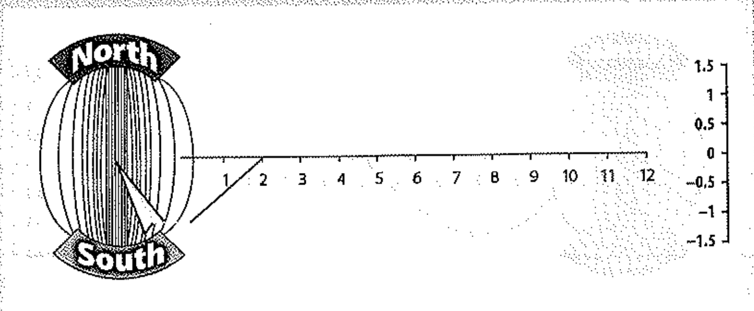
In Figure 1, current is induced to flow in a coil of wire when it passes through a magnetic field and "cuts" lines of flux. The coil (represented by the triangle) above is rotating in a clockwise position. However, at the position shown it is traveling parallel to the flux lines. No lines of flux are cut, and no current is induced.

Figure 2



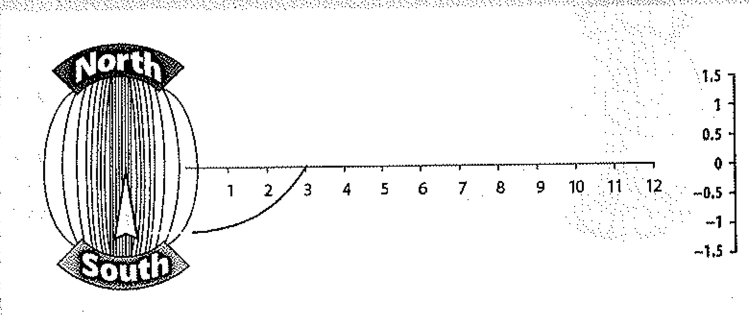
At the point of rotation the coil is rotating nearly parallel to flux lines, but it has cut through some. The magnetic field is relatively weak near the outside because the lines of flux are far apart and relatively little current flows. The line stretching from the coil (triangle) to #1 on the x-axis is drawn between the value representing the amount of current generated at the first point of rotation from above (zero) is plotted at position one, and the amount generated during this point of rotation.

Figure 3



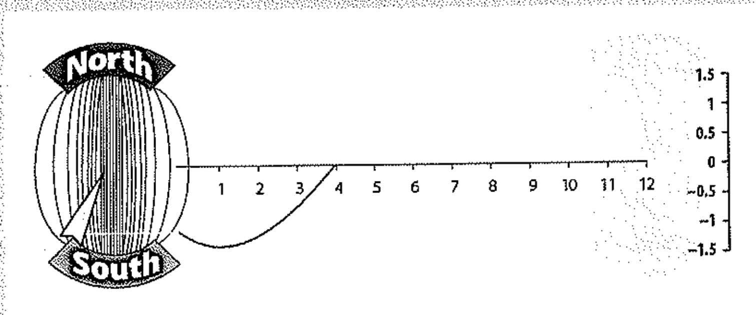
By the time the coil reaches the position in Figure 3, it is passing more perpendicular to the flux lines. The flux lines have become more concentrated since they are nearer the center of the magnet and more current is induced to flow.

Figure 4



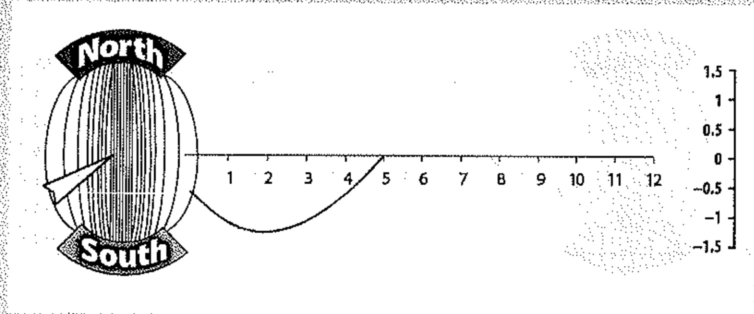
In Figure 4, the coil is passing directly perpendicular to the lines of flux at the south pole and is directly in the center of the magnet. At this point, the maximum amount of current is induced to flow.

Figure 5



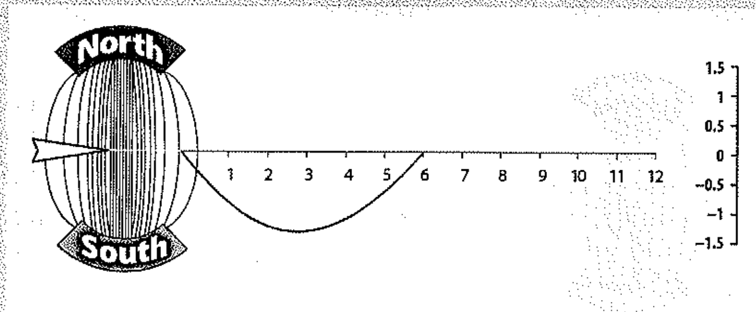
In Figure 5, the coil has passed the center and is beginning to move back up and to the outside of the magnetic field. At this point, exactly the same amount of current is induced to flow as in Figure 3. The same number of flux lines are being cut by the coil and the path of travel is identical relative to the lines of flux.

Figure 6



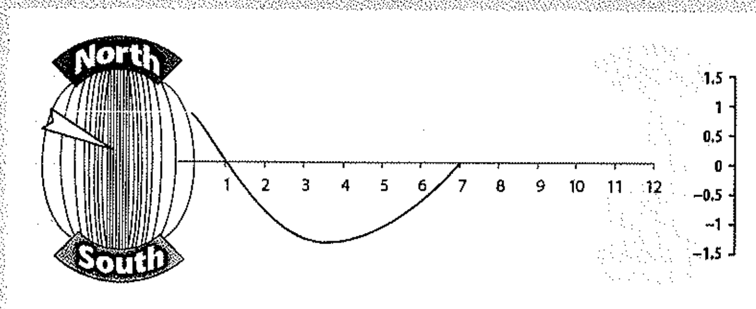
The point in Figure 6 induces the same amount of current as position as Figure 2 because the path of travel and number of flux lines being cut are identical to Figure 2.

Figure 7



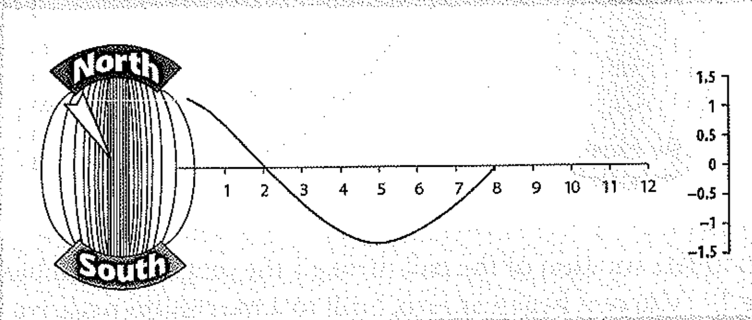
In Figure 7, the coil is passing exactly parallel to the lines of flux, just like in Figure 1. No current is induced, and our plot is now back to zero. We began at zero, built to a maximum value of negative 1.5, then moved back to zero again.

Figure 8



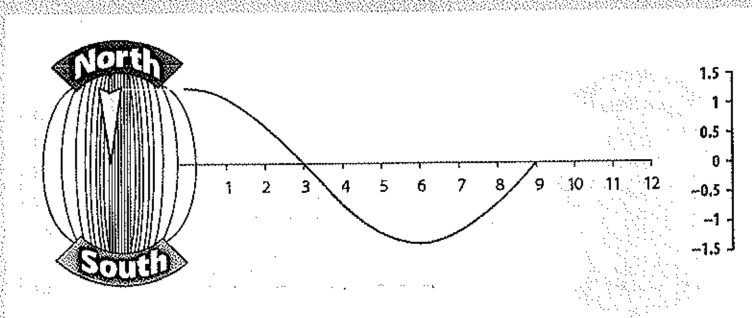
Now, in Figure 8 the coil is beginning to cut lines of flux again; however, notice that the lines are now being cut from left to right. Up to this point, the coil cut the lines from right to left. Since the direction of the coil through the lines of flux has reversed, the current is induced to flow in the opposite direction. The values plotted now have exactly the same magnitude as their counterparts in Figure 1 through Figure 7, except they are now positive rather than negative.

Figure 9



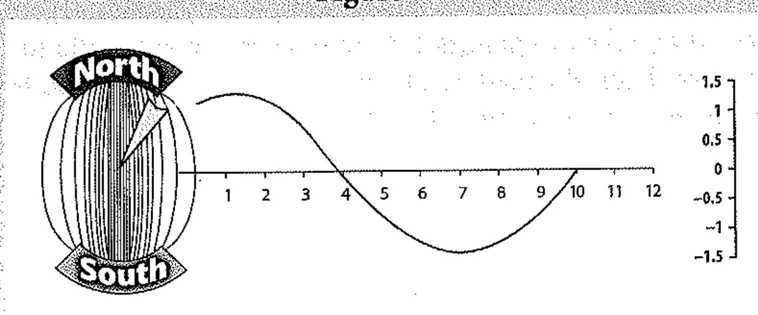
The coil is nearing the maximum positive point in Figure 9, and is generating the same current as in Figure 3 and Figure 5, except the value is now positive.

Figure 10



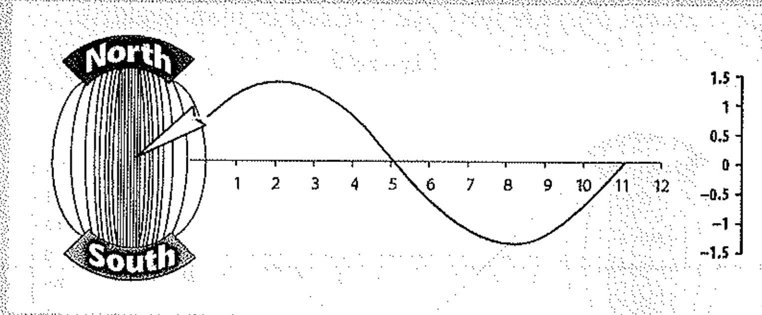
The coil in Figure 10 is at maximum positive value and the maximum current is induced with a positive value. Note that it does not matter to an alternating current electrical device whether the current is positive or negative. It is the magnitude of the current doing the work. In reality, an AC circuit has current flowing back and forth, or alternating directions. We identify the direction by measuring positive or negative voltage.

Figure 11



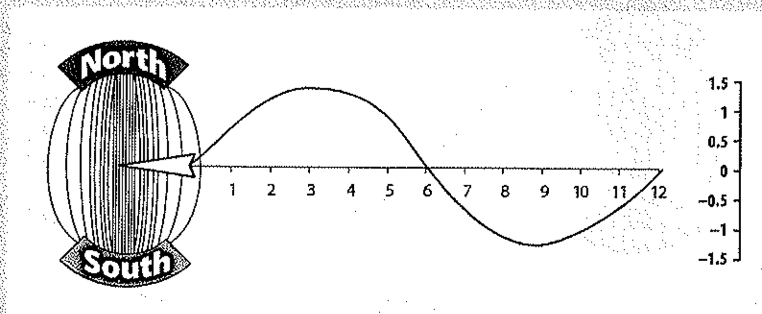
The coil in Figure 11 is heading back down and the corresponding current value is dropping back towards zero. Note that the plot is taking the shape of a sine wave.

Figure 12



Almost one complete rotation of the coil through the magnetic field has been complete in Figure 12. Current began at zero, built to a maximum negative current amount of −1.5, dropped back to zero, built to a maximum positive current amount of 1.5 and is now almost back to zero again. The current literally flowed through the wire in one direction during the negative value portion of rotation, then stopped and flowed in the opposite direction when the values became positive.

Figure 13



Finally, in Figure 13, current is now back to zero as the coil again passes exactly parallel to flux lines. The cycle now begins again. The speed of this cycle is measured in Hertz (Hz). Current in the U. S. is generated at 60 Hz, meaning that this cycle repeats itself 60 times per second and requires that the generator spin at 3600 revolutions per minute. Notice that each cycle has two changes of polarity (from negative to positive). This means that polarity changes 120 times each second (7200 time per minute). If you have ever been shocked by 110-volt current, the buzz you felt was from the alternating current changing polarity 7200 times per minute.

What Makes an Electric Motor Spin?

A **HORSESHOE MAGNET** is a magnet that is bent in the shape of a horseshoe. Imagine if you laid the horseshoe magnet on a table so that the north pole was on your right and the south pole was on your left. If you placed a compass between the poles, the compass needle would align itself so that it is pointing to the right, at the north pole.

What would happen to the compass needle if you flipped the magnet over, so that the north and south poles reversed positions? Of course, the needle would spin 180 degrees and point to the left, where the north pole moved. What would happen if you continued to flip the horseshoe magnet back and forth? The compass needle would spin at the same rate as the flipping magnet, because it will always point north. The faster you flipped the magnet, the faster the needle would spin.

This is the same principle used in electric motors, except electric motors use electromagnets instead of horseshoe magnets. You will recall that a magnetic field, with a north and south pole, is created when current is sent through a copper wire. Because of the physics of electricity, the magnetic field would reverse when the direction of the current flowing through the wire is switched. What was the north pole would now be the south pole and vice versa.

Now, instead of using a horseshoe magnet, assume two coils of wire straight across from each other on a table. Imagine you are facing due north for this example, and you place one of the coils on your left (west) and the other on your right (east). Next, place a compass between the coils. The coils of wire are made of copper, so they are not magnetic. The compass needle will point north, because of the Earth's magnetic field. The coils of wire would have no effect on the compass so long as no current is flowing through them.

Next, imagine you energize the copper coils of wire, which creates a magnetic field that is stronger than the Earth's magnetic field. The compass needle will now swing until it points at whichever coil is magnetic north. What will happen if you reverse the direction of current in the copper coils of wire? Magnetic north reverses from one coil to the other, and the needle will swing to point to the new north pole. If you were to continue switching the direction of current flowing through the copper coils of wire, the compass needle would continue to revolve. In effect, the compass needle is "chasing" the north pole, and the faster you switch the direction of current, the faster the needle will spin.

Now, assume the coils of wire are larger so that the magnetic field they produce becomes stronger and replace the compass needle with a powerful bar magnet. Finally, assume a strong steel shaft is attached to the center of the bar magnet and each end of the shaft is supported with bearings so that it can spin and attach a fan to one end of the shaft. Now, when you energize the copper coils of wire, they will produce a very strong magnetic field. The bar magnet will spin to "chase" the north pole, and because it is attached to the steel shaft, it will spin the fan at the end of the shaft. If you change the direction of the current in the copper coils of wire very rapidly, the bar magnet will spin very fast and the fan will blow a significant amount of air.

This is how an **ALTERNATING CURRENT MOTOR** works. Because the current feeding the coils of wire is changing polarity 7200 times per minute, the magnetic field in the coils changes at exactly the same rate—7200 times per minute. If the north pole started in our coil on the left, it will move to the coil on the right when the sine wave changes polarity. And it will return to the left when the polarity changes again. Therefore, it takes two changes of polarity for the compass needle to make one full revolution. With 7200 changes of polarity each minute, the needle will rotate at 3600 revolutions per minute (RPM).

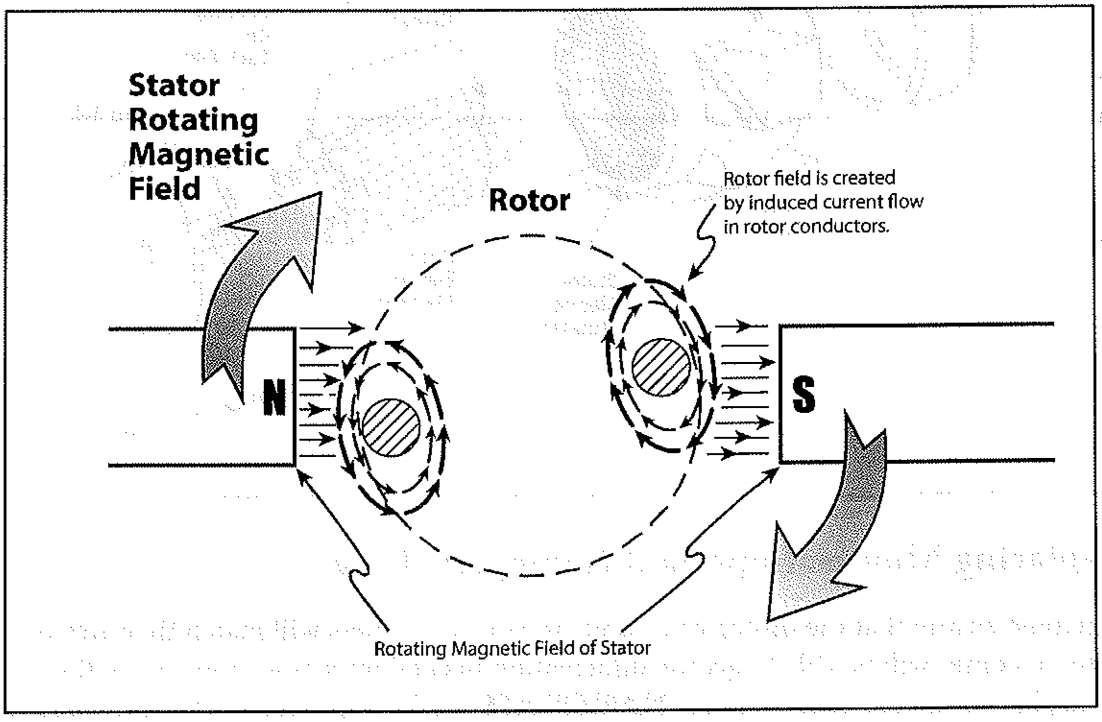
Electromagnetic Induction

ELECTROMAGNETIC INDUCTION is the production of electric current by moving a conductor (such as a copper wire) across a magnetic field. Just as sending electrical current through a conductor creates a magnetic field, moving a wire through a magnetic field induces current to flow in that conductor. Just as reversing the direction of flow in a conductor reverses the polarity of the magnetic field, reversing the direction of the conductor moving through a magnetic field reverses the direction of current induced in the conductor. This phenomenon occurs whether a wire moves through a stationary magnetic field, or whether a moving magnetic field passes a stationary wire.

Let's go back to our example of the motor, where we had electromagnets (coils of wire) at our left and right, and a bar magnet between them. Remember that when current was sent through the coils of wire, they became magnetized and the bar magnet aligned itself with the north pole of the magnetic field just produced. Let's imagine the same set up, but let's replace the bar magnet with a non-magnetic bar. We'll wrap a coil of wire around each end of the bar and connect the coils together so that current can flow from one coil to the other and back again. We'll attach the bar to our steel shaft just like the bar magnet was, and we'll keep the fan attached to one end of the shaft.

We have created a device with four coils of wire. Assume two coils (called **STATOR COILS**) are stationary and connected to an alternating current (AC) power source. The other two coils of wire (called **ROTOR COILS**) are free to rotate about the steel shaft. They are not wired to anything but each other. All the copper wire coils are without current so they are non-magnetic. Then we'll turn on the power so that current flows through the stator coils and a magnetic field will be created. As the strength of this magnetic field grows and shrinks with the changing alternating current, it moves past the coils of wire in the rotor and induces current to flow through them. The induced current now flowing through the rotor coils produces another magnetic field. The magnetic field in the stator rotates because of the constantly changing polarity of the alternating current, and the magnetic field produced by the induced current in the rotor "chases" the rotating stator field. This type of motor is called an **INDUCTION MOTOR**.

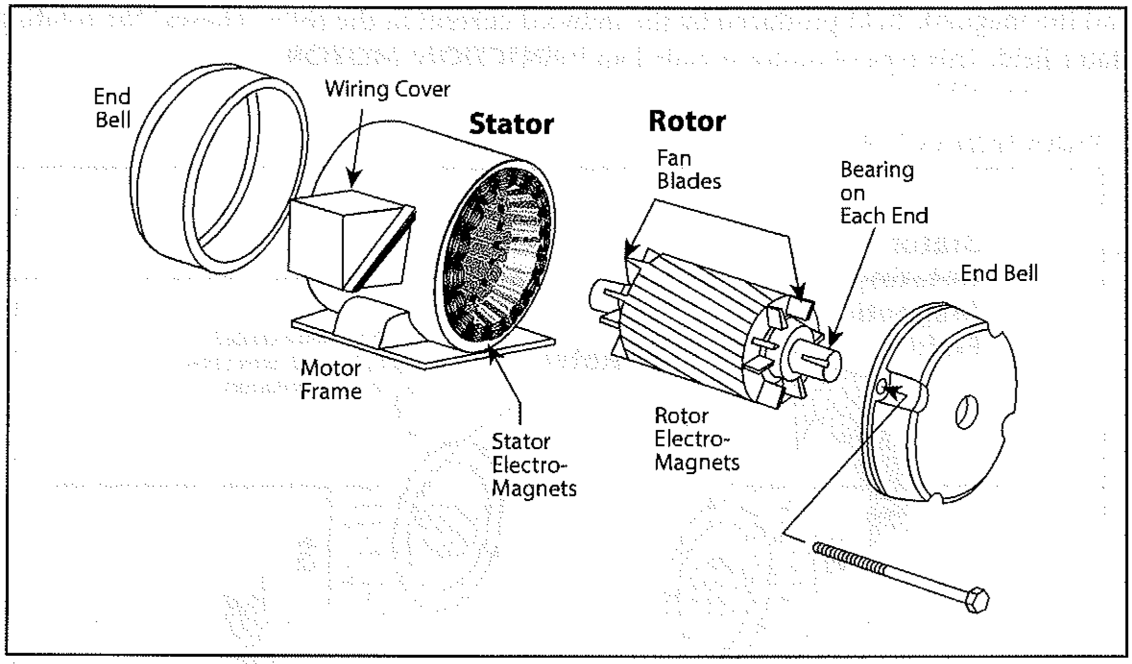
INDUCTION MOTOR



Remember that an electric motor is a device that takes advantage of a magnetic field that is rotating because of the changing polarity of alternating current, and immobile windings are called *stator windings*. Together, they make up the **STATOR**. And the windings that rotate as they chase the stator's magnetic field are called *rotor windings*. Together, they make up the **ROTOR**.

The stator is mounted to the **MOTOR FRAME** (*or motor case*). At each end of the frame are **END BELLS**, which house **BEARINGS** that support the shaft on which the rotor is mounted.

PARTS OF AN INDUCTION MOTOR



Replacing Motors: Important Nameplate Data

You must ensure that the motor you supply to your customers will match their needs. Your customer will be able to get the information needed for a new motor from the nameplate of the old one. A motor **NAMEPLATE** is a description from the manufacturer listing specific information about the motor's characteristics. Here is a list of items found on nameplate data that must meet old motor ratings:

- **HORSEPOWER (HP):** The power the motor can deliver to the shaft. This is an important rating because the load (fan, compressor, etc.) will require a certain amount of power in order to operate.
- **VOLTAGE (V):** The electric potential expressed in volts must be matched to the voltage of the application.
- **FULL LOAD AMPS (FLA):** Maximum amount of amp draw the motor can handle at full load. It is common to see a motor capable of being wired for both 115 and 230 volts. The nameplate will list both voltages (115/230 V). The nameplate will also list the amperage draw of the motor at both voltages (i.e., 14.4/7.2 A). Electrical power is measured in
- **WATTS**, which can be found by multiplying voltage by amperage by power factor. Notice that 115 x 14.4 is the same as 230 x 7.2. In other words, the motor produces the same power no matter which voltage is supplied. You will notice that amperage for 230 volts is exactly half the amperage for 115 volts. Since electrical distribution systems (wires, fuses, switches, etc.) are sized for amperage, using a higher voltage results in a lower amperage draw, and thus, less expensive components.

- **PHASE (PH):** Indicates whether the motor is single- or three-phase, typically shown as one (1) or three (3).
- **FREQUENCY (HZ):** A rating of cycles per second. U.S. motors operate at 60 cycles per second (Hz). Other countries supply electricity at 50 Hz.
- **LOCKED ROTOR KVA CODE (KVA CODE):** When AC motors start, they require more power than when they are running at full speed, just as your car requires more power to accelerate away from a light than it does to cruise down the highway. **INRUSH CURRENT**, the current draw during startup, is many times higher than normal full load amps (FLA). You might see inrush current listed as **LOCKED ROTOR AMPS (LRA)**. The term "locked rotor" means a rotor that is at a standstill, so locked rotor amps are the amps needed to take a motor from standstill to operating speed. The start inrush current is designed with a letter, which corresponds to a standardized value of kVA (kilovolt amperes) per horsepower (kVA/hp). A chart such as the one shown below shows the inrush current. For example, a nameplate with the KVA CODE of J will require between 7.1 and 7.99 kVA per horsepower during startup.

NEMA* Code Letter	KVA/HP with locked rotor	Approximate Mid-Range Value
A	0-3.14	1.6
B	3.15-3.55	3.3
C	3.55-3.99	3.8
D	4.0-4.49	4.3
E	4.5-4.99	4.7
F	5.0-5.59	5.3
G	5.6-6.29	5.9
H	6.3-7.09	6.7
J	7.1-7.99	7.5
K	8.0-8.99	8.5
L	9.0-9.99	9.5
M	10.0-11.19	10.6
N	11.2-12.49	11.8
P	12.5-13.99	13.2
R	14.0-15.99	15.0
S	16.0-17.99	
T	18.0-19.99	
U	20.0-22.39	
V	22.4-and up	

*NEMA stands for the National Electrical Manufacturers Association

- **DUTY CYCLE (DUTY):** Amount of time a motor can be operated every hour. A duty cycle of 20 means that the motor can only operate for 20 minutes every hour. It must be shut down for 40 minutes to cool down. If a motor must run all the time, the duty cycle would be listed as "continuous."
- **SPEED, IN REVOLUTIONS PER MINUTE (RPM):** Many motors can be wired to run at various speeds, but the motor must match the needs of the application. It is common for single speed motors to be rated for 3450 or 1725 RPM. Some motors that look identical and have the same horsepower rating are designed to run at different speeds. Make sure the customer gets the motor with the speed needed to match the old motor if it is a single speed motor that is being replaced.
- **MAXIMUM AMBIENT TEMPERATURE (MAX AMB):** Rating for the maximum temperature a motor can operate in without overheating. This temperature is often given in Celsius, such as 40°C. Note that this is the temperature of the air surrounding the motor. It is **NOT** the temperature of the motor itself. (See the next bullet on insulation class to see how hot the motor itself can be operated.)
- **INSULATION CLASS (INS OR INSUL CLASS):** Standard classification set by NEMA, and lists the motor's ability to survive for a period at a maximum temperature. It is important to make sure that a motor is not operated above the listed temperatures for its insulation class. A temperature rise of 50°F above rating can reduce the lifetime of the motor by 50%. The table below lists the insulation classes and maximum operation temperature allowed (per NEMA) for motors expected to last 20,000 hours of operation.

Temperature Tolerance Class	20,000 Hour Life Maximum Operation Temperature Allowed	
	°C	°F
A	105	221
B	130	266
F	155	311
H	180	356

- **SERVICE FACTOR (SF):** A percentage that a motor can operate above full load for short periods. For example, a one horsepower motor with a service factor of 1.25 can operate at 1.25 horsepower for a short period. If a service factor is only one, it may be omitted from the nameplate. That means that if no service factor is given, you can assume that it is 1.0. A motor should not be selected that will operate often in the service factor area. It is better to select the next bigger size.

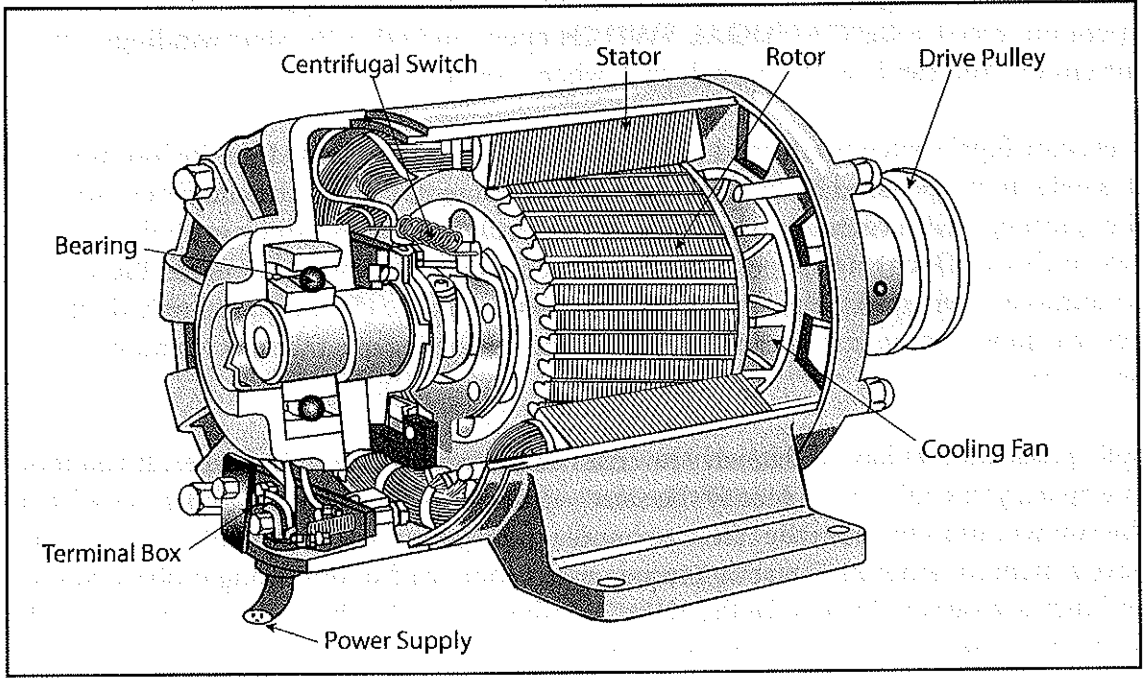
- **FRAME SIZE:** Indicates what frame the motor has connected to the housing. You must also make sure that the frame size matches the application or the bolt holes won't line up and the shaft may not be the correct distance away from the frame. As you might expect, there is a table for frame size, which is not included here. You may access to one at work or on the Internet.

Types of Motors

The HVACR industry uses many **SINGLE-PHASE ELECTRIC MOTORS.** Most often, they will be fractional-horsepower (less than one horsepower) motors. Earlier, you saw an example of coils of wire wound around an iron bar in the rotor to help explain how induction motors operate. Motors that use this technique are called **WOUND-ROTOR MOTORS.**

Most, if not all of the electrical motors you will see are called **SQUIRREL-CAGE MOTORS**. Instead of wound coils of copper wire, squirrel-cage motors use a rotor shaped like a wheel in a hamster cage. The "wheel" is typically made of aluminum (and sometimes copper) conductors connected at the ends with rings. Instead of being hollow, the center is made of a laminated iron core, and if you took away the laminated iron core, the remainder looks like a hamster wheel. The following illustration shows a cutaway of a single-phase induction motor with a squirrel-cage rotor.

SINGLE-PHASE INDUCTION MOTOR WITH SQUIRREL-CAGE ROTOR



The description of the compass needle that we used to explain how an electric motor works is accurate, but when we replace the permanent magnet used in the compass needle with a wound-rotor or squirrel-cage rotor, our explanation becomes inaccurate. It is accurate to say that the magnetic field created by the current flowing in the stator induces current to flow in the rotor. It is also accurate to say that the induced current flowing in the rotor produces a second magnetic field. However, it is not accurate to say that these two magnetic fields cause rotation to start in a single-phase motor. A pure single-phase induction motor cannot start on its own. It requires some sort of imbalance in electrical phase to get it going. However, once it starts it can continue to run without any artificial electrical imbalance.

It is beyond the scope of this book to explain why because a more advanced electrical theory is required. However, it is important for you to know that single-phase induction motors cannot start on their own without some artificial means to get them going. The method used to get them started depends on the starting and running torque that the motor is required to provide. The method of starting is important enough that we call single-phase induction motors by the name that describes how they are started: single-phase.

Split-Phase Motors

SPLIT-PHASE MOTORS have two sets of windings in the stator. One is used for starting the motor and the other is used for both starting and running the motor. Because a motor requires more torque during start up, a split-phase motor uses two sets of winding while the motor is coming up to speed. Once the motor has reached approximately 75% of its operating speed, a **CENTRIFUGAL SWITCH** opens and takes the start windings out of the circuit. You can hear this switch click when it opens.

The centrifugal switch is attached to the shaft and is normally closed (in the "on" position). It is held in this position by small springs. When the motor starts, the centrifugal force of the spinning shaft eventually overcomes the force of the springs, which are holding the switch closed. Once this happens, the switch opens and the flow of current to the start windings is interrupted. The run windings are always in the circuit, so not only do they help the motor come up to speed, they also keep it running once the start windings have been turned off.

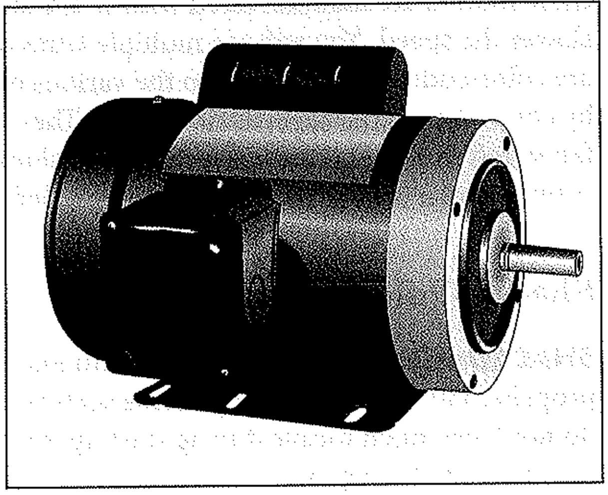
Split-phase motors have a relatively low cost when compared to other types. If you took one apart, you could easily identify the start windings. They are made of heavier wire than the run windings because they have to handle the higher starting currents. These motors have a medium amount of starting torque when compared to other single-phase motors and they are rather efficient. In the HVACR industry, single-phase motors are usually less than one horsepower and used to run fans.

Capacitor-Start, Induction-Run (CSIR)

A **CAPACITOR-START, INDUCTION-RUN (CSIR) MOTOR** (also called a *capacitor-start*) is exactly the same as a split-phase motor with one exception: it also has a **START CAPACITOR** wired in series with the starting windings. When we say "wired in series," we mean that the current that goes through the start capacitor also goes through the start windings. For example, batteries in a flashlight are connected in a series.

The capacitor adds starting torque to the motor. A capacitor-start motor has more starting torque than a split-phase motor. Because the capacitor is wired in series with the start windings, it is taken out of the circuit at the same time as the start windings. Once up-to-speed, capacitor-start and split-phase motors develop similar torque because they both operate on only the run windings. You can tell when a motor has a capacitor by looking at it. You will see a metal housing on the case of the motor to house the capacitor, as shown.

CAPACITOR-START, INDUCTION-RUN MOTOR



Capacitor-Start, Capacitor-Run (CSCR) Motor

The **CAPACITOR-START, CAPACITOR-RUN (CSCR) MOTOR** is similar to the capacitor-start, induction-run (CSIR) motor, with the addition of another capacitor. However, it operates quite differently. In this motor, the start winding, run winding and run capacitor are always in the circuit when the motor is running. Only the start capacitor is taken out of the circuit by the start switch when the motor comes up-to-speed.

CSCR motors are very efficient motors and have more starting torque compared to other single-phase motors. They are used for heavy loads such as compressors and fans. The two capacitors in these motors are not the same. The run capacitor has a lower rating than the start capacitor. Together, they combine to help start the motor. The run capacitor is left in the circuit to increase the efficiency of the motor.

Some CSCR motors have two capacitor housings on top that look something like mouse ears. Others have a box mounted on the motor that houses the two capacitors.

Permanent Split-Capacitor Start (PSC) Motor

The **PERMANENT SPLIT-CAPACITOR START (PSC) MOTOR** is another version of a split-phase motor. It has a start winding, run winding, and run capacitor. All three components are always in the circuit when the motor is running, so there is no switch in these motors. These are very efficient motors, but because they have low starting torque, they are used in applications where little torque is needed to get the load spinning. When starting a fan, these motors start slowly and take some time to get up-to-speed. This reduces noise and wear and tear on the components.

You will commonly see PSC motors in the squirrel-cage fans found in furnaces. Many of these motors are manufactured with 2, 4, 6 and 8-pole configurations. The more poles, the slower the speed. You will see multiple wires coming out of these fans. The different wires are color-coded and attached to the various poles. The speed of the motor can be selected by connecting to the appropriate wires. These motors provide a common way to change fan speed from a low setting for low air volumes needed in winter to a higher setting for summer when higher air volumes are needed.

Shaded-Pole Motors

SHADED-POLE MOTORS are low cost and relatively inefficient motors used to drive propeller fans found on components such as condensing units and evaporator coils. They do not have much torque during start up, so they are limited to light-duty applications in less than one horsepower sizes. These motors use a small starting winding called a shaded pole mounted to one side of the main stator coil. Rotation of the motor depends on which side of the pole the shaded pole is mounted.

Electronically Commutated Motor (ECM)

ELECTRONICALLY COMMUTATED MOTORS (ECMs) have become very common in many applications, including HVACR, where they are used in air handlers, furnaces, air conditioners, heat pumps, and refrigeration systems. These motors are capable of variable speed and variable power, so systems that utilize them may have more than one stage of heating and/or cooling.

ECMs were once called "Integrated Control Module (ICM) motors" because they have an electronic control module supplied with the motor. In fact, the current ECM motors are actually two components: the motor and the motor control. You may hear the motor control referred to as the "control module" and the motor called the "motor module."

ECMs are inherently more efficient than shaded-pole and permanent-split-capacitor (PSC) motors. Unlike the shaded-pole and PSC motor, the ECMs are not induction motors. They do not use an electromagnetic rotor as do wound-rotors or the squirrel-cage rotors used in the induction motors. Rather, ECMs use a permanent magnet for the rotor. A **PERMANENT MAGNET** is an object made from a magnetized material that creates its own persistent magnetic field, e.g., a refrigerator magnet used to hold notes on a refrigerator door. Because the rotor is a permanent magnet, it always has a north and south pole. Of course, it also has a magnetic field. It does not need induction to produce a magnetic field.

ECM motors use electronics to change single-phase AC first to DC, and then to three-phase AC. The electronics control the frequency of the three-phase current, which controls the speed of the motor and the level of current it supplies, which controls the power of the motor. Because the control module converts single-phase AC current to direct current, the motors are called **DC MOTORS**. When the ECM control module converts DC to three-phase AC, it alternately *communicates* (or reverses the direction) of the current.

Variable Speed ECM Motor

An ECM motor's role is to provide constant airflow for a specific operating condition in a piece of HVACR equipment. A variable flow system can have many points of operation, so the ECM motor designed to maintain constant speed is actually a variable speed motor. It maintains an appropriate constant speed and each programmed point of operation.

The HVACR original equipment manufacturer (OEM) calculates the speed and torque of the motor required for each desired cubic feet per minute (cfm) in a variable flow piece of equipment, and this information is programmed into the control module. Thus, the ECM control module is custom-programmed for each piece of equipment into which it is installed. When installed, the program from the OEM determines the airflow needed based on the demand on the equipment.

A typical AC induction motor operates at a single speed. If the furnace filter gets dirty, the amount of air flowing through the system will be diminished. By contrast, the control module in the ECM will adjust the output of the motor to maintain the correct airflow, even when a filter gets dirty. Unlike the X13 ECM (which is discussed next), the variable speed ECM monitors both speed and torque, while the X13 monitors only torque.

ECMs are more expensive than constant-speed induction-type AC motors, but they are more efficient. Further, their variable speed and variable power capabilities allow HVACR systems to operate at part-load conditions. This reduces short-cycling (on-and-off operation), which increases the life of the system. Part-load operation also enables HVACR systems to operate more efficiently. Overall, the ECM motors provide a benefit beyond motor efficiency alone.

Constant Torque ECM (X13)

The **CONSTANT TORQUE MOTOR (MODEL X13)** is a type of ECM motor that is programmed for constant torque rather than constant airflow. The OEM provides torque values for up to five levels of system demand (such as heating, cooling, or fan alone). Similar to the constant-airflow ECM, each piece of equipment generates a unique set of torque values. Those values are programmed into the control module. During operation, the control module's constant torque program ensures that the desired torque value is delivered, even if external static pressure changes due to something like a dirty filter, closed or blocked registers, or with an undersized duct system.

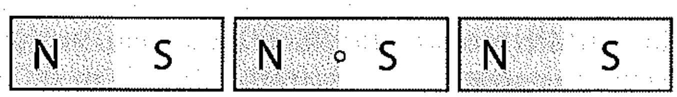
The ability to provide up to five values for torque makes the application of this motor similar to the PSC motor with multiple taps for various speeds. The advantages over a conventional PSC motor are higher efficiency, the ability to maintain desired torque regardless of changes in external static pressure, and delivery of more precise airflow. These motors are used on split system air handlers and package systems with single stage applications and on some furnaces.

Three-Phase Motors

Other than the ECM motor, all the motors in the preceding section need something to help them start, such as a capacitor or start winding. Both the capacitor and start winding create an imbalance, which is needed in the single-phase motor to get rotation started. Once the motor is going, the speed of the motor creates the imbalance needed to keep it going. Motors with run capacitors keep a capacitor in the circuit to add more torque to the motor.

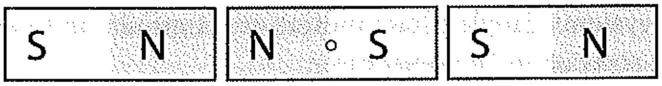
In reality, single-phase motors do not produce a rotating magnetic field. Instead, the field pulsates as it reverses its poles in time with the alternating current sine wave. Imagine a single-phase motor with two poles, as in Position 1 below. The magnet on the left is one pole of the stator, and the pole on the right is the other pole of the stator. The magnet in the middle is the rotor. In the position shown, the rotor is aligned to be attracted to the north and south poles of the stator.

POSITION 1

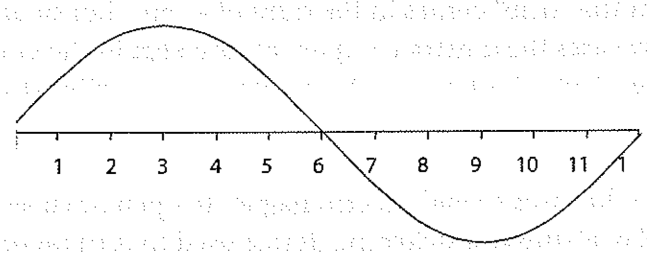


In Position 2, the magnetic fields in the stator have reversed. The rotor is now in a position to be repelled from each pole of the stator. But which way will it spin? The force is exactly equal in both directions, so there is nothing to start it spinning.

POSITION 2

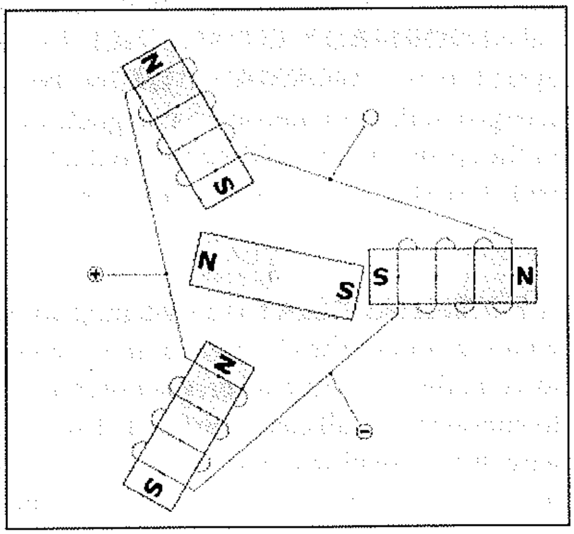


Notice in the sine wave below, there is no gradual change from positive to negative. The change occurs when the sine wave passes through the middle of the graph at point 6. When the wave is at point 3, the magnetic field in the stator is strong. It is weak at point 5 and disappears at point 6. At point 7 it is again weak, but now in a reversed direction. In summary, the magnetic field either has its north pole in one coil of the stator or the other. The north pole is never between the coils.



The result is zero torque to start the spinning motion of a single-phase rotor. Once the rotor begins to rotate, it will continue to rotate under its own power. Without a start capacitor or start winding, a single-phase motor would simply hum with energy. It might be hard to imagine, but you could spin the shaft by hand to start rotation, and within seconds, the motor would come up to running speed. But, without your help or the help of a capacitor or start winding, the motor would simply sit there and hum.

A **THREE-PHASE MOTOR** will and does start on its own. Because it has three poles instead of just one, the north pole of the magnetic field doesn't simply shift back and forth between one pole and the other. In the figure below, you can see that as the north pole moves from pole to pole, it moves a third of the way around the motor. Now, instead of simply switching from one side to the other, the magnetic field truly rotates. Thus, a three-phase motor is self-starting and needs no additional help to get going.



Compared to single-phase motors, three-phase motors are more efficient and have more starting torque. They also have fewer components because they do not need capacitors or switches to get them started. Fewer components mean less can go wrong with the three-phase motor. It is possible to run three-phase motors from a single-phase power source, with the addition of a converter designed for that purpose. Three-phase motors are available in sizes up to several hundred horsepower and are used for large commercial and industrial HVACR systems. Single-phase motors are common up to about 5 horsepower and are available in sizes up to 10 horsepower.

Electric Motor Components

Some components are common to all electric motors, including the case, stator, rotor, windings, bearings, and frame. Previously, you learned that single-phase motors need help to start and that the "help" comes in the form of a capacitor or an extra winding. You learned that in many cases these extra components are kept in the circuit until the motor reaches approximately 75% of full speed. At that point, a centrifugal switch opened to take them out of the circuit.

A **RELAY** is a device that uses a small electromagnet to open or close contacts in a switch. In other words, a relay is simply a switching device used to turn on or turn off a circuit. The components of the switch that enables electrical current to pass are called **CONTACTS**. When the contacts are touching, they are in a "closed" state and the switch is "on." When the contacts are pulled apart, there is an opening between them and no path for current to flow. They are in an open "open" state and the switch is "off."

In a relay, the contacts are held in place with a spring, which may hold the contacts together (closed) or apart (open). **NORMAL** is the term for the de-energized position of the contacts when the relay is brand new. A relay with contacts held together (closed) is called **NORMALLY CLOSED (NC)**. The term for describing when the contacts are held apart (open) is **NORMALLY OPEN (NO)**. There is a coil of wire inside the relay. When energized, this coil becomes a magnet, and the force of the magnet overcomes the force of the spring that is holding the contacts in place. When energized, a normally open relay will close (turn from "off" to "on") and a normally closed relay will open (turn from "on" to "off").

A **POTENTIAL RELAY** is a switching component used to take start capacitors or start windings out of the circuit as a motor comes up to speed. Rather than using centrifugal force as the switching force, the potential relay uses current generated in the start winding to energize a small electromagnet. This potential relay uses a coil with high resistance wire. It has small wire with many turns. It uses normally closed (NC) contacts. This means that when a motor is started, the normally closed contacts allow current to flow to the start capacitor or start winding. When the electromagnet is energized, the electrical contacts open to take the start capacitor or start winding out of the circuit.

When a motor starts, it acts as both a motor and as a generator. The spinning magnetic field in the rotor actually generates a back electromotive force (called a **BACK EMF**) and small amount of current in the stator windings. Note that electromotive force is another way of saying voltage. The faster the motor turns, the greater the back EMF and current generated. At about 75% motor speed, the current is great enough to energize the electromagnet in the potential relay and open the contacts to remove the start capacitor from the circuit.

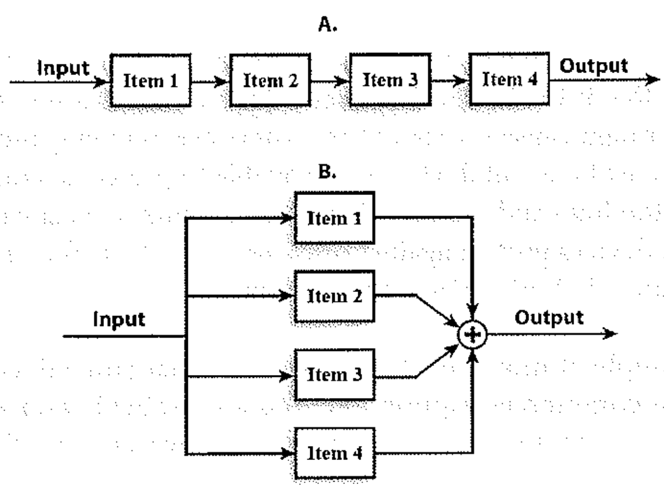
Potential relays are wired in parallel with the start or auxiliary winding. This means that current flows independently though each component. Potential relays are typically used in hermetic motors and perform the same function as the centrifugal switch in many other motors.

Current Relay

Rather than using high resistance wire (light wire with many turns) like a potential relay, a **CURRENT RELAY** uses low resistance wire (heavy wire with few turns). Current relays use normally open contacts instead of normally closed contacts, and they are wired in series with the run (main) winding of the motor. **WIRED IN SERIES** means that the current that flows through one device also flows through the other.

The following shows you the difference between a series and a parallel circuit. You can see the difference in appearance between a potential and a current relay. It is common to see the heavy wire exposed in a current relay, while potential relays typically have the coil hidden from view within the relay housing.

SERIES AND PARALLEL CIRCUITS



When a motor starts, it draws a large amount of current, much more than it does during normal running operation. Because the current relay is in series with the run windings, this high current flows through the coil in the relay and turns it into an electromagnet. The electromagnet overcomes the force of the spring that is keeping the contacts in their normally open position and closes them to allow current to flow through the start capacitor or start winding.

As the motor comes up to speed, the amount of current drops and this weakens the electromagnet. At about 75% of full speed, the force of the spring (or gravity) overcomes the force of the electromagnet, and the contacts are pulled back into their normally open position. The start capacitor or start winding is taken out of the circuit.

Motor Starters

As you have just learned, relays are devices that use one electrical circuit to switch another. **CONTACTORS** are essentially the same thing as a relay, except they are used on larger circuits.

MOTOR STARTERS are used to start and stop large motors, but they are also used to protect and control the motor. A motor starter will allow a large amount of current to flow for a short time, but will shut the motor down if the current is too great for too much time. This allows the motor to draw high current during start up, but protects the motor from high current during normal operation. There are many types of motor starters with varying functions.

Motor Protection Devices

Electrical motors are susceptible to damage from excessive heat caused by a motor operating in an area that is too hot for its rating. Poor air circulation or a malfunction in the power supply might cause excessive heat. There are too many motor protection products available to list here, but devices are available to protect against voltage and/or current that is both too high and too low. Other devices protect against ground faults. For three-phase motors, devices protect against *single phasing* (the loss of one phase), phase reversal, and imbalances in both voltage and current.

We will discuss a couple of motor protection devices that you will commonly see on residential and light commercial equipment. You are probably aware of fuses and circuit breakers, devices that protect a circuit against overcurrent. Since a motor may not be the only device on a circuit, fuses and circuit breakers may not trip even if a motor is overloaded.

Some motors are equipped with internal overload protection. Internal thermal overloads are located in or near the windings. Motors with internal overload are typically small motors started with a relay. External protection is used for bigger motors. The most common are **THERMALLY ACTIVATED (TEMPERATURE-SENSING) DEVICES**. One type of temperature sensor is made of bimetal (two metals bonded together). When heated, the two metals expand at different rates. That causes them to warp, and the warping action opens contacts to shut down the motor. Bimetal sensors are designed to "snap" (or break) when they warp so the contacts open quickly.

So how do temperature sensors help protect a motor against high current draw? Higher current draw causes more heat. Line current passes through a small heater that heats the temperature-sensing device, so when a device is thermally activated, it can be reacting to current. It also will trip if a combination of the current and high ambient temperature exceeds the safe threshold of the motor. Another type of thermally activated motor protection uses a solder that melts at a specific temperature. When the solder melts, contacts open to stop the motor. Both the bimetal and the solder pot devices can be reset.

A **MAGNETIC OVERLOAD DEVICE** employs a coil of wire that becomes an electromagnet when energized. Like any coil, the more current, the stronger the magnetic field. When the current (and thus the magnetic field) reaches a specific point, contacts are pulled open by the magnetic field and the motor stops.

REVIEW QUIZ OF INTRODUCTION TO ELECTRIC MOTORS

Answers appear on page 222

1. Which of the following **BEST** defines the term electric current?
   a. The flow of electricity from one place to another
   b. The force that attracts or repels magnets
   c. A stable negatively charged elementary particle with a small mass that is a fundamental constituent of matter and orbits the nucleus of an atom
   d. The electricity only flows in one direction

2. According to this text, one way electricity is generated by a motor is to
   a. spin a gear to turn the coil.
   b. use an anchor to stay in place.
   c. create a circuit.
   d. rotate a coil of wire through a magnetic field.

3. Which of the following makes an electric motor work?
   a. Batteries
   b. Spark plugs
   c. Electromagnets
   d. Electrons

4. When a motor turns, the armature spins because of
   a. gravity.
   b. the inertia from the armature.
   c. a magnetic field.
   d. an alternating current power source.

5. What is a magnetic field?
   a. The flow of electricity from one place to another
   b. The force that attracts or repels magnets
   c. An alternating current that continually reverses direct
   d. An electron flow alternating between positive and negative current

6. The initials RPM stand for what?
   a. Revolutions per motor
   b. Revolutions per minute
   c. Recycle per minute
   d. Revolutions per motion

REVIEW QUIZ OF INTRODUCTION TO ELECTRIC MOTORS

Answers appear on page 222

7. An AC motor is an electric motor that is driven by
   a. alternating current.
   b. transformers.
   c. electricity.
   d. electric current.

8. A motor nameplate is a
   a. branding tool to help technicians know who manufactured the motor.
   b. description from the manufacturer listing only the specific horsepower of the motor.
   c. description from the manufacturer listing only the class of motor.
   d. description from the manufacturer listing specific information about the motor's characteristics.

9. Which of the following uses a rotor shaped like a wheel in a hamster cage, with the center made of a laminated iron core?
   a. A hamster cage motor
   b. A motor nameplate
   c. A squirrel cage motor
   d. A stator

10. What of the following is a switching device used to turn on or turn off a circuit?
    a. Wired in series
    b. Relay
    c. Parallel circuit breaker
    d. Three-phase motor

11. What is the term that describes a single frequency indefinitely repeated in time?
    a. Sine wave
    b. Voltage
    c. Sine curve
    d. Electrical current

12. When two like poles, such as two north poles, approach one another, what happens?
    a. The two poles are attracted.
    b. Each pole spins toward the north.
    c. The two poles repel each other.
    d. Each pole spins toward the south.

REVIEW QUIZ OF INTRODUCTION TO ELECTRIC MOTORS

Answers appear on page 222

13. Which of the following terms describes the lines of force associated with a magnetic field?
    a. Magnetic field lines
    b. Zero current lines
    c. Maximum flux lines
    d. Magnetic flux lines

14. What is the term that describes a rating of cycles per second?
    a. Frequency (Hz)
    b. Full load amps (FLA)
    c. Horsepower (Hp)
    d. Service factor (Sf)

15. Which of the following electric motors is typically a less than one horsepower engine?
    a. Squirrel cage motor
    b. Single-phase electric motor
    c. Split-phase motor
    d. Capacitor-start, inception run motor

16. Which of the following motors has more starting torque than other single-phase motors?
    a. Capacitor-start, induction-run motor
    b. Permanent split-capacitor start motor
    c. Capacitor-start, capacitor-run motor
    d. Electronically commutated motor

17. Which motor is self-starting and needs no additional help to operate?
    a. Variable speed ECM motor
    b. Shaded-pole motor
    c. Permanent split-capacitor motor
    d. Three-phase motor

18. Which of the following terms describes a relay with contacts held together?
    a. Normally open
    b. Wired in series
    c. Normally closed
    d. Parallel circuits

REVIEW QUIZ OF INTRODUCTION TO ELECTRIC MOTORS

Answers appear on page 222

19. Which of the following are similar to relays, except that they are used on larger circuits?
    a. Current relays
    b. Contractors
    c. Motor starters
    d. Contacts

20. All of the following are motor protection devices **EXCEPT**
    a. Internal thermal overloads
    b. Thermally activated devices
    c. Current relays
    d. Magnetic overload devices

ANSWERS TO REVIEW QUIZ

CHAPTER 5

INTRODUCTION TO ELECTRIC MOTORS

1. a. The flow of electricity from one place to another
2. d. rotate a coil of wire through a magnetic field.
3. c. Electromagnets
4. d. an alternating current power source .
5. b. The force that attracts or repels magnets
6. b. Revolutions per minute
7. a. alternating current.
8. d. description from the manufacturer listing specific information about the motor's characteristics.
9. c. A squirrel cage motor
10. b. Relay
11. c. Sine curve
12. c. The two poles repel each other.
13. d. Magnetic flux lines
14. a. Frequency (Hz)
15. b. Single-phase electric motor
16. c. Capacitor-start, capacitor-run motor
17. d. Three-phase motor
18. a. Normally open
19. b. Contractors
20. c. Current relays

GLOSSARY OF TERMS

A.F.U.E.: *See* Annual Fuel Utilization Efficiency.

Absorption: The gas or liquid is taken into the solid substance.

Absorption cycle: A refrigeration cycle that runs on a heat source to generate power to run the refrigeration system.

Accumulator: A tank that allows only vapor to leave. Accumulators are installed between the evaporator and the compressor.

Adsorption: The gas or liquid molecules remain on the surface of the other substance.

Air conditioning: The process of treating air to control its temperature, humidity, cleanliness, and distribution to meet requirements of the conditioned space.

Air control devices: Hydronic specialties for eliminating air from the system. Includes boiler and tank fittings and vents for heat emitters and piping. *SEE* Air control fittings.

Air control fittings: Boiler or tank fittings designed to prevent air from getting into the piping system and to direct air into the air cushion tank.

Air distribution systems: Structures that bring conditioned (heated and cooled) air to people occupying a building, and therefore directly affect occupant comfort.

Air handler: The fan unit of a furnace and the fan-coil unit of a split-system, packaged air conditioner or heat pump.

Air-cooled condenser: A condenser that cools the refrigerant using air, used most commonly in the residential and light commercial markets. Commonly made of finned tube, integral-fin, or microchannel construction.

Air-source heat pump (ASHP): A device that can heat and cool by reversing refrigerant flow. During heating mode, the indoor coil receives hot refrigerant vapor from the compressor, while the outdoor coil is supplied with cold refrigerant, which adsorbs energy from the surrounding air. During cooling mode, the indoor coil is supplied with cold refrigerant that adsorbs energy from inside air, while the outdoor coil receives hot refrigerant vapor from the compressor and rejects energy to the surrounding air.

Alkybenzene: A synthetic oil similar to mineral oil, but with better solubility with some refrigerants.

Alternating current (AC): An electric current that repeatedly changes its direction or strength, usually at a certain frequency or range of frequencies.

Alternating current motor: An electrical machine that converts alternating-current (ac) electric energy to mechanical energy.

Ambient temperature: The temperature that surrounds an object.

American Society of Mechanical Engineers (ASME): The organization that writes code for boiler construction. ASME International, Three Park Avenue, New York, NY 10016-5990. Telephone: 1-800-843-2763

Ammonia: Used as a refrigerant in large industrial and commercial applications, but does not belong to a group of refrigerants. *Also called R-717.*

Ampere: A unit in the International System specified as one International coulomb per second and equal to 0.999835 ampere.

Annual Fuel Utilization Efficiency (AFUE): An efficiency rating given to boilers by the manufacturer, required by the U.S. Department of Energy (DOE).

Atmospheric burner: A burner that uses atmospheric pressure for combustion, and commonly found in older or lower efficiency furnaces.

Atomizing humidifier: A device that sprays very small droplets of water into the airstream, where they are quickly evaporated.

Automatic combination gas valves (ACGV): A gas valve that combines the regulator, a manual shutoff, the gas supply and controls for the pilot, and the main gas valve and controls.

Automatic expansion valve (AXV): A valve that maintains a constant pressure in the evaporator, unlike the thermostatic expansion valve, which maintains a constant evaporator superheat.

Average water temperature: The average of the temperature of the water leaving the boiler and the water returning to the boiler. *Also called the design water temperature.*

Azeotrope: A blend of refrigerant that has only one boiling point for a given pressure. *Also called Azeotropic mixture.*

B vent: A double-wall pipe made with an aluminum inner pipe and a galvanized or aluminum outer pipe separated by an air gap. It is available in round and oval and in a number of sizes.

Back electromotive force: The voltage, or electromotive force, that pushes against the current which induces it.

Back EMF: *See back electromotive force.*

Back seated: Position of a service valve that opens the flow of the refrigerant between the compresor and system, and does not flow between the compressor and the service port. Also known as the open position.

Balancing valve: A valve used to equalize water distribution in multiple circuit systems.

Baseboard emitter: A heat emitter that replaces conventional baseboard trim along the floor of the room to be heated.

Bearing: A device that supports, guides, and reduces the friction of motion between fixed and moving machine parts.

Belt drive: A system that uses belts and pulleys, similar to the belts and pulleys on an automotive engine. For this to work, both the motor and the compressor shafts have to be parallel to one another, which means the motor and compressor must sit side-by-side.

Bimetallic strip: A flame sensing device that has two pieces of different metals bonded together.

Black iron pipe: *See Carbon steel pipe*

Bladder expansion tank: *See Diaphragm expansion tank*

Blower door safety switch: A device designed to prevent injury by preventing the furnace from firing when the furnace blower door panel is removed.

Boiler: A closed pressurized container in which a liquid is heated.

Boiler gauge: A gauge that measures water temperature and pressure within the boiler.

Boiling temperature: The temperature at which a chemical changes from a liquid into a gas. Boiling temperature varies with pressure—the higher the pressure, the higher the boiling temperature.

Bore: The inside of a tube or hole.

Brazing: The process of joining two metal pieces together by applying heat and adding a filler metal.

NOTE: Soldering is different from brazing.

British thermal unit (Btu): The standard unit of energy, and amount of heat necessary to raise the temperature of one pound (1 lb) of water by one degree F.

British thermal units per hour (Btu/h): A measurement for the number of Btu delivered by the equipment in one hour. Btu/h is also used for sizing the capacity of a piece of heating or cooling equipment.

Btu: *See British thermal unit.*

Btu/h: *See British thermal unit per hour (Btu.h)*

Btu/h to gpm: Step One: Multiply 500 x the number of degrees in the water temperature drop (usually 20 degrees). Step Two: Divide the total calculated heat loss for the building by the answer from Step One (The answer to Step One will usually be 10,000 for residential systems). This will give you the pump capacity (gpm) needed to produce the needed amount of heat.

Btu/h to MBH: Divide Btu/h UH by 1000. (Move decimal in Btu/h 3 places to the left.) Example: 8200 Btu/h is equal to 8.2 MBH

Building envelope: The elements—the roof, exterior walls, and floor of a structure—that form a barrier that separates the interior of the building from the outdoor environment.

Bypass humidifier: A type of household appliance that increases humidity (moisture) in a single room or in the entire house; mounted to the return air duct. It can also be mounted to the supply air plenum. Because the supply air plenum is under positive pressure and the return air duct or plenum is under negative pressure, air is forced to flow through the humidifier from the supply air plenum, through the round duct, and into humidifier on the return air duct. As the air passes through the humidifier, it evaporates water from a drip pad in the humidifier. This humid air is then drawn into the return air duct. From there it is drawn into the main blower and circulated through the air distribution system to the entire building. *Also called flow-through humidifier.*

Calculated heat loss: *See Heat loss.*

Capacitor-start, capacitor-run (CSCR) motor: A type of capacitor motor that has a capacitor and starting winding connected in series at all times.

Capacitor-start, induction-run (CSIR) motor: A type of capacitor motor that uses two capacitors, one for starting the motor, and one that remains in the circuit while the motor is running.

Capillary tube: A metering small-diameter tube designed to restrict the flow of refrigerant. *Also called cap tube.*

Carbon dioxide: A popular refigerant before being replaced with CFCs and HCFCs through the 1940s and 1950s. Being reevaluated given its low cost and safety. *Also called R-744.*

Carbon monoxide: A deadly gas that can be produced by abnormal combustion. It is produced when insufficient oxygen is present during the combustion process.

Carbon steel pipe: Steel pipe that is coated with a varnish-type oil to protect the pip during shipping and initial storage. *Also called plain or black iron pipe.*

Cast iron boiler: A boiler with several cast iron sections attached to each other through which the water flows, with fire below to heat the water.

Centrifugal atomizing humidifier: A wheel (slinger or impellor) to spin water and break it into tiny droplets to humidify the air.

Centrifugal compressor: A compressor that uses a rotating impeller to accelerate refrigerant vapor to a high velocity, and then convert the dynamic energy from the high velocity refrigerant vapor to pressure energy.

Centrifugal switch: A type of switch that operates using the centrifugal force created from the rotating shaft; switch activates and de-activates depending on the speed of the motor.

CFC refrigerant: A substance used in a heat cycle, made up of chlorine (the first C), fluorine (the F), and carbon (the last C). The abbreviation for chlorofluorocarbon (CFC) is used to describe these refrigerants.

Check valve: A valve that closes to prevent backward flow of liquid; it allows flow only in one direction.

Chiller: A machine designed to chill water rather than air. Large institutions, such as hospitals, or universities, use central chilled water plants to produce chilled water for the entire campus.

Chiller barrel: A chiller's shell and tube evaporator.

Chimney liner: *See Z-Vent*

Circuit: One complete pipe look between the supply main and the return main of the boiler.

Circulator: A small capacity pump to circulate water in a closed hot water comfort heating system. *Also called a booster pump.*

Clamshell heat exchanger: Two pieces of stamped metal that are seamed together to form an inner passage for hot combustion gasses. Air from the building is circulated over the outside surface of the heat exchanger to be warmed. Each burner is inserted into one "clamshell" and so the heat exchanger will have a section for each burner. Clamshell heat exchangers commonly use a ribbon or slotted atmospheric burners with natural or induced-draft furnaces.

Coefficient of performance (COP): Basic measure of refrigeration system efficiency. COP is a ratio of output divided by input. More specifically, it is the output power divided by the input power.

Combination valve: A gas valve that includes a valve for the pilot.

Combustion: A chemical reaction between a fuel and oxygen that produces heat, carbon dioxide (CO_2), and water vapor.

Comfort heating system: A system that is designed to maintain living area temperatures at levels that allow heat loss from the human body to occur at a comfortable rate.

Commercial equipment: An air conditioning unitary market sector that provides capacities larger than 135,000 Btu/h and serves large commercial buildings.

Compression tank: *See Air cushion tank.*

Compressor: In HVACR, a machine that works like an air compressor except it compresses refrigerant vapor instead of air. It is important to note that the refrigerant must be in a vapor state rather than a liquid state when it enters the compressor.

Condenser coil: A series of copper tubes that allow refrigerant to flow back and forth in a serpentine path. The copper tubes are covered with numerous very thin aluminum fins. These fins increase the surface area of the tubes and provide for much more heat transfer.

Condensing boiler: uses all the energy created by combustion by capturing the heat from the exhaust, through condensing the moisture in the exhaust gas. To work, the return water must be lower than the exhaust gas dew point (less than 136°F).

Condensing unit: A machine that rejects the heat adsorbed by the evaporator coil, the heat generated by the compressor, and for hermetic compressors, the motor heat.

Conduction: The process of transferring heat, by contact, from one molecule to another within the material heated.

Conductive load: The term for heat gained or lost through the building envelope.

Connecting rod: A rod that connects to the eccentric bearing surface (throw) of the crankshaft at one end. The other end connects to the piston using a wrist pin.

Constant torque motor: An AC motor that can develop the same torque at each speed, thus power output varies directly with speed; used in applications with constant torque requirements such as mixers, conveyors, and compressors.

Contactors: A device similar to a relay but used on larger circuits.

Contacts: The components of a switch that enable electrical current to pass.

Convection: The process of transferring heat by circulation of molecules in the material that is heated. For example, heat transfer by circulation of molecules of heated air.

Convector: A radiation heat emitter consisting of a finned heating element enclosed in a cabinet designed to promote air circulation.

Conventional furnace: A furnace rated at about 56% to 78% AFUE. These furnaces use atmospheric burners and exhaust the combustion byproducts up the flue at 350°F to 400°F.

Conventional thermal expansion tank: A thermal expansion tank with no separating device between the air cushion and the water.

Copper: A reddish metal that is durable, yet soft and easily shaped. Also often used in alloy form as brass or bronze.

Copper pipe: A tubular section or hollow cylinder made of copper commonly used for fuel gas systems and has been approved by major code organizations. It is lighter than steel, and when soft copper coils are used, the copper can be bent and routed through tight spaces.

Corrugated stainless steel tubing (CSST): A flexible steel pipe with a plastic covering and is relatively new material used for fuel gas. Like copper, CSST is available in coils and can be bent and routed through tight spaces. In addition, you can actually pull it through a building like you were pulling wire.

Crankcase heater: A heater that keeps the crankcase (the metal casing that encloses the crankshaft in some engines) of the compressor warmer than other parts of the system when the system is turned off.

Crankshaft: A part of a motor that coverts the motor's circular motion into the back and forth motion needed by the pistons.

Cross liquid charge: A type of sensor bulb for a thermostatic expansion valve, which uses a different refrigerant than used in the system. *See also Thermostatic expansion valve.*

Cross vapor charge: A type of sensor bulb for a thermostatic expansion valve, which uses a small amount of liquid different than the type of refrigerant in the system. *See also Thermostatic expansion valve.*

Current relay: A relay that operates at a specified current value rather than at a specified voltage value.

Damp air: Air that has a high relative humidity. *Also called process air.*

DC motor: A direct current motor.

Desiccant: A material that is hygroscopic, which means that it can attract and hold water molecules. Those little bags of silica gel that you find in the box of some new products are examples of a desiccant.

Design heat loss: The amount of heat lost from a building as calculated on the basis of charts showing the normal low outside temperature for the specific locality. *See also Heat loss.*

Design load: The maximum amount of something a system is designed to handle or the maximum amount of something that the system can produce.

Design water temperature: *See Average water temperature.*

Design water temperature drop: *See Water temperature drop.*

Desuperheating: To cool a vapor.

Diaphragm: A thin metal disk, that seals the top of the valve from the bottom of the valve.

Diaphragm expansion tank: A small tank used to protect closed water heating systems and domestic hot water systems from excessive pressure, with a flexible diaphragm separating the water from the air. *Also called Bladder expansion tank.*

Dip tube: A tube that runs to the bottom of the tank so that only liquid can enter. *Also called pickup tube.*

Direct current: A continuous electric current that flows in one direction only.

Direct expansion (DX) evaporator: A type of evaporator which gets refrigerant from the metering device already boiling at the designed temperature. The evaporator is designed to completely boil the entire refrigerant by the time it reaches the end of the coil. *Also called dry-type evaporators.*

Direct return system: A two-pipe system in which the heat emitters are connected to the return pipe in the same order in which they are attached to the supply pipe.

Direct spark ignition (DSI): An ignition device in which the burner is lit directly.

Direct-drive: A system that aligns the motor and compressor end-to-end and connect the shafts with a flexible coupling.

Discus valve: A valve arrangement which allows the piston to travel closer to the cylinder head, thus reducing the amount of refrigerant vapor that remains during discharge and increasing efficiency.

Distill: Boiling a blend of at least two liquids, each with its own boiling point.

Distributor: A small device located at the outlet of an expansion device that distributes refrigerant evenly to numerous refrigeration circuits and blends the liquid/vapor mix so all circuits receive the same mix.

DOE: U.S. Department of Energy.

DOE heating capacity: *See Heating capacity.*

Downfeed system: A system in which the supply pipe is above the heat emitters.

Drip-type humidifier: A humidifier that uses a pad instead of a drum. A hose leads to the top of the pad. A solenoid valve opens when the blower starts to allow a small amount of water to dribble down through the pad. Air that circulates around the pad evaporates water from the pad.

Drum-type humidifier: A humidifier that uses a drum that rotates using a small electric motor. The drum is covered with a sponge-type material and rotates into a reservoir of water that is evaporated when the sponge rotates through the warm air stream.

Duct: A tube, pipe, or channel through which something can flow or be carried, e.g. in air-conditioning equipment.

Duct air tightness: A measurement of an air duct system's resistance to the uncontrolled leakage of air and the water vapor it contains.

Duct board: A foil-faced duct made of 1, 1 ½, or 2 inches of thick fiberglass.

Ductless mini-split: An air conditioning unit that features one or more wall or ceiling mounted evaporator coils connected to a common condensing unit. Often used for retrofit air conditioning in homes without an existing duct system, mini-splits provide a means to locate cooling coils (evaporators) throughout the building without the need to run ductwork.

Ductwork: A system of metal or fiberglass tubes that run through a home or building and that are part of the heating and air conditioning system.

Duty cycle: The length of time specified on a motor's nameplate during which the motor can carry its rating safely. Most often, this is continuous ("Cont").

DX coils: Finned coils which circulate refrigerant.

EDR: Equivalent Direct Radiation

Efficacy: Ratio of light output from a lamp to the electric power it consumes; measured in lumens per watt (LPW).

Electric boiler: A boiler that uses electric heating elements to heat the water.

Electrical current: A measure of the amount of electrical charge transferred per unit time.

Electricity: A fundamental form of energy observable in positive and negative forms that occurs naturally or can be produced and is expressed in terms of the movement and interaction of electrons.

Electromagnetic induction: The process during which a conductor placed in a changing magnetic field (or a conductor moving through a stationary magnetic field) causes the production of a voltage across the conductor.

Electron: A negatively charged subatomic particle.

Electronic expansion valve (EEV): Valves which use electronic controls to monitor the temperature and pressure of the evaporator constantly.

Electronically commuted motor (ECM): A newer motor design that requires 67% less energy than a comparable permanent-split capacitor PSC motor; generally very small and range from fractional HP to about 2 HP.

Emitter: *See Radiation.*

End bells: Devices used to hold the rotor and stator of a motor in position.

Energy: The capacity of a physical system to perform work.

Energy efficiency ratio (EER): Measures energy output divided by energy input.

Energy recovery ventilator (ERV): A type of air-to-air heat exchanger that not only transfers sensible heat but also latent heat. Since both temperature and moisture is transferred, ERVs can be considered total enthalpic devices.

Energy Star program: A program from the EPA to help consumers find high efficiency products. Energy Star ratings are higher than the minimum required ratings for manufacturers.

Enthalpy: A term used to describe the total energy in a system or substance.

Enthalpy wheel: *See Total-energy wheel.*

Equilibrium: The point at which pressure of the vapor molecules in the space above the liquid becomes so great that number of liquid molecules becoming vapor is equal to the number of vapor molecules becoming liquid.

Equivalent Direct Radiation (EDR): A rating system for rating heat emission (output)of cast iron radiators. One square foot of Equivalent Direct Radiation = 240 Btu/h.

Evaporative humidifier: A "cool mist" household appliance that increases humidity (moisture) in a single room or in the entire house, which consists of just a few basic parts: a reservoir, wick and fan.

Evaporator: A coil, inside the house, that does not look like a coil at all. It consists of copper tubing surrounded by aluminum fins.

Fan limit switch: A combination switch that turns the main fan on and off based on the temperature of furnace.

Fill valve: A control the flow of water into the system as it is being filled. A manual bypass may allow for quick filling.

Filter: A device made of or containing a porous material used to collect particles from a liquid or gas passing through it.

Filter-drier: A device installed in a refrigeration system that filters the refrigerant to trap small particles.

Finned tube unit: A radiation emitter, usually used in commercial buildings, which is made up of one or several metal tubes with fins attached to increase heat transfer surface. The tube may be installed with or without a cover.

Finned-tube coil: A type of condenser which uses fins to help cool the refrigerant. The most common air-cooled condensers.

Finned-tube type: A type of direct expansion (DX) coil which uses aluminum fins over copper tubes.

Fins-per-inch (FPI): The ratio of fins in an inch that have been placed on the copper tubes. The spacing of the fins is dependent on the temperature of the coil and the amount of moisture (or frost) that is expected on the coil surface.

Fire tube boiler: A boiler with hot gas tubes immersed in the water to heat the water.

Fixed-orifice metering device: A small, fixed size, device that creates a restriction in the liquid line between the condenser and evaporator. Very common in unitary residential air conditioning and heat pump systems.

Flame rectification: A flame sensing device that converts alternating current (AC) to direct current (DC). This operates on the fact that a flame can conduct electricity.

Flame rollout sensor: A safety device to open if the flame rolls outside of the heat exchanger into the area where the gas valve and wiring are located.

Flame sensing device: A device used to ensure that the flame has actually ignited and do not allow the main gas valve to open until a flame has been established.

Flash boiler: A boiler which has water-filled copper coils surrounded by fire and hot gases.

Flexible duct: A flexible material over a metal wire when used for HVAC. The flexible duct can be insulated, usually with a glass wool with a thin flexible cover over the insulation. It's normally used for short runs, because of greater pressure loss when compared to other types of material. *Also called flex.*

Flooded evaporator: A type of evaporator which is used for heat transfer between air and refrigerant. As heat is absorbed, the refrigerant is boiled and the vapor is drawn off the top.

Flow check valve: A valve to prevent gravity circulation of water when the booster is shut off.

Flow control valve: A valve that prevent unwanted flow from occurring in an "off" zone when another zone is calling for heat.

Forced air heating system: *See Hot air heating system.*

Forced circulation system: A comfort hot water heating system which uses a circulator (booster pump) to circulate the water.

Frame size: An indication of which frame the motor has connected to the housing.

Frequency (Hz): The SI unit of frequency defined as the number of cycles per second of a periodic phenomenon.

Front seated: Position of a service valve that stops the flow of the refrigerant between the compressor and system, but now flows between the compressor and the service port. Also known as the closed position.

Full load amps (FLA): The minimum amount of amp draw the motor can handle at full load.

Furnace: A device that combines a hydrocarbon with oxygen from the atmosphere and has some sort of heat source to start combustion.

Furnace efficiency: A measure of how much heat energy we get out of fuel compared to how much heat energy is actually in the fuel. For example, if a furnace that burned natural gas delivered 800 Btu of heat to the house for every cubic foot of gas it burned, it would be 80% efficient:

$$\frac{800\ Btu}{1000,\ Btu} = 80\%$$

Furnace plenum: A metal box, attached to the furnace, which connects the furnace to the supply side or return side duct work.

Fusible plug: A spot of solder with a specific melting temperature used to seal a hole drilled in the system.

Gallons per minute (gpm): A measure of flow or amount.

Galvanized: Coated with zinc.

Gas manifold: A device that pipe that is connected to the outlet of the gas valve with evenly spaced holes drilled and tapped for mounting the spuds.

Gas regulator: A valve that adjusts the pressure of the gas that feeds the gas valve.

Gas valve: A valve that opens when the thermostat calls for heat, allowing gas to flow to the burners, and is located downstream from the gas regulator.

Global warming potential (GWP): A measure of how much heat a greenhouse gas can trap in the atmosphere.

gpm: Gallons per minute, a measure of flow or amount.

Gravity circulation system: A hot water comfort heating system which uses the difference in the weight of hot water and cold water to create flow due to the force of gravity.

Gross output: *See Heating capacity.*

Ground: A conducting object, such as a wire, that is connected to such a position of zero potential.

HC Refrigerant: Refrigerants that contain hydrogen and carbon. HCs have no fluorine or chlorine. *Also called hydrocarbon refrigerants.*

HCFC refrigerant: Refrigerants that contain hydrochlorofluorocarbons, which are hydrogen (H) in addition to the chlorine (C), fluorine (F), and carbon (C) used in CFC compounds.

Head pressure: *See Pump head.*

Heat: A form of energy associated with the motion of atoms or molecules and capable of being transmitted through solid and fluid media by conduction, through fluid media by convection, and through empty space by radiation.

Heat energy: The capacity to increase the molecular activity of a substance and thereby increase its temperature.

Heat exchanger: A device that transfers energy from the flame and hot combustion products to the air circulated through the furnace by the main fan. It is separated into sections, with one section for each burner.

Heat loss: The rate at which heat is lost from a heated building to the outdoors. Heat loss calculation is based on many factors. Heat loss is measured in Btus per hour (Btu/hs). *Also called calculated heat loss or design heat loss.*

Heat pump: A reversible air conditioner.

Heat recovery ventilator (HRV): A type of air-to-air heat exchanger that is a sensible only device because it can only exchange sensible heat.

Heating capacity: The actual amount of heat available for distribution throughout the piping system to heat the building. Technically, this figure is the amount of heat generated minus the amount of heat lost up the smoke stack/chimney. This term (heating capacity) is used primarily for residential boilers. For larger boilers, this is called output or gross output.

Heating control system: A system of regulating devices used to keep the heating system operating within the prescribed limits (water and combustion limits).

Heating seasonal performance factor (HSPF): Department of Energy's measure of seasonal heating efficiency for heat pumps during the heating season. *Also see heat pump.*

Heating, ventilating, air conditioning, and refrigeration (HVACR) systems: Systems responsible for human comfort within a building.

Hermetic compressor: A compressor that is air tight. Hermetic compressors and their motors are mounted inside a steel shell housing and then the housing is welded tight. In this type of compressor, the motor and compressor are permanently connected to each other with a common shaft.

High efficiency furnace: rated from between 87% and 98.5%. Like mid-efficiency furnaces, high-efficiency furnaces use induced or forced-draft systems. Exhaust gasses from these furnaces have the coolest exhaust gasses of all furnaces, from only 110°F to 120°F.

High efficiency particulate air (HEPA) filter: An air filter that removes 99.97% of all particles greater than 0.3 micrometre from the air that passes through.

High head pressure: A pressure reading that results when the flow of air or water used to cool the condenser is interrupted for some reason. Because the condenser will no longer be able to reject heat, it will not cool the refrigerant.

High limit switch: A flame sensing device designed to shut the furnace down if it gets too hot.

High pressure switch: A switch that turns the system off if the pressure rises too high, so it will open on a rise in pressure.

High temperature refrigeration: Air conditioning system used in the refrigeration industry. High temperature applications cool to temperatures above approximately 45°F, such as a florist cooler or a wine cooler.

Horsepower (HP):

1. A unit of power used to describe machine strength. One horsepower equals 33,000 ft-lbs of work per minute, or 746 watts.
2. On a nameplate, shaft horsepower is a measure of the motor's mechanical output rating, its ability to deliver the torque required for the load at rated speed. It is usually given as "HP" on the nameplate.

Horseshoe magnet: A magnet bent in the shape of a horseshoe.

Hot air heating system: A comfort heating system that transfers heat by moving hot air, by use of a blower, through ducts to points of use and then heats the desired areas by convection. *Also called forced air heating system.*

Hot surface ignition (HSI) system: Replaces spark igniters on either intermittent pilot or direct ignition of the main burner.

Humidifier: A device or machine that keeps the air moist inside an enclosed space.

HVACR: Heating, ventilating, air conditioning, and refrigeration.

Hydrocarbons: Compounds made up of carbon and hydrogen atoms. The fuels we burn are made of hydrogen and carbon.

Hydroscopic: Has an affinity for water.

Hydronic heating system: A comfort heating system which uses a fluid (generally water) to transfer the heat to points of use.

Hydronic specialties: Accessories (valves, air control devices, etc.) which improve the performance of the major components (boiler, emitters, piping) of a hydronic heating system.

Hydronics Institute of GAMA: Organization with information about hydronic heating. The Hydronics Institute is comprised of more than 60 manufacturers of hydronic heat ing equipment. It became of division of the Gas Appliance Manufacturers Association (GAMA) in 1995. Hydronics Institute Division, 35 Russo Place Berkeley Heights, NJ07922. Telephone: 908-464-8200

I=B=R: *See Institute of Boiler and Radiator Manufacturers.*

I=B=R net water rating: *See Net rating.*

Ignition: A heat source, used to start a fire.

Inches of water column (inWC): The measurement of the difference in water column heights in a u-tube manometer. *See also manometer.*

Induction motor: A type of brushless electric motor in which an alternating supply fed to the windings of the stator creates a magnetic field that induces a current in the windings of the rotor.

Inflitration: To gain entrance gradually or surreptitiously.

Input rating: The amount of heat energy from fuel (usually given in Btu/h) put into the boiler.

Inrush current: The initial surge of current into the windings; can be up to ten times higher than the continuously needed current because there is low initial resistance.

Institute of Boiler and Radiator Manufacturers (I=B=R): A function of the Hydronics Institute. I=B=R provides ratings for various hydronic products.

Insulation class: A system developed by NEMA, there are four NEMA insulation classes based thermal endurance of the system for maximum temperature rating purposes. For simplicity, they have been designated by the letters A, B, F, and H.

Intergral-fin condenser: A type of condenser made of copper or aluminum and have fins extruded as part of the tube itself.

Intermittent pilot (IP) systems: An ignition device which uses a spark igniter to light a pilot, which is then used to light the main burner.

Internal load: The sources of heat (and humidity) inside the building.

inWC: *See inches of water column.*

Kinetic energy: Energy that a body possesses by virtue of being in motion.

King valve: A service valve that is mounted on the outlet of a receiver and found downstream from a liquid line receiver. *Also called a liquid line service valve or an isolation valve.*

KVA code: On a nameplate, a letter code defines the locked rotor kVA on a per-hp basis. Generally, the farther the code letter from A, the higher the inrush current per hp. A replacement motor with a "higher" code may require different upstream electrical equipment, such as motor starters.

kW/ton: Kilowatt per ton (12,000 Btu/h) of cooling. Larger commercial and industrial cooling systems (chillers) are commonly rated in this way.

Laminar flow: A flow in which molecules tend to stay in the same place in relation to other molecules. With laminar flow, there is little thermal interaction between molecules of a fluid.

Latent heat: The quantity of heat absorbed or released by a substance undergoing a change of state, such as ice changing to water or water to steam, at constant temperature and pressure. *Also called heat of transformation.*

Law of conservation of energy: Law of physics which states energy cannot be created or destroyed, but may be changed from one form to another.

Light commercial equipment: An air conditioning unitary market sector that serves small businesses and ranges from 65,000 Btu/h up to 135,000 Btu/h (11 1/4 tons) and can be either single-phase or three-phase, although three-phase is more common.

Line port: The port of a service valve where it is connected to one of the refrigeration lines.

Line set: The term for the set of two soft copper coils in standard lengths, typically ranging from 15 to 50 feet that connect the condensing unit to the indoor air conditioning unit. *See also Suction line and Liquid line.*

Line tap valve: A type of Schrader valve that can be soldered in the refrigeration system. *Also commonly called a Saddle valve or Piercing valve. See also Schrader valve.*

Liquid charge bulb: A type of sensor bulb for a thermostatic expansion valve, which uses the same refrigerant than used in the system. *See also Thermostatic expansion valve.*

Liquid flame sensor: A flame sensor with a bulb filled with a liquid. When the flame goes out, the liquid in the bulb cools and contracts, opening the contacts at the diaphragm, and the gas valve closes.

Liquid line: A smaller tube in the Line set is usually 3/8 inches in diameter and carries liquid refrigerant from the discharge side of the condenser to the metering device located inside next to the evaporator. Sometimes the liquid line is insulated.

Liquid slug: Any liquid in a reciprocating compressor that enters during intake and has no place to go.

Liquid-line filter-drier: A filter containing a desiccant capable of removing moisture and other dissolved contaminants in the refrigerant stream.

Liquefied petroleum gas (LPG): A general term used to describe several liquid mixtures of propene, propane, and butane. One of the two most common fuels used for gas furnaces. *Also referred to as LPG, GPL, LP gas, liquid petroleum gas, or propane.*

Loads: The amount of heat that must be added or removed in an hour to maintain a comfortable room temperature.

Locked rotor: A rotor that is at a standstill.

Locked rotor KVA code (KVA code): When AC motors start, they require more power than when they are running at full speed, just as your car requires more power to accelerate away from a light than it does to cruise down the highway.

Locked rotor amps (LRA): The torque that a motor produces when full power is supplied to the motor and the rotor is not yet moving.

Low temperature refrigeration: A system cools to below the freezing temperature of water (32°F). Most low temperature systems operate at temperatures well below 32°F. In commercial applications, frozen food should not be stored above 0°F.

Low pressure switch: Turns a system off if the pressure drops too much, so it will open on a drop in pressure.

Low-ambient fan control: A pressure switch used to start and stop the condenser fan motor depending on the pressure in the condenser.

LP gas: *See Liquefied petroleum gas.*

Magnetic field: A field of force surrounding a permanent magnet or a moving charged particle, in which another permanent magnet or moving charge experiences a force.

Magnetic flux lines: Lines of force associated with a magnetic field.

Magnetic overload device: A type of overload relay that senses the strength of the magnetic field that the current flow produces. Magnetic relays are often used in areas that experience extreme changes in temperature.

Main: The large pipe in a piping system that feeds other smaller circuit pipes or risers.

Mainless system: *See Series loop system.*

Mandrel: A tool used to shape a copper tube.

Manometer: An instrument used to measure pressure

Maximum ambient temperature (MAX AB): Greatest ambient temperature or the temperature of the air surrounding the motor or the room temperature in the vicinity of the motor. This is the "threshold point" or temperature that the entire motor would assume when it is shut off and completely cool.

MBH: Thousand Btus per hour. One MBH = 1000 BTUH.

MBH to Btu/h: Multiply MBH X 1000. (Move decimal in the MBH 3 places to the right) For example, 125 MBH = 125,000 Btu/h.

Medium temperature refrigeration: A system that cools to temperatures from above the freezing point of water (32°F) to about 45°F. Most refrigerated foods are kept in medium temperature applications, such as a refrigerator, at temperatures ranging from just above freezing (34 - 35°F) to no more than about 38°F.

MERV: *SEE* Minimum Efficiency Reporting Value

Metering device: A device that measures and records the quantity or flow of the refrigerant.

Methanethiol: A colorless gas with a smell like rotten cabbage. *Also known as methyl mercaptan.*

Microchannel condenser: A type of condenser used in automotive and aviation applications because they are very light. They are made of flattened aluminum tubes with aluminum fins zigzagging between tubes.

Micron (µm): A unit of linear measurement equivalent to one-millionth of a meter.

Microparticle Performance Rating (MPR): System used to demonstrate a filter's ability to capture the smallest airborne particles—from 0.3 to 1 micron in size from the air passing through the filter. The higher the MPR, the better the filter's ability to capture particles from the air as it passes through the filter.

Mid-efficiency furnace: rated 80% to 83% AFUE. These will typically use induced or forced-draft systems. You can tell these furnaces are more efficient because they exhaust the combustion byproducts at cooler temperatures (275°F to 300°F) than conventional furnaces.

Milinch: A measure of pressure or pressure drop. One milinch is equal to the pressure produced by 0.001 (1/1000) of an inch of water. One milinch = pressure of 1/1000 inch of water or 12,000 milinches = pressure produced by one foot (12 inches) of water.

Mineral oil: An oil that includes any of various light hydrocarbon oils, especially a distillate of petroleum that has been used in systems with CFCs, HCFCs, and ammonia refrigerants for many years.

Minimum Efficiency Reporting Value (MERV): Standard method for comparing the efficiency of an air filter. The higher the MERV rating, the better the filter is at removing particles from the air.

Miscibility: When the refrigerant and oil mix well and remain mixed over the range of temperatures and pressures in the system.

Mobile home furnace: *See Conventional furnace.*

Molecule: The smallest physical unit of a substance that can exist independently, consisting of one or more atoms held together by chemical forces.

Monoflo fittings: *See One-pipe fittings.*

Monoflo system: *See One-pipe system.*

Motor frame: Dimensions set for electric induction motors based on size and construction of the motor; standards set by National electrical Manufacturers Association (NEMA).

Motor starter: A manual switch with overload protection used to provide control to a motor.

MPR: *See Microparticle Performance Rating*

Multiple circuit system: A piping system that uses more than one complete loop to connect emitters and boiler. (*NOT* the same as a zoned system.)

Nameplate: A manufacturer's description on a motor listing specific information about the motor's characteristics.

Natatorium: An indoor swimming pool.

National Refrigeration Safety Code: Classifies refrigerants into three groups based on safety requirements.

Natural gas: One of the two most common fuels used for gas furnaces. Since it is supplied to the building in an underground pipe, natural gas is the most convenient fuel available.

Natural refrigerant: A naturally occurring substance, such as hydrocarbons, carbon dioxide, ammonia, water and air.

Negative (-): In electricity, negatively charged substances are repelled from negative and attracted to positive. An object will be negatively charged if it has an excess of electrons, and otherwise be positively charged or uncharged.

Net rating: The amount of heat available for radiation after theoretical allowances are made for heat lost in piping and in pickup from cold starts. The net rating is used for residential boiler selection. *Also called Net water rating or I=B=R net water rating.*

Normal: The term for the de-energized position of the contacts when the relay is new.

Normally closed (NC): The term to describe when the contacts are held together or closed.

Normally open (NO): The term to describe when the contacts are held apart or open. An NO contact symbol has parallel lines showing an open connection.

Nucleus: The positively charged central region of an atom, composed of protons and neutrons and containing almost all of the mass of the atom.

Oil pressure safety control: A pressure switch that senses the difference in pressure between the intake and discharge of the oil pump, and shuts the compressor off if the pressure differential falls below a set value, usually 10 psi. Because these switches have to sense pressure in two locations, they will have two pickups instead of one.

Oil separator: An oil tank just downstream from the compressor.

One-pipe fittings: Special tee fittings which divert part of the water from the main into the risers on a one-pipe system. *Sometimes called monoflo fittings.*

One-pipe system: A piping system using one continuous pipe (or main) making up both the supply and return pipe, with emitters connected to the main by vertical risers. *Sometimes called a monoflo system.*

One-time relief valve: Fusible plugs, which are temperature-operated. A fusible plug is simply a spot of solder with a specific melting temperature used to seal a hole drilled in the system.

Open drive configuration: A compressor in which the motor and compressor are separated and independent of each other. Both are fully serviceable, and one can be replaced without having to replace the other.

Organic fluoride: A compound containing fluoride and carbon.

Orifice: A precisely drilled hole in a small part called an orifice spud. *See also orifice spud.*

Orifice spud: A small part that threads into the gas manifold and meters the fuel gas to the burners. Each burner has its own spud, and each spud must be changed when converting from one fuel to another.

Output: *See Heating capacity.*

Ozone depletion potential (ODP): A measure of how badly a chemical compound can damage the earth's ozone layer located in the stratosphere.

Packaged boiler: A boiler that is preassembled by the manufacturer with burner, circulator, and controls, and is ready for hookup to piping, fuel line, and wiring.

Packaged equipment: An air conditioning unit that comes as one piece with a full charge of refrigerant and all connections made at the factory.

Packaged terminal air conditioner (PTAC): Similar to a window air conditioner, except these are designed to be semi-permanently or permanently installed through the wall, typically through a sleeve. Capacities can be larger than window units. *Also known as room air conditioners or through-the-wall air conditioners.*

Packing gland: The space around a valve stem as it rises out of the top part of the valve, which is called the valve bonnet, that holds the packing in place.

Peak cooling load: The total amount of heat energy that must be removed from a system by a cooling mechanism in a unit time, equal to the rate at which heat is generated by people, machinery, and processes, plus the net flow of heat into the system not associated with the cooling machinery.

Peak heating load: The total amount of heat energy that must be added from a system by a heating mechanism in a unit time.

Permanent magnet: An object from a magnetized material that creates its own persistent magnetic field, such as a refrigerator magnet.

Permanent split-capacitor start (PSC) motor: A motor commonly consisting of two basic parts, an outside stationary stator having coils supplied with alternating current to produce a rotating magnetic field, and an inside rotor attached to the output shaft that is given a torque by the rotating field.

Pex tubing: Cross-linked polyethylene tubing.

Phase: On a nameplate, "phase" represents the number of ac power lines supplying the motor. Single and three-phase are the norms.

Piercing valve: *See Schrader valve.*

Piping layout: A scale drawing showing the location of the boiler, emitters, and piping system.

Piping system: The combination of supply pipe (which takes heated water from the boiler) and the return pipe (which returns cooled water to the boiler) and the various associated fittings and valves attached to these pipes.

Piston: The moving component that moves back and forth (or up and down) inside the cylinders and draws in the refrigerant vapor through the suction port when the connecting rod pulls the piston down to expand the volume in the cylinder.

Plain bearings: Type of bearing with no spinning parts. They are the simplest type of bearing. Plain bearings are pressed into place to prevent them from spinning, or are provided with some other method to prevent spinning, such as small tabs that fit into small slots.

Plate heat exchangers: A way to dissipate heat by having one fluid flows between every other plate, while the other flows in the alternate spaces. Large surfaces for heat transfer exist on the plates, and a large number of plates can be positioned in a small area. The plates are stamped (embossed) into a corrugated pattern to increase surface area even more and to promote turbulent flow.

Plenum: *See Furnace plenum.*

Plenum-mount humidifier: A humidifier designed to mount to the side of the furnace plenum.

Polyalkylene glycols (PAGs): Lubricant used with R-134a in automotive systems, and absorbed by water.

Polyolesters (POEs): Lubricant used in systems containing HFCs. They contain no wax, performing better in low temperature systems.

Positive (+): In electricity, positively charged substances are repelled from other positively charged substances, but attracted to negatively charged substances.

Potential energy: The energy possessed by a body by virtue of its position relative to others, stresses within itself, electric charge, and other factors.

Potential relay: A switching component used to take start capacitors or start windings out of the circuit as the motor comes up to speed.

Pounds per square inch (psi): A measure of pressure or weight.

Pounds per square inch gage (psig): An expression of pressure in relation to atmospheric pressure.

Power: The rate at which energy is transferred, used, or transformed.

Power humidifier: A humidifier with its own blower and fan to circulate and supply air to the air distribution system.

Precharged: A state that exists when a line set already contains refrigerant.

Pressure: Force applied uniformly over a surface, measured as force per unit of area.

Pressure drop: The friction-caused loss of pressure between any two points in the piping system. Measured in milinches per foot of pipe, or in feet of water.(12,000 milinches = 1 foot).

Pressure loss(es): A state that occurs whenever there is friction or turbulence.

Pressure reducing valve: A valve designed to reduce the pressure of water coming into the system if the incoming water is under greater pressure than the water already in the system.

Pressure relief valve: *See Safety relief valve.*

Pressure switch: A diaphragm inside the heater that closes contacts when the fan is on. If the pressure switch does not "make" (turn on), then the furnace will not light.

Pressure-type lubrication system: A lubrication system that uses an oil pump much like an automotive engine. Oil drains to the low point of the compressor where it is picked up and pumped throughout the compressor to lubricate all parts. Splash systems require oil levels high enough for the crankshaft to reach, while pressure systems require the extra components for pumping and distributing oil.

Propane: *See Liquefied petroleum gas.*

Protective cap: A removable cover that protects the sensitive valve internal's from dust, dirt, and humidity. If valve caps are lost, they should be replaced immediately in order to avoid expensive damage later. A service technician has to unscrew the cap before the valve can be turned.

psi: Abbreviation for pounds per square inch, which is a measure of pressure or weight.

psig: Abbreviation for pounds per square inch gage, which expresses pressure in relation to atmospheric pressure.

Pump: *See Circulator.*

Pump capacity: The number of gallons per minute (gpm) a pump can move.

Pump curve: A graph/chart showing the relationship between the amount of water (capacity in gpm or gph) a pump can move and the amount of pressure (head) pump can develop. *Also called a pump performance curve.*

Pump down: A process that pumps all the refrigerant to the receiver and traps it there.

Pump head: The amount of pressure a pump can develop to move water against the resistance (friction) caused by the passage of water through piping or tubing. Pump head is usually measured in feet of water. Sometimes called head or head pressure.

R-values: A measure of insulation's ability to resist heat traveling through it. The higher the R-value, the less heat will be gained or lost.

Radial load: The type of force that motors and pulleys put on bearings; a spinning load.

Radiant floor heating: A radiant panel system that uses flexible tubing under the floor to carry the hot water and produce radiant heating in the room above.

Radiant heating system: A heating system that depends upon the use of invisible heat rays which travel from the heat source to human body.

Radiant Panel Association: Organization providing information about radiant panel heating. Radiant Panel Association, PO Box 717, Loveland, CO 80539. Telephone:1-800-660-7187

Radiant panel system: A heating system that circulates the hot water through a series of flexible tubes or coils embedded in (or attached under) the floor or ceiling.

Radiation:
1. A heat transfer without the use of molecules Fire transfers heat by means of heat rays (or heat waves) through this process.
2. Output devices (often called emitters) used to transfer heat from the water into the rooms to be heated.

Radiation load calculation: Calculated energy from the sun that has been accounted for in a system.

Radiation outlet devices: Devices in the rooms that release heat, that was carried by the water, into the room.

Receiver: A container to store refrigerant within the closed refrigeration system.

Reciprocating compressor: A compressor that uses pistons and cylinders to compress refrigerant vapor by moving a piston back and forth. ("Reciprocate" means to move back and forth.)

Redundant valves: *See Automatic combination gas valves (ACGV)*

Reed valve: A type of check valve in the openings at the top of a compressor. One is for suction and the other is for discharge. *Also called ring valves or flapper valves.*

Refrigerant: A body or substance that acts as a cooling medium by extracting heat from another body or substance.

Refrigerant blend: The result of mixing two or more refrigerants together to create a new refrigerant.

Refrigeration cycle: A fixed supply of refrigerant in a closed system is continuously circulating, evaporating, and condensing. *Also called vapor compression cycle, in this course.*

Regulator: *See Metering device.*

Relay: An electrically operated switch.

Relief valve: A valve used in refrigeration systems to relieve the pressure within system if the pressure or temperature gets too high.

Replacement refrigerant: A new refrigerant that is used in equipment in place of a refrigerant that has been phased out. Some HCFCs are used as retrofit or replacement refrigerants for CFCs, but due to be phased out and will soon need to be retrofitted and replaced themselves.

Residential system: An air conditioning unitary market sector that uses single-phase electricity (usually 220 volts for the condensing unit and 110 volts for the inside unit) and have cooling capacities of 65,000 Btu/h (about 5 ½ tons) or less.

Retrofit refrigerant: A process used to change out an existing system. The old refrigerant is recovered, the system is modified as needed, and then charged with the retrofit refrigerant.

Return pipe: The pipe that returns cooled water to the boiler from the radiation.

Reverse return system: A two-pipe system in which emitters are connected to the return main in reverse order from the way they are connected to the supply main.

Ribbon burner: A burner designed to deliver a solid flame from one end to the other.

Ring valve: A valve circular in shape and are held closed with a spring. When the pressure caused by the piston moving back and forth becomes greater than the spring pressure, the ring valve opens and allows refrigerant vapor to flow.

Risers: Small vertical pipes that connect radiation emitters (baseboard or convectors) to a main in a one- or two-pipe system.

Roller bearings: A bearing that uses some sort of round shape between two loads. The most common and cheapest roller bearing is the ball bearing. The balls are held in place by inner and outer races, rings with a round groove in it. The groove contains the balls and provides a path for them to move. The outer race has the groove on its inside diameter.

Rooftop unit (RTU): Self-contained packaged air conditioning units are mounted to a roof curb and connected to ducting to distribute air. An electrical connection is also required, as well as gas-piping if equipped with burners for heating.

Rotary compressor: Compress refrigerant using some type of rotating mechanism. They offer smoother operation than reciprocating compressors because they don't have parts going back and forth like reciprocating do.

Rotary-vane compressor: A compressor in which a number of spring-loaded vanes mounted to the rotating piston. This provides multiple compression strokes per revolution.

Rotor: A rotating part of an electrical or mechanical device.

Rotor coil: The rotating armature of a motor or generator.

Saddle valve: *See Line tap valve.*

Safety relief valve: A valve on a boiler that will open to prevent buildup of excess pressure. *Also called a pressure relief valve.*

Saturated: In chemistry, holding as much water or moisture as can be absorbed; soaked.

Schrader valve: A valve that allows a technician to connect a gauge manifold to the system. The core is depressed when the gauge manifold is connected to allow refrigerant or oil to flow into or out of the system.

Screw compressor: A compressor in which use single or twin-screw design forcing a certain volume of refrigerant vapor will be compressed with each cycle of the compressor. *Also called rotary screw compressors.*

Scroll compressor: A compressor type that uses two mating spiral-shaped scrolls. One scroll remains stationary, while the other scroll moves in an orbital motion (oscillates). Note that the motion of the moving scroll is not circular—it does not spin. Rather, it orbits within and around the stationary scroll.

Seal: A tight closure used where the shaft penetrates the casing to hold refrigerant inside the compressor while shaft spins. The seal has a surface that rubs against the shaft to prevent leaks into or out of the compressor.

Sealed heat exchanger: A heat exchange that has burners located at the top. Systems that use sealed heat exchangers cool the exhaust gasses so much that the water vapor condenses.

Seasonal energy efficiency ratio (SEER): Estimates how efficient a piece of equipment will operate over an entire cooling season. SEER is based on a formula defined by the U.S. Department of Energy for residential air conditioning systems of less than 65,000 Btu/h (5.42 tons).

Semi-hermetic compressor: A compressor that is bolted together rather than welded together. *Also called a serviceable hermetic compressor.*

Sensible heat: The heat absorbed or transmitted by a substance during a change of temperature which is not accompanied by a change of state; in contrast to latent heat.

Sensible heat ratio (SHR): The ratio of sensible load to total load. In other words, it tells us how much work the coil will have to do to cool the air as compared to the total work it will have to do.

Series loop piping system: A piping system using a continuous pipe loop with the water passing through the supply pipe, each emitter in series, the return pipe, and back to boiler.

Service factor: On a nameplate, service factor is required on a nameplate only if it is higher than 1.0. Industry standard service factor includes 1.15 for open-type motors and 1.0 for totally-enclosed-type motors. However, service factors of 1.25, 1.4, and higher exist.

Service valve: A valve that allows access to the inside of a refrigeration system, and has three valve ports and two valve seats.

Setpoint: A temperature in which the building has been set to warm up or cool off to.

Shaded-pole motor: A single-phase motor that is 1/20 HP or less and is used in devices requiring low torque.

Sheave: A wheel or pulley with a groove in it for a belt, rope, or cable.

Sight glass: A transparent tube through which the technician can observe the refrigerant flowing within, mainly to check if there is any water in the system.

Silica gel: A granular, vitreous, porous form of silicon dioxide made synthetically from sodium silicate.

Sine curve: The graph of sine function; the equation $y = \sin x$.

Sine wave: A mathematical curve that describes a smooth repetitive oscillation or swing between two points.

Single screw compressor: A compressor that use a main rotor with a helical (spiral) groove, similar to the thread of a wood screw, along with one or two "gate rotors." One end of the screw is open to the intake port, while the other is open to the discharge port.

Single-phase electric motor: A type of motor with low horsepower that operates on 120 or 240 volts; often used in residential appliances such as washing machines and air conditioners.

Single-port burner: A type of burner that is much shorter and does not extend into the heat exchanger. Instead, are mounted at the opening of the heat exchanger and the flame is pulled in using an induced-draft fan.

Slotted burner: A burner that has a series of slots from one to the other.

Solar gain: Refers to the increase in temperature in a space, object, or structure that results from solar radiation. The amount of solar gain increases with the strength of the sun, and with the ability of any intervening material to transmit or resist the radiation.

Solenoid valve: An automatic valve that is operated by an electromagnet that either opens or closes the valve.

Specific heat: A measure of the amount of energy required to warm or cool one pound of a material one degree Fahrenheit.

Speed, in revolutions per minute: A measure of the frequency of a rotation.

Splash-type lubrication system: A lubrication system that houses oil in the lower part of the compressor housing called the crankcase. As the compressor runs, the crankshaft splashes through the oil.

Split-phase motor: A single-phase motor that consists of a running winding, starting winding, and centrifugal switch. The reactance difference in the windings creates separate phases, which produce the rotating magnetic field that starts the rotor.

Split-system: Unitary systems delivered in more than one factory-assembled component. A typical central air conditioning system for a home is an example of a split-system. Residential split-systems consist of two parts: the condensing unit, which houses the compressor and condenser, and the indoor unit, which includes the evaporator and metering device.

Spontaneous combustion: The bursting into flame of a mass of material as a result of chemical reactions within the substance, without the addition of heat from an external source.

Spring-loaded relief valve: A relief valve that operates on pressure. When system pressure overcomes the tension of the spring, the valve opens to vent refrigerant until the spring pressure is stronger than the system pressure.

Squirrel-cage motor: A motor that uses a rotor shaped like a wheel in a hamster cage.

Stack effect: Flow of air resulting from warm air rising, creating a positive pressure area at the top of a building and negative pressure area at the bottom.

Standing pilot: A pilot light that always burns.

Start capacitor: A single-phase motor with a capacitor. The capacitor gives the motor more starting torque.

Static pressure: The amount of pressure (measured in feet of water) created by the weight of the water in the vertical pipes of the system.

Stator: The stationary part of a motor, dynamo, turbine, or other working machine about which a rotor turns.

Stator coil: A mechanical device consisting of the stationary part of a motor or generator in or around which the rotor revolves.

Steam humidifier: A humidifier that injects steam directly into the airstream.

Stepper motor: A motor that is part of an electronic expansion valve, and can operate at approximately 200 steps per second. They typically have over 1,500 steps between fully open and fully closed.

Subcooling: The process of cooling a liquid below its boiling point.

Suction line: A larger tube (usually 3/4, 7/8, or 1 1/8 inches in diameter) that carries refrigerant vapor from the evaporator (located inside) to the suction side of the compressor (located outside). The suction line is always insulated. *Part of the Line set.*

Suction-line filter-drier: A manufactured device used in the suction line of a system, whose element is partly or wholly composed of a desiccant and intended to remove and retain moisture as well as solid contaminants from the refrigerant.

Suction manifold: The horizontal copper tube which connects the multiple tubes of a coil.

Superheated vapor: When a gas has warmed above its boiling point.

Supply pipe: The pipe that supplies hot water from the boiler to the radiation.

Surface area: The sum of all the areas of all the shapes that cover the surface of the object.

Synthetic oil: Oil investigated to overcome the limited solubility of some refrigerants in mineral oils.

Temperature: The degree of hotness or coldness of a body or environment.

Temperature glide: A change in the boiling temperature at constant pressure, which occurs when one or more of the refrigerants in the blend changes phase faster than the rest.

Terminal device: *See Radiation outlet device.*

TEV: *See Thermostatic expansion valve.*

Thermal expansion tank: A tank used to hold extra water as the heated water expands and to maintain desired system pressure. *Also called an expansion tank or a compression tank. See Conventional tank; Diaphragm tank.*

Thermal mass: A dense concrete-like material poured as a sub-floor or a finished floor when using radiant floor heating. The thermal mass stores heat, distributes heat between the tubes or coils, and transfers the heat to the surface of the floor.

Thermally activated (temperature-sensing) device: External devices intended to protect motors, controllers, and branch-circuit conductors against excessive heating due to prolonged motor overcurrents up to and including locked rotor currents.

Thermocouple: A sensor that is used to sense when a flame is burning.

Thermopile: Several thermocouples wired together to increase voltage.

Thermostatic expansion valve: A modulating type of metering device. This means that it can adjust itself to varying conditions, making it a superior metering device.

Three-phase motor: A motor with a continuous series of three overlapping AC cycles offset by 120 degrees; used for all large AC motors and is the standard power supply that enters homes and factories.

Throw: The eccentric bearing surfaces of the crankshaft in which has been machined into them where the piston connecting rod is attached.

Thrust load: The type of force that tries to pull a bearing off a shaft or push it further onto the shaft.

Tip speed: Refers to the speed at the outer diameter of the impeller.

Tons: A unit of measure in the United States equal to 907 kg or 2,000 lb A ton of cooling is based on the cooling effect due to melting one ton of ice in a 24-hour period.

Total load: The sum of the sensible and latent heat load for the coil.

Total pressure: The sum of static and velocity pressure.

Total-energy wheel: A type of desiccant dehumidifier is used to transfer both heat and moisture from outdoor air brought into a building for ventilation, to an exhaust airstream that is vented to the outside. *Also called enthalpy wheel.*

Tubular heat exchanger: Bent pieces of pipe through which the hot combustion gasses flow. Clamshell heat exchangers have an inherent weak point at the seams. This weak point is eliminated with the tubular heat exchanger. Tubular heat exchangers are commonly used in conjunction with inshot burners and induced-draft blowers. There is one tube for each burner, and burners are typically located at the bottom of the heat exchanger.

Twin-screw compressor: Type of compressor that uses two main rotors. The rotors are designed in "mating" pairs. One rotor is machined with helical (spiral) lobes (like a thread) and is called the male rotor. The other is machined with grooves or flutes (similar to a drill bit) and is called the female rotor. The pair is "mated" by machining the shape of lobes of the male rotor to fit exactly into shape of the grooves in the female rotor. *Also called double helical rotary screw compressors or twin helical screws.*

Two-pipe system: A system that has one pipe as a supply main and a separate pipe for a return main.

TXV: *See Thermostatic expansion valve.*

Type B vent: *See B vent.*

U-tube manometer: *See Manometer.*

Ultra low penetration air (ULPA) filter: A filter that can remove from the air at least 99.999% of dust, pollen, mold, bacteria and any airborne particles with a size of 120 nanometres (0.12 micron) or larger.

Under-duct humidifier: A humidifier in which a hole is cut into the bottom of the duct and these are mounted to the bottom of the duct so that the wetted media extends into the duct.

Unitary air conditioner: An air conditioner that contains an evaporator (cooling coil), a compressor, and a condenser. Often, unitary equipment also provides heating using fossil-fuel burners (natural gas or propane) or electric resistance coils.

Upfeed system: A system in which the supply pipe is below the emitters.

Valve: A mechanical device used to control flow media.

Valve body: The outer casing of most or all the valve that contains the internal parts or the "guts" of the valve.

Valve disc: The part of the valve that rests against the valve seat (sometimes referred to as boss). There are many valve designs, but service valves used in refrigeration systems use a valve disc and two valve seats to control flow, so we introduce you to that type of valve here. It may help you to think of the valve seat as a hole in a valve and a valve disc as the plug used to prevent flow through the hole.

Valve packing: The deformable sealing material inserted into a valve stuffing box which, when compressed by the gland, provides a tight seal about the stem.

Valve plate: A device located below the cylinder head and the compressor housing. It holds both the suction and discharge valves. Bolts passing from the head, through the valve plate and into the compressor housing hold everything in place. Gaskets on both sides of the valve plate seal the refrigerant vapor inside the compressor.

Valve port: An opening in the valve closure member which permits flow through the valve.

Valve seat: The mating surface in the valve assembly that permits tight closure. If the valve seat or the valve is damaged, the valve will leak no matter how much it is tightened.

Valve stem: The rod or shaft transmitting motion from an operator (handwheel or gear operator) to the closure element of the valve. The valve disc is attached to the valve stem and moves up and down as you turn the valve stem.

Vane: A flat blade that moves in motion. A windmill sail is an example of a vane. Is spring loaded and moves up and down as the piston rotates to separate the suction gas from the compressed gas.

Vapor charge: A type of sensor bulb for a thermostatic expansion valve, which uses only a small amount of liquid refrigerant, so that at certain times during operation, all of the liquid will be vaporized. *See also Thermostatic expansion valve.*

Vapor compression cycle: *See Refrigeration cycle.*

Vapor pressure: The pressure exerted on a vapor in a closed system.

Variable-refrigerant-flow (VRF) heat pump: Relatively recent to the market, pumps similar to mini-split systems in that multiple indoor *DX COILS* are supplied by a single condensing unit. VRF heat pumps and mini-split systems differ in the number of coils that can be connected. Where mini-splits are typically limited to a small number of zones, 30 or more indoor DX coils can be supplied with refrigerant from a single condensing unit. Furthermore, these systems can heat and cool simultaneously by using hot refrigerant gas in some coils while cold refrigerant circulates to others. *See also DX coils.*

Velocity pressure: Is pressure resulting from some medium in motion, such as the air following the shock front of a blast wave.

Ventilate: To provide a room or other enclosed space with fresh air or a current of air.

Ventilation: Bringing fresh air into a building using a fan.

Venturi: A short tube that narrows which is used to determine different velocity, pressures and total pressure.

Voltage: An electromotive force or potential difference expressed in volts.

Water column pressure: The difference in height between the two columns, in the manometer.

Water temperature drop: The difference between the temperature of the water leaving the boiler and the temperature of the water returning to the boiler. The temperature is chosen as part of the design of the system, so it is sometimes called the design water temperature drop.

Water tube boiler: A boiler containing a fire pot with water tubes running through it to heat the water.

Water-source heat pump (WSHP): Pumps that operate like the air-source heat pump, except water is used as a heat source for heating and a heat sink for cooling. The water source can be a lake, stream, well, or close-loop arrangement coupled with the earth.

Watt: An International System unit of power equal to one joule per second.

Wind speed: The rate at which air is moving horizontally past a given point.

Window air-conditioner: A device designed to install through an open window, these units feature a partition that separates the inside unit from the outside unit. The inside unit contains the evaporator, while the condenser and compressor are housed outside the partition. Some provide heating as well, typically using electric resistance heat.

Wired in series: A term that means the current that flows through one device also flows through another.

Wound-rotor motor: A type of three phase rotor that contains windings and slip rings, which permits control of rotor current by connecting external resistance in series with the rotor windings.

Z-Vent: A vent usually made of flexible stainless steel or aluminum pipe, but rigid systems are also available.

Zeotrope mixture: Blends of refrigerants that have various boiling points for a given pressure. *Also called Zeotropic mixture.*

Zone: A section of the piping system which is regulated by a separate zone thermostat and controlled by zone valves.

Zone pump: An integral part of any hydronic system. Pumps are used to send water to an area of the hydronic system when it is called for, or to keep the flow of water in the system.

Zone valve: A valve, operated by thermostats, to control flow in individualized section (zones) of a zoned system.

Zoned system: A heating system that uses two or more thermostats to control the heat in several section (zones) of the system independently.

Zoning: The practice of heating and cooling areas within a structure separately.

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