# Refrigeration and Heat Transfer

- *Heat Transfer*
- *Basic Refrigeration Principles*
- *Refrigeration System Components*
- *Refrigeration Cooling Cycle*
- *Refrigeration Heating Cycle*



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# PREFACE

The purpose of this publication is to explain the fundamental concepts of heat transfer and refrigeration in simple, everyday terms. Explanations are general in nature and are not intended as a course in thermodynamics.

The refrigeration circuits described are basic and do not cover wide variations in design of air conditioning equipment. Modern refrigeration circuits contain some components that are not described here. Operating pressures in actual systems vary greatly depending upon efficiencies, cost and the purpose for which a particular design is intended.

The necessity for understanding basic principles cannot be overstated.

Note: This publication is general in nature and is intended for INSTRUCTIONAL PURPOSES ONLY. It is not to be used for equipment selection, application, installation, or specific service procedures.

# TABLE OF CONTENTS

## HEAT TRANSFER

Heat is a form of energy. Heat energy cannot be created nor destroyed, but can be transferred from one substance to another substance.

Heat energy can be produced by changing mechanical, electrical or chemical energy into heat.

All substances contain heat until the temperature of the substance is reduced to 460° Fahrenheit below zero. At this temperature molecular motion and heat ceases to exist and is referred to as absolute zero. Man cannot create a machine that will reduce a substance to absolute zero; therefore, every substance contains some heat.

Every day we refer to substances as hot, warm or cold. What we really mean is that some substances contain more heat than others. For example, we may refer to a block of ice as cold and a block of red glowing metal as hot, but both contain heat.

Cold may be defined as a lesser amount of heat than a substance that contains more heat just as darkness could be defined as a lesser amount of light.

**Temperature is the intensity of heat in a substance.** Many different scales and methods have been used for measuring temperature. The most familiar scale to most of us is the Fahrenheit scale that is based on water freezing at 32°F. and boiling at 212°F. at sea level pressure.

With the increased use of the metric system we must also consider the Celsius (formerly Centigrade) scale. This scale is based on water freezing at 0°C and boiling at 100°C at sea level pressure. Figure 1 illustrates Fahrenheit, Celsius and Absolute temperature scales.

This publication will use the Fahrenheit scale throughout the text.

Temperature is an important factor in the study of heat transfer since heat will transfer or move from a warm substance to a colder substance only. The rate or amount of heat transfer depends upon the temperature difference in the substances, the distance separating them and the medium through which the heat is to be transferred.

Heat may be transferred by three basic methods: conduction, convection and radiation. All three methods are utilized in air conditioning and heating.

**Conduction** is most often associated with solid substances such as walls, glass, refrigerant coils and other solid bodies. For example, in the cold wintertime heat will flow through a wall from the warm interior of a house to the colder outside temperature. The greater the temperature difference across the wall, the faster heat will flow. This conduction is referred to as the heat loss of that particular wall.

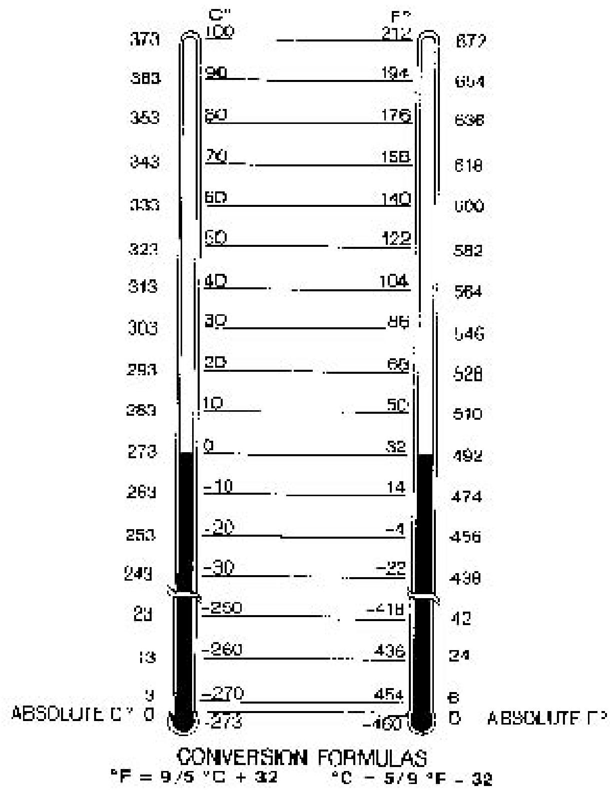


FIG. 1 — TEMPERATURE SCALES

Conduction of heat through a wall or other surface is referred to as the "U" factor of the surface. "U", or **conductance of a surface is equal to the number of BTU per hour that will travel through one square foot of the surface per °F. difference across the surface.**

In the summer when the outdoor temperature is higher than the indoor temperature, the wall or other surfaces conduct in the opposite direction and result in a heat gain or heat increase within the structure. The conduction or "U" factor is the same for heat loss or heat gain.

Since heat loss and heat gain are both undesirable losses, insulation is used to reduce these losses. The term "R" factor or "R" value is used to designate the resistance to conduction of heat through walls and other surfaces. **The "R" value of insulation and wall surfaces is defined as the temperature difference across a wall or other surface required for 1 BTU to travel through one square foot of the surface in one hour.** For example, an insulating material rated at R-20 will permit 1 BTU to travel through one square foot of the surface in one hour when the temperature difference across the surface is 20°F.

An insulating material rated at R-40 will permit exactly one half the conduction as R-20 through the same surface at the same temperature differential.

When the R value of builiding materials such as brick, concrete, dry wall, plaster, glass, insulation, and other construction material is known, and each material's square foot area is known, the heat loss and heat gain of the structure can be accurately calculated at design temperature differences and equipment selected to properly heat and cool the structure.

Each area of the country uses specific design temperatures based on average U.S. Weather Bureau data for winter and summer. Figure 2 illustrates heat transfer by conduction.

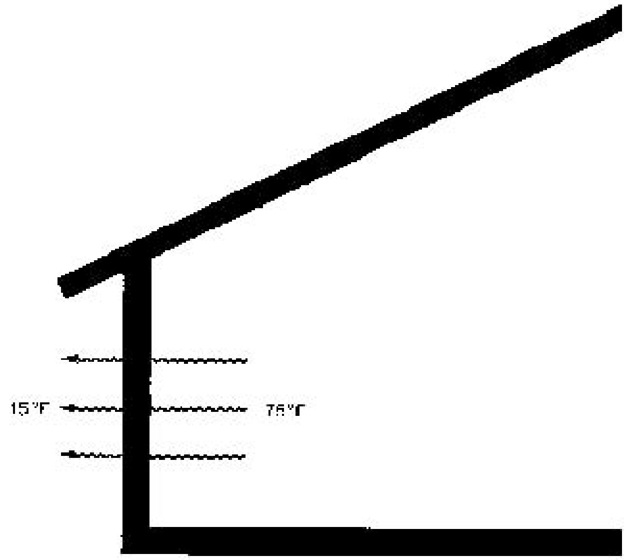


FIG. 2 — HEAT TRANSFER BY CONDUCTION

**Convection** is heat transfer caused by air contacting a warmer substance. The heated air rises and is replaced with cooler air which removes more heat from the warmer substance. Circulation of air due to heat differential is referred to as **free convection.** If a fan or other mechanical device is used to force air over a warmer or colder surface to transfer heat the method is called **forced convection.** Most modern heating and cooling systems utilize forced convection in conjunction with an air duct system to heat or cool the structure. Figure 3 illustrates both free and forced heat transfer by means of convection. Figure 4 illustrates a forced convection air duct system.

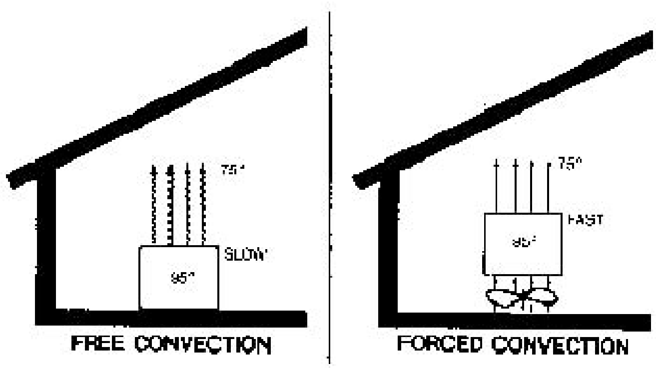


FIG. 3 — HEAT TRANSFER BY CONVECTION

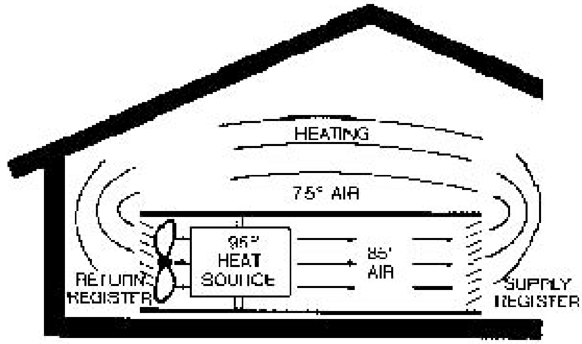


FIG. 4 — HEAT TRANSFER BY FORCED CONVECTION

**Radiation** is the transfer of heat by rays to a cooler substance through a medium such as air without heating the medium itself. The heat generated by the sun, an electric lamp or open flame are examples of radiant heat.

Heat generated by the sun shining through windows is a desirable heat gain in the winter but undesirable in the summer since heat is added to the structure by radiation. Figure 5 illustrates radiant heat.

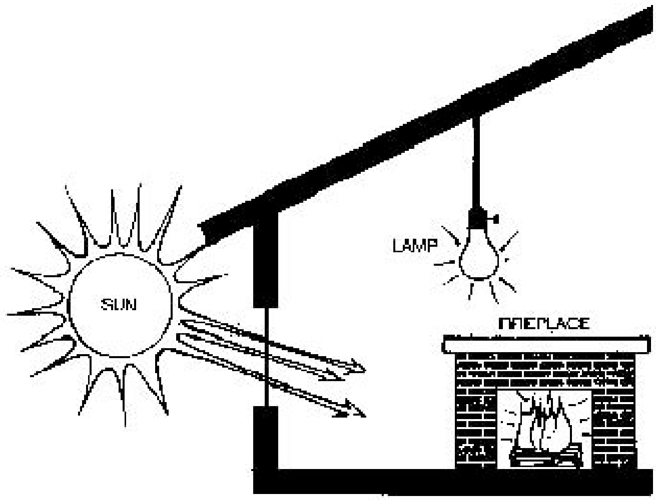


FIG. 5 — RADIANT HEAT

## BASIC REFRIGERATION PRINCIPLES

The study of mechanical refrigeration requires the student to thoroughly understand the basic principles that govern the behavior of refrigerants, air, and the mechanical components necessary to control the refrigeration system and accomplish the desired results. A few basic laws apply to all refrigeration systems from simple refrigerators and air conditioners to the most complex commercial systems. Complexity of a system is purely mechanical. A 2 ton air conditioner and a 100 ton air conditioner must perform the same basic functions to operate properly.

Heat energy transferred by air conditioning and heating equipment is measured in British Thermal Units (BTU). **The BTU is the amount of heat necessary to raise one pound of water 1 °F.** One pound of water is approximately one pint. Eight pounds of water is 0.96 gallons.

*(Cont.)*

The heat required to raise one pound of any other substance may be more or less than 1 BTU. **The specific heat of any substance is the amount of heat required to raise the temperature of 1 pound of that substance 1°F.** For example 0.24 BTU is required to raise the temperature of one pound of air 1°F.; therefore the specific heat of air is 0.24. The temperature of the substance has no effect on specific heat. 0.24 BTU will increase the temperature of one pound of air from 1°F. to 2°F. or from 150°F. to 151°F.

Another term that is used to designate heat energy in air conditioning equipment is the ton. **A ton of refrigeration is the amount of heat necessary to melt one ton (2000 pounds) of ice at 32°F. in a 24 hour period and is equal to 12,000 BTU per hour.**

Before attempting to analyze the operation of a refrigeration system, it is necessary that we understand the behavior of liquids and vapors when heat is applied. For this purpose we will analyze the behavior of water since it is universally known for its freezing and boiling characteristics. All liquids that will change to a vapor when heat is applied and return from a vapor to a liquid when heat is removed has been assigned a refrigerant number. Water has been assigned a refrigerant number of R-718.

We would all agree that water will freeze at 32°F. and boil at 212°F., but **we must always remember that this condition exists only at sea level pressure which is accepted as 14.7 pounds per square inch pressure (PSI).**

Atmospheric pressure is the pressure exerted on the earth's surface by the weight of air above the earth's surface and will vary with elevation above sea level and weather conditions. A column of air from the top of the atmosphere resting on one square inch of the earth's surface at sea level weighs 14.7 pounds, resulting in a sea level pressure of 14.7 PSI. Water will boil at 212°F. at this pressure.

At 14,000 feet above sea level atmospheric pressure is reduced to 8.4 PSI since a one square inch column of air has less height and therefore weighs less. Water will boil at 185°F. at elevations of 14,000 feet above sea level due to the decrease in pressure.

| TEMPERATURE °F | PRESSURE P.S.I.A. | TEMPERATURE °F | PRESSURE P.S.I.A. |
|---|---|---|---|
| 600 | 1552.5 | 225 | 18.7 |
| 500 | 680.4 | 212 | 14.7 |
| 400 | 250.0 | 205 | 12.3 |
| 350 | 135.6 | 175 | 6.7 |
| 300 | 67.2 | 140 | 2.9 |
| 275 | 45.3 | 80 | .4 |
| 250 | 29.7 | 32 | .09 |

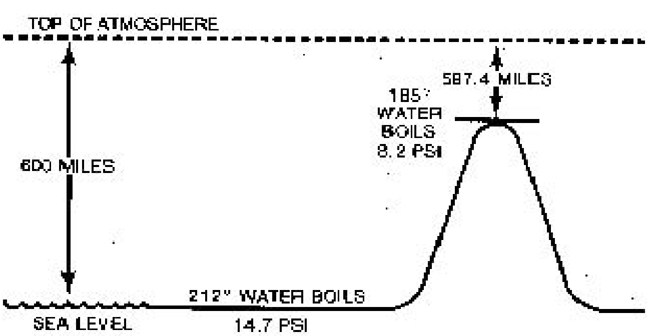


FIG. 6 —
PRESSURE EFFECT ON BOILING TEMPERATURE OF WATER

The most important rule in refrigeration principles is that **a liquid's boiling temperature changes with changes in pressure exerted on the liquid. An increase in pressure increases the boiling temperature. A decrease in pressure decreases the boiling temperature.**

Refrigeration systems mechanically control the pressures within the system forcing the refrigerant to boil at a specific temperature required to maintain the desired temperatures within the system. Figure 6 shows the pressure-temperature characteristics of water.

Figure 7 illustrates the behavior of water in an open container at sea level pressure.

When heat is applied to the water the thermometer will indicate an increase in the water temperature. Since the addition of heat can be "sensed" or seen as a change in temperature indicated by the thermometer, the heat added is called **sensible heat. When heat is added to a liquid the temperature of the liquid will increase until the boiling point of the liquid is reached.**

When enough heat is added to the water to cause the water to boil, the thermometer will no longer indicate a change in temperature but will remain at 212°F. even though heat continues to be added. When this occurs we have reached the saturation temperature for water at 14.7 PSI pressure.

**The saturation temperature of a liquid occurs when heat continues to be added and a thermometer indicates no change in temperature,** therefore the saturation temperature of water at 14.7 PSI is 212°F.

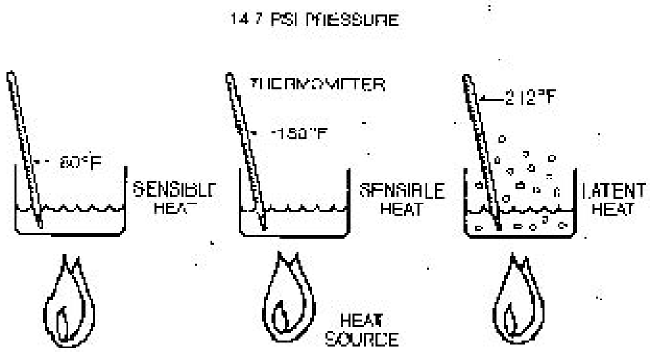


FIG. 7 — SENSIBLE AND LATENT HEAT

It is obvious that heat energy continues to be added but since the work done is not indicated by a change in temperature, the energy input is "hidden" or latent. **When heat energy is utilized to change a liquid to a vapor without a change in temperature, it is called a change of state. The heat energy used during this change of state is called the latent heat of vaporization. When vapor is mixed with the liquid from which it was evaporated or is in contact with the liquid, it is called a saturated vapor.** The temperature of a vapor cannot be increased above the boiling point as long as any liquid is present.

If a vapor is removed from its physical contact with liquid and additional heat is added to the vapor, the temperature of the vapor can be increased. **A vapor that has been heated above its boiling point is called a superheated vapor.** Figure 8 illustrates the change from a saturated vapor to a superheated vapor. When heat is applied to the liquid, the temperature of the liquid and saturated vapor will remain a constant 212°F. When additional heat is added to the vapor, the vapor will be superheated to a temperature above its boiling point. In Figure 8 the thermometer measuring the cloud of superheated vapor indicates 252°F. Since the boiling temperature of the water at 14.7 PSI is 212°F. and the measured temperature of the superheated vapor is 252°F., the vapor has been superheated 40°F.

**Superheat is defined as the measured temperature difference between the boiling temperature of a liquid and the measured vapor temperature.**

Heat required to boil the water is **latent heat** and the heat required to superheat the vapor is **sensible heat.** If more heat is added to the water, the water will boil faster but the water temperature will remain at 212°F. If more heat is added to the vapor, the vapor temperature will increase, therefore increasing the superheat.

**When heat is added to a liquid in sufficient quantity to cause the liquid to change to a vapor, the liquid is described as boiling or evaporating.**

**When heat is removed from a vapor in sufficient quantity to cause the vapor to change to a liquid, the vapor is described as condensing.**

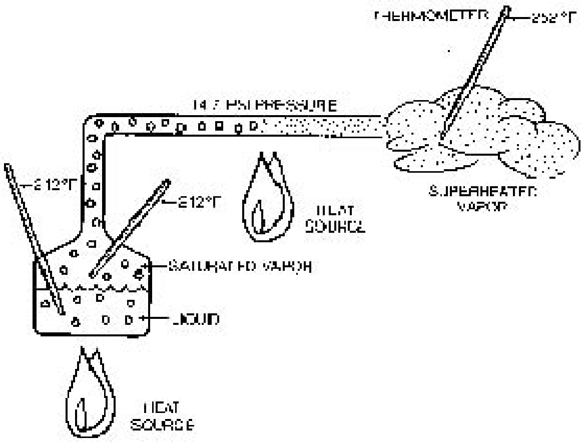


**FIG. 8 — WATER EVAPORATING AND SUPERHEATING**

When heat is removed from a vapor it will condense or change back to a liquid at exactly the same temperature as its boiling temperature as long as the pressure remains the same.

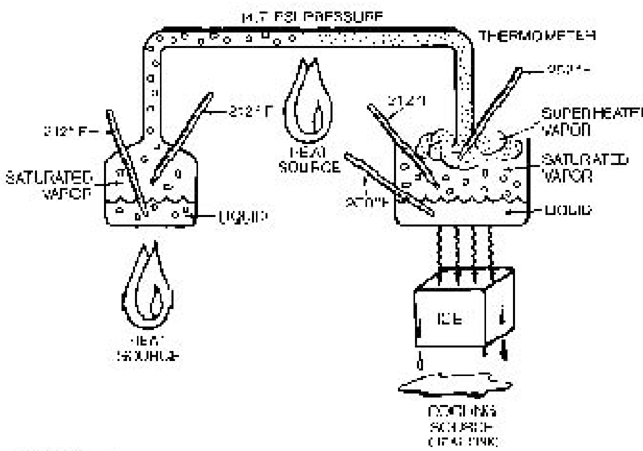


**FIG. 9 —**
**WATER EVAPORATING, SUPERHEATING AND CONDENSING**

It can be stated that the boiling or evaporating temperature, the saturated temperature, and the condensing temperature of a substance is exactly the same temperature when the pressure remains constant. The terms merely denote whether heat is added or removed. Figure 9 illustrates the evaporation and condensing of water at 14.7 PSI pressure.

When the superheated vapor contacts a cool container the vapor condenses into a liquid. Note in Figure 9 that the water is condensing at 212°F., but adequate heat is removed to cool the liquid to 200°F. which is 12°F. cooler than the condensing temperature of 212°F. **The measured temperature of a liquid below its condensing temperature is called subcooling.** The liquid in the condensing container is subcooled 12°F. and contains no vapor. The water in the condensing container could be returned to the evaporating container and used over and over again without replenishing the liquid supply. Actually, in an open system operating at atmospheric pressure some of the liquid would be lost due to evaporation into the air surrounding the system, but in actual refrigeration systems the circuit would be sealed and none of the refrigerant would be lost and would not require additional refrigerant for the life of the system.

If the water system that we have analyzed were sealed and the pressure increased 15 PSI above atmospheric pressure of 14.7 PSI, or to 29.7 PSI, the same evaporating, superheating and condensing would occur but the evaporating and condensing temperatures would increase from 212°F. to 252°F. due to the increase in pressure.

In a refrigeration system the same phenomenon occurs except the system is sealed into a closed circuit, refrigerants other than water are used, and the pressures in the system are controlled to produce temperatures required to meet the refrigeration circuit's requirements.

## BASIC AIR CONDITIONING HEAT TRANSFER

The function of an air conditioning system is to create an atmosphere where the temperature and humidity of a structure are controlled to meet the requirements of the structure. Requirements of a structure housing people may vary greatly from a structure housing machinery, food products or other materials. For example, residential structures that house people and the machinery necessary for their everyday living needs generate both heat and moisture. The residential air conditioner must remove both heat and moisture to maintain a comfortable atmosphere.

Heat generated by electric ranges, motors and many other household appliances add heat to the air within the structure but do not add moisture. This heat increases the air temperature which can be measured or sensed as a temperature increase by an ordinary thermometer. **Heat generated by a device that increases the temperature of a substance without adding moisture or removing moisture is called sensible heat.**

*(Cont.)*

Steam generated by cooking, bathing, washing dishes or clothes, and many other daily household activities add moisture to the air within the structure. The moisture in the air cannot be measured by an ordinary thermometer but adds to the total heat load and causes occupants to feel uncomfortable. Since the moisture content of the air cannot be measured with an ordinary thermometer, it is "hidden" or latent. **When heat is added or removed from a substance with no change in the temperature of the substance, it is called latent heat.**

People, clothes washers, clothes dryers, dish washers and many other household devices generate both sensible and latent heat.

In most households about 70% of the heat generated is sensible and the remaining 30% is latent. These percentages can vary with climatic conditions in different geographical locations and the living habits of the household occupants.

The air conditioning system must be designed to remove both sensible and latent heat in corresponding ratios to maintain a comfortable climate within the structure. Figure 10 illustrates a typical air conditioning evaporator where the refrigerant temperature is controlled to accomplish this purpose. Heat from the 75°F. entering air causes the 38°F. saturated refrigerant in the coil to boil or evaporate. Heat removed from the air is transferred to the refrigerant, resulting in 55°F. air leaving the coil.

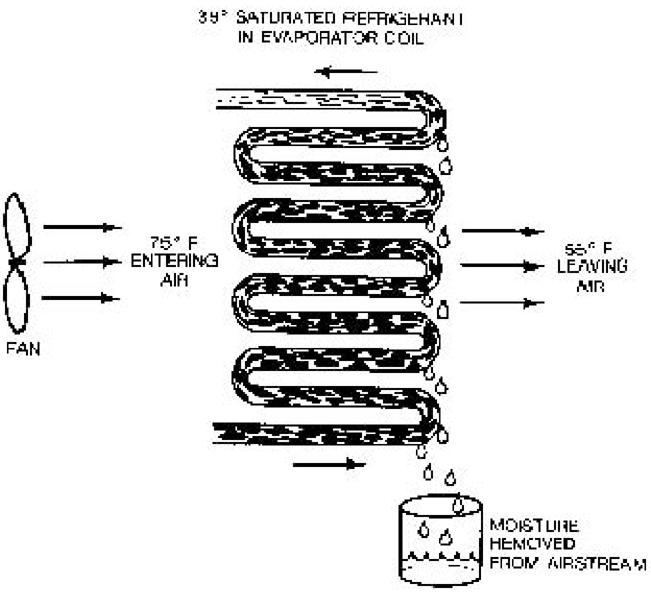


**FIG. 10 — SENSIBLE AND LATENT HEAT TRANSFER**

The measurable difference in entering and leaving air temperature is 20°F. representing the sensible cooling accomplished by the coil or, simply stated, the capability of the coil to change the air temperature. **In air conditioning and heating work a change in temperature, either an increase or a decrease, is denoted by the symbol ΔT.** The Δ symbol is derived from the Greek alphabet letter Delta, meaning change.

The amount of sensible heat removed from the airstream depends upon the volume of air passed through the coil and the ΔT resulting.

Air volume is measured in cubic foot per minute (CFM). To determine the actual heat removed from air, volume (CFM) must be converted to weight. The weight of air is stated in pounds (Lbs).

One pound of dry air occupies about 13.33 cubic feet of space; therefore, 13.33 cubic feet of air equals one pound. To change the temperature of one pound of air 1°F. requires 0.24 BTU. The sensible heat ($H_s$) removed by air conditioning equipment is stated in BTU per hour (BTUH). The sensible cooling capacity can be determined when the ΔT across the coil and the Lbs/hr. of air through the coil are known.

**BTUH Sensible Heat Removed = CFM x ΔT X 1.08**

Where: 0.24 = BTU required to raise 1 lb of air 1°F.

$$\frac{60 \text{ min./hr.}}{13.33 \text{ Cu. Ft./Lb.}} = 4.5$$

.24 X 4.5 = 1.08

Note in Figure 10 that the refrigerant inside the evaporator coil is evaporating or boiling at 38°F. The air passing across the external surface of the coil is at 75°F. In simple terms, it could be stated that the refrigerant inside the coil is attempting to reduce the coil surface temperature to 38°F. At the same time, the 75° air passing across the coil is attempting to increase the coil surface temperature to 75°F. The resulting coil surface temperature will be somewhere between 38°F. and 75°F. In most air conditioning systems the evaporator surface temperature will be 10°F. to 15°F. above the evaporating temperature of the refrigerant inside the coil. In this case the surface temperature would be between 48°F. and 53°F. or a nominal 50°F.

This temperature is cold enough to cause some of the moisture contained in the entering air to condense or change into water on the surface of the coil where it is normally drained away.

The amount of water that condenses on the coil depends upon the surface temperature of the coil and the moisture content of the air. Colder surfaces and high moisture content air will result in a greater condensation of water.

The air leaving the coil will not only be reduced in temperature by the sensible capacity of the coil but will also contain less moisture per pound due to the latent capacity of the coil resulting in cooler, dehumidified leaving air.

The work energy required of the air conditioner to remove one pound, approximately one pint, of water from air is 1060 BTU.

If we apply basic theory to an example evaporator, we could determine whether or not the evaporator is functioning properly.

For the example, assume:

Evaporator airflow = 1000 CFM
ΔT = 20°F
Moisture removal = 8 Lb./hr.

Sensible capacity
**BTUH sensible = CFM X ΔT X 1.08**
or
21,600 = 1000 X 20°F X 1.08

Latent capacity
**BTUH latent = Lb./hr. X 1060**
8,480 = 8 X 1060

The total cooling capacity is equal to the sensible capacity plus the latent capacity, or: 21,600 BTUH sensible + 8,480 BTUH latent = 30,800 BTUH total. The percentage of sensible capacity is equal to the sensible divided by total, or:

$$\frac{21{,}600\ \text{BTUH}}{30{,}080\ \text{BTUH}} = 72\%\ \text{SENSIBLE}$$

The remaining 28% is latent, resulting in a 72% to 28% ratio and is referred to as a 72/28 sensible latent capacity split.

## THE MECHANICS OF A BASIC COOLING SYSTEM

In order to accomplish the basic requirements necessary to maintain comfort conditions within a structure, the mechanical refrigerant system must be designed to carefully control pressures within the system that will assure that the air conditioner accomplishes its purpose.

Figure 11 shows the components necessary for the operation of a basic air cooled air conditioning system. These components consist of a compressor, condenser, expansion device, and the evaporator. The functions of each of these basic components are explained in the following paragraphs.

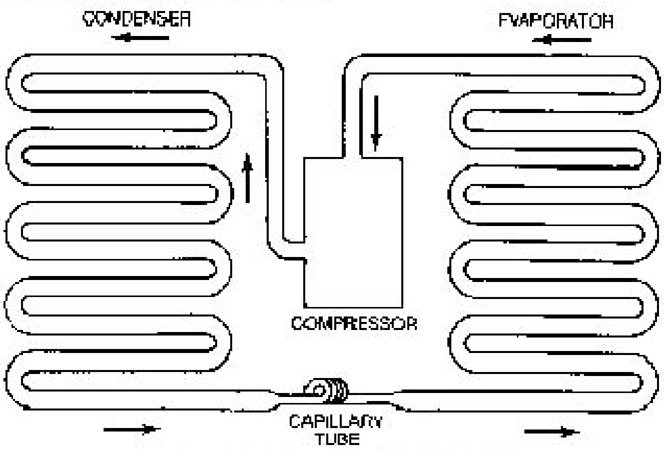


**FIG. 11 — BASIC CIRCUIT COMPONENTS**

## THE COMPRESSOR

**The function of the compressor is to maintain a pressure differential between its inlet (suction) and its outlet (discharge) that will cause the refrigerant within the refrigerant circuit to flow in sufficient quantities to meet the cooling requirements of the system.**

A compressor circulating Refrigerant 22 must be capable of circulating about 180 pounds of refrigerant per hour for each 12,000 BTUH cooling capacity of the evaporator. The compressor motor input energy required for each 12,000 BTUH capacity is about 1-3/4 horsepower.

For example, a 36,000 BTUH air conditioner circulates about 540 pounds of refrigerant per hour and requires about 5-1/4 horsepower. This represents a large amount of heat energy that must be dissipated by the motor. In most compressors used in air conditioning equipment today, the motor is installed in the same housing with the compressor so that refrigerant circulating in the system must pass over the motor. The great volume of refrigerant vapor passing over the motor dissipates motor heat rapidly resulting in very small motors with high horsepower ratings.

In fact, a 5-1/4 horsepower compressor motor cooled by refrigerant may be no larger than a 1/2 horsepower motor designed to operate in a free air location.

**When the compressor motor is located in the same housing with the compressor and sealed into the refrigerant circuit such that circulating refrigerant passes over the motor for the purpose of cooling the motor, it is called a hermetic motor-compressor.**

Heat dissipated into the refrigerant by the compressor must be rejected by the condenser.

Most hermetic compressors are equipped with a thermal overload protector buried in the motor winding. The protector senses current to the motor and the temperature of the motor winding. Any combination of motor current and winding temperature that could cause damage to the motor will automatically disconnect the electrical circuit to the motor.

This type motor protection system serves to interrupt power to the compressor if enough refrigerant is lost from the system that insufficient flow would cause the motor to overheat. This type of system eliminates the need for low pressure cut-outs in most applications since the low pressure cut-out performs the same basic low refrigerant charge protection function.

Refrigerant compressors are designed to pump refrigerant vapor only. If a saturated vapor or liquid is permitted to enter the compressor, it can result in dilution of the oil and damage to compressor bearings and valves.

The damage or resultant failure of the compressor depends upon the amount of liquid permitted to enter the compressor.

Figure 12 shows a cut-away view of a typical hermetic motor-compressor.

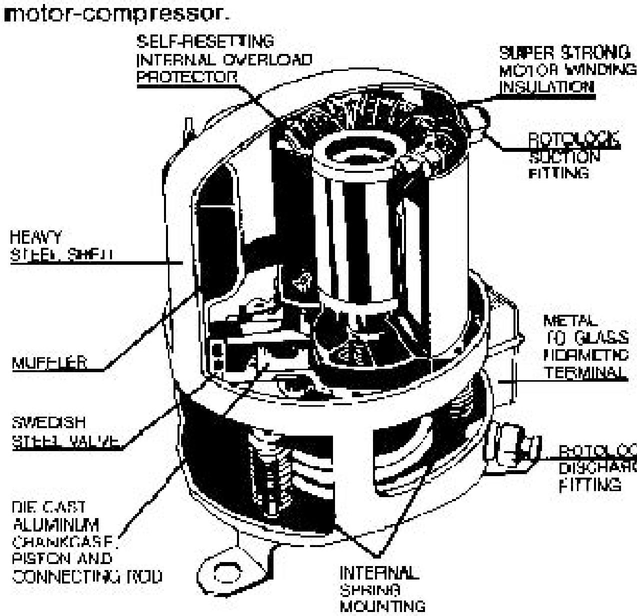


**FIG. 12 — CUT AWAY VIEW COMPRESSOR**

## THE CONDENSER

**The function of the condenser is to change the high pressure, high temperature vapor discharged from the compressor to a high pressure liquid.** Refrigerant vapor leaving the compressor contains the total heat removed by the evaporator, heat dissipated by the compressor motor, heat of friction generated by bearings and heat caused by molecular friction of the refrigerant itself.

Vapor entering the condenser is at high pressure and highly superheated. Since the air across the condenser is much cooler than the vapor inside the condenser tubing, heat is transferred from the refrigerant to the condenser where it is dissipated or rejected into air surrounding the condenser.

The refrigerant condenses to a liquid and is subcooled by the condenser.

Liquid refrigerant leaving the condenser is normally subcooled by 10°F. to 20°F.

**Proper operation of the condenser requires that it furnish a continuous supply of subcooled liquid to the expansion device.**

Any dirt or foreign material that clogs the condenser or low air volume across the condenser could result in a saturated vapor instead of a subcooled liquid entering the expansion device. If this condition occurs, it is referred to as "gassing the expansion device", and will result in improper operation of the air conditioning system and may cause the evaporator to freeze ice on its surface.

## EXPANSION DEVICES

Capillary tubes, expansion valves or calibrated metering orifices are often referred to as flow controls, metering controls or expansion controls.

Actually, the expansion device, regardless of its construction, introduces a calibrated friction loss that controls the evaporator inlet pressure.

**The purpose of the expansion device is to maintain an evaporator pressure that will result in a saturated vapor temperature in the evaporator below entering air temperature so that heat can be transferred from the air to the refrigerant.**

In air conditioning applications, it is desirable to control the evaporating or boiling temperature of the refrigerant at least 20°F. below the temperature of the air entering the evaporator surface but maintain the evaporator surface temperature above 32°F. to prevent ice from forming on the evaporator surface.

Expansion devices are carefully selected for the specific system for which they were designed.

Any deviation from original capillary tube length and internal bore or deviation from tonnage rating of an expansion valve will result in improper system operation.

## THE EVAPORATOR

**The purpose of the evaporator is to transfer heat from air entering the evaporator to the refrigerant in the evaporator.**

For maximum heat transfer it is necessary to maintain a constant refrigerant temperature throughout the evaporator. This can only be accomplished if the evaporator tubing is supplied with a saturated vapor that will evaporate at a constant temperature throughout the evaporator.

An evaporator that is filled with a saturated vapor is said to be "fully refrigerated". In other words, the entire evaporator has some liquid content in the saturated vapor that will evaporate at a constant temperature.

If the supply of refrigerant in the evaporator is evaporated before reaching the evaporator outlet, the vapor in the remainder of the evaporator will be superheated by the air across the evaporator and effective heat transfer for the superheated portion of the evaporator will be lost. This condition is referred to as a "starved evaporator" or "not fully refrigerated."

If more saturated vapor is supplied to the evaporator than can be evaporated by the heat contained in the evaporator airstream, some of the saturated vapor will leave the evaporator and continue down the suction line to the compressor. When the refrigerant leaving the evaporator contains some liquid, the condition is referred to as "evaporator flooding" or "flooding the compressor." This is an undesirable condition since liquid entering the compressor can be detrimental to compressor reliability.

Any reduction of heat load on the evaporator will cause flooding with a capillary tube or metering orifice flow control. Evaporator unloading can be caused by dirty air filters, closing of air registers, failure of the evaporator motor or fan belt, or icing of the evaporator coil.

Some refrigerant systems utilize a suction accumulator located between the evaporator outlet and the compressor inlet to prevent liquid from entering the compressor when the evaporator is not fully loaded.

Operation of suction accumulators will be discussed in succeeding paragraphs.

## OPERATION OF A TYPICAL R-22 SYSTEM

Refrigerants used in air conditioning systems are selected for their stability, non-toxic characteristics, chemical effects on oil and metals, ability to produce maximum refrigeration at minimum power input and operate at pressures suitable for the type of compressor used in the system.

Refrigerant 22 (R-22) is the most widely used refrigerant for air conditioning systems since it meets the basic requirements and is among the leading refrigerants in operating efficiency ratio of power input to work accomplished.

Figure 13 is a chart showing the temperature-pressure characteristics for R-22.

Temperature-pressure charts list the temperature of the refrigerant in a saturated vapor state at various pressures. In other words, the refrigerant must contain some liquid and some vapor for the temperature-pressure relationship shown on the chart to be useful.

| Temp. °F. | Pressure PSIG | Temp. °F. | Pressure PSIG | Temp. °F. | Pressure PSIG | Temp. °F. | Pressure PSIG |
|---|---|---|---|---|---|---|---|
| −40 | 0.5 | 7 | 30.0 | 34 | 60.1 | 82 | 148.4 |
| −38 | 1.3 | 8 | 30.9 | 35 | 61.5 | 84 | 153.2 |
| −36 | 2.2 | 9 | 31.8 | 36 | 62.8 | 86 | 158.2 |
| −34 | 3.0 | 10 | 32.8 | 37 | 64.2 | 88 | 163.2 |
| −32 | 3.9 | 11 | 33.7 | 38 | 65.6 | 90 | 168.4 |
| −30 | 4.9 | 12 | 34.7 | 39 | 67.1 | 92 | 173.7 |
| −28 | 5.8 | 13 | 35.7 | 40 | 68.5 | 94 | 179.1 |
| −26 | 6.9 | 14 | 36.7 | 42 | 71.4 | 96 | 184.6 |
| −24 | 7.9 | 15 | 37.7 | 44 | 74.5 | 98 | 190.2 |
| −22 | 9.0 | 16 | 38.7 | 46 | 77.6 | 100 | 195.9 |
| −20 | 10.1 | 17 | 39.8 | 48 | 80.8 | 102 | 201.8 |
| −18 | 11.3 | 18 | 40.8 | 50 | 84.0 | 104 | 207.7 |
| −16 | 12.5 | 19 | 41.9 | 52 | 87.4 | 106 | 213.8 |
| −14 | 13.8 | 20 | 43.0 | 54 | 90.8 | 108 | 220.0 |
| −12 | 15.1 | 21 | 44.1 | 56 | 94.3 | 110 | 226.4 |
| −10 | 16.5 | 22 | 45.3 | 58 | 97.9 | 112 | 232.8 |
| −8 | 17.9 | 23 | 46.4 | 60 | 101.6 | 114 | 239.4 |
| −6 | 19.3 | 24 | 47.6 | 62 | 105.4 | 116 | 246.1 |
| −4 | 20.8 | 25 | 48.8 | 64 | 109.3 | 118 | 252.9 |
| −2 | 22.4 | 26 | 49.9 | 66 | 113.2 | 120 | 259.9 |
| 0 | 24.0 | 27 | 51.2 | 68 | 117.3 | 125 | 277.9 |
| 1 | 24.8 | 28 | 52.4 | 70 | 121.4 | 130 | 296.8 |
| 2 | 25.6 | 29 | 53.6 | 72 | 125.7 | 135 | 316.6 |
| 3 | 26.4 | 30 | 54.9 | 74 | 130.0 | 140 | 337.2 |
| 4 | 27.3 | 31 | 56.2 | 76 | 134.4 | 145 | 358.9 |
| 5 | 28.2 | 32 | 57.5 | 78 | 139.0 | 150 | 381.6 |
| 6 | 29.1 | 33 | 58.8 | 80 | 143.6 | 155 | 405.1 |

**FIG. 13 — TEMPERATURE PRESSURE CHART (REFRIGERANT 22)**

For example, the chart indicates a temperature of 100°F. at a pressure of 195.9 pounds per square inch gauge (PSIG). **PSIG is the pressure measured with a pressure gauge. Gauge pressure is equal to pounds per square inch absolute (PSI or PSIA) plus 14.7 pounds atmospheric pressure.** This relationship exists only if the refrigerant contains some liquid and some vapor. The relationship is accurate if the refrigerant is evaporating, condensing, or at rest in a partially filled container. If R-22 at 195.9 PSIG is at a temperature below 100°F. it would be pure liquid with no vapor content or would be a subcooled liquid by the number of degrees measured below 100°F.

If R-22 at 195.9 PSIG is at a temperature above 100°F. it would be all vapor with no liquid content. The measured temperature above 100°F. would indicate the amount of superheat contained in the vapor.

Example:
R-22 at 195.9 PSIG and 100°F. is saturated vapor.
R-22 at 195.9 PSIG and 80°F. is 20° subcooled liquid.
R-22 at 195.9 PSIG and 120°F. is 20° superheated vapor.

To fully understand the operation of a refrigerant system, it is absolutely necessary to understand the temperature-pressure characteristic of the refrigerant and to understand whether saturated vapor, liquid or superheated vapor must be present in each functioning component in the system.

Figure 14, shown on page 10, illustrates the refrigerant circuit operation of a typical air conditioning system.

The superheated vapor enters the condenser at 277.9 PSIG and 230°F. The 95°F. outdoor air across the condenser rapidly removes the superheat from the refrigerant since the temperature difference between the air and refrigerant is 135°F. The refrigerant begins to condense. Note that the refrigerant pressure has dropped to 270.6 PSIG at the condenser mid-point. Pressure losses due to friction between the refrigerant and tubing walls and between the refrigerant particles themselves occur in all heat transfer tubing and also in connecting tubing. These losses are referred to as "pressure drop" within the coil. The coil shown in figure 14 has an entering pressure of 277.9 PSIG and a leaving pressure of 259.9 PSIG, resulting in an 18 PSIG pressure drop in the coil. The magnitude of pressure drop in a heat transfer coil is determined by the inside diameter of the tubing, configuration of the tubing and velocity of the refrigerant.

Pressure drop in heat transfer coils represent an efficiency loss in the system. Coils and refrigerant piping are designed to minimize pressure drop.

The refrigerant at the coil mid-point at 270.6 PSIG is condensing at 123°F. As the refrigerant progresses through the coil, the total latent heat is transferred to the airstream and a solid column of liquid forms. The 95°F. air continues to remove heat from the liquid resulting in a sensible change in temperature of the liquid. When the liquid leaves the condenser at 259.9 PSIG and 105°F. it has been subcooled. The degree of subcooling is determined by subtracting the measured temperature of the liquid line from the saturated temperature shown on a temperature chart at 259.9 PSIG.

*(Cont.)*

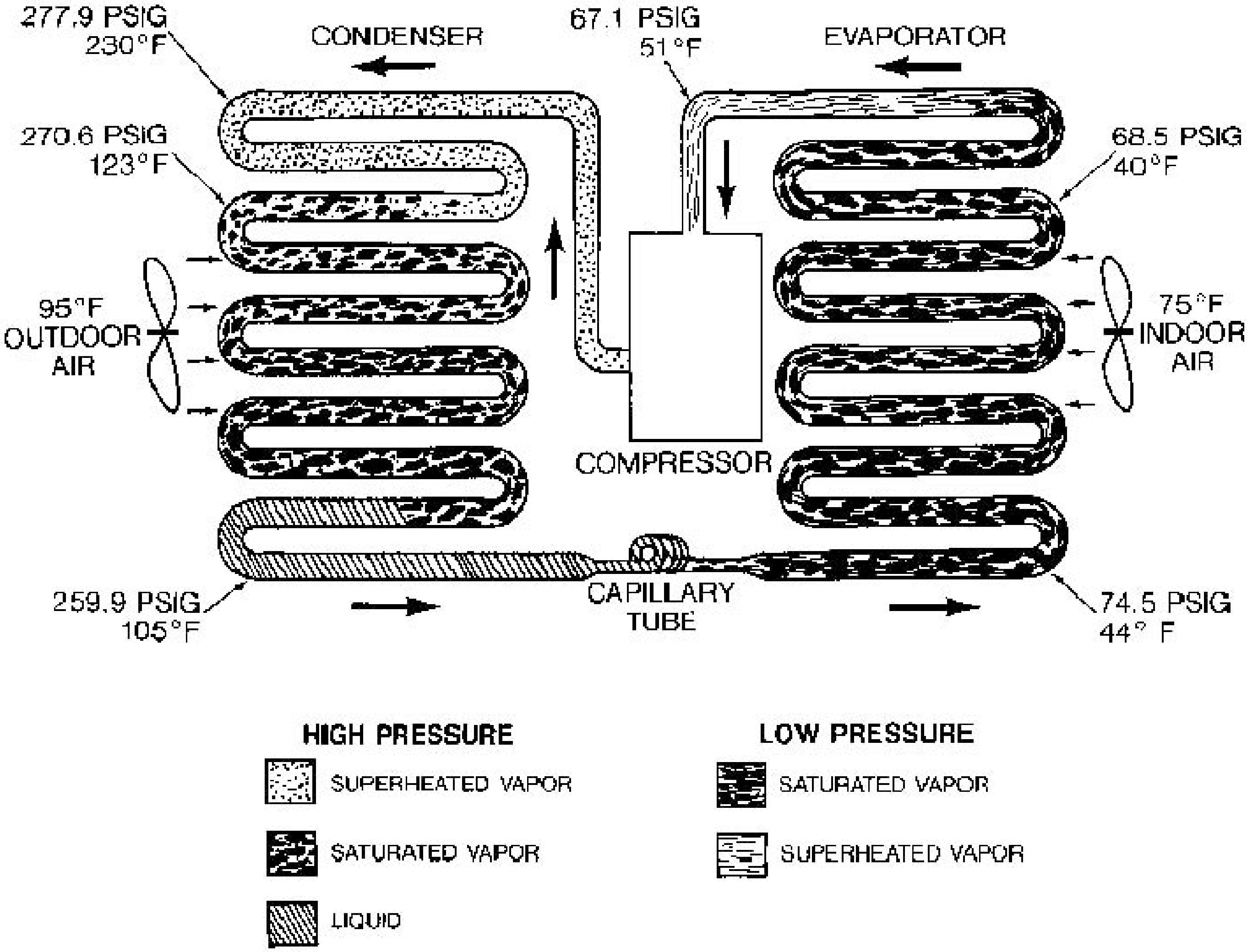


**FIG. 14 — TYPICAL OPERATING SYSTEM**

Example: 120°F. (saturated temperature @ 259.9 PSIG minus 105°F. measured liquid temperature) = 15°F. subcooling.

Air cooled R-22 condensers are normally designed to provide 10°F. to 20°F. subcooled liquid; however, subcooling will vary with load conditions on the system and variations in air volume across the condenser coil.

**The condenser must supply the expansion device with a subcooled liquid at a pressure adequate to overcome the restriction of the expansion device and fully refrigerate the evaporator.**

The capillary tube is a highly restrictive tube that causes the refrigerant to increase velocity, creating a pressure drop of such magnitude that the outlet pressure is reduced to 74.5 PSIG.

Refrigerant fed into the evaporator evaporates or boils since the evaporator tubing is above the 44°F. saturated temperature of the refrigerant. Heat is transferred from the 75°F. indoor airstream to the refrigerant.

As long as the refrigerant in the evaporator contains some liquid, it will continue to evaporate at a constant temperature. The evaporator in Figure 14 is fully refrigerated since the evaporator contains a saturated vapor throughout its tubing.

The refrigerant leaving the evaporator is at 67.1 PSIG and 51°F., indicating that all liquid has been evaporated and the remaining vapor has been superheated before entering the suction line and the compressor. Superheat in the suction line can be determined by subtracting the measured suction line temperature of 51°F. from the saturated temperature for R-22 at 67.1 PSIG, which is 39°F. according to a temperature-pressure chart.

The superheat in this case is 12°F.

Air conditioning systems are normally designed to operate with a 10°F. to 15°F. superheat in the suction line at full load conditions. Suction line superheat will vary with indoor load conditions and outdoor temperatures that affect the operating head pressure. Capillary tube and metering orifice flow controls tend to operate the system at higher superheat when the outdoor temperature is low and may saturate or flood the suction line when outdoor temperatures are extremely high.

Expansion valve flow controls are designed to maintain a constant suction line superheat over a broad range of load conditions. Expansion valves will be discussed in succeeding paragraphs.

A simple analysis of an operating air conditioning system could be reduced to the following requirements:

1. The system must utilize a compressor or other source of energy that will maintain a pressure differential in the system that will cause a constant flow of refrigerant.

2. The condenser must reject that total system heat into air, water or other media, condense and subcool the refrigerant and maintain adequate pressure to supply the refrigerant requirements of the evaporator.

3. The expansion device must control the pressure at the evaporator inlet that will produce a saturated vapor temperature below the air temperature across the evaporator and above the freezing temperature of water that forms on the evaporator coil.

4. Refrigerant leaving the evaporator and entering the compressor must be a superheated vapor to prevent damage to the compressor. The refrigerant charge in a capillary tube or metering orifice system controls suction line superheat. Expansion valves maintain a constant superheat in the suction line.

## SUCTION ACCUMULATORS

Figure 15 depicts a typical suction line accumulator. The purpose of this device is to prevent liquid refrigerant from entering the compressor when the system evaporator is flooded.

The accumulator is used with capillary tube and metering orifice flow controls in some applications.

The accumulator is located between the evaporator outlet and the compressor inlet.

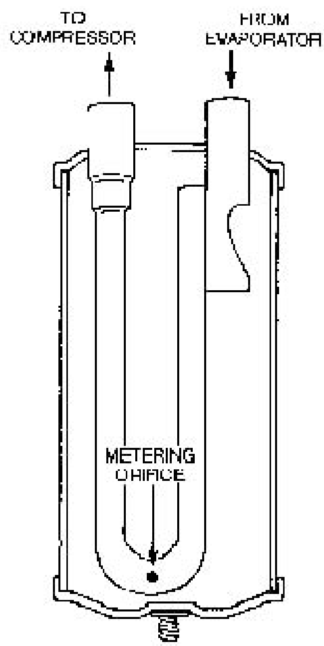


**FIG. 15 — SUCTION ACCUMULATOR**

Any liquid refrigerant that leaves the evaporator enters the body of the accumulator. Note in Figure 15 that the suction line inlet supplying the compressor is located near the top of the accumulator. Liquid from the evaporator is stored in the lower portion of the accumulator such that refrigerant vapor from the top of the accumulator is supplied to the compressor. The "U" tube configuration of the compressor inlet tube prevents accumulation of oil that circulates with the refrigerant from being trapped in the accumulator. Changes in pressure within the accumulator will cause trapped refrigerant to evaporate and return to the circulating system; however, any oil trapped in the accumulator will not evaporate and would remain in the accumulator, defeating the purpose of refrigerant storage and reducing the oil supply in the compressor. A small hole is drilled in the lower portion of the accumulator "U" tube that will force any liquid, whether oil or refrigerant, to return to the compressor in calibrated quantities. This hole is referred to as the accumulator metering orifice.

Accumulators are not normally used with expansion valve flow controls since the expansion valve prevents liquid flooding from the evaporator under normal operating conditions.

Accumulators are not normally used with capillary tubes or metering orifices when the system refrigerant charge can be controlled.

Heat pumps utilizing capillary tubes or metering orifices in the heating function require the use of accumulators or other refrigerant storage devices.

## THERMOSTATIC EXPANSION VALVES (TXV)

Expansion valve flow controls utilize a temperature sensing element and a pressure sensing element that are connected to the outlet of the evaporator coil. The valve is designed such that any change in pressure or temperature at the evaporator outlet will cause the metering orifice within the valve to allow more or less refrigerant to enter the evaporator and maintain a fully refrigerated evaporator, but will not permit liquid refrigerant to leave the evaporator and flood the compressor.

Figure 16 shows the basic operation of a thermostatic expansion valve. The thermal sensing element exerts pressure on the upper side of the valve diaphragm. Suction pressure exerts pressure on the lower side of the valve diaphragm. The diaphragm opens or closes the valve orifice permitting more or less refrigerant to enter the evaporator as the evaporator load requirements change. The valve is preset to maintain a specific superheat at the location of the thermal and pressure sensing elements.

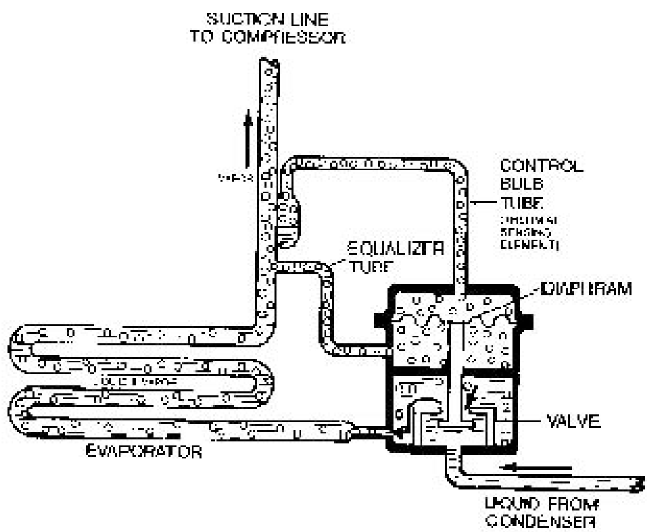


**FIG. 16 — THERMOSTATIC EXPANSION VALVE**

## BASIC HEAT PUMP OPERATION

The heat pump refrigerant system operates exactly like a basic cooling system as far as basic refrigeration principles are concerned. The differences in an air conditioner and a heat pump system are:

1. The heat pump utilizes a switchover valve to reverse the flow of refrigerant in the heating function.

2. A separate expansion device is required for both the heating and cooling modes of operation.

3. Check valves are required to route the refrigerant through the proper expansion device when the system reverses from cooling to heating and visa versa.

4. A defrost system is required to defrost the outdoor coil when outdoor temperatures are below freezing in the heating mode because the outdoor coil functions as the evaporator.

Figure 17 shows the refrigerant flow direction in a basic heat pump refrigerant circuit in the cooling mode of operation. Note that the switchover valve is positioned such that discharge refrigerant is routed to the outdoor coil which is utilized as a condenser in the cooling mode. Liquid refrigerant leaving the condenser flows through the outdoor check valve which is in the open position during cooling operation. The outdoor capillary tube is by-passed by the check valve, because refrigerant flows in the line of least resistance.

The indoor check valve is closed during the cooling mode causing the liquid to enter the indoor capillary tube. The capillary tube feeds the indoor coil which functions as the evaporator. Refrigerant from the evaporator is routed through the switchover valve to the compressor suction inlet to complete the refrigerant circuit. The refrigerant circuit performs exactly like an air conditioning system when it is operating in the cooling mode.

Figure 18 shows the basic heat pump circuit in the heating mode of operation. Note that the only change in the refrigerant circuit is the position of the switchover valve which reverses the flow of refrigerant in the system.

Discharge refrigerant is routed to the indoor coil which functions as the condenser. Heat rejected by the condenser is discharged to the indoor area of the structure where the indoor coil is located.

Liquid from the indoor coil now enters the liquid line in a reverse direction causing the indoor check valve to open, by-passing the indoor capillary tube. The outdoor check valve closes due to the reverse flow and forces the refrigerant through the outdoor capillary tube.

Refrigerant from the capillary tube feeds the outdoor coil which functions as the evaporator in the heating mode. Refrigerant from the evaporator is routed through the switchover valve to the compressor suction inlet completing the heating refrigerant cycle.

Refrigerant flow from the compressor discharge line to the switchover valve, and flow from the switchover valve to the compressor suction inlet, is in the same direction in both the heating and cooling modes.

During cold weather operation in the heating mode, the outdoor coil functioning as an evaporator will operate with the refrigerant in the coil evaporating at a temperature below 32°F which will cause moisture from the air entering the coil to freeze on the coil surface. When enough ice freezes on the coil to cause a heat transfer reduction of a magnitude that impairs the capacity and efficiency of the system, an electromechanical circuit located in the outdoor unit will sense the icing condition and automatically switch the system to a defrost mode of operation.

Defrost is accomplished by reversing the refrigerant flow. The defrost sensing circuit causes the switchover valve to change position and revert to the cooling mode of operation.

**BASIC HEAT PUMP CIRCUIT**

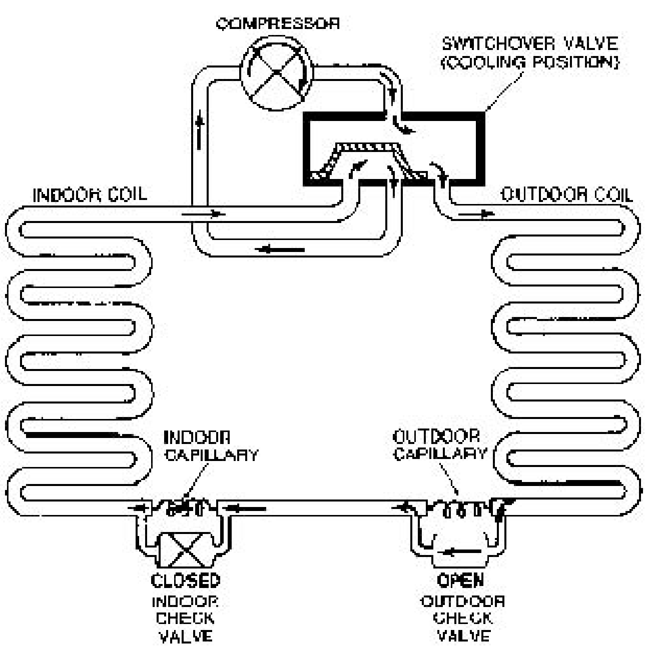


FIG. 17 — COOLING MODE

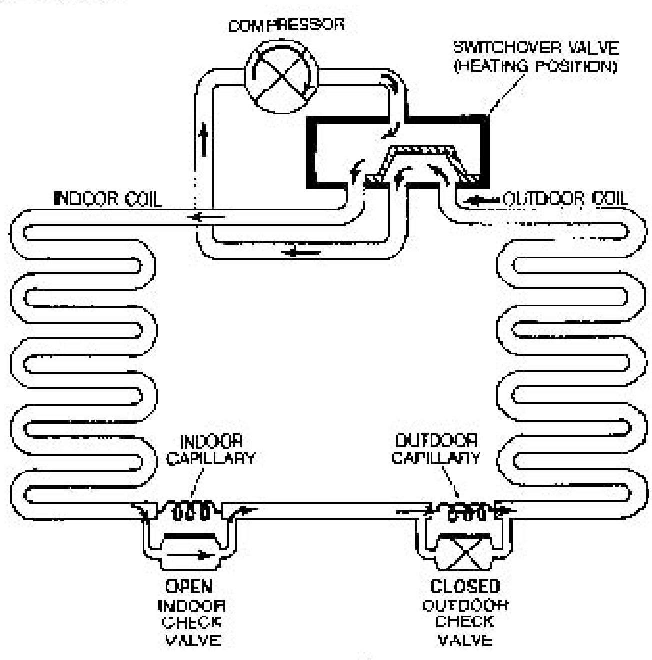


FIG. 18 — HEATING MODE

Hot refrigerant from the compressor is routed through the outdoor coil causing the ice to melt from the surface of the coil. The outdoor fan stops during defrost operation to shorten the time required for defrost. The same electro-mechanical sensing circuit that initiated the defrost cycle also senses when the coil is free of ice. The sensing circuit automatically terminates the defrost cycle by switching the switchover valve back to the heating position and restarting the outdoor fan.

During the defrost cycle, the indoor coil functions as the evaporator and delivers cool air into the structure. Electric heaters or other secondary souces of heat located in the indoor airstream are automatically energized during the defrost cycle to prevent cool drafts and to prevent the temperature within the structure from dropping to an uncomfortable temperature.

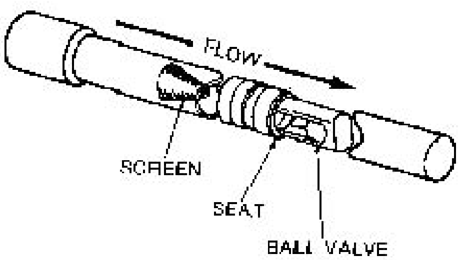


FIG. 19 — CHECK VALVE

## CHECK VALVES

Figure 19 is a cut-away view of a typical check valve used in a heat pump system. When the refrigerant flow is in the direction indicated by the flow arrow, the valve offers no restriction to the flow of refrigerant. When refrigerant flow is reversed, the ball valve will contact the seat and close the path for refrigerant flow. The valve is refrigerant flow operated.

## SWITCHOVER VALVES

Switchover valves are often referred to as reversing valves or four-way valves. The valve is operated by an electrical solenoid coil connected to a pilot valve.

The solenoid coil is electrically energized by the system room thermostat when the cooling mode of operation is selected or by the defrost electrical system.

When the solenoid coil is energized, the pilot valve connects one end of the main switchover valve to the compressor suction line. Pressure in that end of the valve is reduced to suction pressure. Pressure on the opposite side of the main valve slider is connected to the compressor discharge line. Pressure differential

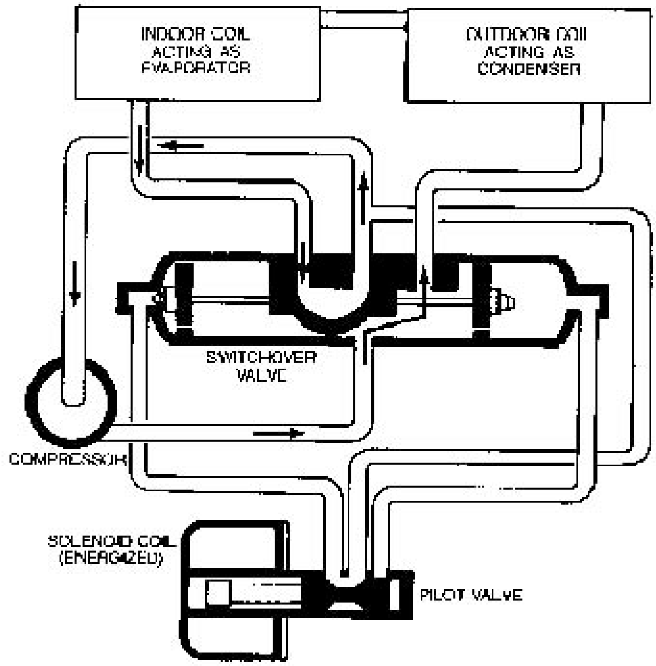


FIG. 20 — COOLING CYCLE

across the slider causes the slider to move to the position shown in Figure 20. Refrigerant is routed through the valve in the direction indicated by Figure 20.

The switchover valve solenoid coil is de-energized when the system room thermostat is placed in the heating position. The pilot valve connects suction pressure to the opposite end of the main valve slider causing the slider to move to the position shown in Figure 21. The position of the main valve slider determines the direction of refrigerant flow in the heat pump refrigerant system. Figure 21 indicates the direction of flow in the heating mode of operation.

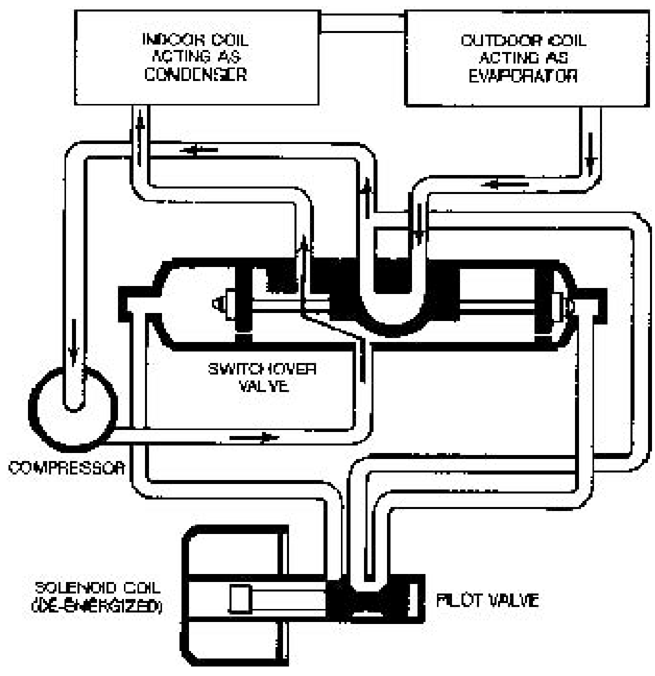


FIG. 21 — HEATING CYCLE