BASIC HEAT PUMP THEORY

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INTRODUCTION

In recent years air conditioning industry technology has advanced rapidly. An important byproduct of this growth has been development of the heat pump.

Altogether too much mystery has surrounded operations of the heat pump cycle, and as a result the average refrigeration service engineer has little knowledge of what goes on within these units.

The purpose of this section is to provide a basic understanding of heat pump theory and a more practical approach to the solution of problems which arise in conjunction with heat pump operation.

WHAT IS A HEAT PUMP?

Basically a heat pump is any machine that pumps heat.

As an example, a typical refrigeration circuit of an air conditioner, can, by tracing the refrigerant flow, be classified as a heat pump.

ANALYSIS OF HEAT PUMP THEORY

An analysis would start at the evaporator where cold liquid is changed into a gas as it picks up heat from room air passing over the coil. Cool gas from evaporator then flows to the compressor, where it is compressed and hot gas containing heat of compression and heat of vaporization is pumped to the condenser where heat is removed by outdoor air passing over it. Thus heat has been pumped from evaporator to condenser.

If this hypothetical air conditioner was constructed so that evaporator or indoor coil became the condenser or outdoor coil and vice versa, it could be used to both heat and cool.

Several early attempts were made to do this. First, rotating the unit and second, altering flow of air through the unit so that heated air was directed into room and cooled air directed out-doors. Both of these methods left much to be desired and necessitated development of a more economical and practical method. This was accomplished by adding valves and by-pass piping in the refrigerant circuit, making it possible to direct the flow of refrigerant through indoor and outdoor coils so that either heating or cooling is achieved as desired.

A result of design effort is illustrated in Figure 26F02 which shows a system with four valves installed in the circuit. By closing valves 2 and 3, and opening valves 1 and 4, the unit will operate as a cooling unit. By reversing the procedure — opening valve 2 and 3 and closing valves 1 and 4 the unit will operate as a heating unit.

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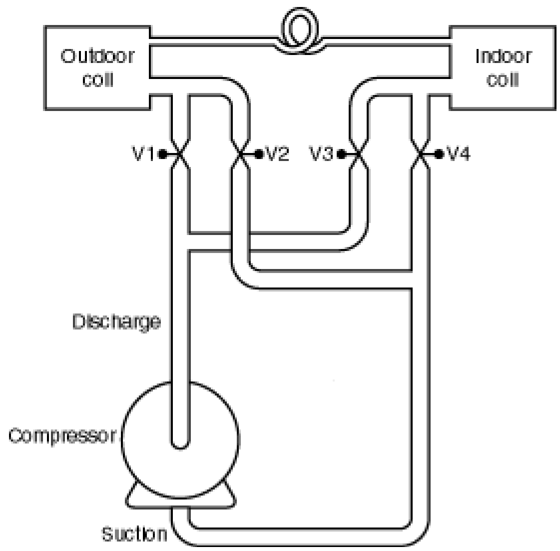

Figure 26F02

By combining two of these valves into one as shown in Figure 26F02A it is possible to quickly switch from cooling to heating or vice versa. Solenoid operated two-way transfer valves make an automatic heat pump possible, by allowing electrical switching of refrigerant flow. The next logical step is use of one valve to replace two two-way valves.

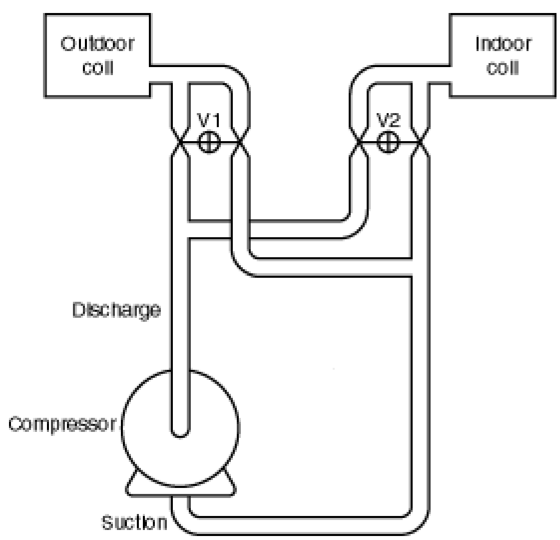

Figure 26F02A

Advancement in any field is gradual. As a typical example the first four-way valves were hand-operated. Desired condition of heating or cooling required manual change-over.

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The valve as illustrated is positioned for cooling. Its stem is screwed all the way in causing both valves to seat at left. With valve in this position, discharge gas which enters through center bottom opening is directed into center cavity of valve and is forced to leave through top left opening which leads to outdoor coil.

To obtain heating the stem is turned out until valves are both seated to the right. Discharge gas still enters through center bottom opening but is now forced to leave through top right opening leading to indoor coil. Cool gas returning from outdoor coil enters through top left opening into left cavity of valve. Gas must be returned to right cavity of valve before it can be returned to compressor. This is accomplished by the cross-over or by-pass tube which allows suction gas to pass to right cavity where it can now be returned to compressor through bottom right opening.

REVERSE CYCLE VALVE OPERATION

At this point it is appropriate to emphasize that as the compressor functions as the heart of the refrigerant circuit, the reverse cycle valve serve as "nerve center". It is directly responsible for system's operation for heating or cooling.

There are several manufacturers of reverse cycle valves but all valves have the same general configuration. The main section of the valve is a cylinder which contains a slide piston that moves across openings of three tubes. Center tube of the three is always the suction connection to compressor. Two outer tubes connect to either coil. Single tube on opposite side of cylinder is always discharge connection from compressor.

The small cylinder to which solenoid coil is attached is actually a valve itself-called a "pilot valve". Its function is to relieve pressure on ends of large cylinder allowing slide piston to move to either indoor or outdoor coil.

OPERATION FOR COOLING

With solenoid coil de-energized, valve is in position. Spring loaded piston in pilot valve closes left port and opens right port. This allows discharge pressure, bleeding through bleed hole in right side of piston in main body of valve, to be relieved through the right capillary, then through right port of pilot valve, and through the common capillary to suction tube. Discharge pressure will also bleed through bleed hole in left side of piston and pressure will build up, due to blocked left capillary. This moves piston to the right.

As the piston seats at right side it seals port of right capillary. Since both left and right capillaries are now blocked, pressures on both sides of piston will equalize and valve will remain in this position throughout the cooling cycle. The slide port will straddle suction tube and tube to indoor coil. Tube to outdoor coil will be open to discharge tube through main body of valve.

OPERATION FOR HEATING

When solenoid is energized, plunger in pilot valve will move to left, opening leftport and closing right port. This relieves discharge pressure, bleeding through bleed hole in left side of position in main body of valve. This bleed off continues through the left capillary, through left port of pilot valve and through common capillary to suction tube.

Discharge pressure in main body of valve will also bleed through bleed hole in right side of piston, causing a pressure build-up because right capillary is blocked by plunger in pilot valve body. This will cause piston to move to left, a reversal of the action taking place for cooling operation.

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The piston will then seal port of left capillary. Once again, pressure on two sides of piston will equalize and valve will remain in this position throughout the heating cycle.

The slide port will straddle suction tube and tube to outdoor coil. The tube to indoor coil will be open to discharge tube through main body of valve.

REFRIGERANT CIRCUIT APPLICATION

If a reverse cycle valve is placed in a refrigerant circuit, result will be the configuration shown in Figure 26F03A. Note reverse cycle valve is in cool position. Refrigerant flows from indoor coil, through loop of "RC" valve to suction of compressor, then discharge from compressor, again passes through "RC" valve to outdoor coil. The only component missing here is some type of expansion device between outdoor indoor coil.

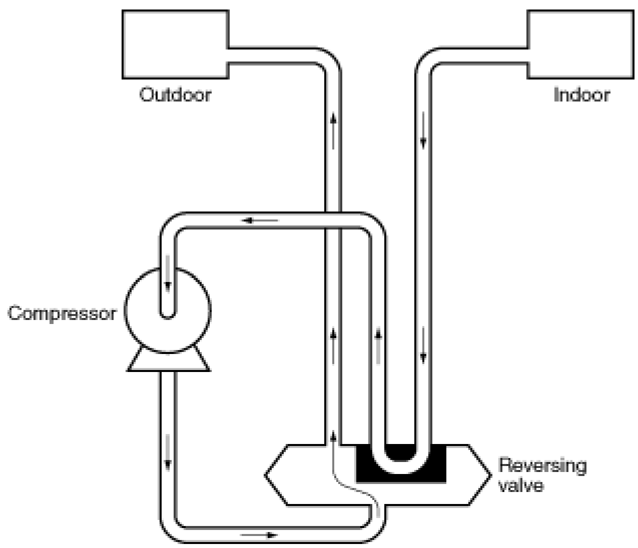

Figure 26F03A

Energizing solenoid coil causes slide to shift into heat position. Refrigerant flow is then from outdoor coil, through loop of "RC" valve, through suction line, to compressor, out of compressor through discharge line, through "RC" valve to indoor coil. Note that indoor coil is condenser and outdoor coil is evaporator.

Circuitry shown in Figure 26F03A is basic in all heat pumps. Liquid line and expansion devices are purposely omitted because they are components which change in various types of heat pumps.

EXPANSION DEVICE APPLICATION

Capillary Tube

If a capillary tube were superimposed on a basic circuit, as shown in Figure 26F03B, a complete heat pump refrigerant circuit would now exist. The capillary would be used as expansion device with "RC" valve in position for cooling cycle. This basic circuit, except for reversal of "RC" valve is used for heating cycle.

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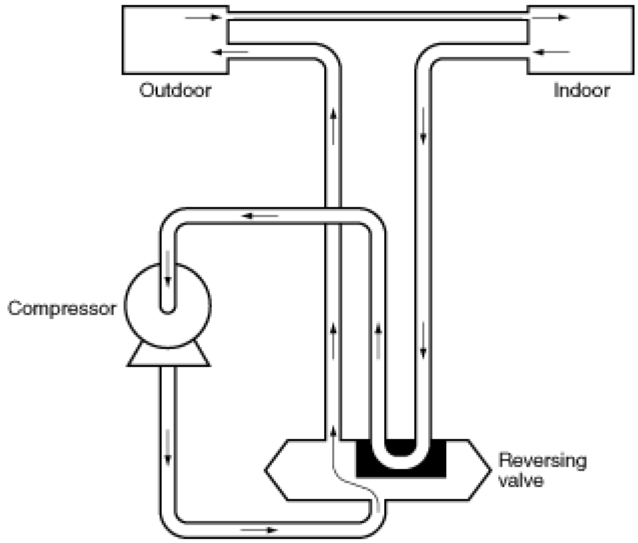

Figure 26F03B

Capillary Tube-Expansion Value Combination

Figure 26F04 pictures use of a capillary tube for cooling and thermal expansion valve for heating cycle. Note the two check valves in series — parallel with expansion valve and capillary tube. These are used to direct refrigerant flow either through or around expansion devices as desired. The check valve in parallel with capillary tube is open on heating and closed on cooling cycle. Conversely, check valve in parallel with heating expansion valve is closed on heating and open on cooling cycle.

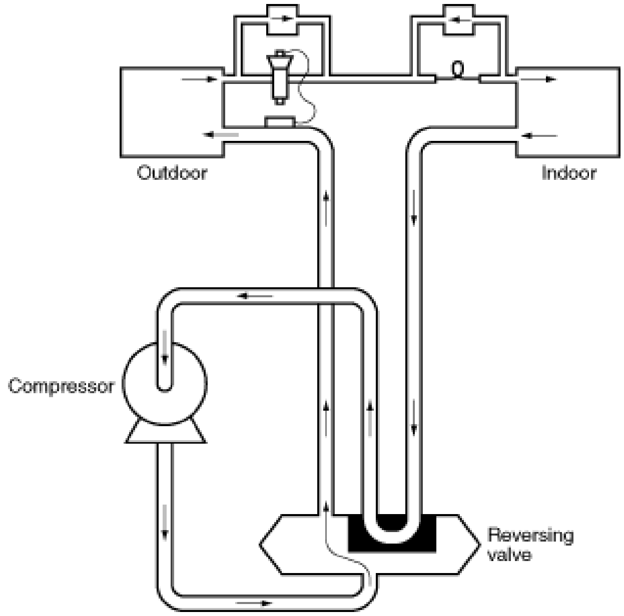

Figure 26F04

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Figure 26F04 also shows refrigerant flow on cooling cycle. Refrigerant flow of heat pump will reverse on heating cycle when a "T.X." valve and capillary tube are employed as refrigerant metering devices.

Another variation in expansion devices used two expansion valves and two check valves. This circuit operates similar to one pictured in Figure 26F04. Check valve near indoor coil is closed on cooling and open on heating with check valve at outdoor coil operating in reverse. Refrigerant flow in this figure indicates cooling cycle operation.

Figure 26F04A shows the refrigerant flow during heating cycle when two expansion valves and two check valves are used.

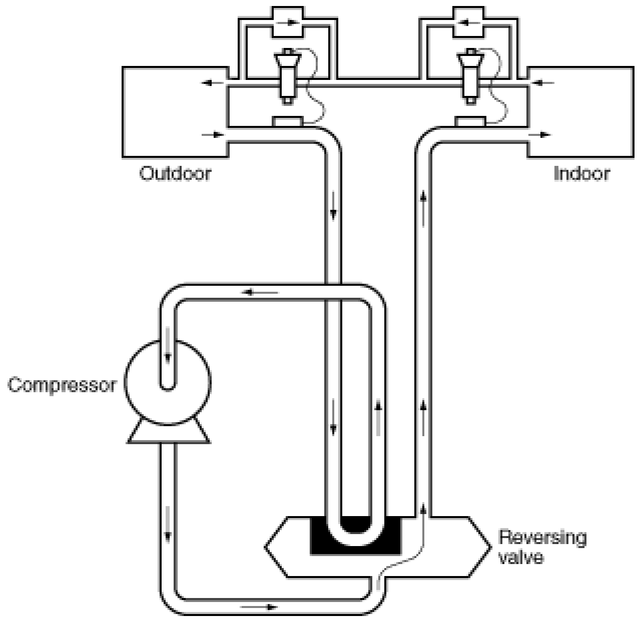

Figure 26F04A

Figure 26F04B presents a circuit using two expansion valves, two check valves and the addition of a subcooler and two receivers.

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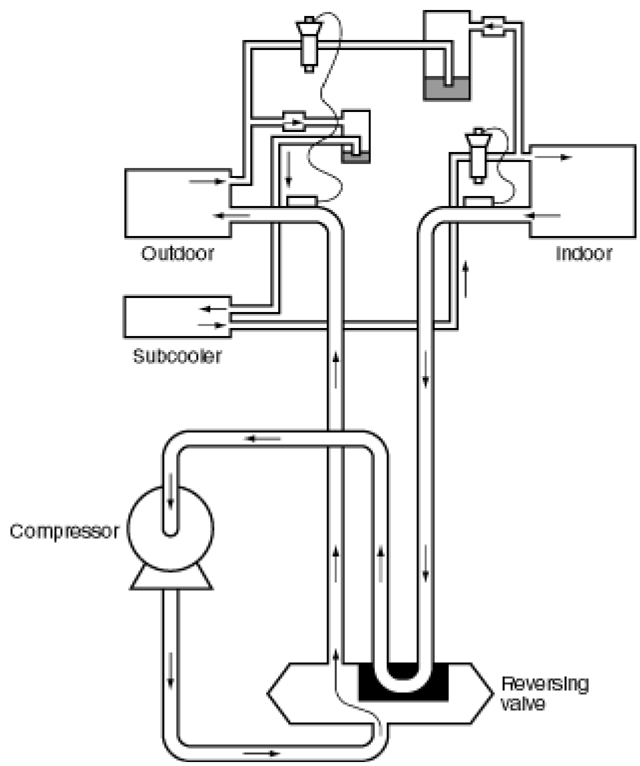

Figure 26F04B

Purpose of subcooler and receivers is to gain added subcooling and insure liquid at expansion valve.

On cooling cycle, discharge gas leaves compressor, passes through "RC" valve to outdoor coil. It passes through outdoor coil check valve into receiver, through receiver, and subcooler, to indoor expansion valve. From valve, refrigerant flows through indoor coil and back to "RC" valve and enters compressor through the suction line.

As shown in Figure 26F05, with "RC" valve energized on heating cycle, refrigerant flows through indoor coil and check valve to receiver. From receiver refrigerant flows though outdoor expansion valve, outdoor coil, "RC" valve and back to compressor. In this application, subcooler is used only on cooling cycle.

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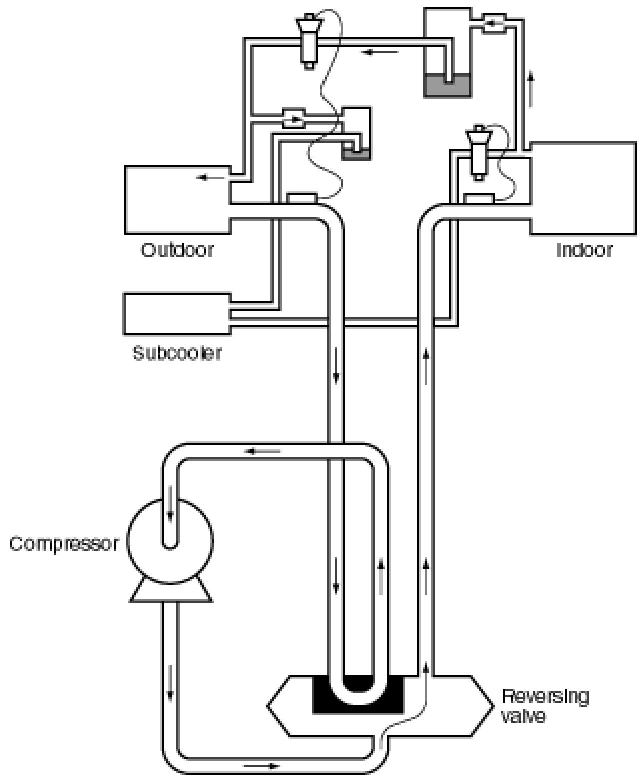

Figure 26F05

Figure 26F05A indicates further modifications in system circuitry utilizing four check valves, two expansion valves, and two subcoolers. Also note expansion valve distributor feeds which are extended into coil passes beyond headers.

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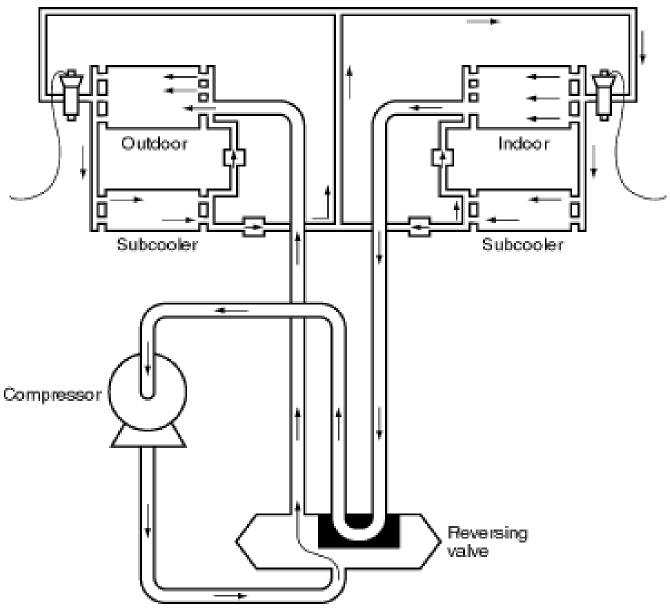

Figure 26F05A

This Figure 26F05A also shows refrigerant flow on cooling cycle. Refrigerant gas flows from compressor through "RC" valve to outdoor coil, after passing through condenser, where it becomes a high pressure liquid. Liquid then flows through header, down into subcooler where it is subcooled. It then flows through open check valve, through liquid line to expansion valve on indoor coil. Distributors feed refrigerant through both coils which now act as evaporators. The open check valve allows refrigerant from both coils to flow through a common suction line to "RC" valve and back to compressor.

The heating cycle is similar to cooling cycle with indoor coil functioning as condenser and subcooler, and outdoor coil as evaporator when energized "RC" valve reverses refrigerant flow.

This circuit affords added efficiency on the heat cycle because of heat removed from liquid by subcooling.

'SLAVE VALVE' APPLICATION

This valve is essentially a small "RC" valve with pilot valve and solenoid removed. Suction capillary is brazed shut, with remaining two capillaries extended and attached to vapor line to both coils. One capillary is attached to vapor line of indoor coil and one to vapor line of outdoor coil. Thus, when vapor line to outdoor coil is the discharge line on cooling cycle, high pressure will move slide in the valve in one direction. When main "RC" valve is energized and vapor line to indoor coil becomes the discharge line, high pressure pushes the slide in the other direction.

To trace refrigerant flow in this circuit on a cooling cycle one must refer back to Figure 26F05B. The main "RC" valve is de-energized, and hot gas flows to outdoor coil. High pressure on upper end of this 'slave' "RC" valve causes slide to move down. Liquid leaves the condenser and flows through 'slave' "RC" valve, to expansion valve. It then loops through the 'slave' "RC" valve again and into indoor coil. From there it flows down suction line, to main "RC" valve and back to compressor.

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Energizing the main "RC" valve causes discharge gas to flow to indoor coil. Resulting high pressure on the bottom end of 'slave' "RC" valve causes slide to move up. Liquid will now flow through 'slave' valve, to expansion valve. It will then travel through 'slave' valve upwards to outdoor coil, and back to main "RC" valve and compressor.

Thus far, the basic heat pump circuit, consisting of compressor, "RC" valve and associated piping and various types of expansion devices and coil circuit arrangements has been the major topic of this presentation. At this point air circuits should be covered briefly, as knowledge of this phase of heat pump operation is equally important.

AIR CIRCUITS

In a cooling only unit there are two fixed air circuits–indoor air and outdoor air. In a heat pump, however, indoor or outdoor air can be either condenser or evaporator air at any given time. Therefore, the unit and the installation must be designed to handle varying conditions.

CONDENSER AIR

On the cooling cycle when outdoor coil is the condenser, conditions are those we are familiar with. Any obstruction of air flow will cause high head pressure. Duct-work or external resistance cannot be applied to propeller fans. Air quantity is usually fixed and cannot be varied without radically changing the unit.

If air is too cold, problems of low head pressure arise. This can head to low suction pressure and evaporator freeze-ups.

When the indoor coil becomes the condenser, as it does on the heating cycle, several new conditions arise....Air quantity is variable, either by use of adjustable pulleys on belt driven blowers, or by restriction of duct-work applied. Here duct design should take into consideration the fact that nominal air quantity is needed.

In defining restrictions of the indoor coil, the old nemisis dirty filters should not be overlooked. Since this coil is the condenser, restriction caused by such filters will result in high head pressures. Too much air, and this is seldom a factor, can result in lowered head pressure.

EVAPORATOR AIR

Normally, the indoor coil is the evaporator. Everyone should be familiar with this application.

When the outdoor coil becomes evaporator on heat cycle, conditions arise which must be recognized. First, suction pressure will be lower than normally seen on cooling units.

Second, a lower coil temperature will exist.

Since the unit is removing heat from outdoor air, air off temperature will be lower than ambient temperature. Operating in this manner with coil temperature below 32°F the coil will frost even at ambient temperatures above freezing.

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THREE FUNCTION CONTROL REQUIRED

Controls are the most interesting components in a heat pump system. More controls are needed for a heat pump than for a cooling unit....Why? Because it must perform three functions instead of one. it must cool, it must heat, and it must defrost outdoor coil when ice accumulates on it. Why does ice collect on the coil? Contrary to indicating poor design, this is just a natural result of extracting heat from relatively cold air by use of a colder coil.

CONDENSER COIL ICING

This condition can be qualified by consulting a psychrometric chart. Assume outside air is 45°F D.B. and relative humidity 70%. Hypothetical unit, of three-ton capacity, has a suction pressure of 50 lbs. A T.P chart will show suction temperature of about 25°F. As relatively warm air flows through the colder coil, D.B. temperature drops, but moisture content remains the same. When air reaches 35°F D.B. it will have a relative humidity of 100%. This is dewpoint and water is formed on coil. Air temperature continues to drop to 32°F, at which point water will freeze and form ice. Ice collects in the coil, and, prevents air from passing through, air that does get through will get colder and more ice will form. Eventually, the coil becomes blocked with ice and must be defrosted.

DEFROSTING METHODS

It is obvious that in order to defrost the coil, heat must be added to melt the ice. Of two methods available, one, incorporating electric heaters imbedded in the coil is rarely used, although it was tried on older units. The more common method is to reverse the cycle making the outdoor coil the condenser, and using discharge temperature to clear the coil of ice. To increase temperature of condenser, we can raise head pressure by stopping outdoor fan.

DEFROST CONTROLS

Timer Control

There are numerous methods of signaling the control circuit when unit needs a defrost cycle. A timer, temperature control or pressure control can be used. The use of a timer is a simple method requiring no sensing bulbs or external devices, but this control cannot sense need for defrosting in advance of the critical point, causing excessive defrost periods or in rare cases, delaying a defrost cycle until coil is completely frozen.

Figure 26F06C illustrates another type of timer defrost initiating control... The capillary tube and sensing bulb control defrost cycle termination and will be covered later in the text.

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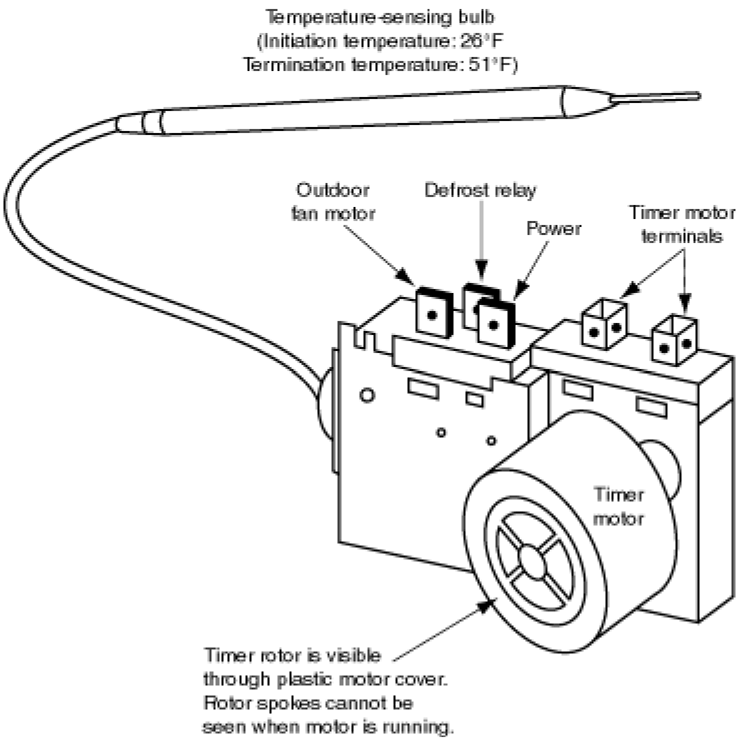

Figure 26F06C

Temperature Sensing Controls

Another method involves use of the temperature differential between coil and outside ambient temperature. As ice accumulates on the coil, the coil temperature drops. Therefore the differential between the ambient temperature and the coil temperature will increase. Figure 26F07 shows a control which is a switching device with two sensing bulbs. One is attached to outside coil. The other mounted so that it senses outdoor ambient temperature. When spread between temperatures of the two bulbs reaches a pre-set point, the control switches unit into defrost cycle.

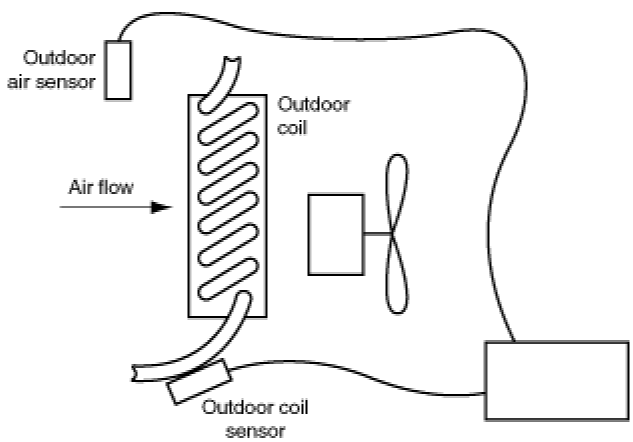

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Figure 26F07

Air Pressure Sensing Control

When ice builds up on outdoor coil, it allows less air to pass through coil. This resistance can be measured by using a control such as shown in Figure 26F07A. This is a diaphragm type control with pressure taps on each side. One tap is connected to outside of unit. The other is mounted inside unit to sense air flow through outdoor coil. When this differential, which is increased by ice build-up, reaches a pre-set point, the control causes unit to go into a defrost cycle.

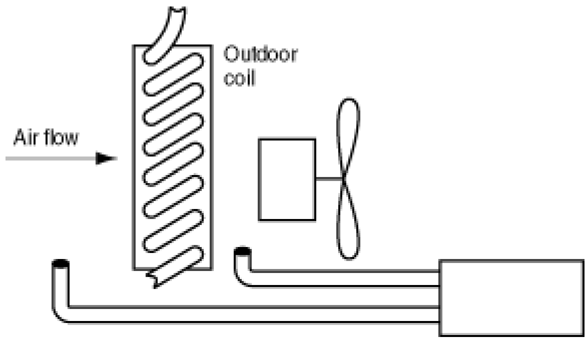

Figure 26F07A

In contrast to a straight timing device, the last two types of defrost initiation devices illustrated do exercise some control over ice accumulation and thus avoid unnecessary defrosting.

DEFROST CYCLE TERMINATION

Having initiated a defrost cycle, a method must be provided to terminate defrosting when ice has melted off coil. Again, there are several ways of accomplishing this. One could be a timer with switching arrangement so that after a period of running on defrost cycle, it would put the unit back on heat cycle.

Another method could be a head pressure control which would sense a rise in head pressure as ice melted off and coil warmed up. To speed up this process, the outdoor fan is stopped during defrost period.

Temperature of liquid out of outdoor coil could also be measured. This would give the same reaction as pressure difference. As temperature rose after ice melted a thermostat bulb on liquid line would sense this change and terminate defrost cycle.

A few examples of defrost controls are given in the following:

Figure 26F06C illustrated a timer initiating defrost control with temperature sensing bulb and capillary tube, with bulb attached to liquid line from coil, this control terminates defrost by measuring temperature of liquid leaving outdoor coil.

Another type of temperature defrost termination control is one in which the diaphram type sensor is clamped to liquid line outlet from condenser.

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CONTROL WIRING DATA

Cooling Application

How some of these controls fit into a typical system is explained in Figure 26F08, L1 and L2 are the power lines. By connecting compressor, outdoor fan motor and indoor fan motor across the lines, a cooling unit would exist, but without control.

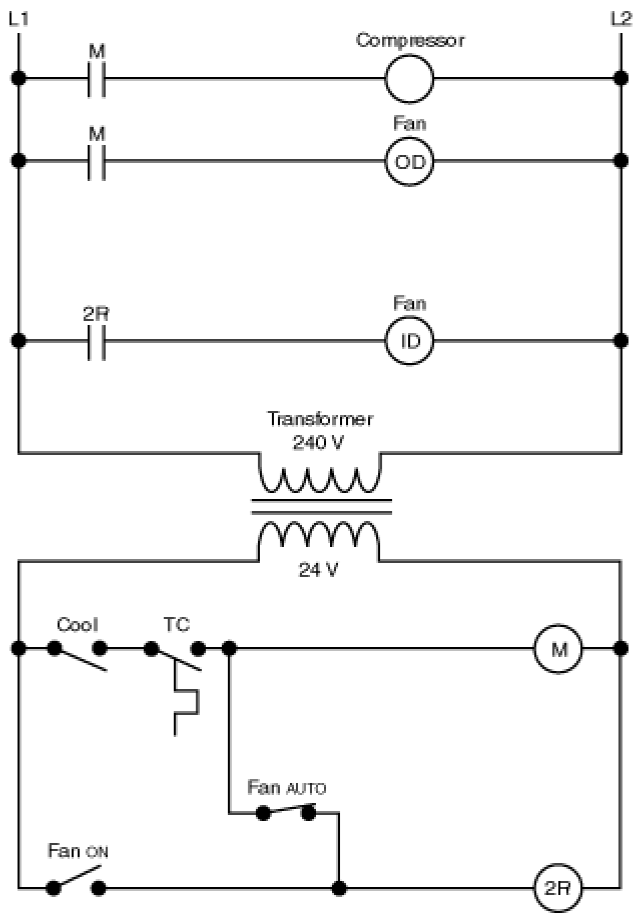

Figure 26F08

To control operation of this unit, a thermostat with a "cool" switch and "fan" switch is needed. The manual cool switch and bi-metal operated mercury switch control the magnetic coil of contactor "M". Contacts of "M" operate compressor and outdoor fan.

The fan switch controls 2R relay whose contacts operate indoor fan. The "auto" switch allows cool switch to operate indoor fan only when compressor runs.

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Heating Application

To convert the cooling unit into a heating unit, more controls are added, as shown in Figure 26F08A. These include a reverse cycle valve to divert discharge gas to the indoor coil, and a solenoid coil, connected across L1 and L2. To control the heat cycle, a heat switch on thermostat to operate relay 4R is also employed. 4R1 contacts energizer "RC" valve coil. 4R2 contacts control compressor contactor "M" so that compressor will run on heat cycle.

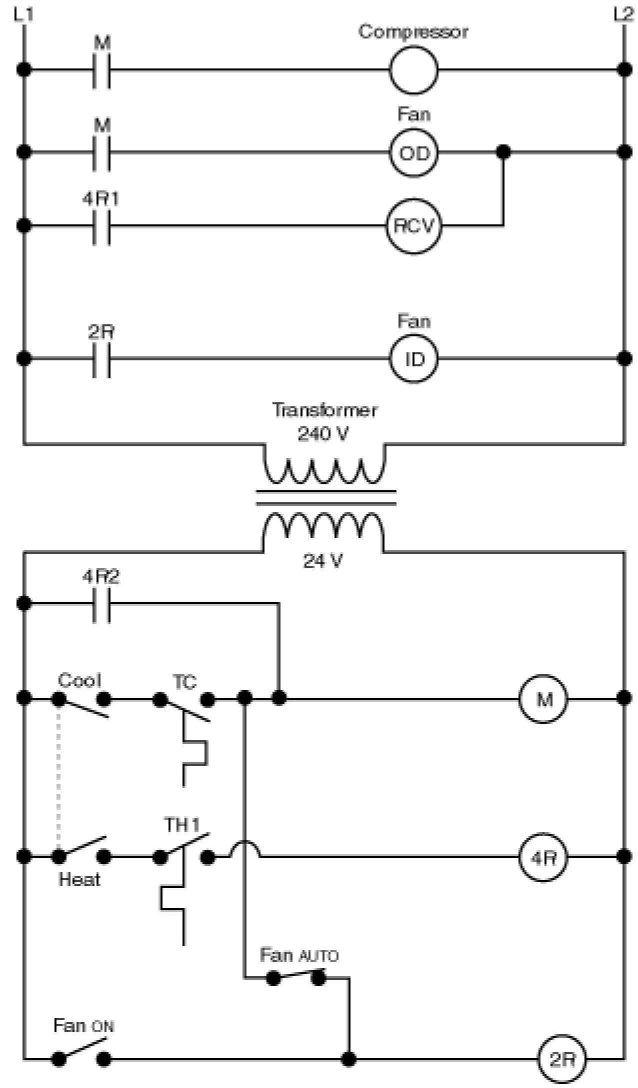

Figure 26F08A

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Defrost Initiation

When unit is operated on heating, outdoor coil accumulates ice, and must be defrosted. To accomplish this, controls are added, as shown in Figure 26F08B, a timer..."TM" is used. Timer motor is connected in parallel with "RC" valve solenoid and operates whenever valve is energized.

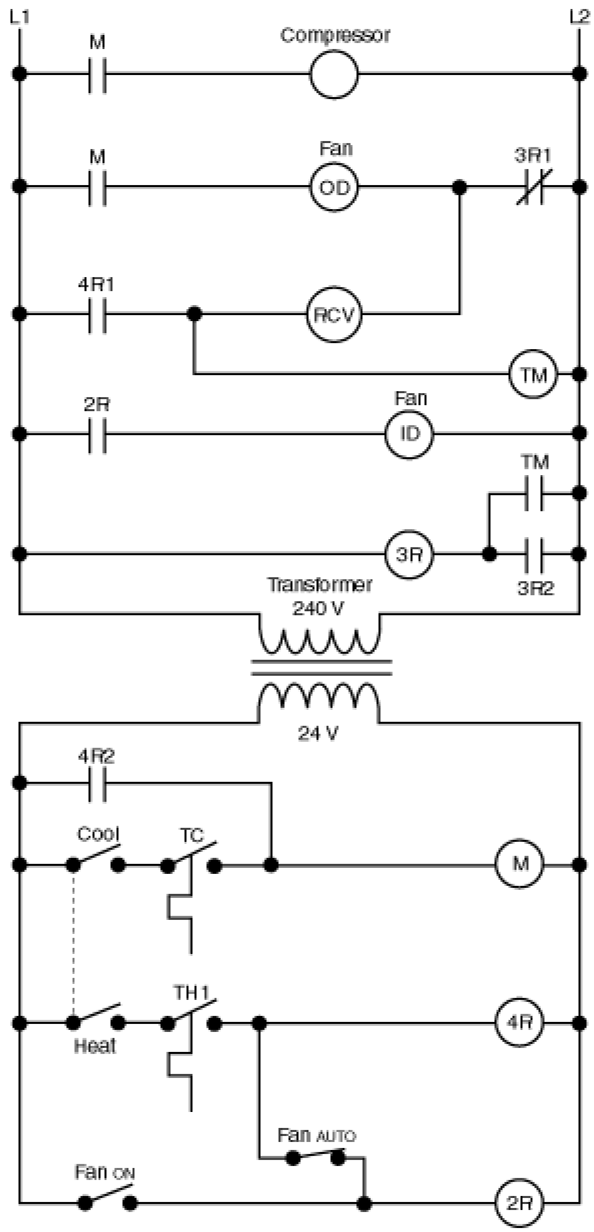

Figure 26F08B

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Timer runs for one hour and then closes "TM" contacts. 3R relay is in series with"TM" contacts and is energized when "TM" is closed. 3R2 contacts are also in series with 3R coil and in parallel with "TM" contacts, thus 3R2 contacts hold 3R coil energized one "TM" contacts are closed.

After twenty-seconds,"TM" contacts open, but 3R coil is held energized by 3R2. 3R1, normally closed, in series with "RC" valve coil, stops outdoor fan and de-energizes "RC" valve.

This allows the unit to operate as a cooling unit, with outdoor or condenser fan stopped. Head pressure and resultant temperature will rise rapidly and melt frost from coil.

Defrost Termination

Figure 26F09 illustrates wiring details of control to terminate defrost cycle, the defrost termination switch, which can be temperature or pressure operated, senses liquid line temperature or pressure and at a pre-determined point opens circuit to 3R. When 3R1 reverts to its normally closed position, outdoor fan starts and "RC" valve is energized into heat position. Unit is now on heating cycle.

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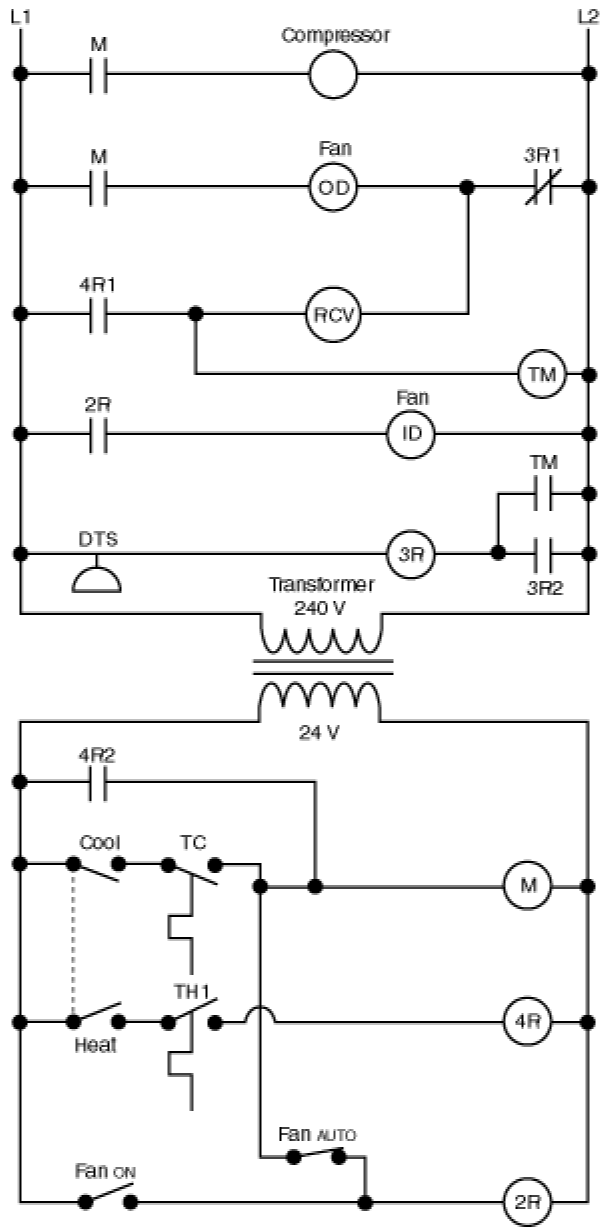

Figure 26F09

AUXILIARY HEATING

Auxiliary electric heat is normally added to heat pumps to provide the required heating capacity at low outdoor temperatures and as Figure 26F09A indicates operates off the second-stage of the thermostat. To prevent heaters from operating when compressor can supply enough heat, thermostat ODT-1 is placed in series with heater relay.

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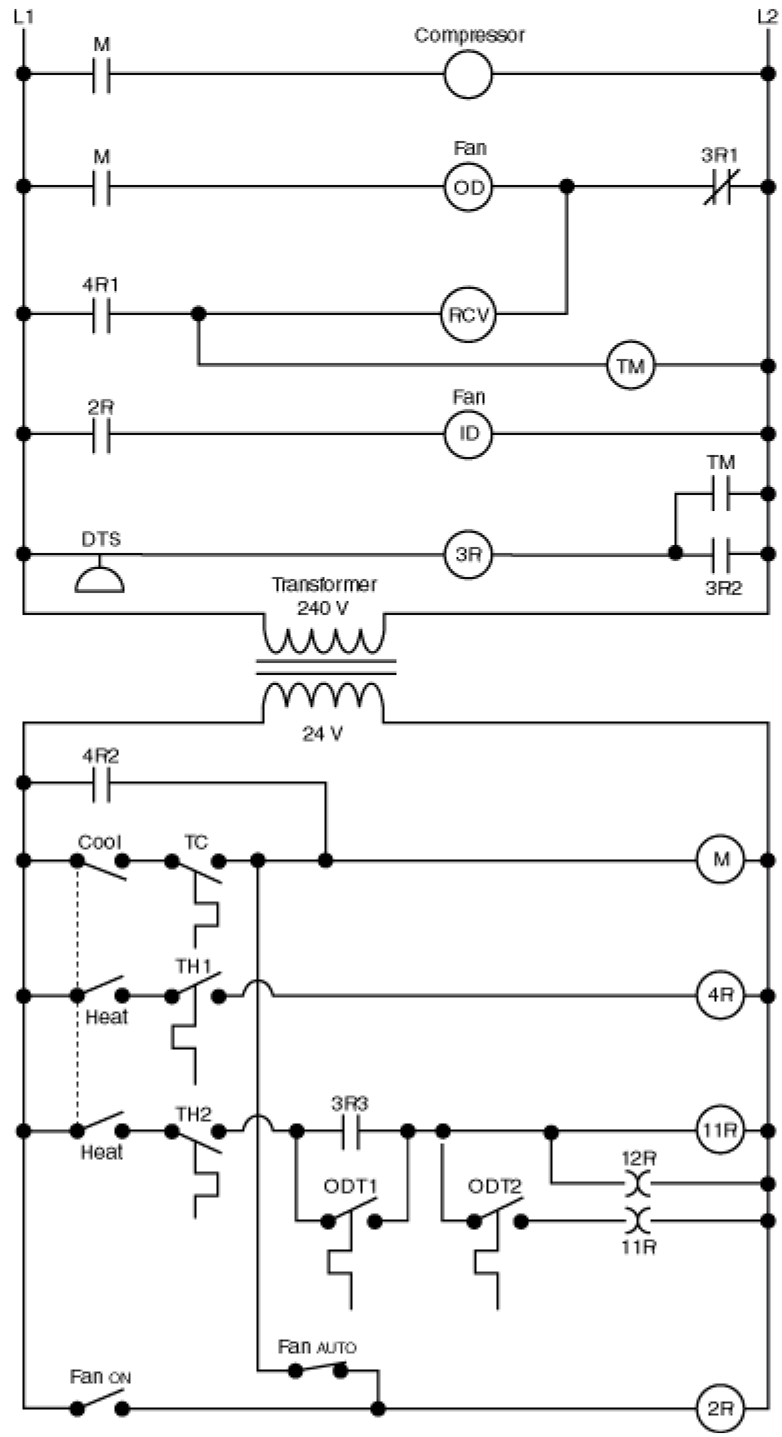

Figure 26F09A

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This thermostat is adjustable and can be set to close at desired temperature. Thus, when ODT-1 is closed, TH-2 (mercury switch) will control relay 10R which operates first bank of electric heat. 12R is a time delay relay which operates second bank of heaters.

ODT-2 is another adjustable outdoor thermostat which controls operation of 11R time delay relay and third bank of heaters.

Contact 3R3 is in parallel with and by-passes ODR-1 on defrost cycle to allow at least one stage of electric heat during defrost cycle when indoor coil is evaporator.

PERFORMANCE DATA

BTU Output

Because of higher outdoor temperatures the heat pump cycle is more economical to operate than auxiliary heaters, an effort should be made to set outdoor thermostats at lowest possible settings commensurate with comfort of conditioned space.

Table 26T09C illustrates performance data of a typical three-ton unit. It is apparent that at 0°F outdoor temperature that heat pump will supply 12,250 BTU's. At 70°F it will supply 44,500 BTU's. Other data shows performance with one, two, or three heaters.

Table 26T09C — Total Heating Capacity for Typical 3-Ton Unit

AIR TEMP ON INDOOR COIL DEG.F.	AIR TEMP. ON OUTDOOR COIL-DEG.F.					
	70 BTUH	50 BTUH	45 BTUH	40 BTUH	20 BTUH	0 BTUH
70	44,500	36,000	34,000	29,400	19,000	12,250
70	"	"	47,650	43,050	32,650	25,900
70	"	"	61,300	56,700	46,3000	39,550
70	"	"	74,950	70,350	59,950	53,200

Auxiliary Heat Requirement

This data as plotted in Figure 26F09B with required heat load, shows when it is necessary to use electric heaters to supplement heat pump.

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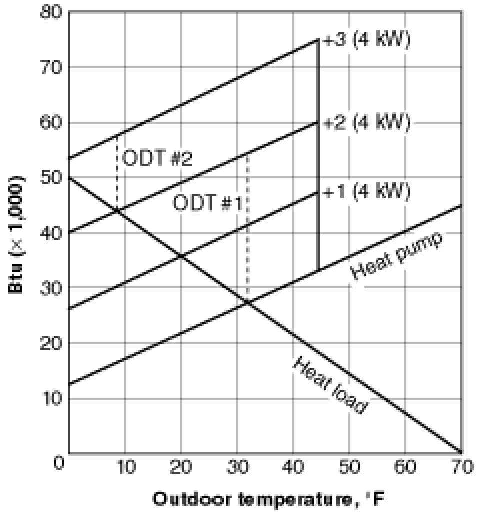

Figure 26F09B

Note that in this illustration heat loaded is 50,000 BTU's at 0°F and 0 BTU's at 70°F.

The heat pump will handle the load down to 32°F. Here one or two banks of heaters must be energized. At 9°F a third heater is needed. On an actual installation heaters would be energized at somewhat higher temperatures than indicated in Figure 26F09B to allow for losses not calculated and other variables.

Discussing this typical three-ton unit, let's look a little deeper into the operation of the unit.

Service Curves

Some manufacturers have service curves available for heat pumps similar to Figure 26F10 on this chart suction pressure is across bottom and discharge pressure on left side. Air on outdoor coil in dry bulb temperature and air on indoor coil, wet bulb temperature make up the rest of the data.

BASIC HEAT PUMP THEORY

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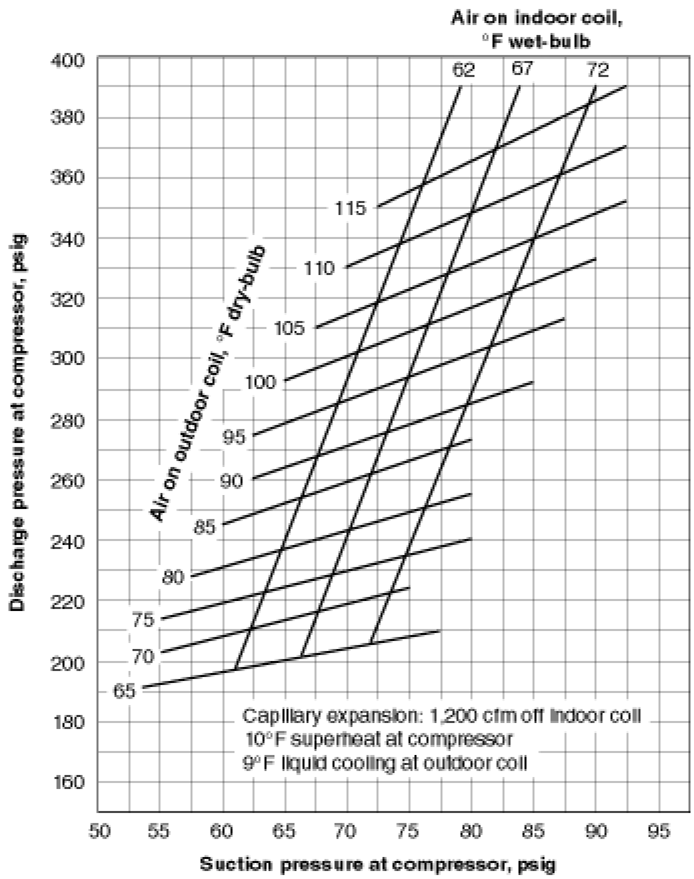

Figure 26F10

Assuming some conditions of outdoor and indoor ambients much can be learned from this chart. As an example, select a room temperature of 80°F dry bulb and 65°F wet bulb, with air on outdoor coil 95°F. These conditions when plotted on curve should give 288 lbs. head pressure and 72 lbs. suction pressure.

Cooling Cycle Performance

Performance of refrigerant circuit can be determined in Figure 26F10A. At compressor, discharge pressure is 288 lbs. Temperature equivalent of this is 127°F assuming 70°F or 80°F superheat in discharge line, one can then expect a temperature of 200°F to 210°F.

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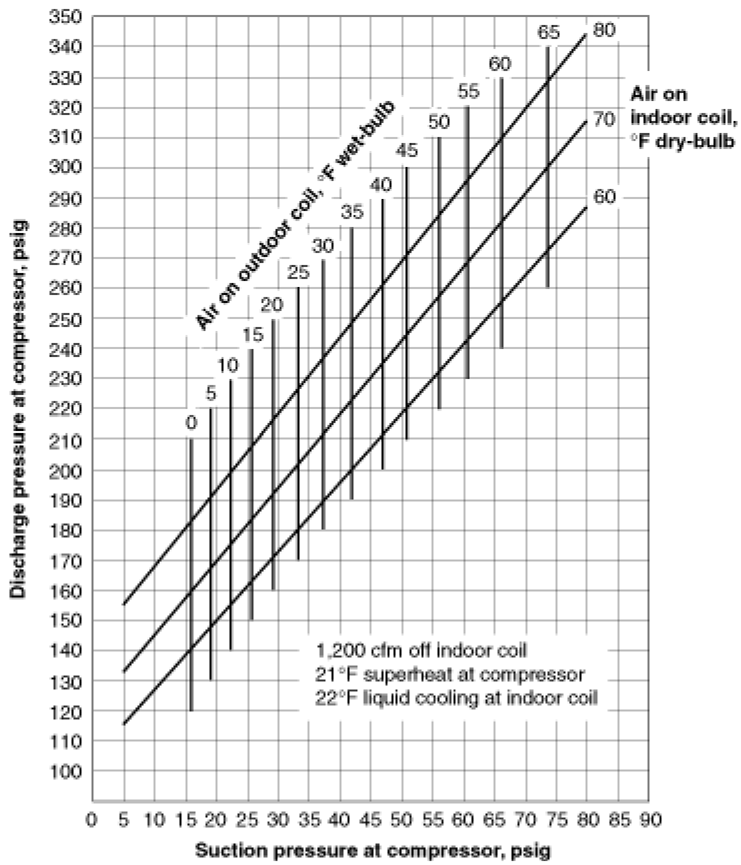

Figure 26F10A

This superheat will be removed in condenser so the next assumption would be that temperature out of condenser would be about 125°F with no subcooling. Since some subcooling is also provided in condenser, temperature of 110°F could be assumed. Liquid pressure is still 288 lbs. less any pressure drop in condenser and liquid line.

At expansion device, pressure drops to 72 lbs. Evaporator temperature will be 42°F because of addition of superheat, suction temperature at compressor will be 58°F. Suction pressure will be 72 lbs. less any pressure drop in suction line.

Air on evaporator was assumed to have a temperature of 80°F. Air off evaporator should then have a temperature of approximately 60°F. Air temperature off condenser should be 115°F.

These figures are approximaate but, if unit is operating properly, they are indicative of pressures and temperatures expected.

Heating Cycle Performance

Figure 26F10B illustrates the same procedure on heating cycle, assuming outdoor temperature of 45°F dry bulb and 40°F wet bulb with room temperature of 70°F dry bulb. These conditions when plotted show a head pressure of 255 lbs. and a suction pressure of 47 lbs.

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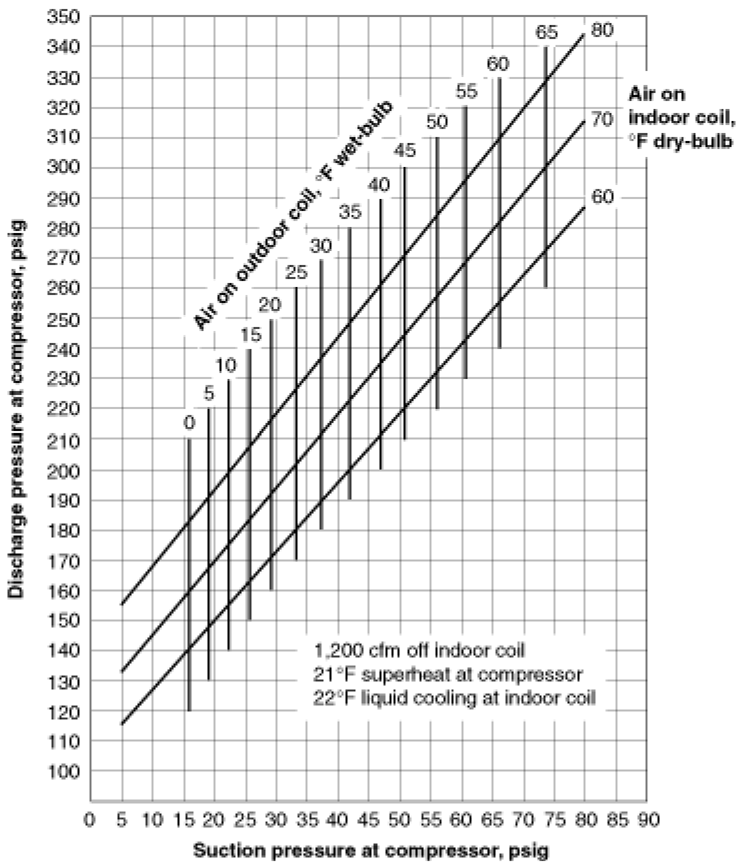

Figure 26F10B

This information, applied to refrigerant circuit and followed through as with the cooling cycle, provides data as shown in Figure 26F11.

BASIC HEAT PUMP THEORY

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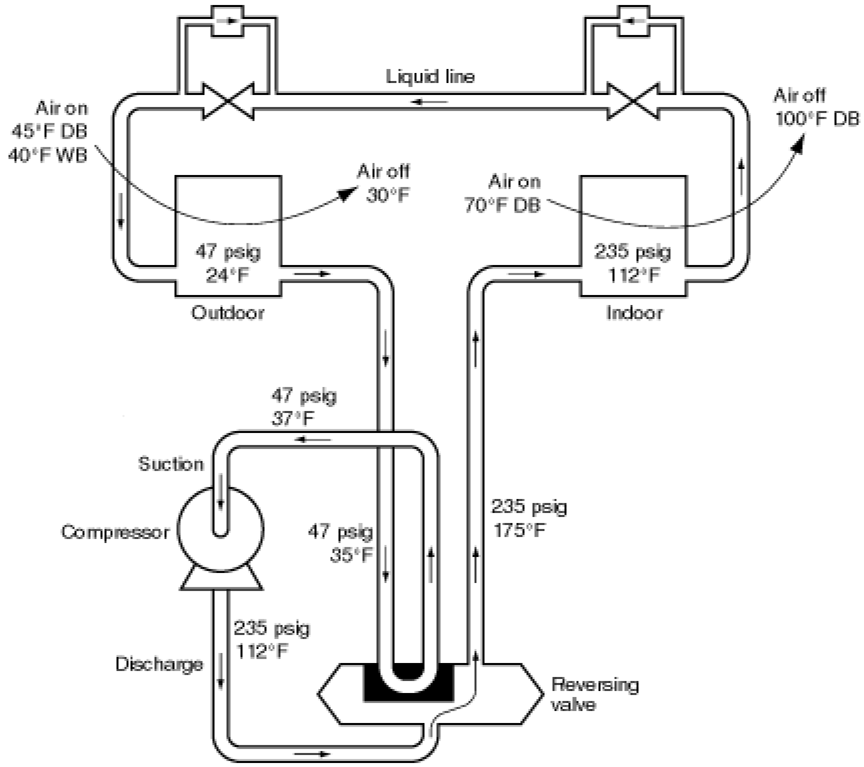

Figure 26F11

Note that temperature of outdoor coil is below freezing which means that it will accumulate ice and must be defrosted.

Air temperature off indoor coil is approximately 100°F which means comparatively low temperature air is being supplied to room and must be handled accordingly with regard to drafts and comfort. If 70°F air on indoor coil is allowed to decrease, resultant air off temperature will decrease causing long heat recovery cycles during which room will be cold.

These factors must be considered in duct-work design and operation of heat pump.