Heat Pumps Part 1: Reversing Valves

When the Arab nations cut back on oil exports in 1973, making it apparent that fossil fuels would eventually be depleted, energy costs soared. Energy saving devices would have to be made available as soon as possible.

An energy-saving machine termed a “heat pump” had been around for some time, but sales had been poor, and consequently, development of heat pump technology stagnated. The energy crisis changed that. There was now a demand for such a device. Manufacturers of heat pumps experienced growth of 200% to 300% per year.

Much mystery surrounded the operation of a heat pump. As a result, proper installation, operation, and maintenance of heat pumps suffered. Knowing what a “heat pump” is and how it works, was and still is, a needed skill in today’s marketplace.

A heat pump is a machine that pumps heat! Every air conditioner is, technically, a heat pump. Heat is pumped from the evaporator to the condenser. If the air conditioner was constructed so that the evaporator (the indoor coil) became the condenser (the outdoor coil) and vice-versa, the air conditioner could be used to both heat and cool an enclosed space. Early attempts to do this were very primitive. One of the first heat pumps simply rotated the whole unit! Another used a duct and damper system to direct the heated and cooled air to the conditioned space. All of the methods left a lot to be desired.

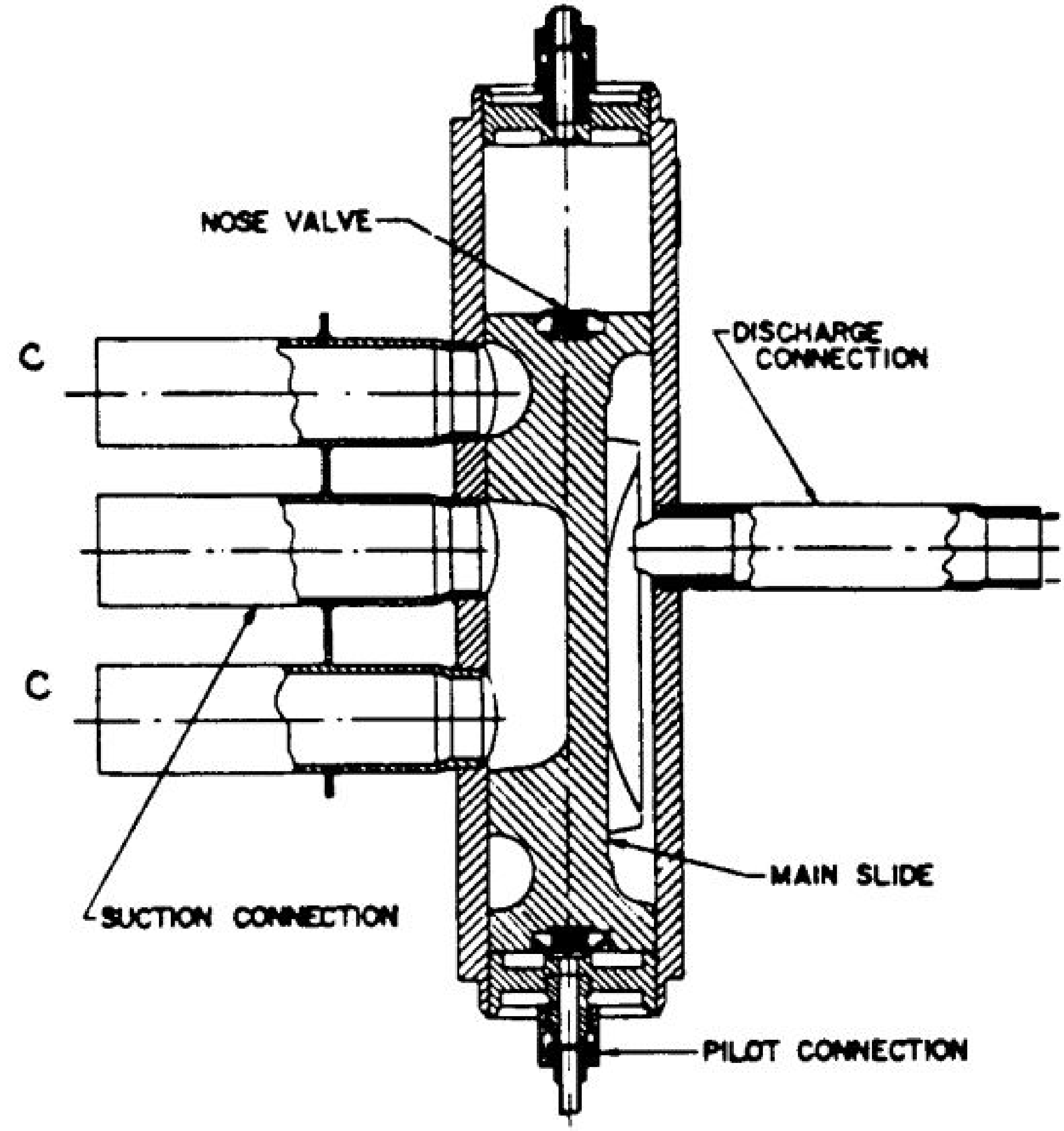
Soon, manufacturers found that by adding valves and by-pass piping to the refrigerant circuits, it was possible to make the indoor and outdoor coils behave so as to have either space heating or cooling.

The first efforts used four hand valves to direct refrigerant flow. Then, these valves were combined with two valves, which became solenoid operated. Finally, the four-way “reversing valve” was developed, and is in use today. In a heat pump, the compressor may be the heart of the system, but the reversing valve is the nerve center.

Two types of reversing valves were developed, a poppet-type and a slide-type. The slide-type proved to be the better of the two, and poppet-type valves have been obsolete for many years.

While there are many manufacturers of slide-type reversing valves, their basic construction and operation is the same.

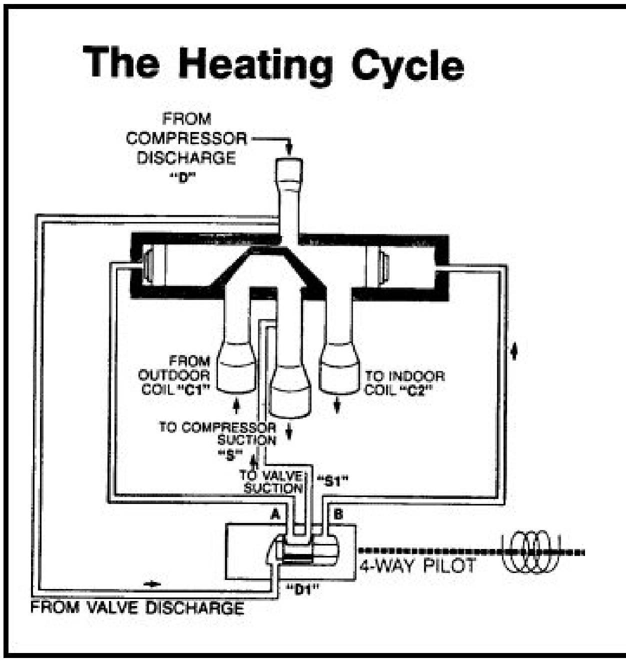
Figure 1 shows a typical slide-type valve without its piloting valve. The two connections labeled “C” next to the suction connection would connect to either the indoor or outdoor coil, depending on the configuration of a pilot valve.



Slide type reversing valve

Figure 1.

In **Figures 2 and 3**, a solenoid operated pilot valve has been added to the slide valve. The pilot valve is usually mounted directly to the slide valve, so a complete reversing valve consists of a slide valve and pilot valve.



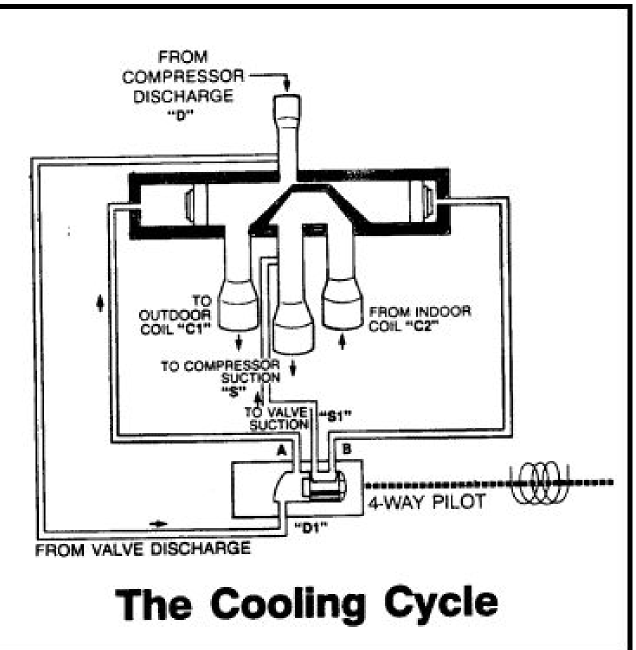


Figure 2.

Figure 3.

In Figures 2 and 3, the pilot valve has been configured so that when the pilot valve is de-energized, the system is in the heating mode, and energizing the pilot valve the system is in cooling mode. Reversing valves can easily be configured for opposite operation. Manufacturers of heat pumps vary the configuration of the valves, depending on whether they feel the system should "fail" to the heating mode or "fail" to the cooling mode.

This depends on how the reversing valve is piped. In Figures 2 and 3, to fail to cooling mode the indoor coil would be connected to valve port "C1" and the outdoor coil to port "C2."

In Figure 2, the system is on the heating cycle with discharge gas flowing through reversing valve ports "D" to "C2" making the indoor coil the condenser. The suction gas is flowing from the outdoor coil (evaporator) through reversing valve ports "C1 to "S" and back to the compressor.

With the 4-way solenoid pilot de-energized, the slide is positioned so as to connect ports “D1” with “B”, and “A” with “S1.” When the pilot is de-energized, high-pressure discharge gas builds up on the end of the main slide. The other end of the main slide is isolated from the high pressure by a cup seal and exposed to low-pressure suction gas. Thus, the unbalanced force, due to the difference between discharge and suction pressures acting on the full end area of the main slide, holds the slide in position as shown in figure 2.

When the coil is energized, the slide in the pilot solenoid valve shifts, now connecting pilot ports “D1” with “A”, and “B” with “S1”. With the pilot solenoid so positioned, the discharge pressure imposed on the other end of the main slide will flow through the pilot solenoid valve to the suction side of the system. At the right end of the main slide, high-pressure discharge gas will accumulate so as to increase the pressure. An unbalanced force in that direction is again due to the difference between discharge and suction pressures acting on opposite ends of the main slide.

This unbalanced force moves the main slide to the position as shown in Figure 3 and the force unbalance across the area of the main slide holds the slide in the new position.

The system has now changed over to the cooling cycle with the discharge gas flowing through reversing valve ports “D” to “C1” making the outdoor coil the condenser with the suction gas flowing through reversing valve port “C2” to “S” . . . making the indoor coil the evaporator.

Figures 2 and 3 show a modern 4-way pilot valve. Many reversing valves are made with 3-way pilot valves, as shown in **Figure 4**. Note that the slide valve is the same whether piloted by a 3-way or 4-way valve. Therefore, one can replace the other.

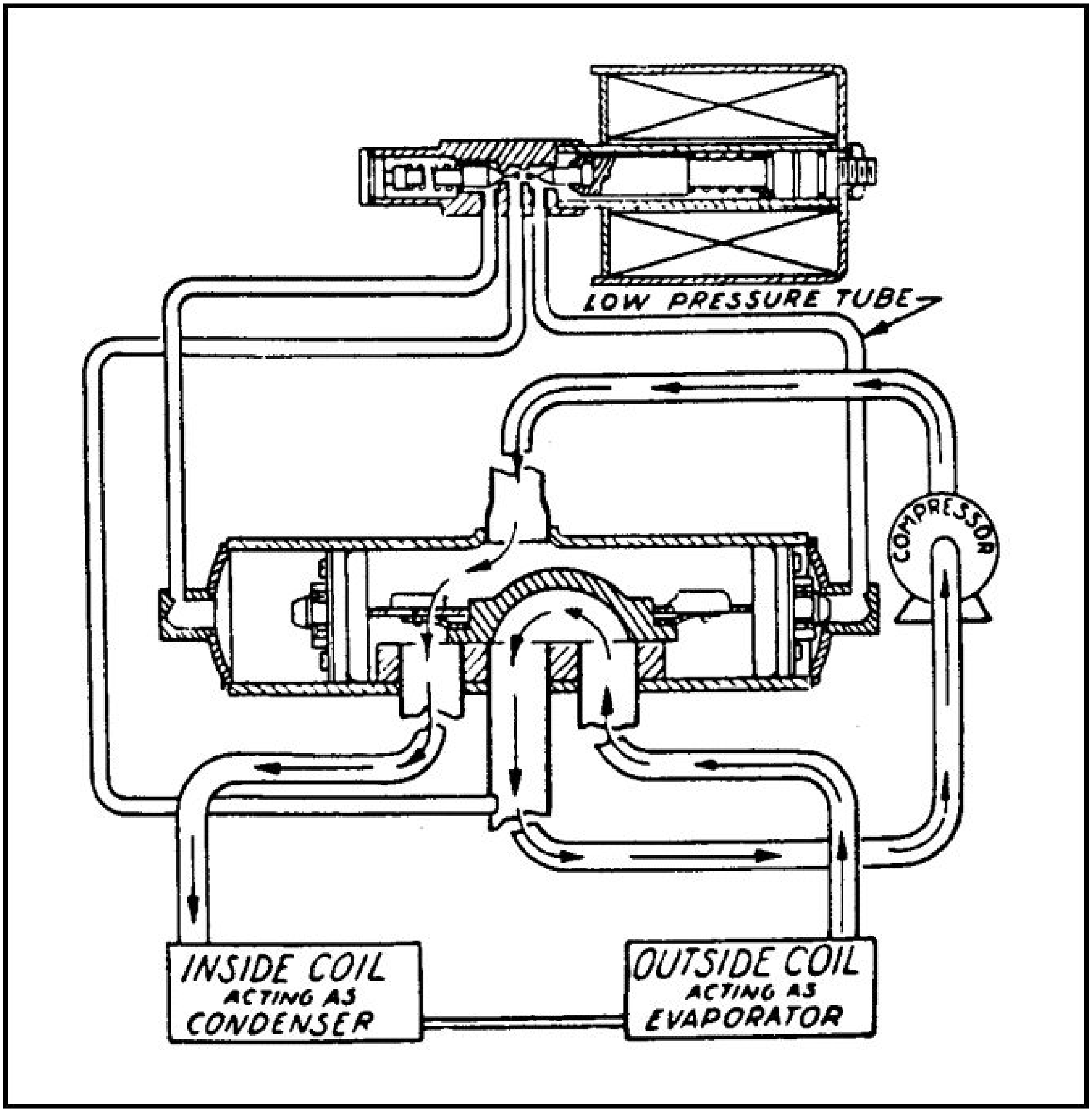


Figure 4.

Four-way pilot valves are being used more and more, as evidenced by Alco using 4-way pilot valves on their new series of reversing valves. Older style 401 Alco valves used 3-way pilot valves. Four-way pilot valves are more expensive than 3-way, but they last longer and have more spacious cavities in them to allow system debris to pass rather than clog the pilot. They also assure full system DP across the slide during shifting for reliable operation. Reversing valves are expensive. Contractor prices range from about $90.00 to over $300.00, depending on capacity. They are delicate! They are easily damaged in shipping and handling. A dent, even a tiny dimple can make the slide stick. Handle any reversing valve with extra care!

As we will see later, when describing heat pump systems, you cannot simply add a reversing valve to an air conditioner and make a heat pump.

The most common cause requiring reversing valve replacement is compressor burnout. When you have a compressor burnout, **REPLACE THE REVERSING VALVE!** You cannot clean up a reversing valve! It is first in line from the compressor discharge, and as the compressor is cremated, combustion products leave the compressor. Carbon particles, tar, resins, acids, a wide assortment of burnout products are generated by the breakdown of Freon, oil, and electrical insulation. These vaporized substances find a resting-place in the nearest cooler object, the reversing valve, where they condense. Trying to clean a reversing valve is a total waste of time. Actually, the valve has made system clean up after a burnout easier. It contains most of the debris that contaminates the system.

The discharge line connection is always the single port connection on one side of the slide valve. The suction line connection is always the center port on the other side of the slide valve, where there are three connections. The two connections, one on each side of the suction connection, go either to the indoor or outdoor coil, depending on how the system is configured when the pilot valve is energized and de-energized.

Other than replacing a burned out coil on the pilot valve, there is no other field service for a reversing valve. An Alco RV or 401RD will replace any other brand of reversing valve. To replace the valve, one needs to know:

1. The voltage of the pilot valve coil.

2. What refrigerant is in the system? (99% of the time it will be R-22)

3. Nominal line sizes.

4. Capacity, in tons, of the heat pump. Capacity tables in the Alco catalog are based on a 2-psi

DP across the valve suction ports. The 2-psi DP is a standard used for capacity ratings.

Undersizing the capacity rating will result in too high a pressure drop, which will cause a loss of BTU capacity of the system. Oversizing may result in poor or no operation of the reversing valve. A larger than necessary capacity rating will result in a very low pressure drop, possibly so low that the slide will not move, may chatter, or not seat well when the pilot valve is either energized or de-energized. It is the pressure difference across the slide that moves the slide.

Chances are a reversing valve in the selected capacity will have line sizes available to match the valve being replaced. It is not crucial that line sizes match up perfectly. Fittings may be used to increase or decrease the connections to fit the existing tubing. If the replacement valve has grossly mismatched line sizes, you've probably selected the wrong capacity valve.

Reversing valves can be mounted in any conceivable position. The replacement valve will usually be mounted in the same position as the valve being replaced. Today's reversing valves are very reliable, long-lasting devices. Except when the compressor burns out, they almost never have to be replaced.

In Part II, we'll examine the various heat pump systems in regard to refrigerant circuits.

Heat Pumps Part 2: Heat Pump Systems

In this section, we will confine our discussion to the various expansion device configurations for heat pumps. (Complete system design is far beyond the scope of this discussion. A good heat pump system must take into consideration many factors, such as duct work, air flow, insulation, etc.)

Large commercial and industrial heat pumps are custom tailored to a specific job. Small commercial and residential heat pumps are turned out production-line style. Most of these are of the "air to air" type. This article will cover the residential air-to-air heat pump, as it is the predominant configuration.

Probably the most popular configuration is one that has a TEV on the outside coil and a cap tube on the inside coil. See **Figures 1 and 2**. The use of a TXV on the outside coil results in controlled flow at all outside ambient conditions. The TXV's used for heat pump applications have special low superheat ranges. Alco's heat pump TXV's have an "HCA" bulb charge. Above 40 degrees F ambient, this charge operates the same as any regular air conditioning bulb charge with standard superheat. Below 40 degrees F, the HCA bulb charge provides 0 degrees F superheat. This results in controllable, wet suction gas to cool the compressor. Hermetic compressors have been "beefed up" to withstand the heavy-duty use imposed by heat pumps.

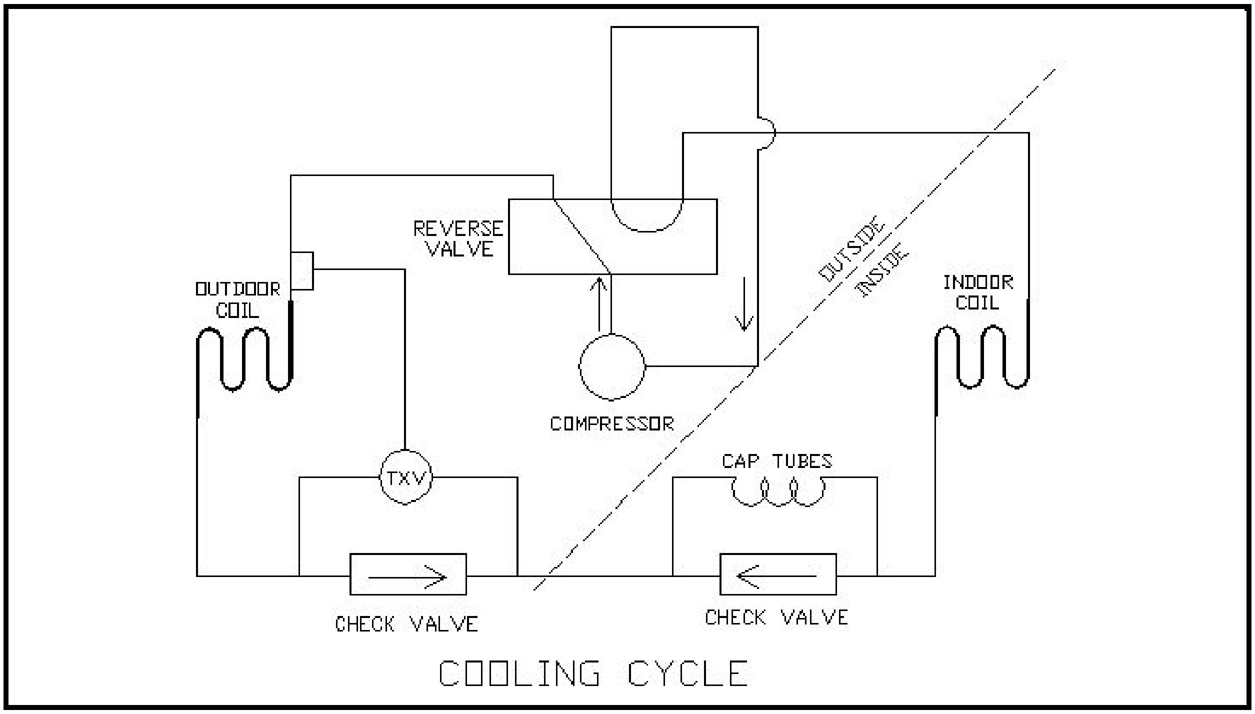

REVERSE VALVE
OUTDOOR COIL
OUTSIDE
INSIDE
INDOOR COIL
COMPRESSOR
TXV
CAP TUBES
CHECK VALVE
CHECK VALVE
COOLING CYCLE

Figure 1.

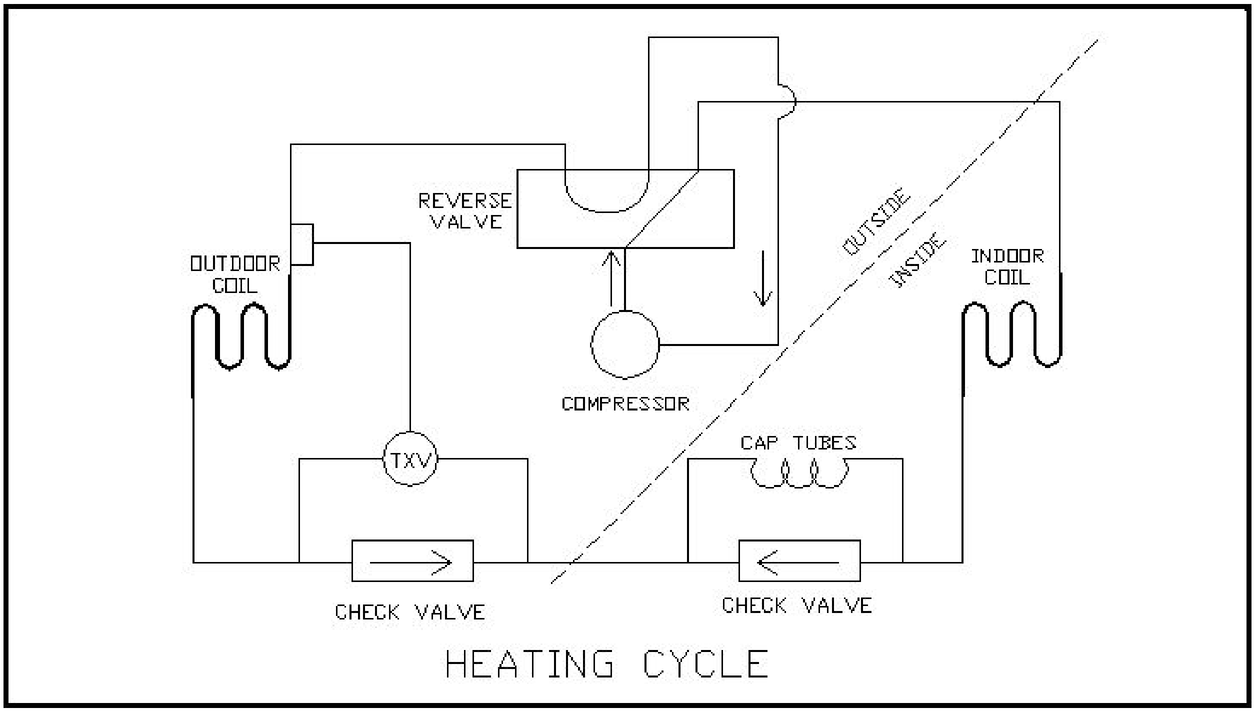


Figure 2.

Note: When replacing a TXV on a heat pump outdoor coil, do not use a standard TXV. A TXV with a low superheat range is needed.

The capillary tube used on the indoor coil keeps down expense. On some “deluxe” units, the cap tube will be replaced with a standard air conditioning TXV.

Low cost packaged heat pumps (overgrown window units) typically use two cap tubes, a larger cap tube for heating, and a smaller cap tube for cooling. See **Figures 3 and 4**.

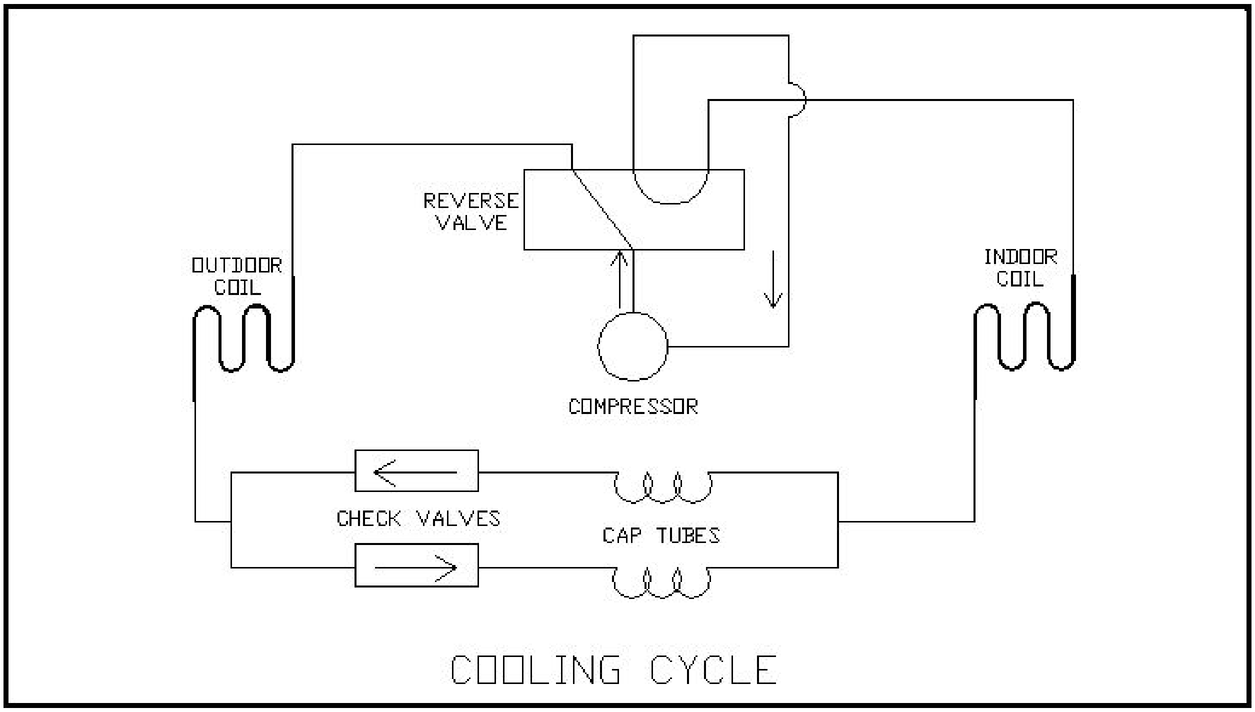

REVERSE
VALVE
OUTDOOR
COIL
INDOOR
COIL
COMPRESSOR
CHECK VALVES
CAP TUBES
COOLING CYCLE

Figure 3.

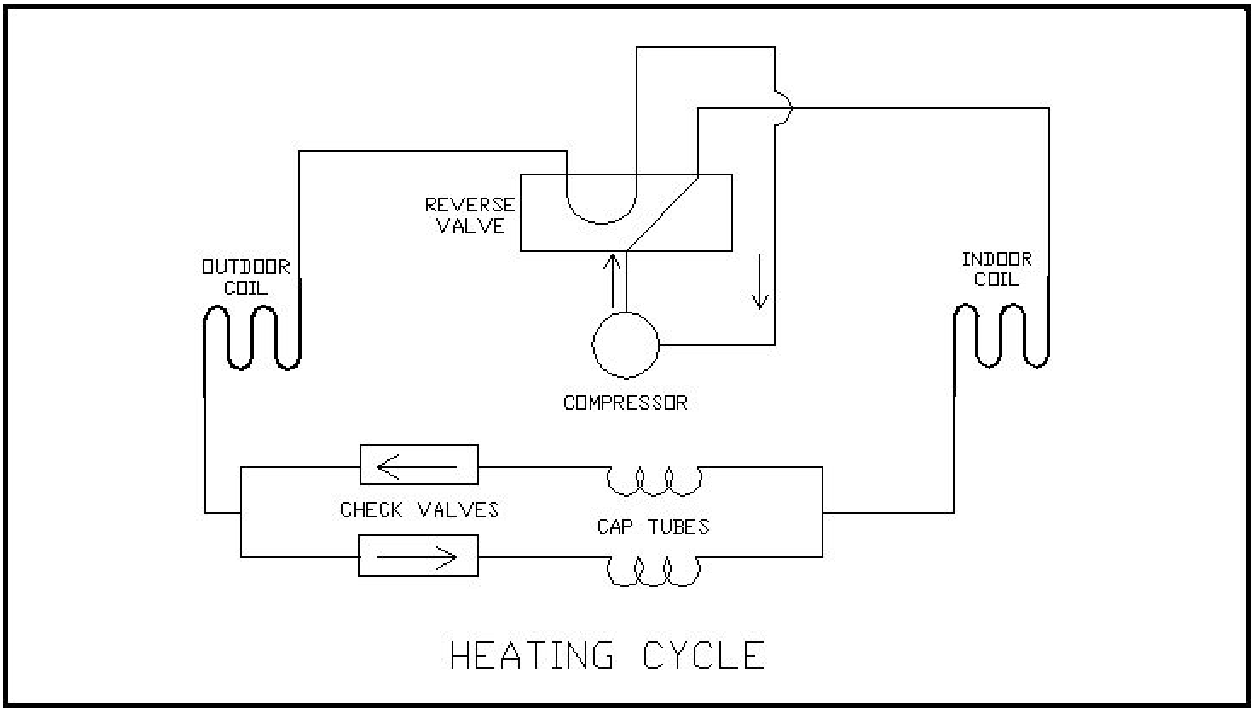


Figure 4.

Another system consists of one common TXV with bi-directional flow, as in **Figure 5**.

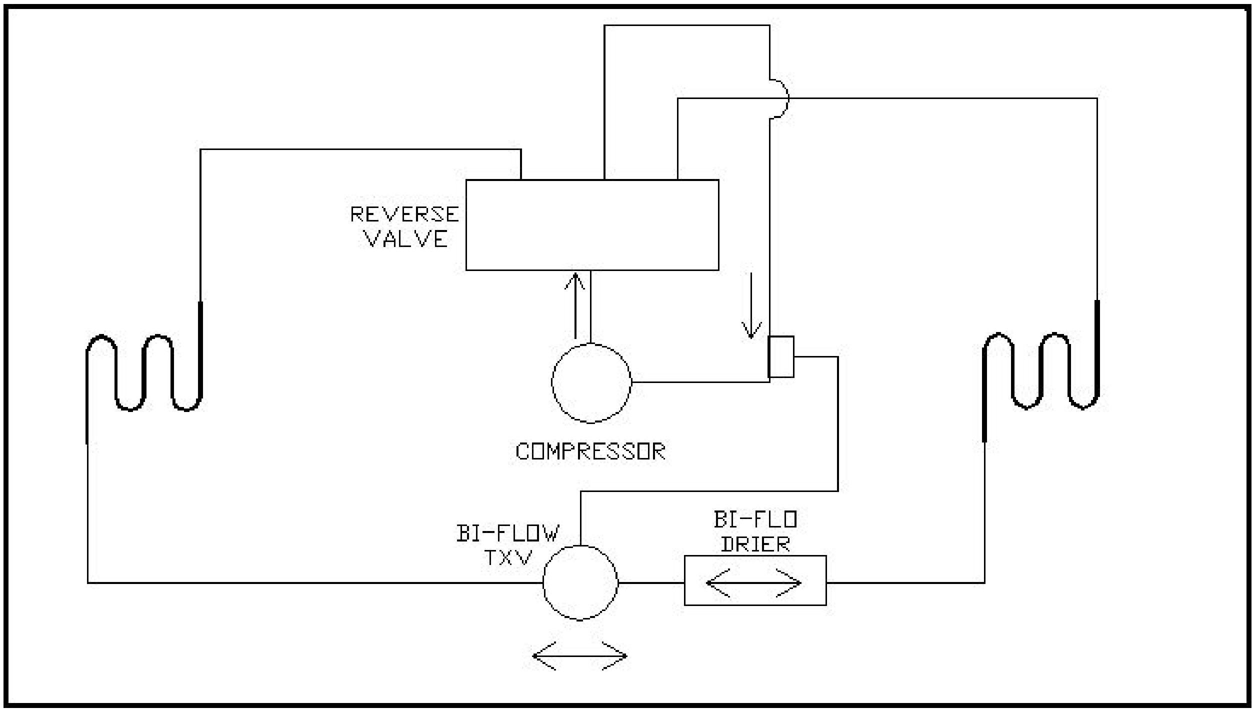


Figure 5.

The Alco TLE is a bi-flow TXV with a CA charge. It is sold only to OEM's but can be field serviced using TCLE parts and reusing the TLE body flange.

The development of the bi-flow TXV required a bi-flow filter dryer. Alco BFK dryers are bi-flow dryers. As you can see, this bi-flow system eliminates check valves and one other expansion device. This means lower cost to the OEM's so these systems are quite popular.

Note that the bulb of the bi-flow TXV is located on the suction line between the reversing valve and the compressor. In all our illustrations, no accessories were shown for clarity's sake. Many other devices will be on a heat pump system. Sight glasses, accumulators, distributors, even discharge mufflers may be part of the heat pump refrigerant system. Note that one thing always was absolutely necessary – the reversing valve.

In Part III, we will discuss heat pump controls.

Heat Pumps Part 3: Thermostat & Defrost Controls

Of all the heating and cooling systems used in residential applications, the heat pump is the most complex. When you first look at a heat pump control system, it can be overwhelming. Breaking out the individual requirements for each control will show the logic involved and make it easier to grasp once you understand each control's function.

Control systems utilize low voltage circuits since line voltage systems would be difficult and expensive to wire. We will look at only those devices associated with a residential heat pump. (Contactors, time delays, high and low-pressure controls, etc. are the same on a heat pump as on a cooling unit only.)

Thermostats

The space temperature sensor needs to be at least a two-stage thermostat. The idea of heat pump control is to use the most economical heat source first, and the auxiliary heat source, usually electric resistance heat, only when the heat pump can't handle the load. When the compressor output exactly equals the heat needed, the compressor will run 100% of the time. No auxiliary heat should be utilized until there is a demand for more heat. The two-stage heat pump thermostat is designed to do this.

The use of auxiliary heat is not only determined by outdoor temperature, but also by actual heating requirements of the building. Using a multistage heat pump thermostat will govern the use of auxiliary heat by actual demand. Auxiliary heat and compressor will not start at the same time, and under high load, the heat pump will run constantly instead of being cycled. The two stages make contact sequentially. There is a degree or two of offset between stages one and two so that the second stage, auxiliary heat, is made only when the heat pump can't handle the load.

The cycle rate of a heat pump thermostat is different than a thermostat used with fossil fuels. At 50% load, fossil fuel thermostats cycle a furnace about 5 or 6 times an hour. Being a refrigeration system, a heat pump is better off being cycled 2.5 to 3 times an hour.

Some heat pump thermostats have voltage heat anticipation instead of current anticipation. Using voltage anticipators, the heat added to the thermostat is fixed, no matter what the load is. A constant amount of heat is produced during the "on" cycle. In this way, the cycle rate is designed into the thermostat. See **Figure 1**.

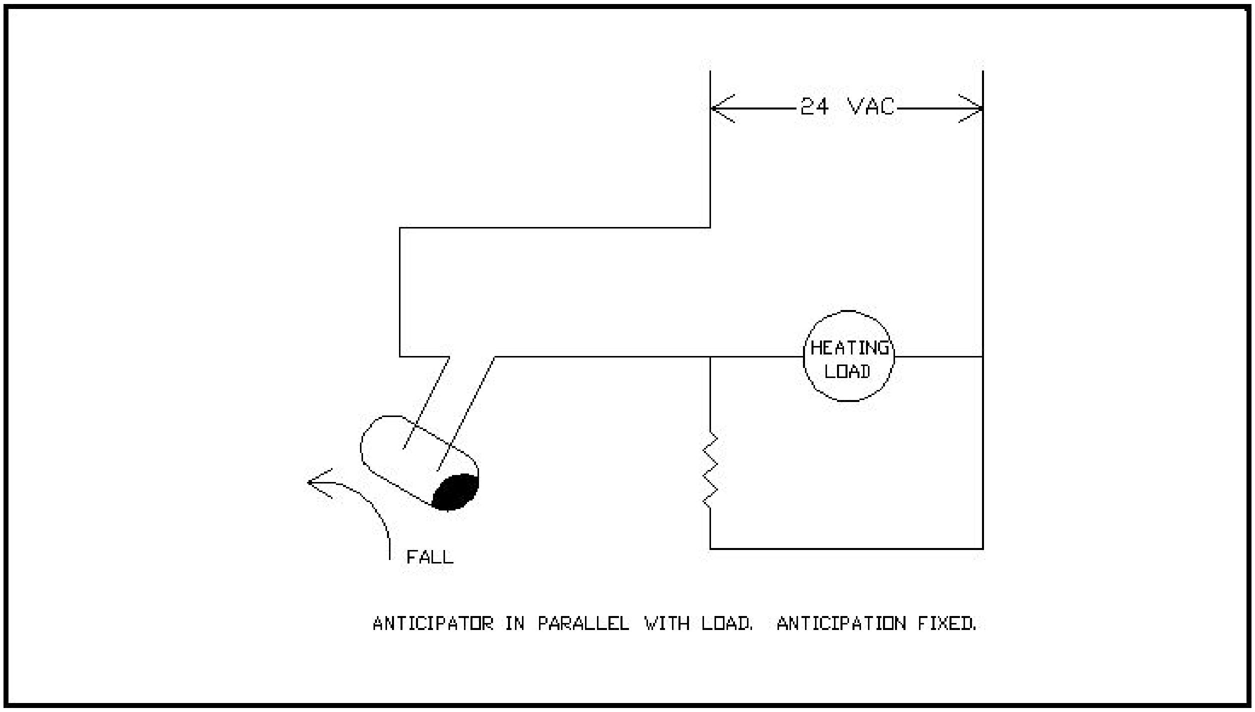


Figure 1.

Outdoor reset was often applied to heat pump systems to minimize droop under high load conditions. There could be a large offset between the setpoint and actual room temperature.

Outdoor reset has the effect of automatically raising the setpoint under high load, cold outdoor temperatures. The thermostat is actually being de-calibrated to compensate for differential and droop so it appears to still switch near setpoint.

At warm outdoor temperatures, heat is added to the thermostat by the heat anticipator and at cold outdoor temperatures, this extra heat is automatically removed. The reset heater in the thermostat is connected in series with a thermistor sensor that measures outdoor temperature. The thermistor has low resistance in warm weather, allowing high current flow to the heat anticipator. In cold weather, the thermistor has high resistance, resulting in low current flow and little or no heat being added to the thermostat by the anticipator.

The advent of electronic thermostats has eliminated droop and heated anticipators. Cycle rate is programmed into an electronic thermostat. But there are many heat pumps in use with outdoor reset systems and many that do not use an electronic thermostat, so knowing how outdoor reset is applied is still necessary.

Changeover can be either manual or automatic. Changeover can be for heating or cooling. For instance, a system that's changed over manually to cool, the reversing valve would be energized by a sub-base switch. The thermostat manual heat/cool switch can either energize or de-energize the reversing valve, depending on how the system is configured.

Automatic changeover usually requires a thermostat with an additional switch or stage. The first stage will energize the reversing valve. The second stage will turn on the compressor.

Most heat pumps have two stages for heating and one stage for cooling. Some deluxe model heat pumps now come with two speed compressors. The speeds may be controlled by sensing outdoor temperature or space temperature or a combination of both. Multistage thermostats are available for any heat pump system in any configuration.

While on the subject of thermostats, we will address the subject of "**night setback**." Traditionally, the heat pump was considered a poor candidate for night setback. It was assumed that the cost of the auxiliary heat fuel, usually electric heat, needed to bring the space temperature back to the day setting would cost more than any savings acquired through set back.

Actually, that was not the main reason. Fuel cost savings could be made setting back a heat pump about 5° or 6° below the day setting. The real reason manufacturers discouraged setback was a legitimate concern for the compressor. Setback results in an extended off time at the beginning of setback. This is usually late at night when outdoor temperatures are low. After anywhere from two to four hours pass, the compressor is restarted to hold night set temperature. This could impose a lot of stress and possible slugging of the compressor. Manufacturers preferred to keep the compressor "warm" and running under these conditions.

However, with new compressors and much better equipment, this is no longer a concern. Microelectronic thermostats have been developed to handle the requirements of heat pump systems, many with "intelligent recovery." Upgrading a newer heat pump system from a mechanical thermostat to a microelectronic thermostat can be cost effective.

Capacity control reduces cycling rate and improves efficiency. Capacity control systems, such as unloading, or multiple compressors, are not used on residential heat pumps, but are used on many commercial heat pumps, especially larger ones of 10 tons or more.

As previously mentioned, two speed compressors are used in some deluxe units for capacity control. There are two control strategies used by OEM's. One of the systems uses a two-stage heating thermostat with an outdoor thermostat. The outdoor thermostat is set at the balance point of the system. As an example, if the heat pump were able to handle the heating load down to +15°F, the outdoor thermostat would be set just below that to allow auxiliary heat to come on. See **Figure 2**.

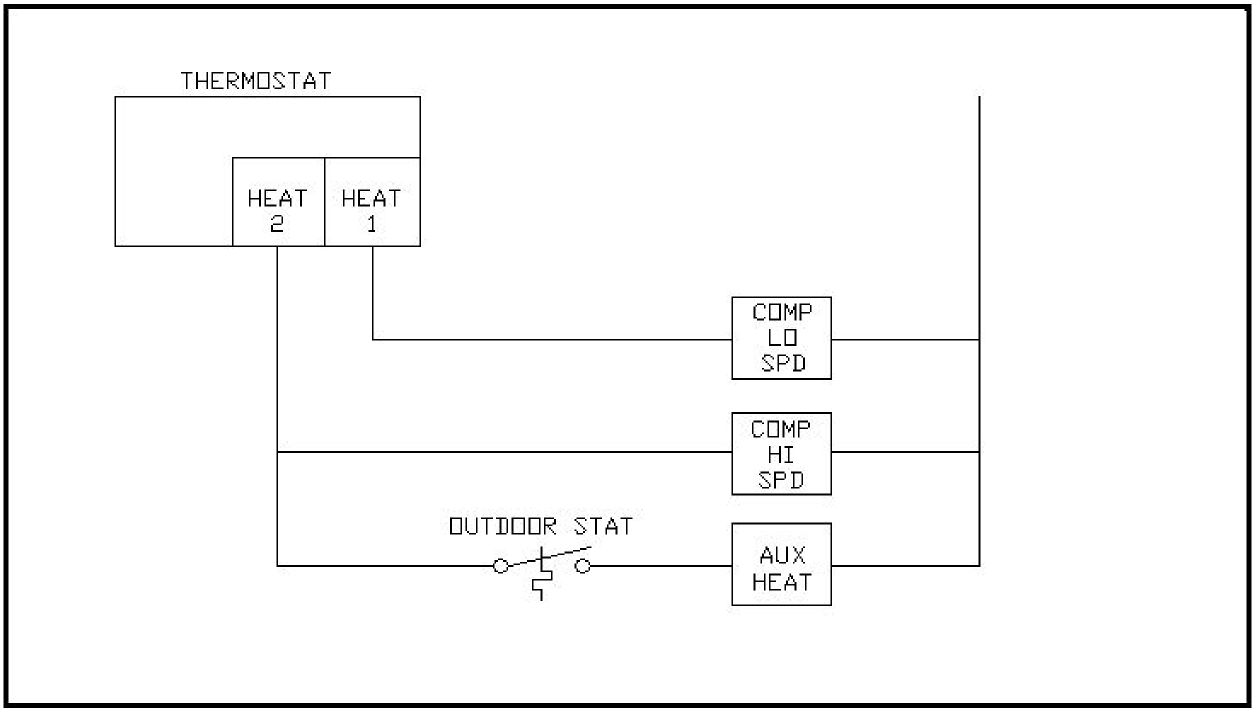


Figure 2.

Additional stages of auxiliary heat can be added with our without the control of outdoor thermostats. One advantage of this system is the ability to adjust the outdoor thermostat to match the installed system's actual performance. In other words, one can find the outdoor temperature at which the heat pump is at maximum capacity.

Figure 3 shows a three-stage heat thermostat. No outdoor thermostat is used. The advantage of this system is that no auxiliary heat is used until the space actually needs it.

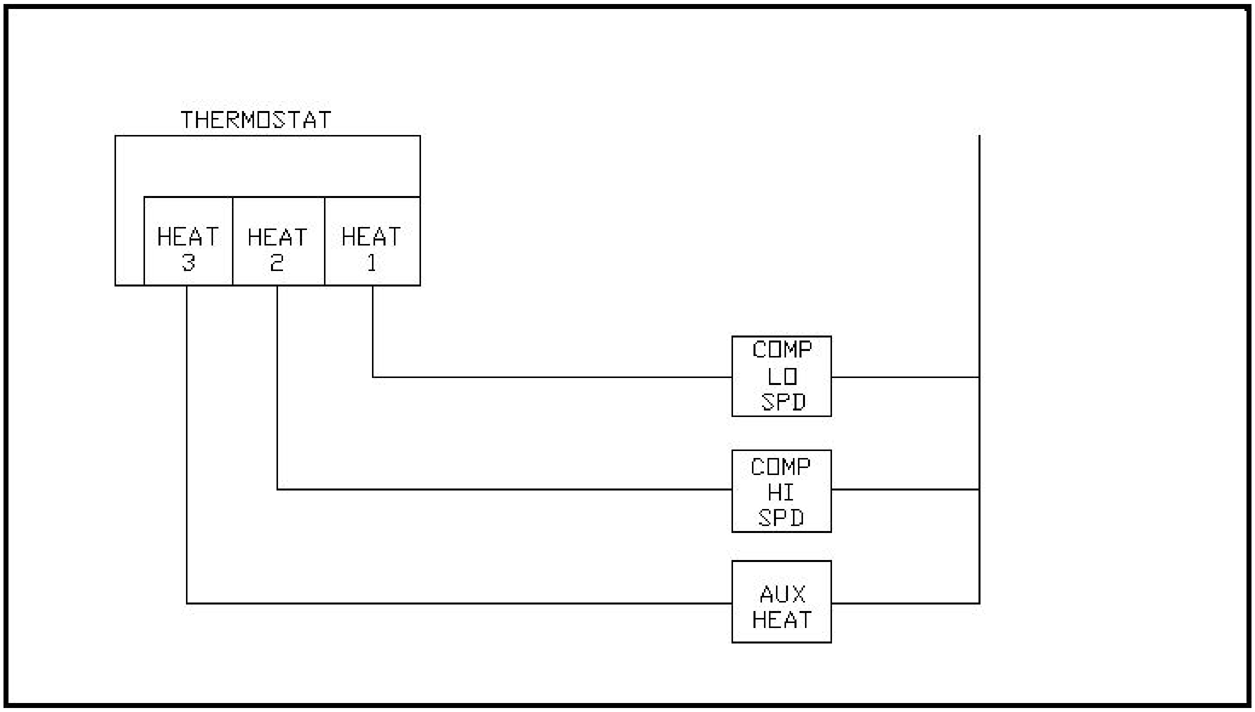


Figure 3.

The modern heat pump thermostat will usually have fault and performance indication. LED indicator lights are used to annunciate one or more of the following: filter light, check or service light, emergency heat light, lockout light, auxiliary heat light.

Some manufacturers incorporated a low temperature lockout. They believed that since the efficiency dropped off at low outdoor temperatures (below 1.0 COP), it is more fuel efficient to stop the compressor from running. Other manufacturers felt it was better to let the compressor run rather than to restart it, after a long off, even if the efficiency was low.

Newer heat pump designs do not reach a COP of 1.0 until well below 0°F. Some claim even to be 1.0 at –20°F! Because of better designed heat pump compressors, crankcase heaters that are "on" only when the compressor is "off," thereby compensating for lowered compressor efficiency, virtually all heat pump manufacturers have eliminated the low temperature lockout that was set at about 10°F.

Defrost Control

Every heat pump requires some method of defrosting the outdoor coil when in heating mode. Without going into detail and using a psychometric chart, simply put, one must remember that ***heat only flows from high to low energy regions*** (warm to cool). Therefore, in order to extract heat from the outdoor air, the outdoor coil must be cooler than the surrounding outdoor air, no matter what the ambient air temperature is. Ambient air always contains moisture, which will condense on the coil. If the coil is cold enough, this moisture will form ice. Ice build-up inhibits airflow through the coil. Even at relatively warm outside air temperatures, ice can still form on the outside coil. This ice must be removed or the heat pump will fail to heat.

It is obvious in order to defrost the coil; heat must be added to melt the ice. Manufacturers use various methods to defrost the outdoor coil.

One method was to incorporate electric heaters in the outdoor coil. While some older heat pumps may still have this type of system, it is rarely used anymore. The most common method is to reverse the cycle, turning the outdoor coil back into a condenser, and using the hot discharge gas to defrost the coil.

When in defrost, the heat pump is no longer heating. It's actually changed over to the cooling mode, so defrost must be accomplished as quickly as possible. Therefore, more control-initiated actions are required. The outdoor fan is turned off to increase the head pressure, and consequently, the temperature, to speed up the melting action. A defrost relay contact is needed to control the outdoor fan. Other contacts may be needed to power the reversing valve or to power the auxiliary heat or some portion of the auxiliary heat while the heat pump is in defrost. OEM's may configure the heat pump system to automatically bring on auxiliary heat when in defrost, or rely on the thermostat to call for auxiliary heat as needed.

The single most perplexing problem encountered by heat pump manufacturers is "when and for how long" to defrost.

Timely defrosting is essential for heat pump operation. Failure to defrost often enough allows too much ice build up on the outdoor coil. This hurts efficiency and can result in compressor damage. Not enough defrosting is a condition OEM's take every precaution to avoid.

Ice build-up that causes a 50% reduction in outdoor airflow is as much as can be tolerated by any heat pump. Restricted airflow causes a greater load on the compressor, the coil runs colder, suction pressure goes down, and the compressor runs hot!

On the other side, defrosting too often hurts the overall efficiency of the system. In terms of heating the space, defrosting is a big loss. Not only does the system stop heating, but also it is actually taking heat out of the space! Further, auxiliary heat may have to be brought on to maintain space temperature.

So, concern for equipment safety suggests frequent defrosts. Economy of operation suggests fewer defrost cycles. The OEM and the installing contractor have to choose a balance between these two concerns.

There is two general schemes for initiating defrost: Timed and Demand.

Demand defrost systems were tried at one time or another by almost all heat pump manufacturers. They were DP or DT systems.

A DP system operated on the principle that ice on the coil resulted in an increase in the pressure differential across the coil. A pressure differential control compared the pressure on both sides of the outdoor coil. When the difference between the two pressures reached a preset level, a switch closed and initiated defrost.

A DP system must respond to small changes in differential pressure. A gust of wind could cause the defrost control to initiate a defrost cycle. A time delay had to be added to require a sustained increase in DP before initiating defrost. Dirt, leaves, or snow build-up around the coil could result in initiating defrost. Where and how the outdoor coil was installed was very critical.

The difference between the outdoor air and coil temperature operates a DT temperature differential system. The theory was that as ice built up on the coil, the refrigerant could not absorb as much heat from the outdoor air. The coil gets colder. Normally the coil runs 5 to 15°F colder than ambient air. As ice accumulated, this DT increases because the coil temperature drops. When a preset DT was reached, defrost was initiated.

While both are true demand systems, they were unreliable, difficult to properly apply, and did not “fail safe.”

Too many outside factors, such as wind, dirt, and mechanical problems affected the control point. Installation was difficult. They also were expensive.

As a result, timer systems predominate. While not perfect, the timer method of defrost is now the industry standard because of reliability and low cost.

Initially, the first timer systems used only a time clock. The timer was set for some accumulated run time on the compressor, usually 30, 45, or 90 minutes. The timer then initiated defrost, no matter if the coil needed defrost or not, for a set period of time before terminating defrost. Both timings were adjustable, and each system was supposed to be adjusted for a specific installation through “experience” with the system. This almost always resulted in too many defrost cycles of too long a period.

Although this was an inexpensive system and almost foolproof in operation, it wasted a lot of energy. The whole idea of a heat pump system is to save energy, not waste it. Owners complained of high-energy costs.

OEMs soon realized that they could not depend on contractors or owners to constantly readjust the timer settings for changing ambient conditions.

But the low cost, ease of application, basic simplicity and fail-safe features of timer systems appealed to the heat pump industry, so additional devices were added to timed defrost systems to make them more energy efficient. The problem of defrosting too often still exists, but with careful installing contactor set up, the overall seasonal efficiency of a heat pump is now acceptable.

Figure 4 shows a typical heat pump timer system, used by most residential heat pump manufacturers.

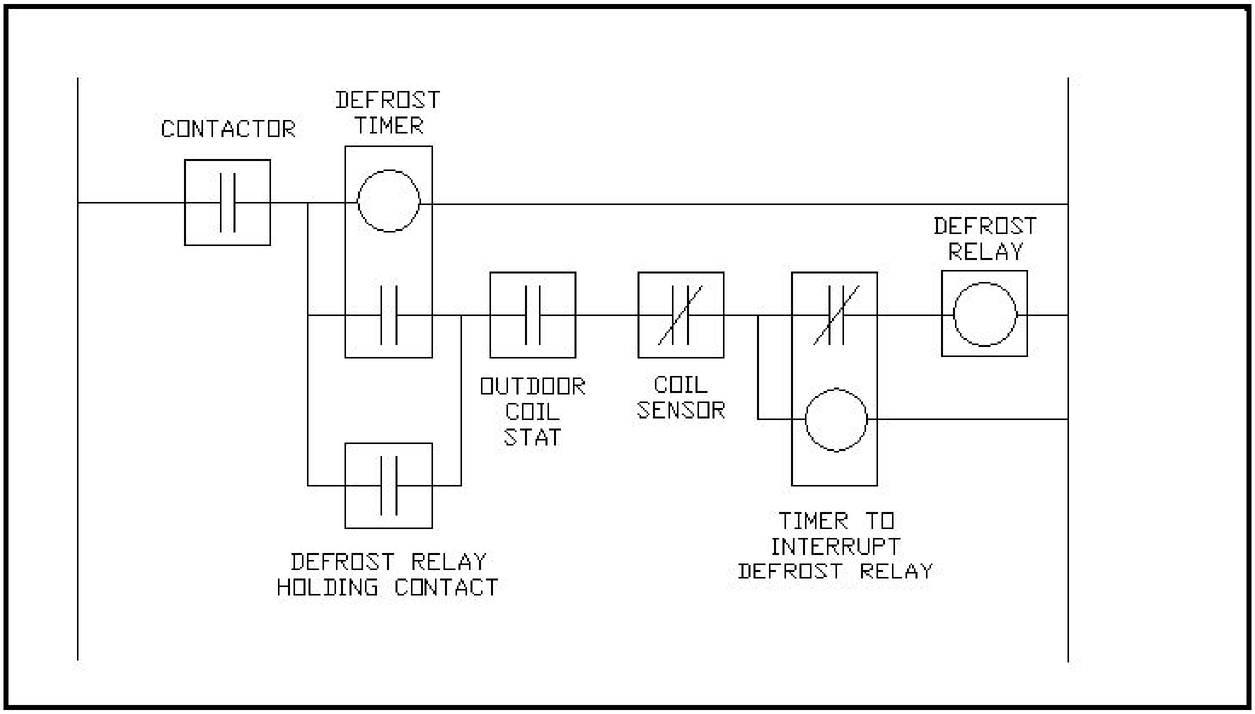


Figure 4.

Note that the defrost timer motor is powered through the contactor, so it will only run when the compressor runs. The outdoor coil thermostat has its sensing bulb on the outdoor coil. The defrost clock closes its contact for about 10 seconds every set defrost period. As an example, let's say this is every 90 minutes. The outdoor coil thermostat is set for 32°F and closes on temperature fall. If during the 10 second period the outdoor thermostat is open, a defrost will not be initiated, and the timer must go around another 90 minute cycle before trying again. If the outdoor thermostat is closed, the defrost relay is energized, closing the holding contact and initiating defrost.

To terminate defrost, the coil sensor senses the coil temperature rise and its normally closed contact opens, de-energizing the defrost relay and terminating the defrost cycle. As long as ice is on the coil during defrost, its temperature will be near 32°F. After the ice is melted, the coil temperature will rise rapidly.

On some heat pumps, another timer is incorporated to limit the maximum length of a defrost cycle. This is usually set for 10 minutes. This timer motor is powered at the same time as the defrost relay, its normally closed contact in series with the defrost relay. This timer is used as a back up in case the coil sensor fails and doesn't terminate defrost. It is automatically reset each time it is de-energized.

The timer method of defrost is the most used method of defrost for residential heat pumps. It is reliable and low cost. It eliminates the risk with demand systems of failing in defrost mode. The installing contractor needs to use his or her experience when setting the timers. Dry areas, like Phoenix, Arizona, would use longer timing for the defrost timer, shorter timing for the interrupting fail-safe timer. Humid areas would, of course, require shorter intervals for the defrost timer, longer intervals for the fail-safe timer.

As stated earlier, the compressor is the heart of a system, the reversing valve the nerve center, and now the control system, the “brains” of the system. When they all work together in a well-designed heat pump system, the heat pump can be a very cost-efficient alternative to other fossil-fueled heating and cooling systems.