HEAT PUMP CONTROLS

Of all the heating and cooling systems commonly used in residential applications, the heat pump is the most complex. The controls required on a heat pump reflect that complexity. There are two reasons for this.

Since the same machinery is used for both heating and cooling, changeover controls must be provided. This means having correct thermostat switching to give stable and economical control in both modes of operation.

The use of multiple sources of heat is another complicating factor not found in conventionally fueled heating systems. Control logic must provide a means of using the most economical heat source first and still maintain good comfort. In the event of a heat pump malfunction, the controls must be capable of handling an emergency heat source.

Combining all these requirements into a single control system results in some very complex circuits. This becomes obvious when you examine the circuits for multistage thermostats used with heat pumps. There’s a lot going on. In fact, a heat pump control system, considered in a single look, can be overwhelming; but the individual requirements for each control function are logical and relatively easy to grasp once you understand their purpose.

SPACE TEMPERATURE SENSING—THE THERMOSTAT

Low Voltage Controls

Control systems for heat pumps almost always utilize low voltage control circuits. The variety of control functions required and their relative complexity require a versatile and economical method of control. There are a number of interlocks and indication functions that would be more difficult and expensive to wire in line voltage circuits. Low voltage controls provide the precision and flexibility needed.

The thermostat we use then, is a low voltage device. It will have good temperature sensitivity and a number of manual and automatic switching capabilities.

One of the basic elements of heat pump control strategy is to use the most economical heat source first. Most heat pumps are backed up by relatively expensive electric resistance heat. This means the heat pump should be activated first, and auxiliary sources used only when its capacity can’t handle the heating load.

So, a 2-stage thermostat becomes the clear choice. Stage one of the thermostat time modulates the ON period of the compressor to meet the heating demand of the building. At the balance point, compressor output exactly equals the heat requirement and the heat pump runs 100 percent of the time. However, no additional capacity (auxiliary heat) will be brought on until there is an actual demand for more heat.
This is the principal advantage of the 2-stage thermostat and its application to heat pumps. The use of less efficient auxiliary heat sources is not determined only by a calculation of outdoor temperature, but on the actual heating requirements of the building as measured by the thermostat.

So there are at least three good reasons for using a multiple stage thermostat with a heat pump:

1. Use of auxiliary heat is governed by actual demand.
2. Auxiliary heat and the compressor do not start at the same time, spreading out the starting electrical loads.
3. Under higher loads, the heat pump runs constantly instead of being cycled.

In a 2-stage thermostat, the two stages "make" sequentially as the temperature drops. There's a degree or two between stages so that the second stage—the one controlling the auxiliary heat—makes only when the heat pump alone can't handle the load. That's how we implement the strategy of using the most economical heat first.

**Cycling Rate**

Normally we would set a thermostat to cycle a fossil fuel furnace about 5 or 6 times an hour (at 50 percent load). This provides a reasonable balance between comfort, stability and economy.

A heat pump, being a mechanical refrigeration system, is better off being cycled at a rate of two and one-half to three times an hour. Most cooling thermostats are designed to cycle the compressor at 2-3 cph. With a standard thermostat, this can be accomplished by setting the anticipator at about 140 percent of the total current draw of the controlled device (the contactor and, possibly, the changeover relay or valve). More than likely the compressor will operate from the first stage of the thermostat.

In some systems, however, the changeover relay may be controlled from stage one and the compressor from stage two. The anticipation heater for the stage controlling the compressor is the one to adjust for slower cycling.
The second stage normally will control the auxiliary heaters. This heat anticipator can be set for the current draw of the electric heat contactor coil, and will result in good control.

**Voltage Anticipation**

Although not a specific requirement for heat pumps, you’ll find that some multistage thermostats have voltage heat anticipation instead of current anticipation.

With voltage anticipation, the amount of heat added to the thermostat is constant no matter what load is connected to it. The anticipator sees a constant voltage and produces a constant amount of heat during the ON cycle. In this way, the cycling rate can be "designed into" the thermostat. The heat pump manufacturer is assured of correct performance independent of later adjustments to the thermostat.

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**Outdoor Reset**

Outdoor reset is sometimes applied in heat pump systems to help minimize the effect of the differential between stages. It takes more than a degree change in temperature to bring on the second stage and full heating. Added to a certain inevitable amount of droop under high loads, there can be a fairly large offset between the set point and the room temperature.

Without some method of counteracting this situation, the temperature offset from the set point could be as much as four degrees under high load conditions. It is not likely that the occupants will accept this without making frequent changes to the thermostat setting.

Outdoor reset has the effect of raising the set point at cold outdoor temperatures. Then, even with a few degrees droop, the space temperature will stay near the desired setting.
This is done by calibrating the thermostat high by 5°F—the amount of offset expected. This miscalibration compensates for differential and droop at high load factors so the thermostat switches at the set point. At warm temperatures, heat is added to the thermostat to compensate for this miscalibration. The extra heat is automatically removed at cold temperatures. The effect is that of raising the set point as the outdoor temperature goes down.
You can also view this as varying the ON time by changing the amount of anticipation heat added.

This is particularly important on 3-stage thermostats. The additional stage means that more droop will be introduced when the system is in operation.

**Outdoor Reset—How It Works**

The reset heater in the thermostat is connected in series with a thermistor sensor that measures outdoor temperature. In warm weather, the thermistor has very low resistance, permitting a large current to flow in the heater. This generates a relatively large amount of heat in the thermostat. In cold weather, the outdoor sensor has high resistance which results in low current flow and little or no heat being added to the thermostat.

**Changeover**

Changeover between heating and cooling can be accomplished either automatically or manually, depending mostly on the application. Changeover can come with heating or with cooling.

With manual control, the changeover valve is energized as long as the subbase function switch is in the appropriate position. For instance, on a system that changes over manually on cooling, the valve will be energized whenever the subbase switch is in the cooling mode.

Automatic changeover control is accomplished by using one of the mercury bulb switches in the thermostat. On a system with automatic changeover on cooling, the changeover valve will be energized when the first stage cooling switch in the thermostat makes. The second stage switch will turn on the compressor.

It is more common to find that automatic changeover occurs with cooling—that is, the changeover valve is energized to produce cooling. Most heat pumps have two stages of heat but only one stage of cooling. So, one mercury switch on the cooling side of the thermostat is available for changeover in some models.
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By: James R. Cole
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Whether automatic or manual changeover is used and whether the reversing valve is energized with cooling or with heating, a heat pump system can be controlled by the appropriate multistage thermostat. Models are available that will meet any of these types of operation.

Night Setback

Traditionally, almost everyone has considered the heat pump to be a poor candidate for night setback. This is thought to be because of the need to use electric strip heat to return to the day setting in the morning. Compared to heat from the heat pump (COP 2.0 or 2.5) the auxiliary heat (COP 1.0) is quite expensive.

Actually this is not the case. Even considering the need to use auxiliary heat. Good savings can be achieved by using setback with heat pump systems.

Our computer simulation studies show that a significant amount of energy is saved. The optimum amount of setback appears to be 6° or 7°F below the day setting. Savings will amount to just a percent or two less than with a gas-or oil-fired system.

Knowing about this savings potential, what are the reasons that setback is virtually nonexistent on heat pump systems?

Besides the widespread belief of lack of savings, there is also legitimate concern for the "health" of the compressor.

Setback will result in an extended period—two to four hours —of compressor OFF time at the beginning of setback. This comes late at night when outdoor temperatures are low. Restarting the compressor after a couple of hours results in a lot of equipment stress and presents an opportunity to slug the compressor.

Some manufacturers would prefer to keep the compressor running under these conditions. That precludes the use of night setback unless a very complicated control system is applied to the unit.

We are, however, at a time in the development of the heat pump when equipment advances are coming rapidly. New models have major improvements over older ones. Compressors are better adapted to low temperatures. So the resistance we see now to setting back heat pumps may diminish over the next few years.

Finally, more sophisticated control is required. Setting back a 2-stage device, such as a heat pump, is a bit more complicated a switching job. This is especially true if priority must be given to either the compressor or auxiliary heat during setback or morning warm-up.

New controls and systems will be developed to handle these new requirements. Both conventional electromechanical and new microelectronic controls will be used to do these jobs.

COMPRESSOR SWITCHING

Switching the compressor requires a contactor capable of handling 20 to 30 amperes for the typical residential heat pump. Normally the same contactor will also switch the outdoor fan motor.

The compressor must be energized on a call for either heating or cooling. The thermostat and subbase have circuitry to do this.

There are a number of special requirements for controlling heat pump compressors that are not always found in other heating and cooling systems.
MINIMUM-OFF TIMER

Preventing rapid cycling is one of the prime equipment protection functions required of the control system on any mechanical refrigeration system. This includes heat pumps.

In a typical heat pump, the difference in pressure between the high side and the low side can range from 100 to almost 300 psi, depending on the mode of operation and temperatures. This pressure differential is felt across the compressor and the expansion valve.

After the compressor is turned off, this pressure differential slowly "equalizes" as refrigerant from the high side escapes through the expansion valve to the low side. With no airflow across the evaporator, the thermostatic expansion valve may permit only a very small amount of refrigerant to flow. Some minutes may pass before the pressure is equal on both sides of the valve.

The motor in the typical residential heat pump hermetic compressor is sized quite closely to the power required by the compressor under normal conditions. Normal conditions include starting the compressor after system pressure has equalized and seeing full load only after it is up to full speed.

Attempting to start the compressor before pressure equalizes may require more torque than the motor can deliver. In other words, it won't start.

In a stalled condition, excessive current flow will very quickly overheat the motor. The result will be to cycle the motor from the overload protectors until the pressure equalizes. It's not a good situation and there is a high likelihood of damage to the motor.

The control system must have some means of preventing the heat pump compressor from being short-cycled.

Compressor minimum-off-time is provided by an electronic or electromechanical timer in the contactor control circuit. The contactor cannot be pulled in until a specified amount of time has passed since the end of the last run cycle. Three or five minutes are commonly used times.

The thermostat heat anticipator should be adjusted to the current draw of the time delay device. One problem is that some time delays have a variable current draw, which tends to disrupt the cycling rate and quality —of control we would normally expect to get with a good low voltage thermostat.
LOW TEMPERATURE LOCKOUT

Some manufacturers of heat pumps used to control their unit so that the compressor was locked out below a specified outdoor temperature. This was done because of the stress placed on the compressor by the very cold temperatures, and the fact that efficiency drops off at low temperatures.

Other manufacturers say that although efficiency is low at cold temperatures, the problem of starting the cold compressor is the most critical point. So, they feel it's better to keep it running than to shut it off and then try to restart when the temperature warms up to plus 10°F. Also, the crankcase heater, which may run only when the compressor is off, compensates for the lower compressor efficiency. In other words, it's just as well to let the heat pump run even with a COP slightly less than one, than to turn it off and then have to run the crankcase heater.

Another point favoring this control strategy is the fact that newer heat pump designs maintain a fairly good efficiency even at outdoor temperatures well below zero. Some brands do not reach 1.0 COP until minus 25°F.

Virtually all manufacturers now let the heat pump run continuously rather than lock it out at cold temperatures.

TWO-STAGE HEAT PUMP

Staging residential-size heat pumps is a fairly new requirement, which comes about because of the need to make heat pumps as efficient as possible. One of the methods of improving overall seasonal efficiency is to reduce the amount of time the machine is operating in a transitional mode. That would be starting and stopping in addition to recovering from defrost. Under light loads, when the heat pump is cycling on and off, this can amount to a fair amount of time and result in a significant reduction in efficiency.

Capacity control is one way to reduce the cycling rate and improve the efficiency.

One way to control capacity is to use a 2-speed compressor. Units with this feature first arrived on the market in late 1978.

Other capacity control methods used on other refrigeration systems (unloading, multiple compressors) are not as likely to be seen on residential heat pumps. They are, however, common on commercial systems-units of 7.5 tons or more.
We saw that with a single stage heat pump we normally controlled the compressor with the thermostat first stage and the auxiliary heat with the second stage. Several thermostats are available for this type of heat pump application.

With a 2-stage compressor, the two thermostat switches control the individual compressor stages. Auxiliary heat is controlled, along with the compressor stage two, by the thermostat second stage. It will come on with the compressor high speed if an outdoor thermostat, wired in series with it, is made.

The outdoor thermostat is set at the balance point with both heat pump stages running. So, if the heat pump can handle the heating load down to 20°F, that's where the outdoor thermostat would be set. Below 20°F, the auxiliary heat will come on with the second stage of the compressor.

In effect, what this control strategy does is to change the size of the second stage, depending on the amount of heat needed. Additional stages of auxiliary heat can be added with or without the control of more outdoor thermostats. (See "Auxiliary Heat.") Another way to control a 2-stage heat pump is with a 3-stage thermostat.

The advantage of this system is that no auxiliary heat is used until there is an actual demand from the controlled space.
FAULT AND PERFORMANCE INDICATION

In addition to providing automatic system control, the thermostat also presents a convenient place for the building occupants to see an indication of system performance or problems. Some of the possibilities include:

FILTER—It is very important to keep the filters clean in a heat pump. Restricted airflow can be dangerous to the equipment. A device can monitor the pressure drop across the filter and warn the homeowner when it gets too dirty by turning on a light on the thermostat.

CHECK or SERVICE—Heat pump manufacturers may choose to have some indication of a malfunction or impending malfunction. The manufacturer, in his owner literature, gives some instruction on what to check and when to call the service technician.

EM. HT. (emergency heat)—A red light that comes on whenever the subbase function switch is in the emergency heat position. It's important to tell the homeowner that the backup source is heating the house, not the heat pump. This is because the backup heat will be 2 to 3 times as expensive.

Lockout—The heat pump may be equipped with an automatic method of locking out the compressor in the event of certain abnormal conditions. The LOCKOUT light tells the occupant that this has happened.

AUXILIARY HEAT—An indicator light that comes on when the second stage of the thermostat makes to bring on auxiliary heat.

POWER SOURCES

Typical residential size heat pumps (1-1/2 to 3 tons) require a 240V, single-phase power source. The outdoor unit of a split system (the compressor and outdoor fan) has a current requirement in the range of
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20 or 30 amperes (full load). Manufacturers recommend No.10 or even No.8 wire to hook up the outdoor unit. The inrush current is 80 to 150 A (the locked rotor rating).

The load rating of wire usually used in residential heat pump application is:

<table>
<thead>
<tr>
<th>Copper Wire Size</th>
<th>Maximum Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.12</td>
<td>20 A</td>
</tr>
<tr>
<td>No.10</td>
<td>30 A</td>
</tr>
<tr>
<td>No. 8</td>
<td>40 A</td>
</tr>
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The indoor unit, which includes the indoor blower and the auxiliary heat elements, also operates on a 240V source. Current draw depends on the amount of auxiliary heat installed.

OUTDOOR DISCONNECT

The National Electrical Code requires the installation of a disconnect switch within sight of the outdoor unit of an air conditioner or heat pump. This is for the safety of any technician working on the unit. It’s so that he can see that the unit remains unpowered. It is never safe to rely on the contactor alone to de-energize the outdoor section of the heat pump. Even with a 2-pole contactor some circuits, such as the crankcase heater, will still be energized when the contactor is dropped out. The only safe procedure is to open the main disconnect switch.

SWITCHING VARIOUS POWER SOURCES

120 V, Single-Phase

(Depending on the particular distribution system, this voltage may be 110 or 115V, too. Actual voltage available at the heat pump may vary considerably.)

Circuits of 120V are rarely, if ever, used to power the compressor in a central air conditioner or heat pump but they are commonly used in other household appliances, including central gas and oil furnaces.

A 120V circuit consists of a HOT wire and a NEUTRAL wire that carry the current to and from the load. The neutral wire is always white, that is, it has white insulation. The hot wire is some color other than
white (neutral) or green (ground). Be careful to differentiate between neutral and ground. Neutral is a current-carrying part of the circuit. It is also grounded at the distribution box and the supply transformer. The ground wire is not a current-carrying part of the circuit. Its purpose is to keep the appliance at ground potential as a safety factor. It may either be a separate wire, either bare or with green insulation, or it may be the B-X, thinwall, or Greenfield conduit used in the system.

The ground conductor comes into play if there is a short circuit in the appliance. It is connected to the metal frame of the piece of equipment, such as the heat pump outdoor unit, and goes to earth ground. Its purpose is to insure that the machine housing can never become hot and, thus, be a hazard to someone touching it. If the hot side of the line comes in contact with the metal case of the machine, it will be shorted to ground. This will increase the current draw enough to blow the fuse and in this way protect the operator.

In a 120V circuit, the white (neutral) wire is NEVER switched. Switches and fuses are always located in the hot side of the circuit.

To switch a 120V, single-phase load, we would use a single-pole contactor or relay in the hot leg of the circuit as shown in the previous diagram.

240v, Single-Phase

(Depending on the distribution system, this voltage could be 220, 230 or 240V.)

Residential heat pumps virtually always require a 240V, single-phase power source. This power supply is delivered on 2 hot wires. There is also an equipment ground wire that does not normally carry any current.
Double-Pole Vs. Single-Pole Switching

Two methods are currently used to switch a 240V compressor motor: single-pole and double-pole contactors. We are referring here to how many of the power supply conductors are interrupted or switched by the contactor.

Double-pole contactors traditionally have been used on 240V air conditioning and heat pump compressors. Both hot wires to the compressor are broken.

Beginning 10 years ago, the single-pole contactor has replaced the double-pole model at most manufacturers for two main reasons. First of all, it's a little less expensive so the OEM can save some money by using it.

Another factor is the increased use of internal trickle heat on heat pump compressors instead of a strap-on or insertion crankcase heater. The trickle heat setup requires that the start winding of the motor be partially energized during the compressor OFF cycle.
Safety—One-Pole vs. Two-Pole Contactors

One of the arguments against single-pole contactors is that they leave one hot conductor connected to the compressor all the time—a condition that could be hazardous. The other side of that position is that this only becomes a hazard if the service technician is working on the wiring without first having opened the main disconnect. That's not a smart thing to do in any case.

In fact, it might be argued that the use of a double-pole contactor can provide a false sense of security, since there may be hot circuits in the outdoor unit even when the contactor is not energized (crankcase heater, fan motor, control circuits). The only way to be safe is to open the disconnect.

Both single-and double-pole contactors are used in modern heat pumps. Different manufacturers find different arguments convincing. However, the trend is toward the single-pole contactor, because of the trickle heat and also economy. Exceptions are three-phase equipment, some "deluxe" models which the OEM wants to distinguish from "builder" models and some special application models.

Three-Phase Power

Most heat pump manufacturers offer the option of 3-phase compressor motor on heat pumps intended for commercial applications. Those are usually about 3 or 4 tons and larger.
Technically, there is no reason that a 3-wire, 3-phase compressor motor could not be switched with a 2-pole contactor and, in fact, this has been done in some cases. However, some local codes prohibit this practice.

So, the conventional way of handling a 3-phase compressor is to break all three leads to the motor. Thus, a 3-pole contactor is needed.

**480Y/277 Volt, 3-Phase, 4-Wire Distribution**

The 480Y/277 Volt, 3-phase, 4-wire distribution system is increasingly popular in commercial and industrial buildings. The 3-phase feeders are brought to each floor of the building. The 480 Volt, 3-phase power is available for motors and large resistive loads, while the 277 Volt, single-phase is used for fluorescent lights. Step-down transformers provide 208Y/120 Volt circuits for outlets, local lighting and appliances.
240 VOLT, 3-PHASE, 3-WIRE DISTRIBUTION

This is another system that is sometimes used. It provides 240V between phases and, by center tapping one of the phase transformers, 120V grounded circuits.

SINGLE-PHASING PROTECTION

Three-phase power is essentially three separate power sources applied to one motor. There are circumstances in which one phase could go dead while the others remain hot. In this case, current in one
or both of the remaining phases will become excessive, with the very great likelihood of damage to the motor.

Single-phasing protection consists of a solid state device resembling a circuit breaker. When it detects an overload in any phase, it interrupts all three phases and, thus, prevents any damage to the motor.

Johnson Controls, Inc.