Chapter 9

Limit Controls & Thermostats


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Chapter 9

Limit Controls and Thermostats

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There are a large variety of limit controls, thermostats, and switching relays used in heating systems. It's important for technicians to keep in mind that these devices are just switches that turn things on and off.

Some of the older types of these switches are turned on and off by the warping or flexing action of bimetal blades and some use magnets and springs. Others are controlled by a fluid that expands and contracts quickly. Some are line voltage and some are low voltage. Some need transformers to change the voltage so that low voltage switches can control line voltage loads. Most of the controls currently installed in the field use solid-state microprocessors that perform all the functions of older controls and do so more efficiently.

Electrical control circuit

The hot (L1) wire for the basic burner circuit begins at the service panel circuit breaker, travels to the main shutoff switch, then to a junction box that is usually located on the ceiling near the burner. Some states and local codes require a thermal or Firomatic® switch at this junction box. From the junction box, the hot line (which is generally a black wire), runs to the service switch, through the limit control(s) and then to the limit terminal of the primary control. From the primary control, wires are connected to the burner motor, oil valve and electronic ignitor.

The neutral (L2) which is generally a white wire also starts at the main service panel and passes to the L2 terminal or the white lead of the primary control. There

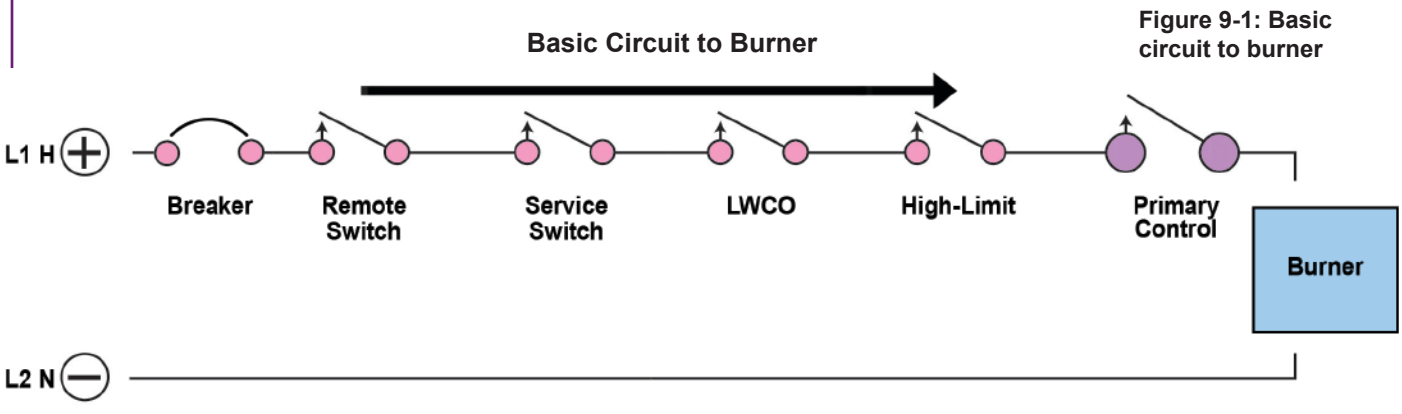

Figure 9-1: Basic circuit to burner

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should never be any switches or fuses in the neutral side of the circuit.

The low voltage (24 volt) side of the burner control circuit starts at the step-down transformer in the primary control and is utilized through the TT terminals to allow a thermostat or other device to turn the burner on and off. In some applications, mainly hot water boilers and water heaters, the TT terminals are jumpered and on/off control is provided by line voltage controls. Figures 9-1 (previous page) and 9-2.

Burner switches

The burner switches are used to shut off the system in an emergency or as a convenience switch when servicing the appliance. There should be two disconnect switches. The first is called a customer or emergency switch and it is normally located at the head of the basement stairs or at the entrance to the utility room. The second switch is a service switch and is located on or near the appliance.

Thermostats

Principles and design

Thermostats are either mechanical or electronic switches that automatically open or close a circuit as room temperature changes. The thermostat's purpose is to start the burner and/or circulator or blower when the temperature is below the established setting, and to shut them off when the heat demand is satisfied. Thermostats must be extremely sensitive to temperature changes. In older thermostats, a bimetal element warps or unwinds to open or close a switch in response to a temperature change. In a solid-state thermostat, the room temperature changes the resistance of an electronic device to open and close circuits.

Figure 9-2: Circuit wiring

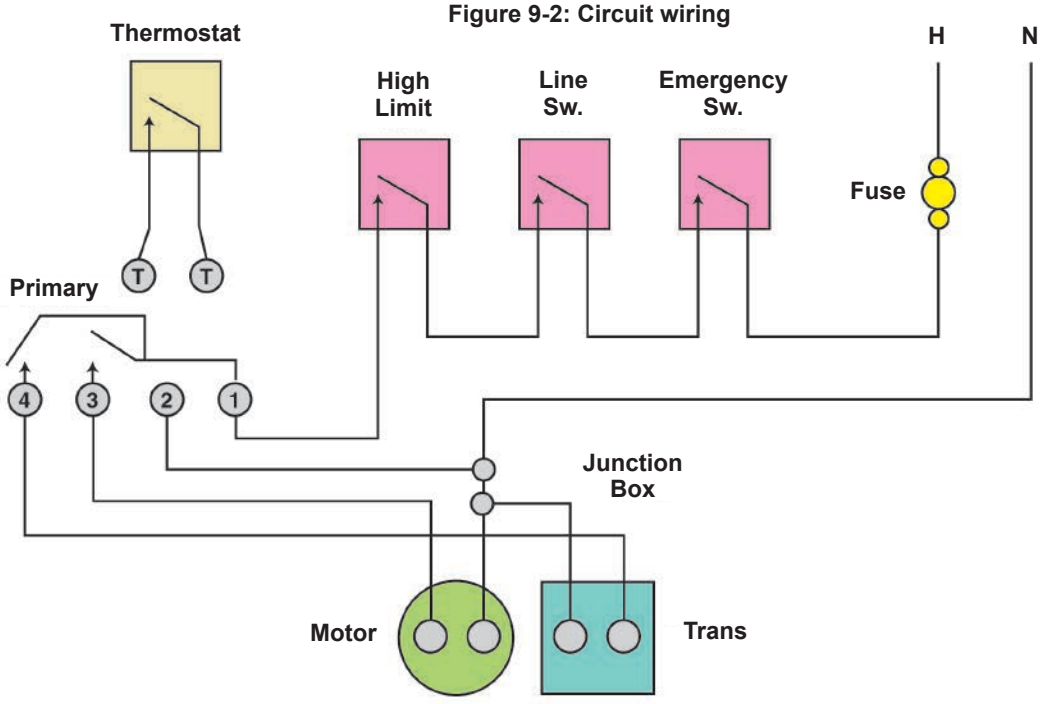

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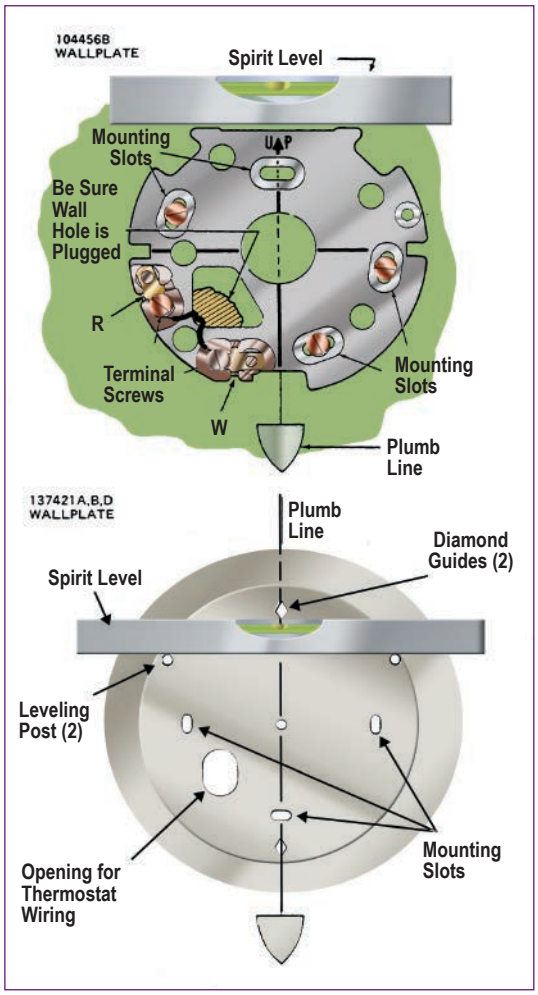
Figure 9-3

Some older thermostats installed in the field still use a bimetal element and mercury switch to function. Figure 9-3 shows the most common type used. The replacements are mostly electronic and will be discussed later.

The bimetallic element is made of two dissimilar metal strips, bonded together, which expand or contract with a change in temperature. By expanding or contracting, it creates a mechanical force that flips a mercury switch to make or break a pair of contacts. As with all mercury switches, these thermostats must be installed level. Figure 9-4 shows how to level the T87 thermostat. Mercury is a hazardous substance and should be disposed of properly, contact *https://www.thermostat-recycle.org/* for more information.

Figure 9-4: T-87 thermostat



3 wire thermostats vs. 2 wire thermostats

Some very old-style thermostats needed three wires to operate. When replacing an old three wire thermostat with a new two wire model, eliminate the red wire. Today there are some three wire thermostats that operate zone valve motors and dampers. A circuit is necessary to drive the valve or damper open and another circuit must drive it closed. The switching action of these thermostats is single pole, double throw as opposed to a single pole, single throw switch for the two wire circuits.

Line voltage thermostats

In some systems, line voltage thermostats are used to directly control the circulator. Line voltage thermostats are not as sensitive as low voltage types and this often leads to wide fluctuations in the room temperature. In addition, the contacts in line voltage thermostats tend to pit due to electrical arcing which leads to unreliable operation.

Differentials and heat anticipation

The differential of a thermostat is the temperature difference between the opening and closing of its contacts. For example, if a thermostat's contacts opened at 70°F,

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and closed at 67°F, its differential would be 3°. Without a differential, thermostats would cause heating systems to "short cycle," turning on and off continually with very minor temperature fluctuations such as those caused by a door opening or closing or even just by someone walking by.

Most manual thermostats have pre-set differentials that can't be adjusted. Some, but not all, programmable thermostats have adjustable differentials.

Heat anticipation

Older mechanical thermostats incorporated an anticipating heater to increase the sensitivity of the thermostat. The heat anticipator is a small electrical resistance heater that fools the thermostat into thinking it is warmer in the room than it actually is. Heat anticipation was necessary because large radiators would emit a significant amount of heat after shutdown and the home would overheat.

Figure 9-5: Check control or manual for proper current to set heat anticipator

Outputs:
Motor: 120 Vac, 10 full load amps (FLA), 60 locked rotor amps (LRA)
Note: Reduce motor FLA rating by ignitor current
Ignitor: 120 Vac, 3 A @ 0.7 PF min
Solenoid Valve: 120 Vac, 1 A @ 0.7 PF min
Thermostat Anitcipator Current: 0.1 A (if applicable)
Thermostat Voltage: 24 Vac (if applicable)

The anticipating heater must be adjusted to match the current that is supplied to the thermostat. Set the anticipator to the amp rating found inside the cover of the control, Figure 9-5, to which the thermostat is directly connected.

Figure 9-6: T-87F heat anticipator

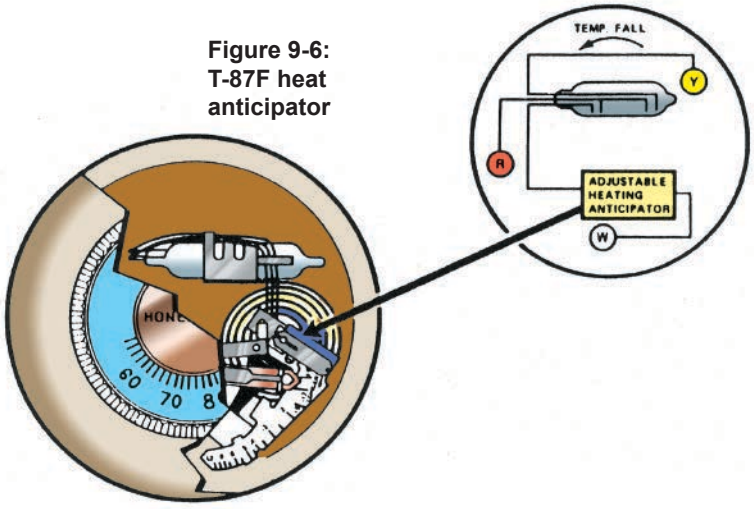
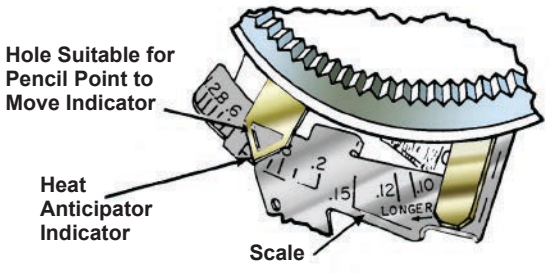


Figure 9-6 shows the location of the heat anticipator in a heating and cooling thermostat. Notice the anticipator in the R-W circuit. This is because the anticipator is only used for heating and is not in the air conditioning circuit (R-Y).

Figure 9-7 shows the heater indicator and the scale in a thermostat. Newer thermostats have a fixed differential and have a cycle per hour (CPH) adjustment that is set by the type of system the thermostat is controlling. See chart below.

Figure 9-7: T-87F heater adjustment



Cycle per Hour Chart	
System Type	
Steam, Gravity	1 CPH
Hot Water, 90% eff.	
Warm Air, Heat Pump	3 CPH
Gas/Oil Warm Air	5 CPH
Electric Warm Air	9 CPH

Digital thermostats

Figure 9-8 shows some examples of digital thermostats. These thermostats rely on solid-state technology to not only operate the equipment, but to maintain and store temperature settings, day, date, and number of cycles. Most of these thermostats can have multiple settings for all seven days of the week.

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Figure 9-8: Electronic thermostats

Figure 9-9: Internet connected thermostat

Internet connected thermostats are becoming very popular. These can be connected directly through wifi or communicate through a hub that is connected to the internet. Figure 9-9

Always follow manufacturer guidelines with digital and connected thermostat installation and wiring, as they can vary widely between brands and models.

Location of the thermostat

A thermostat should be installed about 5 feet from the floor on an inside living or dining room wall, or a wall where there is good natural air circulation. It may be wise to select several good locations, pointing them out to the homeowner, and then let them choose from the suggested locations. **Some locations that will cause trouble are:**

1. Above a TV, stereo, computer, or lamp.
2. On or near an outside wall.
3. Near a heat emitter.
4. In line with the air stream from a register.
5. On a wall containing steam pipes, hot water pipes, warm air risers, or chimneys.
6. On a wall with high internal air movement.
7. Behind a door or other obstruction to free air circulation.
8. In an over radiated or under radiated room.
9. Near a window or door frequently opened to the outside.
10. In a room with a heat source such as refrigerator, stove or fireplace.
11. On a wall or partition subject to excessive vibration.

Mounting thermostats

- Servicing or installing a thermostat is a job for clean hands. Do not mar or soil wall surfaces.
- Be absolutely sure that all wires are connected to their proper terminals and that all connections are tight. If a color code is being used, be certain that it is followed.
- If mercury switches are used in the thermostat, be absolutely certain the

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thermostat back plate and/or the thermostat itself are level.

- All excess wire should be pushed back into the hole in the wall, and the hole should be plugged with putty to prevent cool air drafts from affecting the thermostat performance.

Limit controls

A limit control is an automatic temperature, pressure or water level switch which controls power to the burner. These controls are generally divided into two groups, safety limits and operating limits.

- **Safety limits** are automatic switches that prevent a burner from operating if high temperature, high pressure or low water conditions exist. Some safety limits are manual reset type controls that must be reset when the limit is exceeded, other types reset automatically when conditions return to normal. Most residential limit controls are listed as both safety and operating controls. They do not have separate high limit safety controls. They rely on their operating limits to keep within the correct parameters.
- **Operating limits** are automatic switches that cycle a burner within normal temperature or pressure range during a call for heat or during standby. These controls are generally SPST as high limits or may be SPDT as low (standby) limits that also manage circulators.

Warm air system limit controls

Warm air system limit controls, control the on and off operation of the furnace's fan motor and provide high limit control of the burner. These functions are handled either through fan/limit controls or electronic furnace control boards (also known as fan boards, furnace circuit boards or integrated furnace controls).

Remember, in electricity, open means that there will be no flow of electricity and closed means electricity can flow through the switch.

Fan/limit controls

Fan/limit controls feature a helix type bimetallic element that operates both a fan control switch and a high limit control switch. Figure 9-10 shows a combination fan and limit control. A single dial as shown in Figure 9-11 (old and newer version) is connected to the helix and has indicators for the fan on temperature, the fan off temperature and the high limit setting. The dial turns in one direction (depending on the model, either clockwise or counterclockwise) as temperature in the heat exchanger rises and in the opposite direction as temperature decreases.

The function of the fan control is to operate the system blower when the furnace air temperature is within the fan control dial settings. The fan control will permit the fan to operate when the air temperature in the furnace is above the fan on setting as prescribed for the specific system or

Figure 9-10: Combination fan and limit control

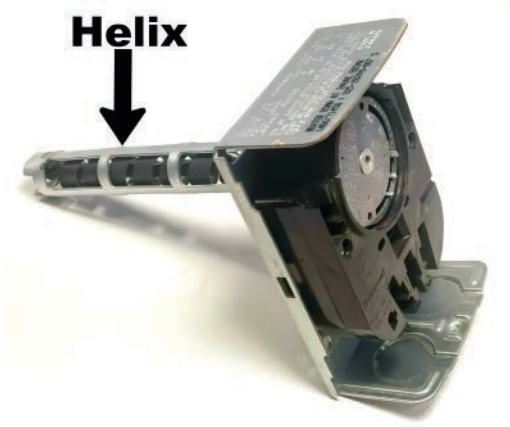

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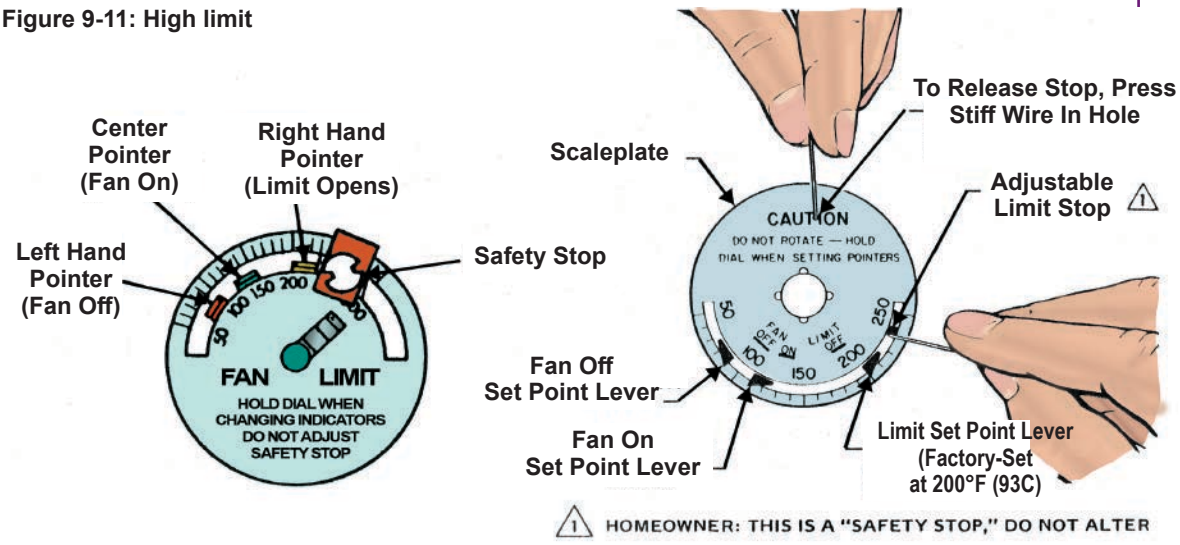
Figure 9-11: High limit



the manufacturer's requirements. The fan control prevents blower operation when the air temperature is below the fan off setting. This prevents cool air from being forced into the living area during cold weather.

Typical fan/limit operation during a call for heat

In this section the settings from Figure 9-12 are used as an example.

During a call for heat, the burner warms the heat exchanger and the helix senses the temperature rise and begins to turn the dial. When the dial reaches the fan-on (140°F) setting, the blower will move air across the heat exchanger and through the air distribution system of the building. If the temperature falls below the fan-off (110 ºF) setting, the blower will stop until the temperature rises again to the fan-on (140 ºF) setting. The burner will continue to operate until the room thermostat is satisfied, at which time it will stop and the fan will continue to run until the fan-off (110ºF) temperature is reached to remove the remaining heat from the heat exchanger. The heat exchanger of the furnace is still hot, although the burner, controlled by the thermostat, is not running—warm air currents will continue to rise to the control. Under certain conditions this heat may be sufficient to again elevate the temperature to the fan-on (140ºF) setting and the blower will again operate until all of this heated air is delivered to the living area.

On a properly operating system, the burner should not shut off on limit since the burner is directly controlled by a thermostat. If the temperature should exceed the limit setting, the limit switch will open and stop the burner. The burner will not start again until the limit temperature (minus the differential) is reached. (typically 25ºF below the limit setting.)

Figure 9-12

Average Warm Air Limit Settings			
	Limit	Fan = On	Fan = Off
Average furnace, average system	200°F	140°F	110°F

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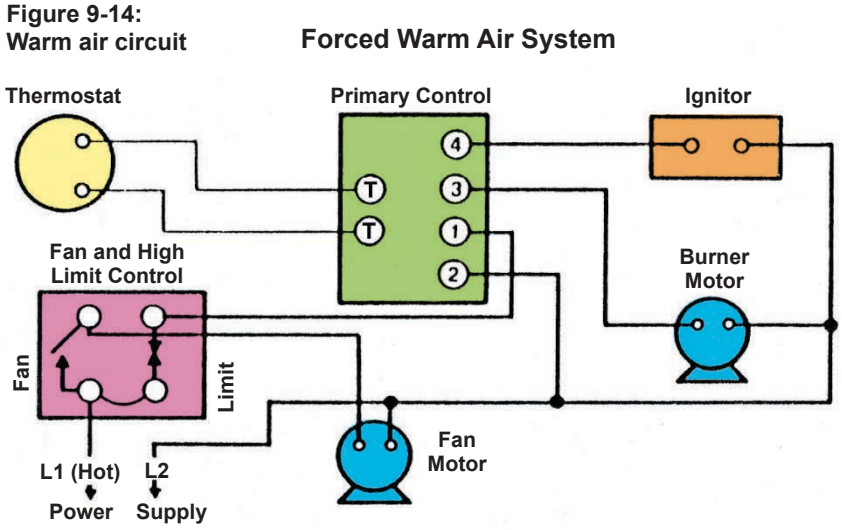
Figure 9-14:
Warm air circuit



Reasons why the limit setting may be reached:

- Limited airflow, typically caused by dirty filters or damaged ductwork
- Accumulation of dust in the blower fan blades
- Blower belt or motor is broken
- Furnace is too large for the air distribution system or ductwork is undersized
- Too many register dampers in the closed position

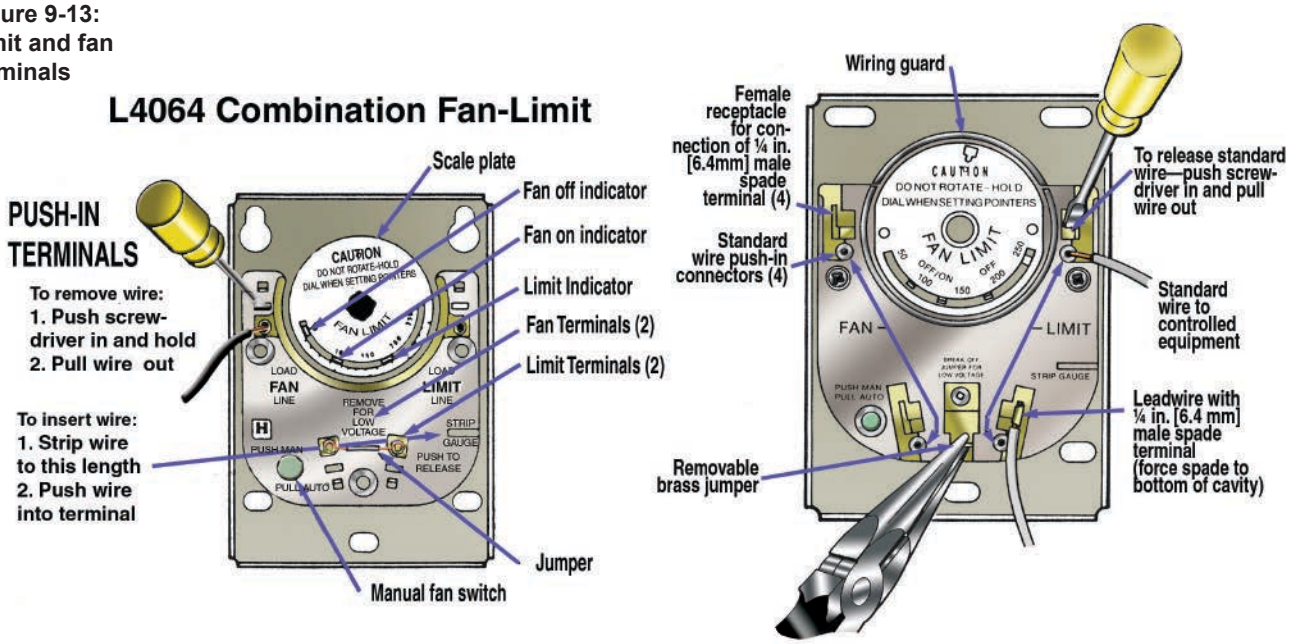
Always consult manufacturer's instructions before replacing a fan limit control. The helical element of the fan limit control must be located in the manufacturer specified location to assure safe and proper operation.

Some wiring notes for Fan/Limit controls

Figure 9-13 shows how the line voltage wires are connected to the control. There is a removable jumper since power for the blower and burner circuits can be separated in this control.

Figure 9-14 is a schematic wiring diagram showing how a Honeywell L4064B combination control is wired into the heating system electrical circuit. As is required,

Figure 9-13:
Limit and fan
terminals



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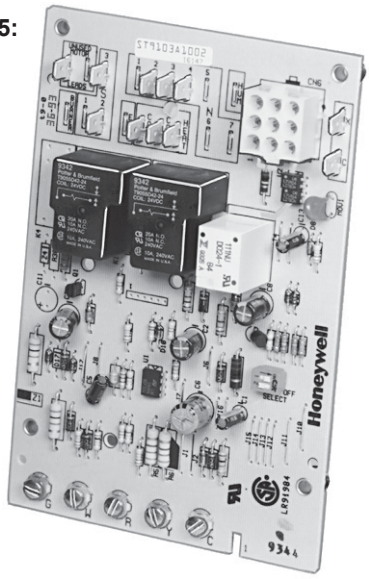
the limit control is wired in series with and prior to the primary control. *Note that the fan motor is wired into the system circuit in parallel with the primary control and the high limit control. The fan control should always be connected in this manner to enable the fan motor to operate independently of the burner.*

Figure 9-12, previous page, lists the typical warm air limit setting and fan control on and off setting. The lower these settings can be without creating uncomfortably cool air delivery into the living area, the more economical the operation of the heating system will be.

Figure 9-15: Electronic fan timer



Electronic fan timer center

Most new warm air furnaces incorporate heating, air conditioning, humidification and air cleaning capability in one unit. They also feature either ECM or PSC multi-speed direct drive blower motors. To operate all these devices, an electronic fan center, usually called a fan board, is needed. A typical example of this device is the Honeywell ST9103A Electronic Fan Timer, Figure 9-15, which integrates the control of all burner and system fan operations.

This control serves as the central wiring point for most of the electric components of the furnace and enables the thermostat to control heating, cooling and system fan demands. It also monitors a limit switch string, which energizes the circulating fan whenever a limit switch opens. Electronic air cleaner, humidifier terminals and a means for operating continuous indoor air circulation is also available. See Figure 9-16, for ST9103A wiring connections and Table 9-1 (following page) for the operating sequence.

Steam system controls

Pressure controls

Limit controls that respond to changes in steam pressure are called pressure controls,

Figure 9-16: Honeywell ST9103A wiring connections

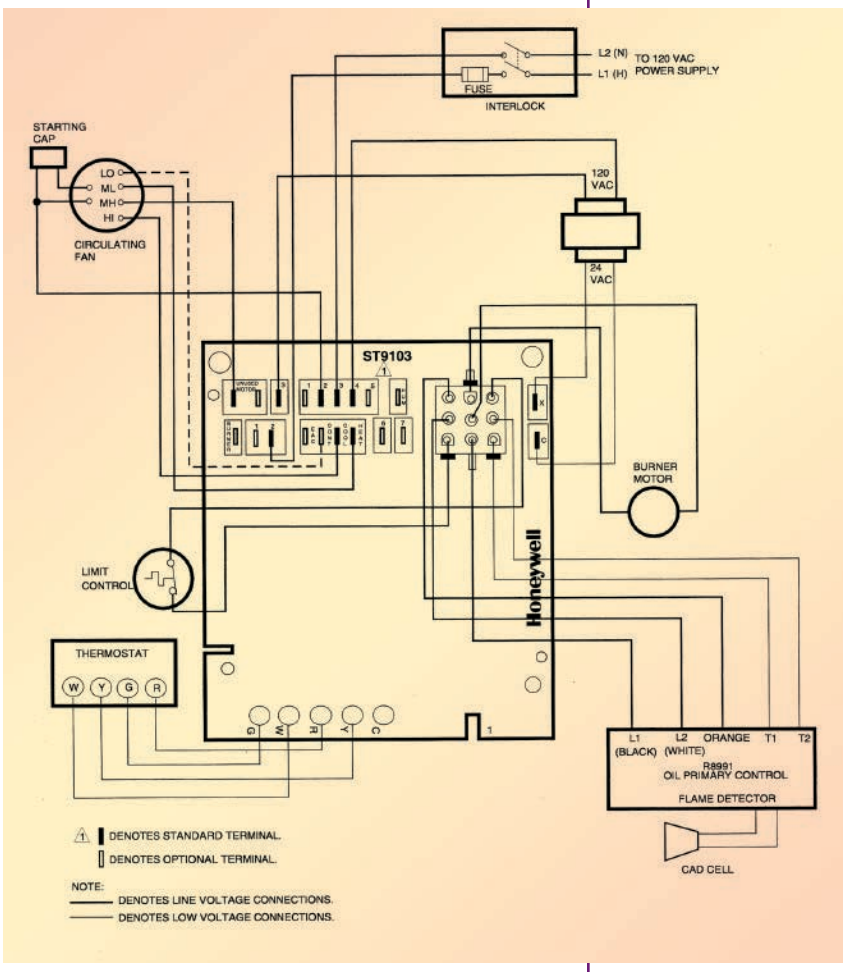


Table 9-1

Action	System Response
Thermostat calls for heat. (W terminal is energized)	• ST9103A closes primary control T-T connections. • Ignition system and primary control start the furnace.Fuel flows as long as primary control senses flame. • Burner motor is energized and heat fan on delay timing begins. When timing is complete, the circulating fan is energized at heat speed and warm air is delivered to the controlled space.
Thermostat ends call for heat	• Primary control is de-energized, terminating the burner cycle. • Heat fan off delay timing begins. When timing is complete, the circulating fan is de-energized. • ST9103A returns to standby mode (primary control and circulating fan are off.
Burner fails to light	• Primary control locks out within lockout timing (timing depends on primary control). • Burner motor is de-energized. • If heat fan has started, it continues through the selected delay period.
Established flame fails	• Burner motor is de-energized and primary control goes into recycle mode. • If selected heat fan off delay is longer than the recycle delay timing, the heat fan continues to run through the next trial for ignition.
Thermostat begins call for cool (G and Y terminals are de-energized)	• Circulating fan is energized at cool speed. • Cooling compressor turns on immediately.
Thermostat ends call for cool (G and Y terminals are de-energized)	• Circulating fan and cooling compressor turn off immediately.
Thermostat begins call for fan (G terminal is energized)	• Circulating fan is energized immediately at cool speed. • ST9103A may be factory-configured to operate heat speed in this mode.
Thermostat ends call for fan (G terminal is de-energized)	• Circulating fan is de-energized.
Limit switch string opens	• Primary controls shuts off burner. • Circulating fan is energized immediately at heat speed. • ST9103A opens primary control T-T connections. • Circulating fan runs as long as limit string stays open. • If there is a call for cooling or fan, the circulating fan switches from heat speed to cool speed.
Limit switch string closes	• ST9103A begins heat fan off delay sequence. • Circulating fan turns off after the selected heat fan off delay timing. • ST9103A recloses primary control T-T connections. • Primary control is energized, initiating burner light off.
Continuous circulating fan is connected	• Circulating fan is energized at low speed when there is no call for heat, cool or fan. • If fan operation is required by a call for heat, cool or fan, the ST9103A switches off the continuous fan speed tap before energizing the other fan speed.
Electronic air cleaner is connected (Optional connectors are available for 120 Vac electronic air cleaner)	• Electronic air cleaner (EAC) connections are energized when the heat or cool speed of the circulating fan is energized. EAC connections are not energized when the optional continuous fan terminal is energized.
Humidity control connected (Optional connectors are available for 120 Vac humidifier)	• Humidifier connections are energized when burner motor is energized.

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or Pressuretrols®. As is the case with warm air limit controls and hot water controls, pressure controls will also complete or break a circuit by opening or closing their contacts. Their contacts are of the micro switch design, or the older examples may be of the mercury tube type. The operating range of a pressure control must never exceed the design pressure of the boiler. All residential and most commercial boilers are of the low pressure type with a maximum pressure range not to exceed 15 PSI. Therefore, pressure controllers must be limited to the 0 to 15 PSI range.

Occasionally a steam system may be required to maintain pressure and the use of an operating controller may be necessary. In this case, two separate pressure controllers are necessary: one acting as the safety limit and the other as the operating limit. Residential steam systems never require more than 2 PSI.

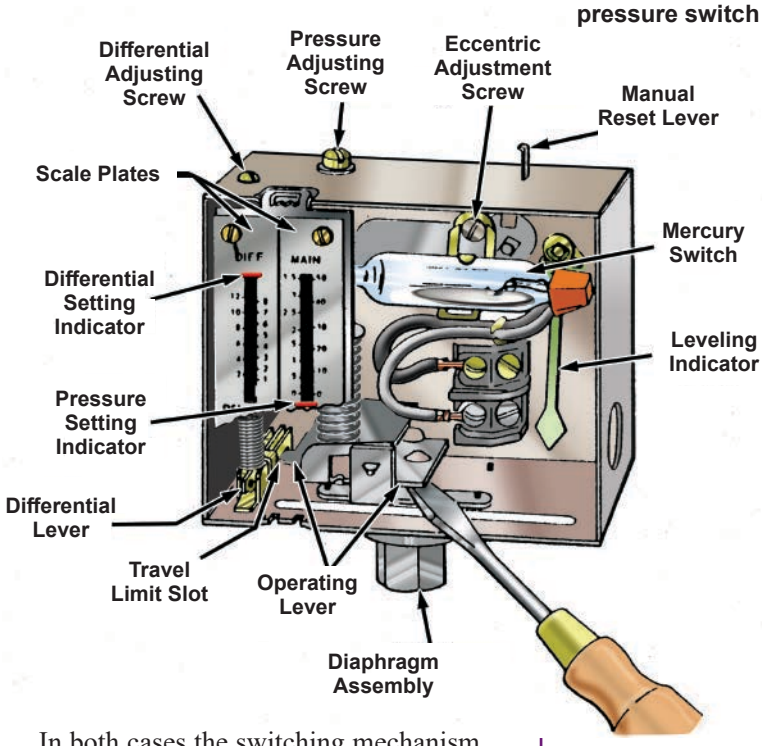
Most pressure controls are not sensitive enough for the low operating pressures required for some residential steam systems. In these systems, better results are obtained with a vapor control that operates on ounces of pressure instead of pounds, Figure 9-17.

Figure 9-17: Pressure control, vapor control

As the steam pressure changes, an expansion or contraction of a bellows actuates the switching mechanism. The cut-in and cut-out pressures can usually be independently set to meet any requirement. The snap-acting switch type does not require leveling.

If mercury switches are employed, the control must be leveled. Figure 9-18 shows a control with a mercury switch.

Figure 9-18: Mercury tube pressure switch



In both cases the switching mechanism is actuated by a diaphragm—the steam pressure counteracts the pressure exerted by the spring in the control. The tension of the spring is predetermined by the pressure adjustment screw, or main scale set point screw.

It is important to read the pressure adjustment instructions for the particular

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pressure controller being adjusted. On some controls, the differential is subtractive, meaning that if the pressure cut-out is set for 3 PSI and the differential is set for 2 PSI, the cut-in point will be 1 PSI. On other controls, the differential is additive and if the cut-in point is set at 1 PSI and the differential is set at 2 PSI, the cut-out point will be 3 PSI.

The cut-out point is the pressure at which the burner will shut off. The cut-in point is the pressure at which the burner will restart. It is very important to remember that if the cut-out point is changed and the differential is left the same, the cut-in point will also change. The same thing happens in reverse, if the cut-in point is changed, the cut-out point also changes.

Figure 9-18, previous page, shows a mercury tube pressure switch with the cover off, indicating various parts and adjustment points.

The pressure control must always be installed above the water level of the boiler, and a pigtail, or siphon, as shown in Figure 9-19, must be installed between the boiler and the control. The siphon loop prevents steam from damaging the control.

The pressure control should be installed in the fitting provided by the boiler manufacturer, or in the pressure control mounting of the low-water cutoff. When making pipe connections, use pipe dope sparingly. Excess dope may clog the small opening of the pressure control, thus preventing it from operating properly.

When mounting a mercury switch pressure control, follow the method shown in Figure 9-19. Be certain to mount it in such a manner that its face is perpendicular to the siphon loop circumference. The reason for this is that the siphon loop tends to expand causing a motion that could cause the mercury switch to operate improperly.

**Figure 9-19:
Pressure control,
pigtail**

Installation of a Mercury Switch Pressure Control

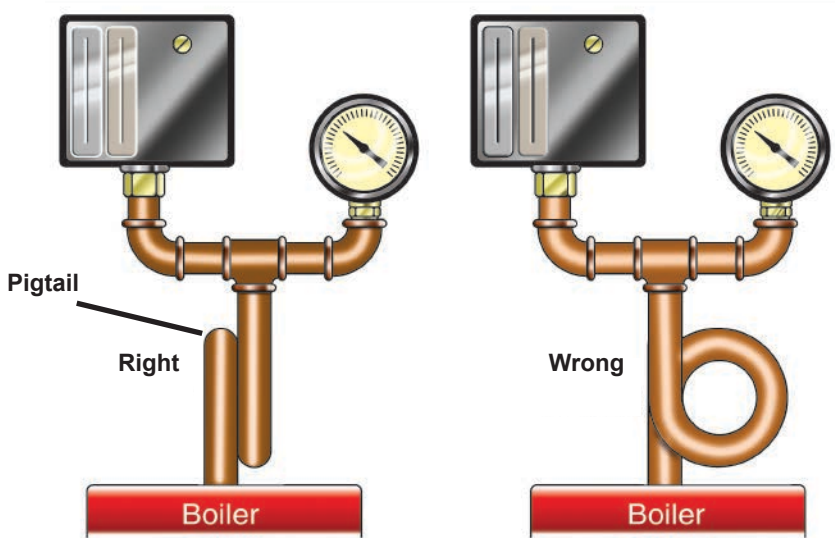

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Figure 9-20:
Pressure control
wiring

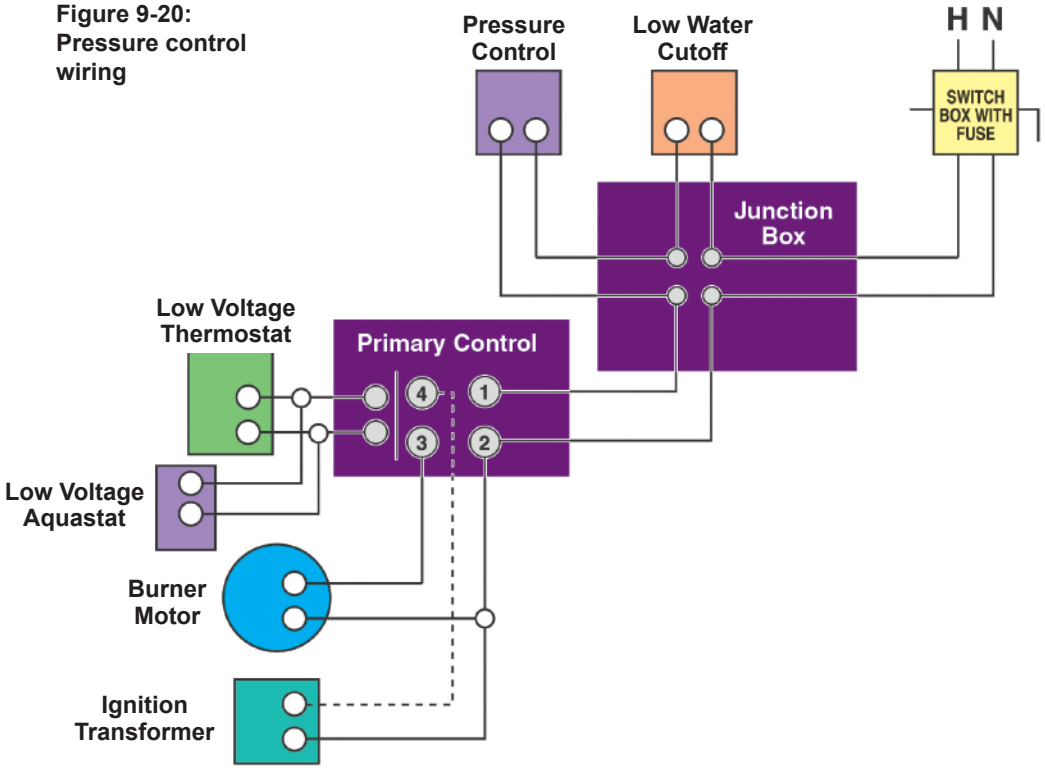

Figure 9-20 is a wiring diagram showing the pressure control. Like all other high limit controls, it is wired into the hot line in series with the primary control.

Low-water cutoff

The low-water cutoff prevents a burner from operating if the water level is too low in the boiler. This device is required on all steam boilers whether used for space heating or in a process application and should be installed on all new hot water boilers.

Figure 9-21 shows a float operated external low-water cutoff. Internal low-water cutoffs, with the float located inside the boiler, are also available.

With either type, when the float is in a level position, it holds a single-pole single-throw switch in a closed position. In the event the water level inside the boiler drops below the safe operating level, the float will also drop, thus opening the switch and breaking the hot line circuit to the burner.

Figure 9-21: External low-water cutoff

Probe type low-water cutoffs are becoming very common on most boilers, replacing the float types. These cutoffs may

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have timing devices to prevent nuisance shut downs should the boiler water surge. Probe type cutoffs send a low voltage charge through the water to ground on the boiler's metal. Never switch to a probe type low water cutoff without first getting the boiler manufacturer's recommendations as to where it should be installed.

In Figure 9-20, the wiring diagram shows how the low-water cutoff is connected into the main heating plant circuit. The low-water cutoff is connected in the hot line as all limit controls are and in series with the pressure control preceding the primary control. Low-water cutoffs on steam boilers may be incorporated with, or wired to, electronic solenoid water valves called automatic water feeders.

Boiler water temperature & circulator controls

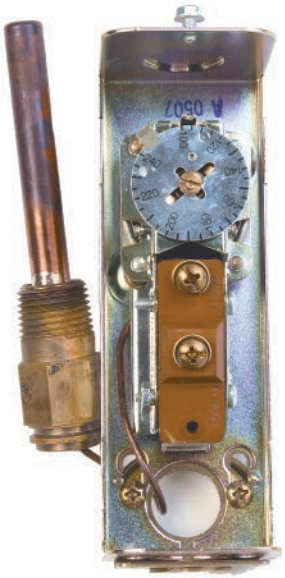
Boiler temperature controls, commonly called Aquastats® (a trademark of Honeywell), control water temperature in the boiler. They are switches that function automatically and, depending on the model, either open or close a circuit on a rise in temperature ("temperature rise").

Those that open a circuit on temperature rise are called "direct acting" and those that close a circuit on temperature rise are called "reverse acting."

These controls perform a variety of functions including:

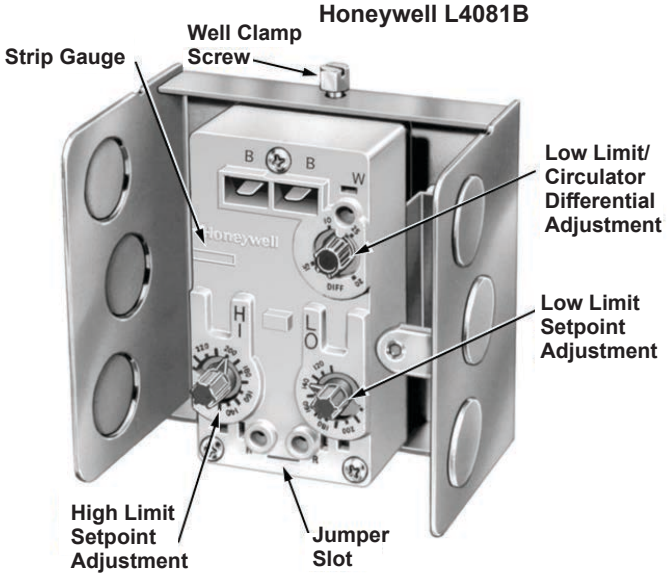
- High-limit protection & operating controls (SPST direct acting) break on temperature rise, make on temperature fall. These cycle the burner on and off based on boiler water temperature, Figure 9-22
- Reverse controls (SPST reverse acting) make on temperature rise, break on fall. These prevent circulator operation when the boiler water temperature is below the control setting to protect domestic hot water temperature. Some controls include both a SPST high limit protection and a SPST reverse acting switch in the same control. Figure 9-23.

Figure 9-22: Single function aquastat



A single function aquastat can be either direct acting (i.e. Honeywell L4006A or equivalent) or reverse acting (Honeywell L4006B or equivalent.) **The only way to tell the difference is the marking on the control.**

Figure 9-23: Honeywell L4081B



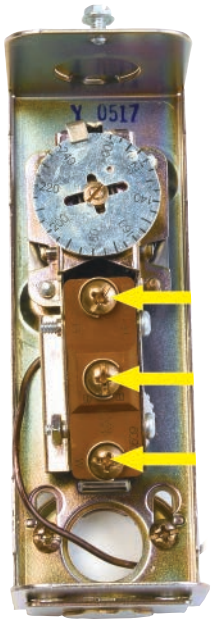


Figure 9-24: Multifunction aquastat

Reverse acting

Input

Direct acting

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25:26

- Turn on fan coils (SPST reverse acting) make on temperature rise, break on fall
- Also, some are SPDT providing either direct acting or reverse acting in a single control, Figure 9-24

Limit controls are generally of the immersion type, they feature a sensor that is installed in an immersion well that is inserted into a boiler tapping, Figure 9-25.

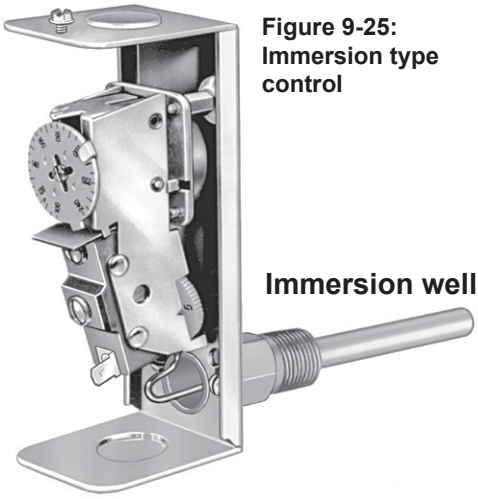

Figure 9-25: Immersion type control

- Older model sensors are filled with a liquid which expands and contracts due to temperature changes, and are attached to the control with a capillary tube that connects to an internal diaphragm, to open and close a switch
- Newer controls, such as the Beckett AquaSmart, Hydrolevel Hydrostat or Honeywell L7224, utilize thermistors that increase or decrease electrical resistance based on temperature and send that data to the boiler temperature control to open or close switches

Immersion temperature control mounting recommendations:

1. Install the well in a manufacturer designated tapping in the boiler. In boilers with tankless coils, there is usually a tapping in the coil plate so that the low and reverse limits can react quickly to temperature changes near the coil.
2. Avoid using bushings on the well. Bushings may prevent the temperature sensing element from extending far enough into the boiler to properly sense water temperature.
3. Handle the control with care. Do not damage the sensing element.
4. The sensor of the temperature control must be of sufficient length to insert all the way into the immersion well.

On/Off and Differentials

Once the boiler water temperature reaches the set-point and the control switches off, a small decline in boiler water temperature could cause the control to switch back on again. This action would cause rapid cycling of the temperature control and short cycling of the burner. To prevent this, boiler controls use a "differential" function, Figure 9-26.

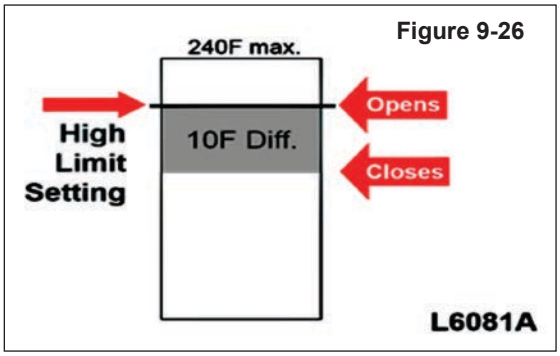

Figure 9-26

With a differential function, the set point remains as above when the boiler water temperature is below the set point. However, once the boiler water temperature has increased above setting and the burner has shut off, the set point is altered by subtracting a differential value. For example,

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if the set point is 180°F and the differential is 10°F, the control contacts will remain closed while the boiler water temperature is increasing up to 180°F. Once the contacts open and the boiler water temperature begins to fall, the contacts will remain open until the boiler water temperature falls below the set point of 180°F, minus the 10°F differential, or 170°F. At that point, the contacts will again close allowing the burner to begin heating the boiler water again.

Controls can have a fixed differential or a variable differential that allows user adjustment. New controls feature a variable differential. Refer to manufacturer instructions regarding differential settings for the specific control being used.

Basic Boiler Temperature Controls

Single function boiler temperature controls are automatic temperature actuated switches that have SPST switching that either:

- break on temperature rise and make on fall (limit or direct acting)

OR

- make on temperature rise and break on fall (reverse acting)

Basic multifunction (dual action) boiler temperature controls have SPDT switching that can do either or both.

Figure 9-22 (page 154) shows a typical single function aquastat, the Honeywell L4006 with two terminals and Figure 9-23 (page 154) shows a multifunction Honeywell L6006 aquastat with three terminals.

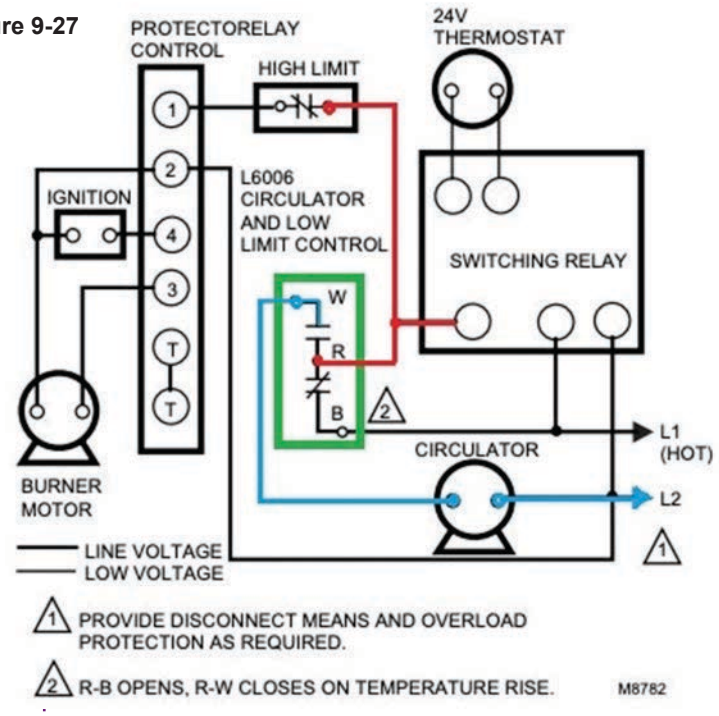
Figure 9-27 shows a boiler wiring schematic using a SPST direct acting high-limit temperature control and a SPDT temperature control, that provides a low operating limit, as well as a reverse limit to protect the domestic hot water supply.

High Limit and Circulator Aquastats
(aka Dual Aquastats or Multi-function Aquastat Controller)

These controls combine two separately functioning single aquastats in the same enclosure. They are typically found on boilers with domestic hot water coils. The most common version technicians are likely to find in the field is the Honeywell L4081B or equivalent. Refer to Figure 9-28.

This control includes a high limit switch to operate the burner and a reverse acting switch to prevent circulator operation when the boiler water temperature drops below the setting.

Figure 9-27



Circulator switching relays

Switching relays control a line voltage load with a

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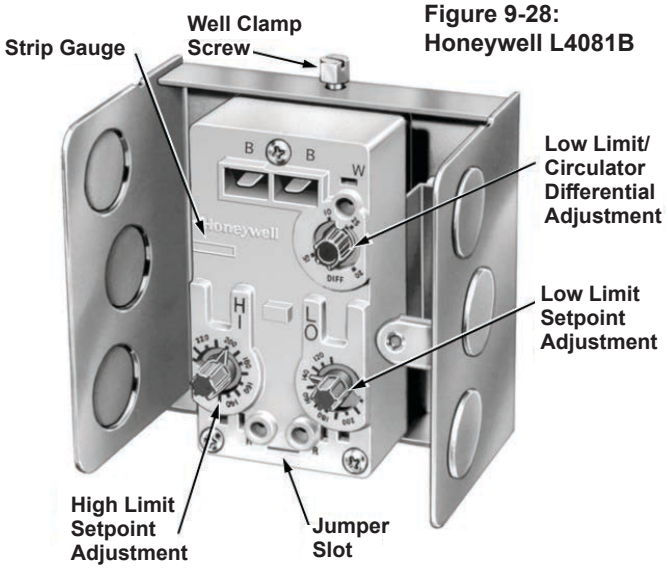


Figure 9-28: Honeywell L4081B

low voltage thermostat. They are used extensively on forced hot water systems to provide for multiple zones. For a switching relay to use a low voltage switch (thermostat) to control the line voltage loads (the circulator), it must contain a step-down transformer (from 120 to 24 volts), a relay or relays and the necessary line and low voltage connections.

Most of today's switching relays are double-pole, double-throw (DPDT), but can be found in several configurations. The one pictured in Figure 9-29, (R89) is SPST, an older type that can control only one load.

Figure 9-30 (Honeywell 8845 or TACO 501) shows a double-pole, single-throw (DPST) relay that allows for two devices to be switched at the same time. A typical application is where the switching relay turns on the circulator and activates the primary control.

Figure 9-30: TACO 501

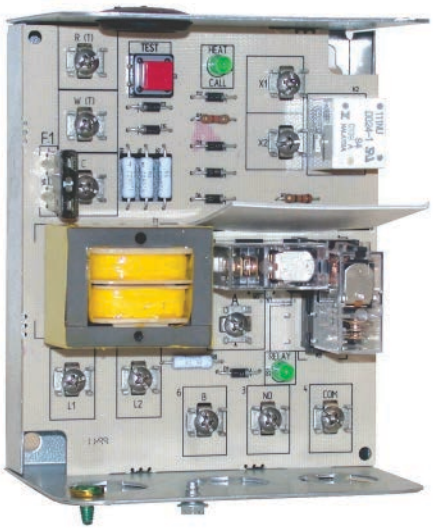


Figure 9-31 (TACO 501) shows a DPDT switching relay typically used to control an additional zone in conjunction with a combination boiler temperature control.

Figure 9-29: Honeywell R89

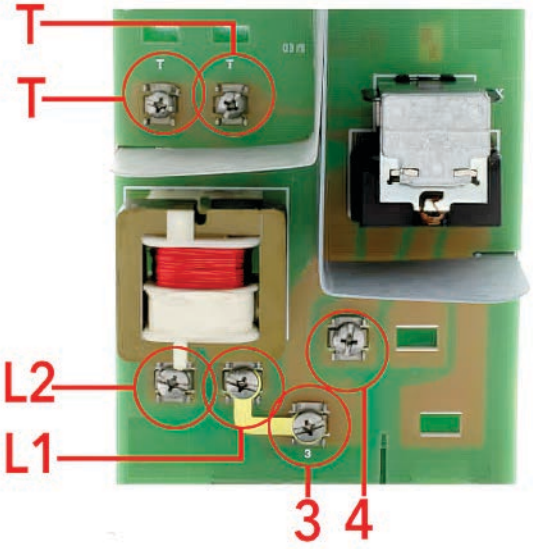
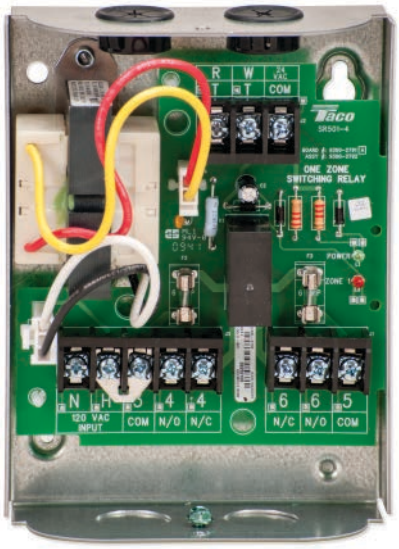


Figure 9-31: TACO 501



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32:14

Operation of single function boiler temperature controls in conjunction with a switching relay:

In Standby: L1 provides power to the B (normally closed) terminal on the SPDT low limit control, continuing through the R (common) terminal to the high-limit control and then to the burner to maintain the low limit temperature, Figure 9-27.

Call for Heat:

- When the room thermostat closes, it completes the circuit on the T-T terminals, which powers the #4 terminal in the switching relay, which then powers the R terminal (bypassing the B-R switch) in the SPDT low limit control.
- The burner will then operate until the high limit is reached and will cycle between the high-limit and its differential. Also, the circulator will run as long as the boiler temperature is above the low limit setting (which keeps the R-W switch in the closed position). If during the call for heat, the boiler water temperature falls below the low limit setting, power to the circulator will be suspended until the temperature rises above the low-limit setting.
- These functions will continue until the call for heat is satisfied and all controls return to standby.

Separate single function limit controls and switching relays are no longer widely used on residential systems. Typically, all the functions of these controls are combined into a single combination control.

Combination (integral) boiler temperature controls

Combination boiler temperature controls on hot water systems integrate all major control functions into a single control. These controls manage all limit functions of the boiler, contain input terminals for power and thermostat control and output terminals to power the burner primary control and a circulator. There are often terminals that can be wired to external zone relays and zone panels to prevent circulators from operating below the reverse limit of the combination control, as well as an input terminal to signal a call for heat from those external zone controls.

There are two major types of combination controls:

- Dual-function high-limit / relay controls (such as the Honeywell L7148 and L8148 Aquastat Relays)
- Triple-function high-limit / low-limit / relay controls (such as the Hydrolevel Hydrostat; Beckett AquaSmart; and Honeywell L8124 and L7224 Triple Aquastat Relays)

Dual function boiler temperature controls are manufactured for "cold-start" boilers that do not maintain temperature to provide domestic hot water from a tankless coil. The wiring of these controls is fairly straightforward with line voltage power connected to L1–L2, the burner connected to B1-B2 and the circulator connected to C1-C2. All number 1 terminals are power terminals and all number 2 terminals are neutral terminals. The thermostat is connected to the low voltage T-T terminals.

Operation of a dual function boiler temperature control:

In standby: The control will be idle providing no power to the B1 (burner) and C1 (circulator) terminals.

Call for heat:

- When the room thermostat closes, it completes the circuit on the T-T terminals, B1 and C1 are powered which starts both the burner and circulator.
- If the high limit is reached during the call for heat, B1 terminal will stop pow-

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36:00

er to the burner, which will then cycle based on the high limit setting and its differential.

- The C1 terminal will be powered constantly to run the circulator until the call for heat from the room thermostat is satisfied and the control returns to standby.

Triple function boiler temperature controls are manufactured for boilers that maintain temperature to provide domestic hot water from a tankless coil. These controls provide:

- A high limit during calls for heat
- A low limit to maintain a temperature during standby to provide domestic hot water
- And a reverse limit to prevent circulators from operating when the temperature of the boiler is below the low limit

Some triple function boiler controls can be programmed to operate as dual function controls by disabling the low limit. See the manufacturer's manual for instructions.

The wiring of these controls is similar to the dual function controls, line voltage is connected to L1–L2, the burner is connected to B1-B2 and the circulator connected to C1-C2.

The thermostat is connected to the low voltage T-T terminals.

These controls also have two terminals to communicate with external zone controls to mirror the domestic water protection of the main circulator and to provide the combination control with a signal that there is a call for heat from an external zone.

- ZC is powered whenever the boiler temperature is above the low limit setting. This power can be connected to external zone relays to provide reverse limit control of multiple zones
- ZR – when line voltage (typically from an external zone relay) is applied to ZR, the B1 terminal is powered and the burner will start and run until the high limit setting is reached

Operation of a triple function boiler temperature control using T-T:

In standby: The control will provide power to the burner, B1, to maintain the low limit temperature. In addition, ZC is also powered when water temperature is above the low limit.

Call for Heat:

- When the room thermostat closes, it completes the circuit on the T-T terminals. B1 and C1 are powered, which starts both the burner and circulator.
- If the high limit is reached during the call for heat, B1 will stop power to the burner, which will then cycle based on the high limit setting and its differential.
- If, during the call for heat, the boiler water temperature falls below the low limit, power to the C1 and ZC terminals will be suspended until the temperature rises above the low-limit setting. These functions will continue until the call for heat is satisfied and the control returns to standby.

Operation of a triple function boiler temperature control using ZR:

In standby: The control will provide power to the burner, B1, to maintain the low limit temperature.

Call for Heat:

- A line voltage input to ZR from an external zone relay or panel will signal a call for heat. Terminals B1 and ZC are then powered, which starts the burner and external zone circulators that are calling for heat.
- The main circulator, C1, will not be

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39:39

powered during a call from ZR, unless there is a call from TT at the same time.

- If the high limit is reached during the call for heat, B1 will stop power to the burner which will then cycle based on the high limit setting and its differential.
- If the boiler water temperature falls below the low limit during the call for heat, power to the C1 and ZC terminals will be suspended until the temperature rises above the low-limit setting. These functions will continue until the call for heat is satisfied and the control returns to standby.

Triple function boiler temperature controls with integral burner primary functionality are produced to save costs for boiler manufacturers. They have become unpopular due to the high cost to replace them. The functionality is identical to other triple combination controls and when they fail they can be replaced with a new boiler temperature control and a separate primary control. Figure 9-32.

Service vehicle inventory today benefits from a variety of controls which can be adjusted to replace dual function and triple function controls, so that only a single control is needed in inventory for replacement work. Some newer models also provide low-water protection to the boiler.

Figure 9-32: Honeywell 8182

In 2012 the DOE (Department of Energy) issued a rule requiring that boiler manufacturers must equip each boiler, other than a boiler equipped with a tankless domestic water heating coil, "with automatic means for adjusting the temperature for the water supplied by the boiler to ensure that an incremental change in inferred heat load produces a corresponding incremental change in the temperature of water supplied." Simply stated, this means that all new boilers, except those equipped with domestic hot water coils, must be able to automatically adjust to varying weather conditions and/or indoor temperatures."

Control manufacturers have met this requirement in different ways. Consult the manufacturer's instructions when servicing these controls, what appears to be a defective control may be the that control is using an energy saving algorithm.

Adding zones with circulators

Full zoning control of multiple circulators can be achieved through the use of circulator switching relays. These relays need to be at least DPST to provide an input to the boiler temperature control on the ZR terminal and to provide domestic hot water protection through the ZC terminal.

Figure 9-33 shows the switching relay in standby mode.

Call for heat:

- When thermostat 2 closes, current flows from terminal 3 (which has a jumper from terminal 1) to terminal 4 and from terminal 4 to terminal ZR in the boiler temperature control.
- The boiler temperature control recognizes the power on ZR as an external zone calling for heat and then powers B1 to start the burner. Terminals 5 and 6 also close allowing current to flow from

ZC through terminals 5 & 6 to power the zone 2 circulator.

- If during the call for heat, the boiler water temperature falls below the low limit, power to the ZC terminal will be suspended until the temperature rises above the low-limit setting.
- When thermostat 2 opens, the zone 2 circulator stops and the boiler temperature control returns to standby unless other zones are still calling for heat.

If multiple zones are needed, they may be added by using multiple switching relays wired in parallel.

However, zone panels that can control multiple thermostats and circulators are available. They provide a cleaner and neater installation and are easier to troubleshoot, Figure 9-34.

Adding zones with zone valves

Wiring zone valves seems to be the most intimidating thing to service techs but it is quite simple.

Zone valve wiring is divided into two sections:

- An actuator (motor) which opens and closes the valve
- An end switch which makes when the valve opens to complete a circuit.

Figure 9-34: Zone panel used with circulators

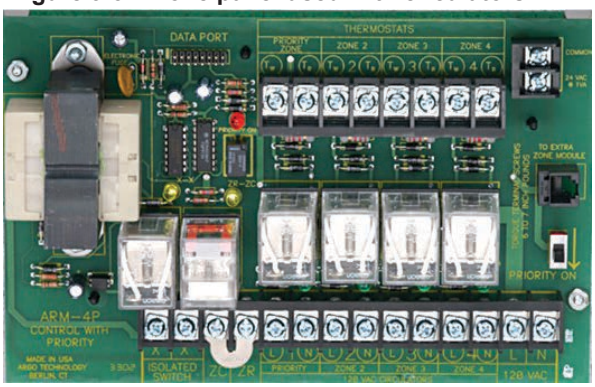
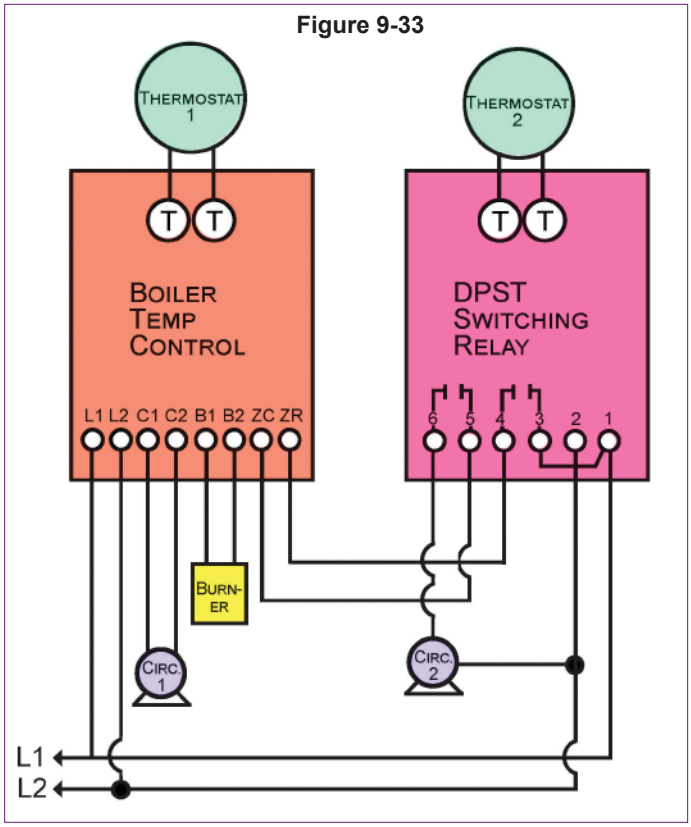


Figure 9-33



When wiring or troubleshooting these two sections should be considered independently.

Actuator motor wiring: Remember, a simple series circuit consists of a power source, a switch and a load. Electrical current flows from the power source through the switch, then through the load and returns to the power source. In Figure 9-35 on following page, follow the solid lines to see that the zone valve actuator is wired the same way. Power flows from the 24V transformer (power source) to the thermostat (switch) to the zone valve actuator (load) and then returns to the transformer. Subsequent zone valves, (dotted lines), can be wired in parallel to this circuit. Refer to the manufacturer's instructions regarding how many zone valves can be powered by a single 24V-40VA transformer.

End switch wiring: End switch wiring is typically connected to the T-T terminals

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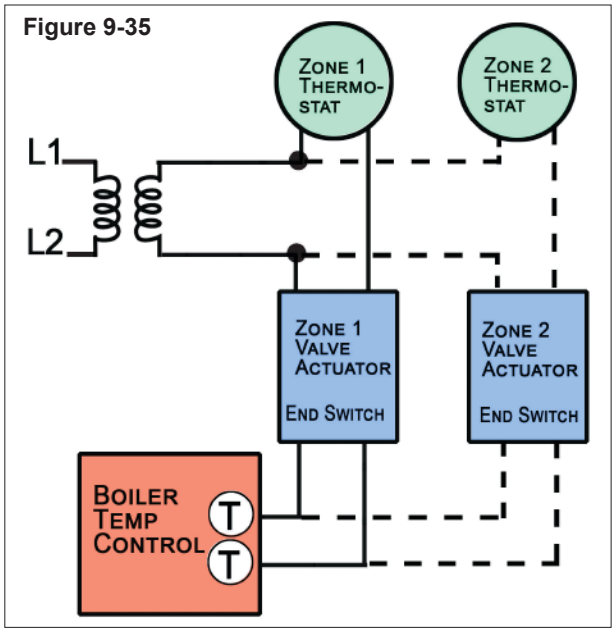
Figure 9-35



in a boiler temperature control or switching relay. Additional zones, Figure 9-35, are wired parallel to the first zone.

4 connection vs 3 connection wiring: Some valves have four wire connections as shown in Figure 9-35 and some have three. In actuality, the three connection valves are wired internally the same, but share a common connection on their terminal boards. In Figure 9-36, terminals 1-2 control the actuator and terminals 2-3 are connected to the end switch.

Alternatively, wiring can be done with a zone valve panel similar to those used for circulator zoning to help organize and make troubleshooting simpler.

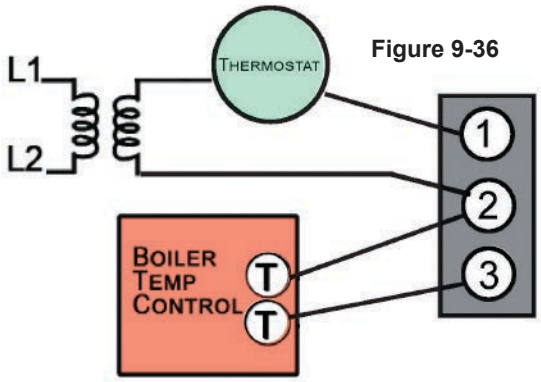
Zone Valve operation:

Standby: Valve is closed end switch is open.

Call for heat:

- When the room thermostat closes, it completes the circuit through the actuator, opening the valve.
- When the valve opens, the contacts on the end switch close, completing the circuit between T-T in the boiler temperature control which will then operate the burner and circulator as described above.
- When the room thermostat is satisfied, the actuator will close the valve and the end switch will open its contacts, putting everything back to standby.

Figure 9-36



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https://Learning.NORAweb.org/limit_controls_thermostats