Hot-Water and Steam-Heating Systems

Hot-water and steam heating are common in many parts of North America. Boilers distribute their heat through a system of pipes and *heat emitters*. The term — *hydronic heating* — means both steam and hot-water heating to some people and to only hot-water heating to other people. We use the term hydronic to refer to water-based heating and cooling systems.

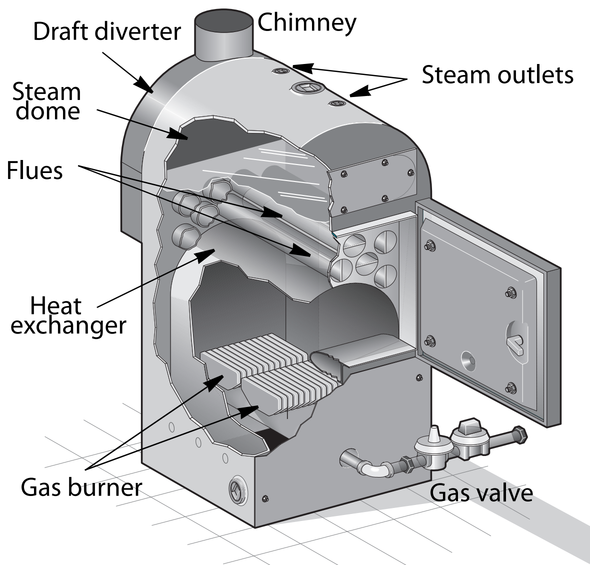
Steam heating is simpler than hot-water heat because it requires no pump. The steam builds pressure in the boiler, expands into pipes, pushing into the heat emitters. After the steam fills the radiators, the steam condenses, transferring its latent heat to the metal radiator. Steam heating is the least efficient heating option because of its high cycling losses and difficulty of achieving precise room-temperature control.

Hot-water heating is easy to zone and offers more energy-efficient control options than steam. However, cooling is difficult to incorporate into small to medium sized steam and hot-water systems. Chillers (water-cooling air conditioners) can use the same hydronic distribution piping; this option only works for large buildings.

Pipe insulation is often cost-effective for steam distribution pipes in most cases and for hot-water distribution pipes, depending on the temperature of the water and the cost of the insulation. Foam pipe sleeves are the most convenient type of pipe insulation for hot-water systems. Steam pipes are insulated with fiberglass, which is resistant to their higher temperature.

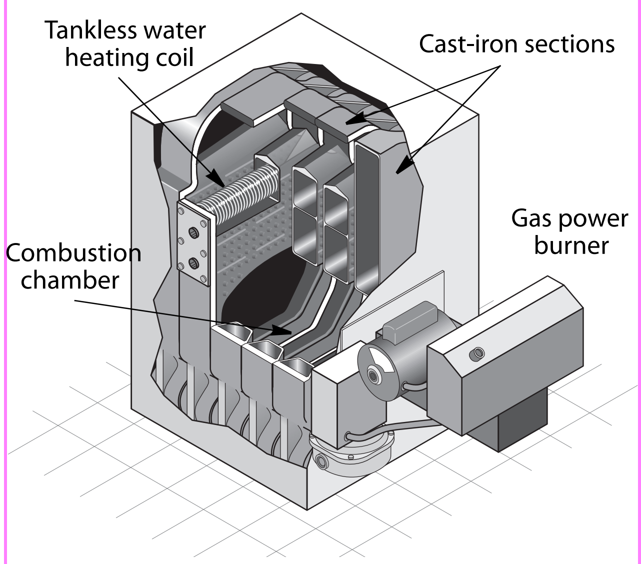
See "Pipe Insulation" on page 234.

Steel Fire-Tube Steam Boiler



Steel fire-tube boilers are common in larger and older residential buildings with steam or hot-water heat.

Cast-Iron Sectional Boiler



Cast-iron sectional boilers have individual sections joined by header pipes or gaskets. Spaces between the sections are flues.

Boilers

The three most common types of boilers for single and multifamily buildings are the cast-iron sectional boiler, the copper water-tube boiler, and the steel fire-tube boiler. These boiler designs are used for hot-water and steam heating systems. Hot-water boilers are completely filled with water and don't actually boil their water. Steam boilers have an air space at their water vessel's top, called the steam dome, where steam forms.

High-limit pressure and temperature controls protect boilers from damage by shutting off burners if the boiler gets too hot. Boilers also have another safety control that shuts the burner off if the water level in the boiler falls below a certain line. Local codes often require duplicate high-limit and low-water controls for larger buildings in case one control fails.

Controls also help the boiler optimize its performance and efficiency. Steam boilers often operate at excessive steam pressures, wasting energy. Hot-water boilers often heat water too hot and keep it hot for too long. Heating professionals solve these problems by adjusting automatic controls.

Correctly sizing boilers is important to their efficiency. The more oversized a boiler, the greater its cycling losses and inability to provide adequate heat during the coldest weather. In multifamily buildings, the energy wasted by frequent cycling can be reduced by installing smaller boilers and staging them to match the actual heating load. In an existing multifamily building, owners may install a smaller boiler next to the existing large boiler to heat the building during most of the year when the weather is mild. The older and less-efficient boiler only operates during very cold weather.

Boilers for space heating are sometimes used for water heating as well. See "Water Heating Integrated with Space Conditioning" on page 230.

Hot-water Distribution Systems

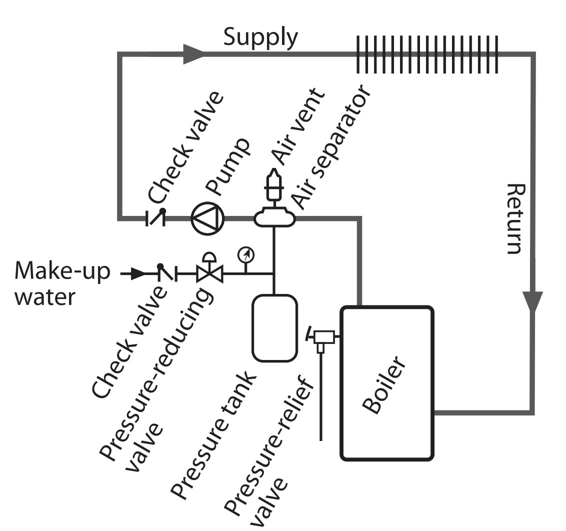
Hydronic heating systems combine a boiler or hydronic heat pump with heat emitters, piping, and controls. A pump circulates heat from the boiler or heat pump through the heat emitters. Hydronic systems often include domestic hot-water heating as part of the system.

See "Heat Pumps" on page 182.

The most common heat emitters are standing radiators, baseboard convectors, and fan coils. European-style wall-hung radiators and radiant floors are becoming more common.

An expansion tank allows the water in a hydronic piping system to expand and contract as it's heated and cooled. An air separator and vents expel air from the system to prevent circulation problems and metal corrosion.

Piping and Near-Boiler Devices

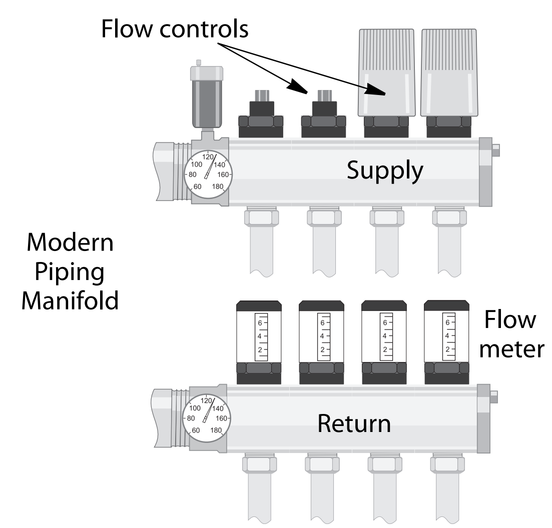


The piping near the boiler is critically important to proper functioning and safety. In particular, the circulator should be located downstream from the air separator and pressure tank.

Piping and distribution — There are three common types of distribution circuitry: series, parallel, and primary-secondary. Series has all the heat emitters in the same loop, which is simple and economical. However the water temperature is lower at the inlet of every successive heat emitter, and this must be factored into design. Parallel is a very common piping method featuring the ability for zoning. A reverse-return parallel piping system equalizes head loss of its parallel circuits to reduce temperature variation in rooms.

Piping systems may be zoned to offer different temperature setpoints and schedules to different parts of a home or multifamily building. One way to zone a hydronic system is with zone valves controlled by thermostats. The other way is with separate circulators for each zone. When the thermostat, located in the zone, calls for heat, the zone valve opens and/or the zone circulator starts. Zone valves have switches inside them that activate circulators and boilers after the valves open.

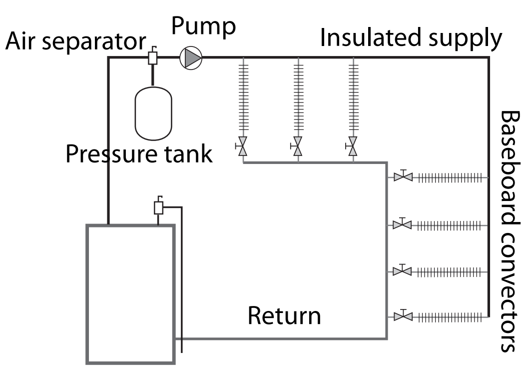
Modern Zone Control



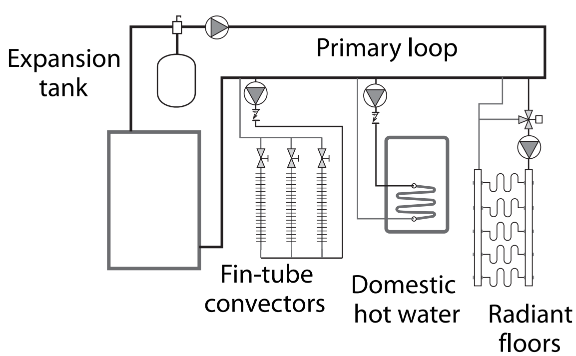
To make sure that hot water radiators are full, open the bleeder valve annually. You may hear a slight hissing. Wait until water squirts out — then close the valve.

The most advanced piping arrangement for using separate circulators is primary-secondary piping. This piping system employs a primary or boiler loop with a number of secondary loops piped through the home's heating zones. The boiler loop has its own circulator, but this loop and circulator doesn't provide water to any heat emitters directly. Each secondary circuit has a circulator that moves warm water to and from the heat emitters.

Piping Strategies: Traditional and Modern



The reverse-return piping design has a similar length of total supply and return piping connected to each radiator.



The primary loop or boiler loop supplies hot water to its secondary loops, which have their own circulators.

The most important benefit of primary-secondary piping is its versatility in providing different water temperatures and flow rates to the different types of heat emitters in the zones, while protecting the boiler from low return-water temperatures that cause flue-gas condensation and corrosion.

Circulators can use considerable electrical energy in larger hydronic systems. Designing the circulator properly and then testing the system for the correct operating pressures minimizes circulator energy. Existing systems with excessive pressure and operating power can be retrofitted by trimming the pump's impeller on a lathe or ordering a smaller impeller for the pump.

Heat emitters for hydronic systems —

Modern fin-tube convectors are an improvement over old-style hydronic radiators, because the fin-tube convector is longer than a radiator and is installed on the floor where it provides better air convection and air mixing.

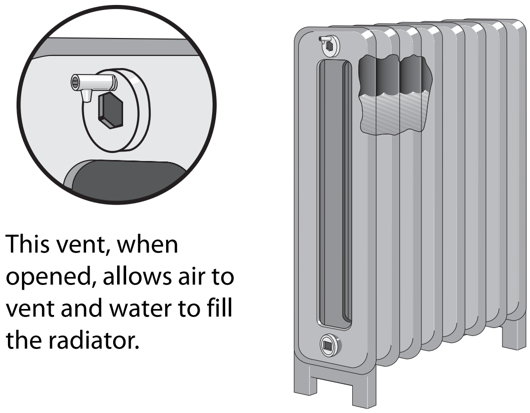
Some multifamily buildings use fan-coil units that combine fin-tube piping with a fan to distribute the heat. If they are equipped with drip pans, fan coils can also circulate cooled water during the cooling season. Larger fan coils, called hydronic air handlers, connect to supply and return ducts like a forced-air furnace. Modern hydronic air handlers may contain an A-coil for cooling or a heat-recovery ventilator for whole-building ventilation.

Panel radiators have become popular in recent years for both new and retrofit applications. Panel radiators are made from steel or aluminum panels welded or pressed together into flat sections.

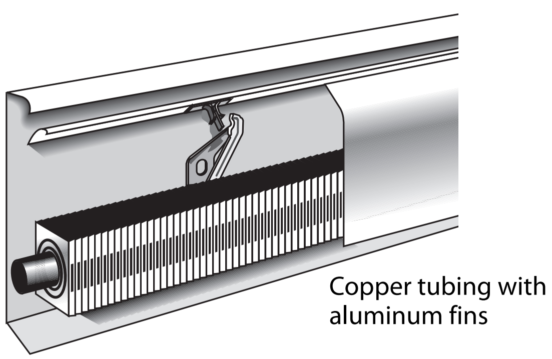
Panel radiators are either designed primarily for radiation or for a combination of radiation and convection. The difference in design between radiators and radiator/convectors is the addition of steel fins mounted vertically to the back of the panel or between two panels.

Radiant floors offer unbeatable comfort, superior energy efficiency, and the ability to use a condensing boiler or hydronic heat pump to its full potential. Radiant floors require relatively low water temperatures that condensing boilers and hydronic heat pumps can provide. Without the radiant floor's low water temperatures, these heat sources can't be as efficient. Radiant tubing can be incorporated into traditional concrete slabs, thin masonry slabs, or all-wood floors.

Common Hydronic Heat Emitters



Radiators like this one actually heat by both radiation and convection.



Hydronic convectors are the most common heat emitter, used in more modern buildings.

Controls for hot-water hydronic systems — The simplest hydronic heating systems have a thermostat controlling a relay that activates both the boiler and circulator. Hot-water boilers also have a control called an aquastat that turns the burner off when the high-limit temperature is reached. The better aquastats have a separate switch that operates the pump after the thermostat turns the burner off to deliver heat stored in the boiler.

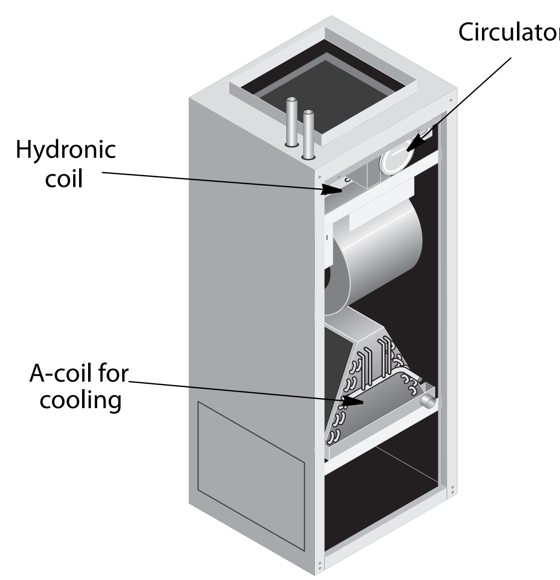
Many existing hot-water heating systems circulate or store water hotter than necessary to heat the building. Excessive temperature leads to greater standing losses and overheating the living spaces.

Boilers in single-family homes don't need to store a boiler full of heated water, unless the boiler has a tankless coil for water heating. This situation is sometimes referred to as a hot boiler. If a hot boiler has no tankless coil, a service technician may rewire the controls so that the burner doesn't fire unless the thermostat calls for heat.

The ideal aquastat setting for a boiler would be the lowest setting that gives satisfactory comfort without creating condensation in the boiler or its venting. A range of ideal temperatures between 140°F and 180°F depends on the outdoor temperature. In cold weather, the ideal temperature is higher, and in mild weather it is lower.

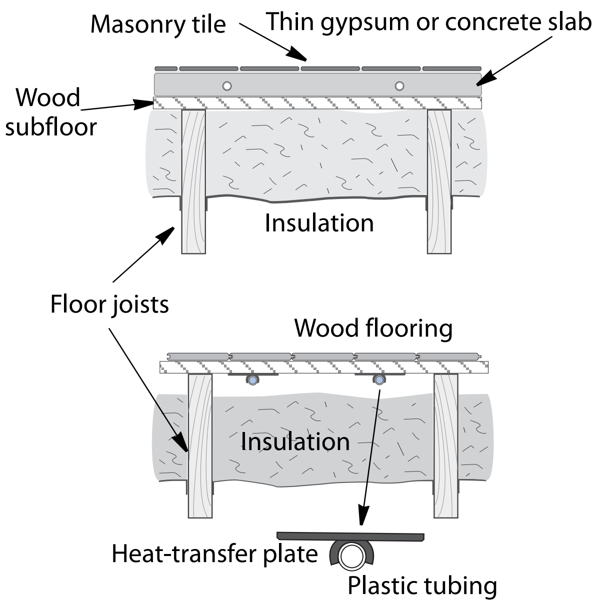
Self-adjusting aquastats called reset controllers adjust the water temperature up or down according to the outdoor temperature. Reset controllers are very effective for multifamily buildings where large boilers store many gallons of water. Reset controllers are often combined with cutout controllers that prevent boiler operation when outdoor temperatures rise above 60°F.

Hydronic Air Handler



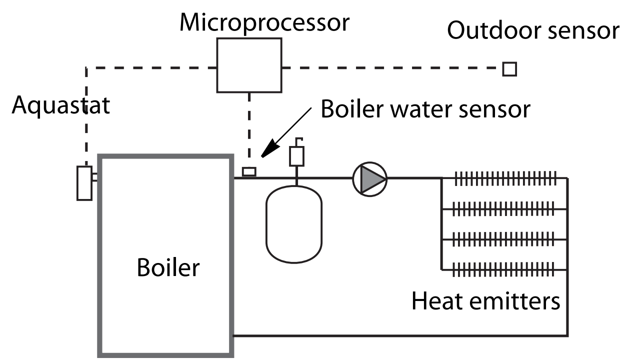
Both standard air handlers and heat-recovery ventilators are now available with hydronic coils.

Radiant Floors

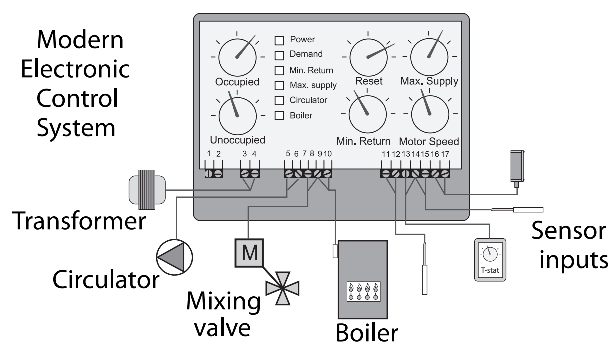


Radiant floors use lower water temperatures, which offer both comfort and efficiency advantages over the higher temperatures of other heat emitters.

Energy Controls: Simple and Complex



A reset controller adjusts boiler water temperature according to outdoor temperature.



Today's hydronic controllers combine a variety of functions, including thermostat, circulator, mixing valve and hot-water reset control.

Electronic controllers for hydronic systems have improved rapidly in their control capabilities and reliability in the past couple of decades. Their precision and advanced capabilities help to maximize comfort and minimize energy use. Electronic controls can perform more functions and can regulate hydronic systems more precisely than simpler electromechanical controls.

Modern electronic controllers measure temperature, process information, and switch power to the boiler, circulators, zone valves, and mixing valves. Electronic controllers provide digital readouts of system status and give warnings of sensor failure and other system faults. Electronic controllers can: reset boiler water temperature, prevent warm-weather boiler operation, control the position of mixing valves, activate multiple boilers in stages, control the speed of injection pumps, and activate and deactivate heating loads in order of priority.

Thermistors are electronic sensors that measure indoor temperature, outdoor temperature, and water temperature. Thermistors signal the electronic controller to regulate boiler and other components intelligently.

Hydronic heating systems are zoned using several different control strategies. Thermostats control zone valves on systems with a central circulator, or each zone has its own thermostat controlling a dedicated circulator. In advanced systems, zone circulators run constantly at variable speeds, injecting heated water as needed according to the changing demands of the zone. The domestic hot-water system is another zone, heated by the central boiler and equipped with its own circulator and control.

A multi-zone relay center controls the heating zones along with the domestic hot-water circuit. The controls give the domestic hot-water circuit priority whenever residents draw hot water from the tank. The electronic controller can prioritize zone operation to allow a relatively small boiler to heat a relatively large load. Electronic controllers often provide a post-purge control that leaves a circulator on after the heat source turns off to deliver left-over heat into the zones. Electronic controllers can also anticipate large loads and start boilers early to fill the demand.

The multi-zone relay center combines a number of control components into one box, where technicians make connecting all the wiring easy and convenient. Centralized zone controls, mounted on the piping manifolds, makes these controls space-efficient and easy to troubleshoot.

Common problems with hot-water heating systems — Most hydronic systems have iron and steel components that corrode if oxygen sneaks into the system. There are two common ways oxygen gets in.

1. Water escapes through the pressure-relief valve or a leak. The make-up water valve then provides water with dissolved oxygen.
2. The circulator creates too great a suction within the valves and piping. Oxygen from the air is sucked in through vents or small openings in the piping.

A waterlogged pressure tank causes hot-water flow out of the pressure relief valve, wasting energy and bringing new oxygen-bearing water into the system. Technicians either replace the pressure tank or simply recharge it with air.

Air in the hot-water distribution system displaces water in radiators and interferes with circulation. Technicians bleed radiators using special bleed valves and install air eliminators that trap air and vent it out of the system.

A particular threat to boilers is combustion gas condensate that corrodes boilers and chimneys. The most common cause of this condensation is return water temperature to the boiler that is too cool (less than 140°F). Control systems must be designed, installed, and adjusted to avoid this condition.

Steam Distribution Systems

Steam distribution systems consist of a boiler, piping, and radiators or other heat emitters. Other important piping accessories include steam traps, air vents, radiator temperature controls, and condensate tanks, and condensate pumps.

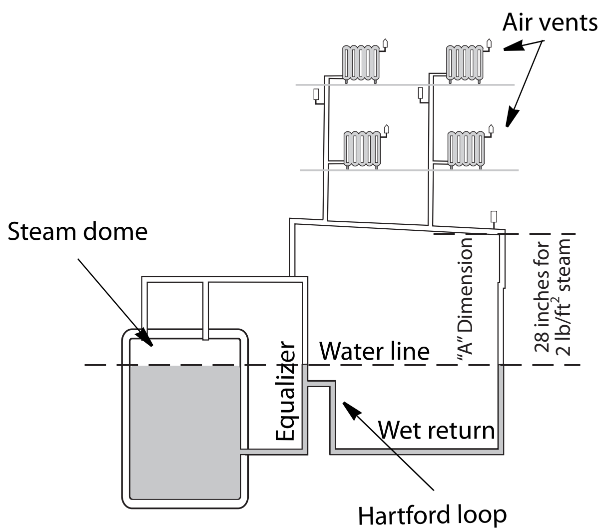
Efficiency-conscious boiler operators set the steam boiler's pressure controller at less than 2 pounds per square inch. Excess steam pressure wastes energy and causes steam systems to malfunction.

Ideally, the boiler cycles off as soon as the radiators are all full of steam to prevent overheating, and a timed-cycle controller varies the cycle length depending on outdoor-temperature signal.

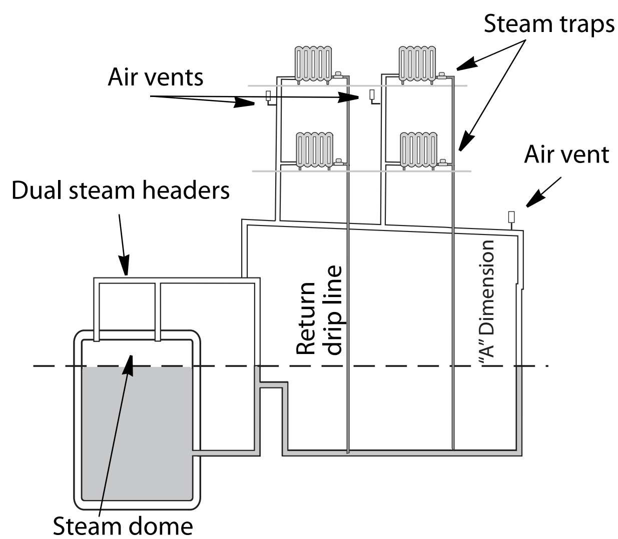
There are two main kinds of steam distribution systems: one-pipe and two-pipe.

One-pipe steam — In one-pipe steam distribution systems, steam expands, filling pipes and radiators using the steam pressure produced by the boiler. Ideally, air leaves the pipes and radiators quickly to allow the steam into the radiators. Air vents expel air from the pipes and radiators to make room for the expanding steam. The air vents close automatically using a bimetal element that senses steam. For air to escape quickly, there must be enough air vents, and the vents must be working. Sometimes scale plugs the vents. Sometimes the main vents aren't large enough, and the air struggles to escape through tiny radiator vents, while steam pressure builds delaying radiator heating.

Gravity-Return Steam Distribution Systems



One-pipe steam systems deliver the steam and collect the condensate through the same risers. Water is fed back into the boiler by a combination of gravity and left-over steam pressure. The equalizer equalizes pressure on both sides of the boiler water to prevent water from being forced out of the boiler. The Hartford loop prevents the boiler water level from falling more than two inches below its normal level.



Dual steam headers prevent exiting steam from drawing water out of the boiler into steam headers. Condensate draining into a water-filled main return prevents water hammer.

With one-pipe steam, gravity returns condensed water to the boiler through the same single pipe the steam used to rise up into the radiators. The most common problem with one-pipe steam: parts of the distribution system are blocked by air that can't escape. Condensate flowing down collides with steam coming up, an event called water hammer, when air delays the steam.

When service technicians install large-volume air vents to the ends of main supply pipes, the performance and efficiency of one-pipe systems improves. Replacing undersized or malfunctioning radiator vents allows steam to move more quickly into the radiators.

Thermostatic air vents restrict the flow of air out of the radiator, and thus control the flow of steam into the radiator. Thermostatic air vents can prevent oversized radiators from over-heating rooms.

Whenever water and steam meet, steam pressure hurls the water against pipe joints, causing water hammer. Water hammer can plague steam systems during startup, in cold weather, and when the boiler has been replaced without the proper system-design changes. One-pipe systems also have problems with water hammer, if radiators or pipes rise or fall for some reason. The building settles or pipes sag, for example.

***Two-pipe steam* —** With two-pipe steam distribution systems, steam traps operated by bimetal elements hold the steam in the radiator until it condenses into water. After the steam condenses into water, the trap opens and the water returns to the boiler through the return pipes.

Steam should never return to the boiler room through the return pipes. When the radiator steam traps fail, steam escapes into the boiler or return pipes. When steam flows through the radiators and into returns, water hammer can occur. Steam traps generally last three to six years and when some traps fail, the resulting water hammer can ruin the remaining traps.

Steam radiator orifices are an option for replacing steam traps. Orifices regulate the steam flow to an amount that can condense in the radiator as fast as the steam enters. The orifices don't fail because they are a simple metal disc with a hole in the center.

Thermostatic radiator valves (TRVs), installed at the radiators entrance, can reduce overheating and increase the steam system's efficiency. Air vents on steam mains can improve the heating performance of radiators farther away from the boiler.

Steam boiler replacement — Replacing a steam boiler often requires changes to the steam distribution system. It takes a bona-fide steam expert to anticipate problems, make distribution-system design changes, and troubleshoot the new system after the boiler is installed.

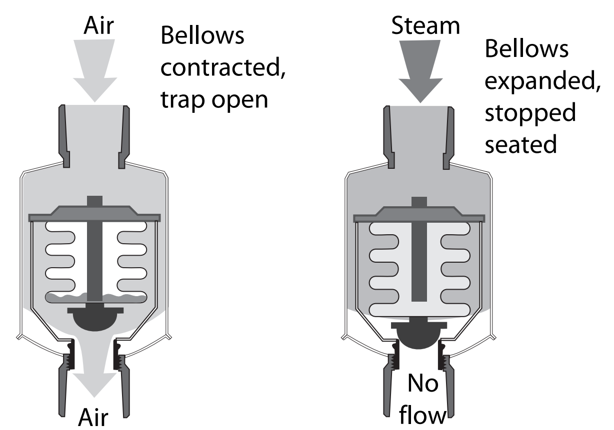
When the boiler water level changes, the critical "A" dimension changes, which can allow steam and condensate to contact each other in the lower reaches of the condensate return lines connected to the new boiler. New boilers have smaller steam domes than old boilers. The new boiler may produce wet steam or even push water into the steam mains. Owners and operators avoid these problems by good design and expert installation.

Water Treatment for Boilers

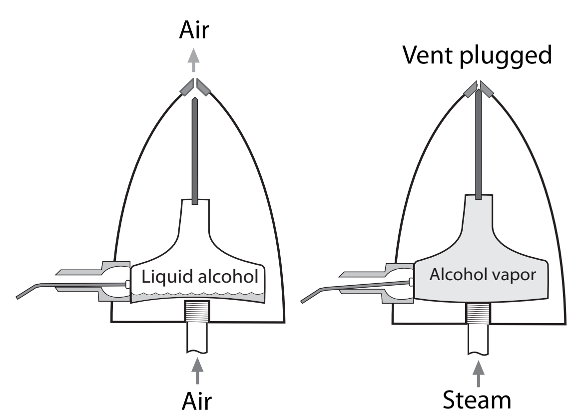
Dirt reduces the efficiency of hot-water and steam-heating systems. Technicians or boiler operators should check combustion for CO, dirt, and soot. The tubes or sections and other fire-side surfaces should be cleaned as often as necessary. Residents should dust radiators once a year to improve room heat transfer.

Steam-boiler operators put chemical additives into boilers and drain water out regularly to remove sediment — a process called blow-down. Blow-down removes dirt, rust, and scum from the boiler. Water treatment makes the water less corrosive and also helps keep particulates in suspension so they can be removed from the system by regular blow-down. Water treatment also reduces foaming, which delivers wet steam — less effective for heating than dry steam — into the pipes. Water treatment is a fairly complicated subject. Since water characteristics vary greatly from place to place, local experts are the best source of information on water treatment.

Steam Traps and Vents: Open Versus Closed



The steam trap's bellows operate a stopper that traps steam when the steam boils the alcohol solution in the bellows.



Radiator air vents operate on the same principle as the steam trap, passing air and stopping steam.

Hot-water systems shouldn't need blow-down or water treatment beyond their initial filling. Before the initial filling, the installer should fill the system with a cleaning solution, which then circulates for several hours to remove grease, oil, and chemicals from solder and flux. If the city water is corrosive, an initial charge of water treatment may sometimes be necessary. After the initial fill, a properly designed and correctly functioning hot-water system should operate indefinitely without needing cleaning or additional water.

New Energy-Efficient Combustion Furnaces and Boilers

The most important advances made by newer energy-efficient heaters over older conventional models are control of combustion air and elimination of dilution air. Draft inducer fans or high-pressure, forced-draft fans ration combustion air to the heat exchanger. This forces combustion by-products through tighter spaces, where more heat is removed compared to older heaters. Dilution air — which exhausts heated air from the home — is eliminated because a small blower controls the chimney draft instead of the dilution device.

High-efficiency furnaces and boilers have AFUEs of 80% to 97%, compared to conventional furnaces and boilers with AFUEs of 65% to 78%. The high-efficiency furnaces and boilers contain a number of important improvements over older models:

- Electronic ignition (no pilot light).
- Heat exchangers that restrict combustion gases, squeezing more heat out of them.
- Fans to move the combustion air through the smaller flues.
- Water condensed from flue gases in a corrosion-resistant heat exchanger for extra efficiency.
- Compact size and lighter weight, reducing off-cycle losses.

When replacing a furnace or boiler, do the following:

- Insist on proper installation.
- Be sure that deficiencies in ducts, piping, chimney, gas service, and electrical supply be corrected as part of the installation.
- Confirm that parts and service will be available in the future.
- Compare the competing warranties of the furnaces or boilers.
- Establish a maintenance schedule for the new furnace or boiler.

Characteristics of Gas Furnaces

AFUE	SSE	Operating characteristics
60+	70+	Category I chimney, draft diverter, no draft fan, standing pilot, non-condensing, indoor combustion and dilution air.
78+	80+	Category I chimney, no draft diverter, draft fan, electronic ignition, indoor combustion air, no dilution air.
90+	90+	Category IV chimney, no draft diverter, draft fan, low-temperature plastic venting, positive draft, electronic ignition, condensing heat exchanger, outdoor combustion air is strongly recommended.