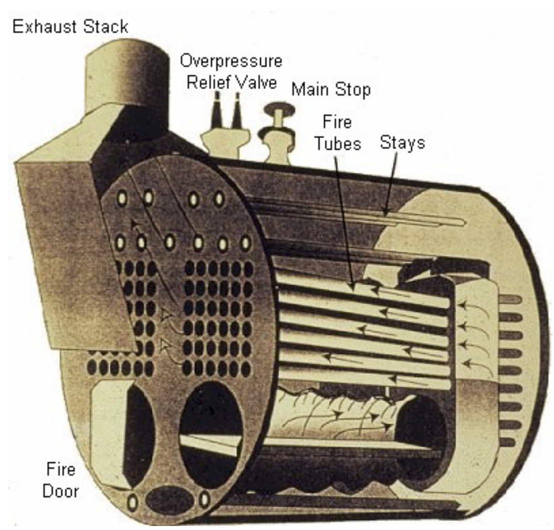
Chapter 2 Boiler 101: *typical NYC residential heating system*

One and two family homes often use forced-hot-air heating systems, which include a burner, heat exchanger and blower(s). In these types of systems, hot air is forced through ducts to every room in the house, where it blows out of vents that are usually located at floor level.

Many buildings in New York City, particularly multiunit apartments and commercial office buildings, use forced hot water or steam systems for heating. These types of systems use a boiler to heat water—the resultant hot water or steam flows through pipes to baseboard or free-standing radiators located in each room. As these radiators get hot, they radiate heat into the room.

NYC Dept. of Environmental Protection issues certificates for boilers that are rated over 2.8 million BTU/hr, and issues registrations for boilers that are rated between 350,000 BTU/hr and 2.8 million BTU/hour. These figures exclude very large sources (power plants) and small sources (individual homes). DEP does not exercise regulatory authority over power plants, which are regulated by state and federal Title V permits with emission controls. DEP's regulations also exclude fuel burning equipment in one or two family homes, or equipment with a gross input of 350,000 BTU/hr. or less; boilers meeting these exemptions will use No. 2 heating oil or natural gas.

What is a boiler?

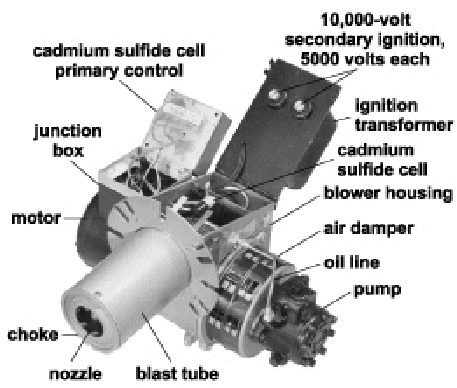


A boiler is an enclosed vessel in which water is heated and/or boiled—the water is circulated from the boiler as hot water or steam for heating or power.[1] There are two types of boilers used for residential and commercial heating systems: hot water and steam boilers. Both types are used in conjunction with baseboard heaters or radiators to transfer the heat throughout a building. They can be fired using fuel oil or natural gas.

A hot water boiler consists of a fuel burner(s), an ignition source, a blower fan, a refractory liner (to protect the floor of the boiler and building), a heat exchanger, a circulating pump, an expansion tank and at least one radiator.

A steam boiler consists of a burner(s), an ignition source, a blower fan, a refractory liner, a heat exchanger, a boiler water regulator, a condensate return pump and at least one radiator (with a steam control valve).

Oil-fired burner



Source: American Burner Corp.

How a boiler works

A heating system is controlled by a thermostat, regardless of the fuel burned or whether it produces hot water or steam. The thermostat measures the temperature within the room(s) to be heated. If the temperature falls below a preset limit, the thermostat signals the heating system to provide additional heat[2].

In a hot water system, the water in the boiler is kept at approximately 180°F at all times during the heating season. When the room thermostat calls for more heat, the circulating pump turns on, circulating the hot boiler water to the radiators in the room(s). As heat is removed from the water by the radiators, its temperature falls and the burner turns on to bring it back up to 180°F in the boiler.

In a hot water system, the burner cycles on and off to keep the water in the boiler at the right temperature, while the circulating pump cycles on and off to provide heat to the rooms.

Residential hot water boiler—gas fired

Source: Firstech Services

In a steam system, the boiler water is also kept at approximately 180°F most of the time—below the temperature required to produce steam. When the room thermostat signals that more heat is needed, the burner turns on, increasing the temperature of the boiler water above 212°F and producing steam. This steam rises throughout the building to the room radiators.

A steam system does not have a circulating pump and the burner can cycle on and off either to keep the idling boiler at approximately 180°F, or to increase boiler temperature to produce steam needed to heat the rooms.

Hot water boiler

If the temperature of the boiler water falls below 180°F, a hot water boiler's controller will initiate combustion. In an oil-burning boiler this is accomplished by a fuel pump drawing the liquid fuel from the storage tank through a filter and pumping it into the burner assembly located in the combustion chamber.

The burner assembly atomizes the fuel into a fine mist, which mixes with forced air from a blower fan, while the ignition system creates a spark. This spark ignites the fuel-air mixture (this is called light off). Once lit, the flame is stable but the ignition system continues to spark to ensure continuous combustion.

Large natural gas burner

Source: Arco Fluid

This flame is directed, using refractory bricks, toward the heat exchanger and swirl inducers. After flowing through the heat exchanger, the combustion exhaust gases are directed to an exhaust stack (chimney), which typically exits the building at roof level.

The heat exchanger consists of a series of connected metal tubes that hold the water to be heated. It also includes a circulating pump that moves the water through the system. As the flame and exhaust gases pass over the tubes of the heat exchanger, the water inside absorbs heat. The hot water is pumped to the baseboard heaters/radiators to release its stored heat before returning to the heat exchanger to repeat the process. This is called the boiler water loop, since it is a circular system.

For a natural gas-fired hot water boiler, almost all of the components are the same except for the equipment used to supply fuel to the burner (the gas train). A natural gas-fired heater does not include a fuel pump because the natural gas fuel is not a liquid. Instead it includes a connection to the utility gas supply and a valve/pressure regulator to control the flow of pressurized gas from the utility connection into the burner. The burner configuration is also somewhat different than in an oil-fired boiler because the fuel does not need to be atomized before mixing with air.

Steam boiler

Steam boilers operate much like hot water boilers, except that initiation of combustion is controlled by either the boiler water thermostat or the room or outdoor air thermostat (see discussion above). Steam boilers can burn either liquid fuel oil or natural gas, and depending on the fuel, will contain burner assemblies as described above.

The difference between a hot water and a steam boiler is in the design of the heat exchanger/combustion chamber. In a steam boiler, the heat exchanger pipes surround the combustion chamber.

Large residential steam boiler—oil fired

Source: Firstech Services

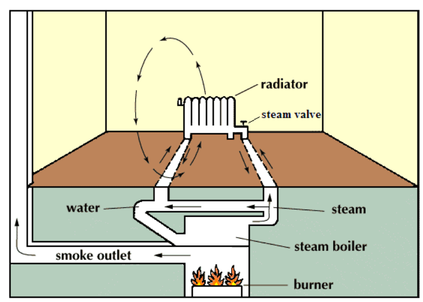
These heat exchanger pipes are filled with water, but there is headspace above them where steam can collect as it bubbles out of the water. This steam is lighter than air and will rise through the pipes to be distributed to the individual radiators, without the need for a circulating pump. In most buildings the radiators in each room are equipped with manual valves that are either open (on) or closed (off). When the valve is open steam enters the radiator, and when it is closed it does not. It is possible to equip individual radiators with valves that control the amount of steam going to each radiator, for more precise control of room temperature, but this is not common. After the steam has given up its stored heat energy within the radiator, it condenses back into water, which drains back to the boiler.

Boiler system efficiency

All new boilers smaller than 300,000 Btu/hr come with an efficiency rating called the annual fuel utilization efficiency rating (AFUE). Calculated using a standard methodology developed by the U.S. Department of Energy, AFUE is a measurement of the percentage of fuel input energy that will be converted to useful heat over an entire heating season. This rating was established to help consumers compare different options when purchasing a new piece of equipment or upgrading an existing system.

For example, an AFUE rating of 80% means that for every gallon of fuel burned in the boiler, 80% of the energy it contains will be transferred to the hot water or steam in the heat exchanger and be directed to the room radiators for heating the building. The remaining 20% of fuel input energy will be exhausted through the stack and will be lost. AFUE only refers to the unit's fuel efficiency, not its electrical usage.

Residential steam system



Source: Britannica Online Encyclopedia

Boilers with a higher AFUE will use less fuel to heat the same amount of space because less energy is lost through the exhaust stack.

The U.S. Department of Energy (DOE) mandated that, beginning in 1992, all newly manufactured small residential boilers must have a minimum AFUE of 80%. In comparison, many old boilers have AFUE ratings of only 55–65%.[3] Today, there are many residential natural gas furnaces and boilers that have AFUE ratings of 95% or higher.

AFUE ratings do not apply to the larger boilers used in multi-family apartment buildings and commercial buildings. These boilers are typically rated for efficiency using various non-DOE rating systems.

Hot water heat vs. steam heat

Hot water and steam heat systems each have distinct advantages and disadvantages. These characteristics can determine what type of system is best suited for a specific building. The discussion of advantages and disadvantages below assumes that either type of system is maintained and working properly.

Hot water generally provides even heat distribution throughout the building since the water is forced through the system using circulating pumps. It is also practical to create multiple zones within a building, each controlled by a separate room thermostat. Hot water systems are very quiet because there isn't any air in the system and they generally require little maintenance since there are few moving parts.

System type	Advantages	Disadvantages
Hot water heating	• Even heat distribution • Quiet operation • Low maintenance • More efficient	• Slower to deliver heat • High electricity consumption • Small reservoir of heat capacity • Less practical for very tall buildings
Steam heating	• Large reservoir of heat capacity • Low electricity consumption • Fast heat delivery	• Uneven heating • High fuel consumption • Large radiators • Noisy operation

On the other hand, hot water systems are slower to deliver heat than steam systems as they have a smaller reservoir of heat. They can have higher electricity consumption because of the power required by the circulating pumps to keep the water flowing in the water loop. Hot water systems have generally not been used for buildings higher than six floors—because of the high static water pressure developed in the system. However, their greater efficiency makes them worth while even in moderately tall buildings.

Steam systems have a large capacity to store heat since it takes a lot of energy to turn water into steam; this means that a steam system can deliver heat quickly because of the stored energy. Steam systems also have low electricity consumption because they use the natural buoyancy of steam to deliver it throughout the building and don't require electrically driven circulating pumps. Steam systems can be used in multistory buildings.

Steam systems, however, can often produce uneven heating throughout the building since there isn't a pump to force the heat to the radiators. Also, the radiators generally must be larger than those used in a hot water system, to help extract as much heat as possible from the steam. It is more difficult to create multiple heating zones in a building heated with steam than it is in one heated with hot water.

Steam systems can be noisy because of a condition known as "steam-hammer," in which water condenses in a horizontal section of pipe and cannot drain back to the boiler. When the system is subsequently turned on again, this water can be picked up by the steam and hurled into the pipe fittings, creating a loud bang that sounds like someone hitting the pipe with a hammer.

Major boiler manufacturers

- Carrier Corporation
- Bryant Heating and Cooling
- Smith Cast Iron Boilers
- Trane Residential
- York International
- Peerless Heater Company
- Crown Boiler Company
- Weil-McLain
- Burnham

Steam systems are generally significantly less efficient than hot water systems, requiring more fuel to heat the same amount of space. This is somewhat offset by their lower electricity use.

Other building heating system components

Additional equipment is necessary for a boiler to run, including a feed water supply, a boiler loop/ heat delivery system, fuel storage and supply, and temperature control.

Feed water supply

A feed water supply is essential for boiler operation. For a hot water boiler, the inside should be completely filled with water. For a steam boiler, there should be a headspace left at the top for steam to form. Both hot water and steam boilers have the same feed water components, only the set point for the boiler water level is different. The feed water components usually include:

- Water feed valve (with level sensor)
- Pressure reducing valve
- Air purge vent
- Backflow preventer
- Water supply pump

Boiler loop/heat delivery

The boiler loop is the distribution circuit for heat delivery. The boiler loop for a hot water system is usually a closed system, meaning that all water that leaves the boiler to go to the radiators eventually returns to the boiler. This loop has a supply and a return pipe to and from the boiler. On the return side, there is a circulating pump to keep the water moving. On the supply side, there is a flow control valve and an expansion tank to allow for changes in water pressure.

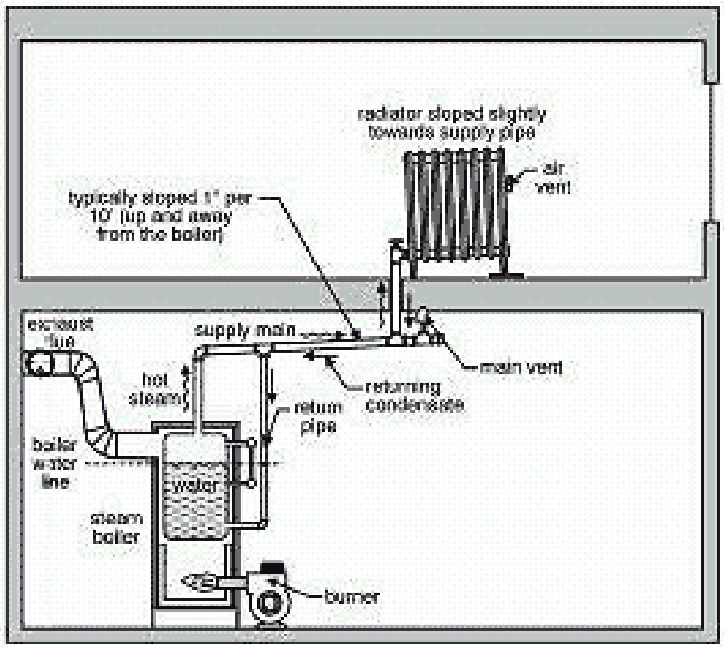
Like a hot water heating loop, a steam system is also a closed loop. This steam loop can have single pipe or double pipe arrangement.

A single pipe system uses the same pipe to supply steam and return the condensed liquid (condensate) back to the boiler. In a double pipe arrangement there is an inlet and an outlet from the radiator. This allows much more controlled, even heating, as well as improved efficiency.

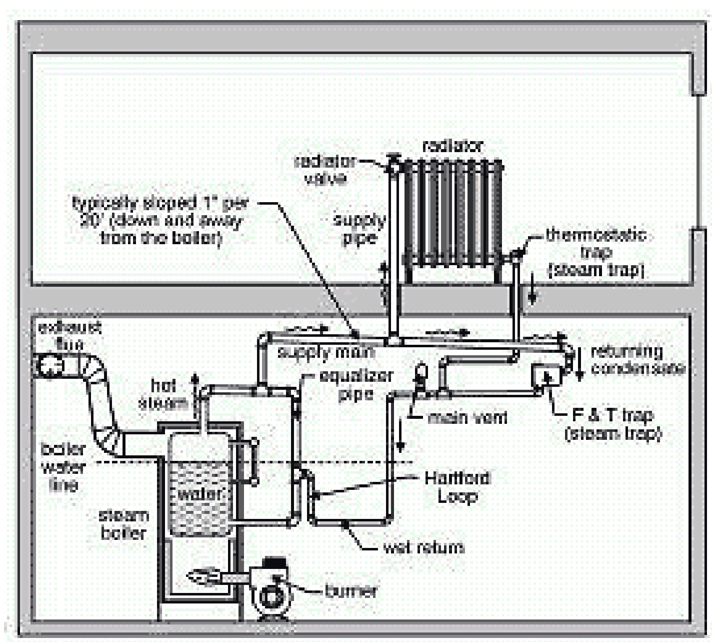
Heat delivery can be a baseboard heater (hot water), a radiator (steam or hot water), or bare pipes behind walls or under the floor (hot water). All of these designs use convection currents to release heat into the room before the hot water or condensate returns to the boiler.

Steam system designs

Single pipe system



Double pipe system



Fuel Storage and Supply

For a boiler that burns fuel oil, a storage tank is necessary to hold the fuel. These tanks are usually located aboveground near the boiler, inside or outside of the building, or buried underground. Residential fuel tanks typically hold 275–330 gallons for aboveground tanks and 550–1,000 gallons for underground tanks.[4]

Hot water boiler steel expansion tank

Source: High Performance HVAC

An oil supply system is used to transfer the fuel oil from the tank to the boiler. First, the fuel is drawn from the tank using a fuel delivery pump. Next, the pump forces the fuel through a strainer and/or filter, removing any impurities in the oil. Lastly, the fuel flows into the burner assembly for combustion.

For a boiler that burns natural gas, there is no storage tank, only supply equipment. Natural gas is supplied from a utility pipeline in the street to a meter that is usually located on the outside of the building or in the basement. The meter measures the amount of fuel used. Downstream from the meter there is usually a pressure regulator to maintain a set pressure. After the regulator and near the boiler there is a gas valve that modulates the amount of natural gas flowing to the burners. The gas valve receives instructions from the boiler control system to deliver the amount of fuel needed.[5]

Temperature control

Heating area temperature control is monitored by a thermostat. A thermostat is a thermometer attached to a set point relay, which sends a signal to the boiler.

The thermostat monitors the temperature in a target area. If the temperature falls below a preset temperature, the thermostat sends a signal to the boiler controller to initiate light off. When the target area reaches the desired temperature, the thermostat sends another signal to the boiler controller to stop firing.

As discussed previously, many steam systems in New York City are controlled by a thermostat that monitors outside air temperature rather than interior room temperature. This method of boiler control is much less efficient.

References

[1] The Free Dictionary, Definition: Boiler, http://www.thefreedictionary.com/boiler (accessed August 14, 2008).

[2] Many stream boilers in New York City are controlled by a thermostat that measures outdoor air temperature rather than internal room temperature to determine when and how long to run the burner to make stream. This method of burner control is much less efficient

[3] American Council for an Energy-Efficient Economy, “Heating Systems: Furnaces and Boilers,” http://www.aceee.org/consumerguide/heating.htm (accessed September 3, 2008).

[4] Fuel Merchants Association of New Jersey, “Guide to Oil Heat Storage Tanks,” www.fmanj.org/pdf/FMATankBrochure.pdf (accessed August 15, 2008).

[5] High Performance HVAC, “Gas Furnace Components,” http://highperformancehvac.com/gas-furnace-components.html (accessed August 15, 2008).