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Topic: **Water Heater Systems**
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Plumbing Apprentices & Students – prep for state licensing test
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Note:

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Welcome to the Water Heater Systems online class. It is designed to fulfill continuing education requirements for journeyman plumbers and prepare apprentices or students for the plumbing state licensing test.

In this lesson, you go through an overview of water heaters, learn about types, safety, sizing, testing, and Uniform Plumbing Codes (UPC). It will provide you with the essential baseline knowledge necessary for projects with water heaters. At the end, there will be a multiple choice quiz to test what you have learned. Let's get started.

I. Lesson Preparation

Before we begin this lesson, you need to become familiar with commonly used terms for water heaters. Review the terms and definitions in the following table.

A. Water Heater Terms/Glossary

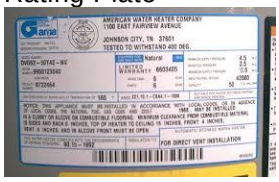
Absorber ☼	The blackened surface in a collector that absorbs the solar radiation and converts it to heat energy.
Active System ☼	A solar heating or cooling system that requires external mechanical power to move the collected heat.
Ambient Temperature	The temperature of the surrounding air.
Angle Stop 	An angle stop is a shutoff valve between the water supply and plumbing fixture. It is used to shut off water flow while you repair the connected item.

Anode Rod	An anode rod is a rod located inside a water heater that protects the water tank from corrosion by magnesium or aluminum.
Appliance Fuel Connector 	An assembly of listed semirigid or flexible tubing and fittings to carry fuel between a fuel-piping outlet and a fuel-burning appliance.
Closed-Loop Refrigerant Line	A closed loop system is one where fluid or gas refrigerant are contained in a piping system and are not exposed to the outside environment.
Auxiliary Heat	The extra heat provided by a conventional heating system for periods of cloudiness or when a solar heating system cannot provide enough.
Backdraft	When gas-fired water heater exhaust fumes spill back into the water heater or home.
Burner 	Component inside of gas-fired water heaters that produce a flame.
Batch Collector Water Heater ☼	Also called an integrated collector storage system, this is one of the oldest types of solar water heaters that's still popular because it's easy to install and only needs a little sunshine to heat water.
Check Valve 	A non-return or one-way valve that allows a gas or liquid to flow freely in one direction while preventing reverse flow in the opposite direction.
Circulation Pump 	Pipe that carries cold water into a water heater system.
Coil Circulation	Heat transfer surface composed primarily of water tubes that requiring circulation.
Cold Inlet Temperature	Temperature of water coming into a water heating system.
Cold-Water Valve 	Valve that switches the cold-water inlet pipe on and off.
Collector ☼	A device that collects solar radiation and converts it to heat.

Combustion Chamber	The part of the gas water heater where air and fuel are mixed to create combustion.
Commercial Water Heater	Water heater with input rate of more than 75,000 BTU/HR (gas) and 105,000 BTU/HR (oil).
Concentrating Collector ☼	A device that concentrates the sun's rays on an absorber surface which is significantly smaller than the overall collector area.
Conduction	Heat transfer through a material from more energetic particles to less energetic particles.
Control Circuit	Parts that measure tank temperature, direct the unit to begin heating and provide safety controls to prevent overheating or other unsafe operating conditions.
Convection	Heat transfer that occurs between a fluid in motion and a bounding surface when the two are at different temperatures.
Cover Plate ☼ 	A sheet of glass or transparent plastic placed above the absorber in a flat plate collector.
Dedicated Loop	A circulation pump on a pipe that connects to the water heater tank down low. This is the cooler side of the loop, or the return.
Delivery	Amount of hot water a heater can supply, most commonly over the period of one hour. Delivery = Recovery + 80% of storage.
Delta-T ☼	Temperature difference, usually referred to in solar hot water systems as the temperature difference between the storage tank and the collector.
Dielectric Connection	Water connectors that reduce the flow of electricity related to galvanic corrosion, from the house piping to the water heater.
Differential Controller ☼	Device (powered by AC or Photovoltaic power) that controls the collector loop circulator pump, moving heat energy from the collector to the storage tank.
Direct Vent	System with indoor water heater, combustion air connections between heater and outside atmosphere, flue gas connections between heater and vent cap, vent cap for outdoors so all air for combustion is obtained from outside atmosphere and all flue gases are discharged to outside.
Dip Tube 	Pipe that deposits cold water into the hot water storage tank.

Draft Hood 	Round, funnel shaped piece of metal that wraps around the vent pipe above gas-fired water heaters.
Drain Cock 	Water spigot located at the bottom of hot water storage tanks used to flush the tank.
Electrical Resistance Heating Element 	Rods inside of electric tank-type water heaters that convert electrical energy into heat.
Evacuated Tube Collector ☼	A solar collector made of two layers of pyrex glass that are treated to be strong, hard, and able to withstand high temperatures.
Drain Down System ☼	A pipe system where potable water is circulated from the storage tank through the collector loop.
Drain Back System ☼	A system where the solar heat transfer fluid (usually water) automatically drains into a tank by gravity when the pump is not running. Note: A heat exchanger is necessary
Evacuated Tube Collector ☼	A collector with rows of parallel transparent glass tubes, each of which contains an absorber tube inside a vacuum that prevents heat loss to the outside air.
Expansion Tank 	A tank on the incoming water line that absorbs expanding water and prevents pressure build up inside the water heater.
Flat Plate Collector ☼	An absorber plate bonded to pipes inside the panel, usually made of copper or aluminum that's painted or chemically etched black to absorb maximum energy.
Flow Sensor 	Sensor inside of tankless water heaters attached to the cold-water inlet pipe that turn on the tankless water heater system when they detect cold water flowing into the system.
Flue Baffle 	Tube that runs from the burner to the vent of gas-fired tank-type water heaters that helps remove exhaust and by-products that result from the combustion process.
Flushing	A routine maintenance that involves turning off your water heater and flushing out sediment buildup.

Gallons Per Hour (GPH) Recovery	The amount of water, in gallons per hour, that a water heater can raise by 90° increase in temperature.
Galvanic Corrosion ☼	A condition caused as a result of a conducting liquid making contact with two different metal that are not properly isolated physically and/or electrically.
Gas Control Valve 	Valve attached to gas pipe that turns the flow of gas on or off.
Gravity Convection ☼	The natural movement of heat that occurs when a warm fluid rises and a cool fluid sinks under the influence of gravity.
Headers ☼	The pipe that runs across the edge of an array of solar collectors, gathering or distributing the heat transfer fluid from, or to the risers in the individual collectors.
Heat Dump ☼	Diversion of water flow from the solar panel to the radiator when the cylinder has reached its design temperature.
Heat Storage ☼	A device or medium that absorbs collected solar heat and stores it for use during periods of inclement or cold weather.
Heating Element 	The device that heats water in electric water heaters.
Heat Exchanger	A device that transfers heat from the burner to water. *Note: Main component in tankless gas water heaters.*
Heat Transfer Fluid ☼	Liquid used in a closed solar collector system loop.
Hot-Water Circulating System	A plumbing system that moves hot water to fixtures quickly without waiting for the water to get hot
Hot-Water Outlet Pipe	Pipe that carries hot water out of the water heater and into hot water pipes.
Hot Water Storage Tank	Cylindrical tank that stores hot water in tank-type water heaters.
Hybrid Solar Energy System ☼	A system that uses both active and passive methods in its operation.
Isolation ☼	Not to be confused with insulation, it is the total amount of solar radiation direct, diffused and reflected-striking a surface exposed to the sky over a given time period. Insolation is expressed as watts per square meter per minute (or hour or day or year).
Irradiance ☼	Solar irradiance is the power of the sun reaching the surface earth and expressed as watts per square meter. The solar constant (maximum value) is expressed as 1,000 watts per square meter of exposed surface.
Kilowatt (KW)	Measure of electric power. 1KW = 1,000 Watts.
Lag Time	Time it takes for hot water to reach the appropriate appliance or fixture.

Mixing Value 	A mechanical or electrical device that mixes cold and hot water to deliver tempered water at a safe temperature even if the water is super-heated above 120°F.
Nipple	Threaded fittings provided on some models for incoming and outgoing water pipe connections.
Open Loop System ☼	An open system is one that is open to the atmosphere. Water heated by a solar collector goes to the hot water faucet.
Passive System ☼	A solar heating or cooling system that uses no external mechanical power to move the collected solar heat.
Photovoltaic Cells ☼	Semiconductor devices that convert solar energy into electricity.
Pilot Assembly 	Assembly that consists of a pilot, ignitor and thermocouple connected to the burner and the gas valve.
Point-of-Use Water Heater	Point-of-use water heaters refers the practice of installing a water heater close to a fixture that is located a long way from the central water heater to reduce heat loss and boost the temperature of water at a fixture that it services.
Rating Plate 	A label on the water heater that lists information about the unit: model number, serial number, manufacturer, warranty length, when it was manufactured and other essential information. Locate it on the water heater so that you're prepared to take a picture or provide information for your plumber.
Risers ☼	The flow channels or pipes that distribute the heat transfer liquid across the face of an absorber.
Sacrificial Anode Rod	An anode rod in tanked water heater that has corroded in place.
Shut-Off-Valve 	A valve that prevents leaks by shutting off the inlet water supply to a water heater when its sensors detect a leak.
Solar Collector ☼	A solar panel that converts sunlight into heat to heat the water supply in a building.
Stacking	Very high temperatures at the top of the water heater tank caused by increased cycling of the burner or heating elements during short draws of water.
Standby Heat Loss ☼	Heat lost though storage tank and piping walls.
Supply Pipe	General term like delivery pipe used for both the cold-water inlet pipe and hot-water outlet pipe.
Temperature & Pressure Valv (T&P Valve)	A safety valve that protects water heaters from overheating and over-pressurization by opening and releasing water through a pipe when it detects water within the unit has exceeded limits creating unsafe tank conditions.

Thermal Capacity ☼	The quantity of heat needed to warm a collector up to its operating temperature.
Thermal Expansion	Expansion of water as it is heated.
Thermistor ☼ 	A resistor on smart water heaters that assists the control board in regulating the water temperature
Thermostat 	A mechanical switch on non-smart water heaters that turns the heating element or burner on or off.
Thermostatic Mixing Valve 	Valve that prevents scalding by adding cold water to a stream of hot water.
Thermosyphoning ☼	The process that makes water circulate automatically between a warm collector and a cooler storage tank above it.
Temperature & Pressure (T&P) Deposit Pipe	Pipe that releases water when the pressure or temperature inside of a hot water storage tank is too high.
Temperature & Pressure (T&P Valve	Safety valve located at the top of hot water storage tanks.
Tilt Angle ☼	The angle that a flat plate collector surface forms with the horizontal plane.
Trickle Type Collector ☼	A collector in which unpressurized heat transfer liquid flows over corrugated plates rather than through tubes.
Tube-in-Plate-Absorber ☼	A type of solar thermal collector where the heat transfer fluid flows through tubes formed in the absorber plate.
Tube-Type Collector ☼	A collector in which the heat transfer fluid flows through metal tubes that are fastened to the absorber plate with solder, clamps or other means
Uniform Energy Factor (UEF)	Overall efficiency of a water heater is calculated by testing tank draw efficiency, recovery efficiency, and standby efficiency using the DOE protocol.
Water Heater Exhaust Vent 	Vent that comes out of gas-fired water heaters and carries combustion by-products outside of the building.

Key: ☼ Solar Water Heater Term | Heat Pump Term

II. Introduction to Water Heaters

Water heaters are considered standard equipment in plumbing systems. Finding the best choice for a project can easily consume a considerable amount of your time. This is especially the case if you are unfamiliar with the large variety of categories or types and technology available. If you search online for information, there will be multiple ways used for categorizing water heaters, many different names for types, and inconsistent usage of terms, which makes sorting and comparisons difficult.

For example, The U.S. Department of Energy (DOE) groups water heaters with the terms of conventional storage, tankless or on demand, heat pump, solar, tankless coil and indirect. Plumbing & Mechanical Magazine uses the water heater categories or types of water storage, tankless, direct-fired, and indirect-fired. Yet another source, the top manufacturer of A. O. Smith, refers to “Point-of-Use” Water Heaters.

For this lesson, water heaters are broken out into six categories, types, or groups indicated below with the terms used:

- Combination Boiler & Water Heater
- Condensing Water Heater or Condensing Boiler
- Direct Contact Water Heaters
- Heat Pump Water Heater

- Solar Water Heater
- Tank Water Heater
- Tankless Water Heater

One of the largest industries for water heaters is residential where they are a standard appliance in home plumbing systems. They provide hot water for showers, bathtubs, sinks, dishwashers, clothes washers, etc. In homes, electric tank water heaters are the most popular in the United States (U.S.). Shipments reached a new record high of 4.9 million in 2023, according to the Air Conditioning, Heating, and Refrigeration Institute (AHRI). Electric tank water heaters were number one, surpassing U.S. gas tank water heater shipments of 4.29 million by 613,000.

In the healthcare industry, facilities like hospitals, clinics, and surgical centers consider water heaters a critical piece of equipment. Without them, operations would not be possible since on-demand hot water is required for surgery, medical procedures, tests, patient care, cleaning, sterilization of medical equipment, cooking, washing, laundering, sanitation, etc. Hospital plumbing systems typically include a combination of different types of water heaters, like commercial tank, tankless, heat pump, solar, and condensing water heaters.

Restaurants and cafeterias rely on a steady flow of hot water as well. It is required for food preparation, cooking, washing, maintaining proper heat, dishwashing, cleaning, sanitation, etc. In food and beverage, manufacturers use electric water heaters for pre-heating (i.e., brew kettles, ovens) and cleaning. They provide an automated way of maintaining specific temperatures without supervision, preventing spoilage, overcooking, and undercooking.

Direct-contact water heaters are used in the industrial industry for closed-loop applications such as tank heating, chemical heating, and railcar warming. Other industries that use water heaters include industrial (i.e., chemical production), education (i.e., schools, universities), construction (i.e., concrete mixing, site cleaning), energy production (i.e., power plants), agriculture (animal care, crop processing), laboratories (scientific research), and firefighting.

In the future, the preferred or considered standard water heater design will need to change in many industries and applications due to changing government regulatory standards. In recent months, The U.S. Department of Energy (DOE) published and mandated new water heater energy conservation standards called Energy Conservation Standard Rules (ECSR). The new rules target the frequently installed electric tank water heaters over 30 gallons in size (40 gallons is average), making current models no longer an option. All electric tank water heaters must now have heat pump technology for higher efficiency and lower emissions. Gas-fired instantaneous water heaters have been targeted as well. Models must now have condensing technology to achieve efficiency gains.

This lesson will assist you in sorting through the inconsistent information about water heaters. It will also help you establish a good working knowledge of the options available. Plus, a glossary is included with basic water heater terms.

A. Types of Water Heaters

- **Combination Boiler & Water Heater**

  A combination boiler and water heater or combi boiler, is a combination boiler and water heater for both a building's heat and hot water. The system uses a combustion process fueled by natural gas, oil, LPG, or electric power. The water heating process begins the fixture being turned on. The flow sensor detects it and activates a diverter valve which switches the system from central heating to hot water mode. The heat

exchanger responds by drawing in water and heats it instantaneously as it flows through the boiler.

The components of a combined boiler & water heater include the following:

1. Thermostat: Measures and regulates water and heating system temperatures.
2. Control Panel: Panel for setting controls like temperature.
3. Burner: Heats the water.
4. Heat Exchanger: Transfers heat from the burner to water.
5. Pump: Circulates heated water throughout the system.
6. Expansion Vessel: Accommodates the expansion of water.
7. Diverter Valve: Directs water flow direction.

The latest models use fuel efficiency modulating burners that automatically adjust the flame size based on demand, and smart controls for optimizing heating schedules. But as with all systems, there are limitations. Since the system works at the pressure level of its cold water source, issues common to low pressure can occur. Combined water heaters are not capable of servicing large homes, multifamily dwellings like apartments, or commercial buildings due to higher demand levels that capacity.

- **Condensing Water Heater or Condensing Boiler**

  Condensing water heaters or condensing boilers are designed for efficiency with advanced technology. Their primary heat exchanger has more surface area than a conventional heat exchanger which increases the amount of heat recovered.

Condensing water heaters can operate at up to 95% efficiency as compared to 80–85% for standard water heaters.

The components of a condensing water heater include the following:

- Burner: Heats water in the primary heat exchanger.
- Primary Heat Exchanger: Transfers heat from the burner to water.
- Secondary Heat Exchanger: Condenses water vapor and captures additional heat from flue gases.
- Condensate Drain: Removes acidic condensate produced during the heat exchange process.

Condensing water heaters operate at a higher level of efficiency than non-condensing models (UEF up to .96 compared to .80). They also have higher flow rate, longer lifespans. and can be vented with PVC or PP pipe. However, they have a higher price tag and run better on natural gas. They are known for corrosion issues, problems with condensation, and having special venting requirements.

- **Direct Contact Water Heaters**

  Direct contact water heaters are used for industrial water heating systems. They provide a highly efficient and rapid method for heating large volumes of water. Unlike traditional water heaters that use indirect heating, water is heated through direct contact with the heat source, typically hot combustion gases.

The components of a direct contact water heater include the following:

- Combustion Chamber: Chamber where combustion occurs, which has a burner, fuel supply system, and air supply system.
- Heat Exchange Zone: Area where water droplets contact hot combustion gases, causing direct heat exchange.
- Exhaust System: A flue or chimney and exhaust fan that remove cooled combustion gases.
- Water Collection & Storage: A collection tank and distribution system that delivers hot water to the point of use.
- Control System: Interface panel to control the system including the temperature of water produced.

Some systems also have structural components (i.e., frames, casting, insulation), condensation drains, temperature and pressure relief valves, and water treatment systems.

The advantages of direct contact water heaters, include higher efficiency, reduced energy consumption, less emissions, and lower operating costs. However, the initial investment is higher for these systems and installation may require making substantial changes to your electrical system or gas lines.

- **Heat Pump Water Heaters**

  Heat pumps are an established option for heating and cooling residential buildings and industrial processes. There are also heat pump water heaters, sometimes called hybrids, that provide hot water using heat transfer and a

refrigeration cycle. Basically, the system moves heat from a cooler area to a warmer area using mechanical energy, often reversing the natural flow of heat.

Heat pump water heaters can be installed as part of a heat pump heating and cooling system or as a stand-alone appliance. They operate on electricity for moving heat from the source to an enclosed tank where the water is heated.

Heat pump water heaters are broken out into three types that correspond with their source. They are:

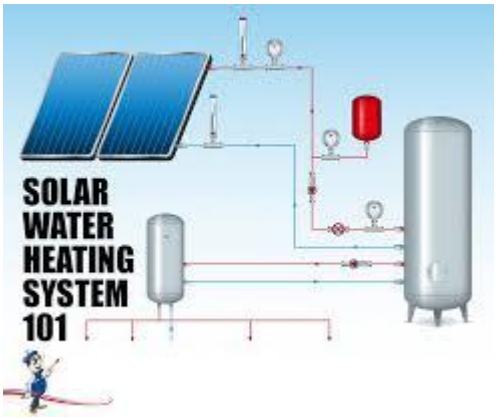
- Air-Source Heat Pumps (ASHP) - extract heat from the air.
- Ground-Source (Geothermal) Heat Pumps (GSHP) - extract heat from
- Water-Source Heat Pumps - use bodies of water like lakes or ponds.

Heat pump water heaters require installation in locations that remain in the 40º–90º F range year-round and must have at least 1,000 cubic feet (28.3 cubic meters) of air space around the water heater.

The components of a heat pump water heater include the following:

- Evaporator: Absorbs heat from the environment (air, ground, or water) into the refrigerant.
- Compressor: Compresses the refrigerant, raising its temperature and pressure.
- Condenser: Releases the absorbed heat into the target area (indoors for heating or outdoors for cooling).
- Expansion Valve: Lowers the pressure of the refrigerant, cooling it down before it enters the evaporator again.

Heat pump water heaters are highly energy efficiency, producing three to four times more heat energy than the electrical energy they consume. However, you also need to consider they have higher up-front costs with can be twice the price of other models. Some of the heat pump water heaters can be difficult to keep operating in cold climates when the temperature drops, and air becomes cold. They also take more time to heat water than conventional water heaters. Plus, they require a lot of space so are not suited for small homes.



- **Solar Water Heaters**

  Solar water heaters use the sun's thermal energy to heat water. They are an environmentally friendly and cost-effective alternative to conventional water heating methods. Solar water heaters operate by collecting, capturing and converting sunlight to heat.

  There are several different solar water heater systems, and they are categorized as either active or passive systems. Active Systems use pumps and controls to circulate water or heat-transfer fluid through collectors. The types are:

  - Direct Circulation Systems - Pumps circulate household water through the collectors and into the home.
  - Indirect Circulation Systems - Heat-transfer fluid circulates through the collectors and heat exchanger to heat the water.

  Passive Systems do not use pumps or controls, instead, natural circulation of water or heat-transfer fluid. The types are:

  - Integral Collector-Storage Passive Systems – The system combines the collector and storage tank in one unit.
  - Thermosiphon Systems - Water flows through the system when warm water rises as cooler water sinks. The collector is mounted below the storage tank to facilitate natural circulation.

  The components of a solar water heater include the following:

  - Collector: Captures solar energy.

- Circulation System: Moves the heat transfer fluid through the system.
- Heat Exchanger: Transfers heat from the solar collector to the potable water.
- Storage Tank: Holds the heated water.
- Controller: Manages the operation of pumps and valves.
- Backup Heater: Ensures hot water availability during cloudy days or high demand.

Solar water heaters deliver savings with lower energy bills and contribute to decreasing greenhouse gas emissions. They also cost less to operate and only need minimal maintenance for continued efficient operation. But as with everything, there are disadvantages to consider as well, especially up-front. The equipment you needed to purchase costs much more than standard water heaters. The installation process is also more complex and difficult, requiring a lot more time. They also require sufficient roof space and direct sunlight to function. The system also does not function on cloudy, rainy, or foggy days.

- **Tank Water Heaters**

  A tank water heater, also known as hot water tank or storage water heater, is the standard type regularly installed in U.S. home and other residential buildings. How they operate is very simple: when the water temperature with a water heater is too low, the heater turns on and if too high, it turns off.

  The components of a tank water heater include the following:

- Heating Element: Coils, rods or burners (depends on fuel used) heat water inside the tank.
- Tank: Insulated container that holds the heated water.
- Thermostat: control device that senses water temperature and activates heating element to maintain set temperature.
- Cold Water Inlet: Entry point for cold water.
- Dip Tube: Ensures cold water is delivered to the bottom, allowing hot water to be drawn from the top.
- Hot Water Outlet: Exit point for hot water at the top of the tank.
- Pressure Relief Valve: Safety valve at the top of the tank that releases water if pressure exceeds thresholds.
- Anode Rod: Rod within the tank that protects it from corrosion.
- Drain Valve: Valve for draining out tank water.
- Insulation: Material that reduces heat loss.
- Heat Traps: Device or loops in the inlet and outlet pipe that prevents heat loss through the pipes when water is not being used.
- Control Panel: Panels for you to control, monitor, and protect your water heater.

Other components only in gas tank water heaters include:

- Flue Pipe: Pipe within the tank for moving exhausts combustion gases outside that has a baffle for increasing heat transfer efficiency.
- Thermocouple: Safety device that detects if the pilot light is on and shuts off the gas supply if it is not, preventing gas leaks.
- Pilot Light or Ignition System: Electronic igniter or spark generator.

Tank water heaters are the most affordable option and provide a steady flow of hot water. The simplicity of their design makes them easy to install. But keep in mind, they consume a lot of energy to maintain the temperature of all water in the tank. They also require a larger amount of space for insulation. Plus, the amount of water available is limited by tank size.

- **Tankless Water Heaters**

  Installations of tankless water heaters, also called on-demand water heaters, have been increasing because of their high energy-efficiency and being environmentally friendly. They can operate on electricity, natural gas, or propane fuels. During operation water is heated as it passes through a heat exchanger within the unit instead of a storage tank.

  The components of a tank water heater include the following:

  - Heat Exchanger: Transfers heat from the gas burner or electric element to the water as it flows through the unit.
  - Flow Sensor: A sensor located at the cold water inlet that detects the flow of water when a hot water tap is opened and activates the heating process.
  - Cold Water Inlet: The entry point for cold water into the unit.
  - Hot Water Outlet: Description: The exit point for hot water from the unit.
  - Control Panel: Panel for user interface, either on the unit or a remote control.
  - Temperature Sensors: Sensors within the unit that monitor the water temperature.
  - Pressure Relief Valve: A safety device that releases pressure if it exceeds safe limits.
  - Water Filter: A filter at the water inlet that removes debris
  - Overheat Cutoff Sensor: A safety sensor that shuts down the unit if water temperature exceeds a safe limit.

Other components only in electric tankless water heaters include:

- Electric Heating Element: High-powered electrical elements that heats water as it passes over.

Other components only in gas tankless water heaters include:

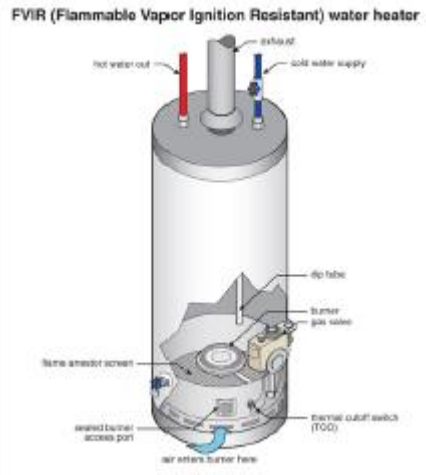
- Burner Assembly: It includes the gas burner, igniter, and gas valve. It burns natural gas or propane to generate heat for the heat exchanger.
- Gas Valve: A valve that regulates the flow of gas to the burner.
- Ventilation System: Vent pipes and a vent hood for discharging exhausts combustion gases outside the building.
- Ignition System: Electronic igniters or pilot lights.

Tankless water heaters reduced exposure to corrosive elements whereby reducing wear & tear on parts which extends operational life. Another advantage is its rapid speed for heating and distributing hot water. Tankless water heaters are also smaller and need less space that tank water heaters. However, they also have higher upfront costs, can require addition upfront setup work, and have a limited flow rate.

III. Safety

Safety should always be a top priority, especially when it comes to water heaters. Associated risk factors, including high pressure, temperature, sediment build-up, faulty thermostats, electrical shorts, and gas leaks. All can cause catastrophic events like explosions, harmful toxic gas environments, and personal injuries. Extensive damage can be made to a building, its plumbing system, and the water heater. Therefore, you need to be aware of the risks and give them due consideration when designing, selecting, installing, and maintaining a plumbing system. Plus, incorporate strategies to mitigate these risks and ensure every person, place, and thing is safe.

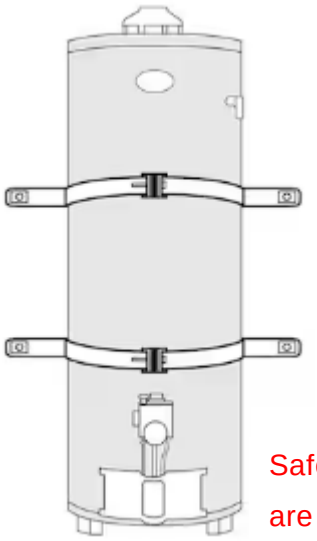
Safety is about watching for signs of potential water heater issues, problems and failures, especially in relation to pressure. Both electric and gas water heaters come with safety features to prevent overheating and leaks. Gas water heaters usually have a flammable vapor ignition resistance (FVIR) system to reduce the possibility of accidental fires. However, at the same time, you have the safety risk factors of combustible gas, non-fire-retardant insulation, open flames in pilot lights, and more. Therefore, taking precautionary steps for all areas that pose a risk, regardless of level, is critical to keeping a water heater operating safely.



A. Preventative Measures

- **Earthquake Straps**

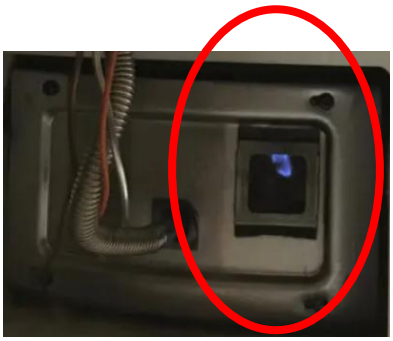
  If you live in an earthquake zone, you are required by code to strap down a water heater. It is done as a preventative measure to ensure the water heater will not fall over if a seismic event occurs. One strap should be around the top one-third of the water heater, and a second on the bottom one-third of the tank.



Safety straps are required by the UPC.

- **Unobstructed Vents**

  You should check water heater vents regularly to ensure they are clean and without any obstructions. Remove paper, dust or other combustibles from inside the system and around it. This is essential to prevent a water heater from overheating. It also enables a water heater to continue operating efficiently.



- **Flammables: Pilot Light Off** (gas only)
  Before using flammable liquids or aerosol bug bombs near a water heater, you need to extinguish the pilot light to prevent any potential ignition of fumes that could occur.
- **Garage Elevation** (gas only)
  Water heaters that are located within a garage, need to be raise up so their pilot light is 18 inches above the floor. This will prevent ignition of gasoline vapors that collect near the floor.
- **Burners Free & Clear**
  To prevent any risk of fire or overheating, gas- and oil-fired water heater burners should be cleaned once a year.

- **Automatic Shut Off Valve** (gas only)
  You should install automatic gas-shutoff valves on all gas water heaters. The device will automatically stop the flow of gas to prevent fires if a gas line breaks caused by events like floods, earthquakes or other disasters.
- **Vent & Draft Diverter Size Should Match**
  Vents you install should be the same diameter as a water heater's draft diverter to ensure adequate circulation for overheating prevention. Also, vents should be without any dips and go straight up so they do not hinder, reduce or slow circulation. Poor circulation can also cause fumes and carbon monoxide to reenter the room instead of going outside.
- **Draft Hood & Flue Exhaust Vent 6" Clearance**

At the top of a natural gas water heater, there is a draft hood and flue exhaust vent. From the end of both parts, you need to leave the first six inches free of pipe tape or insulation.

- **Check Temperature – 120° F Avoid Scalding**

  If water coming out of a water heater is too hot it can scald or burn a person. To prevent this breach in safety, regularly check the temperature of water coming out of fixtures. The International Residential Code (IRC) requires that devices used in tubs, showers, whirlpool bathtubs, and tub-shower combinations limit water temperature to a maximum of 120º F. The International Code Council (ICC) states water should be at a temperature of not less than 110° F and maintained at a maximum the temperature of 120° F.

- **Check Temperature – 140° F Prevent Bacteria**

  Especially in closed systems, water heater tanks can become the perfect environment for bacteria to grow and if ingested it can make you sick. To prevent it from happening, the Occupational Safety and Health Administration (OSHA) and American Society of Sanitary Engineering (ASSE) recommend water heaters be set to 140° F to prevent Legionella bacteria buildup in a water heater's tank.

- **Keep Water Heater Area Clear**

  You need to keep the areas around a water heater clear of any debris or flammable materials to prevent potential fires.

- **Carbon Monoxide Detector is a Must**

  You are required by codes to install a carbon monoxide detector in the room where a water heater is located. The reason for this is the device will provide life-saving alerts to warn and prevent exposure to toxic gas by any person in the building.

- **Frequent & Consistent T&P Valve Testing**

  The Temperature & Pressure Valve (T&P Valve) in a water heater plays a critical safety role. The device ensues temperature and pressure levels do not exceed safety limits. If the water heater is close to reaching its threshold of usually 150 psi, the valve automatically relieves excess temperature and/or pressure from the appliance. Therefore, it is important

the valve's operation be tested frequently and consistently because the device can lock up, fail and jeopardize safety. To test it, simply lift the tab on the valve and let it go.

- **Drain Water**

  Periodically, about every 12-16 months, drain a bucket of water from the drain faucet at the bottom of the water tank in order to remove sediment. If left in the water heater, build up can corrode the unit, reduce its heating efficiency, and cause leaks or overheating.

- **Inspect Water Lines & Valves**

  Consistently and on a regular basis, inspect water lines, fittings, and valves connected to a water heater. Test them to make sure they are operating correctly. Also, look for signs of leaking, damage, cracks, etc. A leak can send cold or very hot water unexpectedly flowing that has the potential of causing injuries if someone slips and falls or comes in contact with the hot water. Leaking water can also cause damage wherever it travels.

- **Check Materials**

  If someone else installed the water heater, you should check what materials were used. Sometimes, water heaters are placed on particle board, which is an engineered wood product that is prone to disintegration when exposed to water. If the is the case, replace it with a drain pan (also called a drip pan) placed under the water heater.

- **Choose the Correct Size**

  Make sure your water heater is the correct size and not too big or small which can be a safety hazard. Improperly sized tanks can reach unsafe temperature and pressure levels.

- **Install Anti-Scald Device**

  Another way to prevent scalding is installing anti-scald devices on your faucets and showerheads. These devices automatically shut off the water flow when it reaches a certain temperature, preventing hot water from reaching dangerous levels.

- **Inspect For Leaks**

A cracked or damaged pipe, valve, or connector can create a leak that causes hot water to flow out onto equipment, walls, floors, etc. This type of occurrence is not only unsafe but is likely to cause damage that will require spending time and money on restoration.

- **Pick The Right Room**

  Particularly in residential applications, the place where an owner wants a water heater installed may be a garage or little shed attached to their house. Those type of locations can add more safety issues than traditional places like laundry rooms. Do your best to persuade the owner a laundry or utility room would be the best place for installation.

- **Fire Chamber Cover On**

  Always keep the fire chamber cover ON the water heater because it contains errant flames that could cause a fire.

- **Keep Updated on Recalls**

  Water heater manufacturers sometimes issue recalls for a product series or specific model. They tend to occur after the manufacturer has discovered a design issue or receives multiple customer complaints about the same series or model. Some recalls have been related to safety issues, so it is best to stay up to date on manufacturer recalls.

B. Testing

Gaining high, reliable, and consistent performance from a water heater requires not only scheduled maintenance but testing as well. Frequently testing a water heater, its devices and parts will enable you to identify issues before they turn into problems that can threaten safety operation. Preventative testing also keeps down operating, maintenance, replacement, and repair costs. Test you should regularly run on a water heater include the following.

Essential Water Heater Tests

- **Leak Test**

Leaks from a water heater can be elusive. Just because you see no puddles of water on the floor doesn't mean a water heater is not leaking. There can be a small crack that in time will turn into a big leak. It you see a drop or two of water on the floor, do the paper towel test of laying a paper towel over the area. If there are no signs leaks on the paper towel after 24 hours, the drops of water were most likely just condensation.

For the most precise leak detection, plumbers often use the method of inspecting the plumbing systems with video pipe inspection equipment. They use a small camera mounted on long flexible fiber optic cables. It is inserted into fixtures like faucets and other plumbing outlets to find any current leaks and other areas with the potential of becoming one.

- **T&P Valve Test**

  One of the most important safety devices in a building is the temperature and pressure (T&P) relief valve that is located inside of a water heater. This device is what makes a water heater safe to operate. It keeps the risk level to people and property low by opening the valve and releasing pressure from inside the water heater. This occurs when the limits are exceeded of 210° F for temperature and 50 psi with pressure.

  Without a T&P relief valve, pressure can build up and cause the water heater to explode since it has nowhere to go. Therefore, regular testing of the T&P relief valve is critical. Specifically, how often between testing varies between experts, with most recommending at one, three or six month intervals. To test a TPR valve, simply lift it up and down the lever several times which should lift the attached brass stem, and hot water should get flow out of the drainpipe.

- **Thermostat Test**

  Another water heater device to test regularly for safe operation is the thermostat. If it starts malfunctioning or fails, the temperature of water within a tank can rise to levels that risk safety. Such an occurrence also has the potential of becoming an expensive event.

To test a thermostat, use a multimeter and preferably one that is digital. When you are finished, adjust the thermostat temperatures back to normal, replace the insulation, and screw the panels back on.

- **Heating Element Test**

  - **Electric Water Heaters**
    Testing an electric water heater's heating element can help you identify issues with a hot water supply. Indicators of a problem include: no hot water, hot water running out too quickly, and a circuit breakers keep tripping. To test a heating element, use a multimeter to measure the resistance between the two screw terminals on the upper heating element. A good element will have a resistance between 5 and 25 ohms. If the reading is very low or zero, the element needs to be replaced. Here are the steps to execute:
      1. Turn off the power to the water heater and make sure it's not receiving voltage. You can use a non-contact voltage detector to check the wires going to the thermostat.
      2. Loosen a screw on the heating element and disconnect the wire.
      3. Set the multimeter to RT1k (resistance times 1,000 ohms).
      4. Touch one probe to the loosened screw and the other to the remaining screw.
      5. The multimeter should read between 10 and 30 ohms if the element is working properly. If the reading is very low or zero, the element may need to be replaced.
      6. If your water heater has multiple elements, repeat the process for each one.
      7. Reattach the wires, replace any insulation, and secure the metal cover panels.

- **Gas Water Heaters**

  In natural gas water heaters, the burner that heats water is ignited by a pilot light. To test it, use the following steps.

  1. Begin by inspecting the burner to see if it's dirty or blocked and clean it out if needed.
  2. Open the burner chamber access panel and see if the pilot light is lit. The panel is located at the water heater's base, just below the gas control valve. If the pilot light is out, then light it following the instruction on the device.
  3. Check the pilot lights flame. A healthy pilot light should have a steady blue flame that burns hot enough. A flickering or wavering flame could indicate an issue with the temperature, such as a draft or dirt. A yellow flame could mean there's not enough airflow, a dirty pilot tube, or incomplete gas combustion.
  4. Check the control panel's lights which may either stay on, blink, or change colors. There should be instructions on the water heater that indicate what the light indication means and where to troubleshoot.

- **Draft Test**

  You need to conduct a draft test to make sure where a water heater is located provides enough air and circulation for safe operation. Poor vent installation or obstructions can cause back-drafting, which is a safety problem. A backdraft event occurs when exhaust gases from an atmospherically vented water heater spills into a room instead of leaving through a vent. This creates a safety hazard because the room is filled with carbon monoxide and high levels of moisture which are unsafe to breath.

  To perform a draft test, do the following:

  1. Run the water heater for a short time to allow the vent connector to warm up.

2. Cup your hands around the draft hood without touching it.
3. If you feel warm, moist air escaping, the water heater is back-drafting.
4. For visual confirmation, hold a small mirror or glass up to the draft hood to see if it fogs up

- **Plumbing Crossover Test**

  A problem that occurs more often in residential water heaters is plumbing crossover. When a crossover occurs, the flow of hot water is unexpectedly allowed to flow into the cold water system or cold water into a hot water system. This causes water temperature fluctuation, long wait times, and incidents of either not enough hot water or hot water running out too quickly. To test for a plumbing crossover successfully do the following:

  1. Turn OFF hot water at the water heater.
  2. Turn ON all hot water faucets.
  3. Wait for several minutes until the water flow stops.
     If you see any water flowing, then you have a problem with the plumbing crossover.
  4. Turn OFF all the faucets.
  5. Turn on all hot water faucets and wait for the flow to stop.
  6. If water continues to flow, there may be a problem with the plumbing crossover.
  7. Turn off all faucets and open one hot water fixture at a time, switching to the cold water side. If water flows, the problem has been located.

- **Drain Valve Test**

  A water heaters drain valve should be tested periodically to ensure it is working properly and can be used to drain the tank. To test the valve, you will need a hose, bucket, and wrench. Once you have the items, do the following:

  1. Turn off the power supply to the water heater.

2. Find the drain valve which is located on the side of a water heater at the bottom. Check for damage, corrosion, leaks, or debris. If issues are found, the drain valve may need to be replaced.
3. Attach a hose to the drain valve and put the end into a bucket to catch water as it discharges. Be careful since the water discharging will be hot.
4. Open the drain valve with a wrench and allow a small amount of water to flow out into the bucket. If nothing comes out, the water heater could be clogged by sediment which you will need to remove. If only a small flow of water discharges from the tank you may have sediment build up. If so, the water heater will need to be drained, and sediment flushed out.
5. Close the valve with a wrench.

Completion of all these tests will cover all the standard areas experts recommend.

IV. Plumbing Codes, Standards, Regulations & Requirements

Water heaters are an essential appliance people rely on every day. When a person turns on a faucet they expect to receive hot water. But making this happen is not as simple as buying a water heater, setting it up, connecting water lines, and turning the appliance on. In the United States (U.S.), each individual water heater's installation, operation, and maintenance must be done within federal, state, and local government regulations, rules, and guidelines. Plus, it must comply with plumbing industry and related organizations codes and standards. For example, codes require every water heater have a Temperature & Pressure (T&P) Relief Valve (T&P Valve) as a safety device to prevent problems from pressure like leaks, damage, and hazards.

A. Sources

The main developers and publishers of regulatory requirements, codes, and standards for plumbing are in the following list:

- **U.S. Department of Energy (DOE), Energy Efficiency and Renewable Energy Office**

  Title: 2023-06-21 Energy Conservation Program: Test Procedure for Consumer Water Heaters and Residential-Duty Commercial Water Heaters; Final Rule

  Description: This final rule incorporates the latest version of the industry testing standards for consumer water heaters and residential-duty commercial water heaters and adopts relevant portions of those standards into the Federal test procedures.

  Title: Appliance & Equipment Standards

  Description: Minimum energy conservation standards for more than 60 categories of appliances and equipment.

- **International Association of Plumbing and Mechanical Officials** (IAPMO) & **American National Standards Institute** (ANSI)

  Title: Universal Plumbing Code (UPC)

  Description: A set of minimum standards and requirements for plumbing systems that aims to protect public health, safety, and welfare.

  Title: A40 Safety Requirement for Plumbing (2024)

  Description: Codes that address the installation of all pipes so that they do not leak or break under normal use conditions, including allowing enough room for expansion when a pipe freezes during cold weather.

- **International Code Council (ICC)**

  Title: International Plumbing Code (IPC)

  Description: Set of rules and guidelines that establish minimum requirements for plumbing systems and components in commercial buildings.

  Title: International Residential Code (IRC)

Description: Code for residential buildings that creates minimum regulations for one- and two-family dwellings of three stories or less, bringing together all building, plumbing, mechanical, fuel gas, energy and electrical provisions for one- and two-family residences**.**

- **Council of American Building Officials**
  Title: I-Codes
  Description: Complete set of comprehensive, coordinated building safety and fire prevention codes.
- **The American Society of Mechanical Engineers (ASME)**
  Title: B31 Piping, Boiler and Pressure Vessel Code
  Description: A set of codes and standards on the design, construction, inspection, and preservation of piping systems.
- **State and Local Administrative Codes**
  Most states use the IPC, UPC, or a combination of both. There are a few that have their own set of plumbing codes, and most are based on the IPC or UPC. The states that do are listed below.
  - Louisiana State Plumbing Code
  - New Mexico Plumbing Code
  - Oregon Specialty Plumbing Code
  - Wisconsin Statues, Comm 81-87, and Plumbing Code
  - Washington State Building Code, Uniform Plumbing Code

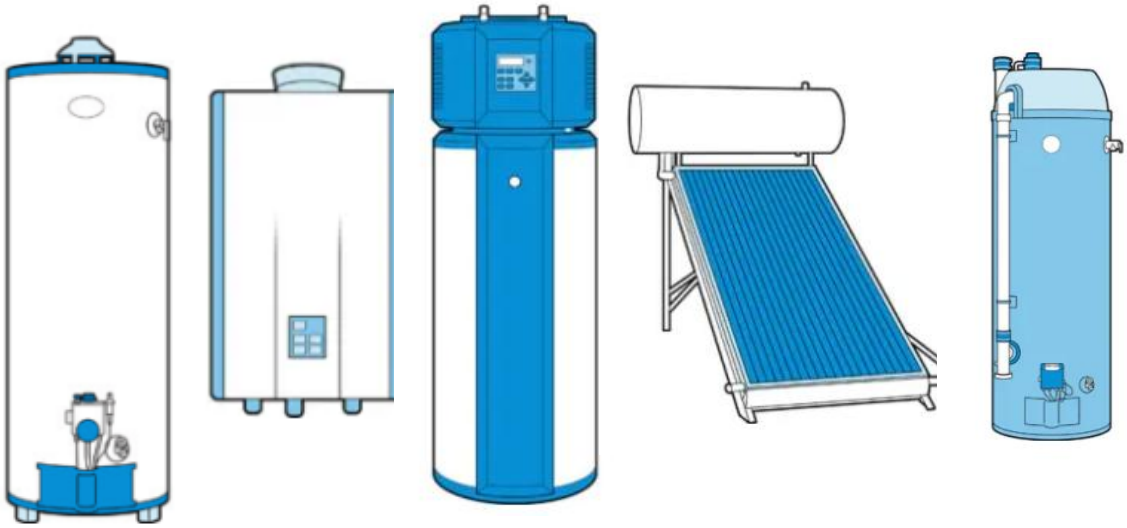
  Other individual applicable codes come from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), National Fire Protection Association (NFPA), American National Standards Institute (ANSI), National Electrical Code (NEC) National Electrical Safety Code (NESC), and ICC International Mechanical Code (IMC).

  The requirements change frequently as new legislation, laws, and code amendments are passed. Therefore, you need to monitor these organizations and make adjust in what you design, select, and install as well as how it's done.

B. Water Heater Classification, Categories or Types

Water Heater Systems Class

There are laws, regulations, rules, codes, and standards for nearly everything that makes up a water heater system. However, finding the pertinent requirements for a specific model of water heater can be difficult. Below is a chart that illustrates this with some of the different ways water heater systems are classified and termed.



Department of Energy (DOE)	International Code Council (ICC)	ConsumerReporrts.org	Manufacturers	Wikipedia
Storage Water Heaters	Electric, Household Storage	Storage Tank Water Heate	Tank	Storage Water Heaters (tank-type)
Demand-Response	Oil-Fired Storage Tank	Tankless (On-Demand) Water Heater	Tankless	Instantaneous wate heaters
Residential-Duty Commercial	Gas-Fired, 75 000 Btu/h or less, Storag	Heat Pump (Hybrid) Water Heater	Combination Boil (building heat & hot water)	Point-of-use (POU)
Heat Pump	Electric, Commercial Storage	Condensing Water Heater	Heat Pump	Geothermal Heatin
Solar Water Heate	Electric Instantaneou	Solar Water Heater	Solar Water Heaters	Solar Water Heaters
Tankless Coil & Indirect Water Heaters	Solid Fuel-Fired			Gravity-fed System

Specialty	Gas-Fired, above 75 000 Btu/h, Storage a Instantaneous			Centralized Hot Water Heaters

The lack of established standard types termed the same way and consistent use can make finding relevant rules, codes and standards for water heater systems challenging. Regardless of how think about water heater terms and types, be prepared to work with how the DOE does it for government regulations and ICC in industry codes and standards.

C. Government Regulatory Requirements

- **Residential Consumer Water Heaters**

  A new DOE "Final Rule" went into effective on July 5, 2024, for residential consumer water heaters. Compliance is required on or after May 6, 2029. Changes that have been made include:

  - Requires the flow rate during the FHR test to be 1.5 ± 0.25 gpm (5.7 ± 0.95 L/min) for water heaters with a rated storage volume less than 20 gallons.
  - Specifies that the first required measurement for each draw of the 24-hour simulated-use test is 15 seconds after the draw is initiated.
  - Requires maintaining the ambient temperature for non-heat pump water heaters within a range of 67.5 °F ± 5° F, and with an average of 67.5° F ± 2.5° F.
  - Flow rate requirements are to be modified during the first-hour rating (FHR) test for less than 20 gallon water heaters.
  - Standard temperature is 60° F and the standard pressure is 30 inches of mercury column (101.6 kPa).
  - Gas-fired circulating water heaters must be tested using an unfired hot water storage tank with a storage volume between 80 and 120 gallons.

    An overview summary with all the changes can be found at https://www.regulations.gov/document/EERE-2019-BT-TP-0032-0058)

- **Permits**

Most states and cities require you obtain a permit and pay a fee before installing a water heater.

D. Construction & Plumbing Industry Requirements

- **Relief Valves**

  Water heater systems are required by code and standards to have at least one temperature relief valve and one pressure relief valve. Another options are a combined temperature and pressure relief valve, and it is listed in the B. Pressure section. When you install a temperature sensing element it should be placed is in the hottest water within the top 6 inches of the tank.

- **Draft Hoods and Regulators**

  When you plan to mount a draft hood or a barometric draft regulator for a water heater, it needs to be installed in the same room as the water heater system.

- **Vents & Ducts**

  The ducts you install need to be made of galvanized steel or a material having equivalent corrosion resistance, strength, and rigidity. Those you install in dwelling units, need to end in unobstructed studs and joist spaces. If the duct goes into an attic, it should not have a screen on top.

  When installing air ducts, if the system has an upper and lower combustion opening, you need to connect each opening to a separate duct or vent line. The two cannot be serviced by the same duct.

- **Single-Wall Heat Exchangers**

  If you install an indirect-fired water heater it must have potable water or contain a fluid recognized as safe by the Food and Drug Administration (FDA) and classified as food grade. The unit must also have on it the following labels:

  - ***Caution***
  - ***The heat-transfer medium shall be potable water or other nontoxic fluid recognized as safe by the FDA.***
  - ***The maximum operating pressure of the heat exchanger shall not exceed the maximum operating pressure of the potable water supply.***

- **Catch Pans**

  When a catch pan becomes necessary, the one you select must be composed of number 24 galvanized steel or an approved plastic material. It must also meet the minimum .0354" (.9 mm) thickness requirement. For gas water heaters, any plastic catch pans need a material with a flame spread index of less than 25.

- **Shut Down Valve**

  When you install water heater, it must have an automatic gas shutoff valve that provides emergency temperature protection as well as prevents gas leaks and fires.

- **Sediment Traps**

  Sediment traps, also known as drip legs, dirt legs, or drip tees, are required for gas-fired water heaters to prevent debris and sediment from entering the appliance and causing damage. These deposits can clog the burner and lead to malfunctions.

- **Temperature Ranges**

  When you set the temperature for a water heater system, the safe range is between 120 °F to 160° F. The standard temperature for most water heaters is 140° F, but the Department of Energy recommends turning down the temperature to 120° F to save energy.

- **Louvers, Grilles, & Screens**

  When you size openings for combustion, ventilation, and dilution air they should be based on the net free area of each opening.

  - Wood Louvers 25%
  - Metal Louvers and Grilles 75%

- **Piping Capacity**

  Before you connect additional appliances to a gas piping system, you need to first check if there is adequate capacity. If capacity is inadequate, you need to enlarge the existing system to meet the new requirements.

- **Installation**

  - **Combined Spaces**

    If you're combining spaces on the same story, they must become one area with an opening of at least 1 square inch per 1000 Btu/h

(0.002 m2/kW) of the total input rating for all appliances in that space. For an air opening, it needs to be at least 3 inches (76 mm).

- **Closets**

  You can install fuel-burning water heaters in a closet that is located within a bedroom or bathroom if it is a direct-vent type. It also needs to be equipped with a listed gasketed door assembly and self-closing device. The door assembly needs to be installed with a threshold and bottom door seal. The closet must be exclusively used for the water heater. Exceptions can be made by the local authority that has jurisdiction.

- **Residential Garages**

  Water heater can be installed in residential garages or adjacent spaces that open to the garage as long as it's not a living space of a dwelling unit. The burners and burner-ignition devices need to be located at least 18 inches (457 mm) above the floor unless listed as being flammable vapor ignition resistant.

- **Self-Closing Doors**

  When installing self-closing doors, they must swing easily and freely and have a self-closing device that cause the door to close and latch after each opening. The closing mechanism cannot have a hold-open feature.

- **Appliance Clearance**

  When you install a water heater, it must be done so there is enough clearance created between the water heater and any object or part of the structure. Residential electric water heaters must have zero inches of clearance from combustible materials on the top, bottom, sides, and back of the unit. There should also be a minimum of 24 inches for clearance: 6" in front, 6" on the top, and 6" on each side for service.

- **Seismic Straps**

Some local codes in earthquake-prone areas require seismic straps on the top and bottom of the water heater. These straps secure the heater to the wall, keep it upright and stable in the occurrence of

an earthquake. Check the local codes to determine if your area requires these straps before installation.

- **Shutoff & Check Valves**
  All water heaters must have a shut off valve on the cold water supply pipe to the water heater. There should be no shutoff valve between the valve and the tank. The valve can be a lever-handle ball valve or a round-handle gate valve. When the valve is closed, it should also shut off water to all hot water pipes.
- **Appliance Protection**
  A water heater includes many components that need protection from dents and damage. Typically, you will need to build a barrier surrounding a water heater. The exception is when the water heater system is in an isolated location with a low risk of damage or contact from outside sources.

  Additionally, when considering the installation of a water heater, it's important to factor in how long it takes for the water heater to recover after heavy use. This recovery time can vary depending on factors such as the size and type of water heater, as well as the demand level for hot water in the building.
- **Discharge Pipes**
  Discharge pipes need to be attached to a TPR valve to reduce leaks and potential water damage when it releases steam or drains extra water. These pipes should direct water either outside of the building, into an indoor catch pan or a floor drain. The water heater installation codes specify that the water needs to easily drain to a safe area that won't cause damage or flooding inside the home.

This concludes the lesson on water heaters. For more information on UPC requirements visit https://www.iapmo.org/publications/read-uniform-codes-online/.

Next Step

Your next step is to complete the multiple choice test on water heaters. There is a link in the menu titled “Water Heater Test”.