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Design Considerations for Hot Water Plumbing

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DESIGN CONSIDERATIONS
FOR
HOT WATER PLUMBING

Overview

Heating water is typically the second largest use of energy in residential and commercial buildings (after space heating and cooling). Despite its resource intensity, the hot water delivery system is seldom an area of significant focus when constructing a building. As a result, many buildings today are built with poor performing, inefficient hot water delivery systems that take minutes to deliver hot water to the point of use and waste large amounts of energy and water in the process.

The key to proper water heating system design is to correctly identify the quantity, temperature and time characteristics of the hot water requirement. The goal is to reduce hot water wait time to 10 seconds or less, which is considered acceptable for public lavatories. A wait time of 11 to 30 seconds is considered borderline and a wait time of 30 seconds or more is unacceptable.

This course will outline the design strategies that will deliver hot water as efficiently as possible while meeting the increasingly challenging regulatory codes and user expectations.

The course is divided into nine sections:

- PART – 1: Estimating Hot Water Demand
- PART – 2: Hot Water Generation - Water Heaters
- PART - 3: Sizing Storage Water Heaters
- PART - 4: Hot Water System Design
- PART - 5: Hot Water Plumbing System Installation & Layouts
- PART - 6: Sizing Hot Water Circulator and Piping
- PART - 7: Hot Water Temperature Control
- PART - 8: Facts, Formulas and Good Engineering Practices
- PART - 9: Regulatory Standards and Codes

PART -1 ESTIMATING HOT WATER DEMAND

An adequate supply of hot water is a must for showers, kitchens, bathrooms, washing machines, dishwashers and other appliances in homes, motels, hotels or commercial buildings. Users expect hot water in adequate amounts, just as they expect lights at the flick of a switch. Improper sizing and design of hot water supply will invariably lead to dissatisfaction and/or wasteful energy expenses.

SIZING HOT WATER DEMANDS

The information on sizing the potable water (cold & hot water) is defined in the American Society of Heating, Refrigeration and Air Conditioning Engineers ASHRAE 1991 Applications Handbook, the Uniform Plumbing Code (UPC), and the American Society of Plumbing Engineers (ASPE) handbooks. All of these criteria take into consideration people use factors; people socio-economic factors, facility types, fixture types, and a host of other factors.

Before we proceed, let's define few important terms:

1. **Fixture -** A device for the distribution and use of water in a building. Example: shower, urinal, fountain, shower, sink, water faucet, tap, hose bibs, hydrant etc.
2. **Maximum Possible Flow** –The flow that occurs when all fixtures are opened simultaneously. Since most plumbing fixtures are used intermittently and the time in operation is relatively small, it is not necessary to design for the maximum possible load.
3. **Maximum Probable Flow –**The flow that occurs under peak conditions for the fixtures that are expected to be in use simultaneously and NOT the total combined flow with all fixtures wide open at the same time. The probability that all fixtures will be used in a building at the same moment is quite remote. Generally, as the number of fixtures increases, the probability of their simultaneous use decreases. The plumbing system is normally designed on probability theory. If pipe sizes are calculated assuming all taps are open simultaneously, the heater size and the pipe diameters will be prohibitively large, economically unviable and unnecessary. Maximum probable flow is also referred to as "peak demand" or "maximum expected flow".
4. **Intermittent Demand** – Plumbing fixtures that draw water for relatively short periods of time are considered an intermittent demand. The examples include bathroom

fixtures, kitchen sinks, laundry trays and washing machines. Each fixture has its own singular loading effect on the system, which is determined by the rate of water supply required, the duration of each use, and the frequency of use.

METHOD - 1

Estimating Hot Water Demand on Fixture Units

The fixture unit concept is based on theory of probability. The method is based on assigning fixture unit (w.s.f.u) value to each type of fixture based on its *rate of water consumption;* the *length of time* it is normally in use, and on the *average period between successive uses*. All the above factors together determine the maximum probable rate of flow. Table 1 lists the demand weights in "fixture units" as determined by the National Bureau of Standards.

TABLE 1

Demand weights of plumbing items in 'water supply fixture unit, w.s.f.u

Fixture or Group	Occupancy	Total Building Supply HW & CW	Cold Water (CW) only	Hot Water (HW) only
Water Closet (Flush Valve)	Public	10	10	--
Water Closet (Flush Tank)	Public	5	5	--
Pedestal Urinal (Flush Valve)	Public	10	10	--
Stall or Wall Urinal (Flush valve)	Public	5	5	--
Stall or Wall Urinal (Flush Tank)	Public	3	3	--
Lavatory (Faucet)	Public	2	1-1/2	1-1/2
Bathtub (Faucet)	Public	4	3	3
Shower Head (Mix valve)	Public	4	3	3
Service Sink (Faucet)	Office	3	2-1/4	2-1/4
Kitchen Sink (Faucet)	Hotel/ Restaurant	4	3	3
Water Closet (Flush valve)	Private	6	6	--
Water Closet (Flush tank)	Private	3	3	--
Lavatory (Faucet)	Private	1	¾	
Bathtub (Faucet)	Private	2	1-1/2	1-1/2
Shower Head (Mix valve)	Private	2	1-1/2	1-1/2
Shower (Mix valve)	Private	2	1-1/2	1-1/2
Kitchen Sink (Faucet)	Private	2	1-1/2	1-1/2
Laundry Trays (Faucet)	Private	3	2-1/4	2-1/4
Combination Fixture (Faucet)	Private	3	2-1/4	2-1/4
Washer	Private	4	3	3

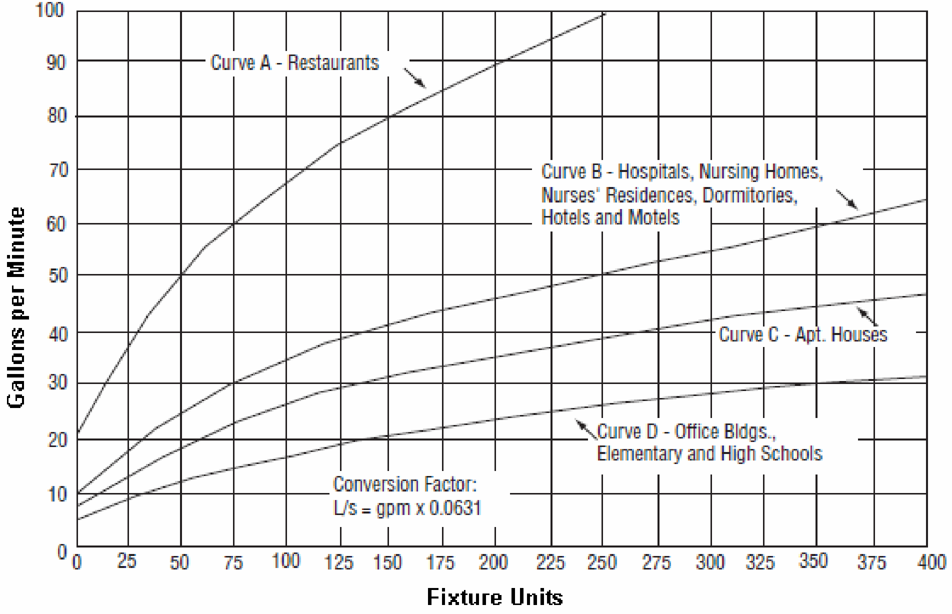
(Source: National Bureau of Standard Reports: BMS 65 by Dr. R. B. Hunter)

From the Table above, the designer can assign fixture unit weights to the specific fixtures in his design. When these are added their total provides a basis for determining the maximum probable flow that may be expected in a water pipe. As a rule, separate hot and cold water demand can be taken as ¾ the total portable water demand; for example, a lavatory faucet with a total demand of 2 w.s.f.u would be counted as 1½ fixture unit on the cold water system, and 1½ fixture unit on the hot water. Supply piping would be calculated accordingly, while the total figure of the two fixture units would be used to design the drainage piping.

Fixture Unit – Flow Relationship

Once the total fixture count is obtained, the next step is to correlate this to the probable flow. In buildings with normal usage, the probability of simultaneous flow is based on statistical methods derived from the total number of draw-off points, average times between draw-offs on each occasion, and the time interval between occasion of use. There is a complex formula to get the probable water demand, however a simple chart and table are used to determine the probable water. The figure below shows the probability of flow as a function of fixture unit count.

Figure -1
Flow -Fixture Units Relationship



(Source: Figure:24, ASHRAE Applications Handbook,2003, Chapter 45)

Sum up the fixture units for your application; enter from the bottom on the X-axis; and read up to the curve that best fits the application. Then read to the left for the corresponding gallons per minute (gpm) requirement. Pipe size can then be calculated by referring to the pipe flowchart that depicts the relationship between the flow in gpm to the pipe diameter in inches.

Example

Estimate the hot water flow rate for a small hotel building consisting of 52 flush valve water closets, 30 flush valve urinals, and 40 lavatories.

Solution

Step 1

Determine the total fixture unit load for all the fixtures serviced by your water heater application using the Fixture Units in Table 1.

Fixture Type	**Qty.**	**Fixture demand weight**	**Hot Water**	**Cold Water**	**Total (Hot & Cold)**
WC (flush valve)	52	@ 10	-	520	520
Urinals	30	@ 5	-	150	150
Lavatories	40	@ 2	-	-	80
Lavatories	40	@ 1.5	60	60	
Total			**60 f/u**	730 f/u	750 f/u

Since the hot water is required only at lavatories, the total fixture load is 60 f/u.

Step 2

Using Hunter Curves (Figure 1), enter the graph from the bottom at 60 fixture units and go up to curve C. Then move to the left horizontally to read approximately **27** gallons per minute of hot water capacity required.

Caution

The fixture count method is based on theory of probability. This method is considered accurate for large groups of fixtures but for smaller applications, this may yield erroneous results. The reader is advised to use discretion and refer to the local codes and standards.

Second, the flow probability as a function of fixture units will also vary with the type of facility and it depends on the usage time duration and other specific requirements. A 100% simultaneous draw-off may occur in buildings, such as factory wash-rooms, hostel toilets, showers in sports facilities, places of worship, and the like. In these cases, all fixtures are likely to be open at the same time during entry, exit and recess. Other methods are discussed below.

METHOD -2

Estimating Hot Water Demand on Fixture Types

The ASHARE applications handbook, Chapter 45, provides the hot water demand in gallons per hour based on the fixture types directly. This is a simplified approach that saves the effort of first estimating the fixture units, and then estimating flow against the fixture units, as explained above.

TABLE 2

Hot Water Demand per Fixture for Various Types of Buildings

(Gallons of water per hour (GPH) per fixture @ 140°F)

Fixture Type	Apartment	Club	Gym	Hospital	Hotel	Industry	Office	School
Basin (lavatory private)	2	2	2	2	2	2	2	2
Basin (lavatory public)	4	6	8	6	8	12	6	15
Bathtub	20	20	30	20	20	-	-	-
Dishwasher	15	50-150	-	50-150	50-200	20-100	-	20-100
Foot basin	3	3	12	3	3	12	-	12
Kitchen Sink	10	20	-	20	30	20	20	20
Laundry	20	28	-	28	28	-	-	28
Pantry Sink	5	10	-	10	10	-	10	10
Shower	30	150	225	75	75	225	30	225
Service Sink	20	20	-	20	30	20	20	20
Hydrotherapeutic Shower	-	-	-	400	-	-	-	-

Fixture Type	Apartment	Club	Gym	Hospital	Hotel	Industry	Office	School
Hubbard Bath	-	-	-	600	-	-	-	-
Leg Bath	-	-	-	100	-	-	-	-
Arm Bath	-	-	-	35	-	-	-	-
Sitz Bath	-	-	-	30	-	-	-	-
Continuous Flow Bath	-	-	-	165	-	-	-	-
Circular Wash Sink	-	-	-	20	20	30	20	-
Semicircular Wash Sink	-	-	-	10	10	15	10	-
Demand Factor [Note1]	0.30	0.3	0.4	0.25	0.25	0.4	0.3	0.4
Storage Capacity Factor [Note2]	1.25	0.9	1.0	0.60	0.80	1.0	2.0	1.0

(Source: ASHRAE Applications Handbook, 2003, Chapter 45, Table 9)

If a particular fixture or a specific building type is not listed above, the flow rate can be assigned based on engineering judgment, best practices historical data, or supplier's instructions.

Notes:

1. **Note**[1]: A Demand Factor is applied to calculate the Maximum Probable Demand, which is the rate at which the heater will generate hot water and is also termed as "the recovery rate or heater capacity**"**. A high demand factor will mean a higher recovery rate or heater size.
2. **Note**[2]: The storage volume of the tank needs adjustment for usable volume to account for the drop in temperature resulting from withdrawal of hot water and continuous entry of cold water in storage tank. The "maximum probable demand" is thus factored by the "storage capacity factor" to determine the "storage tank capacity".

Example

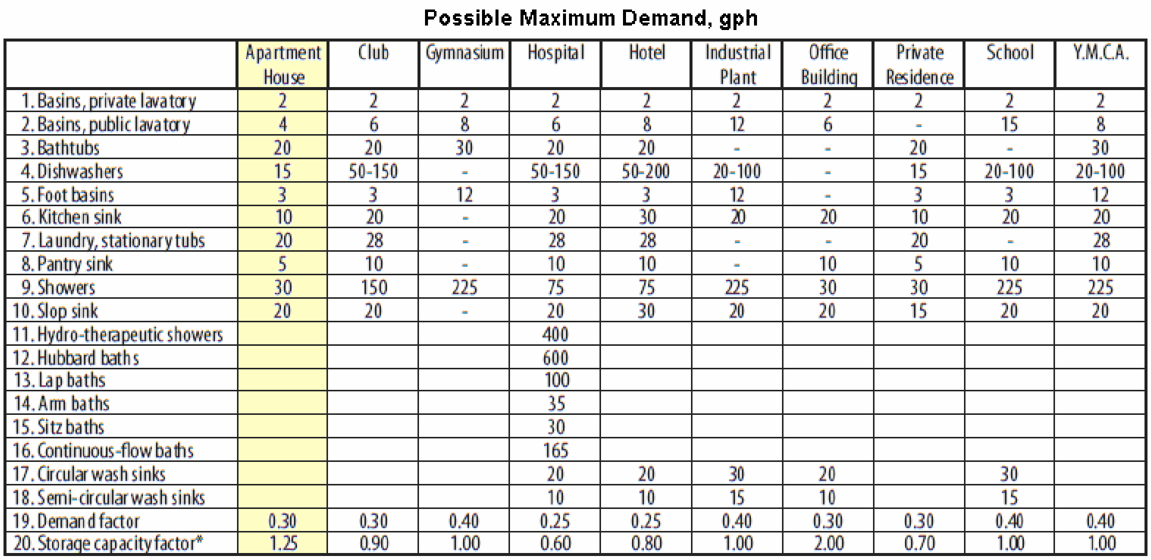
Determine the heater and storage tank size for an **apartment building** having the following fixtures.

Item	**Qty**
Basins:	60 no.

Bathtubs:	30 no.
Showers:	30 no.
Kitchen sinks:	60 no.
Laundry tubs:	15 no.

Solution

From table below, estimate the possible maximum demand for the respective fixtures.



Possible Maximum Demand, gph

	Apartment House	Club	Gymnasium	Hospital	Hotel	Industrial Plant	Office Building	Private Residence	School	Y.M.C.A.
1. Basins, private lavatory	2	2	2	2	2	2	2	2	2	2
2. Basins, public lavatory	4	6	8	6	8	12	6	-	15	8
3. Bathtubs	20	20	30	20	20	-	-	20	-	30
4. Dishwashers	15	50-150	-	50-150	50-200	20-100	-	15	20-100	20-100
5. Foot basins	3	3	12	3	3	12	-	3	3	12
6. Kitchen sink	10	20	-	20	30	20	20	10	20	20
7. Laundry, stationary tubs	20	28	-	28	28	-	-	20	-	28
8. Pantry sink	5	10	-	10	10	-	10	5	10	10
9. Showers	30	150	225	75	75	225	30	30	225	225
10. Slop sink	20	20	-	20	30	20	20	15	20	20
11. Hydro-therapeutic showers				400						
12. Hubbard baths				600						
13. Lap baths				100						
14. Arm baths				35						
15. Sitz baths				30						
16. Continuous-flow baths				165						
17. Circular wash sinks				20	20	30	20		30	
18. Semi-circular wash sinks				10	10	15	10		15	
19. Demand factor	0.30	0.30	0.40	0.25	0.25	0.40	0.30	0.30	0.40	0.40
20. Storage capacity factor*	1.25	0.90	1.00	0.60	0.80	1.00	2.00	0.70	1.00	1.00

Item	**Qty.**	**Flow/unit**	**Total flow**
Basins:	60 no. x	2 GPH	= 120 GPH
Bathtubs:	30 no. ×	20	= 600 GPH
Showers:	30 no. ×	30	= 900 GPH
Kitchen sinks:	60 no. ×	10	= 600 GPH
Laundry tubs:	15 no. ×	20	= 300 GPH
Possible maximum demand:			= 2520 GPH
Maximum Probable Demand:			= 2520 × 0.30 = 756 GPH --- (See Table 2, Note 1)
Or heater capacity:			= 756 GPH
Storage Capacity:			= 756 × 1.25 = 945 gal --- (See Table 2, Note 2)

METHOD - 3

Estimating Hot Water Demand on Occupants/Units

The Method-2 provides the demands in gallons per hour for various types of fixtures and for various types of buildings. However, it does not provide the **time factor usage** rate. For more realistic results, two basic determinations must be made:

1) Maximum load (or hourly peak demand)
2) Working load (influenced by duration of use)

Maximum load - The maximum load of a water heater is the maximum amount of water used daily per person per hour. It is also called hourly peak demand since the amount of daily water used is spread over several hours. The amount of water varies with style of living and type of building. To determine the size of the hot water heater for a building, consider the maximum hourly use and number of users.

Working Load – Working load is influenced by the duration of that peak demand and is defined as the percentage of maximum load expected under normal conditions in any given hour.

Table 3 below is an empirically derived approach that relies on the historical actual measured data for specific building categories.

TABLE 3

Peak Hot Water Demands and Use for Various Types of Buildings

Type of Building	Maximum Hour	Maximum Day	Average Day
Men's Dormitories	3.8 gal/student	22 gal/student	13.1 gal/student
Women's Dormitories	5.0 gal/student	26.5 gal/student	12.3 gal/student
Motels: No. of Units			
20 or less	6.0 gal/unit	35.0 gal/unit	20.0 gal/unit
60	5.0 gal/unit	25.0 gal/unit	14.0 gal/unit
100 or more	4.0 gal/unit	15.0 gal/unit	10.0 gal/unit
Nursing Homes	4.5 gal/bed	30.0 gal/bed	18.4 gal/bed
Office Buildings	0.4 gal/person	2.0 gal/person	1.0 gal/person
Food Service Outlets:			

Type of Building	Maximum Hour	Maximum Day	Average Day
Type A – Full meal restaurants & cafeterias Type B – Drive-in, grilles, luncheonettes, snack shops	1.5 gal/max meals/hr 0.7 gal/max meals/hr	11 gal/max meals/hr 6.0 gal/max meals/hr	2.4 gal/average meals/hr 0.7 gal/average meals/hr
Apartment houses: No. of apartments			
20 or less	12.0 gal/apt	80.0 gal/apt	42.0 gal/apt
50	10.0 gal/apt	73.0 gal/apt	40.0 gal/apt
75	8.5 gal/apt	66.0 gal/apt	38.0 gal/apt
100	7.0 gal/apt	60.0 gal/apt	37.0 gal/apt
200 or more	5.0 gal/apt	50.0 gal/apt	35.0 gal/apt
Elementary schools	0.6 gal/student	1.5 gal/student	0.6 gal/student
Junior and Senior high schools	1.0 gal/student	3.6 gal/student	1.8 gal/student

(Source- ASHARE applications handbook, 2003, chapter 45, Table 7)

Example

Determine the monthly hot water consumption for a 2000-student high school.

Solution

Refer to Table 3,

- Average day consumption = 1.8 gal per student per day
- Total monthly hot water consumption = 2000 students × 1.8 gal per student per day × 22 days = 79,200 gal.

METHOD – 4

Estimating Hot Water Demand on Daily Use

TABLE 4

Type of Building	Hot Water Required per Person @140°F	Max. Hourly Demand in Relation to Day's Use	Duration of Peak Load Hours	Storage Capacity in Relation to Day's Use	Heating Capacity in Relation to Day's Use
Residences, Apartments, Hotels etc (Note a & b)	20-40 gal/day	1/7	4	1/5	1/7
Office Buildings	2 to 3 gal/day	1/5	2	1/5	1/6
Factory Buildings	5 gal/day	1/3	1	2/5	1/8

Notes:

a. Daily hot water requirements and demand characteristics vary with the type of building; for instance the commercial hotel will have a lower daily consumption but a high peak load. A better class 4 or 5 star rated hotel has a relatively high daily consumption with a low peak load.

b. For residences and apartments, the increasing use of dishwashers and laundry machines will require additional allowances of 15 gal/dishwasher and 40 gal/laundry washer.

Example

Determine the peak hot water requirement for an apartment building housing 200 people?

Solution

From the data in Table 4 above:

- Hot water required per person = 40 gal/day ------ (conservative assumption)
- Number of people = 200
- Daily requirements = 200 × 40 = 8000 gal.
- Maximum hours demand = 8000 × 1⁄7 = 1140 gal.
- Duration of peak load = 4hr.

- Water required for 4-hr peak = 4 × 1140 = 4560.

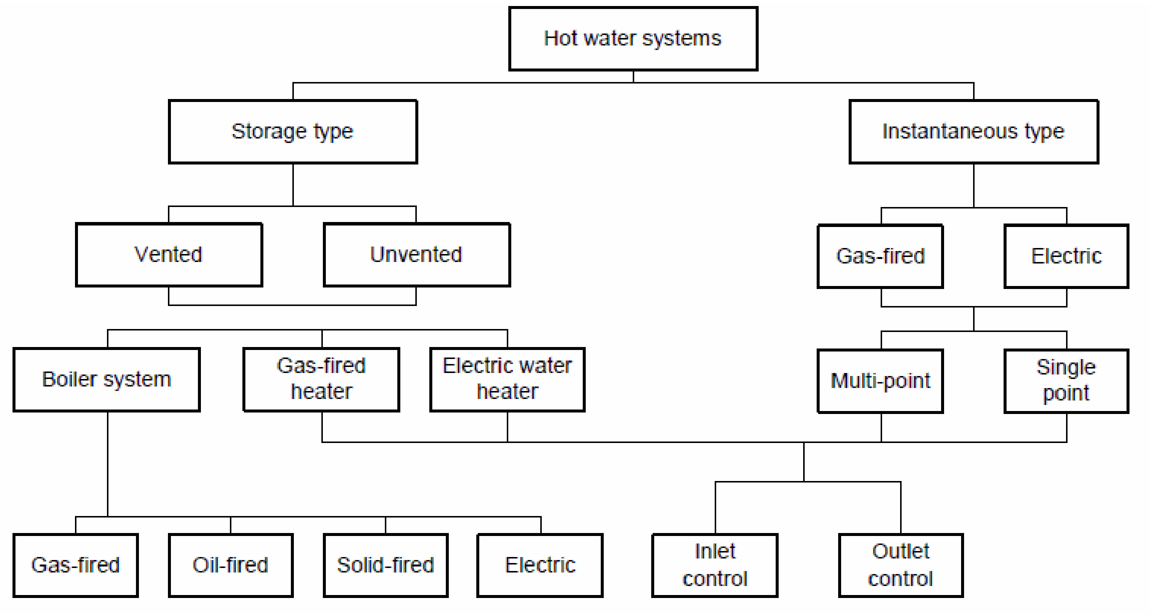
PART- 2: HOT WATER GENERATION - WATER HEATERS

There are several methods of heating water, but the availability of fuel and the costs involved in operating and maintaining the system are especially important in choosing the suitable type. The types of fuel currently available are:

1. Electricity
2. Solid fuel- coal
3. Gas
4. Solar
5. Steam
6. Oil
7. Heat pumps

Water heaters are sometimes called boilers and may be so labeled. This is because the gallon capacity of the tank and/or the energy input is above a level for which some codes require ASME (American Society of Mechanical Engineers) construction. Essentially the requirement applies when the water-containing capacity is in excess of 120 gallons or the heat input is above 200,000 Btuh (58.6 kW). Caution, some local inspectors interpret the code to mean including 120 gallons and 200,000 Btuh. The “boiler” requirement can cause cost escalation or system rejection if not taken into consideration by the system designer. One way that more expensive heater costs are often avoided is by combining several “smaller” heaters into a system instead of one large unit.

Two main types of hot water heaters are: 1) storage water heaters, and 2) instantaneous or continuous flow water heaters. Heaters are further classified as below:



STORAGE TYPE HEATERS

The most common type of water heater is a storage or tank type heater. The hot water in the storage tank is usually heated to a relatively high set temperature (usually between 140ºF and 150ºF) and kept ready for use in a tank. Hot water is drawn from the top of the tank and is replaced by cold water at the bottom. The temperature drop is sensed by a thermostat, which turns on the heater or gas burner at the bottom of the tank. When you draw off hot water faster than the cold water can be heated up, the cold layer can eventually move to the top of the tank, and you'll run out of hot water.

The two main types of systems are the open vented and the un-vented. The open vented water system relies on a large volume of stored water tank. The weight of stored water is usually sufficient to push water down the pipe to any tap or shower outlet. The un-vented stored water system, in general terms, relies on main water pressure to push the water out of the cylinder or through the pipe circuit to the tap or shower outlet.

What size?

How large of a water heater to buy will be determined by how much hot water you use. The most important considerations when selecting the right storage water heater is “first hour delivery” (FHR), peak demand, and the recovery rate.

- First Hour Rating is a measure of the amount of hot water that can be drawn from the tank in one hour.

- The Recovery rate is a measure of the speed at which a unit heats water and represents the amount of water the system can heat to a specific temperature rise in one hour.

When considering a water heater, your peak-hour demand must be determined. A heater is selected to ensure that the FHR meets or exceeds that number. The first-hour rating also includes the "recovery rate." This is a combination of how much water is stored in the water heater and how quickly the water heater can heat cold water to the desired temperature. A bigger storage tank doesn’t always equate to a higher FHR. A small unit with a high recovery rate could out-perform a large unit with a slow recovery rate. The first hour rating is dependent on the Btu’s of the burner. The higher Btu’s equals a higher first hour rating as well as a quicker recovery rate after the tank has been emptied. We will discuss this in detail in Part 3 of the course.

Advantages

1. High flow rates depending on height of stored water or water main pressure;
2. Power shower capability depending on choice of cylinder;
3. Low maintenance costs especially with electric heating (excluding remote boiler); and
4. Less risk of being without a hot water supply due to breakdown.

Disadvantages

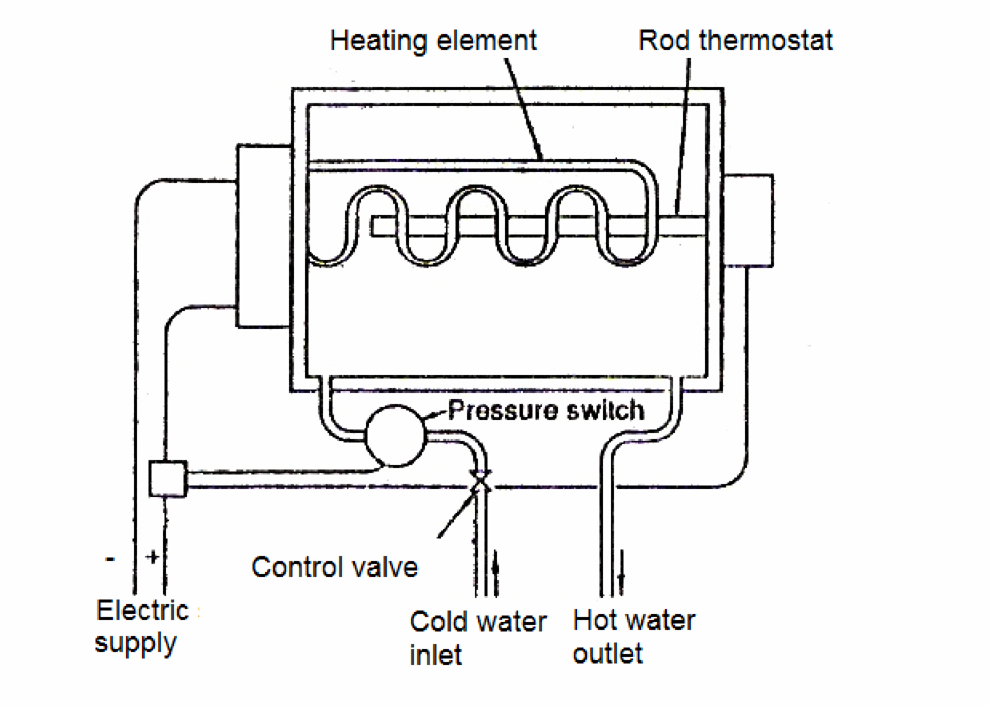
1. Regular maintenance required on un-vented units;
2. Need to pre-heat hot water to match demand;
3. Hot water availability is restricted by the heat recovery time period and size of cylinder;
4. Require storage tanks and space; and
5. Risk of pipes freezing in winter.

The storage type heater is normally considered where hot water demands are not constant.

INSTANTANEOUS HEATERS

The instantaneous water heaters also called “tankless” water heaters or “on-demand” water heaters instantly heat cold water as it passes through the heater. These heaters are compact since storage is not required.

Operation of Instantaneous Heater



An Instantaneous Electric Water Heater

When the cold water control valve is turned on, water flows and exerts pressure on a pressure switch which in turn completes the electrical circuit so that the element can now heat the water as it passes through. The pressure switch is the safeguard that the heating element is only on when water is flowing. The heating element is thermostatically controlled using a rod thermostat.

Advantages and Disadvantages

Here are some advantages to on-demand water heating:

1. Instantaneous water heaters are compact in size and virtually eliminate standby losses or energy wasted when hot water cools down in long pipes or while it's sitting in the storage tank.
2. By providing warm water immediately where it's used, instantaneous water heaters waste less water. People don't need to let the water run as they wait for

warm water to reach a remote faucet. An instantaneous water heater can provide unlimited hot water as long as it is operating within its capacity.

3. Equipment life may be longer than storage type heaters because they are less subject to corrosion. Expected life of instantaneous water heaters is 20 years, compared to 10 to 15 years for tank-type storage water heaters.
4. Instantaneous water heaters range in price from $200 for a small under-sink unit, up to $1000 for a gas-fired unit that delivers 5 gallons per minute. Typically, the more hot water the unit produces, the higher the cost.
5. In most cases, electric tankless water heaters will cost more to operate than gas tankless water heaters.

Here are some drawbacks to on-demand water heating:

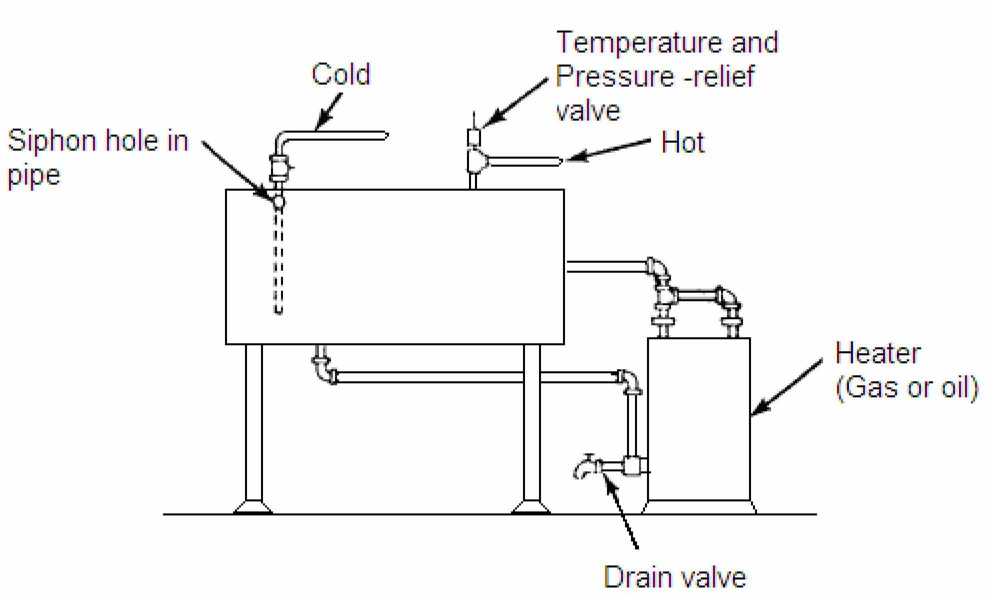
1. Instantaneous water heaters usually cannot supply enough hot water for simultaneous uses such as showers and laundry.
2. Unless your demand system has a feature called modulating temperature control, it may not heat water to a constant temperature at different flow rates. That means that water temperatures can fluctuate uncomfortably, particularly if the water pressure varies wildly in your own water system.
3. Electric units will draw more instantaneous power than tank-type water heaters. If electric rates include a demand charge, operation may be expensive.
4. Electric type instantaneous water heaters require a relatively high electric power draw because water must be heated quickly to the desired temperature. Make sure your wiring is up to the demand.
5. Instantaneous gas water heaters require a direct vent or conventional flue. If a gas-powered unit has a pilot light, it can waste a lot of energy.

STORAGE WATER HEATERS - TYPES

Storage water heaters are classified into four categories: range boilers, gas fired, oil-fired and electric storage heaters. Each type has a temperature- and a pressure-relief valve and a sediment drain at the lowest part of the tank. Relief valves are set to allow water to blow into a drain line when the temperature exceeds 210°F (81°C), or when the pressure exceeds 125 psi.

Range Boilers

A range boiler is an oldest type of domestic hot water heater which uses an independent hot water tank connected to a heating boiler. Water is heated by circulating the water from within a water storage tank through a heat exchanger which is inside or connected to the exterior of a heating boiler.



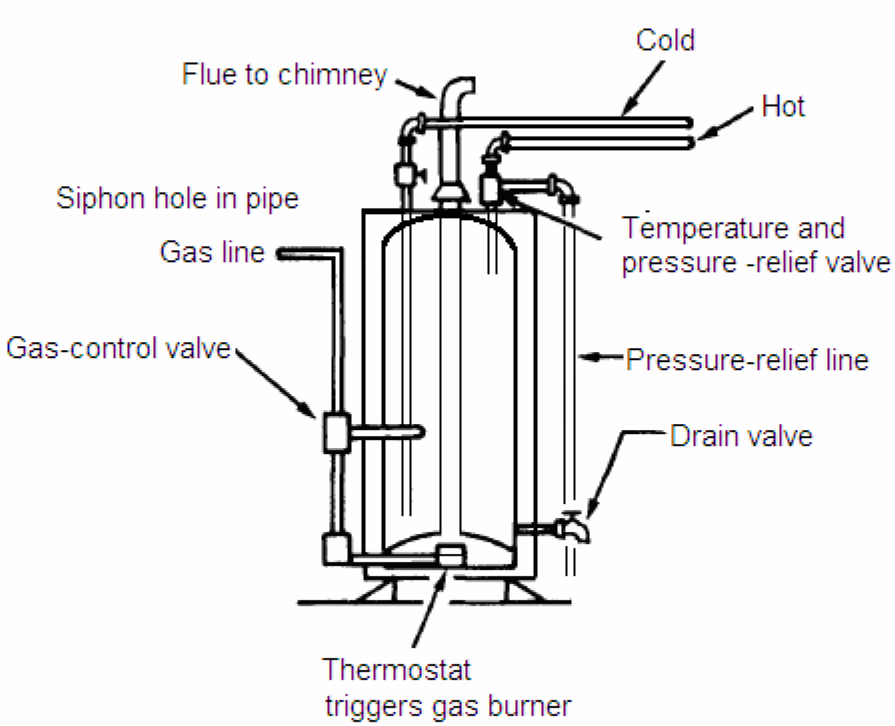
Range Boiler and Heater Installation

Range boilers can provide a large volume of hot water, depending on the tank size. But they have a slow recovery rate. It would be unusual to find a range boiler installed as new equipment in a modern building.

Gas Hot Water Heaters

The gas storage heaters have a burner under the tank and an exhaust stack/heat exchanger running through the middle of the tank. The exhaust stack has two functions: it acts as a vent for the burner and it transfers heat to the water. The gas flow rate is controlled through a control vale and thermostat in response to the setpoint temperature.

The storage tank can be fabricated of galvanized-iron, copper, or porcelain-lined (gas-lined) steel enclosed in an insulating jacket. The most common standard size is 40 gallons.



Gas Storage Heater

The three types of gas water heaters commonly used are as follows:

1. An atmospheric direct-vent water has a vent pipe that passes straight up through the roof. These are particularly good for airtight energy efficient construction because they use outside air for both combustion and exhaust. Intake air for combustion and exhaust gases is conducted to and from the side of the house.

2. Direct-vent heaters typically are located adjacent to an outside wall and vent through that wall. They have a double-walled vent that permits combustion air to be drawn from outside the space where the heater is located, unlike atmospheric-vent heaters. This ensures that there can be no back-drafting of fumes into a residence, provided that no window is located close to the outlet for the wall vent. Direct-vents eliminate the need for a vent to pierce the roof and can be useful in snug homes where changes in air pressure by fans cause pilot lights to be snuffed out.

3. Power-vent heaters have a fan that blows exhaust gases out the vent pipe. They are used when the heater location is far inside a building and long; possibly horizontal vent runs are needed. They also have electronic controls that are generally more expensive than simpler water heaters.

Installation guidelines for gas-fired heaters can be found in the **NFPA Standard 54**.

Oil-Fired Storage Heater

The oil-fired storage heater is similar to the gas storage heater, except that heat is supplied by a vaporizing or a pressure oil burner. In either case, the burner is usually situated to throw a flame under the tank. The exhaust gases are vented either through a hollow core at the center of the tank or around the tank sides. Because fuel-fired heaters heat the tank, which in turn heats the water, there will be more wear and tear on the tank.

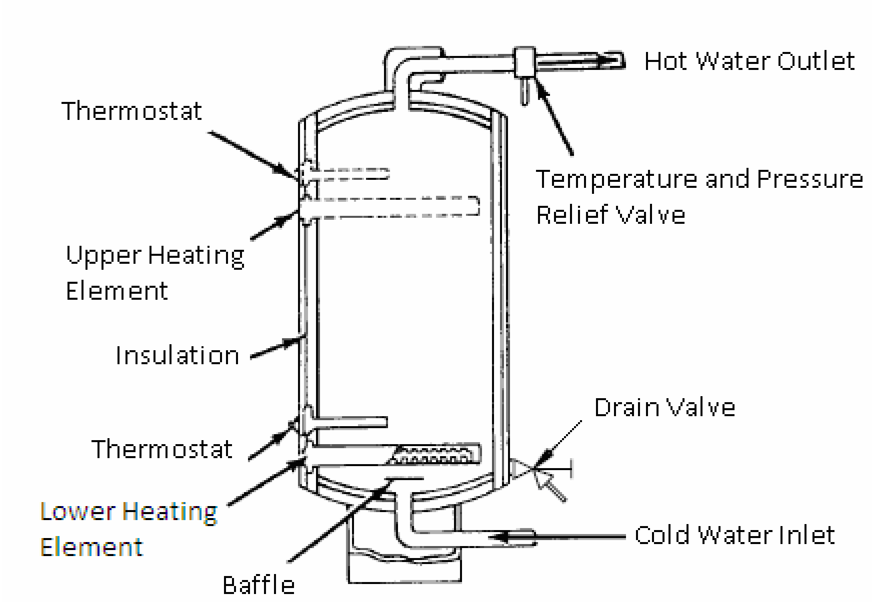
Electric Storage Heater

Electric water heaters use immersion type heating elements to convert electrical energy into heat. Two heaters are usually installed; the upper heater usually has higher wattage than the lower. Power is delivered to each element through a thermostat; a switch that senses the water temperature. When the temperature drops, the switch closes to allow current flow and it opens when the temperature reaches its preset limit. Thermostats have a dial for setting the maximum water temperature, generally between 130°F and 140°F, or as low as about 120°F for increased energy savings and scald protection.

The size of the heating element has a direct bearing on the heating up time, which is also related to the size of the storage cylinder. A general guide for adequate supply is:

- 35 gallons - 1500 watts
- 50 gallons - 2000 watts

Both the 50 gallons with a 2000 watt element and the 35 gallons with a 1500 watt element will reach a temperature of 140ºF in 5 hours and 15 minutes, based on cold water entering the cylinder at 50ºF.



Electric Storage Heater

Caution – Some states prohibit the use of electrical heaters for domestic hot water on storage tanks over 80 gallons (303 liters) unless the following requirements can be met:

a) An engineering analysis indicates electric heating to be the most economical method on a life cycle basis;

b) Provision is made to generate the hot water "off peak" by providing larger storage tanks or by storing it at a higher temperature of 160°F to 180°F, and distributing it through a blending valve at the desired temperature of 100°F to 110°F; and

c) The facility has a maximum total energy consumption of less than 60,000 Btu's per square foot per year at a nominal 40-hour week use or less than 118,000 Btu's per square foot per year around-the-clock use.

Some utilities offer incentives for installing storage heaters for off-peak applications; i.e. water is heated at night during low demand and stored for next day use.

Electric water heaters typically have slower recovery rates than the gas models. They make up for that with larger tanks. The draw efficiency of an electric water heater storage tank is considered to be 70%; i.e.

- 30 gallon storage size will have 21 gallon draw (suitable for 1 bath residence).
- 40 gallon size (28 gallon draw) suitable for two bath residence or one bath with an automatic clothes washer.

- 50 gallon size (35 gallon draw) for three bath residence or two baths with an automatic clothes washer.

Electric heaters are generally more expensive to operate than natural gas models; they do have some advantages over gas. Electric units have no flue pipe, so you can put one almost anywhere, for instance, in a closet, or under a sink. These have a higher life expectancy because of less wear and tear.

Heat Pump Water Heaters

Heat pump water heaters use electricity to move heat from one place to another instead of generating heat directly. This is much the same as a vapor compression air conditioning or refrigeration cycle operating in reverse mode.

- A heat pump system uses around one-third of the electricity of an electric element storage hot water system.
- A heat pump system has a lower operating cost compared to the normal peak rate electric storage units because of high efficiency. When used in conjunction with a timer and the reduced fee rate scheme of the utility company, operating costs are even lower.

Heat pump water heaters can be purchased as integral units with built-in water storage tanks or as add-ons that can be retrofitted to an existing water heater tank. These systems have a high initial cost. They also require installation in locations that remain in the 40°F to 90°F range year-round and contain at least 1000 cubic feet (28.3 cubic meters) of air space around the water heaters. To operate most efficiently, they should be placed in areas having excess heat, such as furnace rooms. They will not work well in a cold space.

SOLAR WATER HEATERS

A solar water heater typically includes collectors mounted on the roof or in a clear area of the yard, a separate storage tank near the conventional heater in the home, connecting piping, and a controller. There are many types of solar water heater systems but only two are appropriate: the closed-loop heat exchanger and drain-back systems. Both of these types have protection against winter freezing. This subject is vast and requires a separate course. In this course we will be focusing on the generic hot water system design features.

SELECTION CRITERIA

Three primary factors influence the selection:

1. Capacity and frequency of use
2. Heater Performance
3. Operating costs

Capacity and Frequency of Use

- For low hot water demand (~100 liters or less per day), an instantaneous gas hot water system could be an optimum choice.
- For a medium and large demand, which corresponds to approximately 200 liters per day or more, a storage system is recommended.

Heater Performance

The standard measure of water-heater efficiency is the energy factor (EF); the higher the EF, the more efficient the appliance and the less energy it wastes. According to the U.S. Department of Energy, EFs vary considerably:

- Electric resistance heaters, 0.9 to 0.97
- Gas-fired heaters, 0.59 to 0.67
- High-efficiency gas heaters, 0.8

Electric resistance heaters have the highest EF but this is a very expensive way to generate heat and it has a huge impact on the environment. This is because; electricity is generated using heat energy as the primary source. Electricity generation from solid fuel such as coal is typically about 30% efficient, meaning that only 30% of the heat energy is converted into electricity with the rest being dissipated as heat into the environment. Energy consumed as part of the generation process and energy lost in distribution use about 10% of this, leaving only 27% of the original energy available for use by the consumer. By comparison, state-of-the-art heating equipment, which utilizes natural gas as a fuel, is more than eighty percent efficient. Distribution losses in natural gas pipelines account for another 5 percent, making natural gas approximately three times more efficient as a heat energy source than electricity.

Two other performance rating factors are:

1. First Hour Rating
2. Recovery rate

First Hour Rating

First Hour Rating is a measure of the amount of hot water that can be drawn from the tank in one hour and it is required by law to appear on the unit's Energy Guide label alongside efficiency rating. When you shop for a heater, estimate your peak hour demand and look for a unit with an FHR that meets or exceeds this value in that range. Gas water heaters have higher FHRs than electric water heaters of the same storage capacity. Therefore, it may be possible to meet your water-heating needs with a gas unit that has a smaller storage tank than an electric unit with the same FHR.

Recovery Rate

The Recovery rate is a measure of the speed at which a unit heats water and represents the amount of water the system can heat to a specific temperature rise in one hour. Once you draw water faster than it's heated, the temperature drops. However, because the tank stores hot water, its capacity also affects the ongoing availability at the tap.

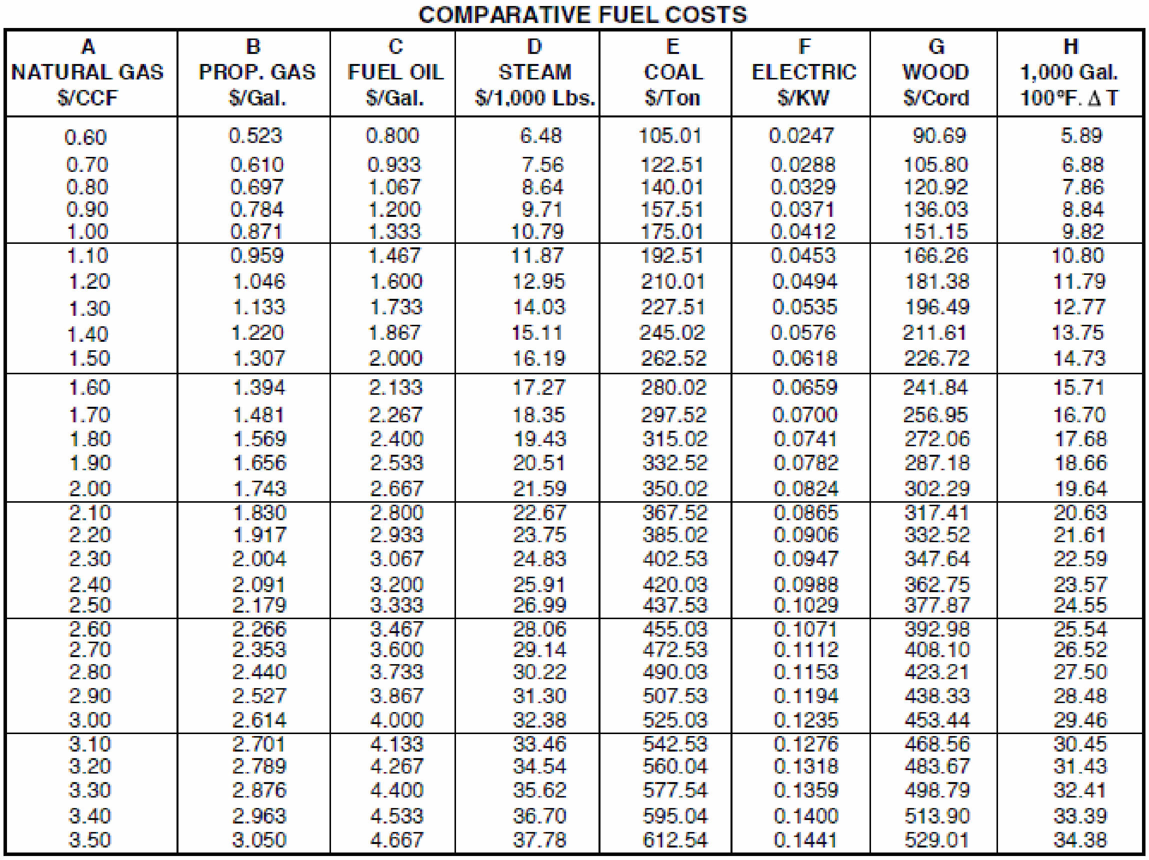
- The heater recovery rate is emphasized on longer demands. Short demands usually mean placing emphasis on tank size. The dividing line between long and short demands is about 3 to 4 hours.
- Instantaneous heaters have a high recovery rate and very little storage, while storage type heaters have a lower recovery rate and significant storage capacity. Storage type water heaters are normally provided to satisfy peak flow and where hot water demand is not constant.
- Unnecessary large hot water storage will lead to a tremendous waste of heating energy due to equipment heat loss plus it requires a large space for installation. Insufficient storage capacity may, otherwise, lead to insufficient hot water temperature during peak consumption periods. Instantaneous heaters provide nearly constant hot water temperature.

Choosing a water heater that has an appropriate capacity and recovery rate depends on how much water your space demands and how your unit heats the water. Typically, heaters with low recovery rates have a high tank capacity. Although it takes longer to heat the water, there's more of it for intermittent use. Electric heaters in general have the lowest recovery rate. On the other hand, a gas fired or fuel-fired heater has a high recovery rate and does not need a large tank because it can heat the water faster. (Refer to Section 3 for more details).

Operating Costs

When choosing among different models, it is wise to analyze the life-cycle cost. The initial purchase cost may be a consideration when deciding on the type of heater, but note that lifetime operating energy costs of that system can be between two and fourteen times the initial purchase cost based on a typical electric or gas hot water system. Often, the least expensive water heater to purchase is the most expensive to operate. The table below illustrates the cost comparisons between different fuels for 1000 gallons of hot water at 100°C rise.

Select the fuel being considered in columns "A" thru "G". (e.g.: Natural Gas - "A"). Find the closest local fuel cost per billing unit (say local cost is $1.2 per ccf). Use $1.2 in column A' and then follow the line to the right to column H to read the "Approx cost per 1,000 gal of hot water at 100°F rise", which will be equal to $11.79.



COMPARATIVE FUEL COSTS

A NATURAL GAS $/CCF	B PROP. GAS $/Gal.	C FUEL OIL $/Gal.	D STEAM $/1,000 Lbs.	E COAL $/Ton	F ELECTRIC $/KW	G WOOD $/Cord	H 1,000 Gal. 100°F. Δ T
0.60	0.523	0.800	6.48	105.01	0.0247	90.69	5.89
0.70	0.610	0.933	7.56	122.51	0.0288	105.80	6.88
0.80	0.697	1.067	8.64	140.01	0.0329	120.92	7.86
0.90	0.784	1.200	9.71	157.51	0.0371	136.03	8.84
1.00	0.871	1.333	10.79	175.01	0.0412	151.15	9.82
1.10	0.959	1.467	11.87	192.51	0.0453	166.26	10.80
1.20	1.046	1.600	12.95	210.01	0.0494	181.38	11.79
1.30	1.133	1.733	14.03	227.51	0.0535	196.49	12.77
1.40	1.220	1.867	15.11	245.02	0.0576	211.61	13.75
1.50	1.307	2.000	16.19	262.52	0.0618	226.72	14.73
1.60	1.394	2.133	17.27	280.02	0.0659	241.84	15.71
1.70	1.481	2.267	18.35	297.52	0.0700	256.95	16.70
1.80	1.569	2.400	19.43	315.02	0.0741	272.06	17.68
1.90	1.656	2.533	20.51	332.52	0.0782	287.18	18.66
2.00	1.743	2.667	21.59	350.02	0.0824	302.29	19.64
2.10	1.830	2.800	22.67	367.52	0.0865	317.41	20.63
2.20	1.917	2.933	23.75	385.02	0.0906	332.52	21.61
2.30	2.004	3.067	24.83	402.53	0.0947	347.64	22.59
2.40	2.091	3.200	25.91	420.03	0.0988	362.75	23.57
2.50	2.179	3.333	26.99	437.53	0.1029	377.87	24.55
2.60	2.266	3.467	28.06	455.03	0.1071	392.98	25.54
2.70	2.353	3.600	29.14	472.53	0.1112	408.10	26.52
2.80	2.440	3.733	30.22	490.03	0.1153	423.21	27.50
2.90	2.527	3.867	31.30	507.53	0.1194	438.33	28.48
3.00	2.614	4.000	32.38	525.03	0.1235	453.44	29.46
3.10	2.701	4.133	33.46	542.53	0.1276	468.56	30.45
3.20	2.789	4.267	34.54	560.04	0.1318	483.67	31.43
3.30	2.876	4.400	35.62	577.54	0.1359	498.79	32.41
3.40	2.963	4.533	36.70	595.04	0.1400	513.90	33.39
3.50	3.050	4.667	37.78	612.54	0.1441	529.01	34.38

Source: A.O. Smith

PART -3: SIZING STORAGE WATER HEATERS

The major determination in sizing water heaters is establishing the maximum probable demand. Information sources for estimating hot water demand include the ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers) guide, and equipment manufacturers (for dishwasher and washing machines, for example).

Here are some definitions that will be helpful as we talk about heater sizing:

1. **Cold Inlet Temperature -** The temperature of outside water coming into a water heating system. Throughout most of the U.S. this temperature is considered to be 40°F (during the coldest months).
2. **Draw Rate -** The rate at which hot water is drawn from a water heating system, usually expressed in gallons per minute (GPM).
3. **Temperature Rise -** The difference in temperature between the desired hot water and the incoming cold water, expressed in degrees Fahrenheit. For example, the desired temperature at the faucet is 120°F and the incoming cold water is 70°F. The required temperature rise is 50°F (120 - 70 = 50).
4. **Input rating:** The amount of fuel (electricity, gas or oil) consumed by heater in a given period of time. It is usually expressed in British Thermal Units per hour (BTUH) or Kilowatt hours (KWH); consuming one Kilowatt-hour of electricity produces 3413 Btu per hour.
5. **BTU:** The amount of heat required to raise the temperature of one pound of water to 1 degree F. Since one gallon of water weighs 8.33 pounds, it would require 8.33 BTU to raise one gallon of water one degree F. Knowing the quantity of water to be heated, the temperature rise and the specific heat of water, we can calculate the amount of heat required using equation:

   Energy required (BTU/hr) = weight (lbs) x spec. heat (BTU/lb °F) x Temp. rise (°F)

   Example

   An electric immersion heater is required to heat a 10 gallon tank of water. The initial water temperature is 70°F and the final temperature required is 100°F. Water must be brought up to final temperature in 1 hour and no additional water is added to the system. The customer has an ideal system with zero heat loss. Calculate the wattage required to heat the water.

Solution:

Energy required (BTU/hr) = weight (lbs) x spec. heat (BTU/lb°F) x Temp. rise (°F)

From properties of liquids and engineering conversions charts:

1 gallon of water = 8.3 pounds (lbs)

Specific heat of water = 1 BTU/lb

Therefore,

Energy required = (10 gal x 8.3 lbs/gal) x 1 BTU/lb°F x (100°F - 70°F) = 2490 BTU/hr

Convert BTU to Watts

Watt = 3.414 BTU

Wattage = 2490/ 3.412 = ~730 watts

6. **Heat- up Time:** In order to achieve the greatest convenience and the best running cost, knowledge of the heat-up time for water heaters is important. Capacities of water heaters vary according to requirements, storage size and heat input. This is the reason why most heaters have to be turned on before use as they need time to heat up. The heat-up time is included in the energy equation as:

$$\text{Energy required (Btu/hr)} = \frac{\text{weight (lbs) x spec. heat (btu/lb °F) x temp. Change (°F)}}{(\text{3.414Btu/watt-hr x } \textbf{heat-up time (hrs)})}$$

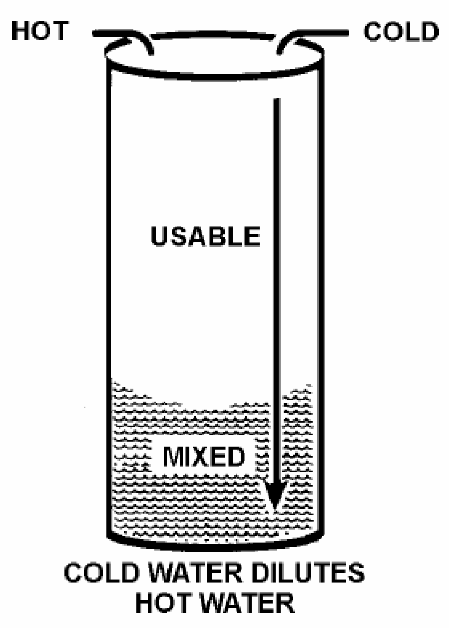
In the example above, if you want to speed up the heating and achieve the final temperature in half an hour, the wattage will double.

7. **Peak Period -** Refers to the time during the day when the heating system experiences the greatest demand (draw). With the exception of applications that require continuous hot water draw, tests have shown that the peak period of hot water usage will occur once or twice a day in residential applications. Peak periods for commercial applications are dramatically different. By contrast, a peak period in a school gymnasium shower may occur every hour.

8. **Storage Capacity and Usable Capacity** – Storage capacity is the net capacity of the tank. All of the stored hot water is not available from the tank at the desired system temperature. This is because as a hot water faucet is turned on, the dip tube, attached on the cold water inlet side of the heater, delivers the cold water at the

bottom of the tank. The pressure of the incoming cold water pushes the hot water out of the tank. Once enough cold water has entered the tank and mixed with the hot water, this will cause the water to turn warm, then tepid, then cold. The term usable storage is employed to indicate the quantity of water which must be available from the tank before dilution reduces temperature to an unusable level. Therefore, tank size should be increased by a percentage to cover the expected loss of hot water temperature so enough usable water will be available.

As a rule, when a specific drop off characteristic for a system is unknown or tank efficiency is not given, **70%** useful capacity is considered appropriate.



This means that the usable capacity will be: net storage capacity x 0.70; i.e. for a 40-gallon tank the usable capacity will be 28 gallons. The table below indicates the usable capacities for different tank configurations.

Tank capacity in gallons	**Gallons of hot water available at 120 degrees (usable capacity 70% rule)**
30	21
40	28
50	35
66	46

80	56
120	84

9. **Recovery rate -** Recovery rate is the amount of hot water the water heater is capable of providing in a given period of time. It depends on several factors: the rating of heater element (wattage), the temperature rise, and the time frame for which the recovery rate is being measured. The table below indicates recovery rate in gallons per hour (GPH) at the indicated temperature rise.

HEATING ELEMENT WATTAGE	60 Deg.	70 Deg.	80 Deg.	90 Deg.	100 Deg.
750	5.1	4.4	3.8	3.4	3.1
1000	6.9	5.8	5.1	4.5	4.1
1250	8.5	7.3	6.4	5.7	5.1
1500	10.2	8.8	7.7	6.8	6.1
2000	13.7	11.7	10.2	9.1	8.2
2500	17.1	14.6	12.8	11.4	10.2
3000	20.5	17.5	15.4	13.6	12.3
3500	23.9	20.5	17.9	15.9	14.3
3800	26.0	22.3	19.5	17.3	15.6
4000	27.3	23.4	20.5	18.2	16.4
4500	30.7	26.3	23.0	20.5	22.5
5000	34.1	29.2	26.6	22.7	20.5
5500	37.6	32.2	28.2	25.0	22.5
6000	41.0	35.0	30.7	27.3	24.6

Example:

For an electric water heater with 4500 watts element; 40 degrees F incoming water temperature; and 120 degrees F output (temperature rise of 80 degrees), the recovery rate will be 23.0 GPH.

The recovery rate can also be estimated using the following equation:

For Electric Heaters

Recovery rate = watts/ [2.42 x (temp rise, °F)]

Example:

I have a 30 gallon electric heater, non-simultaneous operation, 4500 watt elements. What is the recovery rate (GPH), if my cold water is 40°F and my thermostat is set to 120°F?

4500 / [2.42 x (120 - 40)] = 23 gallons per hour

For Gas Heaters

Recovery rate = Hourly input (BTUs) / [11.0 x (temp rise, °F)]

Example:

I have a 30 gallon gas heater rated at 40,000 BTUs. What is the recovery rate (GPH) If my cold water is 40°F and my thermostat is 120°F?

40,000 / [11.0 x (120 - 40)] = 45 gallons per hour

Generally, the higher the BTU or wattage input rate, the faster the recovery rate is.

Note - Standard recovery rate is usually expressed in terms of gallons per hour (GPH) at a 100-degree temperature rise.

10. **Recovery Efficiency:** The ratio of the heat in the hot water delivered to the heat input. Gas-fired water heaters are generally considered to have 75% recovery efficiency. This means 75% of the total heat produced by the burner is absorbed into the water in the tank. The remaining 25% of the heat is used to move the products of combustion through the flue to the outdoors. Electric water heaters are generally considered to have 100% recovery efficiency. This is because immersion style elements place all the heat into the water and there is no exhaust flue.

11. **First Hour Rating (FHR) –** First Hour Rating is a term used to explain the performance abilities of a water heater within the first hour of use when recovered to the thermostat setting. Approximate first hour rating can be determined with the following formula:

    FHR = Usable capacity + Recovery

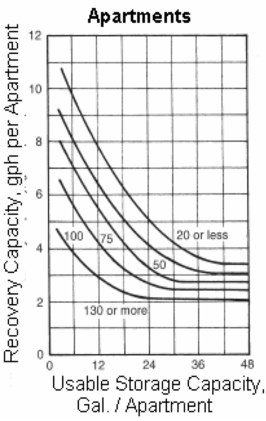
    Or

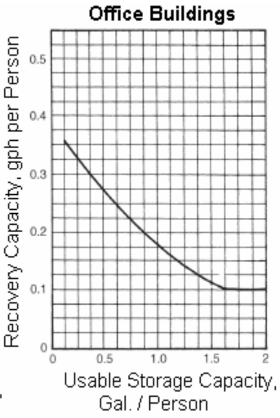
    FHR = Storage capacity x 70% + Recovery

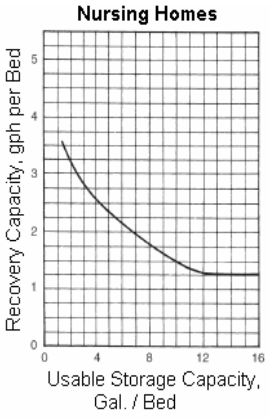
    The key to proper sizing is to achieve the proper balance between usable stored water in the tank and the recovery rate. If you select a storage capacity more than required, you will be overpaying and the fuel cost will be high. If you buy less capacity, there may be a shortage of hot water.

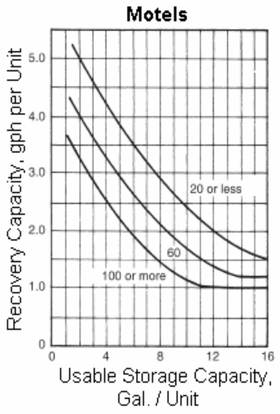
- Tank size is usually more important than recovery capacity when large quantities of hot water are required in a short period of time (less than 3 or 4 hours).
- If the hot water demand period is more than 3 or 4 hours, recovery capacity usually becomes more important than storage capacity.

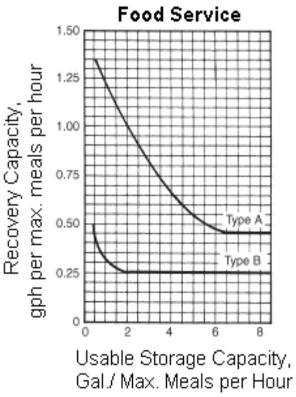
Note - A bigger storage tank doesn't always equate to a higher FHR. A small unit with a high recovery rate could outperform a large unit with a slow recovery rate. The first hour rating is dependent on the Btu's of the burner. The higher Btu's equals a higher first hour rating as well as a quicker recovery rate after the tank has been emptied. When the peak demand and the duration of that demand are known, it is possible to select any number of combinations of storage and recovery capacities to satisfy the requirements. A set of curves are available in the ASHARE Applications Handbook, 2003 edition showing the relationships between recovery and storage capacity for various types of buildings. Samples are depicted below (not to scale):

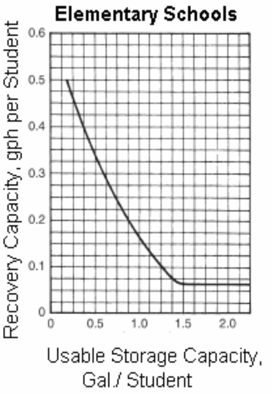


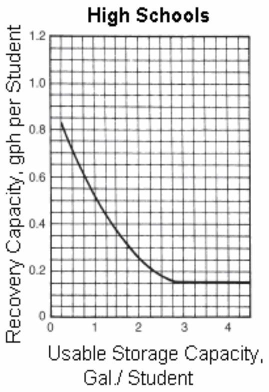


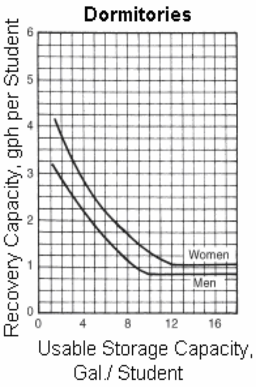












From these curves, a selection among the numerous combinations of recovery rate and usable storage capacity for a given design can be made. Typically, selection of the minimum recovery capacity and the maximum storage capacity on the curves will yield the smallest hot water capacity capable of satisfying the building demand. Minimizing the recovery capacities will place less demand on the heat source.

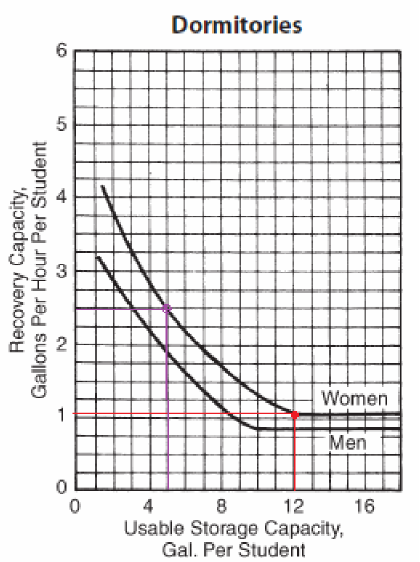
The following examples, taken from the American Society of Heating, Refrigeration, and Air-Conditioning Engineers Applications Handbook (ASHRAE 2003), illustrate the use of the tables and curves for selecting storage and recovery capacities:

Example -1

Determine the required water heater size for a 300-student women's dormitory using the following criteria:

1. Storage system with minimum recovery rate.
2. Storage system with recovery rate of 2.5 GPH per student.

Solution



1. With a minimum recovery rate of 1.1 GPH per student:
   a. Recovery rate = 300 x 1.1 = 330 GPH.
   b. Storage = 12 gal. per student OR 300 x 12 = 3600 gallons
   c. Tank size = 1.43 x 3600 = 5150 gallons ---------- [* On 70% net usable basis multiply by factor of 1.43 ---------(1/0.7)]

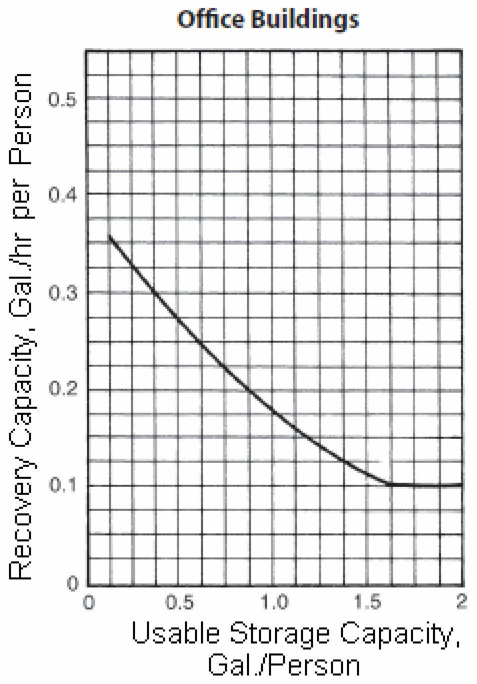
2. At a recovery rate of 2.5 GPH per student:
    a. Recovery = 300 x 2.5 = 750 GPH
    b. Usable Storage Capacity = 5 gallons, OR 300 x 5 = 1500 gallons
    c. Tank size = 1.43 x 1500 = 2150 gallons ---------- [On 70% net usable basis]

Example - 2

Determine the water heater size and monthly hot water consumption for an office building to be occupied by 300 people.

1. Storage system with minimum recovery rate.
2. Storage system with 1.0 gal per person storage.

Solution



2. With a minimum recovery rate of 0.10 GPH per person:
    a. Recovery rate = 300 x 0.1 = 30 GPH.
    b. Storage = 1.6 gal per person or 300 x 1.6 = 480 gallons
    c. Tank size = 1.43 x 480 = 690 gallons [* On 70% net usable basis multiply by factor of 1.43 ---------(1/0.7)]
3. For storage @ 1 gal per person:

a. Storage = 300 x 1 = 300 gallons

b. Recovery capacity = 0.175 GPH per person

c. Recovery = 300 x 0.175 = 52.5 GPH.

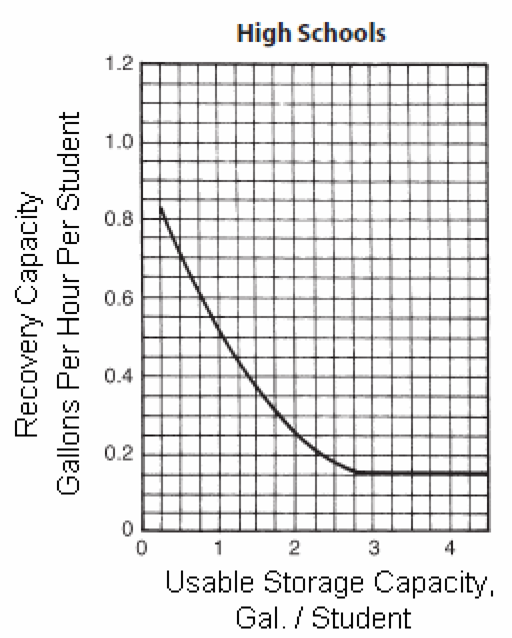
d. Tank size = 1.43 x 300 = 430 gallons [* On 70% net usable basis multiply by factor of 1.43 ---------(1/0.7)]

Example - 3

For a 2000-student high school, determine:

1. Storage system with minimum recovery rate.
2. Storage system with a 4000-gal maximum storage capacity.

Solution



1. With the minimum recovery rate of 0.15 GPH per student:
    - Recovery rate = 2000 x 0.15 = 300-GPH.
    - The storage required is 3 gal per student, or 2000 × 3 = 6000-gal storage.
    - The tank size is 1.43 × 6000 = 8600 gal.
2. When maximum storage capacity is stated as 4000 gallons:
    - Usable storage capacity = 0.7 x 4000 = 2800 gallons

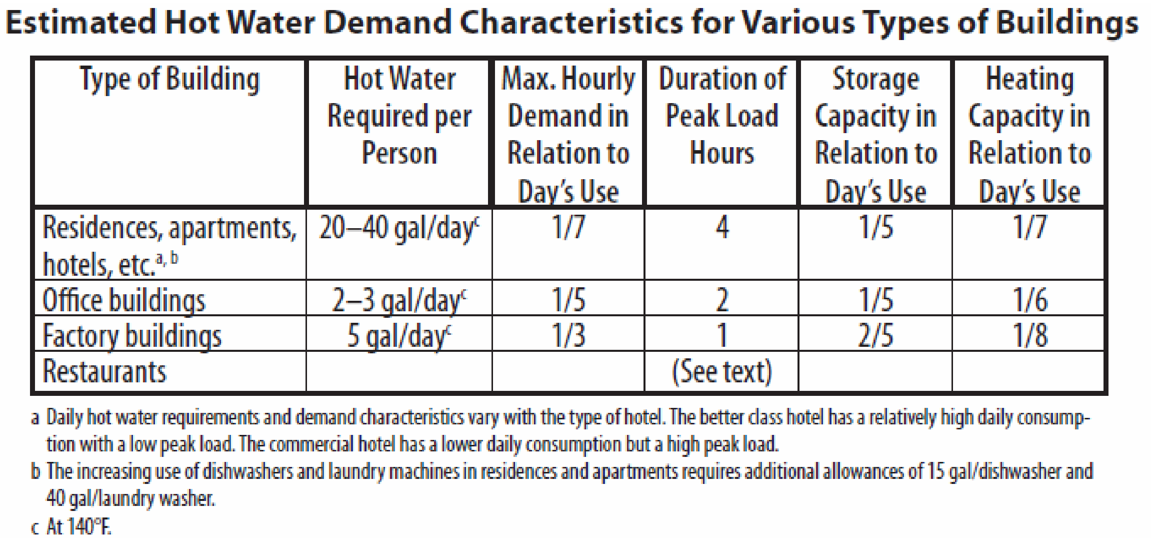
- Storage capacity per student = 2800 / 2000 = 1.4 gal per student
- From the curve, the recovery capacity at 1.4 gal per student = 0.37 GPH per student
- Therefore, total recovery = 0.37 x 2000 = 740 GPH

Example- 4

Determine the required heater capacity for an apartment building housing 200 people, if the storage tank has a capacity of 1000 gal. What heater capacity will be required if the storage tank is changed to 2500-gal capacity?

Solution

Refer to the Table 4 (reproduced below):



Estimated Hot Water Demand Characteristics for Various Types of Buildings

Type of Building	Hot Water Required per Person	Max. Hourly Demand in Relation to Day's Use	Duration of Peak Load Hours	Storage Capacity in Relation to Day's Use	Heating Capacity in Relation to Day's Use
Residences, apartments, hotels, etc.[a, b]	20–40 gal/day[c]	1/7	4	1/5	1/7
Office buildings	2–3 gal/day[c]	1/5	2	1/5	1/6
Factory buildings	5 gal/day[c]	1/3	1	2/5	1/8
Restaurants			(See text)		

[a] Daily hot water requirements and demand characteristics vary with the type of hotel. The better class hotel has a relatively high daily consumption with a low peak load. The commercial hotel has a lower daily consumption but a high peak load.

[b] The increasing use of dishwashers and laundry machines in residences and apartments requires additional allowances of 15 gal/dishwasher and 40 gal/laundry washer.

[c] At 140°F.

From the data in above table:

- Hot water required per person = 40 gal/day ------ (on the conservative side)
- Number of people = 200
- Daily requirements = 200 × 40 = 8000 gal.
- Maximum hour demand = 8000 × 1⁄7 = 1140 gal.
- Duration of peak load = 4 hrs.
- Water required for a 4-hr peak = 4 × 1140 = 4560.

- If a 1000-gal storage tank is used, hot water available from the tank = 1000 × 0.70 = 700.
- Water to be heated in 4 hrs = 4560 – 700 = 3860 gal.
- Heating capacity per hour = 3860⁄4 = 965 gal.
- If instead of a 1000-gal tank, a 2500-gal tank had been installed, the required heating capacity per hour would be [4560 – (2500 × 0.70)]/4 = 702 gal.

Summarizing:

Water heater selection is best made on the basis of hot water usage. However, calculations may lead to a combination of tank size and heat input which do not exist. In this case, the tank size and/or heat input must be balanced to achieve the desired result. Therefore, it is necessary to understand that heat input provides hot water, at the hourly recovery rate, hour after hour. The storage tank represents instant hot water at greater-than-heater recovery. The following key features are:

1. Select maximum recovery and minimum storage if the hot water demand period is longer than 3 or 4 hours (long demand). Storage must be sufficient to handle any peaks within the demand period.
2. Select minimum recovery and maximum storage if the hot water demand period is less than 3 or 4 hours (short demand). Heater recovery must be sufficient to reheat the entire tank contents before the next demand period.
3. Equipment sizing calculations may lead to a combination of heater recovery and storage tank which are not made. If so, both factors may be “adjusted” to favor one or the other as desired. Here’s how:
    - Where it is important that hot water temperature be maintained (as opposed to “within a 30°F drop” being o.k.), increase recovery capacity in preference to increasing tank size. This will aid in maintaining system temperature. Also, assume 10% less draw efficiency than if the 30°F drop was acceptable.
    - Where it is important to maintain water volume (for demands possibly in excess of heater recovery), increase tank size in order to provide “instant” hot water.

4. For instantaneous use, heater recovery is most important for all practical purposes, i.e. it heats the water at the rate it is being used. If a tank type water heater is used, the tank size is minimum or just large enough to put the heat into the water.
5. Check for the possibility of any hot water needs occurring during the recovery period which could affect the reheating of the system. Add heater recovery and/or storage tank capacity as necessary to handle unusual conditions.

****

PART - 4: HOT WATER SYSTEM DESIGN

The primary design objective is to ensure adequate supply of water to all fixtures at all times and at a proper pressure, temperature and flow rate. Especially important is the quality of service such as the wait time for hot water, water temperature (not too hot or too cold), and safety in operation.

Earlier Designs

Earlier hot water designs rely on **natural** circulation wherein the movement of the water is the result of buoyancy forces set by the temperature difference. The hot water being lighter tends to rise naturally on the vertical leg and flows through the branch piping to the fixtures. These systems do not utilize a pump and are lower in energy costs and are silent.

But their primary drawback is that these systems do not circulate well in large networks because of buoyancy loss associated with temperature drop. Also these systems are notorious for causing delays, especially at first use or after periods when water cools down in the pipes. The table below shows the time required for hot water to arrive at a fixture based on the fixture flow rate as well as the length and diameter of the dead-end branch pipe supplying the fixture.

Time in Seconds required to get hot water at fixtures									
Fixture Flow (GPM)		**0.5**		**1.5**		**2.5**		**4.0**	
Piping Length (Feet)		**10**	**25**	**10**	**25**	**10**	**25**	**10**	**25**
Copper Pipe	½”	25	63	8	21	5	13	3	8
	¾”	48	119	16	40	10	24	6	15
Steel Pipe	½”	63	157	21	52	13	31	8	20
	¾”	91	228	30	76	18	46	11	28
CPVC Pipe	½”	64	159	21	53	13	62	8	20
	¾”	95	238	32	79	19	48	12	30

(Source: (ASPE Domestic Water Heating Design Manual)

From the table one can infer that longer pipe runs and/or diameter of the distribution line increases wait times at the farthest fixtures because a larger volume of room-temperature water must be purged before hot water arrives. This also creates increased hot water volume in dead legs and greater potential for heat losses.

The American Society of Plumbing Engineers (ASPE) standard limits the maximum hot-water length “not to exceed 100 feet” from the source and requires reducing the wait time to 10 seconds or less for public lavatories. A wait time of 11 to 30 seconds is considered borderline and a wait time of 30 seconds or more is unacceptable. This standard has been adopted as reference by all major plumbing codes including the Uniform Plumbing Code, International Plumbing Code and the National Standard Plumbing Code.

The potential solution to overcome long waits time is to consider recirculation loop and booster pump. It ensures:

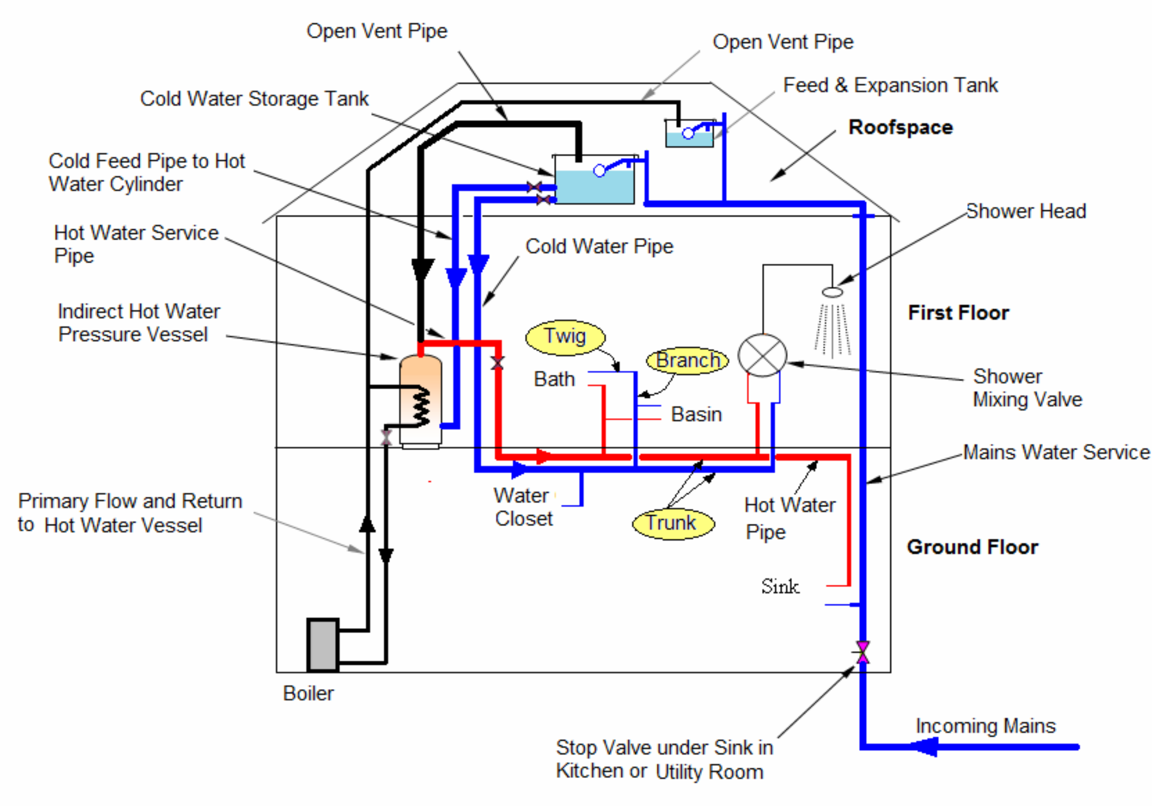
- Continuous availability of hot water on demand;
- Reduces the wait time for water use;
- Minimizes hot water and energy waste caused during the waiting period, and
- Prevent degradation of the system supply water temperature.

The system has drawbacks. The main disadvantage is the waste of energy created by constant use of the circulator. This can however be partially offset by adopting a control strategy that uses a brief pump operation to circulate hot water to fixtures on demand. This is done via a motion sensor or button (hard wired or remote).

This section will outline the common hot water distribution systems and suggest design strategies that will deliver hot water as efficiently as possible while meeting the increasingly challenging regulatory codes and user expectations.

CENTRALIZED HOT WATER SYSTEM DESIGN

In centralized systems, water is heated and stored centrally by means of boiler or furnace and distributed to the hot water faucets, shower or other locations where hot water is needed. The schematic below provides an overview of a typical hot water distribution system in a typical dwelling house:



The figure shows the various components of a centralized hot water supply: 1) a boiler heated by gas, oil or electricity; 2) a hot water storage cylinder or calorifier; 3) cold water storage tanks linked to supply and circulatory pipework; and 4) hot water distribution system with a storage tank consisting of a main ‘trunk’ line from the water heater to the furthest hot water usage point, smaller ‘branches’ off the trunk which supply hot water to multiple fixtures, and smaller-still ‘twigs’ that serve an individual fixture.

Elements of a Centralized Hot Water System

The operation and efficiency of the centralized hot water distribution system is dependent upon the following:

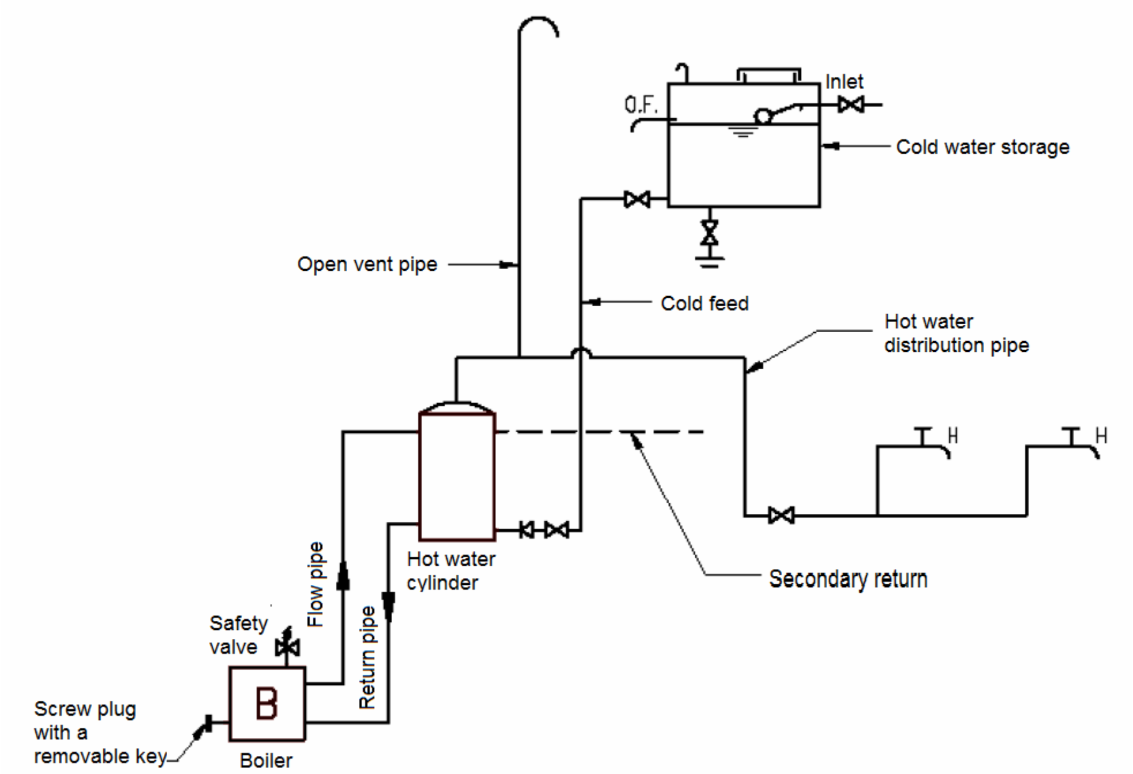
- Type of heating system used:
    a. Direct system
    b. Indirect system
- Types of hot water distribution systems:
    - Simple distribution (supply piping with no return loop)

- Pumped circuit continuous recirculation (supply piping with return loop and pump)
- Demand Circulation
- Distributed Generation

- Types of installation and layout used:
  a. Up-feed and Gravity return
  b. Overhead feed and gravity return
  c. Pump circuit system

Direct Heating System

In this method, the water that is being heated by the boiler is actually used out of the hot water faucets. The figure below shows a simple system with a boiler, hot water cylinder, circulating pipes and a cold water storage cistern.



Direct Centralized Hot Water System

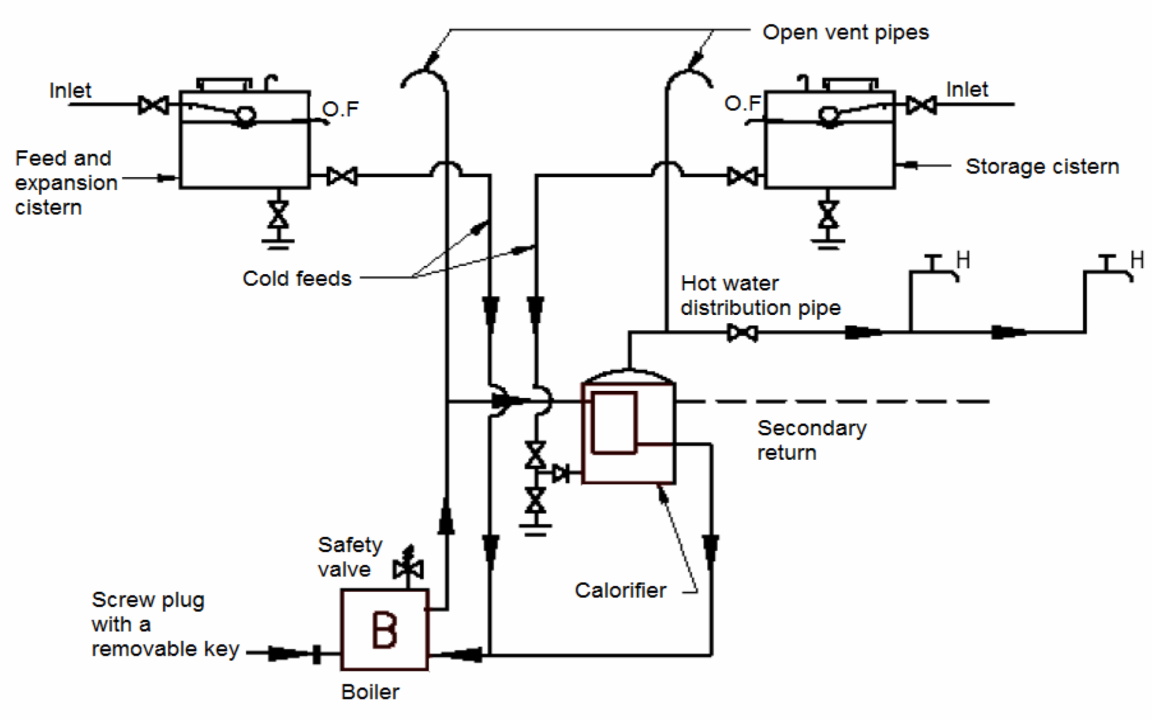
The water is heated as follows:

1. Radiant heat from the fire is conducted through the boiler plate;

2. The water in contact with the boiler plate becomes heated and therefore becomes less dense than the cold water;
3. The cold water pushes the heated water to the top of the boiler, and as more heat is applied, the water passes up the flow pipe; and
4. Hot water enters the cylinder and convection currents are set up until warm water eventually passes down the return pipe, and being at a lower temperature than the water in the flow pipe, and therefore heavier, it continues to push the water being heated in the boiler up the flow pipe and into the cylinder until all the water in the cylinder is heated.

Indirect Heating System

In this system, the water that is heated by the boiler is never used out of the hot water faucets, but circulates through a heat exchanger. This takes the form of a coil pipe within the hot water storage tank. The heated water circulates through the system and, in turn, heats the water held within the storage tank, causing the boiler to be reheated. The common type of indirect heating is “Calorifier”, which is a continuous coil of pipe within a vertical cylinder. In hospitals and factories where steam is already being generated for other uses, it can be used to heat the water by the indirect method through the calorifier. The figure below shows a simple schematic arrangement.



Indirect Centralized Hot Water System

The water is heated as follows:

1. Radiant heat from the fuel is conducted through the boiler plate.
2. The water in contact with the boiler plate becomes heated and therefore becomes less dense than the cold water.
3. The cold water pushes the heated water to the top of the boiler and, as more heat is applied, the water passes up the flow pipe.
4. Hot water enters the coil in the indirect cylinder (calorifier) and transfers its heat by conduction to the cooler water surrounding the coil. Heat will always travel from the hotter to the cooler in any element and will continue to do so until the difference in temperature disappears. In giving off its heat to the surrounding water, the water within the coil cools and becomes heavier than the hot water following from the boiler. The cooler water returns to the boiler via the primary return pipe to be reheated. This is an ongoing process and will continue until the water in the cylinder reaches the temperature required. This is a basic heating circuit.

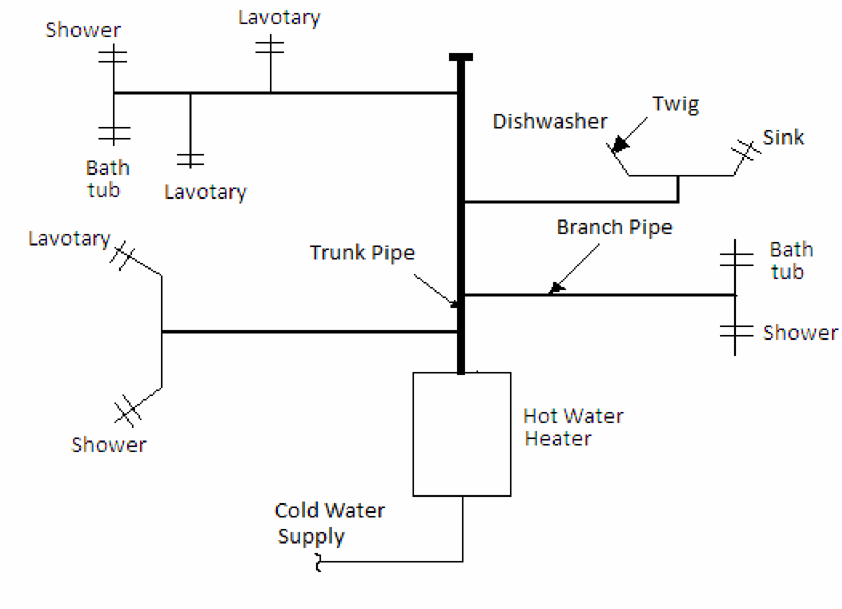
HOT WATER DISTRIBUTION SYSTEMS

There are four main types of hot water distribution systems:

1. Simple distribution (supply piping with no return loop)
2. Continuous recirculation (supply piping with return loop and pump)
3. Demand Circulation
4. Distributed Generation

Simple Distribution (Trunk & Branch System)

A simple distribution system uses trunk, branch and twig configuration to deliver water from the heater to the points of use. The piping is essentially "one-way" supply from the hot water source (heater) to the water use (sink, shower, dishwasher, etc.) and no return loop (See figure below):



Simple Trunk & Branch System

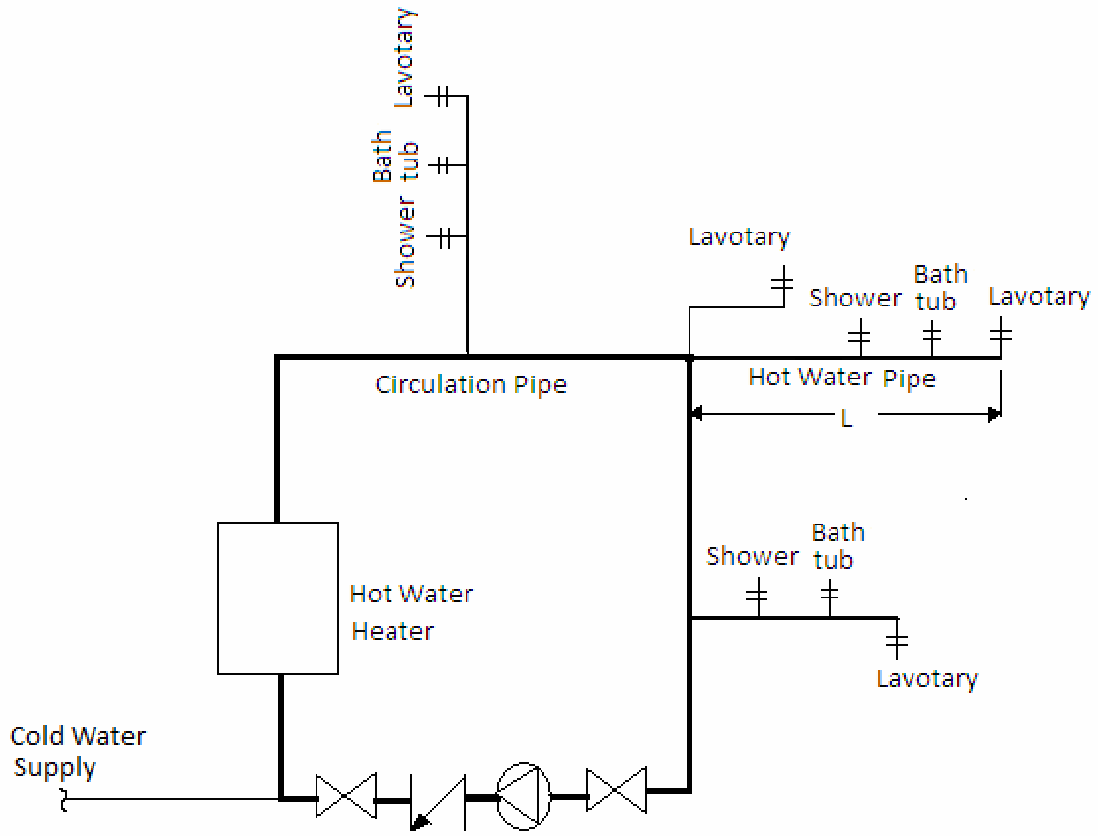
- A "trunk" line is the main pipe that comes from a water heater and then branches out with smaller pipes.
- A "branch" line serves more than one fixture and goes all the way to the individual bathroom or kitchen.
- A "twig" serves each individual fixture (for example, if a bathroom has two sinks, a tub and a separate shower, four hot water twigs are run to the bathroom faucets). As a good practice, the twig lines serving individual fixtures are small in

volume (length times inside diameter); ideally less than 10 feet long and no larger than ½ inch nominal diameter.

There can be one (and sometimes two or more) hot water main trunk lines that serve multiple fixtures through either branches or individual twigs. Simple distribution systems are typically used only for small single or double story homes where distribution lines are less than 60 feet. **<u>Note:</u>** The total length of the pipe is from the hot water tank to the last fixture.

Continuous Recirculation

Continuous recirculation system uses a booster pump to force hot water through a closed piping loop to the farthest fitting. Closed loop implies that the trunk pipe is extended from the last outlet back to the water heater. The arrangement ensures that there is hot water in the trunk line at all times and, in essence, the water heater supply node moves closer to points of use.



Hot Water System with circulation pipe

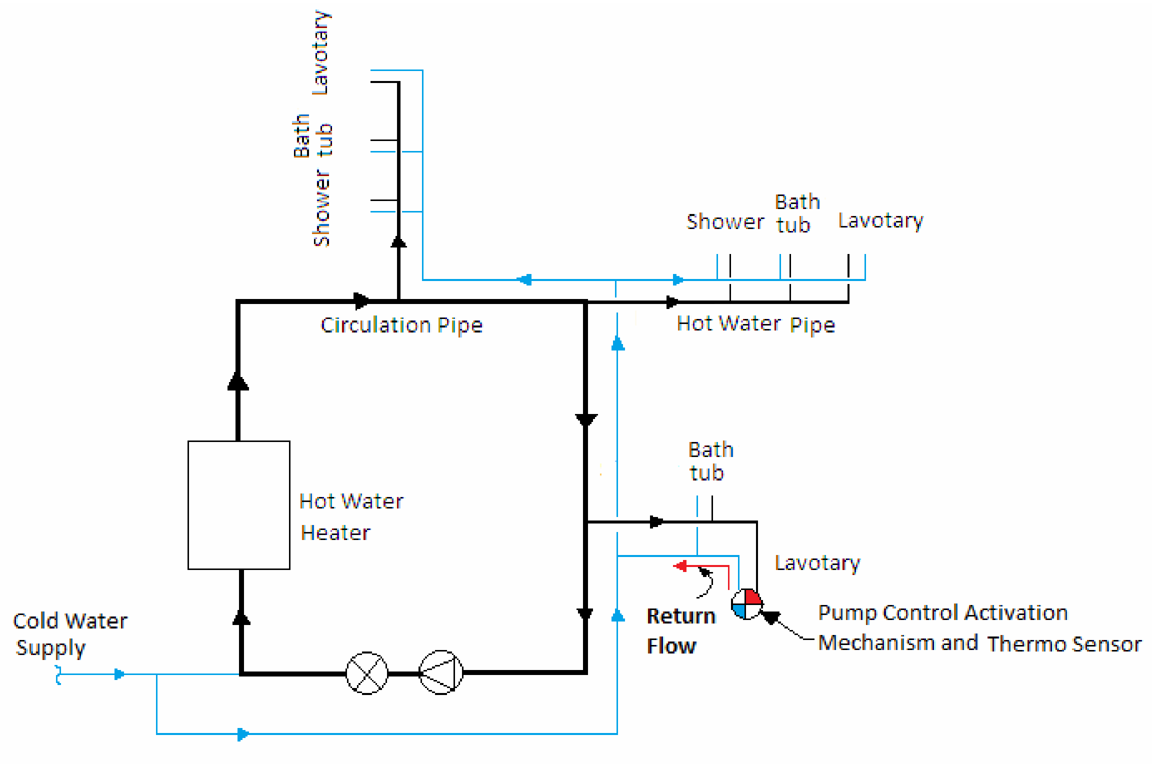
Note: For a closed loop, the pipe length is taken from the taping point of the pipe network, unlike a natural circulation system where the pipe length is measured from the hot water tank to the last fixture. The scheme reduces the waiting time considerably.

Few important things must be carefully evaluated on a loop recirculation system:

1. Route hot water recirculation lines as close to the fixtures as possible. The circulation loop shall be located such that it is both: as short as possible and within 10 plumbing feet of every fixture. The closer the recirculation line to the fixture, the less time it will require to receive hot water at the fixture.
2. The connection line to fixtures or appliances shall be no larger than ½ inch diameter. Except for the friction losses due to its length, it has few other restrictions to flow. Ideally, the only fittings in the circulation loop are the tees for the branch lines feeding each fixture.
3. If the building has multiple hot water mains, each branch should have a balancing valve and check valve prior to connection to the hot water return main. This prevents short cycling of the hot water through the closest circuit of piping, or taking the path of least resistance.
4. All hot water pipes should be insulated. (It is very common to find a 5°F to 10°F temperature drop from the water heater to the furthest fixtures in a house. For a given flow rate, R-4 insulation will reduce the temperature drop by half.)
5. An on-demand pumping system with electronic controls and activation mechanisms placed in key locations throughout the house, generally one per hot water using location.

Demand Circulation

Demand circulation as the name implies, incorporates a control strategy that operates the circulation pump only when there is a need for hot water.



Hot Water Demand Circulation

The system comprises of a thermo-sensitive control valve interconnecting hot and cold lines at the faucet and which is located farthest from the heater or alternatively at a faucet having the highest demand. It also includes an activation mechanism comprising of a pressure sensor, a motion sensor or a pushbutton which provides an “on-off” signal to the circulation pump. When hot water is desired at the faucet, an activation mechanism triggers the control valve, which:

1. Temporarily closes and transfers Luke-warm water contained in the hot water supply line into the adjacent cold water supply line (remember, the cold water line coming into the building is also connected to the inlet of the water heater).
2. Energizes the pump which begins pumping water quickly on a “round-trip” through a loop starting from the water heater, through the hot water supply line to the fixture, and back to the water heater through the cold water supply line in the direction labeled “reverse flow” shown above.
3. On sensing in water temperature, deactivates the valve and the hot water begins to flow normally from the fixture. Now, when the hot water tap is turned on, the delivery of hot water happens within seconds. Every time the occupancy sensor

calls for the pump to run, the unit checks the water temperature. If it senses that the water in the pipe has not cooled down, it does not activate the pump.

This demand control strategy does help in limiting energy use somewhat when the circulator is cycled off, but the system still does not address the issue of ‘no use’ situations. So some other form of regulation could be installed, which may include the use of:

1. Thermostatic (temperature regulated) controls,
2. A timer, or
3. Temperature control and a timer together.

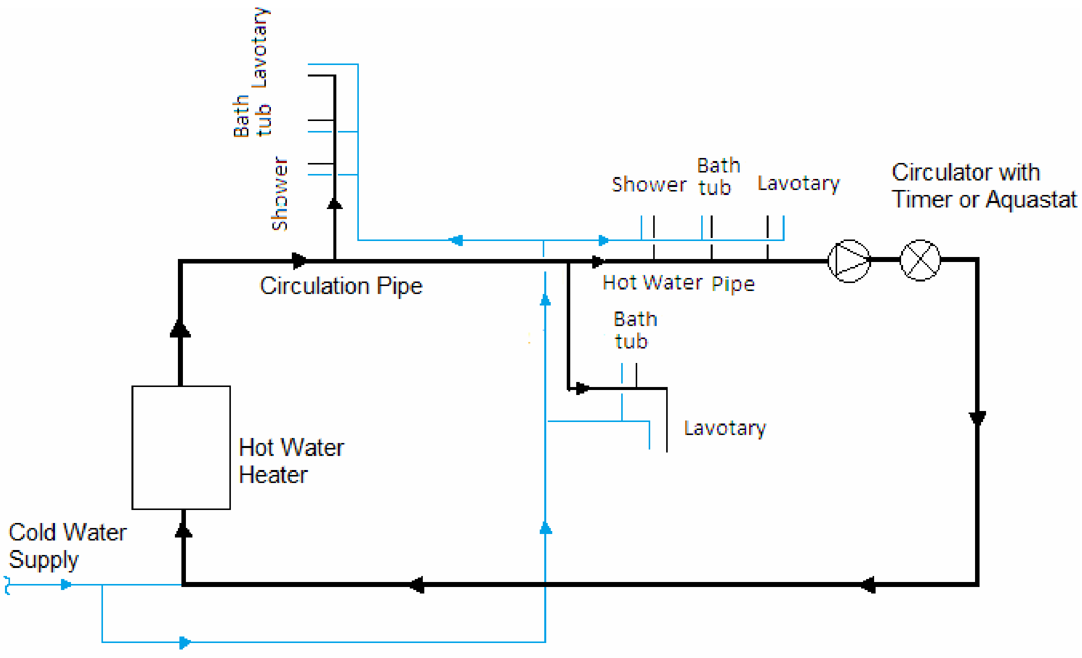
Temperature regulated circulation

This is a circulation system that uses temperature controls to cycle pump operation to maintain circulated water temperatures within certain limits. An installed automatic thermostatic control can respond to the temperature of water returning to the water heater through the recirculation piping, thereby cycling the pump on and off. Most prevalent systems in the U.S. utilize the Delta T principle which incorporates thermo-sensitive electronics, meaning that the circulator energizes only when the temperature of the circulated hot water is at least 18°F lower than the standard set point for the water heater.

Timer regulated circulation

This is a circulation system that uses a timer control to cycle circulator operation based on time of day. In this system, the timer can be manually set so that the circulator is not in operation during pre-specified times, such as overnight, or perhaps the middle of the day when no one is home. During the hours where the circulator is in operation, it behaves as a continuous circulation system. The circulator will be located at a point on the circulation system that is easily accessible by the user, in order to facilitate use of the timer.

During times of high use, hot water is available immediately at all fixtures. However, energy is conserved by shutting down the system during generalized times of little or no use. This does mean that if there is a demand for hot water during the scheduled ‘off’ time, the wait for hot water will be equivalent to that of a system without a circulator pump. Also, when the pump is on, it circulates water continuously, potentially wasting energy. Both in a temperature and timer regulated hot water circulation system, the circulator is likely to be located at the furthest fixture to minimize pump operation.



Hot Water Regulated Circulation (Timer Controlled)

Temperature and timer regulated circulation

This is a circulation system that uses both temperature and timer. As a combination of the above-discussed methods, this system can be shut down completely when hot water is not required, and will be cycled on and off by an automatic sensor during operating hours. This is the most energy efficient of the continuous circulation systems, combining shutdown periods with temperature-sensitive operation. During times of high demand, hot water is still available almost immediately at all fixtures. Despite being the most efficient of the continuous systems, a temperature- and timer-regulated system still has the potential to waste energy due to efforts to keep water hot during times where it may not be required.

Distributed Generation

Distributed generation utilize point-of-use water heaters or a hybrid hot water system that combines a central water heater (storage type or tankless) with point-of-use electric heaters. Point-of-use heaters are small instantaneous water heaters plumbed to cold water lines at the fixtures. Their location at the fixtures ensures almost immediate hot water, and they save energy because no hot water is left in the pipes after the water is shut off. This also eliminates the need for a dedicated hot water line and consequent pipe surface losses due to radiation and convection.

A small point-of-use heater may be used in different ways:

- In a kitchen sink to provide immediate extremely hot water for cooking and other applications;
- In remote locations as a booster to reduce draw-off volumes while waiting for hot water from the central heater; and
- On very low flow hand washing sinks using best in class 0.375 gpm aerators for the faucets.

However, installing too many point-of-use heaters at locations of hot water use can be expensive. The energy requirements of the individual units can be very high in comparison to storage type heaters, causing problems during peak times when many areas are drawing on their heaters. Since point-of-use heaters have limited heating capacities, and since they are unlikely to be installed at every hot water application, they need to be used in conjunction with a central water heater.

PART - 5: HOT WATER SYSTEM INSTALLATION AND LAYOUTS

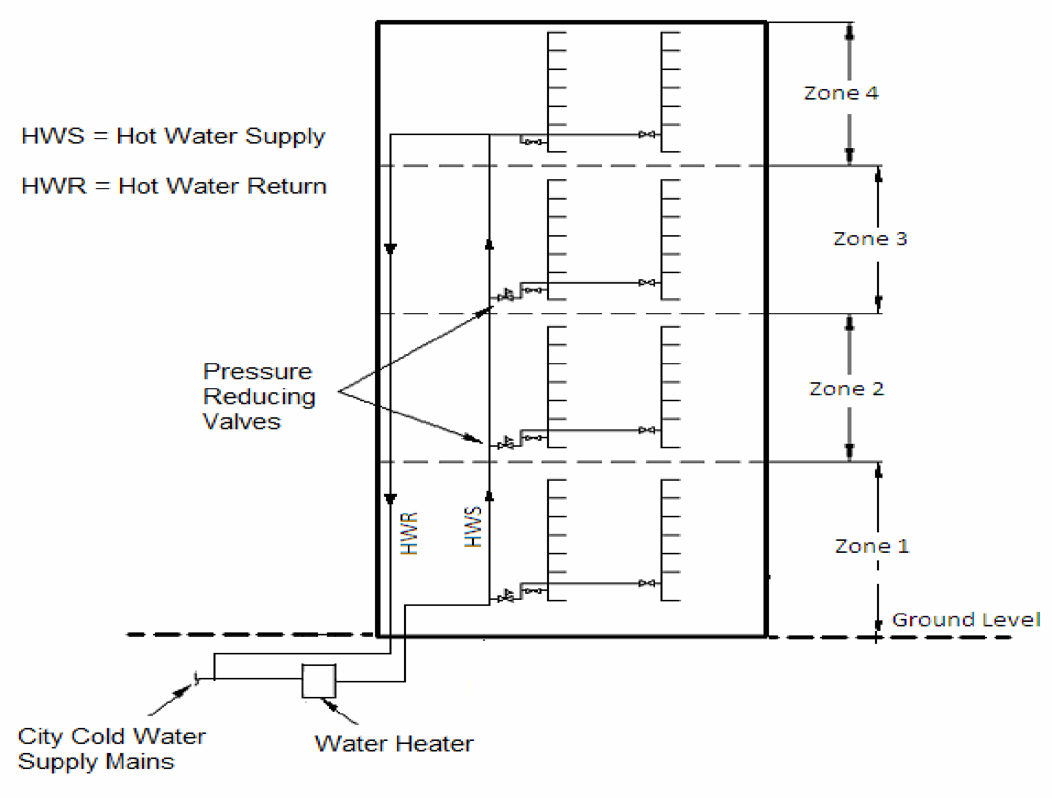
Two basic types of supply systems used in buildings are: an upfeed system and a downfeed system. The application of these depends on the project and its individual needs and specifications. Some basic principles must however be followed for efficient and economical design.

UPFEED SYSTEM

An upfeed system uses pressure in a water main to directly supply fixtures.

- Limit: 40' – 60'
- Supply from city main is 40 to 80 psi

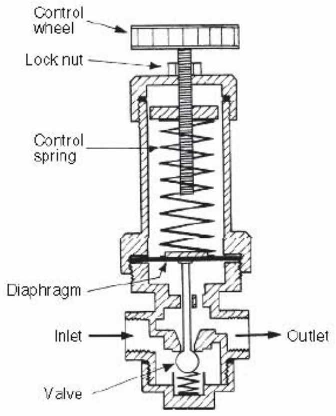
Pressure must be sufficient to overcome friction in pipes, fittings, meter and static head, but still have enough pressure to operate fixtures. The figure below shows the hot water is supplied from the bottom and is fed from the city main line.



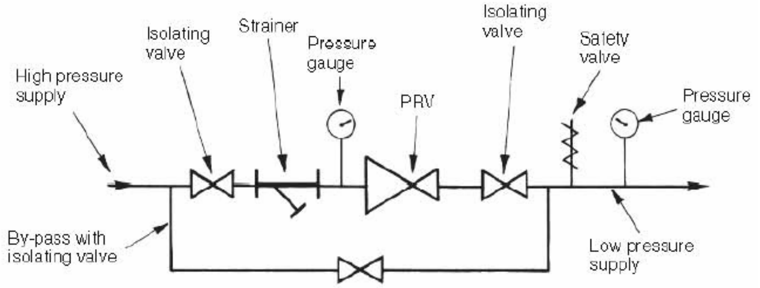
Typical Pumped-Upfeed Schematic

The upfeed arrangement produces the largest pressures at the bottom, and as the water moves to the top zones, energy is expended in friction losses as the water passes through the pipe and fittings. Also, part of the pressure is expended to overcome gravity which is the pressure required to push the weight of water vertically up the riser (static pressure loss). For example, if a pressure of 80 psi is available at the base of a plumbing system riser, the maximum height water can rise vertically is 185 ft. This is because 1 psi pressure can lift water to 2.31 ft. and therefore 80 psi would lift water to 185 ft {80 psi * 2.31 ft. = 185 ft}. Considering the floor-to-floor height of 12 ft, a pressure of 80 psi would drive water about 15 stories, but only if there were no friction losses or fixture operation pressures to consider. When friction loss occurs (as a rough rule 5 psi per 100-ft length of pipe), practical design limitations typically establish about 60 ft. This limits a conventional upfeed system to buildings typically 40 to 60 ft high.

If water supply is insufficient, a downfeed system or a pumped upfeed system may be considered for high rise buildings, where water enters one or more pumps where its pressure is boosted to 150 to 250 psi or more. The vertical riser carries this high pressure water to fixtures at the top of the building. But such a pressure in the distribution system is too great to be used in plumbing fixtures and the model plumbing codes restrict the maximum pressure at the plumbing fixture to 80 psi. A pressure-reducing valve (PRV) must be installed at each tap off zone to limit the maximum pressure to 80 psi and it also ensures that water is available to plumbing fixtures at each zone at a constant pressure. It is possible that the main risers of the system will be subjected to pressures exceeding 80 psi, but this is allowed by the International Plumbing Code, (IPC , section 604.8, 2000) “exception” for main supply risers”.



Typical PRV

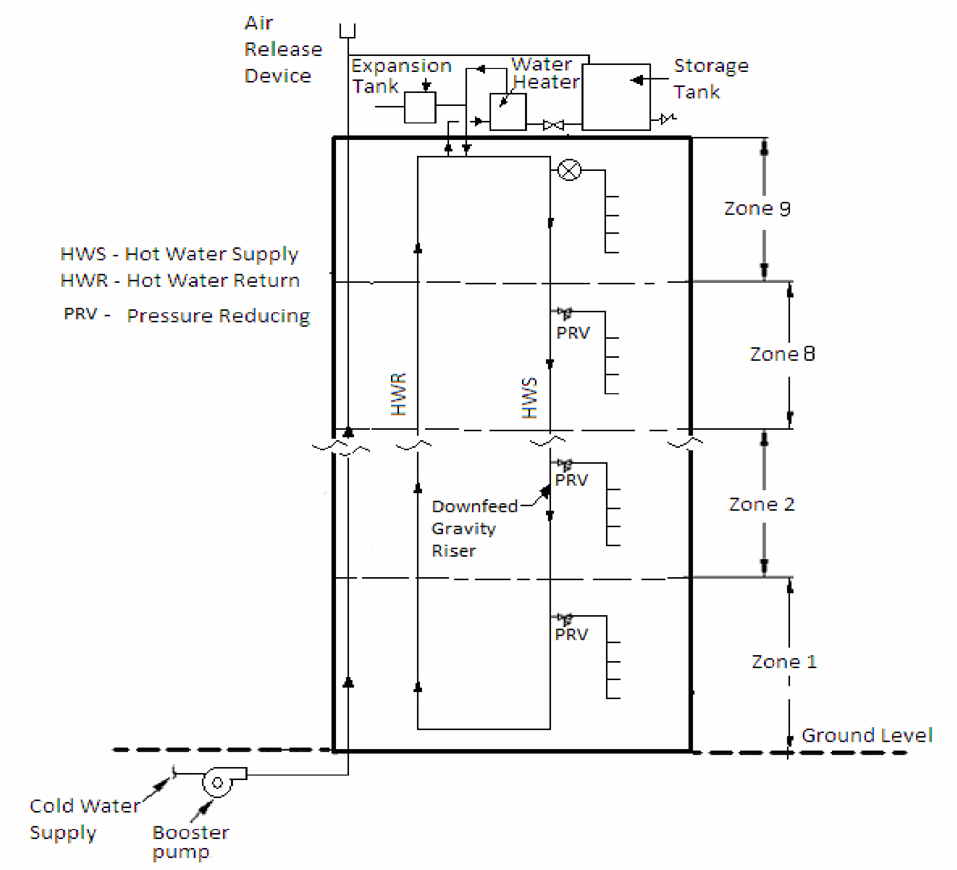


Typical Installation

Upfeed systems are predominantly used in medium-rise buildings typically 40 to 60 ft high.

DOWNFEED SYSTEM

When a building is too tall for an upfeed system, a downfeed system is used. Here, the water is first pumped to upper level storage tanks and then flows by gravity to the fixtures. The figure below shows a typical downfeed configuration, where zones are arranged in a similar fashion to the pumped-upfeed system, but vertically inverted. The gravity tanks, sometimes aided by a hydropneumatic pressure tank, supply the necessary pressure, if gravity pressure is inadequate at the top floors due to the low head of water.



The operation of the system relies on the buildup of hydrostatic pressure and the pressure at any point is determined by distance from the outlet of tank.

Tall buildings will experience very high water pressure at the lower floors owing to high static head; for example an 80-story building would require more than 350 psi. Therefore suitable pressure reducing valve (PRV's) must be considered at each zone and also multiple zone feeders may be considered ideally one for every 150 ft. height.

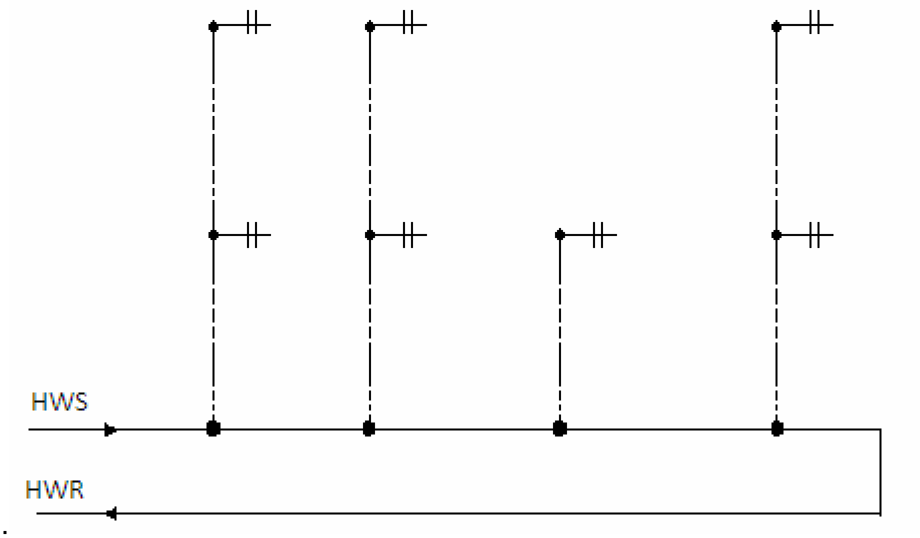
Variations of these distribution systems are illustrated as sample schematics in the following paragraphs.

SAMPLE SCHEMATICS OF HOT WATER CONFIGURATIONS

Depending upon the complexity of the building and position of the hot water generation plant, there can be other layouts or combinations. The following schematics show a number of fundamental examples of the design of the piping for distribution of domestic hot water. The hot water supply pipe (HWS) is defined as the pipe from the hot water unit to the joint, while the circulation pipe (HWR) is defined as the pipe from the joints to the hot water unit.

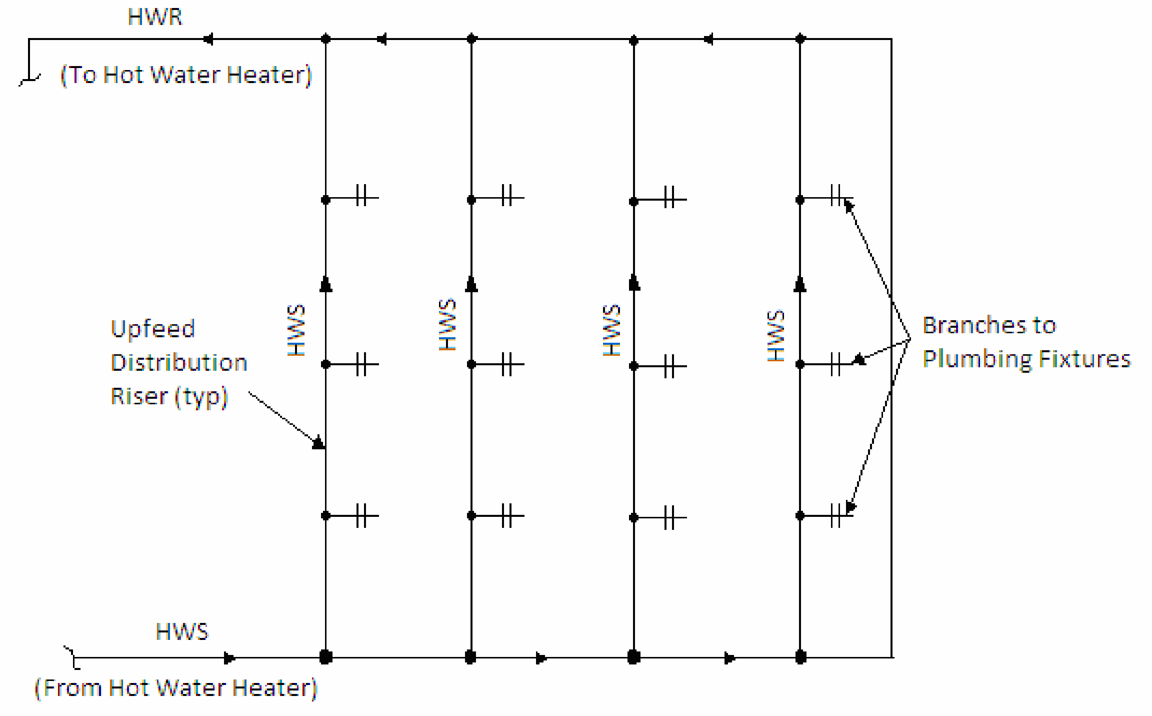
Upfeed System – Single Pressure Zone

Upfeed single pressure zone system comprises of one supply main (lateral) forming a loop on the lowest floor. Single or multiple upfeed risers branch off the main loop and distribute hot water to the above floors. A circulation pump drives the flow around the main loop and the excess water is returned to the heater. The hot water circulation occurs only on the horizontal manifold pipes. The system is also referred to as a "tree system".



Upfeed System – Multiple Pressure Zones

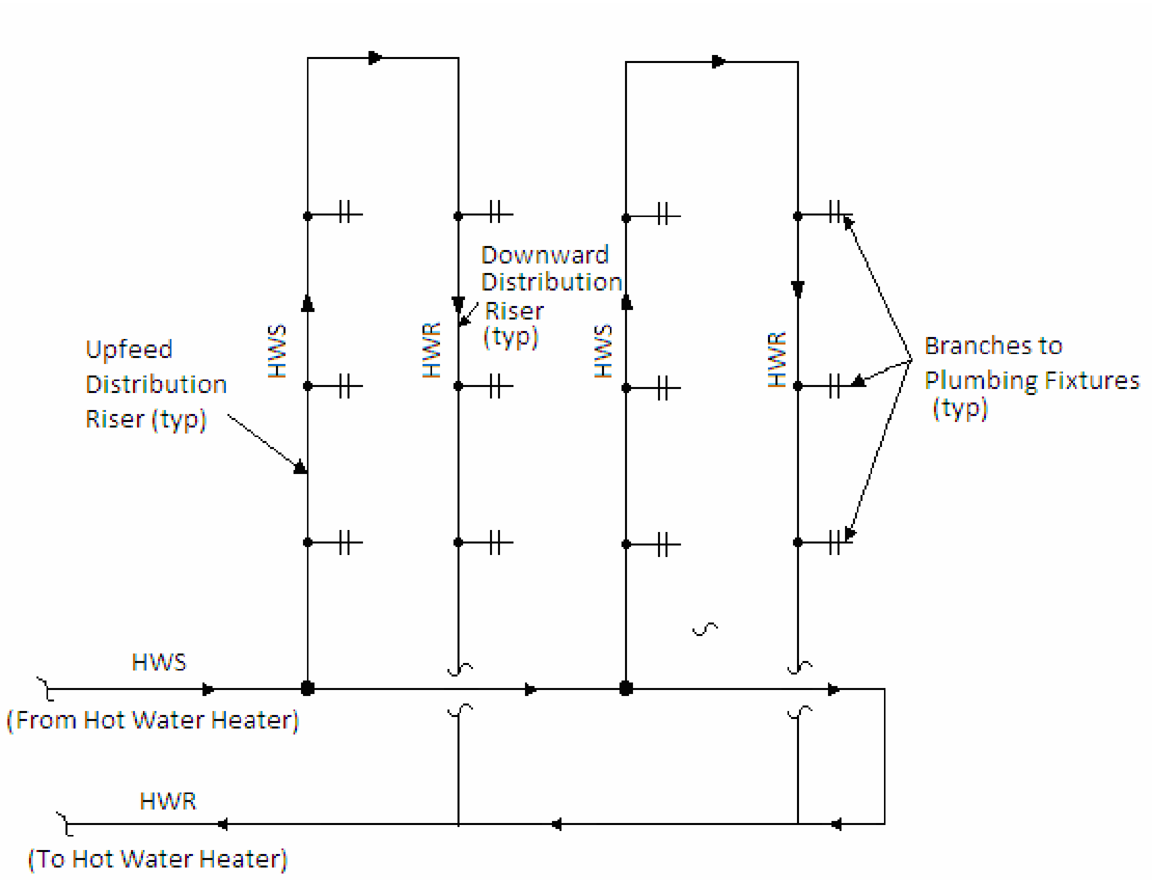
This system comprises of several loops, with circulation pipe shared between several supply pipes. Multiple upfeed risers branch off of the main and distribute hot-water to the above floors. A circulating return main is located at the top of the pressure zone that collects the excess hot water from the risers. The upper main feeds the surplus hot water to a downfeed riser where it is returned to the heater. A "circulation pump" drives the flow around the circulation loop.



Typical Hot Water Upfeed System (Multiple zones)

Upfeed/Downfeed System – Single Pressure Zone

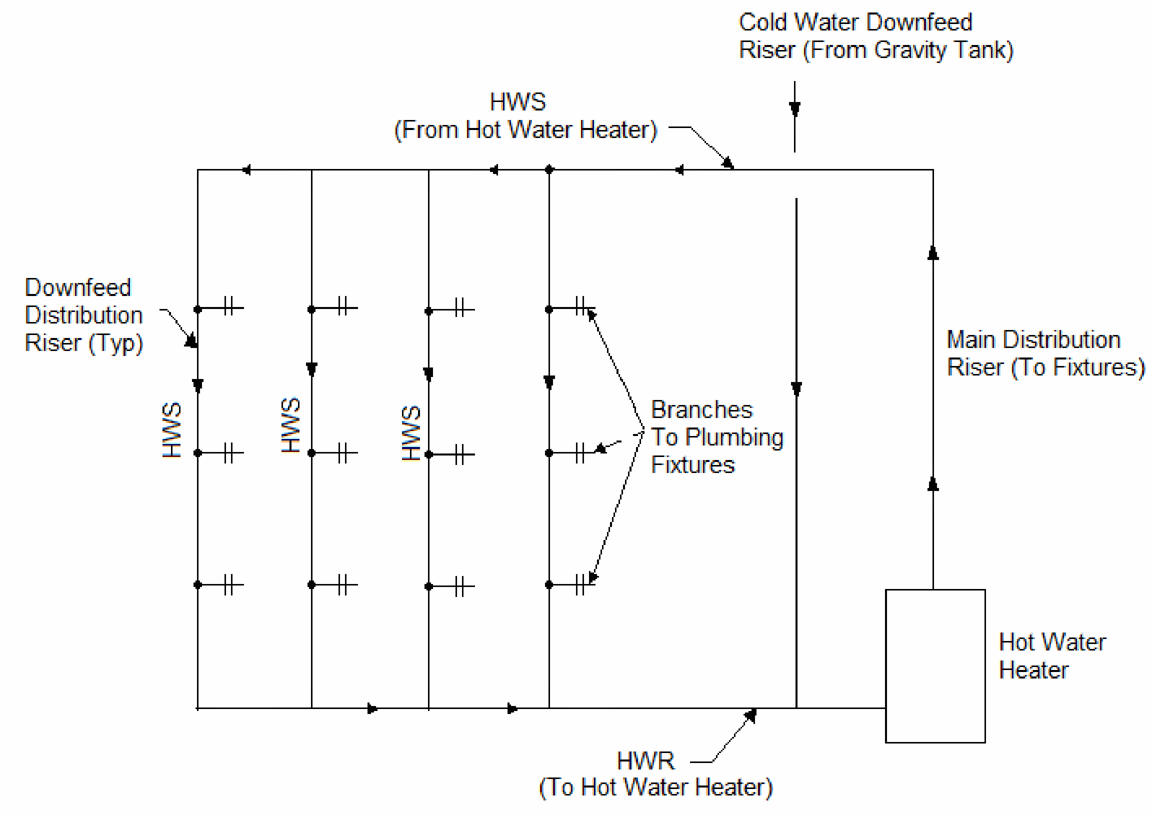
A combination upfeed/downfeed hot water configuration can be used as an alternative to the upfeed arrangement. Unlike the above upfeed system, this combined arrangement locates the supply main and circulation main on the same floor. Water is fed through the hot-water supply main, via the water heater, to multiple upfeed distribution risers. The circulation loop is formed by imposing a "crossover" link at the top of the zone, which allows water to flow back through a downfeed distribution riser to serve other customers. The excess hot water is collected in a circulation main at the bottom of the zone. Water is then returned to the heater and joined with incoming cold-water. Again, the circulation process is driven by a pump.



Typical Hot Water Upfeed/Downfeed System (Single Zone)

Downfeed System – Single Pressure Zone

This arrangement places the hot water heater below the gravity tank at the lowest points of each zone. This configuration is applicable to single zone situations. Cold water is downfed from the gravity tank to the heater. The heated water then "rises to seek its own level (discharging from the water heater and flowing through an upfeed riser) at the hot water header, becoming available there for hot water downfeed on demand". The water is then distributed via downfeed riser(s) to the fixtures below. Special care must be taken to ensure adequate pressures at the top of zone, and to avoid excessive pressures at the bottom. The excess hot water at the bottom zone is directed back to the heater where it is combined with fresh cold-water. The circulation loop is driven by a pump.

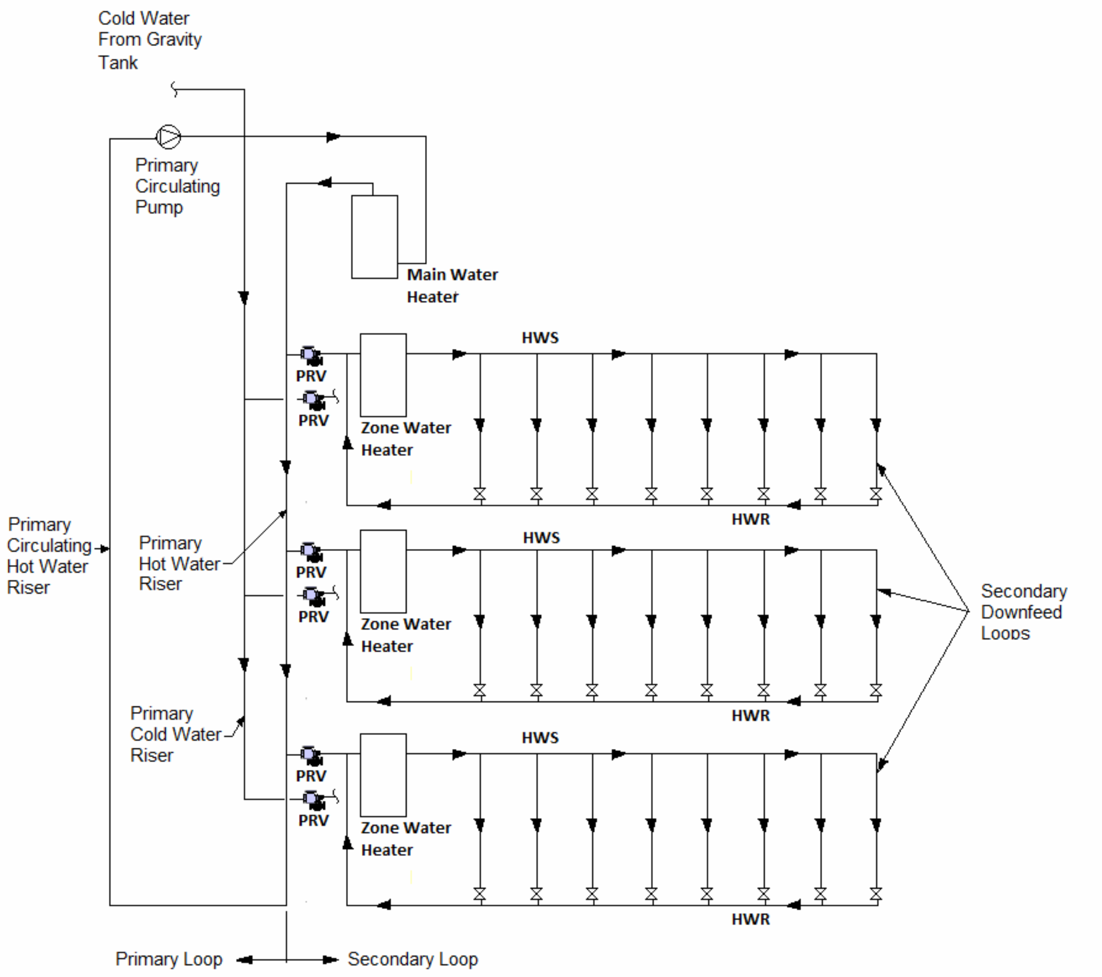


Typical Hot Water Downfeed System (Single Zone)

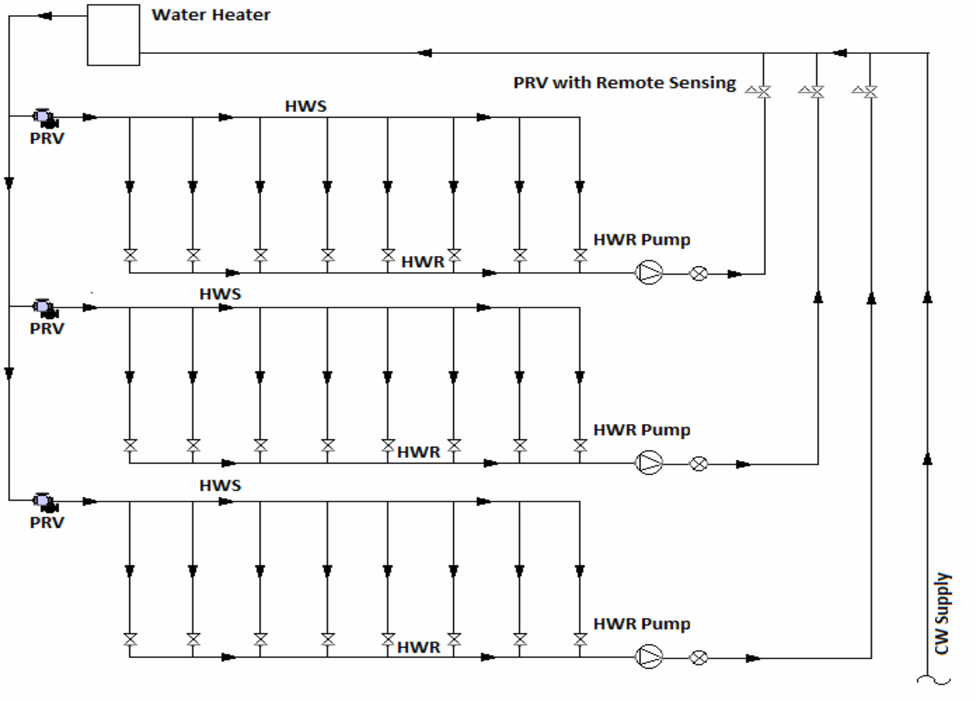
Downfeed/Downfeed System – Multiple Pressure Zones

Multiple pressure zones can be served with one hot-water circulation system. These applications utilize a “downfeed – downfeed” approach, and are typically coupled with downfeed cold-water arrangements. Here, each zone requires a pressure reducing valve, so as to reduce the pressure at the lowest floor to an acceptable level. The hot water heater is located at the top-most zone. When used in conjunction with a downfeed cold water configuration, water is pulled directly off of the gravity tank and fed to the water heater. This is ideal because heaters, which are typically expensive, are not susceptible to damages from high pressures. Ideally water pressure at the heater should be kept below 30 psi. Hot water discharges from the heater to a main hot water riser which feeds the lower pressure zones. Each zone, except the top zone, is equipped with a PRV. The hot water is then circulated through the individual zone loop with a circulation pump, and a smaller booster heater is employed to restore any lost heat. It is important to note that the hot water is not circulated back to the main hot water riser, but is kept within the individual zone loop. These types of systems are also referred to as “primary-secondary” configurations and can be designed in various variants. Four variants of multiple zone downfeed systems are illustrated below:

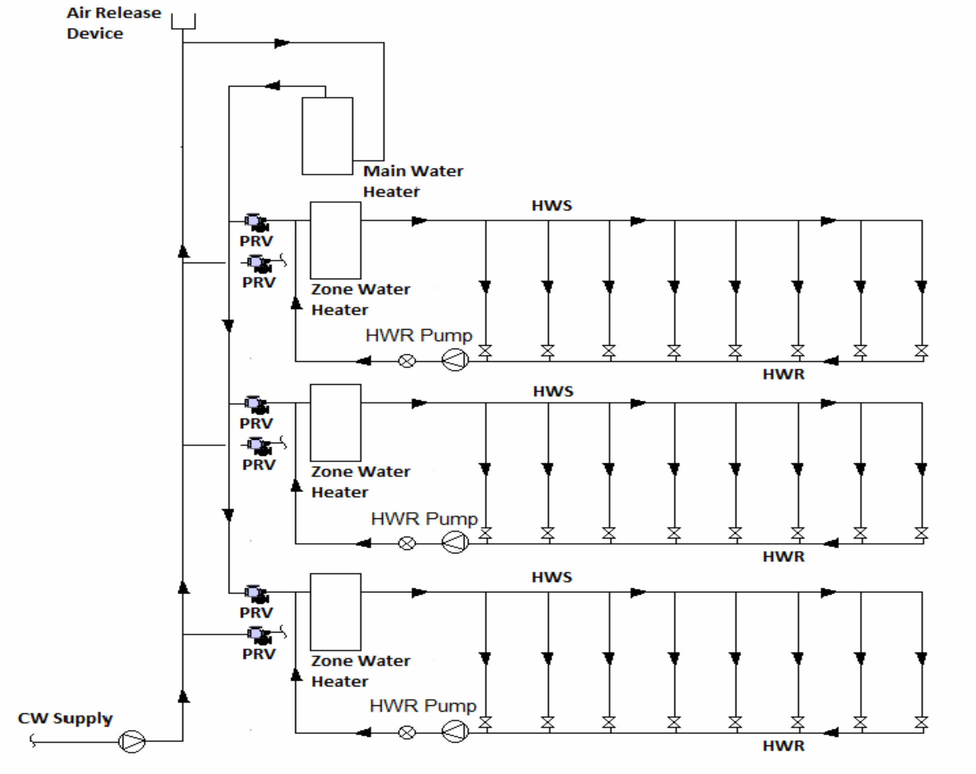
1. Multiple Zone Downfeed System with Multiple Heaters and Single Pump
2. Multiple Zone Downfeed System with Multiple Pumps and Single Heater
3. Multiple Zone Downfeed System with Multiple Heaters and Multiple Pumps
4. Multiple Zone Downfeed System with Single Heater and Single Pump



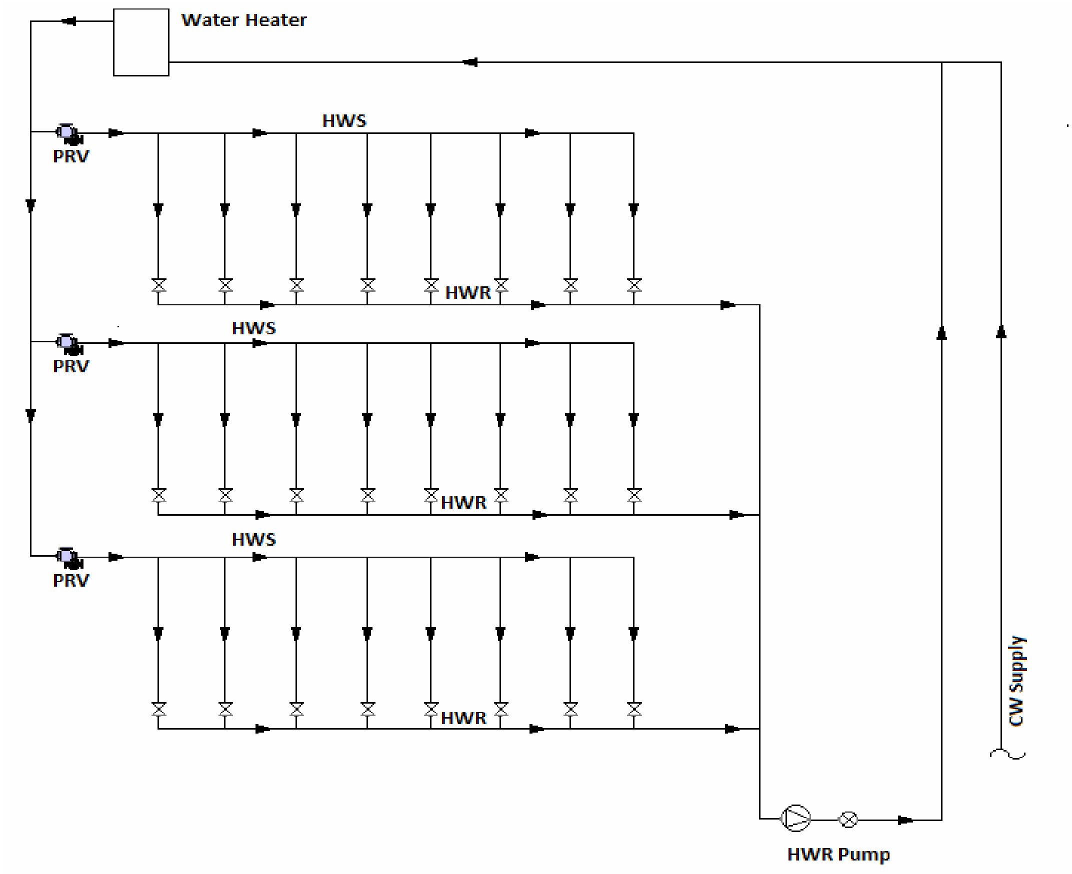
Multiple Zone Downfeed System with Multiple Heaters & Single Main Pump



Multiple Zone Downfeed System with Single Heater and Multiple Pumps



Multiple Zone Downfeed System with Multiple Heaters and Multiple Pumps



Multiple Zone Downfeed System with Single Heater and Single Pump

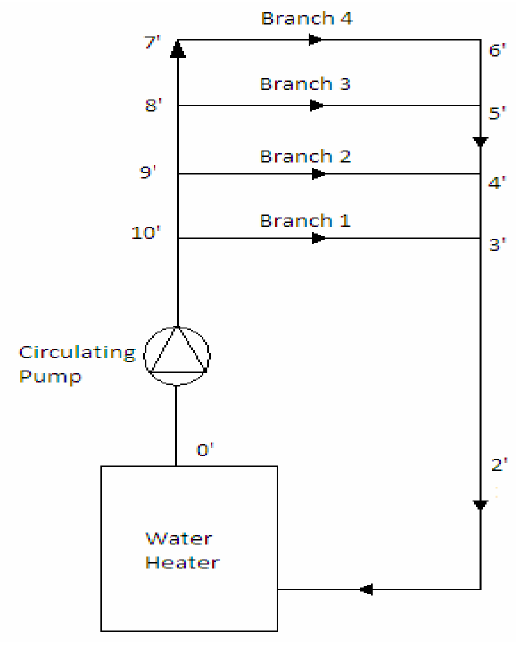
REVERSE PIPING ARRANGEMENT

Water follows the path of least resistance. The reverse return piping system provides equal pressure drop throughout the entire piping system. The system uses 2 parallel pipes arranged such that the pipe length to each branch circuit is the same, thus ensuring close balancing and equal water flow at every point. There is a bit more piping involved, but considering life term reliability, it is well worth installing.

This system is suitable where the circuits are long and where there is a likelihood of the least favorably placed fixtures not receiving adequate flow or pressure.

Let’s check this with an example:

Consider an upfeed system comprising of a hot water generator, a circulator, and a hot water distribution system serving 4 branches. (Refer to the figure below.) As the water moves away from the circulator, the pressure differential across each circuit becomes less and less.

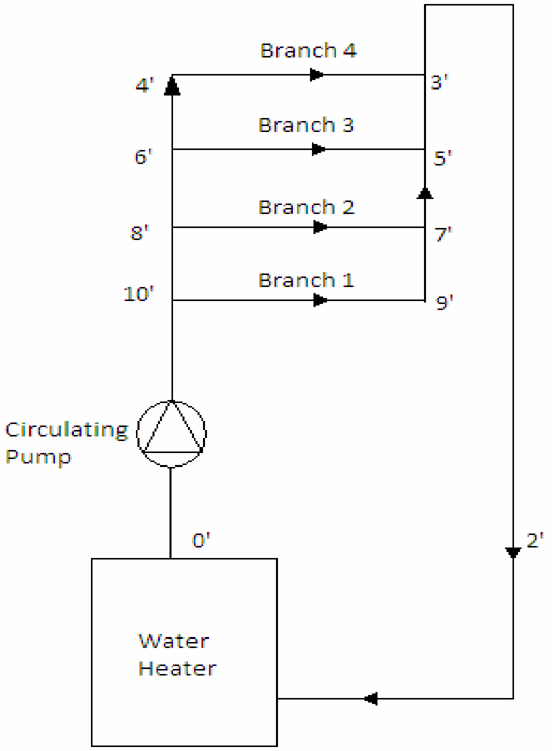


Normal Upfeed Distribution System

On branch 1, the system has 10 feet of head pressure on the supply, and 3 feet on the return side of the zone. That means there is a pressure differential of 7 feet, and this 7-foot differential will cause a certain amount of flow to take place in that zone. At the farthest zone, which has 7 feet of head pressure on the supply, and 6 feet on the return side, only 1 foot of pressure differential exists. A difference in pressure is what causes water flow, and the greater the pressure differential, the greater the flow rate. In the scheme above, the farthest circuit or zone might have no-flow, or very scarce flow.

How is this imbalance problem solved?

The reverse-return piping system provides the solution to this problem. A reverse-return scheme maintains an equal pressure drop throughout the entire piping system and ensures adequate flow to all the branch circuits. There is a bit more piping involved, but maintaining water at every point makes it well worth installing.



Reverse Return System

Notice the length of the circuit via branch 4 (from pump discharge back to the hot water generator) and branch 1 is the same, resulting in a somewhat equivalent pressure drop in both circuits. Consider putting balancing valves on the return side of each circuit. By appropriate setting, the pressure drop in each circuit will be the same. With equal pressure drops in each circuit, there is no "path of least resistance", and so there will be adequate flow in each circuit.

This concept can be applied when two or more heaters are used in parallel. The inlet and outlet piping should be arranged in a way that an equal flow is received from each heater under all demand conditions. With a reverse return system it is easy to obtain parallel flow. The unit having its inlet closest to the cold water supply is piped so that its outlet will be farthest from the hot water supply line.

Summarizing….

The above hot-water circulation configurations describe only a few of the feasible arrangements that could satisfy hot-water demands. The placement of circulation pumps as well as supply and circulation mains and risers is up to the designer.

In some cases, and especially for high-rise structures, the structure must serve different purposes for the various occupant types. For example, a high-rise structure may contain apartments, condos, hotels, office buildings, commercial stores, etc. The occupant diversity encountered in large buildings leads to complicated water situations. These complications must be addressed by the building's owner and reflected in the configuration of the distribution system. For example, the building's owner may be responsible for supplying water to the commercially zoned properties, while residentially zoned units are responsible for their own plumbing systems. These types of situations require careful solutions so that water is adequately supplied to all customers. Furthermore, the responsibilities of supplying the water should be bestowed on the correct party.

Both the upfeed and downfeed configurations may sometimes be used in concert with each other to effectively supply water. A thorough study must be conducted to completely understand the demands of a building, and hence apply the best solution technique. The rule of thumb is:

- Lower floors of high rise (say up to 40 ft.) = upfeed system
- Upper floors of high rise (say above 40 ft.) = downfeed system

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PART - 6: SIZING HOT WATER CIRCULATOR AND PIPING

As discussed in previous sections, the necessity of designing the system with a circulator arises due to the acceptable waiting times; this may be achieved only if adequate sizing of the circulator and pipes are provided.

SIZING THE CIRCULATOR

A hot water circulator is a pump which transfers hot water from the water heater to outlets at the end of the hot water distribution system, sending cooled water back to the water heater. The operation of the pump may be continuous, or regulated in some way.

The ASHRAE applications handbook suggests a simplified pump sizing method to allow for 1 gpm for every 20 fixture units in the system, or to allow 0.5 gpm for each ¾ or 1 inch riser; 1 gpm for each 1-1/4 inch or 1-1/2 inch riser, and 2 gpm for each riser 2 inch or larger.

The ASPE Data Book has a precise way of selecting and sizing the circulating pump based on a 20°F temperature loss from the water heater out to the farthest fixture, and back to the circulator near the water heater. If the system has 140°F degree water in the water heater, the sizing method maintains 130°F hot water at the end of the system. Back at the cold-water inlet to the water heater, the temperature would then be approximately 120°F. The calculation is based on heat loss in the hot water piping circuit. The steps are as follows:

1) Determine the total length of all hot water supply and return piping.
2) Choose an approximate value for piping heat losses from the table below and multiply this value by the total length of piping involved. (A quick and simple way to estimate insulated pipe heat loss is to assume 25 to 30 Btu / hr - linear foot of pipe, ignoring the hot water supply and return pipe size.)

HEAT LOSS OF PIPE
(at 140°F inlet, 70°F ambient temperatures)

Nominal Pipe Size, inches	Bare Copper Tube (Btu/h-ft)	½” glass fiber insulated Copper Tube (Btu/h-ft)
¾	30	17.7
1	38	20.3
1-1/4	45	23.4
1-1/2	53	25.4
2	66	29.6

(Source ASHRAE Applications handbook, chapter 45, table 2)

3) **Estimate Recirculation Pump Flowrate:** The equation for determining the flow rate in a recirculation line is:

$Q = q / (Cp * \Delta T)$

Where,

- Q = flow rate (pounds of water/hour)
- q = heat loss (Btu/hr)
- Cp = specific heat of water = 1
- ΔT= temperature drop in circulating lines (°F)

Simplified Recirculation Equation

Changing the Pounds of water/hr to gallons per minute (gpm), divide by 8.33 pounds/gallon of water and divide by 60 min per hour resulting in:

$Q = q / (8.33*60*1* \Delta T) = q / (500\ \Delta T)$

Where,

- Q = flow rate (gpm)
- q = heat loss (Btu/hr)
- Cp = specific heat of water = 1Btu/lb-°F
- ΔT= temperature drop in circulating lines (°F)
- ρ is the density of water (8.33 lb/gal),

For a 20°F temperature differential simply divide the heat loss by 10,000 to obtain the required flow rate. This is how the pump's capacity in gallons per minute (gpm) is determined.

4) **Determine Pump Head:** The pressure driving the water along the pipes is the head. This pressure is opposed by the friction losses in the pipes, which can be thought of as the pressure-difference-per-ft. needed to push the water along at the flow rate you want. One way to find the pressure difference between the ends of a pipe is to use the Darcy-Weisbach equation. This predicts how much pressure would be needed to push the water along a pipe at a particular speed. The formula looks like this:

$$P = f \times v^2 \times \frac{\rho}{2} \times \frac{L}{D}$$

Here, the pressure difference (P) needed to achieve a flow velocity (v) depends on the length L and diameter D of the pipe as well as the density of the fluid (ρ - about 8.33 lb/gal for cold water). It also depends on f, a friction factor, which is included to account for the effects of the pipe material surface. A simplified pipe friction loss curve is available to estimate the frictional losses (refer subsequent paragraphs).

The other important pressure loss is due to the **static head**, which is the pressure required to push the weight of water upward vertically up the riser. It takes 0.433 psi to lift the water up 1 ft. vertically. Conversely, a 1.0 psi pressure can push the water upward 2.31 ft. vertically. Pushing water up 20 ft. vertically will thus require a pressure of at least 8.68 psi at the base of the riser because 20 / 0.433 psi = 8.68 psi.

Example I: A 10 story building has a floor to floor height of 12 feet; a pressure of 15 psi is needed at faucet. What is the required water pressure at the base of the building?

Total lift = 10 stories x 12' = 120'

= 120/2.3 psi

= 52.2 psi

Therefore 52.2 psi + 15 psi (faucet) = 67.2 psi

Example II: If there was additional pressure drop of 12 psi due to friction in pipe and fittings, what will be the required pressure at base?

P_{TOTAL} = 52.2 psi + 15 psi + 12 psi = 79.2 psi (min)

Example III:

How much pressure is lost in static head at a fixture 40' above a water main with a pressure of 45 psi (ignoring friction loss?)

40' (.434 $lbf/in^2/ft$) = 17.36 psi

The remaining pressure at the 40' level is:

45 psi – 17.36 psi = 27.64 psi

Circulator Pressure: The circulator pressure must be sufficient to overcome the energy expended in friction losses and the static pressure losses*. Additionally, there must be sufficient pressure left at the remote fixture to drive flow of water through the fixture (add 30 to 40 psi). Once the total pressure is known, simply select a pump at the calculated flow, and pressure from the pump curves. Small circulating pumps for domestic use are standard and it may not be necessary to calculate the pressure differential in a small size network unless the customer or codes specifically require it.

Caution*: When water is recirculated in a closed loop, the static head is zero. This remains true regardless of the elevation difference between the upper and lower portions of the loop. The total pressure is essentially the pressure required to overcome the friction generated by the water flowing in the closed loop.

But note that the hot water potable water systems are essentially open systems since water is drawn from the taps. There are branches taken from the trunk loop which are open to the atmosphere and therefore the system as a whole is an open system. Don't get confused with a hot water circulation system for a space heating system feeding radiators or convectors, which is truly the closed loop circulation.

PIPE SIZING

Sizing based on Velocity Limitation

In accordance with good engineering practice, it is recommended that maximum velocity in water supply piping be limited to no more than 6 ft/s. This is a deemed essential in order to avoid such objectionable effects such as the production of whistling line sound noise, the occurrence of cavitation, and the erosion of the pipe wall.

When copper piping is the likely choice for system piping, the following maximum velocity recommendations, as advised by the Copper Development Association, should be observed to prevent pipe wall erosion:

- 6 feet per second for domestic cold water.
- 5 feet per second for domestic hot water.
- 4 feet per second for hot water return.

Velocity limitation is generally advisable and recommended in the sizing of the inlet and outlet piping for water supply pumps. Friction losses in such piping affect the cost of pumping and should be reduced to a reasonable minimum. It is recommended that maximum velocity be limited to no more than 4ft/s in branch piping from mains, headers, and risers outlets at which supply is controlled by means of quick-closing devices such as an automatic flush valve, solenoid valve, pneumatic valve, quick closing valve or faucet of self closing, push-pull, or other similar type. This limitation is deemed necessary in order to avoid development of excessive and damaging shock pressures in piping equipment when flow is suddenly shut off.

Low velocity pipe less than 1.6 ft/s can cause precipitation of sand and others in the pipe.

Sizing based on Friction Losses

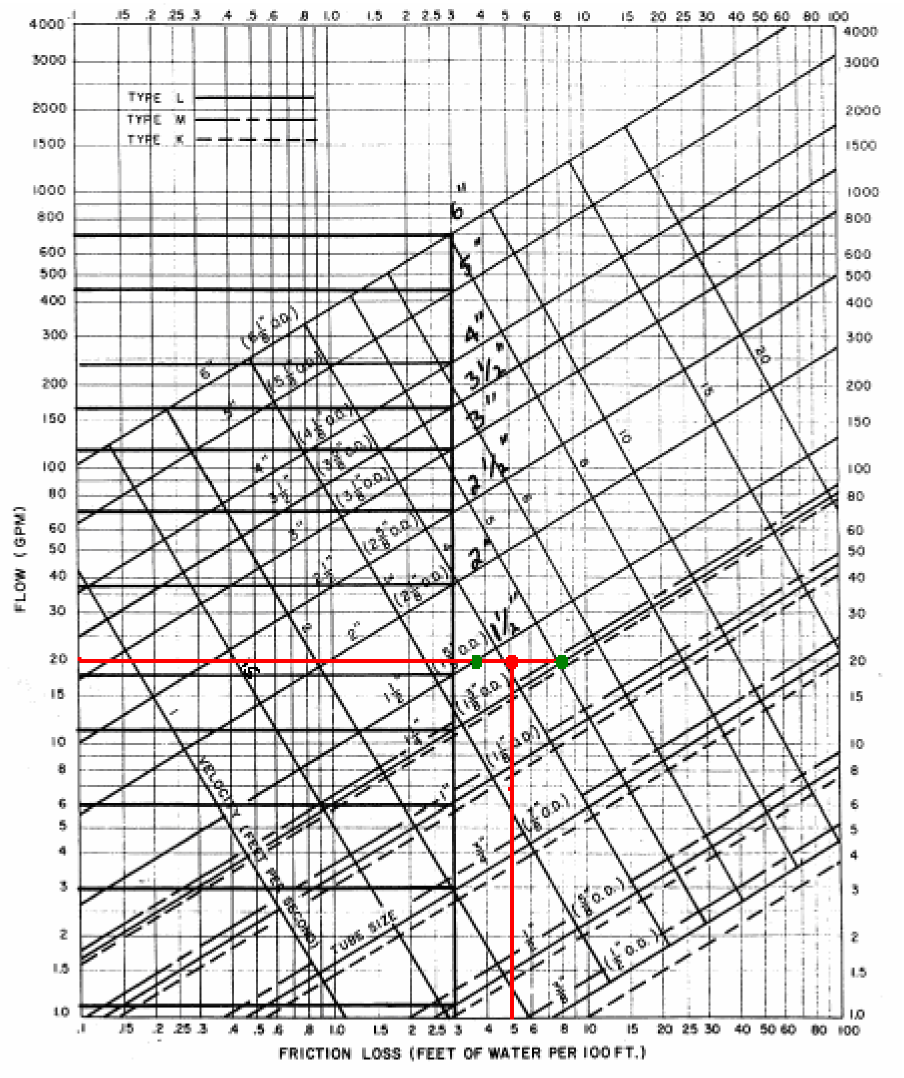
The acceptable pressure drop per 100 ft is around 2 to 5 psi, in order to avoid excessive pressure loss and the need for higher pressure to maintain the flow rate.

Pipe flow charts are available for different pipe materials such as copper water tube, galvanized iron, and plastic pipe, which show the relation between the water flow in gallons per minute (gpm), pressure drop in psi/100 ft., pipe diameter in inches, and the corresponding flow velocity in ft/s.

How to use the pipe flow-chart

The use of the pipe flow chart is best presented by an example:

A copper pipe is used to deliver 20 gpm of water at ordinary temperature with a maximum allowed pressure drop of 5 psi/100 ft. What is the recommended pipe size that can be used?



Copper Pipe Sizing Chart

Solution: Enter the figure along the abscissa with the value of 5 psi/100 ft, move upward to the ordinate where QV is 20 gpm. From the intersection, read the values of (D) and the corresponding flow velocity (V).

Now it is clear that the intersection lies between 1¼" and 1½" diameter. If the 1¼" pipe is used, the pressure drop will be 8 psi/100 ft which is greater than the given value. This is unacceptable. If the 1½" pipe is used, the pressure drop will be 4 psi/100 ft which is less than the maximum allowed pressure drop. A pipe diameter of 1½" with a flow velocity less than 4 fps is recommended.

Minimum Pipe Size for Trunk Risers

The piping pressure drop changes as the flow rate changes. Unlike cold water branch lines which experience sudden instantaneous draw rate because of flush valves, hot water distribution lines are not subject to wide variations of flow (flush valves are commonly used in WC's). The pressure fluctuation in hot water system fixtures is therefore comparatively small. A minimum pipe size of ¾" for hot water return system piping where the distance is greater than 50 feet is recommended. A ½" pipe flowing 3 gpm will have a head loss of 16.5 feet of head per 100 feet of length of pipe. If the piping circuit is 300 feet long, the pump head required would be 49.44 feet. This exceeds the head on most small circulators. If a larger circulator is installed, the velocity increases and erosion of the inside of the pipe wall typically occurs. Any decision to reduce pipe size to save cost must be carefully evaluated. It must be noted that the cost savings derived from the reduction of 1" pipe to ¾" is minimal. Cost savings seem low in comparison with implied risk factors. This is because there is a 4-time increase in pressure drop associated with one nominal pipe size reduction for any given flow rate.

Minimum Pipe Size for Branches/Twigs

It may appear that the required size of branches and twigs may be obtained in the same manner as the building main supply header/riser using the permissible friction loss/velocity criteria described above. This is true for the cold water lines but doesn't always hold true for hot water lines.

Remember, the primary objective in hot water distribution is to reduce waiting time and to improve the delivery performance. *Shorter pipe lengths, smaller diameter pipes, reduced restrictions to flow and an increased flow rate will all contribute to reducing the time taken for hot water to arrive at a fixture.* For example, when a faucet designed for 1.5 gpm flow is installed on the sink at a distance of 10 ft from the riser loop, a ¾ inch diameter branch pipe will contribute to 16 seconds of wait time and an estimated 0.28 gallons of water loss before the hot water reaches the faucet. This breaches the 10-second wait time criterion.

So what's the solution!

There are two possibilities:

1) Reduce the branch line to ½ inch, which will reduce the waiting time to nearly half (8 seconds) and/or,

2) Try locating the fixture as close to the hot water heater (hot water trunk line) as possible. If ¾ inch pipe line must be used between the trunk line and the twig line, then two feet is the longest length before wait times breach the ten-second threshold for acceptable performance. In this situation, extending the trunk line will probably reduce the length of branch piping to the faucet. While this approach resolves the delivery performance issue, it increases the length of the trunk line and system cost.

Sizing based on Standard Tables

Pipe sizing tables simplify design work and can be easily established from the fixture unit-pipe sizing chart correlations for friction loss rate and/or velocity parameters. The tables shown below are based on a 5 psi friction loss limitation (no velocity restriction) per 100 feet of pipe.

Copper Tubing @ 5 PSI/100 ft Friction Loss

No. of Fixture Units (Flush Tank/Hot water Service)	**GPM Demand**	**Copper Tube**		**Number of Fixture Units (Flush Valve-Cold Water Service)**
		Type	**Size**	
0 - 2	0 – 2.1	K	½	Check with manufacturer
2.5 – 7.5	2.1 – 6.2	K	¾	Do
7.5 – 18	6.2 – 13	K	1	Do
18 – 36	13 – 23	*	1-1/4	Do
36 - 70	23 – 35		1-1/2	10-28
70 – 240	35 – 75		2	28 – 130
240 – 575	75 – 140		2-1/2	130 – 500
575 - 1200	140 - 520		3	500 - 1200

Tables can also be used for M type tubing; differences are not significant.

Rough Pipe @ 5 PSI/100 ft Friction Loss Rate

No. of Fixture Units (Flush Tank/Hot water Service)	**GPM Demand**	**I. P. S**	**Number of Fixture Units Flush Valve**
0 - 1	0 – 1.5	½	Check with manufacturer
1 – 4.5	1.5 - 4	¾	Do
4 – 11	4 – 8.5	1	Do
11 – 20	8.5 – 15	1-1/4	Do
22 - 35	15 – 23	1-1/2	Do

35 – 120	23 – 46	2	10 – 42
120 – 275	46 – 85	2-1/2	42 – 170
300 - 520	85 - 130	3	170 - 400
520 - 1400	130 - 260	4	400 - 1400

SIMPLIFIED STEP BY STEP PROCEDURE FOR SIZING PIPING (Based on Velocity limitation)

The procedure consists of the following steps:

1. Obtain the following information:
    - Design basis for sizing
    - Materials for system
    - Characteristics of the water supply
    - Location and size of water supply source
    - Developed length of system (straight length + equivalent length of fittings)
    - Pressure data relative to source of supply
    - Elevation
    - Minimum pressure required at highest water outlet
2. Provide a schematic elevation of the complete water supply system. Show all piping connection in proper sequence and all fixture supplies. Identify all fixture and risers by means of appropriate letters numbers or combinations.
3. Mark on the schematic elevation for each section of the complete system, the hot and cold water loads conveyed in terms of water supply fixture units in accordance with table (wsfu –gpm).
4. Mark on the schematic elevation adjacent to all fixture unit notations, the demand in gal/min or liter/sec, corresponding to the various fixture unit loads in accordance with table (wsfu-gpm).
5. Mark on the schematic elevation for appropriate sections of the system, the demand in gal/min or liter/sec for outlets at which demand is deemed continuous, such as outlets for watering gardens irrigating lawn, air-conditioning apparatus refrigeration machines, and others using continuously water. Add the continuous

demand to the demand for intermittently used fixtures and show the total demand at those sections where both types of demand occur.

6. Size all individual fixture supply pipes to water outlets in accordance with the minimum sizes permitted by regulations. Minimum supply pipe sizes are given in Table 1.
7. Size all parts of the water supply system in accordance with velocity limitations recognized as good engineering practice (recommended 4 ft/s).

MATERIALS FOR MAINS, RISERS & BRANCHES

Because hot water is corrosive, circulating pumps must be manufactured with corrosion resistant material. Contributing to the corrosion process is the fact that domestic hot water plumbing is essentially an open system with air and oxygen entrained in water.

The circulator pump must be constructed of non-ferrous materials like bronze, stainless steel or another non-corroding material. Cast iron pumps will generally not last.

Piping Materials:

Traditional piping materials include:

1. Galvanized Iron (G.I.) pipes and fittings, schedule 40 - It is moderately corrosion resistant and suitable for mildly acid water. It is connected to its fitting with threaded connections. It is available in diameters from 12 mm (1/2”) to 300 mm (12”) at a length of 6 meters (20 feet).
2. Polyvinyl chloride (PVC) pipes and fittings, schedule 40 - Its economy and ease of instruction make it popular, especially on low budget projects.
3. Copper Pipes and Tubing
    - Type K- used primarily for underground water service. It is color-coded in green.
    - Type L- is most popular for use in water supply system. It is color-coded in blue.
    - Type M- it has the thinnest wall and is used where water pressure is not too great. It is color-coded in red.

Stringent regulations requiring potable water treatment before distribution can cause water to become more corrosive. Therefore, depending on the water quality, traditional galvanized steel piping or copper tubing may no longer be satisfactory, due to accelerated corrosion. Galvanized steel piping in particular is susceptible to corrosion: a) when hot water is between 140°F and 180°F, and b) where repairs have been made using a copper tube without a nonmetallic coupling.

Common pipe materials in fresh water plumbing systems

Pipe material	**Cold water**	**Hot water**
Copper	Y	Y
Ductile Iron	Y	Y
Galvanized Iron with PVC -C lining	Y	Y
Galvanized Iron with PVC –U/PE lining	Y	N
Polybutylene	Y	Y
Polyethylene	Y	N
Chlorinated Polyvinyal Chloride (PVC –C)	Y	Y
Crosslinked Polyethylene	Y	Y
Stainless steel	Y	Y

Plastic piping used for hot water distribution must be water pressure rated for not less than 100 psi at 180°F. The working pressure rating for certain approved plastic piping materials varies depending on pipe size, schedule and method of joining. Where necessary, one or more pressure reducing valves must be provided to regulate the hot and cold water supply pressure to not more than 80 psi.

Note: Plastic pipe or tube must not be used downstream of instantaneous water heaters, immersion water heaters, or other heaters not having approved temperature safety devices.

Before selecting any water piping material or system, consult the local authority having jurisdiction.

Summarizing….

Correct pipe sizes will ensure adequate flow rates within appliances and avoid problems, such as:

- Oversized Pipework
- Additional and unnecessary installation costs
- Delays in obtaining hot water at outlets
- Increased heat losses from hot water pipes

Undersized Pipework

- Inadequate delivery from outlets
- Variation and fluctuation in temperature and pressure at outlets (e.g. showers and other mixers)
- Increase in noise levels

For small and simple installations, pipes are often sized based on experience and convention.

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PART - 7: HOT WATER TEMPERATURE CONTROL

For domestic use, most plumbing codes require that hot water be stored at a minimum of 140°F (to prevent the growth of Legionella bacteria). It must be tempered with a thermostatic mixing valve at the hot water generator discharge to permit distribution at a temperature range between 120 to 130°F. The maximum hot water temperature distribution design set point must be 120°F.

It is recommended to provide flexibility in the system to increase system temperature for specific applications other than domestic use. For instance, 180°F may be required for a commercial dishwasher rinsing application, or above 130°F for infection control purposes in a medical treatment facility. It is extremely important to note that at this temperature, the exposure time for a first-degree burn is approximately 45 seconds. This is considered an adequate period for a fully aware adult to remove the exposed body area from the stream of a sink or lavatory, thereby maintaining a relatively safe condition at these fixtures without the requirement for an anti-scald valve. Infants or persons desensitized by a medical condition or treatment may be endangered by water at this temperature. At no time should the hot water limit control be set above 210°F. This can cause severe personal injury, death, or substantial property damage if ignored.

Typical temperature requirements for some services are shown below:

Use	***Temperature (°F)***
Lavatory- Hand Washing	105
Lavatory – Shaving	115
Showers and tubs	110
Therapeutic baths	95
Commercial or institutional laundry	Up to 180
Residential dish washing and laundry	140
Surgical Scrubbing	110
Commercial spray type dish washing (wash)	150 minimum
Commercial spray type dish washing (final rinse)	180 to 195

(Source: ASHRAE Applications Handbook, chapter 45, table 3)

MIXED WATER TEMPERATURE CONTROL

As stated above the various plumbing codes require hot water to be stored at a minimum of 140°F, and to prevent injury, the code also requires that the maximum outlet temperature for sanitary fixtures in all new buildings be 120°F. This results in the need to mix cold water into the hot water flow before it reaches the outlet. The expression below determines the relationship of temperature and mix ratio.

$$\text{Ratio \% HW} = \frac{T_{mix}\,(^{\circ}F)\ -\ T_{cw}\,(^{\circ}F)}{T_{hw}(^{\circ}F)\ -\ T_{cw}\,(^{\circ}F)}$$

Where,

- T_{mix} = Mixture Temperature in deg. F
- T_{cw} = Cold Water Temperature in deg. F
- T_{hw} = Hot Water Temperature in deg. F

What percentage of hot water need to mix with cold water to achieve a mix water temperature of 100°F, when hot water temperature is 140°F and cold water temperature is 40°F?

$$\text{Ratio \% HW} = \frac{100\ -\ 40}{140\ -\ 40} = 60\%$$

The most obvious problem concerning temperature stability (say for e.g. showerhead) is the temperature of the entering hot service water and cold/hot water flow changes associated with varying pressure drop in the distribution system. Minor ratio mix changes will cause a mixed water temperature change. The ratio change to temperature change relationship is on the order of 1°F temperature change per 1% flow mix ratio change per side, or 1½% total.

It is apparent that a combined fluctuation of both the HW supply temperature and the flow mix ration can cause significant variation in mix temperature. Fortunately, these are usually not simultaneous occurrences. HW heater temperature control is generally associated with light load demands while the distribution piping pressure drop resulting in flow mix stability problem is associated with high load demands. As one problem increases, the other moderates.

How is Mixing Achieved?

Tempering valves

A standard device for delivering safely cooled water to an outlet is a tempering valve. This device mixes the streams of hot and cold water to provide a cooling effect in the situation that the hot water from the water heater exceeds the desired outlet temperature.

Thermostatic Mixing Valves (TMV)

Thermostatic Mixing Valves (TMVs) also mix the streams of hot and cold water to provide safely cooled hot water, but to greater accuracy than a tempering valve. The temperature sensitive element within the valve reacts to water temperature entering the TMW, automatically adjusting the volume of each stream entering the valve to deliver a stable final temperature. With a reliable fail-safe mechanism, TMVs are often used in hospitals, aged care facilities, child care centers and the like.

TMVs can provide group control or point of use control. Where incorporated into the water distribution system at or near the water heater, they can provide a uniform distribution temperature for all hot water fixtures. For optimum performance, minimization of dead legs is required in a TMV installation.

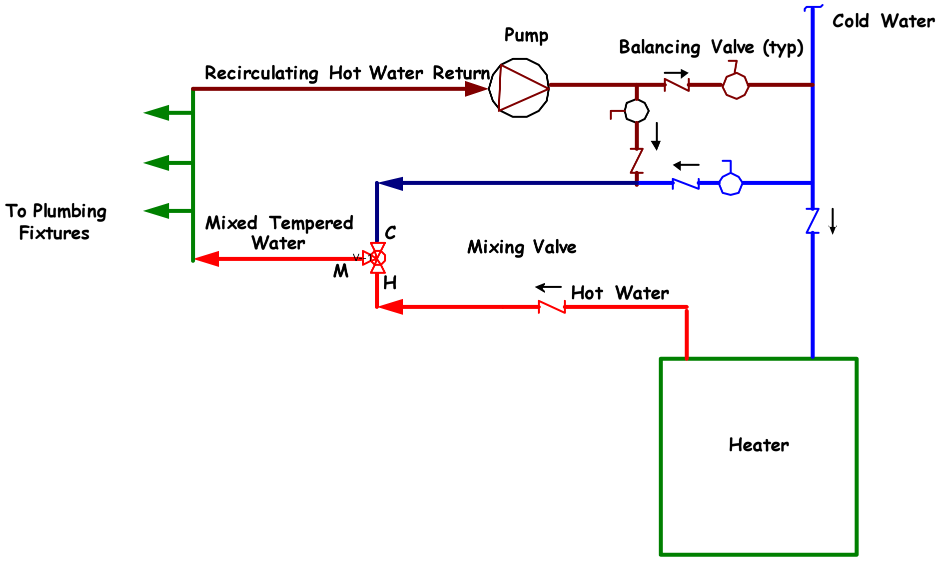
Mixing Configurations

The cooling process and/or supplying appropriate terminal service temperature can be achieved through the use of 3 distinct options:

1. Master Mixing Valve Arrangement
2. Two-Temperature Service Arrangement
3. Local Mixing Valves

Master Mixing Valve Arrangement

The master mixing valve scheme is provided close to the water heater. This ensures tempering of the water (the mixing of hot cold) at the plant room before it is distributed at the point-of-use fixtures. The hot water supplied to the fixtures should not exceed 120°F as prevention for potential scalding. Booster heaters can be provided to obtain the required temperatures of around 180°F for relatively high temperature applications such as dishwashing and pot washing.



Hot Water Recirculation System with Master Mixing Valve

Note the connection of the tempered water return to the water heater. The tempered water return is split and routed to the cold-water side of the mixing valve and to the cold-water inlet of the water heater. A balancing valve should be placed in the line going to the water heater and the mixing valve for flow adjustments if needed. If this is not done, the temperature of the tempered water system will rise to nearly the thermostat setting on the water heater.

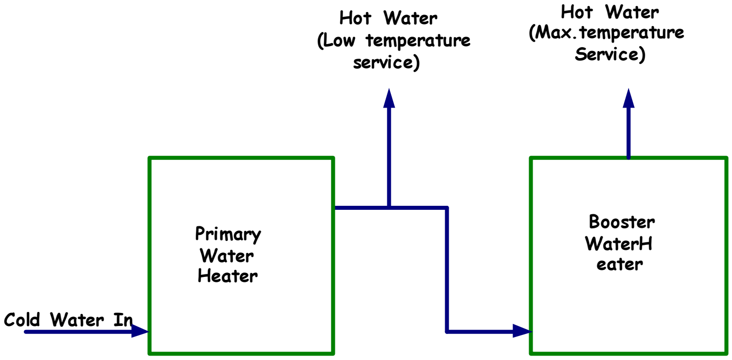
Also, if the hot water return was connected directly to the hot water heater, the mixing valve would open to temper the water. Because there is no flow through the system, cold water would not be able to enter the mixing valve to blend with hot water. Manufacturers refer to this as a “valve hunting for right temperature”. This condition causes fluctuations in temperature and pressure. To correct this problem, the tempered return line must split and be routed to two locations.

There can be flow from both sides of the mixing valve by placing an additional hot water line with appropriate valving to the cold-water side of the mixing valve. Most mixing valve manufacturers require a minimal temperature differential between the hot and cold sides of the mixing valve in order for the valve to function properly. A 20°F differential in the mixing valve setting and the hot water return temperature should be acceptable. ASPE hot water return pump sizing is based on a 20°F range.

The size of the circulator depends on a minimum flow requirement for the tempering valve. The minimum flow rate of the tempering valve must be maintained. If the circulator is too small, the tempering mixing valve performance will be erratic.

Two-Temperature Service Arrangement

When the predominant usage is at lower temperatures, a good engineering approach will be to heat all the water to the lower temperature, and then use a separate booster heater to further heat the water for higher temperature service. Alternatively, two separate heaters can be used: one for low temperature service and the other for high temperature service. Both work independently, but to increase reliability, it is common to cross-connect the heaters with an isolating valve.



**Two-Temperature Service with
Primary Heater & Booster Heater in Service**

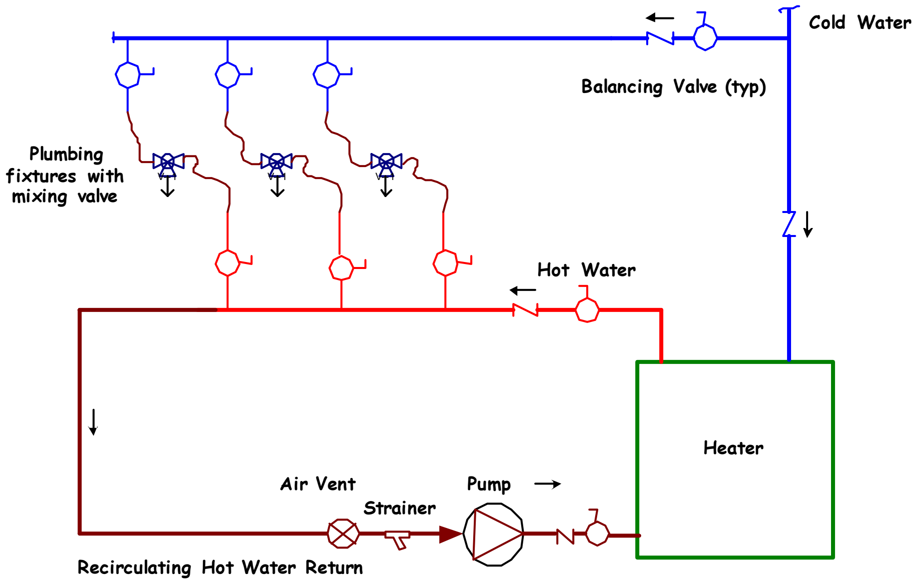
Where the bulk of the hot water is needed at the higher temperature, a lower temperature can be obtained by mixing hot and cold water either centrally, or at the point of use. The local mixing valve arrangement discussed below uses blending at the point of use.

Local Mixing Valves

This scheme is the easiest to install and maintain. It is cost effective because a single pipe can be installed for the hot water temperature out, which then can be mixed down to the various usage temperatures near the point of use fixtures.

The hot water pipe from the water heater is plumbed in a loop, which continues back to the water heater through a third line; the return line. A small pump recirculates the hot water in a continuous loop, shutting off only by the action of a timer or thermostat.

Multiple smaller branches are taken to the point of use fixtures independently and the mixing valve is utilized at the fixture, such as a mixing tap or shower. The theory is that smaller branch lines move water more quickly, thereby shortening the wait for hot water, and consequently using less water to make hot water.



Hot Water Recirculation System with Local Mixing Valve At Point of Use Fixtures

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PART - 8: FACTS, FORMULAS AND GOOD ENGINEERING PRACTICES

Formulas and Facts

1. 1 gallon of water weighs 8.33 lbs
2. 1 gallon of water has a volume of 231 cubic inches
3. 1 cubic foot of water weighs 62.38 lbs and contains 7.48 gallons of water
4. 100 feet of 3/4“ copper pipe contains 2.5 gallons of water; 1” pipe contains 4.3 gallons
5. 8.33 BTU will raise 1 gal of water 1°F at 100% efficiency (electricity)
6. 11 BTUs are required to raise 1 gallon of water 1°F at 70% efficiency (gas)
7. 3,412 BTU equals 1 kilowatt hour (Kwhr)
8. 1 Kwhr will raise 410 gallons of water 1°F at 100% efficiency
9. 1 BTU X 0.293 = watts
10. 1 KW = 1000 watts
11. 2.42 watts are required to raise 1 gallon of water 1°F
    - 1 Kwhr will raise 10.25 gal of water 40 degrees F at 100% efficiency
    - 1 Kwhr will raise 6.8 gal of water 60 degrees F at 100% efficiency
    - 1 Kwhr will raise 5.1 gal of water 80 degrees F at 100% efficiency
    - 1 Kwhr will raise 4.1 gal of water 100 degrees F at 100% efficiency

Formula for mixing hot water

(M-C) / (H-C) = Percent of hot water required to produce desired mixed temperature.

Where,

- M = mixed water temperature;
- C = cold water temperature; and
- H = hot water temperature.

Example:

How much of a shower is hot water and how much is cold water? My shower temperature is 105°F, my water heater thermostat is set on 120°F, and the cold water inlet temperature is 50°F.

(105 – 50) / (120 – 50) = 79% of the shower is 120° hot water. This formula for mixing hot water is important when explaining a "NOT ENOUGH HOT WATER" trouble call and the water heater is functioning properly.

Fahrenheit to Centigrade

(°F - 32) * .556

For example: Convert my water heater thermostat setting of 120°F to Celsius.

(120° - 32) * .556 = (88) * .556 = 49°C

Centigrade to Fahrenheit

(°C * 1.8) + 32

For example: Convert the outside temperature of 49°C to Fahrenheit.

(49° * 1.8) +32 = (88.2) + 32 = 120°F

Costs

Three resources impacted by hot water design:

1. Water
2. Energy used to heat the water (electric, natural gas, etc.)
3. Electricity used for any pumps

In order of costs:

1. Energy used to heat the water and the heat losses are substantial. Depending on the building size and use, this can be worth thousands of dollars per year.
2. Electricity to run the pump –This can be worth a few hundred dollars a year.
3. Water –This also can be worth a few hundred dollars per year.

Estimating Water Heating Costs

Cost = (Gallons per time period) x (8.25) x (temp. rise) x (cost of fuel per sale unit / [(Btu content of fuel per sale unit) x (Heater efficiency)]

For Electric heaters

Cost example of heating 50 gallons of water with electricity:

Cost = (50) x (8.25) x (100) x (.08) / [(3413) x (1)]

Cost = 2062.5 / 3413

Cost = 96 cents based on 100% efficiency, plus demand and fuel adjustment charges if applicable.

Notes

- 8.25 - Weight of gallon of water
- 8.00¢ per kwh assumed
- 1 kW = 3413 Btu/h if applicable. Efficiency = 1 (100%)

Caution - When Using Electricity to Heat Water

The system designer may want to modify the preceding heater recovery and storage tank capacity information when using electricity to heat water.

Electricity is often sold on a demand rate basis, i.e. it has two part billing. This means, in addition to the energy charge used for actual heating (measured in kWh), there is a charge for the demand (measured in kW) that a customer imposes upon the electrical service. The demand charge on kW doesn’t heat water but cost dollars. Your power company will provide and explain rate information upon request.

The presence of a demand rate means the system designer should minimize recovery (heater kW rating) and maximize storage capacity (heater tank size.) Demand charges can greatly increase the cost of using electricity to heat water. Another approach to minimize electric demand is to provide enough hot water storage to allow the elements to be turned off during periods of peak electrical usage. This may be done by installing a timer or through other demand limiting equipment.

How to obtain gallons per hour (GPH) recovery

Electric	**Gas**
WATTS / [2.42 x (temp rise ° F)] I have a 30 gallon electric heater, non-	HOURLY INPUT (BTUs) / [11.0 x (temp rise ° F)]

simultaneous operation, 4500 watt elements. What is the recovery GPH if my cold water is 40°F and my thermostat is set to 120°F? 4500 / [2.42 x (120 - 40)] = 23 gallons per hour	I have a 30 gallon gas heater rated at 40,000 BTUs. What is the recovery GPH if my cold water is 40°F and my thermostat is 120°F? 40,000 / [11.0 x (120 - 40)] = 45 gallons per hour

How to determine temperature rise (ºF)

Electric	**Gas**
WATTS / (2.42 x GPH) I have a 30 gallon electric heater, non-simultaneous operation, 4500 watt elements. What is the maximum temperature rise if the heater can recover 23 gallons per hour? 4500 / (2.42 x 23) = 80 degrees temp rise	HOURLY INPUT (BTUs) / (11.0 x GPH) I have a 30 gallon gas heater rated at 40,000 BTUs. What is the maximum temperature rise if the heater can recover 45 gallons per hour? 40,000 / (11.0 x 45) = 80 degrees temp rise

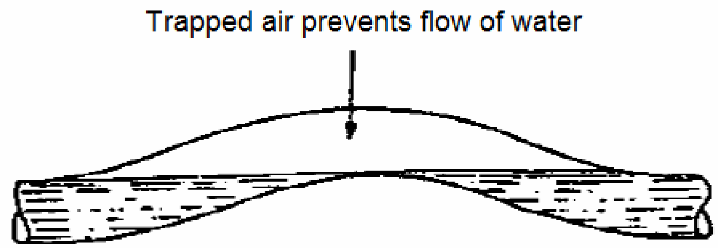
DEFECTS IN HOT WATER SYSTEMS

Generally speaking, most problems in domestic hot water systems are the result of lack of knowledge and appreciation of basic plumbing principles.

Air Locks

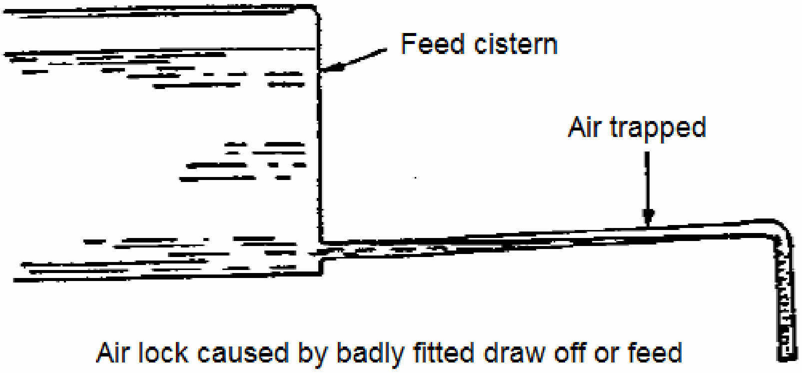
Air locks are a very common cause of trouble with both hot water and heating systems. Most air locks are caused by unventilated arches formed in badly fitted pipework.

An air lock is a small quantity of air trapped in a pipe, which due to the very low circulating pressure available prevents water passing through the pipe. Even when an air lock does not completely stop the flow of water it can reduce the flow considerably. Air locks are very often the results of pipes sagging, or not being laid truly horizontally or to appropriate falls. The figure below shows how an air lock occurs in a pipe run, although they are not always as obvious as this.



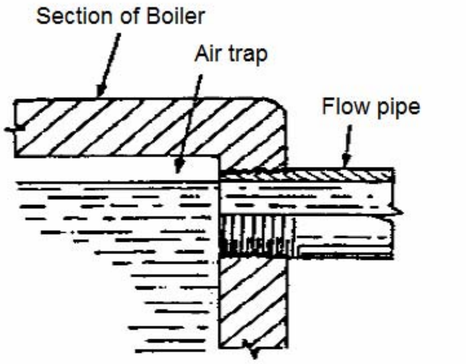
Formation of air lock in pipe run

Another common cause of air locks is where the cold feed, instead of falling away from the cistern, rises causing an unventilated arch in the bend.

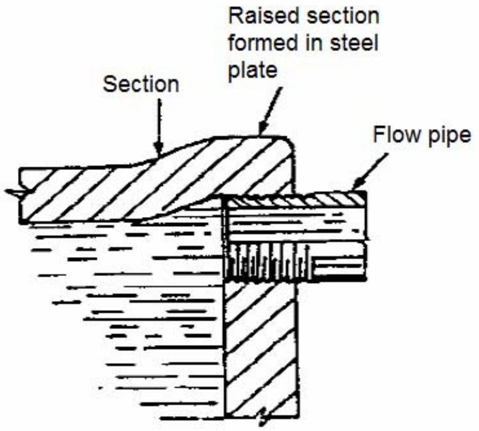


Air lock caused by badly fitted draw off or feed pipes. This is possible the most common cause of air locks in small domestic hot water systems.

Air may also be locked in a boiler due to defective tapings. Boiler manufacturers are aware of this and usually the flow connection is in the position shown in the figure below. Probably the worst effect of defective tapings would be a rather noisy boiler. Care must therefore be exercised when installing boilers and primary circulating pipes to avoid collections of pockets of air.



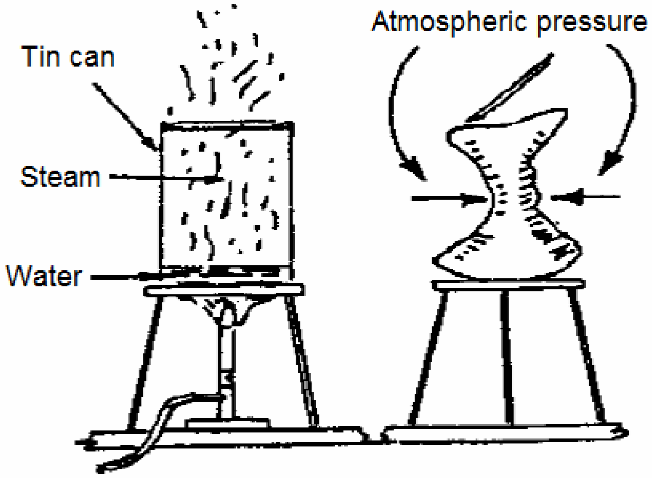
Incorrect: A boiler with flow tapping incorrectly fitted is likely to be the casue of noise.



Correct: Shows how some manufacturers from steel boiler plates to raise soffit of the flow pipe so that no air can be entrapped. With certain types of boilers an air valve may be fitted in the top.

Cylinder Collapse

Cylinder collapse is due to the pressure on the inside of the cylinder becoming less than that of the atmosphere. A simple experiment is shown below, which illustrates quite clearly the effect of atmospheric pressure.



Experiment illustrating cylinder collapse

A small amount of water is put into a can which has a close fitting air tight lid. This lid is removed and the water is heated until it boils and gives off steam. When the source of heat is removed the lid is firmly replaced on the can allowing the contents to cool. When the steam condenses and the air in the can cools, it occupies less space, consequently lowering the pressure inside the can. The atmosphere exerts a pressure of nearly 14.5

psi, and since this pressure will be far greater than inside the can, the walls of the can will be forced inward until the can has been completely deformed.

Various situations can occur whereby similar conditions can arise in hot water storage vessels causing their collapse. In freezing weather, if the vent pipe is exposed and becomes frozen, any expansion of the water will take place via the cold feed pipe to the storage cistern. As the water temperature increases, steam may form, pushing more water back up the cold feed. Should the water in the cold feed pipe freeze, the cylinder now becomes closed to the atmosphere, and a situation now exists similar to that of the tin filled with steam. As the steam in the cylinder condenses, the pressure within drops below that of the atmosphere and the cylinder collapses.

Another cause of cylinder collapse is when a hot water draw off tap at a lower level is opened with both the vent and cold feed frozen. Water will flow from the tap, but as none can enter the cylinder to replace it, a siphon is started. As the water is withdrawn, the pressure inside the cylinder becomes less than that of the atmosphere so the cylinder sides are crushed inwards.

Scale Deposits

Hot water is a complex environment that enhances the existing capability of naturally occurring minerals to cause corrosion, scale deposits and odor problems. These minerals are already present in the cold water supply. When water is heated, it acts differently than cold water.

Heating water causes existing minerals to settle faster and in larger quantities. As the water is heated, it becomes lighter and less dense. The naturally occurring solids, although not visible to the eye, will settle at a faster rate. The result is formation of scale deposits in the circulating pipes and sediment collecting at the bottom of the tank.

Hot water is more corrosive than cold water. Water is a universal solvent and will naturally corrode (or dissolve) most materials. This corrosion is nothing more than a chemical reaction (steel + water + oxygen = rust). Storage tanks fabricated of mild-steel are protected from water corrosion by a lining of one or two layers of spun glass, often called vitreous enamel. The mild steel can also be corroded by forming an electrolytic cell with copper water pipes, which are common. So these tanks have a magnesium rod (called a sacrificial anode) inside them that corrodes first, and which you need to check (and usually replace) at least every five years in order to prevent damage to the tank.

Tank materials

Storage tanks must withstand high water temperatures and pressure, and have to be protected against corrosion.

- Mild-steel tanks are protected from water corrosion by a lining of one or two layers of spun glass, often called vitreous enamel. The mild steel can also be corroded by forming an electrolytic cell with copper water pipes, which are common. So these tanks have a magnesium rod (called a sacrificial anode) inside them that corrodes first, and which you need to check (and usually replace) at least every five years in order to prevent damage to the tank. Mild-steel tanks usually have 5- to 10-year warranties.
- Stainless steel is resistant to water and electrolytic corrosion. Tanks made from stainless steel are more expensive to buy, but generally last longer and don't require as much maintenance as mild-steel tanks. They usually carry a 10-year warranty.

Regardless of the tank material, hot water systems will require ongoing maintenance such as occasional replacement of valves and seals.

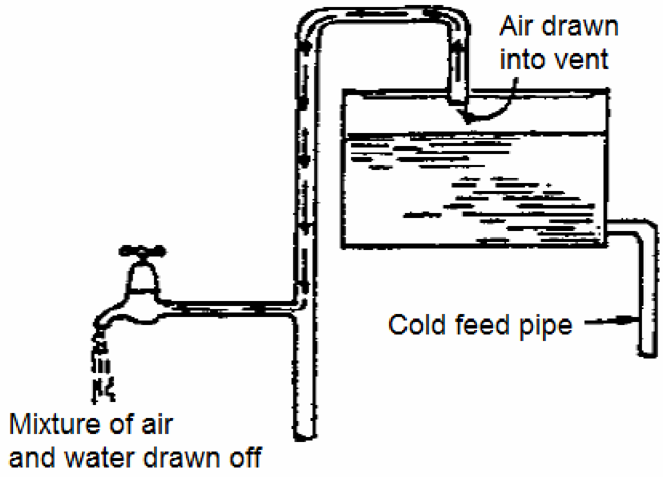
Note: Tank warranties usually only apply if the water quality is within certain limits. For example, depending on the concentration of suspended solids in your water, mild-steel tanks may require different types of anodes, and stainless steel may not be compatible with bore water. Check with the installer whether a particular type of tank is suitable for the water in your area before you buy.

The Importance of the Vent

In domestic plumbing systems the minimum diameter of the vent pipe is ¾ inch, as smaller pipes would be more prone to obstruction. The vent is a very important part of the system. It's main function is to maintain atmospheric conditions in the pipe-work and permit the escape of air which has entered the system, and more rarely in the event of the water becoming overheated, allows it to discharge over the feed cistern.

Another important factor to observe in relation to vent pipes is to make sure they are terminated well above the flood level, not the overflow level, of the storage cistern. If this is not done, should the vent become submerged, cold water could be siphoned out of the cistern when a hot draw off is opened.

It is also very important to ensure that the vent pipe is well insulated and securely fixed. If a draw off connection is taken from too high on the vent pipe, this could result in a mixture of air and water coming from the taps as shown in the figure below. A cold feed of insufficient diameter can also be the cause of this problem.



Effect of fitting hot draw off too high on vent or fitting cold feed of insufficient diameter

GOOD ENGINEERING PRACTICES

The detailing of the hot water system must consider good engineering practices for safety and energy conservation. A few important aspects may be noted:

1. Size both cold and hot water piping to keep the pressure differential minimum at the point of use. Sudden changes in flow at the fixture can cause discomfort and a possible scalding hazard. Use of a pressure compensating device is recommended.
2. Minimize distribution piping pressure drop especially for cold water piping to guard against high-pressure drop changes. Cold-water distribution systems, particularly those with flush valve type fittings, are subject to wide pressure and flow variations.

3. Minimize the pressure drop across the three-way mix valve on the hot water side. A high-pressure drop at a 3-way valve can cause an abrupt flow ratio and thus temperature change at the showerhead.
4. For circulator sizing, a high order of pressure drop should be assigned to the feed lines from the distribution main, or risers to the mix point. The feed line pressure drop will include the feed line tubing itself plus the hot water and cold water manual throttle fixture valves, either individually or in combination as a shower mixing valve.
5. The assigned minimum feed line pressure drop should be on the order of 20 psi (5 psi allowable distribution piping pressure drop) and should be maximized consistent with available pressure, long valve seat and disc life. A shower mix valve shall be specified for a total required shower-head flow rate so as to provide a pressure drop on the order of 20 psi at that flow rate.
6. A shower-head requires a flow rate of 4 gpm at a 15 psi pressure drop for good performance. Given an available static pressure of only 20 psi in the distribution piping at the point of usage, only 5 psi will be available for feed line pressure drop. A minor distribution piping flow change will cause a mixed flow temperature change. As available static pressure decreases, wild mixed flow temperature fluctuations may occur. It is important to provide "a minimum static pressure at the point of usage equal to the shower head requirement flow"; pressure drop need plus satisfactory excess for the feed line needs for flow mix stability.
7. If mixing valves, water blenders or combination fittings are to be used, the cold water supply to these fixtures shall be drawn from the same source that supplies the hot water apparatus in order to provide a balanced pressure and to obviate the risk of scalding, should the supply at the source fail or be restricted for any reason.

Safety Considerations

There have been many reports of exploding or bursting tanks, damage to property, and scalding and injury of persons because of hazardous pressures and temperatures. Standard plumbing equipment, including hot water heaters and storage tanks, are designated for a working pressure of 125 psi. Any pressure in excess of this 125-psi limit can therefore be considered hazardous.

Water expands as it is heated. The increase in its volume for a 100°F temperature rise can be calculated to be 1.68% of its original volume. Since water is considered to be incompressible, the increased volume results in a buildup of pressure. It is absolutely necessary to provide a positive means of relieving this excess pressure. A pressure-relief valve, or a combined pressure and temperature-relief (T&P) valve, satisfactorily meets this requirement. The thermal-relief capacity of the valve can generally be considered equal to or in excess of the temperature rating; in other words, it has the capacity of relieving thermal expansion in the system so long as the heat input does not exceed the rating of the valve.

The temperature-relief valve, or the temperature-relief element of a combined valve, must have a relieving capacity not less than the heat input operating at maximum capacity. The name plate rating on the temperature-relief or combined T&P-relief valve shows the temperature rating in terms of the maximum heater input on which the valve can be used. Separate temperature and pressure-relief valves may be used, but usually a combined T&P-relief valve is preferred because it offers a more economical and yet effective protective procedure.

A relief valve on a water supply system is exposed to many elements that can affect its performance, such as corrosive water that attacks materials and deposits of lime that close up waterways and flow passages. Products of corrosion and lime deposits can cause valves to become inoperative or reduce the valve capacity below that of the heater. For these reasons, the minimum size of a valve should be ¾ of an inch for inlet and outlet connections, with the waterways within the valve of an area not less than the area of the inlet connection.

Relief valves must be installed so there is always free passage between the heater (or tank) and the relief valve. There should never be any valves or check valves installed between the relief valve and the equipment it is protecting.

A pressure-only relief valve can be installed in the cold supply to the tank, in the hot supply from tank, or directly in the heater. The temperature-relief valve or combined T&P-relief valve must always be installed in a position in which the hottest water in the system can come in contact with the temperature actuator or valve thermostat. If this is not done, the valve becomes an ineffective protective device. Wherever possible, the valve should be installed in a tapping in the tank or heater.

Every valve should have a discharge pipe connected to its outlet and terminated at a point where the discharge will cause no damage to property or injury to persons. The discharge pipe size shall be at least the size of the valve discharge outlet, shall be as short as possible, and shall run down to its terminal without sags or traps.

The pressure setting of the valve should be 25 to 30 lbs higher than the system operating pressure to avoid false opening and dripping due to normal pressure surges in the system. The pressure setting, however, must always be less than the maximum working pressure of the material in the system.

An aquastat in the tank or heater (which will shut off the heat source when excessive temperatures develop) is a safety precaution that is strongly recommended and often required by code. It is also referred to as a high-temperature energy cutoff.

Energy Conservation

Hot water delays can be avoided simply through better design of water distribution systems. Shorter pipe lengths, smaller diameter pipes, reduced restrictions to flow and an increased flow rate will all contribute to reducing the time taken for hot water to arrive at a fixture. Designing a water layout to take these factors into account can reduce the waiting time to a point where the need for a circulator is much diminished. The good engineering practices are listed:

1. **Choose the right location -** Installing a hot water system as close to the kitchen or bathroom facilities, or utilities requiring regular hot water, means taps do not have to run cold water out for too long before the hot water comes through. Keeping pipe runs as short as possible can help minimize the heat loss from pipes.
2. **Be efficient by choosing the right fittings -** Install water efficient fittings such as shower-heads and taps. Also the use of flow control valves can help save water.
3. **Insulate effectively -** Insulate hot water pipes between the tank and the taps to help minimize heat loss from the pipes. Synthetic rubber insulation is best for this purpose, covering at least 4-inch thick hot pipes enclosed for at least six feet, and insulating cold water pipes at least 3 feet from the water heater.

4. **Turn off when not in use -** Unless your business relies on hot water flowing 24/7, turn it off when it is not needed for extended periods of time, such as during non-trading periods or holidays. Remember to allow the tank to heat up before turning the hot tap on after you've allowed it to get cold.
5. **Reduce the minimum hot water settings -** The temperature on many water heaters is set at an unnecessarily high level. Check that the thermostat is set at a level that is appropriate for the purpose of hot water use. If the hot water system has an adjustable thermostat, adjust the temperature to provide the minimum hot water temperature required. The optimum water temperature for storage hot water systems is between 140°F and 150°F, in the tank. Instantaneous hot water systems should be set to no more than 120°F.
6. **Be mindful of where to install constant pressure storage tanks -** Constant pressure storage tanks boosted by solid fuel heaters should be installed directly above the solid fuel heater to make full use of the natural rise of the heated water to supply the tank.
7. **Know when to turn the water heater off -** Turning off the hot water systems and circulating pumps at night and on weekends prevents unnecessary water heating and saves money on the associated energy costs. Adding a timer to electric water heating units to automatically turn the system on and off, depending on when hot water is required, makes this process even simpler.
8. **Heaters -** Where certain water heaters are dedicated to specific tasks, rather than heating water needlessly, switch these units on only when needed.
9. **Insulate the source -** Insulate hot water storage tanks and shelter them from the weather. This will help reduce heat loss from the hot water system.
10. **Check for leaks -** Ensure the entire hot water system is checked regularly and that leaks are repaired immediately. Fix dripping hot water taps and replace any leaking plugs.
11. **Ensure regular maintenance -** Gas water heater burners should be cleaned and tested periodically to make sure that the fuel is being burned as efficiently as possible. Have the hot water system installed by a registered plumber and electrician, perform regular maintenance, and ensure it is serviced according to

the manufacturer’s instructions to maintain the efficiency and longevity of the system.

12. **Position solar panels to extract the most energy from the sun -** If you have solar panels, face the solar collectors of solar hot water systems due north, in full sun and positioned at the correct angle.

13. **Recirculation Systems -** Although recirculation loops save water, they are high on energy consumption. Recirculation systems typically run 24 hours per day and therefore must be controlled. The following options may be considered:

    - Time Clocks – They are a non-sustainable solution, as they run the pump too much when they are ‘ON’ creating unnecessary heat losses, and run the pump too little when they are ‘OFF’ creating unnecessary water waste.

    - Temp Regulators – They turn the pump off when there is already hot water in the pipes. (They will continue to run the pump during periods of no demand to keep the pipes constantly hot.) Although the pump uses less electricity, they keep the distribution hot, thus creating the same heat losses as a continuous pump. They are better than time clocks but not the best.

    - Time/Temp – They are a combination of a time clock and a temperature regulator. (They will run the pump as needed to keep pipes hot only during the "on" period.) Although they are better than individual timers or temp regulators, they still have the combination of the same problems, making them only semi-sustainable.

    Controlled recirculation is always better than no recirculation or continuous recirculation.

<u>Long Term</u>

1. **Go Solar -** Installing and using solar water over other types of systems can be an efficient solution because solar systems harness energy from the sun. This is a proven technology that in the right environment can supply most of a business’ hot water needs, or if used in conjunction with a conventional hot water system, it will reduce the costs for many small businesses with large water-heating needs.

2. **Install an Electric Heat Pump -** Heat pump-type hot water systems extract warmth from the air to heat water. These are currently the most energy efficient type of electric hot water system and some are estimated to be 65 percent more energy efficient than storage-type electric hot water systems.
3. **Buy a new system with a high Star Rating -** Purchasing a new gas or solar hot water heater with an Energy Rating label is a good way to achieve energy efficiency savings. Similarly, when purchasing equipment that uses hot water, choose energy efficient models. While the initial outlay on more efficient systems may be higher, typically the more stars; the more energy efficient the unit and potentially lower running costs and the lower the greenhouse gas emissions.
4. **Go for gas -** Gas systems typically produce less greenhouse gas emissions and maybe cheaper to operate than electric systems.
5. **Install dedicated units -** If different parts of your business require significantly different water temperature, it may be more efficient to install separate heaters for high temperature and low temperature areas. This will save unnecessary heating costs associated with needlessly heating large quantities of water to higher temperatures than required.
6. **Choose the right size of unit -** When selecting the size of the water heating units; consider the maximum number of hot water outlets likely to be in use simultaneously. Ideally go with a capacity that will meet demand without wasting energy, heating excessive amounts of water.
7. **Relocate the water heater -** Relocating the water heater as close as possible to the main point of use of the hot water may see significant efficiency savings by reducing heat loss from pipes and by minimizing the length of hot water pipes that transport the water from the heater. This may mean a reduction in the temperature needed to heat the water before it reaches its point of use.
8. **Buy water efficient appliances -** When purchasing equipment such as dishwashers or washing machines that require a hot water connection, make sure these have a high water efficiency rating.

Cost Benefits

The above mentioned actions can result in significant cost benefits:

- lower running costs and associated energy expenditure;
- reduced maintenance costs on equipment; and
- a longer lifespan for hot water system equipment.

Environmental Benefits

The associated environmental benefits may include:

- water savings;
- less emissions, including greenhouse gases; and
- resource conservation through increasing the lifespan of existing hot water system devices, equipment and appliances with regular maintenance, repairs and improvements.

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PART - 9: REGULATORY STANDARDS AND CODES

USA

In the United States, plumbing regulations follow different codes on a state-by-state basis. The majority of the states refer to one of four codes:

1. International Plumbing Code (IPC)
2. Uniform Plumbing Code (UPC)
3. National Standard Plumbing Code (NSPC)
4. Standard Plumbing Code (SPC)

Most adopt these codes with some variations, although some states have codes entirely of their own. The IPC and NSPC include a requirement for ‘temperature maintenance’ when the distance from the water heater to the furthest hot water fixture exceeds 100 feet, without specifying conditions on the form this maintenance is to take. Other common standards include:

- ANSI Z21.10.1 - The testing and safety standards which govern all residential gas fired water heaters up to 100-gallon capacity and up to 75,000 BTU's.
- ASHRAE - An association which recommends standards and test methods used today, primarily for commercial water heaters. Prior to the NAECA law which now governs residential water heaters, the ASHRAE Standard 90A-1980 was used as a standard for high efficiency water heaters. While no longer applicable, residential water heaters continue to meet this standard.
- ASME (American Society of Mechanical Engineers) - May be required on commercial water heaters over 120 gallons or over 200,000 BTUs. The ASME code is generally adopted on a state-by-state basis.
- D.O.E. (Department of Energy) - Regulates the efficiency standards of all residential gas and electric water heaters with capacities from 20 to 120 gallons and inputs up to 75,000 BTU. The current NAECA standards are administered by the Department of Energy which is required to review and recommend changes to the efficiency standards.
- NAECA - National Appliance Energy Conservation Act of 1987 - The Federal Law enacted by Congress which sets minimum energy efficiency standards for

residential water heaters and other products. Effective with water heaters produced on or after January 1, 1990. NAECA supersedes all previous state and local energy efficiency requirements.

- SCAQMD (South Coast Air Quality Management District) - Required by the Environmental Protection Agency to limit the amount of nitrous oxide (Nox) emissions from residential natural gas water heaters up to 75,000 BTU. The SCAQMD requirements are enforced in various areas of California.

Some cities within the U.S. also have their own plumbing codes. The city of Fontana, California has amended its plumbing code to require that: “all dwelling units shall be provided with an approved recirculating hot water system, and all hot water piping connected to that system must be insulated with a minimum of R-3 [R0.6 in SI units] insulation around the piping material, throughout the recirculating hot water system." (Industrial News, 2006)

Other cities have incorporated water recirculation requirements into local building standards and guidelines.

Energy Efficiency Standards

Oceanside, California, Reno/Sparks, Nevada, and the State of Massachusetts are just some of the localities that now require hot water recirculation systems on all new construction. Cambria, California mandates hot water recirculation pumps for all new construction and existing homes. Other localities across California, Arizona, New Mexico and Texas are in the planning phase of implementing hot water recirculation programs.

Changes within California are occurring as a result of that State’s Energy Efficiency Standards for Residential and Non-residential Buildings. The California Energy Commission has, since 1978, produced Energy Efficiency Standards for residential and non-residential buildings. The 2005 Standards incorporate a Residential Compliance Manual which details requirements on hot water systems incorporating circulator pumps. Such requirements include:

- that recirculating sections of domestic hot water systems must be insulated (the entire length of piping, whether buried or exposed);

- that recirculating systems serving multiple dwelling units must have controls (e.g. timer controls, time and temperature controls) to turn off the pumps when hot water is not needed;
- that continuous recirculation systems must be laid out to within 8 ft of all hot water fixtures served by the recirculating loop;
- that 'temperature control' recirculation systems must have an automatic thermostatic control installed to cycle the pump on or off;
- that 'timer control' systems have a permanently installed timer, permitting the pump to be off for at least eight hours per day; and
- that 'demand control' systems must have an automatic shut off either by a temperature sensing device or a limited run time.

These definitions allow for clarity in determining compliance with particular energy efficiency 'packages' detailed in the document. They do not place restrictions on the performance or efficiency of any one device. The Non-residential Compliance Manual has no requirements regarding hot water circulation.

Other standards

CE Marking

CE marking indicates that a product has met all the essential requirements of the relevant European Directive. At present, European Directive 88/378/EEC outlines the efficiency requirements of hot-water boilers, but there is no explicit directive for hot water circulator pumps.

EU Energy Labeling

This is a Europe-wide labeling system that aims at communicating information about the relative efficiency performance of different appliances to consumers, retailers and manufacturers mainly through the use of a categorical efficiency scale. EU Energy labeling is not yet extended to circulator pumps, but the four main manufacturers (80% of the European market) and Europump (the European pump association) have made a self-commitment to EU-style labeling. This labeling is based on the European Directive 98/11/EC with regard to the energy labeling of household lamps.

The Europump labeling scheme allows for energy classes from A to G, and has been created to focus on energy saving potential in appliances. While it is voluntary, signatories to the agreement are subject to sanctions or exclusion from the scheme upon non-compliance and the scheme is open to all pump manufacturers. This energy efficiency labeling is aimed mainly at circulator pumps used in heating and cooling European houses. These pumps are expected to run continuously, which means that energy efficiency can be determined independently of end use. The Europump labelling is not currently applied to dedicated hot water circulation pump models.

Japan – Energy Saving Labeling Program and Top Runner

In line with the 'Law Concerning the Promotion of Procurement of Eco-friendly Goods and Services by the State and Other Entities', Japan has introduced the Top Runner Program. This program sets efficiency targets within product categories for manufacturers and importers, rather than individual products. The labeling program associated with Top Runner is known as the Energy Saving Labeling Program (ESLP). ESLP labels inform the consumer as to whether a product has achieved or exceeded the target energy efficiency set for the category. At present, this labeling program is voluntary and not applicable to circulator pumps, although certain water heaters are included.

Sustainable housing guidelines

Various countries have introduced voluntary and/or mandatory sustainable housing guidelines, some of which are detailed below.

LEED

Leadership in Energy and Environmental Design (LEED) is a voluntary rating system initiated by the U.S. Green Building Council, but which has been adopted also in international projects across 41 countries. LEED provides rating systems for new construction for many project types including commercial, renovation, neighborhood development and homes. LEED provides a checklist of 'green' building features available under different areas, such as energy efficiency, health and safety, and material resource efficiency. Features provide the building with a certain number of points, with specified levels to achieve ratings such as 'gold' or 'silver'. Options for water heating include pipe insulation, efficient hot water heaters, and smart plumbing incorporating a hot water circulation loop.

BREEAM

In England, the Code for Sustainable Homes and Eco-homes are mandatory environmental assessment methods produced by the Building Research Establishment Environmental Assessment Method (BREEAM) to rate new and refurbished homes respectively. Eco-homes is used for all housing in Scotland and Wales. These codes are designed to calculate the emissions from energy for hot water systems, and focus primarily on the efficiency of fixtures and appliances, with no mention of hot water circulation.

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Summary

It has been established that a significant amount of water is lost during the wait for hot water at a household fixture. This delay is due to water cooling in the pipes, and the length of the delay is dependent on the layout and insulation of the distribution system, as well as the power and efficiency of the water heater. The installation of hot water circulators is, therefore, one important component that ensures hot water in the line and minimizes wasted water.

Hot water circulators can be used in a circulation system in a variety of ways. They can be run in a continuous, regulated, or on demand system. These systems are defined by their additional components (thermostatic sensors, timers and activation switches, etc.) and differ largely on the length of time the circulator pump is in operation each day. The behavior of the end user can influence the choice of an appropriate system, comparing the consistently immediate hot water of a continuous system with the activated (and therefore delayed) hot water of an on demand system.

For a detailed study of the subject, refer to:

- Chapter 4, 1989 edition, of the ASPE Data Book for pumped recirculation systems; and
- Chapter 45, 1995 edition, of the ASHRAE Handbook for pumped recirculation systems and electric heat traced systems.