PDHonline Course M151 (3 PDH)

Hot Water Plumbing Systems

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2020

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Hot Water Plumbing Systems

Course Content

PART 1 Estimating Hot Water Demand

Plumbing service design practice may be regarded as an art rather than a science. Hot water demand varies with the type of establishment, usage, occupancy, fixture types, time of day and host of other factors. The system should be capable of meeting peak demand at an acceptable efficiency levels.

For small domestic applications the estimate can be found by applying standard rule of thumbs.

How much hot water do you need?

Domestic hot water use varies widely depending upon a number of factors including how many people live in your home and the age of those people.

To make your choice easier, just ask yourself the following questions:

- How many people are there in your family?
- How many bathrooms do you have?
- How many appliances such as washing machines, dishwashers etc require hot water?
- Do you have a pool or spa?
- Do you have many visitors staying in your home?
- Are there teenagers in the family? (They tend to use more water)

Hot water demand varies with each individual living habit, but 15-20 gallon per person per day is a conservative estimate.

DOMESTIC HOT WATER USE

Three primary usage of hot water in domestic needs is in bathroom, kitchen and laundry.

Bathroom

Typically most hot water is used in the bathroom. The amount of hot water you consume will depend on whether you prefer to take showers or baths.

If you take showers, you can calculate the amount of total water you use by multiplying the running time of your shower by the flow rate of the showerhead.

Total water use =running time x flow rate of showerhead

Showerhead flow rates can vary between 1.5 and 7gpm. A standard showerhead can deliver up to 7gpm (70 gallons for a 10 minute shower) while a low-flow showerhead typically averages a delivery rate of 1.5 to 4gpm (15-40 gallons for a 10 minute shower). The best way to determine your showerhead flow rate is to time how long it takes to fill a container of known volume, such as a 5 liter bucket. The following equation will help you to calculate the flow rate (liters per minute):

Flow rate = (60 seconds ÷seconds taken to fill container) x container volume in liters

For example, if a 5-liter bucket takes 40 seconds to fill, then the flow rate is equal to 7.5 liters per minute (~2gpm) (60 seconds ÷40 seconds x 5 liters).

Remember to consider your future needs when estimating your hot water consumption.

A hot water system will last you a number of years so you will need to consider any possible changes to your household in the future. Younger children grow up to become teenagers who have a tendency to take longer showers

Once you've multiplied the flow rate of the showerhead by the shower running time, you need to multiply the result by the ratio of hot water to cold water used to determine your total hot water use. Generally, hot water is mixed with around 30-40%cold water in the shower.

Total hot water use =total water used x hot water mix (60%-70%)

A low flow showerhead with a flow rate of 2.5gpm during a 10-minute shower will use 25 gallons of water. With a hot water mix of 70%, the total hot water use is 17.5 gallons (25 x 0.7).

If you take baths, you can calculate your hot water use by multiplying the total volume of water required to fill the bath by the hot water mix. If your bath takes 25 gallons of water to fill (which is about average), it will require about 15 to 17.5 gallons of hot water (based on a cold water mix of 30%-40%).

Spa baths typically take ~ 65 to 90 gallons of water to fill and will therefore require a larger volume of hot water.

Some spa baths and larger spa pools are connected to a cold-water tap and heat their own water. If this is the case, their hot water consumption does not need to be taken into account when sizing your hot water system, as they do not place a demand on your hot water system.

Laundry

The laundry is another room that places a demand on your hot water system.

A standard warm wash cycle typically uses ~ 8 to 13 gallons of hot water per wash. You can save on hot water use by washing clothes in cold water or using a front-loading machine if you still need to wash clothes in hot water. Front-loading machines generally use much less water than top loading machines.

Kitchen

The amount of hot water you use in the kitchen will vary depending upon whether you have a dishwasher and if so, how it is set up. Most dishwashers are connected to the cold-water tap and use an electric element inside the dishwasher to heat the water. If this is the case, they will place a demand on your electricity bills and not on your hot water system.

If your dishwasher does have a hot water connection, it will consume between 3 and 25 gallons of hot water per wash and, therefore needs to be taken into consideration when sizing your hot water system. Proper flow pressure must be maintained to achieve efficient dishwashing. National Sanitation Foundation (NSF) standards for dishwasher water flow pressures are 15-psig minimum, 25-psig maximum and 20-psig ideal. Flow pressure is the line pressure measured when water is flowing through the rinse arms of the dishwasher. A pressure regulator (set at 20 psig) should be installed in the supply water line adjacent to the dishwasher and external to the return-circulating loop, if used. To find out which type of dishwasher you have and how much water it uses, simply consult the operating instructions.

Typical Residential Usage of Hot Water per Task

Use	High Flow (gal)	Low Flow (gal) when water savers used
Food Preparation	5	3
Hand dish washing	4	4
Automatic dishwasher	15	15
Clothes washer	32	21
Shower or bath	20	15
Face and hand washing	4	2

(Source ASHRAE Application Handbook, Chapter 45, table 4)

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, Uniform Plumbing Code (UPC) and American Society of Plumbing Engineers (ASPE) handbooks. All these criterions focus on the use of probability theory to compensate for unknowns. The required flow rates are defined based on “Fixture Unit Count” method, which takes into consideration people use factors, people socio-economic factors, facility types, fixture types and host of other factors. This method permits the tabulation of total fixture units by summing individual fixture demands. The water demand can than be estimated from a fixture unit-water demand curve.

Table-1 below provides a list of representative fixtures.

TABLE – 1
Demand weights of plumbing items in ‘Fixture Unit’

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*
Bathroom Group (Flush valve)	*Private*	*8*	*8.25*	*2.25*
Bathroom Group (Flush tank)	*Private*	*6*	*5.25*	*2.25*
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	*Private*	*3*	*2-1/4*	*2-1/4*

Fixture or Group	Occupancy	Total Building Supply HW & CW	Cold Water (CW) only	Hot Water (HW) only
(Faucet)				
Washer	*Private*	*4*	*3*	*3*

(Source: National Bureau of Standard Reports: BMS79 by R. B. Hunter. Another source of information is available in chapter 45, ASHRAE Applications Handbook, Table-1 that provides information on the fixture unit's facility wise for apartments, club, gymnasium, hospital, hotels, industrial plant, office building, school etc. The above table is generic and can be conceptually applied to any application)

From the tabulated fixture units as shown above, the designer can assign fixture unit values to the specific fixtures of concern in his design. The sum total of fixture units is total fixture unit count.

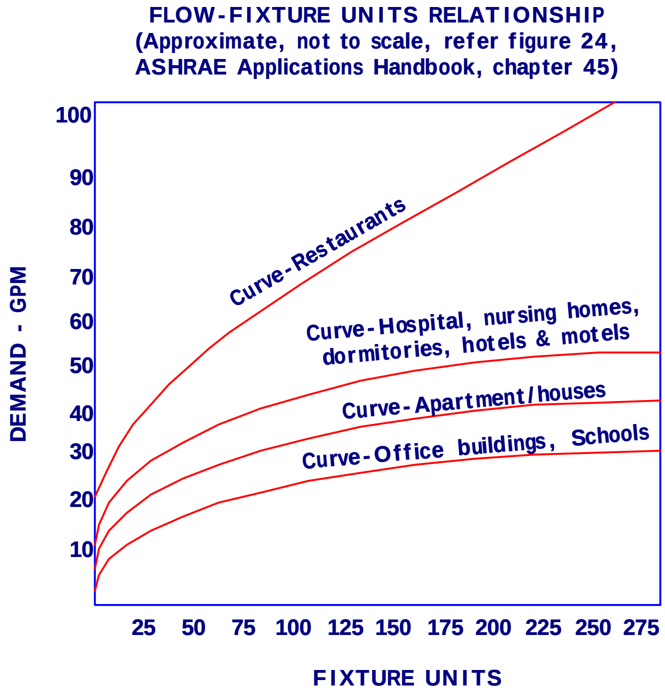
Both hot and cold service water will be needed inside the building. *As a rule, separate hot and cold-water demand can be taken as ¾ the total shown.*

Note: The fixture unit count method could be applied to any of the residential or non-residential demand.

Fixture Unit – Flow Relationship

Once the total fixture count is obtained, the next step is to co-relate this to the probable flow.

It is well known that as the number of fixtures increases the probability of simultaneous use decreases. Flow probability, as a function of fixture unit count shall vary with type of facility and depends on time usage and other specific requirements. The figure below shows the probability of flow as a function of fixture unit count.



Service water distribution pipe flow rate can be related to the fixture count served by any branch or main section of piping. In practice, the engineer counts fixtures from the circuit end, totaling fixture units as he proceeds to the circuit start. Each piping section then serves a stated number of fixture units, which is related to the flow requirement as in figure above. This method shall be used for sizing instantaneous/ semi-instantaneous water heaters and also the pipe sizing.

The minimum recommended size for semi-instantaneous heater is 10gpm, except for restaurants, which require 15gpm. While the fixture count method bases heater size on hot water flow, hot water piping should be sized for the full flow to the fixtures for every branch.

ASHARE applications handbook, chapter 45, table 9 (replicated below) provides hot water demand per fixture directly. This is a simplified approach that saves designer's effort of first estimating the fixture units and than estimating flow against the fixture units as explained above.

TABLE- 2

(Hot water demand in gallons per hour GPH per fixture @ 140°F)

Fixture Type	Apartment	Club	Gym	Hospital	Hotel	Industry	Office	School
Basin (private)	2	2	2	2	2	2	2	2
Basin (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	-	-	-	-
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	0.30	0.3	0.4	0.25	0.25	0.4	0.3	0.4
Storage Capacity Factor	1.25	0.9	1.0	0.60	0.80	1.0	2.0	1.0

(Source: ASHRAE Applications Handbook, 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.

Estimating Plumbing Fixtures

Plumbing fixtures specifications conform generally to American Society of Mechanical Engineers, ASME standards series A112 or International Association of Plumbing and Mechanical Officials; IAMPO standards series Z124.

Most of the information on the quantity and type of plumbing fixtures is available from the building lead usually an architect. While conceptualizing, it is possible that the exact information on the fixture quantity may not be available. In absence of preliminary information, the minimum number of plumbing facilities can be estimated from the table 403.1 of International Plumbing Code (IPC). The table is replicated below and the fixtures shown are based on one fixture being the minimum required for the number of persons indicated. The number of occupants could be determined by the building code.

TABLE -3

(Minimum number of plumbing fixtures)

Occupancy		Water Closets		Lavatories	Bathtub/ Showers	Drinking Fountain	Others
		Male	Female				
ASSEMBL	Theaters	1 per 125	1 per 65	1 per 200	-	1 per 1000	1 service sink
	Nightclubs	1 per 40	1 per 40	1 per 75	-	1 per 500	1 service sink
	Restaurants	1 per 75	1 per 75	1 per 200	-	1 per 500	1 service sink
	Halls/ Museums	1 per 125	1 per 65	1 per 200	-	1 per 1000	1 service sink
	Churches	1 per 150	1 per 75	1 per 200	-	1 per 1000	1 service sink

Occupancy		Water Closets		Lavatories	Bathtub/ Showers	Drinking Fountain	Others
		Male	Female				
Y	Stadiums	1 per 100	1 per 50	1 per 150	-	1 per 1000	1 service sink
Educational		1 per 50		1 per 50		1 per 100	1 service sink
Factory& Industrial		1 per 100		1 per 100		1 per 400	1 service sink
High Hazard		1 per 100		1 per 100		1 per 1000	1 service sink
INSTITUTIONAL	Residential Care	1 per 10		1 per 10	1 per 8	1 per 100	1 service sink
INSTITUTIONAL	Hospitals, ambulatory nursing home patients	1 per room		1 per room	1 per 15	1 per 100	1 service sink per floor
INSTITUTIONAL	Day nurseries, Sanitariums, nursing homes	1 per 15		1 per 15	1 per 15	1 per 100	1 service sink
INSTITUTIONAL	Employees other than residential care	1 per 25		1 per 35	-	1 per 100	-
INSTITUTIONAL	Visitors other than residential care	1 per 75		1 per 100	-	1 per 500	-
INSTITUTIONAL	Prisons	1 per cell		1 per cell	1 per 15	1 per 100	1 service sink
INSTITUTIONAL	Asylums, reformatories	1 per 15		1 per 15	1 per 15	1 per 100	1 service sink
Mercantile		1 per 500		1 per 750	-	1 per 1000	1 service sink
RES.	Hotel, motels	1 per room		1 per room	1 per room		1 service sink
RES.	Lodges	1 per 10		1 per 10	1 per 8	1 per 100	1 service sink
RES.	Multiple families	1 per dwelling unit		1 per dwelling unit	1 per dwelling unit		1 service sink & 1clothes washer per 20 dwelling units
RES.	Dormitories	1 per 10		1 per 10	1 per 8	1 per 100	1 service sink
RES.	One or two family dwellings	1 per dwelling unit		1 per dwelling unit	1 per dwelling unit		1 service sink & 1clothes washer per 20 dwelling units
Storage		1 per 100		1 per 100	-	1 per 1000	1 service sink

(Source: Table 403.1, International Plumbing Code)

Alternatively for preliminary design use table below to make an estimate:

Type of Building	***Fixture Units***
Hospital or nursing home	*2.5 per bed*
Hotel or motel	*2.5 per room*
Office building	*0.15 per person*
Elementary School	*0.30 per student + shower load*
Apartment House	*3.0 per apartment*

(Source: ASHRAE Applications Handbook, chapter 45, Table 14)

HEATER & STORAGE SIZING

Methods for sizing hot water demand and heaters vary. Other than the fixture unit method discussed above, another straightforward method of sizing hot water system for large commercial and institutional applications such as hotels, motels, hospitals, nursing homes, office buildings, food service establishments etc is based on generic curves of "recovery rate v/s usable storage capacity". These curves provide a straight relationship for example for hot water demand based on the number of beds in hospitals or hot water demand based on number of students in the school. These curves are provided in the ASHARE applications handbook, chapter 45.

Let's consider an example of a medical facility to illustrate the concept of 'fixture count' and 'number of beds' procedure. The later should be applied during preliminary stage and should be detailed out based on fixture count method. Note that the data available in various handbooks is generic. No facility is alike; for instance a 100-bed hospital or 100-room hotel may be categorized in 3-star, 5-star or 7-star category each offering different level of luxuries and equipment. There may be certain specific design features for each facility that must be accounted for in your design. Some of these are listed below and must be carefully evaluated when applying safety margins or demand factors. The best way to capture the specific conditions is to take a reference historic data from an already running facility and applying sound judgment.

HOSPITALS & NURSING HOMES

For hospitals and nursing homes, the hot water is required for

- Tubs & showers
- Wash basing
- Kitchen equipment

- Food service to the patients and pantry service for guests
- Laundry service

As a preliminary estimate, some designers use a rule of thumb of 125 gallons of 140ºF water per bed per day as basis for the hot water requirement.

The detailed design must consider the record of all fixtures (fixture unit method) to estimate the hot water requirements.

Method of Sizing

1) Determine the number of fixtures required for the application and calculate the total hot water demand for those fixtures.

   Number of Fixtures x Gallons of Water per Hour per Fixture = Possible Maximum Demand

2) Determine the Probable Hot Water Demand for the application.

   Probable Hot Water Demand = Possible Maximum Demand x 0.25 (refer to the explanation of the example below; higher demand factor shall increase the heater size and lowers the storage volume)

Fixture Unit Basis:

Consider an example of a small medical facility with the following fixture schedule:

Item	Quantity	Flow per number (gph)	Total Flow
Clinic Sinks	12	4	48
Plaster Sink	1	10	10
Public Lavatories	8	6	48
Clinic Lavatories	12	8	96
Mop Service Basins	2	20	40
Arm Whirlpool Bath	1	35	35
Leg Whirlpool Bath	1	100	100
Foot Whirlpool Bath	1	15	15
X-Ray Film Processor	1	15	15
Possible Maximum Demand			407

Using the Demand Factor of 0.40 yields

Probable Maximum Demand = *Possible* Maximum Demand X Demand Factor

Or recovery rate or heater capacity = 407gph X 0.40

= 162.8gph

The storage capacity factor of 1.00 is applied to this recovery rate or heater capacity to determine the

Storage Tank Capacity = Heater Capacity X Storage Capacity Factor

= 162.8 X 1.00

= 162.8 gal

Explanation of Example:

1) A Demand Factor is applied to the *Possible* Maximum Demand to calculate the *Probable* Maximum Demand. *The Probable Maximum Demand is the rate at which the heater shall generate hot water and is also termed as the recovery rate.* The high demand factor shall mean higher recovery rate or heater size. The economical demand factors are shown in Table 2 above but could be varied on designer's analysis of historical data for similar projects, experience and discretion.

   Why 0.40 demand factor?

   The Demand Factor and Storage Capacity Factor are listed in Table-2, column 19; which provides information on various building types. The table includes hospital but not medical clinic, dental clinic, nor laboratory. A Demand Factor of 0.40 and Storage Capacity Factor of 1.00 are considered representative of a clinic upon review of similar data and the factors for the other building types shown.

2) The 'Probable Maximum Demand' is factored by the 'Storage Capacity Factor' to determine the 'Storage Tank Capacity'. The storage tank capacity is the capacity available for use and could be reduced for steam heating system provided an unlimited supply of steam is available for heating. Storage tanks are not considered to be 100% usable and thus, a usable storage tank factor shall be applied to the calculated storage tank capacity. The percent capacity considered usable for most tanks is 70%, thereby resulting is a 1.43 usable storage tank factor. The usable storage tank factor for systems utilizing instantaneous generators or multiple tank arrangements shall be coordinated with the design agency.

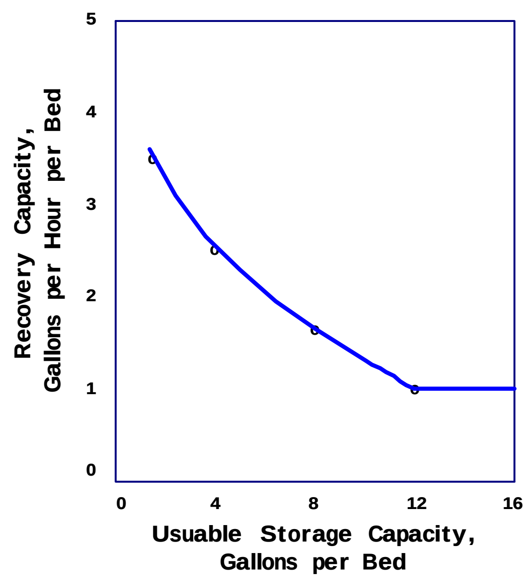
Relationship between recovery and storage capacity

The recovery rate represents the amount of water the system can heat (to a specific "temperature rise") in one hour. The storage capacity describes the hot water volume or the tank size.

With storage system it is possible to select the bigger or smaller storage capacity by varying the recovery rate. Typically with minimum recovery rate (heater capacity), the storage volume shall be maximum. The key to proper sizing is to achieve the proper balance between usable stored water in the tank and the recovery rate.

Note that the storage tank can only provide 70% to 80% of its stored water as useable water in one hour. So, we'll get a portion of the hot water demand from storage during our peak period, leaving the balance needed to come from the system's recovery capacity. Finally, after the peak period is over, we'll have to reheat the gallons drawn from storage to restore the unit to full capacity

There are set of curves available in ASHARE Applications Handbook (figure 15 through 22) showing relationships between recovery and storage capacity for the various building categories. For nursing home the curve (figure 17 of ASHARE) is replicated below:



(NURSING HOMES)

The end user can select among the numerous combinations of recovery rate and usable storage capacity for his design. Any combination of storage and recovery rates that fall on the proper curve will satisfy the building requirements.

The recovery rate is specified in gallons per hours (gph) while the storage capacity is estimated in gallons per person/unit. Check the relationship in the example below, which is, based straight on number of beds.

Determine the required water heater size for a 300-bed nursing home for the following criteria:

a. Storage system with minimum recovery rate

b. Storage system with recovery rate of 2.5 gph per bed

From the figure shown above, the minimum recovery rate is 1.25gph per bed or 375gph total. At this rate, storage required is 12 gal per bed or 3600 gal total. On a 70% net usable basis, the necessary tank size is 3600/0.7 = 5150 gal.

For the second part, the curve shows that for 2.5gph recovery rate per bed, the storage requirement shall be 4 gal per bed. This implies 4 x 300 = 1200 gal storage with recovery of 2.5 x 300 = 750gph. The effective tank size shall be 1200/0.7 = 2150 gal.

Notes to Consider:

- The fixture-unit method is conservative design approach for typical usage. It should be noted that this method may lead to a system that is oversized if there is a high percentage of bedridden patients. Since bedridden patients do not use the volume of water for cleaning purposes such as ambulatory patients, it is recommended to use a suitable demand diversity factor on such special applications.
- Expanded usage for food service, non-standard fixtures, or abnormal usage patterns (extreme low or high demand peaks or erratic peak duration and occurrence) shall be factored into the sizing calculations. For example, food-service fixture demand factors need to be adjusted if disposable service ware is used. Concentrated patient treatment for sick call or other instance of high-peak usage is another example of fixture hot water demand adjustment.
- Special care must be taken when sizing the needs of a hospital or nursing home. Ensure all fixtures requiring hot water are recorded and note any special needs for hot water and how its usage affects the peak demand.
- Therapeutic baths typically require approximately 75 gallons of warm water at about 110ºF.
- Many hospitals have bedpan sanitizers on every floor requiring 180ºF domestic water.
- For kitchen and laundry requirements, see the appropriate sections regarding those sizing needs.

The U.S Department of Health and Human Services established 1983/1984 guidelines for hot water provided for hospitals and medical facilities as follows:

	Clinical	Dietary	Laundry
Gallons per hour per bed	3.0	2.0	2.0
Water temperature ºF	110	120	160

(Source- US Department of Health & Human Services, 1983/84)

General "Rules of Thumb" For Sizing

	Max. Hour	Max. Day	Avg. Day
Nursing Homes	4.5 gal/bed	30.0 gal/bed	18.4 gal/bed

(Source- ASHARE Chapter 45, Table 7)

Hot Water Demand per Fixture Detail Sizing

Fixture	Gallons of water per hour per fixture (calculated at a final temperature of 140ºF)
Basins, private lavatory	2
Basins, public lavatory	8
Bathtubs	20
Showers	75
Service sink	30

(Source- ASHARE Chapter 45, Table 9; refer table-2 for details)

The same methodology shall be applied to other facilities as well. The brief description is given below for hotels, apartments, restaurants, schools and gymnasiums.

HOTELS & MOTELS

Ensuring adequate supply of hot water to the guest rooms all the time is of prime importance to prevent potential dissatisfied customers and guests. Hot water requirements are for tubs and showers, lavatories and general cleaning purposes. Peak demand, usually from shower use may last 1 to 2 hours and then drops off sharply. Food service, laundry and swimming pool requirements must be considered separately.

General "Rules of Thumb" For Sizing

Motel/Hotels Number of units	Max. hour	Max. Day	Avg. Day
20 unit or less	6.0 gal/unit	35.0 gal/unit	20.0 gal/unit
60 units	5.0 gal/unit	25.0 gal/unit	14.0 gal/unit
100 units or more	4.0 gal/unit	15 gal/unit	10.0 gal/unit

(Source- ASHARE Chapter 45, Table 7)

Hot Water Demand per Fixture Detail Sizing

Fixture	Gallons of water per hour per fixture (calculated at a final temperature of 140ºF)
Basins, private lavatory	2
Basins, public lavatory	8
Bathtubs	20
Showers	75
Service sink	30

(Source- ASHARE Chapter 45, Table 9; refer table-2 for details)

Notes to Consider:

- The first and most important step in system sizing for hotels is determining the hot water demand for a specific timeframe, referred to as the peak period. In a hotel, there will normally be two peak periods, one in the morning and a second in the early evening. Sizing for these periods should not include requirements for the hotel's laundry facilities. All hot water during peak periods should be devoted to serving the guestrooms. Laundry should only be done during "off-peak" hours.
- Many of the design considerations that applied to apartments and multi-dwellings in regards to recirculation lines, hot water storage and sizing also applies to motels and hotels.
- The designer should pay extra attention to special situations for instance whether the hotel contains either garden tubs or whirlpool tubs in the rooms. In these applications the hot water system must be able to rapidly fill the tub while maintaining temperature.

- The designer should also note additional needs that may be required for those establishments that cater to conventions, banquets, assemblies, and conference or have a high occupancy rate.
- For big hotels, base your calculations on a one-hour peak demand period in the morning and one-hour peak demand period in the evening. Size your requirements based on two-hour peak demand. For short stay facilities such as small motels or bread & breakfast type, peak can be compressed to one hour as the guests get up and get out faster than normal.

Method of Sizing

1. Determine the number of fixtures required for the application and calculate the total hot water demand for those fixtures.

Number of Fixtures x Gallons of Water per Hour per Fixture = Possible Maximum *Demand*

2. Determine the Probable Hot Water Demand for the application.

Probable Hot Water Demand = Possible Maximum Demand x 0.25

APARTMENTS & MULTI-DWELLINGS

Hot water requirements for an apartment include showers, lavatories, kitchen sinks, dishwashers, clothes washers and general cleaning purposes. Clothes washer can be either in individual apartment or centrally located. Hot water system design for an apartment ensuring an adequate supply of hot water is the utmost importance. Just as an undersized system creates potential problems, an oversized system can create problems such as being an uneconomical system through an increase in standby losses.

The designer should consult with local building inspector and/or housing authorities on the need to meet specified requirements on recovery capacity and storage tank size. Some areas base the requirements on per apartment unit or per person basis. The designer should pay extra attention to those situations, which the dwelling units contain and it is good to check for the following answers:

- How many people shall stay in the apartment?
- How many bathrooms does an apartment have?
- How many appliances such as washing machines, dishwashers etc require hot water?
- Does the dishwasher have its own heating arrangement?
- Does the apartment have a pool or spa?

- Does the dwelling unit contain either garden tubs or whirlpool baths?

General "Rules of Thumb" For Sizing Apartments

Apartments Number of Units	Max. Hour	Max. Day	Avg. Day
20 unit or less	12.0 gal/unit	80.0 gal/unit	42.0 gal/unit
50 units	10.0 gal/unit	73.0 gal/unit	40.0 gal/unit
75 units	8.5 gal/unit	66.0 gal/unit	38.0 gal/unit
100 units	7.0 gal/unit	60.0 gal/unit	37.0 gal/unit
200 units or more	5.0 gal/unit	50.0 gal/unit	35.0 gal/unit

(Source- ASHARE Chapter 45, Table 7)

General "Rules of Thumb" For Sizing Dormitories

Dormitories	Max. Hour	Max. Day	Avg. Day
Men's dormitory	3.8 gal/student	22.0 gal/student	13.1 gal/student
Women's dormitory	5.0 gal/student	26.5 gal/student	12.3 ga;/student

(Source- ASHARE Chapter 45, Table 7)

Hot Water Demand per Fixture Detail Sizing

Fixture	Gallons of Water per Hour per fixture (calculated at a final temperature of 140ºF)
Basins, private lavatory	2
Basins, public lavatory	4
Bathtubs	20
Dishwasher	15
Kitchen sink	10
Laundry, stationary tubs	20
Pantry sink	5
Showers	30
Service Sink	20

(Source- ASHARE Chapter 45, Table 9; refer table-2 for details)

Method of Sizing

1. Determine the number of fixtures required for the application and calculate the total hot water demand for those fixtures.

   Number of Fixtures x Gallons of Water per Hour per Fixture = Possible Maximum Demand

2. Determine the Probable Hot Water Demand for the application.

   Probable Hot Water Demand = Possible Maximum Demand x 0.30

Restaurants

Hot water requirements for restaurants are primarily for dish washing and also for food preparation, cleaning pots/pans, floors and hand washing for employees and customers. When designing a hot water system for kitchen needs at a restaurant, the designer should note that both 140ºF and 180ºF temperature water is required. An ample supply of 180ºF is used for the final rinse on many automatic dishwashers and the 140ºF supply of water is used for general cleaning and food preparation. The main concern when designing a hot water system for a restaurant is to ensure adequate hot water to maintain sanitation requirements.

General "Rules of Thumb" For Sizing

Food service establishments	Max. hour	Max. Day	Avg. Day
Type "A"			
Full meal restaurant/cafeterias	1.5 gal/max. meal/hour	11.0 gal/max. meal/hour	2.4 gal/max. meal/hour
Type "B"			
Drive-ins, grilles, luncheonettes, deli shops	0.7 gal/max. meal/hour	6.0 gal/max. meal/hour	0.7 gal/max. meal/hour

(Source- ASHARE Chapter 45, Table 7)

Hot Water Demand per Fixture Detail Sizing - Kitchens

Fixture Type	Gallons of water per hour per fixture (calculated at a final temperature of 140ºF)
Vegetable sink	45
Single pot sink	30
Double pot sink	60
Triple pot sink	90
Pre-scrapper (open type)	180
Pre-flush (hand-operated)	45
Pre-flush (closed type)	240
Recirculating pre-flush	40
Bar sink	30
Basin, lavatory	5

Type and sink of dishwasher	Flow rate gpm	Hot Water requirements at 180ºF to 195ºF maximum	
		Heaters without internal storage gph	Heater with internal storage gph
Door type:			
16 X16	6.94	416	69
18 X18	8.67	520	87
20 X 20	10.4	624	104
Under counter type	5	300	70
Conveyor type:			
Single tank	6.94	416	416
Multiple tank (dishes flat)	5.78	347	347
Multiple tank (dishes inclined)	4.62	277	277
Silver washers	7	420	45
Utensil washers	8	480	75
Make-up water requirement	2.31	139	139

(Source: National Sanitation Foundation NSF Final Rinse Water Requirements for Dishwashing Machines)

Method of Sizing

1. Determine the number of fixtures required for the application and calculate the total hot water demand for those fixtures.

   Number of Fixtures x Gallons of Water per Hour per Fixture = Possible Maximum *Demand*

2. Determine the Probable Hot Water Demand for the application.

   Probable Hot Water Demand = Possible Maximum Demand x Demand Factor

   Demand Factors: Kitchens = 1.00

Notes to Consider:

- For estimating purposes it can be assumed that 1.5 gallons of 140ºF is required for every meal served.
- The type of dishwasher in addition to the manufacturer, model number and the rinse cycle requirement is essential to properly sizing the hot water system. It is essential to note that some dishwashers have a high GPM flow rate and a low GPH consumption or a low GPM flow rate with a high GPH consumption.
- In fast food restaurants, hot water is mainly used for food preparation and cleanup. Dishwashing is usually not a significant load. Fast food restaurants typically consume 250 to 500 gallons per day.
- When sizing for small diners, the calculated First Hour Rating* can be reduced as much as 30% in some cases. This reduction is based on the needs of the facility for food preparation and dish washing.
- When sizing for hotel restaurants or restaurants which serve elaborate meals, the calculated First Hour Rating should be increased as much as 25% in some cases. This increase is again based on the needs of the facility for food preparation and dish washing.

*Note: ‘First hour rating’ describes the amount of hot water that the water heater can supply in one hour of operation, starting with the tank full of heater water.

SCHOOLS & GYMNASIUMS

In designing a hot water system for a school there are generally three uses for hot water; kitchen / cafeteria needs, gymnasium /lavatory/ shower needs and general maintenance needs. In general this means that the designed hot water system should provide large quantities of 140ºF water as well as 180ºF water.

General "Rules of Thumb" For Sizing

	Max. Hour	Max. Day	Avg. Day
Elementary School	0.6 gal/student	1.5 gal/student	0.6 gal/student
Jr. and Sr. High School	1.0 gal/student	3.6 gal/student	1.8 gal/student

(Source- ASHARE Chapter 45, Table 7)

Hot Water Demand per Fixture Detail Sizing - Gymnasiums

Fixture	Gallons of water per hour per fixture (calculated at a final temperature of 140ºF)
Basins, public lavatory	8
Bathtubs	30
Foot basins	12
Showers	225

(Source- ASHARE Chapter 45, Table 9; refer table-2 for details)

Hot Water Demand per Fixture Detail Sizing - Schools

Fixture	Gallons of water per hour per fixture (calculated at a final temperature of 140ºF)
Basins, public lavatory	15
Dishwashers	20-100
Kitchen sink	20
Pantry sink	10
Showers	225
Service sink	20
Circular wash sink	30

(Source- ASHARE Chapter 45, Table 9; refer table-2 for details)

Method of Sizing

1. Determine the number of fixtures required for the application and calculate the total hot water demand for those fixtures.

Number of Fixtures x Gallons of Water per Hour per Fixture = Possible Maximum *Demand*

2. Determine the Probable Hot Water Demand for the application.

   Probable Hot Water Demand = Possible Maximum Demand x Demand Factor

   Demand Factors: Schools = 0.40

   Gymnasiums = 0.40

   Kitchens = 1.00

Notes to Consider:

- When sizing the hot water needs for a school cafeteria it should be noted that the hot water usage is generally 30 percent less per student than the per person average used in restaurants.
- In schools where there are more than one lunch period, there is a possibility that the peak demands of the kitchen may occur simultaneously with the peak demand of a shower period and should be considered when sizing the system.
- When considering the amount of usage for showers, wash basins and wash fountains, the average clean-up period is generally 10 minutes after each class.
- In co-educational schools, the water usage for the boys and girls locker rooms should be considered simultaneously.
- When the gymnasium is used for sporting events, sufficient hot water should be available for both teams and this usage should be considered a dump load. When sizing for a dump load such as this, ensure there is adequate storage available.
- Since most maintenance occurs during the evening, the hot water usage required for cleanup is generally small and may not be considered in the sizing of the system.

PART 2 Choosing the Type of Hot Water System

To determine which hot water system best suits your needs, you need to calculate your daily hot water requirement. Carefully considering your hot water needs and choosing the most appropriate system for your household can significantly lower your energy bills.

STORAGE OR CONTINUOUS FLOW

Which type you choose will depend on the demand for hot water in your home, the amount of space available and your budget?

There are two main types of hot water systems: storage water heaters and continuous flow water heaters sometimes referred to as instantaneous water heaters. Both can be suitable for most households, although there are restrictions on the installation of gas fired hot water systems indoors.

Storage Systems

Storage hot water system heats water to the temperature you select then stores it in an insulated tank, ready for use throughout the day. As hot water is used, it is displaced by incoming cold water, which in turn is heated. Storage systems constantly heat incoming water even if there is no demand for the hot water. The hot water in the storage tank is maintained at the set temperature usually 140°F and is thermostatically controlled. They are suitable for most applications and can be installed inside or outside.

These units are available to supply hot water either at mains pressure, or operate at low pressure.

Mains pressure type: Mains pressure storage systems provide hot water at a similar pressure as your cold water supply. It means multiple outlets can be used simultaneously without affecting your hot water pressure.

Low-pressure type: In this type, hot water is delivered at lower pressure than mains pressure units. They are normally located in the roof space of a home, and the pressure depends on the vertical distance between the tank and point of use. Constant pressure units are often cheaper to purchase and have much longer life expectancies than mains pressure systems. Correctly plumbed, they will provide satisfactory service. They are also known as 'gravity feed' systems.

The tank size is important and you should discuss with your supplier your specific size requirement. Hot water storage tanks shall be sized to provide sufficient hot water to provide both daily requirements and hourly peak loads of the occupants of the building.

If the tank is too small for the number of people, hot water can temporarily run out.

If the tank is too large, operating costs will be higher than necessary. Heat will be lost from the tank and losses depend on the temperature setting, the tank size and insulation of the tank. Smaller size tank shall have reduced heat losses.

Storage type heaters operate most economically on solar energy. Solar hot water systems use solar thermal collectors (basically, black pipes in an insulated box with a glass lid) to heat the water, with a booster inside the tank.

Other storage hot water systems could use electric element similar to that in a kettle, a heat pump or a gas or fuel burner with a heat exchanger.

Storage tanks must be protected against excessive temperatures and pressure conditions as specified in the code.

Continuous or Instantaneous Flow Systems

Continuous flow systems save you money as they only heat the amount of hot water you need. The system begins heating water as soon as the tap is turned on and stops heating the moment you turn the tap off. In case of gas-fired units, as soon as the hot water tap is turned on, the flow of water activates a valve or switch causing gas to flow. The gas is ignited and heats the water. When the hot water tap is turned off, water flow ceases and gas flow to the burner is extinguished.

With continuous flow system, the hot water is always available on demand and there is little chance of running out of hot water. And because a large tank to store pre-heated water is not required, continuous flow systems tend to be compact and can be mounted on an external or internal wall, or even in a cupboard. Features of instantaneous water systems include:

- Water is heated only when required and therefore does not require a storage tank.
- The first cost of these units is low compared to storage type.
- These units saves energy by not having to constantly heat a storage tank of unused water, and guarantees a constant supply of hot water.
- As water is heated instantaneously, they do not ‘run out’ of hot water.
- These are smaller in size than storage systems, and can be mounted on a wall or in a cupboard (gas units must have a flue).
- These are connected to the mains water supply and deliver hot water at a slightly reduced pressure
- The standard units can generally deliver adequate hot water to one or two points simultaneously. High powered, high efficiency units can serve larger households.

- It is vital that units are sized according to the maximum number of hot water outlets likely to be used simultaneously.
- Some units have electronic remote controls for precise temperature control.
- These operate most economically on natural gas, but can also use LPG and electricity. Gas units generally require a larger gas supply line than storage systems, potentially increasing installation costs.
- Gas instantaneous hot water systems usually have a relatively long life, provided they are well maintained. Warranties of up to 10 years are offered for their heat exchangers and the heat exchanger can often be replaced without having to purchase a complete new system.
- Electric instantaneous hot water systems generally do not last as long as gas instantaneous hot water systems and some have a comparatively short life compared to other systems.

For a low demand (around 100 liters per day), an instantaneous gas hot water system may be the best buy.

For a medium sized household with more than one bathroom (around 200 liters per day), a storage hot water system or a larger instantaneous system may be suitable.

With electric storage systems, it is possible to effectively control the maximum demand charges by switching off heater and using the stored hot water volume during peak hours. Many utility companies provide incentives of reduced electrical usage during peak hours and encourage consumers to heat water during night for use in the morning hours when demand peaks. With electric instantaneous heaters the peak usage penalty could be very high.

When deciding on which type of hot water system to buy, you may consider the initial purchase cost but remember you can spend between two and fourteen times the initial purchase cost of that system on running energy costs over its lifetime (based on a typical electric or gas hot water system).

PART 3 Types of Fuel

Choosing the right type of fuel to heat your water can make a significant difference to the running costs of the system and the amount of greenhouse gases emitted.

Heat transfer equipment is either direct or indirect type. For direct equipment the heat is derived from the combustion of fuels or direct conversion of electrical energy into heat and is applied within the water heating equipment. For indirect equipment, heat energy is developed from remote heat sources such as boilers, solar collection, cogeneration, refrigeration or waste heat and is transferred to water in a separate piece of equipment. Storage tanks may be part of either type of heat transfer equipment.

The common fuels for hot water systems are electricity, natural gas, LPG, solar heating and solid fuels.

Natural Gas

- ✓ Can be used for storage and continuous flow systems
- ✓ Systems are rated for their energy efficiency with ‘Energy Rating Star Labels”— the more stars, the more energy efficient.
- ✓ Many state regulations require natural gas hot water systems to be located only outdoors. Both internal and external heater models are available.
- ✓ If inside a room, sealed flue (internally balanced) is required to maximize safety.
- ✓ A pilot light, which burns continuously, is common, although some of the newer models save energy by replacing this with electronic ignition. Electronic ignition units use no gas at all when not being used. Avoid continuous flow systems with standing pilot lights.
- ✓ Installation guidelines for gas-fired heaters can be found in the national fuel gas code, NFPA Standard 54 (ANSI Z223.1). This code also covers the sizing and installation of venting equipment and controls.
- ✓ Installation guidelines for oil fired water heaters can be found in NFPA standard 31, installation of oil burning equipment ANSI Z95.1.

Electricity

- ✓ Electric water heaters are generally automatic storage type or instantaneous type consisting of immersion heating elements attached to line voltages of 120, 208, 240, 480 or 600V. Element wattages are selected to meet recovery requirements or electrical demand considerations.

- ✓ Electrical water heating elements consist of resistance wire embedded in refractory having good heat conduction properties and electrical insulating values.
- ✓ Can be very expensive to run so should only be used when other options are not possible
- ✓ Common in apartments, flats and units, where space is limited and where flueing is difficult
- ✓ Lower tariffs may be available in off-peak periods. However, to take advantage of ‘off-peak ’electricity you will need a much larger tank (160 liters capacity or greater) to ensure you do not run out of hot water during the day when boosting becomes much more expensive.
- ✓ Running costs are more than natural gas
- ✓ For peak demand reduction utility companies recommend to heat water overnight to provide adequate hot water for daily usage
- ✓ Residential storage water heaters range up to 120 gal with input up to 12 kW. They have a primary resistance heating element near the bottom and often a secondary element located in the upper portion of the tank. Each element is controlled by its own thermostat.
- ✓ Twin element units can operate with a 24 hour off-peak boost. If hot water runs out, water is reheated automatically on the off-peak tariff
- ✓ Instantaneous electric heating is commonly used for dishwasher rinse, hot tub, whirlpool bath and swimming pool applications.

Solar Energy

- ✓ Provides approximately 60–70% of your hot water free of charge in sunshine areas and is very beneficial to the environment.
- ✓ Generally the cheapest systems to run, but have a relatively high purchase cost with an average payback period of around ten years
- ✓ All solar hot water systems come with electric, gas or wood boosting to supply hot water on days when the sun alone is insufficient.
- ✓ The panels are generally located on the roof. The water storage tank can be located on the roof above the panels, within the roof or as a pumped system at ground level.
- ✓ Mains pressure and constant pressure systems are available.
- ✓ Traditionally, solar hot water systems come with the storage tank mounted above the collectors but is now offered as ‘split-systems’ with the tank or instantaneous heater mounted at ground level.

- ✓ Thermostatic tempering valves are available to stop the solar hot water system delivering water that is too hot in summer.

Liquefied Petroleum Gas (LPG)

- ✓ Used in areas where natural gas is not available
- ✓ Running costs average around 2.5–3 times the price of natural gas or electricity.
- ✓ Suitable for storage and continuous flow units
- ✓ Typically bought in 45 kg cylinders, although reticulated LPG is available in some areas. Points outlined above for natural gas also apply to LPG.

Solid Fuels (wood, briquettes, coal etc)

- ✓ Can be used alone, or in conjunction with electricity and/or solar in constant pressure storage units
- ✓ Cost of fuels varies greatly
- ✓ Water can be heated using a ‘wetback’ attached to a slow combustion wood heater, or a stand-alone water heater powered by solid fuel.
- ✓ Must not be used with mains pressure systems, unless a heat exchanger is used
- ✓ Not available for continuous flow systems.
- ✓ Major problems with urban air quality can occur due to wood fires, so its use in urban areas needs to be considered carefully

Fuel Oil

- ✓ Where natural gas is not available many industrial & commercial applications use diesel, Naphtha and other grade #2 fuel oil in hot water boilers (calorifiers).
- ✓ Dedicated fuel oil hot boiler use burner, which heats the heat transfer surface containing water in tubes. The combustion and thermal efficiency depends on the burner type and adjustment of burner for proper excess air control.
- ✓ Installation guidelines for oil fired water heaters can be found in NFPA standard 31, installation of oil burning equipment ANSI Z95.1

Heat Pumps

Heat pump storage hot water systems is highly efficient method that uses around 70%* less electricity to heat water compared to electric resistance hot water systems. They use an electrically powered compressor and a refrigerant gas to extract heat from the air (much the same as a reverse cycle air conditioner or your refrigerator) to heat the water stored in an insulated tank for later use.

* Source: Sustainable Energy Development Authority (SEDA)

- ✓ A heat pump storage hot water system uses around one third of the electricity of an electric element storage hot water system.
- ✓ Have lower running costs than normal peak rate electric storage units because of their high efficiency, and when used in conjunction with a timer and the reduced tariff scheme of utility company, running costs are even lower.

In general solar and heat pump hot water systems return their investment cost quickest for households with a high demand.

PART 4 Design Considerations

Hot water systems typically are comprised of heat transfer equipment, a fuel source to heat water, hot water distribution to outlet points, and cold water feed to the heat transfer equipment.

Ensuring adequate supply of hot water is the utmost importance. Also important is the quality of service; time delay to fixture outlet, water not too hot or too cold, safety considerations etc. With piping and labor being so expensive, the plumbing design is driven by economics and is not always the best design. The inconvenience of waiting for hot water is not welcome and results in costly waste of water and energy.

Efficiency of the overall system depends on the system design, type of water heating equipment, the length and size of piping installed, the set point of the water heater, and the quantity of hot water consumed. The bigger systems shall have higher radiation losses through the storage tank and the distribution piping. System efficiencies may range from less than 50 percent to about 85 percent. Just as an undersized system creates potential problems, an oversized system can create problems of being uneconomical.

Hot water accounts for around one quarter of the average household's energy costs, so it's important to think carefully before designing your hot water system.

REQUIREMENTS

Having hot water discharge promptly is important for energy and water conservation. A general guidelines state that discharging hot water within zero to 10 seconds after the faucet is opened is acceptable. With stringent water conservation laws in place, the plumbing manufacturers are restricting the flow rate to new faucets to as low as 0.5gpm. The low flow delivery rate further reduces the velocity through the pipes and it can be quite a while before hot water, especially from a distant hot water main, flows from the faucet.

According to ASHRAE, the return piping systems (with recirculation pump) are commonly provided where it is desirable to have hot water available continuously at the fixtures. This includes cases where the hot water piping system exceeds 100 ft.

STANDARD PLUMBING

The traditional hot water passive designs rely on natural circulation of hot water in a vertical loop of piping. Hot water being lighter than cold water rises naturally and the cold water fall back to the water heater in a return leg from the highest portion of the system.

Depending on where the fixtures are located, the hot water line runs as a main line then branches to the fixtures. In most cases, the branches are short and the main hot water line is long. If the piping is installed properly the circulation will occur naturally.

The passive systems use energy only for heating water. No other form of energy is needed to distribute or maintain hot water close to the faucet.

The passive systems have limited applications to small structures, as these systems do not circulate well because the hot water looses its buoyancy due to water-cooling off in large network. These systems are generally limited to three floors. The complex multistoried & diverse structures rely on forced recirculating systems that use pumps to rapidly move water from water heater to fixtures.

The concern…

Standard plumbing systems installed without hot water recirculating pumps are notorious for causing time delays while allowing the cooled water in the hot water piping to pour down the drain line while waiting for the warm water to get from the water heater to the farthest fixture. The water drained during waiting period is a waste of energy and a cost to the owner for wasted fuel, water and sewer rates.

For example; consider a 50-gallon water heater serves two showers and six lavatories located 100 feet away with a 1-inch hot water supply pipe with no hot water recirculation. How much time it will take for water to reach lavatory outlet?

The lavatory fixtures are designed for 3 to 5 gallons per minute. Considering a single 3gpm lavatory connected to a 1-inch hot water main shall have a flow velocity of ~1.17 feet per second. For 100ft pipe length, one has to wait almost 85 seconds, before the hot water arrives at fixture for the first draw. During this time water that had been previously heated shall pouring down to drain.

The Energy Policy Act of 1992 requires lavatory faucets to have a maximum of 2.5gpm flow rate and many manufacturers offer 2gpm, 1gpm and 0.5gpm flow restrictors on their faucets. A 2gpm lavatory faucet in fully open position through 1-inch hot water main shall have a waiting period of 128 seconds. That is more than two minutes standing at the sink watching cooled hot water pour down the drain before the hot water arrives. Most people would not wait that long — they would simply wash their hands in the ambient temperature cool water and be on their way.

Table below shows the time required for usable hot water to arrive at a fixture based on the fixture flow rate (available from industry and manufacturer's data) and the length and diameter of the dead-end branch pipe supplying the fixture. The time lag should generally not exceed 30 seconds. For residential and office applications, the owner may prefer a limit of 10 seconds.

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)

QUICK DELIVERY OF HOT WATER

For remote fixtures, a means of heat maintenance must be provided. The example above illustrates the need for swift supply of hot water to the faucet. Many builders tend to install two or more heaters in a facility for no other reason than to get hot water to the fixtures more quickly. Yes it helps if the heaters are placed near to the fixtures but remember hot water volume is not the issue here. If means of quick distribution are employed, a single water heater could be more than sufficient.

Two common methods to approach this problem are;

a. Electric Tracer Systems

b. Pumped Recirculation Systems

Self-regulating heat tracing tape is applied to the piping to maintain the water temperature. Heat tracing uses electrical energy to maintain water temperature, and it eliminates the need for return piping and components required in a recirculation system. Heat tape systems may be utilized if cost justified, but are considered less desirable due to reported system malfunctions and difficulty in locating the malfunction point. The system is good for retrofitting applications or freeze protection applications.

The pumped recirculation system utilizes a circulating pump and parallel supply & return piping for distribution of hot water. This paper briefly discusses the typical design configurations of pumped recirculation systems. For detailed reading refer to:

Chapter 4, 1989 edition, of the ASPE Data Book discusses pumped recirculating systems. Chapter 45, 1995 edition, of the ASHRAE Handbook mentions pumped recirculating systems and briefly mentions electric heat traced systems.

Why Recirculation Systems?

The domestic hot water system design guides from ASHRAE and ASPE suggest that it is acceptable to have a hot water system without pumped recirculation, as long as the distance from the water heater to the farthest fixture does not exceed 100 feet. This is only a subjective guideline and is not a mandatory requirement. This recommendation however gained importance with an advent of the Energy Policy Act of 1992, which require restricting flow rate of the plumbing faucets and which in turn result in increased delay to get hot water at the remotest fixture. (Refer example above)

ASPE recently suggested changing the 100-foot distance guideline to include a time delay of maximum 10 seconds wait time for residential and office buildings. ASPE also recommends 11 to 30 seconds as marginally acceptable for other building types depending on the application. Any wait exceeding 30 seconds shall consider being unacceptable. Therefore most modern hot water systems have to use recirculation pumps to meet this strict criterion.

The entire concept of the recirculation system is to move hot water rapidly from the storage tank to the farthest fitting as needed. The scheme uses two main parallel pipes one for supplying hot water and other for return back to the water heater. With the press of a button, an innovative hot water recirculation system can send hot water to fixtures in seconds. A recirculation pump rapidly pulls hot water from a water heater and simultaneously pushes cooled-off water from hot water lines back to the water heater to be reheated. In addition to having the convenience of hot water on-demand, the system conserves hot water/ energy.

In summary, recirculation system is provided to reduce wait time for water use, to minimize hot water & energy waste caused during the waiting period, and to prevent degradation of the system supply water temperature. Few things must be carefully considered with recirculated hot water return (HWR) piping:

1) ***Routing:*** Route hot water re-circulation lines as close to fixtures as possible; the closer you can get the recirculated line to the fixture, the less time it will require getting hot water at the fixture.

2) ***Balancing Valves:*** If the building has multiple hot water mains, each branch should have a balancing valve and check valve before connecting to the hot water return main. This prevents short cycling of the hot water through the closest circuit of piping or the path of least resistance.

3) ***Minimum Pipe Size:*** The piping pressure drop changes as the flow rate changes. The hot water distribution lines are not subject to wide variations of flow as the cold-water branch lines, which experience sudden instantaneous draw rate because of flush valves. (Flush valves are commonly used in WC's). The pressure fluctuation in hot water system fixtures is therefore relatively consistent. It is recommended to use a minimum pipe size of ¾" for hot water return system piping where the distance is greater than 50ft. A ½" pipe flowing 3gpm shall have a head loss of 16.5' per 100' length of pipe. If the piping circuit is 300 feet long, the pump head required would be 49.44 feet. This would exceed the head on most small circulators. If a larger circulator is installed, the velocity increases and typically erosion of the inside of the pipe wall occurs.

   Any attempt to reduce the pipe sizes to save cost need to be carefully evaluated. It must be noted that the cost savings for 1" pipe to ¾" is minimal. Cost savings would seem low in comparison with implied risk factors because of the four times pressure drop increase associated with a one size reduction for any given flow rate.

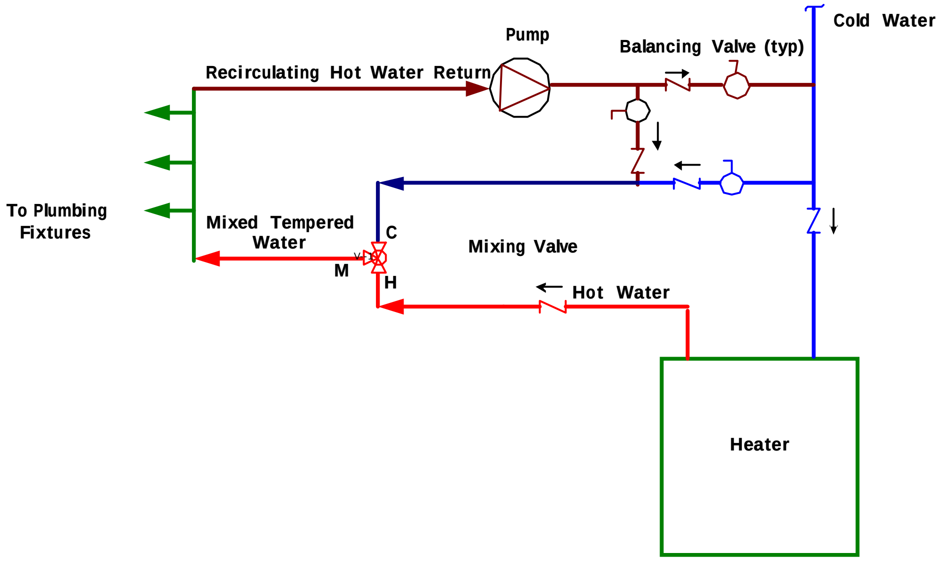
4) ***Reverse Return System:*** Water follows the path of least resistance. The reverse-return piping provides equal pressure drop throughout the entire piping system. Unlike tree type distribution system, the reverse return manifold system uses 2 parallel pipes so arranged that pipe length to each branch circuit is same thus ensuring equal water flow at every point. There is a bit more piping involved, but considering life term reliability it's well worth installing.

DESIGN CONFIGURATIONS

Recirculating systems are becoming more popular due to the population's increasing interest in saving water and adding convenience to their lives. The common recirculation system design configuration schemes are discussed here under.

Master Mixing Valve Arrangement

The master mixing valve scheme is provided close to the water heater. This ensures tampering of water (hot-cold mix) at the plant room itself 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. For relatively high temperature applications such as dishwashing and pot washing booster heaters could be provided to obtain the required temperatures of around 180°F (82°C).



Hot Water Recirculation System with Master Mixing Valve

Note the connection of tampered water return to the water heater. The tampered 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.

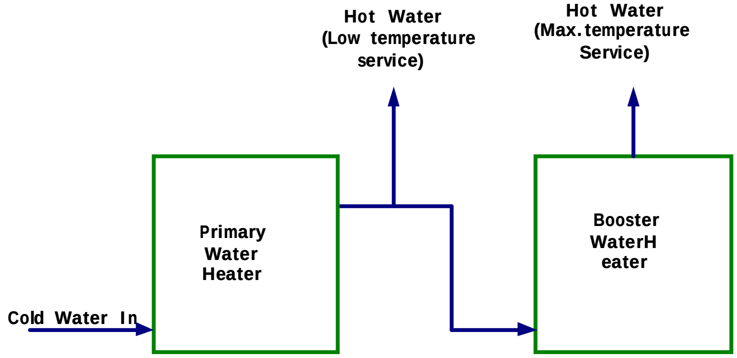
Also if the hot water return were connected directly to the hot water heater, the mixing valve would open to tamper the water and because there is no flow thorough the system, cold water would not be able to enter the mixing valve to blend with hot water. Manufacturers refer this to ‘valve hunting for right temperature’. This condition causes fluctuations in temperature and pressure. To correct this problem the tampered return line must split and routed to two locations.

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

Size of circulator depends on minimum flow requirements of the tempering valve. Minimum flow rates of the tempering valve must be maintained. If circulator is too small the tempering mixing valve performance shall be erratic.

Two-Temperature Service Arrangement

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



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

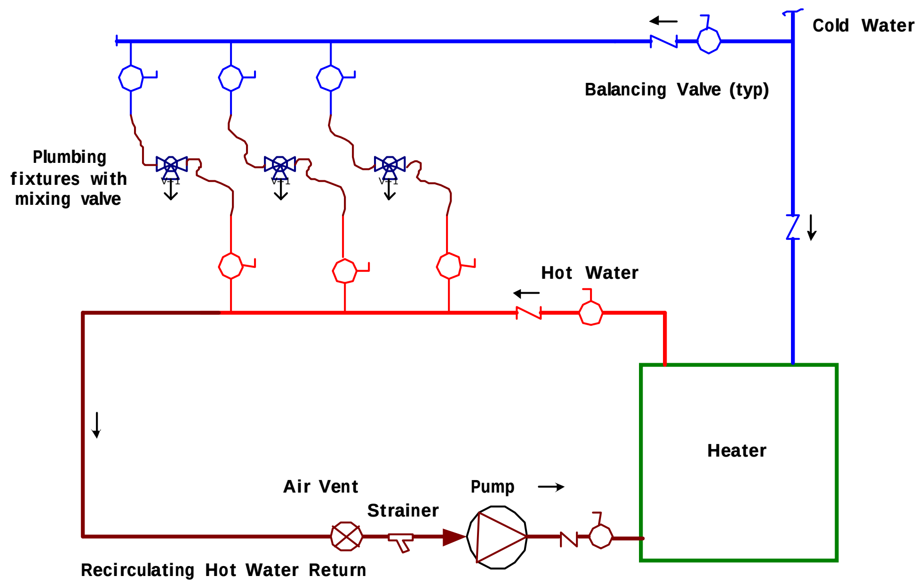
Where the bulk of the hot water is needed at the higher temperature, lower temperature can be obtained by mixing hot and cold water either centrally or at the point of use. The local mixing valve arrangement discussed below uses blending at the point of use.

Local Mixing Valves

This scheme is easiest to pipe and maintain. This is cost effective because you can pipe only one hot water temperature out and mix down to 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 (return line). A small pump re-circulates the hot water in a continuing loop, only shutting off with 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 (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 get hot water.

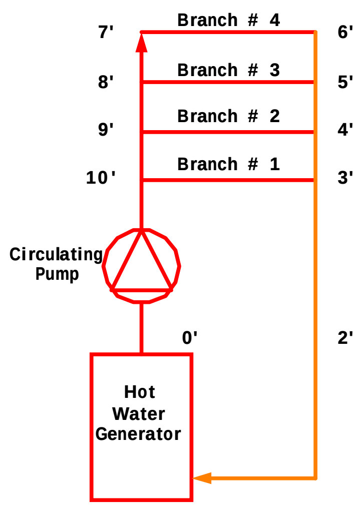


Hot Water Recirculation System with Local Mixing Valve At Point of Use Fixtures

Reverse Return System

The basic principle of water distribution lays in the relationship between pressure and flow…'*Lower Pressure Equals Lower Flow'*

If there isn't enough pressure differential (delta P) across the flow circuit, the water "short circuits" through the closer circuits (zones).



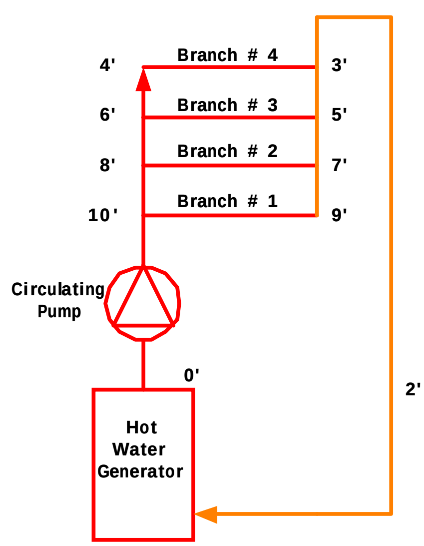
Normal Distribution System

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

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

How do we solve this imbalance problem?

The reverse-return piping provides answer to this problem. Reverse-return maintain 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 circuit via branch 4 from pump discharge back to the hot water generator and via branch 1 is same resulting in somewhat equivalent pressure drop in both the circuits. Consider putting balancing valves on the return side of each circuit. By appropriate setting, the pressure drop in each circuit shall 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.

The 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 reverse return system it is easy to get 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.

Sizing the Circulator

The ASHRAE applications handbook suggests a simplified pump sizing method to allow for 1gpm for every 20 fixture units in the system, or to allow 0.5gpm for each ¾ or 1" riser; 1gpm for each 1-1/4" or 1-1/2" riser and 2gpm for each riser 2" 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- 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 is to assume 25 to 30 Btu/h-linear feet, 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) Determine the pump capacity using equation Q = q/ (60 x p x cp x delta T) or

Simply Q = q/ (500 x delta T)

Where Q is pump capacity (GPM), q is heat loss (Btu/h), p is density of water (8.33 lb/gal), cp is specific heat of water (1Btu/lb-°F) and delta T is allowable temperature drop (°F). (Note 8.33 x 60 = 500 is conversion to gallons per minute when q is in Btu/h).

For a 20°F temperature differential simply divide the heat loss by 10,000 to get the required flow rate. This is how the GPM is determined for the pump size.

4) For the pump head requirement, simply select the pump at the calculated flow and from the pump curves determine the optimum head at this flow. The small circulating pumps are standard and it may not be necessary to calculate the friction drop in small size network unless customer or codes require that specifically.

Multiply the head by 100 and divide by total length of hot water return piping to determine the allowable friction loss per 100 ft of pipe. The friction drop not exceeding 4' per 100' length of pipe is generally acceptable.

Distribution Systems

When laying out hot water distribution system, there are number of design options. Two common schemes are a *'tree'* system where individual outlets branch from main trunk lines, and a *'parallel'* piping system where each outlet is fed from an individual line directly from a manifold.

For a tree system, the piping is progressively smaller to a minimum of 1/2-inch inside diameter. The parallel piping system consists of 1/2- or 3/8-inch diameter tubing with one pipe dedicated to each load.

A distribution system should be properly designed, sized and insulated to deliver adequate water quantities at temperatures satisfactory for each application. Heat traps between recirculation mains and infrequently used branch lines reduce convection losses to these lines and improve heater system efficiency.

It is *very* important that there no air is trapped the pipe. To prevent air from collecting in the return line, slope all the pipes so that airflow to the highest point in the return line and then put a valve there so that air can be released periodically.

Pipe Sizing

Estimates of water flow in each pipe section and the minimum pressure available at the water service are used in the pipe sizing procedure. The water flow load at each outlet is based on a water-supply fixture unit (w.s.f.u.) value as determined in the code or handbooks for each type of outlet. Each pipe section is assigned a total w.s.f.u, which shall be converted to flow in gallons per minute. For example, a typical full bath group, which includes a tub/shower, sink, and water closet, shall have a w.s.f.u of 2.7 for the cold water supply and 1.5 for the hot water supply. The branch piping that service a full bath group shall be sized to supply the flow rates associated with the total w.s.f.u of this bathroom. The main distribution piping includes branches to other outlets. The main pipe shall be sized for the total w.s.f.u, which is sum of all the w.s.f.u served by the entire branch piping circuits. Additional tables specify the minimum pipe size for a given w.s.f.u and are based on the minimum water pressure available. Remember the pipe sizing is based on the maximum possible flow expected by the system without any demand factor. The heater sizing however is based on probable flow which is maximum possible flow multiplied by demand factor. The reason is that probability of simultaneous use of all fixtures in all branches at the same time is remote.

Mandatory local code requirements, such as minimum pipe sizes, pressure allowances for special valves, and maximum velocities may affect the plumbing system design. The manifold piping systems for instance have unique requirements. The minimum pipe size in a manifold system is 3/8-inch, unless the code or supplier requires a different size.

Pipe Sizing 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 5psi per 100 ft friction loss limitation (no velocity restriction).

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

Materials

Because hot water is corrosive, circulating pumps shall be specified with corrosion resistant material.

The plumbing hot water pumps shall be constructed of non-ferrous bronze or stainless steel parts due to corrosion problems. Since the domestic plumbing hot water is essentially an open system with air and oxygen entrained in water, this contributes to corrosion process.

Space heating hydronic systems are closed systems with air eliminators to keep air and oxygen out of the piping circuit. Some hydronic systems use corrosion-inhibiting chemicals to help prevent corrosion of the ferrous metals.

Piping Materials:

Traditional piping materials have included galvanized steel. Copper piping and copper tube K, L or M have been used with brass, bronze or wrought copper solder fittings. Legislation and plumbing code changes have banned the use of lead in solders or pipe jointing compounds in potable water piping because of possible lead contamination of the water supply.

The stringent regulations requiring potable water treatment before distribution may cause water to become more corrosive. Therefore depending on the water quality, traditional galvanized steel piping or copper tube 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 and 180 deg F and b) where repairs have been made using copper tube without a nonmetallic coupling.

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

Alternate materials that may be considered are;

- Stainless steel tube
- Various plastic piping and tubes

Particular care must be taken to make sure that the application meets the design limitations set by the manufacturer and that the correct materials and methods of joining are used. The use of incompatible piping, fittings and joining methods or materials may be avoided as they can cause severe problems.

Plastic Piping:

Plastic piping used for hot water distribution shall be water pressure rated for not less than 100psi at 180°F.

NOTE: The working pressure rating for certain approved plastic piping materials varies depending on pipe size, schedule and method of joining.

Plastic pipe or tube shall not be used downstream for instantaneous water heaters, immersion water heaters or other heaters not having approved temperature safety devices.

Piping within two feet of flue or vent connectors shall be approved metallic pipe or tube.

The normal operation pressure in water distribution piping systems utilizing approve plastic pipe or tube for hot water distribution shall be not more than 80psi. Where necessary, one or more pressure reducing valves shall be provided to regulate the hot and cold water supply pressure to not more than 80psi.

A pressure relief valve at the water heater set no higher than 100 psi shall limit the pressure in the piping system. When the heater is protected by a pressure relief valve or combination pressure-temperature relief valve having a pressure setting higher than 100 psi, a separate pressure relief valve shall be provided to protect the piping.

Storage Tank

There are various sorts of tanks for storage hot water systems including copper; glass (enamel) lined steel tanks and stainless steel tanks. Copper and glass-lined tanks typically have a sacrificial anode to reduce tank corrosion and it's worth ensuring this is replaced at the appropriate time.

Warranties offered for hot water services range from five to ten years for glass (enamel) lined tanks, seven to ten years for stainless steel tanks, seven years for copper tanks and around ten years for heat exchangers of continuous flow water heaters.

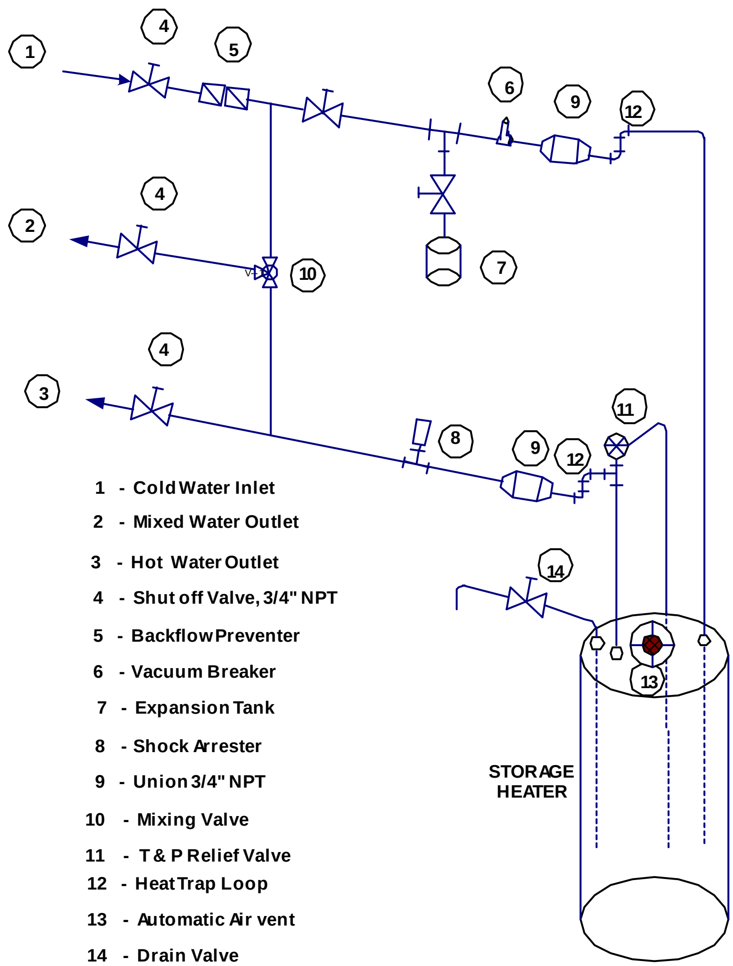
SYSTEM COMPONENTS

The detailing of the hot water system must consider the good engineering practices for safety and the methods required by local codes. Few important aspects are:

- ✓ The check valves are required to prevent fixtures from taking hot water through the return lines.
- ✓ Shutoff valves are needed to allow cleaning and replacing balancing devices.
- ✓ Include strainers to remove sediment, which could damage the pump and/or affect the flow balancing devices.
- ✓ Size the pump and piping based on the temperature drop allowed between the water available at the water heater and the water delivered at the fixture.
- ✓ The return piping will almost always be smaller than the supply piping, but should never be smaller than ½" to prevent problems with the pump.
- ✓ Make provision for removal of air in all return lines.
- ✓ Where topmost fixtures cannot vent the returns line, install automatic air venting at the top of the return piping.

- ✓ Designs for recirculating hot water systems shall include provisions for isolating and balancing the system.
- ✓ Anti-scald valves shall be provided as close as possible to the taps of “whole-body” fixtures such as showers, bathtubs, and hydrotherapy baths.
- ✓ When using a recirculating loop, insulate both supply and return water lines.
- ✓ Aquastat is used to control the on-off position of the circulator. Aquastat is set 5° to 10° lower than mixed water outlet of the mixing valve. The circulator cannot run continuously as bypass through the mixing valve will eventually allow the temperature on the piping to climb to the water heater temperature during draw periods.
- ✓ T&P relief valve discharge piping must be:
    - Made of material serviceable for temperatures of 250°F or greater
    - Directed so that hot water flows away from occupancy
    - Installed so as to allow complete draining of the T&P relief valve and discharge line
- ✓ T&P relief valve discharge piping must not be:
    - Excessively long; using more than 2 elbows or 15 feet of piping can reduce discharge capacity.
    - Directly connected to a drain; terminate discharge piping within 6" from floor. Refer to local codes.
    - Plugged, reduced or restricted
    - Subjected to freezing

Hot water system design should consider the following components:



HOT WATER SYSTEM COMPONENTS

How long will my system last?

The tank corrosion is the main cause of storage system failure, which is mainly due to water quality, high temperature and pressures. Stainless steel and copper tanks tend to have a longer life span than those lined with vitreous enamel or glass.

Continuous flow water heaters have a relatively long life. Major components such as heat exchangers can be replaced without having to purchase a complete new system.

HOT WATER TEMPERATURE

For domestic use many codes require hot water to be generated and stored at 140°F. It shall be tempered with a thermostatic mixing valve at the hot water generator discharge to permit distribution at a temperature range between 120-130° F. The maximum hot water temperature distribution design set point shall be 120°F.

For specific applications other than domestic use, it is recommended to provide flexibility in system to increase system temperature. For instance 180°F may be required for the commercial dishwasher application or above 130°F for infection control purpose in 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 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***
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

All showers and bath/shower combinations shall be protected from excessive mixed water temperature due to fluctuations in supply water flows/pressures or loss of the cold water supply. Protection shall be provided by thermostatic, pressure balancing, or combination control valves, which shall reduce or shut off the mixed water supply if unsafe conditions occur. Valves shall have an adjustable stop to limit the movement of the control handle toward the full hot position. Thermostatic control valves shall have a maximum limit setting of 120°F and shall be so arranged to resist tampering. Pressure balancing control valves shall be adjusted after installation to provide not more than 120°F outlet temperature with normal water pressures and temperatures available.

In single family dwelling units having individual water heaters, the protection may be provided by sizing the entire water distribution piping system serving the showers or bath/showers for a maximum flow velocity of 4 feet per second at the design flow rates. The temperature of water from tank less water heaters shall be controlled to permit not more that 140°F when intended for domestic uses.

Mixed Water Temperature Stability

Showerhead temperature stability requires stable hot & cold-water temperatures and a stable mix ratio of hot & cold water.

The expression below determines the relationship of temperature and mix ratio.

$$\text{RATIO \% HW} = \frac{\text{Mix (deg F)} - \text{CW (deg F)}}{\text{HW (deg F)} - \text{CW (deg F)}}$$

The ratio percentage of 140 °F required for mix with 40 °F CW to provide 100 °F mixed temperature can establish by the formula as below:

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

The most obvious problem concerning showerhead temperature stability is temperature of the entering hot service water and cold/hot water flow changes associated with varying pressure drop in distribution system. Minor ratio mix changes will cause mixed water temperature change; the ratio change to temperature change relationship is the order of 1°F temperature change per 1% flow mix ratio change per side or 1-1/2% total.

It is apparent that a combined fluctuation of both HW supply temperature and the flow mix ration can cause significant variation in mix temperature. Fortunately, these are usually not the 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.

The design of mix water application should be carefully evaluated in consultation with experienced plumber and could be stabilized by control of pressure drop. The following notes can be stressed concerning service water pressure drop relationships:

1) Sizing both cold and hot water piping to keep the pressure differential minimum at the point of use. The sudden changes in flow at fixture can cause discomfort and a possible scalding hazard. Use of pressure compensating device is recommended.

2) Distribution piping pressure drop should be minimized. Great care must be taken in cold water pipe sizing to guard against high-pressure drop changes. Cold-water distribution system particularly with flush valve type fittings is subject to wide pressure and flow variations.

3) Hot water side temperature control three-way mix valve pressure drop should be minimized. A high-pressure drop at 3-way valve can cause 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 individual or in combination as a shower mixing valve.

5) The assigned minimum feed line pressure drop should be to the order of 20psi (5psi allowable distribution piping pressure drop) and should be maximized, consistent with available pressure and long valve seat and disc life. A shower mix valve shall be specified for a total required showerhead flow rate so as to provide the order of 20psi pressure drop at that flow rate.

6) A showerhead requires a flow rate of 4 GPM @ 15psi pressure drop for good performance. Given an available static pressure of only 20psi in the distribution piping at the point of usage, only 5psi will be available for feed line pressure drop. Minor order distribution piping flow change will then cause 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.

SAFETY CONSIDERATIONS

It is essential to check with the regulatory code requirements and comply with the manufacturer’s instructions. In general, the following recommendations may be used as a guide.

1. To reduce risk of excessive pressures and temperatures in water heater, install temperature and pressure protective equipment required by local codes, but no less than a combination temperature and pressure (T&P) relief valve certified by a nationally recognized testing laboratory. T&P relief valves should be listed and labeled by the AGA, ANSI Z21.22 or ASME Boiler and pressure vessel code. The T&P relief valve shall have

a water discharge capacity equal to or exceeding the heat input rating of the water heater.

2. Do not install any valve between T&P relief valve and tank connection, or on T&P relief valve discharge piping. Do not plug T&P relief valve or discharge piping. Improper placement and piping of T&P relief valve can cause severe personal injury, death or substantial property damage.
3. A relief valve should be installed in any part of the system containing a heat input device that can be isolated by valves. The heat input device may be solar water heating panels, desuperheater water heaters, heat recovery devices or similar equipment. The valve must be marked with a maximum working pressure of the water heater and shall be set to prevent water temperature from exceeding 210° F.
4. Thermal expansion control devices limit the pressure that results when the water in the tank is heated and expands in a closed system. If a backflow preventer, check valve, or pressure reducing valve is piped on cold water inlet of water heater, you must install an expansion tank on cold water supply line to prevent normal thermal expansion from repeatedly forcing open T&P relief valve. The T&P relief valve is not intended for constant duty, such as relief of pressure due to repeated normal system expansion. Refer to expansion tank manufacturer’s instructions for proper sizing. Failure to follow the above could result in severe personal injury, death or substantial property damage. This shall not be required for instantaneous water heaters.
5. Temperature limiting devices (energy cutoff/high limit) prevent water temperatures from exceeding 210° F by stopping the flow of fuel or energy. These devices should be listed and labeled by underwriter’s laboratories (UL), the American Gas Association (AGA), or other recognized certifying agencies.
6. Install automatic air vent provided with water heater, using suitable pipe dope or tape.
7. Installation must conform to manufacturer’s instructions and also where applicable local, state, provincial, and national codes, laws, regulations and ordinances.
8. Most of hot water heaters are exempt from ASME Section VIII, Division 1 Code construction per Interpretation VIII-1-86-136. Check with local codes for applicability.
9. Installation location must provide adequate clearances for servicing and proper operation of the water heater. Zero clearance is permissible to either side of water heater, but the top (vertical) clearance is generally 12" minimum. Refer to manufacturer’s instructions.

10. Dishwashers, clothes washers, and fast-closing positive shutoff valves incorporated in the system all contribute to creating water shock. Install a water hammer arrester to prevent damage to pipes and appliances.

11. The Uniform Plumbing Code – Paragraphs L3.2 and L3.3 states that single-wall heat exchangers are permitted if they satisfy all of the following requirements —

    The heat transfer medium is potable water or contains only substances, which are recognized as safe by the U. S. Food and Drug Administration.

    The pressure of the heat transfer medium is maintained less than the normal minimum operating pressure of the potable water system.

12. Single wall heat exchanger in water heater complies with National Standard Plumbing Code, provided that:

    Boiler water (including additives) is practically non-toxic, having toxicity rating or class of 1, as listed in Clinical Toxicology of Commercial Products, and

    Boiler water pressure is limited to maximum 30 psig by approved relief valve.

13. Studies have indicated that dangerous bacteria, including legionella, pneumophila, can form in the potable water distribution system if certain minimum water temperatures are not maintained. Contact your local health department for more information.

14. Heaters are expected to leak at the end of their useful life. They should be placed where such leakage does not cause damage. Use drain pans pipes to drains.

15. Water heaters not requiring combustion air may generally be placed in any suitable location, as long as relief valve discharge pipes open to a safe location.

16. Water heaters requiring ambient combustion air must be located in areas with air opening large enough to admit the required combustion/dilution air.

17. For gas or oil fired water heaters located in areas where flammable vapors are likely to be present, additional precautions should be taken to eliminate the probable ignition of flammable vapors; check with requirements of NFPA standard 54, sections 5.1.9 through 5.1.12)

18. New hot water system installations in residential dwellings must provide hot water to fixtures and appliances used primarily for personal hygiene at a temperature not exceeding 120°C, to avoid the likelihood of scalding. An approved temperature flow control valve must be fitted.

19. *<u>Domestic water piping</u>*

- Union on domestic hot water outlet should be piped at a higher elevation than domestic water drain valve. This will make draining water heater easier.
- Install unions for easy removal of water heater. Use dielectric unions or couplings to protect hot and cold-water fittings from corrosion when connecting dissimilar materials such as copper and galvanized iron pipe.
- If copper pipe is used for domestic water connections, first solder pipe to a threaded adapter, and then screw adapter into cold-water inlet on top of water heater.
- When water supply pressure is higher than T&P relief valve rating, install a pressure-reducing valve on cold water supply line to prevent water loss through T&P relief valve.
- If water heater will replace tank less coil in boiler, disconnect piping to coil or remove coil from boiler and replace with a cover plate. Allow water to drain from coil. Do not plug tank less coil.
- Plugging tank less coil inlet and outlet will result in severe personal injury, death or substantial property damage.

19. *Boiler piping*
    - If plastic pipe is used for boiler water piping, it must have a maximum oxygen diffusion rate of 0.1 mg/liter-day for boiler and water heater protection.
    - Boiler water (including additives) must be practically non-toxic, having toxicity rating or class of 1, as listed in Clinical Toxicology of Commercial Products.
    - If antifreeze is used in boiler system, local codes may require a backflow preventer on cold water supply line. Use antifreeze specifically intended for hydronic heating systems. Inhibited propylene glycol is recommended.
    - Do not use automotive, ethylene glycol or petroleum-based antifreeze.
    - Do not use any undiluted antifreeze. This can cause severe personal injury, death or substantial property damage.
20. Hot water storage tanks must be equipped with a drain valve or other means of emptying the tank for periodic cleaning.
21. Hot water storage tanks shall be permanently marked in an accessible place with maximum allowable working pressure, in accordance with the applicable standard.

ENERGY EFFICIENCY

The installation and use of your hot water system has substantial influence on its running costs and life span. The information contained below is on good engineering practices and it is strongly recommended to consult the energy efficiency office and manufacturer's instructions when purchasing and installing the hot water system.

1) Water heaters of different sizes and insulation may have different standby losses, recovery efficiency, and thermal efficiency or energy factors.
2) All gas hot water systems display energy labels with star ratings for energy efficiency. At present electric water heaters do not carry energy rating labels but are required to meet minimum energy performance standards. The more stars, the more you save! The more stars (six is best), the less gas used and the lower the operating costs. When purchasing a new water heater, reach for the stars!
3) A distribution system must be properly designed, sized and insulated to deliver adequate water quantities at temperatures satisfactory for the uses served. This reduces system standby loss and improves hot water distribution efficiency
4) Controlling circulating pumps to operate only as needed to maintain proper temperature at the end of the main reduces losses on return lines. This improves overall system efficiency
5) Provision of shutdown of circulators during building vacancy reduces system standby losses.
6) Buying an energy efficient water heater that uses a low greenhouse impact fuel is a great start to a healthier environment.
7) With the exception of solar energy, every fuel that is used to heat water gives off gases, which contribute to the greenhouse effect.
8) Keep hot water pipe runs as short as possible to minimize the heat losses from pipes. Have your hot water system installed as close as possible to all points of hot water use. If this is not possible, locate it close to where small, regular amounts of hot water are required (usually the kitchen).
9) Heat traps between recirculation mains and infrequently used branch lines reduce convection losses to these lines and improve heater system efficiency.
10) Consider installing a low flow showerhead and other fixtures, or fit a flow-restricting valve to existing showerheads.

11) Some low flow showerheads are not compatible with some instantaneous hot water systems as they can restrict the flow of water to the extent that the hot water system turns off. Ensure you select a showerhead that is suitable for the flow rate from your hot water system.

12) Install solar hot water collector panels facing as close to north as possible.

13) If you decide on a storage hot water system, estimate your hot water needs as accurately as possible to ensure your tank is not oversized for your household.

14) Gas storage systems usually reheat water more quickly than electric storage systems. This means that the size of the storage tank can usually be smaller for gas hot water systems than electric hot water systems, without compromising your hot water requirements.

15) To save money with a storage system, set the thermostat to 140°F and ensure you know how to turn it off when you go away on holidays. The optimum water temperature for storage hot water systems is between 140-150°F, in the tank.

16) Adjust setting of the thermostat on electric storage units and check whether it is cutting in and off as per the set point. Some have electronic temperature controls, which can be adjusted from a control unit inside the house.

17) Install a timer on peak rate electricity storage units to control the maximum demand charges from the utility companies.

18) Electronic ignition uses a lot less energy over the year than a gas pilot light. Electronic ignition units use no gas at all when not being used. Avoid continuous flow systems with standing pilot lights.

19) 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.

20) For solar hot water systems, face solar collectors true north, and ensure they are inclined correctly.

21) Keep a 2" clearance between the hot and cold water lines.

22) Branches off the main hot water supply should be kept as short as possible.

23) Recirculation Systems:

    Studies have shown that recirculation loops are not energy efficient. Although it saves water, the energy costs can be very high. Circulating hot water slowly means that the water will re-enter the water heater at a lower temperature because of distribution losses.

The water heater will constantly cycle on and off during this recirculation process as it attempts to bring the water in the water heater up to its original temperature.

Recirculation systems typically run 24 hours per day. It is recommended to install an approved quality timer; or a thermostat; or running on both a timer and a thermostat. The water circulation pump may be controlled by a thermostat (in return line) set to start and stop the pump over an acceptable temperature range. An automatic time switch or other control should turn the water circulation off when hot water is not required for extended periods.

PART 5 Solar Water Heaters

Every household uses different amounts of hot water. How much you will save on your electricity bill by using solar hot water heating will depend on how you use the system, the size of your system and where you live. As a rule of thumb, you can expect to save up to 75% of your hot water bill by using solar energy.

System Sizing

Solar water heating systems are design to provide 60% to 80% of hot water demand year around. In order to determine the proper size of your solar heating system you must first estimate your daily demand of hot water, which your system must meet. Hot water demand varies with each individual living habit, but 15-20 gallon per person per day is a conservative estimate.

Rule of thumb sizing:

2-3 people with modest demand 50 gal.
3-5 people 65 gal.
4-6 people 80 gal.
Once daily hot water demand is calculated the total Sq-Ft. of the solar collectors can be determined by your geographical location and the panel's orientation to the sun. Typically one square foot of collector will heat up to 2 gallons of water in the Sun Belt area.

Components

Solar heaters have 3 primary components, the solar panel, solar storage tank and solar circulator. Solar systems can be categorized as active pumped recirculation systems and the passive systems. For pumped circulation, the solar panels can be mounted anywhere on the roof regardless of the relative height or position of the hot water cylinder. However, to keep heating losses to a minimum, it is advisable to keep the distance between the hot water cylinder and the solar panels to a minimum.

Passive (Thermo siphon) systems have the tank located slightly above the panel and use natural heat convection to circulate the water through the panel, removing heat and storing it in the tank. Passive systems have a slightly slower recovery rate than active systems and the supporting structure must be able to support the load of a tank full of water; (8.33 lbs/gal). Other Passive systems are called "Batch" or "Breadbox" Heaters and the "collector" and "storage" is combined into one.

Panels

The optimum number of panels for a building is dependent on how the hot water is used, the temperature at which hot water is kept in the cylinder, the size of the hot water cylinder, the orientation of the solar panels, and to a lesser extent, the geographic location of the system.

The following table gives typical rule of thumb installation sizes, which may slightly vary from place to place. For a properly designed panel, the collector area required is independent of the make of panel.

Number of occupants in household	Minimum collector area (m^2)	Hot water cylinder size (litres)
3	3.5	180
4	3.5 - 4.7	180 - 270
5	4.7	270
6	4.7+	270 - 360

Ideally, solar panels are mounted on a roof where no shading occurs (study winter shading patterns) angled at 12-22 deg. and facing within 15 deg of true south. The closer the angle of incidence to 90 degrees, the better the performance of the panel will be. Also, please realize that siting panels for maximal winter gain is ideal because winter is our coolest time of year and we have the least amount of sun, yet need the most hot water. If it is not possible to site solar panels in the most ideal configuration it may be necessary to increase the square footage of the solar array. A good ratio to size solar panels to is 2.5 gallons per square foot if the collector is ideally situated. To compensate for loss of efficiency due to a less ideal site, 2 gallons or less/square foot of collector area should be considered.

The panels pointing due north and set at an angle above the horizontal equal to the latitude of the system gives better summer performance than winter performance. The panels can be installed at a shallower angle (up to 20 degrees below the latitude angle) to improve summer performance even more, though at the expense of poor winter performance.

The orientation of the panels is critical for efficiency. The table below provides the multiplication factor to give the additional number of panels needed for non-optimum orientations to give the same performance as an optimum system. Where there are local weather conditions that predispose towards, say cloudy mornings, it is then useful to have the panels pointing more towards north-west rather than north.

.	.	Flat	Panel inclination				Vert.
Orientation E-W		0°	20°	40°	60°	80°	90°
West	270°	.	1.18	1.25	1.39	1.67	1.89
.	300°	Not	1.09	1.09	1.16	1.37	1.54
.	330°	Allowed	1.02	1.01	1.04	1.25	1.41
North	0°	.	1.03	1.00	1.06	1.25	1.43
.	30°	.	1.06	1.05	1.14	1.35	1.54
.	60°	.	1.14	1.16	1.30	1.54	1.75
East	90°	.	1.25	1.37	1.56	1.92	2.17

Storage Tanks

Solar storage tanks are larger than standard water heaters, better insulated, and usually have 1or 2 more ports for the solar loop connections. The larger storage will provide the homeowner with reserve capacity of hot water during periods of no or less sunshine. There are two ways to size the solar system. The first is to size to the potential population of a home, the 2nd is to the actual number of people living there.

Most solar storage tanks have a single 240V AC 4500-watt heating element, which should be on a dedicated breaker, but could simply be plugged into an outlet when required. If the solar system is properly sized the homeowner will rarely need to use the electric element to keep the water hot.

It is important to note that the solar hot water cylinder plays an important role in an effective solar hot water heating system. A specially designed hot water cylinder that is optimized for solar heating ensures that the supplementary electrical heating is kept to a minimum and that the element is not trying to heat the same water that the solar panels are also heating.

The solar hot water system should only be connected to stainless steel "mains pressure" hot water cylinders: many high pressure cylinders are of enamel coated steel construction that can suffer from micro-fractures at water temperatures above 80°C. This temperature can be easily be attained in summer. The storage tank could have a glass lining and an anode rod for maximum corrosion protection. Its internal manifold provides even distribution of heat; injected foam insulation minimizes heat loss.

When to Install?

A particularly good time to install solar is when the building is under construction. Installation costs can be kept to a minimum by plumbing and wiring the system before the wall coverings are put up.

An initial investment in solar water heating systems range $1,000 - $3,000 depending on your hot water requirements. This initial investment is higher than regular electric or gas water heaters but the cost of the solar water heating system is lower in the long run since your system will use an energy source that is free

Quality components coupled with good design and thoughtful conscientious installation will provide the owner with excellent Return on Investment and minimal maintenance.

PART 6 General Information & Terminology

What size?

Hot water systems must be sized to meet your hot water requirements. This is typically reflected by the number of people in the household. The following tables can be used as guide to sizing hot water systems, however, consult your supplier for specific local recommendations.

ELECTRIC STORAGE HOT WATER SYSTEM			
Off-Peak		**Peak Rate**	
Number of Persons Served	*Capacity (liters)*	*Number of Persons Served*	*Capacity (liters)*
1-3	*160*	*1*	*25*
2-4	*250*	*1-2*	*50*
3-6	*315*	*2-3*	*80*
5-8	*400*	*3-5*	*125*

NATURAL GAS & LPG WATER HEATERS			
Storage		**Continuous Flow**	
Number of Persons Served	*Capacity (liters)*	*Number of outlets served at one time**	*Capacity (liters)*
1-3	*90*	*1*	*16*
2-4	*130*	*2*	*20*
3-5	*170*	*2-3*	*24*
4-6	*200*	*3+*	*32*
5-9	*260*		

*** Continuous flow systems are sized according to the required flow rate.**

SOLAR HOT WATER SYSTEM			
Number of Persons Served	*Hot Water Delivery (liters per day)*	*Approximate Size of Tank (liters)*	*Collector (sq-m)*
1-2	*120*	*180*	*2*
3-4	*200*	*300*	*4*
5-6	*300*	*440*	*6*

(Note 1USgallon = 3.79 liters)

Terminology

Recovery Efficiency: Heat absorbed by the water divided by the heat input to the heating unit during the period that water temperature is raised from inlet temperature to the final temperature.

Thermal Efficiency: Heat in the water flowing from the heater outlet divided by the heat input of the heating unit over a specific period of steady-state conditions.

Energy Factor: An indicator of the overall efficiency of a residential storage water heater representing heat in the estimated daily quantity of delivered hot water divided by the daily energy consumption of the water heater.

First hour rating: The amount of hot water that the water heater can supply in one hour of operation, starting with the tank full of heater water.

Standby loss: The amount of heat lost from the water heater during periods of no use of service hot water.

Hot water distribution efficiency: Heat contained in the water at point of use divided by the heat delivered at the heater outlet at a given flow

Heater/system efficiency: Heat contained in the water at points of use divided by the heat input to the heating unit at a given flow rate (thermal efficiency times distribution efficiency)

Overall system efficiency: Heat in the water delivered at points of use divided by the heat supplied to the heater for any selected time period

System standby loss: The amount of heat lost from the water heating system and the auxiliary power consumed during periods of no use of serving hot water.

BTU Content of Various Fuels

Fuel	Amount	BTU
Coal	1pound	10,000 - 15,000
Coal	1 ton	25,000,000
Electricity	1 kilowatt	3,412
#2 Oil	1 gallon	138,500
Butane	1 pound	21,300
Butane	1 gallon	102,600
Butane	1 cubic foot	3,260
Natural Gas	1 cubic foot	1,000
Propane	1 pound	21,600
Propane	1 gallon	91,000
Propane	1 cubic foot	2,570

Useful Equations

1 BTU will raise 1 pound or 0.12 gallons of water 1°F

Natural Gas

- ✓ 1 psi = 28" water column
- ✓ 1 psi = 16 ounces
- ✓ 1psi = 2.036 inches of mercury
- ✓ BTU/Hr Input = Q x 60 x p x cp x delta T

Where Q is the flow rate in gpm, p is density of water (8.33 lb/gal), cp is specific heat of water (1Btu/lb-°F) and delta T is temperature rise (°F). Divide by heat value of fuel to get the quantity of gas.

Electric

- ✓ kW = GPH x 8.3 x Temperature Rise (deg F)/ 3413
- ✓ 1kW = 3413 Btu/h
- ✓ 1USgallon = 3.79 liters