Domestic Water Heating Systems

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Note: In determining your answers to the CE questions, use only the material presented in the corresponding continuing education article. Using information from other materials may result in a wrong answer.

Properly designing the domestic hot water supply system for any building is extremely important to ensure a safe and adequate supply of hot water as well as conformance to all applicable codes plus the regulations of the authority having jurisdiction (AHJ). A properly designed domestic hot water distribution system should do the following:

- Provide adequate amounts of water at the prescribed temperature to all fixtures and equipment at all times of use.
- Perform its designed function safely.
- Utilize an economical heat source.
- Provide a cost-effective, efficient, and durable installation.
- Provide an economical operating system with reasonable maintenance.
- Minimize risk to those using the fixtures it serves.

A well-designed system delivers hot water at the prescribed temperature to the outlet with very little delay, thereby satisfying the users and avoiding the wasteful running of water until the desired temperature is achieved. Hot water should be available at any time of use, day or night, and during low-demand periods as well as peak flows. Plumbing codes provide some guidance here; for example, per the 2012 Uniform Plumbing Code, Section 607.2, hot water dead-end legs should be 50 feet or shorter. However, the minimum code requirements may be unsatisfactory to users. The balance between near-instantaneous hot water delivery and incremental project cost also must be maintained.

Safety must be built into any hot water system, and plumbing codes require specific methods that must be used to achieve certain levels of safety. National standards recommend additional methods, which, while not having the force of law, nevertheless are accepted as good engineering design practices.

The three paramount dangers that must be guarded against are excessive pressure, excessive temperature, and contamination. Excessive temperatures and pressures are avoided by using correctly sized temperature and pressure (T&P) relief valves at water heaters. Where check valves are present, as on hot water circulation systems and backflow preventers, thermal expansion tanks are to be used. The risk of scalding and thermal shock can be reduced by using many types of mechanical, pressure-balanced, or thermostatic mixing valves, installed at the hot water source and/or the point of use.

As with the domestic cold water system, water hammer arresters should be used to mitigate anticipated pressure spikes at quick-closing solenoid-operated valves. Strategically placed pressure gauges and thermometers, which may be wired back to the building automation system (BAS), allow easy monitoring of the system.

Contamination of the domestic hot water system is prevented by many of the same methods used with the domestic cold water system. Cross-contamination is prevented by using appropriately selected backflow preventers for both hazard type and temperature. Double-wall heat exchangers are required for use with indirect-fired water heaters.

Warm water, such as that present in dead-end legs, low-temperature circulating loops, and storage-type water heaters at low temperatures, provides the ideal environment for waterborne bacterial growth. Legionella pneumophila, which experience growth amplification at temperatures between 77°F and 108°F (25°C and 42°C), are of particular concern. Thus, health concerns from waterborne bacterial growth must be considered in all hot water designs. Waterborne bacterial control measures should be included in the design whenever hot water is supplied to high-risk occupancies, such as hospitals or nursing homes. It is also good engineering practice to address waterborne bacterial control in hotels. Again, the designer must balance the need for reasonable public safety with excessive project costs.

An economical heat source will save on energy costs. Typical energy sources include natural gas, liquefied petroleum gas, oil, electricity, steam, boiler hot water (hydronics), waste heat, and solar thermal. The availability and cost of any of these sources or combinations of these sources dictate equipment and system selection. Where an especially economical energy source is available but not adequate to satisfy the total demand, it might be used to preheat the cold water supply to the heater.

A cost-effective and durable installation begins with the judicious selection of the proper materials and equipment. As with the domestic cold water system, the pipe materials and layout, joining methods, hangers, and insulation all must match the project's needs and will determine the cost as well as the ease of replacement and repair.

An economical operating system with reasonable maintenance depends on all of these considerations. The location of piping, ease of circulation, bypasses around source and mechanical equipment, adequate valve placement, accessibility, and provisions for the future all are items affecting the operation and maintenance of a system.

Finally, extra capacity and redundancy need to be tailored to each application.

CODES AND STANDARDS

The need to conform to various codes and standards determines many aspects of the design of a domestic hot water system as well as the selection of components and equipment.

Some of the most often used codes and standards follow:

- Regional, state, and local plumbing codes

- ANSI/ASHRAE/IES 90.1: *Energy Standard for Buildings Except Low-Rise Residential Buildings*
- ASHRAE Guideline 12: *Minimizing the Risk of Legionellosis Associated with Building Water Systems*
- International Boiler and Pressure Vessel Code
- CSA/ANSI Z21.22: *Relief Valves for Hot Water Supply Systems*
- Underwriters Laboratories (UL) listings for electrical components
- NSF International listings
- American Gas Association (AGA) listings for gas-burning components
- National Fire Protection Association (NFPA) standards
- NFPA 70: National Electrical Code
- ASSE International standards

In addition, the federal government, agencies with jurisdiction over public schools and public housing, and many other agencies have specific requirements that must be observed when designing projects and selecting equipment.

DOMESTIC WATER HEATER SIZING

Sizing a domestic water heater is as much an art as a science. For anything other than a small residential system, it is not reasonable to simply go to a table or chart and make a selection. Codes do not indicate how much hot water is required. Instead, they contain only generalizations such as "Provide adequate amounts of hot and cold water to all sinks, lavatories, showers, etc." Codes do, however, provide information about minimum and maximum flow rates to fixtures and address safety concerns such as maximum temperatures and required water heater safety devices.

The design of a domestic water-heating system begins with estimating the facility's load profile and identifying the peak demands. To accomplish these steps, you must talk to the users of the space, determine the building type, gather fixture and equipment information, and learn any owner requirements. The information thus gathered will establish the required capacity of the water-heating equipment and the general type of system to be used.

A number of factors must be considered when sizing a system, and experience plays a big part. Every system is different, so the path that leads to final selection varies for each system. Two buildings might have the same number and type of fixtures, but the water requirements could be vastly different. For instance, an apartment building for retired people would have different hot water needs than one that primarily houses families or college students.

To help with sizing, water heater manufacturers maintain substantial sizing guidelines and instructional manuals, all kept current with industry standards and trends.

Information Gathering

The first step to sizing a domestic hot water system is to collect the information needed to define the system parameters. Some of the information will be readily available, already gathered as part of the domestic cold water system design, but some may require further investigation. Following is a partial list of sample questions.

- In what type of building will the system be installed?
- Where is the building located?
- What codes should be followed?
- Do any local code amendments apply?
- Does the owner or operator of the building have any unusual requirements?
- Does the owner or operator of the building prefer a particular type of system?
- How much system redundancy does the owner or operator of the building want?
- Does the building have any other hot water systems?
- What area of the building will the system serve?
- What is the area used for?
- How many plumbing fixtures will be installed?
- Who will be using the plumbing fixtures?
- Are any high-usage fixtures, such as hot tubs, included?
- Does the owner plan to expand the facility in the future?
- Does the building include laundry, foodservice, or health club areas?
- How many areas will be used simultaneously?
- How much space is available for the system?
- What energy sources are available?
- Where in the building will the equipment be placed?
- Will flues or combustion air be a problem due to the location?
- What is the building's cold water source?
- What are the water hardness, pH, total dissolved solids, and other water quality parameters?
- Will the system be inactive for long periods?
- How far from the heater will the furthest fixture be?
- How many showers will be used simultaneously and for what duration?

Water Heater Sizing Methods

With the correct information gathered, the load profile and peak demand can be calculated. Once again, this is not necessarily a straightforward process. Several methods for calculating the load of a building are available, and one method is not always better than another. Two methods from the American Society of Plumbing Engineers (ASPE) are outlined here. Other methods are available from other societies, government sources, and water heater manufacturers, and they are valuable resources as they include building types not addressed by the following two methods. Some owners, and notably government projects, prescribe which method should be used.

Method 1: Average Hourly Demand

The first method utilizes average hourly data in gallons per hour (gph) (liters per hour) for various types of buildings and occupancies. The sizing chart is shown in Table 6-1. To calculate using this method, count the fixtures, multiply the number of fixtures by the gallons per hour (L/h) for the fixture in the particular type of building, and add them. Then multiply this total by the simultaneous usage factor to get the maximum hourly demand for the system. The minimum recommended storage volume then is calculated by multiplying the total demand by the storage factor. This is a simple method, but it has limitations:

- It can be applied only to the types of facilities listed.
- It can be used only for the sizing of storage tank systems.
- It does not consider the types of occupants.
- It does not address high-use or high-volume fixtures.

Table 6-1 Hot Water Demand per Fixture for Various Types of Buildings at a Final Temperature of 140°F (60°C), gph (L/h)

Fixture	Apartment	Club	Gymnasium	Hospital	Hotel	Industrial Plant	Office	Private Residence	School	YMCA
Basins, private lavatory	2 (7.6)	2 (7.6)	2 (7.6)	2 (7.6)	2 (7.6)	2 (7.6)	2 (7.6)	2 (7.6)	2 (7.6)	2 (7.6)
Basins, public lavatory	4 (15)	6 (23)	8 (30)	6 (23)	8 (30)	12 (45.5)	6 (23)		15 (57)	8 (30)
Bathtubs	20 (76)	20 (76)	30 (114)	20 (76)	20 (76)		20 (76)		30 (114)	
Dishwashers[a]	15 (57)	50-150 (190-570)		50-150 (190-570)	50-200 (190-760)	20-100 (76-380)		15 (57)	20-100 (76-380)	20-100 (76-380
Foot basins	3 (11)	3 (11)	12 (46)	3 (11)	3 (11)	12 (46)		3 (11)	3 (11)	12 (46)
Kitchen sink	10 (38)	20 (76)		20 (76)	30 (114)	20 (76)	20 (76)	10 (38)	20 (76)	20 (76)
Laundry, stationary tubs	20 (76)	28 (106)		28 (106)	28 (106)		20 (76)		28 (106)	
Pantry sink	5 (19)	10 (38)		10 (38)	10 (38)		10 (38)	5 (19)	10 (38)	10 (38)
Showers	30 (114)	150 (568)	225 (850)	75 (284)	75 (284)	225 (850)	30 (114)	30 (114)	225 (850)	225 (850)
Service sink	20 (76)	20 (76)		20 (76)	30 (114)	20 (76)	20 (76)	15 (57)	20 (76)	20 (76)
Hydrotherapeutic showers				400 (1,520)						
Hubbard baths				600 (2,270)						
Leg baths				100 (380)						
Arm baths				35 (130)						
Sitz baths				30 (114)						
Continuous-flow baths				165 (625)						
Circular wash sinks				20 (76)	20 (76)	30 (114)	20 (76)		30 (114)	
Semicircular wash sinks				10 (38)	10 (38)	15 (57)	10 (38)		15 (57)	
Demand factor	0.30	0.30	0.40	0.25	0.25	0.40	0.30	0.30	0.40	0.40
Storage capacity factor[b]	1.25	0.90	1.00	0.60	0.80	1.00	2.00	0.70	1.00	1.00

[a]Dishwasher requirements should be taken from this table or from manufacturers' data for the model to be used, if this is known.
[b]Ratio of storage tank capacity to probable maximum demand per hour. Storage capacity may be reduced where an unlimited supply of steam is available from a central street steam system or large boiler plant.
Source: 2011 ASHRAE Handbook—HVAC Applications
Note: Data predates low-flow fixtures.

Method 2: Occupancy Type

The second method of calculating hot water usage is outlined in *Domestic Water Heating Design Manual*. It addresses specific occupancies (see Tables 6-2 and 6-3) and tailors the calculation process to the type of building. A separate method for calculating the load for each building type is based on a building's individual operating characteristics. Not all types of facilities are addressed, but those that are can be accurately calculated

Table 6-3 Hot Water Demand and Use for Multifamily Buildings, gal (L)/person

Demand	Peak 5 Minutes	Peak 15 Minutes	Peak 30 Minutes	Maximum per Hour	Maximum 2 Hours	Maximum 3 Hours	Maximum Day	Average Day
Low	0.4 (1.5)	1.0 (4.0)	1.7 (6.5)	2.8 (10.5)	4.5 (17.0)	6.1 (23.0)	20.0 (76.0)	14.0 (54.0)
Medium	0.7 (2.6)	1.7 (6.4)	2.9 (11.0)	4.8 (18.0)	8.0 (31.0)	11.0 (41.0)	49.0 (185.0)	30.0 (113.6)
High	1.2 (4.5)	3.0 (11.5)	5.1 (19.5)	8.5 (32.5)	14.5 (55.0)	19.0 (72.0)	90.0 (340.0)	54.0 (205.0)
Note: These volumes are for domestic hot water delivered to the tap at 120° F (49° C).								

using this method. It can be used to establish the sizing for systems using a storage tank, instantaneous heater, or semi-instantaneous heater. It also addresses additional concerns such as high-usage and high-volume fixtures.

Table 6-2 Occupant Demographic Classifications

No occupants work Public assistance and low income (mix) Family and single-parent households (mix) High percentage of children Low income	High demand
Families Public assistance Singles Single-parent households	Medium demand
Couples High population density Middle income Seniors One person works, one stays home All occupants work	Low demand

BASIC FORMULAS AND UNITS

The equations in this chapter are based on the principle of energy conservation. The fundamental formula for this expresses a steady-state heat balance for the heat input and output of the system.

Equation 6-1

$$q = r\, w\, c\, \Delta T$$

where

q = Time rate of heat transfer, British thermal units per hour (Btuh) (kilojoules per hour)
r = Flow rate, gph (L/h)
w = Weight of heated water, pounds (kilograms)
c = Specific heat of water, Btu per pound per °F (kilojoules per kilograms per °K)
ΔT = Change in heated water temperature: temperature of leaving water minus temperature of incoming water, represented as Th – Tc, °F (°K)

For purposes of this discussion, the specific heat of water is constant, c = 1 Btu/lb/°F (c = 4.19 kJ/kg/°K), and the weight of water is constant at 8.33 lb/gal (999.6 kg/m^3).

Equation 6-2

$$q = \text{gph}\ \left(\frac{1\ \text{Btu}}{\text{lb/°F}} \times \frac{8.33\ \text{lb}}{\text{gal}} \times \Delta T\right)$$

$$\left[\ q = \frac{m^3}{h}\left(\frac{4.188\ \text{kJ}}{\text{kg/°K}} \times \frac{999.6\ \text{kg}}{m^3} \times \Delta T\right)\ \right]$$

Example 6-1

Calculate the heat output rate required to heat 600 gph from 50°F to 140°F (2.27 m^3/h from 283.15°K to 333.15°K).

From Equation 6-2,

$$q = 600\ \text{gph}\ \left(\frac{8.33\ \text{Btu}}{\text{gal /°F}} \times [140 - 50°\text{F}]\right) = 449{,}820\ \text{Btu/h}$$

$$\left[\ q = 2.27\ m^3/h\ \left(\frac{4{,}188.32\ \text{kJ}}{m^3/°K} \times [333.15 - 283.15°\text{K}]\right) = 475{,}374\ \text{kJ/h}\right]$$

Note: You should be aware that water heaters installed in high elevations must be derated based on the elevation. The water heater manufacturer's data should be consulted for information on the required modifications.

HEAT RECOVERY—ELECTRIC WATER HEATERS

It takes 1 Btu of energy to raise one pound of water 1°F. Since 1 kilowatt is equal to 3,413 Btu and 1 gallon of water weighs 8.33 pounds, then it would take 1 kilowatt of electrical power to raise 410 gallons (1,552.02 L) of water 1°F. This can be expressed in a series of formulas, as follows:

Equation 6-3

$$\frac{410\ \text{gal}}{\Delta T} = \text{gal of water per kW at } \Delta T$$

$$[\frac{1,552.02 \text{ L}}{\Delta T} = \text{L of water per kW at } \Delta T]$$

Equation 6-4

$$\frac{\text{gph} \times \Delta T}{410 \text{ gal}} = \text{kW required}$$

$$[\frac{1,552.02 \text{ L}}{\Delta T} = \text{kW required}]$$

Equation 6-5

$$\frac{\text{gph}}{\text{gal of water per kW at } \Delta T} = \text{kW required}$$

$$[\frac{\text{L/h}}{\text{L of water per kW at } \Delta T} = \text{kW required}]$$

where

ΔT = Temperature rise (temperature differential), °F (°C)

gph = Gallons per hour of hot water required

L/h = Liters per hour of hot water required

Equation 6-3 can be used to establish a simple table based on the required temperature rise (see Table 6-4), which can be used with Equation 6-5 to solve for the electric element (in kilowatts) needed to heat the required recovery volume of water.

Example 6-2

An electric water heater must be sized based on the following information:

- 40 gph (151.42 L/h) of hot water at a temperature of 140°F (60°C) is required.
- The incoming water supply during winter is 40°F (4°C).

Using Equation 6-5 and Table 6-4:

$$\frac{40 \text{ gph}}{4.1 \text{ gal } (100°\text{F})} = 9.8 \text{ kW required}$$

$$[\frac{151.42 \text{ L/h}}{15.52 \text{ L } (38°\text{C})} = 9.8 \text{ kW required}]$$

Table 6-4 Required Temperature Rise

Temperature Rise, ΔT, °F (°C)	Gal (L) of Water per kW
110 (43)	3.73 (14.12)
100 (38)	4.10 (15.52)
90 (32)	4.55 (17.22)
80 (27)	5.13 (19.42)
70 (21)	5.86 (22.18)
60 (16)	6.83 (25.85)
50 (10)	8.20 (31.04)
40 (4)	10.25 (38.8)

HOT WATER TEMPERATURE

The generally accepted minimum hot water temperatures for various plumbing fixtures and equipment are given in Table 6-5. Both temperature and pressure should be verified with the client and checked against local codes and the equipment manuals.

Table 6-5 Typical Hot Water Temperatures for Plumbing Fixtures and Equipment

Use	Temperature, °F (°C)
Sink, handwashing	105 (40)
Sink, shaving	115 (45)
Showers and tubs	110 (43)
Therapeutic baths	95 (35)
Sink, surgical scrubbing	110 (43)
Commercial and institutional laundry	140–180 (60–82)
Residential dishwashing and laundry	120 (48)
Commercial, spray-type dishwashing, single- or multiple-tank hood or rack type, wash	150 min. (66 min.)
Commercial, spray-type dishwashing, single- or multiple-tank hood or rack type, final rinse	180–195 (82–91)
Commercial, spray-type dishwashing, single-tank conveyor type, wash	160 min. (71 min.)
Commercial, spray-type dishwashing, single-tank conveyor type, final rinse	180–195 (82–91)
Commercial, spray-type dishwashing, single-tank rack or door type, single-temperature wash and rinse	165 min. (74 min.)
Commercial, spray-type dishwashing, chemical sanitizing glassware, wash	140 (60)
Commercial, spray-type dishwashing, chemical sanitizing glassware, rinse	75 min. (24 min.)
Note: Be aware that temperatures, as dictated by codes, owners, equipment manufacturers, or regulatory agencies, occasionally will differ from those shown.	

MIXED WATER TEMPERATURE

Frequently, higher-temperature hot water must be blended with cold or cooler-temperature water to obtain a desired mixed water temperature. In such a case it is useful to have a quick method for determining the relative volumes of all three water temperatures involved.

In Equation 6-6, P is a hot water ratio, or multiplier, and it can be used to determine the percentage of supply hot water that will blend with the cooler water to produce a desired mixed water temperature.

Equation 6-6

$$P = \frac{T_m - T_c}{T_h - T_c}$$

where

P = Hot water ratio, unitless

T_h = Supply hot water temperature, °F (°C)

T_c = Inlet cold water temperature, °F (°C)

T_m = Desired mixed water temperature, °F (°C)

Values of P for a range of hot and cold water temperatures are given in Table 6-6.

Table 6-6 Hot Water Multiplier, P

110°F (43°C) Hot Water System Temperature				
Cold Water Temperature, °F °C)	Water Temperature at Fixture Outlet, °F (°C)			
	110 (43)	105 (41)	100 (38)	95 (35)
45 (7)	1.0	0.92	0.85	0.77
50 (10)	1.0	0.92	0.83	0.75
55 (13)	1.0	0.91	0.82	0.73
60 (16)	1.0	0.90	0.80	0.70
65 (18)	1.0	0.89	0.78	0.67

120°F (49°C) Hot Water System Temperature						
Cold Water Temperature, °F °C)	Water Temperature at Fixture Outlet, °F (°C)					
	120 (49)	115 (46)	110 (43)	105 (41)	100 (38)	95 (35)
45 (7)	1.0	0.93	0.87	0.80	0.73	0.67
50 (10)	1.0	0.93	0.86	0.79	0.71	0.64
55 (13)	1.0	0.92	0.85	0.77	0.69	0.62
60 (16)	1.0	0.92	0.83	0.75	0.67	0.58
65 (18)	1.0	0.91	0.82	0.73	0.64	0.55

130°F (54°C) Hot Water System Temperature								
Cold Water Temperature, °F °C)	Water Temperature at Fixture Outlet, °F (°C)							
	130 (54)	125 (52)	120 (49)	115 (46)	110 (43)	105 (41)	100 (38)	95 (35)
45 (7)	1.0	0.94	0.88	0.82	0.76	0.71	0.65	0.59
50 (10)	1.0	0.94	0.88	0.81	0.75	0.69	0.63	0.56
55 (13)	1.0	0.93	0.87	0.80	0.73	0.67	0.60	0.53
60 (16)	1.0	0.93	0.86	0.79	0.71	0.64	0.57	0.50
65 (18)	1.0	0.92	0.85	0.77	0.69	0.62	0.54	0.46

140°F (60°C) Hot Water System Temperature										
Cold Water Temperature, °F °C)	Water Temperature at Fixture Outlet, °F (°C)									
	140 (60)	135 (58)	130 (54)	125 (52)	120 (49)	115 (46)	110 (43)	105 (41)	100 (38)	95 (35)
45 (7)	1.0	0.95	0.89	0.84	0.79	0.74	0.68	0.63	0.58	0.53
50 (10)	1.0	0.94	0.89	0.83	0.78	0.72	0.67	0.61	0.56	0.50
55 (13)	1.0	0.94	0.88	0.82	0.76	0.71	0.65	0.59	0.53	0.47
60 (16)	1.0	0.94	0.88	0.81	0.75	0.69	0.63	0.56	0.50	0.44
65 (18)	1.0	0.93	0.87	0.80	0.73	0.67	0.60	0.53	0.47	0.40

Table 6-6 Hot Water Multiplier, P (continued)

150°F (66°C) Hot Water System Temperature

Cold Water Temperature, °F °C)	Water Temperature at Fixture Outlet, °F										
	150 (66)	145 (63)	140 (60)	135 (58)	130 (54)	125 (52)	120 (49)	115 (46)	110 (43)	105 (41)	100 (38)
45 (7)	1.0	0.95	0.90	0.86	0.81	0.76	0.71	0.67	0.62	0.57	0.52
50 (10)	1.0	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50
55 (13)	1.0	0.95	0.89	0.84	0.79	0.74	0.68	0.63	0.58	0.53	0.47
60 (16)	1.0	0.94	0.89	0.83	0.78	0.72	0.67	0.61	0.56	0.50	0.44
65 (18)	1.0	0.94	0.88	0.82	0.76	0.71	0.65	0.59	0.53	0.47	0.41

160°F (71°C) Hot Water System Temperature

Cold Water Temperature, °F °C)	Water Temperature at Fixture Outlet, °F										
	160 (71)	155 (68)	150 (66)	145 (63)	140 (60)	135 (58)	130 (54)	125 (52)	120 (49)	115 (46)	110 (43)
45 (7)	1.0	0.96	0.91	0.87	0.83	0.78	0.74	0.70	0.65	0.61	0.57
50 (10)	1.0	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64	0.59	0.55
55 (13)	1.0	0.95	0.90	0.86	0.81	0.76	0.71	0.67	0.62	0.57	0.52
60 (16)	1.0	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50
65 (18)	1.0	0.95	0.89	0.84	0.79	0.74	0.68	0.63	0.58	0.53	0.47

180°F (82°C) Hot Water System Temperature

Cold Water Temperature, °F °C)	Water Temperature at Fixture Outlet, °F										
	180 (82)	175 (79)	170 (77)	165 (74)	160 (71)	155 (68)	150 (66)	145 (63)	140 (60)	135 (58)	130 (54)
45 (7)	1.0	0.96	0.93	0.89	0.85	0.81	0.78	0.74	0.70	0.67	0.63
50 (10)	1.0	0.96	0.92	0.88	0.85	0.81	0.77	0.73	0.69	0.65	0.62
55 (13)	1.0	0.96	0.92	0.88	0.84	0.80	0.76	0.72	0.68	0.64	0.60
60 (16)	1.0	0.96	0.92	0.88	0.83	0.79	0.75	0.71	0.67	0.63	0.58
65 (18)	1.0	0.96	0.91	0.87	0.83	0.78	0.74	0.70	0.65	0.61	0.57
110 (43)	1.0	0.93	0.86	0.79	0.71	0.64	0.57	0.50	0.43	0.36	0.29
120 (49)	1.0	0.92	0.83	0.75	0.67	0.58	0.50	0.42	0.33	0.25	0.17
130 (54)	1.0	0.90	0.80	0.70	0.60	0.50	0.40	0.30	0.20	0.10	—
140 (60)	1.0	0.88	0.75	0.63	0.50	0.38	0.25	0.13	—	—	—
150 (66)	1.0	0.83	0.67	0.50	0.33	0.17	—	—	—	—	—
160 (71)	1.0	0.75	0.50	0.25	—	—	—	—	—	—	—

Example 6-3

A group of showers requires 25 gallons per minute (gpm) (1.58 liters per second) of 105°F (41°C) mixed water temperature. Determine how much 140°F (60°C) hot water must be supplied to the showers when the cold water temperature is 50°F (10°C).

$$P = \frac{105 - 50°F}{140 - 50°F} = 0.61$$

$$\left[\ P = \frac{41 - 10°C}{60 - 10°C} = 0.61\right]$$

Therefore, 0.61 (25 gpm) = 15.25 gpm of 140°F water required [0.61 (1.58 L/s) = 0.96 L/s of 60°C water required]. Table 6-3 also may be used to determine P.

WATER HEATERS

Many types of domestic water heaters are available. The most commonly used type of water heater for homes, office buildings, multiple-unit dwellings, and similar establishments is the direct-fired automatic storage water heater. Such heaters are simple, inexpensive to install, and low maintenance. They generally have a low Btu input, with the heating of the water spread over the design hour. Commonly used energy sources include electricity, fuel oil, and natural gas.

Instantaneous-type (also called tankless) water heaters must have sufficient capacity to provide the maximum instantaneous flow rate of hot water. Historically, a gas-fired instantaneous heater finds its best application where water-heating demands are constant, such as swimming pools, certain dishwasher booster requirements, and industrial processes, but currently available models have much improved electronic modulating control. They also are beneficial where space conditions are a prime consideration. Instantaneous water heaters have near zero standby losses.

Booster heaters are used to raise the temperature of the regular hot water supply to some higher-than-normal temperature needed to perform special functions. Booster heaters are utilized in applications such as commercial dishwashers and sterilizers with a limited use of very hot water. They can be located near their point of intended use and have simple controls.

Semi-instantaneous heaters contain approximately 10 to 20 gallons of storage, varying according to their rated heating capacity. This small quantity of water is adequate to allow the temperature control system to react to sudden fluctuations in water flow and to maintain the outlet water temperature within ±5°F (2.7°C). The temperature control system is almost always included with this type of heater as a package.

Indirect-fired water heaters, including solar thermal systems, have the advantage of physically separating the production of the necessary heating energy (e.g., boiler or solar collector) from the hot water storage tank. This modular design permits efficient and economical servicing. Copper-type heat exchanger boilers can be used in conjunction with a storage tank when a high-temperature circulating loop is used to prevent condensation, taking advantage of copper's superior thermal efficiency. Steam indirect-fired water heaters generally are used where large quantities of hot water are needed and they can efficiently tap into the building's steam supply.

Controls

The purpose for having controls on a hot water generator is to ensure a safe and sufficient volume of hot water at the desired temperature. Water heater controls are provided by the equipment manufacturer. The control components for water heaters differ depending on the type of heater and the manufacturer, and acceptable outlet temperature variations differ as well. Also, the various regulatory and testing agencies have requirements for controls that depend on the size and type of equipment used.

The distinction between water heater outlet temperature and plumbing fixture delivery temperature is critical. ASSE 1017: *Performance Requirements for Temperature Actuated Mixing Valves for Hot Water Distribution Systems* addresses source distribution temperature requirements, and other ASSE standards apply to the various plumbing fixtures. Three primary ASSE standards addressing fixture delivery temperature include ASSE 1016/ASME A112.1016/CSA B125.16: *Performance Requirements for Automatic Compensating Valves for Individual Showers and Tub/Shower Combinations,* ASSE 1069: *Performance Requirements for Automatic Temperature Control Mixing Valves,* and ASSE 1070: *Performance Requirements for Water Temperature Limiting Devices.* ASSE 1071: *Performance Requirements for Temperature Actuated Mixing Valves for Plumbed Emergency Equipment* was published in 2012 for emergency eyewashes, face washes, and drench showers.

Stratification in Storage-Type Heaters and Tanks

Because of its light density, warm water rises to the top of a storage tank. The result of this rising action, known as stratification, occurs in all uncirculated tanks. It has been found that the amount of usable water in stratified horizontal and vertical tanks could be as low as 65 percent and 75 percent respectively, depending on the design.

Stratification during recovery periods can be reduced significantly by mechanical circulation of the water in the tank. During periods of high demand, however, it might be useful to have stratification since this increases the availability of water at a usable temperature. For example, if a tank were equally stratified between 140°F (60°C) at the top and 40°F (4°C) at the bottom, this tank, in theory, could still deliver half its volume at 140°F (60°C). If the two layers were completely mixed, the tank temperature would drop to 90°F (32°C), which in most cases is an unusable temperature.

HOT WATER TEMPERATURE MAINTENANCE

Hot water of a desired temperature should be readily available at any fixture. Hot water supply piping transmits heat to the surrounding lower-temperature air by conduction, convection, and radiation. Insulation reduces but does not eliminate this heat loss. In large systems, if the heat loss is not addressed, users may become frustrated waiting for the desired temperature water. Water is wasted, and the associated energy and wastewater utility costs are incurred. This is particularly true in systems using low-flow and electronic faucets where the wait time can be very long.

Two common methods used to achieve satisfactory remote temperature maintenance include a hot water circulation system or a self-regulated electrically heated system. Hybrid circulation and heat trace systems may be used as well.

Standards and Codes

There is little regulation regarding circulation and heat-trace systems. The two aspects of systems most often referenced are the system temperature and the volume of hot water between the main and the fixture.

Table 6-7 provides limitations based on the volume of water from the temperature-maintained piping to the fixtures. This is potentially the amount of cold water that will be discharged before hot water arrives.

Table 6-7 Volume Limitation Standards

	IPC	ASHRAE	IgCC (Faucets)	IgCC (Other Fixtures)
Volume	0.601 gal (2.29 L)[a]	0.125 gal (0.47 L)	(0.06 L)	0.188 gal (0.71 L)
Length	50 ft (15 240 mm)	10.33 ft (3149 mm)[a]	1.3 ft (396 mm)	15.5 ft (4724 mm)[a]
Wait Time to a 0.5-gpm (1.89-L/min) Fixture	1 m, 14 s	15 s	2 s	23 s

[a] Based on internal diameters of ½ NPS (15 DN) type L copper pipe

Sources: ASHRAE 191PTheStandard for the Efficient Use of Water in Building, Site and Mechanical Systems; 2012 International Plumbing Code; International Green Construction Code

Domestic Hot Water Recirculation Systems

Domestic hot water recirculation systems maintain their temperature by using a pump to continuously pass hot water through the system and return it to the heating source to be recirculated. This provides readily available hot water near the fixtures for delivery. With that in mind, the system can be thought of as an extension of the water heater.

Supply System

The supply system is the recirculated portion of domestic hot water piping that supplies hot water to the fixtures. This does not include the entire domestic hot water supply, as uncirculated fixture branches are not included. The sizing of this system is discussed earlier in this chapter and should take into consideration the continuous flow from the recirculation system. The heat loss from the supply system is what determines the recirculation system flow.

Return System

The connection to the return system is made near the end of a branch supplying hot water to one or more fixtures needing temperature maintenance. The connection is followed by a balancing valve to throttle the flow and check valve to prevent reversal of flow caused by the discharging of fixtures. The return system passes the water that has dropped below the design temperature back to the water heater to be reheated. Since the return system has no fixture connections, the heat loss from this system is irrelevant when determining the necessary recirculation system flow. Sizing the return piping is dependent on the flow in each segment. The piping should be sized well below the 5-fps (1.5-m/s) velocities required for the hot water system. Since friction is the primary design factor when determining return system pipe sizes, selections should be based on uniform friction loss.

Balancing Valves

The flow through each segment is a set percentage of the total system flow and is regulated by the balancing valves. A properly balanced recirculation system will result in the same temperature drop at each balancing valve. Balancing valves can be adjusted by manual calibration or thermostatic means. Thermostatic balancing valves will adjust their opening depending on the temperature of the water entering the return system, providing an equal temperature drop at each valve without calibration.

Pump

The total flow through the system is selected based on the heat loss from the supply system when fixtures are not in use. This is controlled by the pump. The necessary flow through the system is a function of the heat loss over time and the acceptable temperature drop to the balancing valves (see Equation 6-7). If this flow is increased, the temperature drop will decrease. Therefore, take precautions when using safety factors, especially if thermostatic balancing valves are used. If a thermostatic mixing valve is used, the pump should discharge the flow into both the water heater and the mixing valve. This allows a portion of the water to be exchanged in the water heater and then mixed with the lower temperature water from the return, providing the design temperature to be recirculated back to the fixtures.

Equation 6-7

$$\text{System heat loss} / (500 \times \text{Temperature drop}) = \text{gpm}$$

$$[\text{System heat loss} / (15{,}077 \times \text{Temperature drop}) = \text{L/sec}]$$

Common practice has been to provide an aquastat on the recirculation pump to shut down the system during periods of no demand. However, this practice has been condemned by OSHA and the ASHRAE 188P standard as it has been discovered to create suitable incubation environments for Legionella.

Refer to *Plumbing Engineering Design Handbook, Volume 4* for pump selections and head loss from friction calculations.

Thermostatic Mixing Valve

In systems where the domestic hot water temperature is to be lower than the temperature stored in the water heater, a thermostatic mixing valve (TMV) should be used for tempering. A TMV performs best when mixing water of two extreme temperatures to create tempered water for supplying fixtures. If the temperature of the cold water inlet is too close to the set temperature (as is the case when being recirculated), the TMV will temper inaccurately. Therefore, it is critical that a calibrated balancing valve be added to the supply inlet of the return piping to the water heater to regulate the flow (Knight, 2012).

Water Heater

As the system recirculates, heat is lost through the piping and insulation. To maintain the system temperature, the heat loss needs to be in equilibrium with the heat gained from the water heater. The demand that this equilibrium imposes on the water heater is dependent on the heat loss from the supply and return piping. Using a variation of the equation above, the temperature drop at the end of the return system can be determined as follows.

Equation 6-8

$$\text{Btuh} / (500 \times \text{gpm}) = {}^\circ\text{F}$$

$$[\text{kJ/h} / (15{,}077 \times \text{L/Sec}) = {}^\circ\text{C}]$$

Using the equation for mixed water temperature (Equation 6-6), calculate the ratio of flow to be reheated by substituting the temperature at the end of the return system for the cold water temperature. The product of this value with the system flow is the flow from the return system to the water heater. This flow should be calibrated with a balancing valve. The rest of the flow is directed to the cold water inlet on the thermostatic mixing valve.

Calculating the Balancing Valve Flows

The flow required to compensate for the heat loss of the supply system is easily calculated as shown earlier. However, the flow at each balancing valve requires calculations to be made for each division of flow (node) in the recirculated supply piping. Each node represents a division of flow direction or a connection to the return system. Since the piping closer to the water heater will be carrying the flow of more balancing valves, the compensation for the heat loss will be distributed among the balancing valves being supplied.

The first node divides the entire system in two segments: segment a and segment b. Segment a will flow to node a, and segment b will flow to node b. Supposing that node a is another division of flow (as opposed to being a connection to the return system), segments aa and ab are followed by node a, each leading to nodes with their respective designations. This designation is represented by the variable n and is used for defining nodes and segments for the system.

The ratio of flow through each segment is defined by the relative heat loss of either segment to the total heat loss of both segments at any given node. This is demonstrated below in Equations 6-9a and 6-9b. This ratio is carried over when calculating the ratio of the next consecutive node. The segment flow is a product of the flow ratio and the total system flow as shown in Equation 6-10.

Equation 6-9a

$$r_{n+a} = \frac{r_n \sum L_{n+a}}{\sum L_n}$$

Equation 6-9b

$$r_{n+b} = \frac{r_n \sum L_{n+b}}{\sum L_n}$$

Equation 6-10

$$q_s r_n = q_n$$

After calculating the flow for each balancing valve, values can be confirmed by determining the temperature drop for the piping between each node according to the flow. Equation 6-11 can be used to perform this calculation.

Equation 6-11

$$\frac{\sum L_n - (\sum L_{n+a} + \sum L_{n+b})}{c \bullet q_n} = \Delta T_{n1:n2}$$

where

n = Node identity
a = Segment of lower heat loss
b = Segment of higher heat loss
r_{n+a} = Ratio of flow to segment n+a
r_{n+b} = Ratio of flow to segment n+b
q_s = System flow
q_n = Flow through segment n.
$\sum L_{n+a}$ = Sum of heat losses from segments with the prefix n+a
$\sum L_{n+b}$ = Sum of heat losses from segments with the prefix n+b
$\Delta T_{n1:n2}$ = Temperature drop between two consecutive nodes.
c = 500 (15,077)

Note: Compounding values a and b are used for n. With each node, an a or b is added as the suffix of the previously compounded values. This taxometric structure reflects the path and division of flow to the node. The first node is equal to 0. The following nodes will be a and b, ba and bb, and so forth. A segment is defined by the first node in the direction of flow.

As a guide to sizing circulation piping and circulation pumps, the following empirical methods are given, but they are not recommended in lieu of the more accurate procedures outlined above.

- An allowance of 0.5 gpm (1.8 L/m) is assigned for each small hot water riser (¾–1 inch [19–25 mm]), 1 gpm (3.8 L/m) for each medium-size hot water riser (1¼–1½ inches [32–38 mm]), and 2 gpm (7.6 L/m) for each large hot water riser (2 inches [50 mm] and larger).
- An allowance of 1 gpm (3.8 L/m) is assigned for each group of 20 hot water-supplied fixtures.

Self-Regulating Heat Trace Systems

A heat trace system is used for hot water temperature maintenance. This type of system utilizes self-regulating electrical cable installed on the hot water supply pipes underneath the standard pipe insulation. The cable adjusts its power output to compensate for variations in water and ambient temperatures. It produces more heat if the temperature drops and less heat if the temperature rises. The heating cable replaces supply pipe heat losses at the point where heat loss occurs, thereby providing continuous hot water temperature maintenance and eliminating the need for a recirculating system. Heat trace systems are practical for small systems, systems where added flexibility of terminal runs is needed, or situations where recirculation piping is impractical.

Selection variables affecting the performance of the heat trace system include the system temperature range, time to tap, water wastage, and energy efficiency. Installation and life-cycle costs also should be considered.

All heating cable components are UL listed for use as a part of the system to maintain hot water temperature. Component enclosures are rated NEMA 4X to prevent water ingress and corrosion. Electronic control modules are available, permitting programmed temperature profiles, including bacteria-killing high-temperature nighttime programs.

RELIEF VALVES

Water-heating systems shall be protected from excessive temperatures and pressures by relief valves. Temperature and pressure relief valves are available either separately or combined. A combination T&P relief valve offers economical and effective protection.

A relief valve on a water supply system is exposed to elements that may affect its performance, such as corrosive water that attacks materials and deposits of lime that close up waterways and flow passages. For these reasons, the minimum size of the valve should be ¾ inch (19 mm) for inlet and outlet connections, with the waterways within the valve of an area not less than the area of the inlet connection. Relief valves should be tested on a regular basis to ensure safe and proper operation.

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

Typically, T&P relief valves are tested to comply with the standards of ASME International, American Gas Association, or National Board of Boiler and Pressure Vessel Inspectors and are so labeled. The designer should verify which agency's standards are applicable to the water-heating system being designed and follow those standards for the sizes, types, and locations of required relief valves.

Sizing Pressure and Temperature Relief Valves

The following information applies to heaters with more than 200,000-Btu (211,000-kilojoule) input. Temperature relief valves shall have the capacity to prevent water temperatures from exceeding 210°F (99°C). They shall be water rated on the basis of 1,250 Btu (1,319 kilojoules) for each gph of water discharged at 30-pounds (13.6-kilograms) working pressure and a maximum temperature of 210°F (99°C).

The temperature rating is the maximum rate of heat input to a heater on which a temperature relief valve can be installed and is determined as follows:

Equation 6-12

$$\frac{\text{gph water heated} \times 8.33 \times \Delta T(°F)}{0.8} = \text{Btu valve capacity required}$$

$$\left[\frac{\text{L/h water heated} \times 1 \text{ kg/L} \times \Delta T(°C)}{0.8} = \text{kJ valve capacity required}\right]$$

Pressure relief valves shall have the capacity to prevent a pressure rise in excess of 10 percent of the set opening pressure. They shall be set at a pressure not exceeding the working pressure of the tank or heater.

The pressure rating is the maximum output of a boiler or heater on which a pressure relief valve can be used and is determined as follows:

Equation 6-13

$$\text{gph water heated} \times 8.33 \times \Delta T(°F) = \text{Btu valve capacity required}$$

$$[\text{L/h water heated} \times 1.0 \text{ kg/L} \times \Delta T(°C) = \text{kJ valve capacity required}]$$

Determine the Btu capacity required and then refer to the manufacturer's catalog for valve size selection. Note that on high-Btu systems, multiple T&P relief valves may be required at the storage tank.

THERMAL EXPANSION

Water expands when heated, and this expansion must be accommodated in a domestic hot water system to avoid damage to the piping, fixtures, and accessories. Use of a properly sized thermal expansion tank will accomplish this. Plumbing codes require some type of thermal expansion compensation, especially when there is either a backflow prevention device on the cold water service to the building or a check valve in the system.

Relying only on the T&P relief valve to relieve the pressure is not good practice. Most local codes now require thermal expansion tanks for systems more than 4 gallons (8.8 L) in capacity.

The relevant properties of water are shown in Table 6-8.

Table 6-8 Thermal Properties of Water					
Temperature	Saturation Pressure	Specific Volume	Density	Weight	Specific Heat
°F (°C)	psig (kPa)	ft3/lb (m3/kg)	lb/ft3 (kg/m3)	lb/gal (kg/m3)	Btu/lb-°F-h (J/kg-°C-h)
32 (0.0)	29.8 (3,019.6)	0.01602 (0.00100)	62.42 (999.87)	8.345 (1,001.40)	1.0093 (4,225.74)
40 (4.4)	29.7 (3,009.5)	0.01602 (0.00100)	62.42 (999.87)	8.345 (1,001.40)	1.0048 (4,206.90)
50 (10.0)	29.6 (2,999.4)	0.01603 (0.00100)	62.38 (999.23)	8.340 (1,000.80)	1.0015 (4,193.08)
60 (15.5)	29.5 (2,989.2)	0.01604 (0.00100)	62.34 (998.59)	8.334 (1,000.08)	0.9995 (4,184.71)
70 (21.1)	29.3 (2,969.0)	0.01606 (0.00100)	62.27 (997.47)	8.325 (999.00)	0.9982 (4,179.26)
80 (26.7)	28.9 (2,928.4)	0.01608 (0.00100)	62.19 (996.19)	8.314 (997.68)	0.9975 (4,176.33)
90 (32.2)	28.6 (2,898.0)	0.01610 (0.00100)	62.11 (994.91)	8.303 (996.36)	0.9971 (4,174.66)
100 (37.8)	28.1 (2,847.4)	0.01613 (0.00101)	62.00 (993.14)	8.289 (994.68)	0.9970 (4,174.24)
110 (43.3)	27.4 (2,776.4)	0.01617 (0.00101)	61.84 (990.58)	8.267 (992.04)	0.9971 (4,174.66)
120 (48.9)	26.6 (2,695.4)	0.01620 (0.00101)	61.73 (988.82)	8.253 (990.36)	0.9974 (4,175.91)
130 (54.4)	25.5 (2,583.9)	0.01625 (0.00101)	61.54 (985.78)	8.227 (987.24)	0.9978 (4,177.59)
140 (60.0)	24.1 (2,442.1)	0.01629 (0.00102)	61.39 (983.37)	8.207 (984.84)	0.9984 (4,180.10)
150 (65.6)	22.4 (2,269.8)	0.01634 (0.00102)	61.20 (980.33)	8.182 (981.84)	0.9990 (4,182.61)
160 (71.1)	20.3 (2,057.0)	0.01639 (0.00102)	61.01 (977.29)	8.156 (978.72)	0.9998 (4,185.96)
170 (76.7)	17.8 (1,803.7)	0.01645 (0.00103)	60.79 (973.76)	8.127 (975.24)	1.0007 (4,189.73)
180 (82.2)	14.7 (1,489.6)	0.01651 (0.00103)	60.57 (970.24)	8.098 (971.76)	1.0017 (4,193.92)
190 (87.8)	10.9 (1,104.5)	0.01657 (0.00103)	60.35 (966.71)	8.068 (968.16)	1.0028 (4,198.52)
200 (93.3)	6.5 (658.6)	0.01663 (0.00104)	60.13 (963.19)	8.039 (964.68)	1.0039 (4,203.13)
210 (98.9)	1.2 (121.6)	0.01670 (0.00104)	59.88 (959.19)	8.005 (960.60)	1.0052 (4,208.57)
212 (100.0)	0.0 (0.0)	0.01672 (0.00104)	59.81 (958.06)	7.996 (959.52)	1.0055 (4,209.83)
220 (104.4)	2.5 (253.3)	0.01677 (0.00105)	59.63 (955.18)	7.972 (956.64)	1.0068 (4,215.27)
240 (115.6)	10.3 (1,043.7)	0.01692 (0.00106)	59.10 (946.69)	7.901 (948.12)	1.0104 (4,230.34)
260 (126.7)	20.7 (2,097.5)	0.01709 (0.00107)	58.51 (937.24)	7.822 (938.64)	1.0148 (4,248.76)
280 (137.8)	34.5 (3,495.9)	0.01726 (0.00108)	57.94 (928.11)	7.746 (929.52)	1.0200 (4,270.54)
300 (148.9)	52.3 (5,299.6)	0.01745 (0.00109)	57.31 (918.02)	7.662 (919.44)	1.0260 (4,295.66)
350 (176.7)	119.9 (12,149.5)	0.01799 (0.00112)	55.59 (890.47)	7.432 (891.84)	1.0440 (4,371.02)
400 (204.4)	232.6 (23,569.4)	0.01864 (0.00116)	55.63 (891.11)	7.172 (860.64)	1.0670 (4,467.32)
450 (232.2)	407.9 (41,332.5)	0.01940 (0.00121)	51.55 (825.75)	6.892 (827.04)	1.0950 (4,584.55)
500 (260.0)	666.1 (67,495.9)	0.02040 (0.00127)	49.02 (785.22)	6.553 (786.36)	1.1300 (4,731.08)
550 (287.8)	1030.5 (104,420.6)	0.02180 (0.00136)	45.87 (734.77)	6.132 (735.84)	1.2000 (5,024.16)
600 (315.6)	1528.2 (154,852.5)	0.02360 (0.00147)	42.37 (678.70)	5.664 (679.68)	1.3620 (5,702.42)

Example 6-4

Using Table 6-8, determine the thermal expansion of a typical residence. Assume the initial heating cycle has incoming water at 40°F (4°C) and a temperature rise of 100°F (38°C). The water heater has 50 gallons (189 L) of capacity, and the piping system volume is 10 gallons (38 L).

According to Table 6-8:

- Specific volume of water at 40°F (4°C) = 0.01602 cubic foot per pound (0.00100 m^3/kg)
- Specific volume of water at 140°F (60°C) = 0.01629 cubic foot per pound (0.00102 m^3/kg)

0.01602 ÷ 0.01629 (0.00100 ÷ 0.00102) = 1.66 percent increase in volume

Total volume = 50-gallon (189-L) tank + 10-gallon (38-L) system = 60 gallons (227 L)

60 gallons (227 L) x 1.66 percent volume increase = 1-gallon (3.79-L) expansion

1 gallon (3.79 L) x 8.33 lb/gal (1 kg/L) x 0.01628 ft^3/lb (0.0010 m^3/kg) =

0.1356 ft^3 (0.0038 m^3) =

19.5 $in.^3$ (380 cm^3)

THERMAL EFFICIENCY

No water heating process is 100 percent efficient. The actual input energy is always higher than the usable, or output, energy. The four primary measurements of water heater efficiency (among the common 12 to 15 measurements) are combustion efficiency, thermal efficiency, energy factor, and annual fuel utilization efficiency (AFUE).

Combustion efficiency (for fuel-fired water heaters) is a misnomer, as it has little to do with the efficiency of the combustion process. Rather, combustion efficiency is simply the total input energy minus the flue losses.

Thermal efficiency is a refinement of combustion efficiency, also accounting for jacket losses. In equation form:

$$\text{Thermal efficiency} = \text{Combustion efficiency} - \text{Jacket losses}$$

Energy factor and AFUE are continued refinements, attempting to bring real-world meaningful values to consumers. Not every efficiency measurement is applicable to every water heater. For example, AFUE only applies to water heaters with an input of 300,000 Btuh or less. Similarly, the testing protocol used to obtain an energy factor rating includes a 19-hour standby period, obviously benefiting instantaneous and tankless water heaters.

New government-mandated energy-efficiency rules are issued through the U.S. Environmental Protection Agency and the U.S. Department of Energy. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers is an industry leader in promoting part-load efficiency ratings for modulating equipment and seasonal efficiency information. The Air-Conditioning, Heating, and Refrigeration Institute is the primary testing and certifying organization.

Direct-fired gas water heaters lose part of their total energy capabilities to heated flue gases, inefficiencies of combustion, and radiation at heated surfaces. Their thermal efficiency, E_t, is defined as the heat actually transferred to the domestic water divided by the total heat input to the water heater. Expressed as a percentage, this is:

Equation 6-14

$$E_t = \frac{q - B}{q} \times 100\%$$

where

E_t = Thermal efficiency ratio, unitless

B = Internal heat loss of the water heater, Btuh (kJ/h)

q = Time rate of heat transfer, Btuh (kJ/h)

Refer to Equations 6-1 and 6-2 to determine q. Many water heaters and boilers provide input and output energy information.

Example 6-5

Calculate the heat input rate required for the water heater in Example 6-1 if this is a direct gas-fired water heater with a thermal efficiency of 80 percent.

From Example 6-1, q = 449,820 Btuh (475,374 kJ/h). Thus, the heat input is:

$$\frac{q}{E_t} = \frac{449{,}820 \text{ Btuh}}{0.80} = 562{,}275 \text{ Btuh}$$

$$\left[\frac{q}{E_t} = \frac{475{,}374 \text{ kJ/h}}{0.80} = 594\ 217.5 \text{ kJ/h}\right]$$

LEGIONNAIRES' DISEASE

Legionnaires' disease is a potentially fatal respiratory illness that gained notoriety when a number of American Legionnaires contracted it during a convention. That outbreak was attributed to the water vapor from the building's cooling towers. The bacteria causing Legionnaires' disease are widespread in natural sources of water, including rivers, lakes, streams, and ponds. In warm water, the bacteria can grow and multiply to high concentrations.

Prevention and control of Legionella bacteria is a major concern in healthcare facilities. While there are several potential sources of the bacteria in hospitals (water features are especially problematic), for the purposes of this section, only Legionella in domestic hot water systems is addressed.

The Legionella bacteria can be found in many domestic hot and cold water systems in trace amounts. There are no health concerns with the bacteria until it colonizes (forming higher concentrations), and the bacteria are atomized and inhaled or aspirated. In most documented cases of Legionnaires' disease, transmission occurred when water containing the organism was aerosolized in respirable droplets (1–5 micrometers in diameter) and inhaled or aspirated by a susceptible host. No data indicates that the bacteria are of concern when swallowed, and no data supports Legionella being spread through person-to-person transmission. Legionella has been shown to most greatly affect immunosuppressed people. In a hospital, organ transplant patients, cancer patients receiving radiation or chemotherapy, patients with HIV, and surgical patients are most susceptible to Legionella infection.

Temperature Range for Legionella Growth

Many different temperature ranges for Legionella bacterial growth are published. The Centers for Disease Control and Prevention (CDC) lists a favorable bacterial growth range of 90–113°F (32–45°C). ASHRAE lists a favorable bacterial growth range of 77–108°F (25–42°C), and *Legionellae Control in Healthcare Facilities* lists the optimal temperature range for bacterial growth at 68–122°F (20–50°C) (95–115°F [35–46°C] ideal). The American Society for Healthcare Engineering (ASHE) and the Joint Commission list a range of 77–108°F (25–42°C). Combining these ranges would indicate a potential range of growth of 68–122°F (20–50°C). All available information indicates that almost all bacteria die at temperatures above 130°F (54°C). The higher the temperature, the faster the bacteria die.

Legionella Hot Spots

As mentioned, available information indicates almost all Legionella bacteria die at temperatures above 130°F (54°C). Therefore, a common method of Legionella control is to maintain the domestic hot water system temperature above 130°F (54°C), with a preferable distribution system temperature of 140°F (60°C) and a return hot water temperature of at least 124°F (51°C).

However, on older piping systems that don't have thermostatic mixing valves at all outlets, a system cannot be operated at 130°F (54°C) or above and still maintain code compliance. As mandated by most local codes, the maximum hot water temperature to plumbing fixtures in patient care areas is 115°F (46°C). This is to minimize scalding hazards due to excessive water temperature. Often, the shower valves in a hospital facility are not of the thermostatic mixing valve type, which would allow the system to be operated at an elevated temperature. As a result, a hospital's domestic hot water system is operated at approximately 115°F (46°C), with a return hot water temperature of 105–110°F (41–43°C). Unfortunately, regardless of the code, this temperature range is in the Legionella bacteria growth temperature range.

Bacterial growth is most prominent in stagnant areas such as storage tanks and dead ends of piping. Bacteria typically grow in the biofilm, scale, slime, and sediment found in these locations. It tends to not grow in sections of the piping distribution system that are actively flowing and have little biofilm or sediment buildup. Increased water velocity in a piping system can help reduce biofilm, but excessive water velocity can be detrimental to a piping system. Care should be taken to not exceed 4 fps (1.2 m/s) of velocity in the pipe, or erosion could take place, causing pipe failure.

Legionella bacteria also can reside in the scale buildup on showerheads. The showerhead provides a sieve effect, and the additional rough surface of the scale provides additional area for biofilm. Other locations of bacterial growth include spas, whirlpools, and water feature pools. There also have been reports of bacteria growing on natural rubber washers.

Controlling Legionella

Many methods of controlling the colonization of Legionella bacteria are available. These include elevated temperature maintenance, heat and flush cycles, copper-silver ionization, chlorine dioxide injection, halogenization, ultraviolet (UV) radiation, ozonation, hyper-chlorination, filtration/rechlorination, and combinations of these.

Elevated Temperature Maintenance

This involves keeping the system temperature continually at or above 140°F (60°C), as recommended by several of the agencies noted previously. However, it is frequently impractical in large, old facilities where point-of-use thermostatic mixing valves have not been installed.

Heat and Flush

This is a method of disinfecting the piping system by elevating the system temperature to 150°F (66°C) or higher and flushing the high-temperature water through every outlet for at least 30 minutes. This method has proven effective in killing the bacteria present in most domestic hot water systems. Large quantities of biofilm in the piping system might require additional contact time with the high-temperature water.

The advantages of this method are that it involves no capital expenditures for equipment and can be implemented immediately. Disadvantages include increased labor, difficulty coordinating the flushing of the system without risking a scalding injury to patients, and inefficiency on fixtures with thermostatic mixing valves. There is no residual protection, so this is a non-permanent solution to Legionella contamination. The bacteria will eventually return and colonize in the system.

Copper-Silver Ionization

This method involves installing a flow-through ionization chamber containing copper-silver electrodes. As electrical current is applied to the electrodes, positively charged copper and silver ions are released into the water system. The positively charged ions bond to the microorganisms, causing them to die. The optimal concentration of copper-silver ions is said to be 400 parts per billion (ppb) for copper and 40 ppb for silver.

The advantages of this alternative are that the equipment is relatively easy to install and maintain and it provides permanent, continuous disinfection. The disadvantages are the initial equipment costs and continuing operating and maintenance costs. Copper-silver ionization often is recommended as an option for use on domestic hot water systems serving immunodeficient patient care areas.

Chlorine Dioxide Gas Injection

This is effective in the control of Legionella bacteria in domestic hot water systems. It penetrates biofilm and slime and kills bacteria at its growth sites. Its advantages are that it stays in solution for long periods, and since it requires low concentrations, it minimizes chlorine-induced corrosion concerns. The disadvantages are that the equipment is best suited for use in small to medium-size applications; the equipment is fairly expensive; a chlorine dioxide gas generator is required for each hot water system; and water chemistry must be monitored closely. For large facilities, it might be necessary to install multiple injectors. Chlorine dioxide is a viable option for use on domestic hot water systems serving immunodeficient patient care areas if closely monitored.

Halogenization

The use of halogens (chlorine, bromine, and iodine) at dosages ranging from 0.3–1 parts per million (ppm) is a viable option only if the water pH is controlled precisely. As the water pH drops, so does the efficiency of the halogen as a biocide. A final but critical consideration is the issue of carcinogenic halogenated compounds being released into the waterway. A byproduct of chlorine treatment of water is total trihalomethanes (TTHM), which may elevate the risk of certain cancers. While the risk may be small, the EPA is attempting to reduce TTHM concentrations in U.S. water systems. Halogens therefore are seldom recommended for use in healthcare facilities.

Ultraviolet Radiation

UV radiation is effective in killing the bacteria as it flows through a single point in the system. It is effective only for use on small, localized systems and short runs of pipe. It is ineffective in large systems and does not eliminate the growth of existing colonies in other portions of the system. The effect of UV on Legionella within protozoan vesicles (protozoan bodies loaded with Legionella cells) is also not known.

Ozonation

Ozone is effective in killing the bacteria in the immediate vicinity of the ozone generator. Its advantage is that TTHMs are not produced by ozone treatment. Its disadvantages are that decomposition of the ozone in the system quickly dissipates the concentrations required to kill bacteria; it can cause corrosion problems in old piping; it is ineffective in large systems; and it does not eliminate the growth of existing colonies in other portions of the system. This is also an expensive option.

Hyperchlorination

This method is effective in killing the bacteria, but it has several very important negative aspects. First, high chlorine concentrations are required to kill the bacteria. Second, chlorine byproducts are TTHMs, which are potential carcinogens. Third, chlorine is corrosive and can cause degradation leading to potential failure of the piping. It therefore is not recommended for regular use in most hospital facilities.

Filtration/Rechlorination

This involves the use of 5-micron filters in conjunction with a rechlorination system. It first filters foreign matter being introduced into the piping system from an unfiltered water supply, thus reducing the scale and sediments in which the biofilm can propagate. Rechlorination then is used to maintain a chlorine level more conducive to inhibiting biofilm growth. Chlorine concentrations should be closely monitored to prevent over-chlorination. This type of system typically is used on non-municipal-type water systems and does not apply to hospitals receiving a central water supply.

Legionella Control Recommendations

For hospitals, Joint Commission Environment of Care Standard EC.1.7 requires the facility to develop a management plan establishing and maintaining a utility systems management program to "reduce the potential for organizational illness." This management plan shall provide processes for "managing pathogenic agents in…domestic water and aerosolizing water systems."

Two approaches are recommended in the CDC guidelines for Legionella prevention and control. The first approach involves periodic, routine culturing of water samples from the hospital's potable water system. For large hospitals, the CDC does not recommend random sampling. For large hospital facilities, the second approach listed is more practical to implement. The recommended approach follows:

- Educate the hospital staff to increase their awareness of the symptoms of Legionellosis. Maintain a high index of suspicion for Legionellosis and appropriately use diagnostic tests for Legionellosis in patients with nosocomial pneumonia who are at risk of developing the disease and dying from the infection.
- Initiate an investigation for a hospital source of Legionella upon identification of one case of definite or two cases of possible nosocomial Legionella disease.
- Routinely use only sterile water for filling and terminal rinsing of nebulization devices.

For high-risk areas such as operating rooms, ICU, AIDS, and cancer treatment areas, it often is recommended that the hospital install chlorine dioxide or copper-silver ionization equipment on the domestic hot water systems feeding these areas.

Following is a checklist for existing domestic hot water piping systems to help minimize system-wide Legionella growth.

- Remove dead legs in the domestic hot water system. Establish a policy of removing leftover piping.
- Replace heavily scaled showerheads.
- Extend hot water recirculation lines to the furthest point from the supply to ensure full system circulation.
- All new piping should be copper, which is more corrosion-resistant than galvanized steel piping. The formation of rust pockets is conducive toward biofilm proliferation and Legionella growth. Corrosion also leads to slime and scale buildup.
- Change the water and sanitize the integral piping in whirlpools and spas frequently.

If the disease is detected and confirmed, disinfection of the piping system will be required. Of the above methods, the most immediately available form of disinfection is usually the heat and flush method. This will involve the least capital investment; it can be quickly implemented; and when properly executed it is effective in eradicating most existing bacteria colonies. After disinfection, a Legionella control system should be installed, and a program should be instituted to monitor bacteria levels in the piping. It is also advisable to get concurrence from the medical facility's relevant committees, such as the infection control committee.

SCALDING

A research project by Moritz and Henriques at Harvard Medical College looked at the relationship between time and the water temperature necessary to produce a first-degree burn, which is the least serious type of burn and results in no irreversible damage. The results of the research show that it takes a 3-second exposure to 140°F (60°C) water to produce a first-degree burn. At 130°F (54°C), it takes approximately 20 seconds, and at 120°F (49°C) it takes 8 minutes to produce a first-degree burn.

The normal threshold of pain is approximately 118°F (48°C). A person exposed to 120°F (49°C) water would immediately experience discomfort, so it's unlikely that the person would be exposed for the 8 minutes required to produce a first-degree burn. However, people in some occupancies (e.g., hospitals), as well as those over the age of 65 and under the age of one, may not sense pain or move quickly enough to avoid a burn once pain is sensed. If such a possibility exists, scalding protection should be considered, and it often is required by code. (For more information on skin damage caused by exposure to hot water, see Table 6-9.)

Table 6-9 Time/Water Temperature Combinations Producing Skin Damage

Water Temperature, °F (°C)	Time, seconds
> 140 (> 60)	< 1
140 (60)	2.6
135 (58)	5.5
130 (54)	15
125 (52)	50
120 (49)	290

Note: The above data indicate conditions producing the first evidence of skin damage in adult males.

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CE Questions — "Domestic Water Heating Systems" (CEU 255)

Test written by David Becker, CPD

1. Research shows it takes a 3-second exposure to ________ water to produce a first-degree burn.
    a. 150°F
    b. 140°F
    c. 130°F
    d. 120°F

2. What is the hot water storage capacity factor for a school at a final temperature of 140°F?
    a. 2.0
    b. 1.25
    c. 1.00
    d. 0.80

3. The return piping system should be sized well below the ________ velocities required for hot water systems.
    a. 8-fps
    b. 7-fps
    c. 6-fps
    d. 5-fps

4. The risk of scalding and thermal shock can be reduced by using ________.
    a. check valves
    b. temperature and pressure relief valves
    c. thermal expansion tanks
    d. thermostatic mixing valves

5. What is the hot water multiplier for 105°F mixed water with 140°F hot water and 45°F cold water?
    a. 0.63
    b. 0.61
    c. 0.59
    d. 0.56

6. Typically, T&P relief valves are tested to comply with the standards of which of the following organizations?
    a. ASPE
    b. ASSE
    c. ASME
    d. ASHRAE

7. All available information indicates that almost all bacteria die at temperatures above ________.
    a. 150°F
    b. 140°F
    c. 130°F
    d. 120°F

8. What is the specific volume of 180°F water?
    a. 0.01639 ft^3/lb
    b. 0.01645 ft^3/lb
    c. 0.01651 ft^3/lb
    d. 0.01657 ft^3/lb

9. Which of the following can dictate typical hot water temperatures for plumbing fixtures and equipment?
    a. codes
    b. equipment manufacturers
    c. regulatory agencies
    d. all of the above

10. Pressure relief valves shall have the capacity to prevent a pressure rise in excess of ________ of the set opening pressure.
    a. 5 percent
    b. 10 percent
    c. 15 percent
    d. 20 percent

11. ________ water heaters have near zero standby losses.
    a. instantaneous
    b. indirect fired
    c. semi-instantaneous
    d. booster

12. Annual fuel utilization efficiency, AFUE, only applies to water heaters with an input of ________ or less.
    a. 600,000 Btuh
    b. 500,000 Btuh
    c. 400,000 Btuh
    d. 300,000 Btuh