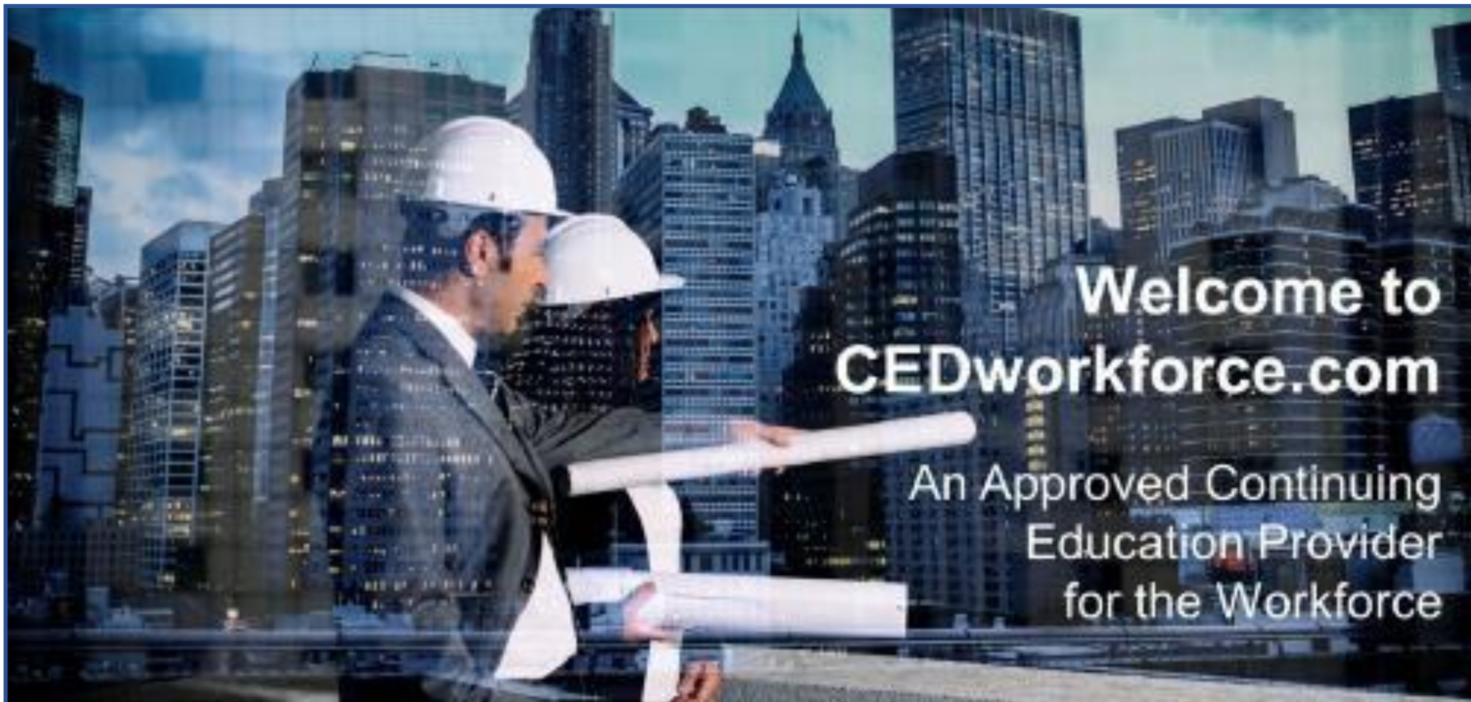

Plumbing Systems Design

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This course was adapted from the Naval Facilities Engineering Command, "Plumbing Systems", which is in the public domain.

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2. Drainage Systems

2.1 Sanitary Systems

2.1.1 Sumps and Sump Pumps

Drains which cannot discharge into the building sewer by gravity shall discharge into a tightly covered and vented sump from which the effluent will be pumped.

(1) Sumps. Sumps shall be sized so that their contents in gallons (liters) between high and low water level will be approximately twice the capacity of the sump pump in gallons per minute (liters per second). In sizing the sump, it must be remembered that the high-water level must be somewhat lower than the inlet to the sump, and the low water level will be approximately 1 foot above the bottom of the sump.

(2) Sump Pumps. Sump pumps are classified and arranged as follows.

(a) Classification. Sump pumps are intended for use where drainage is free of solids. Sewage ejectors are intended for use where drainage contains solids.

(b) Number required. Provide a single unit where the function of the equipment is not critical, and provide duplex units where the function of the equipment is critical and where six or more water closets are being served. When duplex units are provided, the capacity of each unit shall be sufficient to meet the requirements of the facility.

(c) Controls. Automatic controls shall be provided for each pump. Duplex units shall be equipped with controls to alternate the operation of the pumps under normal conditions and to operate pumps simultaneously when one pump cannot handle the flow.

(d) Alarms. A high-water alarm actuator shall be installed within sump and shall operate on audible or visual alarm when the normal high-water level within sump has been exceeded.

(e) Capacity. Pump capacity in gallons per minute (liters per second) shall be 1-1/2 to 2 times the inflow to the sump. For minimum capacities of ejectors serving toilet facilities, see Table 1.

2.1.2 Interceptors

Interceptors shall be provided to separate grease, volatile liquids, sand, hair, and plaster from liquid wastes when those ingredients would create a fire or explosive hazard within the system or adversely affect the operation of the system. Interceptors may be of the prefabricated type or field-fabricated type.

No. of water closets [1]	Cap. of each pump (gpm)(L/s) [1]	No. of water closets [1]	Cap. of each pump (gpm)(L/s) [2]
1	50 (3.2)	11 to 14	200 (12.6)
2	75 (4.7)	15 to 20	250 (16.0)
3 or 4	100 (6.3)	21 to 25	300 (19.0)
5 or 6	125 (8.0)	26 to 30	350 (22.0)
7 to 10	150 (9.5)		

Table 1. Sewer Ejector Capacities

[1] Includes a reasonable number of fixtures, such as lavatories, urinals, showers, etc., which are part of a normal installation.
[2] Pump capacities shall be increased if the rate of seepage into the sump is more than 50 percent of indicated pump capacities.

(1) Location. Interceptors may be located within or outside of buildings.

(a) Inside installations. Units installed within the building at or near the source of the undesirable ingredient are of a relatively small capacity and are usually the prefabricated type. The use of this type of unit eliminates or reduces to a minimum the length of piping between the source and the separator, thereby alleviating the possibility of line stoppage and reducing the fire hazard due to the presence of flammable liquids and vapors within the piping system.

(b) Outside installation. Units installed outside of a building normally are provided to accommodate multiple fixtures and may be prefabricated or field-fabricated type. The advantages of this type of interceptor are: (a) access is convenient for inspection and cleaning, (b) cleaning is accomplished without interfering with normal operation of the facility, and (c) servicing is confined to a single location.

(2) Sizing of Interceptors. The size of interceptors depends upon the use and location. When located inside of a building, units used for intercepting solids and units used for intercepting volatile liquids shall be selected in accordance with manufacturer's recommendations. For units located outside of a building, refer to applicable industry standards.

(3) Fixtures Requiring Grease Interceptors. Grease interceptors shall be provided to receive the wastes from pot sinks, pre-wash sinks, dishwashers without pre-wash sections and soup kettles. Interceptors shall not be installed to accommodate kitchen fixtures in private living quarters.

2.1.3 Chemical Wastes

Wastes containing acids or other chemicals which can adversely affect the piping system may require treatment prior to being discharged into the sanitary drainage system.

(1) Treatment. Treatment may be inside or outside of a building and shall consist of dilution or neutralization by running the chemical wastes through a treatment sump. Wastes with low chemical concentrates may be run directly into the sanitary sewer when sufficient dilution will occur within the piping system as a result of mixing with other wastes.

(2) Piping. Piping conveying chemical wastes to areas of treatment shall be of a material highly resistant to the chemical being conveyed.

2.1.4 Backwater Valves

Backwater valves shall be provided where required to protect areas within the building from being flooded as a result of overloads or of surges within the system. When a combined sanitary-storm sewer is encountered, all areas of the building located below grade shall be protected against backflow.

2.1.5 Food Waste Grinders

Food waste grinders shall be installed only with the approval of local authorities. Unit shall be equipped with a P-trap on its outlet and shall discharge directly into the sanitary sewer and never through a grease interceptor.

2.1.6 Floor Drains

Floor drains with suitable drain traps shall be provided for certain equipment and areas. (A single floor drain may serve more than one area.) When it is anticipated that a floor drain trap may lose its water seal because of infrequent use, means for automatically maintaining the seal shall be provided. Automatic priming of traps may be by a drain from a fixture within the area or by a connection to the water system. When automatic priming is through a device connected to the water system, that device shall be equipped with a vacuum breaker. Floor drains are not required in service sink rooms and transformer rooms. Floor drains serve, but shall not be limited to, the following areas and equipment:

(1) Gang toilets shall be interpreted as those having three or more water closets, and gang shower drying rooms as those serving two or more showers.

(2) Subsistence buildings are as follows:

(a) Dishwashing, scullery or pot-washing, and food-cart washing areas.
(b) Vegetable peelers and vegetable preparation areas.
(c) Steam table and coffee urn areas.
(d) Soda fountain area.
(e) Adjacent areas to ice chests, ice-making machines, and walk-in, reach-in, and garbage refrigerators.

(f) Steam cookers and steam-jacketed kettles.

(3) Cold-storage buildings are as follows:

(a) Fat-rendering, processing, salvage, and receiving rooms.
(b) Receiving and issuing vestibules.
(c) Adjacent areas to meat coolers and milk, butter, and egg and rooms.

2.2 Storm Drainage Systems

2.2.1 General

The storm drainage system consists of (1) the piping system used to convey rain water from roofs, areaways and other areas exposed to the weather and (2) the sub-soil drainage system. The system size shall be based on the rainfall intensities, frequencies, and duration indicated in Table 2.

2.2.2 Downspouts

Downspouts (leaders) may be exterior or interior. Exterior downspouts usually are of sheet metal and require protection from damage when they are located in areas used for parking or truck loading. Downspouts in such areas shall connect to steels or cast-iron pipe 5 feet above the paving or loading platforms. When exterior downspouts are to be connected to a storm sewer and are not in an area where damage is likely to occur, they shall be connected, above grade, to an extension of the underground piping system.

2.2.3 Sub-Soil Drains

A sub-soil drainage system shall be provided to prevent water seepage through walls and floors located below grade. Drains may be installed under floor or at outer perimeter of the building walls and shall be installed at an elevation so as to restrict the accumulation of sub-surface water to a level below the lowest floor. Drain may be perforated or open-joint pipe and may be connected to the building storm sewer or spilled into a sump from which it may be pumped to storm sewer or outfall. If directly connected to a storm sewer, sub-soil drain shall be protected by an accessible backwater valve.

2.2.4 Piping System

The storm drainage piping system shall be independent of any other piping system. Drains which are too low for gravity flow shall be drained into a sump where the effluent will be pumped. For criteria on sump pumps, see paragraph 2.1.1, Sanitary Systems.

2.3 Combined Sanitary and Storm Drainage System

2.3.1 System Layout

When a combined drainage system is to be provided, the systems shall be maintained as separate systems within the building. Systems shall be combined outside of the building and preferably at a manhole.

2.3.2 Backflow

Drains from the lower floors, especially drains from areas which are located below grade and may be subject to backflow, shall be equipped with accessible backwater valves.

State	City	Inches (mm) per hour	State	City	Inches (mm) per hour	States	City	**Inches (mm) / hour**
AL	Birmingham	6 (150)	KY	Lexington	5 (130)	OH	Toledo	5 (130)
	Mobile	7 (180)		Louisville	5 (130)	OK	Oklahoma City	5.5 (140)
	Montgomery	6 (150)	LA	New Orleans	7 (180)	OR	Baker	2 (50)
AK	Fairbanks	3 (75)		Shreveport	6 (150)		Portland	2.5 (65)
	Juneau	1.5 (40)	ME	Eastport	4 (100)	PA	Erie	5 (130)
AZ	Phoenix	3.5 (40)		Portland	4 (100)		Harrisburg	5 (130)
AR	Bentonville	6 (150)	MO	Baltimore	6.6 (165)		Philadelphi	5 (130)
	Fort Smith	5 (130)	MA	Boston	4 (100)		[a]Pittsburgh	5 (130)
	Little Rock	5.5 (140)		Nantucket	4 (100)		Scranton	4.5 (115)
CA	Eureka	2 (150)	MI	Detroit	6.5 (150)	RI	Block Island	4 (100)
	Fresno	3 (180)		East Lansing	4 (180)		Providence	4 (100)
	Los Angeles	3 (150)		Grand Rapids	4 (150)	SC	Charleston	6 (150)
	Pt. Reyes	2 (75)		Port Huron	5 (75)		Columbia	5.5 (140)
	Sacramento	2.5 (40)	MN	Duluth	4 (40)		Greenville	5.5 (140)
	San Diego	2.5 (40)		Minneapolis	5 (40)	SD	Huron	5 (130)
	San Francisco	2.5 (150)		St Paul	4 (150)		Pierre	5 (130)
	San Jase	1.5 (130)	MS	Meridan	5 (130)		Rapid City	4 (110)
CO	Denver	4.5 (140)		Vicksburg	5 (140)	TN	Chattanooga	5 (150)
	Grand Junction	2.5 (150)		Columbia	5 (150)		Knoxville	5 (130)
	Pueblo	4 (180)		Kansas city	6 (180)		Austin	5.5 (140)
CN	Hartford	5 (150)		St louis	6 (150)		Corpus Christi	5.5 (140)
	New Haven	5.5 (75)		Springfield	6 (75)		Dallas	6.5 (165)
DC	Washington	6 (40)	MT	Havre	5.5 (40)		El Paso	6 (150)
FL	Jacksonville	6.5 (40)		Helena	5.5 (40)		Fort Worth	6 (150)
	Key West	5.5 (150)		Miles City	5.5 (150)		Galveston	3.5 (90)
	Miami	5.5 (130)	NE	Lincoln	3.5 (130)		Houston	5 (130)
	Pensacola	6.5 (140)		Omaha	3 (140)		San Antonia	7 (180)
	Tampa	7.5 (150)	NV	Reno	4.5 (150)		Port Arthur	7 (180)
GA	Atlanta	7 (180)	NH	Concord	6 (180)	UT	Modena	7 (180)
	Augusta	6 (150)	NJ	Atlantic City	2.5 (150)		Salt Lake City	6 (150)
	Macon	6.5 (75)		Sandy Hook	5 (75)	VT	Burlington	3 (75)
	Savannah	6.5 (40)		Trenton	5 (40)		Northfield	3 (75)
HI	Honolulu	6 (40)	NM	Albuquerque	5 (40)	VA	Cape Henry	4.5 (115)
ID	Boise	6 (150)		Santa Fe	5 (150)		Norfolk	5 (130)
	Lewiston	5 (130)	NY	Albany	5 (130)		Richmond	6 (150)
	Pocatello	4.5 (140)		Binghamton	3 (140)	WA	Port Angeles	6 (150)
IL	Chicago	2 (150)		Buffalo	3.5 (150)		Seattle	2.5 (65)
	Peoria	2.5 (180)		Ithaca	4.5 (180)		Spokane	2 (50)
IN	Springfield	3 (150)		New York	5 (150)		Tacoma	2 (50)
	Fort Wayne	5.5 (75)		Rochester	4 (75)	WV	Elkins	2.5 (65)
	Indianapolis	5 (40)		Syracuse	5 (40)		Parkersburg	2 (50)
	Terre Haute	5.5 (40)	NC	Charlotte	5.5 (40)	WI	Green bay	5 (130)
IA	Davenport	5 (150)		Hatteras	4.5 (150)		La Crosse	5 (130)
	Des Moines	5 (130)		Raleigh	6 (130)		Madison	5 (130)
	Dubuque	5.5 (140)		Wilmington	5.5 (140)		Milwaukee	5 (130)
	Sioux City	6 (150)	ND	Bismarck	5 (150)	WY	Cheyenne	4.5 (115)
	Dodge City	5 (180)		Williston	5.5 (180)		Sheridan	4 (100)
	Tola	5 (150)	OH	Cincinnati	5 (150)	PR	San Juan	6 (150)
	Topeka	5 (75)		Cleveland	5 (75)			
KS	Wichita	5.5 (40)		Columbus	4.5 (40)			
				Dayton				

[1] Commonwealth

Table 2. Rainfall Intensity Based on 10-Year Frequency and 10-Minute Duration

2.3.3 P-Traps in Storm Drainage Systems

In a combined drainage system, the sewer gas from the sanitary system, if permitted, will flow through the storm drainage system and escape through roof drain and area drains.

P-trap(s) shall be provided to prevent the escape of this gas into areas where an offensive or hazardous condition would be created. The P-trap(s) shall be installed as part of the storm drainage system prior to being combined with the sanitary drainage system.

2.4 Venting of the Drainage Systems

The drainage systems must be vented to protect the traps from being subject to under pressures and overpressures. Adequate and economical venting of the system can be achieved by the use of circuit or loop venting to serve groups of fixtures and adjacent fixtures. Venting of each fixture should be avoided when one of the above methods of venting can be employed.

3. Water Supply Systems

3.1 Piping Systems

3.1.1 Water Service

The water service to each building shall be capable of supplying water at a flow rate and pressure to satisfy the peak requirements. In addition to domestic requirements, the fire protection and air conditioning requirements, if any, shall be considered in determining the demands of the facility.

(1) Excessive Pressure. Excessive water pressures will result in

(a) excessive flows at fixtures with a resultant waste of water, (b) high velocities with a resultant noisy piping system, and (c) water hammer with a resultant noise and destructive effect on the piping and fixtures. The installation of pressure regulating valves shall be considered when the residual pressure at fixtures exceeds 50 pounds per square inch (345 kPa). The pressure reducing station shall consist of a pressure regulator, strainer, isolating valves, pressure gauges, and a reduced-size bypass with a manually operated flow-control valve.

(2) Inadequate Pressure. When water pressure is inadequate, means for increasing the pressure shall be provided. For pressure booster systems see Part 2 of this section.

(3) Velocities. Normally, water velocities shall not exceed 10 feet per second (3.28 m/s). In hospitals and similar facilities, where a quiet system is desired, velocities shall not exceed 7 feet per second (2.13 m/s).

3.1.2 Water Hammer Arrestors

Water hammer arrestors shall be provided only in conjunction with automatically operated quick-closing valves. Arrestors shall be the mechanical type and shall be sized and located in accordance with applicable industry standards.

3.2 Booster Systems and Pumps

3.2.1 Hydro-Pneumatic System

Water pressure may be increased by using a hydro-pneumatic system consisting of a tank, pumps, compressed air system, and associated control devices.

(1) Tank Pressure. The minimum pressure maintained within the tank is at low-water level and is equal to the pressure required to meet the fixture demands. The high pressure at high water level depends on the operating pressure differential selected for the system. A reasonable and most commonly selected pressure differential is 20 pounds per square inch (138 kPa).

(2) Pumps. Pumps normally are provided in duplex. Each pump is sized to meet the requirements of the facility. Pump capacities in gallons per minute (liters per second) shall be in accordance with Table 3. Pump head shall be equal to the high pressure maintained within the hydro-pneumatic tank.

Location	No. of Fixtures	Gpm (L/s) per Fixture		Min. pump Capacity gpm (L/s)	
Administration building	1-25	1.23	(0.08)	25	(1.6)
	26-50	0.9	(0.06)	35	(2.2)
	51-100	0.7	(0.045)	50	(3.2)
	101-150	0.65	(0.04)	75	(4.7)
	151-250	0.55	(0.03)	100	(6.3)
	251-500	0.45	(0.03)	140	(7.8)
	501-750	0.35	(0.02)	230	(15.0)
	751-1000	0.3	(0.02)	270	(17.0)
	1000-up	0.275	(0.02)	310	(20.0)
Apartments	1-25	0.6	(0.04)	10	(0.6)
	26-50	0.5	(0.03)	15	(0.9)
	51-100	0.35	(0.02)	30	(1.9)
	101-200	0.3	(0.02)	40	(2.5)
	201-400	0.28	(0.02)	65	(4.1)
	401-800	0.25	(0.015)	120	(7.6)
	801-up	0.24	(0.015)	210	(13.0)
Hospitals	1-50	1.0	(0.06)	25	(1.6)
	51-100	0.8	(0.05)	55	(3.5)
	101-200	0.6	(0.04)	85	(5.4)
	201-400	0.5	(0.03)	125	(7.9)
	401-up	0.4	(0.025)	210	(13.0)
Industrial buildings	1-25	1.5	(0.10)	25	(1.6)
	26-50	1.0	(0.06)	40	(2.5)
	51-100	0.75	(0.05)	60	(3.8)
	101-150	0.7	(0.045)	80	(5.0)
	151-250	0.65	(0.04)	110	(7.0)
	251-up	0.6	(0.04)	165	(10.5)
Quarters and barracks	1-50	0.65	(0.04)	25	(1.6)
	51-100	0.55	(0.03)	35	(2.2)
	101-200	0.45	(0.03)	60	(3.8)
	201-400	0.35	(0.2)	100	(6.3)
	401-800	0.275	(0.02)	150	(9.5)
	801-1200	0.25	(0.015)	225	(14.5)
	1201-up	0.2	(0.01)	300	(19.0)
Schools	1-10	1.5	(0.09)	10	(0.06)
	11-25	1.0	(0.06)	15	(0.9)
	26-50	0.8	(0.05)	30	(1.9)
	51-100	0.6	(0.04)	45	(2.8)
	101-200	0.5	(0.03)	65	(4.1)
	200-up	0.4	(0.025)	110	(7.0)

Table 3. Tank Fill Pumps

(3) Tank Capacity. Tank capacity shall be based upon a withdrawal, in gallons (liters), of 2-1/2 times the gallon per minute (liter per second) capacity of the pump and a low water level of not less than 10 percent of total tank capacity or 3 inches (76 mm) above top of the

tank outlet, whichever is greater. Table 4 indicates high water levels and withdrawals for efficient operation of tanks with bottom outlets and a 10-percent residual. Using this table, the tank capacity may be determined as per Example 1. Pressure ranges are given in pounds per square inch (psi) and kilopascals (kPa).

(4) Example 1. Determine the tank capacity when pump capacity is 150 gallons per minute and tank operating pressure range is 40 to 60 pounds per square inch. (Referring to Table 4, the withdrawal from the tank is 24 percent of the tank capacity.)

$$\text{Total tank capacity} = \frac{2.50 \text{ x } 150 \text{ gpm } (568 \text{ L/min})}{0.24 \text{ percent}} = 1{,}563 \text{ gallons } (5916 \text{ liters})$$

Pressure range psi	(kPa)	**High Water Level (% of total tank cap)**	**Withdrawal (96 of total tank cap)**
20-40	(140-275)	43	33
30-50	(205-345)	38	28
40-60	(275-415)	34	24
50-70	(345-480)	32	22
60-80	(415-550)	28	18
20-45	(140-310)	48	38
30-55	(205-380)	42	32
40-65	(275-450)	37	27
50-75	(345-520)	35	25
60-85	(415-590)	32	22

Table 4. HydroPneumatic Tank High Water Levels and Withdrawals (Based on bottom outlet tanks and a 10-percent residual)

(5) Compressed Air. Compressed air is supplied for tank operation according to the tank capacities. Satisfactory operation has been attained by providing 1.5 cubic feet per minute (cfm) for tank capacities up to 500 gallons (1893 L) and 2 cfm for capacities from 500 to 3,000 gallons (1.89 to 11.35 m └3┘]). For each additional 3,000 gallons (11.35 m └3┘]) or fraction thereof, add 2 cfm (0.0566 m └3┘]min.). (Quantities are expressed in cubic feet (cubic meter) per minute free air at pressure equal to the high pressure maintained within the hydro-pneumatic tank.)

(6) Controls. The controls of a hydro-pneumatic system shall maintain the predetermined pressures, water levels, and air-water ratio within the tank. When duplex pumps are provided, controls shall start only one pump at a time. Pumps shall be operated alternately and shall run simultaneously only when the predetermined low pressure cannot be maintained by a single pump. Controls shall admit compressed air into the tank only when tank pressure at high water level is below normal.

3.2.2 Booster Pumps

Booster pumps may be the “on-off” type or continuous running type.

(1) On-Off Type. The installation of an “on-off” type of pumping system should be considered when relatively long periods of pump on or pump off is anticipated. Pumps shall be activated, only when pressure is inadequate, by a sensing device located in the pump suction line. Flow normally will be through a full-size pump bypass having a check valve with two normally open isolating valves. Whether the installation has one pump or multiple pumps, only one bypass shall be

(2) Continuous Running. Variable speed, constant pressure, continuous running pumps shall be considered when anticipated pressure fluctuation would result in short-cycling of the “on-off” type of pumps. Whether the installation is a single pump or multiple pumps, only one full-size pump bypass with a gate valve normally closed shall be provided. Each pump shall be provided with isolating valves.

3.3 Hot Water Systems

3.3.1 Water Temperatures

Information contained herein for calculating hot water requirements is based on incoming water at 40 deg. F (4.4 deg. C) heated and stored at 140 deg. F (60 deg. C). When incoming water temperature is above 40 deg. F (4.4 deg. C), adjustments shall be made in accordance with Table 5. When hot water at a temperature above 140 deg. F (60 deg. C) is required, such as 180 deg. F (82.2 deg. C) for dishwashing, it shall be provided by (a) a booster heater, (b) a separate storage heater for 180 deg. F (82.2 deg. C) water only, or (c) heating and storing all hot water at 140 deg. F (60 deg. C) and utilizing mixing valves to satisfy the demands for 100 deg. F to 110 deg. F (37.8 deg. C to 43.3 deg. C) water.

Incoming cold water temperatures deg. F (deg. C)	Factor [1]
40(4.4)	1.00
50(10.0)	0.96
60(15.6)	0.90
70(21.1)	0.82
80(26.7)	0.71

Table 5. Correction Factors for Sizing Water Heaters and Auxiliary Equipment (Based on hot water being tempered to 110 deg. F (43.3 deg. C) at fixtures)

[1] Do not apply when meeting the requirements of kitchen and dishwashing equipment of subsistence buildings, laundry washing machines, and other similar types of equipment which depend on high temperature water for efficient operation. However, the heater capacity shall be rated to heat the incoming water to 140 deg. F (60 deg. C) rather than through 100 deg. F (37.8 deg. C) rise which is commonly assumed.

3.3.2 Water Heaters

Single or multiple water heaters with applicable protective devices shall be provided to meet various storage requirements and hot water demands.

(1) Storage Type. The storage type heater is normally provided where hot water demands are not constant and where it is economically advisable to provide water storage to satisfy periods of peak flow. The storage capacity of the unit serves to supplement the heating capacity and to permit the use of a unit with a relatively reduced recovery rate.

(a) Limitations on use of electric resistance domestic water heating. The use of electrical resistance heating for domestic hot water is prohibited on storage tanks over 80 gallons (303 liters) unless the following requirements can be met:

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

2. Provision is made to generate the hot water "off peak" by providing larger storage tanks or by storing it at a higher temperature of 160 deg. F to 180 deg. F (71.1 deg. C to 82.2 deg C) and distributing it through a blending valve at the desired temperature of 100 deg. F to 110 deg. F (37.8 deg. C to 43.3 deg. C); and

3. The facility has a maximum total energy consumption of less than 60,000 Btu's per square foot per year (681.4 MJ/m └2┘]a) at a nominal 40-hour week use or less than 118,000 Btu's per square foot per year (1340 MJ/m └2┘]a) around-the-clock use.

(b) General sizing. Heating and storage capacities shall be calculated in accordance with Table 6. For an example of calculation procedures, see Example 2. For estimating hot water requirements for a facility when the type and number of fixtures are not known, Table 7 shall be used. For water heater capacities for one- and two-family living units, see Table 8.

(c) Sizing for hospitals.

(d) Example 2. Calculate the hot water requirements, in accordance with Table 6, of an enlisted men's barracks with subsistence facilities. All water is to be heated and stored at 140 deg. (60 deg. C). A booster heater will be provided to boost water temperature from 140 deg. F to 180 deg. F (60 deg. C to 82.2 deg. C) for dishwashing and utensil washing; incoming water is at 70 deg. F (21.1 deg. C).

Fixtures outside of kitchen area:

30 lavatories, public @8 (30 L)	240 gph	(908 L/hr)
6 lavatories, private @2 (7.6 L)	12 gph	(45 L/hr)
30 showers @150 (568 L)	4500 gph	(17 032L/hr)
8 clothes washers @25 (95 L)	200 gph	(757 L/hr)
6 service sinks @20 (76 L)	120 gph	(454 L/hr)
3 laundry stationary tubs @25 (95 L)	75 gph	(284 L/hr)
TOTAL	5,147 gph	(19 480 L/hr)

	Apartmen t House	Club	Gymnasiu m	Hospital	BOQ	Industrial plant	Office building	Family residence	School	Kitchen area	
1. Basin, 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. Basin, private lavatory	4 (15)	6 (23)	8 (30)	30 (114)	20 (76)	20 (76)	-	-	20(76)	-	5 (19)
3. Bathtubs	20(76)	4 (15)	6 (23)	8 (30)	30 (114)	20 (76)	20 (76)	-	-	-	-
4. Dishwashers (Domestic)[b]	15 (57)	-	-	50-150	-	-	-	15(57)	-	-	-
5. Clothes Washer[c]	c	-	-	-	c	-	-	c	-	-	-
6. Kitchen Sink	20 (76)	20 (76)	-	20 (76)	18 (69)	20 (76)	20 (76)	20 (76)	20 (76)	-	30 (114)
7. Laundry, Stationary tubs	55 (19)	10 (38)	-	10 (38)	5 (19)	-	10 (38)	5 (19)	-	-	5 (19)
8. Pantry sink	30 (114)	150 (56)	225 (85)	75 (284)	30 (114)	225(852)	30 (114)	30 (114)	225(852)	-	-
9. Showers	30(114)	20 (76)	20 (76)	-	20(76)	20 (75)	20 (76)	-	20 (76)	-	30(114)
10. Hydro-therapeutic showers	-	-	-	400(1514)	-	-	-	-	-	-	-
11. Leg baths	-	-	-	100(375)	-	-	-	-	-	-	-
12. Arm baths	-	-	-	35 (132)	-	-	-	-	-	-	-
13. Sitz bath	-	-	-	30 (114)	-	-	-	-	-	-	-
14. Continuous flow bath	-	-	-	165 (625)	-	-	-	-	-	-	-
15. Vegetable sink	-	-	-	-	-	-	-	-	-	-	45 (170)
16. Single pot sink	-	-	-	-	-	-	-	-	-	-	30 (114)
17. Double pot sink	-	-	-	-	-	-	-	-	-	-	60 (227)
18. Triple pot sink	-	-	-	-	-	-	-	-	-	-	90 (341)
19. Utensil washer[b]	-	-	-	-	-	-	-	-	-	-	-
20. Hubbard bath	-	-	-	600(2271)	-	-	-	-	-	-	-
21. Pre-scrapper	-	-	-	-	-	-	-	-	-	-	180(681)
22. Pre-flush(hand oper)	-	-	-	-	-	-	-	-	-	-	45 (170)
23. Pre-flush(closed)	-	-	-	-	-	-	-	-	-	-	240 (908)
24. Pre-flush (recirculation)	-	-	-	-	-	-	-	-	-	-	40 (151)
25. Bar sink	-	-	-	-	-	-	-	-	-	-	30 (114)
26. Demand factor	0.3	0.3	0.4	0.25	0.3	0.4	0.3	0.3	0.4	0	0.3
27. Storage capacity factor	1.25	0.9	1	0.6	11.3	1	2	0.7	1	1	1

[a] Commercial-type Kitchens such as for subsistence buildings, hospitals, school, etc

[b]Dishwashers and Utensil washer requirements shall be taken from manufactures data if the model to be used is known

[c]Allow 3 gph per pound (25 L/h per kilogram) capacity

[d]Ratio of storage capacity to demand factor

Table 6. Hot Water Demand per Fixture for Various Types of Buildings

Gallons (Liters) of water per hour per fixture (water at 140 deg F (60 deg C) except as indicated

Type of Building	Daily Demand (gal. / liters)	Max Hourly Demand [1] (gal. / liters)	Duration of Sustained Load (hrs)	Storage Capacity [1] (gal. / liters)	Heating Capacity per hr. (gal. / liters)
Administration	3 (11)	20 (76)	2	20 (76)	10 (38)
Bachelor officers apartment quarters	40[2] (151)[2] 35[2] (132)[2]	15 (57) 25 (95)	4 2	18 (68) 20 (76)	14 (53) 15 (57)
Barracks with subsistence	40 (151)	12 (45)	2.5	10 (38)	8 (30)
Barracks without subsistence	30[2] (114)	14 (53)		12 (45)	8 (30)
Hospital [3]	-	-	-	-	-
Industrial	5 (19)	30 (114)	1	20 (76)	20 (76)
Subsistence	10 (38)	20 (76)	2	15 (57)	15 57)

Table 7. Estimated Hot Water Demand Characteristics for Various Types of Buildings

[1] Percent of days use

[2] Increase total daily demands by 15 gallons (55 liters) per domestic-type dishwasher and by 45 gallons (170 liters) per clothes washer.

Probable maximum demand:

5,147 gal/hr. (19 480 L) x 0.20 = 1,030 gph (3896 L/hr)

Storage: 1,030 x 1.25 = 1,287 gals. (4871 liters)

Adjustments for 70 deg. F incoming water (Table 5)
1,030 gph x 0.82 = 845 gph (3198 liters) (demand)
1,287 gal x 0.82 = 1,056 gal. (3997 liters) (storage)

o Fixtures within kitchen area:

1 dishwasher	300 gph	(1135 L/hr)
1 utensil washer	80 gph	(303 L/hr)
2 double pot sinks @60 (227 L)	120 gph	(454 L/hr)
1 vegetable sink	45 gph	(170 L/hr)
TOTAL	545 gph (	2062 L/hr)

545 x 1.0 (demand factor = 545 gph (2062 L/hr) (demand)
545 x 1.0 (storage factor = 545 gal (2062 Liters) (storage)

Storage and Tankless Type domestic water heater											
Number of bathrooms		1-1 1/2			2-2 1/2			3-3 1/2			
Number of bedrooms		2	3	4	3	4	5	3	4	5	6
Storage Type-gas											
Storage, gal, (liters)		30 (114)	30 (114)	40 (151)	40 (151)	40 (151)	50 (190)	40 (151)	50 (190)	50 (190)	50 (190)
1000 Btuh (kilowatt) Input		30	30	30	33	33	35	33	35	35	35
Storage Type-electric											
Input i? kilowatts	Upper Element	1.5	1.5	2	2	2	2.5	2	2.5	2.5	2.5
	Lower Element	1	1	1	1.25	1.25	1.25	1.5	1.25	1.5	1.5
	Single Element	2.5	2.5	3	3	3	4	3	4	4	4
Boiler connected indirect water heaters internal or external type with tank-boiler water 180F/82.8C											
Manufacturer rated, gal, (liters in 3 rein. 100F (37.8)C deg rise		49 (185)	75 (284)	75 (284)	75 (284)	75 (284)	75 (284)	75 (284)	75 (284)	75 (284)	75 (284)
Tank capacity in gallon (litters)		66 (250)	66 (250)	66 (250)	82 (310)	66 (250)	82 (310)	82 (310)	82 (310)	82 (310)	82 (310)
internal or external type- tankless boiler water 200F/83.3C											
Manufacturer rated, draw, gal, (liters in 3 rein. 100F (37.8)C deg rise		15 (57)	15 (57)	25 (95)	25 (95)	25 (95)	35 (132)	25 (95)	35 (132)	35 (132)	35 (132)

Table 8. Tank Water Heater Capacities for One-and Two-Family Living Units

o Total hot water requirements for building:

	Heating		Storage	
Outside of kitchen area	845	(3198)	1,055	(3993 liters)
Inside of kitchen area	545	(2062)	545	(2062 liters)
	1,390 gph	(5260 L/hr)	1,600 gal	(6055 liters)

o Provide two water storage heaters as follows:

Storage Capacity: 1601 gal (6060 L) x 0.66 = 1056 gal (3997 L) (each)
Heating Capacity: 1390 gal (5260 L) x 0.66 = 917 gph (3471 L/hr) (each)

Note: Water for dishwashing and utensil washing must be heated from 140 deg. F (60 deg. C) to 180 deg. F (82.2 deg. C). This may be done by providing one heater to meet the demands of both pieces of equipment or specifying booster heaters as integral parts of the equipment.

(2) Semi-Instantaneous Type. The semi-instantaneous type water heater has a high capacity heating coil and a small storage capacity. It is suitable mostly for use where the hot water demands are characterized by a high-sustained demand load with only small peaks on top of the sustained load. The heating coil is sized to satisfy the high-sustained demand load, and the small peak demands are satisfied by the small amount of storage. This type of water heater is not suitable for use in barracks, quarters, commercial-type laundries, and messing facilities. These types of facilities, because of their high peak demands of relatively short duration, require a water heater with storage. To determine the suitability and size of semi-instantaneous water heater to be used for other than the above types of facilities, an analysis in accordance with the following guidelines should be made.

(a) Guidelines for sizing. The following information shall be used as a guide for sizing.

(i) Determine the estimated maximum hot water flow by the method described in the National Standard Plumbing Code.

(ii) Determine the water heating capacity required, in gallons per minute, by multiplying the estimated maximum flow by the following factors: hospitals, .25; living quarters, .33; subsistence buildings, other than kitchen and dishwashing equipment, .33 (for kitchen and dishwashing equipment, see paragraph (iii) below); and office buildings, .25. For other types of buildings, use the factor above for the buildings having a demand rate which most nearly approaches the demand rate of the building in question.

(iii) In addition to the estimated maximum flow as determined above, hot water to satisfy the simultaneous and continuous demand of special-group fixtures (commercial-type laundry machines and kitchen and dishwashing equipment in subsistence buildings) shall be provided when applicable.

(b) Guidelines for determining suitability. The following information should be used to determine suitability of use.

(i) Determine the coil capacity, in gallons per hour, (liters per hour) of hot water which would be required with a storage-type heater sized in accordance with Table a.

(ii) If the coil capacity thus determined is equal to, or greater than, the coil capacity which would be required for a semi-instantaneous unit (determined in accordance with paragraph (a) above), it can be assumed that maximum instantaneous steam demand of the semi-instantaneous unit will not be significantly greater than that of a storage type unit. In this case, the semi-instantaneous unit should be used.

(iii) If the coil capacity thus determined is less than, but at least two thirds of, the size which would be required for a semi-instantaneous unit, the semi-instantaneous unit may be used. This unit may be used provided that the additional instantaneous steam demand of the unit, as compared to a storage-type unit (which can be assumed to be semi-proportional to the difference in coil size), can be tolerated. The semi-instantaneous unit can also be used provided that use of the unit can be justified by an economic analysis. Such an analysis would take into account any differences in the capital cost of boiler plant and steam service line, the installed cost of the water heaters, and the cost of mechanical room space (if affected).

(iv) If the coil capacity thus determined is less than two thirds of the capacity which would be required for a semi-instantaneous unit sized in accordance with paragraph (a) above, it can be assumed that the demand for hot water in the facility is not of the sustained type and that use of the reduction factors in paragraph (a) (ii) are not justified. Instead, resize the unit assuming that the water heating capacity required is equal to the maximum hot water flow determined in paragraph (a) above. A semi-instantaneous heater sized on this basis may be used provided that the additional instantaneous steam demand of this unit, as compared to a storage-type unit, can be tolerated and that use of the unit can be justified by an economic analysis (see paragraph (b) (iii)).

(3) Instantaneous Type. The instantaneous water heater has little or no storage capacity. This type of unit shall be provided only where the hot water demand is relatively constant or where there are no periods of peak demand which would necessitate the selection of a unit that, except for relatively short periods of the day, would be grossly oversized. Fluctuating water temperature is a characteristic of an instantaneous heater. To guard against scalding and to ensure a constant predetermined water temperature at the fixtures, a water mixing valve shall be provided as an auxiliary to the unit. The instantaneous water heater must be capable of heating the water as it is being used. The capacity of the unit, expressed in gallons per minute, is calculated by the fixture unit method. For heater capacities for one- and two-family living units, see Table 8.

(4) Water Heaters for Laundries. Water heaters are provided for laundries according to hot water requirements based on the capacity of washers in pounds (kilograms) of dry clothes or the number of persons to be served by the plant. Storage capacity in gallons (liters) shall be equal to 80 percent of the hourly heating capacity.

(a) Total heating capacity, H ⌈W⌉, and peak demand, D ⌈W⌉, of hot water based on capacity of washers in pounds (kilograms) of dry clothes will be computed as in Equations (1) and (2).

EQUATION: $H\,\lceil w \rceil = R \times 5 \times 0.60$ gph (1a) or

$$H\,\lceil w \rceil = R \times 41.6 \times 0.60 \text{ Lph} \quad (1b)$$

EQUATION:

$$D\,\lceil w \rceil = \frac{R \times 5 \times 0.60 \text{ gpm}}{3 \times F \times C} \quad (2a)$$

or

$$D\,\lceil w \rceil = \frac{R \times 41.6 \times 0.60 \text{ Lpm}}{3 \times F \times C} \quad (2b)$$

where,

R = total rated capacity of washers, pounds (kilograms) of dry clothes per hour
5 = gallons of water (hot & cold) per pound of dry clothes
41.6 = liters of water (hot & cold) per kilogram of dry clothes
0.60 = 60 percent of total amount of water is hot water

1/3 = that portion of the number of machines assumed to be drawing water simultaneously
F = time required to fill each machine with water, minutes
C = number of fill cycles per hour per machine

(b) Total heating capacity, H Γp˥, and peak demand, D Γp˥, of hot water based on the number of persons will be computed as in Equations (3) and (4).

EQUATION:

$$H\ \Gamma p\urcorner = \frac{N \text{ x } P \text{ x } 5 \text{ x } 0.60 \text{ gph}}{H} \qquad (3a)$$

or

$$H\ \Gamma p\urcorner = \frac{N \text{ x } P \text{ x } 41.6 \text{ x } 0.60 \text{ Lph}}{H} \qquad (3b)$$

EQUATION:

$$D\ \Gamma p\urcorner = \frac{N \text{ x } P \text{ x } 5 \text{ x } 0.60 \text{ gpm}}{H \text{ x } 3 \text{ x } F \text{ x } C} \qquad (4a)$$

or

$$D\ \Gamma p\urcorner = \frac{N \text{ x } P \text{ x } 41.6 \text{ x } 0.60 \text{ Lpm}}{H \text{ x } 3 \text{ x } F \text{ x } C} \qquad (4b)$$

where,

N = number of persons
P = pounds (kg) of dry clothes per person or patient per week (15 pounds (7 kg) per person or 35 pounds (16 kg) per hospital bed).
5 = total gallons of water (hot & cold) per pound of dry clothes.
0.60 = 60 percent of total amount of water is hot water
H = number of work hours per week
1/3 = that portion of the number of machines assumed to be drawing water simultaneously
41.6 = total liters of water (hot & cold) per kilogram of dry clothes
F = time required to fill each machine with water, minutes
C = number of fill cycles per hour per machine

(5) Multiple water Heaters. Hospitals, laundry buildings, subsistence buildings, bachelor officers' quarters with mess and enlisted men's barracks with mess shall be provided with multiple water heaters and storage tanks. Other facilities shall be provided with a single water heater and storage tank. Multiple units, however, may be justified by circumstances such as (1) facility configuration, (2) space limitations, (3) limited access to tank room, and (4) hot water requirements necessitating a unusually high capacity heating and storage unit. When two units are provided, each shall have a capacity equal to two thirds of the calculated load. When more than two units are provided, their combined capacity shall be equal to the calculated load.

(6) Relief Valves. Automatic relief valves shall be provided for the protection of all water heating and storage equipment.

(a) Type. A temperature relief valve and a pressure relief valve are provided for all equipment with a storage capacity in excess of 120 gallons (454 liters) and an input rating in excess of 100,000 British thermal units per hour (35 000 watts). A combination temperature-pressure relief valve is provided for equipment with a storage capacity of 120 gallons (454 liters) or less and a input rating of 100,000 or less British thermal (35 000 watts) units per hour.

(b) Capacity. The pressure relief valve shall have a relieving capacity equal to or in excess of the input of the heater, and it shall be set to relieve at or below the maximum allowable working pressure of the equipment. The temperature relief valve shall be of ample capacity to prevent the water temperature from exceeding 210 deg. F (99 deg. C).

(c) Location. Temperature relief valves or combination temperature-pressure relief valves shall be installed in the hot water outlet of an instantaneous heater or at the top of a storage tank with the thermal element located within the top a inches (152 mm) of the tank. Pressure relief valves shall be installed in the cold water inlet to the heater. No valves shall be installed between the relief valves and the equipment being protected. For typical installations of relief valves, see Figure 1.

(7) Vacuum Breaker. A vacuum breaker shall be provided on a copper-lined storage tank to prevent the creation, within the tank, of a vacuum which could cause loosening of the lining.

3.3.3 Hot Water Circulation

A hot water circulation system ensures instant hot water at the fixtures and promotes water conservation. In addition to circulation through the piping system, circulation is induced through the storage tank, thereby preventing water stratification within the storage tank and, in effect, increasing the amount of available hot water.

(1) Application. A forced circulation system shall be provided when the pipe run from storage tank to the farthest fixture exceeds 100 feet (30.5 meters) or when the hot water storage is in excess of 200 gallons (757 liters).

(2) Rate of Circulation. Circulation shall be at a rate that will limit the water temperature drop to 20 deg. F (6.7 deg. C) (maximum temperature difference between supply and return). A method which has proved satisfactory and is generally accepted for determining rate of circulation is to allow 1 gallon (3.8 liters) per minute for each 20 fixtures using hot water.

(3) Valves. Valves for balancing the circulation shall be provided in each return branch.

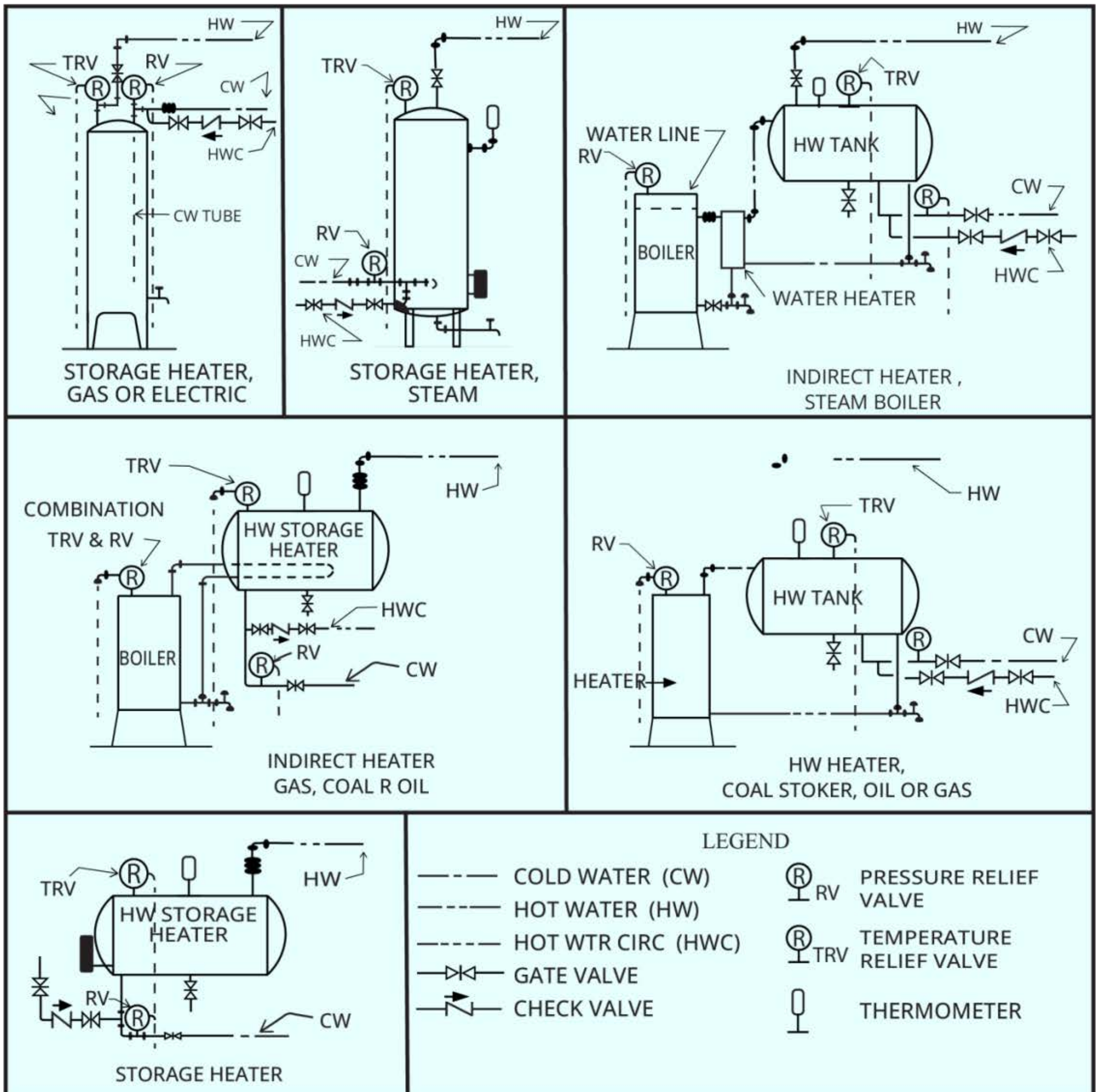
3.4 Chilled Drinking Water Systems

3.4.1 Types of Units

Chilled drinking water may be provided by self-contained cooler fountains or by a central refrigeration unit from which chilled water is piped to multiple drinking fountains. Self-contained units shall be provided unless a piped system with a central refrigeration unit can be justified economically.

3.4.2 Design

The design of chilled drinking water systems shall be in accordance with the procedures outlined in the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE).



NOTES:

1- DIAGRAM ILLUSTRATE THE LOCATION OF RELIEF VALVES WHEN SEPARATE TEMPRATURE AND PRESSURE RELIEF VALVES ARE REQUIRED. THE LOCATION OF THE TEMPERATURE RELIEF VALVE INDICATES, ALSO, THE LOCATION OF THE COMBINATION TEMP-PRESSURE RELIEF VALVE WHEN THE COMBINATION VALVE IS REQUIRED (PAR 3b (6) (b))

2- WHEN ADEQUATE CIRCULATION BETWEEN STORAGE TANK AND HEATER CANNOT BE ACHIEVED BY GRAVITY, A CIRCULATING PUMP SHALL BE PROVIDED.

Figure 1. Typical Connections to Water Heaters and Hot Water Storage Tanks

4. Insulation of Plumbing Systems

4.1 Hot Water Systems

Insulate service hot water piping and storage to meet the following minimum requirements.

4.1.1 Unfired Water Storage

The heat loss from unfired storage tanks shall not exceed 13 Btu per hour per square foot (41 watts per square meter) of external tank surface area at a design ambient of 65 deg. F (18 deg. C) and shall not exceed the temperature of the stored water.

4.1.2 Electric Water Heaters

Insulate all electric water heaters and backup heaters with a storage capacity of 80 gallons (303 liters) or less and an input rating of 12 kW or less to limit the heat loss to less than 13 Btu per hour and per square foot (41 watts per square meter) of the external tank area. Also insulate heaters based on a temperature difference of 80 deg. F (44 deg. C).

Insulate electric storage heaters with storage capacity greater than 80 gallons (303 liters) or input ratings greater than 12 kW to an R value of10 square feet [multiplied by] hour [multiplied by] deg. F per Btu (1.76 meter squared [multiplied by] deg. C per watt) or to a standby loss of 13 Btu per hour per square foot (41 watts per square meter) of tank surface area.

4.1.3 Gas and Oil-Fired Water Heaters

Limit standby heat loss, loss when the heater is not fired, for water heaters rated 75,000 Btu/h (22 kW) or less to:

EQUATION:

$$S = 2.3 + \frac{67}{\text{volume in gallons}} \qquad (5a)$$

$$S = 2.3 + \frac{\text{or } 250}{\text{volume in liters}} \qquad (5b)$$

Where S is expressed in a percent per hour of stored capacity.

Limit standby heat loss for all gas and oil-fired water heaters with input capacities greater than 75,000 Btu/h (22 kW), but less than 4,000 Btu/h per gallon (0.3 kW/liter) of stored water, to:

EQUATION:

$$S = 2.8 + \frac{67}{\text{volume in gallons}} \qquad (6a)$$

or

$$S = 2.8 + \frac{250}{\text{volume in liters}} \qquad (6b)$$

4.1.4 Recirculated Systems

Hot water systems using a circulating pump will be insulated to limit the heat loss to a maximum of 17.5 Btu/h per linear foot (16.8 watts per linear meter).

4.1.5 Insulation

Insulate all service hot water piping with asbestos-free pipe insulation having a "K" value of approximately 0.27 Btu inch per hour [multiplied by] foot [multiplied by] F (0.039 watt per m [multiplied by] C) or greater and the following minimum thicknesses: 0.5 inch (12.7 mm) for nominal pipe diameters up to 1 inch (25.4 mm); 1 inch (25.4 mm) for nominal pipe diameters of 1 and 1.25 inches (25.4 mm and 38.1 mm, respectively); 1.5 inches (38.1 mm) for nominal pipe diameters of 1.5 and 2 inches (38.1 mm and 50.8 mm, respectively); and 2 inches (50.8 mm) for nominal pipe diameters greater than 2 inches (50.8 mm).

(1) In a heat recovery system, insulate all hot gas refrigerant pipes located outdoors with a minimum 1 inch (25.4 mm) thick 0.27 "K" waterproof insulation.

4.2 Miscellaneous Systems

Insulation may be required for the following plumbing items:

4.2.1 Cold Water

Where the temperature of the cold water entering a building is below the average normal dew point of the indoor ambient air and where condensate drip will cause damage or create a hazard, insulate with a vapor barrier type of insulation to prevent condensation. All chilled water piping from a central drinking water cooling system must be insulated with vapor barrier type insulation to prevent condensation.

4.2.2 Heating System

Where the heat loss from the hot water heating system piping will not beneficially add to the heat required for that space, insulate piping the same as in paragraph 4.1.5.

4.2.3 Rainwater Conductors

To prevent condensation, insulate horizontal conductors and roof drains inside the building.

4.2.4 Freezing Temperatures

Although insulating water pipes, tanks, and cooling tower will not prevent water from freezing, these devices shall be insulated and possibly heat traced for protection against damage. The proper thickness or conductivity factor for this insulation shall be determined by the design engineer.

4.2.5 Design

The insulation requirements and maximum heat loss rates stated in this section are minimum design requirements. The designer is encouraged to upgrade the quality of insulation if he can show an improvement in the system performance or that the insulation is cost effective or both.

5. Fuel Gas Systems

5.1 Design

Design of systems for natural gas, manufactured gas, and liquified gases shall be in accordance with the applicable NFPA Standards.

5.2 Safety Precautions

Safety precautions for fuel gas systems are as follows:

5.2.1 System Pressure

Only low- pressure gas (approximately 5 inch [1.24 kPa] water column) shall be distributed within the building.

5.2.2 Pressure Regulator Location

In areas where outside temperatures remain above freezing, the pressure regulators shall be installed within a ventilated enclosure adjacent to the building.

In areas where freezing temperatures are encountered, location of regulators shall be in accordance with local policy.

Vent pipe from regulator shall terminate outside of building.

5.2.3 Seismic Consideration

In areas subject to earthquakes or other natural phenomena which may cause pipe rupture, local codes shall dictate the use of automatic shutoff valves and the precautions to be taken to avoid pipe rupture.

5.2.4 Ventilation

When gas piping is run through a crawl space, the crawl space shall be ventilated in accordance with industry standards.

6. Energy Conservation

6.1 Air Source Heat Pumps

6.1.1 General

An air source heat pump used for heating of domestic hot water includes an evaporator that extracts heat from an air stream and transfers this heat to a refrigerant. This low-level heat is raised to a higher usable level by compressing the refrigerant gas. The higher level of heat is then transferred through a vented double wall condenser to the domestic hot water. This system requires a small water circulating pump to circulate the heated water to a storage vessel and a fan to blow the heat source air over the evaporator coil.

6.1.2 Packaged Water Heater Heat Pump

The water heater heat pump (WHHP) is used to save energy and must be connected to a conventional water heater for backup and storage. The WHHP operates on the principle of a non-reversible heat pump; the heat extracted from the air plus the heat added by the compressor, the circulating pump, and a blow-through fan is transferred to the hot water. The operating cost of the system is the electricity purchased to power the WHHP. Depending on the evaporator's ambient air temperature, relative humidity and the temperature of leaving hot water, the ratio of the total heat transferred to the water can be as much as 2 to 4 times the energy (heat) input to the WHHP. This means that for each unit of purchased energy (heat), 2 to 4 times that amount of heat will be transferred to the water. The difference between purchased heat and the heat in the water is the heat extracted from the air by the evaporator.

(1) Coefficient of Performance (COP). Heat pumps are rated in Btu/h (kWh) of capacity and in COP. The COP of a packaged WHHP is the total amount of heat transferred to the hot water divided by the heat input of the compressor, fan, and pump motors.

EQUATION:
$$COP = \frac{\text{energy output in Btu/h (kWh)}}{\text{energy input in Btu/h (kwh)}} \qquad (7)$$

(2) System. A water heating system will include the packaged WHHP, a storage tank, a backup heating source, and controls for automatic operation. See Figure 2, Air Source Heat Pump.

6.1.3 Sizing

Section 3 of this course shall be used to determine the required storage capacity and the hot water demand for a project. The practical maximum water temperature that a WHHP can produce is 135 deg. F (57 deg. C). If the temperature rises above 135 deg. F (57 deg. C), the COP of the unit can fall below 2 making the unit uneconomical for heating water. When water temperatures above 135 deg. F (57 deg. C) are required, booster heaters shall be used.

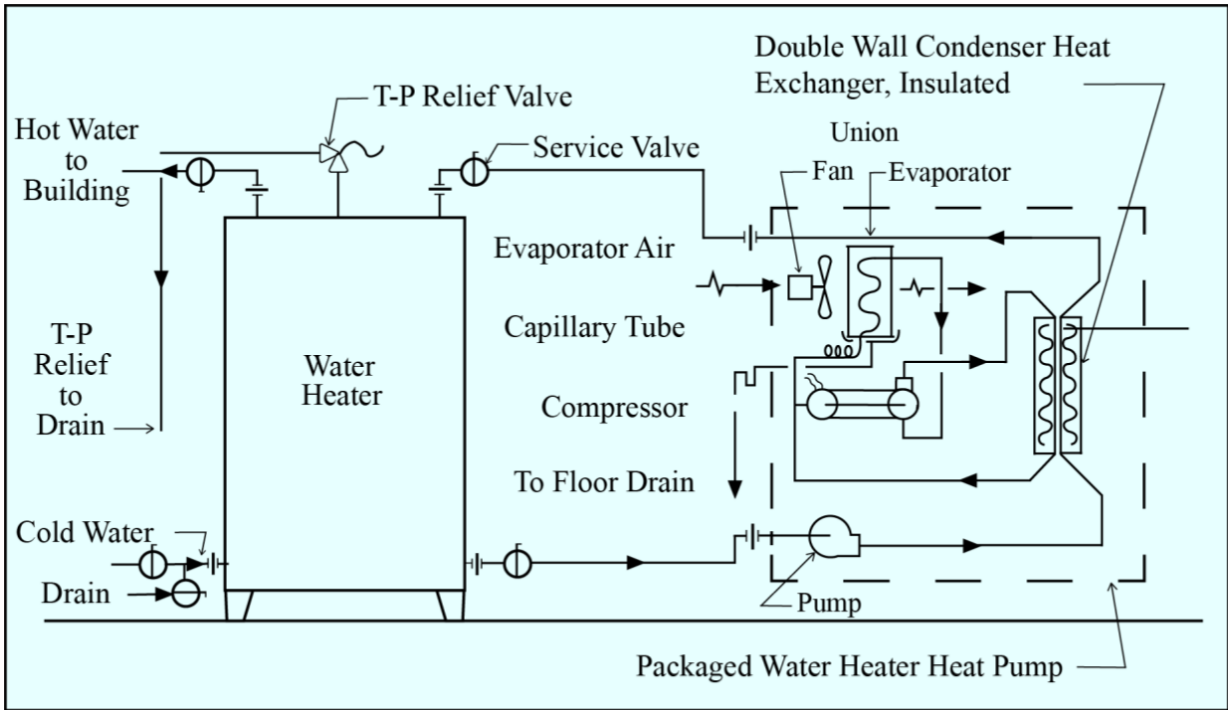


Figure 2. Air Source Heat Pumps

(1) Recovery. The heat recovery rate or heating capacity of a WHHP varies depending upon the dry bulb temperature and relative humidity (RH) of the air and the temperature of the heated water. For example, at a constant supply water temperature of 135 deg. F (57 deg. C), a air temperature of 50 deg. F (10 deg. C), and an RH of 25 percent, a WHHP may produce 1000 units of heat. At 135 deg. F (57 deg. C) water temperature, 90 deg. F (32 deg. C) air temperature, and a 65 percent RH, the same WHHP can produce 1960 units of heat. The impact of the heating capacity change due to a change in leaving water temperature, while the air temperature remains constant, is shown by carrying this example further: The heating capacity of a unit with water at 135 deg. F (57 deg. C), air at 90 deg. F (32 deg. C), and 65 percent RH is 1960 units of heat. At 115 deg. F (46 deg. C) water temperature and the same air conditions, the

heating capacity is 1972 units of heat. The heating capacity of a WHHP is affected more by changes in the evaporator's ambient air temperature than by changes in the heated water temperature. See Figure 3, Typical WHHP-Performance.

(2) Temperature. To obtain the maximum efficiency from the WHHP system, the hot water should be kept at as low a temperature as possible. Almost all hot water needs, other than for dishwashing, medical facilities, and some special requirements, can be handled with 105 deg. F to 110 deg. F (41 deg. C to 43 deg. C) water temperature. In the rage of 70 deg. F to 85 deg. F air temperatures, the WHHP heating capacity increases approximately 600 Btu/h (0.176 kWh) as the water temperature drops from 135 deg. F (57 deg. C) to 115 deg. F (46 deg. C). There are small changes in capacity at higher air temperatures and larger changes at lower air temperatures. See Figure 3, Typical Performance.

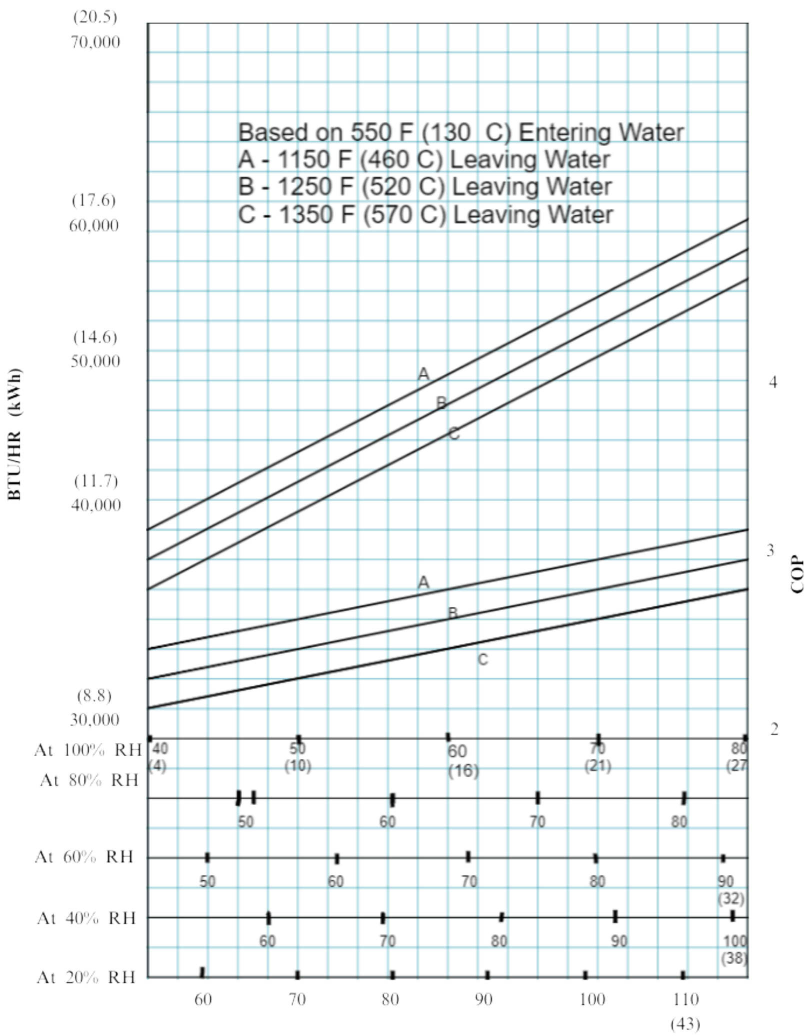


Figure 3. Typical WHHP Performance

DRY BULB TEMPERATURE °F (°C)
OF AIR ENTERING EVAPORATOR

(3) Installation. The designer must locate the WHHP whore there is adequate space for service and must provide clearances as required by the manufacturer to obtain maximum heating efficiency. The location of the WHHP relative to the storage tank influences the size of the interconnecting water pipe. The circulating pump in the WHHP is small and has a low head capability; therefore, the closer the two components are, the smaller the pipe size will be. A separate WHHP and storage tank are used to allow the designer to locate air intakes and exhaust outlets properly, to enclose the WHHP to reduce the noise transmitted to occupied spaces, and to increase the availability (sources) of replacement parts. The WHHP must have its condensate drain piped to a floor drain or to the outside of the building. The fan moving air over the evaporator generates noise that must be suppressed to eliminate noise problems in adjacent occupied spaces. If the WHHP is located where the evaporator air is drawn from an area laden with lint, leaves, dust, or other airborne material, the designer must provide air filtration. The designer must specify a manual lock type switch to permit the manual selection, by authorized people, of either the WHHP or the backup heat source in the event the WHHP is not usable.

(a) Under emergency operation, the controls must shut off the WHHP and transfer the water temperature control to the backup heater. If the temperature of air entering the evaporator drops to 45-50 deg. F (7-10 deg. C), the WHHP should automatically shut off to allow the backup water heater to heat the water.

(b) The designer must determine the hardness of potable water in the area where the WHHP will be installed and specify the necessary water softening equipment to prevent scale formation in the double wall condenser heat exchanger.

6.1.4 Retrofit

Any existing domestic water heater can become the storage and backup heater when retrofitted with a WHHP as the source for the hot water. If the existing storage capacity is small or non-existent, additional new storage, sized for the project, may be required.

(1) The retrofitting of an existing water heater system requires the re-piping of the cold water into the WHHP and then back to the existing water heater. Some existing water heaters and some new ones have no more than two connections, one hot and one cold, and some have an anode or other obstruction in one of the connections. The installation of the WHHP may

require a special fitting on the water heater to make the system work properly. The designer must verify the need for these special requirements.

(2) Prior to the retrofit installation, sludge and particulate matter must be removed from the existing water heater and piping system to prevent damage to the WHHP and its piping. Water pipes between the heat pump unit and the tank must be insulated to maximize savings. The cold and hot water pipes should not be installed in a common insulation jacket.

(3) The power source for the WHHP must be investigated to ensure that there is adequate power available and that the voltage and phase are correct. Some WHHP units require 115-volt single-phase power for their small circulating pumps and 208- or 220-volt single-phase power for their compressors. Some of the larger compressors require three-phase power.

6.1.5 Geographic Influence

The air source WHHP must be equipped with a low ambient air thermostat to prevent its operation below 45-50 deg. F (7-10 deg. C). Below this temperature, the backup heater must heat the water. If outside air is the source of heat for the evaporator, an analysis must be made of the number of hours the outside temperature is below 50 deg. F (10 deg. C), the cost of electricity and the cost of the alternate energy to heat the water. At some combination of these three factors, the premium cost of the WHHP will rule out its use for domestic water heating because the payback will be too long.

Example 1. Assume that a WHHP has a COP of 2.2 when the evaporator air is at 50 deg. F (10 deg. C) and 25 percent RH and that it generates 135 deg. F (57 deg. C) hot water. If electricity costs $0.08 per kWh, 1 million Btu (293 kWh) of heated water would cost:

$$\text{Electrical Cost} = \frac{\text{Btu}}{\text{COP x 3,413}} \text{ x cost per kwh}$$

$$= \frac{1{,}000{,}000}{2.2 \text{ x } 3{,}413} \text{ x } 0.08 = \$10.65$$

or

One million Btu (293 kwh) of water heated by a gas heater operating at 75 percent efficiency and using gas at $0.80 a therm (29 kWh) would cost:

$$\text{Gas Cost} = \frac{\text{Btu}}{\phantom{\text{efficiency x 100,000}}} \text{ x cost per therm}$$

$$= \frac{\dfrac{1{,}000{,}000}{\text{efficiency x } 100{,}000}}{0.75 \text{ x } 100{,}000} \text{ x } 0.80 = \$10.66$$

Or

$$= \frac{\text{kWh x } 3{,}413}{\text{efficiency x } 100{,}000} \text{ x cost per therm}$$

$$= \frac{293 \text{ x } 3{,}413}{0.75 \text{ x } 100{,}000} \text{ x } 0.80 = \$10.66$$

If the ambient temperature were high enough to allow the WHHP to operate at a COP of 3.3 while heating water to 135 deg. F (57 deg. C), the cost to heat water with a WHHP at $0.08 per kWh would be $7.10 for one million Btu (293 kWh). At a COP of 3.6, the cost would be $6.51. One million Btu (293 kwh) represents an estimated one month's residential use at an average rate of 67 gallons (254 liters) per day of hot water heated from 55 deg. F (13 deg. C) to 115 deg. F (46 deg. C). Based on the cost of energy used above, it is easy to see that if the outside ambient temperature is above 50 deg. F (10 deg. C) for a significant number of hours during the time when hot water can be made and stored, the WHHP may be an economical system to use. It should be remembered that an outdoor air thermostat will not let the WHHP operate at ambient temperatures below 45-50 deg. F (7-10 deg. C).

As a rule of thumb, if the outdoor dry bulb ambient temperature for a given geographical location between the hours of 0800 to 2000 does not fall below 50 deg. F (10 deg. C) for more than 350 hours per year, the outdoor air source WHHP water heating system should be investigated. During the 350 hours, approximately one month, the backup heater would be used to heat the hot water. If during the remaining 4030 hours the WHHP could operate at an average COP of 3.3, the cost for one million Btu (293 kWh) at $0.08 per kWh would be $7.10. The net saving for a year would be $39.16 when compared to gas heating at $0.80 per therm. If the WHHP was installed for $650.00 on this project, the payback would be 16.6 years, which may not be attractive. When compared to direct resistance heating of water, costing $23.43 per month at $0.08 per kwh, the savings per year would be $195.96 for a payback of 4.2 years, which is very attractive, and is based upon present value of money discounted 10 percent.

The conclusion to be drawn is that the designer must analyze the cost of electricity and other fuels, the geographical weather conditions, Engineering Weather Data and the premium cost of the WHHP system to determine the most economical way to heat water. The cost of electricity is the amount the utility charges the Government for power, not the amount the Government charges its users.

The analysis of the economies of using a WHHP must include a determination of the system's impact on the electric demand. Time-of-use rate schedules for electricity, such as on-peak, mid-peak, off-peak, winter-summer, etc., may have an important bearing on the type of water heating system to be used.

6.1.6 Equipment Location

An air source WHHP will be more efficient if it is located in an area where there is a good source of waste heat, such as near a boiler, furnace, clothes dryer, etc., or near the ceiling, where the warmest air collects. The air source heat pump evaporator requires a air flow rate of approximately 450 cfm (0.21 m L3┘/sec.) for approximately 15,000 Btu/h (4.4 kWh) heat rejection. Normally outside air is the source of evaporator air, but if building air is used it must be able to pick up heat within the building without causing drafts or uncomfortable conditions in the occupied spaces. The air discharged from the evaporator is cooled and dehumidified. It may be used to supplement existing space cooling in warm weather or to help control humidity in moist areas, or it may be exhausted to the outside. The outside air intake and exhaust outlet must be adequately sized and located so the two air streams do not mix. The designer must follow the manufacturer's limits for maximum static pressure when the supply and exhaust air are ducted. All supply and exhaust openings in the buildings must be provided with protection against the entry of precipitation, animals, birds, etc. In colder climates, dampers are required.

In geographic areas where freezing temperatures are common, the location and installation of the WHHP must provide freeze protection for the water piping. When a WHHP is installed outside or in a space where freezing temperatures occur, the designer must specify that the WHHP have a built-in thermostat to turn on the circulating pump when the outside air temperature is below 42 deg. F (6 deg. C). The pump will circulate warm tank water through the unit and prevent freezing of the pipes. In colder climates, basements and some crawl spaces tend to be maintained at 50 deg. F (10 deg. C) by heat gain from the earth, making these areas acceptable locations for the installation of a WHHP.

6.1.7 Exhaust Air

Exhaust systems are a good source of relatively constant temperature air for a WHHP if the dry bulb temperature does not exceed 125 deg. F. In many facilities, toilet room exhaust fans are running whenever a building is occupied, which is the time hot water is needed. This type of installation requires the WHHP to be mounted near the exhaust duct to minimize resistance in the evaporator duct connection. No attempt should be made to use exhaust air from range hoods, fume hoods, etc., as a heat source because of the contaminants or corrosives in the air. See Figure 4, Exhaust Air Heat Pump.

6.2 Water Source Heat Pumps

6.2.1 Consider Water Source

A packaged water source heat pump operates the same as an air source heat pump except that water instead of air is the source of heat. A facility that has water cooled air conditioning equipment that is required to run during occupied hours has a ready source of heat for such a heat pump. The heat normally rejected to the atmosphere can be used to heat the service hot water. See Figure 5, Water-to-Water Heat Pump.

Efficiency. With condenser water temperatures in the 60 deg. F to 75 deg. F (16 deg. C to 24 deg. C) range, the COP of the heat pump can be as high as 4.5. The designer must provide some sort of head pressure regulation to protect the heat pump from damage due to high temperature condenser water.

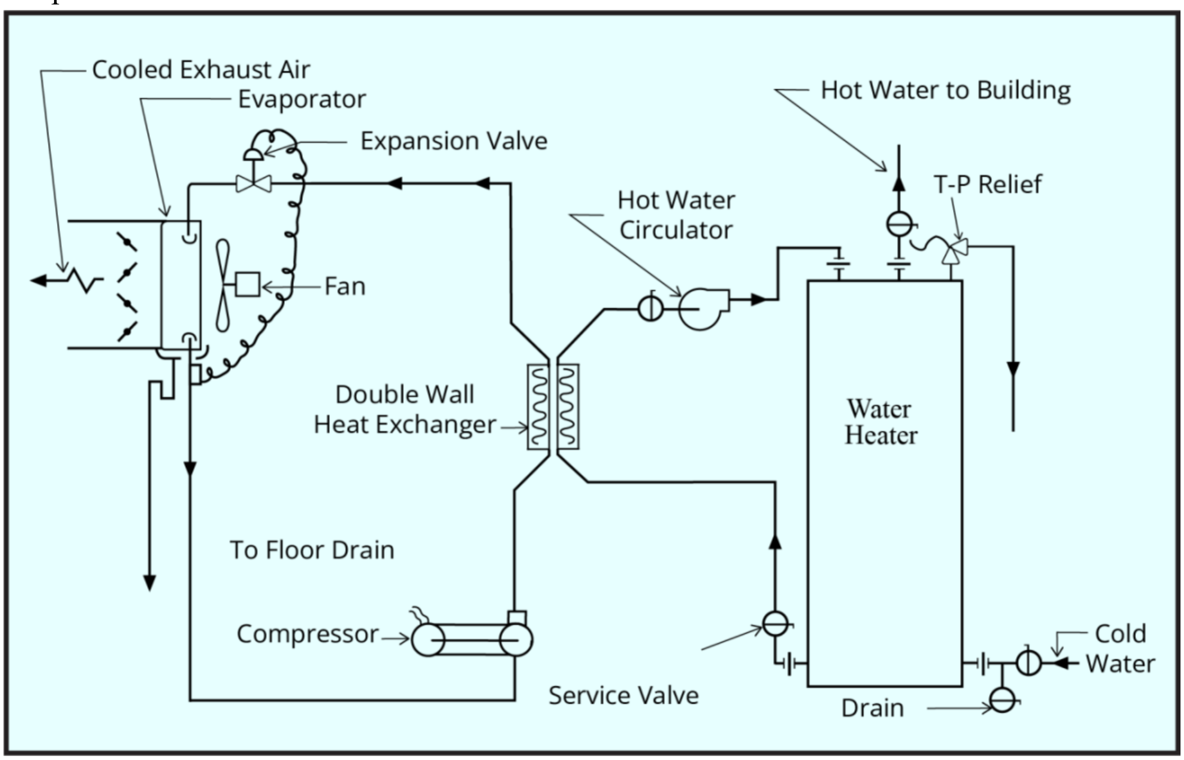


Figure 4. Swing Exhaust Air Heat Pump

6.2.2 Exhaust Air to Water

Where an exhaust system is on during occupancy, exhaust air can be the heat source for a closed loop water source heat pump. Installing a cooling coil in the exhaust duct allows the heat pump to be installed in an equipment room near the storage tank some distance away. See Figure 6, Exhaust Air Heat Source.

If a heat recovery coil is installed in a new or existing exhaust duct system, the designer must evaluate the impact of the added coil pressure drop on the operation of the exhaust fan, the cost of duct transitions, and the cost of the coil, piping and the pump. These added costs must be charged to the water heating system. The addition of a cooling coil to an existing exhaust system in some cases may require a larger exhaust fan motor.

6.2.3 Process Fluid

Some buildings require cooling water for such things as computers, condensate coolers, process cooling, etc. This cooling water is a good source of waste heat that can be used by a water-to-water heat pump. Generally, the fluid temperature should be no lower than 50 deg. F (10 deg. C) for an efficient system.

A heat exchanger should be used between process water and the heat pump where the fluid and the materials of the heat pump evaporator are not compatible or where the temperature of the process fluid is high and requires regulation to protect the heat pump.

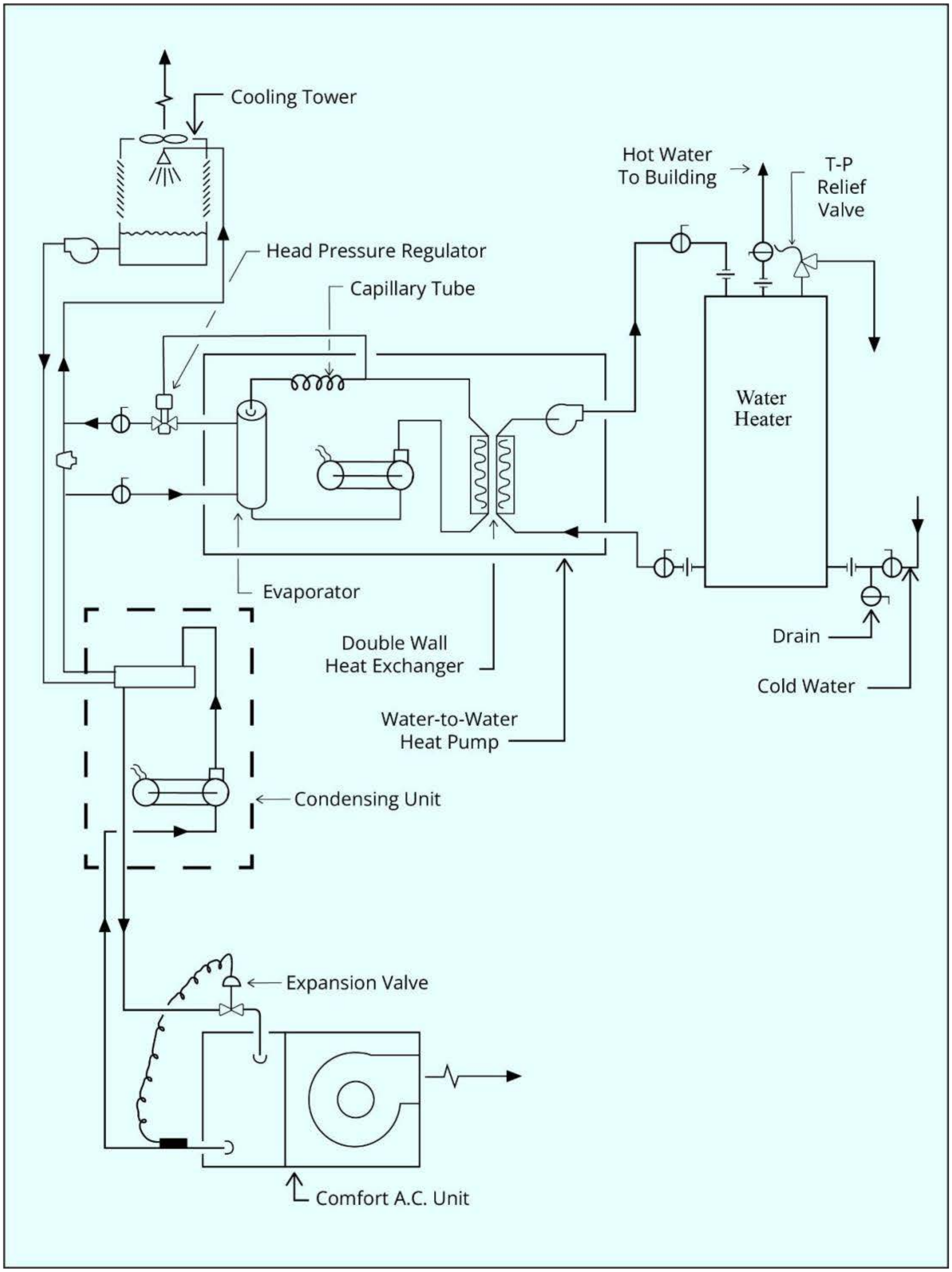


Figure 5. Water-to-Water Heat Pump

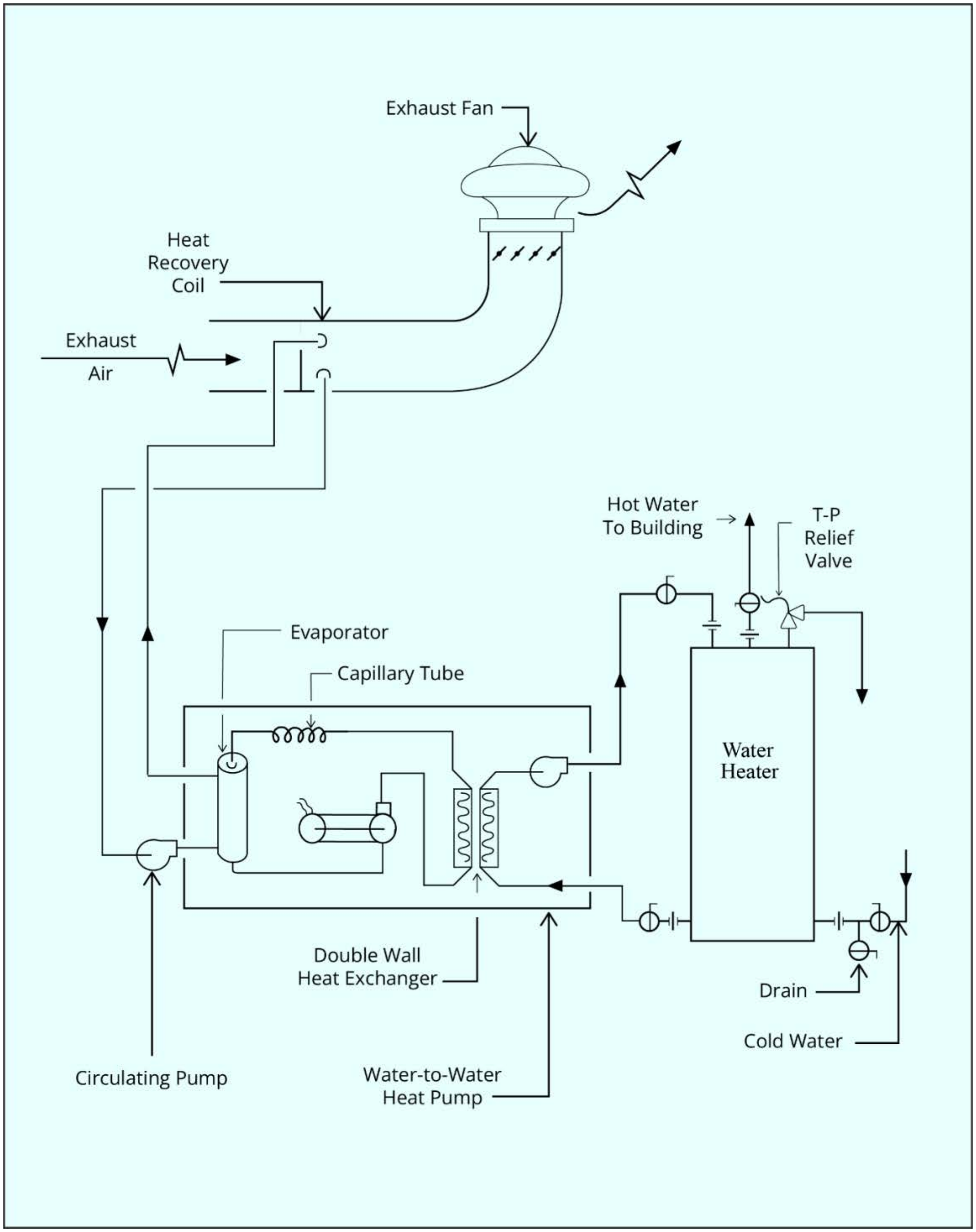


Figure 6. Exhaust Air Heat Source

6.2.4 Groundwater

The natural groundwater temperature in many geographic areas is 50 deg. F (10 deg. C) or above, which is ideal for a water-to-water heat pump. The designer must determine if there is an adequate water flow rate from the well to satisfy his project and must also determine if there are any code or EPA requirements concerning surface discharge of the pumped water or if the water must be returned to an aquifer.

6.2.5 Buried Pipe

The soil temperature at some depth below the freeze line is, in some locations, 55 deg. F (13 deg. C) or above, allowing the earth to be used as a heat source. It transfers heat to water circulated in a closed loop in buried pipes. Such a system includes a field of pipes buried in horizontal trenches or in vertical wells or holes and backfilled. This is a renewable source of heat. Provide cathodic protection for buried pipe and dielectric couplings for iron-to-copper connections.

The designer must be specific about the type of backfill used around the pipe. This is necessary to ensure good thermal conductivity between the ground and pipe (plastic, iron, copper) and eliminate air gaps. Backfilling with lumpy soil, especially clay, construction rubble, cinders, etc., causes poor thermal conductivity due to air gaps and possibly corrosive attack of the pipes.

6.2.6 Storage Tanks and Standpipes

Large storage vessels used to store potable water and pressurize water sprinkler systems, particularly in warm geographic areas, are huge thermal storage vessels. Water can be pumped from a tank through the evaporator of a water-to-water heat pump and back to the tank to recover heat. This system is limited to those buildings having such storage tanks which represent an inexpensive source of heat for a heat pump.

6.2.7 Solar Thermal Storage

Solar Thermal Storage. A thermal storage tank heated by a solar collector is a good source of heat for a water-to-water heat pump. In a solar heat pump system, the solar water heat sink tank can be drawn down from 135 deg. F (57 deg. C) to 50 deg. F (10 deg. C). The conventional system draws the tank down to about 105 deg. F (41 deg. C). The heat pump system must have a temperature control valve in the evaporator pumped circuit to limit the maximum temperature of water fed to the evaporator. This system can be applied in areas where long periods of cloudy weather are normal. See Figure 7, Solar Water Source Heat Pump, for system details. The size of the domestic hot water storage tank is based on the facility's hot water use and demand as determined in previous sections of this course.

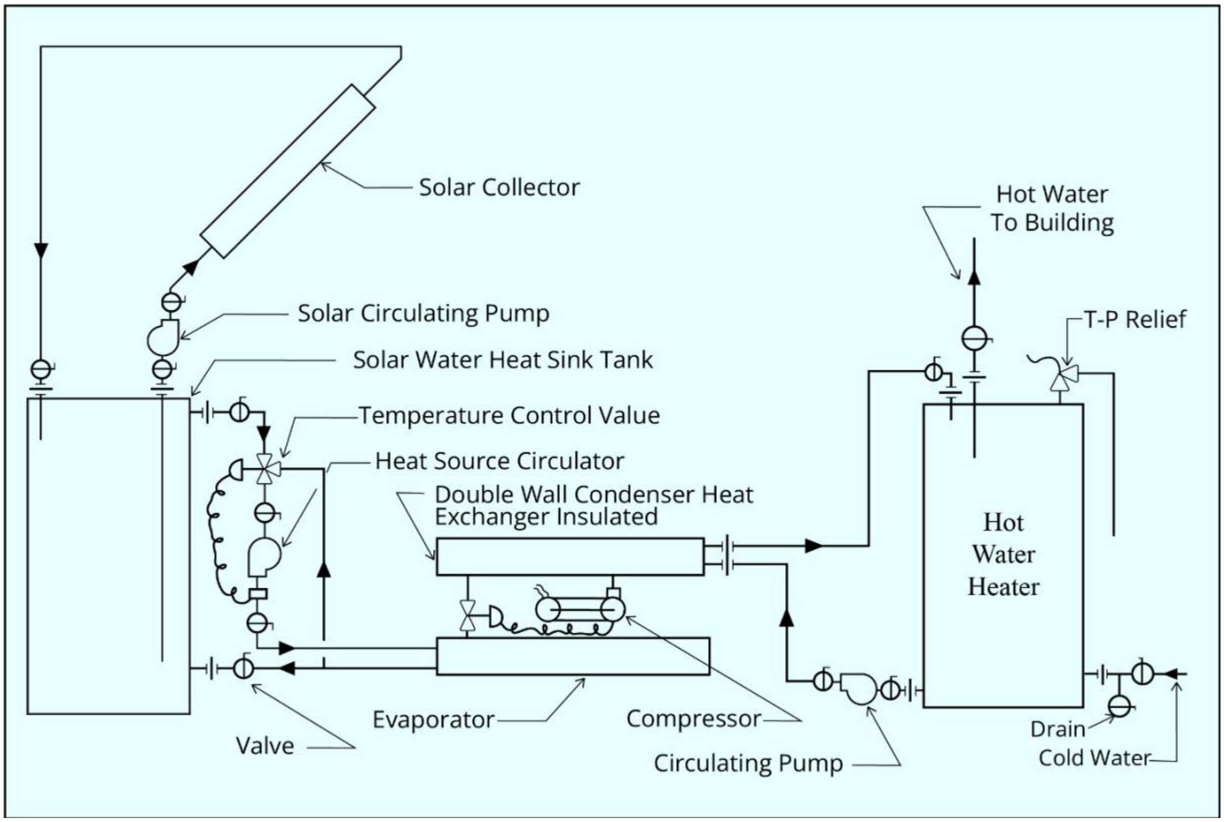


Figure 7. Solar Water Source Heat Pump

6.3 Heat Recovery Air Conditioning Systems

6.3.1 Auxiliary Condensers

Any building requiring comfort air conditioning (A.C.) whenever the building is occupied has a good source of free heat for heating water. The A.C. system requires the installation of an auxiliary double wall vented condenser in parallel with either the standard water cooler or air-cooled condenser. This system can provide as much heat for heating water as would normally be rejected to the atmosphere through the standard condenser or be sized to meet only the hot water demand of the building. Figure 8, Heat Recovery A.C. System with Auxiliary Condenser, is a simplified diagram of this system. Additional valves and controls are needed to make this completely automatic system. All the energy required for heating water is free with this system.

(1) The addition of a water-cooled condenser to an air conditioning system for the purpose of heating potable water can create both high and low head pressure problems if the system is not properly controlled. Therefore, the flow of refrigerant to the heat recovery water cooled condenser is regulated by controlling the refrigerant pressure in the air- or water-cooled condenser. Referring to Figure 8, Heat Recovery A.C. system with Auxiliary the solenoid-energized liquid line regulator (1), when not activated, acts as a pressure regulator, opening farther as the pressure increases. This occurs during the heat recovery mode. During the cooling-only mode, the solenoid is energized, and the regulator opens to pass the full flow of refrigerant. The pressure setting of this device determines the temperature of the hot water.

The hot gas regulator (3) bypasses hot gas to the receiver to maintain head in the receiver during start-up and during the heat recovery mode. It is closed by a solenoid valve during the cooling-only mode. The float switch (4) operates to maintain a liquid level that prevents hot gas from blowing through the condenser. As the liquid level rises, the float valve cycles the liquid solenoid valve (2) to maintain the liquid level. The heat recovery temperature control (5) cycles the air-cooled condenser fans in response to the heating demand. As the leaving domestic hot water temperature drops, indicating an increased load, the fans cycle off, saving energy and decreasing the heat rejected to the atmosphere. A hot water flow switch is used to place the entire control system into a heat recovery mode when there is a demand for hot water. The designer must insulate all hot gas lines outside the building and must design refrigerant piping to drain oil back to the compressor from vertical hot gas lines. This system requires additional refrigerant as compared to a standard air conditioning system because of the receiver, water cooled condenser liquid level, and the liquid refrigerant held up in the air cooled condenser and the extra piping. The designer must contact the compressor manufacturer to determine its special requirements for refrigerant controls, piping and temperature limits for this system.

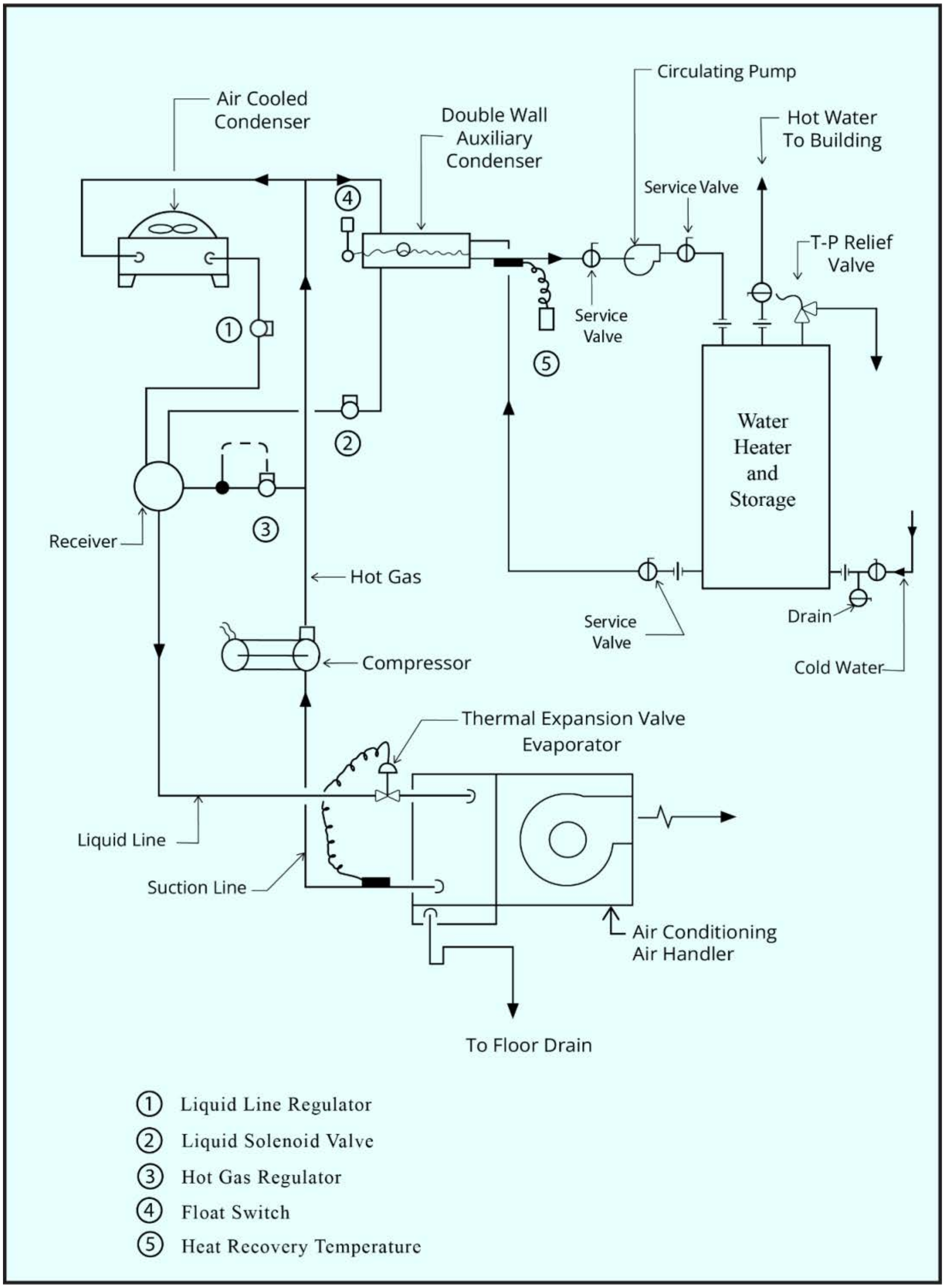


Figure 8. Heat Recovery A.C. System with Auxiliary Condenser

(2) Refrigerant Piping. When an auxiliary condenser is added to a system, the designer must design the refrigerant piping and physically locate the components of the system to prevent liquid slugging of the compressor and the production of flash gas ahead of the expansion valve. The designer must size and pitch the gas lines to promote the return of oil to the compressor. The auxiliary condenser should be near and at the same level as the standard condenser and drain the condensed refrigerant to a common receiver. An oversized receiver is required for this system. When this system is located in colder geographic areas, head pressure control through the use of cycling fans, damper modulation, or a combination of both must be incorporated into the design to provide adequate head pressure regulation for the expansion valve and to ensure that heat recovery works properly. If freezing temperatures are possible, the water lines outside the building must be protected from freezing by heat tracing. The hot water pipe and refrigerant lines must be insulated to reduce heat loss.

6.3.2 Desuperheater

When the hot water requirements in a building do not require a major portion of the heat available from condensing refrigerant, a double wall vented desuperheater can be installed for heating the hot water. A desuperheater is installed in the hot gas line and should be sized to desuperheat only. Little or no condensing should take place. If the desuperheater is oversized, it can act as an uncontrolled auxiliary condenser and cause operating problems such as low head pressure, low back pressure, and poor expansion valve control. Adequate hot water storage for the building's use must be provided for this system to work properly. Water temperatures from 105 deg. to 135 deg. F (41 deg. to 57 deg. C) are normal for this system. The storage size will depend on building hot water use, the A.C. unit size, and its hours of operation. See Figure 9, Heat Recovery A.C. System with Desuperheater. If the capacity of the desuperheater cannot satisfy all the hot water usage, it may be used as a preheater, thus saving energy.

When a desuperheater is added to the hot gas line, the capacity of the A.C. unit decreases because of the pressure drop in the desuperheater. Part of the decrease in capacity due to the pressure drop is recovered by the addition of the condenser surface of the desuperheater. This course cannot be definitive on the overall effect on the capacity change due to the pressure drop and the increased condenser surface; therefore, it is recommended that the designer review all data available and contact the manufacturer for advice.

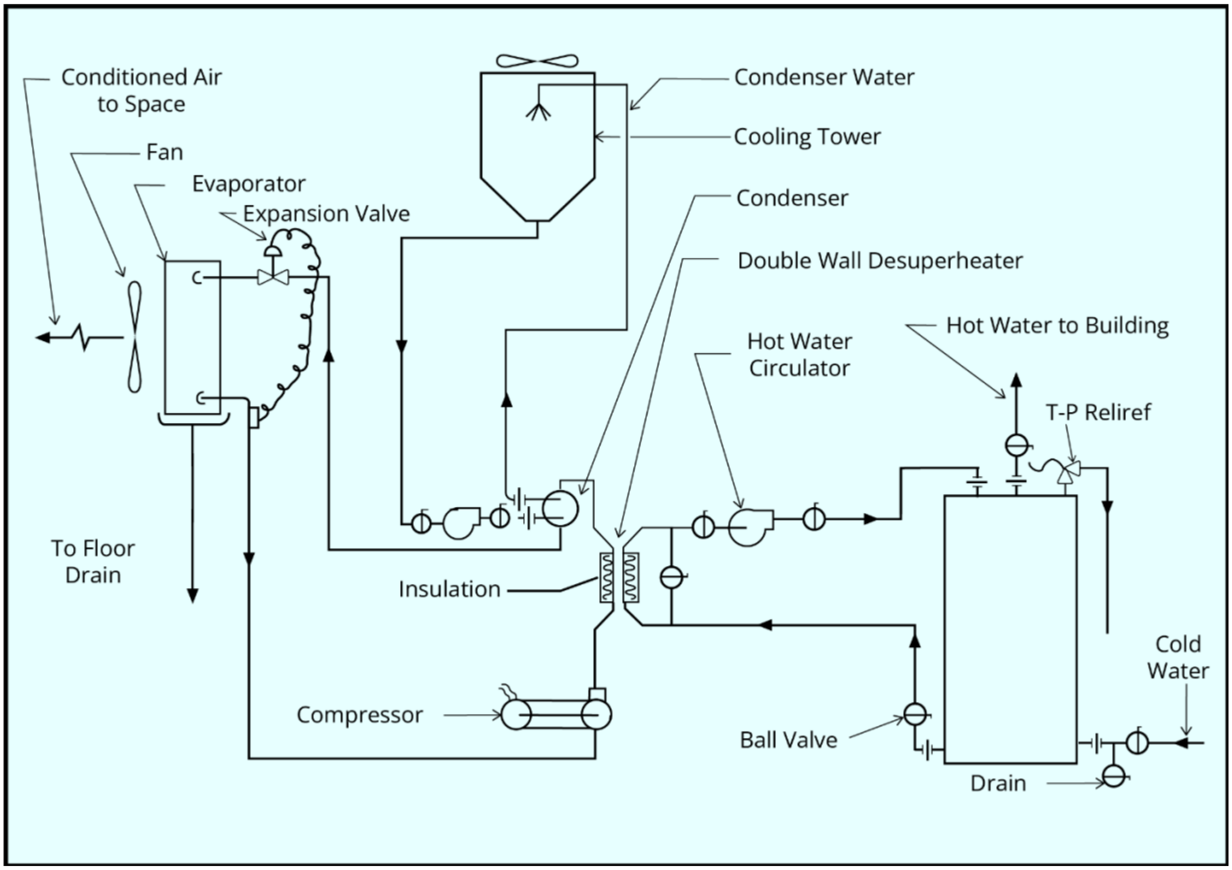


Figure 9. Heat Recovery A.C. System with Desuperheater

6.4 Heat Recovery From Refrigeration

6.4.1 Auxiliary Heat Exchanger

Low temperature refrigeration systems, such as beverage coolers, cold boxes, freezers, etc., in galleys, clubs, commissaries, and buildings with subsistence facilities are other sources of heat for hot water. The installation of an auxiliary double wall vented heat exchanger or desuperheater in a hot gas line can generate up to 135 deg. F (57 deg. C) water depending on entering water temperature and flow rate. Low temperature refrigeration equipment usually has a long on-cycle and is therefore a fairly reliable source of heat when combined with a properly sized storage system or when used as a preheater for the water heating system.

A refrigeration system often has a low cooling capacity and, therefore, requires a large hot water storage capacity. Several refrigeration systems can be fitted with desuperheaters to provide enough hot water to satisfy usage or to serve as preheaters.

6.4.2 Water Loop

Refrigeration equipment with water cooled condensers is sometimes used in commissaries for freezer and display boxes. The condenser water loop is another source of heat for the water-to-water heat pump previously discussed.

6.5 Solar Domestic Hot Water

6.5.1 System Types

Several types of systems are used.

(1) Thermosiphon Systems. As shown in Figure 10, Typical Solar Systems, thermosiphon systems heat potable water directly and use natural convection to transport it from collectors to storage. They are applicable in climates where freezing is infrequent or for summer-only use in colder climates. Pressure reducing valves are required when city water pressure is greater than the working pressure of the collectors. In a thermosiphon system, the storage tank must be elevated above the collectors, which sometimes requires designing the upper level floor and ceiling joists to bear this additional weight. Also, extremely hard or acidic water can cause scale deposits that obstruct or corrode the absorber fluid passages.

Since thermosiphon flow is induced whenever there is sufficient sunshine, these systems do not need pumps. Reverse thermosiphoning must be eliminated by using a low pressure drop check valve or thermally actuated check valves.

(2) Recirculation Systems. Recirculation systems (Figure 10) are direct water heating systems that pump potable water from storage to the collectors when there is enough solar energy available to warn it and then return it to the storage tank until needed. Since a pump circulates the water, the collectors can be mounted either above or below the storage tank. Recirculation systems are practical only in areas where freezing is infrequent. Freeze protection for extreme weather conditions is provided either by recirculating warn water from the storage tank or by flushing the collectors with cold water. Direct water heating systems should not be used in areas where water is extremely hard or acidic. Scale deposits may quickly obstruct or corrode the absorber fluid passages.

This type of system is exposed to city water line pressures and must be assembled to withstand test pressures as required by local code. Pressure reducing valves and pressure relief valves are required when the city water pressure is greater than the working pressure of the collectors. A recirculation system often uses a single storage tank for both solar energy storage and the auxiliary water heater, but a two-tank storage system can be used.

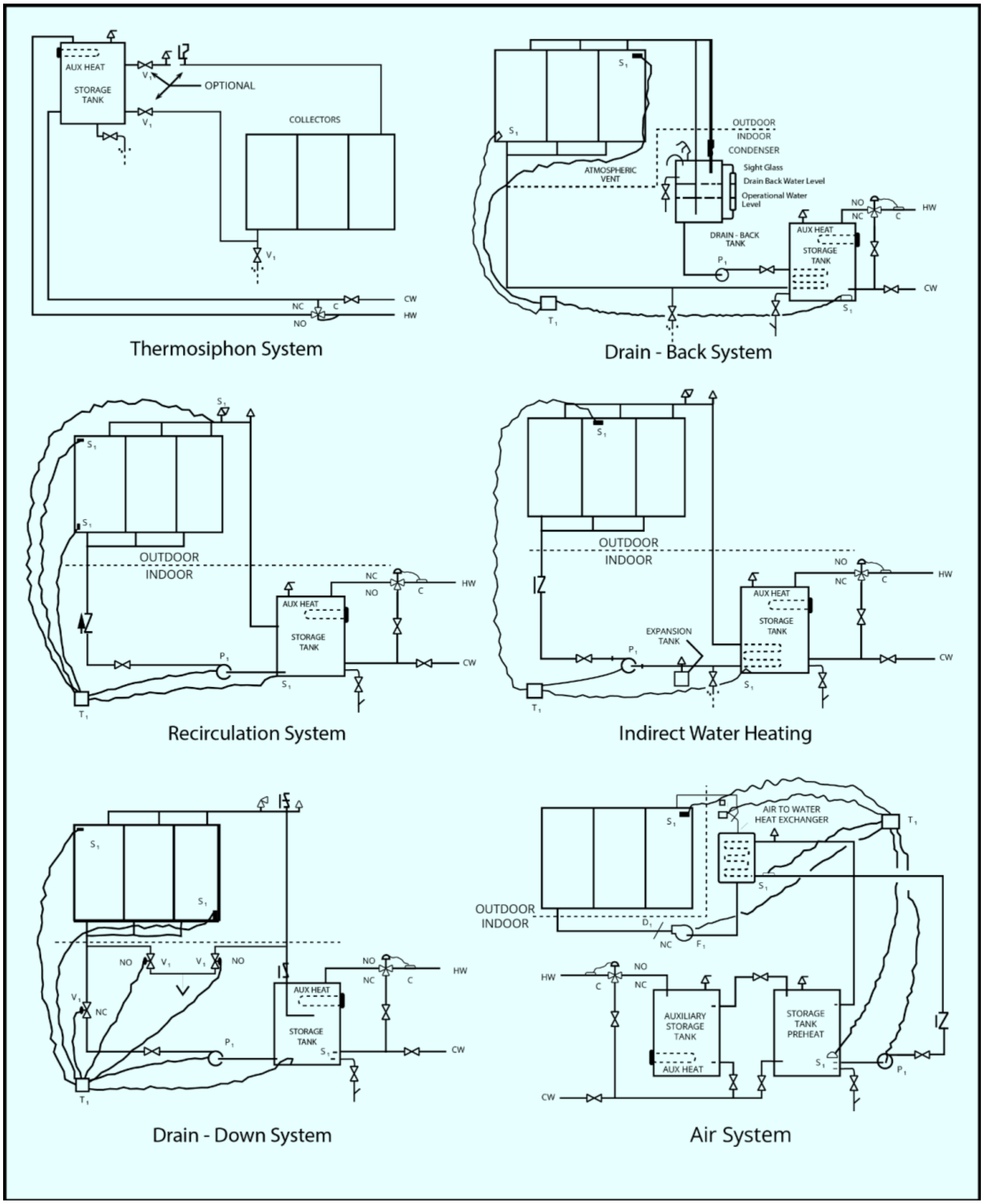


Figure 10. Typical Solar Systems

(3) Drain-Down Systems. Drain-down systems (Figure 10) are pumped circulation, direct water heating systems that circulate potable water from storage to the collector array where it is heated. Circulation continues until usable solar heat is no longer available. When a freezing condition is anticipated or a power outage occurs, the system drains automatically by isolating the collector array and exterior piping from city water pressure and draining it using one or more valves. The solar collectors and associated piping must be carefully sloped and vented to drain the collectors' exterior piping.

This type of system is exposed to city water pressures and must be assembled to withstand test pressures as required by local code. Pressure reducing valves and pressure relief valves are required when city water pressure is greater than the working pressure of the collectors. One- or two-tank storage systems can be used. Scale deposits and corrosion can occur in the collectors with hard or acidic water.

(4) Drain-Back Systems. Drain-back systems (Figure 10) are generally indirect water heating systems that circulate treated or untreated water through the closed collector loop to a heat exchanger, where its heat is transferred to the potable water. Circulation continues until usable energy is no longer available. When the pump stops, the collector fluid drains by gravity to a reservoir or drain-back tank. In a pressurized system, the tank also serves as an expansion tank when the system is operating and must be protected from excessive pressure with a temperature and pressure relief valve. In an unpressurized system, the tank is open and vented to the atmosphere.

Since the collector loop is isolated from the potable water, valves are not needed to actuate draining, and scaling is not a problem. The collector array and exterior piping must be sloped to drain completely.

(5) Indirect Water Heating Systems. An indirect water heating system (Figure 10) circulates a freeze-protected heat transfer fluid through the closed collector loop to a heat exchanger, where its heat is transferred to the potable water. The most commonly used heat transfer fluids are water/ethylene glycol and water/propylene glycol solutions although other heat transfer fluids, such as silicone oils, hydrocarbons, and refrigerants, can also be used. These fluids are non-potable, are sometimes toxic, and require double wall heat exchangers. The double wall heat exchanger can be located inside the storage tank, or an external heat exchanger can be used. The collector loop is closed and, therefore, requires an expansion tank and a pressure relief valve. One- or two-tank storage systems can be used. Additional over-temperature protection may also be needed to protect the collector fluid from decomposing or becoming corrosive.

Designers should avoid automatic water makeup in systems using water/antifreeze solutions because a significant leak may induce enough water into the system to raise the freezing temperature of the solution above the ambient temperature, causing the collector array and exterior piping to freeze. Also, an antifreeze system with a large collector array and long pipe run may need a time-delayed bypass loop around the heat exchanger to avoid freezing the heat exchanger on startup.

(6) Air Systems. An air system (Figure 10) is an indirect water heating system that circulates air through the collectors via ductwork to an air-to-liquid heat exchanger. There its heat is transferred to the potable water, which is pumped through the tubes of the exchanger and returned to the storage tank. Circulation continues as long as usable heat is available. An air system can use single or double storage tank configurations. The two-storage tank system is used most often since air systems are generally used for preheating domestic hot water and may not be capable of reaching 120 to 160 deg. F (49 to 71 deg. C) delivery temperatures.

Air does not need to be protected from freezing or boiling, is non-corrosive, and is free. However, air ducts and air handling equipment need more space than piping and pumps. Ductwork is very laborious to seal, and air leaks are difficult to detect. Power consumption is generally higher than that of a liquid system because of high collector and heat exchanger static pressure loss. All dampers installed in air systems must fit tightly to prevent leakage and heat loss.

Dampers might be needed in the collector ducts to prevent reverse thermosiphoning at night, which could freeze the water in the heat exchanger coil. No special precautions are needed to control overheating conditions in air systems.

6.5.2 Applications

(1) Building Types. Solar hot water systems should be considered for buildings having relatively large hot water requirements throughout the year and high energy costs for water heating.

(2) System Types. Selection of system types should be based on geographic location, quantity of hot water required, time of day when the hot water is used, type and size of hot water storage, water quality, and the ability of local maintenance forces.

(a) Advantages and Disadvantages. Each type of system in each location will have advantages and disadvantages as described in Paragraph 5a that must be evaluated in conjunction with performance and economics.

(b) Criteria. Since the performance of solar systems is very dependent on the magnitude and time of hot water use, good estimates or measurements of hot water use should be obtained for similar buildings.

6.5.3 Performance

The expected performance of solar hot water systems should be evaluated for each specific application in comparison with other hot water systems.

(1) Energy Savings. The energy savings from a solar hot water system should be determined by using the appropriate industry standards.

(2) Temperature. Since the performance of solar hot water systems is dependent on hot water temperature, the designer must determine the lowest temperature at which it is possible to generate and store hot water for use. In the absence of other acceptable criteria, the water temperatures shown in Section 3 of this course shall be used.

(3) Backup System. The backup system for the solar hot water system should be sized by assuming the solar system does not operate and should be in accordance with Section 3 of this course.

Before using the backup system, use two tanks in the system design to make maximum use of solar-heated hot water.

(4) Operating Energy. Energy used for pumps and fans and heat losses in the solar system should be minimized by the designer and included in the performance evaluation.

(5) Conventional Systems. The performance evaluation of solar hot water systems should include any impact on the performance of backup systems, such as reduced efficiency or increased losses, when making comparisons with conventional hot water systems.

6.5.4 Economics

Economic evaluations of solar hot water systems should be made and compared with conventional hot water heating systems.

(1) First Cost. The installed cost for the solar system should be determined, including all other modifications to the hot water system and to the building that are necessary for proper operation and maintenance.

(a) Solar Equipment. Include all costs for collectors, piping, insulation, pump and fans, and controls.

(b) Backup Equipment. Include all costs for backup water heating system.

(2) Operating Cost. All costs associated with operation and maintenance of the solar system should be included in the economic analysis.

(a) Energy. Include all costs of energy to operate the solar system and backup water heating system as determined in the performance evaluation in paragraph 5c.

(b) Operation. Include all costs for people, equipment, and supplies necessary for day-to-day operation and inspection of the solar system.

(c) Maintenance. Include all costs for regular maintenance of the system and for reasonable unexpected maintenance and repair.

(3) Life Cycle Cost. A complete life cycle cost analysis should be performed.

6.5.5 Design Criteria

(1) Sizing. The sizing of major solar system components should be determined to minimize life cycle cost and provide flexibility to operate under a variety of conditions normally encountered.

(a) Collectors. Solar collectors should be sized by referring to the applicable industry standards.

(b) Storage. Sizing of hot water storage should be in accordance with Section 3 of this course and may be increased when necessary to allow greater utilization of solar energy economically.

(c) Backup System. Sizing of the backup hot water heating system should be in accordance with Section 3 of this course, assuming no contribution from solar. Where the energy used in the backup system has an impact on the sizing of boilers or when electricity is used, appropriate means should be provided to limit the heating capacity.

(2) Component Selection. Components of solar systems should be selected to provide reliable long-term performance. Where packaged or predesigned systems are utilized, they should meet the requirements of applicable industry standards.

(a) Collectors. Solar collectors should be tested in accordance with applicable industry standards.

(b) Storage. Storage systems should be tested in accordance with applicable industry standards. Insulation of storage systems should be in accordance with Section 4 of this course. The designer must perform an energy and economic evaluation to determine if additional insulation is warranted. Storage tanks should be located so they are completely accessible for inspection and maintenance. Means for routine drainage of storage, piped to a floor drain, should be provided.

(c) Backup System. Selection of the backup system should be in accordance with Section 3 of this course.

(d) Controls. Selection of controls should provide automatic, unattended, fail-safe operation. Provision should be made for regular adjustment and calibration.

(e) instrumentation. Sufficient instrumentation should be provided to allow instantaneous determination of solar system performance, including thermometers and pressure and flow measuring and indicating devices. Provision should be made to allow continuous recording of temperatures, pressures, and flows by means of portable instruments for diagnostic purposes. Where feasible, energy use by the backup system should be measured with an integrating meter to allow periodic meter readings. The initial and maintenance costs of this instrumentation can be expensive and need to be assessed against the size and overall cost of the proposed installation.

(f) Pumps. Selection of pumps should be in accordance with applicable industry standards. Where pumps are used for fluids other than water, a spare shall be provided. Pressure gauges should be provided on the suction and discharge of each pump.

(g) Heat Exchangers. Heat exchangers should be designed to allow ready access for cleaning and replacement. Thermometers and pressure gauges with appropriate ranges should be provided to measure inlet and outlet temperatures and pressures for each fluid.

(h) Heat Transfer Fluids. Double wall heat exchangers should be utilized with heat transfer fluids other than water. Fluids other than water should not be used in family housing. Beat transfer fluids should meet the requirements shown in the Housing and Urban Development (HUD) Intermediate Minimum Property Standards Supplement for Solar Heating and Domestic Hot Water Systems.

(i) Water Treatment. Means should be provided for occasional or continuous treatment and monitoring of all heat transfer fluids.

(j) Expansion Tanks. An expansion tank should be provided for any closed circulation system.

(k) Piping. The type of piping selected should be compatible with the fluids employed. Pipe insulation should be in accordance with Section 4 of this course. The designer must perform an energy and economic evaluation to determine if additional insulation is warranted. The designer should provide dielectric or non-metallic couplings when joining dissimilar materials, provide for pipe expansion over the range of temperatures to be encountered, slope all piping requiring drainage at least 1/4 inch per foot, and provide automatic air vents at all high points in the piping. When a multiple collector system is used, reverse return piping with balancing valves and flow indicators should be used.

(3) Other Considerations. There are several other considerations when designing solar systems.

(a) Freeze Protection. Where the possibility of freezing exists, provision should be made to preclude damage to the solar system.

(b) Stagnation. The designer should make adequate provision to accommodate the temperatures encountered during times when there is no flow through the solar collectors.

(c) Corrosion. Where the possibility of corrosion exists, provisions should be made to test and add inhibitors.

(d) Maintainability. The designer should require the preparation of detailed operating and maintenance instructions.

(e) Equipment Location. All components of the solar system other than piping, ductwork, and wiring should be readily accessible. Where collectors and other equipment are located on the roof, means should be provided for routine inspection and maintenance.

(f) Acceptance Testing. The designer should require that each solar system be formally tested to demonstrate its performance prior to acceptance.

6.6 Water-To-Water Recovery

Some buildings have equipment or processes that use high temperature fluids or have large steam condensate discharges that can heat hot water. By circulating hot fluid at 110 deg. F (43 deg. C) or higher through one side of a plate heat exchanger and potable water through the other side, potable water can be directly heated and stored for use in a building. A plate heat exchanger or a double wall heat exchanger must be used to prevent contamination of the potable water. A plate heat exchanger eliminates possible contamination because a leak in either water circuit will be to the atmosphere.

6.7 Point-of-Use Heaters

6.7.1 Booster Heaters

The most energy efficient hot water heating system is one that heats water to the lowest possible temperature, has no heat loss, heats only as needed, and has no storage capacity. A heater that comes closest to fitting this description is a booster or an instantaneous heater. This type of heater is required in facilities where higher temperature water, say 180 deg. F (82 deg. C), is needed and is not available from the building hot water system. To conserve energy, the booster heater should be installed as close as possible to the fixture requiring the higher temperature water, sized conservatively, set to produce the lowest acceptable temperature, and have little or no storage capacity.

Dishwashers in public and subsistence facilities require hot water at 180 deg. F (82 deg. C) for rinsing. Dishwashers in family housing can use 110 deg. F (43 deg. C) water if good low-temperature dishwashing detergents are used. The contents are sanitized by the electric drying cycle rather than a hot water rinse. Another option the designer may choose is to specify a dishwasher with a booster heater to heat the rinse water to a higher temperature.

6.7.2 Line Heaters

The use of a central water heater system is not generally advised if individual fixtures or small fixture clusters are widely separated and remote from the proposed water heat location. The heat loss in the storage tank and the hot water distribution pipes is inefficient and can, in some systems, equal or exceed the energy required to heat the hot water actually used. Line heaters located at the fixtures eliminate these losses and are particularly applicable in office buildings, industrial plants, hobby shops and schools where only low temperature water is used for short durations and in small quantities. The designer must compare the cost of the heat lost from central plant storage and piping with the usually higher cost of energy and installation costs required for line heaters. The designer must also include in his cost analysis the piping costs for both systems. When line heaters are used, no hot water pipe is required except from the line heater to the fixture.

When a circulating pump is used in a central system to keep the water at the fixtures hot at all times, the pump must be equipped with an automatic time switch to shut it off when the facility is not occupied. The circulating pump should run only during the occupied hours, which requires a timer switch to be programmed for a seven-day week and have skip-a-day features to allow for holidays, etc.

6.7.3 Modular Boilers

When there is a demand for higher temperature water for short durations, the modular boiler concept should be analyzed. For example, assume the majority of the hot water demand is for 110 deg. F to 115 deg. F (43 deg. C to 46 deg. C) water, but a food service area requires 180 deg. F (82 deg. C) water for 2 hours once a day. A primary boiler can heat all the water to 115 deg. F (46 deg. C), and a second boiler, acting as a booster heater, can heat only that water drawn by the food service area. Advantages of the modular concept are the reduction in heat loss of high temperature storage and the automatic firing of the high temperature boiler only when there is a demand for higher temperature water.

(1) If there is a wide variation in the amount of hot water used at one temperature, as in barracks, a modular boiler system can be designed to automatically stage as many boilers on and off the line as are required as the usage increases and decreases. This matches the modular boiler system's capacity to the usage, keeps each burner efficiency high, and minimizes or eliminates storage capacity.

(2) When fossil fuel burning water heaters are used, the designer must look at state-of-the-art energy saving equipment, such as condensing boilers, pulse burners, and stack combustion air heaters.

6.8 Total Energy Recovery

6.8.1 Cogeneration

Whenever a facility has a large, repetitive daily demand for hot water and, at the same time, requires electricity, a cogeneration unit with heat recovery should be analyzed. One facility that can use this equipment is a laundry. With a heat recovery cogeneration system, heat from the engine radiator, crankcase oil, and exhaust gases is recovered and used to heat or preheat the domestic hot water through a water-to-water heat exchanger. The heated water is then stored to satisfy the hot water demand variations. The electrical output of the generator, with parallel feed, is used to supplement the existing electrical service, not replace it. There are manufacturers claiming that the packaged cogenerator and heat recovery unit can utilize as much as 96 percent of the total energy input to the engine. See Figure 11, Cogeneration Heat Recovery.

(1) Capacity. The designer must not oversize the electric generator for the sake of satisfying the building's electrical needs unless the cost of the generated electricity is less than that of the purchased power. The unit must be sized so the heat rejected is approximately the same as or less than the hot water requirements to make this system efficient and cost-effective.

(2) Protection. When this system is used in climates with freezing temperatures, glycol should be used in the non-potable piping system outside the building, or the water lines must be traced to prevent freezing. Glycol cannot be used in potable water systems.

(3) Cost. Because of the high capital cost of this system, a life cycle cost analysis must be made, based specifically on the building under study.

(4) Equipment. The packaged cogeneration unit consists of an engine using natural gas, propane, or diesel fuel driving an electric generator. The designer is required to design the piping from the backup water heater storage and the cogeneration unit, the electrical connections, switchgear, fuel lines, and fuel storage, if required. The designer is also required to meet local codes and satisfy the utility company's requirements.

6.8.2 Stand-Alone System

In sizing a stand-alone system, the building's electrical demand determines the generator size. If there is excess heat not used by the water heater, it can be used to provide space heat, if and when needed, or be wasted to the atmosphere.

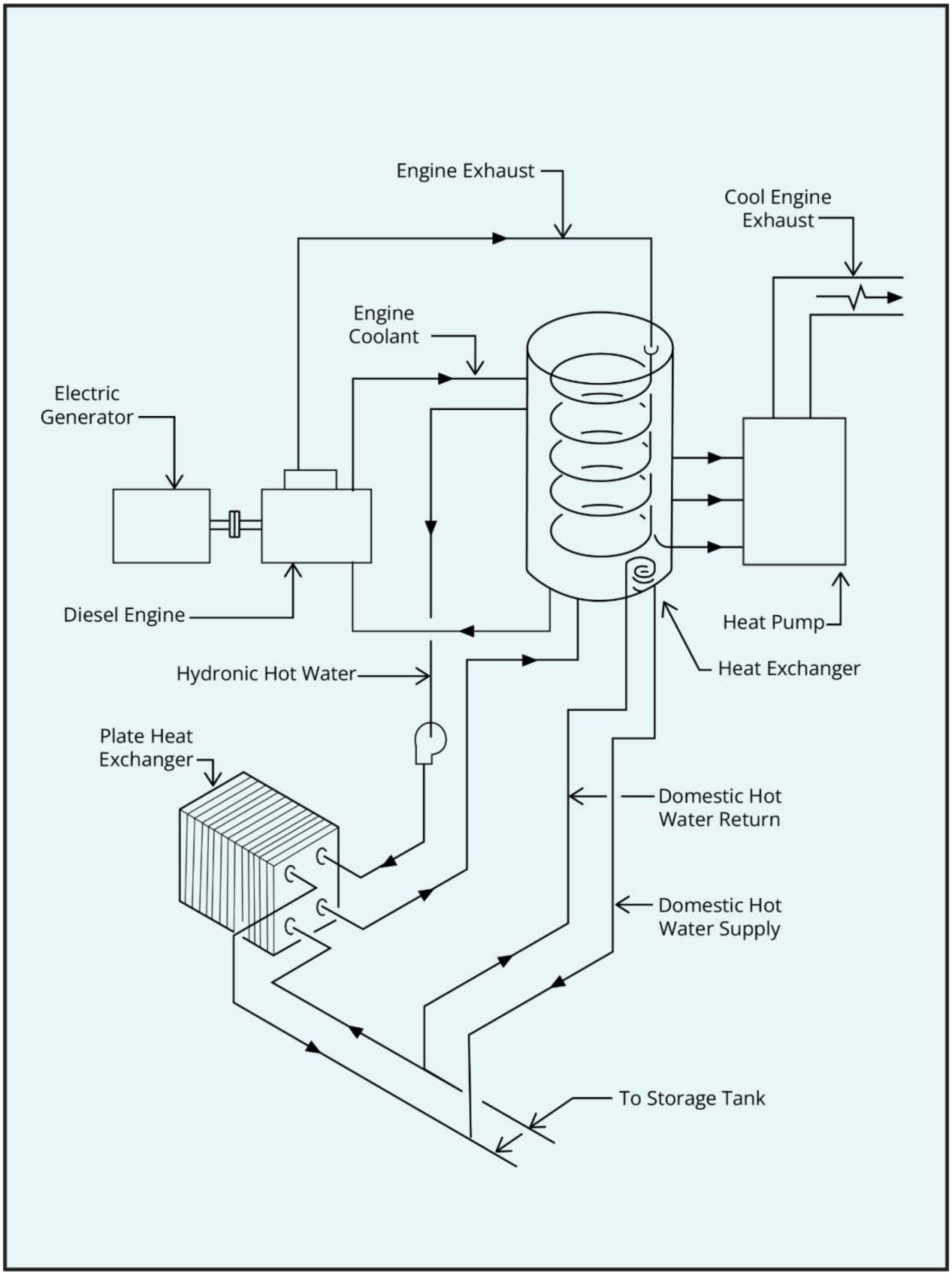


Figure 11. Cogeneration Heat Recovery

6.9 Power Burners

6.9.1 Water Heaters

The preferred burner for a gas fired water heater is a power burner. Comparing manufacturers' ratings of power burner and atmospheric burner water heaters of the same size shows that power burner units are at least 5 percent more efficient. The higher efficiency results from the ability of a power burner to force the combustion gases through more baffles and tubes than an atmospheric burner, which gives more heat transfer surface to work with, plus the fire is hotter. During the off-cycle of a water heater, room air passes through the water heater's gas passages and is heated as it passes through to the stack. This is a heat loss. The additional restrictions offered by baffles and the fan wheel in a power burner unit decrease the convective heat loss as compared to an atmospheric burner unit. If water heating load fluctuations cause the burner to be off for long periods of time, the system efficiency of an atmospheric burner heater is even worse than the 5 percent difference already noted. The additional convective losses can reduce the system efficiency by an additional 3 to 10 percent. See Figure 12, Power and Atmospheric Burners.

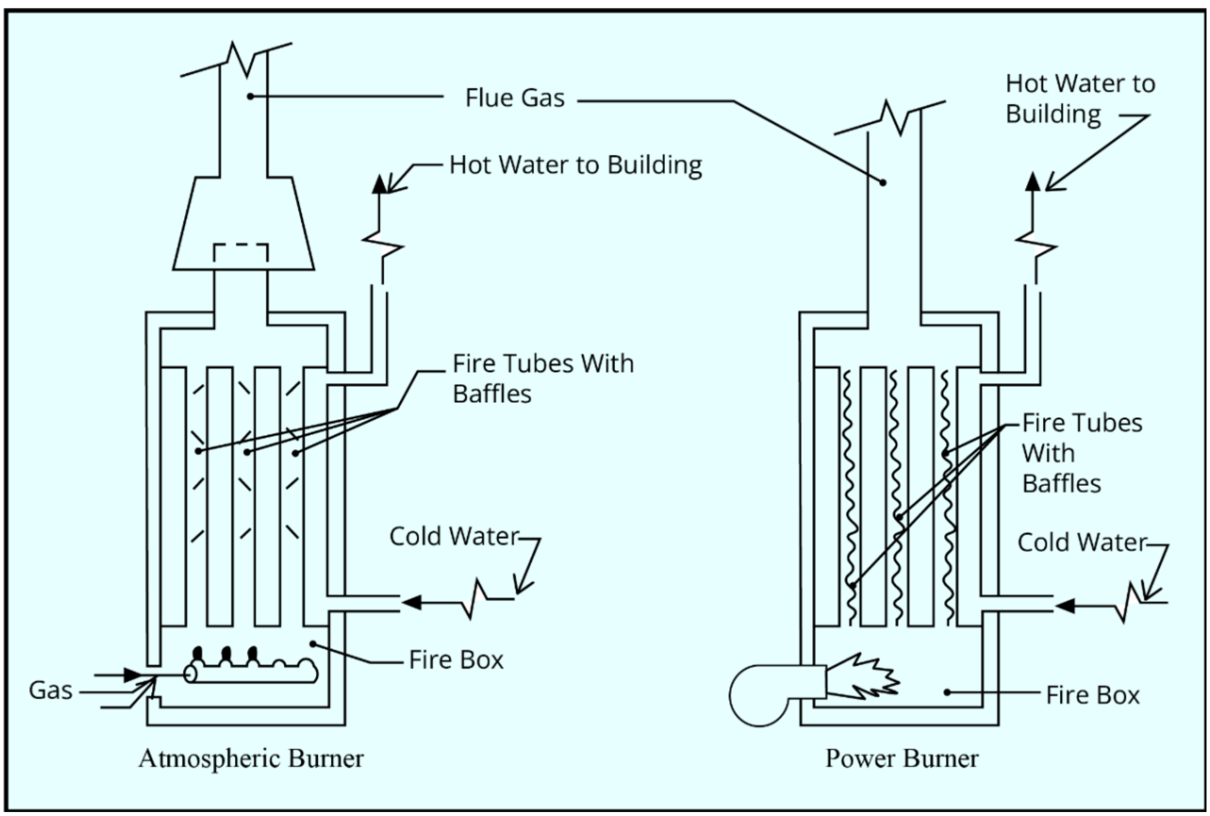


Figure 12. Power and Atmospheric Burners

6.9.2 Tankless Heater

When the demand for hot water is of short duration, an instantaneous tankless water heater should be considered. A tankless heater has very little storage capacity and heats only when there is a demand for hot water; therefore, there is little tank heat loss, and the system efficiency is improved. The analysis of a tankless heater for a project must include its impact on fuel cost, fossil fuel or electric. Some electric utility rate schedules impose an extra charge for high-surge loads at certain times of the day.

6.10 Flow Control

6.10.1 In-Line Flow Regulators

Flow regulators must be installed in hot water pipes to all fixtures, other than washing machines and dishwashers, to limit the maximum flow, regardless of pressure variations, and to conserve water heater energy. Most devices are tamperproof when installed in hot water pipes. The control mechanism of one device consists of a cup with holes in its side. The cup is spring-loaded so that it moves in response to changes in the pressure drop across the device as flow varies. As the flow rate tends to increase, the increased pressure drop causes the cup to move and cover up more holes; the reverse takes place as the flow rate decreases. The result is a limit to flow rate through the device independently of pressure variations of the supply system. The flow rate of the device is factory set by selecting the proper cup and spring for a given flow rate.

(1) Flow Rate. The flow rate should be limited to 0.5 gpm (1.9 Lpm) maximum for public and private lavatories and to 3 gpm (11.34 Lpm) for showers and kitchen sinks when the supply pressure is 80 psig (550 kPa) or below.

(2) Water Pressure. Some water utilities and base water systems have street pressures in excess of 80 psig (550 kPa). Where this condition exists, the pressure should be reduced by a pressure reducing valve to no more than 80 psig (550 kPa) inside the building. If the building requires a booster house pump, gravity water tank, or a hydropneumatic system, the maximum pressure should be limited to 80 psig (550 kPa).

6.10.2 Automatic Valves

Automatic shutoff hot water valves in addition to the flow regulators should be analyzed for use in public, commercial, and office buildings. These valves do not in themselves ensure a reduced use of hot water. In some cases the use of hot water is greater, but they do eliminate the chance of a tap being left open and wasting hot water.

6.11 Cost of Energy

6.11.1 Evaluation

The analysis of any energy conservation system's cost reduction must be based on the cost of energy to the Government. With the continued increase in the costs of all forms of energy, conservation becomes more attractive. The many formulas for computing the cost of electric energy cannot be explained in this course, and a quick guide to comparing the costs of fuels is offered instead. The quick guide to the costs of hot water and energy is given in Figure 13, Hot Water Energy Costs, which converts the unit cost of fuel dollars per 1,000,000 Btu (293 kWh) for various systems and fuels.

6.11.2 Example

Determine the costs per 1,000,000 Btu (293 kWh) to heat water with a WHHP using electricity at $0.09 per kWh and operating at a COP of 3.2. Determine the costs per 1,000,000 Btu (293 kWh) for a gas water heater using gas at $0.75 per therm (29 kWh) and having an atmospheric burner of 75 percent efficiency.

For the WHHP, enter the graph at $0.09 per kWh, project up to the 3.2 COP line, then left to read $8.24 per 1,000,000 Btu (293 kWh).

For gas, enter at $0.75 per therm (293 kWh), project up to the G curve, then left to $10.00 per 1,000,000 Btu (293 kwh). For a gas water heater to be comparable to a WHHP operating at 3.2 COP, gas would have to cost $0.a1 per therm (293 kWh). This is determined by entering the graph on the left at $8.24 per 1,000,000 Btu (293 kWh), the cost for the WHMP, projecting right to the G curve, and reading down to the price of gas of $0.61 per therm (293 kWh).

To compute electric costs, E Γe˥, per 1,000,000 Btu (293 kWh) use Equation (8).

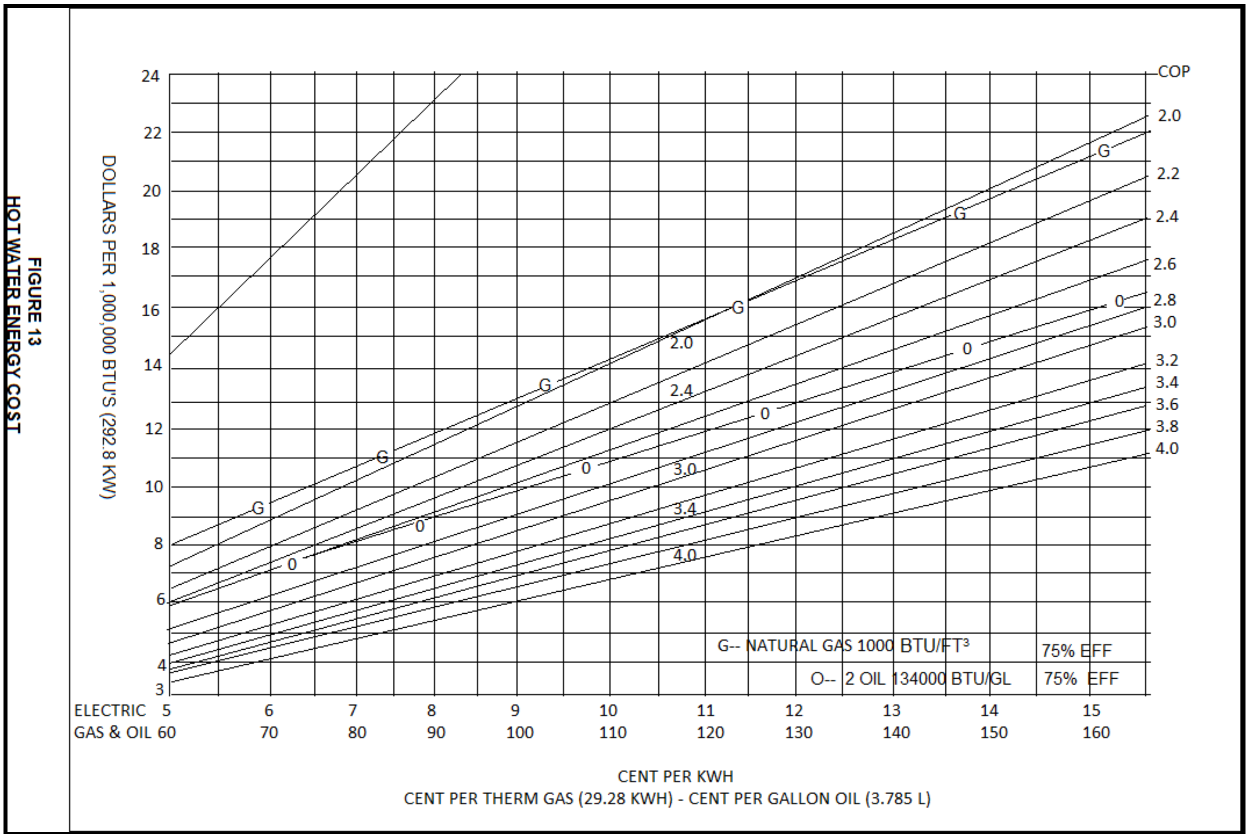


Figure 13. Hot Water Energy Cost

EQUATION:

$$E_e = \frac{293 \times C_e}{COP} \qquad (8)$$

where,

C_e = cost of electricity per kilowatt hour, dollars
COP = coefficient of performance

To compute gas costs, E_g, for the same units, use Equation (9).

EQUATION:

$$E_g = \frac{10 \times C_g}{e} \qquad (9)$$

where,

C_g = cost of gas per therm, dollars
e = efficiency of heater

6.11.3 Metering

When water is heated with electricity, the local utility rate schedule must be reviewed to determine if there are special schedules that can reduce the cost of heating water. Some utilities offer reduced rates for water heaters that operate during night hours. This may require special wiring, switches, circuit breakers, and piping--all extra cost items. Where utilities have on-peak and off-peak rate schedules, it may be economically desirable to add a time switch to limit electric water heater usage to off-peak hours.

6.11.4 Control

All water heater supply systems should be equipped with automatic temperature controls designed to be field adjustable for the lowest possible acceptable water temperature. Time clocks can be used to shut off the water heater supply system and the circulating pump when the building is unoccupied; however, the designer must check to see if the heat loss from the water heater system during the unoccupied time is greater than the energy used to bring the system water temperature up to the thermostat setting each morning when the building is occupied. The system with the lower operating cost should be the basis of design.

6.12 Ratings and Warranties

6.12.1 Capacity

All water heaters should have heating and recovery ratings certified by the appropriate national society or association for gas, oil, or electric water heaters. At this time there is no rating group for the WHHP or for desuperheaters. The WHHP manufacturers are presently using the Gas Appliance Manufacturers' Association (GAMA) method to determine the heating and recovery rate of a WHHP. This may be a good way to rate the equipment. However, the designer is cautioned that the GAMA method of determining recovery rate account for WHHP capacity changes as the ambient air temperature changes and that there is no rating group that has enforcement powers. It is, therefore, a good idea to write both an equipment and a performance specification for WHHP equipment.

6.12.2 Special Problems

Some manufacturers of refrigeration and air conditioning equipment void their warranties or guarantees if desuperheaters or auxiliary condensers are added to their equipment without their prior approval. In such a case, if a modification is made and something happens to a system component, the contractor and the Government will have to pay for any repairs required. The designer's solution to this problem is not to accept or use such manufacturers' equipment or not to attempt field modifications of their equipment.

(1) Existing Equipment. If the designer determines that existing equipment still under warranty will be modified with the addition of a desuperheater or auxiliary condenser, the manufacturer should be consulted. The manufacturer will be able to provide such information as the maximum size desuperheater permitted, the maximum pressure drop allowed, the minimum head pressure required for proper operation, and other factors that will guide the designer or that may change the warranty.

(2) Assurance. The specifications for a WHHP must call for the equipment to be Underwriters Laboratories, Inc., (UL) listed and must indicate the pressure class of the water side of the equipment. This will ensure that the equipment meets the pressure class and electrical requirements of UL and other applicable industry standards.

7. Appendix A

ENERGY ANALYSIS EXAMPLE

(a) Selection of point-of-use water heaters will be dependent on energy savings and cost effectiveness based on life cycle cost analysis. Each retrofit and new construction opportunity must be analyzed to determine, on a comparative basis, if a point-of-use heater will offer benefits. Separate analysis of each opportunity is a necessity because of the variations in water heater prices and regional energy costs. Two sample calculations are shown in this Appendix and should provide the reader with sufficient guidance for making his own calculations.

(b) The two examples to be used for illustrating energy analysis and life cycle costing include:

- Office building lavatories and slop sinks retrofit.
- Flight training facilities lavatories and slop sink new construction.

(c) Office Building Lavatories Retrofit Example

Assume, in this example, a 35-year-old, two-story barracks building which has been converted to low-density office space. The old shower stalls are not required. There is one lavatory on each of the two floors plus one slop sink. Each lavatory contains six basins but four have been disconnected. Building occupancy is 25 persons, eight hours per day, five days per normal week, 250 total days per year. Hot water to the two lavatories and slop sink is supplied by an oil fired, 30 gallon heater with thermostat set at 120 deg. F. Groundwater temperature averages 45 deg. (range 35 deg. F - 55 deg. F). Fuel oil costs $0.85 per gallon which is equal to $6.07 per 1,000,000 Btu. Electricity is billed at $0.050 per kWh or $14.60 per 1,000,000 Btu. We will compare instantaneous and small tank point-of-use heaters to the existing circumstances.

The first step is to determine the size of point-of-use heaters required for each lavatory and slop sink. The temperature required is 95 deg. F (tepid) at each lavatory and 120 deg. F at the slop sink. Water usage is determined as follows:

Lavatory,	2-1/2 gal/min	3 x 25 gal/day
1 basin	flow rate per basin	total for 4 basins
slop sink	3-3/4 gal/min	10 gal/day flow rate

Each lavatory will require one heater whose maximum flow rate will be 2-1/2 + 2-1/2 = 5 gallons per minute. The temperature must be based on the lowest annual groundwater temperature to meet the mandated tepid water requirement.

Further, the temperature at the highest annual groundwater temperature should not exceed 120 deg. F to guard against scalding.

R = 0.16P (T ΓO˥ - T Γi˥)
F = 2 x 2-1/2 = 5 since one heater must occasionally supply 2 faucets
R = 0.16 x 5 x (95 - 35)
R = 48 kW

No commercial 50 kW heater was found in this example. The largest unit found was 20 kW. It is obvious that a straightforward retrofit with off-the-shelf instantaneous heaters is not possible. An alternative involving flow restrictors will be considered later on because the required 60 deg. F minimum rise at 5 gallons per minute cannot be achieved with instant heaters.

The correct size for a mini-tank heater cannot be calculated from available information and manufacturers' representatives must be consulted. A maximum 5 gallons per minute flow rate and 38 gallons per day can easily be met by a small unit. A 1/2 gallon unit could meet the requirement, but 2 units would be needed because a special faucet is required. A 1 kW, 1 gallon unit is used. Three units are required, one for each lavatory and one for the slop sink. Energy use calculations proceed as follows.

Present Circumstances

- Heating energy for lavatories

E = 8.3 x G x (T ΓO˥ - T Γi˥) / e   where G, gal per year, = 3 x 25 x 250

$$= \frac{8.3 \times 3 \times 25 \times 250 \times (140 - 120)}{0.70}$$

E = 16,674,107 Btu per year

- Heating energy for slop sink

$$E = \frac{8.3 \times 10 \times 250 \times (120 - 45)}{0.70}$$

E = 2,223,214 Btu per year

- Standby loss

The loss from a 30-gallon oil heater set for 120 deg. F in a 60 deg. F (average) room cannot be determined from the literature. It can be very roughly estimated at 1000 Btu per hour or 8,760,000 Btu per year.

- Line losses

One hundred twenty feet of 1/2-inch water pipe are in the building and contain about 5 gallons. Daily use is 85 gallons, so it is assumed that line losses are, again, very small compared to total energy demand of the heater. The total annual energy use for the existing water heater in this example is then heating energy plus standby loss:

16,674,107 + 2,223,214 + 8,760,000 = 27,657,321 Btu per year

The annual cost in this case would be:

$$\frac{\$6.07 \times 27{,}657{,}321 = \$167.88}{1{,}000.000}$$

First Alternate - Instantaneous Heaters

It was shown that there is no heater available to provide a 60 deg. F temperature rise at a flow rate of 5 gallons per minute.

Second Alternate - Mini-Tank Heaters

Three heaters will be required. One is needed for each lavatory (2 basins each) and one is needed for the slop sink.

The units will be "always on" and set for 140 deg. F with a tampering valve to supply tepid water for the basins ad 120 deg. F water for the slop sink.

- Heating energy for each lavatory (2 basins)

$$E = \frac{8.3 \times G \times (T_O - T_i)}{e}$$

$$= \frac{8.3 \times (37\ 1/2 \times 250\ \text{gal/yr})\ (95 - 45)}{0.95}$$

= 9,828,946 Btu per year

- Heating energy for slop sink

$$= \frac{8.3 \times (10 \times 250)\ (120 - 45)}{0.95}$$

= 1,638,158 Btu per year

- Standby losses

No data have been published for standby losses from small, 1 gallon heaters. An estimate can be made using the following ratio of tank surface areas:

30 gallon tank 3391 square inches
1 gallon tank 297 square inches

lavatories and slop sink - 3 units st at 140 deg. F

(1) (460) Btu per hour x 24 x 365 x 297/3391 = 1,058,795 Btu per year

The total annual energy use for this alternative is then heating energy plus standby loss.

9,828,946 + 1,638,158 + 1,058,795 = 12,525,899 Btu per year

The annual cost in this case would be

$$\frac{\$14.60 \times 12.525{,}899}{1{,}000{,}000} = \$182.88$$

and the savings for the first year would be

$167.88 - 182.88 = $15.00 per year INCREASE

27,657,321 - 12,525,899 = 15,131,422 Btu per year DECREA

This alternative does not present the greatest potential for energy savings. Restriction of water flow would reduce hot water usage, would permit consideration of two different types of point-of-use heaters, and would reduce the cost of installing the mini-tank standby losses. We have assumed a 2-1/2 gallon per minute flow rate and 3 gallons per person per day. Flow rate may be restricted to 1/2 gallon per minute with an aerator at lavatory basins. This has been estimated to reduce per-person-per-day usage to 2 gallons. Slop sink flow rate can be reduced to 1-1/2 gallons per minute, but this would not affect the 10 gallons per day used for janitorial purposes. The age of the plumbing fixtures in the building is such that faucets must be replaced to allow the attachment of flow restricting aerators.

Third Alternate - Instantaneous Heaters with New Faucets

Remember that three heaters will be required and that we must design for simultaneous operation of 2 faucets at the lowest annual groundwater temperature.

- Heating energy for each lavatory

R = 0.16 (1/2 + 1/2) (95 - 35)
= 9.6 kW

- Check maximum temperature (one faucet case) at highest groundwater temperature

R=0.1F(TΓO˥ -TΓi˥)
9.6 = 0.16 (1/2) (T ΓO˥ - 55)
T ΓO˥ = 175 deg. F

It is obvious that this is a highly dangerous temperature for a wash basin and, therefore, one instant heater cannot serve 2 basins at the extremes of usage (1 basin - 2 basins) and the extremes of groundwater temperature (35 deg. F - 55 deg. F). One 4.8 kW heater must be used on each of the 4 basins in the office building. This installation will then provide a service water temperature range of 95 deg. F (tepid) to 115 deg. F (non-scalding).

With slop sink flow now reduced to 1-1/2 gallons per minute, the proper size instant heater is

R = 0.16 (1.5) (120 - 35)
= 20.4 kW

- check maximum temperature at highest groundwater temperature (one faucet case)

20.4 = 0.16 (1.5) (T ΓO˥ - 55)

T ΓO˥ _= 140 deg. F, which is not too hot for janitorial use. Select a 20 kW unit

- Heating energy for each lavatory (4 basins)

$$E = \frac{8.3 \text{ x } (12\ 1/2 \text{ x } 250)\ \frac{(95 + 115 - 45)}{2}}{0.95} = 1{,}638{,}158$$

4 basins = 6,552,32 Btu per year

- Heating energy for slop sink

$$E = \frac{\frac{8.3\,(10 \times 250)\,(120 + 140 - 45)}{2}}{0.95} = 1{,}763{,}750$$

Total annual energy use for this alternative is

6,552,532 + 1,763,750 = 8,316,382

The annual cost in this case would be

$$\frac{\$14.60 \times 8.316.382}{1{,}000{,}000} = \$121.42$$

Fourth Alternate - Mini-Tank with New Faucets and Flow Restrictors

The incorporation of 1/2 gpm flow restrictors will permit setting the two lavatory tank thermostats to the desired service temperature and will eliminate the tampering valves

- Heating energy for each lavatory (2 basins)

$$E = \frac{8.3 \times (25 \times 250)\,(95 - 45)}{0.95} = 2{,}730{,}263 \text{ Btu per year}$$

2 lavatories, 4 basins = 5,460,526 Btu per year

- Heating energy for slop sink 1,638,158 from second alternate.

There is no benefit to installation of a flow restrictor unless it will reduce the size of the heater, thermostat setting, or annual use.

- Standby loss

Reducing storage temperature to 95 deg. F in the two lavatories will reduce standby loss to a negligible amount. Therefore, the standby loss for the slop sink is only considered from the second alternate.

$$\frac{1{,}058{,}795}{3} = 352{,}932 \text{ Btu per year}$$

The total annual energy use for this alternate is the heating energy plus standby loss:

5,450,526 + 1,638,158 + 352,932 = 7,451,616 Btu per year

The annual cost would be

$$\frac{\$14.60 \times 7{,}451{,}616}{1{,}000{,}000} = \$108.79$$

There are, of course, more alternatives to consider than those detailed above. All of the possible alternatives, their annual energy use, and cost are summarized in Table A-1.

Lavatory Basin Heater	**Slop Sink Heater**	**Flow Restrictors**	**Water Use Energy Demand, Basins**	**Btu/Yr slop sink**	**Stand-by Loss Basins**	**Btu/Yr slop sink**	**Total annual energy demand Btu/Yr**	**Total annual energy cost**
Storage	Storage	NO	16,674,107	2,223,214	8,760,000	-	27,657,32	167
Instant	Instant	NO	NILL	NOT	APPLY			
1 Gal. Tank	1 Gal. Tank	NO	8,190,790	1,638,158	705,863	352,932	10,887,74	158
Instant	Instant	Yes	6,552,632	1,763,750	-	-	8,316,382	121
Instant	1 Gal. Tank	Yes	6,552,632	1,638,158	-	352,932	8,543,722	124
1 Gal. Tank	Instant	Yes	5,460,526	1,763,750	-	-	7,224,276	105
1 Gal. Tank	1 Gal. Tank	Yes	5,460,526	1,638,158	-	352,932	7,451,616	108

Table A-9. Summary of Water Heater Alternatives

New Flight Simulator Building Example

The data required for this example are essentially the same as used in the office building example. The building being designed calls for two lavatories with 2 basins each requiring tepid water, and 1 slop sink requiring 120 deg. F water. The design of the building calls for flow restrictor faucets with 1/2 gallon per minute at the basins and 2 gallons per minute at the slop sink. Occupancy/water use is the same as in the office building example. Groundwater average temperature is 60 deg. F with a range of 55 deg. - 65 deg. F. The alternative to be considered in design is one storage heater, 30 gallons, gas heated versus the alternatives calculated in the office building example. Natural gas costs $3.67 per 1,000.000 Btu and electricity costs $14.56. The design of new facilities in this example introduces a new cost consideration. The point-of-use water heaters will make it possible to eliminate 120 feet of 314 inch copper pipe from the building construction. Annual energy use and cost calculations using the format of calculations from the previous example are summarized below.

First Alternative - Storage Heater

- Heating energy for lavatories

$$\frac{8.3 \times 2 \times 25 \times 250\ (120 - 0)}{0.75} = 8{,}300{,}000 \text{ Btu per year}$$

(NOTE: If thermostat setting reduced to 95 deg. F, the annual use would be 4,841,667 Btu)

- Heating energy for slop sink

$$\frac{8.3 \times 10 \times 250\ (120 - 60)}{0.75} = 1{,}660{,}000 \text{ Btu per year}$$

- Standby loss

The heater is now in conditioned space (70 deg. F)
800 Btu per hour x 24 x 365 = 7,008,000 Btu per year

Some analysts may choose to ignore this figure since the heat is not "lost" when the water heater is in conditioned space (slop sink closet). However, the tank-to-air heat transfer does generate an operating cost which must be accounted for in the life cycle cost analysis.

- Total annual energy use

8,300,00 + 1,660,000 + 7,008,000 = 16,968,000 Btu per year

$$\frac{\$367 \times 16{,}968{,}000}{1{,}000{,}000} = \$62.27 \text{ per year}$$

Second Alternative - Instant Heater

- Recheck basin heater size for a5 deg. F and 55 deg. F. R = 0.16 (1/2) (95 - 55)

= 3.2 kW

3.2 = 0.16 (1/2) (T ΓO˥ - 65)

TΓO˥ =105
A 3 kW, 110 V unit may now be used.

- Heating energy for each lavatory (4 basins)

$$\frac{8.3 \times 12\ 1/2 \times 250 \left(\frac{95 + 105}{2} - 60\right) \times 4}{0.95} = 4{,}368{,}421 \text{ Btu per year}$$

- Heating energy for slop sink

$$\frac{8.3 \times 10 \times 250 \left(\frac{120 + 130}{2} - 60\right)}{0.95} = 1{,}419{,}737 \text{ Btu per}$$

(NOTE: If used as booster for 95 deg. F water, 546,052 Btu)

- Total annual energy use

$$4{,}368{,}421 + 1{,}419{,}737 = 5{,}788{,}158 \text{ Btu per year}$$

$$\frac{\$14.56 \times 5{,}788{,}158}{1{,}000{,}000} = \$84.28 \text{ per year}$$

Third Alternative - One-Gallon Tank Heater

- Heating energy for lavatories

$$E = \frac{8.3 \times 2 \times 25 \times 250 \times (95 - 60)}{0.95} = 3{,}822{,}3a8 \text{ Btu per year}$$

- Heating energy for slop sink

$$E = \frac{8.3 \times 10 \times 250 \times (120 - 60)}{0.95} = 1{,}310{,}526 \text{ Btu per year}$$

- Standby losses (from example 2, fifth alternate)

- 352,932 Btu per year

- Total annual energy use

$$3{,}822{,}368 + 1{,}310{,}526 + 352{,}932 = 5{,}485{,}826 \text{ Btu per year}$$

$$\frac{\$14.56 \times 5{,}485{,}826}{1{,}000{,}000} = \$79.87 \text{ per year}$$

Fourth Alternative - One-Half Gallon Tank Heater

- Heating energy for each lavatory

$$E = \frac{8.3 \times (12\ 1/2 \times 250)\ (95 - 60) = 955{,}592 \times 4}{0.95} = 3{,}822{,}368 \text{ Btu per year}$$

- Standby loss (from Table A-2) 1,534,485 Btu per year

- Slop sink (from Alternative 2a) 1,419,737 Btu per year

- Total annual energy use

3,822,368 + 1,534,485 + 1,419,737 = 6,776,590 Btu per year

$14.56 x 6.776,590 = $98.67 per year

1,000,000

Water heating costs for this example are summarized in Table A-2, and Life Cycle Costs analysis is displayed in Table A-3.

Alternatives	Lavatory Basin Heater	Slop Sink Heater	Water Use Energy Demand , Basins		Stan d-by Loss Btu/ Yr		Total annual energy demand Btu/Yr	Total annual energy cost
			Basins	Slop Sinks	Basins	Slop Sinks		
1a	Storage (120)	Storage	8,300,000	1,660,000	7,008,000		16,968,000	62.27
1b	Storage (95)	Instant	4,841,667	5,460,552	5,840,000		11,227,719.00	47.15
2a	Instant	Instant	4,368,421	1,419,737	-		5,788,158	84.28
2b	Instant	1 Gal. Tank	4,368,421	1,310,526	-	352,932	6,031,879	87.82
3a	1 Gal. Tank	1 Gal. Tank	3,822,368	1,310,526	-	352,932	5,485,826	79.87
3b	1 Gal. Tank	Instant	3,822,368	1,419,737	-		6,776,590	78
4a	1/2 Gal. Tank	Instant	3,822,368	1,419,737	1,543,485		5,356,826	98.67
4b	1/2 Gal. Tank	1 Gal. Tank	3,822,368	1,310,526	1,543,485	352,932	7,020,31	102.22

Table A-10. Summary of Water Heating Alternatives

Installation Alternatives	1a	1b	2a	2b	3a	3b	4a	4b
Basin Heaters	Storage	Storage	Instant	Instant	1 Gal. Tank	1 Gal. Tank	1/2 Gal. Tank	1/2 Gal. Tank
Slop sink Heaters	1 Gal. Tank	Instant	Instant	1 Gal. Tank	1 Gal. Tank	Instant	Instant	Storage
Purchase Storage Heater	$190.00	$190.00	-	-	-	-	-	-
Purchase 1- 9 Kw Inst.		120	120	120	-	-	$120.00	$120.00
Purchase 4 - 3 Kw Inst.	-	-	$480.00	$480.00	-	-	-	-
Purchase 3 - 1/ Gal Heat.	-	-	-	-	$456.00	-	-	-
Purchase 2 -1 /2 Gal Heat.	-	-	-		-	$304.00	-	-
Purchase 1- 1/2 Gal Heat.	-	-	-	$152.00	-	-	-	-
Purchase 4 - 1/2 Gal Heat.								
110V Elec- to								
5 Appliance	-	-	-	$150.00	-	-	-	$160.00
4 Appliance	-	-	$120.00	-	-	-	128	-
3 Appliance	-	-	-	-	96	-	-	-
2 Appliance	-	-	-	-	-	64	-	-
220V Elec- to								
1 Appliance	-	$50	$50				50	
Plumbing Connection	-	$67.00						
Install copper pipe from heater to basin	439	$439.00	-	-				
Total Installed Cost	629	$866.00	$1,113.00	$1,134.00	1134.00	774.00	997.00	1018.00
Annual Energy Cost in 1980		$47.16	$84.28	$84.28	$87.82	78.00	98.67	102.22

Table A-11. Summary of Life Cycle Costing Inputs