SECTION FOURTEEN

PLUMBING—WATER-SUPPLY, SPRINKLER, AND WASTEWATER SYSTEMS

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This section treats the major subsystems for conveyance of liquids and gases in pipes within a building. The pipes generally extend beyond the building walls to a supply source or a disposal means, such as a sewer.

14.1 PLUMBING AND FIRE PREVENTION CODES

Plumbing codes were created to prevent illness and death from unsanitary or unsafe conditions in supply of water and gases in buildings and removal of wastes in pipes. There are two commonly recognized model plumbing and fire prevention codes:

“International Plumbing Code” and “International Fire Code,” International Code Council Inc., Falls Church, VA.

“Uniform Plumbing Code” and “Uniform Fire Code,” International Association of Plumbing and Mechanical Officials, Walnut, Calif.

These codes are generally revised on 3-year cycles.

In addition to these model codes, several cities and states have adopted their own plumbing and fire prevention codes. The “National Standard Plumbing Code,” administered by the National Association of Plumbing, Heating and Cooling Contractors, Inc., Washington, D.C., has been adopted in some localities. The American National Standards Institute (ANSI) has also adopted the “National Plumbing

Code,'' ANSI A.40.8, which is administered by the Mechanical Contractors Association of America, Rockville, Md. Also, numerous fire-safety codes and standards are contained in ''National Fire Codes,'' National Fire Protection Association, Quincy, Mass.

Persons involved in the design and installation of plumbing systems should check with all local code authorities to determine which code is in effect prior to beginning a project. Also, local governmental authorities should be contacted about special regulations relating to sewer and water systems. Those involved in the design of plumbing systems should also be familiar with ANSI A117.1 and the Americans with Disabilities Act (ADA), which require that provision be made in buildings for accessibility and usability of facilities by the physically handicapped. Plumbing designers and architects should work together to assure strict compliance with these requirements.

14.2 HEALTH REQUIREMENTS FOR PLUMBING

Plumbing codes place strict constraints on plumbing installations in the interest of public health. Following are typical basic provisions:

All buildings must be provided with potable water in quantities adequate for the needs of their occupants. Plumbing fixtures, devices, and appurtenances should be supplied with water in sufficient volume and at pressures adequate to enable them to function properly. The pipes conveying the water should be of sufficient size to provide the required water without undue pressure reduction and without undue noise under all normal conditions of use.

The plumbing system should be designed and adjusted to use the minimum quantity of water consistent with proper performance and cleansing of fixtures and appurtenances.

Devices for heating and storing water should be designed, installed, and maintained to guard against rupture of the containing vessel because of overheating or overpressurization.

The wastewater system should be designed, constructed, and maintained to guard against fouling, deposit of solids, and clogging.

Provision should be made in every building for conveying storm water to a storm sewer if one is available.

Recommended tests should be made to discover any leaks or defects in the system. Pipes, joints, and connections in the plumbing system should be gastight and watertight for the pressure required by the tests.

Plumbing fixtures should be located in ventilated enclosures and should be readily accessible to users.

Plumbing fixtures should be made of smooth, nonabsorbent materials. They should not have concealed fouling surfaces. Plumbing fixtures, devices, and appliances should be protected to prevent contamination of food, water, sterile goods, and similar material by the backflow of wastewater. Indirect connections with the building wastewater system should be provided when necessary

Every fixture directly connected to the wastewater system should be equipped with a **liquid-seal trap.** This is a fitting so constructed that passage of air or gas through a pipe is prevented while flow of liquid through the pipe is permitted.

Foul air in the wastewater system should be exhausted to the outside, through vent pipes. These should be located and installed to minimize the possibility of clogging and to prevent sewer gases from entering the building.

If a wastewater system is subject to the backflow of sewage from a sewer, suitable provision should be made to prevent sewage from entering the building.

The structural safety of a building should not be impaired in any way as a result of the installation, alteration, renovation, or replacement of a plumbing system. Pipes should be installed and supported to prevent stresses and strains that would cause malfunction of or damage to the system. Provision should be made for expansion and contraction of the pipes due to temperature changes and for structural settlements that might affect the pipes.

Where pipes pass through a construction that is required to have a fire-resistance rating, the space between the pipe and the opening or a pipe sleeve should not exceed ½ in. The gap should be completely filled with code-approved, fire-stopping material and closed off with close-fitting metal escutcheons on both sides of the construction.

Pipes, especially those in exterior walls or underground outside the building, should be protected, with insulation or heat, to prevent freezing. Underground pipes should be placed below established frost lines to prevent damage from heaving and in high traffic areas should be encased in concrete or installed deep enough so as to not be damaged by heavy traffic. Pipes subject to external corrosion should be protected with coatings, wrappings, cathodic protection, or other means that will prevent corrosion. Dissimilar metals should not be connected to each other unless separated by a dielectric fitting. Otherwise, corrosion will result.

Each plumbing system component, such as domestic water, natural gas, and wastewater pipes and fixtures, should be tested in accordance with the plumbing code. All defects found during the test should be properly corrected and the system retested until the system passes the requirements of the test.

WATER SUPPLY

Enough water to meet the needs of occupants must be available for all buildings. Further water needs for fire protection, heating, air conditioning, and possibly process use must also be met. This section provides specific data on all these water needs, except those for process use. Water needs for process use must be computed separately because the demand depends on the process served.

14.3 WATER QUALITY

Sources of water for buildings include public water supplies, groundwater, and surface water. Each source requires careful study to determine if a sufficient quantity of safe water is available for the building being designed.

Water for human consumption, commonly called potable water, must be of suitable quality to meet local, state, and national requirements. Public water supplies generally furnish suitably treated water to a building, eliminating the need for treatment in the building. However, ground and surface waters may require treatment prior to distribution for human consumption. Useful data on water treatment are available from the American Water Works Association, Denver, Col.

Useful data on water supplies for buildings are available in the following publications: American Society of Civil Engineers, ‘‘Glossary-Water and Sewer Control Engineering;’’ E. W. Steel, ‘‘Water Supply and Sewerage,’’ McGraw-Hill

Publishing Company, New York; G. Fair, J. C. Geyer, and D. A. Okun, ‘‘Water and Wastewater Engineering,’’ John Wiley & Sons, Inc., New York; and E. Nordell, ‘‘Water Treatment for Industrial and Other Uses,’’ Van Nostrand Reinhold, New York. The ASTM ‘‘Manual on Industrial Water’’ contains extensive data on process-water and steam requirements for a variety of industries. Data on water for fire protection are available from the American Insurance Association, New York, and the National Fire Protection Association (NFPA), Quincy, Mass.

Water for buildings is transmitted and distributed in pipes, which may be run underground or aboveground. Useful data on pipeline sizing and design are given in J. Church, ‘‘Practical Plumbing Design Guide,’’ and C. E. Davis and K. E. Sorenson, ‘‘Handbook of Applied Hydraulics,’’ McGraw-Hill Publishing Company, New York. The American Insurance Association promulgates a series of publications on water storage tanks for a variety of services.

Characteristics of Water. Physical factors of major importance for raw water are temperature, turbidity, color, taste, and odor. All but temperature are characteristics to be determined in the laboratory from carefully procured samples by qualified technicians utilizing current testing methods and regulations.

Turbidity, a condition due to fine, visible material in suspension, is usually due to presence of colloidal particles. It is expressed in parts per million (ppm or mg/L) of suspended solids. It may vary widely in discharges of relatively small streams of water. Larger streams or rivers tending to be muddy are generally muddy all the time. The objection to turbidity in potable supplies is its ready detection by the drinker. The U.S. Environmental Protection Agency (USEPA) limit is one nephelometric turbidity unit (NTU).

Color, also objectionable to the drinker, is preferably restricted to 15 color units or less. It is measured, after all suspended matter (turbidity) has been centrifuged out, by comparison with standard hues.

Tastes and odors due to organic material or volatile chemical compounds in the water should be removed completely from drinking water. But slight, or threshold, odors due to very low concentrations of these compounds are not harmful-just objectionable. Perhaps the most common source of taste and odor is decomposition of algae.

Chemical Content. Chemical constituents commonly found in raw waters intended for potable use and measured by laboratory technicians include hardness, pH, iron, and manganese, as well as total solids. Total solids should not exceed 500 ppm. Additionally, the USEPA is continually developing, proposing, and adopting new drinking water regulations as mandated by the Safe Drinking Water Act.

Hardness, measured as calcium carbonate, may be objectionable in laundries with as little as 150 ppm of $CaCO_3$ present. But use of synthetic detergents decreases its significance and makes even much harder waters acceptable for domestic uses. Hardness is of concern, however, in waters to be used for boiler feed, where boiler scale must be avoided. Here, 150 ppm would be too much hardness and the water would require softening (treatment for decrease in hardness).

Hydrogen-ion concentration of water, commonly called pH, can be a real factor in corrosion and encrustation of pipe and in destruction of cooling towers. A pH under 7 indicates acidity; over 7 indicates alkalinity; 7 is neutral. Tests using color can measure pH to the nearest tenth, which is of sufficient accuracy.

Iron and manganese when present in more than 0.3-ppm concentrations may discolor laundry and plumbing. Their presence and concentration should be determined. More than 0.2 ppm is objectionable for most industrial uses.

Organic Content. Bacteriological tests of water must be made on carefully taken and transported samples. A standard sample is five portions of 10 cm^3, each sample a different dilution of the water tested. A state-certified laboratory will use approved standard methods for analyses.

Organisms other than bacteria, such as plankton (free-floating) and algae, can in extreme cases be important factors in design of water treatment systems; therefore, biological analyses are significant. Microscopic life and animal and vegetable matter can be readily identified under a high-powered microscope.

Maintenance of Quality. It is not sufficient that potable water just be delivered to a building. The quality of the water must be maintained while the water is being conveyed within the building to the point of use. Hence, the potable-water distribution system must be properly designed to prevent contamination.

No cross connections may be made between this system and any portion of the wastewater-removal system. Furthermore, the potable-water distribution system should be completely isolated from parts of plumbing fixtures or other devices that might contaminate the water. Backflow preventers or air gaps may be used to prevent backflow or back siphonage. Many states or municipal water systems now have regulations which require that backflow prevention devices be installed at the building potable and fire system services. These devices are required to protect the municipal water systems from contamination. All backflow prevention devices are required to have annual inspection, testings and certification.

Backflow is the flow of liquid into the distribution piping system from any source other than the intended water-supply source, such as a public water main.

Back siphonage is the suction of liquid back into the distribution piping system because of a siphonage action being applied to the distribution pipe system. The type of backflow preventer to use depends on the type of reverse flow expected (backflow or back siphonage) and the severity of the hazard. In general, double check-valve-type backflow preventers are normally approved for low-hazard backflow conditions and vacuum breakers are approved for low-hazard back-siphonage conditions. Where the hazard is great, reduced-pressure principal backflow preventers are normally required. The local code authorities should be consulted about local and state regulations pertaining to backflow prevention.

14.4 WATER TREATMENT

To maintain water quality within acceptable limits (Art. 14.3), water supplied to a building usually must undergo some form of treatment. Whether treatment should be at the source or after transmission to the point of consumption is usually a question of economics, involving hydraulic features, pumping energies and costs, and possible effects of raw water on transmission mains.

Treatment, in addition to disinfection, should be provided for all water used for domestic purposes that does not fall within prescribed limits. Treatment methods include screening, plain settling, coagulation and sedimentation, filtration, disinfection, softening, and aeration. When treatment of the water supply for a building is necessary, the method that will take the objectionable elements out of the raw water in the simplest, least expensive manner should be selected.

Softening of water is a process that must be justified by its need, depending on use of the water. With a hardness in excess of about 150 ppm, the cost of softening will be offset partly by the reduction of soap required for cleaning. When synthetic detergents are used instead of soap, this figure may be stretched considerably. But when some industrial use of water requires it, the allowable level for hardness must be diminished appreciably.

Since corrosion can be costly, corrosive water must often be treated in the interest of economics. In some cases, it may be enough to provide threshold treatment that will coat distribution lines with a light but protective film of scale. But in other cases—boiler-feed water for high-pressure boilers, for example—it is important to have no corrosion or scaling. Then, deaeration and pH control may be necessary. (The real danger here is the failure of boiler-tube surfaces because of overheating due to scale formation.)

(American Water Works Association, ''Water Quality and Treatment,'' McGraw-Hill Publishing Company, New York; G. M. Fair, J. C. Geyer, and D. A. Okun, ''Elements of Water Supply and Wastewater Disposal,'' John Wiley & Sons, Inc., New York.)

14.5 WATER QUANTITY AND PRESSURES

Quantity of water supplied must be adequate for the needs of occupants and processes to be carried out in the building. The total water demand may be calculated by adding the maximum flows at all points of use and applying a factor less than unity to account for the probability that only some of the fixtures will be operated simultaneously (Art. 14.8).

In addition, the pressure at which water is delivered to a building must lie within acceptable limits. Otherwise, low pressures may have to be increased by pumps and high pressures decreased with pressure-reducing valves. Table 14.1 lists minimum flow rates and pressures generally required at various water outlets. The pressure in Table 14.1 is the pressure in the supply pipe near the water outlet while the outlet is wide open and water is flowing.

In delivery of water to the outlets, there is a pressure drop in the distribution pipes because of friction. Therefore, water supplied at the entrance to the distri-

TABLE 14.1 Required Minimum Flow Rates and Pressures during Flow for Fixtures

Fixture	Pressure, psi*	Flow, gpm
Basin faucet	8	3
Basin faucet, self-closing	12	2.5
Sink faucet, ⅜-in	10	4.5
Sink faucet, ½-in	5	4.5
Dishwasher	15–25	†
Bathtub faucet	5	6
Laundry tub cock, ¼-in	5	5
Shower	12	3–10
Water closet ball cock	15	3
Water closet flush valve	15–20	15–40
Urinal flush valve	15–20	15
Garden hose, 50 ft, and sill cock	30	5

*Residual pressure in pipe at entrance to fixture. 20 psi minimum required at water conserving type fixture. Verify minimum pressure reqirements with fixture manufacturer.

†As specified by fixture manufacturer.

bution system must exceed the minimum pressures required at the water outlets by the amount of the pressure loss in the system. But the entrance pressure should not exceed 80 psi, to prevent excessive flow and damage to system components. Velocity of water in the distribution system should not exceed 10 ft/s.

A separate supply of water must be provided for fire-fighting purposes. This supply must be of the most reliable type obtainable. Usually, this requirement can be met with water from a municipal water supply. If the municipal water supply is not adequate or if a private water supply is utilized, pumps or storage in an elevated water tank should be provided to supply water at sufficient quantities and pressures. Generally, such water should be provided at a pressure of at least 15 psi residual pressure at the highest level of fire-sprinkler protection for light-hazard occupancies and 20 psi residual pressure for ordinary-hazard occupancies. Acceptable flow at the base of the supply riser is 500 to 700 gpm for 30 to 60 minutes for light-hazard occupancies and 850 to 1500 gpm for 60 to 90 minutes for ordinary-hazard occupancies.

If a building is so located that it cannot be reached by a fire department with about 250 ft of hose, a private underground water system, installed in accordance with NFPA 24, ‘‘Installation of Private Fire Service Mains and Their Appurtenances,’’ may have to be provided. Many municipalities require that the water system for a building site be a type generally called a ‘‘loop-to-grid’’ system. It consists of pipes that loop around the property and has a minimum of two municipal-water-system connections, at opposite sides of the loop, usually at different water mains of the municipal system. Hydrants should be placed so that all sides of a building can be reached with fire hoses. The requirements for fire hydrants should be verified with the local code officials or fire marshal.

14.6 WATER DISTRIBUTION IN BUILDINGS

Cold and hot water may be conveyed to plumbing fixtures under the pressure of a water source, such as a public water main, by pumps, or by gravity flow from elevated storage tanks.

The water-distribution system should be so laid out that, at each plumbing fixture requiring both hot and cold water, the pressures at the outlets for both supplies should be nearly equal. This is especially desirable where mixing valves may be installed, to prevent the supply at a higher pressure from forcing its way into the lower-pressure supply when the valves are opened to mix hot and cold water. Pipe sizes and types should be selected to balance loss of pressure head due to friction in the hot and cold-water pipes, despite differences in pipe lengths and sudden large demands for water from either supply.

Care should be taken to assure that domestic water piping is not installed in a location subject to freezing temperatures. When piping is installed in exterior walls in cold climate areas, the piping should be insulated and should be installed on the building side of the building wall insulation. Piping installed in exterior cavity walls or chases may require heat tracing, although the installation of high and low wall-mounted grilles, which allow heated air from the building to naturally flow through the cavity, will usually prevent the temperature in the cavity from falling below a temperature where water in the piping will freeze. Designers should thoroughly investigate local climatic conditions and building methods to assure proper installation. Designers should also specify freeze-proof-type hydrants (hose bibs) for exterior applications.

14.6.1 Temperature Maintenance in Hot-Water Distribution

In large, central, hot-water distribution systems, many fixtures that require hot water are not located very close to the water-heating equipment. If some means of maintaining the temperature of the hot water in the piping is not provided, the water temperature will fall, particularly during periods of low demand. The supply to remote fixtures would have to run for a long period before hot water would be available at the outlet thereby wasting precious water. For this reason, designers should provide a temperature maintenance system whenever a fixture requiring hot water is over 25 ft away from the source of hot water.

One method of temperature maintenance is to use a hot-water recirculating system, which consists of a hot-water return piping system, a circulating pump, and a water-temperature controller to operate the pump. The return piping system starts at the end of each remote branch main and runs back to the water-heater cold-water-supply pipe connection. The circulating pump circulates hot water through the supply piping, return piping, and the water heater whenever the controller senses that the water temperature has fallen below a preselected set point. To reduce heat loss, all hot-water supply and return piping should be insulated.

Another method employs self-regulating, electric heat tracing that is applied directly to the hot-water supply piping prior to the installation of the piping insulation. The self-regulating heat tracing is made of polymers, which have variable electric resistances, depending on the surface temperature of the pipe. As the surface temperature of the pipe falls, the resistance increases and more heat is given off by the heat tracing. The opposite is true if the surface of the piping is hot. This type of system requires less maintenance once it is installed and less energy to maintain the hot-water temperature in the piping.

Horizontal pipe runs should not be truly horizontal. They should have a minimum slope of about ¼ in/ft toward the nearest drain valve when possible. An adequate number of drain valves should be provided to drain the domestic water system completely.

14.6.2 Up-Feed Water Distribution

To prevent rapid wear of valves, such as faucets, water should only be supplied to building distribution systems at pressures not more than about 80 psi. This pressure is large enough to raise water from 8 to 10 stories upward and still retain desired pressures at plumbing fixtures (Table 14.1). Hence, in low buildings, cold water can be distributed by the up-feed method (Fig. 14.1), in which at each story plumbing fixtures are served by branch pipes connected to risers that carry water upward under pressure from the water source.

In Fig. 14.1, cold water is distributed under pressure from a public water main. The hot-water distribution is by a discontinuous system. Hot water rises from the water heater in the basement to the upper levels under pressure from the cold-water supply to the water heater.

When an up-feed distribution system is desired, but the city water pressure is not sufficient to provide adequate water pressure, the water pressure may be boosted to desired levels by the installation of a packaged, domestic water-booster pump system. This equipment usually consists of a factory-built system with multiple pumps, a pressure tank, and all operating controls to maintain the required water pressure. This type of system may also be used in buildings in excess of 10 stories by proper zoning and the use of pressure-reducing valves at each zone.

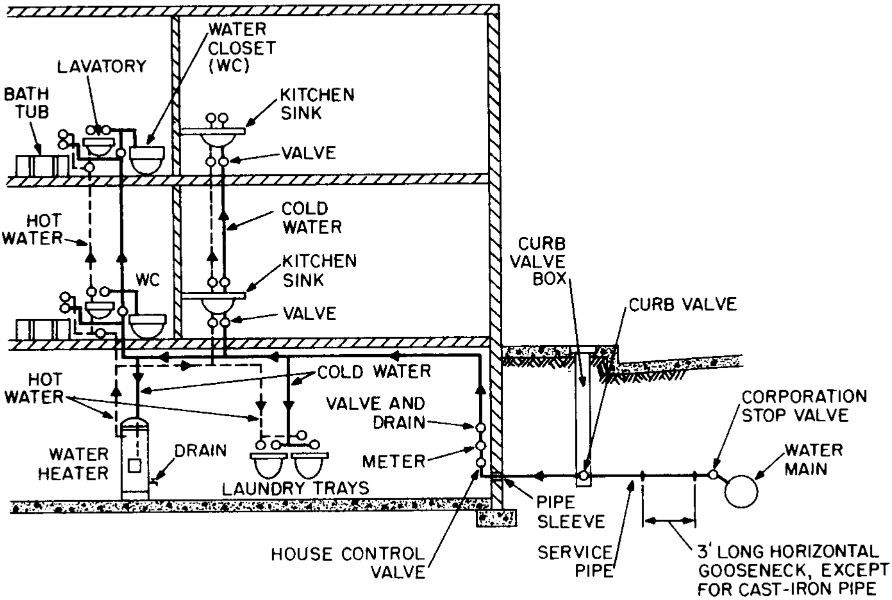


FIGURE 14.1 Up-feed water-distribution system for a two-story apartment building. (*Reprinted with permission from F. S. Merritt, "Building Engineering and Systems Design," Van Nostrand Reinhold Company, New York.*)

14.6.3 Down-Feed Water Distribution

For buildings more than 8 to 10 stories high, designers have the option to pump water to one or more elevated storage tanks, from which pipes convey the water downward to plumbing fixtures and water heaters. Water in the lower portion of an elevated tank often is reserved for fire-fighting purposes (Fig. 14.2). Generally, also, the tank is partitioned to provide independent, side-by-side chambers, each with identical piping and controls. During hours of low demand, a chamber can be emptied, cleaned, and repaired, if necessary, while the other chamber supplies water as needed. Float-operated electric switches in the chambers control the pumps supplying water to the tank. When the water level in the tank falls below a specific elevation, a switch starts a pump, and when the water level becomes sufficiently high, the switch stops the pump.

Usually, at least two pumps are installed to supply each tank. One pump is used for normal operation. The other is a standby, for use if the first pump is inoperative. For fire-fighting purposes, a pump must be of adequate size to fill the tank at the rate of the design fire flow.

When a pump operates to supply a tank, it may draw so much water from a public main that the pressure in the main is considerably reduced. To avoid such a condition, water often is stored in a suction tank at the bottom of the building for use by the pumps. The tank is refilled automatically from the public main. Because refilling can take place even when the pumps are not operating, water can be drawn from the public main without much pressure drop.

Figure 14.2 is a simplified schematic diagram of a down-feed distribution system of a type that might be used for buildings up to 20 stories high.

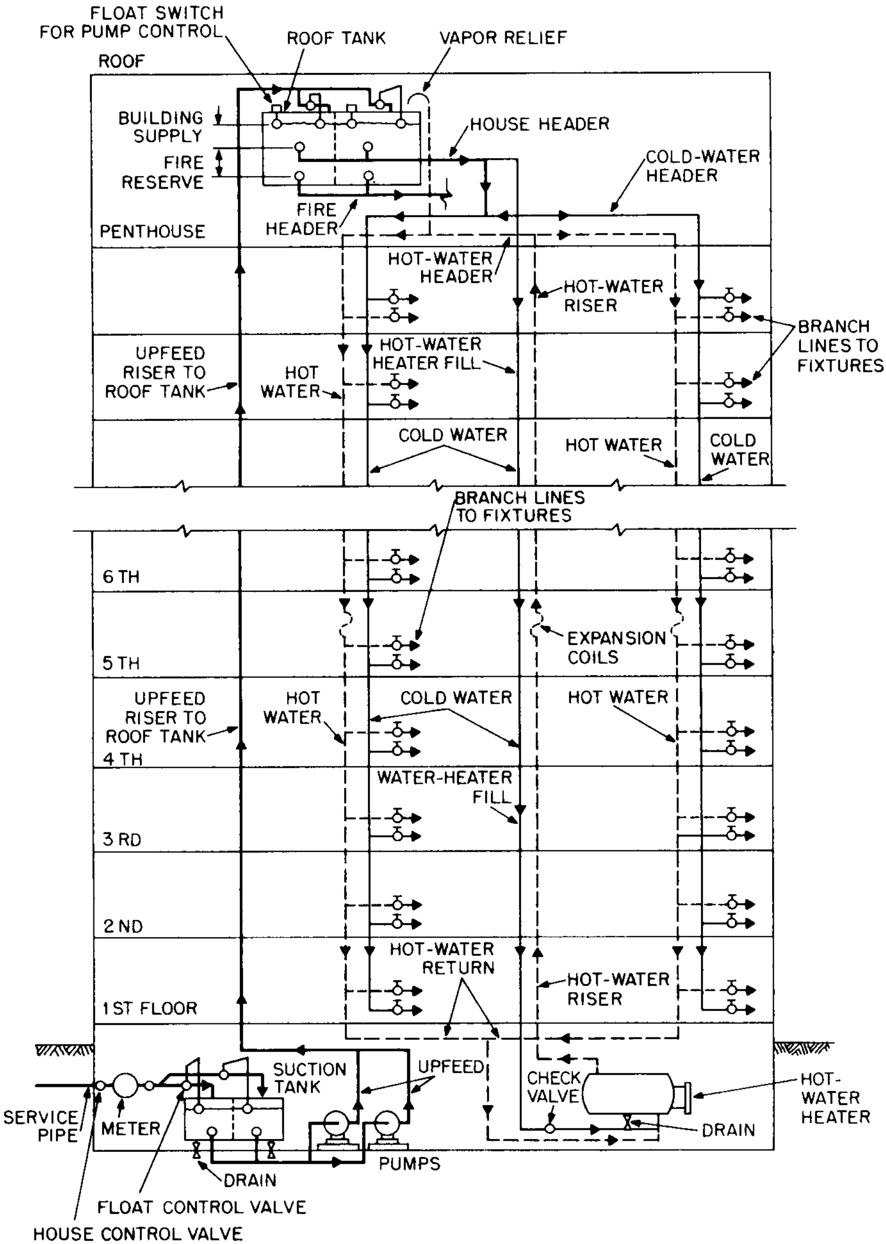


FIGURE 14.2 Down-feed water-distribution system for a tall building. (*Reprinted with permission from F. S. Merritt, "Building Engineering and Systems Design," Van Nostrand and Reinhold Company, New York.*)

Tall buildings may be divided into zones, each of which is served by a separate down-feed system. (The first few stories may be supplied by an up-feed system under pressure from a public main.) Each zone has at its top its own storage tank, supplied from its own set of pumps in the basement. All the pumps draw on a common suction tank in the basement. Also, each zone has at its base its own water heater and a hot-water circulation system. In effect, the distribution in each zone is much like that shown in Fig. 14.2.

If space is not available to install storage tanks at the top of each zone, the main water supply from a roof-mounted storage tank may be supplied to the zones if pressure-reducing valves are utilized to reduce the supply-water pressure to an acceptable level at each zone.

14.6.4 Prevention of Backflow

All water-supply and distribution piping must be designed so there is no possibility of backflow at any time. The minimum code-required air gap (distance between the fixture outlet and the flood-level rim of the receptacle) should be maintained at all times. Domestic water systems that are subject to back siphonage or backflow should be provided with approved vacuum breakers or backflow preventers (Art. 14.3). Before any potable-water piping is put into use, it must be disinfected using a procedure approved by the local code authorities.

14.6.5 Pipe Materials

Pipes and tubing for water distribution may be made of copper, brass, polyvinyl chloride (PVC), polybutylene, ductile iron, or galvanized steel, if they are approved by the local code. When materials for potable-water piping are being selected, care should be taken to ensure that there is no possibility of chemical action or any other action that might cause a toxic condition.

14.6.6 Fittings

These are used to change the direction of water flow (because it usually is not practical to bend pipe in the field), to make connections between pipes, and to plug openings in pipes or close off the terminal of a pipe. In a water-supply system, fittings and joints must be capable of containing pressurized water flow. Fittings should be of comparable pressure rating and of quality equal to that of the pipes to which they are connected.

Standard fittings are available and generally may be specified by reference to an American National Standards Institute or a federal specification. Fitting sizes indicate the diameters of the pipes to which they connect. For threaded fittings, the location of the thread should be specified: A thread on the outside of a pipe is called a **male thread,** whereas an internal thread is known as a **female thread.**

Ductile-iron pipe is generally available with push-on mechanical joint or flanged fittings. Brass or bronze fittings for copper or brass pipe also may be flanged or threaded. Flanges are held together with bolts. In some cases, to make connections watertight, a gasket may be placed between flanges, whereas in other cases, the flanges may be machine-faced. Threaded fittings often are made watertight by coating the threads with an approved pipe compound or by wrapping the threads with teflon tape before the fittings are screwed onto the pipe.

14.6.7 Valves

These are devices incorporated in pipelines to control the flow into, through, and from them. Valves are also known as faucets, cocks, bibs, stops, and plugs. The term **cock** is generally used with an adjective indicating its use; for example, a sill cock (also called a hose bib) is a faucet used on the outside of a building for connection with a garden hose. A **faucet** is a valve installed on the end of a pipe to permit or stop withdrawal of water from the pipe.

Valves usually are made of cast or malleable iron, brass, or bronze. Faucets in bathrooms or kitchens are usually faced with nickel-plated brass.

The types of valves generally used in water-supply systems are gate, globe, angle, ball, and check valves.

Gate valves control flow by sliding a disk perpendicular to the water flow to fit tightly against seat rings when a handwheel is turned. This type of valve is usually used in locations where it can be left completely open or closed for long periods of time.

Globe valves control the flow by changing the size of the passage through which water can flow past the valves. Turning a handwheel moves a disk attached at the end of the valve stem to vary the passage area. When the valve is open, the water turns 90° to pass through an orifice enclosed by the seat and then turns 90° again past the disk, to continue in the original direction. Flow can be completely stopped by turning the handwheel to compress the disk or a gasket on it against the seat. This type of valve usually is used in faucets.

Angle valves are similar to globe valves but eliminate one 90° turn of the water flow. Water is discharged from the valves perpendicular to the inflow direction.

Check valves are used to prevent reversal of flow in a pipe. In the valves, water must flow through an opening with which is associated a movable plug (or flapper). When water flows in the desired direction, the plug automatically moves out of the way; however, a reverse flow forces the plug into the opening, to seal it.

Ball valves are quick-closing (¼ turn to close) valves, which consist of a drilled ball that swivels on its vertical axis. This type of valve creates little water turbulence owing to its straight-through flow design.

14.6.8 Pipe Supports

When standard pipe is used for water supply in a building, stresses due to ordinary water pressure are well within the capacity of the pipe material. Unless the pipe is supported at short intervals, however, the weight of the pipe and its contents may overstress the pipe material. Generally, it is sufficient to support vertical pipes at their base and at every floor. Maximum support spacing for horizontal pipes depends on pipe diameter and material. The plumbing code should be consulted to determine maximum horizontal and vertical hanger spacings allowed.

While the supports should be firmly attached to the building, they should permit pipe movement caused by thermal dimensional changes or differences in settlement of building and pipe. Risers should pass through floors preferably through sleeves and transfer their load to the floors through tight-fitting collars. Horizontal pipe runs may be carried on rings or hooks on metal hangers attached to the underside of floors. The hangers and anchors used for plumbing piping should be metal and strong enough to prevent vibration.

Each hanger and anchor should be designed and installed to carry its share of the total weight of the pipe.

All piping installed should be restrained according to the requirements specific to the exact earthquake zone where the building is located. The local code authorities should be consulted about these requirements.

14.6.9 Expansion and Contraction

To provide for expansion and contraction, expansion joints should be incorporated in pipelines. Such joints should be spaced not more than 50 ft apart in hot-water pipe. While special fittings are available for the purpose, flexible connections are a common means of providing for expansion. Frequently, such connections consist of a simple U bend or a spiral coil, which permits springlike absorption of pipe movements.

14.6.10 Meters

These are generally installed on the service pipe to a building to record the amount of water delivered. The meters may be installed inside the building, for protection against freezing, or outside, in a vault below the frost line. Meters should be easily accessible to meter readers. Meter size should be determined by the maximum probable water flow, gal/mm.

14.6.11 Water Hammer

This is caused by pressures developing during sudden changes in water velocity or sudden stoppage of flow. The result is a banging sound or vibration of the piping system. It frequently results from rapid closing of valves, but it also may be produced by other means, such as displacing air from a closed tank or pipe from the top.

Water hammer can be prevented by filling a closed tank or pipe from the bottom while allowing the air to escape from the top. Water hammer also can be prevented by installing on pipelines air chambers or other types of water-hammer arresters. These generally act as a cushion to dissipate the pressures.

14.7 PLUMBING FIXTURES AND EQUIPMENT

The water-supply system of a building distributes water to plumbing fixtures at points of use. Fixtures include kitchen sinks, water closets, urinals, bathtubs, showers, lavatories, drinking fountains, laundry trays, and slop (service) sinks. To ensure maximum sanitation and health protection, most building codes have rigid requirements for fixtures. These requirements cover such items as construction materials, connections, overflows, installation, prevention of backflow, flushing methods, types of fixtures allowed, and inlet and outlet sizes. Either the building code or the plumbing code lists the minimum number of each type of fixture that must be installed in buildings of various occupancies (Table 14.2). Since these numbers are minimums, each project should be reviewed to determine if additional fixtures should be provided. This is especially true for assembly occupancies, where large numbers

TABLE 14.2 Minimum Plumbing Fixtures for Various Occupancies[a]

Type of building or occupancy	Water closets[b]		Urinals	Lavatories		Bathtubs or showers	Drinking fountains[c]
Dwelling or apartment house[d]	1 for each dwelling or apartment unit			1 for each dwelling or apartment unit		1 for each dwelling or apartment unit	
Office or public building	Male 1 for 1–100 2 for 101–200 3 for 201–400	Female 3 for 1–50 4 for 51–100 8 for 101–200 11 for 201–400	1 for 1–100 2 for 101–200 3 for 201–400 4 for 401–600 Over 600 add 1 fixture for each additional 300 males	Male 1 for 1–200 2 for 201–400 3 for 401–750	Female 1 for 1–200 2 for 201–400 3 for 401–750		1 per first 75[e]
	Over 400, add one fixture for each additional 500 males and 2 for each 300 females			Over 750, add one fixture for each additional 500 persons			
Office or public buildings—for employee use	Male 1 for 1–15 2 for 16–35 3 for 36–55	Female 1 for 1–15 3 for 16–35 4 for 36–55	0 for 1–9 1 for 10–50 Add one fixture for each additional 50 males	Male 1 per 40	Female 1 per 40		
	Over 55, add 1 fixture for each additional 40 persons						
Schools—for staff use All schools	Male 1 for 1–15 2 for 16–35 3 for 36–55	Female 1 for 1–15 2 for 16–35 3 for 36–55	1 per 50	Male 1 per 40	Female 1 per 40		
	Over 55, add 1 fixture for each additional 40 persons						
Schools—for student use Nursery	Male 1 for 1–20 2 for 21–50	Female 1 for 1–20 2 for 21–50		Male 1 for 1–25 2 for 26–50	Female 1 for 1–25 2 for 26–50		1 per 75
	Over 50, add 1 fixture for each additional 50 persons			Over 50, add 1 fixture for each additional 50 persons			
Elementary	Male 1 per 30	Female 1 per 25	1 per 75	Male 1 per 35	Female 1 per 35		1 per 75
Secondary	Male 1 per 40	Female 1 per 30	1 per 35	Male 1 per 40	Female 1 per 40		1 per 75

TABLE 14.2 (Continued) Minimum Plumbing Fixtures for Various Occupancies[a]

Type of building or occupancy	Water closets[b]		Urinals	Lavatories		Bathtubs or showers	Drinking fountains[c]
Other (colleges, universities, adult centers)	Male 1 per 40	Female 1 per 30	1 per 35	Male 1 per 40	Female 1 per 40		1 per 75
Worship places—educational and activities unit	Male 1 per 125 2 for 126–250	Female 1 per 75 2 for 76–125 3 for 126–250	1 per 125	1 per 2 water closets			1 per 75
Dormitories—school or labor[f]	Male 1 per 10 Add 1 fixture for each additional 25 males (over 10) and 1 for each additional 20 females (over 8)	Female 1 per 8	1 per 25 Over 150, add 1 fixture for each additional 50 males	Male 1 per 12 Over 12 add one fixture for each additional 20 males and 1 for each 15 additional females	Female 1 per 12	1 per 8 For females, add 1 bathtub per 30. Over 150, add 1 per 20	1 per first 75[e]
Dormitories—for staff use	Male 1 for 1–15 2 for 16–35 3 for 36–55 Over 55, add 1 fixture for each additional 40 persons	Female 1 for 1–15 3 for 16–35 4 for 36–55	1 per 50	Male 1 per 40	Female 1 per 40	1 per 8	
Assembly places—theaters, auditoriums, convention halls—for permanent employee use	Male 1 for 1–15 2 for 16–35 3 for 36–55 Over 55, add 1 fixture for each additional 40 persons	Female 1 for 1–15 3 for 16–35 4 for 36–55	0 for 1–9 1 for 10–50 Add one fixture for each additional 50 males	Male 1 per 40	Female 1 per 40		
Assembly places—theaters, auditoriums, convention halls—for public use	Male 1 for 1–100 2 for 101–200 3 for 201–400 Over 400, add one fixture for each additional 500 males and 2 for each 300 females	Female 3 for 1–50 4 for 51–100 8 for 101–200 11 for 201–400	1 for 1–100 2 for 101–200 3 for 201–400 4 for 401–600 Over 600, add 1 fixture for each additional 500 males	Male 1 for 1–200 2 for 201–400 3 for 401–750 Over 750, add one fixture for each additional 500 persons	Female 1 for 1–200 2 for 201–400 3 for 401–750		1 per first 75[e]

TABLE 14.2 Minimum Plumbing Fixtures for Various Occupancies[a] (*Continued*)

Type of building or occupancy	Water closets[b]		Urinals	Lavatories		Bathtubs or showers	Drinking fountains[c]
Industrial, warehouses, workshops, foundries, and similar establishments—for employee use[g]	Male 1 for 1–10 2 for 11–25 3 for 26–50 4 for 51–75 5 for 76–100 Over 100, add 1 fixture for each additional 30 persons	Female 1 for 1–10 2 for 11–25 3 for 26–50 4 for 51–75 5 for 76–100		Up to 100, 1 per 10 persons Over 100, 1 per 15 persons[h]		1 shower for each 15 persons exposed to excessive heat or to skin contamination with poisonous, infectious, or irritating material	1 per 75
Institutional—other than hospitals or penal institution (on each occupied floor)	Male 1 per 25	Female 1 per 20	0 for 1–9 1 for 10–50 Add one fixture for each additional 50 males	Male 1 per 10	Female 1 per 10	1 per 8	1 per 75
Institutional—other than hospitals or penal institutional (on each occupied floor)—for employee use	Male 1 for 1–15 2 for 16–35 3 for 36–55 Over 55, add 1 fixture for each additional 40 persons	Female 1 for 1–15 3 for 16–35 4 for 36–55	0 for 1–9 1 for 10–50 Add one fixture for each additional 50 males	Male 1 per 40	Female 1 per 40	1 per 8	1 per 75
Hospitals							
Individual room	1 per room			1 per room		1 per room	
Ward room	1 per 8 patients			1 per 10 patients		1 per 20 patients	1 per 75
Hospital waiting rooms	1 per room			1 per room			1 per 75
Hospitals—for employee use	Male 1 for 1–15 2 for 16–35 3 for 36–55 Over 55, add 1 fixture for each additional 40 persons	Female 1 for 1–15 3 for 16–35 4 for 36–55	0 for 1–9 1 for 10–50 Add one fixture for each additional 50 males	Male 1 per 40	Female 1 per 40		
Penal Institutions—for prison use							1 per cell block floor

TABLE 14.2 Minimum Plumbing Fixtures for Various Occupancies[a] (*Continued*)

Type of building or occupancy	Water closets[b]		Urinals	Lavatories		Bathtubs or showers	Drinking fountains[c]
Cell	1 per cell			1 per cell			
Exercise room	1 per exercise room		1 per exercise room	1 per exercise room			1 per exercise room
Penal Institutions—for employee use	Male 1 for 1–15 2 for 16–35 3 for 36–55 Over 55, add 1 fixture for each additional 40 persons	Female 1 for 1–15 3 for 16–35 4 for 36–55	0 for 1–9 1 for 10–50 Add one fixture for each additional 50 males	Male 1 per 40	Female 1 per 40		1 per 75
Worship places, principal assembly place	Male 1 per 150 2 for 151–300	Female 1 per 75 2 for 76–150 3 for 151–300	1 per 150	1 per 2 water closets			1 per 75
Restaurants, pubs, and lounges[i]	Male 1 for 1–50 2 for 51–150 3 for 151–300 Over 300, add 1 fixture for each additional 200 persons	Female 1 for 1–50 2 for 51–150 4 for 151–300	1 for 1–150 Over 150, add 1 fixture for each additional 150 males	Mae 1 for 1–150 2 for 151–200 3 for 210–400 Over 400, add 1 fixture for each additional 400 persons	Female 1 for 1–150 2 for 151–200 3 for 201–400		

[a] Based on ''Uniform Plumbing Code,'' 1990, International Association of Plumbing and Mechanical Officials, Walnut, Calif.

The table lists the number of fixtures required for the number of persons indicated. Minimum exiting requirements determine the minimum number of occupants to be accommodated.

Every building should include provisions for the physically handicapped. (Refer to local authorities or ''Specifications for Making Buildings and Facilities Accessible to, and Usable by, the Physically Handicapped,'' ANSI A117.1, American National Standards Institute.)

Building categories not listed in the table should be considered separately by the administrative authority.

Consideration should be given to the accessibility of the fixtures. Application of the table data strictly on a numerical basis may not produce an installation suited to the needs of building occupants. For example, schools should have toilet facilities on every floor on which there are classrooms.

Temporary facilities for workers: one water closet and one urinal for every 30 male workers and every 30 female workers, or fraction thereof. Through urinals are prohibited. Walls and floors around every urinal should be lined with nonabsorbent materials. The lining should extend on the floor from the wall to 2 ft in front of the urinal lip, and on the wall, 4 ft above the floor and at least 2 ft on both side of the urinal.

[b] The total number of water closets for females should be at least equal to the sum of the water closets and urinals required for men.

[c] There should be at least one drinking fountain per occupied floor in schools, theaters, auditoriums, dormitories, and office and public buildings. Drinking fountans should not be installed in toilet rooms. Where food is consumed indoors, water stations may be substituted for drinking fountains.

[d] One kitchen sink for each dwelling or apartment unit. One laundry tray or automatic washer standpipe for each dwelling and two laundry trays or two automatic washer standpipes or combination of these for every 10 apartments.

[e] One additional fountain for each additional 150 persons.

[f] One laundry tray for every 50 persons. One slop sink for every 100 persons.

[g] As required by local authorities or ''Sanitation in Places of Employment,'' ANSI Z4.1.

[h] Where there is exposure to skin contamination from poisonous, infectious, or irritating materials, one lavatory should be provided for every 5 persons. A wash sink 24 in long or a circular basin 18 in in diameter, when equipped with water outlets for these dimensions, may be considered equivalent to one lavatory.

[i] Any business that sells food for consumption on th epremises is considered a restaurant. Employee toilet facilities should not be counted toward meeting the restaurant requirements in the table. Hand washing must be available in the kitchen for employees. The number of occupants for a drive-in restaurant should be taken equal to the number of parking stalls.

of people may utilize the restroom facilities in a short period of time; for example, at half-time at a football game.

The plumbing fixtures are at the terminals of the water-supply system and the start of the wastewater system. To a large extent, the flow from the fixtures determines the quantities of wastewater to be drained from the building.

Traps. Separate traps are required for most fixtures not fitted with an integral trap. The trap should be installed as close as possible to the unit served. More than one fixture may be connected to a trap if certain code regulations are observed. For specific requirements, refer to the governing code.

A water seal of at least 2 in, and not more than 4 in, is generally required in most traps. Traps exposed to freezing should be suitably protected to prevent ice formation in the trap body. Clean-outs of suitable size are required on all traps except those made integral with the fixture or those having a portion which is easily removed for cleaning of the interior body. Most codes prohibit use of traps in which a moving part is needed to form the seal. Double trapping is also usually prohibited. Table 14.4 lists minimum trap sizes for various fixtures.

Showers. Special care should be taken in selection of showers, especially shower valves. To ensure that a user is not scalded when pressure fluctuations occur in the water distribution system, pressure-balancing or temperature-limiting shower valves that prevent extreme variations in the outlet water temperature may be specified. In facilities with large numbers of showers, a central tempered water system may be used to serve the showers. As with the shower valves, the mixing valve serving a tempered water system should also be of a pressure-balancing or temperature-limiting type.

Water Closets. These consist of a bowl and integral trap, which always contains water, and a tank or a flushometer valve, which supplies water for flushing the bowl (Fig. 14.3). The passage through the trap to the discharge usually is large enough to pass a solid ball 2 to 3 in in diameter. Siphon-jet flushometer valves generally require a pressure of at least 15 psi for operation and blowout flushometer valves generally require 25 psi for operation. The water level in a tank of a tank-type water closet is raised above the water level in the bowl so that gravity provides sufficient pressure for flushing.

The cleansing action of water flow in the bowl may be achieved in any of several different ways. One method is illustrated by the **siphon jet** in Fig. 14.3*b*. The tank discharges water around the rim and also jets water into the up leg of the trap. As a result, the contents of the bowl are siphoned out of the down leg of the discharge pipe. Other types of action include the **reverse trap** (Fig. 14.3*c*), which is similar to the siphon-jet type but smaller; the **siphon vortex** (Fig. 14.3*a*), in which water from the rim washes the bowl, creates a vortex, becomes a jet, and discharges by siphonage; the **washdown** (Fig. 14.3*d*), in which pressure buildup causes the up

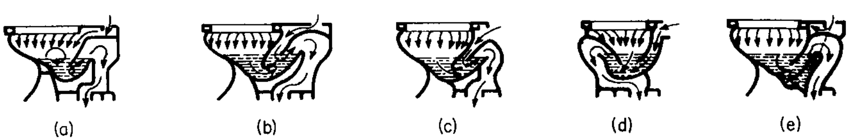


FIGURE 14.3 Typical water closets: (*a*) siphon-vortex; (*b*) siphon-jet; (*c*) reverse trap; (*d*) washdown; (*e*) blowout.

leg to overflow and create a discharge siphon; and the **blowout** (Fig. 14.3*e*), used with a flushometer valve, which projects a strong jet into the up leg to produce the discharge. Blowout-type water closets are generally reserved for use where clogs due to solids in the bowl are common, such as in penal institutions, stadiums, or arenas. Because of the large amount of water consumed during the flush of a blowout type of water closet, these types of fixtures are not used to the extent they once were. Siphon-jet type water closets are the most common type of water closets specified.

As part of the Energy Policy Act of 1992, all water closets manufactured after January 1, 1994, for use in the United States were required to have a maximum water use of 1.6 gallons per flush. Blowout water closets were required to have a maximum water use of 3.5 gallons per flush and urinals were required to have a maximum water use of 1.0 gallon per flush.

Air Gaps. These should be provided to prevent backflow of wastewater into the water supply (Art 14.6.4). At plumbing fixtures, an air gap must be provided between the fixture water-supply outlet and the flood-level rim of the receptacle. Building codes usually require a minimum gap of 1 to 2 in for outlets not affected by a nearby wall and from 1½ to 3 in for outlets close to a wall. Table 14.3 lists minimum air gaps usually used.

In addition to the usual drain at the lowest point, receptacles generally are provided with a drain at the flood-level rim to prevent water from overflowing. The overflow should discharge into the wastewater system on the fixture side of the trap.

Floor and Equipment Drains. Floor drains should be installed at all areas where the possibility of water spillage occurs. Common areas that are provided with floor drains include restrooms, mechanical rooms, kitchens, and shower and locker rooms. Equipment that requires piped discharge from drains or relief devices, such as boilers, require recessed-type drains of adequate size, preferably with a funnel receptor. Large commercial kitchens often require deep, receptor floor sinks to receive indirect wastes from kitchen equipment.

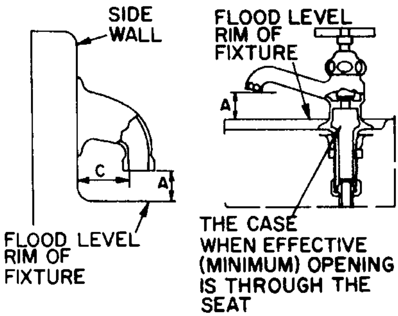
14.8 WATER DEMAND AND FIXTURE UNITS

For each fixture in a building, a maximum requirement for water flow, gal/min, can be estimated. Table 14.1 indicates the minimum flow rate and pressure required by code. The maximum flow may be considerably larger. Branch pipes to each fixture should be sized to accommodate the maximum flow and minimum pressure the fixture will require. Mains serving these branches, however, need not be sized to handle the sum of the maximum flows for all branches served. It is generally unlikely that all fixtures would be supplying maximum flow simultaneously or even that all the fixtures would be operating at the same time. Consequently, the diameters of the mains need be sized only for the probable maximum water demand.

In practice, the probable flow is estimated by weighting the maximum flow in accordance with the probability of fixtures being in use. The estimate is based on the concept of fixture units.

Fixture unit is the average discharge, during use, of an arbitrarily selected fixture, such as a lavatory or water closet. Once this value is established, the discharge rates of other types of fixtures are stated in terms of the basic fixture. For example,

TABLE 14.3 Minimum Air Gaps for Generally Used Plumbing Fixtures



Fixture	Minimum air gap A, in: Away from a wall*	Minimum air gap A, in: Close to a wall*
Lavatories with effective openings not greater than ½-in diameter	1.0	1.50
Sink, laundry trays, and goose neck bath faucets with effective openings not greater than ¾-in diameter	1.5	2.25
Overrim bath fillers with effective openings not greater than 1-in diameter	2.0	3.00
Drinking fountains with a single orifice not more than 7⁄16 in in diameter or multiple orifices with a total area of 0.150 in^2 (area of a 7⁄16-in-diameter circle)	1.0	1.5
Effective openings greater than 1-in	†	§

* Side walls, ribs, or similar obstructions do not affect the air gaps when spaced from inside edge of spout opening a distance[c] greater than three times the diameter of the effective opening for a single wall, or a distance greater than four times the diameter of the effective opening for two intersecting walls (see figure).

† Vertical walls, ribs, or similar obstructions extending from the water surface to or above the horizontal plane of the spout opening require a greater air gap when spaced closer to the nearest inside edge of spout opening than specified in note* above.

‡ 2 × effective opening.

§ 3 × effective opening.

when the basic fixture is a lavatory served by as 1¼-in trap, the average flow during discharge is 7.5 gal/min. So a bathtub that discharges 15 gal/min is rated as two fixture units (2 × 7.5). Thus, a tabulation of fixture units can be set up, based on an assumed basic unit.

A specific number of fixture units, as listed in Table 14.4, is assigned to each type of plumbing fixture. These values take into account:

- Anticipated rate of water flow from the fixture outlet, gal/min
- Average duration of flow, min, when the fixture is used
- Frequency with which the fixture is likely to be used

The ratings in fixture units listed in Table 14.4 represent the relative loading of a water-distribution system by the different types of plumbing fixtures. The sum of the ratings for any part or all of a system is a measure of the load the combination of fixtures would impose if all were operating. The probable maximum water demand, gal/min, can be determined from the total number of fixture units served by any part of a system by use of graphs shown in Fig. 14.4.

The demand obtained from these curves applies to fixtures that are used intermittently. If the system serves fixtures, such as air-conditioning units, lawn sprinklers, or hose bibs, that are used continuously, the demand of these fixtures should be added to the intermittent demand. For a continuous or semicontinuous flow into a drainage system, such as from a pump, pump ejector, air-conditioning system, or similar device, two fixture units should be used for each gallon per minute of flow. When additional fixtures are to be installed in the future, pipe and drain sizes should be based on the ultimate load, not on the present load.

14.9 WATER-PIPE SIZING

The required domestic-water pipe sizes should be determined by application of the principles of hydraulics. While economy dictates use of the smallest sizes of pipe permitted by building-code requirements, other factors often make larger sizes advisable. These factors include:

1. Pressure at the water-supply source, usually the public main, psi
2. Pressure required at the outlets of each fixture, psi
3. Loss of pressure because of height of outlets above the source, pressure loss due to friction caused by the flow of water through water meters and backflow preventers, and friction from water flow in the piping
4. Limitations on velocity of water flow, ft/s, to prevent noise and erosion
5. Additional capacity for future expansion (normally 10% minimum)

14.9.1 Method for Determining Pipe Sizes

1. Sketch all the proposed risers, horizontal mains, and branch lines, indicating the number and the type of fixtures served, together with the required flow
2. Compute the demand weights of the fixtures, in fixture units, using Table 14.4
3. From Fig. 14.4 and the total number of fixture units, determine the water demand, gal/mm
4. Compute the equivalent length of pipe for each stack in the system, starting from the street main
5. Obtain by test or from the water company the average minimum pressure in the street main. Determine the minimum pressure needed for the highest fixture in the system
6. Compute the pressure loss in the piping with the use of the equivalent length found in item 4
7. Choose the pipe sizes from a chart like that in Fig. 14.5 or 14.6, or from the charts given in the plumbing code being used

TABLE 14.4 Fixture Units and Trap and Connection Sizes for Plumbing Fixtures

	Domestic water				Drainage	
	Fixture-unit value as load factors		Min size of connections, in			
Fixture type	Private	Public	Cold water	Hot water	Fixture-unit value as load factors	Min size of trap, in
Bathtub† (with or without overhead shower	2	4	½	½	2	1½
Bidet	2	4	½	½	2	Nominal 1½
Combination sink and tray	3		½	½	2	1½
Combination sink and tray with food-disposal unit	4				3	1½
Dental unit or cuspidor		1	⅜		1	1¼
Dental lavatory	1	2	½	½	2	1¼
Dishwasher, domestic	2				2	1½
Drinking fountain	1	2	⅜		1	1¼
Floor drains‡	1				2	2
Kitchen sink	2	4	½	½	2 or 3	1½
Kitchen sink, domestic, with food-waste grinder	3				2	1½
Lavatory¶	1		⅜	⅜	1	Small P.O. 1¼

TABLE 14.4 Fixture Units and Trap and Connection Sizes for Plumbing Fixtures

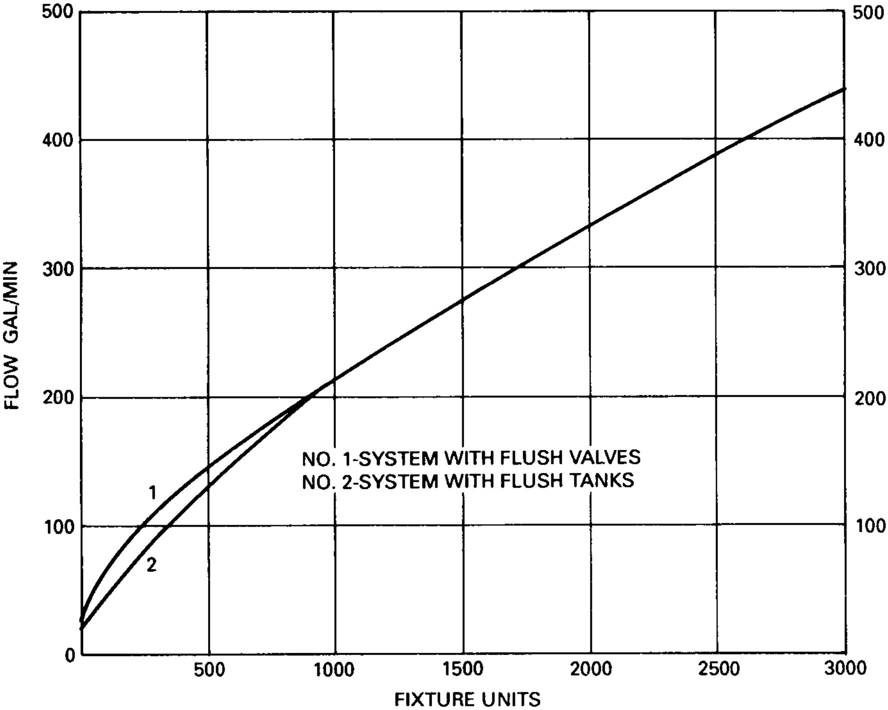
Fixture type	Domestic water: Fixture-unit value as load factors: Private	Public	Min size of connections, in: Cold water	Hot water	Drainage: Fixture-unit value as load factors	Min size of trap, in
Lavatory¶		2	½	½	2	Large P.O. 1½
Lavatory, barber, beauty parlor		2			2	1½
Lavatory, surgeon's	2				2	1½
Laundry tray (1 or 2 compartments)	2	4	½	½	2	1½
Shower, per head	2	4	½	½	2	2
Sinks:						
Surgeon's	3		½	½	3	1½
Flushing rim (with valve)		2	¾	¾	6	3
Service (trap standard)	3		½	½	3	3
Service (P trap)	2	4	½	½	3	2
Pot, scullery, etc.		4			3	1½
Urinal, pedestal, siphon jet, blowout		10	1		6	Nominal 3
Urinal, wall lip		5	½		2	1½
Urinal stall		5	¾	2	2	2
Urinal with flush tank		3			2	1½
Wash sink (circular or multiple) each set of faucets		2	½	½	3	Nominal 1½
Water closet, tank-operated	3	5	⅜		4	Nominal 3
Water closet, valve-operated	6	10	1		6	3

*Fixture units listed in the table give the total water-supply demand of fixtures with both hot-water and cold-water supply. Fixture units for the maximum demand of either cold water or hot water alone may be taken as 75% of the fixture units in the table.

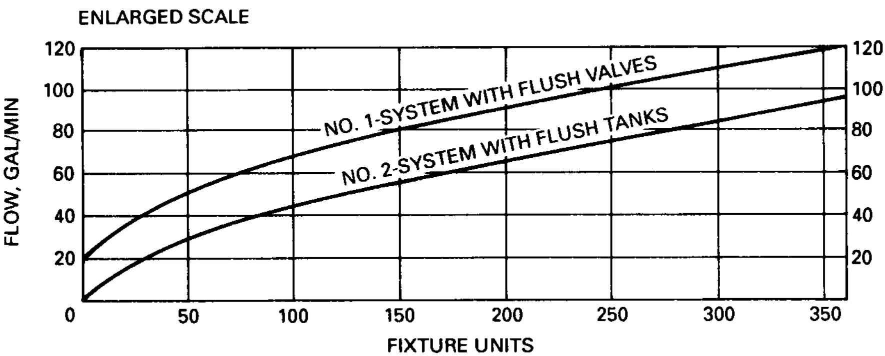
†A shower head over a bathtub does not increase the fixture value.

‡Size of floor drain should be determined by the area of surface water to be drained.

¶Lavatories with 1¼- or 1½-in trap have the same load value; larger P.O. (plumbing orifice) plugs have greater flow rate.



(a)



(b)

FIGURE 14.4 Estimate curves for domestic water demand. (*a*) The number of fixture units served determines the rate of flow. (*b*) Enlargement of the low-demand portion of (*a*).

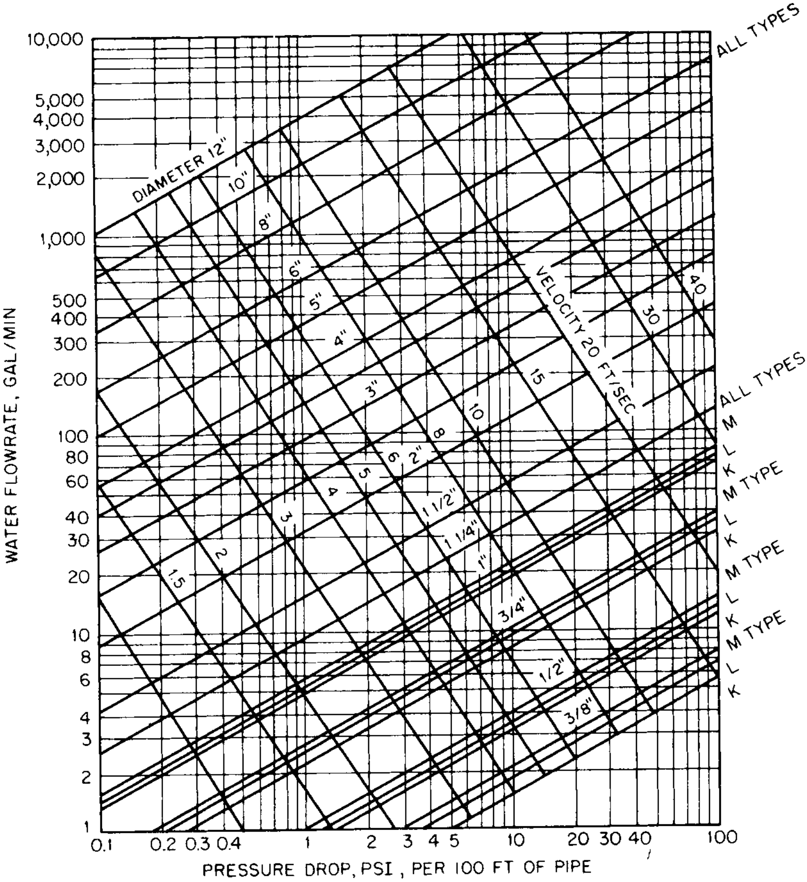


FIGURE 14.5 Chart for determination of flow in copper tubing and other pipes that will be smooth after 15 to 20 years of use.

14.9.2 Effects of Pressure

Rate of flow, ft^3/s, in a pipe is determined by

$$Q = AV \tag{14.1}$$

where A = pipe cross-sectional area, ft^2
V = water velocity, ft/s

In general, V should be kept to 8 ft/s or less to prevent noise and reduce erosion at valve seats. Hence, pipe area should be at least the flow rate Q divided by 8. Mains may be allowed to have a velocity of 10 ft/s, but lower velocities are preferred.

The minimum pressures at plumbing fixtures generally required by building codes are listed in Table 14.1. These pressures are those that remain when the

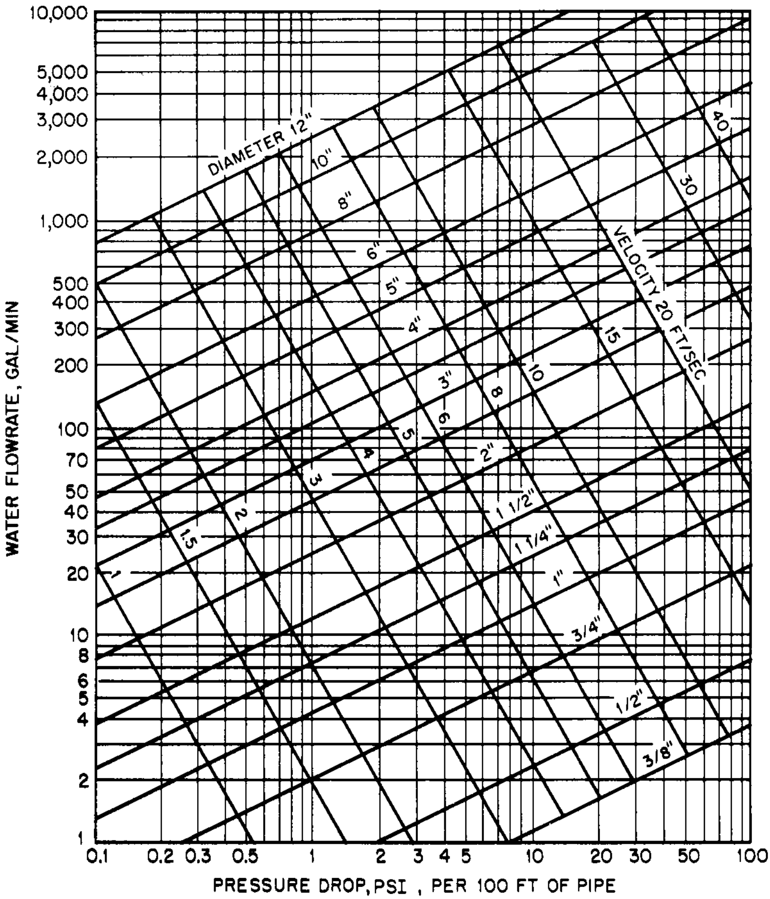


FIGURE 14.6 Chart for determination of flow in pipes such as galvanized steel and wrought iron that will be fairly rough after 15 to 20 years of use.

pressure drop due to height of outlet above the water source and the pressure lost by friction in pipes are deducted from the pressure at the water source. The pressure loss due to height can be computed from

$$p = 0.433h \tag{14.2}$$

where p = pressure, psi
h = height or pressure head, ft

The total head H, ft, on water at any point in a pipe is given by

$$H = Z + \frac{p}{w} + \frac{V^2}{2g} \tag{14.3}$$

where Z = elevation, ft, of the point above some arbitrary datum
p/w = pressure head, ft
w = specific weight of water = 62.4 lb/ft^3
$V^2/2g$ = velocity head, ft
g = acceleration due to gravity, 32.2 ft/s^2

When water flows in a pipe, the difference in total head between any two points in the pipe equals the friction loss h_f, ft, in the pipe between the points.

Any of several formulas may be used for estimating h_f. One often used for pipes flowing full is the Hazen-Williams formula:

$$h_f = \frac{4.727}{D^{4.87}} L \frac{Q_{1.85}}{C_1} \tag{14.4}$$

where Q = discharge, ft^3/s
D = pipe diameter, ft
L = length of pipe, ft
C_1 = coefficient

The value of C_1 depends on the roughness of the pipe, which, in turn, depends on pipe material and age. A new pipe has a larger C_1 than an older one of the same size and material. Hence, when pipe sizes are being determined for a new installation, a future value of C_1 should be assumed to ensure adequate flows in the future. Design aids, such as charts (Figs. 14.5 and 14.6) or nomograms, may be used to evaluate Eq. (14.4), but if such computations are made frequently, a computer solution is preferable.

In addition to friction loss in pipes, there are also friction losses in meters, valves, and fittings. These pressure drops can be expressed for convenience as equivalent lengths of pipe of a specific diameter. Table 14.5 indicates typical allowances for friction loss for several sizes and types of fittings and valves.

The pressure reduction caused by pipe friction depends, for a given length of pipe and rate of flow, on pipe diameter. Hence, a pipe size can be selected to create a pressure drop in the pipe to provide the required pressure at a plumbing fixture, when the pressure at the water source is known. If the pipe diameter is too large, the friction loss will be too small and the pressure at the fixture will be high. If the pipe size is too small, the friction loss will be too large and the pressure at the fixture will be too small.

14.9.3 Minimum Pipe Sizes

The minimum sizes for fixture-supply pipes are given for cold water and hot water in Table 14.4.

Sizes of pipes for small buildings, such as single-family houses, can usually be determined from the experience of the designer and applicable building-code requirements, without extensive calculations. For short branches to individual fixtures, for example, the minimum pipe diameters listed in Table 14.4 generally will be satisfactory. Usually also, the following diameters can be used for the mains supplying water to the fixture branches:

½ in for mains with up to three ¾-in branches

¾ in for mains with up to three ½-in or five ⅜-in branches

TABLE 14.5 Allowances for Friction Losses in Valves and Fittings, Expressed as Equivalent Length of Pipe, Ft*

Diameter of fitting, in	90° standard elbow	45° standard elbow	Standard 90° tee	Coupling or straight run of tee	Gate valve	Globe valve	Angle valve
⅜	1	0.6	1.5	0.3	0.2	8	4
½	2	1.2	3	0.6	0.4	15	8
¾	2.5	1.5	4	0.8	0.5	20	12
1	3	1.8	5	0.9	0.6	25	15
1¼	4	2.4	6	1.2	0.8	35	18
1½	5	3	7	1.5	1	45	22
2	7	4	10	2	1.3	55	28
2½	8	5	12	2.5	1.6	65	34
3	10	6	15	3	2	80	40
4	14	8	21	4	2.7	125	55
5	17	10	25	5	3.3	140	70
6	20	12	30	6	4	165	80

*Allowances based on nonrecessed threaded fittings. Use one-half the allowances for recessed threaded fittings or streamlined older fittings.

1 in for mains with up to three ¾-in or eight ½-in or fifteen ⅛-in branches

The adequacy of these sizes, however, depends on the pressure available at the water source and the probability of simultaneous use of the plumbing fixtures.

14.10 DOMESTIC WATER HEATERS

The method of heat development for water heaters may be direct (heat from combustion of fuels or electrical energy directly applied to water) or indirect (heat from a remote heat source utilizing some other medium, such as steam, to heat water).

Direct-heat-type water heaters are classified as follows:

1. Automatic storage heaters, which incorporate burners or heating elements, storage tank, outer jacket, insulation, and controls as a packaged unit
2. Circulating tank heaters, which consist of what is essentially an instantaneous heater and an accessory storage tank. Hot water is circulated through the heating section by means of a circulating pump
3. Instantaneous heaters, which have little water storage capacity and generally have controls that modulate the heat output based on the demand
4. Hot-water supply boilers, which provide high-temperature hot water in a manner similar to hot-water heating boilers

Fuel for direct-fired water heaters is generally one of the fossil fuels, such as natural gas or oil, or electric power.

Indirect-type water heaters are classified as follows:

1. Storage type, which consists of a heat exchanger installed in a storage tank (Fig. 14.7) or in a separate storage tank and stand-alone heat exchanger provided with a circulating water system.

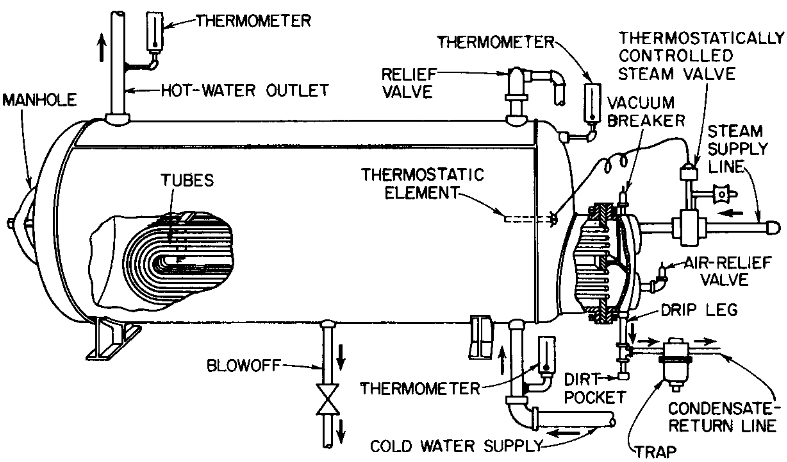


FIGURE 14.7 Storage heater for domestic hot water.

2. Indirect immersion type, a self-contained water heater, utilizing one of the fossil fuels as a heating medium for a horizontal fire tube containing a finned-tube bundle. Water, or some other heat-transfer fluid, is heated in the finned bundle in the burner section and is pumped to a water-heating bundle located in the shell or storage tank installed below the fire tube.
3. Instantaneous type, which is suited for facilities requiring steady, continuous supplies of hot water (Fig. 14.8). The rate of flow is indirectly proportional to the temperature of the water being supplied.
4. Semi-instantaneous type, which have limited storage to meet momentary hot-water peak demands. These types of heaters consist of a heating element and a control system that closely controls leaving-water temperature. A hot-water storage tank provides additional hot water when required during periods of peak momentary hot-water demand.

The heat-transfer media normally utilized for indirect domestic hot-water heaters are steam and heating hot water. The heat-transfer media use heat provided by boilers and, in some instances, solar collectors, which collect heat from the sun. (For detailed guidance in the sizing of domestic water heating systems, see ‘‘Service Hot-Water Systems,’’ Chap. 4, ASPE Data Book, American Society of Plumbing Engineers, Westlake, CA 91362. Recovery versus storage curves that have been developed based on extensive research can be utilized to compare various combinations available.)

Plumbing designers should also assure that all required safety devices and controls have been provided to prevent an explosion of the storage vessel. There have been numerous instances of injury and death to occupants due to overfiring conditions caused by malfunctioning controls and safety-relief devices that did not operate properly. All storage vessels should be provided with AGA/ASME-rated pressure and temperature (P&T) relief valves, installed as directed by the vessel manufacturer. The rating of the P&T valves should meet or exceed the Btu input rating of the water-heating apparatus.

As water is heated, the volume required to contain the heated water increases. In the past, the increased volume and resulting increased pressure was allowed to

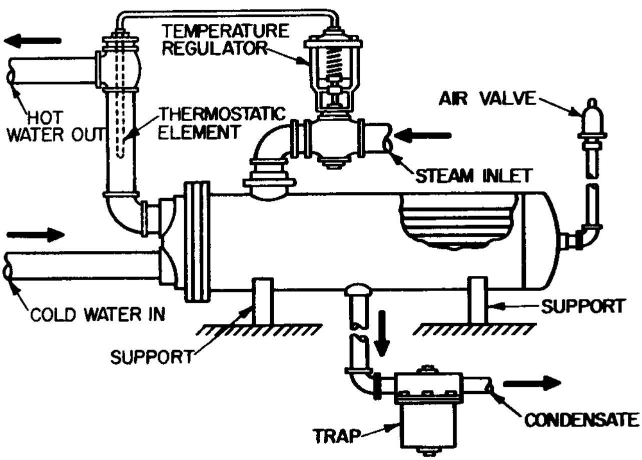


FIGURE 14.8 Instantaneous heater for domestic hot water.

expand back into the domestic cold water system. With the increased use of backflow prevention devices in domestic water systems, the potential for expansion of hot water has been limited. In many instances, water heater tanks have failed due to variations in pressure associated with expansion during heating. Most plumbing codes now require the installation of an expansion tank on domestic hot water systems to prevent premature tank failure.

Most storage tanks are constructed of steel and therefore are subject to rusting when in direct contact with water. Various liners are available such as cement, glass, copper, and nickel. The designer should select a liner that best meets the needs of the building being designed. Storage tanks should be ASME certified.

The hot-water load for a given building is computed in a manner similar to that described in Art. 14.8 but with Table 14.6 and the tabulated demand factor for the particular building type. The heating-coil capacity of the heater must at least equal the maximum probable demand for hot water.

For storage-type heaters, the storage capacity is obtained by multiplying the maximum probable demand by a suitable factor, such as 1.25 for apartment buildings to 0.60 for hospitals. Table 14.7 lists representative hot-water utilization temperatures for various services. It should be noted that service-water temperatures in the 140°F range should be provided, to prevent the growth of *Legionella pneumophila* bacteria which causes Legionnaires' disease.

Example. Determine heater and storage tank size for an apartment building from a number of fixtures.

Solution. Calculation of the maximum possible demand with the use of Table 14.6 is shown in Table 14.8. Table 14.6 also gives a demand factor of 0.30 for apartment buildings.

$$\text{Probable maximum demand} = 2520 \times 0.30 = 756 \text{ gph}$$

This determines the minimum heater or coil capacity, 756 gph. From Table 14.6 also, the storage capacity factor is 1.25

$$\text{Storage tank capacity} = 756 \times 1.25 = 945 \text{ gal}$$

WASTEWATER PIPING

Human, natural, and industrial wastes resulting from building occupancy and use must be disposed of in a safe, quick manner if occupant health and comfort are to be safeguarded. Design of an adequate plumbing system requires careful planning and adherence to the codes in effect and to state or municipal regulations governing these systems.

14.11 WASTEWATER DISPOSAL

There are three main types of wastewater: domestic, storm, and industrial. Separate plumbing systems are generally required for each type.

Domestic wastewater is primarily spent water from the building water supply, to which is added wastes from bathrooms, kitchens, and laundries. It generally can be disposed of by discharge into a municipal sanitary sewer, if one is available.

TABLE 14.6 Hot-Water Demand per Fixture for Various Building Types*
[*Based on average conditions for the building type, gal/h of water per fixture at 140°F* (*60°C*)]

	Apartment buildings	Gymnasiums	Hospitals	Hotels	Industrial plants	Office buildings	Dwellings	Schools
Lavatory, private	2	2	2	2	2	2	2	2
Lavatory, public	4	8	6	8	12	6		15
Bathtubs	20	30	20	20			20	
Dishwashers†	15		50	50	20		15	20
			190	190	76			76
Foot basins	3	12	3	3	12		3	3
Kitchen sink	10		20	30	20	20	10	20
Laundry, stationary tubs	20		28	28			20	
Pantry sink	5		10	10		10	5	10
Showers	30	225	75	75	225	30	30	225
Service sink	20		20	30	20	20	15	20
Hydrotherapeutic showers			400					
Hubbard baths			600					
Leg baths			100					
Arm baths			35					
Sitz baths			30					
Continuous-flow baths			165					
Circular wash sinks			20	20	30	20		30
Semicircular wash sinks			10	10	15	10		15
Factors								
Demand factor	0.30	0.40	0.25	0.25	0.40	0.30	0.30	0.40
Storage capacity factor‡	1.25	1.00	0.60	0.80	1.00	2.00	0.70	1.00

*Based on data in ''ASPE Data Book,'' American Society of Plumbing Engineers, Westlake, Calif.

†Dishwasher requirements should be taken from this table or from manufacturers' data for the model to be used, if this is known.

‡Ratio of storage-tank capacity to probable maximum demand per hour. Storage capacity may be reduced where an unlimited supply of steam is available from street steam system or large boiler plant.

TABLE 14.7 Hot-Water Temperatures for Various Services

Use	Temperature °F	Temperature °C
Lavatory		
Hand washing	105	40
Shaving	115	45
Showers and tubs	110	43
Therapeutic baths	95	35
Commercial and institutional laundry	180	82
Residential dishwashing and laundry	140	60
Commercial spray-type dishwashing		
Single or multiple tank hood or rack type		
Wash minimum temperature	150	65
Final rinse	180–195	82–90
Single tank conveyor type		
Wash minimum temperature	160	71
Final rinse	180–195	82–90
Single tank rack or door type		
Single-temperature wash and rinse	165+	74+
Surgical scrubbing	110	43
Chemical sanitizing types (consult manufacturer for actual temperature required)	140	60
Multiple-tank conveyor type		
Wash minimum temperature	150	65
Pumped rinse minimum temperature	160	71
Final rinse	180–195	82–90
Chemical sanitizing glasswasher		
Wash	140	60
Rinse minimum temperature	75	24

TABLE 14.8 Hot-Water Demand for Apartment-Building Example

Number of fixtures	Flow per fixture, gal/h (from Table 14.6)	Hot-water demand, gal/hr
60 lavatories	2	120
30 bathtubs	20	600
30 showers	30	900
60 kitchen sinks	10	600
15 laundry tubs	20	300
Possible maximum demand		2520

Storm water is primarily the water that runs off the roof or the site of the building. The water usually is directed to roof drains or gutters. These then feed the water to drainpipes, which convey it to a municipal or private storm-water sewer system. Special conditions at some building sites, such as large paved areas or steep slopes, may require the capture of storm water in retention areas or ponds to prevent the municipal storm sewer systems from being overloaded. From these areas or ponds, the storm water is generally conveyed to the storm sewers through outfall structures designed to delay and control the flow of storm water to the municipal storm sewer systems. Discharge into sanitary sewers is objectionable, because the large flows interfere with effective wastewater treatment and increase treatment costs. If kept separate from other types of wastewater, storm water usually can be safely discharged into a large body of water. Raw domestic wastewater and industrial wastes, on the other hand, have objectionable characteristics that make some degree of treatment necessary before they can be discharged. Nevertheless, municipal combined sewers (sanitary and storm wastes) exist in some areas. Appropriate local authorities should be consulted to determine which type of system is available and specific regulations that relate to connection to these systems.

In areas where municipal sanitary sewers are not available, some form of wastewater treatment is required. Prefabricated treatment plants are available in various sizes and configurations. Most treatment systems are complex and require many steps. These include filtration and activated-sludge and aeration methods. The degree of treatment necessary generally depends on the assimilation potential of the body of water to receive the effluent, primarily the ability of the body to dilute the impurities and to supply oxygen for decomposition of organic matter present in the wastewater.

Industrial waste may present special problems because (1) the flow volume may be beyond the public sewer capacity, and (2) local regulations may prohibit the discharge of industrial waste into public sewers. Furthermore, many pollution regulations prohibit discharge of industrial waste into streams, lakes, rivers, and tidal waters without suitable prior treatment. Industrial wastes generally require treatments engineered to remove the specific elements injected by industrial processes that make the wastes objectionable. Often, these treatments cannot be carried out in public wastewater treatment plants. Special treatment plants may have to be built for the purpose. Treatment methods for a variety of industrial wastes are discussed in W. W. Eckenfelder, Jr., ‘‘Industrial Water Pollution Control,’’ McGraw-Hill Publishing Company, New York. Specific design procedures for sewers, drains, and wastewater treatment, with accompanying numerical examples, are given in T. G. Hicks, ‘‘Standard Handbook of Engineering Calculations,’’ McGraw-Hill Publishing Company, New York.

14.12 SEWERS

A sewer is a conduit for water carriage of wastes. For the purpose of this section, any piping for wastewater inside a building will be considered plumbing or process piping; outside the building, wastewater lines are called sewers.

Sewers carry wastewater. And a system of sewers and appurtenances is **sewerage.** Sanitary sewers carry domestic wastes or industrial wastes. Where buildings are located on large sites, or structures with large roof areas are involved, a storm sewer is used for fast disposal of rain and is laid out to drain inlets located for best collection of runoff.

14.12.1 Determination of Runoff

For figuring rates of runoff to determine storm-sewer requirements, the so-called rational method may be used. It employs the formula

$$Q = CIA \tag{14.5}$$

where Q = maximum rate of runoff, ft^3/s
C = runoff coefficient of the runoff area
I = rainfall intensity, in/hr
A = watershed area, acres

The runoff coefficient C indicates the degree of imperviousness of the land. It ranges from 0.6 to 0.9 for built-up areas and paved surfaces and from 0.30 to 0.50 for unpaved surfaces, depending on the surface slope. In storm-sewer design, however, it is necessary to know not only rate of runoff and total runoff, but also at what point in time after the start of a storm the rate of runoff reaches its peak. It is this peak runoff for which pipe must be sized and sloped. (The conduit designed to handle the peak runoff is for conveyance of runoff volume only and should not be considered for storage.)

14.12.2 Determination of Sewer Size

Sanitary sewers or lines carrying exclusively industrial wastes from a building to disposal must be sized and sloped according to best hydraulic design. The problem is generally one of flow in a circular pipe. (C. V. Davis and K. E. Sorenson, "Handbook of Applied Hydraulics," McGraw-Hill Publishing Company, New York.) Gravity flow is to be desired, but pumping is sometimes required.

Pipe should be straight and of constant slope between access holes, and access holes should be used at each necessary change in direction, slope, elevation, or size of pipe. Access holes should be no farther apart than 200 ft for pipes 24 in and smaller, and 500 ft for pipes 30 in and larger.

The sewer from a building must be sized to carry out all the water carried in by supply mains or other means. Exceptions to this are the obvious cases where losses might be appreciable, such as an industrial building where considerable water is consumed in a process or evaporated to the atmosphere. But, in general, water out about equals water in, plus all the liquid and water-borne solid wastes produced in the building.

Another factor to consider in sizing a sewer is infiltration. Sewers, unlike water mains, often flow at less pressure than that exerted by groundwater around them. Thus, they are more likely to take in groundwater than to leak out wastewater. An infiltration rate of 2000 to 200,000 gal/(day · mi) might be expected. It depends on diameter of pipe (which fixes length between joints), type of soil, groundwater pressure, and workmanship.

In an effort to keep infiltration down, sewer-construction contracts specify a maximum infiltration rate. Weir tests in a completed sewer can be used to check the contractor's success in meeting the specification; but unless the sewer is large enough for workers to traverse, prevention of excessive infiltration is easier than correction. In addition to groundwater infiltration through sewer-pipe joints, the entry of surface runoff through access hole covers and thus into sewers is often a factor. Observers have gaged as much as 150 gal/min leaking into a covered access hole.

Size and slope of a sanitary sewer also must satisfy a requirement that velocity under full flow be kept to at least 2.5 ft/s to keep solids moving and preventing clogging. In general, no drain pipe should be less than 6 in in diameter; an 8-in minimum is safer.

14.12.3 Sewer-Pipe Materials

Vitrified clay, concrete, ductile iron, polyvinyl chloride (PVC), acrylonitrile butylene styrene (ABS) composite pipe, or steel may be used for pipe to carry wastewater and industrial wastes. PVC or ABS are used for the smaller diameters. Steel or reinforced concrete are generally used for larger sizes (>24 in).

Choice of pipe material depends on required strength to resist load or internal pressure; corrosion resistance, which is especially vital for pipe carrying certain industrial wastes; erosion resistance in sewers carrying coarse solids; roughness factor where flat slopes are desirable; and cost in place. Sewer piping installed on the discharge side of pumps should have a pressure rating well in excess of the pressure that will be experienced.

Reinforced concrete pipe must be made well enough or protected to withstand effects of damaging sewer gas (hydrogen sulfide) or industrial wastes. Ductile-iron sewer pipe is good under heavy loads, exposed as on bridges, in inverted siphons, or in lines under pressure. Steel is used chiefly for its strength or flexibility. Corrugated steel pipe with protective coatings is made especially for sewer use; its long lengths and light weight and ease of handling and jointing. Plastic pipes are used because of corrosion resistance, light weight, and low installation cost.

14.13 WASTEWATER-SYSTEM ELEMENTS

The usual steps in planning a plumbing system are: (1) secure a sewer or waste-disposal plan of the site; (2) obtain architectural and structural plans and elevations of the building; (3) tabulate known and estimated occupancy data, including the number of persons, sex, work schedules, and pertinent details of any manufacturing process to be performed in the building; (4) obtain copies of the latest edition of the applicable codes, (5) design the system in accordance with code requirements, and (6) have the design approved by local authorities before construction is begun.

The typical plumbing layout in Fig. 14.9 shows the major elements necessary in most plumbing systems. **Fixtures** (lavatories, water closets, bathtubs, showers, etc.) are located as needed on each floor of the structure (Art. 14.7).

Each fixture is served by a **soil stack,** or **waste stack,** a **vent** or **vent stack,** and a **trap** (Fig. 14.9). Vertical soil or waste stacks conduct waste solids and liquids from one or more fixtures to a sloped **house drain,** or **building drain,** generally located below the lowest floor of the building. Each vent stack extends to a **stack vent** that projects above the building roof to a vent through roof (VTR). The vent stack may or may not have **branch vents** connected to it. Vents and vent stacks permit the entrance of fresh air to the plumbing system, diluting any gases present and balancing the air pressure in various branches. (See also Art. 14.20.)

Traps on each fixture provide a water seal, which prevents sewer gases from entering the working and living areas. In some areas, the plumbing regulations require installation of a building or house trap. The building drain delivers the discharge from the various stacks to the **house trap,** or **building trap** (Fig. 14.9),

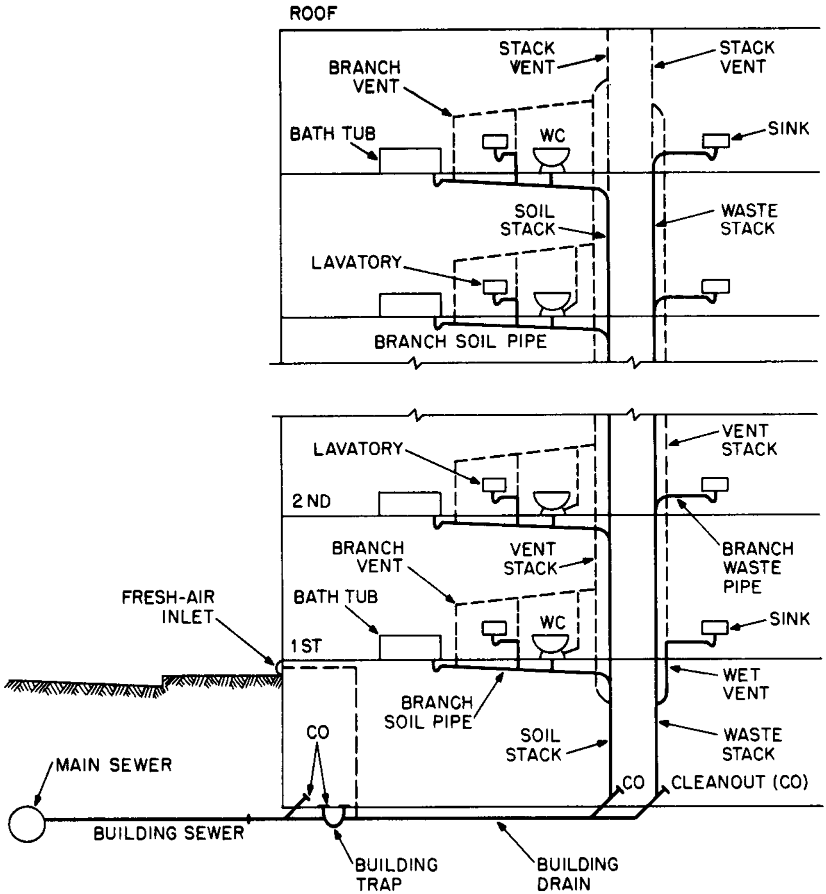


FIGURE 14.9 Wastewater-removal system for a multistory building. (*Reprinted with permission from F. S. Merritt, "Building Engineering and Systems Design," Van Nostrand Reinhold Company, New York.*)

which is generally provided with a separate vent. Between the building trap and **public sewer,** or other main sewer pipe, is the **building sewer.** The building sewer is outside the building structure, while the building trap is just inside or outside of the building foundation wall.

Where the building drain is below the level of the public sewer line, some arrangement for lifting the wastewater to the proper level must be provided. This can be done by allowing the building drain to empty into a suitably sized **sump pit.** The wastewater is discharged from the sump pit to the public sewer by a pneumatic ejector or motor-driven sewage ejector pump.

Pipe Supports. Pipes of wastewater-removal systems should be supported and braced in the same way as pipes of water-supply systems (Art. 14.8). Vertical pipes generally should be supported at every floor. Horizontal pipes should be supported at intervals not exceeding the following: cast-iron soil pipe, 5 ft and behind every hub; threaded pipe, 12 ft; copper tubing, 10 ft. Supports also should be provided at the bases of stacks.

Consideration should be given to the possibility of building settlement and its effects on vertical pipes and to thermal expansion and contraction of pipes, especially when the pipes have a high coefficient of expansion or are made of copper.

Clean-outs. A clean-out is an opening that provides access to a pipe, either directly or through a short branch, to permit cleaning of the pipe. The opening is kept plugged, until the plug has to be removed for cleaning of the sewer. In horizontal drainage lines, at least one clean-out is required for each 100 ft of pipe. Clean-outs should be installed at the base of all stacks, at each change of direction in excess of 45°, and at the point where the building sewer begins. For underground drainage lines, the clean-out must be extended to the floor or ground level to allow easier cleaning. Clean-outs should open in a direction opposite to that of the flow in the pipe, or at right angles to it.

In pipes up to 4 in, the clean-out should be the same size as the pipe itself. For pipes larger than 4 in, the clean-out should be at least 4 in in diameter but may be larger, if desired. When underground piping over 10 in in diameter is used, an access hole is required at each 90° bend and at intervals not exceeding 150 ft.

14.14 WASTE-PIPE MATERIALS

Cast iron is the most common pipe material for systems in which extremely corrosive wastes are not expected. Polyvinyl chloride (PVC) is often used because it is inexpensive, lightweight, and easy to install. Galvanized steel, copper, and acrylonitrile butylene styrene (ABS) also are used.

Plumbing piping should conform to one or more of the accepted material standards approved by the plumbing code applicable in the area in which the building is located.

For cast-iron pipe, the fitting joints are calked (with oakum or hemp and filled with molten lead at least 1 in deep), push-on which use rubber gaskets inserted into the bell of the pipe, or are no-hub (drawn stainless steel bands with neoprene gaskets). Copper pipe is commonly soldered or brazed, while steel and wrought-iron pipe have screwed, flanged, or welded connections.

When planning a plumbing system, designers should check with the applicable code before specifying the type of joint to be used in the piping. Joints acceptable in some areas may not be allowed in others.

14.15 LAYOUT OF WASTE PIPING

Sanitary sewer systems should be sized and laid out to permit use of the smallest-diameter pipes capable of rapidly carrying away the wastewater from fixtures without clogging the pipes, without creating annoying noises, and without producing excessive pressure fluctuations at points where fixture drains connect to soil or waste stacks. Such pressure changes may siphon off the liquid seals in traps and force sewer gases back through the fixtures into the building. Positive or negative air pressure at the trap seal of a fixture should never be permitted to exceed 1 in of water.

Flow in Stacks. The drainage system is considered a nonpressure system. The pipes generally do not flow full. The discharge from a fixture drain is introduced to a stack through a stack fitting, which may be a long-turn tee-wye or a short-turn or sanitary tee. The fitting gives the flow a downward, vertical component. As the water accelerates downward under the action of gravity, it soon forms a sheet around the stack wall. If no flows enter the stack at lower levels to disrupt the sheet, it will remain unchanged in thickness and will flow at a terminal velocity, limited by friction, to the bottom of the stack. A core of air at the center of the stack is dragged downward with the wastewater by friction. This air should be supplied from outdoors through a vent through roof (Fig. 14.9), to prevent creation of a suction that would empty trap seals.

When the sheet of wastewater reaches the bottom of the stack, a bend turns the flow 90° into the building drain. Within a short distance, the wastewater drops from the upper part of the drain and flows along the lower part of the drain.

Slope of Horizontal Drainage Pipes. Plumbing codes generally require that horizontal pipes have a uniform slope sufficient to ensure a flow with a minimum velocity of 2 ft/s. The objective is to maintain a scouring action to prevent fouling of the pipes. Codes therefore often specify a minimum slope of ¼ in/ft for horizontal piping 3½ in in diameter or less and ⅛ or ¼ in/ft for larger pipes.

Because flow velocity increases with slope, greater slopes increase pipe-carrying capacity. In branch pipes, however, high velocities can cause siphonage of trap seals. Therefore, use of larger-size pipes is preferable to steeper slopes for attaining required capacity of branch pipes.

See also Art. 14.20.

14.16 INTERCEPTORS

These are devices installed to separate grease, oil, sand, and other undesirable matter from the wastewater and retain them, while permitting normal liquid wastes to discharge to the sewer.

Grease interceptors are used for kitchens, cafeterias, restaurants, and similar establishments where the amount of grease discharged might obstruct the pipe or interfere with disposal of the wastewater. Oil separators are used where flammable liquids or oils might be discharged to the sewer. Sand interceptors are used to remove sand or other solids from the wastewater before it enters the building sewer. They are provided with large clean-outs for easy removal of accumulated solids.

Other types of applications in which interceptors are usually required include laundries, beverage-bottling firms, slaughterhouses, and food-manufacturing establishments. The local authorities should be contacted to determine applicable local code or municipal regulations.

14.17 PIPING FOR INDIRECT WASTES

Certain wastes like those from food-handling, dishwashing (commercial), and sterile-materials machines should be discharged through an indirect waste pipe. This pipe is not directly connected with the building drainage pipes. Instead, it discharges waste liquids into a plumbing fixture or receptacle from where they flow directly to the building sanitary drainage system. Indirect-waste piping is generally required for the discharge from rinse sinks and such appliances as laundry washers, steam tables, refrigerators, egg boilers, iceboxes, coffee urns, dishwashers, stills, and sterilizers. It is also required for units that must be fitted with drip or drainage connections but are not ordinarily regarded as plumbing fixtures.

An air gap is generally required between the indirect-waste piping and the regular drainage system. The gap should be at least twice the effective diameter of the drain it services, but not less than 1 in. A common way of providing the required air gap is to lead the indirect-waste line to a floor drain, slop sink, or similar fixture that is open to the air and is vented or trapped in accordance with the governing code. To provide the necessary air gap, the indirect-waste pipe is terminated above the flood level of the fixture.

For a device that discharges only clear water, such as water from engine-cooling jackets, air-handling-unit coil condensate, sprinkler systems, or overflows, an indirect-waste system must be used. Clear water wastes from roof-mounted air-conditioning equipment can usually be discharged to roof drains or rainwater gutters. Although some jurisdictions require clear water wastes to be discharged to sanitary sewers, others allow or require clear water wastes to be discharged to the storm sewer system or dry wells.

Hot water above 140°F and steam pipes usually must be arranged for indirect connection into the building drainage system or into an approved interceptor.

To prevent corrosion of plumbing piping and fittings, any chemicals, acids, or corrosive liquids are generally required to be automatically diluted or neutralized before being discharged into the plumbing piping. Sufficient fresh water for satisfactory dilution, or a neutralizing agent, should be available at all times. A similar requirement is contained in most codes for liquids that might form or give off toxic or noxious fumes.

14.18 RAINWATER DRAINAGE

Exterior sheet-metal **gutters** and **leaders** for rainwater drainage are not normally included as part of the plumbing work. Interior leaders or storm-water drains, however, are considered part of the plumbing work. Depending on local codes or ordinances in the locality, rainwater from various roof areas may or may not be led into the sanitary sewer (Art. 14.11). Where separate rainwater leaders or storm drains are used, the building drains are then called **sanitary drains** because they convey only the wastes from the various plumbing fixtures in the building.

Interior storm-water drain pipes may be made of cast iron, steel, plastic, or wrought iron. All joints must be tight enough to prevent gas and water leakage. When a combined system is utilized, it is common practice to insert a cast-iron running trap between the storm drain and the building drain to maintain a trap seal on the storm drain at all times. Use of a combined system does not eliminate the need for separate drains and vents for wastewater. All codes prohibit use of storm drains for any type of wastewater.

Water falling on the roof may be led either to a gutter, from where it flows to a downspout (Fig. 14.10*a*), or it may be directed to a roof drainage device by means of a slope in the roof surface. Many different roof drainage devices, such as roof drains (Fig. 14.10*b*) and parapet drains, are available for different roof constructions and storm-water conditions.

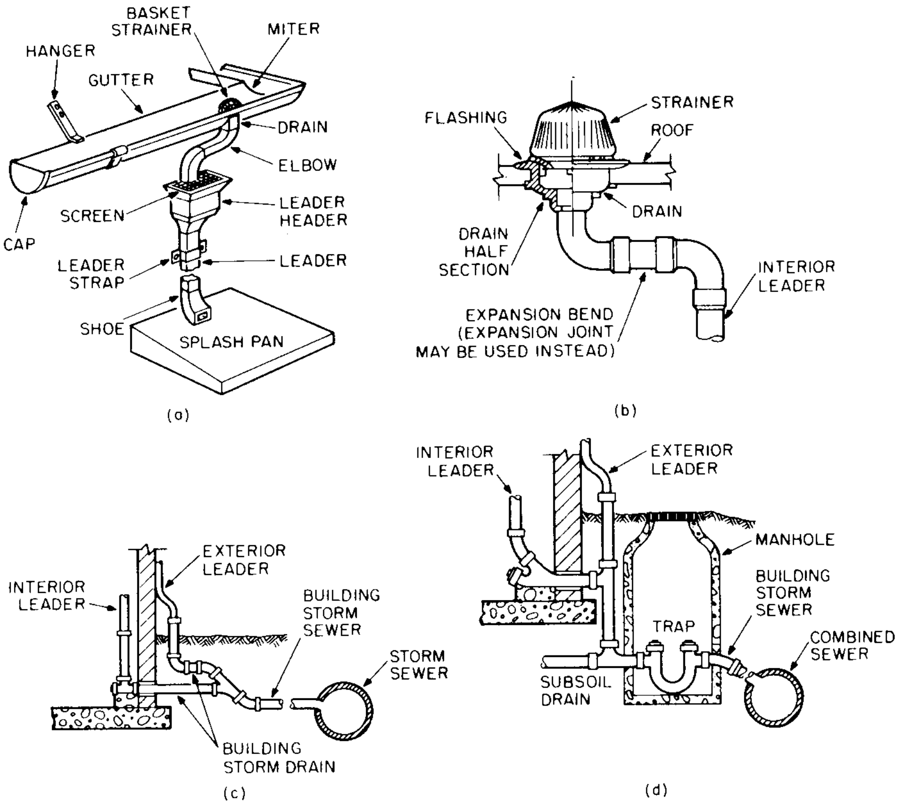


FIGURE 14.10 Elements of a storm-drainage system: (*a*) roof gutter, exterior leader, and splash pan; (*b*) roof drain and top portion of interior leader; (*c*) piping to a storm sewer; (*d*) piping to a combined sewer. (*Reprinted with permission from F. S. Merritt, "Building Engineering and Systems Design," Van Nostrand Reinhold Company, New York.*)

Most plumbing codes include provisions to prevent the collapse of the building structure due to water ponding on the roof because of a clogged storm drainage system. In most cases, these codes require installation of overflow roof drains or parapet overflow scuppers to relieve water from the roof in the event of such a condition. Local authorities should be contacted to determine what requirements apply in their jurisdiction.

When vertical leaders are extremely long, it is common practice to install an expansion joint between the leader inlet and the leader itself. Figure 14.10*c* shows an example of a connection of a building storm drain to a storm sewer. When the drain must be connected to a combined sanitary-storm sewer, a trap should be installed before the connection to the sewer (Fig. 14.10*d*).

Sizes of vertical leaders and horizontal storm drains depend on the roof area to be drained. Table 14.9 indicates the maximum horizontal projection of roof area permitted for various sizes of leaders and horizontal storm drains.

Semicircular gutters are sized on the basis of the maximum projected roof area served. Table 14.10 shows how gutter capacity varies with diameter and pitch.

TABLE 14.9 Sizes of Vertical Leaders and Horizontal Drains*

Vertical conductors and leaders		
Size of leader or conductor, in†	Maximum projected area, ft^2	Flow, gal/min
2	2,176	23
2½	3,948	41
3	6,440	67
4	13,840	144
5	25,120	261
6	40,800	424
8	88,000	913

Horizontal building storm drains and building storm sewers						
	Maximum projected roof area, ft^2, and flow, gal/min, for various slopes					
	⅛ in per ft slope		¼ in per ft slope		½ in per ft slope	
Drain diameter, in	Area	Flow	Area	Flow	Area	Flow
3	3,288	34	4,640	48	6,576	68
4	7,520	78	10,600	110	15,040	156
5	13,360	139	18,880	196	26,720	278
6	21,400	222	30,200	314	42,800	445
8	46,000	478	65,200	677	92,000	956
10	82,800	860	116,800	1,214	165,600	1,721
12	133,200	1,384	188,000	1,953	266,400	2,768
15	238,000	2,473	336,000	3,491	476,000	4,946

*Roof areas and flows are based on a maximum rainfall intensity of 1 in/hr for a duration of 1 hr. For regions with different maximum rainfall intensity in storms with a 100-year recurrence interval, divide tabulated areas and flows by that intensity, in/hr.

†The area of rectangular leaders should equal or exceed that of the circular leader required. The ratio of width to depth of rectangular leaders should not exceed 3 to 1.

TABLE 14.10 Sizes of Semicircular Roof Gutters*

	Maximum projected roof area, ft^2, and flow, gal/min, for gutters of various slopes							
	1⁄16 in per ft slope		⅛ in per ft slope		¼ in per ft slope		½ in per ft slope	
Gutter diameter, in	Area	Flow	Area	Flow	Area	Flow	Area	Flow
3	680	7	960	10	1,360	14	1,920	20
4	1,440	15	2,040	21	2,880	30	4,080	42
5	2,500	26	3,520	37	5,000	52	7,080	74
6	3,840	40	5,440	57	7,680	80	11,080	115
7	5,520	57	7,800	81	11,040	115	15,600	162
8	7,960	83	11,200	116	14,400	165	22,400	233
10	14,400	150	20,400	212	28,800	299	40,000	416

*See assumption of rainfall intensity and duration in note for Table 14.9.

†Gutters other than semicircular may be used if they have an equivalent cross-sectional area.

Where maximum rainfall is either more than, or less than, 1 in/hr, refer to the plumbing code for suitable correction factors.

Drains for building yards, subsoil drainage systems, and exterior areaways may also be connected to the storm drainage system. Where this is not possible, these drains may be run to a dry well. When a dry well is used, only the discharge from these devices may be run to the dry well.

14.19 WASTE-PIPE SIZING

There are two ways of specifying the pipe size required for a particular class of plumbing service: (1) directly in terms of area served, as in roof-draining service (Table 14.9) and (2) in terms of fixture units (Table 14.11).

As can be seen from these tables, the capacity of a leader or drain varies with the pitch of the installed pipe. The greater the pitch per running foot of pipe, the larger the capacity allowed, in terms of either the area served or the number of fixture units. The reason for this is that the steeper the pitch the larger is the static head available and hence the larger is the amount of liquid that the pipe can handle.

The steps in determination of pipe sizes by means of fixture units (Art. 19.8) are: (1) list all fixtures served by one stack or branch; (2) alongside each fixture list its fixture unit (Table 14.4, p. 14.22); (3) add the fixture units and enter the proper table (Tables 14.4, 14.11, or 14.13) to determine the pipe size required for the stack or the branch.

Fixture branches connecting one or more fixtures with a soil or waste stack are usually sized on the basis of the maximum number of fixture units for a given size of pipe or trap (Table 14.4). Where a large volume of water or other liquid may be contained in a fixture, such as in bathtubs or slop sinks, an oversize branch drain may be provided to secure more rapid emptying.

TABLE 14.11 Maximum Capacities of Building Drains and Building Sewers, Fixture Units*

	Slope of pipe, in/ft			
Pipe diameter, in	1⁄16	1⁄8	1⁄4	1⁄2
2			21	26
2½			24	31
3			42†	50†
4		180	216	250
5		390	480	575
6		700	840	1,000
8	1,400	1,600	1,920	2,300
10	2,500	2,900	3,500	4,200
12	2,900	4,600	5,600	6,700
15	7,000	8,300	10,000	12,000

*Maximum number of fixture units that may be connected to any portion of a building drain or building sewer. Consult the administrative authority for public sewers for sizing of on-site sewers that serve more than one building.

†A maximum of three water closets or three bathroom groups (water closet, lavatory, and bathtub or shower, or both) may be installed in single-family dwellings and two water closets or bathroom groups, in other types of construction.

TABLE 14.12 Size and Length of Vents

Size of soil or waste stack, in	Fixture units connected	Required vent diameter, in								
		1¼	1½	2	2½	3	4	5	6	8
		Maximum length of vent, ft								
1¼	2	30								
1½	8	50	150							
1½	10	30	100							
2	12	30	75	200						
2	20	26	50	150						
2½	42		30	100	300					
3	10		30	100	200	600				
3	30			60	200	500				
3	60			50	80	400				
4	100			35	100	260	1000			
4	200			30	90	250	900			
4	500			20	70	180	700			
5	200				35	80	350	1000		
5	500				30	70	300	900		
5	1100				20	50	200	700		
6	350				25	50	200	400	1300	
6	620				15	30	125	300	1100	
6	960					24	100	250	1000	
6	1900					20	70	200	700	
8	600						50	150	500	1300
8	1400						40	100	400	1200
8	2200						30	80	350	1100
8	3600						25	60	250	800
10	1000							75	125	1000
10	2500							50	100	500
10	3800							30	80	350
10	5600							25	60	250

TABLE 14.13 Horizontal Fixture Branches and Stacks

Pipe diameter, in	Max number of fixture units that may be connected to: Any horizontal fixture branch*	One stack of 3 stories in height or 3 intervals, or less	More than 3 branch intervals: Total for stack	More than 3 branch intervals: Total at one story or branch interval
1¼	1	2	2	1
1½	3	4	8	2
2	6	10	24	6
2½	12	20	42	9
3	20†	30‡	72‡	20†
4	160	240	500	90
5	360	540	1100	200
6	620	960	1900	350
8	1400	2200	3600	600
10	2500	3800	5600	1000
12	3900	6000	8400	1500
15	7000			

*Does not include branches of the building drain.
†Not over two water closets or bathroom groups in each branch interval.
‡Not over six water closets or bathroom groups on the stack.

14.20 VENTING

Waste pipes are vented to the outside to balance the air pressure in various branches and to dilute any gases present. The availability of air prevents back pressure and protects traps against siphonage.

14.20.1 Types of Vents

The **main vent** is the principal artery of the venting system. It supplies air to **branch vents,** which, in turn, convey it to individual vents and wastewater pipes.

Every building should have at least one main **vent stack.** It should extend undiminished in size and as directly as possible from outdoor air at a level at least 6 in above the roof to the building drain. The main vent should be so located as to provide a complete loop for circulation of air through the wastewater-removal system. As an alternative to direct extension through the roof, a vent stack may be connected with a stack vent, if the connection is made at least 6 in above the flood-level rim of the highest fixture.

A **stack vent** is the extension of a soil or waste stack above the highest horizontal drain connected to the stack. This vent terminates above the roof.

A vent through roof (**VTR**) is any vent that extends through the roof to allow escape of sewer gases and to equalize pressures in the drainage system to prevent siphonage from trap seals. In colder climates, a VTR should be at least 4 in in diameter to prevent blockage from formation of frost and should terminate at least 12 in above the roof, but higher if the VTR is installed in regions with high snowfall rates.

An **individual vent,** or **back vent,** is a pipe installed to vent a fixture trap and is connected to the venting system above the fixture served or terminated outdoors.

To ensure that the vent will adequately protect the trap, plumbing codes generally limit the distance downstream that the vent opening may be placed from the trap. This distance generally ranges from 2½ ft for a 1¼-in fixture drain to 10 ft for a 4-in fixture drain, but not less than two pipe diameters. The vent opening should be located above the bottom of the discharge end of the trap (Fig. 14.11). In general, all trapped fixtures are required to have an individual vent, although vents may be eliminated under some exceptional conditions. The plumbing code should be reviewed to determine where and how individual vents are to be installed.

To reduce the amount of piping required, two fixtures may be set back to back, on opposite sides of a wall, and vented by a single vent (**common vent**). In that case, however, the fixtures should discharge wastewater separately into a double fitting with inlets at the same level.

A **branch vent** is a pipe used to connect one or more individual vents to a vent stack or to a stack vent.

A **wet vent** is a pipe that serves both as a vent and as a drainage pipe for wastes other than those from water closets. This type of vent reduces the amount of piping from that required with individual vents. For example, a bathroom group of fixtures may be vented through the drain from a lavatory, kitchen sink, or combination fixture if such a fixture has an individual vent (Fig. 14.ll*a*).

A battery of fixtures is any group of similar fixtures that discharges into a common horizontal waste or soil branch. A battery of fixtures should be vented by a circuit or loop vent. (Building codes usually set a limit on the number of fixtures that may be included in a battery.)

A **circuit vent** is a branch vent that serves two or more traps and extends from the vent stack to a connection to the horizontal soil or waste branch just downstream from the farthest upstream connection to the branch (Fig. 14.11*b*).

A **loop vent** is like a circuit vent but connects with a stack vent instead of a vent stack (Fig. 14.11*c*). Thus, air can circulate around a loop.

In some instances, conventional venting methods cannot be applied, such as with island sink fixtures. Some codes allow the use of air admittance devices, commonly known as quick vents. These devices allow air to enter the vent system while preventing sewer gasses from escaping.

Soil and waste stacks with more than 10 branch intervals should be provided with a relief vent at each tenth interval installed, starting with the top floor. A **branch interval** is a section of stack at least 8 ft high between connections of

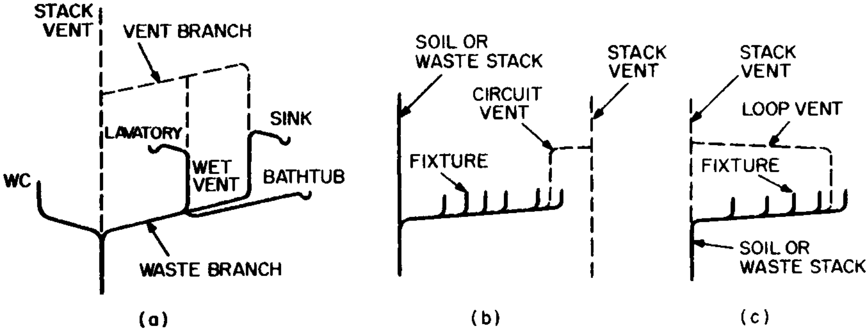


FIGURE 14.11 Venting of waste branches: (*a*) wet venting of bathtub drainage pipe; (*b*) circuit venting, and (*c*) loop venting of a battery of plumbing fixtures.

horizontal branches. A **relief vent** provides circulation of air between drainage and venting systems. The lower end of a relief vent should connect to the soil or waste stack, through a wye, below the horizontal branch serving a floor where the vent is required. The upper end of the relief vent should connect to the vent stack, through a wye, at least 3 ft above that floor. Such vents help to balance the pressures that are continuously changing within a plumbing system.

14.20.2 Slopes and Connections for Vent Pipes

While the venting system is intended generally to convey only air to and from the drainage system, moisture may condense from the air onto the vent pipe walls. To remove the condensation from the venting system, all individual and branch vent pipes should be sloped and connected as to conduct the moisture back to soil or waste pipes by gravity.

14.20.3 Sizing of Vent Pipes

Fixture units (Art. 14.19) are also used for sizing vents and vent stacks (Table 14.12). In general, the diameter of a branch vent or vent stack should be one-half or more of that of the branch or stack it serves, but not less than 1¼ in. Smaller diameters are prohibited, because they might restrict the venting action.

14.20.4 Combined Draining and Vent Systems

These offer the possibility of considerable cost savings over the separate drainage and venting systems described in Art. 14.20.1.

One such system, introduced by the Western Plumbing Officials Association, employs horizontal wet venting of one or more lavatories, sinks, or floor drains by means of a common waste and vent pipe adequately sized to provide free movement of air above the flow line of the pipe. Relief vents are connected at the beginning and end of the horizontal pipe. The traps of the fixtures are not individually vented. Some building codes permit such a system only where structural conditions preclude installation of a conventional system. Where this combined drainage and vent system may be used, it may require larger than normal waste pipes and traps. Each of the model codes has different requirements for this type of system and, therefore, the code in effect must be carefully reviewed during the design process.

The **Sovent system** is another type of combination system. It requires drainage branches and soil stacks, with special fittings, but no individual and branch vents and no vent stacks.

The system has four basic parts: a soil or waste stack with a stack vent extending through the roof, a Sovent aerator fitting on the stack at each floor, horizontal branches, and a Sovent deaerator fitting on the stack at its base and at horizontal offsets (Fig. 14.12). The aerator and deaerator provide means for self-venting the stack. In a conventional drainage system, a vent stack is installed to supply air to vent pipes connected to the drainage branches and to the soil or waste stack to prevent destruction of the trap seals. In the Solvent system, however, the vent stack is not needed because the aerator, deaerator, and stack vent avoid creation of a strong suction.

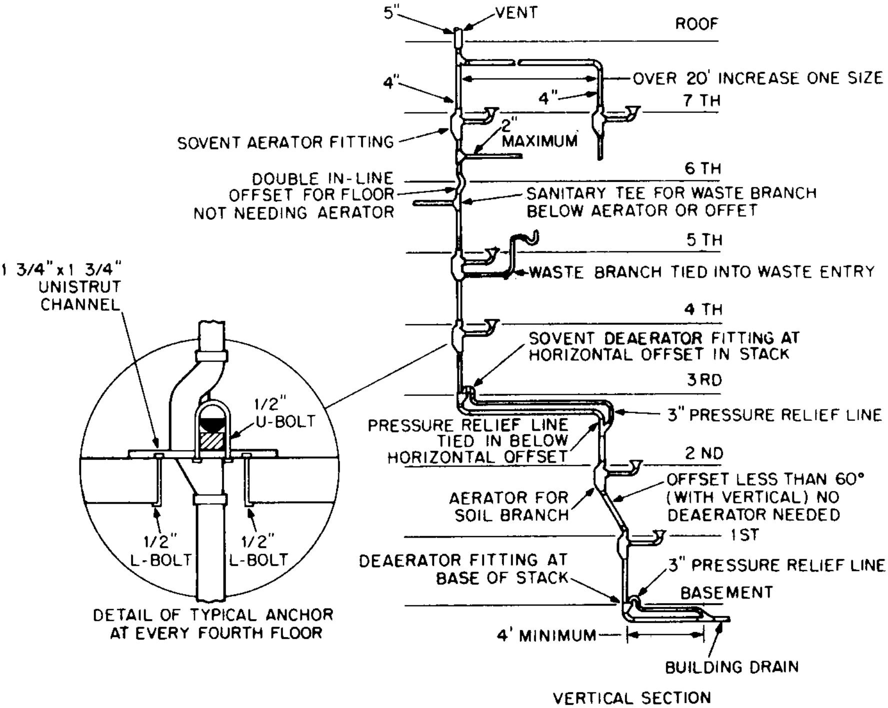


FIGURE 14.12 Copper single-stack Sovent plumbing system. (*Courtesy of Copper Development Association, Inc.*)

The aerator does the following: It reduces the velocity of both liquid and air in the stack. It prevents the cross section of the stack from filling with a plug of water. And the fitting mixes the wastewater from the drainage branches with the air in the stack.

The deaerator separates the airflow in the stack from the wastewater. As a result, the wastewater flows smoothly into a horizontal offset or building drain. Also, air pressure preceding the flow at 90° turns is prevented from rising excessively by a pressure relief line between a deaerator and a stack offset or the building drain to allow air to escape from the deaerator.

An aerator is required on the stack at each level where a horizontal soil branch or a waste branch the same size as or one tube size smaller than the stack discharges to it. Smaller waste branches may drain directly into the stack. At any floor where an aerator fitting is not required, the stack should have a double in-line offset, to decelerate the flow (Fig. 14.12). No deaerators are required at stack offsets of less than 60°.

14.21 PLUMBING-SYSTEM INSPECTION AND TESTS

Plans for plumbing systems must usually be approved before construction is started. After installation of the piping and fixtures has been completed, both the new work and any existing work affected by the new work must be inspected and tested. The plumber or plumbing contractor is then informed of any violations. These must be corrected before the governing body will approve the system.

Most plumbing codes allow air or water to be used for preliminary testing of drainage, vent, and plumbing pipes. After the fixtures are in place, their traps should be filled with water and a final test made of the complete drainage system.

When a system is tested with water, all pipe openings are tightly sealed, except the highest one. The pipes are then filled with water until overflow occurs from the top opening. With this method, either the entire system or sections of it can be tested. In no case, however, should the head of water on a portion being tested be less than 10 ft, except for the top 10 ft of the system. Water should be kept in the system for at least 15 min before the inspection starts. During the inspection, piping and fixtures must be tight at all points; otherwise approval cannot be granted.

An air test is made by sealing all pipe outlets and subjecting the piping to an air pressure of 5 psi throughout the system. The system should be tight enough to permit maintaining this pressure for at least 15 min without the addition of any air.

The final test required of plumbing systems uses either smoke or peppermint. In the smoke test, all traps are sealed with water and a thick, strong-smelling smoke is injected into the pipes by means of a suitable number of smoke machines. As soon as smoke appears at the roof stack outlets, they should he closed and a pressure equivalent to 1 in of water should be maintained throughout the system for 15 min before inspection begins. For the peppermint test, 2 oz of oil of peppermint are introduced into each line or stack.

GAS PIPING

Natural and manufactured gases are widely used for heating in stoves, water heaters, and space heaters of many designs. Since gas can form explosive mixtures when mixed with air, gas piping must be absolutely tight and free of leaks at all times. Usual plumbing codes cover every phase of gas-piping size, installation, and testing. The local code governing a particular building should be carefully followed during design and installation.

(''National Fuel Gas Code,'' ANSI Z223.1, American National Standards Institute and National Fire Protection Association; see also model plumbing codes and mechanical codes of the various building officials associations listed in Art. 14.1.)

14.22 GAS SUPPLY

The usual practice is for the public-service gas company to run its pipes to the exterior wall of a building, terminating with a brass shutoff valve and gas meter. The gas piping from the load side of the meter is generally extended to the inside of the building. From this point, the plumbing contractor or gas-pipe fitter runs lines through the building to the various fixture outlets. When the pressure of the gas supplied by the public-service company is too high for the devices in the building, a pressure-reducing valve can be installed near the point where the line enters the building. This valve is usually supplied by the gas company.

Besides municipal codes governing design and installation of gas piping and devices, the gas utility serving the area will usually have a number of regulations that must be followed. Typically, meters are required to be installed outside the building. The gas supply should not enter the building from below grade unless certain venting requirements are met, and gas pressure regulators installed inside the building must be vented to the outdoors. The local authorities and gas utility should be consulted as to special regulations relating to the installation of the gas piping system.

14.23 GAS-PIPE SIZES

Gas piping must be designed to provide enough gas to appliances without excessive pressure loss between the appliance and the meter. It is customary to size gas piping so the pressure loss between the meter and any appliance does not exceed 0.3 in of water during periods of maximum gas demand. Other factors influencing the pipe size include maximum gas consumption anticipated, length of pipe and number of fittings, specific gravity of the gas, and the diversity factor.

(C. M. Harris, "Handbook of Utilities and Services for Buildings," McGraw-Hill Publishing Company, New York.)

14.24 ESTIMATING GAS CONSUMPTION

Use the manufacturer's Btu rating of the appliances and the heating value of the gas to determine the flow required, ft^3/hr. When Btu ratings are not immediately available, the values in Table 14.14 may be used for preliminary estimates. The average heating value of gas in the area can be obtained from the local gas company, but when this is not immediately available, the values in Table 14.15 can be used for preliminary estimates.

Example. A building has two 50-gal storage hot-water heaters and 10 domestic ranges. What is the maximum gas consumption that must be provided for if gas with a net heating value of 500 Btu/ft^3 is used?

Solution. From Table 14.14,

$$\text{Heat input} = 2(55{,}000) + 10(65{,}000) = 760{,}000 \text{ Btu/hr}$$

Maximum gas consumption is therefore $760{,}000/500 = 1520\ ft^3/hr$. The supply piping would be sized for this flow, even though all appliances would rarely operate at the same time.

(C. M. Harris, "Handbook of Utilities and Services for Buildings," and H. E. Bovay, Jr., "Handbook of Mechanical and Electrical Systems for Buildings," McGraw-Hill Publishing Company, New York.)

TABLE 14.14 Minimum Demand of Gas Appliances, Btu/hr

Appliance	Demand
Barbecue (residential)	50,000
Bunsen burner	3,000
Domestic clothes dryer	35,000
Domestic gas range	65,000
Domestic recessed oven section	25,000
Domestic recessed top-burner section	40,000
Gas engineers, per horsepower	10,000
Gas refigerator	3,000
Steam boilers, per horsepower	50,000
Storage water heater:	
Up to 30-gal tank	30,000
30- to 40-gal tank	45,000
41- to 49-gal tank	50,000
50-gal tank	55,000
Water heater, automatic instantaneous:	
2 gal/min	142,800
4 gal/min	285,000
6 gal/min	428,400

TABLE 14.15 Typical Heating Values of Commercial Gases, Btu/ft^3

Gas	Net heating value
Natural gas (Los Angeles)	971
Natural gas (Pittsburgh)	1021
Coke-oven gas	514
Carbureted water gas	508
Commercial propane	2371
Commercial butane	2977

14.25 GAS-PIPE MATERIALS

The most common material used for gas piping is black steel pipe conforming to ASTM A53 or ASTM A106. Malleable-iron or steel fittings should be used, except for stopcocks and valves. Above 4-in nominal size, cast-iron fittings may be used. Most plumbing codes require that black steel piping exposed to the elements be treated to prevent deterioration.

Some local codes permit the use of brass or copper pipe of the same sizes as iron pipe if the gas handled is not corrosive to the brass or copper. Brazed or threaded fittings are generally used with these two materials.

Polyethylene (PE) and polybutylene (PB) with heat fusion joints and polyvinyl chloride (PVC) with solvent cement joints are used for outdoor underground installations, since these materials do not corrode and deteriorate as does black steel piping. If black steel is to be used underground, it must be provided with an exterior protective coating or tape or a cathodic-protection system, to prevent failure of the piping due to corrosion.

The usual gas supplied for heating and domestic cooking generally contains some moisture. Hence, all piping should be installed so it pitches back to the supply main, or drips should be installed at suitable intervals. Generally, unions or bushings are not permitted in gas piping systems owing to the danger of gas leakage and moisture trapping. To permit moisture removal, drips are installed at the lowest point in the piping, at the bottom of vertical risers at appliance connections, and at any other location where moisture might accumulate. Figure 14.13 shows typical drips for gas piping.

14.26 SPRINKLER SYSTEMS

Automatic fire sprinkler systems have been protecting property in the United States since the late 1800's; in fact, the *Standard for the Installation of Sprinkler Systems, 1896* was the first standard developed by the National Fire Protection Association (NFPA). Today the NFPA still develops the most widely accepted standards for the design and installation of sprinkler systems: NFPA 13, *Standard for the Installation of Sprinkler Systems;* 20, *Installation of Centrifugal Fire Pumps;* 24, *Installation of Private Fire Services Mains and Their Appurtenances;* 231, *General Storage* and 231C, *Rack Storage of Materials.*

While intended to protect and preserve property, automatic sprinkler systems have other inherent advantages: ''The NFPA has no record of a multiple-death fire in a completely sprinklered building. . .'' Given this inherent advantage, the NFPA has developed a special series of sprinkler standards, NFPA 13D, *Sprinkler Systems, Dwellings* and 13R, *Sprinkler Systems, Residential Occupancies up to and Including 4 Stories,* which are intended to protect life safety, but at significantly less cost than an NFPA 13 designed system.

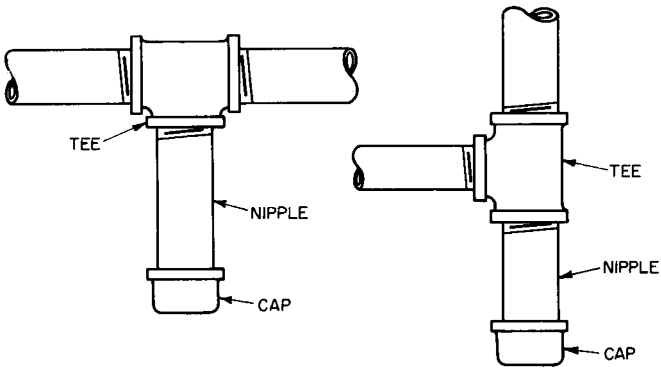


FIGURE 14.13 Drips for gas piping.

In today's built environment, automatic sprinkler systems are installed as a result of minimum building code requirements, local sprinkler ordinances, insurance underwriting stipulations and corporate policy. Consisting of a water supply, horizontal and vertical water distribution pipes and a series of sprinklers to distribute water on a fire, sprinkler systems are quite simple (Fig. 14.21). The simplicity of the sprinkler system is greatly responsible for the historic time tested precedent of success they have become known for: 96% of all fires that occur in fully sprinklered buildings are controlled with the operation of two or fewer sprinklers.

In the design of a sprinkler system there are usually four groups of individuals involved. There are the engineers, responsible for the specification and overall design of the system; Authorities Having Jurisdiction (AHJ's), these include the local building and fire official, insurance carrier, etc., who have the final authority over accepting the design and installation of the system; the building owner; and the sprinkler contractor, who is responsible for the system installation and is often called upon to perform engineering design functions as well. Coordination with the AHJ's regarding their system design expectations is a crucial step in the design of a fire sprinkler system. Where there are multiple AHJ's, conflicts between design expectations must be reconciled to avoid undue construction delays and ambiguity for the construction bidders.

14.27 AUTOMATIC SPRINKLERS

In the past fifteen years the variety of sprinklers available has grown tremendously. Years ago an engineer would simply specify an upright, pendent or sidewall sprinkler, a sprinkler temperature classification and thread and outlet size. Today, sprinkler specification is a much more difficult task. Characteristics such as the Response Time Index, water spray pattern, (Fig. 14.18) operating component type and appearance must be addressed. While there have been numerous advances in sprinkler technology, sprinklers still work in the same manner as they did 100 years ago. Sprinklers are heat sensitive devices, which open to flow water at a preset temperature. More specifically, a sprinkler operating component releases at a specified temperature. Upon release of the operating component, the sprinkler plug falls from the sprinkler orifice and water flows through the orifice, hitting the sprinkler deflector and spraying into a predetermined spray pattern and onto the fuel below.

Of sprinkler components the most interesting is the operating component (see Fig. 14.14). There are two basic types of operating components, the fusible-style operating component, which is a soldered type element that melts when subjected to sufficient heat, and the glass bulb operating components, which is an oil containing glass bulb that become pressurized and fails under sufficient heat. For either type of sprinkler operating component, sufficient heat must be provided over a sufficient period of time to cause the solder to melt or bulb to fail. Neither the fusible or glass bulb operating component are better than the other; however, specification of a quick response operating component, available in either fusible or glass bulb style, will result in faster operating times than a standard response operating component. This is a result of the low mass to surface area ratio of the quick response operating component as opposed to that of a standard response operating component. In offices and other light hazard applications quick response sprinklers have proven superior to standard response sprinklers. As a result, it is a current code requirement that all light hazard occupancies be protected with quick response sprinklers.

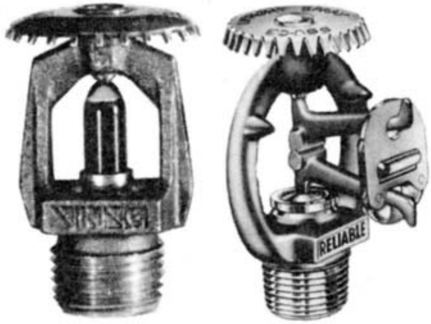


FIGURE 14.14 Fusible style (left) and glass bulb style (right) sprinklers. (*Reprinted with permission from Fire Protection Handbook, Copyright © 1997, National Fire Protection Association, Quincy, MA 02269.*)

14.28 TYPES OF SPRINKLER SYSTEMS

The type of system that should be used depends chiefly on the temperature maintained in the building, damageability of contents, expected propagation rate of a fire, and total fire load.

14.28.1 Wet-Pipe Systems

In the United States the wet-pipe sprinkler system is the most common and affordable sprinkler system available. In consideration of the approximately $1.50/sqft installation cost, minimal maintenance costs, and the impressive record for reliability, wet-pipe sprinkler systems should be every engineer's first choice in sprinkler protection. The wet-pipe sprinkler system is clearly established as the workhorse of the fire protection industry.

Unless out of service, wet-pipe sprinkler systems are always water filled. Consequently, building temperature must be maintained above 40°F to prevent freezing. Other than a gate valve and an alarm valve or ''shot-gun'' riser assembly, there are no devices between the water supply and sprinklers.

To indicate the flow of water as a result of an operating sprinkler or broken pipe, a local alarm bell on the exterior of the building being protected is required. For a wet-pipe sprinkler system this alarm feature is accomplished in one of two ways. In the past it was more common for engineers to specify the installation of an alarm-check valve in the main supply pipe, i.e. system riser. The alarm-check valve (Fig. 14.15) is a swing check valve with an interior orifice that admits water to an alarm line onto which a water-motor-driven gong is attached. To help differentiate between a water pressure surge and a legitimate water flow, a retard chamber is often used. The retard chamber acts to delay pressure surges so they subside prior to causing nuisance alarms. In lieu of a water-motor-gong, and in all cases on ''slick'' wet-pipe systems, a vane-type water-flow indicator can be installed and connected to an electric bell to give notification of water flow. Among the advantages of using a vane-type water-flow switch are that most models include a variable

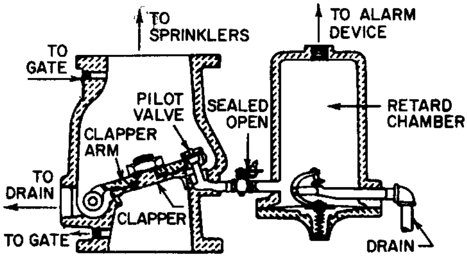


FIGURE 14.15 Alarm-check valve.

time delay to serve as the retard function and they can easily be monitored as a fire alarm device. Figure 14.15 shows a typical alarm-check valve.

14.28.2 Antifreeze Systems

Where a wet-pipe sprinkler system is installed but small unheated areas such as truck docks or attics exist, an antifreeze system, normally a subsystem to a wet-pipe system, will be employed. In most instances, when the capacity of an antifreeze system exceeds 40 gallons, the cost of system maintenance becomes prohibitive and a dry-pipe system is more appropriate.

An antifreeze system consists of an antifreeze U-Loop (Figure 14.16) which includes an indicating control valve, antifreeze solution test ports and drain connection and a check valve or backflow preventer to restrict the migration of antifreeze from the antifreeze side of a system to the wet-pipe side. Since the waterside of an antifreeze U-loop is subject to freezing, the U-loop must be located in a heated area. The operation of a sprinkler on an antifreeze system is identical to that of a wet-pipe system; however, rather than water flowing from the sprinkler immediately, it is first the antifreeze solution, followed by water. While it may be of concern, the antifreeze solutions currently permitted by NFPA 13 are tested for their ability to control fire and they do not detract from the characteristics of water as an extinguishing medium.

Given today's increasingly stringent environmental regulations, the installation of backflow prevention devices are often required on antifreeze systems to prevent antifreeze from flowing into wet-pipe sprinkler systems and endangering potable water supplies. The presence of a backflow preventer in an antifreeze system causes special problems with respect to excess system pressures and where a reduced-pressure backflow (RPV) preventer is used, proper maintenance of antifreeze solution concentrations. Where backflow preventers are included in antifreeze system design, expansion chambers must be used to absorb the excess pressures that may build up on the antifreeze side of the system. Where RPV's are employed, the system owner or person in charge of antifreeze system maintenance must be aware that the antifreeze system solution may change over time if antifreeze bleeds from the system through the RPV's interstitial zone.

14.28.3 Dry-Pipe Systems

In locations where it is impractical to maintain sufficient heat to prevent freezing and the area is too large to be protected by an antifreeze system, dry-pipe systems

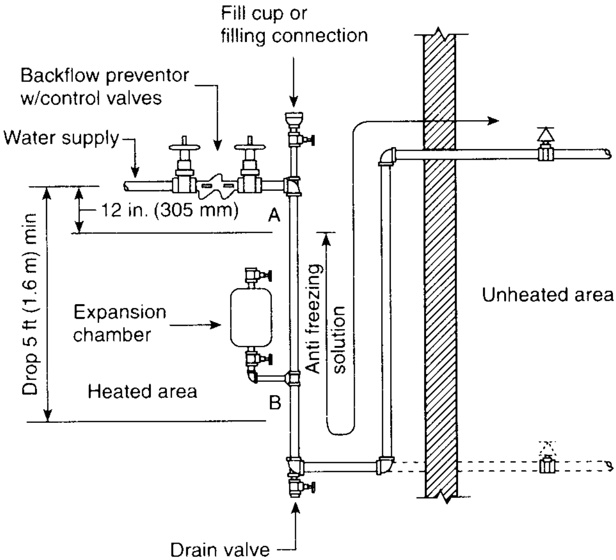


FIGURE 14.16 Acceptable antifreeze u-loop configuration. (*Reprinted with permission from NFPA 13, Installation of Sprinkler Systems, Copyright © 1996, National Fire Protection Association, Quincy, MA 02269. This reprinted material is not the complete and official position of the National Fire Protection Association, on the referenced subject, which is represented only by the standard in its entirety.*)

are often specified. A dry pipe system is similar to that of a wet-pipe system; however, it normally contains air under pressure instead of water. In a dry-pipe system a normally high water pressure is held back by a normally low air pressure through use of a differential type dry-pipe valve. This valve employs a combined air and water clapper (Fig. 14.17) where the area under air pressure is about 16 times the area subject to water pressure. When a sprinkler activates, air is released to the atmosphere through the sprinkler orifice, allowing the water to overcome the pressure differential and enter the piping. On smaller systems, riser mounted air compressors are used to maintain the air pressure such that the dry pipe valve does not operate as a result of small pressure losses over time. Floor mounted air compressors or plant air systems are typically used for air pressure maintenance on larger dry pipe systems.

In dry-pipe systems of large capacity, the relatively slow drop in air pressure when a single head or a few heads are activated is overcome by use of an accelerator or exhauster. The former is a device, installed near the dry-pipe valve, to sense a small drop in pressure and transmit the system air pressure to a point under the valve clapper. The additional air pressure on the bottom side of the clapper causes it to move into the open and locked position faster than it would otherwise; therefore, water reaches the open sprinklers with less delay.

While a dry-pipe system is intended for use in areas of 40°F or less, the dry-pipe valve must be installed in a heated area or enclosure since there is water in the piping up to the valve and priming water in the valve itself.

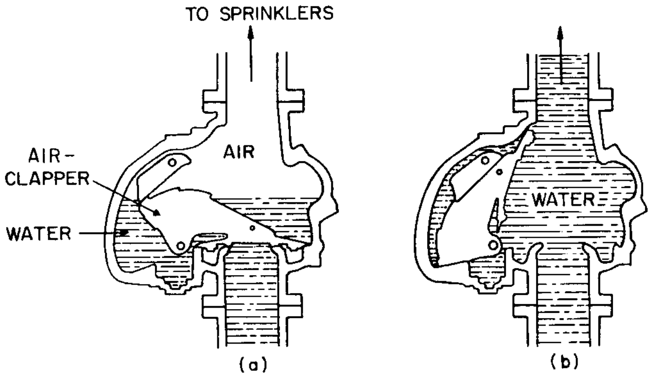


FIGURE 14.17 Differential dry-pipe valve: (*a*) air pressure keeps clapper closed; (*b*) venting of air permits clapper to open and water to flow.

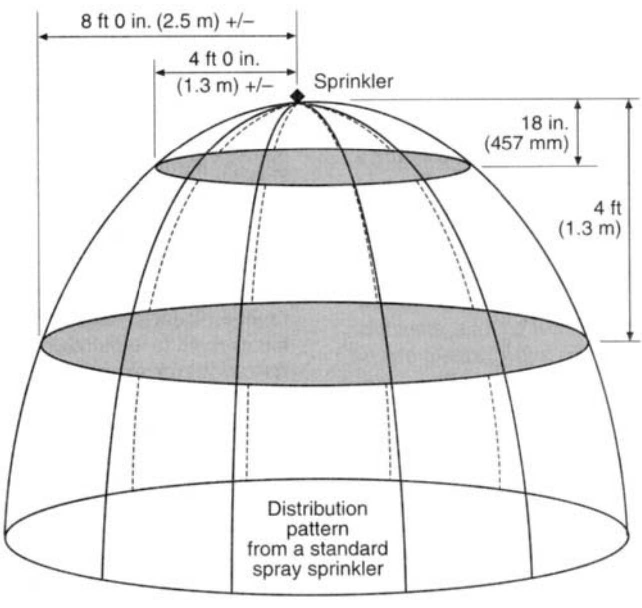


FIGURE 14.18 Typical distribution pattern from a standard spray sprinkler. (*Reprinted with permission from Fire Protection Handbook, Copyright © 1997, National Fire Protection Association, Quincy, MA 02269.*)

The indication of water flow in a dry pipe system is accomplished in a manner identical to that of the wet-pipe system; however, if the option of the electric bell is desired a water pressure switch must be employed. Since a dry-pipe system is normally empty, when a sprinkler operates water rushes into the piping. If a vane-type water-flow indicator were installed, the rushing water could dislodge the vane and cause an obstruction in the sprinkler piping.

14.28.4 Preaction Systems

Preaction sprinkler systems are used where the presence of water, except in emergencies, is unacceptable or where a dry-pipe system is necessary and the additional expense of a detection system can be justified. The water in these systems is controlled by a preaction deluge valve, which is operated by an integrated fire alarm system consisting of heat or smoke detection devices installed throughout the same area the preaction system protects. There are two basic types of preaction systems:

Single Interlock. These systems admit water to their piping upon actuation of an associated detection system. Their primary benefit is that system piping or sprinklers can be damaged or removed without accidental water discharge. Single Interlock systems are commonly used in computer rooms and sometimes museums although wet-pipe systems are normally adequate.

Double Interlock. A combination of a single interlock preaction system and a dry-pipe system, these are filled with compressed air that is capable of holding the water pressure at the preaction deluge valve back until the air pressure is released. Water only enters the piping of a double interlock system after the associated detection system operates and the systems air pressure has been purged. The double interlock system is most frequently used for the protection of refrigerated cold storage/freezer warehouses where a false activation would result in frozen pipes and long periods of business interruption. Often times double interlock sprinkler systems are wrongly specified for the protection of high dollar areas such as computer rooms, museums, etc., where the protection of wet-pipe systems or single interlock preaction systems are adequate.

Since preaction sprinkler systems rely on a fire alarm system, and in the case of the double interlock system, the dry-pipe principle, they are the least reliable of sprinkler systems and require the greatest amount of maintenance.

14.28.5 Deluge Systems

These systems are identical to that of single interlock preaction systems except none of the sprinklers have operating components or caps. Like the sprinkler systems depicted in the movies, the operation of a deluge system results in water flowing from all system sprinklers simultaneously. As with the preaction system, a preaction deluge valve controls the water in these systems. Since deluge systems are often installed in harsh environments where smoke or heat detectors are prone to failure, pneumatic or mechanical means are commonly employed for valve operation. Operation of a pneumatically controlled preaction deluge valve can be by means of a pilot line of small-diameter pipe on which are spaced automatic sprinkler heads at suitable intervals. These heads can be augmented when necessary by use of a mechanical air or water-release device, which operates on the rate-of-rise principle as well as the fixed temperature of the sprinkler heads. Other pneumatic means include small copper air chambers, sensitive to rate-of-rise conditions connected by small-diameter copper tubing to the release mechanism of the valve. In some instances specialized infrared or ultraviolet flame detectors may be used to activate a deluge system. The nature and extent of the hazard and the surrounding ambient conditions always determines the kind of detection required.

While a small two or three sprinkler deluge system may be used to protect an isolated industrial hazard, a large deluge system having as many as one-thousand sprinklers may protect an aircraft hangar, chemical plant, or a portion of a plant where process vessels and tanks containing flammable materials are located. Deluge systems are only justified for the protection of areas where the probability of a fire is likely and the fire growth potential is extreme.

14.28.6 Outside Sprinklers

The types of sprinkler systems referenced above are intended for fire control and on a limited basis fire suppression; however, sprinklers can also be used for exposure protection. In instances where buildings are located too close to one another or to an adjacent fire hazard, such as a combustible liquid storage tank, a ‘‘hybrid’’ sprinkler system can be specified to prevent the spread of fire from a fire area to an exposed building. Such systems have open nozzles directed onto the wall, windows, or cornices to be protected. The water supply may be taken from a point below the inside-sprinkler-system control valve if the building is sprinklered, otherwise from any other acceptable source, with the controlling valve accessible at all times. The system is usually operated manually by a gate valve but can be made automatic by use of a deluge valve actuated by suitable means on the exposed side of the building. The distribution piping is usually installed on the outside of the wall with nozzles provided in sufficient numbers to wet the surface to be protected.

14.29 SYSTEM DESIGN

14.29.1 Establishing Pipe Sizes and Water Supply Acceptability

In the past, pipe schedules were the accepted method of determining the adequacy of system pipe sizes; however, the current standards no longer recognize the pipe-schedule method for new construction. The accepted method for the determination of pipe sizes and water supply adequacy is the performance of hydraulic calculations as outlined in NFPA 13.

The installing contractor may perform hydraulic calculations if qualified, but there is significant advantage to the engineer performing the hydraulic calculations and establishing pipe sizes and water supply acceptability before the bidding process begins. In performing hydraulic calculations, the sprinkler piping layout, nature of the hazard protected and water supply information must be known. Based on this information the area of sprinkler operation, appropriate design density and minimum sprinkler pressures can be used to perform the necessary hydraulic calculations. While it is beyond our scope to further describe the hydraulic calculation procedure an excellent resource is *Fire Protection Hydraulics and Water Supply Analysis,* by Pat Brock, published by Fire Protection Publications of Oklahoma State University.

14.29.2 Sprinkler Piping

There are numerous types of sprinkler piping currently accepted for the installation of sprinkler systems. In all cases the piping specified for a sprinkler system must be installed and used within the parameters of its U.L. Listing.

Most sprinkler piping specified today is black or galvanized, welded and seamless steel pipe. Normally smaller pipe sizes are specified as Schedule 40 and larger sizes as Schedule 10 black steel pipe. The joining methods for sprinkler pipe include the use of flanged fittings, prefabricated welded outlets, cast or malleable iron fittings or mechanical grooved fittings. In all cases, sprinkler pipe and fittings must be capable of withstanding pressures of 175 psi. For further details NFPA 13 and pipe manufacturer catalogs should be consulted.

Areas Protected by Sprinklers. To provide a fully sprinklered building, which is the intent of most building codes and insurance industry sprinkler requirements, all areas of a structure, with few exceptions, must be provided sprinkler protection. Generally, all spaces that are accessible, combustible or intended for storage or occupancy require sprinkler protection. The guidelines for permissible sprinkler omissions in fully sprinkled buildings are contained in NFPA 13. Except for void spaces in walls and noncombustible concealed spaces there are few exceptions and where exceptions do exist they are extremely specific with respect to accessibility, construction and dimensions.

With respect to individual sprinkler spacing requirements, the maximum area protected by one sprinkler should not exceed the area specified for the specific sprinkler as indicated in the manufacturer's specification sheets. Standard spray sprinklers are listed for light hazard, ordinary hazard and extra hazard occupancies for 225-, 130- and 100-^{2} protection areas, respectively.

In most installations, the area or coverage of each sprinkler is usually less than the maximum areas listed.

14.29.3 Sprinkler Position

In areas where construction is unobstructed, sprinkler deflectors should be parallel to and within 12 inches of the ceiling. Where construction is obstructed sprinklers must be within 22 inches of the roof deck above. In all cases, when locating sprinklers the maximum expected ambient temperature of the area being protected must be considered such that unwanted sprinkler activation does not occur.

Undesirable sprinkler water spray obstructions must also be considered when locating sprinklers. Where obstructions such as ducts are greater than 4 feet wide and are located below sprinklers, additional sprinklers should be added to spray below the obstruction. Furnishings such as tables are not considered obstructions unless they are within 18-inches, measured vertically of a sprinkler. When locating all sprinklers NFPA 13 and the sprinkler manufacturer's guidelines must be followed to prevent unwanted water spray obstructions.

Sprinkler System Layout. A sprinkler system is generally laid out as a ''Tree'', ''Loop'' or ''Grid'' type system. Whatever the case, sprinklers are attached directly to pipes called branch lines. Branch lines, normally the smallest of sprinkler pipes, are supplied water from cross mains or feed mains which are directly connected to the system riser.

The riser, configured to control the water supply and monitor water flow and valve position, may support a single sprinkler system or if manifolded, many systems (Fig. 14.19). In any case, the maximum area per floor to be protected by a single riser is 52,000-^{2} for light and ordinary hazard areas and 40,000-^{2} for extra hazard areas.

In high-rise buildings where standpipes and sprinklers are required a combined standpipe/sprinkler system is normally used. In these situations there may be no true system riser; rather, each floor is provided with a floor control valve (Fig. 14.20) consisting of a control valve, drain, test connection and flow switch. In this configuration the individual floor control valves accomplish the function of the system riser. An inherent advantage of using floor control valves is that individual floors can be isolated so sprinkler system repairs on one floor do not reduce the level of protection on another floor.

As a practical matter, when lying sprinkler piping out it is advantageous to consider the pipe hanging arrangement. Where construction consists of joist construction, mains should be run parallel to the joist channels. This accommodates

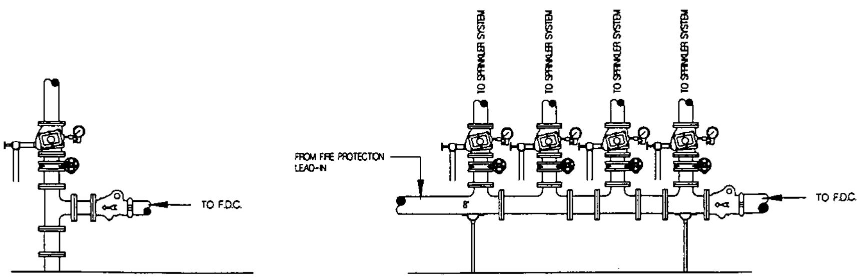


FIGURE 14.19 Single riser (left), manifold system with multiple risers (right).

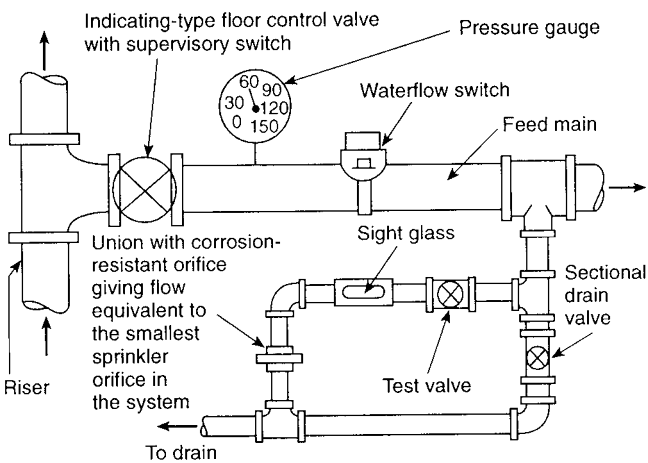


FIGURE 14.20 Floor control valve. (*Reprinted with permission from NFPA 13, Installation of Sprinkler Systems, Copyright © 1996, National Fire Protection Association, Quincy, MA 02269. This reprinted material is not the complete and official position of the National Fire Protection Association, on the referenced subject, which is represented only by the standard in its entirety.*)

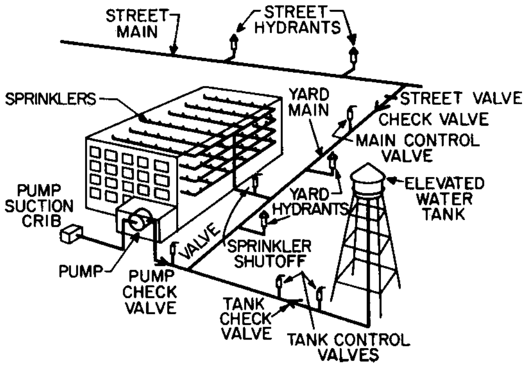


FIGURE 14.21 Water-supply piping for sprinklers.

pipe hanging since the branch lines, which out number the mains, can be hung directly off the joists. Where construction is concrete pipe hanging is an easier task but one should give consideration to the arrangement of beams and bays such that unnecessary fittings and pipe lengths can be avoided.

Drainage of Sprinkler Systems. Provisions must be made for draining all parts of a sprinkler system. For that purpose, valve-controlled drains must be provided at low points in the system. The primary drain for most sprinkler systems is the main drain, normally a 2 inch drain located at the system riser. All drains should discharge directly to outdoors or to a sump capable of handling full flow drain capacity.

Special consideration must be given to the drainage of dry-pipe systems and portions of preaction systems subject to freezing. The branch lines of these systems should be pitched ½ in per 10 feet and mains ¼ inch per 10 feet of length towards a suitable drain connection to accommodate total system drainage. Where trapped piping in dry-pipe systems exceeds 5 gallons capacity, a means must be provided to drain the trapped area without accidentally tripping the dry-pipe valve. This is usually accomplished with use of a drum drip assemble, an assembly which permits isolating trapped water and draining it without loosing air pressure.

Inspector's Test Connections. All sprinkler systems should be tested periodically to ensure their proper function. A test connection for wet- and dry-pipe systems consists of a connection at least 1 inch in diameter with a test valve terminating in a smooth-bore, corrosion-resistant orifice. This orifice connection should be sized to provide a test flow equivalent to the smallest orifice size sprinkler installed in the system. For most systems the test valve connection can be located anywhere down stream of the alarm valve or flow switch, whichever is provided; however, on dry-pipe and double-interlock preaction systems the alarm test valve must be located at the hydraulically remote point of the system. This is to ensure that water will reach the remote end of the sprinkler system without undue delay, usually 60 seconds for large systems.

Approvals of Sprinkler-System Design. In all cases, before a sprinkler system is installed or modified, the applicable drawings and hydraulic calculations should be submitted to the authority having jurisdiction and the insurance underwriter as necessary. Since beneficial reductions in insurance rates may be obtained by suitable installation of sprinkler systems, it is important that the underwriter have sufficient time for a full review of the plans before construction begins. Similarly, municipal approval of the sprinkler-system plans is necessary before the structure can be occupied. In actual construction, the installing contractor generally secures the necessary municipal approval. The existence of this approval should always be confirmed before construction starts.

14.30 STANDPIPES

Standpipes, hose valve connections supplied with water from a piping system that is always under pressure or can be rapidly supplied with water under pressure are the usual means through which firefighters are provided water to fight interior fires in large buildings such as malls and high-rises. NFPA 14, *Standpipe, Hose Systems,* is the recognized standard for the installation and design of standpipe systems. Today, most standpipes installed are intended for use by the fire department; however, some are designed for occupant use. As with sprinkler systems, building codes generally dictate when and where standpipes are required.

14.30.1 Class of Service

Standpipe systems are classified into the following types:

Class I. For use by fire department personnel only. These systems are provided with 2½-inch hose valves located in building stairwells and other protected areas. Water supplies permit two hose streams to be fed simultaneously from a single riser. Each stream provides 250 gal/min at a minimum pressure of 100 psi.

Class II. For occupant use only. Provided with 1½-inch hose valves and hose racks with a minimum 100-feet length of 1½ hose, these standpipes are located in a building such that all areas of a building are within 130-feet of a hose valve (100-feet of hose plus 30-feet of water spray). It should be noted that most authorities having jurisdiction no longer permit hose to be attached to Class II systems since it is felt that the best option for occupants who are not trained in fire fighting procedures is to evacuate the building and report the emergency situation.

Class III. A combination of Class I and Class II systems with both 2½-in hose valves and 1½-in hose valves and hose racks with 100 ft of hose, installed as required for a Class I and Class II system. The calculated water supply at an outlet is the same as for a Class I system.

Riser Sizes. Standpipe pipe sizes can be established based on the performance of hydraulic calculations or for low rise buildings the NFPA 14 Pipe Schedule System, with the hydraulic procedure being the preferred method. The hydraulic calculations for a Class I system are based on flowing 500 gpm at 100 psi at the most remote standpipe and 250 gpm at the top hose connection of all other standpipes with a total not to exceed 1250 gpm.

Maximum Pressure. Standpipe systems should be designed so the maximum gage pressure at the inlet of any Class I hose connection does not exceed 175 psi and Class II hose connection, 100 psi. Where pressures exceed 175-psi, pressure-limiting devices must be installed. Engineers must be extremely cautious in specifying pressure-limiting devices as they are frequently specified improperly.

14.31 WATER SUPPLIES FOR SPRINKLER AND STANDPIPE SYSTEMS

Water supplies for sprinkler and standpipe systems must be reliable. When a municipal water supply has been identified as unreliable or incapable of meeting the demand of a sprinkler or standpipe system, fire pumps and water storage tanks or reservoirs may be required. Even in instances where a water supply is reliable and the protected area is of high value, a secondary water supply employing water tanks and fire pumps is often provided.

In determining the size and elevation of tanks, site conditions should be of primary concern. Often times water storage tanks can be located advantageously at the higher elevations of a property. Other times penstocks, flumes, rivers or lakes may serve as a water supply. In these cases approved strainers must be provided on the water supply inlets to prevent obstructions from entering system piping. In all cases, whether the water supply is from a municipal source or raw source as described above, consideration must be given to the potential effects of Microbiological Influenced Corrosion (MIC) which can rapidly damage sprinkler piping.

While water supply adequacy is heavily reliant on the presence of sufficient flow and pressure, water supply duration is also important. For sprinkler systems the minimum water supply duration is 30, 60 and 90-minutes for light, ordinary and extra hazard areas, respectively. Standpipe water supply duration is 30-minutes. Water supply duration is mandated to ensure that adequate time is available to achieve fire control.

Fire Department Connection. With the exception of small sprinkler systems, all sprinkler and standpipe systems must be provided with a fire department connection (FDC). The FDC, often referred to as the siamese connection, is a means through which fire hoses may be connected to a system to support the hydraulic requirements of the system to which it is attached. In most cases, the FDC is a backup water supply. It should be noted that often times the FDC for standpipes in low-rise buildings is the only source of water supply. These systems are referred to as manual standpipes. Before specifying a manual standpipe the AJH should be consulted.

Depending on the AJH, FDC's may be installed on a side of a building or they may be free standing. Whatever the case, the FDC should be 18- to 36-inches above grade, and within clear sight of a fire department access-way. To speed fire ground operations it is good practice to locate FDC's within 75 feet of a fire hydrant. In addition, high rise buildings should be provided with two remotely located FDC's. While not a code requirement, as a rule of thumb, for each 250-gpm required, as determined in the hydraulic calculations, one 2½-inch FDC outlet should be provided. For a 600-gpm-system demand three 2½-inch FDC outlets should be provided.

As it is becoming common place for fire departments to use quick connecting FDC's, Stortz Connections, and since the fire department is the FDC end user, in all cases the local fire official should be consulted regarding FDC type and location.

14.32 CENTRAL STATION SUPERVISORY SYSTEMS

Any mechanical device or system is more reliable if it is supervised or monitored. Sprinkler systems are designed to be rugged and dependable as shown by their impressive performance record; however, reliability improves where systems are monitored by an approved central-station supervisory service for valve position (open or closed) and water flow switch status.

A central station monitors the equipment specified by the engineer and provided by the contractor and transmits appropriate signals over leased telephone lines or other approved methods, to a constantly attended location. When a signal is received at the central station, no matter what hour, the fire department and any other pre-established emergency contacts are summoned. When notification of a closed valve is provided, the building owner or other acceptable contact should investigate, but notification of water flow should always result in fire department dispatch.

Monitoring services are available across the country and are arranged by contract, usually with an installation charge and a monthly maintenance fee. Requirements for such systems are in NFPA 72, *National Fire Alarm Code.* Where no such service is available, a local or proprietary substitute can be provided.

14.33 ADDITIONAL INFORMATION

Developing proficiency in the proper design and specification of fire sprinkler systems is extremely tedious. While sprinkler system design is admittedly a small portion of the engineering design package for a construction project, the implications of inadequate system design are more than severe. There have been numerous cases where engineers have been named in lawsuits relating to improperly designed automatic sprinkler systems. To obtain additional information regarding the proper design and installation of automatic sprinkler systems the NFPA or Society of Fire Protection Engineers (SFPE) are excellent resources. In addition, to display your proficiency in the field of fire protection engineering, registration as a fire protection engineer is available in most states.