High-Rise Domestic Water Systems

Alfred Steele, PE CIPE

The primary objectives in the design of water supply systems for buildings are to ensure an adequate supply of water at the required pressure to all fixtures, outlets, and equipment at all times and to achieve an economical, efficient, and energy-conserving installation.

Excessive Pressure

Excessive pressure causes operational difficulties and greatly increases the cost of maintenance. Unless a piece of equipment or an operation requires a specified high pressure, it is economic folly to design a system with outlet pressures that exceed a maximum of 70 psi, and it would be desirable, if possible, to limit the maximum to 60 psi. When pressures are above 70 psi, it is difficult to maintain flow velocities (a function of pressure) below the critical velocity of 10 fps. Velocities of 10 fps or higher will result in noises throughout the piping system. Although noise itself may not be objectionable in certain areas or cause damage, excessive pressures and velocities do present some very real problems:

- Excessive wear or erosion of piping
- Wire drawing of valve seats with resultant maintenance problems and faulty operation
- Hydraulic shock (water hammer) and the resulting stresses that could rupture pipes or damage equipment
- Damage to fixtures or equipment that are not designed for high pressure or velocity
- Wasted water at outlets due to high rates of flow in excess of required flow
- The nuisance of water splashing on walls, floors, or the user
- Reduced life expectancy of the system and equipment
- Increased costs of equipment, which requires special construction for operation at the higher working pressures.

To avoid the dangers attributable to excessive pressure, some means must be provided to reduce the pressures to below the maximum of 70 psi. Pressure-regulating valves (PRVs) and vertical zoning have proven to be the best methods of maintaining pressures within desired limits.

PRVs and Zoning

Various schemes have been proposed and utilized throughout the years to minimize the number of PRVs required in a high-rise building. The earliest method was to install a PRV in every branch from a riser where the pressure was excessive. This resulted in hundreds of PRVs for every job. Access had to be provided to service these valves. The cost of the valves and the additional cost for providing access was a decided disadvantage. The earliest attempt to eliminate some of the PRVs was to take a branch from the riser and serve three floors from each branch with a PRV in each branch. The number of PRVs was reduced by two-thirds, but the branch piping became very complicated in many installations. This method never became very popular. In recent years the method of zoning the building vertically and utilizing master PRV stations for each zone was introduced and has proven to be an outstanding success. By the use of zones not only is the number of PRVs drastically reduced, but the design of the hot water distribution system is greatly simplified.

Determining the number of zones for any building is a straightforward procedure. Assume the pressure at fixtures is to be 20 psi. The type of water closet will determine the actual minimum pressure required. Pressure required for proper flushing action of water closets varies from 12 psi to 25 psi. With the assumed 20 psi pressure, there is now an allowable additional pressure of 50 psi that can be accommodated before reaching the maximum pressure criterion of 70 psi. Fifty psi is equivalent to a static pressure of 115.5 ft (50 x 2.31). To obtain the maximum zone heights, a downfeed system should be employed so that gravity is working with the system instead of against it. With a PRV set for an outlet pressure of 20 psi the piping can now be run down for 115.5 ft before reaching 70 psi. If the floor-to-floor height is 12 ft, each zone can then be either 9 or 10 stories each (115.5 ÷ 12 = 9.6). The top zone of any system would never require a PRV. If an up-feed system is used for each zone, the PRV outlet pressure would be set at 70 psi.

Actual Installations

A brief description of the domestic water system designed by the author for an office building that has been built and has been operating very satisfactorily should clarify some high-rise design principles.

Figure 1 is a schematic flow diagram of the cold water distribution system, and Figure 2 shows the cold and hot water piping in a typical zone.

A gravity tank system was selected after a complete and thorough analysis of all the factors. A 10,000-gallon tank was located at the top of the building, and a 15,000-gallon tank was located on the 40th floor. Two pumps located in the lowest level pump up to the 40th-floor tank. This tank serves as the water supply for the 34th floor down to the lowest level and at the same time acts as a suction tank to

supply two pumps on the same 40th floor to pump water to the top tank. This tank supplies water from the 80th floor down to the 35th floor, inclusive. The capacity of the two basement pumps is sized for the total building demand, and the two 40th-floor pumps are sized only for the upper section of the building. Each pump is sized for two-thirds of the load, so if one pump fails in the duplex set-up the other pump is capable of keeping the system in operation.

By placing gravity tanks at the top and middle of the building, we have essentially divided a building of extreme height into two buildings of approximately 500 ft each in height. One-half of the building will now be discussed because the other half is designed in exactly the same manner. A main downfeed riser runs from the tank down to the top of the lowest zone. For the second zone below the tank the pressure will now be approximately 70 psi. For this and every zone below, the pressure must be reduced to approximately 25 psi so as not to exceed 70 psi at the base of each riser. PRVs are utilized for this purpose. After the PRV, a connection is taken off for the water heater for that zone. System pressure at the heaters is always below 30 psi, and the same is true for the hot water circulating pumps. The beauty of this system is that no special materials or extra heavy construction is required (for which a premium is always paid). The only piping in the entire job that is subjected to pressures greater than 70 psi is the pump discharge lines and the main riser from the tanks.

The hot water distribution system is the epitome of economy. From the heater a riser feeds down in one vertical bank of toilet rooms, and at the base runs over to and up the other vertical bank of toilet rooms back to the heater for a closed loop. No additional circulating risers are required, and there are no problems of balancing the system. This ideal set-up can probably be used for many office buildings.

**Multi-Purpose Building**

A multi-purpose structure poses interesting problems for the plumbing engineer. The conceptual design of the water distribution system for Water Tower Place in Chicago was prepared by the author, and thus enough information is available to present the parameters and solutions for this building.
The occupancies of the building are divided into four distinct entities. The owner is obligated to provide only certain basic services to each entity and the responsibility for anything beyond these basic services belongs to each entity. The apartments are condominiums, and everything serving this complex (piping, pumps, heaters, other equipment, operation, and maintenance) is the responsibility of the condominium owners. It is, therefore, necessary to design the water distribution so that, from the point of service provided by the building owner, the entire system is absolutely separate and distinct from any other system in the building. The owner is responsible for tank fill pumps in the third basement, piping to the combination gravity and suction tank, the tank on the 32nd mechanical equipment floor, and the piping from tank to outlet of meter. From the

Water Tower Place, Chicago 838 ft high

meter the condominium complex is thus divorced entirely from the rest of the building and all costs can be accurately allocated for the operation and maintenance of that complex.

The hotel complex and each major department store tenant are treated in the same manner as the condominium complex. An examination of the water flow diagram illustrates how each is isolated (Figure 3).

The office complex, other shops, and any other tenants remain the responsibility of the owner and are identified as the base building.

The total building then breaks down into base building, two separate department stores, hotel, and condominiums.

Water Tower Place is of special interest to the plumbing engineer because it is a combination of most of the design applications recommended in Advanced Plumbing Technology. Both a gravity tank and booster pump system are utilized in the same job. The entire building is zoned to isolate various complexes and to maintain maximum pressures within recommended limits. There are both up-feed and downfeed systems. This should hopefully emphasize that no one system is best for every job.

The illustrations (Figure 4 and Figure 5) of the water distribution systems for other high-rise jobs are given with no comments. They are not presented as recommended systems because, as previously stressed, no two jobs are identical and each must be thoroughly analyzed to select the best design for that particular job. It is impossible to intelligently critique a system until all the background information is available and all the peculiar and special requirements for the job are known. The illustrations are shown to demonstrate the approaches and solutions utilized by various engineers for various jobs.

Hot Water System

In a high-rise building where the water distribution system is zoned vertically to maintain pressures within the maximum criteria established, it is imperative that certain precautions be observed in the design of the hot and circulating water system. Each zone must be considered as a complete system with no interconnection with any other zone. Each zone must have its own water heater, hot water distributing piping, circulating hot water piping, and circulating pumps.

If no economic penalty is involved, it is always desirable to locate the heater at the top of the system. The pressures
the heater and circulating pump are subjected to are much less in this location than at the base of the system. Many times the pressure at the base of a hot water system will require heaters, tanks, and pumps of special construction to withstand the stresses. Under all circumstances, provisions must be made to relieve the air at any and all high points of the system.

One-Pipe Hot Water Distribution System

Due to an exciting innovation, it is now possible to eliminate the requirement of separate water heaters for each zone and specify a one-pipe hot water distribution system with a central water heater for the total project, which requires absolutely no circulating system!

Self-Regulating Strip Heater

Researchers have recently developed a strip heater that responds to localized temperature conditions by self-regulating its heat output. The heart of the heater is a semiconductive polymer, which has been incorporated as the core of a strip heater that consists of the core and two copper bus wires that run in parallel the length of the heater strip. The copper wires are not the heating element; their only function is to provide a voltage potential across the polymer core along the entire length of the heater. The heat generated is due solely to the flow of current through the core from one wire to the other.

Heater Operation

The strip heater is installed in contact with the piping along its entire length. As the polymer core is heated by the pipe, it expands and microscopically reduces its conductive paths. As thermal expansion of the core continues with increased pipe temperature, more electrical paths are disconnected, thus reducing the heat output of the core until the system reaches thermal stability. When the pipe temperature drops, this process is reversed; the core responds by creating or reconnecting additional paths. As the number of conductive paths increases, the resistance to current flow decreases and the strip heater produces more heat. This is the self-regulating characteristic of the core’s molecular memory, which responds to thermal changes independently at every point along the length of the pipe. In operation the self-regulating heater replaces the pipe heat...
loss at the point it occurs along the pipe and thus maintains the temperature of the water from its source (the conventional water heater) to the end of the hot water supply network. By continuously maintaining the water temperature in the supply piping there is no need for the conventional recirculation system!

Although the self-regulating heater is relatively new to the commercial construction industry it has been widely used in industrial applications to maintain the temperature of fluids in pipes. The reliability, savings in energy, simplicity of hot water system design, and ease of installation have led to the installation of more than 60 million ft of self-regulating strip heaters during the past 12 years.

Construction of the heater is shown in Figure 6. Figure 7 illustrates the relationship between the heat output of the heater and the temperature of the water in the pipe.

**Installation**

The installation of the self-regulating heater on the hot water supply piping is extremely simple. The heater is run linearly on the pipe (for most sizes) and fastened with adhesive glass tape every 12 in. Pipe insulation fits around the pipe and heater (see Figure 8).

One end of the heater terminates inside a pipe-mounted junction box, and the wiring from the junction box to the source of electricity is installed by the electrical contractor. The other end of the heater is simply cut to length and terminated with an end seal. The parallel wire circuit design of the heater permits teeing-off to feed multiple risers from one horizontal base heater strip. A typical circuit can be a maximum of 475 ft in length.

**One-Pipe System Versus Two-Pipe System**

The conventional hot water system is a two-pipe system composed of a water heater (with a hot water storage tank when required), supply piping, circulation piping, and circulation pump. The system utilizing the self-regulating strip heater is a one-pipe system composed of only a water heater (with a hot water storage tank when required), supply piping, and self-regulating strip heater. In the one-pipe system the water heater (and storage tank) is exactly the same as in the two-pipe system and functions to bring the cold water supply up to required system temperature. Controls for the heater are the same in both systems.

When the cold water has been brought up to system temperature the self-regulating heater then maintains the water at this temperature throughout the supply piping. The self-regulating heater replaces the heat loss at the points along the supply piping where heat loss occurs, and since the water temperature is continuously maintained there is no need for circulation piping, balancing valves, circulation pumps, and controls.

**Advantages**

The advantages of the one-pipe system can be divided into four basic categories:

1. Lower installed cost
2. Lower energy consumption (lower operating cost)
3. Ease of system design
4. Improved system performance
Lower Installed Cost

Lower installed cost is probably the most obvious advantage of the one-pipe system because of the elimination of all circulation piping, circulation pipe insulation, circulation riser control valves and balancing valves, and circulation pump with its valving, bypass, and controls. Only the cost of the self-regulating heater is added back. An installed cost comparison (using Means Mechanical and Electrical Cost Data Book) of more than 100 buildings indicated savings of more than 40%.

Lower Energy Consumption (Lower Operating Cost)

The one-pipe system requires significantly less energy than the conventional circulation system. In the circulation system the water in the circulation piping is continuously losing heat that must be made up by the heater. Since there is no circulation piping in the one-pipe system, this source of heat loss is eliminated and the need for additional energy is also eliminated. The elimination of the circulation pump also contributes to a significant saving of energy.

To obtain a 105°F delivered water temperature at fixtures the temperature of the hot water leaving the heater in the conventional circulation system must range from 115°F to 125°F. In the one-pipe system the water temperature is continuously maintained at the required temperature and as a result the water heater discharge temperature can be set at 105°F. With lower water temperature throughout the system there will be considerably less heat loss from storage tanks and piping.

In the one-pipe system all the cold water supply to the heater is heated to the desired temperature only. In the two-pipe system all the cold water must be heated to a temperature 10°–20° higher than the required temperature at the fixtures. This overheating represents a significant expenditure of energy.

Cost studies of annual operating costs for a typical high-rise hotel indicated a potential savings of 50% with the one-pipe system.

Ease of System Design

At long last we have an innovation that makes life a little easier for the design engineer. The one-pipe system is easier to design than the conventional two-pipe system. It means fewer pipe runs to size, fewer pipe runs to lay out, no pumps to size and select, and no worries about balancing the system.

High-Rise Design

The self-regulating strip heater probably offers the greatest benefits when it is applied in the design of hot water systems for high-rise buildings. Consider a high-rise building that has three vertical zones in order to eliminate excessively high pressures. Conventional design dictates that a separate water heater must be installed in each zone and the hot water system in each zone must be treated as a self-contained system that is separate from the systems in all other zones. With a conventional hot water system it is impossible to design a central system due to the unequal pressures of the water that would return to the central water heater from each zone. With the elimination of the circulation system in the one-pipe design it is now possible to design a high-rise hot water system using a central water heater, as illustrated in Figure 9. The water heater should be located at the top of the building. If located at the bottom of the building the heater would be subjected to excessively high pressures.

Residential Buildings

Practically all hot water systems for single-residence homes do not have circulation systems. It is a particular annoyance to the homeowner to have to wait a seemingly long time for the hot water at the required temperature to reach the fixtures that are remote from the water heater. This annoyance can now be eliminated by the installation
of the self-regulating strip heater. Not only will hot water be available instantaneously at every fixture, but the wastage of water will be eliminated.

**Expansion of Facilities**

When additional fixtures are located in new areas of an existing building or a new addition is added to a building the one-pipe system offers decided advantages. All that is required is a connection to the existing hot water supply piping and running the temperature-maintained piping to the new fixture areas.

**Electrical Characteristics**

The self-regulating strip heaters are suitable for installation with 120-V or 208-V electrical supply. A typical heater for a 105° F hot water system under maximum demand conditions has a current flow of 0.021 amps per ft at 120V and 0.012 amps per ft at 208 V.

When a greater heat output is required to balance the heat loss from the pipe, then two parallel heater strips must be installed (Figure 8) or the heater strip can be spiraled on the pipe as illustrated in Figure 10.

**Codes**

There is a very serious roadblock to the complete acceptance of the self-regulating strip heater and the resultant elimination of the circulation system. Practically every code specifically requires that the hot water be circulated when the building is more than three stories in height or the run of supply piping exceeds 100 ft. It is important that code-writing authorities be made aware of this breakthrough so that they can make their evaluation and modify the code requirements as expeditiously as possible.

**Conclusion**

The design options available to the engineer when faced with the design of the plumbing systems for a new project generally involve trade-offs between installed cost advantages and operating cost advantages. The self-regulating strip heater concept is unique in that it offers both lower installed cost and lower operating cost. It is the combination of these benefits that makes the one-pipe system such an attractive alternative to the conventional two-pipe hot water system.

---

**Continuing Education from Plumbing Systems & Design**

Kenneth G. Wentink, PE* CPD, and Robert D. Jackson, Chicago Chapter Vice President, Technical

Do you find it difficult to obtain continuing education units (CEUs)? Is it hard for you to attend technical seminars? ASPE has a new program to help you accumulate the CEUs required for maintaining your Certified in Plumbing Design (CPD) status.

ASPE features a technical article in *Plumbing Systems & Design (PSD)*, excerpted from its own publications. Each article is followed by a multiple-choice test and a simple reporting form.

Reading the article and completing the form will allow you to apply to ASPE for CEU credit. For most people, this process will require approximately 1 hour. A nominal processing fee is charged—$5 for ASPE members and $25 for nonmembers (until further notice, the member fee is waived). If you earn a grade of 90% or higher on the test, you will be notified by return mail that you have logged 0.1 CEU, which can be applied toward the CPD renewal requirement or numerous regulatory-agency continuing education programs. (Please note that it is your responsibility to determine the acceptance policy of a particular agency.) CEU information will be kept on file at the ASPE office for 3 years.

No certificates will be issued in addition to the notification letter. You can apply for CEUs on any technical article that has appeared in *PSD* within the past 12 months. However, CEUs only can be obtained on a total of eight *PSD* articles in a 12-month period.

*Ken Wentink is licensed as a professional engineer in Massachusetts.*