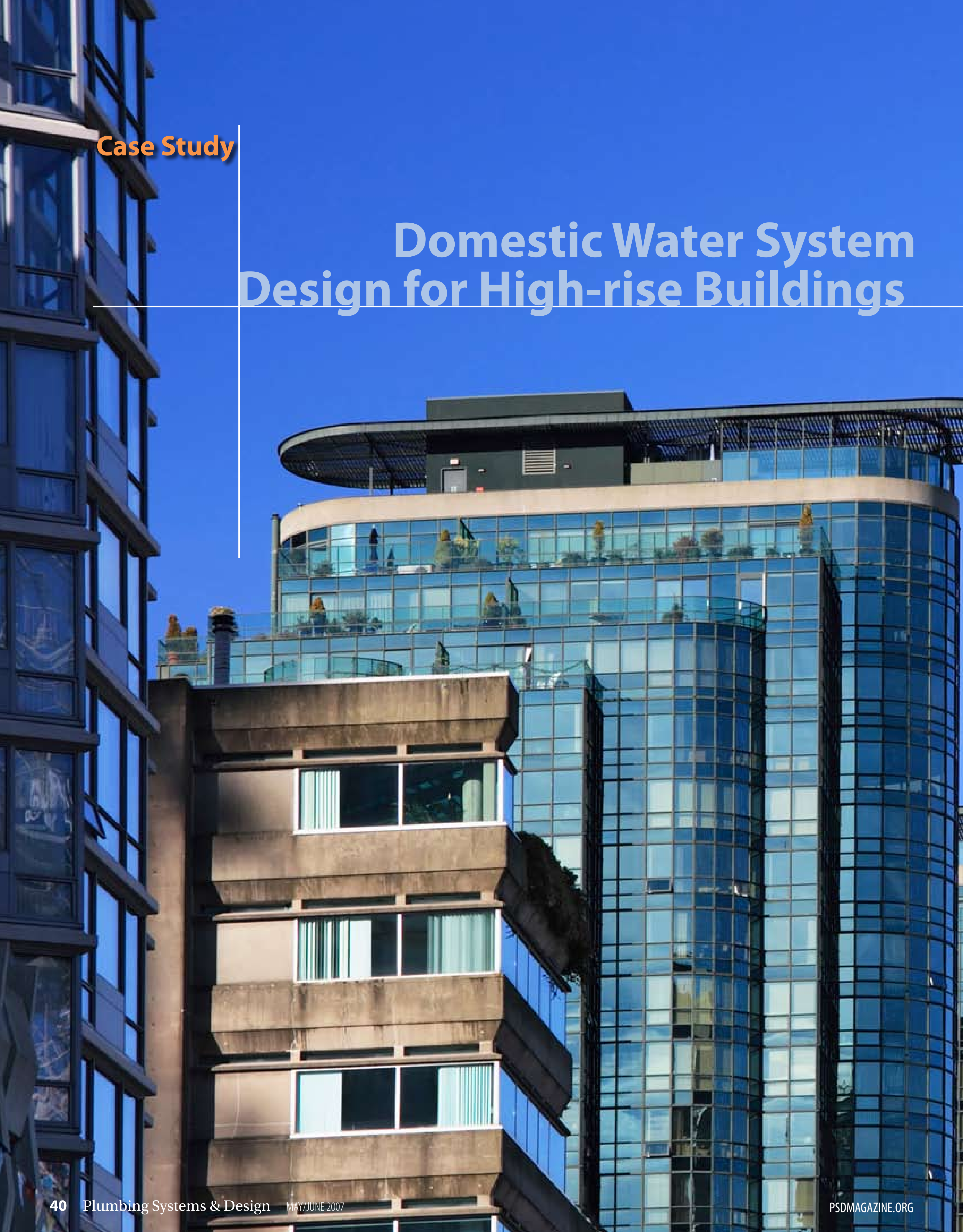
Case Study

Domestic Water System Design for High-rise Buildings



by Jim Beveridge, P. Eng.

Vancouver, British Columbia, is a modern city of 2 million people sitting on the edge of the Straight of Georgia (connected to the Pacific Ocean) to the west, set against a backdrop of the Coast Range Mountains to the north, and bound by the United States border to the south. These geographical constraints, along with steady population growth, have resulted in the engineering and construction of literally hundreds of high-rise buildings, including office buildings, hotels, apartments, condominiums, and multiuse high rises.

I have designed several high-rise building projects over the past two decades and am the plumbing engineer of record for two current high-rise building projects located in Vancouver. Woodwards is a $250 million landmark multiuse redevelopment project on the edge of the city core that includes a 42-story residential condominium high rise plus a 36-story residential condominium tower. The project also includes commercial retail spaces, government office levels, social housing, a food store, a university performing arts center, daycare facilities, and two levels of underground parking covering the entire city block. A second project, 1133 West Georgia Street in the heart of the downtown core, is a 58-story five-star hotel and condominium high-rise building. These prestigious projects, each with water and mountain views from the upper levels, will sell for well over $1 million per condominium unit.

Providing domestic cold and hot water to the upper floors is a fundamental requirement and provides the main challenge for the plumbing system engineer for a high-rise building project. Many parameters must be considered and many possible solutions exist. The engineer must consider building height, available municipal water pressure, pressure requirements not only at the upper floor but also throughout the building, flow demand, booster pump capacity and control, pipe and valve materials, riser locations, pressure zones, pressure-regulating stations, water heater storage capacity and recovery, water heater locations, domestic hot water circulation or pipe temperature maintenance, space requirements in the building, economics, energy efficiency, and acoustics.

The primary role of the project plumbing engineer is to determine the overall design solution that addresses the technical, physical, and economic aspects of the project, complies with the requirements of local codes, and meets or exceeds the client's expectations.

Technical input regarding booster pumping equipment options and costs and domestic water heater equipment options and costs was obtained from local manufacturer's reps. In addition, input on the construction costs associated with some of the various piping options was obtained during value engineering meetings with local trade contractors.

DOMESTIC WATER PRESSURES

Water pressures must be established for all points in the domestic cold and hot water systems. The first requirement is to obtain water pressure information from the local water utility company. Water pressure information is determined either by field measurement while flow testing at two fire hydrants in the vicinity of the project site or utilizing a dynamic computerized flow simulation program. Water pressure information should be provided to the project engineer as the winter, or maximum, static pressure, and the summer, or minimum, residual pressure at a designated flow rate. The maximum water pressure information is necessary, as it determines whether pressure-reducing valves are required for the lower levels of the project served directly by municipal pressure. Minimum water pressure information is necessary for sizing the domestic water booster pumps to serve the upper levels of the building.

Information generated by computer simulation can be advantageous, as it can be designed to account for future developments in the area, future upgrades to the municipal water system such as looped systems, and long-term deterioration of pipe capacity. The water pressures provided by the municipality for the hotel and condominium project are 120 pounds per square inch (825 kilopascals) winter static and 95 psi (650 kPa) at 1,000 gallons per minute flow (3,780 liters per minute flow) summer residual pressure. The engineer should consider reducing the minimum water supply pressure information by 10 psi (70 kPa) or 10 percent to account for other unknowns, future variations in the system, or changes to the piping configuration during installation. For this project, the minimum available municipal design pressure is 85 psi (585 kPa).

The second requirement is to account for pressure losses from the municipal water connection to the building's water supply system booster pumps, including premise isolation backflow prevention devices, water meters, strainers, valves, and pipe losses. For this project, these losses are 10 psi (70 kPa), leaving 75 psi (515 kPa) available at the base of the system at the inlet to the pressure booster pumps.

The next requirement is to establish the residual water pressure required at the plumbing fixtures in the upper levels of the project. Plumbing codes and the ASPE *Data Book* generally state the minimum water pressure at a fixture other than flush valves to be 15 psi (105 kPa) or even less! However, the occupants for this project and many other high-rise condominiums will be people paying $1 million or more for a condominium who may be moving from a single-family home where the water pressure was 50 psi (345 kPa) or more. In hotels where upper-level suites with panoramic ocean and mountain views command several hundreds of dollars per night, the guests similarly will be expecting good water pressure. I recommend a minimum of 40 psi (275 kPa) at the upper levels for these projects.

Plumbing code restrictions and ASPE *Data Book* recommendations limit the maximum water pressure at a plumbing fixture to 80 psi (550 kPa). This pressure comes into effect when we look at pressure zones within the building as later discussed.

Next, the static pressure of the system must be determined. This is the largest pressure component in most high-rise project designs and is the water pressure that occurs based on the height of the piping system from the connection to the municipal water main to the highest plumbing fixture. There is a 0.433-psi (2.98-kPa) static pressure change for each foot of elevation change. For this 58-story project, the static pressure differential is 190 psi (1,310 kPa).

The last pressure that needs to be calculated is the friction loss that results from water flowing through the piping system, which is a function of pipe length, pipe diameter, velocity, volumetric flow in gpm (Lpm), pipe material roughness coefficient, and viscosity. (However, most pipe friction loss tables are based on potable water; therefore, viscosity does not need to be adjusted.) For this project, the friction head is 10 psi (70 kPa). Water velocities were restricted to 5 feet per second (1.5 meters per second) for cold water and 4 fps (1.2 m/s) for hot water and recirculation piping.

The pressure required to be generated by the domestic water booster pumps at the base of the plumbing system now can be calculated:

Residual pressure at the highest fixture (40 psi [275 kPa]) + Static pressure (190 psi [1,310 kPa]) + Friction losses (10 psi [70 kPa]) = Required pressure (240 psi [1,655 kPa]) – Minimum available pressure (75 psi [515 kPa]) = Required pressure by booster pumps (165 psi [1,140 kPa])

EQUIPMENT AND MATERIAL PRESSURE REQUIREMENTS

The domestic water system must be designed to handle the high operating pressures at the base of the system. In this project, the required pressure at the discharge from the booster pumps is required to be 240 psi (1,655 kPa). Therefore, in addition to the booster pumps, the equipment, piping, valves, fittings, and pipe joints also must be designed, specified, and rated to accommodate the high water pressures at the base of the domestic water piping system. Components with a minimum 250-psi (1,725-kPa) rated operating pressure are required.

The rated internal operating pressure for copper tubing also must be considered in systems with high operating pressures, and the limitation is based on the type of alloy used for the joints. Lead as occurs in 50-50 tin-lead solder never should be used in making joints on potable water systems, regardless of the pressure. For example, tin-antimony 95-5 solder has a maximum operating pressure of only 180 psi (1,240 kPa) at 200°F (93°C) for a 6-inch (150-millimeter) pipe diameter joint. Brazing alloys and silver solder have significantly higher operating pressure limits and should be specified for small-diameter copper tubing, while grooved-end mechanical joint systems may be considered for 2-in. (50-mm) diameter and larger copper tubing.

Note that for taller buildings, water pressure requirements at the base of the system are increasingly higher, unless mechanical rooms are provided at intermediate levels within the building and pumping can be staged in series. At levels further up the building, the pressures are correspondingly lower, and equipment and materials can be designed to lower pressure ratings.

DOMESTIC WATER PRESSURE BOOSTER PUMPS

Several domestic water pressure booster pump arrangements were evaluated. The first consideration was to reduce the pumping energy generally associated with booster pump systems. Two factors can contribute significantly to wasted energy. First are systems that incorporate one pump to run continuously, even during low-flow or no-flow periods, and utilize a thermal bleed solenoid valve to dump water that is overheated in the pump casing due to the impeller operating below the demand flow rate. This wastes both energy and water. Second are systems that generate a single water pressure for the entire building that is high enough to satisfy the upper-level fixtures and then reduce that pressure through pressure-reducing valves to satisfy lower-level pressure zones in the building.

The initial design approach for the project was to provide separate booster pumps for each pressure zone in the building with each pump incorporating a variable-speed drive. This would eliminate both of the energy-wasting aspects described above. Each of the five pressure zone booster systems would consist of a simplex pump, with just one additional backup pump that would be interconnected with normally closed valves to all of the zone headers, thus providing backup for each of the zones when one of the simplex pumps was being serviced. The total connected pump horsepower for the project and the total energy consumption were lowest in this scenario. In addition, this arrangement did not require any pressure-reducing stations at the upper floors of the building, thereby increasing valuable floor area and reducing associated adjustments or maintenance work at the public floor levels. However, this scenario required additional risers, one cold water riser and one hot water riser, for each pressure zone in the building, running from the basement-level mechanical room up to the level of each zone. This scenario was presented as the primary system for costing.

The second scenario that was evaluated consisted of one triplex booster package for the cold water system and a separate triplex booster package for the hot water system, with pressure-reducing valve (PRV) stations for each pressure zone, located in valve closets at intermittent floor levels in the building. The domestic water heaters were located in the basement mechanical room on the upstream side of the hot water system pressure booster pumps with their cold water supply at city water pressure.

The third scenario consisted of one triplex booster pump package for the cold and hot water systems, with PRV stations located in valve closets at each pressure zone in the building. To minimize the size of the PRV station closets, the valve stations were staggered, with cold water PRVs on one level, hot water PRVs on a second level, hot water zone circulating pumps on a third level, and hot water zone electric reheat tanks on a fourth level. This pumping scenario required the primary domestic water heaters to be ASME rated for 250-psi (1,725-kPa) operation, as they were located in the basement mechanical room on the downstream side of the booster pumps. However, the lower number of booster pumps and associated interconnecting piping offset the premium cost for the higher pressure rating of the water heaters.

ACOUSTICAL PROVISIONS

Acoustic requirements must be considered when designing pressure booster pump systems. Minimizing noise at the source is by far the best practice. Pumps that operate at 1,750 revolutions per minute are generally quieter than pumps that operate at 3,500 rpm if the performance capacity can be achieved. Incorporating variable-speed drives into the pumping system generally reduces sound levels even further and specifically during periods of low-flow requirements, such as at night when sound issues may be most prevalent.

Vibration isolators should be provided on pump bases in all cases except for pumps mounted on slab on grade. The vibration isolators should include seismic restraint mounts in geographical areas with seismic zones, such as on the West Coasts of Canada and the United States. Flexible connectors should be provided on the inlet and outlet connections to the booster pumps or on the connections to the headers where package pump systems are utilized. Flexible connectors constructed of single- or double-spherical neoprene reinforced with Kevlar with built-in retention rings are recommended over braided stainless steel flexible connectors for two reasons. They permit axial movement as well as lateral movement, and in addition they provide attenuation of noise

transmission in the fluid and piping due to the change in internal shape of the connector. Spring isolators should be considered on the domestic water pipe hangers and supports within the pump room to further mitigate pump noise from transmitting into the structure.

A prudent plumbing engineer should recommend that the client retain a project acoustical consultant to provide recommendations regarding the domestic water pressure booster pump and piping systems. It is far more expensive to remediate noise issues after the project is completed and occupied than to incorporate them into the original design.

DOMESTIC HOT WATER SYSTEM AND EQUIPMENT

The development permit for the project has very specific height restrictions, and constructing an additional level of million-dollar penthouse suites in lieu of a penthouse mechanical room forced the mechanical equipment, including the domestic water heaters, down to the basement-level water-entry mechanical room. Utilizing central-plant, natural gas-fired domestic water boilers at this low level in the building would have been prohibitive due to the high water pressure, routing, and termination requirements of the flues.

Individual electric water heaters located within a closet in each suite were considered and initially favorably priced by one of the plumbing trades; however, this option did not proceed based on the required floor space and loss of closet space within the units, lack of equipment diversity utilizing individual water heaters compared to a central plant system, maintenance and eventual replacement requirements within each suite, and the upsizing of electrical power requirements and distribution within the building.

Downtown Vancouver has a central steam distribution system operated by a private utility company, and steam service was incorporated into the project for HVAC systems as well as domestic hot water generation. Steam to high-temperature heating system heat exchangers were specified by the HVAC engineer, and heating system double-wall immersion heaters were specified for the domestic water heater tanks. Two systems were designed in parallel to provide part-load performance during maintenance periods.

Two system options were considered. Initially, it was anticipated that ASME hot water storage tanks rated for the high-pressure system requirements would be very expensive. Therefore, the first option considered using separate booster pumps for the cold water and hot water supply systems. A low-pressure municipal cold water line would supply cold water to low-pressure-rated water heaters, and downstream separate hot water booster pumps would distribute hot water throughout the building.

Pricing was obtained from a local pump supplier and a storage tank supplier; the costs were evaluated; and the final design solution incorporated one set of booster pumps, double-wall primary heating water to domestic hot water heat exchangers, and ASME high-pressure-rated domestic hot water storage tanks.

DOMESTIC WATER PIPE DISTRIBUTION SYSTEM RISERS AND MAINS

Several configurations of pipe distribution systems may be employed to distribute cold and hot potable water to the suites. Three configurations were considered for this project.

The first configuration consists of a triplex domestic water booster system located in the mechanical room at parking level P-1 supplying water to a main 8-in. (200-mm) diameter potable water riser. Pressure-reducing stations are provided in valve closets to develop pressure zones of approximately six stories per zone. The pressure-reducing stations consist of two PRVs in parallel, each sized for 50 percent demand with no manual bypass, as the pressure would be too high if the manual bypass valve was opened. This keeps the pressure within the zone between approximately 40 psi (275 kPa) at the suites at the top of each pressure zone and 70 psi (480 kPa) at the suites at the bottom of each pressure zone. Downstream of the pressure-reducing stations, subrisers then distribute water to each floor level within the pressure zone. At each story, a floor isolation valve is provided, and distribution mains are routed in the corridor ceiling to suite isolation valves and then into each suite. One advantage of this system compared to others is that all risers and horizontal piping are routed through common areas, and the only piping within a suite is the piping serving fixtures within that individual suite.

A second configuration consists of the same triplex booster pump system, main water riser, and PRV stations approximately every six stories as described. In this configuration, only one horizontal distribution main is routed in the corridor ceiling at the lowest level of each pressure zone, and in turn supplies subrisers located within each set of stacked suites. Isolation valves are provided at the base of each subriser and at the connection to each suite. The obvious disadvantages of this configuration are that common riser piping is routed through individually owned suites and that if the subriser needs to be shut down, all suites on that riser also are required to be shut down.

One negative aspect of most domestic water booster systems where more than one pressure zone is required is that most of the pumps' energy is wasted. This is because the full volume of water for the building is boosted by the pumps to the pressure required at the highest story in the building, and then the pressure is reduced through PRV stations at all pressure zones except the highest zone. With increased emphasis on energy conservation and sustainable design, this led me to a third configuration that I had not heard of previously and do not know of being implemented in any projects to date, which excites me. The wasted energy consumed by PRV stations can be eliminated by designing dedicated booster pumps with variable-speed drives for each pressure zone. Therefore, only the pressure required at any given zone in the building is developed, and only the associated pump energy is consumed.

To reduce capital cost compared to providing duplex or triplex booster pump packages for each pressure zone, a single booster pump with a variable-speed drive is provided for each pressure zone, and one additional backup pump is provided for the entire building, sized for the upper pressure zone with manual interconnected piping and valves such that it could serve any zone in the building as required during servicing or replacement of any dedicated zone booster pump. The pump energy savings is approximately 50 percent, as the full volume of water for the building only is required to be boosted to the average pressure for the building. The capital cost of the pump equipment is reduced as total horsepower is reduced, as is the total connected electrical load, and pressure-reducing stations at intermittent valve closets throughout the building are not required.

The offsetting increase in capital cost is the increased number of risers and total length of riser piping and insulation, plus the interconnecting piping and valves to each of the pumps and the associated installation costs. On building projects where the client will be paying both the capital and long-term operating costs, the payback period may be worthwhile. Unfortunately, in the developer's world where capital cost is king and operating costs are paid by a multitude of unknown owners in the future, payback periods are generally not marketable or sufficient to support these creative engineering solutions.

DOMESTIC WATER PIPE DISTRIBUTION WITHIN THE SUITES

Traditionally in Vancouver, water distribution piping has been Type L copper tube manufactured to ASTM B 88 standards, with wrought copper fittings and 95-5 soldered joints. Distribution piping has been routed within drop ceiling spaces and down within partition walls to the plumbing fixtures. The recent rise in the cost of copper materials and the labor cost of installation necessitated a trend to a different solution.

Over the past several years, cross-linked polyethylene (PEX) tubing has been used extensively. The material has several advantages, including lower material capital cost, lower installation cost, less joints and therefore less potential locations for leaks in concealed spaces, faster installation, and no potential for corrosion by aggressive local municipal water conditions, which has contributed to pinhole damage and expensive replacement of entire copper potable water systems in high-rise buildings. The common installation within a suite consists of brass isolation ball valves on the cold and hot water supplies generally located in a closet wall, short ¾-in. (19-mm) or 1-in. (25-mm) diameter headers with several ½-in. (12-mm) connections, and individual runs of PEX tubing from the headers to each plumbing fixture. The PEX tubing is routed within the structural floor slabs, and one major PEX tubing supplier has obtained a tested third-party listing for a two-hour fire separation rating. Quarter-turn mini ball valves are provided at each plumbing fixture, and water hammer arrestors are provided at dishwashers and clothes washers.

SUMMARY

Many variables must be considered during the engineering of domestic water systems for high-rise buildings, and many design solutions are available to the plumbing engineer. The water pressures vary at each level throughout the building and always must be considered in system layouts and when selecting equipment and pipe materials. Energy efficiency, space allocations, economics, and acoustics all play important roles in a successful project delivery to the client. **PSD**

JIM BEVERIDGE, P. ENG., LEED AP, is a senior associate and the plumbing and fire suppression discipline leader for Stantec Consulting Ltd. in Vancouver, British Columbia. He is a member of ASPE (past president of the British Columbia Chapter), the Association of Professional Engineers and Geoscientists of British Columbia, ASHRAE, and SFPE. For more information or to comment on this article, e-mail **articles@psdmagazine.org.**