HIGH RISE PLUMBING DESIGN

Editorial Note: • Chapters mentioned in the article refer to US Plumbing Codes and not to UIPC-I
• Flushometer Valve is called as Flush Valve in India

High rise buildings have very complex and challenging plumbing piping systems with unique pressure issues and system design issues that are typically an engineered system. There is not much plumbing code language in the model plumbing codes in the United States that addresses high-rise building plumbing design and there are no plumbing system design standards that addresses how to install plumbing systems in a high-rise building. However, there is information available on high rise plumbing design in plumbing design books available from the American Society of Plumbing Engineers (ASPE). Website: https://aspe.org/product-detail

When a building is built in a location where a building code and other codes like plumbing, mechanical electrical and fire codes are adopted and enforced, the requirement to comply with a code or standard is typically enforced by a local ordinance or law. However, some jurisdictions may not have people hired or trained to enforce the codes. In countries or jurisdictions where there is no adopted code, building owners and construction managers typically agree, through a construction contract, to use a specific code from the US or Europe and rely on the engineers to follow building, mechanical, plumbing, fire protection and electrical codes and their referenced industry standards. When there is not a trade school available for each building trade, and/or when there are no building inspectors working for the jurisdictions to enforce the requirements in the codes for each building trade, the owner may rely on the construction manager's trade inspection experts or the engineers for each trade for the building to provide construction inspections. This is to assure conformance with the codes and standards that they have contracted and agreed with the owner to design and build in conformance with.

Model Codes

The model plumbing codes in the United States are developed by code organizations made up of volunteers and paid staff. The codes are developed in a series of hearings that allow ample opportunity for people to comment on proposed code changes before the code committees votes on code changes. The model plumbing codes address the maximum pressure allowable at each fixture and the minimum pressure required at each fixture and a few other things that could apply to high-rise buildings, like requirements for hot water at various fixtures and requirements of maximum hot water temperatures flowing from several types of fixtures, but the code does not fully address hot water or cold-water system sizing, storage sizing or temperatures, distribution temperatures or distribution piping layout and design. The code also does not address domestic cold water booster pump sizing, booster pump types, booster pump controls or the use of, or maintenance of pressure reducing valves in high-rise buildings etc. A few of the code requirements are designed to limit pressure or temperature for health & safety reasons. Excessive pressures can cause vitreous china fixtures to violently rupture. The plumbing code typically addresses health and safety issues. There are not many design or code requirements for saving energy, saving water, and the codes generally do not address system designs to related to sustainable design features and efficiency other than water flow rates.
Life Cycle Cost Design Considerations

The plumbing system design can make a significant difference in life cycle operating and maintenance costs. Often, the least expensive system to install uses the most energy and costs more to maintain over the life of the building. A single pump design using pressure reducing valves on the lower floors can cost 4 to 5 times more to operate than multi-pump water booster systems with separate risers for each pressure zone. Generally, the first cost is cheaper for the single pump system. I have found in my 40 years of experience that a developer will typically build the building for the cheapest first-cost and will sell it shortly thereafter because a developer is not concerned with operating and maintenance costs. Generally, developers are concerned with profit, speed and ease of installation over quality and lower operating and maintenance costs. However, many institutional or corporate clients will prefer the higher quality, more expensive first-cost designs to reduce the operating and maintenance costs for the life of the building.

The plumbing code language in the International Plumbing Codes or Uniform Plumbing Codes is very similar. They have requirements for prevention of cross connections or backflow prevention, they have minimum and maximum pressure requirements, and specific requirements for waste and vent stacks for buildings over 3 stories tall. There are many other code requirements which would apply to high-rise buildings, but the code is silent with respect to system design issues mostly because the code organizations do not want to be too prescriptive with design requirements because they do not want to be too design restrictive. The model codes generally try to allow for modern technology or new methods of construction if it is determined that it provides an equivalent level of health and safety.

This is where a specific design can lead to money wasted because of equipment wearing out prematurely in high rise buildings. When a high rise building plumbing system fails, it can leave the building occupants without water and basic hygiene for many hours or days if they need to order special parts.

As an expert in plumbing system design, and as a forensic investigator of plumbing and mechanical system failures, I have investigated many problems in high-rise buildings. The problems have included: Booster pump sizing; lack of back-up or multiple pumps, lack of multiple water heaters for back-up, systems that exceeded the maximum and minimum pressure zone requirements; water heater pressure zone issues that caused the pressure relief valves to constantly discharge water; domestic hot water return pumping pressure, flow and system balancing issues; and, drainage and vent stack pressure issues. As you can see pressures are very important in high rise buildings.

Pressure Conversions:

Pounds per square inch vs Kilopascals vs feet of head vs meters of head

The pascal (Pa) or kilopascal (kPa) as a unit of pressure measurement is widely used throughout the world and has largely replaced the pounds per square inch (psi) unit, except in some countries that still use the imperial measurement system or the US customary system, including the United States where I live & work.

Converting Head Elevation to Pressure

The following equations are used to convert from different units of measurements for pressure.

Converting head in feet to pressure in psi

Pumps characteristic curves in feet of head can be converted to pressure - psi - by the expression:

\[ p = 0.433 \times h \times SG \]

where:

\( p \) = pressure (psi)

\( h \) = head (ft)

\( SG \) = specific gravity of the fluid

0.433 = Conversion factor pressure psi per foot of head

Converting head in meter to pressure in bar

Pumps characteristic curves in meter of head can be converted to pressure - bar - by the expression:

\[ p = 0.0981 \times h \times SG \]

where:

\( p \) = pressure (bar)

\( h \) = head (m)

\( SG \) = specific gravity of the fluid

0.0981 = conversion factor for head in meter to pressure in bar
Converting head in meter to pressure in kg/cm²

Pumps characteristic curves in meter of head can be converted to pressure - kg/cm² - by the expression:

\[ p = 0.1 \times h \times SG \]

where:
- \( p \) = pressure (kg/cm²)
- \( h \) = head (m)
- \( SG \) = specific gravity of the fluid
- 0.1 = Conversion factor from head in meters to kg/cm²

Converting Pressure to Head

Since pressure gauges often are calibrated in pressure - psi or bar - a conversion to the heads commonly used in pump curves - like feet or meter - may be required.

Converting pressure in psi to head in feet

\[ h = 2.31 \times p / SG \]

where:
- \( h \) = head (ft)
- \( p \) = pressure (psi)
- \( SG \) = specific gravity of the fluid
- 2.31 = Conversion factor feet of head per 1 psi

Converting pressure in bar to head in meter

\[ h = p \times 10.197 / SG \]

where:
- \( h \) = head (m)
- \( p \) = pressure (bar)
- \( SG \) = specific gravity of the fluid
- 10.197 = Conversion factor for pressure in bar to head in meters

Converting pressure in kg/cm² to head in meter

\[ h = p \times 10 / SG \]

where:
- \( h \) = head (m)
- \( p \) = pressure (kg/cm²)
- \( SG \) = specific gravity of the fluid
- 2.31 = Conversion factor for pressure in psi to head in feet

For example: For converting Pump pressure in feet of head to pressure in psi

The pressure - psi - of a water pump operating with head 120 ft can be calculated as:

\[ p = \frac{120 \text{ ft}}{2.31} = 52 \text{ psi} \]

Example - Converting Pressure - psi - to Pump Head - feet

The head in feet water column can be calculated from pressure 100 psi as:

\[ h = \frac{2.31 \times 100 \text{ psi}}{1} = 231 \text{ ft} \]

Where:
- specific gravity of water = 1 feet of head water to psi

Pounds per square inch

The pound per square inch or, more accurately, pound-force per square inch (symbol: Lbs/in²; abbreviation: psi) is a unit of pressure. It is the pressure resulting from a force of one pound-force applied to an area of one square inch: One pound per square inch is approximately 6894.757 Pa.

Kilopounds per square inch

The kilopounds per square inch (ksi) is a scaled unit derived from psi, equivalent to a thousand psi (1000 lbf/in²). Kilopound per square inch (ksi) are not widely used for gas pressures. They are mostly used in materials science, where the tensile strength of a material is measured as many psi.

The conversion in SI Units is 1 ksi = 6.895 MPa, or 1 MPa = 0.145 ksi.

Elevation Head Pressure Facts:

For every foot (0.3048 Meters) in elevation, a water column in a pipe can build up 0.433 pounds (2.9854299 Kpa) of pressure.

So for every story of 10 feet (3.048 meters) there is a 29.8542Kpa increase in pressure

PSI Pressure Conversions:

| psi ↔ pa | 1 psi = 6894.744825 pa |
| psi ↔ kPa | 1 psi = 6.894745 kPa |
| psi ↔ cPa | 1 psi = 689474.482549 cPa |
| psi ↔ mPa | 1 psi = 6894744.825494 mPa |
| psi ↔ uPa | 1 psi = 6894744825.494 uPa |
| psi ↔ N/m² | 1 psi = 6894.744825 N/m² |
| psi ↔ Bar | 1 Bar = 14.5038 psi |
| psi ↔ mbar | 1 psi = 68.947448 mbar |
| psi ↔ ubar | 1 psi = 68947.448255 ubar |
| psi ↔ kgf/m² | 1 kgf/m² = 70.3068306 kgf/m² |
| psi ↔ kgf/cm² | 1 kgf/cm² = 14.223595175051 psi |
| psi ↔ kgf/mm² | 1 kgf/mm² = 1421.941764706 psi |
psi —> gf/cm² 1 psi = 70.30683 gf/cm²
psi —> lbf/in² 1 psi = 1 lbf/in²
psi —> ksi 1 ksi = 1000 psi
psi —> msi 1 msi = 100000 psi
psi —> lbf/ft² 1 psi = 144 lbf/ft²
psi —> lbf/yd² 1 psi = 1296 lbf/yd²
psi —> torr 1 psi = 51.71484 torr
psi —> cmHg 1 psi = 5.171484 cmHg
psi —> mmHg 1 psi = 51.71484 mmHg
psi —> inHg 1 psi = 2.036025 inHg
psi —> Inch mercury (60F) coefficient: 2.041768
psi —> inAg 1 psi = 27.680622 inAg
psi —> ftAg 1 psi = 2.306719 ftAg
psi —> atm 1 atm = 14.695975011122 psi

Ksi Pressure Conversions:
ksi —> pa 1 ksi = 6894744.825494 pa
ksi —> kPa 1 ksi = 6894.744825 kPa
ksi —> cPa 1 ksi = 6894744.825494 cPa
ksi —> mPa 1 ksi = 6894744.825494 mPa
ksi —> uPa 1 ksi = 6894744.825494 uPa
ksi —> N/m² 1 ksi = 6894744.825494 N/m²
ksi —> Bar 1 ksi = 68.947448 Bar
ksi —> mbar 1 ksi = 689474.48255 mbar
ksi —> ubar 1 ksi = 6894744.825494 ubar
ksi —> kgf/m² 1 ksi = 70306.306237 kgf/m²
ksi —> kgf/cm² 1 ksi = 70306.306237 kgf/cm²
ksi —> kgf/mm² 1 kgf/mm² = 1.4219411764706 ksi
ksi —> gf/cm² 1 ksi = 70306.306237 gf/cm²
ksi —> psi 1 ksi = 1000 psi
ksi —> lbf/in² 1 ksi = 1000 lbf/in²
ksi —> msi 1 msi = 1000 ksi
ksi —> lbf/ft² 1 ksi = 144000 lbf/ft²
ksi —> lbf/yd² 1 ksi = 1296000 lbf/yd²
ksi —> torr 1 ksi = 51714.840249 torr
ksi —> cmHg 1 ksi = 51714.840249 cmHg
ksi —> mmHg 1 ksi = 51714.840249 mmHg
ksi —> inHg 1 ksi = 2036.025042 inHg
ksi —> Inch mercury (60F) coefficient: 2041.768364
ksi —> inAg 1 ksi = 27680.62163 inAg
ksi —> ftAg 1 ksi = 2306.719618 ftAg
ksi —> atm 1 ksi = 1469597.5011122 psi

The code is a minimum, so it does not address many of the performance and energy savings issues that make good engineering sense for an energy efficient or sustainable plumbing system. Some of the common problems that I find when investigating problems in high-rise building plumbing systems are domestic cold and hot water system pressure zone problems. Problems occur when the designer or contractor fails to pay attention to the minimum requirements for pressure and maximum requirements for pressure in a plumbing system. These pressures limitation are what establish pressure zones within buildings. Most problems in high rise systems occur when people try to stretch these pressure zones or when they try to circulate hot water through pressure reducing valves.

Developer vs Owner Construction

The model plumbing codes are a minimum document for health and safety and they are not developed to address all the engineering issues associated with high-rise buildings. Another issue is, most high-rise buildings are built by developers who want to build a building for the cheapest first cost without any concern for energy or maintenance costs. A developer wants to build it as cheap as possible, some even get it certified as being green in order to market it to people as energy efficient and then sell it to someone else who will have to deal with the high energy and maintenance costs over the life of the building. Often these developer-built high-rise building use four times as much energy as a building with a properly engineered domestic water booster pump system.

A typical developer-built high-rise building may have a single or duplex booster pump in the basement serving the entire building with pressure reducing valves on all of the lower floors where the supply pressure exceeds 80 psi. This type of system design with a single booster pump package and pressure reducing valves is a very energy and maintenance inefficient plumbing system, but many buyers/owners are stuck with this design if they buy a building with this design concept.

Pressure Reducing Valves = Energy Wasting Valves

Most of these developer-built buildings have pressure reducing valves or what I call “Energy Wasting valves” on the bottom floors. On the top of the building, the upper floors do not require pressure reducing valves. This design will waste hundreds of thousands of dollars or millions of dollars in energy over the life of the building.
depending on the building size. I have always said if you have pressure reducing valves in your design, it is not a Green plumbing system design.

I would like the green certification programs to consider not awarding certifications to a building utilizing PRVs because of their massive energy waste. They should take points away for every floor operated downstream of a PRV in a high-rise water distribution system. There are some exceptions for Pressure reducing valves to reduce normal water pressures down to lower pressures for make-up water to hydronic systems, final rinse water in dishwashers, etc.

There are different quality levels of valves and pumps, and, often in the developer-built buildings, the valves and pumps may be of the lower quality, less expensive type that tends to fail more often. The pumps in this type of design tend to have seal failures and leaks; the lower quality pressure reducing valves typically experience wear on the seats, especially as the pressure differential grows. Even high-quality pressure reducing valves will experience problems with significant pressure differentials across the valve seat. The pressure differentials can be addressed by reducing the pressure in stages, which the developers typically do not want to spend the money on. When the pressure reducing valve wears out, this is often referred to as wire drawing. This causes more money to be spent purchasing replacement parts and more money to be spent on labor to replace the pumps and pressure reducing valves. Wire drawing of valves occurs when high velocity water shoots across the seat of a control valve and any sediment or scale in the water can score the less expensive (softer) valve seats. After a brief period of time, it looks like someone took a hack saw or wire saw and cut a groove in the valve seat. As the valve continues to wear, it loses its ability to maintain downstream pressure, and, during periods of non-use, the downstream pressure can reach the same pressure as the upstream pressure. This can lead to exploding toilets, bursting pipes, flooding, leaking faucets and toilets, which is a significant waste of water when the supply pressure goes from 60 pounds per square inch to, say, 360 pounds per square inch.

**Pipe Pressure Ratings**

There are different categories of high rise buildings as far as design of the water system is concerned. The taller the building is, the higher the pressure rating will be required for the pipe, valves and fittings. Each pipe material has different pressure classifications. It is important to make sure you are using the correct pressure classification for a high-rise building. Often in these developer-built buildings, the water riser is rated at a higher pressure and all piping downstream of the pressure reducing valve is rated at the lower pressure rating. When the pressure reducing valve on a lower floor fails the higher pressure is exposed to the lower pressure rated pipe, valves, fittings and fixtures. The ideal or green and sustainable plumbing design would not use pressure reducing valves. (energy wasting valves).

The plumbing designer should determine the minimum required pressure for the governing fixture on the top floor and make sure the minimum pressure will be maintained during peak flow periods. The designer must also consider the maximum allowable pressure in the plumbing system which is 80 PSI in most model codes in order to protect vitreous china fixtures from damage. If the most demanding (governing) plumbing fixture at the top of the building requires 35 PSI minimum at the top of a pressure zone and the highest pressure allowable per code at the bottom of the pressure zone is 80 PSI a building with floors ten feet (3.048 meters) apart can have about nine or ten floors per pressure zone depending on the friction loss and pipe sizing. The elevation head pressure and allowable friction loss associated with the pipe sizing will dictate how many floors should be in a pressure zone. In the above example if the pipe sizing is generous, then there can be ten floors. If pipe sizing is smaller and velocities and corresponding friction losses are higher, then only nine floors should be in a pressure zone. For example: Elevation head loss is 0.433 per foot of elevation. If the floors are 10 feet from finished floor to finished floor the elevation pressure loss for every floor will be 4.33 pounds per square inch (29.854299 Kpa per floor). The key here is to have enough water pressure on the top floor of a pressure zone to allow the fixture to operate as designed.

The codes address the minimum pressures at the fixtures and they address maximum static water pressures in the water distribution system where they require water pressure reducing valves or regulators where the water pressure exceeds 80 pounds per square inch (psi). The Plumbing fixtures listed in chapter 6 of the model plumbing codes list minimum flowing pressures or residual pressures at each fixture. For example, a bathtub, shower or bidet requires a minimum of 20 psi flowing pressure. That would likely be about 22
psi static pressure. A water closet, siphonic type, flushometer valve requires a minimum of 35 psi residual (flowing) pressure. The newer 1.6 and lower water closet tank type fixtures require 20 psi where the older higher flow models required a minimum pressure as low as 8 psi. Many newer models of water conserving water closets rely on the water supply pressure to force the flow into the bowl and trap as part of the design and operation of the fixture with minimum pressures as high as 45 psi. If the minimum and maximum pressures are not adhered to problems are likely to occur.

**Maintenance issues**

2As with any type of building that has full time maintenance staff some of the problems associated with plumbing system failures begin with the hiring of the maintenance staff. If the building owner does not hire properly trained or certified maintenance staff, the owner should at least pay for or encourage their staff to seek out training that addresses the care and maintenance for the systems they are hired to maintain. I have seen many failures where the maintenance staff contributed to the failure because they did not know what they were doing. For example: firing a boiler before opening the water fill valve. Then realizing they forgot to fill the boiler with water then opening the fill valve and letting cold water rush into a red hot boiler. Boom! The owner just bought a new boiler.

**Domestic water Pressure Booster Pump Start-up**

Another common failure is when there is a prolonged power failure and the tenants in the building can drain the water from the piping system before the power is restored. The maintenance staff must shut-down the domestic water booster pumps so that they do not start-up with no water in the riser. I have seen the results of pump start-ups that were not done properly and it can blow the piping apart causing flooding. If a pump starts up with no water in the downstream piping, there is no backpressure on the pump, so it will operate at the end of the pump curve. This increases the flow volume significantly and the velocity increases also. It is not unusual to see water velocities close to 12-15 feet per second which will pack a whale of a punch when the water in the pipe gets to a fitting like an elbow or tee. The rule of thumb for water hammer is 60 times the water velocity is the potential water hammer pressure spike that can occur. Many failed large diameter pipes have led to significant flood incidents with tens of millions of damages in high rise buildings when pumps have been started-up after a period of down time. If there is a power outage or even a planned outage for draining the piping and replacing pressure reducing valves, which occurs many times per year with the PRV designs. The maintenance personnel must be trained to follow pump manufacturer’s start-up procedures when a domestic water booster pump system has shut-down long enough for the water to be drained from the riser (more than a few minutes). Some pump controls are designed to require a manual start-up after a power failure for this reason.

Water hammer will occur when a pump starts-up and must be controlled by turning off the pump during the outage and closing off all the valves. When the power is restored, the maintenance staff must open a faucet or two at the top of the building (or utilize an automatic air vent) to vent out the air from the high points in the system and then partially open one valve on the booster pump package and manually run one (smaller) pump until water comes out of the fixture(s) at the top of the building. This will slowly introduce water into the system to prevent the water hammer associated with all of the booster pumps coming on with an empty pipe which can blow apart the pipe or fittings and flooding a high rise building.

**Pressure Zones to Avoid High Pressure Rated Pipe, Valves & Fittings**

There are several ways to design the water distribution system in a high-rise building. The most efficient system design utilizes a separate booster pump for each pressure zone in the building up to about 40-60 stories in height (depending on floor to floor height). When the height of the building gets much higher the pressure rating of the pipe, valves and fittings must be higher and the cost goes up. In ultra-high-rise designs they often use a water supply pipe to a suction tank for a higher zone domestic water booster pump and piping system to begin with a higher-pressure zone which may feed the suction tank for even higher-pressure zones if needed. There are many additional issues with these types of ultra-high-rise systems that may include by-pass valves, isolation valves, overflow drains, relief valves, etc. This allows lower pressure pipe, valves and fittings to be used on the lower floors of ultra-high-rise buildings.

For buildings that utilize 300 psi fittings and below (Maximum height 40-60 floors depending
on floor to floor height) multiple booster pumps with dedicated risers for each pressure zone could be used for each pressure zone with no pressure reducing valves. This saves a lot of energy as compared to a single large booster pump which is designed for the full flow and head requirement for the building.

Using one pump with pressure reducing valves would be like carrying many large buckets of water up 100 flights of stairs so that someone can take a sip of water then pour all of the rest of the water down the drain or out a window. There was a lot of energy wasted carrying all that water up to the top floor when only a six-ounce cup of water was needed to satisfy the demand for a drink. This is what happens when a very large booster pump package is installed at the base of a high-rise building and pressure reducing valves are used to reduce the pressure on the lower floors. It wastes tons of energy!

**Maintenance Staff Training issues**

I stayed on the top floor in a high-rise hotel building in Florida not long ago. I had an early flight so, I woke up at 3:45 am to get ready for my flight. When I got in the shower, there was a gurgling sound when I turned on the faucet, but no water was coming out. I tried the sink, not water, more gurgling sounds. It sounded like the faucet was sucking air in instead of flowing water out. I packed up, took the elevator down to the ground floor and drove my car around the complex to the front lobby. As I was driving, I noticed all of the irrigation zones were flowing at the same time which were apparently on the domestic cold water booster pump. This must have used up all the pressure needed to raise the water up to the upper floor, where I was staying. The irrigation system was apparently on the same domestic water booster pump as the hotel rooms in the tower.

I stopped by the front desk to let them know about the problem and suggested they adjust the timing on their sprinkler zones so that they don’t all go off at the same time. The maintenance guy showed up while I was checking out and I told him, I could not get any water from the shower this morning and he said he would go check the boiler & turn the hot water temperature up. I explained the hot
water temperature was not the problem, it was the sprinkler system and too many zones were flowing at the same time. I explained that the domestic water system at the top of the building was being starved by all the sprinkler zones at the ground level flowing simultaneously. At that moment, he reminded me that he had been working there for over 5 years and he worked his way up the building maintenance and he knew what he was doing and he assured me it was a boiler thermostat problem. I told him it was only the gurgling sound of air rushing in so in was probably not a water heater temperature problem. His eyes closed as he seemed to be trying to comprehend what I just told him. He mumbled something like he was still going to check the boiler temperature anyway as he walked away. This made me wonder if there were a lot of problems with the hotels water temperature in the past and this guy would run down to the boiler room and adjust the water heater temperature.

On the plane, I wrote a letter explaining the problem and the hotel chains chief engineer replied to my letter and he explained they changed the cartridge in the room and that should take care of it. I had to follow up with another letter to explain it to the hotel engineer that changing the cartridge would not solve the problem.

**Material substitutions**

There have been lots of cases where material substitutions have been made. It is important for the engineer, contractor and owner to verify the pressure ratings, thermal expansion properties and temperature ratings of the substituted materials to make sure the piping is installed in accordance with the pipe manufacturer’s instructions. In one high-rise building near New York City, CPVC plastic pipe was installed for the domestic hot water piping in a very tall building. When the water heaters were turned on and hot water started flowing, the linear thermal expansion of the riser pipe was such that the pipe grew upward almost 2 feet (0.6 meters) and snapped off a branch pipe on an upper floor causing tens of millions of dollars in water damage on lower floors.

**Do Not Circulate Through Pressure Reducing Valves**

I have seen many high-rise building designs where the water heaters are located in the ground floor or in a penthouse. In these poorly designed buildings, as the water riser goes up in the building it has pressure reducing valves on the lower floors. When the hot water system is distributed this way, there is no way for circulation of the domestic hot water across the pressure reducing valve. In many cases the inexperienced designer, contractor or developer discovers this after the building is built. Then a re-pressurization pump is added on every floor to inject the hot water return back into the hot water return system so the water can flow back to the water heater. These systems are the worst energy violators of all. Pressure reducing valve usually don’t last very long in hot water service and are constantly being replaced. The best solution is to provide local water heaters. If you are going to use central water heaters, the solution is to design the system with the water heater within the pressure zone.

Many of these issues should be considered for inclusion in the green codes or energy codes. At the very least when designing or constructing high-rise buildings we should strive to address these issues before the building is built.