Healthcare-acquired infections (HAIs) affect 5–10 percent of patients (more than 1.7 million) admitted to acute-care hospitals and long-term care facilities annually. The average cost of treating a patient with an HAI is about 100 percent greater than the cost for normal treatment.

Beyond effects on the patients themselves, HAIs also contribute to lower productivity and higher absenteeism in healthcare facility staff and increased use of consumables to treat a pathogen outbreak. All of this translates into an annual direct medical cost of between $35.7 and $45 billion to the healthcare industry, most of which is not reimbursable to hospitals and other facilities.

Despite the alarmingly high number of HAI incidences, at least one-third of these are believed to be preventable. While numerous actions can be taken to reduce incidences of HAIs, their prevention begins with sound building design practices on the part of design professionals. When designing a healthcare facility, plumbing engineers need to be mindful of the practices that promote and hinder the spread of infectious pathogens.

PATHOGENS

About 90 percent of HAIs are caused by bacteria. Although waterborne bacteria make up a small part of the total number that may reside in a healthcare environment, the high mortality rate that some of them carry is of particular concern. Furthermore, colonies of waterborne bacteria can adhere to pipe surfaces and form protective layers of biofilms, making them resistant to disinfection.

Not all people in a healthcare building are equally susceptible to HAIs. Patients with compromised immune systems for example, infants and the elderly, as well as organ and bone marrow transplant, dialysis, HIV/AIDS, and chemotherapy patients—are at the highest risk. Patients who are not immuno-compromised but have open wounds are also susceptible. Areas where these people frequent should be given particular attention during design.

Plumbing engineers should be mindful of the following three primary waterborne bacterial pathogens when designing hospital plumbing systems.

LEGIONELLA

Legionella is probably the most common and recognized waterborne bacteria in a healthcare setting. When Legionella-contaminated water is aerosolized and aspirated, it can cause a pneumonia-like respiratory infection known as Legionnaires’ disease (legionellosis). The mortality rate of this condition in hospitals can be as high as 40 percent. Less frequently, Legionella can cause a milder flu-like condition known as Pontiac fever.

Legionella is of particular concern in hot water systems since it grows optimally in temperatures ranging from 95 - 115°F. At lower temperatures, it propagates less rapidly or becomes dormant, and it dies more quickly as temperatures increase, as shown in Figure 1 and Table 1.
PSEUDOMONAS AERUGINOSA
Pseudomonas aeruginosa tends to colonize in frequently used drains, but it can also be found in therapy pools and on other wet surfaces with stagnant water. When it occasionally contaminates domestic water piping, it is usually due to cross-connections with waste systems. Water contaminated with Pseudomonas aeruginosa becomes most problematic when it becomes aerosolized by splashing. This aerosolized water can then directly contaminate water used to treat patients while also settling on equipment and other surfaces in patient treatment areas. This can lead to a number of serious conditions including skin rashes, wound and bloodstream infections, and pneumonia.

Pseudomonas aeruginosa can survive in temperatures ranging from 40 - 110°F and grows optimally in temperatures ranging from 77 - 108°F. It dies more quickly as temperatures increase, as shown in Table 2.

ACINETOBACTER BAUMANNII
Acinetobacter baumannii colonizes in many of the same places as Pseudomonas aeruginosa - although it can survive for nearly a month on dry surfaces as well - and generally spreads in the same ways. It has shown resistance to a number of antibiotics and can cause life-threatening conditions including meningitis, pneumonia, and skin, wound, and bloodstream infections. Cases of Acinetobacter baumannii infections are most frequently reported in intensive-care units with patients with skin damage and open wounds. Its optimal growth range is 95 - 113°F, and it typically dies within 15 minutes when exposed to temperatures of 145°F and more.

CODE AND STANDARDS IMPLICATIONS
National and state plumbing codes have some requirements that help in designing against outbreaks of waterborne bacteria. However, other guidelines and standards, as well as plumbing design best practices, should also be followed to furnish more adequate protection. In particular, the Facility Guidelines Institute’s Guidelines for Design and Construction of Hospitals and Outpatient Facilities, ASPE’s Plumbing Engineering Design Handbooks, and ANSI/ASHRAE Standard 188-2015: Legionellosis: Risk Management for Building Water Systems provide clearer design direction.

FGI 2014 GUIDELINES
The FGI Guidelines encompass emergency departments, primary-care facilities, several types of hospitals, and several specialty treatment facilities. They are written with a definite focus on HAI prevention and patient safety. Even if a given project is not required to follow the Guidelines, plumbing engineers may still find the following requirements helpful in establishing a foundation against the spread of waterborne pathogens.

Water Features
Improperly maintained water features have been a culprit in several outbreaks of Legionnaires’ disease. Inadequate cleaning combined with stagnant water allow the feature to become a reservoir for Legionella and other opportunistic pathogens. Water features were merely discouraged in previous versions of the Guidelines, but they are expressly prohibited in the 2014 release.

Fish tanks are treated differently and are allowed in public areas only if they are kept covered.

Potable Water Storage Tanks
Potable water storage tanks, both hot and cold, can also become reservoirs for pathogens, especially if they are not used constantly. As such, the Guidelines only allow potable water storage tanks if they are required for an emergency water supply or if they are intended for constant use.

Hot Water Piping
Piping containing heated, stagnant water provides an opportunity for pathogens to grow, especially Legionella, and the Guidelines focus on limiting such piping. As such, all heated potable water serving patient-care areas must be under constant circulation. Non-circulated fixture branches are never allowed to be longer than 25 feet, but the maximum length varies with pipe size (see Table 3).
In addition, dead ends are prohibited in heated water systems, and any such piping in a remodel project must be removed. Dead-end piping may be installed if it is intended for future use, but it must remain empty until put into service.

The Guidelines also establish hot water delivery temperatures for three facility areas (see Table 4). Note that these temperatures are only required at the point of use; hot water storage and circulation temperatures are allowed to exceed them.

Finally, the Guidelines require treatment of heated water systems to control Legionella and other pathogens. The minimum for meeting this requirement is to store hot water at 140°F; other acceptable treatment methods are discussed later.

**Fixture Considerations**

Splashing water is a common culprit in the spread of pathogens into the air and onto nearby surfaces, patients, and staff. Pathogens are also spread by patients and staff touching surfaces with infectious material on them. The Guidelines are written with the intent of minimizing both, and their associated requirements for plumbing fixtures are discussed later.

**ANSI/ASHRAE STANDARD 188-2015**

The recently published ANSI/ASHRAE Standard 188: Prevention of Legionellosis Associated with Building Water Systems is intended to establish minimum legionellosis risk management requirements for building water systems. While primarily intended for use by building owners and managers during occupancy, plumbing engineers can also draw on some of its requirements for use in the design of plumbing systems.

ANSI/ASHRAE 188 does not make recommendations for one method of Legionella control over another. Rather, it makes plumbing system designers, facility managers, and owners ultimately responsible for understanding their building water systems, identifying areas that are at the most risk, installing and implementing methods to control and monitor Legionella levels, maintaining water systems and Legionella control measures, and having procedures to deal with outbreaks if they occur. The full text of the standard is available on the ASHRAE website. It is up to plumbing designers to read and understand the standard and its implications, design plumbing systems that conform to the standard, and work with their clients to develop system maintenance and outbreak eradication procedures once a building is occupied.

**DESIGN CONSIDERATIONS**

When designing plumbing systems to prevent outbreaks of waterborne bacteria, plumbing engineers should consider both proactive and reactive approaches. Proactive approaches are those intended to prevent outbreaks before they occur and are implemented during the design and construction phases - material, fixture, and equipment selection, as well as sound design practices and chemical treatment are examples. Reactive approaches are those taken by building management staff to eradicate an outbreak after it has occurred - for example, thermal eradication, hyperchlorination, and ozonation. To design for the appropriate reactive approaches, plumbing engineers should work with their clients during design to develop plans for dealing with outbreaks and then include design elements that allow for those plans to be implemented.

**PROACTIVE APPROACHES**

**Material Selection**

Selection of the appropriate piping materials can be critical when designing for waterborne bacterial control. Consideration of other proactive and reactive measures that may be used often drives the decision. If hot water is to be circulated at temperatures above those optimal for bacteria growth, the piping must carry adequate thermal ratings. Similarly, drain piping must be adequately rated if thermal eradication is to be considered to eliminate bacteria outbreaks. Metal piping such as copper and stainless steel have been traditional choices for higher-temperature applications, but high-temperature plastics such as CPVC may also be considered. Copper also has inherent antimicrobial characteristics that make it difficult for bacteria to colonize on it.

The plumbing engineer should also consider any possible chemical injection. Antimicrobial chemicals such as chlorine and ozone are corrosive and will degrade most metal piping, whereas plastics such as CPVC and polypropylene are resistant.
Fixture Selection

Plumbing engineers should select fixtures carefully. First note the areas of the building where immunocompromised patients are likely to reside. Once these high-risk areas are identified, the engineer should select fixtures and accessories that minimize the risk of becoming contaminated with and spreading pathogens.

Choosing appropriate faucet outlets in high-risk areas is important. Faucet outlets should not be equipped with aerators since bacteria can colonize in them, and waterborne pathogens often spread when contaminated water is aerosolized into the air. Laminar flow outlets are a better choice since they do not aerate water, although bacteria can still grow in them if they are not cleaned regularly. Faucets with open spouts and flow controls at their base minimize both of these risks.

Waterborne bacteria can also spread when patients and staff touch contaminated surfaces. Therefore, fixtures that can be operated without or with minimal use of the hands should be considered. Faucets with sensor, knee, or foot controls should be considered in sterile, sub-sterile, and isolation areas. Wrist-blade and single-lever faucets can be operated without the use of hands but are more appropriate in lower-risk areas.

The Guidelines require faucets in handwashing sinks in patient care areas to angle away from the sink strainer and not discharge directly onto it. They must also discharge a minimum of 10 inches above the bottom of the sink basin. The outlet water pressure should be reduced to the point that splashing does not occur at maximum flow; the Guidelines do not specify an exact pressure setting, but 50 pounds per square inch (psi) is commonly used. Handwashing sink basins must also have a minimum area of 144 square inches to minimize splashing and the risk of patients and staff touching basin surfaces. Furthermore, faucet controls must be able to operate without the use of hands; single lever or 4-inch wrist-blade handles are acceptable. Electronic faucets may also be used; however, they must function during a failure of normal building power. Splashing risks can be further reduced if the faucet discharges onto an inclined surface, as some specialty sinks offer, although the Guidelines do not require this.

Clinical service sinks present a higher infection hazard than handwashing sinks and therefore must also have faucets that can be operated without using the hands. Single-lever or wrist-blade faucets are acceptable, although wrist blades must be 6 inches long. Surgical scrub sinks must be operated completely hands-free and can only be equipped with foot, knee, or sensor controls.

Other Design Best-Practices

Several other plumbing design practices limit the risk of pathogen outbreaks. First, water piping with dead-ends is susceptible to bacteria and biofilm growth. It therefore should be avoided in new construction and removed in remodels. Second, fixtures that aerosolize or splash water (water features, aerators, misters, etc.) should not be used.

Elevated Temperature Circulation

The pathogens discussed here grow optimally in stagnant, warm water. To avoid this, water should be delivered through constantly circulating loops and heated to a temperature above optimal growth ranges—a minimum of 124°F is advised by FGI. Engineers may go further by circulating water at 140°F or higher, which kills pathogens more quickly.

In the latter case, handwashing and bathing fixtures should be equipped with point-of-use thermostatic mixing valves to prevent scalding, although some plumbing codes require them at lower temperatures. This method’s effectiveness increases further when mixing valves are kept close to the fixtures and runouts from the mains are kept short. While it can carry high material and labor costs, many engineers and building managers prefer this method due to its relatively low maintenance.

Chlorine Dioxide Injection

Chlorine dioxide injection is perhaps the most commonly used method for controlling bacteria in domestic water. Chlorine dioxide gas is a biocide and disinfectant that is broadly effective in attacking bacteria and penetrating biofilms. It may be injected into domestic hot and cold water systems, and when kept to low concentrations (0.2–0.5 ppm), it does not significantly corrode metal piping. However, concentration levels vary with distance from the source equipment and therefore must be monitored to ensure that all areas of the system are adequately protected.

Chlorine dioxide must also be generated on-site, and the chemical precursors must be refilled occasionally. The source equipment is generally expensive.

Copper-Silver Ionization

Certain positive metal ions can bond to negatively charged bacterial cell walls and cause cell death, a process called the oligodynamic effect. Positively charged copper and silver ions can thus be injected into hot water systems to control opportunistic
pathogens and penetrate biofilms. This has been an effective long-term approach for many hospitals in reducing and eliminating Legionella, and it exhibits a residual effect even when the source equipment is turned off. Since high water pH levels - 8.5 and above according to some reports - can reduce its effectiveness, water quality must be monitored. In addition, it is less effective on infrequently used fixtures and low-demand systems. Ion concentrations at fixture outlets should be monitored to ensure that they do not exceed allowed levels. Finally, the equipment is costly, and the copper and silver electrodes must be occasionally replaced.

Ultraviolet Germicidal Irradiation (UVGI)
Ultraviolet light kills bacteria by disrupting its nucleic acids. UV lamps can be placed at a single point or several points in a domestic water system to irradiate bacteria as it passes through. Some studies have shown UVGI to have a significantly faster kill rate of Legionella than chlorine dioxide, ozone, and heat treatment. However, it is only effective at single points in small water systems, and bacteria that survive irradiation are free to cause contamination elsewhere. UV lamps usually require replacement once a year, and it can be labor intensive to do so.

Point-of-Use Filters
Sterile water filters can be quickly placed on faucets to keep waterborne bacteria from spreading into patient areas. The effects are often immediate, and some studies have reported 50 percent or greater decreases in Legionella and Pseudomonas aeruginosa infections in intensive care units. Disposable filters require a significant financial and maintenance commitment since they must be replaced weekly. Reusable filters require frequent cleaning and must be handled carefully to prevent contamination.

REACTION APPROACHES

Thermal Eradication
Thermal eradication - also called superheat and flush - involves circulating water at temperatures that kill bacteria quickly and then flushing it out through all points of use. Water should be heated to 140 - 160°F and circulated for as long as 72 hours before all outlets are opened simultaneously. Although the 2003 Centers for Disease Control and Prevention (CDC) guidelines recommend keeping them open for five minutes, other studies suggest that this is not sufficient and recommend at least 30 minutes. Some other studies recommend that flushing temperatures be maintained at 160-170°F and also that a 30-minute flush at least be attempted, but that the outlet flow rates should not surpass water heater capacity to maintain temperature.

While this procedure is one of the most effective and commonly used methods in dealing with waterborne bacteria outbreaks, the coordination involved is labor intensive. Fixtures protected by thermostatic mixing valves are less affected, and those that are not pose a scalding risk to patients and staff.

Finally, plumbing engineers need to consider this option during design and select water heaters with enough capacity to sufficiently flush the system at the required temperature.

Hyperchlorination
Hyperchlorination is another effective procedure that requires flushing contaminated water systems with 2 - 6 ppm or higher of free chlorine bleach or chlorine gas. Chlorine dioxide may also be used, although some studies suggest that it is less effective.

Once the target concentration is met, the system is often closed and held for as long as 24 hours, drained through the fixtures, flushed, and returned to service. Prior versions of ASHRAE 188 recommendations were even more aggressive; free residual chlorine levels in that case were recommended to be raised to 20 - 50 ppm, maintained at 50 ppm for one hour or 20 ppm for two, and then flushed out.

Facilities with metal water piping should use hyperchlorination sparingly as it is highly corrosive. In addition, the pH of the water must be monitored and not rise above 8 as that significantly reduces chlorine efficiency. All fixtures must also be taken out of service during the procedure.

Ozonation
Ozone gas has germicidal properties and can be injected into contaminated areas of a domestic water system to disinfect the immediate vicinity. Its effects are limited by the quick degradation of ozone molecules and vulnerability to changes in water quality. Since the effects are localized, contaminated areas of piping should be identified before using it. Ozone generators are also costly.

CONCLUSION

HAIs are a serious concern in the healthcare industry and carry significant human and monetary costs. Plumbing engineers have a role in reducing them and have many technologies, products, and design methods at their disposal to do so. Understanding and identifying the risks combined with employing sound design practices to minimize HAIs are the first steps in the right direction. Our clients and their patients are counting on us.
REFERENCES


