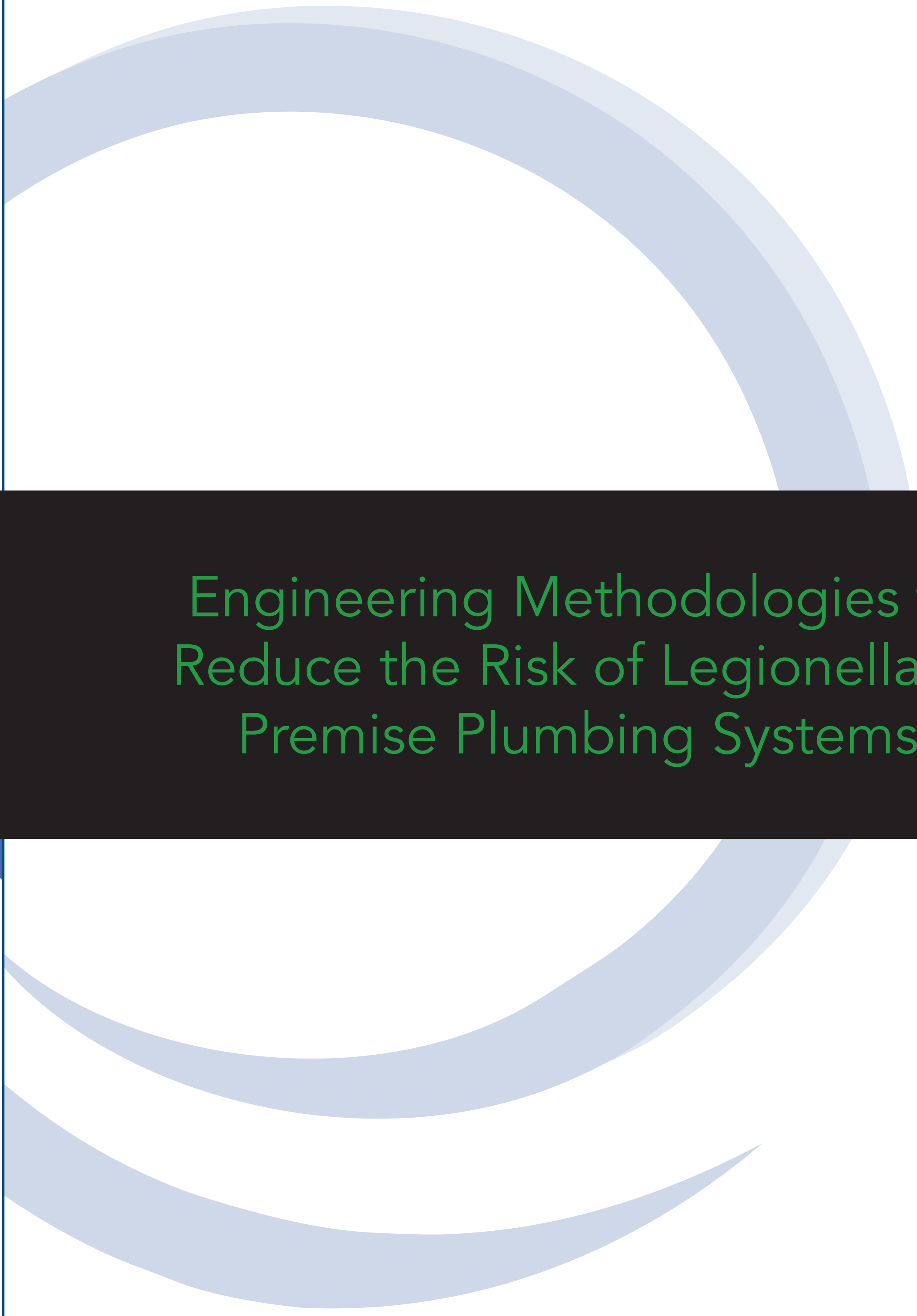

Engineering Methodologies to Reduce the Risk of Legionella in Premise Plumbing Systems

ASPE
American Society of Plumbing Engineers™

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Working Group Members
Christoph Lohr, PE, CPD, LEED AP BD+C, Chair, IAPMO
David Dexter, FNSPE, FASPE, CPD, CPI, LEED BD+C, PE, 3D Engineering Consultants, LLC
Dann Holmes, Building Water Health Technical Consulting, LLC
Carol Johnson, CPD, LEED AP, CFI, FASPE, Dewberry Edmonds
James Dipping, PE, CPD, GPD, LEED AP BD+C, ARCSA AP, Environmental Systems Design
John Lansing, CPD, LEED Green Associate, PAE Consulting Engineers
Ramiro Mata, ASPE
Joe Scott II, CPD, LEED AP, FASPE, Cannon Design
Billy Smith, FASPE, ASPE
Kevin Wong, Uponor
Gary Klein, Gary Klein and Associates, Inc.

Foreword

I. Contextual Overview of Legionnaires' Disease Case Increases

The United States has been witnessing an increase in premise plumbing waterborne pathogens such as *Legionella* year after year. According to the U.S. Centers for Disease Control and Prevention (CDC), reported Legionnaires' disease cases increased nine-fold from 2000 to 2018. As the scientific community has made many improvements in their methods of testing, so has the medical profession in seeking additional testing for their patients suffering from pneumonia-related symptoms to determine if they have contracted Legionnaires' disease. As the number of detectable *Legionella* cases rises, industry professionals need to understand the factors that have played a role in these increases. They include but are not limited to:

- Reductions of water flow in plumbing fixtures to conserve potable water usage (i.e., LEED and EPA WaterSense);
- Plumbing system design using outdated Hunter's curve data, resulting in oversized water supply piping;
- Reduced hot water temperatures required to meet local and national energy codes;
- Prioritizing scald-prevention measures by using reduced hot water temperatures over bacterial growth in building water systems;
- The current state of deteriorating municipal water infrastructure and water quality regulations; and
- Lack of implementation of plumbing engineering designs to minimize the risks related to the growth of waterborne pathogens.

By acknowledging the unintended consequences of some of the decisions that have been made by and for the water and plumbing industry, plumbing engineers can begin to take the proper corrective actions. Parts II through VI below further expand on these contextual items.

Note: This plumbing design guideline focuses predominantly on the bacterium *Legionella* pneumophila (*L.* pneumophila), as it is one of the most robust waterborne pathogens known. Much of the scientific research community theorizes that by implementing design strategies to minimize the opportunity for *Legionella* to grow in premise plumbing systems*,* the risks associated with other waterborne pathogens are also minimized. This guideline focuses on *Legionella* with the full realization that other waterborne pathogens, while also concerning, are left unmentioned. The control of *Legionella* may have unintended consequences against other organisms. However, that is not the purpose of this design guideline. As science advances, the gaps in this guideline will be updated to include plumbing design/engineering strategies to minimize other waterborne pathogens.

Every effort has been made in this design guideline to follow the International System of Units (SI), 2019 edition (2008 where applicable), of NIST SP 300. Temperatures, fluid volume, lengths, etc., will follow the SI unit with an Imperial (IP: inch/pound) equivalent in parenthesis, e.g., 60°C (140°F).

II. History of *Legionella*

Legionella and premise plumbing system engineering and design are deeply intertwined in history. One cannot discuss the history of *Legionella* without mentioning potable plumbing systems in some way. Therefore, to provide a better context to the plumbing engineer/designer, this guideline will look at not only the history of *Legionella*, but also the story of some of the contributing design factors.

The year 1976 stands out in many ways. The average cost of a home was about $43,000, the Dow Jones Industrial Average barely topped 1,000 points, and gasoline cost $0.59 per gallon on average. 1976 also stands out definitively because on July 4th the United States celebrated the bicentennial anniversary of the founding of the United States of America. Americans gathered across the country to celebrate this monumental national achievement.

One such gathering was the annual convention of the American Legion in Philadelphia. On July 21st, approximately 2,000 Legionnaires assembled at the Bellevue-Stratford Hotel in downtown Philadelphia to celebrate their past and plan for the future. Unfortunately, two weeks later, many of those futures were cut short: 130 attending Legionnaires and pedestrians who had walked by the hotel had been hospitalized with symptoms of tiredness, lung complications, chest pain, and fever. Of those experiencing these pneumonia-like symptoms, 34 died.

The CDC investigated this tragedy and found that a cooling tower located on the roof of the Bellevue-Stratford Hotel was contaminated with bacteria. The water plume (drift) from the cooling tower, laden with an unidentified bacterium, migrated onto the sidewalk below, infecting nearby Legionnaires and pedestrians. Because of the severity of this outbreak and how it affected so many members of the American Legion, the medical term “Legionnaires’ disease” (LD) was given to this deadly pneumonia-like illness, and the name “*Legionella*” was given to the bacteria that caused the outbreak.

III. Hunter’s Curve [1]

Dr. Roy Hunter of the National Bureau of Standards developed the first well-known probabilistic method for predicting **peak** water flow rates in domestic water systems. His impact on premise plumbing system design in the United States cannot be overstated. Published in 1940, the Fixture Unit Method, or Hunter’s curve, pipe sizing methodology is currently required in plumbing codes throughout the United States and variations throughout the world. By using a probability of simultaneous use and fixture flow rates, Hunter developed a dimensionless number that would allow the plumbing engineer/designer to reduce the size of the plumbing piping system. The first half of this dimensionless number was created by assuming that the number of fixtures that would be “on” would be staggered in use. This unit of probability was based on a 99% certainty of use for a given plumbing fixture. To put it another way, 99% certainty equates to the plumbing fixture being used by person “A,” who then steps away and person “B” immediately takes their place and uses the fixture. This unit of probability of simultaneous use was combined with the flow rate of the plumbing fixture (based on a water closet), and the dimensionless number was thus named a “plumbing fixture unit.” This was a truly amazing development that has become the widespread *de facto* method of sizing plumbing piping systems in the United States.

However, despite its common use in present times, there are two major concerns of using Hunter’s curve as it relates to *Legionella* risk mitigation.

The first concern, risk mitigation, is easily identified: the volumetric water consumption rates of plumbing fixtures have changed drastically since 1940. A great example of the changes in water volumes is in water closets. Prior to 1980, water closets used between 18.9 and 26.5 liters per flush (Lpf) (5 and 7 gallons per flush [gpf]). In 1980, the U.S. Environmental Protection Agency (EPA) mandated that flow rates be less than 13.3 Lpf (3.5 gpf) to help conserve water. In 1994, the EPA again reduced the maximum flow rate of water closets to 6.1 Lpf (1.6 gpf) to further reduce water usage. Since Hunter’s curve was developed, the volumetric water consumption of a water closet has been reduced 77%. Other plumbing fixtures such as showers, urinals, sinks, and lavatories have also been similarly reduced since 1940.

The second concern revolves around the probability of plumbing fixture use. As previously stated, the curve was developed to predict a 99% certainty of use that equated to a fixture being used, turned off, and then used again by a different person. This frequent usage of plumbing fixtures upon which Hunter’s curve was based resembles a sports stadium at halftime or a theatre at intermission. However, not every building type has this type of usage rate. Hospitals, office buildings, and schools, among others, all have much lower usage rates, while the sizing of the piping is designed as if they were higher.

Based on the concerns above, the issue becomes readily apparent: with Hunter's curve and the fixture unit value required in almost all plumbing codes in the United States and Canada, premise plumbing systems being designed and built today and in the foreseeable future for potable water are now oversized in such a manner they dramatically increase the risk of waterborne pathogen proliferation, dramatically increase water use, dramatically increase construction costs and construction space used for plumbing, and significantly increase energy consumption, and are thus detrimental to public health and safety. Due to the probability of fixture use, most buildings that fall under ANSI/ASHRAE Standard 188-2018: *Legionellosis: Risk Management for Building Water Systems* have oversized potable plumbing systems to the extent that the volume of fresh water cannot replace “old” water quickly enough, thereby causing disinfectant (e.g., chlorines) to dissipate while water slowly moves through the piping system (this will be discussed further in the next section). This issue has been exacerbated by the reduction in flow rates, further slowing the velocity of water and the replenishment rate of disinfectant in the potable plumbing system. Hunter’s work was left unfinished by his death in 1940, and the U.S. is reaping the consequences of this unfinished work today in the form of waterborne pathogens proliferating, sanitary sewer systems clogging, and more.

IV. Epidemiology and Contributing Factors

Strains

Legionella bacteria come in multiple strains and classifications (e.g., *L.* adelaidensis, *L.* Iondiniensis, etc.). Currently, there are more than 58 known species. Predominantly, when discussing Legionnaires’ disease, most often what is being discussed is the genus, species, and serogroup (e.g., *Legionella* pneumophila serogroup 1). *Legionella* pneumophila serogroups 1, 3, 4, and 6 have been linked to disease in humans, with *L.* pneumophila serogroup 1 being the most virulent strain that accounts for most LD outbreaks in the U.S. and the world. ASHRAE Guideline 12: *Minimizing the Risk of Legionellosis Associated with Building Water Systems* lists four contributing factors to the growth of *Legionella* in plumbing systems: water temperature, water quality, water age, and disinfectant residual. Water age is linked to temperature and disinfectant residual and therefore will be discussed within those factors. For the purposes of this guideline, aerating plumbing fixtures and humans with compromised immune systems will also be included as contributing factors to contracting Legionnaires' disease.

Water Temperature

TABLE A[63]

TEMPERATURE	***LEGIONELLA* KILL TIME (lab conditions)**
≥70°C (≥158°F)	*Legionella* bacteria die instantaneously.
66.1°C (151°F)	*Legionella* bacteria die after 2 minutes.
60°C (140°F)	*Legionella* bacteria die after 32 minutes.
55°C (131°F)	*Legionella* bacteria die after 5–6 hours.
≥51°C to ≤55°C (≥124°F to ≤131°F)	*Legionella* bacteria can survive, but do not multiply.
≥20 C to ≤50 C (≥68 F to ≤122°F)	Temperature range for *Legionella* bacteria growth
35°C to 46°C (95°F to 115°F)	Optimal temperatures for *Legionella* bacteria growth
≤20°C (≤68°F)	*Legionella* bacteria can survive but are dormant.

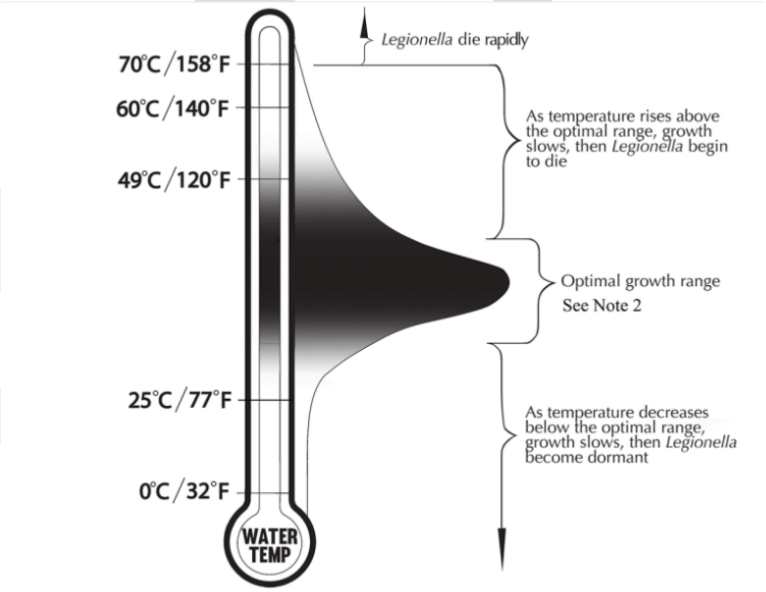
Note: The conditions listed in Table 1 are in laboratory conditions. The times have been shown to be affected by biofilm and/or scale, which act as insulators/incubators protecting the bacteria from higher temperatures.

Water temperature is the most widely known contributing factor to *Legionella* bacteria growth. The temperatures above from ASHRAE Guideline 12 and UPC Appendix N, which is based on ASHRAE Guideline 12 temperatures, are accepted standards of care. The key temperature range for plumbing system designers to be aware of is the ideal growth range for *Legionella* 29°C to 43°C (85°F to 110°F), and these temperatures should be avoided at all costs. Also, plumbing designers should be aware that the growth range for *Legionella* is 25°C to 45°C (77°F to 113°F). Maintaining temperatures in all parts of the hot water circulating system outside of this range is critical for *Legionella* risk management. In the United States, commercial domestic hot water systems are required to be circulated by most model codes, or the temperature must be maintained within the system with a heat trace temperature maintenance system. The latest iterations in the International Plumbing Code (IPC), for instance, require any hot water piping systems in excess of 15.24 meters (50 feet) of developed length to be circulated. The intent of a domestic hot water circulating system is to minimize the temperature loss from the water heater through the piping system. For example, if the water heater is set at 60°C (140°F), the engineer may try to design the system so the hot water return to the water heater is at no less than 55.5°C (132°F) from the hot water piping. Scalding is a serious concern. Historically, a common design practice to prevent scalding was to operate domestic water systems at a lower temperature. This directly contradicts the recent trend to provide higher water temperatures to minimize conditions that encourage *Legionella* bacteria growth. Another solution is to provide anti-scald mixing valves at all points of use, to ensure the contact temperature at the fixture cannot exceed 49°C (120°F). This permits recirculation temperatures above 49°C (120°F). Additionally, the latest energy codes mandate that recirculation pumps turn off when water temperatures are met, which also actively works against *Legionella* risk mitigation strategies.

A number of standards and regulations address the subject of minimum temperatures within domestic hot water piping and storage tanks. While the minimum temperature varies depending on the region, all standards listed in Table 1 recommend or require temperatures no less than 45°C (113°F) within the domestic hot water and return piping. All standards listed in Table 1, except for SANS 10252-1, recommend or require a storage temperature no less than 60°C (140°F).

ASHRAE Guideline 12-2020

Temperature Effects on Survival and Growth of Legionella in Laboratory Conditions



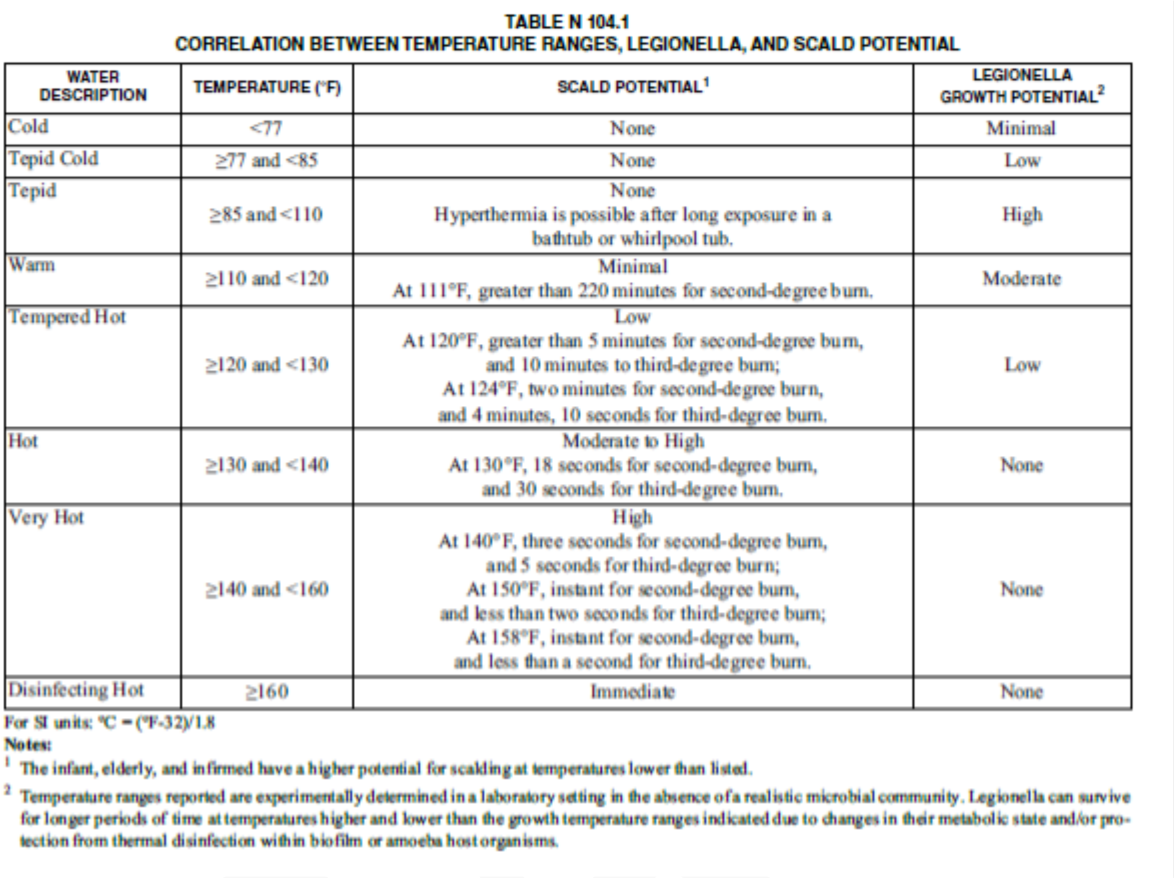


TABLE N 104.1
CORRELATION BETWEEN TEMPERATURE RANGES, LEGIONELLA, AND SCALD POTENTIAL

WATER DESCRIPTION	TEMPERATURE (°F)	SCALD POTENTIAL[1]	LEGIONELLA GROWTH POTENTIAL[2]
Cold	<77	None	Minimal
Tepid Cold	≥77 and <85	None	Low
Tepid	≥85 and <110	None Hyperthermia is possible after long exposure in a bathtub or whirlpool tub.	High
Warm	≥110 and <120	Minimal At 111°F, greater than 220 minutes for second-degree burn.	Moderate
Tempered Hot	≥120 and <130	Low At 120°F, greater than 5 minutes for second-degree burn, and 10 minutes to third-degree burn; At 124°F, two minutes for second-degree burn, and 4 minutes, 10 seconds for third-degree burn.	Low
Hot	≥130 and <140	Moderate to High At 130°F, 18 seconds for second-degree burn, and 30 seconds for third-degree burn.	None
Very Hot	≥140 and <160	High At 140°F, three seconds for second-degree burn, and 5 seconds for third-degree burn; At 150°F, instant for second-degree burn, and less than two seconds for third-degree burn; At 158°F, instant for second-degree burn, and less than a second for third-degree burn.	None
Disinfecting Hot	≥160	Immediate	None

For SI units: °C = (°F-32)/1.8

Notes:

[1] The infant, elderly, and infirmed have a higher potential for scalding at temperatures lower than listed.

[2] Temperature ranges reported are experimentally determined in a laboratory setting in the absence of a realistic microbial community. Legionella can survive for longer periods of time at temperatures higher and lower than the growth temperature ranges indicated due to changes in their metabolic state and/or protection from thermal disinfection within biofilm or amoeba host organisms.

Table 1 - Comparison of Standard Temperatures for Domestic Hot Water Circulation Systems

Publication	National Standard	Minimum Allowable Circulation Temperatures		
		In Piping	Fixture Outlets	Hot Water Storage Tank
SANS 10252-1	South Africa	45°C (113°F)	N/A	55°C (131°F)
GB 50015-2019	China (PRC)	45°C (113°F)	113°F (45°C) within 15 seconds[a]	60°C (140°F)
ASHRAE Guideline 12-2020	United States	49°C (120°F)	49°C (120°F)[b]	60°C (140°F)
HSG 274, BS 8558	United Kingdom	50°C (122°F)	50°C (122°F) within 60 seconds or 0.5L (0.13 gal)	60°C (140°F)
BFS 2014:3	Sweden	50°C (122°F)	NA	60°C (140°F)
WHO	United Nations	50°C (122°F)	50°C (122°F) within 60 seconds	60°C (140°F)
Quebec Construction Code (2021)	Province of Quebec (Canada)	55°C (131°F)	N/A	60°C (140°F)
AS/NZS 3500.4:2021	Australia & New Zealand	55°C (131°F)	N/A – not specified but 45°C (113°F) for vulnerable people	60°C (140°F)

			and 50°C (122°F) for non-vulnerable (e.g. healthcare vs. commercial facility)	
W 551, DIN 1988-200	Germany	55°C (131°F)	55°C (131°F) within 30 seconds	60°C (140°F)
NEN 1006, ISSO 55.1	Netherlands	60°C (140°F)	60°C (140°F) within 15 seconds	60°C (140°F)

[a] 15 seconds for residential occupancies and 10 seconds for healthcare and hotel occupancies

[b] While no maximum wait-time for hot water or maximum volume of water between circulated main and fixture is listed in ASHRAE 12, FGI Guidelines are applicable for healthcare facilities and establish a limit of 0.7 L (24 ounces), equivalent to 4.9 m (16 ft) for DN 15 (½-inch) piping.

Water Quality

Water quality across North America varies greatly, even between one city and the next. Water quality includes items such as the disinfectant used, turbidity, pH, total organic compounds, hardness level, and suspended solids, among others. The wide variance of water quality from one location to another is one of the many reasons that a single approach or solution to *Legionella* control is not feasible. Studies have shown that scale buildup inside premise plumbing systems acts as a nutrient source for biofilm and *Legionella* bacteria and can lead to inefficiencies in water heaters. It is estimated that for every 17.1 g/m^3 (ppm) (1 grain per gallon) of water hardness, water heater efficiency is reduced by 4%[2]. Scale can also build up within piping systems, most notably galvanized steel or copper piping. This scale development reduces flow and creates an environment for biofilm growth, and thus bacterial development. Additionally, poor water quality can reduce disinfectant efficacy. Sediment in the water can also interfere with UV efficacy. In one Legionnaires' disease outbreak, acidic pH levels in a newly changed water supply leached lead from the public water piping system, weakening the immune systems of the people who contracted LD.

Disinfectant Residual

In the United States, water purveyors often use chlorine (in the form of free chlorine, monochloramine, etc.) to disinfect public water supplies. Chlorine has been used in the United States since first introduced into the public water system in Jersey City, NJ, in 1908 to help protect the public from waterborne pathogens. The challenge with disinfectants is that they tend to dissipate in water over time. Changes in water quality or temperature can have major effects on the residual of these disinfectants. Because of the uncertain dissipation timeframe of disinfectants in water, the age of the water is a very real concern when it comes to risk mitigation. Additionally, the answer is not as simple as adding more disinfectant. Excessive amounts of certain disinfectants such as chlorine in a water system can lead to the creation of disinfectant by-products. These by-products are known carcinogens to humans.

Aerating Plumbing Fixtures

Aerating plumbing fixtures have two concerns regarding *L.* pneumophila: (1) the aerating action allows for the transmission of *L.* pneumophila to a person's lungs by the person inhaling the bacteria-laden water vapor, and (2) aerating plumbing fixtures also typically promote low flow rates, which increase the water age in plumbing systems.

Immuno-Compromised People

Not all people who inhale water vapor/droplets laden with *L.* pneumophila develop Legionnaires' disease. Rather, typically those with compromised immune systems (e.g., more than 65 years old, diabetic, former or current smoker, ICU patients, etc.) are most susceptible to developing LD. Therefore, extra precautions should be taken to protect these immuno-compromised populations.

V. General Design Discussion

In 2015, ASHRAE Standard 188 was first published with the intent to instruct the construction industry and facility operators on best practices to mitigate the risk of *L.* pneumophila outbreaks. The CMS (Centers for Medicare & Medicaid Services) adopted ASHRAE 188 first in June of 2017 and then revised their compliance requirements in July of 2018[3] to clarify expectations for providers, accrediting organizations, and surveyors.

VI. Other Waterborne Pathogens

While this design guide is directed primarily at mitigating the risk of *Legionella* pneumophila, it is important to note that there are many different types of waterborne pathogens (WBP) and other opportunistic premise plumbing pathogens (OPPPs) in the domestic water supply. Not all design strategies indicated in this guide will have an impact on other WBP and OPPPs; in fact, some studies are finding that non-*Legionella* OPPPs proliferate when superheated and flushes occur. It is worth considering premise plumbing systems as small ecosystems, where a symbiotic balance occurs between all the different organisms and materials in the water. When one of these elements is removed, the system is thrown out of balance, which can result in different (and potentially more) harmful WBP or OPPPs causing health concerns to users of the premise plumbing system.

Understanding "Best Practices" in the Context of a Design Guide

The Working Group that developed this design guide considers a "best practice" as "a procedure that has been shown by research and experience to produce optimal results and that is established or proposed as a standard suitable for widespread adoption." In the context of this design guide, the procedures indicated and described as "best practices" are those that the Working Group in charge of this document have found to be the most prudent means of engineering premise plumbing systems to reduce *Legionella* development and eradicate existing *Legionella* bacteria. This knowledge is based on a vast amount of research in scientific studies, reviews of other industry-accepted papers and guidelines, and many years of personal, practical experience in the plumbing engineering field. It is on this basis that the Working Group offers this document with an elevated level of confidence that the recommendations made are in fact "best practices" and provide readers with the ability to engineer systems to keep the public as safe as possible from contracting Legionnaires' disease.

Understanding Cost in the Context of a Design Guide

Engineers often are required to balance cost in every step of the design process. In this design guide, the Working Group considers the practices outlined as an occupant life-safety concern. The Working Group understands that these practices will exceed code minimum requirements, etc.; however, as mentioned above they are considered "best practices" in the ongoing quest to reduce *Legionella* development in premise plumbing systems. Engineers have a duty to their clients as consultants, and as such it is their responsibility to make clients aware of the options they have and let them choose how to spend their money. It *is not* an Engineer's responsibility to decide for them or assume a design solution is too expensive. It *is* the Engineer's responsibility to educate clients on what they will get should they decide to spend their money or not. With that said, this design guide is provided so the Engineer can know their options to present the solution(s) best suited for their client.

Guideline

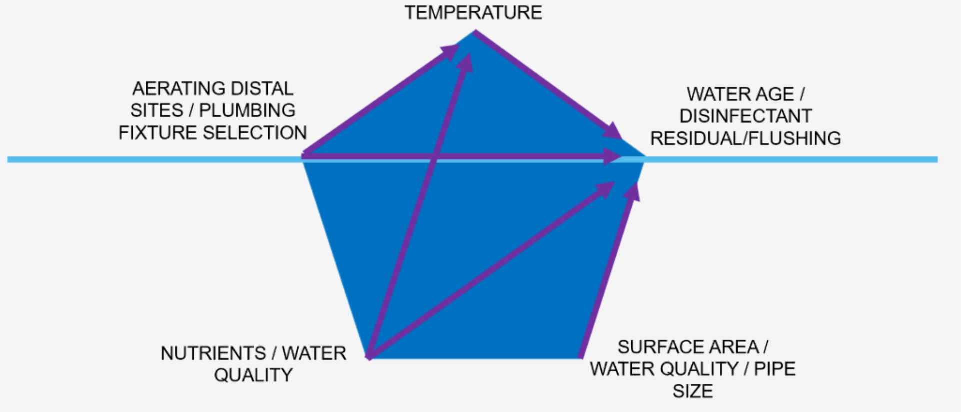
1. General
    - 1.1. Purpose – The purpose of this guideline is to establish the best practices necessary to minimize disease and injury from *Legionella* pneumophila bacteria related to building water systems.
    - 1.2. Scope
        - 1.2.1. The minimum practices established by this guideline apply to the design of potable and nonpotable systems and their associated components. This includes new structures and retrofits of existing plumbing systems.
        - 1.2.2. This guideline applies to human-occupied buildings except single-family residential buildings.
        - 1.2.3. The intent of this guide is to provide guidance and best practices in reducing *Legionella*. Engineers should understand that it is still their responsibility to coordinate and incorporate design provisions to allow for the servicing and maintenance of any equipment or plumbing items mentioned or affected by recommendations in this guideline.
    - 1.3. Unit of Measure – SI units are used in this guideline. Inch/pound units are shown in parentheses. The values stated in each measurement system are equivalent in application, but each unit system is to be used independently. Combining values from the two measurement systems can result in non-conformance with this guideline. All references to gallons are to U.S. gallons. All conversion factors have been rounded off for ease of use.
    - 1.4. References
        - 1.4.1. ASHRAE 188
        - 1.4.2. ASHRAE Guideline 12
        - 1.4.3. CSA B651-12 (R2017): *Accessible Design for the Built Environment*
        - 1.4.4. ASME A112.18.1-2012/CSA B125.1-12 (R2017): *Plumbing Supply Fittings*
        - 1.4.5. ICC/ANSI A117.1-2017: *Accessible and Usable Buildings and Facilities*
        - 1.4.6. "Developing a Water Management Program to Reduce Legionella Growth & Spread in Buildings," CDC (https://www.cdc.gov/legionella/downloads/toolkit.pdf)
        - 1.4.7. "Responding to Stagnant Water in Buildings with Reduced or No Water Use," American Water Works Association and IAPMO
        - 1.4.8. "Recommended Practices for the Safe Shutdown and Startup of Building Water Systems Due to Emergency," IAPMO
    - 1.5. Definitions
        - 1.5.1. Recirculation: Hot water withdrawn from the domestic hot water distribution system and passed through the domestic hot water heater (generator) or storage tank to be reheated before being supplied once again to the domestic hot water distribution system. While the term "recirculation" does not technically exist, colloquially speaking it has existed in the plumbing profession for many years. Something is in either a static condition or, when acted upon by an external force, a dynamic condition (as in being circulated). For the purposes of this guideline, the term is defined and related to the return system within the domestic potable hot water system. The "re" in recirculation is the process of moving the same fluid through the system more than once.

- 1.5.2. Circulation: The movement or flow between the boiler, hot water generator, heat exchanger, etc., and the associated storage tank. Both circulation and recirculation accomplish the same purpose: the movement of a fluid (water in this case) throughout the piping distribution network and associated equipment. This is generally a continuous movement within the system.
- 1.5.3. Distal Site: A plumbing fixture identified by the engineer to be one of the furthest from a source, such as incoming water service or central hot water heating system. This fixture is identified for further testing purposes.
- 1.5.4. Point of Use (POU): The final outlet of the water supply system just prior to discharge to atmosphere.
- 1.5.5.Low Flow Fixtures: A plumbing fixture that utilizes a flow rate below the listed flow rate in the nationally harmonized plumbing codes (UPC, IPC, NPCC) as determined by ASME A112.18.1/CSA B125.1.
- 1.5.6. Primary Disinfectant: The “first” means of disinfecting water to maintain its potability; the disinfect that is introduced by the municipal supplier into their distribution system.
- 1.5.7. Secondary Disinfectant: The means by which the municipal supplier maintains the disinfectant residual throughout the entire water system to inhibit the growth of biofilms.
- 1.5.8. Supplemental Disinfectant: Process(es) installed to augment or enhance the level of disinfectant provided by the municipal supplier or improve the residual level of disinfectant available at the premise point of entry.
- 1.5.9. Residual Disinfectant: The quantity of active disinfectants that remains within the premise distribution system to protect against various pathogens within the system.

2. Building Type
   - 2.1. Refer to ASHRAE 188 for various building criteria that should be considered high risk. In general, but not limited to, the following building types should follow this guideline:
     - 2.1.1. Inpatient and outpatient healthcare facilities
     - 2.1.2. Long-term care facilities (including elderly, disabled, and behavioral care)
     - 2.1.3. Hotels, resorts, and spas
     - 2.1.4. Apartments
     - 2.1.5. Condos
     - 2.1.6. High-rise (more than 10 stories) office buildings
     - 2.1.7. Dormitories
3. Risk-Reduction Methodologies

3.1. Contributing Factors for a *Legionella* Case
  3.1.1. Temperature – *Legionella* grows more rapidly in some temperatures than others.
  3.1.2. Aerating Distal Sites/Plumbing Fixture Selection – Plumbing fixture selection not only can impact the flow of water in building and municipal water systems, but also can become a transmission source via aerosolization.
  3.1.3. Water Age/Disinfectant Residual/Flushing – As water age increases, oxidizing disinfectants from water purveyors dissipate or are consumed in the disinfecting process. A flushing protocol of distal sites can keep more disinfectants in the water by drawing in "fresh" water with a higher residual level of disinfectant.
  3.1.4. Water Quality/Nutrients – The incoming water has the potential to contain nutrients that bacteria and biofilm will use as a food source.
  3.1.5. Surface Area/Water Quality/Pipe Size – Surface area gives *Legionella* bacteria a location on which to grow. This comes in two forms:
    3.1.5.1. Water quality, total suspended solids, and particles that come into the building water supply that the bacteria can attach to for growth locations. Removing excess particulates from the incoming water becomes an important measure to prevent growth locations.
    3.1.5.2. Pipe Size – All surfaces of a pipe present a location for bacteria and biofilm growth. Refraining from unnecessarily oversizing piping becomes important.

Figure 1 Contributing Factors for a *Legionella* Case



3.2. Inter-relation of Contributing Factors – Temperature, plumbing fixtures, water age, water quality, and surface area all relate and impact each other with varying degrees, depending on building location, time of year, and other outside factors.

3.3. Plumbing System Components and Spectrum of Results

3.3.1. Increase the Risk – Conditions inside a plumbing system that increase the risk (e.g., stagnant water, 37.8°C (100°F) hot water, no disinfectant, etc.).

3.3.2. Decrease the Risk – Steps taken during plumbing system design or building operation that help manage the risk inside a plumbing system (e.g., flushing protocol or improving flow, removing sediment of incoming water, etc.).

3.3.3. Control/Mitigate the Risk – Active measures taken to destroy or inactivate bacteria that come into a building or already exist (e.g., UV, chlorine, copper-silver ionization, etc.).

Figure 2 Plumbing System Components and Spectrum of Results

3.4. Water Quality

3.4.1. Considerations – The water quality delivered to the building must be considered in:

3.4.1.1. Specification of point-of-entry filtration

3.4.1.2. Specification of point-of-entry softening

3.4.1.3. Specification of secondary disinfection

3.4.2. Communication – The plumbing engineer/designer shall contact the water purveyor and discuss water quality and how it could impact the project and document the discussions. Topics to discuss are seasonal water quality changes, pH, disinfectant concentrations, TSS, and turbidity.

3.5. Domestic Cold Water System Design

3.5.1. Pipe Sizing – Cold water system pipes should be sized to be adequate for the area and user needs, while not being so oversized that unnecessary surface area is created upon which bacteria can grow. Plumbing engineers should work with the local AHJ (authority having jurisdiction) to determine if code variances are necessary and can be allowed to minimize pipe size (i.e., smaller than 12.7 mm (½ in.)) for public health and safety purposes, particularly when low-flow fixtures are utilized. Any oversizing of cold water systems should consider other means (e.g., supplemental disinfection) to offset the increased risk of Legionnaires' disease.

3.5.1.1. At the time of this writing, there is only one third-party alternate means to reduce the size of pipe, and that is the Water Demand Calculator located in IAPMO's Uniform Plumbing Code (UPC) (Appendix M) and WE*Stand (Appendix C) documents. This currently only applies to residential buildings, either single family or multifamily.

3.5.1.2. Pipe diameter has an impact on:

3.5.1.2.1. Velocity and Pressure Loss – As velocity increases, the pressure loss due to friction increases. Decreasing pipe diameter increases velocity as well as pressure loss.

3.5.1.2.2. Deposition – Given a constant flow rate, as pipe size reduces, velocity increases. As velocity increases, deposition decreases.

3.5.1.2.3. Water Aging – Given a constant flow rate, as pipe size reduces, water age reduces. As water age reduces, this increases the likelihood of disinfectant being present in the water, decreases the likelihood of biofilm development, and increases the likelihood of good overall water quality.

3.5.1.2.4. Cost – As pipe size reduces, material costs all will reduce.

3.5.1.2.5. Energy – As pipe size reduces, especially for hot water systems, energy costs would be expected to decrease as less water will be needed to be heated, reheated, recirculated, and stored.

3.5.2. Goals

3.5.2.1. Simplicity of Design – An engineer's goal should be to simplify design as much as possible. Every complication/component within the plumbing system is another possible point of failure. Some items to consider reducing when possible, with simplicity of design:

3.5.2.1.1. Point-of-use (POU) mixing valves

3.5.2.1.2. Electronic faucets

3.5.2.1.3. Pressure reducing valves (PRVs)

3.5.2.2. Holistic Design – The second goal for engineers should be to make sure system components that are selected and installed coordinate with each other. Thinking through unintended consequences and taking a holistic approach to the system in its entirety (i.e., "source to tap and tap to source") is vital.

3.5.3. Pressure Reducing Valves (PRVs)

3.5.3.1. Pressure reducing valves are often needed in a design to reduce the pressure below the code-mandated maximum limit at the point of discharge; most plumbing codes mandate 80 pounds per square inch (psi).

3.5.3.2. When designing a zoned system in a facility, verify that the design does not cause a large pressure differential at the plumbing fixtures. A large pressure differential between the hot and cold water systems is detrimental to the proper operation of mixing valves and may result in crossover flow.

3.5.3.3. Refer to Appendix D (3.14.4) for pressure reducing valve selection and zoned pressure zone system design. This includes minimizing PRVs used and minimizing pressure zones.

3.5.4. Water Service

3.5.4.1. Redundant Feeds – Certain building types or occupancies are often required to have multiple water service entrances. Additional considerations may need to be taken to minimize risk.

3.5.4.1.1. When one water service entrance has a normally closed valve while the other water service entrance has a normally open valve:

3.5.4.1.1.1. Hose Bibb Drainage Valve – Immediately upstream of each service entrance's isolation valve, place a hose bibb drainage valve. The hose bibb flow rate should be determined and documented. The volume of water from the city main to the isolation valve should be determined. The flush time to displace 100% of the water between the city main and the isolation valve should be determined, and signage should be added to the valve indicating “Flush this valve to drain for [X] number of minutes [prior to opening this isolation valve]” (in the event the isolation is normally closed). (Note: Flushing through a hose bibb will not normally provide sufficient velocity or turbulence to clean or scour the service line. Additionally, drawing in new water to the line may also bring some level of disinfectant. The minimal amount of disinfectant may impact the surface layer of the biofilm but will be insufficient to have any meaningful impact on the biofilm. Standing or stagnate water replacement on a non-regular basis doesn't minimize or reduce the biofilm on the piping walls.)

3.5.4.1.1.2. Slow Open Valve – For any normally closed isolation valve in water service entrances, a sign shall be installed to indicate to staff “Normally closed valve. Open this valve slowly!” The valve should be opened slowly to prevent a surge of water from dislodging debris or biofilm and carrying contaminated water sludge into the building.

3.5.4.1.2. When both water service entrances are normally open:

3.5.4.1.2.1. Coordinate with the city and civil engineers to determine if each branch will have flow.

3.5.4.1.2.2. Install a data-logging flow meter on each water service entrance to track the flow rate of each water service entrance and the cold water supply to the hot water system. Where applicable, connect the data loggers to the building management system (BMS).

3.5.4.2. Filtration – When the incoming water supply has high levels of total suspended solids filtration (1–10 microns) should be installed upstream of plumbing appurtenances such as softeners and booster pumps if incoming pressure conditions allow. Filtration removes sediment that can augment scale and biofilm growth and interfere with disinfectants. Filtration may be considered water treatment and regulated in certain jurisdictions.

3.5.4.3. Softener – Consider the installation of a water softener downstream of the RPZ backflow prevention device. Water-softening levels should be selected based on the application needed. The use of third-party tested devices is regulated by the plumbing code in certain jurisdictions. General guidance for water softener selection is as follows:

3.5.4.3.1. 0 to 51.4 mg/L (0 to 3 grains per gallon) = soft water. Water softening will not be required.

3.5.4.3.2. 51.4 to 119.8 mg/L (3 to 7 grains per gallon) = moderately hard water. Water softening will likely be considered for hot water systems only.

3.5.4.3.3. 119.8 to 171.2 mg/L (7 to 10 grains per gallon) = hard water. Water softening will likely be required for hot water systems and may be considered for the incoming cold water system, depending on the end-use applications.

3.5.4.3.4. >171.2 mg/L (10 grains per gallon) = severely hard water. Water softening should be considered for the incoming cold water system.

3.5.5. Water Storage (Healthcare) – Some healthcare requirements dictate the need for a healthcare facility to have water storage for multiple days/weeks in the event the water delivery is interrupted. The disadvantage of that requirement is that water age, stratification, and a drop in disinfectant mixing increase in storage tanks. As that is the case, supplemental water disinfection as well as mixing/circulation will likely be required for any system employing a storage tank.

Often, simply adding supplemental disinfection will not be enough. Stored water can stratify due to temperature bands, and velocities will be low or "channeled" through the stored water. Supplemental disinfection thus cannot disperse uniformly throughout the water tank. Careful consideration of design features such as a side stream loop or promoting mixing within the tank may be necessary to promote mixing of supplemental disinfection in water storage tanks.

3.5.5.5. Supplemental Disinfection – Supplemental disinfection should be considered based on the following conditions:

3.5.5.5.1. Building population's risk profile.

3.5.5.5.2. Primary or secondary disinfectants (i.e., chlorine and chloramine) in the water from the water purveyor. (Note: Where water is obtained from a municipal source, the plumbing engineer will need to work with the local purveyor as well as the EPA as the potable water processes will be altered. Generally, this implies that the owner is now acting as a public water works and needs to meet certain requirements.)

3.5.6. Water Mains and Branches – Accepted industry best practice is to utilize the smallest pipe diameter possible for mains and branches. Design professionals should design systems to reduce total system volume and thus water age[52].

3.5.7. Water Velocity – Accepted industry best practice is to utilize the smallest pipe possible for mains and branches to increase water velocities consistent with system pressure requirements. Worth noting is one study[11] that found that higher water velocities have minimal to no impact on *Legionella* or biofilm growth. In fact, that study found that a pipe with turbulent flow observed larger concentrations of *Legionella.* However, that study was limited as it only compared smaller fixture branch piping to larger water mains and branches; smaller fixture branch piping, which is often at hydraulically remote locations, likely has higher water age than water mains and branches.

3.5.8. Water Age – Due to the dissipation of oxidizing disinfectants over time, water age has been found to be a key contributor to *Legionella* amplification. As such, minimizing stagnant water conditions (such as those found in dead legs, branches supplying infrequently used fixtures, or, if applicable, improperly balanced cold water supply and return branches) should be a top priority in plumbing design. Some methodologies are:

3.5.8.1. Future Caps and Valves – Future valves and caps should never exceed 6 pipe diameters in distance from an active main.

3.5.8.2. Splitter Valves – The use of Venturi, electronic, or other similar valves split the flow of water from mains into connected branches and back. This approach circulates water closer to the fixture outlets, thereby reducing water age in fixture branches. Designers must consider the extra cost for piping.

3.5.8.3. Provide automatic (e.g., electronically controlled) faucets or flushing valves on the most remote fixtures, remote fixture branches, and/or remote piping branches to flush out the system regularly to replace oxidizing disinfectants in the piping system and/or to help promote the flow of supplemental disinfection into hydraulically remote parts of building.

3.5.9. Piping Material Selection – Piping material selection is an important part of designing a plumbing system to mitigate *Legionella* for a variety of reasons: (a) some materials possibly promote the formation of biofilms more than others; (b) some disinfectants (particularly oxidizing disinfectants) are more compatible with some pipe materials than others; (c) temperature can impact some piping materials more than others; and (d) other constructability concerns. Refer to Table 2 for a summary of considerations.

Table 2

Pipe Material	Biofilm Growth Potential	Disinfectant Compatibility Issues	Water Temperature Limits
Copper	Starts low; becomes high as piping oxidizes.	Increased susceptibility to corrosion with oxidizing disinfectants (e.g., chlorinated compounds)	82.2°C (180°F). Velocity must be reduced as temperature increases.
Carbonized Steel	High	Increased susceptibility to corrosion with oxidizing disinfectants (e.g., chlorinated compounds)	82.2°C (180°F). Velocity must be slowed as temperature increases.
Stainless Steel	Low	N/A	82.2°C (180°F)
Polypropylene Random Copolymer (PP-R)	Medium	Increased susceptibility to degradation with chlorine/chloramine over 4 ppm at 60°C (140°F). Not compatible with copper-silver ionization.	60°C (140°F)
Crosslinked Polyethylene (PEX)	High	Increased susceptibility to degradation with chlorine/chloramine over 4 ppm at 60°C (140°F). Not compatible with copper-silver ionization.	60°C (140°F)
Chlorinated Polyvinyl Chloride (CPVC)	Low	N/A	93.3°C (200°F), but piping pressure rating decreases as temperature increases.

3.5.10. Cold Water Piping Temperature

3.5.10.1. Chilling Incoming Water Service – Particularly in parts of the U.S. where the incoming cold water temperature routinely exceeds 20°C (68°F) (such as the Sonoran Desert during summer), a concern is raised that the cold water system could be a breeding ground for *Legionella*. As such, one suggestion is to bring the cold water temperature to below 20°C (68°F). There are two means of chilling the water, each with their own challenges:

3.5.10.1.1. Instantaneous Chilling – Instantaneous chilling for large incoming water mains is not a currently available technology as of the publication date of this guideline. If and when it is, it makes chilling the incoming water supply a viable technique to mitigate risk, albeit not to control or prevent *Legionella* outbreaks.

3.5.10.1.2. Storage Chilling – Storage chilling utilizes a storage tank and side-stream chiller or heat exchanger (to preheat the incoming hot water makeup to a water heater) to store incoming water and reduce the temperature to below 20°C (68°F). It is worth noting that this cools the incoming cold water and uses the heat of rejection to preheat the hot water, which could be considered a large waste of energy. It also is worth noting that this technique potentially creates other hazards:

3.5.10.1.2.1. By utilizing a storage tank, water age increases; thus, oxidizing disinfects (e.g., chlorine or chloramine) have a higher likelihood of dissipating, meaning the entire cold water system now will have less disinfectant residual, and the hot water system will have even less residual than without a cold water storage tank.

3.5.10.1.2.2. While storage chilling will reduce the risk of bacteria growth in the cold water service lines, it will not kill any amplification of bacteria upstream of the chilling. Therefore, even with chilling the water, a high amount of amplification of *Legionella* bacteria could still come into the building and colonize the cold water system.

3.5.10.1.2.3. If the incoming cold water is chilled, insulation will be required for all cold water piping to prevent condensation of cold water in the plenum. Particularly in dryer, hot climates (such as a desert), this insulation will be an added cost to the project (as cold water insulation is often omitted from projects).

3.5.10.1.2.4. Even with the insulation of cold water, the cold water will likely need to include a recirculation system[13], or the risk of the temperature increasing to above 20°C (68°F) can occur from the plenum space, thereby negating the benefits of reducing the water temperature. As cold water systems typically don't have recirculation systems, this would be a cost addition. Just as for hot water, chilled cold water systems will require sizing to follow the Hardy Cross design methodology.

3.5.10.1.2.5. Supplemental disinfection will likely be needed either after the storage tank and/or for the storage tank itself.

3.6 Hot Water System Design

3.6.1. Refer to Section 3.5 Cold Water System Design. This section is also applicable for design considerations for hot water systems and temperatures.

3.6.2. Utilize Appendix M of the 2021 UPC to estimate the demand load for the hot water supply and principal branches for single- and multifamily dwellings with water-conserving plumbing fixtures, fixture fittings, and appliances.

3.6.3. Pipe Sizing – Hot water system pipes should be sized to be adequate for the area and user needs, while not being so oversized that unnecessary surface area is created upon which bacteria can grow. Plumbing engineers should work with the local AHJ to determine if code variances are necessary to minimize pipe size (i.e., smaller than 12.7 mm (½ in.)) for public health and safety purposes, particularly when low-flow fixtures are utilized. Any oversizing of hot water systems should consider other means (e.g., supplemental disinfection) to offset the increased risk of Legionnaires' disease.

3.6.4. Hot Water Pipe Routing – Hot water pipe routing can incorporate many of the same techniques as cold water piping. However, as temperature maintenance is an additional consideration for hot water piping, the designer may wish to utilize some other techniques:

3.6.4.1. Jump Routing – Routing the hot water supply system (typically at 48.9°C (120°F)) similar to a purified water system by dropping the circulated main down to each fixture requiring hot water and back up again. This is mandated for public lavatories per the latest International Energy Conservation Code (IECC) (2015 or later).

3.6.4.2. POU TMV (Elevated Temperature) – Routing the hot water supply at 60°C (140°F) and utilizing point-of-use thermostatic mixing valves (POU TMVs) to reduce the temperature at each handwashing station and shower to below scald limits (43.3°C [110°F] or less). TMVs may require annual maintenance based on water quality and usage. See Appendix E for additional information.

3.6.4.3. Hybrid Jump/POU – A combination of routing the hot water supply system at an elevated temperature of 60°C (140°F) (or higher) close to each hot water fixture while also providing POU TMVs to prevent scalding.

3.6.5. Hot Water System

3.6.5.1. Disinfection Temperatures

3.6.5.1.1. *Legionella* Temperature Chart – There are several variations of the *Legionella* and Water Temperature Chart, one of which can be found below:

- 70°C (158°F): *Legionella* die instantly.
- 66.1°C (151°F): *Legionella* die in 2 minutes.
- 60°C (140°F): *Legionella* die in 32 minutes.
- 55.6°C (132°F): *Legionella* die in 5 to 6 hours.
- >50°C (122°F): *Legionella* survive but do not multiply.
- 20°C to 50°C (68°F to 122°F): *Legionella* growth range.
- >20.6°C (69°F): *Legionella* can survive, but do not multiply.

It is worth noting that the temperatures shown in this chart were developed in laboratory conditions and do not account for scale or biofilm, both of which can insulate and protect bacteria. This means the temperature chart in some instances could look like this:

- 71.1°C (160°F): *Legionella* die in +1 hour.
- 20°C to 65.6°C (68°F to150°F): *Legionella* growth range.
- >20.6°C (69°F): *Legionella* can survive, but do not multiply.

This was witnessed in a hospital in Germany, where *Legionella* bacteria were able to survive for over an hour in 71.1°C (160°F) water. The design water temperature should be evaluated by the plumbing engineer, and other methodologies should be considered to offset any Legionnaires' disease risk increases due to lower water temperatures.

3.6.5.2. Water Heater Selection

3.6.5.2.1. Storage Type – Storage-type water heaters are among the most common type of water heaters in use. This type of water heater uses a storage tank to reduce the amount of peak energy load supplied to the water heater. Temperature stratification can develop within these water heaters, as low-temperature water can collect at the bottom of the tank while high-temperature water rises to the top, raising some concerns about possible *Legionella* growth potential. To date, no studies have shown this correlation. A negative aspect of storage water heaters is that they slow the water velocity, thereby increasing water age and lowering disinfectant residual. (Also, at higher temperatures many disinfectants dissipate more rapidly, resulting in a lower residual.) A positive aspect is that tank-type water heaters increase the contact time of the high-temperature water with the bacteria.

3.6.5.2.2. Boiler Type with Separate Storage Tank – Boiler-type water heaters with a separate storage tank are a common water heater used often for systems with high heat-gain loads with large instantaneous (peak) flow rates (e.g., laundry rooms). The storage tank is separate from the boiler water heaters and replenished with hot water via circulation pumps located at each boiler. The advantage of this system is the large capacity. The disadvantage of this system is that the heating elements are separate from the tank, leading to system inefficiencies, along with more surface area (tank and additional piping).

3.6.5.2.3. Instantaneous Type – Instantaneous-type water heaters produce hot water at the demand hot water flow rate. Instantaneous-type water heaters occasionally are utilized with storage tanks; however, they are typically utilized without any supplemental storage. The advantage of instantaneous-type water heaters is that the water age is kept relatively lower than in storage-type water heaters. The disadvantage is that these water heaters reduce contact time between high-temperature water and bacteria. To date, no studies have shown that instantaneous-type water heaters reduce the risk of Legionnaires' disease outbreaks. When paired with a storage tank, similar concerns mentioned above would apply.

3.6.5.2.4. Evacuated-tube solar collectors can be used in parallel to water storage tanks, and in concert with an appropriate thermal mixing valve, as a source of heating water or to supplement traditional water heaters. Temperature setting of the system shall be set to allow a maximum storage temperature of 88°C (190°F).

3.6.5.3. Thermostatic Mixing Valves – Mixing valves, regardless of type, have certain physical limitations known as approach temperatures and reaction time. The associated ASSE standards provide control within a relatively narrow temperature band and can have greater temperature swings outside of the stated ASSE temperature band. Additionally, the plumbing engineer must consider the materials of construction when considering the use of thermal sterilization or hyperchlorination to cleanse the system. Either or both may have a detrimental effect on the materials of the valves or the system.

3.6.5.3.1. Mechanical Master Mixing Valves (MMMVs) – Mechanical master mixing valves use a mechanical tempering device to reduce hot water distribution temperatures and are certified to the ASSE 1017 standard. The valves do an admirable job of maintaining hot water temperatures; however, these valves also typically have a 10°C to 14°C (15 to 25°F) approach temperature. This causes challenges with supplemental disinfection and any thermal disinfection goals. As such, the suitability of these types of devices for facilities that fall under ASHRAE 188 is extremely limited. No model code requires the use of these valves.

3.6.5.3.1.1. When used, these devices shall be installed at or near the outlet of the hot water source only.

3.6.5.3.1.2. These valves are not intended for point-of-use applications.

3.6.5.3.1.3. Valves must be sized to match the flow requirements of the system.

3.6.5.3.1.4. These devices alone do not protect against thermal scalding.

3.6.5.3.1.5. To prohibit the cross-flow of hot or cold water through the valve, supplementary check valves are recommended for devices that do not include check valves.

3.6.5.3.1.6. Valves must be sized to match the flow requirement of the system:

Flow Rate	Allowable Temperature Fluctuation
0-0.3 L/s (0–5 gpm)	1.7°C (±3°F)
0.3-2.5 L/s (5–40 gpm)	2.8°C (±5°F)
2.5+ L/s (40+ gpm)	3.9°C (±7°F)

3.6.5.3.1.7 Approach Temperature Considerations - For example, a master mixing valve may have an approach temperature of 6.7°C (20°F), and if the incoming hot water is 60°C (140°F) and the cold water is 15.6°C (60°F), the "highest" tempered water temperature is 48.9°C (120°F). The valve can never produce above 48.9°C (120°F). Refer to the manufacturer's specific design criteria.

3.6.5.3.2. Digital Master Mixing Valves (DMMVs) – Also known as digital recirculation valves due to their ability to precisely control temperature and close off the hot water inlet of the valve if the recirculated water meets the valve's outlet temperature setpoint. This feature eliminates instances of temperature creep. They are master mixing valves designed for recirculating systems. Digital master mixing valves use digital readings from a temperature probe to reduce hot water distribution temperatures and are certified to the ASSE 1017 standard. These valves are superior temperature-control devices and typically have approach temperature differential of 0.5 - 1°C (0 to 2°F). For example, if a digital mixing valve's approach differential temperature is 1°C (2°F), and if the incoming hot water is 60°C (140°F) and the cold water is 15.6°C (60°F), the "highest" tempered water temperature is 58.9°C (138°F). For buildings that fall under ASHRAE 188, the use of DMMVs should be preferred over MMMVs. No model code requires the use of these valves.

3.6.5.3.3. Point-of-Use Mixing Valves (POUMVs) – Point-of-use mixing valves are ASSE 1070 compliant and have a mechanical mixing element to control temperature. They are most commonly located at a sink or lavatory to reduce the temperature to a non-scald level. Both model codes require the use of these valves at all “public” handwashing locations. These valves allow for elevated temperature levels in water mains.

3.6.5.4. Hot Water Recirculation System Engineering

3.6.5.4.1. Hot Water Recirculation Piping Design

3.6.5.4.1.1. Return Piping System – Hot water return piping systems are designed to maintain a design temperature within the hot water supply system. Hot water return systems should not be oversized as this would increase surface area, which increases risk to the facility. The flow rate must be driven by the amount of heat loss being offset, with the pipe size driven by the associated velocity needed to maintain that flow rate. Acceptable velocities are driven by the materials utilized within the system and noise concerns. Additionally, rules of thumb or general methodology should not be utilized to prevent under-sizing of the system, which could lead to stagnant branches. Refer to Appendix 3.14.1 for recommended hot water return design methodology.

3.6.5.4.1.2. Hot Water Recirculation Pipe Sizing – Hot water recirculation piping should be adequately sized, without being grossly oversized, as surface area impacts *Legionella* growth potential. Sizing of hot water recirculation piping systems should adhere to the Hardy Cross methodology and not utilize general rules of thumb. The flow rate must be driven by the amount of heat loss being offset, with the pipe size driven by the associated velocity needed to maintain that flow rate. Acceptable velocities are driven by the materials utilized within the system and noise concerns. Refer to Appendix 3.14.1 for recommended hot water return design methodology.

3.6.5.4.1.3. Hot water recirculation pipe sizing may be increased in size if supplemental disinfection, such as copper-silver ionization, is utilized to meet minimum flow rates and performance criteria to mitigate the risk of *Legionella*. The flow rate must be driven by the amount of heat loss being offset, with the pipe size driven by the associated velocity needed to maintain that flow rate. Acceptable velocities are driven by the materials utilized within the system and noise concerns.

3.6.5.4.1.4. Thermostatic balancing valves shall not be placed in series.

3.6.5.4.1.5. Routing branches from other branches shall be prohibited as this makes balancing difficult if not impossible.

3.6.5.4.1.6. Eliminate long branches. Rather than serving isolated plumbing fixtures that require hot water with a supply and return pipe, look into installing a separate water heater (e.g., POU) for the isolated fixture. Generally, any fixture more than 15 to 30 meters (50 to 100 feet) away from a circulated main should be considered. For electrical POU water heaters, coordinate with electrical engineer if adequate electrical service is available.

3.6.5.4.2. Balancing Valves – The accuracy of any balancing valve will vary with the type of valve and the hydraulic dynamics of the system within which it is installed.

3.6.5.4.2.1. Manual Balancing Valves – Manual balancing valves are a category of balancing valves that require a balancer to physically “set” the valve Cv (flow coefficient), thereby impacting the pressure and flow characteristics for the branch the valve controls. Manual balancing valves have been historically the most common type of valve.

3.6.5.4.2.1.1. Manual Balancing Valve (commonly referred to as “Circuit Setter”) (MBV) – The Cv (flow coefficient) value of adjustable balancing valves (MBVs) can be changed to revise the pressure drop of the valve and thus change the flow through the system. The advantage of these valves is that they are adjustable; the disadvantage is that any revision to a plumbing system would require every valve to be rebalanced. MBVs require a Test & Balance (T&B) report; if no report is received by the plumbing engineer, the system needs to be considered incomplete and incorrectly installed. The formula used to determine the pressure and flow of an MBV is as follows:

$$\text{gpm} = \text{Cv}\sqrt{\frac{\Delta P}{\text{SG}}}$$

$$\Delta P = \left(\frac{\text{gpm}}{\text{Cv}}\right)^2 \text{SG}$$

Where:
Lpm = Liters per minute (gpm = gallons per minute)
Kv = flow coefficient (metric) (Cv = flow coefficient (Imperial))
Delta P = change in pressure, kPa (psi)
SG = specific gravity

3.6.5.4.2.1.2. MBVs shall be rebalanced each time the hot water system is renovated, modified, or revised. MBVs are best used in facilities that will not have a lot of renovation projects, as the entire system will require a rebalance before and after renovation.

3.6.5.4.2.2. Automatic Balancing Valves – Automatic Balancing Valves are valves that do not require any system balancing, as they control the flow through their branch automatically.

3.6.5.4.2.3. Fixed Pressure-Independent Control Valve (FPICV or “Cartridge Type”) – Pressure-independent control valves are valves that modulate their pressure drop automatically to maintain the rated flow rate of the cartridge. They are self-balancing and do not require testing and balancing. However, any desired adjustment to change the flow rate through the FPICV entails removing and replacing the “flow” cartridge. Additionally, mineral buildup within the internal components may reduce the accuracy of the valve.

3.6.5.4.2.4. Adjustable Pressure-Independent Balancing Valve (APIBV) – Adjustable pressure-independent balancing valves are valves that modulate their pressure drop automatically to maintain a flow rate that can be adjusted by a dial on the side of the valve. They are self-balancing and do not require testing and balancing. However, they are a newer device and have yet to gain widespread familiarity.

3.6.5.4.2.5. Fixed Thermostatic Balancing Valve (FTBV) – Fixed thermostatic balancing valves are balancing valves that utilize a fixed cartridge set for a specific temperature that modulates the pressure and flow to maintain said temperature. These valves have a fixed cartridge with a small Cv range, which results in lower pressure drops. Though they are self-balancing and do not require testing and balancing, they may require additional calculations to determine the corresponding head and flow rates for the recirculation pump. Another consideration is that to change the temperature setpoint, the physical cartridge needs to be replaced. These valves are also subject to mineral buildup, which reduces their accuracy.

3.6.5.4.2.6. Adjustable Thermostatic Balancing Valve (ATBV) – Adjustable thermostatic balancing valves are balancing valves that can have adjustable temperature setpoints and modulate the flow and head to maintain the setpoint temperature. They are self-balancing and do not require testing and balancing and can be adjusted by the valve in lieu of replacing a cartridge. However, they have an adjustable cartridge with a large Kv (Cv) range, which can result in higher pressure drops. The higher Kv (Cv) valve can also lead to slower reaction times within the system, causing the potential of reduced flow through the system, which could lead to stagnant conditions. Additionally, these valves may require additional calculations to determine the corresponding head and flow rates for the recirculation pump. Finally, these valves are also subject to mineral buildup, which reduces their accuracy.

3.6.5.4.2.7. Electronically Actuated Balancing Valve (EABV) – Electronically actuated balancing valves are valves that modulate their pressure drop automatically per electronic actuation via a computer logarithm and master controller (e.g., computer or similar device). The actuation of these types of valves is controlled and easily modified. Also, the data-logging features are available (for legal protection), and more fine-tuned control is possible. However, these types of valves will likely have the highest cost index and product unfamiliarity.

3.6.5.4.2.7.1. EABVs likely will be best utilized in facilities that are aggressively trying to mitigate *Legionella* risk, as these valves have data-logging functionality that facilities can utilize in potential litigation to show effort in preventing Legionnaires' disease. EABVs should be BMS compatible and validated at commissioning.

3.6.5.5. Recirculation Pump Selection

3.6.5.5.1. Recirculation pumps should be selected based on the calculation of the head loss through the hot water supply and return (when the hot water system is closed) to promote flow throughout the system. The flow rate must maintain the velocity within an acceptable range for the materials specified (and ultimately installed) and with consideration of noise generation. The materials utilized within the waterway must be compatible with the water chemistry and selected with consideration for higher thermal conditions as well as hyper-disinfecting.

3.6.5.5.2. The Hardy Cross method (as outlined in 3.15) should be utilized to determine the required flow rate and head loss of the closed hot water supply and return system.

3.6.5.5.3. An undersized recirculation pump could lead to stagnant water conditions due to not circulating throughout the entire connected system (when the domestic hot water system is in static condition [i.e., no fixture flow]), which could increase the risk of a Legionnaires' disease outbreak within the facility.

3.6.5.5.4. Recirculation pump selection should consider the following criteria:

3.6.5.5.1. If the facility is expected to remain unchanged for long periods (e.g., a hotel), then a constant-speed recirculation pump is appropriate.

3.6.5.5.2. If the facility is expected to have numerous renovation/addition projects after construction (e.g., a hospital), then a variable-speed (ECM or VFD type motor) recirculation pump with constant flow and constant pressure setpoints is recommended to allow the facility to change settings with each revision to the hot water system. The facility can thus change a setting on the pump without needing to change the impeller or replace the recirculation pump entirely.

3.6.5.5.2.1. Based on the lack of available third-party literature and lack of computational fluid dynamic models (or similar) at the time of publication of this guide, variable-speed pumps utilizing the following settings should not be used in any facility that has the potential for risk-prone populations. The various types of modulating/adapting features that should not be utilized in these types of buildings include but are not limited to:

3.6.5.5.2.1.1. Modulating based on flow.
3.6.5.5.2.1.2. Modulating based on pressure.
3.6.5.5.2.1.3. Modulating based on temperature.
3.6.5.5.2.1.4. Modulating based on a system curve.
3.6.5.5.2.1.5. Modulating based on pump curve.
3.6.5.5.2.1.6. Modulating based on proportional pressure.

3.6.5.6. Hot Water System Balancing

3.6.5.6.1. For manual balancing valves, testing and balancing shall be required.

3.6.5.6.2. For manual balancing valves and automatic balancing valves, system commissioning shall be required.

3.6.5.7. Other Hot Water Considerations

3.6.5.7.1. Scale Formation at Elevated Water Temperatures – As water temperature increases, scale, in the form of calcium bicarbonate, will precipitate out of the water more quickly[14], potentially adding to the growth of biofilm and adding nutrients to the pathogens contained within that biofilm.

3.6.5.7.2. Oxidizer Disinfectant Dissolving at Hotter Water Temperatures – As water temperature increases, oxidizing disinfectants (chlorine, chloramine, chlorine dioxide, ozone) will dissipate more quickly. As the concentration of such disinfectants increases, damage to the materials within the system may also increase. Copper-silver ions are not affected by increasing the water temperature[15, 16, 17]; however, passing through a water softener will negatively impact the concentration of the ions.

3.6.5.7.3. Hotter water temperatures will lead to increased leaching rates[18]. For every 10-degree increase in water temperature, depending on water chemistry, anticipate a 3 to 4 increase in reaction rates (Water Quality Association). This leads to higher leaching rates for certain metals in the piping system. System temperature creep is often a root cause.

3.6.5.7.4. Pipe Material Limits at Elevated Water Temperatures – Hot water systems have a maximum velocity of 1.2 to 1.5 meters per second (mps) (4 to 5 feet per second (fps)) for water up to 60°C (140°F) and 0.6 to 0.9 mps (2 to 3 fps) for water greater than 60°C (140°F). PPR, PEX, and other polypropylene (plastic) piping materials have a maximum temperature of 60°C (140°F) at 4 g/m^3 (4 ppm) chlorine residual; above that temperature and chlorine concentration, the piping begins to either thin or weaken because of erosion from higher velocities and cavitation[19,20]. For CPVC piping, as the water temperature increases, the pressure rating of the pipe material will decrease.

3.6.5.7.5. Discharging water into a sanitary sewer system greater than 60°C (140°F) may not comply with EPA regulations or local jurisdictional requirements. Quenching will be required to prevent the discharge of water greater than 71.1°C (160°F) to the sanitary system because PVC piping, which is approved for use by most model plumbing codes, has a maximum operating temperature of 65.6°C (150°F)[21], according to the Plastics Pipe Institute white paper TN-11/99: Suggested Temperature Limits for Operation and Installation of Thermoplastic Piping in Non-Pressure Applications. However, this could be problematic as the water discharging at any fixture would require quenching before entering the drainage system.

3.6.5.7.6. Thermal expansion due to increasing the water temperature from 48.9°C to 60°C or 71.1°C (20°F to 140°F or 160°F) may require extensive modification to existing piping and components or changes in new design parameters[21].

3.6.5.7.7. If the water temperature is greater than 71.1°C (140°F), users of emergency eyewash and shower stations will be subjected to an increased risk of scalding. Mixing valves serving emergency fixtures are tested and certified to ASSE 1071, which ensures that water can be tempered from temperatures as high as 82.2°C (180°F); however, the life-cycle test is conducted at 60°C (140°F). Consequently, there is no data to prove that the mixing valve will operate properly and safely at 71.1°C (160°F)[21].

3.6.5.7.8. If the water temperature is greater than 60°C (140°F), additional considerations need to be given to thermostatic mixing valves. Where mixing valves are required, they are tested to ASSE 1016/ASME A112.1016/CSA B125.16-2017 and ASSE 1070-2015/ASME A112.1070-2015/ CSA B125.70-15 to ensure that the water can be tempered from temperatures as high as 82.2°C (180°F); however, the life-cycle test for mixing valves is conducted at 60°C (140°F). Mixing valves may fail when consistently exposed to higher temperatures than tested[21].

3.7 Flushing

3.7.1. Flushing System Design Considerations

3.7.1.1. Calculations – Provide a timetable based on design volumetric calculations of domestic water piping for flushing at specific points. The timetable shall be part of the construction documents for the owner to use when flushing. This table shall be adjusted if there are significant changes between the design and construction volumetric calculations.

3.7.1.2. Plumbing Fixture Flushing Considerations – When selecting plumbing fixtures, consider the maximum flow rate, water age, and time to flush and provide this information to the owner. Additional flushing points, such as by hose bibbs, should be considered to help promote greater flow in hydraulically remote portions of the building.

3.7.1.3. Centrally Controlled Flushing Systems – Centrally controlled flushing system options, through a controller, BMS system, computer, or other device(s), will allow the owner to utilize electronically controlled devices to flush the system in addition to or in lieu of manual faucets. The advantage of these systems is that they often provide superior documentation abilities than manual flushing. However, at the time of this writing they often have high initial costs. The types of electronically controlled devices that should be considered as part of the plumbing system design are as follows:

3.7.1.3.1. Electronically Controlled Faucets – Most likely a sensor-type faucet, these can be placed on a flushing program to automatically flush and likely can measure temperature, gallons flushed, etc., as required by a water management program.

3.7.1.3.2. Electronically Controlled Flushing Valves – These valves are electronically controlled and will likely need a floor sink, mop sink, or other receptor to receive flushing water. These valves can be placed on a flushing program to automatically flush and likely can measure temperature, gallons flushed, etc., as required by a water management program.

3.7.2 Construction Flushing Practices and Water Systems Commissioning – During construction it is vital to manage water systems to prevent future risk of *Legionella* proliferation (especially managing biofilm growth). There are several documents that the plumbing designer should be aware of:

3.7.2.1 ASHRAE Guideline 12-2020
3.7.2.2 ASHRAE 188
3.7.2.3 ASHRAE 514
3.7.2.4 For construction practices, follow IAPMO's "Manual on Construction Practices for Potable Water" (forthcoming).

3.7.3 For Regular Building Occupancy Flushing – When the building is occupied, there is established guidance that the designer should be aware of that provides instructions to the building owner. For regular flushing of buildings, refer to the following standards and materials for guidance:

3.7.3.1. ASHRAE Guideline 12-2020
3.7.3.2. ASHRAE 188
3.7.3.3. ASHRAE 514
3.7.3.4. WELL Building Standard v2
3.7.3.5. CSI Master Format Specification Section 220593 Part 3 - Execution

3.7.4. Building Shutdown and Reopening Flushing Procedures – When the building is occupied and then becomes vacant, there are several options to reference:

3.7.4.1. IAPMO Manual of Best Practice
3.7.4.2. WELL Building Standard Health-Safety Rating
3.7.4.3. AWWA/IAPMO: Responding to Water Stagnation in Buildings with Reduced or No Water Use
3.7.4.4. (Forthcoming) IAPMO/AWWA Manual of Recommended Practices for the Safe Closure and Opening of Buildings

3.7.5. Water Management Program – When it comes to flushing protocols for the built environment, engineers may need to provide the following information:

3.7.5.1. Scheduling and Turnover Rates – All scheduling of water flushing in a building shall follow the water management program (WMP) as developed by the water management team. The plumbing engineer/designer may need to calculate the water turnover rates for the WMP.

3.7.5.2. Supplemental Disinfectant Treatment Methodology – If the water management team decides to use supplemental disinfection, they will determine the control limits for this technology. The plumbing engineer/designer should be familiar with residuals for various disinfectants and could provide calculations based on water age.

3.7.6. Authority Having Jurisdiction and Code Compliance

3.7.6.1. The plumbing engineer/designer should be familiar with all project-related AHJ requirements (e.g., JCO, local health department, CMS, state/federal EPA, etc.) and assist the water management team in the required flushing protocols.

3.7.7. Water Purveyor – Municipal Water Treatment

3.7.7.1. The plumbing engineer/designer should consider providing the water purveyor with contact information on the construction drawings to allow the contractor and owner to easily coordinate flushing activities.

3.7.8. Other Organizations

3.7.8.1. AWWA

3.7.8.1.1. AWWA C651-19 – Provides guidance for flushing of municipal distribution systems but is less applicable for buildings.

3.7.8.1.2. AWWA C652-19 – Provides guidance for flushing of municipal distribution systems but is less applicable for buildings.

3.8 Scale Inhibition – Water hardness, in the form of calcium bicarbonate, can cause scale to build up, which can become a harbor on which bacteria can grow. Additionally, the WQA (Water Quality Association) estimates that each 86 g/m^3 (5 grains per gallon) of water hardness causes a 4% loss in efficiency and a 4% increase in the cost of energy in gas storage tank water heaters when using 190 Liters (50 gallons) of hot water per day. Additionally, scale formation can lead to biofilm growth and provide shelter and nutrients for bacteria. Therefore, it is advantageous on multiple dimensions to inhibit the growth of scale. This can be done through several modalities[50,51]:

3.8.1. Water Softening – Water softening is the most common and traditional method of preventing scale buildup. Water softening is a process that reduces or removes dissolved impurities that cause hardness in water. This is most commonly done by an ion-exchange process. The ion-exchange method is a cation-exchange process that replaces dissolved calcium, magnesium, iron, and other multivalent cations with sodium (Na) ions. However, the plumbing engineer/designer must consider several criteria when utilizing a water softener[50,51]:

3.8.1.1. Continuous Flow Rate – The normal expected flow rate. This flow rate will be less than the intermittent flow rate and is directly proportional to pressure loss.

3.8.1.2. Intermittent Flow Rate – Also known as maximum, or peak, flow rate. This flow rate will be more than the continuous flow rate. The water softener should be sized to account for the maximum flow rate through the softener. It is directly proportional to pressure loss.

3.8.1.3. Pressure Loss – The loss in pressure due to the flow rate.

3.8.1.4. Minimum Flow Rate – The minimum flow rate of the water softener and controller. If a building's flow rate is less than the softener's minimum flow rate, channeling of the media could occur, which can damage the softener and strip disinfectants from the water. It is directly proportional to pressure.

3.8.1.5. It is important to balance the above criteria against each other, particularly continuous flow rate, pressure loss, and minimum flow rate. Practically, what this means is that duplex or simplex water softener configurations with large softeners (each at 100%) are concerns for buildings, as minimum flow rates are high, increasing the likelihood of channeling. Conversely, too-small water softeners in simplex or duplex arrangements could exceed the rated capacities of the water softeners. Thus, a solution could be triplex, quadplex, pentaplex, etc., in parallel configurations of water softeners to provide turndown of softeners to allow for low flow rates, while not exceeding maximum flow rates. Such configurations should include a master controller to help cycle through which softener is on lead/lag to make sure each individual softener experiences flow during normal system operation.

3.8.2. Nucleation Site-Assisted Crystallization – This method uses polymeric beads with nucleation sites to convert dissolved hardness into microscopic crystals. Once crystals grow to the template size, the crystals are released and remain in the water without forming scale, to be mechanically filtered out of the water. Flow rate, water chemistry, and pressure loss need to be carefully considered. Unlike softeners, these do not have the same risk of channeling at low flows. However, the media can become less effective when the water has high concentrations of copper particulates. Manganese in very small concentration has been shown to foul the resins quickly as the manganese bonds to the nucleation sites. The use of third-party tested devices is regulated by the plumbing code in certain jurisdictions.

3.8.3. Magnetic, Sine Wave, etc. – Magnetic/sine wave-type technologies work by introducing a magnetic charge on the incoming water. This technology previously had been used on oil rigs to prevent fouling/clogging of piping. This, in turn, was turned toward domestic water systems. These systems work by utilizing wire wrapped around a pipe, or a transformer-like device, to introduce a magnetic wave on the incoming water. In theory, by changing the charge of the ions in the water, they will attract each other and not form scale on the pipe. Some studies have shown that this only slows the formation of scale but does not eliminate it in its entirety. To date, no studies have been shown that this technology disrupts bacteria (like *Legionella*) or prevents their growth[52]. This technology has been shown to manage some species of iron in water, which is a food source for certain biota.

3.8.4. Anti-scaling treatment devices aim to reduce or prevent certain scale deposits that are normal to hard water behavior. This includes technologies such as physical water treatment devices, as well as sacrificial media. These technologies may provide a measurable reduction in hardness depending on the measurement method applied by conversion of calcium and magnesium ions to a precipitate form, but do not provide a reduction of total calcium or magnesium content of the treated stream and are not proven to achieve soft water (less than 17.1 g/m^3 (1.0 grain per gallon) of total hardness).

3.8.4.1. A sacrificial media treatment device releases a chemical such as citric acid or phosphate into the water to discourage the formation of scale.

3.8.4.2. A physical water treatment device modifies the properties of water by physical means as opposed to chemical or mechanical means. Physical water treatment devices do not use and do not impart significant levels of any chemical substance(s) to the water stream being treated. Physical water treatment devices use a range of processes, including media-induced precipitation, magnetic, electronic, electrostatic, and electromagnetic technologies.

3.8.5. While there is research into the performance of many of these devices, there remains some areas of the technologies that are less understood. Varying water qualities in homes throughout the country also make it more difficult to predict the performance of anti-scaling devices in any given residential setting. Consumers should investigate their system selection prior to making a purchase, and as with all water treatment devices, look for anti-scaling water treatment systems that have been demonstrated to meet performance, structural integrity, and safety according to a published standard by an accredited third-party product certifier.

3.9 Plumbing Fixtures

3.9.1. Accessible Fixtures – Fixtures designed to be accessible shall comply with:

3.9.1.1 Dimensional requirements specified in ICC/ANSI A117.1 or CAN/CSA-B651.

3.9.1.2 Performance requirements specified in ASME A112.18.1/CSA B125.1.

3.9.2. Programmable Fixtures – Fixtures incorporating electrical features other than low-voltage circuits shall comply with the applicable UL or CSA electrical standards.

Note: These standards include the following:

3.9.2.1. For controls, the applicable UL 60730 series standard for the U.S. or CSA C22.2 No. 24 or the applicable CSA E60730 series standard for Canada and UL 873.

3.9.2.2. For electric plumbing products and accessories, UL 1951 for the U.S. and CSA C22.2 No. 14 or CSA C22.2 No. 68 for Canada.

3.9.2.3. For parts intended for installation in wet locations, UL 50 for the U.S. or CSA C22.2 No. 94.2 for Canada, for the appropriate degree of protection from the ingress of moisture if applicable.

3.9.3. Low-Flow Supply Fixtures

3.9.3.1. The use of low-flow supply fixtures should be discouraged in buildings that fall under this guideline, particularly those with immuno-compromised populations such as hospitals and long-term memory care[53].

3.9.3.2. If the owner determines that low-flow or high-efficiency fixtures will be used despite the elevated risk and the fixtures have been documented within the management plan, those low-flow fixtures shall be listed to and comply with the applicable requirements of ASME A112.18.1/CSA B125.1 and the corresponding U.S. EPA WaterSense specification.

3.9.3.3. Balance Sustainability Goals with Public Health/Safety – Water scarcity is becoming a more frequent occurrence. It is necessary for plumbing engineers/designers to help protect this resource. Additionally, as many traditional energy sources also begin to dwindle in use, being conscious of energy usage is also important. However, public health and safety must override these concerns. Some examples:

3.9.3.3.1. The use of low-flow fixtures without first reducing the minimum pipe size created many unintended consequences. Reducing pipe flow without reducing pipe diameter increases water age, increases time to tap, increases water consumption, increases energy loss, increases related equipment sizing (softeners, booster pumps, etc.), and increases bacterial amplification while decreasing residual disinfectant.

3.9.3.3.2. Shutting off the recirculation pump via an aquastat when the design temperature is reached can lead to hydraulically remote portions of the hot water system dropping in temperature and staying in the prime growth range for bacteria.

3.10 Aerating Equipment – Misters used for cooling of public spaces or for maintaining moisture on fresh produce or water features shall comply with the requirements of ASHRAE 188 or be approved by the authority having jurisdiction. The use of RO or low-TDS treated water should be considered, not just to capture waterborne pathogens but also to prevent sediment/scale from clogging spray nozzles.

3.11 Water Management Program – A water management program should be developed and should comply with the requirements of ASHRAE 188.

3.12 Combining Design Methodologies – The plumbing engineer/designer should consider all the options presented in this guideline and based on a conversation with the owner and the water management team, select the desired options. The plumbing engineer/designer should consider overlaying multiple design options to build in safety measures, while always considering how the various control or risk-reduction measures interact with each other to make sure adverse effects are eliminated or at least minimized.

3.13 Qualifications/Certification/Recertification – It is recommended that users of this guideline have at least one of the following qualifications, certifications, or credentials:

- 3.13.1 Registered Professional Engineer.
- 3.13.2 Certified in Plumbing Design.
- 3.13.3 Licensed Water Treatment Operator.
- 3.13.4 Minimum of a Bachelor of Science in Engineering or Chemistry.
- 3.13.5 Other water-based technical certification such as:
  - 3.13.5.1 ASSE 12080.

3.14 Appendices

3.14.1 Appendix A: Hot Water Recirculation Design and Sizing

3.14.1.1 Introduction – The sole purpose of a hot water return system is to maintain hot water temperature in the supply piping system, thereby extending the reach of the water heater closer to the plumbing fixture it serves. Hot water returns or recirculation systems are a critical component to the increase or decrease of risk of a Legionnaires' disease outbreak. Oversizing these systems not only can lead to wasting energy, materials, and thereby monies, but also can increase the surface area for bacteria and biofilm to grow on, reduce velocity, and increase water age. Undersizing hot water return systems can cause temperature fluctuations in the hot water return system that can amplify the growth of the bacteria. Therefore, it is vital that hot water return systems are not oversized or undersized, but rather all design considerations are balanced in accordance with each other.

3.14.1.2 Heat Transfer per Distance (W/hr/m (Btu/hr/LF)) – Each lineal meter (foot (LF)) of hot water piping has a given temperature loss based on the following criteria: (1) ambient temperature around the pipe/insulation, (2) fluid temperature inside the pipe, (3) thermal resistance of the material the heat transfer occurs through, and (4) surface area of the heat transfer.

3.14.1.2.1 Supporting Calculations

3.14.1.2.1.1. Heat Transfer – Thermal conductivity and thermal resistance are inversely proportional (dependent on the thickness of the material). Thermal resistance is the measure of a material's ability to reduce heat transfer by way of conduction through a given thickness of the material. The formula is as follows:

R = L/k
Where:
R = thermal resistance, m^2 x °C/Watt (F/(Btu))
L = thickness of the material, millimeters (inches)

3.14.1.2.1.2. Thermal Resistance/Conductivity for a Flat Plate – The transfer of heat through a flat plate can be described by the following formula:

Q = U * A * ΔT
Where:
U = conduction in terms of k/L or 1/R or units of (W)(mm)/(m^2)(°C)(hr), (BTU)(in)/(ft^2)(°F)(hr)

A = surface area of plate in terms of (m^2) (ft^2)

ΔT = temperature difference between one side of the plate to the other side ($T_1 – T_2$) in terms of (°F)

3.14.1.2.1.3. Thermal Resistance/Conductivity for a Cylinder – As the object is a pipe and not a plate, the equation must be modified to be a cylinder. The equation is modified into the following formula:

$Q = 2 * \pi * (k) * (\Delta T) / (L * \ln (D_o/D_i))$

Where:

k = conduction in terms of (W)(mm)/(m^2)(°C)(hr) (Btu)(in)/(ft^2)(°F)(hr)

ΔT = temperature difference in air between one side of the plate to the other side ($T_1 – T_2$) in terms of (°C) (°F)

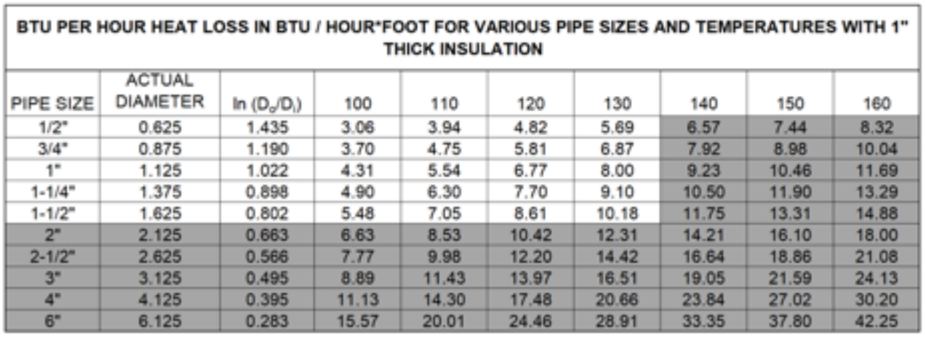
L = length of the pipe

D_o = outer insulation diameter

D_i = inner insulation diameter

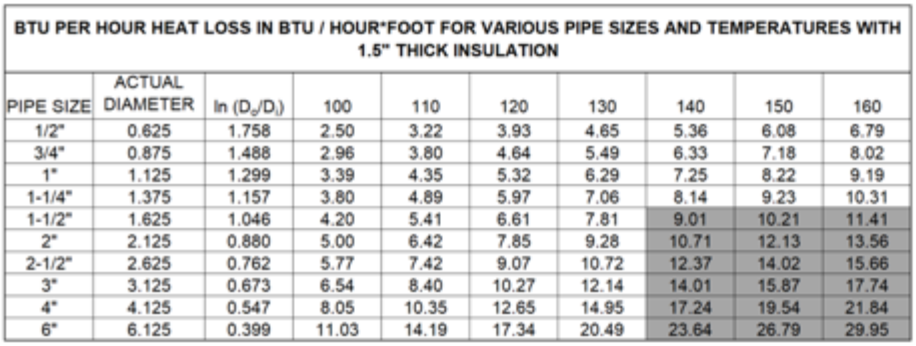
Ln (D_o/D_i) = mean circumference of insulation

3.14.1.2.2 Charts – Utilizing equation 3.14.1.2.1.3 will lead to the creation of tables that show a variation of heat transfer because of pipe size, fluid temperature, and insulation thickness. Heat transfer will (a) increase as the pipe size increases; (b) increase as the fluid temperature increases; and (c) decrease as the insulation thickness increases. Refer to the charts below:



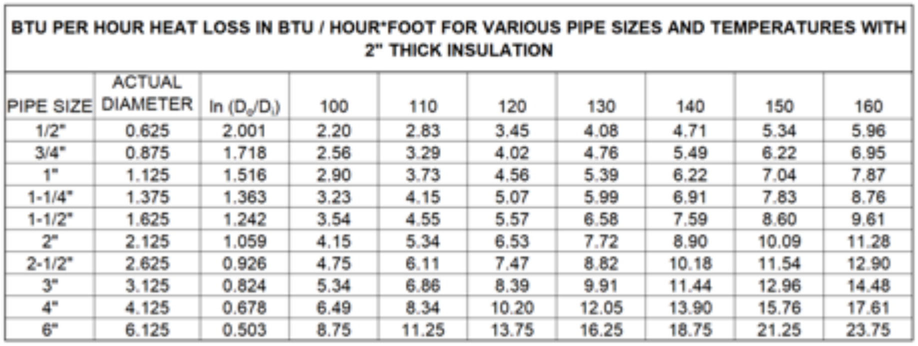
BTU PER HOUR HEAT LOSS IN BTU / HOUR*FOOT FOR VARIOUS PIPE SIZES AND TEMPERATURES WITH 1" THICK INSULATION

PIPE SIZE	ACTUAL DIAMETER	ln (D_o/D_i)	100	110	120	130	140	150	160
1/2"	0.625	1.435	3.06	3.94	4.82	5.69	6.57	7.44	8.32
3/4"	0.875	1.190	3.70	4.75	5.81	6.87	7.92	8.98	10.04
1"	1.125	1.022	4.31	5.54	6.77	8.00	9.23	10.46	11.69
1-1/4"	1.375	0.898	4.90	6.30	7.70	9.10	10.50	11.90	13.29
1-1/2"	1.625	0.802	5.48	7.05	8.61	10.18	11.75	13.31	14.88
2"	2.125	0.663	6.63	8.53	10.42	12.31	14.21	16.10	18.00
2-1/2"	2.625	0.566	7.77	9.98	12.20	14.42	16.64	18.86	21.08
3"	3.125	0.495	8.89	11.43	13.97	16.51	19.05	21.59	24.13
4"	4.125	0.395	11.13	14.30	17.48	20.66	23.84	27.02	30.20
6"	6.125	0.283	15.57	20.01	24.46	28.91	33.35	37.80	42.25



BTU PER HOUR HEAT LOSS IN BTU / HOUR*FOOT FOR VARIOUS PIPE SIZES AND TEMPERATURES WITH 1.5" THICK INSULATION

PIPE SIZE	ACTUAL DIAMETER	ln (D_o/D_i)	100	110	120	130	140	150	160
1/2"	0.625	1.758	2.50	3.22	3.93	4.65	5.36	6.08	6.79
3/4"	0.875	1.488	2.96	3.80	4.64	5.49	6.33	7.18	8.02
1"	1.125	1.299	3.39	4.35	5.32	6.29	7.25	8.22	9.19
1-1/4"	1.375	1.157	3.80	4.89	5.97	7.06	8.14	9.23	10.31
1-1/2"	1.625	1.046	4.20	5.41	6.61	7.81	9.01	10.21	11.41
2"	2.125	0.880	5.00	6.42	7.85	9.28	10.71	12.13	13.56
2-1/2"	2.625	0.762	5.77	7.42	9.07	10.72	12.37	14.02	15.66
3"	3.125	0.673	6.54	8.40	10.27	12.14	14.01	15.87	17.74
4"	4.125	0.547	8.05	10.35	12.65	14.95	17.24	19.54	21.84
6"	6.125	0.399	11.03	14.19	17.34	20.49	23.64	26.79	29.95



BTU PER HOUR HEAT LOSS IN BTU / HOUR*FOOT FOR VARIOUS PIPE SIZES AND TEMPERATURES WITH 2" THICK INSULATION										
PIPE SIZE	ACTUAL DIAMETER	ln (D_o/D_i)	100	110	120	130	140	150	160
1/2"	0.625	2.001	2.20	2.83	3.45	4.08	4.71	5.34	5.96
3/4"	0.875	1.718	2.56	3.29	4.02	4.76	5.49	6.22	6.95
1"	1.125	1.516	2.90	3.73	4.56	5.39	6.22	7.04	7.87
1-1/4"	1.375	1.363	3.23	4.15	5.07	5.99	6.91	7.83	8.76
1-1/2"	1.625	1.242	3.54	4.55	5.57	6.58	7.59	8.60	9.61
2"	2.125	1.059	4.15	5.34	6.53	7.72	8.90	10.09	11.28
2-1/2"	2.625	0.926	4.75	6.11	7.47	8.82	10.18	11.54	12.90
3"	3.125	0.824	5.34	6.86	8.39	9.91	11.44	12.96	14.48
4"	4.125	0.678	6.49	8.34	10.20	12.05	13.90	15.76	17.61
6"	6.125	0.503	8.75	11.25	13.75	16.25	18.75	21.25	23.75

Note: Portions of the charts above shaded in gray indicate sizes and temperatures that do not comply with IECC 2015 or IECC 2018. Refer to the local energy code to validate what insulation thickness is needed based on fluid temperature.
Remember: Water heater setpoints can fluctuate 1–5%, depending on manufacturer. Water heaters set at 60°C (140°F) likely will need to utilize thicker insulation to comply 100% of the time.

3.14.1.2.3 ASPE Data Books from 1997 indicated that the way to size HWR systems was to assume 30 Btu/hr per lineal foot for all pipe sizes. This guideline supersedes that guidance, and the use of a singular Btu/hr of 30 shall be considered null and void.

3.14.1.3 Hardy Cross Methodology – Network flows in a multiloop system cannot be determined by any closed-form equation. Most real-world problems involving multiloop systems are analyzed on a computer (e.g., Excel or MathCAD). Computer programs are based on the Hardy Cross method, which can also be performed manually when there are only a few loops. In this method, flows in all the branches are first assumed, and adjustments are made in consecutive iterations to the assumed flow[54].

3.14.1.3.1 Hardy Cross Calculations

3.14.1.3.1.1. Btu/hr = gpm x 500 x ΔT fluid

3.14.1.3.1.2. Velocity = gpm / Cross-sectional area

3.14.1.3.1.3. Hazen-Williams Equation: head loss =

$$0.2083\,(100/c)^{1.852} \times gpm^{1.852} / d^{4.8655}$$

3.14.1.3.2 Hardy Cross Methodology Applied to HWR

3.14.1.3.2.1. Assume a closed state for the hot water system.

3.14.1.3.2.2. Assign nodes at each piping junction where one of the following situations occurs:

3.14.1.3.2.2.1. Change in pipe size.

3.14.1.3.2.2.2. Change in flow rate due to the divergence of hot water through a hot water return valve.

3.14.1.3.2.2.3. Change in system type (supply or return).

3.14.1.3.2.3. Assume a flow rate for each loop and determine the total gpm of the system. (Recommend starting with 3.8 Lpm (1 gpm) and counting the number of flow control valves to make sure the validation is simplified.)

3.14.1.3.2.4. Using the known heat loss value and assumed flow rate, calculate the temperature drop, velocity, and head loss for the most hydraulically remote loop and least hydraulically remote loop. Validate results as follows:

3.14.1.3.2.4.1. Temperature: Does the temperature drop at the furthest end of the supply system allow for the growth of *Legionella*? Does the temperature drop at the end of the return system allow for the growth of *Legionella*? What is the total temperature drop and does it allow for the growth of *Legionella*?

3.14.1.3.2.4.2. Velocity: Are any velocity limits exceeded in any segment of piping? If so, can the pipe size increase? If so, can the flow rate be decreased?

3.14.1.3.2.4.3. Head loss: Is the head loss of the piping excessive? Will a recirculation pump for the required head gain cause the system to exceed 552 kPa (80 psi)?

3.14.1.3.2.5. If any of the items from 3.14.1.3.2.4. are not ideal, revise the calculation with a new assumed flow rate. Make sure to revise any other related loop equations as well.

3.14.1.3.3 Recirculation pumps shall be sized based on flow and head. Piping systems thus need to be sized primarily for flow and head loss. Sizing hot water return piping only for velocity while not accounting for pressure loss shall not occur. Recirculation pumps shall be uniquely sized; the practice of utilizing a standard recirculation pump with no calculations shall not occur.

3.14.1.3.4 Engineers should take the following actions when designing hot water systems:

3.14.2.3.4.1. The engineer should evaluate the hot water recirculation pump capacity (flow and head) for every project that involved a modification to the hot water system, especially if a new balancing valve is to be added on the drawings.

3.14.2.3.4.2. The engineer should request documentation that the hot water recirculation pump and piping systems have adequate capacity for additional flow and head. This should occur on every renovation project.

3.14.2.3.4.3. If manual balancing valves (i.e., MBV) are utilized within the facility, a pre-design TAB shall be requested. Post-construction, all manual balancing valves that are part of the affected hot water return system shall be rebalanced. All balancing valves should be recommissioned postconstruction to verify that design flow rates are being met.

3.14.2.3.4.4. For new and possibly renovation projects, if the contractor does not provide a TAB for the entire hot water return system, notify the contractor, architect, and owner of the concern of risk.

3.14.2.3.4.5. AHJs should consider requiring special inspections forms for hot water systems located in buildings where *Legionella* risk is elevated. Some considerations for special inspections could be hot water system/pump capacity (flow/head) or design temperature-time delivery.

3.14.2.3.4.6. Place supplemental hot water design information on the drawings. This includes but is not limited to the following:

3.14.2.3.4.6.1. Hot water recirculation pump calculations for the most hydraulically remote loop indicating flow rates, temperature loss, pressure loss, and velocity of each segment (between nodes) for this loop, and label the most hydraulically remote loop on drawings.

3.14.2.3.4.6.2. Control valve schedule, indicating the total number of flow control valves and assigned flow rate, temperature drop, and location of each flow control valve. Provide an update of the entire schedule after each project for the facility.

3.14.1.3.5 Iterative Process – Designing the hot water return system, due to following Hardy Cross methodology, is likely one of the most time-intensive processes (unless automated computer program is used). As an example, engineers for a 200-bed hospital, utilizing the hot water calculation tool provided with this guideline, should expect to spend at least one week on the nodal analysis, calculations, hot water return (and possibly supply) pipe sizing changes, pump selection, and quality control. This is due to having multiple iterations on the various loop evaluations.

3.14.1.3.6 Other Sizing Considerations – In some instances, other sizing criteria may increase the flow rate of the hot water return system. Make sure to document the reason for "artificial" increases on the construction set. Some reasons are as follows:

3.14.2.3.6.1. The use of a copper-silver ionization system installed on the hot water return main. Many copper-silver ionization systems need flow rates between 76 and 114 Lpm (20 and 30 gpm) through the flow cell. If the calculated hot water return flow rate is below this value, the hot water return size may need to increase in flow rate and pipe sizing to make sure the distribution of ions occurs. This typically will only impact small building systems (those buildings with HWR lines smaller than 38.1 mm (1½ inches) in size.

3.14.1.4 HWR Piping System Design

3.14.1.4.1 Series vs. Parallel Piping Principles

3.14.2.4.1.1. Series Principles – Piping in series has the following criteria (assuming a constant flow rate):

3.14.1.4.1.1.1 The head from one pipe size to another pipe size is additive.

3.14.1.4.1.1.2 The velocity of water in a larger pipe will be less than the velocity of water in a smaller pipe.

3.14.1.4.1.1.3 The pressure loss of water in a larger pipe will be less than the pressure loss in a smaller pipe.

3.14.2.4.1.2. Parallel Principles – Piping in parallel has the following criteria (assuming a constant flow rate into the parallel piping system):

3.14.2.4.1.2.1. The head loss of one parallel pipe branch to another is equal.

3.14.2.4.1.2.2. The water will take the path of least resistance. A smaller pipe in a parallel circuit will see greater velocity and thus greater pressure loss at a given flow rate than a larger pipe. Therefore, the system will achieve equilibrium in pressure losses in each branch by the water increasing in flow in a larger branch while reducing in flow in the smaller branch.

3.14.2.4.1.2.3. To get more water through the smaller pipe branch, a restriction must be added on the larger branch or a restriction must be taken away from the smaller branch. This could be in the

form of adding a balancing valve in the larger branch pipe, decreasing the diameter size of the larger branch pipe, or lengthening the distance of the larger pipe branch.
In an effort to reduce or eliminate balancing valves, return piping is sometimes arranged in a configuration known as *reverse return,* which attempts to establish comparable friction loss for each circuit by mirroring piping arrangements to be of an equivalent length. This approach does not allow for the adjustment of circuit flows following installation and may be less balanced as the piping ages and develops varying frictional resistance. Additionally, this approach is primarily suitable for systems with circuits that all require the same flow.

3.14.2 Appendix B: Flushing Time – Engineers should also show flushing times for 100% turnover of the water inside the building.

3.14.2.1 Flushing time can be determined by the following equations:

3.14.2.1.1 Volume of water in system = Length of piping in system x Cross-sectional area

3.14.2.1.2 Flushing time = Volume / Outlet flow rate

3.14.2.2 Flushing schedules should be placed on the floor plan drawings indicating the following:

3.14.2.2.1 Fixture(s) for primary flushing.

3.14.2.2.2 Fixture flow rates.

3.14.2.2.3 Flush time to turn over 100% of water to the fixture(s).

3.14.3 Appendix C: Legal Considerations – The following section is intended to encourage engineers to work with their legal advisers to craft strategies specific to their firms. It is not intended as legal advice and should not be construed in such a manner. All decisions regarding a firm's legal liability and risk management activities should be specific to the firm.

3.14.3.1 Proposals – Engineers likely need to have some kind of legal language in their proposals to help set up projects for success. This can be done in several ways:

3.14.4.3.2. Language in the proposal that indicates when an RFP is for a building that falls under ASHRAE 188 that the engineer will design according to industry standards and that indicates the cost to provide engineering service to comply with *Legionella* risk mitigation and control measures.

3.14.4.3.2. Language in the proposal that includes or excludes involvement in a water management team as part of a water management program.

3.14.3.2 Design Phase – Hold conversations regarding risk mitigation measures and water management programs as early as possible during the design phase (e.g., conceptual, or schematic design). The plumbing engineer could attempt to spur a conversation by requesting space for *Legionella* risk mitigation or prevention technologies in the mechanical room, plumbing room, or central utility plant for a high dollar value to help drive the conversation (e.g., a 7.62-m (25-foot) space requirement that costs $100,000).

3.14.3.3 Construction Phase – During the construction phase, work closely with the contractor to make sure construction activities do not disturb or create a hazardous condition in the plumbing system.

3.14.3.4. Documentation – Document all deviations from engineering recommendations, especially value engineering (VE) options that go against the recommendation of the EOR. Meeting minutes and emails, among others, are admissible in a court of law in most states.

3.14.3.5. Insurance Carrier Coordination – Some building insurance carriers are now offering owners lower costs if they have an active water management plan. Additionally, some existing buildings can qualify under new insurance carrier rules that allow disinfectant equipment to be utilized as a remediation technology, when prior they were considered a maintenance item. Consider working with not only the owner and in-house legal but also external legal experts who specialize in this field to explore this opportunity.

3.14.4 Appendix D: Pressure Zone Design – If pressure is not properly managed in a domestic water system design, situations such as cross-connection, operational dead legs, and improper fixture performance can occur. Properly designing plumbing systems to account for the pressure requirements of the fixtures, equipment, and building geometry is a key component in minimizing *Legionella* risk. This section provides guidance to the plumbing design professional on how to minimize risk of *Legionella* by improving control of pressure differentials in domestic cold and hot water systems.

3.14.4.1. Plumbing System Pressure Requirements:

3.14.4.1.1 Model plumbing codes in the United States require that plumbing systems supply standard plumbing fixtures at 552 kPa (80 psi) maximum pressure. The minimum pressure allowed by code can vary from 103 kPa to 241kPa (15 psi to 35 psi). Engineers should research the applicable code and plumbing fixture minimum performance criteria to determine their design constraints.

3.14.4.1.2 Delivery pressures from water purveyors in the United States are most typically in the range of 414 kPa to 827 kPa (60 psi to 120 psi). Engineers may find that in older metropolitan areas, pressures delivered to the building can be as low as 138 kPa to 207 kPa) 20 to 30 psi. Engineers will need to review the incoming pressure, along with the building geometry and fixture/equipment pressure requirements in the building to understand if modifications to the incoming pressure need to be made via a booster pump or pressure reducing valve assembly.

3.14.4.1.3 Multiple Pressure Zones – Most buildings have a single pressure zone. However, when a building is of a certain height (typically 7 floors or more, or over 32 meters (105 feet tall)) the resulting pressure drop due to height (310 kPa (45 psi) or more) is too large to allow for delivery of water from 241 kPa to 552 kPa (35 psi to 80 psi), so multiple zones are needed. This can be done in several ways.

3.14.4.2. Cold and Hot Water:

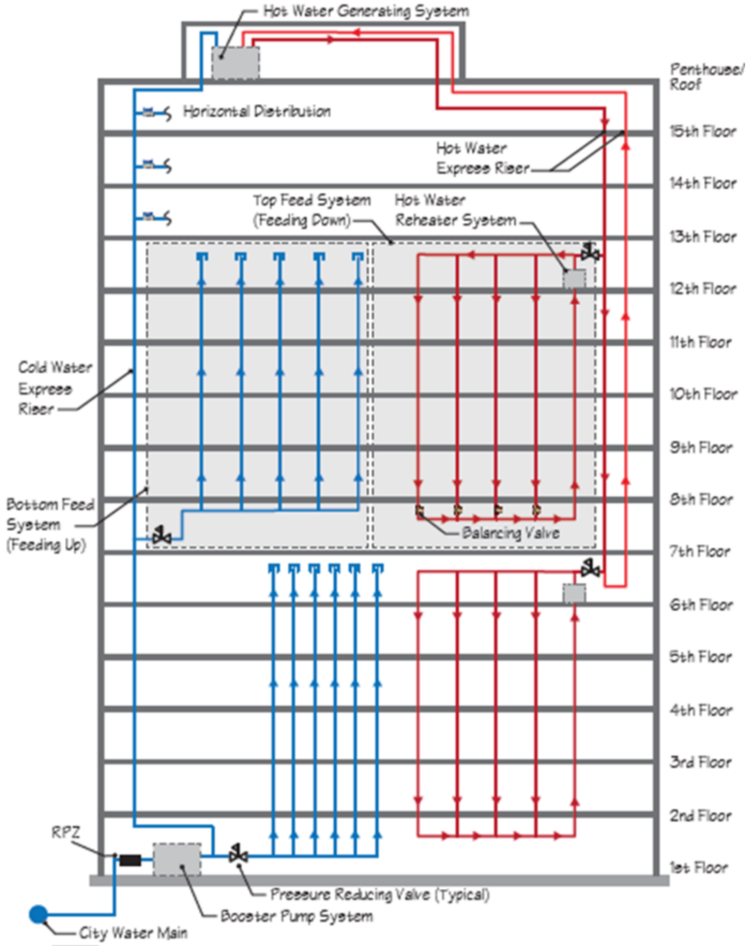
3.14.4.2.1. Bottom-Feed (Up-fed) Distribution System – Water is fed through a PRV located at the bottom of the pressure zone and is set for approximately 552 kPa (80 psi). Distribution to vertical risers takes place at the bottom of the zone, and water flows “up” the risers to the fixtures on each floor within the zone.

3.14.4.2.2. Top-Feed (Down-fed) Distribution System – Water is fed through a PRV located at the top of the pressure zone and is set for approximately 207-276 kPa (30–40 psi) (depending on fixture performance criteria). Distribution to vertical risers takes place at the top of the zone, and water flows “down” the risers to the fixtures on each floor within the zone.

3.14.4.2.3. Horizontal-Feed (Floor by Floor) Distribution System – Water is fed through a PRV and pressure is close to 552 kPa (80 psi) at the PRV and feeds the floor where the PRV is located only.

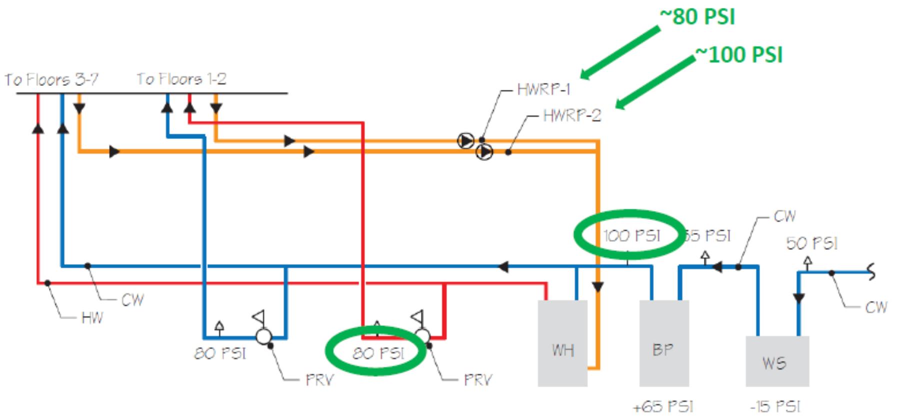
3.14.4.2.4. Hot Water Recirculation Approach in High-Rise Buildings – To maintain proper water conditions, hot water needs to be reheated to stay in *Legionella* kill zones and satisfy user requirements. In high-rise buildings and/or buildings with multiple hot water pressure zones, the following approach is vital to utilize for reheat heaters:

3.14.4.2.4.1 Individual Zone Reheat Heaters – Using a Bottom-Feed or Top-Feed Distribution System, cold and hot water are supplied by a PRV. Once through the PRV, each pressure zone is treated as an individual building by recirculating hot water only within that pressure zone. Water is typically reheated within the zone via plate-and-frame heat exchangers, which keep the high and low pressures separate and greatly simplify balancing since the zone is a constant pressure. As depicted in the diagram below, the hot water return is collected and reheated by connection between the downstream side of the PRV and the heat exchanger. Each zone will utilize a recirculation pump and reheat heater. The reheat heater is a small heater that replaces the lost heat in the pressure zone only. Upstream of the PRV, an express hot riser exists that provides makeup water to the floor. The hot water express riser supplies the makeup hot water and the energy for the reheat heater. This hot water is heated by the main hot water generator that replenishes any hot water discharges by plumbing fixtures (e.g., shower or faucet).



3.14.4.2.4.2. Horizontal-Feed Heaters – Utilizing a Horizontal-Feed, locate hot water generators (e.g., water-to-water heat exchangers) downstream of the PRV on every floor to heat water and distribute the hot water to that floor only. Upstream of the PRV, a “cold water express riser” exists that provides makeup water to the zone.

3.14.4.2.4.3. Cross-Pressure-Zone Connections – Cross-Pressure-Zone Connections are when two different pressure zone water distribution systems are reconnected. This type of connection can cause operational dead legs and must be avoided. An example is as follows. In the example below, HWRP-1 would become an operational dead-leg, as HWRP-2's outlet pressure would overtake the outlet pressure of HWRP-1 and close the check valves, cancelling any flow in the HWRP-1 system.



3.14.4.3. Pressure Reducing Valve Design and Selection – Understanding the operation of PRVs is vital in improving control of plumbing systems. Two two main types of pressure reducing valves on the market are direct acting and pilot operated.

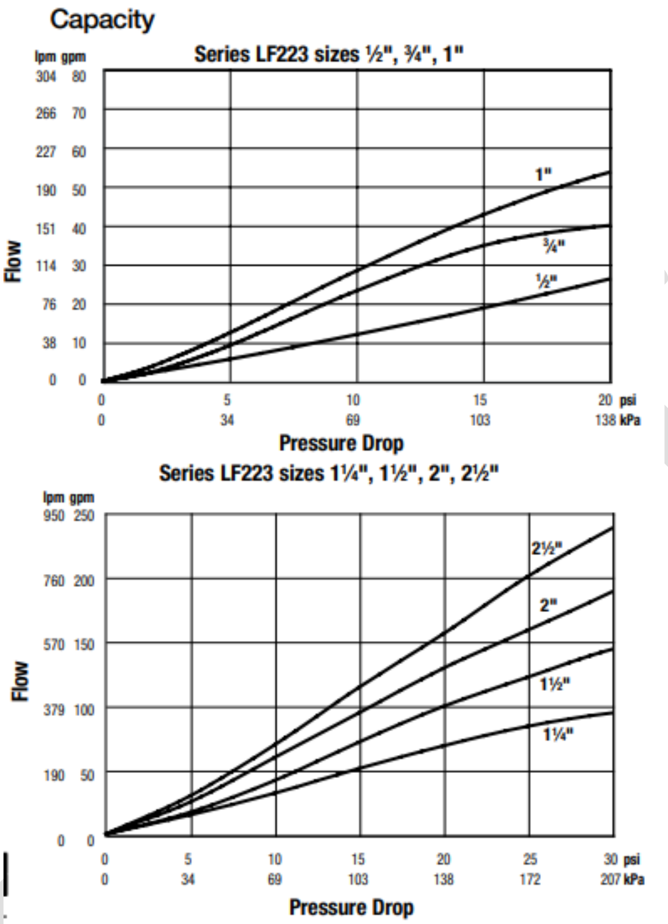
3.14.4.3.1. Direct Acting – Direct-Acting PRVs (DAPRV) function on the principle of applying a force acting directly against the inlet pressure. This force is accomplished with either a flat diaphragm or convoluted bellows. Performance criteria that the plumbing design professional needs to be aware of follow:

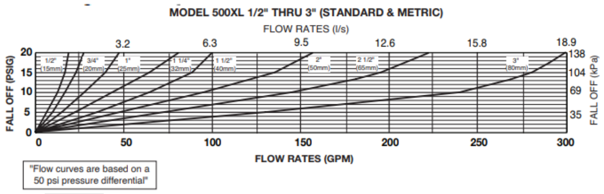
3.14.4.3.1.1. Set Pressure – DAPRVs typically have adjustable outlet pressure setpoint ranges from 172-571 kPa (25–75 psi). Note: The outlet setpoint is determined under no flow conditions.

3.14.4.3.1.2. Falloff Pressure – One very important design consideration of DAPRVs is that they have a falloff pressure. The falloff pressure is the additional pressure loss as flow increases. Engineers must source manufacturer-provided data to know these values.

3.14.4.3.1.2.1. As an example: A 1” DAPRV is set for 517 kPa (75 psi) under no-flow conditions, and then experiences flows of 15 and 20 gpm. Based on the chart below, the outlet pressure of the DAPRV would “fall off” to approximately 483 kPa (70 psi) at 57 Lpm (15 gpm), and 462 kPa (67 psi) at 78 Lpm (20 gpm). Should the flow increase to 114 Lpm (30 gpm), the outlet pressure would be further reduced to 448 kPa (65 psi). Engineers need to understand that if DARP valves are used in parallel, such as for cold and hot supply to a fixture group, the varying flows thru the DAPRVs can introduce pressure inequalities at the fixture, which can lead to cross-connections. Cross-connections alter design temperatures in the piping network and can lead to *Legionella* development. Pressure imbalances can also force close otherwise normally open check valves, creating dead legs.

3.14.4.3.1.2.2.





3.14.4.3.2. Pilot-Operated

3.14.4.3.2.1. Pilot-Operated PRVs (POPRVs) are a pressure-reducing assembly that utilizes an automatic control valve (ACV) that is a direct-acting PRV as the control valve. The ACV valve consists of a lower chamber and a separate upper chamber, with the control valve incorporating a two-way valve into the upper chamber. Performance criteria that the plumbing design professional needs to be aware of includes:

3.14.4.3.2.1.1. These pilot assemblies react to changes in downstream pressure, allowing the main valve to modulate between the open and closed position and ensuring a constant downstream set pressure. Therefore, POPRVs do not have falloff pressure considerations like direct-acting PRVs.

3.14.4.3.3. Selection

3.14.4.3.3.1. Pressure Reducing Valve Selection, Sizing, and Application:

3.14.4.3.3.1.1. Due to the falloff characteristics of DAPRVs, they should be utilized in situations where upstream pressure is controlled via a POPRV and where the downstream application is a single fixture or connection point that can accept a range of pressure that will be output from the DAPRV. DAPRVs are not recommended in applications serving large fixture groups or where large variances in flow are expected.

3.14.4.3.3.1.2. Sizing of a DAPRV is typically based on applied pipe size to reduce the effect of falloff pressure (e.g., 20mm (¾-inch) DAPRV and a 20mm (¾-inch) domestic water pipe)

3.14.4.3.3.1.3. Using multiple DAPRVs in high-low parallel configurations is not recommended.

3.14.4.3.3.2. POPRV Selection:

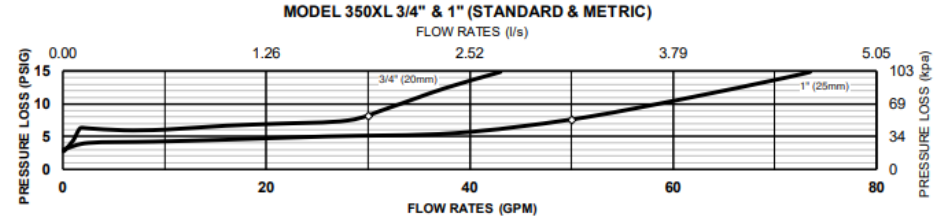
3.14.4.3.3.2.1. POPRVs are often used in conditions where large amounts of flow are required, such as for an entire building or a complete pressure zone. POPRVs are sized based on the flow rates of the system, and due to their geometry and controls, will often not match the applied pipes size on their inlet and outlet.

3.14.4.3.3.2.2. Because POPRVs can have control issues at lower flow rates, they are often arranged in a $^{1}/_{3}$, $^{2}/_{3}$ parallel peak flow arrangement. This means that there is a branch sized for $^{1}/_{3}$ of the peak flow and another branch sized for the remaining $^{2}/_{3}$ of the peak flow. The low-flow bypass setpoint should be about 21-48 kPa (3–7 psi) higher than the ACV setpoint (which is set by the pilot valve). As flow increases through the direct-acting low-flow bypass, the pressure drop will continue to reduce until the ACV valve engages the PRVs set up for the higher flow.

3.14.4.3.3.2.3. POPRVs have specific ranges in which they can reduce pressure safely. Engineers must understand that POPRVs have a “cavitation zone.” This means that if a single valve is placed in a situation where it is asked to reduce “to much” pressure, cavitation will occur inside the valve, and excessive damage and PRV failure are imminent. To avoid these stations, two-stage reduction is required to reduce a high pressure to a required outlet pressure. This is common in the lower pressure zones of a high-rise, where incoming pressure from the booster pump might be 1380 kPa (200+ psi), and the required outlet pressure from the PRV is 240 kPa (35 psi). The two-stage reduction can utilize two POPRVs to go from 1380 to 690 kPa (200 to 100 psi), and then 690 to 240 kPa (100 to 35 psi).

3.14.4.3.3.2.3.1. POPRVs also have “springs” and speed controls that will determine their capability to operate correctly. The springs are a component of the ACV and help the POPRV accurately control the outlet pressure. Each manufacturer will list their spring rates, and engineers should include these selections as part of their specification process. POPRV speed controls are used to determine how quickly a valve opens and closes. This is typically set at the startup process; however, an engineer should be aware of the devices downstream of the PRV. Quick-closing devices downstream of a POPRV that close slowly will allow “pressure leaks,” which is when pressure will exceed the setpoint of the PRV because it did not close as quickly as the devices downstream.

3.14.4.3.3.2.3.2. Compound Double Check Valve Selection as a PRV – In some circumstances where a pressure drop of a few psi is needed to get a system into “compliance,” an alternate option for pressure reduction could be a check valve with a compound check valve. These valves typically have a 34-69 kPa (5–10 psi) pressure drop at low flow rates, due to the compound check valve, which needs a high amount of energy to open. Utilizing a compound double check valve is an alternate approach to reduce pressure below 552 kPa (80 psi) while maintaining a higher outlet pressure.



3.14.5. Appendix E: Water Quality

3.14.5.1. General – As with water temperature, factors affecting water quality may contribute to conditions that encourage *Legionella* growth. A water quality test should be administered prior to construction, retrofits, or other events concerning the installation or modification of the plumbing system. Where conditions prohibit sample collection at the area of concern, a sample may alternatively be collected as close as possible, such as from a nearby building or hydrant. Sampling procedures shall conform to accepted practice. Assessment metrics should include the following:

3.14.5.1.1. Total Suspended Solids (TSS) – The weight of solids remaining after a well-mixed sample is filtered through a standard glass filter and the suspended portion is dried to a constant weight at 103 to 105°C (217.4 to 221°F). TSS can cause disinfectants and other plumbing components to not operate effectively.

3.14.5.1.2. Total Dissolved Solids (TDS) – The weight of solids remaining after a well-mixed sample has been filtered through a standard glass filter and the resultant filtrate is evaporated and dried to a constant weight at 82.2°C (180°F).
3.14.5.1.3. Turbidity – A measure of the cloudiness of water. It is used to indicate water quality and filtration effectiveness (such as whether disease-causing organisms are present). Higher turbidity levels are often associated with the potential of higher levels of disease-causing microorganisms such as viruses, parasites, and some bacteria. These organisms can cause symptoms such as nausea, cramps, diarrhea, and associated headaches.
3.14.5.1.4. Heterotrophic Plate Count (HPC) – An analytic method used to measure the varieties of bacteria that are common in water: the lower the concentration of bacteria in drinking water, the better maintained the water system is. HPC measures a range of bacteria that are naturally present in the environment. It has no health effects.
3.14.5.1.5. Hardness – The amount of dissolved calcium and magnesium in water. Hard water is high in dissolved minerals, largely calcium and magnesium. High levels of hardness can cause scale to grow. Some design considerations follow:

- The WQA (Water Quality Association) estimates that each 86 g/m^3 (5 grains per gallon) of water hardness causes a 4% loss in efficiency and a 4% increase in the cost of energy in gas storage tank water heaters when using 190 Liters (50 gallons) of hot water per day[2].
- Good-quality TMVs (with scale-resistant moving parts) can work well for many years in good quality water. Poor water quality (hard water with high calcium/magnesium content) can cause performance issues an all TMVs and other valves in the system, requiring servicing after only a few months.

3.14.5.1.6. Disinfectant By-Products (DBPs)[4] – Created when chlorine or chloramines (or other oxidizing disinfectants) mix with organic matter in the drinking water supply (like bits of dead leaves). Disinfection by-products have been linked to cancer, especially bladder cancer, but also interference with the proper functioning of the liver, kidneys, central nervous system, and/or reproductive system. As a result, utilities making use of chlorine and chloramine need to balance the risks of pathogenic microorganisms that must be eliminated against the potential longer-term risks to public health.
3.14.5.1.7. Trihalomethanes (THMs)[5] – A group of organic chemicals that often occur in drinking water because of chlorine treatment for disinfectant purposes and therefore, also known as disinfection by-products. Trihalomethanes are formed when chlorine reacts with naturally occurring organic material found in water, such as decaying vegetation. Typically, the following four THMs are found because of chlorination: trichloromethane (chloroform), bromodichloromethane (BDCM), dibromochloromethane (DBCM), and tribromomethane (bromoform). Untreated or raw water rarely contains THMs in significant concentrations. Since chloroform is the THM found in highest concentrations and about which the most is known, the bulk of the information contained in this summary will pertain to chloroform. The EPA has established a maximum contaminant level (MCL) for total THMs in public drinking water systems. MCLs are enforceable drinking water standards determined by balancing the adverse health effects of a particular chemical against the feasibility and costs of treating contaminated water and, in the case of THMs, a consideration

of the benefits of chlorination in reducing the risk from acute gastrointestinal diseases. The MCL for total THMs is 80 parts per billion (ppb = micrograms per liter [ug/L]) (4670 grains per gallon).

3.14.5.1.8. Haloacetic Acid (HAA5)[6] – Formed as disinfection by-products when chlorine is added to kill bacteria and other pathogenic microorganisms. HAA5 reacts with naturally occurring organic matter in water to produce DBPs. HAA5 is more likely to be found at higher levels in water supplies with surface water sources such as rivers or reservoirs since soil and rock act as filters to reduce organic matter found in groundwater. The five haloacetic acids most commonly found in drinking water are monochloroacetic acid, dichloroacetic acid (DCA), trichloroacetic acid (TCA), monobromoacetic acid, and dibromoacetic acid. The U.S. EPA considers DCA and TCA to be potential human carcinogens. In some human studies, exposure to DBPs, including HAA5, increased the incidence of bladder cancer. Human studies have yet to confirm that DCA or TCA exposure increases the risk of cancer. Based on the animal data, at the current HAA5 regulatory level, the cancer risk is estimated to increase by about 1 in 60,000 for every 10 years of exposure.

3.14.5.1.9. Cyanogen Chloride (CK) – A disinfectant by-product of chloramine that is currently not regulated by the U.S. EPA[7, 8]. Cyanogen chloride is a highly volatile and toxic chemical asphyxiant that interferes with the body's ability to use oxygen. Exposure to CK can be rapidly fatal. It has whole-body (systemic) effects, particularly affecting those organ systems most sensitive to low oxygen levels: the central nervous system (brain), cardiovascular system (heart and blood vessels), and pulmonary system (lungs). CK has strong irritant and choking effects. Its vapors are extremely irritating and corrosive. CK is used in tear gas, in fumigant gases, and as a reagent in the synthesis of other compounds (Hawley, 1981)[9]. Cyanogen chloride may be formed as a by-product of the chloramination or chlorination of water. It is also formed by the chlorination of cyanide ions in raw water.

3.14.5.1.10. Chloropicin[10] – Formed in water by the reaction of chlorine with humic acids, amino acids, and nitrophenols. The presence of nitrates increases the amount formed[6]. Chloropicrin has been detected in drinking water; however, in the presence of reducing agents, it is converted into chloroform[6]. In one study, the mean chloropicrin concentration was 0.6 µg/L (35 grains per gallon); the highest concentration observed was 5.6 µg/L in 36 (327 grains per gallon) water supplies expected to have high concentrations of chlorination by-products[8]. When ingested in pure form, chloropicin[11] burns in the mouth, esophagus, and stomach, causing stomach pain, sore throat, nausea, and vomiting (emesis), difficulty breathing or shortness of breath (dyspnea), headache, dizziness, and bluish discoloration of the skin (cyanosis).

3.14.5.2. *Legionella* Control Methodologies

3.14.5.2.1. Temperature – An effective non-chemical means of controlling *Legionella* is temperature. This control method is significantly impacted by plumbing system design. This very cost-effective *Legionella* control method is discussed extensively in ASHRAE 188[59], ASHRAE Guideline 12-2020[60] as well as all other national and international *Legionella* guidelines including CDC[61], EPA[40], OSHA[62], WHO[63]. Although the impact of temperature on *Legionella* control has been documented in many papers and standards**,** it remains one of the most misunderstood methodologies for *Legionella* control. The temperatures for *Legionella* control listed in ASHRAE Guideline 12-2020 are also detailed in the

IAPMO Appendix N graphical summary. IAPMO Appendix N provides an effective and simple chart showing the temperature relationship to scald and *Legionella* risk. The *Legionella* control temperatures listed in ASHRAE Guideline 12 and IAPMO Appendix N are:

3.14.5.2.1.1. High Growth Range for *Legionella* 30-42°C (85–108°F) should be avoided wherever possible. Even with disinfectants in the system, this temperature range poses a higher risk requiring higher control and increased monitoring of disinfectant residual.

3.14.5.2.1.2. Low to Moderate Growth Range for *Legionella* 25-30°C (77–85°F and 108–113°F) – Some level of disinfectant may be needed to control *Legionella* in this temperature range.

3.14.5.2.1.3. Slow Growth Range for *Legionella* (20-25°C (68–77°F) and 45-49°C (113–120°F)) –Frequently *Legionella* can be controlled in this temperature range with little to additional control methods.

3.14.5.2.1.3. No Growth Range for *Legionella* (<20°C and >49°C (<68 and >120°F)) – *Legionella* won't reproduce in these temperature ranges but won't readily die within these ranges. Thus, if hot water circulation systems are kept at or above 49°C (120°F) most of the time, *Legionella,* which is a very slow-growing bacteria, will be controlled in the circulating water. If cold water is below 20°C (68°F) or below 30°C (85°F) with any persistent disinfectant residual, *Legionella* can be effectively controlled, and additional control measures may not be needed.

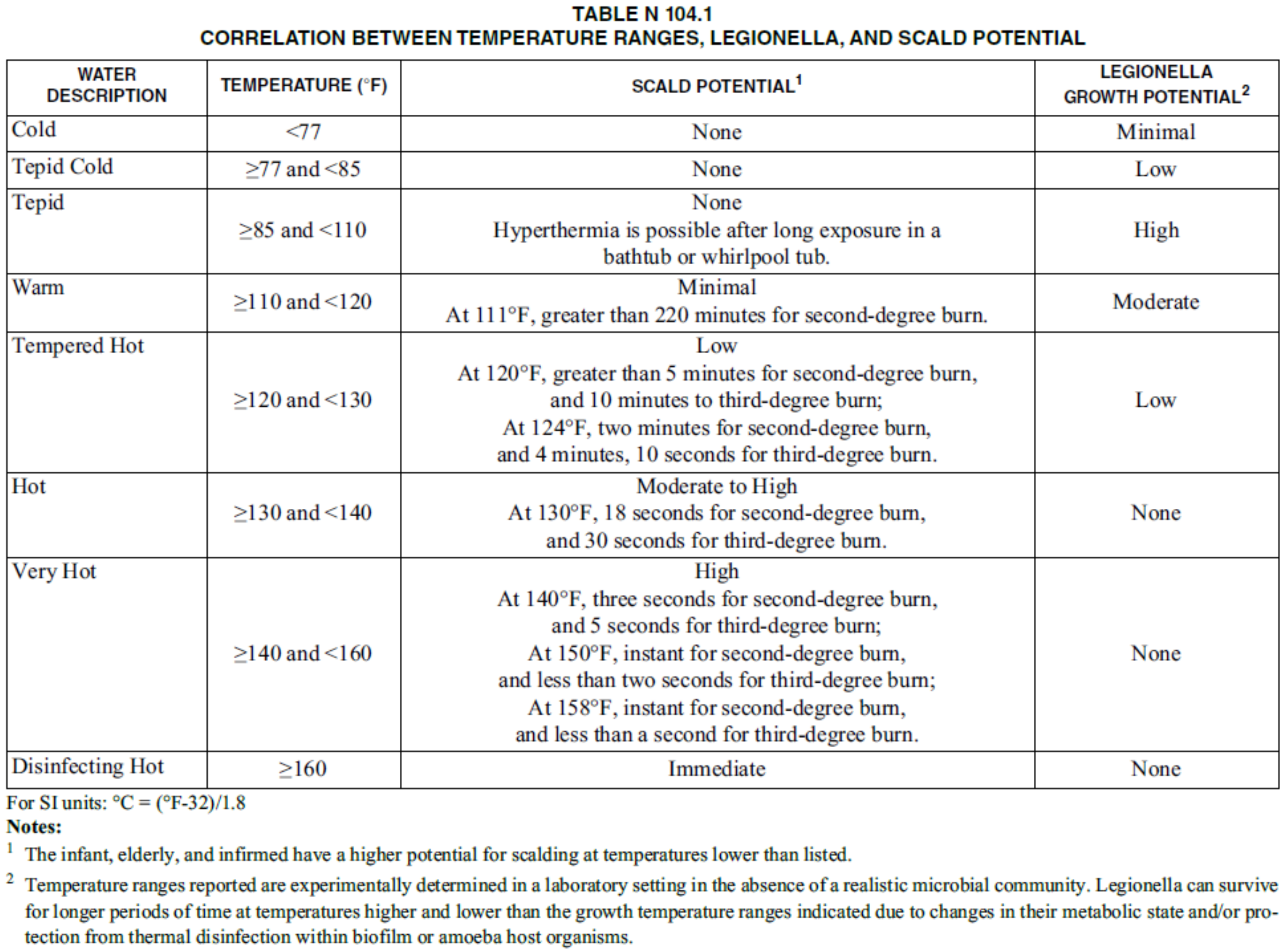


TABLE N 104.1
CORRELATION BETWEEN TEMPERATURE RANGES, LEGIONELLA, AND SCALD POTENTIAL

WATER DESCRIPTION	TEMPERATURE (°F)	SCALD POTENTIAL[1]	LEGIONELLA GROWTH POTENTIAL[2]
Cold	<77	None	Minimal
Tepid Cold	≥77 and <85	None	Low
Tepid	≥85 and <110	None Hyperthermia is possible after long exposure in a bathtub or whirlpool tub.	High
Warm	≥110 and <120	Minimal At 111°F, greater than 220 minutes for second-degree burn.	Moderate
Tempered Hot	≥120 and <130	Low At 120°F, greater than 5 minutes for second-degree burn, and 10 minutes to third-degree burn; At 124°F, two minutes for second-degree burn, and 4 minutes, 10 seconds for third-degree burn.	Low
Hot	≥130 and <140	Moderate to High At 130°F, 18 seconds for second-degree burn, and 30 seconds for third-degree burn.	None
Very Hot	≥140 and <160	High At 140°F, three seconds for second-degree burn, and 5 seconds for third-degree burn; At 150°F, instant for second-degree burn, and less than two seconds for third-degree burn; At 158°F, instant for second-degree burn, and less than a second for third-degree burn.	None
Disinfecting Hot	≥160	Immediate	None

For SI units: °C = (°F-32)/1.8

Notes:

[1] The infant, elderly, and infirmed have a higher potential for scalding at temperatures lower than listed.

[2] Temperature ranges reported are experimentally determined in a laboratory setting in the absence of a realistic microbial community. Legionella can survive for longer periods of time at temperatures higher and lower than the growth temperature ranges indicated due to changes in their metabolic state and/or protection from thermal disinfection within biofilm or amoeba host organisms.

3.14.5.2.1.4. A key to assessing risk associated with *Legionella* growth is understanding that *Legionella* is a very slow-growing bacteria. When labs culture water for Heterotrophic Plate count, the incubation period is either 24 or 48 hours. When labs culture water samples for *Legionella,* the incubation period is typically 10 to 14 days, confirming the slow growth of Legionella.

3.14.5.2.1.5. All guidelines recommend stored water be maintained below 20°C (68°F) for cold water or above 140°F for hot water and hot water be circulated at or above 49°C (120°F). For instantaneous-type water heaters, heaters without storage, this 60°C (140°F) minimum does not apply. These storage temperature recommendations are based on the potential for water aging and stratification to occur in the storage vessels. However, if stratification and water aging are controlled, lower hot water and higher cold water temperatures may be used. Maintaining water heaters with storage at or above 60°C (140°F) adds an extra layer of protection with little to no impact on system efficiency or heat loss.

3.14.5.2.1.5.1. If circulated water is maintained at or above 49°C (120°F) in all parts of the hot water system, this will provide an effective control for *Legionella.* If this temperature, along with a low level of disinfectant, is maintained, then the system will have multiple controls. Circulating water above 54°C (130°F) may increase *Legionella* growth potential because this temperature range will likely destroy any residual oxidant.

3.14.5.2.1.5.2. Many factors impact temperature as a *Legionella* control methodology. In cold water temperatures, below 29°C (85°F), disinfectant decay is much slower, and disinfectants persist longer in the system. In water temperatures above 60°C (140°F), most, if not all chlorine and chlorine dioxide will be readily destroyed. For chloramine, there will be a significant reduction in residual at this higher temperature.

3.14.5.2.1.5.3. Temperature can be used as a secondary control measure in tandem with a disinfectant, as higher temperatures increase biocidal efficacy.

3.14.5.2.1.5.4. High temperatures can also be used as an intermittent *Legionella* control. As stated in ASHRAE Guideline 12, this process of infrequent or routine thermal disinfection can be very costly in man-hours and very likely not to provide effective or cost-effective control of *Legionella*. [57]

3.14.5.2.1.5.5. Temperature is an area where the plumbing system designer has a significant impact.

3.14.5.2.2. Chemical disinfectants can be fed in building water systems when the incoming disinfectant levels in the water supplied by the public water utility are insufficient or unable to control the colonization of *Legionella* and other waterborne pathogens in the building's plumbing systems, or they can be added as an extra risk-reduction measure even if municipal disinfectant levels provide some level of protection. Based on the type of application and the design of the building's plumbing system and/or issues identified with the building users, water supply, or operation, supplemental disinfectants can be fed to the domestic cold water system only, the domestic hot water system only, or both. Three disinfectants are listed in the U.S. EPA Safe Drinking Water Act (SDWA). However, other chemicals are being used to remediate *Legionella* in building domestic hot water systems as well. One of the more widely reported technologies not listed in the SDWA is copper/silver ionization. Whether listed in the SDWA or not, all disinfectants applied to potable water must be EPA-FIFRA listed and approved to ANSI/NSF Std. 60 and/or Std. 61 for potable water use as drinking water additives and components.

Disinfectants	MRDL (mg/L)	Reported *Legionella* Control (mg/L)
Chlorine (HOCl /NaClO)	4 ppm as free chlorine	0.50 – 2.00
Chlorine dioxide (ClO_2)	0.8 ppm as chlorine dioxide	0.30 – 0.50
Monochloramine (NH_2Cl)	4 ppm at total chlorine	2.00 – 3.00

Inorganic Chemicals	MCL (mg/L)	Reported *Legionella* Control (mg/L)
Copper/silver (Cu/Ag)	Cu = 1.3 Ag (SMCL) = 0.10	Cu = 0.30 – 0.40 Ag = 0.03 – 0.04
Ozone	N.A.	0.5 – 1.00

MRDL = Maximum Residual Disinfectant Level
MCL = Maximum Contaminant level
SMCL = Secondary Maximum Contaminant Level (not enforceable)

3.14.5.2.2.1. The stability and the biocidal efficacy of oxidants is influenced differently by water temperature, water age, pH, alkalinity, and hardness. The stability and biocidal efficacy of copper-silver systems is not significantly influenced by water temperature, but like chlorine, copper-silver system efficacy is significantly impacted by pH above 7.8; it is also impacted by phosphates and hardness.

3.14.5.2.2.2. Building owners/managers should refer to their *Legionella* water management plan before applying a supplemental disinfectant to a building water system. Any chemical disinfectant, regardless of the type or technology, must be removed from the water prior to its use to feed kidney dialysis systems in healthcare environments. Regulations regarding the addition of disinfectants in building water systems vary widely from state to state, and the building owners/managers should be aware of the authority having jurisdiction (AHJ) and any regulations regarding supplemental disinfection in building water systems.

3.14.5.2.2.3. This guideline does not promote or endorse any disinfection method.

3.14.5.2.2.4. Chlorine – Chlorine, in the form of sodium hypochlorite (NaClO) and hypochlorous acid (HClO), is used as a primary and secondary disinfectant by public water utilities. Some municipal water treatment plants still use gaseous chlorine (Cl_2) as a chlorine source, but its use has dramatically decreased due to safety concerns. More than 70% of Americans receive drinking water treated with chlorine.

3.14.5.2.2.4.1. Chlorine is one of the most used supplemental disinfectant due to its low cost. Although chlorine is a strong oxidizer, *Legionella* control in building water systems with chlorine could be challenging due to the chemical properties of the molecule[29]. Due to its high oxidant-reduction potential (ORP), chlorine decays quickly in hot water, which makes it difficult to establish a consistent residual throughout the plumbing system of larger buildings or buildings with complex plumbing. Chlorine has been used successfully for Legionella control in building cold and hot water systems at levels commonly found in many municipal water supplies.

3.14.5.2.2.4.4.2. Due to its high reactivity, chlorine does not penetrate the biofilm and reacts with natural organic matter (NOM), potentially forming disinfection by products such as trihalomethane (THMs) and haloacetic acids (HAA5), which are regulated under the SDWA.

3.14.5.2.2.4.4.3. Chlorine is strongly influenced by the pH of the water. High water pH values (>7.8) lead to the formation of hypochlorite ions (ClO^-), which do not have any biocidal efficacy but are corrosive to materials of construction of the plumbing system.

3.14.5.2.2.4.4.4. Peer-reviewed studies in the scientific literature reported that the use of chlorine can increase corrosion rates in a building plumbing system.[64]

3.14.5.2.2.4.4.5. Rooms that store chlorine/bleach solutions are required to follow IBC 415.11 ventilation requirements. Additionally, per OSHA, an emergency shower and eyewash are required to be provided.

3.14.5.2.2.4.4.6. Treatment Options – Chlorine can be used to treat hot, cold, or both hot and cold water systems. If fed to the cold water supply, most of the free chlorine will typically be consumed in water heaters with any storage capacity.

3.14.5.2.2.4.4.7. Feed and Control – When treating hot water systems, chlorine should be injected into the hot water system after the heater and master mixing valve. Chlorine can be automatically fed and controlled in a circulating hot water system by an ORP probe or free chlorine probe. The ORP probe is an indirect measurement of oxidant residual, whereas the free chlorine probe directly monitors and logs actual disinfectant residual.

3.14.5.2.2.4.4.8. Manual Testing – A free chlorine test is quick, easy, and simple. The DPD method is the most commonly used.

3.14.5.2.2.5. Chlorine Dioxide – Chlorine dioxide (ClO_2) is used as a primary disinfectant by public water utilities.

3.14.5.2.2.5.1. A distinguishing feature of ClO_2 is that it is a stable free radical—that is, it has a single unpaired electron. Normally this would make the molecule extraordinarily reactive, but with ClO_2, this is not so. Research has shown that the unpaired electron is spread over the entire molecule, and the molecule is thereby stabilized. The uncharged, non-polar nature of ClO_2, along with its reduced oxidation potential, allows the rapid penetration of ClO_2 into biofilm[65]. Another distinguishing feature of ClO2 is that it does not react with water; it remains a gas in solution.

3.14.5.2.2.5.2. Chlorine dioxide is a novel disinfectant. It is used as a primary municipal water disinfectant for multiple purposes including reducing the formation of trihalomethanes and controlling algae, odor, and manganese. ClO_2 has disinfection properties second only to that of ozone among the commonly used disinfectants, and unlike chlorine and copper-silver disinfectants, its disinfection properties are relatively unaffected by pH. Chlorine dioxide is a broad-spectrum disinfectant effective on *Legionella* as well as other pathogens [73, 74, 75, 76, 77]. No known bacteria have developed a tolerance for ClO2 because it acts as an oxidant and not a bacterial poison.

3.14.5.2.2.5.3. Chlorine dioxide can be fed into the building water system from aqueous solutions with concentrations of < 3,000 ppm (175 grains per gallon) or can be generated onsite. Chlorine dioxide can be generated with two chemical precursors such as hydrochloric acid (HCl) and sodium chlorite ($NaClO_2$) or electrochemically from sodium chlorite or chlorate.

3.14.5.2.2.5.4. Chlorine dioxide has extensive documented success in controlling *Legionella* in building water systems[78, 82, 83, 84] . Some of those were in applications where other disinfectants have failed [70, 71, 72, 81]. One study showed excellent results with little to no fixture flushing [69, 71]. ClO_2 works well in cold or hot water, does not directly produce THMs or HAA_5s, and is significantly less corrosive than chlorine. In one pilot test where several disinfectants were compared, ClO_2 was determined to be the most effective treatment. [69]

3.14.5.2.2.5.5. For those chlorine dioxide generation technologies that involve the storage of a highly concentrated chlorine dioxide solution, additional safety measures must be taken, such as ventilation, as chlorine dioxide is a highly volatile molecule. As per U.S. EPA guidance, chlorine dioxide equipment requires a separate, explosion-proof storage area and trained staff.

3.14.5.2.2.5.6. The chlorine dioxide contact time required to inactivate *Legionella* is low [63]. Chlorine dioxide decay in water leads to its by-products of chlorite (ClO_2^-) and chlorates (ClO_3^-). Chlorite is a regulated contaminant under the SDWA and must be monitored when a chlorine dioxide application is made on a building plumbing system.

3.14.5.2.2.5.7. Peer reviewed studies in the scientific literature, reported[8] that the use of chlorine dioxide can increase the corrosion rates of metallic components in the plumbing system and can embrittle plastic components including cross-linked polyethylene pipes [80]

3.14.5.2.2.5.8. Rooms that store chlorine dioxide solutions and/or equipment are required to follow IBC 415.11 ventilation requirements. Additionally, per OSHA, an emergency shower and eyewash are required to be provided. There are definite safety considerations when dealing with ClO_2. The first and most important issue deals with the storage and handling of the precursor, sodium chlorite. The vast majority of safety incidents deal with this issue.[85] Aqueous sodium chlorite spill should be dealt with in the proper way.[86]

3.14.5.2.2.5.9. Treatment Options – Chlorine dioxide can be used to treat hot, cold, or both hot and cold water systems. If fed to the cold water supply, much of the chlorine dioxide will typically be consumed in water heaters with any storage capacity. When treating hot water systems, chlorine should be injected into the hot water system after the heater and master mixing valve.

3.14.5.2.2.5.10. Feed and Control **–** When treating hot water systems, chlorine should be injected into the hot water system after the heater and master mixing valve. Chlorine dioxide can be automatically fed and controlled in a circulating hot water system by an ORP probe or a chlorine dioxide probe. The ORP probe is an indirect measurement of oxidant residual, whereas the chlorine dioxide probe directly monitors and logs actual disinfectant residual.

3.14.5.2.2.5.11. Manual Testing – A chlorine dioxide test is quick, easy, and simple. The DPD method is the same as the free chlorine test, with glycine added first. The glycine converts any free chlorine into combined chlorine, leaving only chlorine dioxide to show as free chlorine.

3.14.5.2.2.6. Monochloramines – Monochloramine (NH_2Cl) is commonly referred as “chloramine” or “chloramines” and is widely used as a secondary (distribution line) disinfectant by public water systems. As per a survey conducted by the EPA, more than one in five Americans receives drinking water treated with chloramines.

3.14.5.2.2.6.1. The only available monochloramine technologies for building water system applications are onsite monochloramine generators that work with two precursors: a chlorine source (sodium hypochlorite) and an ammonium source (ammonium chloride or ammonium sulfate).

3.14.5.2.2.6.2. Monochloramine is significantly more stable than other oxidizing water disinfectants, and it is therefore easier to establish a consistent residual throughout the building plumbing system. Being a milder oxidant, the contact times required to inactivate *Legionella* are significantly higher than chlorine and dramatically higher than chlorine dioxide. Therefore, higher concentrations of monochloramine, compared to those of chlorine and chlorine dioxide, are required for *Legionella* control. A significant advantage of monochloramine is its stability; it will persist in an uncirculated drop leg much longer than chlorine or chlorine dioxide[87, 88]. Chloramine has been documented to effectively control *Legionella*. Studies have shown that monochloramine does not reliably control mycobacteria or pseudomonas at concentrations lower than 2 ppm (0.12 grains per gallon); therefore, a higher concentration of disinfectant might be needed to control these pathogens[11].

3.14.5.2.2.6.3. Monochloramine efficacy is not impacted by the pH of drinking water due to its higher stability. Monochloramine can fully penetrate the biofilm and reacts less with NOM in the water, therefore producing fewer disinfection by-products (THMs and HAA5) [89, 90].

3.14.5.2.2.6.4. Monochloramine decay leads to the formation of "free ammonia" (NH_4^+). The formation of free ammonia is mainly influenced by water temperature and water age. Although free ammonia is not a regulated contaminant under the SDWA, monitoring is advised as elevated levels of free ammonia can increase corrosion rates for copper piping in building plumbing systems over the long term.

3.14.5.2.2.6.5. The formation of free ammonia can also enhance a process called nitrification, which is the conversion of free ammonia into nitrite (NO_2^-) first and then nitrate (NO_3^-). Nitrification is more a concern in municipal applications due to the elevated residence time of the water with monochloramine in the distribution system. Differently than municipal monochloramine applications, the water residence time in building is low enough that nitrification processes typically do not take place[66, 11].

3.14.5.2.2.6.6. Rooms that store monochloramine generators are required to follow IBC 415.11 ventilation requirements. Additionally, per OSHA, an emergency shower and eyewash are required to be provided.

3.14.5.2.2.6.7. Treatment Options – Chloramine can be used to treat hot, cold, or both hot and cold water systems. If fed to the cold water supply, typically only a small percentage of the chloramine will be consumed in water heaters with properly sized storage capacity. Because of water aging issues or oversized hot water storage tanks, it might be challenging to maintain the desired chloramine residual if injected into the cold water supply only.

3.14.5.2.2.6.8. Feed and Control – When treating hot water systems, chloramine should be injected into the hot water system after the heater and master mixing valve. Chloramine can be automatically fed and controlled in a circulating hot water system by an ORP probe or a total chlorine probe. The ORP probe is an indirect measurement of oxidant and because the oxidant level of chloramine is lower than for chlorine or chlorine dioxide, ORP is not as reliable a control measure for chloramine feed, whereas a flow proportional control might be best option. The total chlorine probe directly monitors and logs actual disinfectant residual and can be used to trim the disinfectant feed rate.

3.14.5.2.2.6.9. Manual Testing – A total chlorine test is quick, easy, and simple. The DPD method is the same as the free chlorine test but uses total chlorine reagent instead of free chlorine reagent. Total chlorine for onsite systems is typically the same as monochloramine. Because the monochloramine test is more complex and takes more time than the total chlorine test, total chlorine is typically used for daily monitoring, and the monochloramine test is used to confirm either weekly or monthly that the total chlorine level is equal to the monochloramine level, and the onsite generator is working properly.

3.14.5.2.2.7 Copper-Silver – Although copper (Cu) and silver (Ag) are not listed as disinfectants under the SDWA, they have been widely used in building domestic hot water plumbing system for *Legionella* control.

3.14.5.2.2.7.1. Copper-silver systems use copper and silver alloy bars that release positively charged metallic cations into drinking water by means of electric current. The rate of copper and silver release is based on water flow and the DC current applied to the alloy bars. The concentration of copper and silver in water should be 0.3 to 0.4 ppm (0.018 to 0.023 grains per gallon) copper and 30 to 40 ppb silver (1753 to 2337 grains per gallon).

3.14.5.2.2.7.2. Copper-silver ions' stability are not significantly influenced by water temperature, but like chlorine its efficacy is significantly impacted by pH above 7.8. The ability of copper-silver ionization to control *Legionella* has been documented to decrease overtime[40, 67, 79]. Water quality variables, such as phosphates added for corrosion control by many water utilities, can reduce the apparent antimicrobial activity. Microorganisms are very adaptive, and some *Legionella* strains have shown to be much more resistant to copper/silver than others.

3.14.5.2.2.7.3. Copper-silver ions do not react with NOM and therefore do not produce any disinfection by-products (THMs, HAA5, chlorites). However, they are regulated contaminants under the SDWA, and their residual in drinking water must never exceed their MCL of 1.3 mg/L (0.076 grains per gallon) and 0.1 mg/L (0.006 grains per gallon) respectively.

3.14.5.2.2.7.4. Copper-silver is effective only as ions in solution. When measuring copper-silver residual in water, the samples should be filtered through a 5-micron filter to remove precipitated metals. Also, sample bottles used for collection of water for *Legionella* testing are pretreated with sodium thiosulfate to reduce any oxidizing biocide that may be present to prevent the oxidizing biocide from destroying any *Legionella* in the water sample. There is no agreed upon sampling and shipping protocol for systems using copper-silver[68]. The standard sodium thiosulfate level maintained for the shipment of *Legionella* samples will have little to no impact on copper-silver.

3.14.5.2.2.7.5. Treatment Options – Copper-silver ionization systems are typically used only to treat circulating hot water systems, although warm weather countries have been using them on whole building water systems.

3.14.5.2.2.7.6. Feed and Control – Copper-silver control systems are typically linked to a flow meter that monitors new water into the system and increases the current applied to the flow cell electrodes, which releases ions into the water flow proportional to the incoming water.

3.14.5.2.2.7.7. Manual Testing – Copper and silver in solution are what should be monitored. When measuring copper-silver residual in water, the samples should be filtered through a 5-micron filter to remove precipitated metals, leaving only ions in solution to be measured.

3.14.5.2.2.8 Ozone – Ozone (O_3) is the oxidant with the highest oxidation potential among all other disinfectants. Although it has the highest disinfectant potential, ozone is rarely used in building water systems as it dissipates too fast in the plumbing system and cannot reach the points of use in the building plumbing systems, especially in the domestic hot water system.

3.14.5.2.2.8.1. Ozone is generated onsite, and the mechanism of disinfection is a synergic action between ozone and the hydroxyl radicals that are formed during the ozone degradation reaction path. Ozone stability and disinfectant efficacy are not influenced by water pH between 6 and 9.

3.14.5.2.2.8.2. Because of its limited use, there are few peer-reviewed studies in the literature that evaluated ozone's effectiveness against *Legionella* in full-scale building plumbing systems. A study published by Edelstein et al. (1982) reported that researchers could not reach a conclusion on the role of ozone in the inactivation of L. pneumophila in a building water system, and the residual ozone in the water led to odor complaints from the building occupants.

3.14.5.2.2.8.3. Ozone does not form any chlorinated disinfection by-product, but its reaction with inorganic bromine can produce bromate (BrO_3^-), which is a regulated contaminant with its MCL set at 0.01 mg/L (0.0006 grains per gallon).

3.14.5.2.2.8.4. Treatment Options – Ozone is not recommended for the treatment of building water systems.

3.14.5.2.2.9. Ultraviolet – UV systems provide a very effective point-of-use disinfection. However, UV provides no residual disinfectant. When used as a point-of-entry disinfection system for a cold water supply, UV will effectively control bacteria in the cold water supply. If the piping system is clean, if there is no biofilm and no cross-contamination, and if the UV system never fails, the UV may provide control of *Legionella* in the plumbing system downstream of the UV, but with UV systems there is no residual to maintain control. The only method of monitoring UV control of pathogens in the system is routine and frequent bacteria testing.

3.14.5.2.2.9.1. UV systems will not impact water temperature; however, oversized systems can add heat to the water and increase temperature.

3.14.5.2.2.9.2. UV systems act with direct light for disinfection. For UV systems to function properly, water entering the UV device should be clean and not contain suspended solids. Typically, filtration is placed upstream of the UV system.

3.14.5.2.2.9.3. UV systems can remove some or all of the oxidizing disinfectant residual. Accordingly, UV systems can potentially increase risk and liability by removing disinfectant in the water supply.

3.14.5.2.2.9.4. UV system operation can be monitored remotely and continuously with sensors monitoring the light level.

3.14.5.2.2.9.5. Treatment Options – UV systems have been used for point-of-entry cold water supply treatment and in high-risk sections of hot water piping where an extra level of protection is desired. UV can also be used for treating hot water supply or return.

3.14.5.2.2.9.6. Feed and Control – UV systems can be monitored continuously and remotely by UV monitors. The monitor will alarm if the UV light is fouled or needs replacement.

3.14.5.2.2.9.7. Manual Testing – Measuring transmittance of UV light in the UV system will provide any indication of bacteria control in the system. Because there is no disinfectant residual, the only method of monitoring *Legionella* and bacteria control is routine *Legionella* and HPC testing.

3.14.5.2.3. Filtration – Based on the quality of water supply, filtration may provide some level of benefit in controlling *Legionella*. By reducing suspended solids, filtration can reduce organic demand for disinfectant, reduce biofilm growth potential, reduce the potential for deposition, and reduce maintenance requirements for plumbing components by eliminating or reducing particulates that can cause erosion or deposition on plumbing components.

3.14.5.2.3.1. Any type of media filter and bag filters, while removing suspended solids from the water, will retain those solids in the filter; if not maintained properly, the organics in the filter can provide an area for bacteria growth and disinfectant decay. Also, media filters (including softeners) that are not properly designed for the application or are oversized for the application can result in channeling of water through portions of the media, allowing the bulk of the media to be stagnant. Accordingly, media filtering, if not properly designed for the application, monitored, and maintained, can increase rather than decrease *Legionella* growth potential.

3.14.5.2.3.2. Submicron filtration down to 0.1 microns or less can remove *Legionella* from the water. Submicron filtration at the point of use in showers, sinks, and ice machines has been documented to successfully control *Legionella*. Compared to other methodologies for *Legionella* control, submicron filtration can be orders of magnitude more expensive to purchase and maintain. Submicron filtration is typically recommended when outbreaks occur or where there is no other long-term viable solution to *Legionella* control.

3.14.5.2.3.3. Carbon filters by design remove all oxidizing disinfectant. In addition to removing oxidizing disinfectant, they can remove organics and metals including lead. By removing oxidant in the system, carbon filters can increase the risk for *Legionella* growth.

3.14.6. Appendix F: Design Approach Examples

NOTE: The design approaches provided in this appendix are for information only. It is offered as an illustrated set of examples/solutions/technologies for use in engineering design approaches and does not imply acceptance or support from ASPE or the Working Group. It is not intended to endorse any specific technology or solution. Engineers are responsible for performing their own research and developing a solution suitable for the specific conditions of their project. Not illustrating technologies in this section does not constitute a lack of acceptance. Engineers should consult with water chemistry experts, local AHJ requirements, and the facility’s water management team in determining specific solutions.

3.14.6.1. Long-Term Care Facility with Supplemental Disinfectant, Shy Owner – This example will go over the design approach for a long-term care facility where the owner challenged the design team to not use supplemental disinfection but still address *Legionella* pneumophila concerns. The owner was open to “experimental” risk-mitigation methodologies. Therefore, the plumbing engineer used a combination of technologies to try to drive down the risk. Each technology chosen was evaluated independently and holistically (i.e., if the technology coordinated with all the other technologies, equipment, piping, appurtenances, etc.). The design pathing was as follows:

3.14.6.1.1. A point-of-entry ultrafiltration (POEUF) device was installed on the incoming water main. Prefiltration was added upstream of this device to optimize equipment performance. Strict instructions were given to the contractor to have all water that ever enters the building go through POEUF.

3.14.6.1.2. Post-POEUF UV equipment was added to further sanitize the water of *Legionella* pneumophila.

3.14.6.1.3. Due to extreme water hardness at the project location (>170ppm(10 gpg)), a water softener system was added to prevent the accumulation of scale, in addition to optimizing water heater efficiencies.
3.14.6.1.4. After the filter and softener, chemical injection ports and isolation valves were added on the cold water main for ease of installation of a supplemental disinfection system, if necessary, at a future date.
3.14.6.1.5. A variable-speed booster pump was required for the project due to the lower incoming water pressure and the significant pressure loss through the filters and water softener. The booster pump selected was able to work without an accumulator tank, thereby reducing the potential of stagnant water.
3.14.6.1.6. To minimize the growth potential of biofilm on the piping system, CPVC piping was used throughout the facility. Schedule 80 piping was used for piping 50mm (2 inches) and larger, while Schedule 40 was used for piping 38mm (1½ inches) and smaller.
3.14.6.1.7. Due to the laundry load and high bathing load, two tank-type water heaters were utilized to serve the entire facility. The water heaters were set to 71°C (160°F). Instantaneous water heaters were considered as part of the design but were ultimately eliminated as there was no perceived risk-reduction advantage from their utilization. (In addition, this helped decrease the size of the natural gas piping.) A digital mixing valve complying with ASSE 1017 was utilized to reduce the water temperature to 60°C (140°F) and distribute it to the rest of the facility. POU TMVs complying with ASSE 1070 were utilized at all handwashing locations. ASSE 1016 P valves were used at all shower locations. (Due to the booster pump, it was assumed that T/P valves would not be needed.) A flow-through expansion tank was used to reduce the amount of stagnant water. An expansion tank was installed per the manufacturer's installation instructions.
3.14.6.1.8. Pressure-independent balancing valves (PIBV) were utilized on the hot water return system to eliminate the need to test and balance the hot water return system.
3.14.6.1.9. Jump routing was utilized for the hot water distribution system in each wing, while venturi valves were utilized on the cold water branches in each wing. This was done to mitigate the amount of stagnant water in various branch pipes.
3.14.6.1.10. Each "wing" had electronically actuated flushing valves located at the end of the cold water line. Each wing also had one of these flushing valves located on the hot water supply near a janitor's closet. These valves were connected to a master controller that allowed the building owner to schedule or manually flush the pipe mains and branches throughout the facility.
3.14.6.1.11. At each wing near a storage room or janitor's closet, the CW, HW, and HWR mains serving that wing were routed to approximately 1 meter (3 feet) above

the finished floor. At that point, supplemental disinfection ports were added with isolation valves if emergency remediation was necessary.

3.14.6.2. Supplemental Disinfection System Selection and the Importance of Documentation – A signature hotel in the downtown area of a large U.S. city hires an engineer to design the plumbing systems. The engineer is concerned about *Legionella,* but the owner is not.

3.14.6.2.1. The engineer, in an effort to comply with ASHRAE 188, recommended that the owner install a supplemental disinfection system on the domestic water system (i.e., copper-silver ionization).

3.14.6.2.2 The owner, not believing that *Legionella* pneumophila was a problem and being primarily concerned about first cost, indicated to the engineer to remove the supplemental disinfection equipment from the project during value engineering. The engineer indicated to the owner that this was not recommended.

3.14.6.2.3 Over the next several years, construction is completed, and the building is occupied. Shortly thereafter, a case of Legionnaires' disease occurs. The family of the victim sues the hotel, which in turn countersues the engineer of record along with the rest of the construction team. The engineer can locate the documentation that indicated that it was the owner's choice to remove the safety precaution against *Legionella* pneumophila, and the lawsuit against them is thrown out.

3.14.6.3. Local Penal System Patient Intake Facility and Supplemental Disinfection – The engineer of record inherits a turnover package of a penal patient intake facility that does not include supplemental disinfection.

3.14.6.3.1. Based on this building type being identified on the listed facility types recommended in ASHRAE 188, the engineer of record includes a secondary disinfection system (in this case, copper-silver ionization) in the design of the hot water supply and return system serving the building to assist in reducing the probability of *Legionella* development. The project is located in a northern climate; thus, a point-of-entry application was deemed not necessary as the cold water would be maintained below 20°C (68°F) in normal operating conditions**.**

3.14.6.3.2. The plumbing contractor proposes a point-of-entry filtration system in lieu of the copper-silver ionization system for the building's *Legionella* control method.

3.14.6.3.3. The engineer of record indicates to the owner and contractor that the point-of-entry filtration system has benefits but cannot be the only method for *Legionella* control as there is no downstream residual to protect against any *Legionella* development in the building piping system. Additionally, the pressure drop associated with the filtration system would have required a booster pump to be added to the design to provide satisfactory building water supply pressure.

3.14.6.3.4. The owner is not familiar with the copper-silver ionization system proposed by the engineer. A meeting with the EOR, owner, contractor, state health department, and CSI equipment manufacturer takes place to explain system operation and controls.

3.14.6.3.5. After consideration, the owner opts to exclude the CSI system proposed by the engineer of record. The engineer of record documents this decision.

3.14.6.3.6. The owner instructs the engineer to include a point-of-entry injection port to allow for hyperchlorination in the event *Legionella* is detected in the plumbing system.

3.14.6.3.7. The owner requests assistance from the engineer of record in developing an ASHRAE 188-compliant water management plan. The engineer provides the owner with the following information:

3.14.6.3.7.1. High-level schematic of paths of water from the point of entry to various areas of the building, mechanical equipment, hot water generating systems, fixture types, etc.

3.14.6.3.7.2. Suggested points of water sampling for testing of water quality and the presence of *Legionella*.

3.14.6.3.7.3. The engineer goes on record stating that a water management plan is a practice that must be maintained during building operation and that the design team has a limited role in its overall success. Any building modifications or operational changes require updates to the water management plan.

3.14.6.3.8. Copper-silver ionization was recommended by the engineer of record for the following reasons:

3.14.6.3.8.1. CSI can both treat an infected system and maintain a disinfected system.

3.14.6.3.8.2. The residual timeframe for CSI is up to 40 days.

3.14.6.4. The engineer of record works with a nationally recognized healthcare provider in upgrading several “beyond life expectancy” domestic hot water systems on campus. The nationally recognized healthcare (owner) is ahead of the curve and recognizes the importance of secondary disinfection of their domestic hot water supply and return systems.

3.14.6.4.1. The engineer of record is instructed by the owner to maintain the same secondary disinfection technology (in this case, copper-silver ionization) and provide all new equipment in conjunction with the new domestic hot water generating equipment.

3.14.6.4.2. The engineer of record incorporates digital mixing valves for precise temperature control and improved hot water return system performance into the design, and the owner agrees.

3.14.6.4.3. New equipment systems are imported across the campus. The owner has a water management team that maintains a water management plan in accordance with the recommendations of ASHRAE 188.

3.14.6.5. Phoenix, Arizona Approach with No Disinfectant Residual

3.14.6.5.1. If a building is being built in Phoenix in an area with no significant disinfectant residual in the water supply and the water system is somewhat large, then:

3.14.6.5.1.1. Option A (least costly) – Add a water meter and feed chlorine to the cold water. For a large building, chlorine use might be $30/month, $350/year. If the building owner wants to have a water treatment company manage it, likely this would be $4,000 or $5,000 in service cost, but if the building already is treating the hot water, adding treatment to the cold would be nominal. Chlorine has issues in very complex systems but would work well for most apartments, hotels, nursing homes, office buildings, etc. The only real problem is large hospitals that are typically complicated plumbing systems.

3.14.6.5.1.2. Option B (no chemical) – Filter incoming water to 5 or 10 microns and then use UV disinfection, which provides no residual disinfectant. However, cold water, even warmer cold water, is a very low risk.

3.14.6.5.1.3. Option C (flushing program) – Use manual or automatic flushing.

3.14.6.5.1.4. Option D (chilling cold water) – If the water exceeds 29°C (85°F), then chilling cold water could be a bacteria control technique as well as a user benefit. *Legionella* growth below 27°C (80°F) is very slow, so the chiller only needs to chill so cold water at end of the system is 27°C (80°F) or less.

3.14.7. Appendix G: Case Studies

3.14.7.1. Apartment Building in Boise, Idaho: An apartment building in design is seeking PassiveHouse certification and is investigating opportunities to reduce energy. The domestic hot water system is expected to be the largest energy load in the building. Because the building type falls within one of the risk categories outlined in ASHRAE 188-2021 Section 5.2, the domestic hot water will be recirculated continuously, as recommended in ASHRAE 12-2020 Section 5.3.1. The distribution temperature is designed for 52°C (126°F), with a 1.7°C (3°F) drop between the mixing valve and the balancing valve. These temperature targets are expected to result in a water temperature at the return connection to the water heater slightly above 50°C (122°F), ensuring that the precision limits of the master mixing valve and balancing valves maintain a temperature above 49°C (120°F). Following the installation of the system, temperature setpoints are checked and the distribution temperature is adjusted to ensure that the best balance between *Legionella* risk mitigation, thermal injury risk at faucets, and heat loss is maintained.

3.15. Additional Research/Actions Needed

3.15.1. Revision to Hunter's Curve – Revision of Hunter's curve for commercial buildings likely will have a major impact on improving public health and safety by reducing water age, increasing disinfectant residuals, and reducing the surface area on which pathogens can grow.

3.15.2. Further specialization in plumbing engineering likely will need to occur. The deposit of knowledge for plumbing engineering is growing rapidly, while HVAC engineering is also increasing in complexity, in part due to the concerns of COVID-19. It is becoming increasingly difficult for "generalist" mechanical engineers to truly have the requisite knowledge for both plumbing and HVAC engineering, particularly for complex buildings such as hospitals. Considering the professional engineering obligation that engineers are to work within their area of expertise, this likely will mean further specialization as society continues to develop.

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