CONNECT AND PROTECT

HWAT HOT WATER TEMPERATURE MAINTENANCE SYSTEM

Special Pathogens Laboratory Independent Review of the nVent RAYCHEM HWAT System Regarding ASHRAE 188

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RAYCHEM

nVent RAYCHEM Hot Water Maintenance System White Paper

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1. Introduction

nVent has designed a hot water maintenance system (HWAT) using heat-trace cables for building water systems. This system was designed to be cost and energy efficient, while replacing the need for a hot water recirculation system. Special Pathogens Laboratory (SPL) was retained to provide an independent, third-party review of the nVent RAYCHEM HWAT system, as compared with a traditional recirculating hot water system, regarding the potential for *Legionella* growth. This paper discusses:

- *Legionella* and Legionnaires' disease
- Building hot water systems
- nVent's HWAT system
- Literature review of hot water temperatures and flow conditions

2. Legionella and Legionnaires' Disease

Legionella is a bacterium that belongs to the *Legionellaceae* family. The family comprises 60 species and over 70 serogroups. *Legionella* species are small (0.3–0.9 μm in width and approximately 2 μm in length) gram-negative rods with polar flagella. Approximately half of the species have been implicated in human disease. *Legionella pneumophila* contaminates up to 70% of all building water systems, both potable and non-potable, and is the species responsible for approximately 90% of Legionnaires' disease infections.

Legionella pneumophila serogroup 1 is responsible for the majority of cases of Legionnaires' disease; however, other serogroups have also caused disease. All other *Legionella* serogroups and species combined account for less than 10% of reported cases. (Benin, Benson, & Besser, 2002)

Percentage of disease caused	**50.5%**	**32.1%**	**1.2%**	**2.0%**	**1.1%**	**1.1%**	**2.9%**	**0.5%**	**1.3%**	**1.5%**	**2.2%**	**2.8%**
***Legionella pneumophila* serogroups**	Lp1	Lp Unknown	Lp2	Lp3	Lp4	Lp5	Lp6	Lp7-14	*L. bozemanii*	*L. dumoffii*	*L. longbeachae*	*L. micdadei*

Legionnaires' disease is a global public health concern. The US Centers for Disease Control and Prevention (CDC), estimates there are between 8,000 and 18,000 cases of Legionnaires' disease every year. The disease has a case fatality rate of approximately 10%, and it can be as high as 30% for healthcare-associated cases. The bacteria can multiply to harmful levels after entering warm water systems in buildings through municipal cold water supplies. The mode of transmission for Legionnaires' disease is either through the inhalation of bacteria-laden aerosols or aspiration of contaminated water. Individuals who are most susceptible to Legionnaires' disease may possess conditions (risk factors) that increase the probability of infection upon exposure. These risk factors include: smoking, diabetes, cancer, steroid use, advanced age, and other forms of immunosuppression. Legionnaires' disease accounts for approximately 2–5% of cases of community-acquired pneumonia.

For building-associated Legionnaires' disease, important factors in assessing and managing risk are: 1) determining whether *Legionella* is present in the water system, 2) what type (species and serogroup) of *Legionella* is present, and 3) the extent and opportunity for exposure. Several risk management methods are available to provide a process for hazard identification and mitigation. Risk management methodologies share core concepts for understanding the system, managing hazards, and verifying results. The American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) has developed standards, such as *ANSI/ASHRAE Standard 188: Legionellosis: Risk Management for Building Water Systems* (ASHRAE, 2000, 2018), to guide these risk management activities.

3. Building Hot Water Systems

Hot water recirculation or heat-trace systems are typically used in large buildings (commercial, hospitality, institutional, and multi-unit residential) as part of the hot water system when there are long distances between a building's hot water supply and the outlet. There are multiple plumbing codes in use throughout the United States, but they generally have similar language in regard to the provision of hot water in buildings. For the purpose of this paper, the 2018 International Plumbing Code (IPC) will be referenced. Chapter 6: Water Supply and Distribution contains code language regarding the delivery of hot water in Section 607: Hot Water Supply System.

- Paragraph 607.2: Hot or tempered water supply to fixtures. The developed length of hot or tempered water piping, from the source of hot water to the fixtures that require hot or tempered water, shall not exceed 50 feet (15.24 meters). Recirculating system piping and heat-traced piping shall be considered to be sources of hot or tempered water.
- Paragraph 607.2.1: Circulation systems and heat trace systems for maintaining heated water temperature in distribution systems. For Group R2, R3, and R4 occupancies that are three stories or less in height above grade plane, the installation of heated water circulation and temperature maintenance systems shall be in accordance with Section R403.5.1 of the International Energy Conservation Code. For other than Group R2, R3, and R4; occupancies that are three stories or less in height above grade plane, the installation of heated water circulation and heat trace systems shall be in accordance with Section C404.6 of the International Energy Conservation Code.

In Chapter 2 of the 2018 IPC, hot water is defined as water at a temperature ≥110°F (43°C), while tempered water is defined as water that is between the temperature range of 85°F (29°C) and 110°F (43°C).

Both recirculated and heat-trace piping systems can be designed to deliver hot or tempered water to distal outlets.

Recirculation systems form a loop within the plumbing to circulate water from the hot water heater around the loop, providing hot water to any usage point, without waiting for the water to be delivered directly from the hot water heater (Peterson, 1990). These systems allow better access to hot water at any point within the building; however, they still contribute to heat and energy loss. While recirculation systems were designed to limit water waste, the Oak Ridge National Laboratory conducted a study of hot water recirculation, proving that this is not necessarily the case. Through their study, it was concluded that in order to achieve hot water immediately at the tap, a push button system that starts the pump to bring hot water to the outlet must be installed. Other methods of achieving immediate hot water include recirculation systems with a thermostat, those with continuous circulation, and timer-controlled systems (Brazeau & Edwards, 2013). Continuous circulation allows quick access to hot water, therefore eliminating the need to run excess water to achieve a warmer temperature. This saves water, but results in heat loss that, in turn, wastes energy. Timer-controlled systems are commonly applied to operate the recirculation system during the peak use hours to ensure quick access to hot water. While this is somewhat beneficial, frequent water use during the day reduces the need for the recirculation system during these hours. However, at night, when the need for hot water recirculation is greater, the pump is turned off. Recirculation system thermostatic controls maintain a preset temperature then turn off the pump when the return water is above the set point. This keeps the water system at a constant temperature, but it is not as beneficial in terms of saving energy (Peterson, 1990). The plumbing codes have an abundance of requirements for sizing pumps, mixing valves, and piping returns to ensure the performance of recirculating hot water systems.

Heat-trace system have fewer associated codes and/or engineering practices, as circulation pumps, mixing valves, and piping returns are not necessary to deliver hot water to distal outlets for a properly designed system.

4. HWAT System Design

The nVent RAYCHEM HWAT system is a heat-trace system that provides buildings with immediate hot tap water without the use of a building recirculation system (Figure 1). The HWAT system is designed to maintain a constant hot water temperature within the supply pipe. Unlike recirculation, HWAT systems do not have to overheat the water to compensate for line heat losses. The main components of the HWAT system include an nVent RAYCHEM electronic controller (HWAT-ECO or ACS-30), self-regulating electric heating cables (HWAT-R2), and the RayClic connection kit.

The HWAT-R2 cables are installed on the hot water supply pipes underneath the prescribed insulation schedule. Flexible temperature control across individual circuits is used to maintain the desired temperature and allows easy scheduling of when the system is on. This allows the system to be easily programmed for use patterns as well as energy savings. A water temperature sensor is utilized to prevent pipe overheating and possible scalding.

Both the HWAT-ECO and ACS-30 controller allow the operating temperature and scheduling to be easily changed at the controller. The HWAT-ECO controls one circuit between 105-140°F (40-60°C), while the ACS-30 controller is configurable for up to 250 circuits and temps between 100°F and 150°F (38°C and 66°C) as well as many other application modes. Each has preset scheduling as well as custom schedule settings, provide building management system (BMS) interface capabilities, monitoring, feedback and alarms based on user settings.

Both controllers provide BMS compatibility, enabling remote temperature maintenance, monitoring, and feedback/alarms. These capabilities allow the system to be integrated into an ASHRAE 188 Water Safety and Management Program by establishing precise temperature control limits and automated alarms when operating outside of control limits to initiate corrective actions.

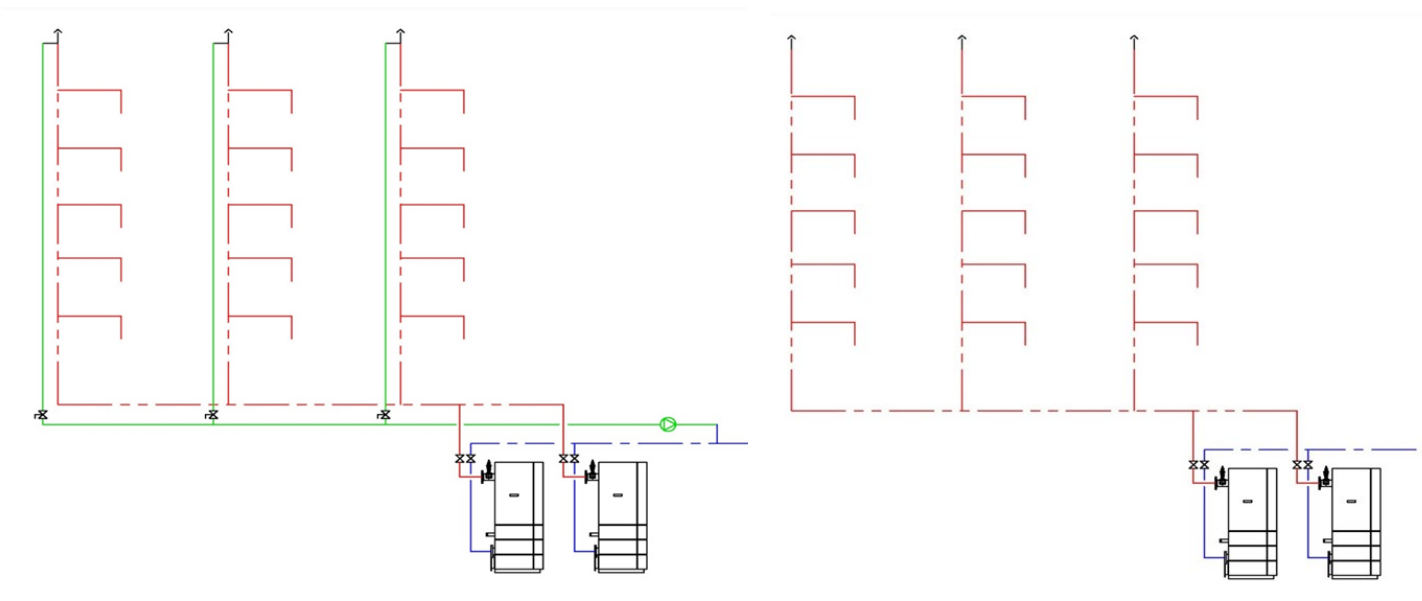

Figure 1. Schematics of a basic Recirculation Hot Water System (left) compared to a HWAT System (right) for the same plumbing layout. The recirculation system illustrates circulating loops and uncirculated branches extending to the termination of the fixture supply line. The HWAT system lacks the recirculation but ensures that branches remain heated even during periods of inactivity.

5. Literature Review

5.1 Temperature

Legionella has been shown to propagate over a wide range of temperatures and plumbing surface materials. Figure 1 illustrates a field/laboratory study conducted by Rogers (Rogers, Dowsett, Dennis, Lee, & Keevil, 1994) that showed *Legionella* growth at varying temperatures and surface material piping (copper [Cu], polybutylene [PB], and polyvinyl chloride [PVC]) over a 21-day period. *Legionella* can survive below 68°F (20°C), but it will remain dormant and not actively grow. However, once the bacteria is within the optimum temperatures of 104–122°F (40–50°C), *Legionella* multiplies. Temperatures of 140°F (60°C) and above have been proven to be bactericidal, reducing *Legionella* numbers within minutes in laboratory settings (Rogers et al., 1994). However, efficacy in the field of using temperature to kill *Legionella* (i.e., thermal eradication or super-heat) is governed by water temperature, contact time, and exposure (free-floating or within biofilm). Historically, effective thermal eradication in the field has been shown to require flushing hot water at a temperature exceeding 160°F (71°C) through fixtures for a minimum of 30 minutes (Best et al., 1983) in order to maintain a biocidal temperature throughout the system. In spite of this, regrowth will occur after a thermal eradication procedure when water temperatures return to a favorable growth range.

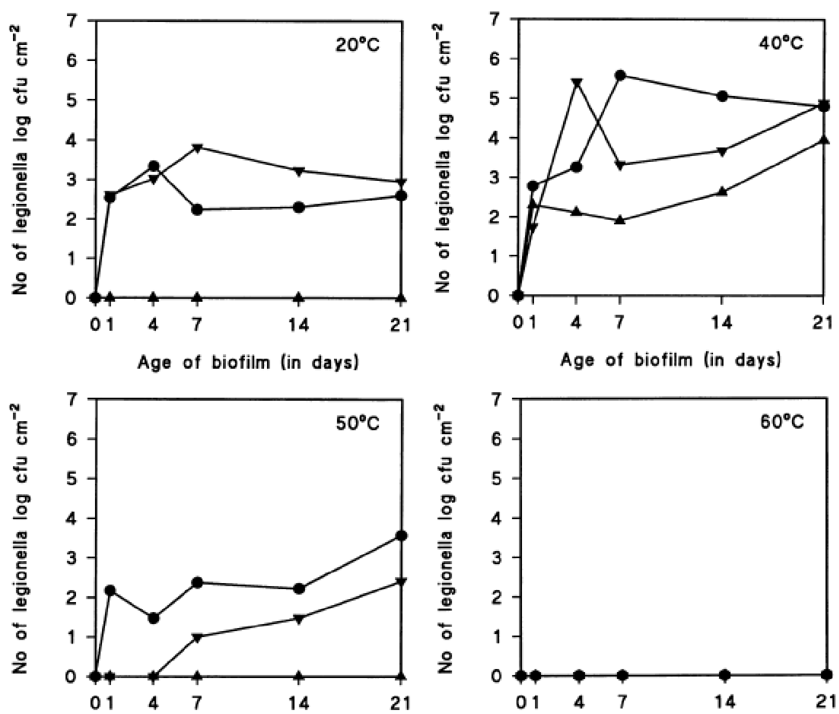

Figure 2. *Number of L. pneumophila organism colonizing the surface of copper, polybutylene, and PVCc at 20, 40, 50, and 60°C. in all cases, the standard deviation is less than log_{10} 0.15 of the plotted mean datum points. (▲) Copper, (●) Polybutylene, (▼) PVCc. (Rodgers et al. 1994)*

In a laboratory study conducted by Wadowsky et al. (Wadowsky, Wolford, McNamara, & Yee, 1985), researchers demonstrated the effects of temperature on naturally occurring *Legionella pneumophila* in membrane filter sterilized tap water. *Legionella* isolates were incubated at 95°F (35°C [control]) and at 77°F, 89.6°F, 98.6°F, 107.6°F, and 113°F (25°C, 32°C, 37°C, 42°C, and 45°C). Figure 2 demonstrates that the most *Legionella* growth occurred between 77°F and 98.6°F (25°C and 37°C). The graph shows that growth at 98.6°F (37°C) and above will occur; however, it takes days for log amplification to occur. At these temperatures, *L. pneumophila* multiplied after one week of incubation, and the maximum increase in log CFU/mL was 2.0–2.3, while, at 107.6°F and 113°F (42°C and 45°C), *Legionella* growth began to decline, but at a slow rate. The times required for a 10-fold decrease in CFU/mL was 7.5 and 2.4 days at 107.6°F (42°C) and 113°F (45°C), respectively. *Legionella* was essentially non-detect after day 25 at 107.6°F (42°C) and non-detect after day 11 at 113°F (45°C) (Wadowsky et al., 1985).

A hot water setting of at least 131°F (55°C) has been shown to reduce growth and viability when maintained consistently throughout a model system; however, *Legionella pneumophila* has been observed surviving brief exposure to 158°F (70°C) (Laperriere, Brassard, & Moreau, 1992; William J Rhoads, Ji, Pruden, & Edwards, 2015). Although higher hot water temperatures reduce the risk of opportunistic pathogens in hot water systems, outlet water at a temperature of 131°F (55°C) presents a high scald risk, and engineering controls should be applied to the outlet (Cloutman-Green et al., 2019).

Furthermore, fluctuating water temperatures within water systems can promote the proliferation of *Legionella* and other opportunistic pathogens. When hot water is introduced to an area of a plumbing system where flow is reduced or stopped, allowing temperatures to cool (i.e., a branch from the recirculation loop to a distal tap), higher temperature settings in the circulating hot water may be required to control *Legionella* growth on the fixture. In systems where there is continuous exposure to elevated temperatures (i.e., heat-trace system or circulated to the distal tap), conditions are less favorable for *Legionella* growth. In a study comparing hot water temperatures within a simple plumbing model of a recirculating system, *Legionella pneumophila* was lower when the temperature was set to 136°F (58°C) compared with 124°F (51°C), and distal taps in the system had a decline in *Legionella* when a temperature of 136°F (58°C) was reached. Although levels of *Legionella* were reduced in a recirculating system maintaining a temperature of 136°F (58°C), it was not totally eradicated (William J Rhoads et al., 2015).

Legionella guidelines, standards, and codes developed by various professional organizations indicate the temperature ranges for consideration as control limits to minimize the risk for *Legionella* growth. These recommendations are based on laboratory evaluations of *Legionella* growth in ideal hot water environments and may not take into consideration all the challenges of generating and supplying hot water in a complex building water system. Typically recommended hot water temperatures for *Legionella* control are in the following ranges:

- Generation/storage: 130–140°F (54–60°C)
- Hot water return: >124°F (>51°C)
- Distal outlet (non-healthcare): 110–120°F (43–49°C)
- Distal outlet (healthcare): 105–110°F (41–43°C)
- Sensor (tempered) outlet: 105–110°F (41–43°C)

5.2 Stagnation and Pipe Orientation

It is often assumed that water stagnation within a system predisposes *Legionella* colonization. A study focusing on the proliferation zone of a water heater showed that *Legionella* developed in the stagnant zone at the base of a domestic hot water heater where the lowest temperatures were found, rarely exceeding 104°F (40°C). This was due to the challenge of maintaining appropriate temperatures with low water usage (Laperriere et al., 1992). Vertical hot water tanks are an additional risk for *Legionella* proliferation due to the potential for thermal stratification, resulting in the tepid/warm water at the bottom of the tank and the hot water on top, which creates ideal temperatures for *Legionella* growth (W. J. Rhoads, Pruden, & Edwards, 2016). In Rhoads' 2016 study, even when the temperature within the hot water tank was raised to 158°F (70°C), the temperature at the bottom of the tank remained below 140°F (60°C); however, this was enough for *Legionella* levels to become undetectable. This can be remedied with the use of a recirculation pump within the hot water tank to minimize thermal stratification and consistently maintain temperatures of >131°F (55°C) throughout the tank. Although an effective method of heating the stagnant zone, recirculation was determined to be costly and unreliable (Laperriere et al., 1992). Laperriere describes that it is the zone of tepid temperature between 86-122 °F (30-50°C), developing during stratification in the bottom of a hot water tank, enables *Legionella* proliferation. When temperatures were raised equally throughout the tank with use of internal and exterior heating elements, *Legionella* growth was managed.

In addition to traditional hot water tanks, building design can produces other regions of tepid water within the hot water system. The design of hot water distribution systems often results in the installation of branch piping and run-outs to distal outlets that are installed in a vertical orientation. These sections of pipe are also typically not part of the recirculating piping system, with flow only occurring when water use at the fixture occurs (Figure 1). Mixing or movement of water may occur in these vertical pipes through convective mixing as temperature differences occur between the recirculating hot water main and cooling water in the branch pipe. The paper by Rhoads et al., 2016 "Convective Mixing in Distal Pipes Exacerbates *Legionella pneumophila* Growth in Hot Water Plumbing" demonstrated this effect in a laboratory setting evaluating downward- and upward-oriented vertical pipes with different end point flushing periods to simulate use. The conclusion of the study included:

> "…experiment supports the conventional wisdom that **maintaining elevated water temperatures at all points in a hot water system is a critical engineering control for inhibiting regrowth of *Legionella***, especially *L. pneumophila*."
> (W. J. Rhoads et al., 2016)

> "…convective mixing currents in hot water systems can maintain ideal growth temperatures and continuously supply nutrients to otherwise stagnant distal taps. As a result, convective mixing has the potential to undermine thermal control strategies."
> (W. J. Rhoads et al., 2016)

This work by Rhoads is further evidence that stagnant conditions in piping systems alone are not the root cause of *Legionella* growth. Convection mixing between the recirculation system and stagnant branches to distal taps provides *Legionella* with ideal temperatures and a continual supply of nutrients. A challenge that traditional recirculating hot water systems have is maintaining steady hot water temperatures to the point of use through different piping orientations and away from the recirculating water loop if the fixture is not located directly off the riser.

Another study evaluated the effect of flow regimes on the presence of *Legionella* within the biofilm of a model plumbing system (Liu et al., 2006). Liu showed that the turbulent flow of water within a piping system could contribute to the increase of oxygen and other available nutrients to the attachment surface for biofilms, supporting their growth and viability. Other opportunistic pathogens, such as *Mycobacterium avium* and *Pseudomonas aeruginosa*, are also supported by the development of biofilms (Falkinham III, Hilborn, Arduino, Pruden, & Edwards, 2015). Conditions, including stagnant, laminar, and turbulent flow in the model piping system, were evaluated in the Liu study (Liu et al., 2006). **Stagnant (no) flow in pipes demonstrated the lowest concentration of *Legionella*, suggesting that noncirculating water may not promote *Legionella* growth,** compared with circulating piping.

5.3 Heat-Trace Systems

In a search of the peer-reviewed literature using Google Scholar and PubMed ("heat-trace" + "*Legionella*"), no published information could be found reviewing the impact of heat-trace hot water systems on *Legionella* growth.

6. Discussion

The purpose of this paper was to review the HWAT system in comparison with a traditional recirculating hot water system regarding the potential for *Legionella* growth. nVent's HWAT system utilizes self-regulating heating cables and control systems (heat-trace) to maintain hot water temperatures in a noncirculating hot water system, which is in contrast with the more traditional recirculating hot water systems in most large buildings.

Peer-reviewed literature indicates that *Legionella* can be found in up to 70% of all building water systems. SPL's experience while conducting building water system assessments over many years is that approximately half (50%) of building hot water systems evaluated will have some *Legionella* findings. Most commonly, *Legionella* is identified at the distal outlets (sinks and showers). Less frequently, points of hot water generation, storage, and return are also identified with *Legionella*.

6.1 Design and Building Code

- Both heat-trace and recirculating hot water systems are indicated in building codes as appropriate systems for maintaining heated water in building water systems.

- Design guidelines and building codes that provide recommendations for both heat-trace and recirculating hot water systems, including sizing, insulation, installation, and operation, are available.

- Regarding the AIA callout for all hospital DHW to be recirculated; We understand this mandate was created to ensure timely hot water delivery and not pathogen control. If true, then guidelines designed around rapid delivery of hot water need to be re-evaluated to include alternative hot water delivery technologies such as heat trace that do not require recirculation.

6.2 Ability to Maintain Temperature

- Both heat-trace and recirculating hot water systems can theoretically be designed to maintain hot water temperatures in the main hot water supply of a building after hot water generation.
    - Peer-reviewed reports, and SPL's experience, demonstrate that it is not uncommon to identify *Legionella* in building hot water systems, despite the best efforts of designers to implement building codes and the minimum requirements for hot water system design and temperature maintenance using traditional recirculating hot water design approaches.

- The HWAT heat-trace system can be installed and operated in different configurations, depending on the hot water system design and system requirements.
    - Heat-trace can be provided on the main hot water piping to maintain hot water temperatures from the heater through the hot water distribution system, similar to the design of a recirculating hot water system.
    - Heat-trace can be installed on the run-outs or branch piping to the distal outlets, providing temperature maintenance up to or close to the point of use, unlike a traditional recirculating hot water system.
    - Heat-trace systems have operational flexibility, allowing different temperature maintenance zones, or automatically providing intermittent increases in temperature, targeting different zones of the plumbing system. Targeting different hot water temperature zones, or providing intermittent temperature increases, is not readily achievable in recirculating hot water systems without multiple pump loops and mixing and balancing valves.

- These design options for a heat-trace system theoretically provide a better opportunity to maintain or adjust hot water temperatures within a building water system, up to the point of use, than a traditional recirculating hot water system.

- While hot water temperature alone may not be sufficient to control *Legionella* growth in a building water system, the ability to achieve and maintain temperatures as high as possible reduces one of the factors that contributes to *Legionella* in building water systems.

6.3 Flow Conditions

- Heat-trace systems are noncirculating by design, which results in no flow through piping when there is no demand for hot water. Recirculating hot water provides water flow in the main piping, but no flow in branch connections or run-outs when there is no use at the outlet. The work by Rhoads evaluated some of the challenges of managing *Legionella* growth in vertically-installed distal pipes associated with recirculating hot water systems.

- The presence or absence of flow alone cannot be used as a predictor for *Legionella* growth in a hot water system, but, rather, it is one of several factors, which, in combination, may contribute to conditions conducive to support *Legionella* growth. As indicated by several studies, factors such as temperature, nutrient availability, water quality, and other microorganisms may have a greater influence on *Legionella* growth than flow conditions alone.

7. Conclusion

The impact of water temperature on *Legionella* growth is well-documented. There is significant discussion in the industry on updating management guidelines, design requirements, and codes to address temperature maintenance up to the point of use as a control method for *Legionella*.

A heat-trace system, like nVent's HWAT system, offers a technology that provides the ability to address some of the shortcomings of a traditional recirculating hot water system by: 1) providing temperature management close to the point of use in noncirculating branches and run-outs, 2) providing flexibility in developing temperature management zones throughout the system without the use of mixing or balancing valves, and 3) providing a means to implement corrective actions or maintenance events by elevating water temperatures in the piping system after hot water generation.

SPL has consistently recommended that when evaluating a new technology to demonstrate its efficacy for *Legionella* control, the evaluation needs to be evidenced-based and follow a four-step approach: 1) in vitro efficacy, 2) anecdotal experience of efficacy in individual hospitals, 3) peer-reviewed controlled studies of prolonged duration documenting efficacy and prevention of Legionnaires' disease, and 4) confirmatory reports from multiple sites with a prolonged duration of follow-up. (Stout & Victor, 2003)

To affirm the efficacy of heat-trace systems in effectively preventing *Legionella* growth (and, more importantly, preventing Legionnaires' disease), these four steps should be performed, including a laboratory evaluation and controlled evaluation of field installations of the systems in operating buildings.

Based on the available information from the literature regarding design/codes, temperature, and flow conditions, there is no information suggesting that a heat-trace system would perform any worse or better than a traditional recirculating hot water system in terms of the potential for *Legionella* growth. From a microbiological perspective, additional scientific evaluation is needed to address the impact on *Legionella* growth; however, current information suggests that a properly designed and installed heat-trace system should not be excluded from consideration as a hot water temperature maintenance system in a building water system.

8. Resources

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