BEYOND THE WATER HEATER
Centralized Storage Water Heaters and Reducing Risk of Legionella throughout the Building Domestic Hot Water Piping System

An Evidence-Based Discussion

Legionella is not new. Valuable research began more than 40 years ago

In the past few years, the topic of Legionella in building plumbing systems has received a great deal of attention in the media and in marketing channels due in no small part to the release of the new ASHRAE 188 Legionella control standard. Despite the amount of recent discussion, the subject of Legionella is more than 40 years old and many hundreds of Legionella-specific and related laboratory and site research projects have been conducted since the late 1970s. As early as the mid-1990s, the UK Department of Health published a Legionella guideline, followed by consensus guidelines from the World Health Organization, the United States Department of Labor through OSHA, ASHRAE, and the health departments of many countries. These guidelines are very similar in recommendations and, although research continues, the information remains pertinent and accurate.

The concept of “old water”

Legionella contamination in sections of a building’s hot water distribution system can all be traced back to one thing: the continual occurrence of “old water.” This phrase describes water that no longer has chlorine residual and, as a result, microbial growth can no longer be controlled. Those areas of the building’s domestic hot water system that are repeatedly exposed to “old water” for extended time, and especially concurrent with warm water temperatures, are prime candidates for microbial contamination and biofilm formation.

Water that leaves a treatment plant is safe to consume but is not sterile. It contains small numbers of microbes whose growth is kept under control by free chlorine or chloramines as water leaves the treatment facility. Some amount of free or residual chlorine remains when the water enters a building’s piping system. Whether or not this remaining free chlorine will decay before the water is used is affected by a number of characteristics that are unique for every building.

Characteristics contributing to chlorine decay and eventually “old water” include:

- The level of existing bacterial contamination; determined by the level of accumulated and distributed sediment and biofilms
- The level of corrosion (particularly iron) in the system due primarily to system age
- A high ratio of surface area to water volume and the rate of water circulation across these surfaces. The greater the surface area relative to the water volume, the greater the rate of chlorine decay due to surface decay kinetics

- High water temperature. Elevated water temperature increases chlorine reaction and chlorine decay
- The initial level of residual chlorine
- Extended residence time of water in the system and inadequate replacement with fresh water; either universally or localized in low-use zones or dead end piping

Water volume by itself has no relation to the creation of "old water" and presence of Legionella

Provided the residence time of the water is short enough to avoid an "old water" condition, the amount of stored water in a domestic hot water system is completely irrelevant. Concerning the water heater, "old water" is prevented by proper sizing; specifically matching hot water demand with an appropriate storage volume and BTU input to provide regular water turnover in the tank while maintaining the necessary outlet water temperature. Proper sizing is easily calculated.

In numerous building surveys, multivariate analysis of salient water heater and building characteristics has failed to show a statistically meaningful link between the gallon capacity of the hot water storage tanks and the presence of Legionella in the tanks or in the building [1,2,4,10,28]. Whether or not Legionella was present, the range of hot water tank capacities in either case was so similar to be purely coincidental; suggesting that something far more meaningful was occurring in the buildings to cause or prevent Legionella. Further evidence is that Legionella has also been found in building domestic hot water systems equipped with centralized instantaneous water heaters [2,12,24].

Of course, the irrelevance of stored water volume to the presence of Legionella only holds true if the water heaters are properly sized and maintained. There have certainly been occasions where Legionella contamination occurred in water heating systems that were massively over-sized in tank volume for the application [5,9]. So oversized in fact, that numbers of storage water heaters were unused and isolated from the piping system but still filled with water. The opposite is also true. Some contaminations can be explained by heaters that were too small in both stored water volume and Btu input to maintain the proper 140°F temperature under the experienced demand conditions allowing warm water to flow into the building plumbing system [1]. Such examples are not the fault of storage water heaters; they are caused by error in water heater system design and sizing.

The Role of Sediment

In 1982, researchers first made the connection between the detection of Legionella in water samples drawn from the bottom of storage tanks and the fact that these water samples contained sediment [29]. This same study showed that after the initial water draw, additional samples drawn only three minutes later (with conceivably less or possibly no sediment) failed to culture Legionella or cultured considerably lower numbers of the bacteria. This Legionella/sediment connection was further supported when secondary tests of tanks that had originally been positive for Legionella were negative two months later. It was discovered that two weeks prior to the second test, the tanks in question were flushed from the bottom, effectively eliminating all the sediment and yielding no Legionella as a result. This evidence was not lost on the researchers and in the conclusion of the report they stated that the simple occasional flushing of the tanks may appreciably decrease or eliminate Legionella contamination of the tanks and the buildings.

A 1984 laboratory study confirmed that sediment amplified Legionella by offering an ideal environment for the growth of biofilms [27]. Formation of biofilm by bacteria is a survival mechanism in a low-nutrient environment; such as drinking water. The diverse biofilm community provides protection from chlorine and temperature, and provides food sources for a number of microorganisms, including Legionella. The tests confirmed that in water with sediment and the accompanying microbes, Legionella survived and multiplied. In sterilized sediment in the absence of the other microbes, the Legionella began to die off.

In further support, another study found that Legionella could not be cultured from tank-type, bottom-fired, residential gas water heaters where the accumulated sediment at the tank bottom was rendered inhospitable to biofilm and Legionella due to the regular sterilizing temperature that occurred with each burner firing cycle [1,11,29]. Conversely, in the same water district, the sediment in the cooler bottom head of electric water heaters was found to harbor Legionella [1,11].

When sediment is taken out of the equation, whether rendered inhospitable to biofilm growth or eliminated from the tank by flushing, the threat of Legionella contamination of the tank and the building appears to be greatly reduced.

The clear advantage to a storage tank is that it’s a lower-water-turbulence environment where sediment falls to the tank bottom allowing regular flushing through the drain and elimination of sediment from the domestic water system. In instantaneous, low-water volume heaters, the higher flow environment is capable of carrying sediment into the piping where it can be difficult, if not impossible, to locate and eliminate. Sediment in the piping provides the same prime Legionella breeding ground as it would in the bottom of a storage tank.

Eliminating sediment from the storage tank is neither time consuming nor difficult. Requirements will vary, but generally flushing the tank through the bottom drain valve for a few seconds every three or four weeks should be sufficient. The process can be easily automated using motorized and timed valves, if desired.

In regularly ridding the tank of sediment and the potential biofilm, the chlorine residual in the tank water is conserved and available in maximum quantity to disinfect other areas of the tank and building piping system.

The essential roles of temperature and time in killing Legionella and amoebae

Perhaps the most corroborated information regarding Legionella is that a water temperature of 140°F is highly effective at killing the bacteria and keeping the building piping system free of contamination [4,10,19,22,28]. For this reason, every consensus Legionella control guideline recommends that water leaving the water heater be 140°F regardless of whether the water heater is a storage type or instantaneous [33,34,35,36].

As illustrated in the table below, killing Legionella with water temperature is a time AND temperature relationship. Temperature of 140°F is recommended because it kills Legionella 50 to 100 times faster than 120°F in open water [23].

Time and Temperature Required to Kill Legionella Pneumophila sg. 1 (unchlorinated water)			
Kill rate	**140°F water**	**130°F water**	**120°F water**
90% (1 log)	2.7 minutes	27 minutes	4.3 hours
99% (2 log)	5.4 minutes	54 minutes	8.6 hours
99.9% (3 log)	8.1 minutes	1.35 hours	14 hours

Water temperature is of greatest concern when considering the presence of amoebae in the building water system. Amoebae ingest Legionella and other bacteria as food. However, Legionella can reverse the enzyme process and consume an amoeba from within, using the energy and protective environment to multiply. When the amoeba dies, hundreds of replicated Legionella bacteria spread into the biofilm. This process is considered the primary replication method of Legionella in domestic water systems [3,8,15,20,30]. While Legionella are susceptible to relatively low levels of chlorine in open water, amoebae are highly resistant to chlorine and unaffected by the residual chlorine levels normally found in a building's water system [6,13]. Therefore, water temperature is crucial for killing amoebae. The time needed to kill amoeba at 140°F is virtually identical to the death of Legionella with a 99.8% kill occurring with 5 minutes exposure [26]. Similar to Legionella, at 120°F death of amoebae can take hours [3].

In the 1960s, 70s and 80s, it was routine for water heaters to be operated with temperatures of 120°F or lower to prevent scalding and save energy. It's not surprising, therefore, that a high percentage of the older buildings surveyed were found to have Legionella contamination throughout the domestic hot water system.

Using the storage water heater as a water sterilizing device

The concept of using a water heater as a water sterilizer was first promoted by Legionella researchers in the mid-1980s [28]. The initial recommendation was instantaneous, blend-down, steam-fired water heaters that generate 180°F to 200°F water temperatures. The heat exchangers contain about one gallon of water and, due to the high flow-through rates under normal demand, the time/temperature relationship for Legionella kill required the extreme set point temperature to instantly sterilize the water. The sanitizing temperature outlet water is then blended with cold before introduction into the building piping system at the desired temperature.

Other "instantaneous" water heaters types, not designed or installed to achieve the "sterilizing temperature/blend down" process, have circumvented this method for Legionella control and should be reviewed for their effectiveness as part of a legionella control program. Under normal hot water demand conditions, water can travel through the entire instantaneous water heater in 30 to 60 seconds. Due to their very low water volume and high flow-through rates, the dwell time at design temperature falls short for an effective kill rate. To achieve an effective kill rate, this style of water heater must have elevated set points (160°F to 170°F) to ensure a complete kill of Legionella before water is released to the hot water plumbing system. A stark contrast to the time/temperature relationship dilemma occurs in a storage water heater, where a Legionella kill can be accomplished without the extreme water temperatures. In a properly sized storage water heater (both storage and input), there is ample residence time in the volume of 140°F water to kill Legionella.

Water stagnation and circulation

Circulating water through the building hot water piping system is essential for Legionella control. Without circulation, during periods of low demand the temperature in the building loop will drop and may fall to the ideal growth range for Legionella (90°F to 100°F). Additionally, the free chlorine will decay faster due to the initial elevated temperature of the water and the amount of surface area relative to water volume that occurs in the smaller diameter building piping. Circulation of the building loop back to through the water heater helps to maintain temperature and can replenish chlorine, although circulation itself also increases chlorine demand.

During these low or no-demand periods, storage water heaters can provide a reservoir of residual chlorine for circulation into the building piping. Low-volume, instantaneous water heaters have no chlorine storage, which can quickly lead to loss of all residual chlorine and the circulation of "old water" throughout the building. If this occurs, the only thing preventing Legionella contamination is temperature.

While water circulation clearly benefits the building piping system by maintaining temperature, there are some claims made about circulation that are simply not true.

Claims are made that the constant flow condition common to that Instantaneous water heaters is superior in defeating Legionella when compared to the lower flow or the standing water environment that occurs at times in storage water heaters. While the claim seems obvious enough, it has actually been proven false by no fewer than five independent research studies, the first conducted in 1999 [7,16,17,21,25]. It is now known that due to mass transfer of nutrients and microorganisms, higher and even turbulent flow rates increase the growth of biofilms and Legionella when compared to a no-flow condition.

Claims that water circulation is sufficient to completely shear biofilm from water heater surfaces are also questionable. While it is possible to introduce flow rates with high enough turbulence to shear biofilm, these flow rates, beginning at an estimated 9 feet per second through small diameter pipe, are well above what is recommended and normally experienced in a water heater or building piping system.

Clearly, a long-term no-flow or stagnant condition is bad because it can lead to an “old water” condition. However, it doesn’t occur instantly. We have already established that a properly sized and maintained storage water heater will not generate “old water” due to adequate water turnover with replenishment of residual chlorine and the elimination of sediment [5]. Being first in line with the water main into the building hot water system, the water heater experiences the greatest amount of free chlorine. For Legionella control, it is not necessary to continuously circulate the water heater storage tank.

Stratification in a hot water storage tank: Does warm water at the bottom mean Legionella?

In 1982, laboratory researchers discovered that Legionella would survive and grow in tap water at temperatures between 90°F and 108°F, with the highest growth rates occurring at 98°F [32]. This study has been cited in other peer-reviewed research papers at least 108 times. It’s the foundation for the wide-spread belief that the warmer temperatures found at the bottom of hot water storage tanks is a primary and unavoidable cause of Legionella growth and, as a result, storage tanks serve as Legionella “amplifiers.”

Taken to its extreme, this argument would quickly indict all hot water storage tanks because all of these tanks stratify to some degree. But why don’t all storage tanks have Legionella contamination, even after many years of operation?

A closer look into this research study provides some insight.

This and subsequent laboratory tests to determine the effect of water temperature on the growth of Legionella were all conducted with no free chlorine or chloramines in the test water samples [31, 32]. Elimination of variables is commonly done to ensure the test outcome reflects only changes caused by the variable being tested; in this case, temperature.

Additionally, the water samples for the tests were taken from biofilm contaminated point sources; including hot water tanks, and contained Legionella and other microbes that had populated the biofilm. The amount of other microbes in the samples was an estimated 16,000 colony forming units (individual bacteria) per milliliter, suggesting a well-established biofilm contamination. As described earlier, a separate research study discovered that Legionella survives and grows prolifically in the presence of the additional microbes populating sediment biofilm. However, when Legionella is isolated from the supportive microbes, it perishes. The study that made the sediment-Legionella connection was conducted at 98°F, which is the reported ideal temperature growth range.

It is incorrect to merely assume this warm water Legionella growth outcome outside of the laboratory. The bottom of a properly maintained hot water storage tank (no or low sediment) is not a zero-chlorine environment. Absent an existing biofilm and a significant contamination by Legionella bacteria, the continual presence of even modest amounts of free chlorine would largely prevent such a situation to begin with. Laboratory tests using a “severe” Legionella contamination level of 3000 bacteria per milliliter indicated a susceptibility to moderate levels of free chlorine [14]. In another laboratory test, drinking water with 0.04 to 0.05 ppm free chlorine was shown to prevent the formation of bacterial biofilms in piping [16].

Clearly, this temperature research has been taken out of context. The environment created in the laboratory mimics an already "run-away" condition, including existing sediment, an established highly populated biofilm and no chlorine residual. The results do not support the theory that Legionella will grow prolifically merely because of warm water located at the bottom of a hot water storage tank. It only further supports the fact that Legionella will grow prolifically in the warm water at the bottom of a hot water storage tank ONLY IF sediment and biofilm are also present and without a free chlorine level.

The laboratory created environment does resemble contaminated tanks from site studies but this should not be considered normal or unavoidable. These conditions resulted from poor maintenance, where sediment was allowed to accumulate and biofilms were allowed to grow unabated.

If the sediment is routinely removed from the bottom of a storage water heater, there will be far less biofilm and microbes that support Legionella growth and there will be a greater amount of residual chlorine. Given this, the temperature at the bottom of the tank is irrelevant and there will not be prolific Legionella growth due to this fact alone.

Maintenance does work despite what some people say

One multiple-site study concluded that maintenance of water heating systems was not effective in preventing Legionella contamination of the tanks and building piping. Unfortunately, there was no evaluation of the quality and effectiveness of the so-called maintenance, and all maintenance programs were given equal value. There were two categories of maintenance in the statistical analysis; a building either had a maintenance program or it did not. Among those that had a program, very effective approaches; including flushing the bottom of the tank every few weeks, were included with far less effective approaches; such as flushing tanks only annually or "occasionally" checking the operating set point. It's ludicrous to suggest that all maintenance is ineffective based upon a statistical analysis of such a broad category. It's also unfortunate that this research study and this observation have been repeated in subsequent published research reports.

Conclusion

Decades ago when little or nothing was known about Legionella, storage water heating systems were operated in a manner that amplified the growth of Legionella and increased the risk of contaminating the domestic hot water system piping. Sediment was allowed to collect for years in the bottom of tanks, temperatures were maintained at 120°F or lower, building loops were not recirculated, heat exchangers were often undersized and tanks were often grossly oversized allowing water to sit unused for sometimes months at a time. As a result, the reputation of storage water heaters still suffers from these mistakes of the past.

Today we know better. Forty years of research and numerous consensus Legionella control guidelines have provided valuable information to properly design and operate these water heating systems. Using this information and some common sense water heater sizing methods, a storage water heater presents no larger risk to building Legionella contamination than other water heating approaches. Nor does a storage water heater require an onerous maintenance program to control Legionella.

There are tens of thousands of centralized storage-type water heating systems serving the entire gamut of building types around the world that are installed and operated in accordance with the Legionella guidelines and are Legionella-free as a result. The fear of stored water causing an imminent Legionella problem in a domestic hot water system is entirely unfounded.

Final Note

In an existing building with extensive Legionella contamination of the entire water distribution system, the water heater cannot be expected to correct the problem regardless of type of heater. These issues require comprehensive solutions; including temperature elevation, supplemental residual chlorination, copper/silver ionization, and, as needed, chlorine and thermal shock eradication.

No one can guarantee that one or any combination of procedures or pieces of equipment will eliminate Legionella growth in a building plumbing system; including water heaters. In centralized water heating systems, there is no definitive superiority in whole building Legionella control of any one type of water heating equipment compared to any other when these systems are properly maintained and operated.

References:

1. **Alary M., Joly J.** (1991). *Risk factors for contamination of domestic hot water systems by Legionella.* Applied and Environmental Microbiology **57:** 2360-2367.
2. **Alary M., Joly J.** (1992). *Factors contributing to the contamination of hospital water distribution systems by Legionella.* Journal of Infectious Diseases **165:** 565-569.
3. **Barbaree P., Fields B., Feeley J., Gorman G., Martin W.** (1986). *Isolation of protozoa from water associated with a Legionellosis outbreak and demonstration of intracellular multiplication of Legionella Pneumophila.* Applied and Environmental Microbiology **51:** 422-424.
4. **Borella P., et al.** (2004). *Legionella infection risk from domestic hot water.* Emerging Infectious Diseases **10:** 457-464.
5. **Ciesielski C., Blaser M., Wang W.L.** (1984). *Role of stagnation and obstruction of water flow in isolation of Legionella Pneumophila from hospital plumbing.* Applied and Environmental Microbiology **48:** 984-987.
6. **Cervero-Aragó L., Rodriguez-Martinez S., Araujo R**. (2015). *Effect of common drinking water disinfectants, chlorine and heat, on free Legionella and amoebae-associated Legionella*. PLoS ONE 10(8): e0134726. doi:10.1371/journal.pone.0134726

7. **Cloete T., Weestaard D., van Vuuren S.J.** (2003). *Dynamic response of biofilm to pipe surface and fluid velocity.* Water Science and Technology **47:** 57-59.
8. **Declerk P., Behets J., Margineanu A., van Hoef V., Keersmaecker B., Olleveir F.** (2007). *Replication of Legionella Pneumophila in biofilms of water distribution pipes.* Microbiological Research **164**: 593-603.
9. **Fisher-Hoch S.P., Smith M.G., Colbourne J.S.** (1982). *Legionella Pneumophila in hospital hot water cylinders.* The Lancet **i:** 1073.
10. **Flannery, B., et al.** (2006). *Reducing Legionella colonization off water systems with monochloramine.* Emerging Infectious Diseases **12:** 588-596.
11. **Joly, J.R**., **et al.** (1985). *Legionella and domestic water heaters in the Quebec City area.* Canadian Medical Association Journal **132:** 160
12. **Kool, J.L., et al.** (1999). *Hospital characteristics associated with colonization of water systems by Legionella and risk of nosocomial Legionnaires' disease.* Infection Control and Hospital Epidemiology **20:** 798-805.
13. **Kuchta, J. et al.** (1993). *Impact of chlorine and heat on the survival of Hartmannella Vermiformis and subsequent growth of Legionella Pneumophila.* Applied and Environmental Microbiology **59:** 4096-4100.
14. **Kuchta, J. et al.** (1985). *Enhanced chlorine resistance of tap water-adapted Legionella Pneumophila as compared with agar medium passaged strains.* Applied and Environmental Microbiology **50:** 21-26.
15. **Lau H. and Ashbolt N.** (2009). *The role of biofilms and protozoa in Legionella pathogenesis: implications for drinking water.* (review article) Journal of Applied Microbiology **107:** 368-378.
16. **Lehtola M., et al,** (2007). *Survival of M. avium, L. pneumophila, E. coli, and caliciviruses in drinking water-associated biofilms grown under high-shear turbulent flow.* Applied and Environmental Microbiology **73**: 2854-2859
17. **Liu Z., Lin Y.E., Stout J., Hwang C., Vidic R., Yu, V.** (2006). *Effect of flow regimes on the presence of Legionella within the biofilm of a model plumbing system.* Journal of Applied Microbiology **101**: 437-442.
18. **Lund V. and Ormerod K.** (1995). *The influence of disinfection processes on biofilm formation in water distribution systems.* Water Research **29**: 1013-1021.
19. **Mouchtouri V., et al.** (2007). *Risk factors for contamination of hotel water distribution systems by Legionella species.* Applied and Environmental Microbiology **73**: 1489-1492.
20. **Nahapetian K., et al.** (1991). *The intracellular multiplication of Legionella Pneumophila in protozoa from hospital plumbing systems.* Applied and Environmental Microbiology **73**: 1489-1492.
21. **Percival S., Knapp J., Wales D., Edyvean R.** (1999). *The effect of turbulent flow and surface roughness on biofilm formation in drinking water.* Journal of Industrial Microbiology and Biotechnology **22:** 152-159.
22. **Plouffe J., Webster L., Hackman, B.** (1983). *Relationship between colonization of hospital buildings with Legionella pneumophila and hot water temperatures.* Applied and Environmental Microbiology **46:** 769-770.
23. **Sanden G., Fields B., Barbaree J., Feeley J.** (1989). *Viability of Legionella Pneumophila in chlorine-free water at elevated temperatures.* Current Microbiology **18:** 61-65.
24. **Sellick Jr. J, and Mylotte J.** (1993) *Nosocomial Legionella pneumonia in a hospital with an instantaneous hot water heater.* Legionella: Current Status and Emerging Perspectives. American Society for Microbiology. Editors Barbaree, Breiman, Dufour.
25. **Simoes L., Azevedo N., Pacheco A., Keevil C., Vieira M.** (2005). *Drinking water biofilm assessment of total and cultural bacteria under different operating conditions.* Biofouling **22:** 91-99.

26. **States S.J., et al** (1993). *Temperature and the survival and multiplication of Legionella Pneumophila associated with Harmannella vermiformis.* Legionella: Current Status and Emerging Perspectives. American Society for Microbiology. Editors Barbaree, Breiman, Dufour.
27. **Stout J., Yu V., Best M. (**1985). *Ecology of Legionella Pneumophila within water distribution systems.* Applied and Environmental Microbiology **49:** 221-228.
28. **Vickers R., et al** (1987). *Determinants of Legionella Pneumophila contamination of water distribution systems: 15-hospital prospective study.* Infection Control **8:** 357-363.
29. **Wadowsky R., Yee R, Mezmar L., Wing E., Dowling J.** (1982). *Hot water systems as sources of Legionella Pneumophila in hospital and nonhospital plumbing fixtures.* Applied and Environmental Microbiology **43**: 1104-1110.
30. **Wadowsky R., et al.** (1988). *Growth-supporting activity for Legionella Pneumophila in tap water cultures and implication of Hartmannellid amoebae as growth factors.* Applied and Environmental Microbiology **54**: 2677-2682.
31. **Wadowsky R., et al.** (1985). *Effect of temperature, pH, and oxygen level on the multiplication of naturally occurring Legionella Pneumophila in potable water.* Applied and Environmental Microbiology **49**: 1197-1205.
32. **Yee R. and Wadowsky R.** (1982) *Multiplication of Legionella Pneumophila in unsterilized tap water.* Applied and Environmental Microbiology **43**: 1330-1334.

Examples of Legionella control guidelines for design, operation and maintenance of building water systems

33. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., (2000). **ASHRAE Guideline 12-2000** *Minimizing the risk of legionellosis associated with building water systems*. Atlanta, Georgia USA.
34. Health and Safety Executive, (2014). **Legionnaire's disease** *Part 2: The control of Legionella bacteria in hot and cold water systems.* United Kingdom.
35. World Health Organization (2007). **Legionella and the Prevention of Legionellosis**. Geneva, Switzerland.
36. Occupational Safety and Health Administration. **OSHA Technical Manual** *Section III: Chapter 7 Legionnaire's disease.* Washington, DC, USA

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