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Growth of *Legionella* during COVID-19 lockdown stagnation

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While "avoiding stagnation" has been the mantra of many building water quality experts, the foundational support for how this terminology is used in peer-reviewed publications and building water management guidelines is not overly convincing. With COVID-19 lockdowns and subsequent reopening, the concern that extended stagnation will trigger increased incidence (or even an epidemic) of legionellosis has been widely raised in the news and social media. Here, we provide a perspective on four simple questions to a complex topic, with hope that it encourages a broader dialogue and more critical assessment of assumptions and communication strategies surrounding stagnation and *Legionella* growth.

Water impact

The decades-old dogma that "stagnation causes *Legionella* growth" has been widely disseminated after COVID-19 lockdowns became prevalent. We argue this "fact" has been over-simplified to a singular concept and is not unilaterally supported in peer-reviewed literature. This review highlights nuances surrounding stagnation in buildings and suggests criteria to carefully consider how results are communicated to practitioners for forthcoming post-COVID-19 building water quality studies being conducted worldwide.

Introduction

It is a widely accepted "fact" that water stagnation in buildings leads to *Legionella* growth.[1–7] This has been amplified considerably following the COVID-19 building shutdowns worldwide, with calls for some intensive actions to be undertaken by building managers (flushing protocols[3,8,9]) being translated to warnings of potentially severe health risks.[10–13] Optimizing hydraulic design and thus maintaining target controls within building networks is clearly beneficial to controlling microbial water quality.[14,15] However, the available scientific evidence regarding the impact of stagnation on *Legionella* growth is more complicated and less convincing than what is frequently conveyed in peer-reviewed literature, *Legionella* control guidelines, news media, and social media. Here, we provide opinion on four fundamental questions related to the impact of stagnation during the COVID-19 lockdown through an assessment of some of the influential literature in the field and identify criteria to be addressed when conducting and reporting on post-COVID-19 *Legionella* studies. A more careful approach in documenting the impacts of stagnation on legionellosis (Legionnaires' disease and the more under-studied and under-reported Pontiac fever) is needed to put health risks of *Legionella* occurrence into context with other problems that can develop during stagnation, or unintended consequences (*e.g.*, improper flushing causing release of contaminants).

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(1) What is stagnation?

Stagnation of water in building plumbing systems coincides with physiochemical water quality changes that alter the trajectory of microbial dynamics in water systems. These changes include water temperatures trending towards and remaining at ambient temperature, decay of disinfection residual (where applicable), destabilization of corrosion scales[16] and biofilms,[17] release of metals such as copper and lead,[18] and changes in the composition and concentration of bio-available nutrients.[19,20] However, part of the confusion and potential for miscommunication regarding the effects of stagnation on water quality is how stagnation is defined. In the context of controlling *Legionella* growth, the term stagnation has been used to describe complete stagnation (no water exchange or flow) in unused water storage tanks[1] or outlets,[21] intermittent demand at individual outlets,[1] existence of dead-end pipes,[22] generally elevated water age due to low demand and/or over-sized components,[23] and no water exchange in the presence of continuous water movement due to water recirculation.[21] The duration of stagnation studied also changes considerably in context of the system, encompassing periods of one night,[17] days,[24] weeks,[21] months,[25] more than a year,[1] and undefined durations.[2] These differences in system components (tanks *vs.* primary branches *vs.* outlets), type of stagnation (complete *vs.* intermittent), and duration (days *vs.* months), undoubtably alter the microbiological response. Unfortunately, "stagnation" is frequently used as an all-encompassing term to describe different aspects of water use in building plumbing systems, which has led to propagation of information that lacks critical nuance. We assert that "stagnation" as currently referred to in literature cannot be viewed a singular concept. Rather, defining the frequency and duration of stagnation that raise concerns should be system specific. Such a definition requires an engineering system assessment on a site-by-site basis that considers that location's prior experiences with stagnation, water quality, and incidence of disease. Moreover, stagnation should be defined and communicated for each building water system (and relevant sub-systems) individually, and novel findings of future studies should be framed in the context of carefully evaluated supporting literature that reports the impact of similar facets of stagnation (components, types, and durations) as the location being studied, where applicable.

(2) Does stagnation cause *Legionella* growth?

Many publications that suggest stagnation supports *Legionella* growth can be traced back to Ciesielski and colleagues (1984),[1] which stated "Conditions known to be favorable for the multiplication of *L. pneumophila* include stagnating warm water" without attribution. Their work demonstrated that reducing stagnation in severely contaminated hot water storage tanks quickly decreased *L. pneumophila* levels, but did not strongly support the conclusion that stagnation increased growth. In fact, they observed diverging trends in the two completely stagnant storage tanks monitored. Their conclusion that stagnation supports *Legionella* growth may have alternatively stemmed from the fact that showers and faucets with aerators in their study were heavily colonized despite negative culture results in the water storage tanks serving them.[26–28] However, differences in biofilm/water sample collection strategies and not treating or replacing the showerheads and faucets aerators prior to the monitoring period severely complicates sound comparisons and conclusions. In addition, the hot water temperature in the online tanks was frequently within *Legionella's* ideal growth range. This suggests intermittent use and the associated fluctuations in temperature, nutrients, and hydraulic conditions cannot be wholly separated from the effects of stagnation alone.

Hoge and Breiman (1991)[4] reviewed a number of earlier publications and concluded that "Sites from which *Legionella* has been cultured include water heaters, shower heads, faucets, and blind loops of plumbing where water can stagnate." Notably, they did not include any direct attribution for this statement, thus suggesting the anecdotal evidence for a link between stagnation and *Legionella* occurrence was well established by at least 1991. A survey of nine buildings by Völker and colleagues (2016)[2] provides somewhat more compelling evidence linking *Legionella* growth with stagnant conditions. In 807 samples analyzed, they observed a correlation between *L. pneumophila* occurrence and temperature, pipe length measures, and stagnation. However, stagnation in this study, as in many studies, was only qualitatively defined and again appeared to be linked to pipes with low/intermittent water use, rather than absolute stagnation. Nonetheless, the seemingly preconceived notion that stagnation always supports *Legionella* growth has been adopted in many control guidelines and standards internationally.[29]

After observing a case where by eliminating dead-legs (thus eliminating points of stagnation) had no impact on *Legionella* colonization,[22] the conventional wisdom that stagnation supported *Legionella* growth was first experimentally challenged by Liu and colleagues (2006).[21] In this study, completely stagnant conditions had the lowest numbers of biofilm-associated *Legionella* spp. relative to turbulent and laminar flow conditions in a 5 week pilot-scale experiment. However, there was very little water exchange (5%) in the flowing conditions, and the experiments were conducted at ambient temperature with no residual disinfectant. These latter two factors are important for *Legionella* growth and typically vary substantially between systems with flowing and non-flowing stagnant conditions (*e.g.*, recirculating hot water systems *vs.* cold). The lack of *Legionella* growth during stagnation was further documented by Bédard and colleagues (2015)[24] in a well-controlled field study where no increase in *L. pneumophila* gene copy numbers was observed in repeat sampling events at outlets of a contaminated building that were completely stagnated for up to 10 days, suggesting that stagnation was not a driving factor for growth in this building.

Highlighting the complexity and challenges with respect to *Legionella* growth and stagnation, Rhoads and colleagues (2015)[30] demonstrated that continuous flow and intermittent stagnation can both support and limit increases in *L. pneumophila* gene copy numbers depending on the water heater setpoint and frequency of exposure. Thus, we assert that there is currently not detailed consensus on the various dimensions of "stagnation" that encompass water quality changes that coincide with stagnation as well as different environmental conditions (*e.g.*, materials used) on the occurrence, and specifically growth, of *Legionella*. We recognize that the literature above is not exhaustive, but we believe that it captures the lack of clarity and contradicting research on the topic. Hence, we identify a clear need for more carefully designed experiments that places novel findings into context with, and which builds upon, relevant prior literature to improve our understanding of the biological processes occurring while water is not being exchange or flowing.

(3) Are legionellosis cases linked to extended stagnation?

In keeping with the conventional wisdom, we would expect well-documented case studies definitively linking extended stagnation to legionellosis cases and outbreaks. Extended stagnation conditions are not altogether uncommon – schools and universities have summer holiday for six to eight weeks; seasonal resorts and sporting facilities annually have months-long periods of substantially lower water demand – making it more curious that there is not more literature on this topic. Early reports of legionellosis cases and outbreak investigations were focused on identifying patient susceptibility factors and these reports do not provide detailed, useful information regarding the actual conditions present.[31,32] Similarly, later legionellosis case reports are also epidemiologic in nature and provide only limited documentation regarding the design, operation, or function of the plumbing mechanical systems, which is essential understanding how stagnation may have contributed to the root-cause of disease and properly identifying and resolving issues.[33] There is a body of work linking construction activities, which includes the associated water system stagnation, with legionellosis.[34] However, in this literature it is difficult to separate the impact of the stagnation relative to the other physical disturbance and pressure fluctuations that tend to occur with construction activities.

Some work does suggest that extended stagnation is more likely to be associated with *Legionella* colonization, but these studies are in the absence of identified legionellosis cases, which is somewhat complicated by the seasonality in legionellosis incidence. For instance, Mouchtouri and colleagues (2007)[25] demonstrated that seasonal operation of hotels was the principal predicting factor for *L. pneumophila* colonization as determined by culture analysis of 1086 samples from 385 hotels in Greece. However, the authors note that hotels in smaller towns were more likely to operate seasonally than large towns or cities, implying that there may be other factors to consider such as awareness and resources available for proper system management. Rakić and colleagues (2011)[35] demonstrated similar findings in 11 seasonally operated hotels in Croatia. But again, the specific conditions of stagnation are not summarized in these or similar surveys.

Even considering the difficulty in conducting legionellosis case investigations due to their time- and health-sensitive nature, the limited information linking extended stagnation directly with legionellosis is perplexing. We assert that this gap exists partially because of the historic focus on the epidemiological aspects of investigations. This gap may be filled by future detailed legionellosis case studies that include better summaries and analysis of engineering, plumbing, and mechanical aspects of the system, designed experimental monitoring of seasonally operated facilities, and potentially retrospective analysis of available case studies that have occurred surrounding well-known periods of extended stagnation (*i.e.*, seasonality).

(4) Have COVID-19 lockdowns increased legionellosis cases?

The end of lockdown and subsequent recommissioning has been ongoing worldwide for months. Yet, not much data has been forthcoming to support suggestions of an emerging public health crisis, either in the form of water analysis data or a spike in legionellosis cases. In the reports we have seen of *Legionella* contamination of stagnant buildings,[36] there is unfortunately no historical data reported or other data to conclude that COVID-19-related stagnation associated with shutdowns caused or exacerbated contamination issues. There have been very few reports legionellosis that may be related to COVID-19. For example, one Legionnaires' disease case was reported in an employee of a school in June 2020, but this school had a fatal Legionnaires' disease cases in April 2019, suggesting there were potentially unresolved issues at the facility prior to COVID-19 lockdown.[37] In a peer-reviewed investigation, Palazzolo and colleagues (2020)[38] speculated on the link between a positive case of legionellosis in Italy following COVID-19 lockdown. Though the title of the study is quite enticing ("*Legionella* pneumonia: increased risk after COVID-19 lockdown?"), Rota and colleagues (2020)[39] point out the authors did not produce supporting evidence that COVID-19-related stagnation had contributed to case and consequently did not provide a clear answer to the poignant question posed in their title. In fact, Palazzolo and colleagues remarked that incidence of legionellosis was 74% lower than historical norms in the Rome health district where the case occurred.

We recognize that it may still be too early for detailed case studies better supporting the causal link between COVID-19 stagnation and legionellosis to have been conducted and disseminated; yet, we remain surprised more case information is not readily available if there is an ongoing or impending public health crisis. Timely, accurate, and contextualized communications are needed to prevent practices that may not be fully effective (*e.g.*, not managing the system after interventions), unintentionally increase risks (*e.g.*, incorrect flushing),[40] or unduly burdensome communities (*e.g.*, being told to test for and respond to *Legionella* health warnings by experts without having adequate decision-making resources).[41] An in-depth retrospective analysis of reporting data will be needed to assess trends in legionellosis and reopening patterns relative to trends in historical incidence data.

Criteria to consider for COVID-19 *Legionella* publications

Given the heightened publicity to the topic, we expect a number of studies dealing with COVID-19 stagnation and *Legionella* occurrence during the following months. In this regard, we pose several questions that should be considered when making such information available, noting that the mere detection of *Legionella* after lockdown is by itself not evidence of growth during lockdown or evidence of increased risk of contracting legionellosis.

(1) Does the study adequately demonstrate COVID-19 stagnation caused the occurrence/growth of *Legionella* by providing appropriate baseline data? Data collected prior to the start of lockdown is ideal. Tracking performance of a building during recommissioning is an alternative, but does not necessarily indicate pandemic-related issues. Single time-point snap shot data of just one building is not meaningful, while snap shot data of many buildings should be placed into context with past surveys indicating wide-spread colonization of *Legionella*.[42–44]

(2) Does the study adequately describe background water demand during lockdown relative to historical norms in addition to the specific stagnation period for outlets tested (*i.e.*, complete stagnation *vs.* low occupancy)? Quantitatively assessing overall water demand and use patterns within the building is ideal. Building occupancy (or surrogates for occupancy[45]) may be helpful.

(3) Were any intensive flushing actions or other interventions taken during stagnation or prior to reopening? Various recommendations exist, and we expect a wide variety of preventative and remedial flushing and/or treatment practices to have occurred in response to COVID-19 lockdowns. Samples collected before and after flushing is clearly important, but inform on the efficacy of flushing, and not necessarily the impact of stagnation. These distinctions must be clearly handled in forthcoming publications and communications.

(4) Does the study adequately characterize plumbing, mechanical, and engineering aspects of the building? For example, the basic plumbing design (circulating systems *vs.* trunk and branch *vs.* manifold), number of outlets, water demand patterns, boiler system design (*e.g.*, volume, heat source, use of master mixing valves), materials, history of construction, and other pertinent building details help readers interpret the results and evaluate how the cause(s) of identified issues may relate to other examples. Often, detailed water quality and engineering aspects of building systems are not reported in peer-reviewed literature.

(5) Is the sampling strategy sensible and clearly described, and done in the context of the plumbing aspects described above? For example, are completely stagnating first draw samples compared to flushed samples, and hot water samples compared to cold water samples? Are data presented in context with the operational settings of the plumbing system (profiles of hot and cold water quality throughout the building)? For instance, Bédard and colleagues (2015)[24] present a sound approach to evaluating temperature; Rhoads and colleagues (2014)[23] present examples for evaluating residual disinfectant levels. Ambient building temperatures and HVAC operation also will likely play an important (and potentially unappreciated) role in microbial growth during stagnation.

(6) How does the study link or correlate *Legionella* occurrence to other relevant physical and chemical water quality data? Measuring temperature, chorine, inorganics, or other variables in samples collected sequentially with flushing, instead of splitting the volume of one sample for all analyses, can lead to misinterpretation of data.

(7) Does the study use culture methods to assess potential risk? Molecular methods are not typically used for risk assessments without long-term trends of detection. If molecular methods are used, does the study differentiate the genetic material of pathogenic species of *Legionella* (*e.g.*, *L. pneumophila*) or only at the genus level that may also contain non-pathogenic species of *Legionella*?

(8) Are culture results put into context with levels of concern? For non-healthcare buildings water systems that do not have high numbers of susceptible occupants, the recent National Academies of Science, Engineering, and Medicine suggest 50 000 CFU L^{-1} as an "action level" warranting serious concern and triggering remediation.[7] Many international standards use 1000 CFU L^{-1}.[46]

We recognize that many COVID-19-related experimental studies were started with limited time for detailed planning, and carried out under very challenging working conditions. Nonetheless, we argue that the more of these criteria can be considered and communicated, the easier it will be to draw sensible and universal conclusions from the results.

Conclusions

Water stagnation in building plumbing is complex. Investigation of legionellosis cases or *Legionella* occurrence requires detailed investigations that benefit from involving multiple disciplines. We recognize that stagnation clearly causes issues in some circumstances, but conclude that the highly variable conditions that can be observed during "stagnation" requires a more detailed definition and accounting of these conditions. Given the costs associated with reducing water system stagnation in buildings, a better understanding of these variables is needed to guide recommended practices. In the current COVID-19 situation, we urge a careful and considered communication approach, both in peer-reviewed publications and in communications with the broader public through news and social media. It is important that well-substantiated facts drive the dissemination of knowledge in this period. For the future, we strongly advocate for properly controlled studies and closer scrutiny of past literature to better understand *Legionella* colonization and growth during stagnation.

Conflicts of interest

There are no conflicts to declare.

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References

1 C. Ciesielski, M. Blaser and W. Wang, Role of stagnation and obstruction of water flow in isolation of Legionella pneumophila from hospital plumbing, *Appl. Environ. Microbiol.*, 1984, **48**(5), 984–987.

2 S. Völker, C. Schreiber and T. Kistemann, Health, E., Modelling characteristics to predict Legionella contamination risk–Surveillance of drinking water plumbing systems and identification of risk areas, *Int. J. Hyg. Environ. Health*, 2016, **219**(1), 101–109.

3 C. R. Proctor, W. J. Rhoads, T. Keane, M. Salehi, K. Hamilton, K. J. Pieper, D. M. Cwiertny, M. Prévost and A. Whelton, Considerations for large building water quality after extended stagnation, *AWWA Water Sci.*, 2020, **2**(4), e1186.

4 C. W. Hoge and R. F. Breiman, Advances in the epidemiology and control of Legionella infections, *Epidemiol. Rev.*, 1991, **13**(1), 329–340.

5 H. Y. Buse and N. J. J. A. Ashbolt, Counting Legionella cells within single amoeba host cells, *Appl. Environ. Microbiol.*, 2012, **78**(6), 2070–2072.

6 C. J. Hoebe and J. Kool, Control of legionella in drinking-water systems, *Lancet*, 2000, **355**(9221), 2093–2094.

7 National Academy of Sciences, *E., and Medicine Managment of Legionella in Water Systems*, The National Academies Press, Washington, D.C., 2020.

8 *Centers for Disease Control Guidance for Reopening Buildings After Prolonged Shutdown or Reduced Operation*, https://www.cdc.gov/coronavirus/2019-ncov/php/building-water-system.html (accessed September 9, 2020).

9 European Study Group for Legionella Infections, *ESGLI Guidance for Managing Legionella in Building Water Systems During the COVID-19 Pandemic*, https://www.escmid.org/fileadmin/src/media/PDFs/3Research_Projects/ESGLI/ESGLI_Guidance_for_managing_Legionella_in_building_water_systems_during_the_COVID-19_pandemic_20200603_v_0300.pdf (accessed September 4, 2020).

10 G. Viglione, As lockdowns lift, new hazards lurk in the water, *Nature*, 2020, DOI: 10.1038/d41586-020-01286-9, https://www.nature.com/articles/d41586-020-01286-9.

11 J. Shiffman, Buildings Closed by Coronavirus Face Another Risk: Legionnaires' Disease, Reuters [Online], 2020, https://www.usnews.com/news/us/articles/2020-04-24/buildings-closed-by-coronavirus-face-another-risk-legionnaires-disease (accessed September 4, 2020).

12 M. Horberry, After Coronavirus, Office Workers Might Face Unexpected Health Threats, *New York Times [Online]*, 2020, https://www.nytimes.com/2020/05/20/health/coronavirus-legionnaires-offices.html (accessed September 4, 2020).

13 A. Clayson, After coronavirus comes another hidden and deadly respiratory disease, experts warn, *The US Sun [Online]*, 2020, https://www.the-sun.com/news/949994/after-coronavirus-hidden-deadly-respiratory-disease/ (accessed September 4, 2020).

14 I. Boppe, E. Bédard, C. Taillandier, D. Lecellier, M.-A. Nantel-Gauvin, M. Villion, C. Laferrière and M. Prévost, Investigative approach to improve hot water system hydraulics through temperature monitoring to reduce building environmental quality hazard associated to Legionella, *Building and Environment*, 2016, **108**, 230–239.

15 J. Darelid, S. Löfgren and B. E. Malmvall, Control of nosocomial Legionnaires' disease by keeping the circulating hot water temperature above 55 C: experience from a 10-year surveillance programme in a district general hospital, *J. Hosp. Infect.*, 2002, **50**(3), 213–219.

16 T. D. D. Speth, M. Schock and D. Lytle, Potential Corrosion Issues Resulting from Extreme Weather Events, *13th CECIA-IAUPR Biennial Symposium on Potable Water Issues in Puerto Rico, Bayamon, PUERTO RICO, February 14–16, 2019*, 2019.

17 E. Bédard, C. Laferrière, E. Déziel and M. Prévost, Impact of stagnation and sampling volume on water microbial quality monitoring in large buildings, *PLoS One*, 2018, **13**(6), e0199429.

18 D. Lytle and M. Schock, Impact of stagnation time on metal dissolution from plumbing materials in drinking water, *J. Water Supply: Res. Technol.–AQUA*, 2000, **49**(5), 243–257.

19 M. Bucheli-Witschel, S. Kötzsch, S. Darr, R. Widler and T. Egli, A new method to assess the influence of migration from polymeric materials on the biostability of drinking water, *Water Res.*, 2012, **46**(13), 4246–4260.

20 Y. Zhang and M. Edwards, Accelerated chloramine decay and microbial growth by nitrification in premise plumbing, *J. - Am. Water Works Assoc.*, 2009, **101**(11), 51–62.

21 Z. Liu, Y. Lin, J. Stout, C. Hwang, R. Vidic and V. Yu, Effect of flow regimes on the presence of Legionella within the biofilm of a model plumbing system, *J. Appl. Microbiol.*, 2006, **101**(2), 437–442.

22 F. P. Sidari III, J. E. Stout, J. M. Vanbriesen, A. M. Bowman, D. Grubb, A. Neuner, M. M. Wagener and V. L. Yu, Keeping Legionella out of water systems, *J. - Am. Water Works Assoc.*, 2004, **96**(1), 111–119.

23 W. J. Rhoads, A. Pruden and M. A. Edwards, Survey of green building water systems reveals elevated water age and water quality concerns, *Environ. Sci.: Water Res. Technol.*, 2016, **2**(1), 164–173.

24 E. Bédard, S. Fey, D. Charron, C. Lalancette, P. Cantin, P. Dolcé, C. Laferrière, E. Déziel and M. Prévost, Temperature diagnostic to identify high risk areas and optimize Legionella pneumophila surveillance in hot water distribution systems, *Water Res.*, 2015, **71**, 244–256.

25 V. Mouchtouri, E. Velonakis, A. Tsakalof, C. Kapoula, G. Goutziana, A. Vatopoulos, J. Kremastinou and C. J. A. Hadjichristodoulou, Risk factors for contamination of hotel water distribution systems by Legionella species, *Appl. Environ. Microbiol.*, 2007, **73**(5), 1489–1492.

26 H. W. Wilkinson, Legionellosis, in *Laboratory diagnosis of infectious diseases*, Springer, 1988, pp. 320–332.

27 P. W. Muraca, V. L. Yu and J. E. Stout, Environmental aspects of legionnaires' disease, *J. - Am. Water Works Assoc.*, 1988, **80**(2), 78–86.

28 A. H. Woo, L. Y. Victor and A. Goetz, Potential in-hospital modes of transmission of Legionella pneumophila. Demonstration experiments for dissemination by showers, humidifiers, and rinsing of ventilation bag apparatus, *Am. J. Med.*, 1986, **80**(4), 567–573.

29 E. Van Kenhove, K. Dinne, A. Janssens and J. Laverge, Overview and comparison of Legionella regulations worldwide, *Am. J. Infect. Control*, 2019, **47**(8), 968–978.

30 W. J. Rhoads, P. Ji, A. Pruden and M. A. Edwards, Water heater temperature set point and water use patterns influence Legionella pneumophila and associated microorganisms at the tap, *Microbiome*, 2015, **3**(1), 67.

31 S. Fisher-Hoch, M. Smith and J. Colbourne, Legionella pneumophila in hospital hot water cylinders, *Lancet*, 1982, **319**(8280), 1073.

32 C. Joseph, J. Watson, T. Harrison and C. Bartlett, Nosocomial legionnaires' disease in England and Wales, 1980–92, *Epidemiol. Infect.*, 1994, **112**(2), 329–346.

33 Z. K. T. Pospichal, A Technical Perspective on Controlling Legionella in Building Water Systems, *Hospital Engineering & Facilities Management*, 2001.

34 L. A. Mermel, S. L. Josephson, C. H. Giorgio, J. Dempsey and S. Parenteau, Association of Legionnaires Disease with Construction: Contamination of Potable Water?, *Infect. Control Hosp. Epidemiol.*, 1995, **16**(2), 76–81.

35 A. Rakić, J. Perić, N. Štambuk-Giljanović, A. Mikrut and A.-S. Baković, Legionella species in year-round vs. seasonal accommodation water supply systems, *Arh. Hig. Rada Toksikol.*, 2011, **62**(4), 335–340.

36 M. C. D. C. Horberry, Closes Some Offices Over Bacteria Discovery, *New York Times [Online]*, 2020, https://www.nytimes.com/2020/08/08/health/cdc-legionnaires-coronavirus.html (accessed September 4, 2020).

37 D. Simon, Former Fairmont High School head custodian died from Legionnaires' disease last year, *WHIO [Online]*, 2020, https://www.whio.com/news/local/former-fairmont-high-school-head-custodian-died-legionnaires-disease-last-year/E4JNEENSBNHGTF764PDE4IDEEU/ (accessed September 4, 2020).

38 C. Palazzolo, G. Maffongelli, A. D'Abramo, L. Lepore, A. Mariano, A. Vulcano, T. A. Bartoli, N. Bevilacqua, M. L. Giancola and E. Di Rosa, Legionella pneumonia: increased risk after COVID-19 lockdown? Italy, May to June 2020, *Eurosurveillance*, 2020, **25**(30), 2001372.

39 M. C. Rota, M. Scaturro and M. L. Ricci, Letter to the editor: importance of a careful investigation to avoid attributing Legionnaires' disease cases to an incorrect source of infection, *Eurosurveillance*, 2020, **25**(34), 2001484.

40 S. Roy and M. A. Edwards, Citizen science during the flint, Michigan Federal Water Emergency: ethical dilemmas and lessons learned, *Citizen Science: Theory and Practice*, 2019, **4**(1), 1–28.

41 M. Horberry, Schools find health risks in water after COVID-19 lockdowns, *New York Times Service [Online]*, 2020, https://www.boston.com/news/health/2020/08/27/schools-water-legionella (accessed September 4, 2020).

42 M. J. Donohue, K. O'Connell, S. J. Vesper, J. H. Mistry, D. King, M. Kostich and S. Pfaller, Widespread molecular detection of Legionella pneumophila serogroup 1 in cold water taps across the United States, *Environ. Sci. Technol.*, 2014, **48**(6), 3145–3152.

43 M. Alary and J. Joly, Risk factors for contamination of domestic hot water systems by legionellae, *Appl. Environ. Microbiol.*, 1991, **57**(8), 2360–2367.

44 M. Alary and J. R. Joly, Factors contributing to the contamination of hospital water distribution systems by Legionellae, *J. Infect. Dis.*, 1992, **165**(3), 565–569.

45 R. Richard, K. A. Hamilton, P. Westerhoff and T. H. Boyer, Tracking copper, chlorine, and occupancy in a new, multi-story, institutional green building, *Environ. Sci.: Water Res. Technol.*, 2020, 1672–1680.

46 Infections., E. S. G. f. L. European Technical Guidelines for the Prevention, Control and Investigation, of Infections Caused by Legionella species. https://www.escmid.org/fileadmin/src/media/PDFs/3Research_Projects/ESGLI/ESGLI_European_Technical_Guidelines_for_the_Prevention_Control_and_Investigation_of_Infections_Caused_by_Legionella_species_June_2017.pdf (accessed September 4, 2020).