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Investigative approach to improve hot water system hydraulics through temperature monitoring to reduce building environmental quality hazard associated to *Legionella*

Inès Boppe [a], Emilie Bédard [a, *], Catherine Taillandier [a], Daphné Lecellier [b], Marc-André Nantel-Gauvin [c], Manuela Villion [d], Céline Laferrière [e], Michèle Prévost [a]

[a] *Department of Civil, Geological and Mining Engineering, Polytechnique Montréal, C.P.6079, succ. Centre-ville, Montréal, QC, H3C 3A7, Canada*
[b] *École Polytechnique, Route de Saclay, 91128 Palaiseau Cedex, France*
[c] *Department of Construction Engineering, École des technologies supérieures, 1100, rue Notre-Dame Ouest, Montréal, QC, H3C 1K3, Canada*
[d] *Centre d'expertise en analyse environnementale du Québec, Ministère du Développement Durable, de l'Environnement et de la Lutte contre les changements climatiques, 2700 rue Einstein, Bureau E-2-220, QC, G1P 3W8, Canada*
[e] *Department of Microbiology, Infectiology and Immunology, Université de Montréal, CP. 6128, succ. Centre-ville, Montréal, QC, H3C 3J7, Canada*

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A B S T R A C T

Several countries have promulgated control measures and design guidelines to limit the proliferation of *Legionella* within hot water distribution systems (HWDS). However, there is little information on how to assess and improve existing HWDS unable to maintain water temperatures ≥55 °C throughout the system. A 50-year old hot water system of a 10 story hospital was investigated in terms of temperature distribution and *Legionella pneumophila* prevalence. Concentrations of *L. pneumophila* were correlated with the maximum temperature reached at the tap, with a significant decrease observed at T ≥ 55 °C. Continuous temperature and flow monitoring was performed on the overall HWDS, characterizing the principal and secondary horizontal return loops for all 9 wings, and detailed investigations of the secondary vertical return loops was completed in Wing 3. Results indicated the system inability to systematically maintain desired operating temperatures of 55 °C. The deficient hydraulic distribution was the root cause of the poor temperature maintenance throughout the secondary loops, but defective devices were also identified as playing an important role in sectorial temperature failure. A simple stepwise investigative approach was developed to identify hydraulic deficiencies. The implementation of flow restrictions on identified recirculation loops and increased pumping efficiency was conducted within a short period of 2 months, with no major system upgrade. These corrective measures resulted in a balanced system with increased flow velocities (>0.2 m/s). As a result, the proportion of taps achieving 55 °C within 2 min increased from 11% to 74% and *L. pneumophila* prevalence decreased from 93.1% to 46.1% after 4 weeks.

1. Introduction

Proliferation of *Legionella pneumophila* in water distribution systems causes an important number of infections with high mortality levels [1] estimated to cost 33 366 US$ per hospitalization in the United States [2]. In the United States, between 2011 and 2012, *Legionella* was responsible for 66% of drinking-water associated infectious outbreaks [3]. The presence of *Legionella* in hot water distribution systems from large buildings can lead to environmental quality issues, especially within healthcare settings. Immuno-compromised patients and vulnerable population can be exposed to *Legionella* via the inhalation of contaminated aerosols generated by equipment such as showers, faucets, air-cooling towers and toilets [4]. Premise plumbing from large buildings often provide multiple favorable conditions for the development of biofilm and *L. pneumophila* [5]. Biofilm offers protection against

* Corresponding author. NSERC Industrial Chair in Drinking Water, Polytechnique Montréal, P.O. Box 6079 Station Centre-ville, Montréal, QC, H3C 3A7, Canada.
E-mail addresses: ines.boppe@polymtl.ca (I. Boppe), emilie.bedard@polymtl.ca (E. Bédard), catherine.taillandier@polymtl.ca (C. Taillandier), daphne.lecellier@polytechnique.edu (D. Lecellier), m.nantelgauvin@gmail.com (M.-A. Nantel-Gauvin), manuela.villion@mddelcc.gouv.qc.ca (M. Villion), michele.prevost@polymtl.ca (M. Prévost).

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disinfection and can harbor amoebas, a growth vector for *L. pneumophila* [6]. The presence of stagnation related to dead legs or inadequate system hydraulic balancing also reduces the disinfectant efficiency in these areas [7]. In addition, bacteria exposed to sub-optimal disinfection and low nutrient environmental conditions can enter a viable but not culturable state (VBNC). Although undetected by standard culture methods [8], VBNC cells can recover culturabilty when they are provided with favorable conditions (lower water temperature, loss of disinfectant, presence of biofilm) [9] [10].

Several regulations, guidelines and recommendations identify design, operating conditions and monitoring frequency required in hot water distribution systems to prevent and control the proliferation of *L. pneumophila* [11]. Typically, they include control measures such as maintaining a water temperature ≥60 °C at the outlet of the water heater and ≥55 °C in the main recirculation loop [12,13]. Furthermore, a temperature of at least 55 °C should be maintained in the HWDS and reached within 1–2 min of flushing at each point of use [12–15]. Extended periods of stagnation and the presence of dead legs should be avoided and minimal water velocity should be maintained at all times within the recirculation pipes. A French technical guideline suggests to define the minimum water velocity as the greatest value between 0.2 m/s and the velocity required to maintain heat loss below 5 °C [13,16]. However, the maximum water velocity suggested is 0.5 m/s to protect the pipes from premature wear.

Periodic monitoring is required to confirm that the control measures described previously are efficient to maintain *L. pneumophila* load below action and alert levels. In European countries like Austria, France, Germany, Netherlands and United Kingdom, periodic monitoring of *Legionella* and temperature is mandatory with a frequency varying from continuous to weekly or annually depending on the parameters, the risk classification and the location of the point of use [12,17–20]. Results from the periodic monitoring are interpreted against established target levels that vary between 1000 and 10000 CFU/L, above which corrective and preventive actions should be undertaken to reduce the risk of infection [12,17–19,21–23]. While maintaining temperatures is considered the first line of defense to limit the growth of *L. pneumophila*, complete eradication is often not possible, especially in systems already contaminated or where adequate control conditions cannot be maintained throughout the systems [24,25]. A single piece of deficient equipment can influence the hot water temperature distribution within an entire wing, causing hot water temperature decrease in those sectors [11].

The *Legionella* risk associated to a large building HWDS can be evaluated using a temperature-based diagnostic approach [11]. Systems that are unable to maintain control temperatures at the point of use despite adequate water heater temperatures are considered at risk and hydraulically deficient. A hot water system that is not hydraulically balanced can lead to higher flowrates in loops with lower head loss and poor circulation or even stagnation in high restriction loops. There are few methodologies that are proposed to perform a detailed assessment of hydraulic deficient areas within an existing HWDS. A technical document suggests the investigation of the following issues: valve obstructions (leading to stagnation or reduced water velocity within the return loop), the type of control elements installed, the recirculation pump design/operation or the lack of balancing between the different secondary flow and return loops [13,16]. Applied investigation approaches are needed to identify corrective actions and ensure an adequate first line thermal control for *Legionella*.

This study presents an investigation approach to evaluate and correct the hydraulics of an existing hot water system based on detailed thermal monitoring. This approach can be implemented promptly to obtain required temperatures at points-of-use as well as recommended minimal flow velocities. The objectives of this study were to: 1) identify malfunctioning zones in the water distribution network using temperatures and flowrates analysis 2) quantify the impact of unfit equipment (pump, faucets, showers) on temperatures and flowrates within a sector of the HWDS 3) propose an investigative procedure to identify and correct the causes of inadequate temperature distribution and 4) investigate the effect of distal temperature on the prevalence and concentrations of *Legionella* and *L. pneumophila*.

2. Methods

2.1. Description of the study site

The study was conducted prospectively, in absence of nosocomial cases of legionellosis in a 450-bed healthcare facility in Québec, Canada. The hot water system investigation was conducted using a temperature diagnostic approach [11]. The 50-year-old hospital is supplied with treated chlorinated surface water. The main hot water network supplies water to nine 10-story wings and copper piping (type K) is the material used for all principal, secondary and tertiary flow and return loops [11]. Copper and flexible braided elastomeric hoses are used for connecting pipes at points of use. Hot water is produced by a steam heat exchanger with a temperature set point of 60 °C. The HWDS has a vertical architecture where the main horizontal flow and return loop supplies water to each wing through horizontal secondary flow and return loops, that feed water to between 9 and 21 secondary vertical flow and return loops depending on the wing (Fig. 1). There are 2–4 devices connected on a riser at each floor and each equipment is connected on the recirculation loop [11]. A detailed study of the secondary and tertiary hot water distribution systems was carried out in Wing 3, supplied by 10 risers. This wing was selected for detailed investigation due to recurrent user complaints about hot water temperatures being unusually low at the point-of-use.

2.2. Water sampling approach for L. pneumophila and physico-chemical evaluation

A one-liter sample of water was collected at the water heater outlet and on the principal return loop pipe after the sampling port was cleaned with alcohol and ultrapure water, and flushing for one minute. For points of use, the first liter of hot water was collected into sterile polypropylene bottles from taps and showers. No prior cleaning or flushing were carried out in order to get a sample representative of the point of use. In total, 29 points of use were selected for sampling, of which 17 were located in Wing 3. Microbiological sampling was conducted once in Wing 3 prior to the implementation of corrective measures. The water heater outlet, recirculation loop and the points of utilization throughout the hospital were sampled twice prior to and once 4 weeks following the implementation of corrective measures. Water samples were cultured according to the quantitative method AFNOR NF T90-431 *Legionella* procedure [26]. Different volumes of water were filtered through sterile 47 mm diameter and 0.45 μm mixed ester cellulose membranes (Millipore, Germany) and an acid untreated sample volume of 0.2 mL were plated on Glycine-Vancomycin-Polymyxin-Cycloheximide (GVPC) selective agar (Biokar diagnostics, France). Before plating, acid treatment was applied to filtered samples (pH = 2; 5 min). All plates were then incubated at 36 °C for 10 days. Typical colonies that developed after 4–10 days were sub cultured on confirmation plates for 2–4 days at 36 °C. Resulting colonies that developed on BCYE agar, but not on BCYE without cysteine, were considered as *Legionella* spp. The *Legionella* latex test (M45,