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Major Article

Controlling *Legionella pneumophila* in water systems at reduced hot water temperatures with copper and silver ionization

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Background: Hospital-acquired Legionnaires' disease is associated with the presence of *Legionella pneumophila* in hospital water systems. In the United Kingdom, the Department of Health recommends maintaining hot water temperatures >55°C and cold water temperatures <20°C at the point of delivery to prevent proliferation of *L pneumophila* in water systems. In this study, we evaluated the efficacy of copper and silver ionization to control *L pneumophila* at deliberately reduced hot water temperatures (43°C) within a newly installed water system in a new building linked to a large health care facility in the United Kingdom.
Methods: One thousand, five hundred ninety-eight water samples were collected between September 2011 and June 2017. Samples were tested using accredited methods for *L pneumophila*, copper and silver ion levels, and total viable counts. Energy consumption and water usage data were also collected to permit carbon emission calculations.
Results: The results of 1,598 routine samples from September 2011 to June 2017, and the recordings of temperatures at outlets in this facility, demonstrated effective (100%) *L pneumophila* control throughout the study period with an average hot water temperature of 42°C. The energy savings and reduction of carbon emissions were calculated to amount to 33% and 24%, respectively, compared to an equivalent temperature-controlled system. Water system management interventions were required to achieve consistently adequate levels of copper and silver across outlets.
Conclusions: This study demonstrated that it is possible to control *L pneumophila* independent of temperature when copper and silver ionization is introduced into a new building in conjunction with an appropriately managed water system.

The *Legionella* genus contains 57 species and subspecies of gram-negative aerobic bacilli found in natural and purpose-built water sources.[1] They are usually found in low numbers and are not associated with human disease. However, when present in larger counts or dispersed in aerosols, some species, especially *Legionella pneumophila*, are opportunistic pathogens. *L pneumophila* consists of 16 serotypes, with serogroup 1 responsible for most serious infections—such as Legionnaires' disease—causing 95% of infections in Europe and 85% of infections worldwide.[2]

Legionnaires' disease is a severe multisystem illness that is potentially fatal, especially in the immunocompromised patient group.[3,4] Risk of disease increases with age, especially in the >45 age group, and infection in children is rare. The mortality rate for patients who develop Legionnaires' disease while in a health care facility is close to 50%.[5] Because of the severity of infection within the immunocompromised patient group, and the risk arising from colonized health care water systems, infection with *L pneumophila* is recognized as an

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important health care–associated infection for which an effective preventative program is required.[6,7]

The US Environmental Protection Agency first acknowledged that potable water distribution systems presented a major source of *Legionella* in 1985.[8] More recently, in Australia, the enHealth guidelines for *Legionella* control states that "health and aged care infrastructure managers need to be aware that even a well-managed water supply from a water service provider does not guarantee *Legionella*-free water."[9]

In the United Kingdom, national legislation underpins safety at work, and specific guidance for the control of *L pneumophila* in water systems is provided in the Health and Safety Executive Approved Code of Practice (L8) and its associated regulations, HSG274 Part 2 and, for National Health Service (NHS) Trusts, the Department of Health Technical Memorandum (HTM) HTM04-01.[10,11]

Certain environmental conditions are recognized as increasing the risk from *L pneumophila* in water systems by either permitting higher levels of growth or creating an infectious aerosol.[12] These include temperatures between 20°C and 45°C, storing water, and the presence of organic and inorganic material in the system. The "traditional" regimen for controlling *L pneumophila* is based on temperature control, keeping cold water <20°C and hot water stored at least at 60°C, distributed so that it reaches 55°C at outlets within 1 minute.[10]

Temperature control requires several considerations. First, outlet water at 55°C presents a high scald risk and thus requires engineering control, such as thermostatic mixer valves, to ensure water hotter than 44°C does not discharge from outlets accessible to vulnerable people. Second, maintaining circulating water at high temperature has a high energy requirement. Third, traditional temperature control methods alone do not control other water borne pathogens, such as *Pseudomonas aeruginosa* and atypical mycobacteria.[13,14] Finally, studies have shown that the temperature control regimen frequently fails to control *L pneumophila*, especially in large complex water systems with poor engineering control, leading to the necessary implementation of additional control methods, such as biocides.[15,16]

One supplementary method is copper and silver ionization (CSI), which provides continuous release of copper (Cu^{2+}) and silver (Ag^{+}) ions into water.[10] Cu^{2+} and Ag^{+} are known antibacterial agents.[17] CSI has previously been shown to be an effective long-term control method for *L pneumophila* in hospital hot water systems, using doses of 0.2-0.4 mg/L Cu and 0.02-0.04 mg/L Ag ions when combined with temperature control.[18-20]

As part of efforts to increase efficiency in hospital buildings, the NHS recognizes the need to move its estates toward a more environmentally sustainable model. Government figures show that the NHS is the largest public-sector contributor to climate change in Europe, emitting 21 million metric tons of CO_2 each year, with an annual energy bill of over £750 million. The United Kingdom's Green Investment Bank estimated that installing energy efficiency measures across the United Kingdom could rapidly cut the NHS's energy usage by 20%.[21]

During the design and planning of a new health care building—within an existing United Kingdom pediatric hospital site but with an entirely new water system—a review was made of the *L pneumophila* control systems available. A decision was taken to apply a derogation to guidelines and install a low temperature CSI hot water system based on the grounds of efficacy, reliability, energy savings, carbon reduction, and cost minimization. In this article, we describe the 6-year experience of using CSI for primary control of *L pneumophila* levels, installed within a newly built hospital wing, in the absence of traditional temperature control.

METHODS

The Morgan Stanley Clinical Building was the first of 2 buildings forming the Mittal Children's Medical Centre, Great Ormond Street Hospital NHS Foundation Trust. With staff, patient, and estates services covering 10 floors, it included new wards, operating theatres, and renal wards. The building was handed over to the Trust in December 2011, for commissioning and clinical occupancy beginning in March 2012. CSI was installed into the main water system but was not present within the dialysis circuit or any of the drinking water systems.

Building design

The site studied was a new extension to a large health care facility in the United Kingdom. All water systems were designed to comply with the HTM04-01 recommendations (updated October 2006), except for hot water temperatures that functioned at 43°C throughout.[10] A derogation to install low temperature CSI control was taken to the Trust Redevelopment Project Board supported by the *Legionella* Steering Committee. The system was primarily Cu pipe, with flexible hoses restricted to variable height baths (managed by regular change). Low temperature water enables avoidance of thermostatic mixer valves, and handwash sink taps were infrared operated (programmable mechanisms permitting automated flushing regimens).

CSI systems

The CSI systems selected for installation were produced by Pro-Economy Ltd (Milton Keynes, United Kingdom). The CSI systems were installed between the bulk storage tank and the 2 softened water and the 2 raw water storage tanks on the 8th floor to deliver Cu and Ag levels in these tanks, so that adequate levels of Cu and Ag ions would be available for distribution to the outlets. Systems were designed to deliver minimum required levels of Cu (>0.2 mg/L) and Ag (>0.02 mg/L) ions at the point of use, with levels of ions released into the water supply and automatically adjusted based on variable flow rates and water quality.

Water sampling and ionization system monitoring

The CSI systems were visually inspected once per month after the systems were commissioned in September 2011.

Water samples were also taken from the CSI systems, tanks, and outlets during the commissioning period, from September 2011 to March 2012, or as part of the routine monitoring period (up to the end of June 2017). Water storage tanks and CSI system samples were analyzed for Cu and Ag ions levels. Sentinel and other outlets were analyzed for *L pneumophila,* total viable counts (TVCs) at 37°C and at 22°C, and for Cu and Ag ion levels.

A total of 12 sentinel outlets were identified using the Health and Safety Executive criteria, and in addition to these sentinel outlets an added 11 outlets were sampled monthly—23 outlets in total per month.[11] These additional rotating outlets were identified on the basis of clinical risk and were regularly reviewed to ensure system safety.

Sample collection

L pneumophila *and TVC samples*

Samples for *L pneumophila* and TVC testing were collected by trained personal and transported as per L8 guidelines, with water samples collected in bottles containing sodium thiosulfate to dechlorinate and neutralize the Cu and Ag in the sample.[11] Water temperature was recorded using a noncontact TN1 infrared thermometer.

CSI samples

Samples for Cu and Ag ions analysis were collected, after those for microbiological testing, in bottles containing 5M nitric acid to ensure

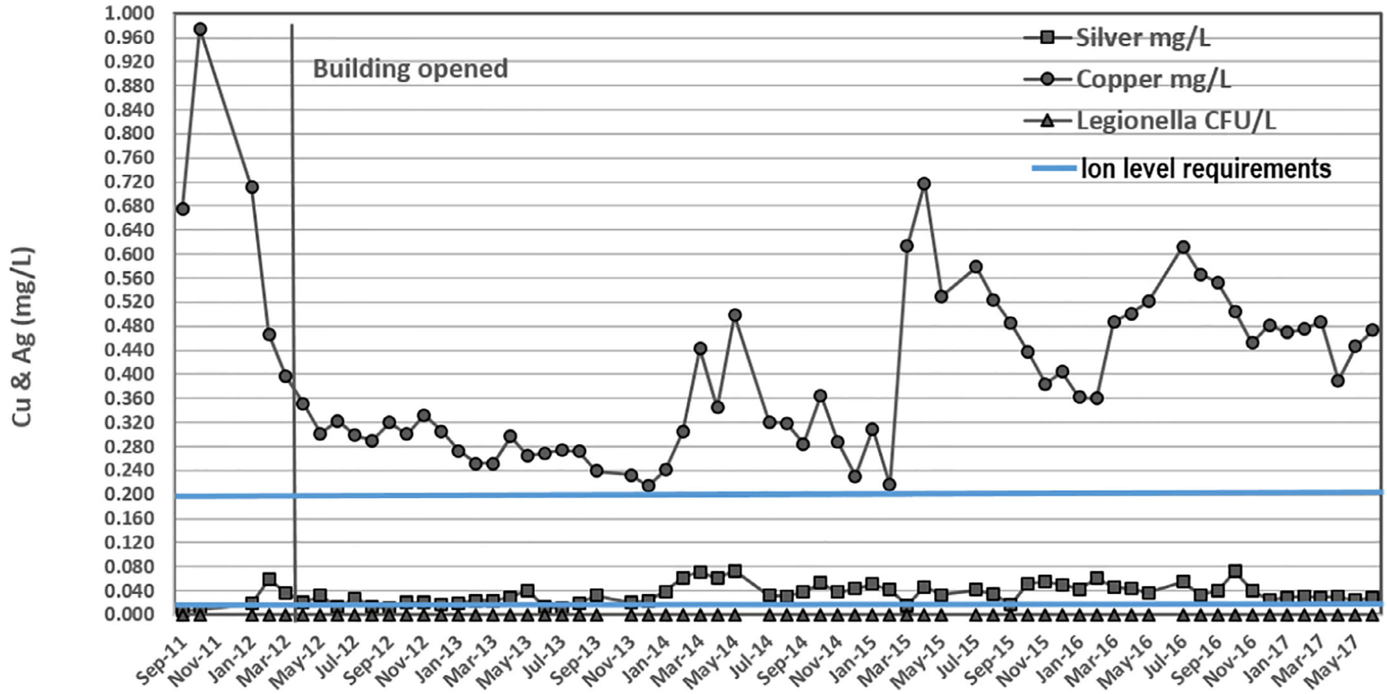

Fig 1. *Legionella pneumophila* counts and average copper and silver levels across 23 sampling points per month from September 2011 to June 2017, at the new building, United Kingdom hospital. CO2e, CO2 equivalent.

that the metal content stayed in solution, free from particulate matter. Samples for Cu and Ag ions testing were placed in a carton box, away from ultraviolet light.

Sample processing

L pneumophila and TVC testing

Samples for *L pneumophila* were processed as per HTM guidelines (BS7592:2008 sampling for *Legionella* bacteria in water systems. Code of practice and ISO11731:1998 water quality—detection and enumeration of *Legionella*). Standard method BSEN is not an abbreviation it is a name linked to the ISO standard and means that it is the English version of the British Standards BSEN ISO6222:1999 was used for TVCs analysis by United Kingdom Accreditation Service (UKAS) accredited laboratories.

CSI testing

Samples were analyzed for Cu and Ag ions by inductively coupled plasma-optical emission spectroscopy/mass spectrometry (Environmental Protection Agency Method 200.5), by UKAS accredited laboratories.

Energy use and carbon footprint evaluation

Calculation method

Data on the volume of water use and water temperatures from both incoming water supply and circulating water supply (both cold and hot) were gathered from the Great Ormond Street Hospital estates team. These data were used to calculate the cost of heating water temperatures to both 45°C and to 60°C, rather than 65°C.

The energy use for heating water was calculated using the equation:

$$q = V\,x\,p\,x\,CP\,x\,\Delta T \qquad (1)$$

where Q is the amount of heat required to raise the temperature of water; V is the volume of water; t is time required to heat to a certain temperature; ΔT is change in temperature; CP is molar specific heat at constant P.

Using the equation, it was possible to obtain the amount of energy used by each building to keep the target temperature, it was assumed there was no heat loss.

After the energy use was calculated, DEFRA carbon emission conversion standards (kg of CO_2e/kWh) were applied to each electricity source as follows: natural gas (0.184), oil (0.276), coal (0.310), nuclear-renewables-on site generated (0.412).[21] According to a survey carried out by the NHS, with more than 1000 hospitals, the energy mix by health care facilities is distributed as follows: natural gas (39%), coal generation (33%), mixture of renewables-nuclear-on site (27%), and oil (1%).[22] A conversion factor of 0.288 kg CO_2/kWh energy-emissions was then used.

RESULTS

Cu, Ag, L pneumophila, *and temperature readings*

A total of 1,598 samples were processed from 23 different outlets from September 2011 to June 2017 for Cu and Ag levels and microbiological culture. *L pneumophila* was not cultured from any sample. Figure 1 shows the mean Cu and Ag ion levels. Hot water temperature recorded during this period (September 2011 to June 2017) at the outlets was an average of 42°C (range = 37°C-44°C).

L pneumophila was not detected in samples taken from outlets either during the commissioning period, from September 2011 to March 2012, or as part of the routine monitoring period (up to the end of June 2017).

Initial data, prior to building hand over, in the raw and softened water from April 1, 2012 to August 8, 2012, showed consistently low Cu and Ag levels at some outlets. In response to this, 1 of the 2 softened water storage tanks and 1 of the 2 raw water

Table 1
Average temperature, Ag and Cu, across 23 sampling points per month from September 2011 to June 2017, at the new building, United Kingdom hospital

Date	Temp CT (°C)	SE	Temp HT (°C)	SE	Ag (mg/L)	SE	Cu (mg/L)	SE
September 2011 to February 2012	19.7	0.291	39.6	0.905	0.032	0.004	0.362	0.019
March 2012 to June 2017	18.4	0.469	41.9	0.191	0.035	0.002	0.384	0.015

CT, cold tap; *HT*, hot tap; *SE*, standard error; *Temp*, temperature.

Table 2
Hot water tanks and ambient temperature, at the new building, United Kingdom hospital, December 2016

Storage buffer tank	Water use	Tank water temp (°C)	Vol (L)	Ambient temp (°C)	Tank surface temp (°C)
1	General	44	3000	21.6	21.6
2	General	45	3000	21.6	21.6
3	General	45	3000	21.6	21.6
4	Kitchen	60	1500	21.4	21.4
5	Kitchen	60	1500	21.4	21.4

Temp, temperature; *Vol*, volume.

storage tanks were decommissioned—rebalancing of the system took place and an outlet flushing regime was implemented. An improvement in the Cu and Ag levels at the outlets was then noted. Prior to occupancy, the average Cu and Ag ion levels recorded from September 2011 to March 2012 at the outlets tested were 0.362 mg/L (standard error [SE] 0.019) for Cu and 0.032 mg/L (SE 0.004) for Ag (Table 1).

The average Cu and Ag levels recorded from building opening (March 2012) to June 2017 at the outlets tested was 0.384 mg/L (SE 0.015) for Cu and 0.035 mg/L (SE 0.002) for Ag (Table 1).

The average hot water temperature during the commissioning period (September 2011 to March 2012) was 39.6°C (SE 0.91) and the average cold water temperature was 19.7°C (SE 0.29) (Table 1).

The average hot water temperature, from when the building was opened to the public in March 2012 to June 2017 (Table 1) was 41.9°C (SE 0.19) and the average cold water temperature was 18.4°C (SE 0.47).

TVCs

The TVCs counts at 37°C from September 2011 to February 2012, just before the building was opened, ranged from 0-14,890 colony-forming units (CFU)/mL and the average was 2,213 CFU/mL (SE 623), and the TVCs counts at 22°C ranged from 0-11,800 CFU/mL and the average was 2,170 CFU/mL (SE 1,101). A reduction in TVCs counts can be observed between the opening of the building in March 2012, and the reading in 2017 from an average of 9,000 to <4,000 CFU/mL (Fig 2).

Energy use

Table 2 shows the temperature readings of the water storage tanks. From measurements obtained at the building, temperatures inside the cold water storage tank were estimated to be 17°C. Therefore, when applying the energy use equation (listed in the Methods

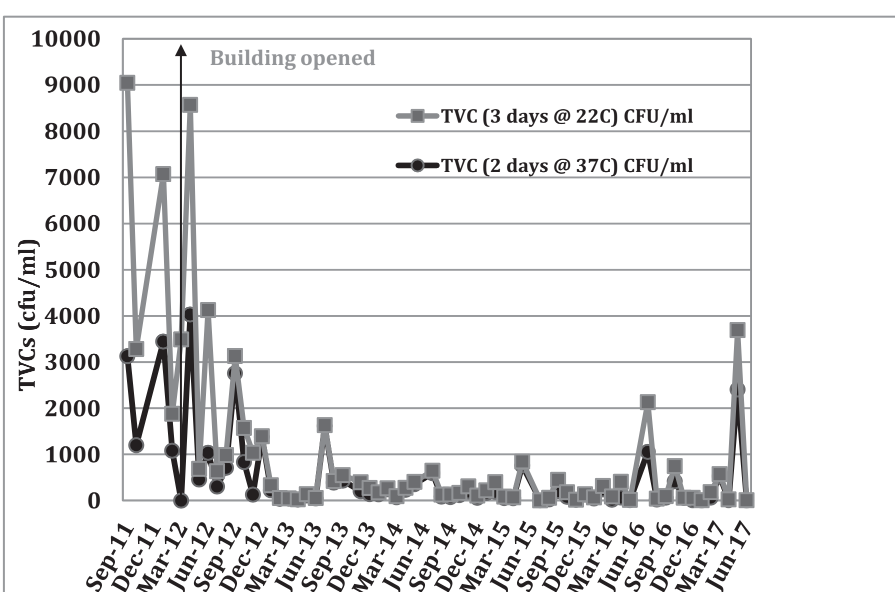

Fig 2. Average total viable count results incubated at 37°C for 2 days and at 22°C for 3 days at outlets from September 2011 to June 2017, at the new building, United Kingdom hospital.

Table 3
Energy required for heating water, temperature reduction is applied, at the new building, United Kingdom hospital, December 2016

	Hot water temperature reduction (hot water at 45°C and 65°C)					
Tank	Tank water temp (°C) (new building)	ΔT	Tank water temp (°C) (traditional)	ΔT	Annual energy use (kWh) 45°C	Annual energy use (kWh) 65°C
1	45	27	65	48	34,421	61,089
2	45	27	65	48	35,691	61,089
3	45	27	65	48	35,691	61,089
4	60	48	65	48	27,370	27,370
5	60	48	65	48	27,370	27,370
Total					160,543	238,005

Δ*T* is the change in temperature from the cold storage water tank (17°C).

section) to the data presented in Table 2, the current energy use for water heating was estimated (Table 3).

If CSI was not being used for pathogen control, water in tanks 1-3 would have been heated to 65°C to achieve 55°C at the outlets. The total energy used under no water temperature reduction was calculated and is shown in Table 3.

It can be observed that if water temperature had not been reduced, the annual energy use for heating water would have been 238,005 kWh, instead of 160,543 kWh, this equates to a 33% reduction in energy use owing to reducing water temperature and using CSI for pathogens control in this building. Separate tanks not on the CSI system supply the kitchen area, in which water is required to be supplied at 60°C.

It was calculated that by reducing water temperature in the facility, a reduction in carbon emissions from 68.55-46.24 TCO_2 (Tons of $C0_2$) was achieved. Therefore, from the analyses of water temperature reduction, it was estimated that 22.3 metric tons of CO_2e was saved per annum as a result of water temperature of tanks being reduced from 65°C-45°C.

DISCUSSION

This study evaluated the efficacy of CSI to control *L pneumophila* at reduced hot water temperatures in a newly built health care facility in the United Kingdom. We also present an energy use analysis of the program compared to conventional heat control of *L pneumophila.*

The results of 1,598 routine samples from September 2011 to June 2017, and the recordings of temperatures at outlets in this facility, demonstrated effective *L pneumophila* control by Cu and Ag ionization at average hot water temperatures of 43°C, with no *L pneumophila* detected during the sampling period. This study also demonstrated that compared with locations operated at 65°C, a considerable energy reduction of over 33% was realized with a reduction in carbon emissions estimated to be 24%.

Most hospital water systems are complex, with many different water fittings, pipe materials, and types of outlets, as well as being extensive.[23] This was observed in the hospital in this study, which initially had excessive storage capacity, a pipe layout comprising of many circuits on each floor, and many sensor taps being fitted. This may not only create niches for bacteria to hide and grow, but also makes it very difficult to consistently maintain the temperatures recommended should temperature be used as the *L pneumophila* control modality.[24] Within this study, owing to the complexity of the water system, interventions were required—including rebalancing and the introduction of a flushing regimen—to achieve adequate, detectable levels of Cu and Ag at outlets and to decrease detected levels of TVC's throughout the system. This finding reflects reports within other published studies.[25]

Previous studies had already demonstrated the failure of using temperature control methods alone against *L pneumophila* in complex water systems.[15,16,26,27] This is not surprising considering the extensive contact times necessary to reduce *L pneumophila* populations—111 minutes at 50°C and 30 minutes at 58°C.[28] Further studies have already demonstrated that *L pneumophila* can be inactivated and controlled in water systems, independent of temperature, by CSI.[18,29-31] The study reported here demonstrates that it is possible to control *L pneumophila* independent of temperature when CSI is introduced and appropriately managed.

The main primary legislation within the United Kingdom impacting on *L pneumophila* control is the Health and Safety at Work Act, which places duties on employers to manage the risks from *L pneumophila* bacteria alongside other hazards, such as scalding and others.[32] The key aspect is that the legislation requires the Trust to operate its location "safely," and the guidance contains practical examples of how this can be achieved. The Trust, therefore, needed to demonstrate that it is operating a safe system, even if it differed from the best practice guidance available. After 6 years of monitored continuous operation, this article demonstrates the system has maintained control of *L pneumophila* risk as well as reducing scalding risk and cost.

Although *L pneumophila* was never detected in any of the 1,598 samples collected, TVC results were elevated when the Cu and Ag levels dropped temporarily below the *L pneumophila* control target levels of >0.2 mg/L Cu and >0.02 mg/L Ag. Low levels of ions at point of use was related to the pipe layout and water flow and use, necessitating careful balancing and additional flushing regimens. Once the Cu and Ag levels were maintained at >0.2 mg/L Cu and >0.02 mg/L Ag at outlets, the TVC results were mostly kept <100 CFU/mL. This highlights the importance regular testing and of flushing to keep Cu and Ag ions in circulation in the system and hence achieving control of pathogens in the water. This also suggests that other microorganisms, besides *L pneumophila,* were being controlled by CSI.

CONCLUSIONS

In this study, the efficacy of CSI to control *L pneumophila* within a low temperature water system of a newly build part of a large health care facility in the United Kingdom was evaluated. The results of routine sampling of 1,598 samples from September 2011 to June 2017, and the recordings of temperatures at outlets in this facility demonstrated effective *L pneumophila* control by CSI at average hot water temperatures of 43°C. Owing to the complexity of the water system, systems management interventions were required to achieve consistent adequate levels of Cu and Ag and decreases in TVC's at outlets, including rebalancing and a flushing regimen. This study demonstrated that it is possible to control *L pneumophila* independent of temperature when CSI is introduced and appropriately managed. A considerable reduction of over 33% in energy use has been realized by operating the hot water system at 43°C.

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