Review of Various Solutions for avoiding critical levels of Legionella Bacteria in Domestic Hot Water System

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ABSTRACT

Low temperature district heating (DH) is designed as 55/25°C for supply/return temperature to fulfill the low energy demand of future buildings. However, to secure the safety of domestic hot water, the supply temperature has to be kept around 60°C to avoid the existence of legionella, which reproduces rapidly at the temperature around 25°C- 45 °C. After several outbreaks of pheumonia and fever caused by legionella bacteria, most countries require 60 °C in the network and 50-55 °C at the faucets with periodic flush by hot water above 60 °C as disinfection solution. That makes obstacles of low temperature DH implementation. Therefore, effective solution of legionella bacteria is in urgent demand.

To select optimal disinfection treatments for certain cases which are quite different in dimension or purpose of use, various methods were reviewed, including shock hyperchlorination, super heating, electric boiler, compact heat exchanger, water filter, chlorine dioxide, Monochloramine, UV sterilization, copper and silver electrodes. The implementary conditions, effect, limits as well as economic performance of them are demonstrated. For buildings with complicated networks and large volume, chemical approach is widely used, and oxidizing disinfectants have a better effect and economic performance. For buildings with DHW volume less than 3 liters, implementation of compact heat exchangers is an effective solution.

By reviewing the efficacy of each method, the optimal solution for low temperature domestic hot water system is recommended by this study, which is of great use to realize low temperature DH system without any risk of legionella.

KEYWORDS

Legionella, domestic hot water system, low temperature district heating, control regulations, thermal treatment, chemical treatment, physical treatment

INTRODUCTION

Legionella is gram-negative bacteria that mainly exists in aquatic circumstance. The most suitable proliferation temperature ranges from 25 °C to 45 °C. This bacteria includes many species, such as the L. pneumophila which causes Legionnaires Disease and L. longbeachae which causes Pontiac Fever. Since 1976, the outbreaks caused by legionella have been reported almost around the planet[1]. Because of its characteristics, legionella can be easily allocated in various human-made water systems. Domestic hot water system is known as the reservoir where legionella appears most frequently, which makes legionella more dangerous, because people can easily get infected by inhaling the aerosol of contaminated water from the kitchen faucets or shower taps.

Plenty of previous research found that the growth of legionella in domestic hot water system has close relationship with the circumstance. Potential factors may include water temperature, dimension and age of the hot water system, system hydraulic structure, materials of plumbing construction, stagnation of the pipework, scale and sediment of hot water itself, commensal microbial flora (biofilm).

The hot water temperature has very crucial impact on legionella's growth. A number of correlation study carried out a consensus that legionella can not survive when the circumstance temperature is above 60 °C. For that sake, by far, the most commonly used method to avoid legionella contamination is to control the temperature of the domestic hot water. Therefore, some countries make regulations about the hot water temperature and use them as control methods of legionella colonization. From EU guidelines, each water heater should deliver water at temperature of at least 60 °C, no less than 55°C at taps after 1 min flushing (European guidelines, 2005). In Denmark, the temperature at the faucet should not be less than 60 °C for the hot water or exceed 25 °C for the cold water after 30 s fully open the faucet (DS / EN 806-2). In United Kingdom, it is recommended to store and distribute hot water at 60°C so that it can reach a temperature of 50°C within one minute at outlets (L8). In Netherland, the temperature at the tap is required at least to be 60 °C by Temporary Decree for Legionella Prevention in Tap Water (IEA). The German code of practice W551 and W552 claim that large system should be designed so that hot water can be heated up to 60 °C once a day (IEA). In France, if water will be stored more than 24 hours, it should be heated up to >60 °C (IEA).

Plenty of disinfection methods have been developed to resolve the legionella's problem. Since the efficacy of disinfection modalities requires long time to test, it's rather a dilemma for administrators to select an appropriate control method at the beginning. Many long-term disinfection practices have proved the efficacy of some treatments for certain cases. In this study, the most commonly used eradication measures for domestic hot water system are reviewed. Their efficacy, operation methods, economic cost, and application condition will be detailed. Furthermore, the advantages and disadvantages are compared in this review. Meanwhile, the optimization and maintenance of domestic hot water system itself are also suggested. The main objective of this study is to summarize various solutions to legionella's growth in domestic hot water system by considering all the aspects. Given full knowledge of each method, people can be able to choose optimal solutions for their special scenarios or situations.

DISINFECTION METHODS

Disinfection methods for legionella inactivation can be various, however, basically they can be divided into three kinds – thermal treatment (e.g. heat and flush), chemical treatment (e.g. chloride biocides), physical treatment (e.g. ultrafiltration membrane).

Thermal disinfection (superheat and flush)

High temperature is of great use of legionella inhabitation. From previous study[2, 3], L pneumophila in vitro is killed rapidly by the temperature higher than 60 °C. For hot water at 60 °C, 70 °C and 80 °C, it takes less than 25 min, 10 min, and 5 min respectively to eradicate legionella completely [3]. It was proved by some laboratory research that to reduce the colonization of legionella by one log at 45 °C, 50 °C, 60 °C, and 70 °C, 2500, 380, less than 5, and less than 1 minute was required[3-5].

As a systematic method, thermal treatment requires to be operated in the whole pipework. The key point is to assure every pipe and every faucet to be flushed by the high temperature hot water for a certain period of time. The World Health Organization recommends heat shock at 70 °C for 30 min to control legionella's multiplication [6]. Normally, an integrated thermal treatment involves such heat shock at least twice during a 72h period following the same conditions and procedures [6-8]. If the hot water is stored in a hot water tank, then the temperature in the tank should be lifted to 70-80 °C first, and be kept at that temperature for 72 h to eradicate the bacteria in the tank, and assure the temperature at the end point can reach 65 °C to 70 °C [9, 10].

Meanwhile, thermal shock is also a kind of short-term efficient treatment. The exclusive utilization of thermal treatment is not very common, unless there is a sudden emergency and the colonization of legionella needs to be reduced in a very short time. Many previous studies show failures by using thermal treatment only, because legionella can get recovered within weeks to months if the temperature in the circulation returned back to 45 °C to 50 °C [7, 8, 10-12]. One of the most possible reasons is because high temperature has little effect on biofilm. Moreover, being treated in superheated circumstance for long time will develop heat resistance or heat acclimated of legionella [6, 7]. So, the application of thermal treatment is recommended to be accompanied with other treatments (e.g. chemical treatment).

Applying conditions

Temperature: temperature of the hot water at distal faucet should be elevated to no less than 60 °C
Time: According to different superheat temperature, certain period of time for flushing is required, and at least 5min flush at every tap.

Advantages

Thermal treatment has good performance in immediate effect, usually is used to control sudden outbreak of legionnaire disease. The process does not need to be operated precisely, and is easy to carry out.

Limits

Because super heating requires every part of the network achieve temperature > 60 °C, it is not suitable for too large or complicated system where it is hard to reach 60 °C for every distal.

This treatment is very labor intensive and time consuming. Since the protocol always costs several days, numerous personnel such as monitor distal sites, temperature measurement, and record the flushing time and etc.
Super heat and flush has very short-term effect for contaminated hot water systems by exclusive use. It can kill the bacteria suspended in the water, but has very little effect on legionella in biofilm. As a result, recolonization will happen within weeks to months.
The high temperature hot water also has the potential of scalding problem. Besides, water flushing may cause the severe leakage of old part of system.

Cost

Since the thermal treatment has no special demand for equipment, the initial investment is negligible if the labour cost is excluded. So, the overall expense of thermal treatment includes fuel cost for superheating, water flow used for flushing, and personnel fee. Surprisingly, the personnel cost accounts for much greater part of the whole expense compared with energy cost. For example, for a building with 120 beds and 380 water points, the annual cost for superheating that taken place every month was €14100, but only €400 was for energy [13].

Chemical disinfection

Chemical disinfection use chemical biocides to kill legionella. This method can be sorted into three kinds- ionization (e.g. copper and sliver), oxidizing agents (e.g. chlorine, chlorine dioxide, hydrogen peroxide and etc.), and non-oxidizing agents (e.g. aldehydes, amines and etc.). Since the oxidizing disinfectants are more popularly used, and were found to be more effective than non-oxidizing ones [14], the non-oxidizing agents was not included in this review.

Ionization

This method works by using two different ionized metals in the water to disrupt the cell wall permeability of bacteria, and cause the denaturing of proteins and subsequent cellular lysis [9, 15]. The most widely used electrodes are copper /silver. The metal ions can be added into hot water system as electrodes or by metal salts. The effective dosages can vary because of the water quality and other factors of the water system. The World Health Organization (WHO) guidelines suggest 2 mg/L of copper as a maximum level and consider that 0.1 mg/L of silver could be tolerated [16, 17]. In a vitro experiment, 0.4 mg/L Cu and 0.04 mg/L Ag were proved being able to achieve a 3-log reduction [18]. In brief, the recommend level is ranging from 0.2-0.4 mg/L for copper and 0.02-0.04 mg/L for silver [19]. Although combined metal ions are used most widely, some laboratory research also proved the efficacy of separate use of the ionized metal. A 6-log reduction of legionella population can be achieved by using copper ion alone at 0.1 mg/L after 2.5 h. For sliver, a dosage of 0.08 mg/L for more than 24h is required to achieve the same level [20].

Applying conditions

Equipment locations: The copper-silver ionization can be installed in the hot water storage tank[21], or on the upstream of the storage tank in recirculation system[22].

Water quality: To ensure a good reaction of ionization, the water should be clean. Meanwhile, the PH value of the water should be lower to avoid formation of insoluble hydroxides of the electrodes [9].

Temperature: There is no temperature requirement for copper-silver treatment. However, maintaining high temperatures in the water system could increase effectiveness of the method [19].

Advantages

The ionization method has good performance of long-term efficiency if the concentration is controlled precisely. The recolonization possibility is much minimized because the ionized metal kills the bacteria rather than suppressed it. Residual protection is able to be provided throughout the water distribute system.

Limits

The ionization treatment is a kind of on-site approach, which means it has little effect on the system already being contaminated. Precise dosages are required to carry out a successful ionization treatment. Moreover, effective concentrations of metals are hard to achieve, since it is difficult to maintain stable residuals of Cu and Ag. High concentrations of copper and silver will cause scaling accumulation and water discoloration [12]. It also has the potential to cause resistance of ionization, but long-term study is lack.

Cost

The overall cost of ionization includes the investment expense and the maintenance cost. The initial investment varies a lot depending on the size of the water system. The annual maintenance cost is mainly for replacing the electrodes, ranging from $1500 to $4000 [8, 12].

Oxidizing agents

Oxidizing agents can be various, for example, chlorine, chlorine dioxide, ozone, monochloramine and hydrogen peroxide. This kind of methods is widely used for bacteria disinfection in water system, and some of them were proven successful for inhibiting legionella's growth. However, if such kind of methods is going to be applied, meticulous control needs to be taken place to ensure the effectiveness of chemicals.

Chlorine

Chlorine is one of the most widely used oxidizing disinfectants in many kinds of water systems, such as swimming pools and cooling water systems. It can be added into water by gas or hypochlorite salts. Dissolved by water, chlorine exists as hyperchlorous acid. It was reported that 4-6 mg/l free chlorine with exposure time as long as 5-6 h can result in 3-log reduction of legionella in a model plumb system[2]. To inactivate and suppress the organism, more than 3 ppm chlorine residual is required [2, 23]. Usually, concentration of 2-6 mg/L is needed for continuous effect [24]. Moreover, higher levels need to be achieved to kill legionella associated with protozoa, for example, >4 mg/l for H. vermiformis (an amoeba)[25], while the normal residual level of chlorine concentration is no more than 1.0 ppm [26, 27].

Shock hyperchlorination is a popular remedial method for legionella disinfection. The free chlorine concentration needs to 20-50 mg/l for some time, and then fresh water is required to flush the whole system for 1-2 h to maintain 1 mg/l concentration of the system [24].

Applying conditions

Temperature: Cold water found to be more effective than equivalent dosages applied to hot water for shock hyperchlorination [28]. However, for L. pneumophila disinfection, water temperature at 25 °C performs better than 43 °C [2].

Time: The concentration of free chlorine needs to be held at required level for certain period of time, usually 1-2 h for chock hyperchlorination. In France, this time is recommended for 12h by French Health Authorities [9].

Advantages

Chlorine is a kind of systematic disinfection method, and it can provide residual concentration throughout the whole system. It has transient effect, but not long-term effect, because it may just suppress legionella rather than kill it [8, 12]. For that sake, legionella can survive when the chlorine concentration decreases [29].

Limits

The chlorine is a kind of highly corrosive chemicals which will lead to serious pipe corrosion. To avoid that, protective coatings are required to be applied.

It is very hard to maintain the required concentration of free chlorine. Moreover, if the system has stagnations or not-frequent-use parts, chlorine might be impossible to concentrate at effective level in those areas. Therefore, legionella can grow rapidly.

Chlorine residual could be toxic to the microorganisms in the plumbing system, and also has the potential to cause a kind of carcinogen of human beings. Therefore, low concentration of free chlorine is required in potable water, or less harmful substitutes are applied. Long-time exposure to chlorine may even cause resistance of legionella [30].

Cost

The cost of chlorine includes investment expense and maintenance fee. Investment can be various according to the chlorinator capacity. If continuous chlorination will be applied, meticulous analyser and monitor equipment are required to control the effective concentration of free chlorine. Maintenance fee is comprised of pipework maintenance cost and labour cost. Because of the corrosion effect of chlorine, the pipes need to be replaced some period. If protective coating such as sodium silicate is applied, the expense of silicate injection devices should be taken into consideration. A ten-year study of an Italian hospital showed €28600 annual cost by using shock hyperchlorination for 380 water points [13].

Chlorine Dioxide

Chlorine dioxide is another oxidizing disinfectant for bacteria in water. It kills the bacteria by disrupting its cellular process [31]. Although chlorine dioxide has been used for water treatment in industrial and municipal water system for many years [32, 33], there were not sufficient reports about its application in domestic hot water system for legionella disinfection.

One previous study showed that residual level at 0.08 mg/l within 1 min can achieve a 4-log reduction in viable L. pneumophila [9]. In cold water system, dosage level of 0.3 ppm was introduced [34]. For shock treatment, maintaining chlorine dioxide at 50-80 mg/l for 1 hour with continuous residual in the water had a good efficacy and biofilm was also reduced dramatically [35]. However, for continuous usage, EPA recommends the level of chlorine dioxide should not exceed 0.8 ppm, and in UK L8, this value is 0.5 ppm.

Applying conditions

Location: chlorine dioxide should be produced on site because it can easily decompose and has potential toxicity risk to store [14].

Temperature: A lot of research shows that chlorine dioxide will be lost rapidly in hot water [31, 36], so it works better in low temperature water.

PH: chlorine dioxide covers wide PH range [37], however, alkali circumstance will still reduce the eradication efficiency of chlorine dioxide.

Advantages

Chlorine dioxide is considered more effective than free chlorine in most cases and can avoid bad odor caused by reaction of chlorine. However, some study reported that in PH=7, chlorine is more effective than chlorine dioxide [38].

Limits

Chlorine dioxide is unstable gas which requires to be produced on site, which is not convenient and will increase the investment. Moreover, the dosage always lost a lot because of its quick reaction with the compounds in the water, which deduces the efficiency lost. The usage of chlorine dioxide will also cause the damage of cross-linked polyethylene pipes, which is not happened when chlorine is applied [39].

Cost

Chlorine dioxide is generally considered as a cost-effective eradication method. The total cost includes investment and management fee for strict injection and monitoring. In an Italian case, the overall cost of a 380-point building was €11640 annually [13].

Ozone

Ozone, as a potent oxidizing agent and biocide, is widely used in Europe. However, because it can easily decompose back to water and can not provide long time efficacy, sometimes, chlorine will be added into water after ozonation to provide continuous eradication. The eradication of ozone works by damage the DNA of the bacteria [14]. 1-2 mg/l ozone residual can induce a 5-log decrease in a L. pneumophila population of 10^7 CFU/ml after five hours [2]. And it was reported to be able to kill 99% L. pneumophila by 0.1-0.3 mg/l within 5 min [40]. Edelstein and etc. also demonstrated that 0.36 mg/l ozone could significantly inhibit L. pneumophila in vitro study [41].

Applying conditions

Temperature, turbidity and PH do not have obvious effect on performance of ozone [2, 40]. There was no big difference between efficacy at 25 °C and efficacy at 43 °C [2].

Location: ozone must be generated on site, because its short half-life and rapid decomposition.

Advantages

Ozone is very effective disinfectant. It reacts very fast, and requires much shorter contact time. Both O_3 gas and dissolved ozone have the disinfection ability [42]. Moreover, lower concentration of ozone has equivalent efficacy of chlorine (0.1 mg/l ozone versus 1 mg/l chlorine) [14]. To the environment, no persist residuals of ozone remain in water under normal condition [40].

Limits

The main limit of ozone is that it dissipates in water very fast. As a result, it needs to be generated on site and it is hard to maintain effective residual level stably. Moreover, the application of ozone disinfection is often accompanied with additional oxidant.

Cost

Comparing with other chlorine-release methods, ozonation is much more expensive because of the on-site generator equipment and extra dose for mass loss. The cost of equipment can be ranging from €30-40,000 per 1,000 beds for 0.5 mg/l of concentration [9].

Hydrogen peroxide

Hydrogen peroxide is not as effective disinfectant as chlorine or ozone, especially for single use. It is usually used accompanied with acid chemicals or silver. 1000 mg/l hydrogen peroxide with 30 min contact time can achieve a 2-log reduction of L. pneumophila [40]. With concentration of 100 ppm, Colloidal silver-hydrogen peroxide can kill L. pneumophila S1 and S2 within 3 hours [43].

Photocatalysis

Photocatalysis starts to be applied in water disinfection these days. The theory is to use sunlight to drive the disinfection process by using a solid catalyst such as titanium dioxide (TiO2). The main oxidant generated by this reaction is hydroxyl radical (•OH) which is accompanied with superoxide anions ($\bullet O_2^-$) and hydrogen peroxide (H_2O_2). Therefore it is very effective to eradicate microorganism in the water. With enough contact time, photocatalysis is able to inactivate various kind of microorganism, such as viruses, bacteria, spores and protozoa [44]. Although many studies have been made to discover the original mechanism of photocatlysis disinfection, none clear conclusion is carried out, for example, the exact contact time or the effective concentration [45].

The main reaction process shows as the following:

$$T_iO_2 + hv \rightarrow e_{cb}^-(T_iO_2) + h_{vb}^+(T_iO_2) \quad (1)$$

$$e_{cb}^- + O_2 \rightarrow O_2^{\cdot -} \quad (2)$$

$$2O_2^{\cdot -} + 2H^+ \rightarrow H_2O_2 + O_2 \quad (3)$$

$$H_2O + h_{vb}^+ \rightarrow \cdot OH + H^+ \quad (4)$$

$$OH^- + h_{vb}^+ \rightarrow \cdot OH \quad (5)$$

Applying conditions

Wavelength of the ultraviolet: The wavelength of the ultraviolet should be no more than 385 nm(UV-A) [46].

Contact time: certain amount of contact time is required for disinfection of different kind of microorganisms, however, no specific standard has been given. Nevertheless, longer contact time is not necessary to make better performance [44].

Temperature: According to the limited previous studies, temperature does not play an important role in the disinfection process.

Advantages

Photocatalysis is an potent disinfection approach that can be applied for both domestic water treatment and indoor air purging [47]. It can even inactivate some kind of bacteria which has strong resistance to other chemical disinfectants [46]. Besides, it makes no toxic residual through the reaction process, and it is very chemical stable.

Limits

Photocatalysis has very limit effective wavelength, only less than 5% of the sunlight. Eventhough new technologies are developing to shift the absorption to visible wavelength, it will cause the decrease of activity of the photocatalysis at the same time [45]. There are no sufficient documents about the long-term efficacy of this method, which is another obstacle of photocatalysis implementation.

Cost

Photocatalysis can be a cost-effective disinfection method because the potential of utilizing the sunlight. Besides, photocatalysis can inactivate almost every kind of microorganism in the water without generating harmful by-product. As a result, it is very suitable to treat portable water.

Ultraviolet Light

The mechanism of ultraviolet light eradication is that with the wavelength of 254 nm ultraviolet light can kill bacteria by hampering DNA replication [48]. By continuous UV disinfection at 30000 µW-s/cm^2 for 20 min, a 5-log reduction of legionella population can be achieved [2]. However, no further progress was observed, and concentration of legionella remains stable at 100-200 CFU/ ml. L. Frenzin and etc. also proved the efficacy of UV to small area by applying it to a nosocomial building, and the concentration was successfully reduced to less than 10 CFU/L at the temperature from 38 °C to 50.5 °C [49].

Applying conditions

Temperature is said to have no effect on UV sterilization. It is considered effective for both cold and hot water. However, the optimal ultraviolet transmission (100%) occurs at a wavelength of 254 nm and an ambient temperature of 40 °C [8].

Location: Because UV has no residual in the treated water, the installation should be on the point of use, for example, the showerheads and faucets. Installation only on the inlets or outlets of the storage tank is not sufficient to prevent contamination.

Advantages

Ultraviolet light has good performance of instant inactivation, but lack of long-term efficacy. That is mainly because UV light has no residual in the treated water to make continuous eradication. High dose of UV can prolong the effective disinfect time [50]. However, the most frequent solution is to accompany UV with other disinfection method. Apart from this, UV has its benefits, such as it has no chemical by-product, no effects on water quality and pipework, it is easy to install and etc.

Limits

UV light has no residual protection, so it has good performance for the control point, but not the whole system. Therefore, UV light may not be effective for the whole system which is already contaminated. UV light also cannot maintain its efficacy for long period. So other treatments such as thermal eradication or chemical eradication are usually used as additional protection. Besides, since the turbidity, mineral deposit can reduce the transmission of UV light, the system should be cleaned regularly.

Cost

For a 500-bed hospital where four large (260 gal/min) and two small (30 gal/min)units were installed, the cost was $50000 [12].

Physical disinfection

Physical disinfection usually has no chemical reaction with the bacteria, the disinfection mechanism is using membrane filter to prevent microorganism get into the water system. Filtration as the most commonly used physical treatment was proved effective for nosocomial Legionellosis in high-risk patient care areas by many previous studies [13, 51, 52].

Limits

One limits of membrane water filter might be the time of service life. As a point-of-use equipment, the filter is used frequently. As a result, the filter needs to be replaces every month normally, which will increase the cost. Another limit is the retrograde contamination. It may happen by either splash water from the water basin during use or by direct contact with contaminated hands and dirty cloths. Concrete guide and introduction are necessary to avoid such problem.

Cost

Cost is basically determined by the time of service life of the filter. In order to achieve acceptable time schedules, filters should be in use for at least one week, without an increased risk for nosocomial infection acquisition [52]. However, the expense is still much higher than other treatments. Reported by *Marchesi*, the cost of water filter for a single water point was €936 per year, which is almost 30 times as much as that of chlorine dioxide [13].

CONCLUSION

Legionella bacteria is widely known as pathogenic creature which mainly exists in hot water system, such as cooling tower, or domestic hot water system. According to this literature review, it was found that this kind of bacteria is very difficult to remove once the system got contaminated. No disinfection method was proven to be able to kill legionella throughout the whole system completely. Each method has its pros and cons, as well as its specific implementation requirements and conditions. Some critical knowledge for applying appropriate disinfection method derived from this paper as conclusion:

- Legionella has very strong resistance, which means it is impossible to make the system absolutely clean from legionella just by using disinfection methods. Base on that, most countries set the trigger concentration of legionella at 1000 CFU/L.
- All the disinfection methods can be divided into systematic method (e.g. thermal treatment, most chemical methods using chemical dosage, such as chlorine, chlorine dioxide) or local method (e.g. photocatalysis, UV light, physical methods). Systematic methods have effects on the whole water system, however, a proper dosage needs to be maintain continuously. While local methods only work at the point of use. Therefore, most local methods do not have any effects on the re-contaminated situation. In spite of that, the local methods is able to treat any kinds of systems, no matter whether an entire building or just a part of it.
- Thermal treatment is usually used to deal with the sudden outbreak of legionella by increasing the temperature to more than 65 °C. However, it is not recommended to use thermal treatment alone since its weak performance in long-term effect. Among the treatments using chemical dosage, chlorine dioxide is considered as the most effective and economic one. It can eradicate bacteria in both hot water system and cold water system. However chlorine dioxide needs to be produce onsite because of its easy decomposition. Photocatalysis and UV light are very promising methods, because the eradication process of them has no effects on the water quality. However, more research is required to prove the effects of exclusive use of them. The physical methods such as membrane filer can be applied to high risk area for its great efficacy. However, the massive use of filters will cause extremely high expense.

- Sometimes, to achieve optimal effect, different kinds of inactivation methods can be applied together. For example, thermal treatment is usually followed by chlorine to achieve continuous effective. Or UV light is also used accompanied with chemical residuals to make the eradication process work throughout the whole system.
- Appropriate hydraulic design plays an important role in reducing legionella risk in the system. Dead legs and low flow sections should be avoided in the system design at the beginning. All pipes should have good insulation to reduce the temperature drop during delivery. Hot water pipes should avoid passing through extremely cold area (e.g. a loft in winter) if not necessary. To keep a new system safe, after the water test, the water should be poured out completely, or the system should be circulated as soon as possible.

Since no specific kind of disinfection methods was proven to be much more effective than the others universally, it is more reasonable to choose specific methods for specific cases. According to Stout's [53] theory, a disinfection system can be evaluated by 4-step process
(1) a demonstrated efficacy in vitro against Legionella organisms, (2) anecdotal experience of efficacy in controlling Legionella contamination in individual hospitals, (3) controlled studies of efficacy in controlling Legionella growth and in preventing cases of hospital-acquired legionnaires' disease in individual hospitals, and (4) confirmatory reports from multiple hospitals with prolonged duration of follow-up (validation step). Only being proved by those four steps, the method can be considered as effective and can be applied extensively. °C

NOMENCLATURE

4DH research centre

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