Venturi system could be major breakthrough

In a follow-up to last month's "Fighting the waterborne menace" article (*HEJ* – March 2010), Dr Tom Makin, directorate manager, medical microbiology, at the Royal Liverpool and Broadgreen University Hospitals Trust, and Martin Pride, new business development, at Kemper UK & Ireland, examine how *Legionella* has become a significant potential issue in hospital water systems, and discuss a novel, venturi-based engineering system co-developed by Kemper and a German university, and recently successfully trialled at a Liverpool hospital, which ensures constant water circulation, significantly reducing the risk of both biofilm, and consequently *Legionella,* build-up.

Legionnaire's disease (LD) is an atypical pneumonia normally contracted by inhaling aerosols or tiny droplets generated from water containing virulent strains of the *Legionella* bacterium. Symptoms can vary, but the majority of cases display flu-like symptoms, including fever, dry cough, myalgia (muscle pain), and headache. Other symptoms (e.g. diarrhoea, which occurs in a third of cases), which appear unrelated to pneumonia, may delay an accurate diagnosis.

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Pre-disposing factors

The mortality rate associated with this infection is approximately 12%, although mortality rates over 40% have been reported in some outbreaks. A number of factors can pre-dispose individuals to Legionnaire's disease. These include a depressed immune system (e.g. following transplantation, or following treatment with high level steroids), increased age (>50), pre-existing respiratory disease (e.g. bronchitis, chronic obstructive airway disease), smoking, alcoholism, diabetes, and recent general anaesthesia following surgery. Certain types of hospitalised patients, particularly those with haematological malignancies, bone marrow transplant patients, and kidney transplant patients, are particularly susceptible to *Legionella* infection.

In outbreaks of LD, males are normally three times more likely to be infected than females, and LD is rare among children. However in 2009 an outbreak of LD occurred among 11 babies in a neonatal unit in Cyprus, and four of the babies died as a result of this infection (*HEJ* – March 2010). It was reported that the source of *Legionella* was the hospital's tanked cold water supply, which was used to top up a humidification system that discharged the contaminated aerosols into the neonatal unit. This unusual occurrence may have been due to infection with a particularly virulent strain of *Legionella* bacteria, or resulted from very large numbers of *Legionella* being present in the contaminated water supply, but it highlights the importance of cold water systems as a source of infection.

LD generally has a low attack rate. In outbreaks only a small proportion of those exposed to the bacterium (usually 1% to 2%) develop the disease, although higher attack rates can occur among more debilitated cohorts, and particularly those in hospital (5% in the Stafford Hospital outbreak in 1985). Approximately 450 cases of LD are reported in England and Wales each year to the Health Protection Agency (HPA), although over the past five years there has been a steady increase each year in cases reported both to the HPA, and to the European Working Group on *Legionella* Infections, which collates data on travel-associated cases. About 50% of the reported cases are associated with travel, and particularly travel abroad.

Under-reporting an issue

There is a significant amount of under-reporting and misdiagnosis of this infection, because LD is not yet classed as a notifiable disease in England and Wales, and the infection cannot be diagnosed without specialised laboratory tests, which are not commonly considered by physicians when patients present with pneumonia.

Prospective clinical studies have shown that LD accounts for around 3% of the 200,000+ cases of community-acquired pneumonias diagnosed in the UK each year. Therefore the actual number of cases occurring in England and Wales may be over 10 times higher than the number of reported cases, and could be in excess of 5,000 cases per annum.

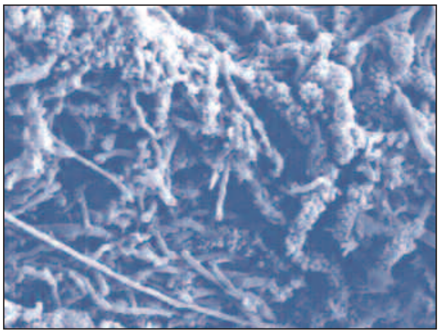
There are no definitive data available on the number of *Legionella* bacteria required to cause infection, although microbiological and epidemiological evidence from some outbreaks suggests that as few as 100 *Legionella* bacteria may be sufficient to induce disease in susceptible individuals. An infective dose of *Legionella* bacteria can be accumulated following a few exposures to the contaminated source over a period of time, and infection can also result from a single brief exposure to the source. In some outbreaks, contact with the source for just a few minutes has resulted in infection.

LD can also occur following aspiration of *Legionella* bacteria present in fluids in the mouth directly into the lung. *Legionella* bacteria are not normally present in the mouth, or other parts of the body, but they may be transient contaminants of the mouth following ingestion of contaminated potable water. This route of infection appears to be uncommon, but may be more widespread in hospitalised patients, notably those with defective cough reflexes, e.g. due to sedation or resulting from a stroke, which can increase a patient's propensity for aspiration of saliva and microbial contaminants directly from the mouth into the lung.

There is no evidence of person-to-person transmission of LD. *Legionella* infection is normally acquired from poorly-managed water systems that become contaminated with larger numbers of virulent *Legionella* bacteria.

Environmental sources and combating growth

Legionella bacteria are natural inhabitants of aquatic environments. They develop as part of a complex community of a wide variety of microorganisms, which form a slime layer, or biofilm, on sub-aquatic surfaces, and which range from a few microns to several millimetres in thickness. Some microorganisms in the biofilm, such as amoebae, can support the proliferation of *Legionella* bacteria, and can further enhance their ability to cause disease. Amoebae can also help protect *Legionellae* from unfavourable environmental conditions such as raised temperatures, biocides (disinfectants), and desiccation.



Biofilm comprises many different microorganisms, including Legionellae.

Legionella bacteria start to multiply in water at temperatures from 20˚C, but significantly increased rates of multiplication occur over 25˚C, and up to 45˚C. In accordance with an EU Directive, UK water suppliers are now permitted to supply water to buildings at temperatures of up to 25˚C. Optimum conditions for *Legionella* growth are found in warm stagnant water reaching temperatures around 35˚C.

The temperature range of 20˚C to 45˚C is common in many man-made water systems, such as cooling towers, parts of domestic hot water systems, cold water systems subjected to heat gain, spa pools, humidifiers, and many other water systems. *Legionella* bacteria can be readily discharged from these water systems in the form of aerosols, and this is the major form of transmission for Legionnaires' disease.

At a temperature of 50˚C *Legionella*

Key documents dealing with the control of Legionella *in water systems.*

bacteria die after a couple of hours, and the majority are killed within a few minutes at 60°C. At temperatures below 20°C *Legionella* bacteria remain viable, but do not normally multiply. Maintaining temperatures outside the growth zone of 20-45°C, and particularly 25-45°C, can help prevent accumulation of the bacterium in potable hot and cold water systems.

Hot and cold potable water systems are regarded as a major source of LD, and in healthcare premises they are recognised as the primary source of nosocomial (hospital-acquired) cases of the disease. A number of measures have been employed to control *Legionella* bacteria in hot and cold potable water systems, and have met with varying degrees of success, generally determined by local conditions and practices.

Legionella control measures include:

- High and low temperatures (>60°C at calorifier outlets, >50°C at hot water distribution outlets, and <20°C at cold water outlets).
- Anti-bacterial water treatment regimes (chlorine dioxide, copper and silver ions, silver and hydrogen peroxide, ozone, UV, etc).
- Regular flushing of outlets, or purging of them immediately prior to use without generating aerosols.
- Point-of-use filtration.

Whichever system is employed to control *Legionella* bacteria in water, it is important that designers, manufacturers, and installers of these systems comply with the Health and Safety Executive's guidance for managing the risks of *Legionella* bacteria as illustrated in the HSE's publication: *The Approved Code of Practice & Guidance for Legionnaires' disease: The Control of Legionella Bacteria in Water Systems (ACOP L8)*. In healthcare premises it is recommended that the Department of Health's Health Technical Memorandum HTM 04-01, "The control of *Legionella*, hygiene, 'safe' hot water, cold water and drinking water systems", is also followed. This standard, which was published in 2006, is currently being updated.

Cold water systems and *Legionellae*

Hot water has long been regarded as the primary source of *Legionella* contamination in potable water systems, as calorifiers commonly support large numbers of bacteria in the warm zone at the base of many of these vessels, where hot and cold waters merge, creating a suitable temperature for *Legionella* proliferation. However, over the last few years *Legionella* bacteria have increasingly been recovered in larger numbers from cold water systems, and

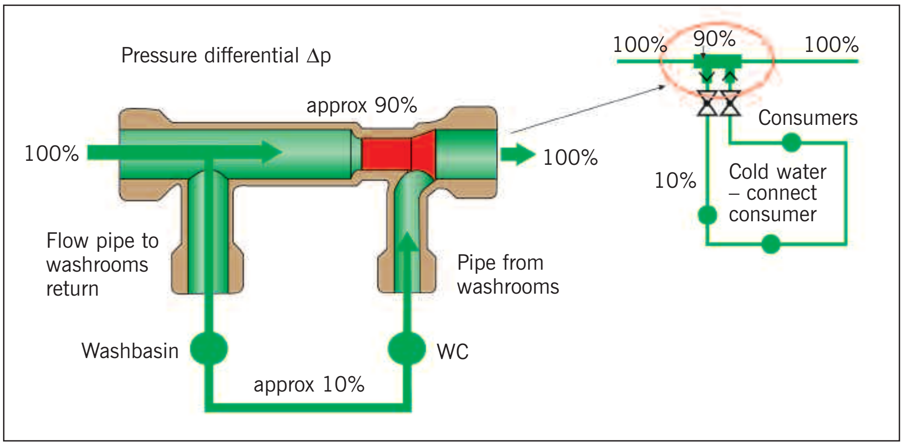


Figure 1: Venturi splitter unit installed within a single circuit.

these are now a common source of infection in healthcare premises.

This contamination has been exacerbated by energy conservation measures, notably in the form of improved insulation in new buildings, which is now mandatory, and is promulgated to promote better heat retention and reduce energy losses. As a consequence, cold water distribution systems, which are a natural heatsink in buildings due to the large temperature differential between these systems and warm ambient air, have become increasingly warm, and this in turn supports the growth of biofilm and *Legionella* bacteria.

In traditionally-designed cold water systems, the distribution pipework consists of single pipes serving outlets directly from the water source, which is either the rising main or cold water storage tanks. Essentially there is no water movement in this pipework unless the taps/showers, or other outlets, are operated. Consequently, if outlets are seldom used, the cold water within the distribution pipes and associated cold water storage tanks can become stagnant, and water temperatures can rise rapidly into the temperature zone that supports the proliferation of *Legionella* bacteria.

Importance of movement of water

Regular movement of cold water around the distribution system, and as close to the outlets as possible, should help reduce the build up of biofilm by preventing stagnation. Distribution of fresh cold water in this way also keeps water temperatures low, which slows *Legionella* growth, and the increased shearing forces created through regular movement of the cold water can help prevent excessive biofilm from accumulating in the distribution pipes.

Studies in Germany have shown that maintaining regular movement of cold water can help reduce the number of general microorganisms and *Legionella* bacteria in the cold water system. Engineering solutions of this type may provide a safer, and more economical, alternative to chemical water treatment in the management of microbial contamination, but can also improve the efficacy of chemical water treatment regimes such as biocides, where they are required, by enhancing dispersal of the treatment chemical throughout the whole water system.

Venturi-based system pioneered

A system that uses the venturi principle, rather than pumps, to move cold water around stagnant peripheral parts of a cold water system, was developed following collaboration between Münster University in Germany and valve manufacturer, Kemper. This system (dubbed the "Kemper Hygiene System" or "KHS") has been installed in a number of newly built hospitals in Germany, and has been shown to improve the microbiological quality of the cold water systems in these hospitals.

Water passing through a constriction within a venturi nozzle experiences a differential pressure across it, and this creates water movement in a secondary circuit driven by the induced positive and negative pressures. The venturi nozzle has been incorporated within a distribution body known as a "venturi splitter".

A number of venturi splitter units can be installed to create movement of water around a series of pipework circuits that would previously have been potentially stagnant cold water systems serving side rooms, washrooms, etc. The splitters would be incorporated into managed zones.

When taps or outlets are used, movement of water is driven via the differential pressure action within the venturi nozzles, not only in the room being served, but also within all of the preceding circuits. The venturi action therefore creates dynamic movement within a complete system, whether the room is occupied or not, and so eliminates "dead-legs", helping to control the proliferation of biofilm.

Monitoring and flushing

Flushing tap and shower outlets can be an effective *Legionella* control procedure. Both ACOP L8 and HTM 04-01 state that *Legionella* control procedures in buildings require regular monitoring. In most buildings where flushing of outlets is undertaken it normally takes place manually, which is labour-intensive, and the flushed water is commonly wasted. Records must also be kept, which requires further resources.

Stagnation prevented

The KHS system comprises the venturi splitter units, and automatic flushing valves, which are installed at the end of cold water lines. Stagnation is prevented when the taps and showers in the system are operated, causing water to move through the venturi splitters, which in turn drives water movement in the secondary circuits. In addition to normal operation of outlets, automatic flushing valves at the end of cold water lines can be set up to open in response to a timed programme sequence, or when temperatures in the cold water rise above a pre-set temperature, or, alternatively, may operate periodically until a defined volume of water is purged from the system. These processes are managed by a logic box control unit, which retains an electronic record of all temperature monitoring and flushing events.

The operation of the automatic purge valves also causes water to pass through the venturi splitters, creating water movement in all linked circuits. Fresh, cool water from the incoming mains water supply replaces the tepid water, and

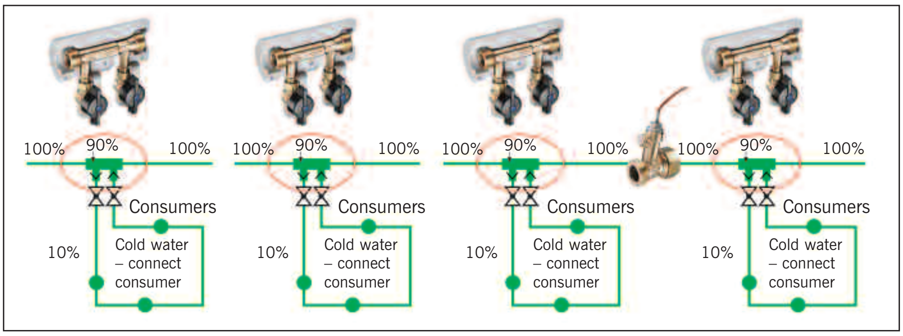


Figure 2: A system of four venturi splitter circuits.

system temperatures fall. Cold water temperatures should be prevented from rising above 25°C, as this will assist in the control of biofilm and *Legionella* bacteria.

Good engineering practice

It is important that building services designers review their traditional approach to cold water system design. Cold water distribution pipework and cold water storage tanks are frequently significantly oversized, and it is common practice for new healthcare premises to be fitted with a surfeit of tap and shower outlets. Some designers have attributed this to increasing demand from infection control professionals for additional washhand basins (WHB), and in some cases a WHB per patient has been stipulated.

Designers and healthcare professionals need to consider the risk of waterborne nosocomial infection arising from the installation of excessive numbers of outlets. It is generally recognised that water usage in operational buildings is far less than that calculated in the original design, and so the number of outlets and the projected water demand should be carefully considered and not overestimated. The capacity of cold water storage tanks should also be kept to a minimum, and consideration should be given to not installing them.

In general the following engineering principals should be considered:

- Water storage in healthcare premises should be reduced to the absolute safe minimum.
- The design demand for water systems should be reduced significantly.
- Water velocities within the pipes should be increased for improved water movement, (2 m/s is recommended but should not be excessive, as this may cause corrosion in some pipes). The shearing force of the water within pipes is a function of water velocity, and this can be effective in controlling the accretion of biofilm
- All pipework should be lagged, and, wherever possible, cold pipes separated from heat sources, i.e. avoid using common service ducts.
- Terminal heating devices, e.g. radiant heating panels, should be kept clear of the cold water distribution system. Commonly these are in close proximity in ceiling voids.
- Conditions downstream of thermostatic mixing valves (TMV) are conducive to the growth of *Legionella* bacteria and biofilm. TMVs should not be overspecified at the design stage, and should only be installed in patient areas, not in "staff only" areas, and only where there is a real risk of scalding to patients.

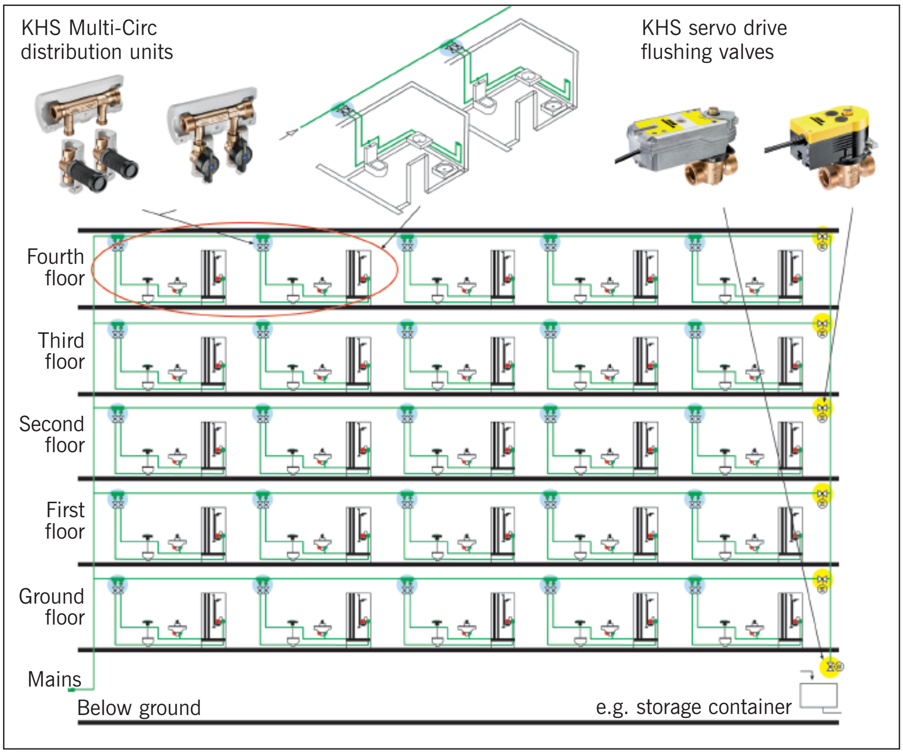


Figure 3: The KHS system with venturi splitter circuits, and automatic flushing.

The 'proof of the pudding'

Trial of the Kemper KHS system at Broadgreen Hospital, Liverpool.

In order to assess the efficacy of the Kemper KHS system in controlling *Legionella* bacteria in a cold water system in the UK, the KHS system was installed in a 20-year-old redundant section of the Alexandra Wing at Broadgreen Hospital, Liverpool*. This section of the building was known to be colonised with *Legionella* bacteria, despite regular flushing of all outlets in accordance with the recommendations in the DH Approved Code of Practice on *Legionella* control (HTM 04-01).

'Well-established' biofilm

It was evident, before the trial commenced, that the presence of biofilm and *Legionella* in the trial site, which had become well-established in the water distribution system in the Alexandra Wing building, would represent a considerable challenge for the KHS system. KHS is primarily designed for installation in new buildings, where biofilm has not become established, where it can assist in preventing the early accretion of significant levels of biofilm.

Microbiological analysis for general bacteria and *Legionella* bacteria was carried out weekly for a period of 15 weeks on a number of outlets around the test site before the KHS system was installed. After baseline microbiological data had been collected, auto-purging devices were installed at the furthest point of the cold water supply in two sections of the building (zones 1 and 2). These devices were required to ensure some water movement in the cold water system in order to operate the venturi splitters, and thus drive the movement of the cold water around the distribution loops.

The venturi splitters would normally operate whenever tap or shower outlets on the distribution pipework were opened, but, as the test site was not occupied by staff or patients, and so was not under normal operation, the auto-purge valves fitted to the end of each line were required to simulate this activity, and were programmed to purge cold water to waste on six occasions daily.

This frequency of flushing maintained

A flushing valve and timer set.

A KHS venturi splitter.

A sentinel sampling tap.

movement, and therefore a shearing force, in the cold water supply, and helped reduce the temperature of the cold water (although six auto-purges per day is considerably less than the frequency of use of cold taps and showers in a typical hospital ward or department under normal operating conditions).

The KHS system was then installed in one part of the test site (zone 2). Another section of the test site (zone 1), where KHS was not installed, was used as a negative control, and this received the same water supply as zone 2. The microbiological quality of the cold water from a number of sample points in both zones 1 and 2 was monitored for a further 19 weeks, and the full evaluation took place from August 2008 to May 2009.

Queen Alexandra Wing cold water system

The cold water services system at the Broadgreen Hospital, Queen Alexandra Wing is a traditional single pipe system, with the storage tanks situated in a rooftop plant room. The storage tanks were exposed to raised temperatures as a result of solar gain and heat from adjacent plant.

During May 2009 the ambient temperature in the plant room was approximately 30°C, and the cold water storage temperature 18°C. The pipework from the cold water storage tanks to the test area was extensive, at over 40 metres, and the heat gain within the system was in excess of 5°C.

To achieve a mean cold water system temperature of 20°C during the trial, (which is the upper temperature limit for cold water systems recommended in ACOP L8, and HTM 04 – 01), it was necessary to auto-flush the system six times per day for two minutes. It is worthy of note that the temperature of the cold water in the well-insulated distribution pipes increased by 6-10°C within the four-hour period between operation of the automatic purge valves.

Results

A total of 236 water samples were collected from outlets in zones 1 and 2 of the test site during the nine-month study. Microbiological analysis showed that 27% of water samples were positive for *Legionella* bacteria, and they were detected in all sample points on at least one occasion. During the 15-week period before the installation of the two auto-purging units, the lowest and highest *Legionella* positivity for individual sample points was 13% and 47% respectively.

The *Legionella* positivity at sample points was monitored for a further seven weeks after the installation of the auto-purge valves, and before the installation of the KHS splitters. The detection of *Legionella* bacteria across all of the sample points during this period reduced slightly, from 27% to 22%, probably as a result of the improved water flow along the main water supply lines that resulted from implementation of auto-purging.

After the KHS system was installed in zone 2, all sample points were monitored for a further 19 weeks. In Zone 1, where KHS was not installed, 29% of water samples were positive for *Legionella* bacteria, but in Zone 2, where KHS was installed, *Legionella* positivity was reduced to 18%. These results indicate that the installation of the KHS system proved effective in reducing the overall positivity of sample points for *Legionella* bacteria by almost 40%. This is a significant reduction in positivity when it is considered that the KHS system is designed for installation in new buildings, but in this trial KHS was installed in a cold water system that already contained well-established biofilm and *Legionella* bacteria.

Multi-centre US study

In a large multi-centre study carried out in healthcare premises in the USA (Stout *et al*. 2007), it was observed that, where *Legionella*-positive outlets exceed 30%,

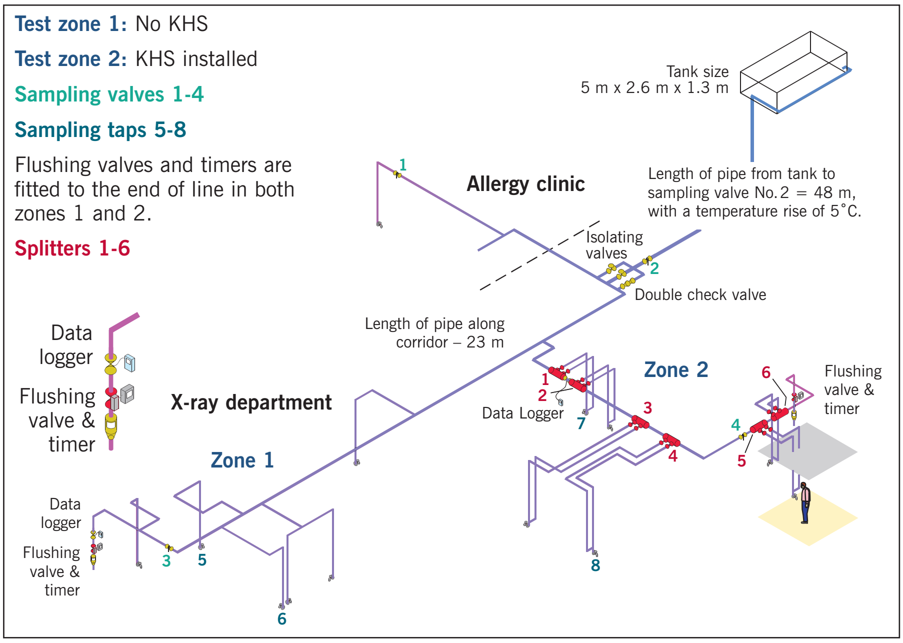


Figure 4: Schematic diagram of test site.

A sampling valve in the cold water line.

Well-lagged cold water distribution pipes.

this was a good predictive indicator of *Legionella* infection, i.e. that cases of LD were likely to occur in that building. KHS reduced the *Legionella* positivity in the Broadgreen trial by almost 40%. In other hospitals where *Legionella* contamination exceeds the positive predictive threshold of 30%, then KHS may reduce *Legionella* contamination in the cold water system to below this level, and thus reduce the risk of LD.

Further evaluation ongoing

Although the KHS system had a significant impact on *Legionella* in the Broadgreen trial – despite the presence of well-established biofilm – it is necessary to assess its efficacy in a new cold water distribution system, for which it is primarily designed. For this purpose, the system is due to be evaluated at St Mary's Hospital in Manchester. Although St Mary's is an old hospital, it has recently undergone a full refurbishment, including replacement of all distribution pipework, and so is effectively a new-build as far as water systems are concerned.

The trial, which commenced in February 2010, is being supported by the Central Manchester University Hospitals NHS Foundation Trust, and the facilities management company Catalyst. Microbiological analysis will take place over two years to determine if the KHS system can be effective in impeding the appearance of *Legionella* and biofilm in a new cold water distribution system.

If KHS does prove effective, it may help to lessen *Legionella* infection and a number of other waterborne infections caused by a range of microorganisms, which are increasingly prevalent in hospitals and other healthcare premises.

**The findings of the Broadgreen trial were presented at the IHEEM Annual Conference in Harrogate in October 2009.*

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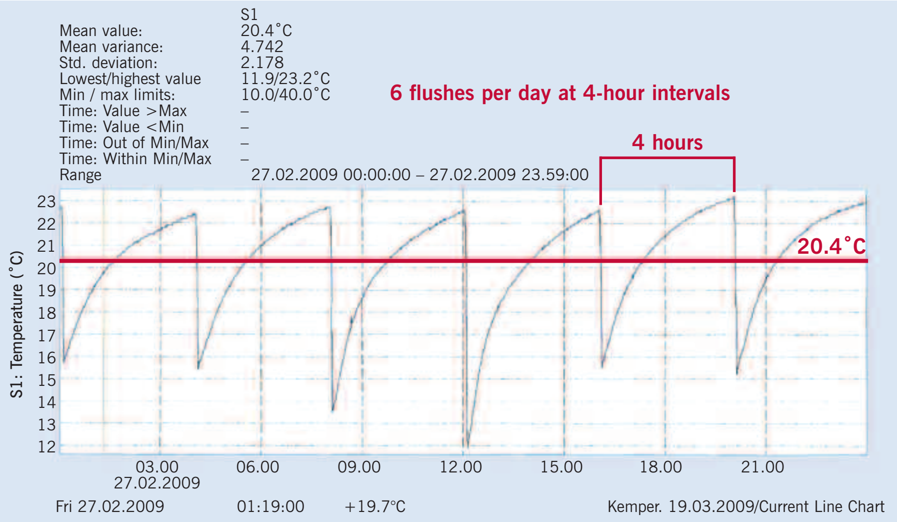

Figure 5: Typical daily flushing regime.

About the authors

Dr Tom Makin

Dr Tom Makin, BA, PhD, CSci, FIBMS, MWMSoc, has been actively involved in diagnostic medical microbiology for over 30 years, and is currently directorate manager of the Department of Medical Microbiology at the Royal Liverpool and Broadgreen University Hospitals Trust, a post he has held for over 20 years. He has researched extensively into the environmental aspects of Legionnaires' disease, and has assessed the effectiveness of various measures in the control of *Legionella* bacteria in water systems. He has also published many papers on this topic in scientific and technical journals, and presented over 200 lectures on *Legionella* at conferences and seminars nationally and internationally.

Co-author of the HSE Approved Code of Practice (L8) on the Control of *Legionella* Bacteria in Water Systems, and also of Department of Health Technical Memorandum HTM 04-01, which provides guidance on the control of *Legionella* bacteria in healthcare premises, he is a member of the working party currently updating this document. An advisor to many UK NHS Trusts on controlling *Legionella* bacteria and other microorganisms in water systems, he has also served as an expert witness in a number of high court and coroner's court cases dealing with Legionnaires' disease outbreaks, including those in Barrow, Hereford, Glastonbury, and Cardiff.

Martin Pride

Martin Pride, IEng MIET, has been actively involved in building services design and applications for over 40 years, and is currently the head of business development for Kemper UK & Ireland.

Having worked extensively on major contracts in both the UK and the Middle East, his experience encompasses all building services disciplines. He has presented lectures and seminars on *Legionella* control within public health systems, as well as in building services commissioning control systems, both nationally and internationally.

Recent work with Kemper in the UK has seen him collate live data to prove the efficacy of the KHS system and its ability both to control *Legionella*, and to environmentally manage potable water within British Standards, UK Codes of Practice, and water by-laws.

He is keen to encourage discussion and debate between UK professionals within hygienic systems control and their partners in mainland Europe.