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THE RISK OF LEGIONELLA DEVELOPMENT IN SANITARY INSTALLATIONS

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ABSTRACT

In order to determine whether it is possible to reduce energy use for domestic hot water (DHW) production and distribution, without increasing the risk of *Legionella pn.* development in sanitary installations, a full-scale test facility was built, consisting of a 200 liters water tank, a circulation system of nearly 40 meters long and 2 draw-off pipes. On a daily basis, a consumption profile corresponding to the DHW use of a single family (4 persons) was applied using two draw-off pipes, one corresponding to a kitchen and the other to a bathroom. *Legionella pn.* was cultivated in a separate water tank and then introduced into the test facility.
In this test facility, applying different types of thermal shocks at 60°C (up to 2h) on a contaminated installation with a DHW production temperature of 45°C was not sufficient to keep *Legionella pn.* concentrations beneath 1000 cfu/l, in both the water tank and the circulation loop. Even daily shocks at 60°C were insufficient. After the thermal shocks the *Legionella pn.* concentrations reached 10^5 - 10^6 cfu/l within a couple of days. The expansion vessel, installed on the cold water inlet of the DHW production, proved to be an important source of recontamination of the installation after a thermal shock. Applying a weekly thermal shock of 24h at 65°C, in combination with regular draw-off during this shock on both draw-off pipes (of minimum 150s in this test setup), lead to stable *Legionella* concentrations <1000 cfu/l.

KEY WORDS: Water supply, hygiene, *Legionella pn.*, development, domestic hot water, disinfection, thermal shock

1. INTRODUCTION

As the energy-use for space heating continues to diminish due to better performances of the building envelope and the use of more efficient heating systems, the energy use for hot water production becomes increasingly relevant. Since the recast of the Energy Performance of Buildings Directive [1] stipulates that by 2020 all new buildings in the European Union should be almost near zero energy buildings, reducing the energy use for hot water production, whilst maintaining the desired comfort level for the building occupants, will become one of the challenges for the future in Europe.

Therefore it becomes ever more important to design DHW production and distribution installations inside our buildings in a more energy efficient way. An optimal design [2] of the drinking water system (hot and cold) includes however also other aspects, of which some are even more important such as the hygienic quality of the water at the taps by avoiding for instance the development of *Legionella pn.*, a pathogenic bacterium, which can lead to a severe pneumonia and death.

Knowing that the *Legionella pn.* bacteria grow between 25°C and about 45°C while it is decimated above 50°C [3,6], the aim of the study was to evaluate whether it is possible to produce and distribute the domestic

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hot water at temperatures within the growth range of the bacteria - i.e. energy –effective but still comfortable in use- in combination with systematic in time limited temperatures rises above 50°C in order to ensure hygienic quality.

While several authors reported studies on the influence of the temperature on the growth/death rate of *Legionella pn.* bacteria in laboratory conditions [3,6] or in a pilot installation [4,5], the full-scale test facility offers the opportunity to study the effect of multiple controlled thermal chocks on the survival of *Legionella pn.* Farat *et al.* [4,5] found that, based on a very limited number of heat shocks, thermal disinfection didn't seem to be efficient enough to eliminate Legionella when it is used as a curative treatment.

2. TEST FACILITY DESCRIPTION

Figure 1 shows a global view of the test facility at the BBRI. There are 2 water tanks (a 'culture' and a 'test' tank), one circulation loop of about 40 m, connected to the test tank and 2 draw-off pipes (with respectively a "kitchen" and a "shower" consumption profile). The 'culture' tank is a 200 liter steel tank, heated at 37°C with *Legionella pn.* concentration at nearly 2.10^5 cfu/l.

The "test" tank is a 200 liters austenic chrome-nickel steel tank. The heating system is an electrical resistance of 6 kW placed in vertical position at the bottom of the tank. The height of the tank is 136 cm. The temperature profile, over whole the tank, is measured by temperature probes placed on the outside wall (under the insulation jacket) and a probe in the middle of the departure pipe. This tank and its circulation loop was initially directly fed with the contaminated water from the "culture" tank (2,64 liters each 30 minutes) during 2 weeks. During the second week, the temperature was changed from 40 °C to 45°C over 5 days. After the 2 weeks, the water supply was connected directly to the district distribution of potable water. The DHW production temperature was then kept at 45°C and a realistic consumption profile (see further) was applied at the draw-off taps (= test phase). Samples of the water circulating in the loop were periodically taken via tap points on the depart of the loop and on its return near the boiler, in order to measure the development of *Legionella pn.* After a couple of weeks, a stable concentration of *Legionella pn.* was reached (nearly 5.10^6 cfu/l).

At the outlet of the 'test' tank, there is a flexible connection to the circulation loop. The circulation loop connected to the test tank consists of nearly 40 m isolated multilayers pipes (figure 1). The loop starts with a horizontal pipe DN50; the vertical pipe is DN32 with 20 mm insulation. The recirculation pipe is a DN16 with 15 mm insulation. Some temperatures probes were placed inside these DN32 and DN16 pipes. A flow regulation valve and a flowmeter were also placed on the last one. At the bottom of the recirculation pipe (1,5 m before entering the tank), another sampling valve makes it possible to take water samples of the "return" water.

Based on the tank capacity (200 l), a realistic consumption profile based on the DHW demand of a 4 person-family was established. The tap schedule is given in the table 1.

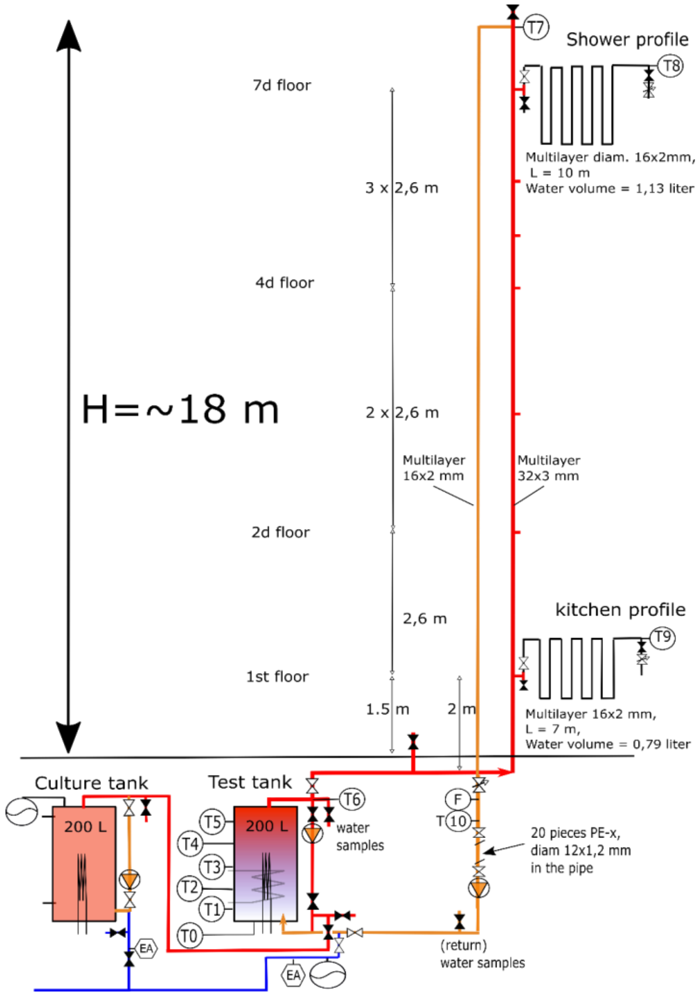

Fig. 1 Scheme of the Legionella test facility.

Table 1 – Applied consumption profile (155,8 l/d DHW @45°C for a 4 person- family)

Start hour	Type of draw-off	DHW Flow rate l /min	Tap duration second	Tapped DHW volume liters
06:59	purge of the shower pipe	6,5	10	1,083
07:00	Shower n° 1	6,5	355	38,5
07:10	Shower n° 2	6,5	393	42,6
08:00	Shower n° 3	6,5	296	32,1
12:00	Kitchen faucet	5	6	0,50
12:30	Kitchen faucet	5	20	1,67
13:45	Kitchen faucet	5	30	2,50
18:15	Children’s bath (40 L)	6,5	311	33,7
19:00	Kitchen faucet	5	6	0,50
19:15	Kitchen faucet	5	3	0,25
20:00	Kitchen faucet	5	30	2,50

According to the temperature setpoint of the tank (45°C), the DHW flowrate of the ‘shower’ draw-off was set on 6,5 l/min (corresponding to a shower with a flowrate of 8 l/min on mixed water at 38°C). The DHW flowrate of the ‘kitchen’ is calibrated on 5 l /min. The total daily DHW volume consumed was about 156 l/day : ~ 148 l via the ‘shower’ and ~ 7,9 l via the kitchen .

3.THERMAL SHOCKS

As the Belgian Superior Health Council recommends concentrations of *Legionella pn.* beneath 1000 cfu/l in health care institutions, by applying the thermal shocks we aimed to stabilize the *Legionella pn.* contamination below this value.

In the experimental set-up, the temperature of the boiler was set to 45°C and regulated by the temperature probe placed in the middle of the tank height, while the temperature in the circulation loop remained between 46.8°C (max. on depart) and 42,8°C (min. on return). For a thermal shock, the regulation is switched to another setting point. A timer is activated for a chosen time after the desired temperature for the thermal shock is reached. At the end of this period, the regulation is then automatically switched to the usual regulation of the tank.
For the thermal shock, the heating of the tank was modified so that a temperature of 63°C was reached at the outlet of the tank and so that 60°C was obtained at the end of the recirculation pipe. Water samples were taken before and a few hours after (early in the morning) the thermal shock. All the temperatures as well as the circulation flowrate were monitored every second.

Some adaptations were progressively made in the test facility and in the thermal shock protocol in order to try to succeed the disinfection at 60°C. Different durations (30 min, 1 hour, 2 hour), homogenisation of the water temperature in the tank by activating re-circulation on the tank and different thermal shock frequencies were tested (see table 2). In the second part of the year, we also changed the thermal shock temperature to 65°C (see table 3).

Table 2 Overview of the tested thermal shocks at 60°C on the installation.

Date	Temperature production (tank)	Temperature heating (thermal shock)	Heating duration	Frequency	Number of thermal shocks
19 & 26/01	45 °C	60 °C	30 min	1x / week	2
2 & 9/02	45 °C	60 °C	1h	1x / week	2
16/02	45 °C	60 °C	30 min	1x / week with extra circulation on tank	1
23/02 & 2 /03	45 °C	60 °C	1 h	1x / week with extra circulation on tank	2
16 & 27/03 3/04	45 °C	60 °C	1 h	1x / week with extra circulation on tank. + 4 x 30 minutes thermal disinfection of taps	1
20/04	45 °C	60 °C	4 x 30 min	1x / week with extra circulation on tank. + 4 x 30 minutes thermal disinfection of taps	1

8/05	45 °C	60 °C	30 min + 4 x 30 min	1x / week with extra circulation on tank. + 4 x 30 minutes thermal disinfection of taps	1
30/05 to 27/06	45 °C	60 °C	1 h	2x / week with extra circulation on tank	9
30/06 to 10/07	45 °C	60 °C	1 h	daily (7x /week) with extra circulation on tank	10

Table 3 Overview of the tested thermal shocks at 65°C on the installation.

Date	Temperature production (tank)	Temperature heating (thermal shock)	Heating duration	Frequency	Number of thermal shocks
11/07	45 °C	65 °C (68°C, with circulation flow rate 1,3 l/min)	30 min	1x / week with extra circulation on tank.	1
18/07	45 °C	65 °C (68°C, with circulation flow rate 1,3 l/min)	1h	1x / week with extra circulation on tank.	1
26/07	45 °C	65 °C (68°C, with circulation flow rate 1,3 l/min)	4 x 30 min	1x / week with extra circulation on tank. + 4 x 30 minutes thermal disinfection of taps	1
31/07	45 °C	65 °C (68°C, with circulation flow rate **4,4** l/min)	1 h	7x / week with extra circulation on tank	7
09/08	45 °C	65 °C (68°C, with circulation flow rate 4,4 l/min ;	4 x 30 min	1x / week with extra circulation on tank. + 4 x 30 minutes thermal disinfection of taps	1
18/08 01/09 08/09	45 °C	65 °C (**65**°C with circulation flow rate 4,4 l/min ;	8 h	1x / week with extra circulation on tank.	3
14/09	45 °C	65 °C (65°C with circulation flow rate 4,4 l/min	24 h	1x / week with extra circulation on tank. + kitchen = 30 s	1
21/09	45 °C	65 °C (65°C with circulation flow rate 4,4 l/min	24 h	1x / week with extra circulation on tank. + kitchen = 90 s	1
28/09 & 05/10	45 °C	65 °C (65°C with circulation flow rate 4,4 l/min	24 h	1x / week with extra circulation on tank. + kitchen =120 s	2
12/10 - - - - - 23/11 30/11 07/12 14/12	45 °C	65 °C (65°C with circulation flow rate 4,4 l/min	24 h	1x / week with extra circulation on tank. + kitchen = 150 s --- = no schock during 5 weeks	1+4

4. RESULTS

4.1 Laboratory tests

In laboratory conditions, a sole thermal treatment on a homogeneous stock solution of *Legionella pn.* strains from the culture vessel was carried out at 60°C, 65°C and 70°C. No (cultivable) *Legionella pn.* bacteria survived the thermal shock at 65°C or 70°C. The concentration of cultivable *Legionella pn.* dropped from 100.000 cfu/l to beneath the detection limit (< 100 cfu/l) even after 5 minutes. However, several laboratory results indicate a *Legionella pn.* resistance up to 60 minutes at 60°C (reduction to 250 cfu/l after 60 minutes for cultivable bacteria).

4.2 Thermal shocks in the test facility

Figure 3 shows the results of de different thermal shocks, described in tables 2 and 3 on the *Legionella pn.* concentration in the circulation loop and the draw-off pipes.

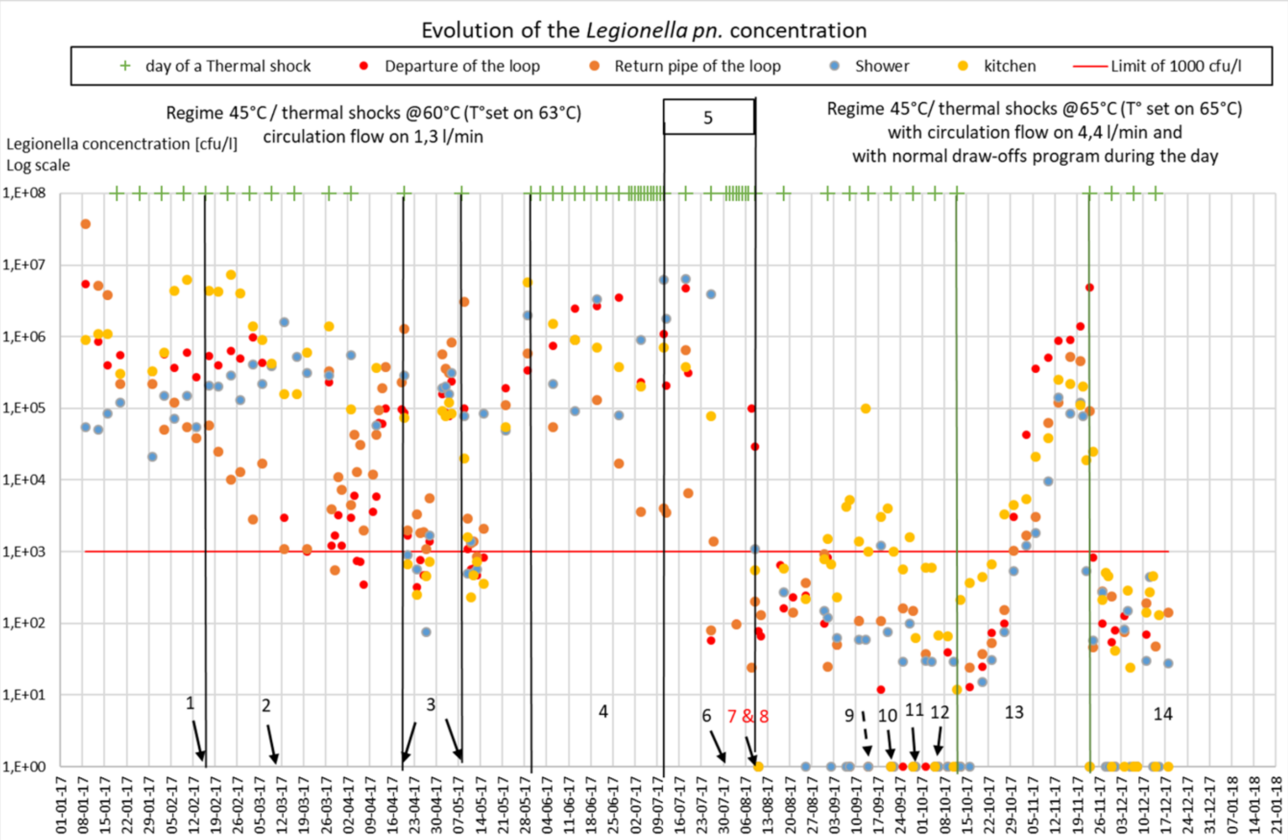

Fig. 3 Overview of the *Legionalla pn.* concentration during the different thermal shocks.

Legend :

1	Extra recirculation flow on the boiler (since 16/02/2017)
2	Systematic desinfection of the sampling valves with alcohol 70° - 2 min. since 09/03/2017
3	Thermal desinfection of draw-offs pipes on 20/04/2017 and 08/05/2017
4	Thermal shock of the loop (1 hour at 60°C) during the night : 2x/week then 1x/day from 30/05/2017 to 10/07/2017
5	Transitional regime 45°C / Temperature set on 68°C for thermal shocks during the night (from

	11/07/2017 to 07/08/2017)
6	Temperature set on 65°C for the thermal shocks and circulation flow set on 4,4 l/min (previously set on 1,3 l/min) since 31/07/17
7	Disassembling of the expansion vessel since 08/08/2017
8	Thermal shock with disinfection by 30 min draw-off on both draw-off pipes on 09/08/2017
9	Automatic kitchen draw-off on 13:45 set on 30 second (initial value) during the thermal shock on 14/09/2017
10	Automatic kitchen draw-off on 13:45 set on 90 second during the thermal shock on 21/09/2017
11	Automatic kitchen draw-off on 13:45 set on 120 sec during the thermal shock on 28/09/2017
12	Automatic kitchen draw-off on 13:45 set on 150 second during the thermal shocks since 05/10/2017
13	Period of 5 weeks without any disinfection
14	Same as 12: Automatic kitchen draw-off on 13:45 set on 150 second during the thermal shocks once a week.

From 08/01/2017 till 10/07/2017 we found that, in this test facility, applying different types of thermal shocks at 60°C (up to 2h) on a contaminated installation with a DHW production temperature of 45°C was not sufficient to keep Legionella pn. concentrations beneath 1000 cfu/l, in both the water tank and the circulation loop.

On 08/08, we took water samples respectively from the expansion vessel via the safety group, in the cold water inlet between the expansion vessel and the circulation return pipe, and in the dead volume of water from the connexion pipe to the culture tank in order to verify the concentration of *Legionella pn* in this special zones. The safety group was thenafter mounted directly on the circulation return pipes.

We found that the *Legionella pn.* concentration in the water from the cold water inlet between the expansion vessel and the circulation return pipe was at the same level as the start point of distribution pipe and could be responsible for a quick re-growth of *Legionella pn.* after a thermal shock (by re-injecting a couple of liters at $1{,}4.10^4$ cfu/l into the storage).

On 09/08 (just the day after the adaptation of the cold water inlet), a new thermal shock was performed (temperature set point still on 68°C) in combination with a thermal treatment (30 minutes of draw-off > 60°C) of the 2 draw-offs pipes respectively to shower and to the kitchen faucet. However, the power of the tank heating system (6 kW) was not sufficient enough to maintain the temperature of 65°C in the test tank during this long draw-offs. So, the test tank was fed via a pre-heater tank (65°C) during the thermal treatment. It was the first time that the samples collected the next morning were all below the limit of 1000 cfu/l (from not detected to 140 cfu/l).

Observing that results were satisfying in combination with the thermal treatment of the two draw-off pipes, it was decided to test this thermal shock in combination with the normal use of the faucets. Since 18/08, the temperature set point of the thermal shock was then reduced to 65°C, flow rate still on 4,4 l/min, without pre-heating system and with the automatic consumption profile (table 1). During the next week, the *Legionella pn* concentration was still below the limit of 1000 cfu/l and no thermal shock was applied (21 to 27/08).

After the second week, only the concentration of *Legionella pn.* in the kitchen draw-off pipe raised again above the 1000 cfu/l despite the thermal shock once a week (24 h at 65°C with the automatic consumption profile during the day). The longest draw-offs for the kitchen faucet was only 30 seconds (respectively on 13:45 and 20:00). This duration was not sufficient to reach a satisfying disinfection of the draw-off pipe (max. temperature was 61°C during 3 s during the thermal shock on 14/09). Therefore, this draw-off duration was progressively increased from 30 seconds to respectively 90, 120 and 150 s. The duration of 150 s (2,5 minutes) permitted – - to reach nearly 65°C during 1 minute (2 minutes > 60°C) and seems to be sufficient, within the settings of our test facility to maintain the *Legionella pn.* concentration below 1000 cfu/l in the tank, the loop and the draw-off pipes (see figure 3).

5. CONCLUSIONS

In this test facility, applying different types of thermal shocks at 60°C (up to 2h) on a contaminated installation with a DHW production temperature of 45°C was not sufficient to keep *Legionella pn.* concentrations beneath 1000 cfu/l, in both the water tank and the circulation loop. Even daily shocks at 60°C were insufficient After the thermal shocks the *Legionella* concentrations reached 10^5 - 10^6 cfu/l within a couple of days.

The expansion vessel, installed on the cold water inlet of the DHW production, proved to be an important source of recontamination of the installation after a thermal shock.

Applying a weekly thermal shock of 24h at 65°C, in combination with regular draw-off during this shock on both draw-off pipes (of minimum 150s in this test facility), lead to stable *Legionella pn.* concentrations <1000 cfu/l.

Tests performed in laboratory conditions (heat shock at 60°C up to 1 hour or 65°C during 5 minutes) on a homogeneous solution of Legionella bacteria in water confirm the results obtained in the test facility.

In general, the importance of reaching and maintaining the desired temperature at all points of the installation for a certain duration was demonstrated as a critical balance in order to control the *Legionella sp*. concentration.

The next step in this research will be to examine the efficiency of heat shocks at 70°C over a short period of time. Afterwards the effect of raising the DHW production temperature to 50°C on the efficiency of the different types of heat shocks will be tested.

ACKNOWLEDGMENT

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