INSTITUT FÜR SOLARTECHNIK

HSR HOCHSCHULE FÜR TECHNIK RAPPERSWIL
FHO Fachhochschule Ostschweiz

Validation of assumptions concerning Legionella prevention in drinking water installations

A contribution to the discussion of the revision of EN-806-2 based on evidence from field studies

Dr. Michel Haller, November 2018

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Executive Summary

In the past, Legionella prevention in sanitary hot water systems has been built on a number of assumptions, which - under the light of evidence from field studies – cannot be confirmed. Furthermore, new evidence has come into light that needs to be included into Legionella safety considerations. This evidence is provided and summarized here as an input for the discussion of the revision of EN 806-2.

This material was compiled based on a literature study of more than 150 documents that are mostly original publications, of which a small fraction gave detailed insights into the determining factors of Legionella growth in sanitary hot water systems in buildings.

A number of publications that are cited are referring to measurements that were performed on single and double family homes. Although these have a considerably smaller risk for Legionella infection than larger systems, much can be learnt from these smaller systems since the influencing variables are fewer and the situation is most of times clearer. In addition, the role that hot water distribution plays in Legionella infections can be studied better since there are also small systems that do not maintain the drinking water distribution lines hot at all times (no DHW recirculation or heat-ribbons), a configuration that is virtually inexistent in large systems for obvious reasons.

The author is grateful for any comments on the findings, and is encouraging feedback in particular if literature has been misinterpreted or additional – new or overlooked - literature is available on a topic and shall be integrated into the discussion.

Content

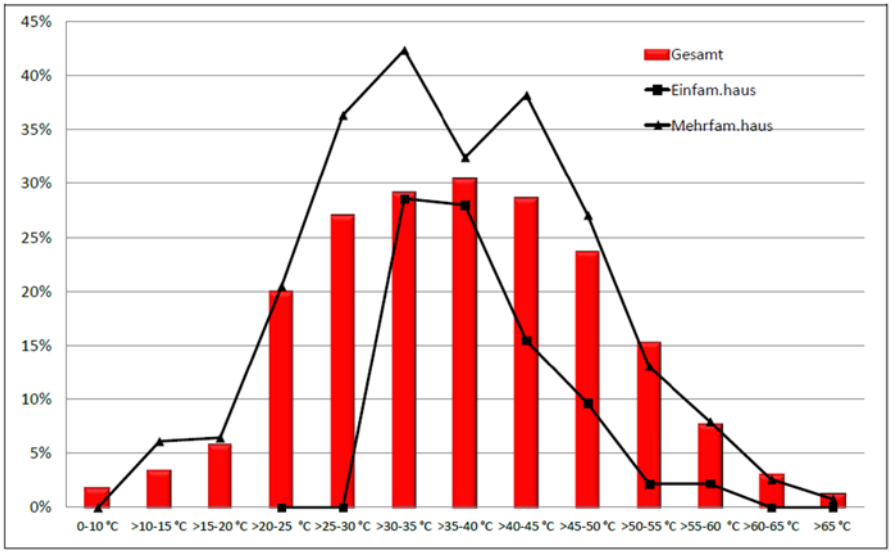
1 Small (single family) vs. large (multifamily, hotels, etc.)

A clearer distinction between hot water systems for single and double family homes or single apartments on the one hand, and large buildings on the other hand is needed:

- In small systems without warm distribution (distribution pipes are cooling down after each tapping) Legionella is very rarely found in large quantities. Such systems can be considered safe with > 52 °C at storage outlet and > 50 °C at the tap.
- For small systems the danger of Legionella increases substantially when hot water re-circulation is installed, and hot water re-circulation or heat-ribbons should be avoided for both hygienic reasons as well as energy savings.
- Larger systems (multifamily houses, hotels, etc.) must be equipped with hot water re-circulation or heat-ribbons both for comfort and for Legionella protection, since the jointly-used distribution pipes can never cool down to ambient.

Evidence:

- Pleischl 2004 (p. 47, German): In large systems 34 – 66 % (depending on type of system, out of a total of 317 large systems) showed, at least in one sample, Legionella concentration above the threshold for intervention. For single and double family homes, only 2% (1/48) showed Legionella above the threshold.
- Tiefenbrunner 1993 (translated from German): "The multiplication potential for Legionella in drinking water installations in single and double family homes is low in comparison to large systems like hospitals or hotels. This can be explained by the shorter pipe distribution system and smaller pipe diameters and thus less surfaces that can be colonized."
- Exner et al. 1993: Six single-family homes were free of Legionella, whereas of 245 large buildings 33% showed Legionella.
- Barna et al. 2016: Private homes with central DHW preparation had > 100 CFU/100 ml in 31% (8/26), private homes with individual DHW preparation in 4% (1/26), large buildings 49% of cases.
- Rühling & Rothmann 2002: see Figure below.



Frequency of Legionella levels > 100 CFU/100 ml for single and double family homes (Einfam.haus) in comparison to multifamily buildings (Mehrfam.haus), depending on temperatures, from Rühling & Rothmann (2002).

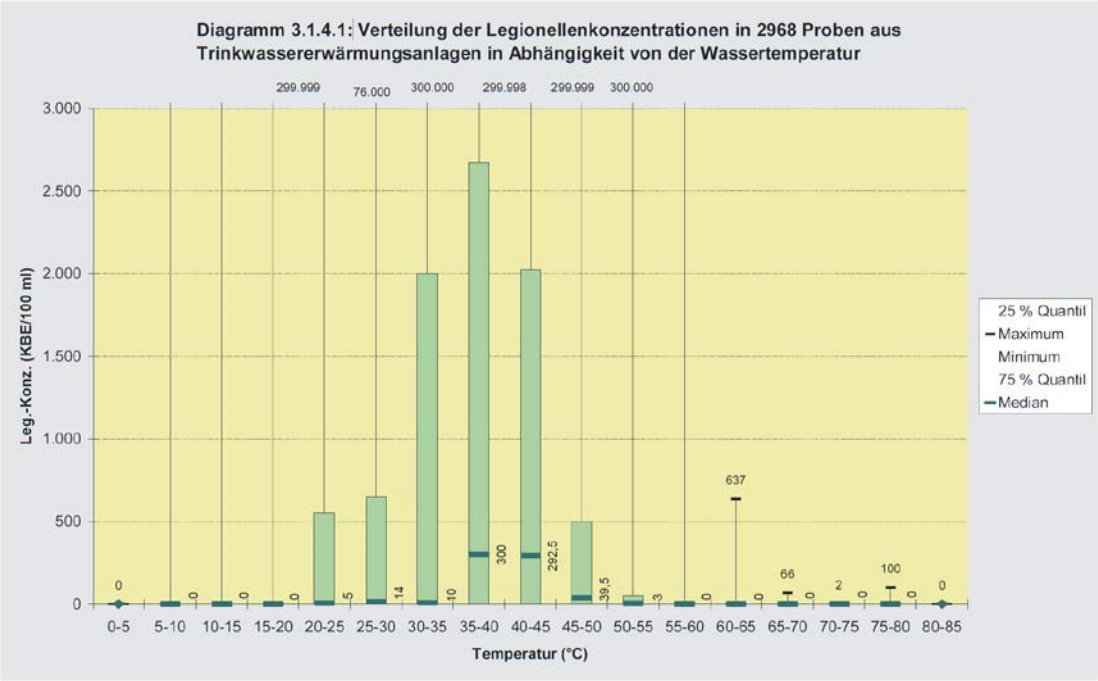
2 Supply temperature and delta-T of return for DHW recirculation

Contrary to what we assumed, field studies show that there is no clear evidence that 60 °C supply temperature into the hot water re-circulation is making a system Legionella-safe. Field studies also show that the implementation of the rule of 5K delta-T from re-circulation supply to return to the heater has no effect on Legionella safety.

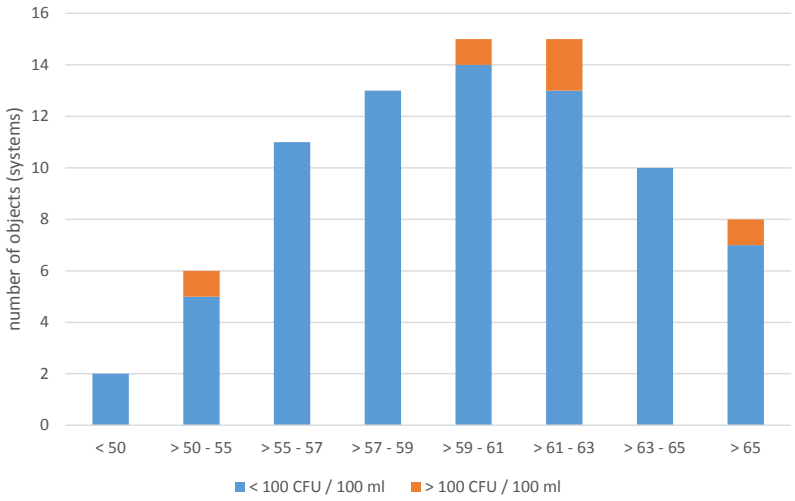
Instead, the return temperature to the heater itself is likely to be the crucial element in Legionella protection, since it defines the lowest temperature of the distribution system. This temperature should be ≥ 52 °C. In general, ≥ 55 °C supply temperature is needed to reach this and can be recommended additionally. For large or complicated distributions, 60 °C supply or even more may be needed.

Evidence:

- Rühling et al. 2018 (p. 137 + 355, from German): “A threshold temperature at the outlet of the water heater [...] above which a contamination with Legionella can be excluded, cannot be given for existing buildings. [...] A modern system that is planned, installed and operated according to the state of the art can be operated with 55 °C supply and 52 °C return of the hot water re-circulation system and still no problems with Legionella are to be expected.”
- Pleischl 2004: 264 systems (2968 samples) were analysed. High numbers of Legionella positive systems for storage temperatures below 50 °C and for cold water temperatures above 25 °C (see Figure).
- Harmuth 2006: Above water temperatures of 50 °C in the storage, Legionella were only present when the storage was (too?) small (see Figure in section 4).
- Mathys et al. 2006: “Raising hot water temperatures to > 60 °C had no influence on Legionella counts”.
- Burger 1993: The detection of Legionella in the storage outlet was not possible for temperatures ≥ 55 °C.
- Totaro et al. 2017: “[...] the European data show some correlations between the Legionella growth in pipework and the presence of specific water physical-chemical parameters, [such] as the temperature of 44–48 °C [...]”
- Borella et al. 2004: “An operating temperature >50 °C was predictive of non contaminated samples (OR 0.25; 95% CI 0.11 to 0.98, p < 0.05).”



Concentration of Legionella in samples depending on the water temperature, according to Pleischl. 2004.



Number of objects, divided according to temperature at the outlet of the water heater (storage) and number of samples > 100 CFU / 100 ml. based on data from Rühling et al. 2018 (p. 40-41).

3 Temperature of re-circulation return to the heater

As evidence shows, Legionella can be detected more frequently when several parallel strings or raisers are distributing hot water, whereas the number of apartments that are connected to the hot water distribution is less crucial (Rühling et al. 2008, p. 119). This leads to the conclusion that often parallel strings are not operated with the same circulation flow rate, and do not return with the same temperature. A minimum return temperature has to be guaranteed for all parallel strings AND for the combined return from the re-circulation to the heater, i.e. for the entire hot water network, and not only at the time of commissioning, but also during the entire lifetime of the system.

Large, complicated or problematic systems will not be able to guarantee a minimum return temperature of, e.g., 52 °C with a temperature of only 55 °C in the supply and will have to operate with higher temperatures of 60 °C or even 65 °C at their inlet. This dependency of supply temperature on the complexity of the system is better understood and automatically introduced by specifying the return temperature of all strings as the master variable. Requiring 60 °C at the heater outlet for any kind of system will be more than necessary for some, and less than needed for others! Increasing the temperature of the distribution more than necessary increases at the same time the risk of Legionella growth in nearby cold water lines, since the temperature in these lines will unintentionally, but inevitable, increase by heat transfer from the hot water lines.

Evidence:

- Rühling et al. 2018 (p. 119): Legionella positive buildings have more parallel raisers than buildings that are free of Legionella.
- Rühling et al. 2018 (p.181, from German): “The length of the circulation string (warm water distribution and return) [...] influences the occurrence of Legionella. Peripheral sampling sites with scarce tappings are more often and higher contaminated.“
- Leoni et al. 2005, Abstract: Apartments with centralized heating were contaminated with a ratio of 41.6%, apartments with independent heating system showed a lower level of colonization (3.6%).
- Kruse et al. 2016: “Positive central samples were taken in 84 of the 233 contaminated buildings (36.1%). In 149 of the contaminated buildings (63.9%), Legionella spp. could exclusively be found in peripheral samples.”
- Barna et al. 2016: “Centrally produced hot water was found to be a key risk factor (46% of the samples were positive vs. 16% in individual systems).”
- Völker et al. 2016: Temperature, stagnation and length of the pipework were identified as main risk factors for Legionella growth.

4 Limits for volumes of stored hot water

A limit of hot water storage volume above which the risk for Legionella increases does not exist. Large volumes are problematic if they are at a temperature at which Legionella can grow, but if their temperature is > 50 °C, they effectively protect from contamination out of the hot water re-circulation or from pre-heating volumes by decimating the load of active[1] Legionella.

Therefore, the „hot“ DHW volume should not be limited to a very low value, as this would reduce Legionella safety if it is too low (to allow for volumes that correspond to 1 daily turnover seems to be reasonable).

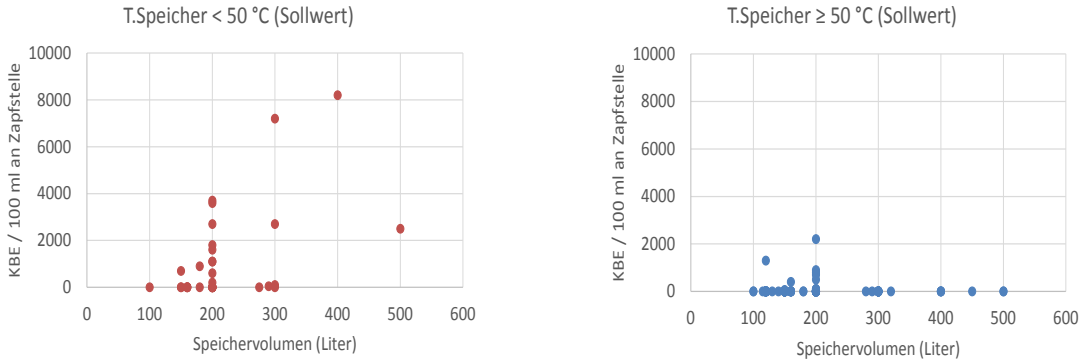
Any pre-heating volume (solar, heat recovery, etc.) should not be larger than twice the “hot” volume in order to guarantee a larger reduction of Legionella in the hot volume than growth in the pre-heating volume. The time to reduce active Legionella by a factor of 10 (D-value) is 2 h at 50 °C, the growth rate under optimal conditions (at 35 – 40 °C) is doubling the population every 6 hours.

Pre-heated water shall not enter the distribution without passing through a large enough „hot“ storage zone.

Evidence:

- Burger 1993 (translated from German): “The conditions in single and double family homes with small water volumes in the drinking water installation and enough water volume in the storage do not give Legionella the possibility to grow. Storage water temperatures between 48 and 60 °C do not lead to growth of Legionella in the storage. Larger dimensioned storages are under these conditions obviously better suited to prevent Legionella growth than too small dimensioned storages.”
- Tiefenbrunner 1993 (translated from German): “A comparison of the average storage volume per person shows that Legionella positive systems have with 50 l/Pers. a lower storage volume than the Legionella negative systems with 68 l/Pers.”
- Stanke 2005: Samples from 203 single and double family homes showed no correlation between storage size and occurrence of Legionella.
- Data from Harmuth 2006 (see Figures below).

[1] Little is known so far about possible risks from the inactivated – but not dead – Legionella, the so called VBNC – states (viable, but not culturable).



Data from Harmuth 2006, split into systems with storage setpoint < 50 °C (left, storage volume correlates with CFU of Legionella found) and storage setpoint ≥ 50 °C (right, storage volume seems to correlate inversely with CFU of Legionella found).

5 Heating up once a day or once a week

It has been shown that heating once a day or once a week to a higher temperature (of 60 or even 70 °C) is increasing the risk for Legionella rather than decreasing it. Such weekly disinfection schemes should therefore be abandoned.

Evidence:

- Rühling et al. 2018 (p. 355, translated from German): "For 6 buildings it is known that they use a preventive weekly temperature raise to 70 °C. From these buildings 3 (50%) are Legionella positive. [...] Does a technical disinfection (preventive thermal disinfection without indication of Legionella contamination, e.g. once a day or once a week) make sense from a hygienic perspective and is it timely from an energetic perspective? – No!"
- Mathys et al., 2008: "[...] raising hot water temperatures to 60 °C only periodically and for very short time intervals seems to favour growth of Legionella and cannot be recommended from the results obtained in this study."

Table 3. Analysis of the influence of intermittent high temperatures, interruptions in circulation and mode of heating on growth of *Legionella* in hot water systems with recirculation in single family residences using analysis of variance (ANOVA); SD = standard deviation, $p<0.05$ means statistically significant at the 95% confidence level

	N	Mean count (CFU *Legionella*/ 100 ml) ± SD	Percentage of *Legionella* positive specimens ± SD	Mean of contamination level (0 = < 1; 1 = 1–99, 2 = 100–999, 3 = 1000–9999, 4 = ⩾10,000 CFU *Legionella*/100 ml) ± SD	Mean of hot water temperature (°C) ± SD
Factor: intermittently raising hot water temperatures >60 °C					
No	284	166 ± 790	13.4 ± 34.1	0.29 ± 0.78	50.4 ± 7.8
Yes	55	1946 ± 13475	16.4 ± 37.3	0.36 ± 0.93	50.1 ± 6.9
p-value		0.03	0.56	0.53	0.84

From Mathys et al. 2008 (single family and double family homes): With a p-value of 0.03, raising the temperature intermittently to > 60 °C has a significant effect on Legionella: it INCREASES the risk.

6 Safety of solar preheating

Solar domestic hot water systems are much safer than ordinary water heaters. Therefore, no additional measures (no “disinfection” heating of pre-heat volumes) are needed to make them safer. It rather seems that other systems need additional measures in order to make them as safe as the solar thermal heated systems.

Evidence:

- Mathys et al. 2008: “Although hot water systems using solar energy to supplement conventional hot water supplies operate at temperatures 3 °C lower than conventional systems, this technique does not seem to promote proliferation of the bacterium.”
- Mouchtouri et al. 2007 (see table).

Study / source	***building type / country***	***time of year***	***without Solar***	***with Solar***
Mathys et al. 2008 (incl. Harmuth 2006)	SFH / DE	Jan. – May	13% (46/352)	5% (2/48)
Mouchtouri et al. 2007	Hotels / GR	Jan. – Sep.	21% (80/385)	10% (8/80)
Totaro 2017	MFH / IT	n.d.	38% (24/64)	35% (12/35)

7 Interruption of hot water recirculation

For single and double family homes, an interruption of the hot water re-circulation at night does not increase the risk of Legionella and therefore should be recommended. This may be different for larger dwellings.

Evidence:

- Mathys et al. 2008 (EFH/DEFH): "Neither interrupting the hot water circulation for some hours at night, nor [...] had a significant effect on Legionella counts."
- Tiefenbrunner 1993 (EFH/DEFH, translated from German): "Systems with uninterrupted circulation or with an interruption with daily timer but operation over most of the day were free from Legionella. Two systems [that were not free of Legionella] operated the pump only once a day for half an hour, other systems [that were not free of Legionella] were operated with natural buoyancy driven re-circulation."

Table 3. Analysis of the influence of intermittent high temperatures, interruptions in circulation and mode of heating on growth of *Legionella* in hot water systems with recirculation in single family residences using analysis of variance (ANOVA); SD = standard deviation, $p < 0.05$ means statistically significant at the 95% confidence level

	N	Mean count (CFU *Legionella*/ 100 ml) ± SD	Percentage of *Legionella* positive specimens ± SD	Mean of contamination level (0 = < 1; 1 = 1–99, 2 = 100–999, 3 = 1000–9999, 4 = ⩾10,000 CFU *Legionella*/100 ml) ± SD	Mean of hot water temperature (°C) ± SD
Factor: interrupting hot water circulation for more than 6 h daily					
No	126	170 ± 611	14.3 ± 35.1	0.32 ± 0.85	48.9 ± 7.1
Yes	246	542 ± 6413	12.1 ± 32.8	0.26 ± 0.75	51.2 ± 7.6
p-value		0.52	0.57	0.65	< 0.05

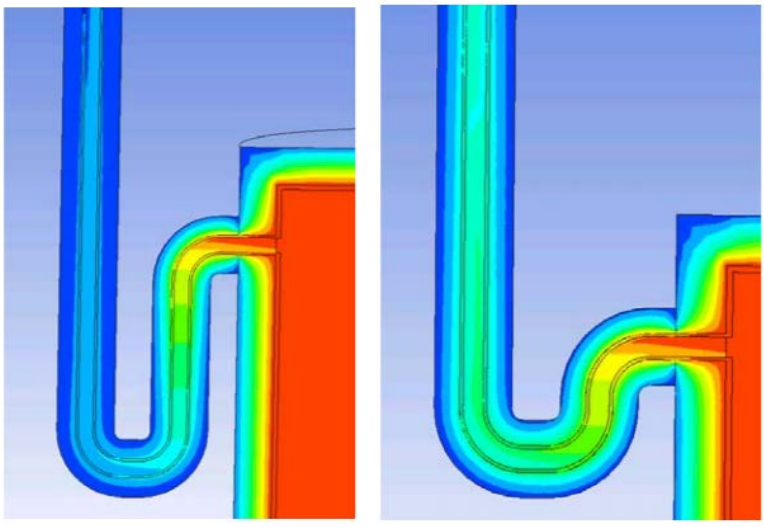
Source: Mathys et al. 2008 (single family and double family homes):With a p-value of 0.52 to 0.65, switching off the hot water circulation for more than 6 hours daily did not have a significant effect on the legionella risk (percentage of positive specimens is slightly higher when the circulation is NOT interrupted, but the difference is statistically not significant).

8 Heat-traps

For hot water distribution lines that are kept warm by re-circulation or by heat ribbons, the re-circulation and the heat-ribbons do not reach the last meters before the tap, where a single pipe is connecting the tap to the circulating system or hot water distribution. If these end-pipes are connected without a heat-trap (i.e. going upward or horizontal from the distribution), in the intervals between the hot-water draw-offs, hot water will raise into them due to buoyancy forces, cool out in these pipes and fall down again within the same pipe. This may lead to undefined temperatures in these last meters and possible large inner surfaces with ideal growth conditions for Legionella. This can be particularly dangerous for pipes that lead to showers that are not used frequently (unoccupied apartments, hotel rooms, guest bathrooms). Heat traps should be used to reduce this problem. For hot water distribution that is not actively kept warm by re-circulation or heat-ribbons, heat traps should be used to separate the "hot" part of the system where temperatures above 50 °C can be guaranteed, from the part of the distribution that is left to cool down after each tapping.

Evidence:

- The analysis above is based on logical deduction and explains the more frequent contamination and larger contamination levels of single-family homes with warm distribution, compared to single-family homes without warm distribution.
- The efficiency of heat traps in reducing heat losses and zones with water at intermediate temperatures between the high temperature of a storage (or pipe) that is maintained hot and the ambient that is at room temperature has been demonstrated by various authors (e.g. Suter 1999; Weber, Brack & Suter 1982-1983; Lauber 2007; Steinweg u.a. 2015; Kliem u.a. 2014; Haller & Battaglia 2017).
- No clear evidence for the role of heat-traps in Legionella growth prevention is available from field studies yet, as heat-traps are mostly not installed and their presence is not reported in field-studies.



Effective (left) and only partially effective (right) heat trap of a storage tank pipe connection. According to Haller & Battaglia (2017).

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