Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Multi-criteria comparison of various drinking water installations for low-temperature supply systems in apartments

To cite this article: Peter Pärisch *et al* 2023 *J. Phys.: Conf. Ser.* **2600** 022022

Multi-criteria comparison of various drinking water installations for low-temperature supply systems in apartments

Peter Pärisch[1*], Mark Distelhoff[1], Jonas Keuler[1], Carsten Lampe[1], Christopher Graf[2] and Anna Cadenbach[2]

[1] Institut für Solarenergieforschung Hameln (ISFH), Am Ohrberg 1, 31860 Emmerthal, Germany
[2] Fraunhofer-Institut für Energiewirtschaft und Energiesystemtechnik (IEE), Joseph-Beuys-Straße 8, 34117 Kassel, Germany

* Corresponding author p.paerisch@isfh.de

Abstract. Rules to prevent from legionnaires disease gain importance as the building sector, esp. multi-family houses, needs to be decarbonized with temperature sensitive heat pumps. As legionella grow often in the peripheries of the pipe networks, we carried out dynamic simulations with TRNSYS of four different piping designs with composite pipes inside a reference apartment (T-piece, in-series, ring and a mix of T-piece for potable hot water (PWH) and ring for potable cold water (PWC)). We applied PWH and PWC tapping profiles for each tap, investigated two different supply temperatures of potable hot water 60 °C and 45 °C, and compared the results using hygienic, comfort and energy efficiency performance indicators. Based on the indicators and the boundary conditions used, classical T-piece and the mix installation show the best results, followed by series and ring, especially when using decentral water heaters with 45 °C.

1. Introduction

The efficiency of renewable heat generators, such as heat pumps or solar thermal, are highly temperature sensitive (e.g. 2-2.5 %/K for heat pumps [1]). In addition to the temperature level of the heating system, the temperature level for drinking water heating and thus drinking water hygiene become the focus of attention as heat losses via the building envelope are progressively reduced.

Bacteria of the genus Legionella occur naturally in drinking water, can multiply to critical levels in domestic drinking water installations, infect mainly elderly men when inhaled, and cause pneumonia, called Legionnaires' disease. Reported case numbers in Germany have increased sharply from roughly 400 to 1,500 over the past 20 years figure 1a), although a high number of unreported cases (about 20,000) is assumed (see [2], [3]). Most cases (about 75 %) are acquired in the private or professional environment (community acquired legionnaires disease = CALD, as distinguished from hospital-acquired and travel-associated) [2]. The lethality is about 5 % [4] and the weekly case numbers show an interesting correlation with cold water network temperatures in the course of the year (cf. figure 1b), which is why the cold water installation is also the main subject of investigations (e.g. [5]) and will be considered in the following paper as well.

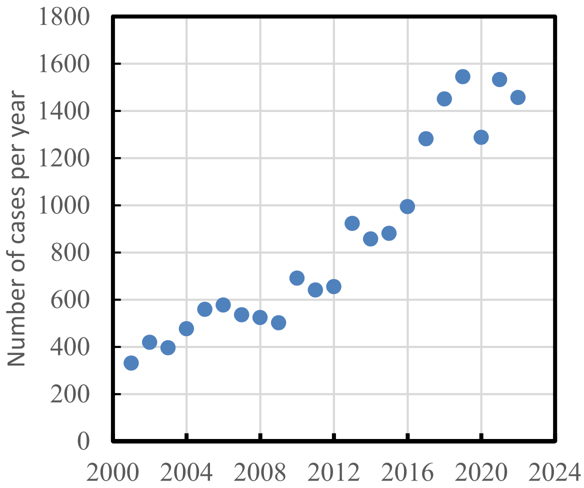


Figure 1. Reported case numbers of Legionnaires' disease in Germany (annual (a) and weekly of the years 2013-2022 (b).

The LeTriWa study concludes that about 63 % of CALD is due to drinking water installations that do not require testing [6]. This and other studies (like [7]) are used to question the exemptions for decentralized water heaters. On the other hand, the increasing numbers of cases and seasonality do not necessarily support the thesis of drinking water installations as the primary source of infection. For Legionella, neither a dose-response relationship nor a minimum infective dose is known (cf. [8]).

This study wants to contribute to a better understanding of the complex interaction of the factors temperature and water exchange and to concretize the rules of engineering, if necessary. For example, there is a conflict between positive and negative effects of higher PWH temperature. Unnecessary anxiety surcharge of PWH temperature decreases flow velocity u, increases stagnation time t and increases temperature ϑ of PWC. Thus it is crucial to find the right balance (cf. figure 2).

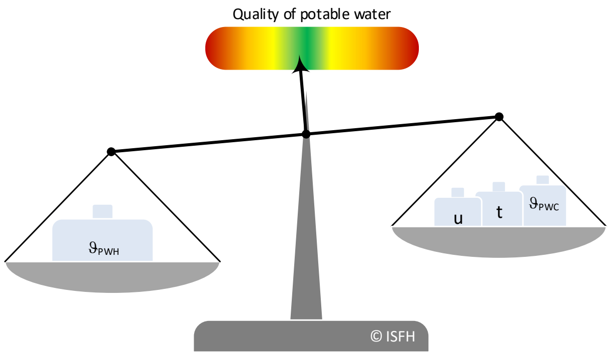


Figure 2. Factors influencing the drinking water quality of drinking water installations and their qualitative relationship.

In general, to improve the water exchange parameter and to reduce the residence time, we recommend instantaneous water heaters (IWH) for PWH. These are used in multi-family houses either centrally with a circulation line or decentrally without a circulation line. While it seems appropriate to lower the PWH temperatures from 60/55 °C towards 55/50 °C for central IWH due to the significantly reduced water volume (cf. [9], [10], and DIN 1988-200), there are no requirements in Germany for decentralized IWH with less than 3 liters to the tap (cf. DIN 1988-200, DVGW W551).

2. Model

Since Legionella predominantly settle in the periphery, we investigate drinking water installations in a reference apartment in this paper. In a TRNSYS simulation study, we looked at the thermal behavior of four different drinking water installations within the apartment and compared them in terms of energy efficiency, hygiene and comfort. All four models have already implemented the connection of the hot taps with PWH from above and PWC from below to reduce the heat exchange between PWH and PWC and to reduce the heating in unused branch lines by pipe internal convection.

The variants considered are the T-piece installation, the looped-through in-series installation, the looped-through ring installation, and a mixture with PWC ring and PWH as T-piece installation.

 2600 (2023) 022022 doi:10.1088/1742-6596/2600/2/022022

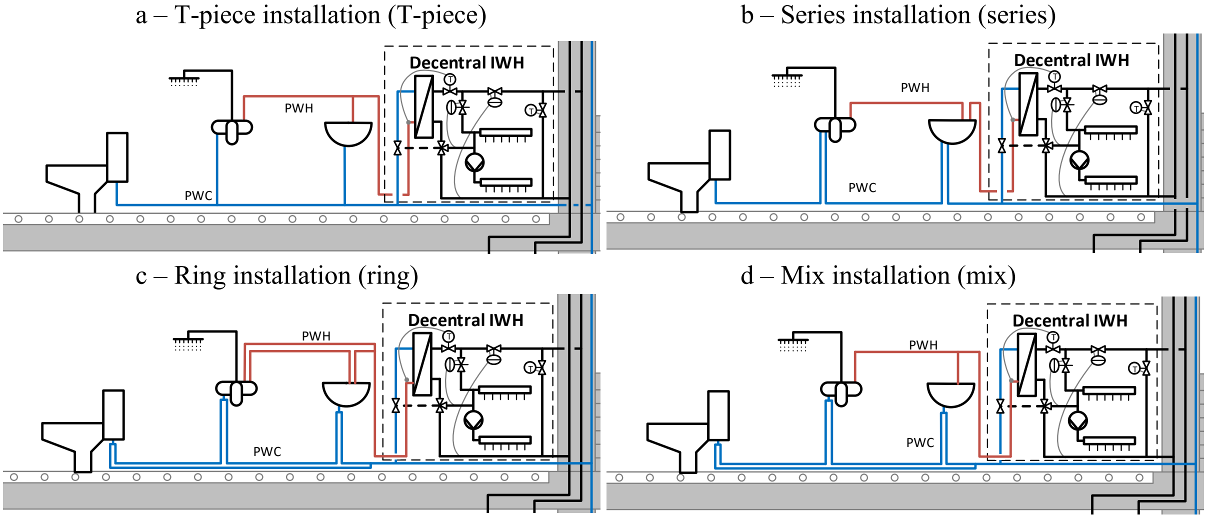
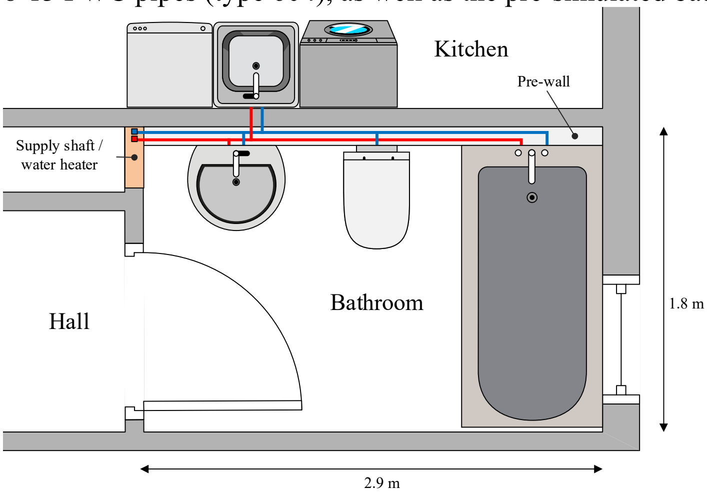


Figure 3. Four different investigated installations (simplified) for potable water.

The arrangement of the taps results from the layout of the bathroom and kitchen. Kitchen sink, washing machine and dishwasher draw at the same point of PWC. The pre-wall installation has been modeled as a thermal capacity with Lump type 963 (heat capacity 0.627 kJ/K, heat transfer coefficient 3.125 W/(m²·K) and surface area 3.864 m²). It is thermally coupled to the 6-10 PWH pipe segments and 8-13 PWC pipes (type 604), as well as the pre-simulated bathroom air temperature (cf. figure 4b).



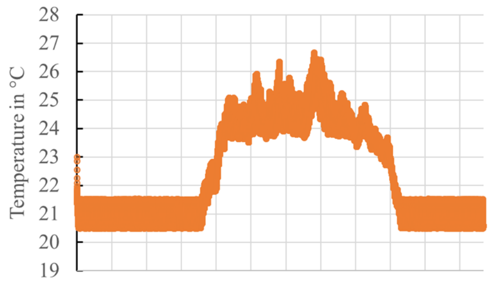


Figure 4. Floor plan of the bathroom with arrangement of the taps in the apartment (a) and the pre-simulated annual variation of the bathroom temperature (b).

The pipe materials, diameters and lengths used are shown in table 1.

Table 1. Applied pipe parameters for the four installations.

	T-piece	Series	Ring	Mix
Pipe material		Composite pipe (polyethylene, aluminium)		
Pipe diameter (inner; outer)	16; 20 mm	16; 20 mm	12; 16 mm	PWH: 16; 20 mm PWC: 12; 16 mm
PWH				
Pipe length; Pipe volume	3.7 m; 0.74 l	4.4 m; 0.9 l	7.6 m; 0.9 l	3.7 m; 0.74 l
PWC				
Pipe length; Pipe volume	5.1 m; 1.0 l	7.1 m; 1.4 l	10.5 m; 1.2 l	10.5 m; 1.2 l

For the ring installation, the volume flows to the taps via two pipes (left and right). As the left and right hydraulic resistances differ for each tap, we pre-calculated the division for each tapping point numerically, neglecting parallel tappings.

Table 2. Pre-calculated volume flow distribution according to Hardy-Cross method for ring installation (kitchen sink incl. dishwasher and washing machine).

Taps	Wash basin	Kitchen sink	Toilet	Shower tray
PWH				
Left	63 %	51 %	-	38 %
Right	37 %	49 %	-	62 %
PWC				
Left	66 %	55 %	45 %	34 %
Right	34 %	45 %	55 %	66 %

For all taps (PWC and PWH), 5 s tap profiles have been generated (cf. [11]), with the tapping profile of a working young couple applied in the apartment under consideration. A central assumption is that only at the shower, there is an extension of the tapping event until the hot water arrives before it is used.

Table 3. Parameters applied and statistics of the seven water consumers and the four draw-off points.

	Wash basin	Kitchen sink	Washing machine	Dish washer	Shower	Bathing	WC
Ø Water demand/tapping	0.7 l	3.0 l	48 l	11 l	48 l	140 l	7.5 l
Ø Water demand l/(P·d)	4.2	7.7	9.2	3.15	32.9	5.8	21
Ø Tappings/(P·d)	6.04	2.55	0.1918	0.2857	0.6857	0.0415	3.0
Water withdrawal l/(P·a)	1822	3330	6720	2300	12418	2170	9173
Desired temperature T_{set}	35 °C	42 °C	-	-	39 °C	42 °C	-
Draw-off points (cf. fig. 4)	1	2 PWH / 2 PWC kitchen incl. sink			3 Shower tray		4 PWC
Average stagnation time	1.69 h	3.91 h /	2.47 h		16.67 h		3.37 h
Median of stagnation time	0.51 h	1.49 h /	0.73 h		12.18 h		1.22 h

In addition to the design of the drinking water installation, the supplied PWH temperature entering the installation is varied between 60 and 45 °C respectively.

3. Key performance indicators (KPI)

The utilization ratio ω_i is calculated for each variation i as ratio of the heat drawn at the taps divided by the heat supplied to the installation. The energy efficiency *EE* is normalized to give values between 0 and 1, which simplifies the comparison of the variations, but may not be interpreted that 0 is no efficiency.

$$EE_i = \left(\omega_i - \min_i \omega_i\right) \cdot \left(1 - \min_i \omega_i\right)^{-1} \tag{1}$$

As criterion for the comfort we summed up the times at each tap k, when the drawn water is colder than the desired temperature T_{set}. The normalized *Comfort* KPI follows from:

$$Comfort_i = \left(\max_i\left(t_{comfort,i}\right) - t_{comfort,i}\right) \cdot \left(\max_i\left(t_{comfort,i}\right) - \min_i\left(t_{comfort,i}\right)\right)^{-1} \tag{2}$$

As KPI for the hygiene we calculated for each variation i the stagnation time ($\dot{V}_j \overset{!}{=} 0$), when the temperature ϑ_j was in the critical range, and summed up, weighted with inner surface area A_j, for all pipes j of PWC and PWH. As reference we chose the inner surface of the T-piece installation, giving a surface weighted stagnation time $t_{hyg,i}$. Hence, installations with large pipe area are disadvantaged (e.g. ring installation has 54 % more surface than T-piece). As critical temperature range we chose 25 °C according to [5] and 50 °C according to [12].

 2600 (2023) 022022 doi:10.1088/1742-6596/2600/2/022022

$$t_{hyg,i} = \sum_j \left(A_j \cdot \sum_{(25 \leq \vartheta_j < 50°C) \wedge \dot{V}_j = 0} \Delta t \right) \cdot A_{T-piece}{}^{-1} \quad (3)$$

The defined KPI does not pursue the goal of modeling the growth of Legionella in drinking water installations, because there are still too many unknowns for this purpose (nutrient supply, interaction of water phase and biofilm, temperature dependence of lag phase). Instead, a qualitative comparison of drinking water installations is carried out, considering the temperature range, stagnation time, type of drinking water installation and the surface of the pipe segments. As a limitation, it should be mentioned that long-term stagnant pipes in warm environments are rated too positively. Based on the frequencies of the stagnation times of the individual pipe segments (without temperature rating), this simplification seems permissible to us. Future studies will make refinements here. The weighted stagnation time is again normalized with the minimum and the maximum value for all variations i, to give values between 0 and 1.

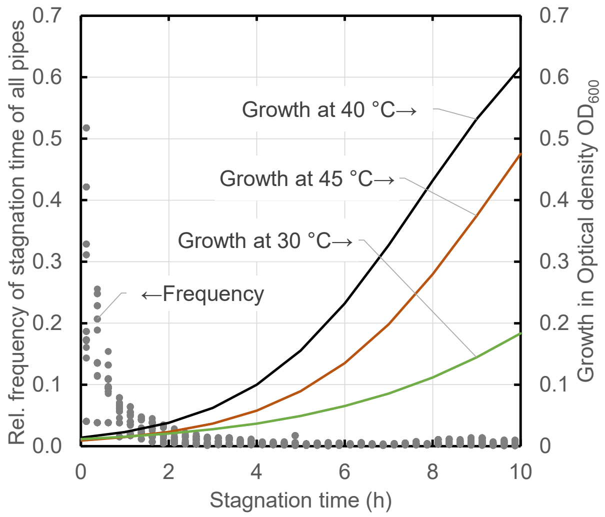


Figure 5. Relative frequency of stagnation times of all pipes for all variations over stagnation time and Legionella concentration on a high-nutrient surface (AYE) at different temperatures acc. to [12].

$$Hygiene_i = \left(\max_i t_{hyg,i} - t_{hyg,i} \right) \cdot \left(\max_i t_{hyg,i} - \min_i t_{hyg,i} \right)^{-1} \quad (4)$$

4. Results

Figure 6 shows the results for the two PWH-temperatures (45 °C, 60 °C) entering the systems.

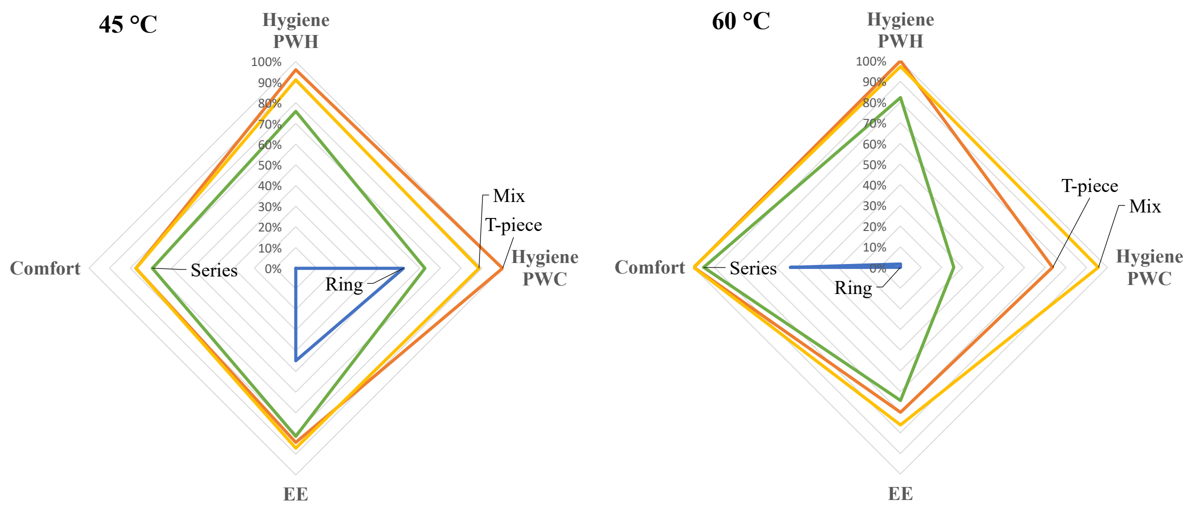


Figure 6. Normalized results of the four installation types for the PWH temperatures 60 °C and 45 °C.

As expected, reducing the temperature from 60 to 45 °C lowers the comfort but increases the energy efficiency. The ring installation shows the lowest results with refer to all considered KPIs, for comfort and PWH hygiene with 45 °C (5495 h) and for energy efficiency and PWC hygiene (571 h) with 60 °C. T-piece installation and mix installation are almost equal at the first place. With respect to PWH hygiene we see the highest ranking for 60 °C with T-piece (2817 h), but the mix installation is close behind (2892 h). Reducing PWH to 45 °C changes the values only slightly (2924 h for T-piece and 3054 h for mix). Frequent hot water flows through many pipes, like at ring and series, is not beneficial for this KPI. For 60 °C, a small part of the stagnation time is above the critical range and, thus, the KPI a little better. Regarding PWC, the ranking changes from mix, T-piece, series, ring at 60 °C to T-piece, mix, series, ring at 45 °C and there is even an improvement with 45 °C (down to 298 h for T-piece). Unlike PWH, frequent flow is advantageous here (mix), but the water change in the ring installation is less due to larger volumes and a shift to PWH due to lower PWH temperatures at the tap.

5. Discussion and Outlook

The results are valid for the specific model under the applied boundary conditions and the assumptions made for the KPIs, especially the KPI for the hygiene. Different boundary conditions, tapping profiles, location of the taps, and a more detailed modelling of legionella growth will change the results. Although the reliability of the defined KPIs can still be enhanced, the integration of hygiene-relevant parameters into the consideration of transient simulations enables the preliminary identification of potential risks and deficiencies within a system through simulation, subsequently allowing for experimental validation.

Acknowledgments

The project "Trans2NT-TWW" is funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK) under the contract 03EN1027, and supported by the State of Lower Saxony. Furthermore, we would like to thank our partners IWW, Solvis, DME Consult, Taconova, and Uponor Kamo for their cooperation and their financial support. The authors are responsible for the content.

References

[1] Pärisch P, Mercker O, Warmuth J, Tepe R, Bertram E, Rockendorf G. Investigations and model validation of a ground-coupled heat pump for the combination with solar collectors. Appl Therm Eng 2014;62:375–81. https://doi.org/10.1016/j.applthermaleng.2013.09.016.

[2] Brodhun B, Buchholz U. Epidemiologie der Legionärskrankheit in Deutschland – Entwicklungen in den Jahren 2010 bis 2020. Epidemiol Bull 2021;2021:3–17. https://doi.org/10.25646/9144.

[3] von Baum H, Ewig S, Marre R, Suttorp N, Gonschior S, Welte T, et al. Community-Acquired Legionella Pneumonia: New Insights from the German Competence Network for Community Acquired Pneumonia. Clin Infect Dis 2008;46:1356–64. https://doi.org/10.1086/586741.

[4] Buchholz U, Lehfeld A-S, Brodhun B, Jahn HJ, Reber F, Lewandowsky MM, et al. Einfluss der häuslichen Trinkwasser-Installation auf das Risiko, an Legionärskrankheit zu erkranken - Ergebnisse aus der Berliner LeTriWa-Studie und den bundesweiten Meldedaten. Epidemiol Bull 2022;2022. https://doi.org/10.25646/10428.

[5] Korth A, Petzoldt H. DVGW-Forschungsvorhaben untersucht Vermehrung von Legionellen im Kaltwasser. Energ Wasser-Prax 2020;2020:34–40.

[6] Lehfeld A-S, Buchholz U, Jahn HJ, Brodhun B, Lewandowsky MM, Reber F, et al. Infektionsquellensuche bei ambulant erworbenen Fällen von Legionärskrankheit – Ergebnisse der LeTriWa-Studie; Berlin, 2016–2020, Teil 2 Ergebnisse und Diskussion. Epidemiol Bull 2022;2022:3–16. https://doi.org/10.25646/10267.

[7] Hippelein M, Christiansen B. Hygienische Bewertung dezentraler Trinkwassererwärmer großer Appartementanlagen hinsichtlich mikrobiologischer Verunreinigungen und einer Legionellenkontamination. Kiel, Germany: Universitätsklinikum Schleswig-Holstein; 2016.

[8] Meyer E. Legionellen-Infektionsprävention: extrem teuer und wenig effektiv. Krankenhaushygiene Up2date 2017;12:159–75. https://doi.org/10.1055/s-0043-104568.

[9] Rühling K, Haupt L, Hoppe S, Löser J, Rothmann R, Lück C, et al. Kurzüberblick und Thesen zum EnEff: Wärme Verbundvorhaben: Energieeffizienz und Hygiene in der Trinkwasser-Installation. Dresden, Germany: TU Dresden, Universität Bonn, IWW, Fraunhofer IEE; 2018.

[10] Haller M. Die neue SIA 385/1 zu Trinkwarmwasser in Gebäuden. Hk Gebäudetech 2021;2021:52–6.

[11] Distelhoff M, Pärisch P, Lampe C. Methodology for the development of temporally high-resolved and spatially accurate tapping profiles. CLIMA 2022 Conf 2022. https://doi.org/10.34641/clima.2022.229.

[12] Hochstrasser R, Hilbi H. The *Legionella* Lqs-LvbR Regulatory Network Controls Temperature-Dependent Growth Onset and Bacterial Cell Density. Appl Environ Microbiol 2022;88:e02370-21. https://doi.org/10.1128/aem.02370-21.