

# Synthesis Report

## LeCo: *Legionella* Control in Buildings





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## Summary

This report is a synthesis of legionella-related topics that are relevant and overarching to various sections of the LeCo project. **CHAPTER 1** considers the topic of *Legionella* species diversity in environmental samples relative to clinical cases. We conclude that although diverse *Legionella* species are found in Swiss drinking water samples, only *L. pneumophila* is responsible for the vast majority of Legionnaires' disease cases, questioning current guidelines that are focussed on *Legionella* spp. We thus recommend: (1) that guidelines for monitoring and management are developed separately for buildings with low-risk users and those with high-risk users, and (2) that legislation is adapted to focus on only *L. pneumophila* for routine monitoring for low-risk user buildings, while high-risk user buildings continue to target *Legionella* spp.. **CHAPTER 2** focuses specifically on risk assessment of showers. We conclude that showers which are contaminated with *L. pneumophila* pose a substantial infection risk, and warmer shower water exacerbates this risk due primarily to increased droplet formation. We elaborate on two recommendations, namely (1) the need for raising public awareness of Legionnaires' disease infection risks from showers and associated mitigation strategies to reduce risks, and (2) better optimizing existing resources focused on reducing risks from showers, particularly where high-risk users are involved. **CHAPTER 3** explores the challenge of linking clinical cases to environmental sources of *Legionella* spp. We conclude that the recovery of both clinical and environmental *Legionella* spp. isolates is a bottleneck for infection source attribution. We further conclude that while showers can be a source of infection for Legionnaires' disease, our data suggest that showers are unlikely to be the primary source of infection in Switzerland. We recommend that (1) more guidelines on environmental source investigations are needed, (2) that a number of steps be taken to ensure more harmonization, and thus more efficient resource allocation, when investigating environmental sources of *Legionella* infections. **CHAPTER 4** examines pragmatic improvements in building plumbing design and operation, which would lower the risk of *Legionella* contamination and growth. We conclude that many of the problems observed in buildings stem from non-compliance of existing guidelines, and also that there is some, albeit limited, possibilities in optimising water temperatures in buildings to save energy while remaining hygienically safe. We recommend (1) improvements to design and operation of hot water storage systems as well as the final meters of distribution, (2) focussing on the temperature in the circulation system (rather than the boiler per se), with 55 °C as a generally considered safe temperature, and (3) increased continuing education and awareness training for all stakeholders. **OVERALL**, we emphasize the need for inter-disciplinary research collaboration, and transdisciplinary interactions between researchers, industry, and government to ultimately reduce *Legionella* infections in Switzerland.

## Zusammenfassung

Der vorliegende Bericht ist eine Zusammenfassung von Themen im Zusammenhang mit Legionellen, die für das LeCo-Projekt wichtig und von übergreifendem Interesse sind. **KAPITEL 1** befasst sich mit der Artenvielfalt von *Legionellen* in Umweltproben im Vergleich zu klinischen Fällen. Wir haben festgestellt, dass in Schweizer Trinkwasserproben zwar verschiedene *Legionellen*-Arten nachgewiesen werden, jedoch nur *L. pneumophila* für die überwiegende Zahl der Fälle der Legionärskrankheit verantwortlich ist, was die geltenden Richtlinien, die auf *Legionella* spp. fokussieren, in Frage stellt. Es wird daher empfohlen, dass (1) unterschiedliche Richtlinien für die Überwachung und das Management von Gebäuden mit Nutzenden mit geringem und mit erhöhtem Erkrankungsrisiko definiert werden und (2) dass die Gesetzgebung dahingehend angepasst wird, damit sich die Routineüberwachung von Gebäuden mit Nutzenden mit geringem Erkrankungsrisiko nur auf *L. pneumophila* fokussiert, während die Routineüberwachung für Gebäude mit Nutzenden mit erhöhtem Erkrankungsrisiko weiterhin auf *Legionella* spp. abzielt. **KAPITEL 2** konzentriert sich speziell auf die Risikobewertung von Duschen. Wir haben festgestellt, dass Duschen, die mit *L. pneumophila* kontaminiert sind, ein erhebliches Infektionsrisiko darstellen, und dass wärmeres Duschwasser dieses Risiko vor allem aufgrund der erhöhten Tröpfchenbildung noch verstärkt. Im Folgenden werden zwei Empfehlungen näher ausgeführt: (1) dass die Bevölkerung für die Infektionsrisiken durch Legionellen in Duschen und die damit verbundenen Strategien zur Risikominderung sensibilisiert werden soll und (2) dass bestehende Ressourcen zur Risikoverringerung bei Duschen optimiert werden sollen, insbesondere dort, wo Nutzende mit erhöhtem Erkrankungsrisiko betroffen sind. **KAPITEL 3** befasst sich mit der Herausforderung, klinische Fälle und Umweltquellen von *Legionella* spp. miteinander in Verbindung zu bringen. Wir haben festgestellt, dass die Gewinnung von klinischen Isolaten von *Legionella* spp. und solchen aus der Umwelt sich für die Zuordnung von Infektionsquellen als sehr schwierig erweisen. Wir kamen zum Schluss, dass Duschen zwar eine Infektionsquelle der Legionärskrankheit sein können, unsere Daten jedoch darauf hindeuten, dass in der Schweiz Duschen nicht die primäre Infektionsquelle sind. Wir empfehlen (1) mehr Richtlinien für Untersuchungen von Umweltquellen sowie (2) verschiedene Massnahmen, um eine bessere Harmonisierung und somit eine effizientere Ressourcenverwendung für die Untersuchung von Umweltquellen für Legionelleninfektionen sicherzustellen. **KAPITEL 4** prüft pragmatische Verbesserungen bei der Planung und dem Betrieb von Gebäudetrinkwasserinstallationen, die das Risiko von Legionellenkontamination und -wachstum senken. Wir haben festgestellt, dass viele der in Gebäuden beobachteten Probleme auf die Nichteinhaltung bestehender Richtlinien zurückzuführen sind und dass es einige, wenn auch begrenzte Möglichkeiten gibt, die Wassertemperaturen in Gebäuden zu optimieren, um Energie zu sparen und gleichzeitig die Hygiene zu gewährleisten. Wir empfehlen (1) Verbesserungen bei der Planung und dem Betrieb von Warmwasserspeichersystemen und der Endverteiler, (2) die Konzentration auf die Temperatur im Zirkulationssystem (anstatt im Boiler selbst), wobei 55 °C allgemein als sichere Temperatur gilt, und (3) mehr Weiterbildungs- und Sensibilisierungsarbeit für alle Stakeholder. **ZUSAMMENFASSEND** betonen wir, dass es eine interdisziplinäre Forschungszusammenarbeit und transdisziplinäre Interaktionen zwischen Forschenden, Industrie und Regierung braucht, um letztlich die Zahl der Legionelleninfektionen in der Schweiz zu senken.

## Résumé

Ce rapport consiste en une synthèse des sujets pertinents liés aux légionelles se rapportant à plusieurs volets du projet LeCo. Le **CHAPITRE 1** aborde la diversité des espèces de *Legionella* dans les échantillons environnementaux en lien avec des cas cliniques. Le projet conclut que, malgré la présence de diverses espèces de *Legionella* dans les échantillons d'eau potable en Suisse, la grande majorité des cas de légionellose est uniquement due à *L. pneumophila*. Ce résultat remet en question les recommandations actuelles axées sur *Legionella* spp. Nous formulons donc les recommandations suivantes : (1) la surveillance et la gestion doivent faire l'objet de directives distinctes en fonction du niveau de risque (faible ou élevé) des utilisateurs hébergés dans les bâtiments ; (2) la législation doit être adaptée afin de se concentrer uniquement sur *L. pneumophila* pour la surveillance de routine des bâtiments abritant des utilisateurs à faible risque, tandis que *Legionella* spp. est ciblée pour la surveillance des bâtiments accueillant des utilisateurs à haut risque. Le **CHAPITRE 2** porte spécifiquement sur l'évaluation des risques concernant les installations de douches. Nous sommes arrivés à la conclusion que ces installations présentent un risque élevé d'infection lorsqu'elles sont contaminées par *L. pneumophila* et que ce risque augmente avec la température de l'eau, principalement en raison de l'augmentation de la formation de gouttelettes. Nous avons élaboré les deux recommandations suivantes : (1) renforcer la sensibilisation du public face aux risques d'infection par la maladie du légionnaire en lien avec les installations de douches et développer des stratégies de réduction des risques ; (2) optimiser les ressources existantes visant à réduire les risques liés à ces installations, en particulier lorsque des utilisateurs à haut risque sont concernés. Le **CHAPITRE 3** porte sur la difficulté d'établir un lien entre les cas cliniques et les sources environnementales de *Legionella* spp. Nous arrivons à la conclusion que la collecte d'isolats cliniques et environnementaux de *Legionella* spp. complique l'attribution de la source d'infection et que, bien que les installations de douches puissent constituer une source d'infection par la maladie du légionnaire, nos données suggèrent que les douches ne sont probablement pas la source principale d'infection en Suisse. Par conséquent, nous recommandons : (1) élaborer de nouvelles directives sur les investigations relatives aux sources environnementales et (2) prendre des dispositions supplémentaires pour garantir une harmonisation, et donc une allocation plus efficace des ressources, lors des enquêtes sur les sources environnementales d'infection par *Legionella*. Le **CHAPITRE 4** propose des solutions pragmatiques visant à améliorer la conception et l'exploitation des installations sanitaires des bâtiments afin de réduire les risques de contamination et de prolifération des légionelles. Nous concluons que de nombreux problèmes observés dans les bâtiments étaient liés au fait que les recommandations existantes n'étaient pas respectées et qu'il existait des possibilités, bien que limitées, d'optimiser les températures de l'eau dans les bâtiments afin d'économiser de l'énergie tout en maintenant un niveau d'hygiène sûr. Nos recommandations sont donc les suivantes : (1) améliorer la conception et l'exploitation des systèmes de stockage de l'eau chaude et des derniers tronçons des conduites de distribution, (2) se concentrer sur la température du système de circulation (plutôt que celle du chauffe-eau lui-même), en considérant 55 °C comme une température généralement sûre, et (3) renforcer la formation continue et la sensibilisation de l'ensemble des parties prenantes. **DE MANIÈRE GÉNÉRALE**, nous soulignons la nécessité de favoriser la collaboration interdisciplinaire en matière de recherche et d'encourager les interactions transdisciplinaires entre chercheurs, industriels et autorités publiques dans l'optique de réduire à terme les infections dues à *Legionella* en Suisse.

## Sintesi

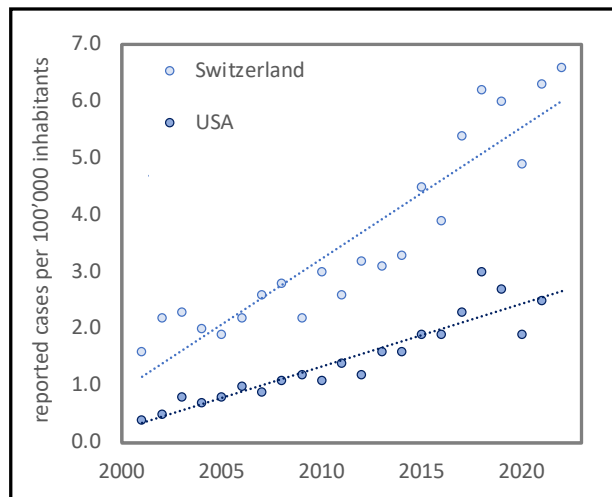
Questo rapporto costituisce una sintesi dei principali argomenti relativi alla *Legionella*, rilevanti e comuni alle diverse componenti del progetto LeCo. Il **CAPITOLO 1** affronta il tema della varietà delle specie di *Legionella* nei campioni ambientali in relazione ai casi clinici. Concludiamo che, sebbene nei campioni di acqua potabile svizzeri siano presenti diverse specie di *Legionella*, *L. pneumophila* è da sola responsabile della maggior parte dei casi di legionellosi, mettendo in discussione le attuali linee guida che si concentrano sulla *Legionella* spp. Raccomandiamo quindi: (1) di sviluppare linee guida separate per il monitoraggio e la gestione degli edifici con utenti a basso rischio e quelli con utenti ad alto rischio, e (2) di adattare la legislazione in modo da concentrarsi solo sulla *L. pneumophila* per il monitoraggio di routine degli edifici con utenti a basso rischio, mentre per gli edifici con utenti ad alto rischio è possibile continuare a concentrarsi sulla *Legionella* spp. Il **CAPITOLO 2** approfondisce nello specifico la valutazione del rischio delle docce. Concludiamo che le docce contaminate da *L. pneumophila* rappresentano un rischio di infezione sostanziale e che l'acqua più calda della doccia aggrava questo rischio, principalmente a causa dell'aumento della formazione di aerosol. Elaboriamo due raccomandazioni: (1) la necessità di sensibilizzare l'opinione pubblica sui rischi di infezione da legionellosi associati all'uso delle docce e sulle strategie di mitigazione associate per ridurli, e (2) una migliore ottimizzazione delle risorse esistenti, focalizzata sulla riduzione dei rischi legati alle docce, in particolare quando sono coinvolti utenti ad alto rischio. Il **CAPITOLO 3** esplora la sfida di collegare i casi clinici alle fonti ambientali di *Legionella* spp. In questo contesto, concludiamo che il recupero di isolati clinici e ambientali di *Legionella* spp. rappresenta un ostacolo significativo per la determinazione della fonte di infezione. Concludiamo inoltre che, sebbene le docce possano costituire una potenziale fonte di infezione per la legionellosi, i nostri dati suggeriscono che è improbabile che esse rappresentino la fonte primaria in Svizzera. Raccomandiamo pertanto (1) lo sviluppo di ulteriori linee guida per le indagini sulle fonti ambientali e (2) l'adozione di una serie di misure per garantire una maggiore armonizzazione e, quindi, un'allocazione più efficiente delle risorse per le indagini che riguardano le fonti ambientali delle infezioni da *Legionella*. Il **CAPITOLO 4** esamina i miglioramenti pragmatici nella progettazione e nel funzionamento degli impianti idraulici degli edifici che potrebbero ridurre il rischio di contaminazione e proliferazione della *Legionella*. Concludiamo che molti dei problemi osservati negli edifici derivano dal mancato rispetto delle linee guida esistenti e che vi sono alcune possibilità, sebbene limitate, di ottimizzare la temperatura dell'acqua negli edifici al fine di risparmiare energia, mantenendo al contempo la sicurezza igienica. Raccomandiamo (1) di migliorare la progettazione e il funzionamento dei sistemi di accumulo dell'acqua calda e dei punti terminali di distribuzione, (2) di concentrarsi sulla temperatura nel sistema di circolazione — piuttosto che sulla caldaia in sé — considerando 55 °C come una temperatura generalmente sicura, e (3) di rafforzare la formazione continua e la sensibilizzazione di tutte le parti interessate. In generale, sottolineiamo la necessità di una collaborazione interdisciplinare nella ricerca e di interazioni transdisciplinari tra ricercatori, industria e governo al fine di ridurre in modo duraturo le infezioni da *Legionella* in Svizzera.

## Introduction

*Legionella* are opportunistic pathogenic bacteria that inhabit natural and engineered aquatic environments, including building plumbing systems. They survive in biofilms and multiply predominantly inside various protist hosts. Upon inhalation of *Legionella*-containing aerosols, pathogenic *Legionella* species can cause legionellosis, typically manifesting as Legionnaires' disease (a severe form of pneumonia) or milder, flu-like Pontiac fever, while other clinical manifestations have also been recorded. Legionnaires' disease is notifiable to health authorities in many high-income countries. Notification rates for the disease have been increasing worldwide during the last two decades; particularly in Switzerland, where there are currently between 6 - 7 notified cases per 100'000 inhabitants (FIGURE 0.1). Both the reported cases proportional to the Swiss population and the rate at which it increases are higher in Switzerland than most other European and North American countries.

To address these concerning trends, three federal offices (Federal Food Safety and Veterinary Office (FSVO); Federal Office of Public Health (FOPH); Swiss Federal Office of Energy (SFOE)) initiated the LeCo (*Legionella* Control in Buildings) project in 2020, focussing on a broad range of fundamental and applied *Legionella*-relevant topics. The project duration was five years and was carried out by a diverse research consortium comprising teams from the Swiss Federal Institute of Aquatic Research (Eawag), the University of Applied Sciences of Luzern (HSLU), the Swiss Tropical and Public Health Institute (Swiss TPH), and the Cantonal Laboratory of Zürich (KLZH). The composition of the consortium reflects the transdisciplinary expertise required to approach the challenge of *Legionella* control in buildings.

The project was focused on building plumbing systems developed around eight thematic questions posed by the federal offices during the initial project call. These included topics dealing with risk assessment, sampling and analysis strategies, epidemiology, building technology related aspects such as temperature and stagnation, energy saving, disinfection and *Legionella* ecology. During the course of the project, research findings have been shared in reports to the federal offices, publications in local trade magazines, and multiple international peer-reviewed publications. The present report is a synthesis of key questions and findings that the project researchers and federal offices identified as relevant and overarching to the various subsections of the overall research project. It is divided into four main topics, and each topic is addressed considering both the latest peer-reviewed literature as well as specific LeCo project results. CHAPTER 1 considers the topic of *Legionella* species diversity in environmental samples relative to clinical cases, and how that impacts guidelines for monitoring and optimal resource allocation when dealing with contaminated buildings. CHAPTER 2 focuses on risk assessment of showers, and how that affects sampling strategies. CHAPTER 3 explores the challenge of linking clinical cases to the vast number of potential environmental sources, and discussing also the use of whole genome sequencing in this endeavour. Finally, CHAPTER 4 examines pragmatic improvements in building plumbing design and operation, which would lower the risk of *Legionella* contamination and growth. Additional project results and recommendations are presented in the final project report, as well as in the various LeCo project publications (provided at the end of this synthesis report).



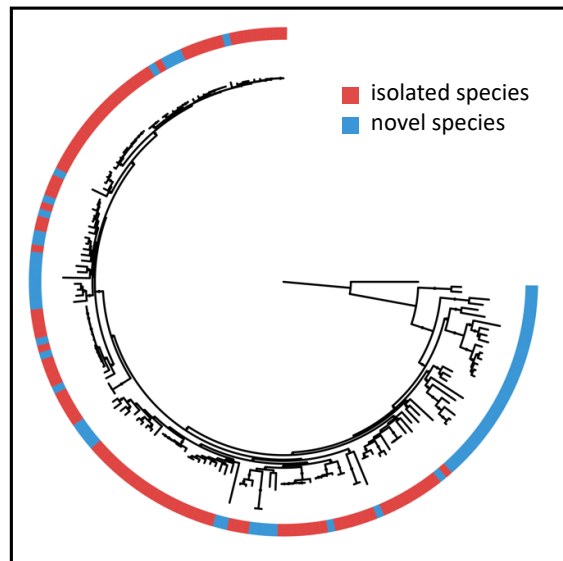
**FIGURE 0.1:** Legionnaires' disease notification rates in Switzerland compared to the USA (2000 – 2022). Data: [www.cdc.gov](http://www.cdc.gov), [www.bag.admin.ch](http://www.bag.admin.ch).

## 1.

Clinical relevance and environmental prevalence of various *Legionella* spp. relative to *L. pneumophila*

## 1.1 Background

The genus *Legionella* is large and diverse: current literature describes 77 species/subspecies, of which 74 are recognized with International Code of Nomenclature of Prokaryotes status (an updated species list is maintained at: [github.com/mgabriell1/LegioSpecies](https://github.com/mgabriell1/LegioSpecies)). Moreover, pangenome analysis suggests as many as 120-130 putative *Legionella* species (Gabrielli et al., 2024). Of the 77 described species, 40 species have been associated with clinical samples at least once. Current European and Swiss drinking-water regulations include all cultivable *Legionella* species (DWBSO 2024; [EU Directive 2020/2184](#)). However, from the 40 *Legionella* species with documented clinical association, only a few species contribute to the majority of Legionnaires' disease cases. Here, *L. pneumophila* is widely recognized as the most common cause of Legionnaires' disease, with > 90 % of global cases attributed to this species (Chambers et al., 2021; Chauhan and Shames, 2021). Hence, regulating (and controlling for) all *Legionella* species (as opposed to only the most clinically relevant species) potentially over-estimates the population risk, and subsequently over-burdens responsible agencies and building owners/operators. Consequently, there has been efforts elsewhere, most notably in The Netherlands and France to (at least partially) focus legislation and management efforts on *L. pneumophila* specifically (Hartemann, 2019; van der Wielen et al., 2021). Here, we assess the current data on *Legionella* species in terms of their environmental prevalence and their clinical relevance, and we discuss whether more defined and targeted legislation would be a sensible approach for Switzerland in the future.



**FIGURE 1.1:** Pangenome analysis reveals a large number of putative species in the *Legionellaceae* family. Data adapted from Gabrielli et al. (2024).

## 1.2 Literature review

**Clinically relevant species:** Only a small number of *Legionella* species are considered clinically relevant with respect to Legionnaires' disease. This was documented in a number of regional and global studies, summarised in TABLE 1.1. In Europe, the vast majority of isolates associated with cases were *L. pneumophila* (95 – 99 %), with the remaining 1 - 5 % attributed to *L. anisa*, *L. bozemanii*, *L. dumofii*, *L. erathra*, *L. gormanii*, *L. longbeachae*, *L. micdadei*, *L. maceachernii*, *L. rubrilucens*, *L. tuarinensis*, *L. tucsonensis*, *L. wadsworthii*. Of these, *L. bozemanii*, *L. longbeachae* and *L. micdadei* seem to be the most important species. There are two ways in which this data can be interpreted. On the one hand, it presents a clear argument to focus on *L. pneumophila* when assessing the risk to the public, particularly if resources are limited. On the other hand, the data also identifies a relatively small number of other *relevant* species, which potentially argues that more attention should be given to the risk posed by these (Salinas et al., 2021). One challenge in estimating this risk, however, is that we do not know the relative infectivity of different *Legionella* species. Current information on the infectivity of *Legionella* spp. is limited to animal dose-response models that are only available for strains of *L. pneumophila* (Armstrong and Haas, 2007). Non-*pneumophila* species may be characterized by lower infectivity, and therefore pose lower risk, as suggested by the discrepancy between their clinical relevance and their environmental prevalence (discussed below).

**TABLE 1.1: Summary of five studies assessing *Legionella* species isolated from clinical cases**

	Doleans et al. (2004)	Svarrer et al. (2012)	Joseph & Ricketts (2010)	Beauté et al. (2020)	Yu et al. (2002)
<b>Location</b>	France	Denmark	EU	EU	Global
<b>Timespan</b>	2001-2002	1993-2010	2007-2008	2008-2017	2002
<b>Nr of cultures</b>	259	735		4884	508
<b><i>L. pneumophila</i> (%)</b>	98.8 %	95.5 %	94.6 %	97 %	91.5 %
<b>Non-<i>pneumophila</i> (%)</b>	1.2 %	4.5 %	5.4 %	3 %	8.5 %
<b>Non-<i>pneumophila</i> spp</b>	<i>L. anisa</i> <i>L. taurinensis</i> <i>L. tucsonensis</i> <i>L. erythra</i> <i>L. rubrilucens</i>	<i>L. bozemanii</i> <i>L. dumoffii</i> <i>L. longbeachae</i> <i>L. micdadei</i>	<i>L. anisa</i> <i>L. bozemanii</i> <i>L. dumoffii</i> <i>L. gormanii</i> <i>L. longbeachae</i> <i>L. maceachernii</i> <i>L. wadsworthii</i>	<i>L. anisa</i> <i>L. bozemanii</i> <i>L. dumoffii</i> <i>L. longbeachae</i> <i>L. micdadei</i> <i>L. feeleii</i> <i>L. sainthelensii</i>	<i>L. anisa</i> <i>L. bozemanii</i> <i>L. dumoffii</i> <i>L. longbeachae</i> <i>L. micdadei</i> <i>L. feeleii</i> <i>L. wadsworthii</i>

**Potential data bias:** Several factors may bias the data and thus highlight the relative importance of *L. pneumophila* over other species. Many hospitals diagnose clinical cases with urine antigen testing, which specifically detects *L. pneumophila* infections and not non-*pneumophila* infections. Hence, non-*pneumophila* infections may simply be under-represented in the clinical data. Cultivation methods used to obtain isolates are also biased towards *L. pneumophila* (Lee et al., 1993), or may simply miss species co-occurring in the same sample as more abundant ones. Most of the case data above is linked to Legionnaires' disease cases; Pontiac fever is severely under-diagnosed, and it is impossible to infer from current data if different *Legionella* species are the causative agents thereof (Edelstein and Roy, 2015).

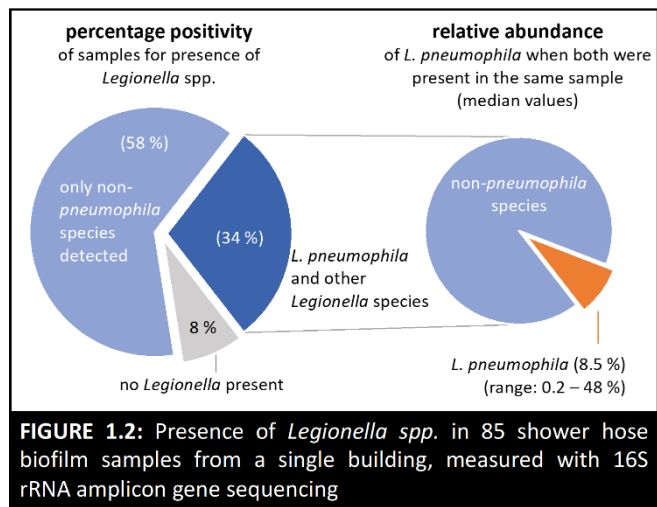
**Immuno-compromised/suppressed people:** The dominance of *L. pneumophila* in clinical cases of Legionnaires' disease is less pronounced when immunocompromised people are specifically considered as a sub-group. Muder and Yu (2002) concluded that "the majority of confirmed infections involving non-*pneumophila* *Legionella* species have occurred in immunosuppressed patients." In one study, the percentage of non-*pneumophila* infections increased to 14 % (dominated by *L. bozemanii*, *L. anisa*, *L. lyticum*) in immunosuppressed patients. This finding supports the hypothesis that non-*pneumophila* species have lower infectivity than *L. pneumophila*. Hence, even more stringent legislation/guidelines may be needed for high-risk environments serving immunocompromised/suppressed people (e.g., hospitals, care facilities, old-age homes etc.).

**Environmental prevalence:** Clinical relevance is argumentatively not the only factor to consider from a legislative/monitoring perspective. The paper from Doleans et al. (2004) captures the essence of the problem: whereas *L. pneumophila* was present in 98.8 % of clinical isolates, it was only found in 75.5 % of environmental isolates. In contrast, *L. anisa* had an extremely low clinical relevance (0.8 % of cases) but was present in 13.8 % of environmental isolates. In a study of c.a. 13'000 warm water installations in southern Germany, Dilger et al. (2018) found *L. pneumophila* the dominant isolate (82 % of all *Legionella* isolates), followed by *L. anisa* (15 %) and 13 other species (3 %). These authors did note clear regional differences in the dominance of certain species. In stark contrast to this, a Dutch study of 6'000 water samples from 200 buildings identified only 3 % of *Legionella*-positive isolates as *L. pneumophila*, with *L. anisa* the dominant species recovered (van der Lugt et al., 2019). This is despite the fact that the vast majority of Legionnaires' disease cases in the Netherlands are caused by *L. pneumophila*. Finally, Salinas et al. (2021) analysed 1750 water samples from environmental sources and obtained *Legionella* isolates from 277 of these samples. *L. pneumophila* was identified as the most prevalent isolate (76 %), while the non-*pneumophila* isolates were identified as: *L. jordanis* (67.5 %), *L. anisa* (22.5 %), *L. taurinensis* (5 %), and *L. donalsonii* (5 %) (expressed as percentage of samples isolated from). Widespread detection of non-*pneumophila* strains in environmental samples is not aligned with the substantially more infrequent detection in clinical cases.

### 1.3 LeCo project results

LeCo project data comprise predominantly environmental samples and are primarily characterized by cultivation-independent analysis methods.

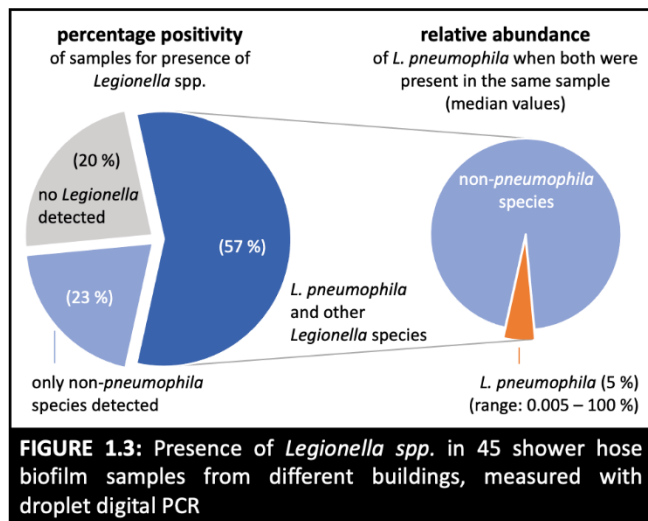
**Shower hose Study-A (biofilm):** The first LeCo study from Cavallaro et al. (2023) assessed 85 shower hose biofilms from a single building with *Legionella* spp. contamination history. Importantly, this study had no known connection to Legionnaire’s disease cases, and all analyses were cultivation-independent. Three important findings are relevant to the current synthesis: First, a total of 92 % of all samples contained gene copies for *Legionella* spp., but only 34 % of these samples also contained *Legionella pneumophila* (ddPCR quantification). When *L. pneumophila* was detected, the median abundance of *L. pneumophila* relative to *Legionella* spp. was 8.5 % (range: 0.2 – 47.6%), indicating a generally low but variable environmental prevalence relative to other *Legionella* species (FIGURE 1.2). Secondly, the analysis showed a broad diversity of *Legionella* species in nearly all of the samples. The study identified 30 unique sequence variants with an average of nine sequence variants per sample. Thirdly, this latter finding showed that multiple *Legionella* species co-occurred in the same biofilm samples. The high diversity and co-occurrence findings led directly to the study of the *Legionella* pangenome (FIGURE 1.1.; Gabrielli et al. (2024)). Based on current databases, we were able to identify the following non-*pneumophila* species in these samples: *L. dumoffii*, *L. bozemanii*, *L. saoudiensis*, *L. drancourtii*, *L. quinlivanii*, *L. nautarum*, but several sequence variants remained unidentified.



**FIGURE 1.2:** Presence of *Legionella* spp. in 85 shower hose biofilm samples from a single building, measured with 16S rRNA amplicon gene sequencing

When *L. pneumophila* was detected, the median abundance of *L. pneumophila* relative to *Legionella* spp. was 8.5 % (range: 0.2 – 47.6%), indicating a generally low but variable environmental prevalence relative to other *Legionella* species (FIGURE 1.2). Secondly, the analysis showed a broad diversity of *Legionella* species in nearly all of the samples. The study identified 30 unique sequence variants with an average of nine sequence variants per sample. Thirdly, this latter finding showed that multiple *Legionella* species co-occurred in the same biofilm samples. The high diversity and co-occurrence findings led directly to the study of the *Legionella* pangenome (FIGURE 1.1.; Gabrielli et al. (2024)). Based on current databases, we were able to identify the following non-*pneumophila* species in these samples: *L. dumoffii*, *L. bozemanii*, *L. saoudiensis*, *L. drancourtii*, *L. quinlivanii*, *L. nautarum*, but several sequence variants remained unidentified.

**Shower hose Study-B (biofilm):** A second LeCo biofilm study (Cavallaro et al., 2024) assessed 45 shower hose biofilms from different households in a community science project. The samples were entirely random and had again no connection to reported Legionnaires’ disease cases. As for Study-A above, the following main observations apply: A total of 80 % of all samples contained *Legionella* spp., and *L. pneumophila* was detected in 57 % of samples (ddPCR quantification). When *L. pneumophila* was present, the median abundance of *L. pneumophila* relative to *Legionella* spp. was 5 % (range: 0.005 – 100 %) (FIGURE 1.3). The data suggests a broader distributed and more abundant presence of *L. pneumophila* when multiple buildings are investigated (opposed to only one building in Study-A above). Diversity and co-occurrence of multiple *Legionella* species in the same biofilm samples were also more pronounced than in Study-A; we identified 99 unique sequence variants (average of 13 sequence variants per sample). The higher diversity observed is attributed to the fact that these samples originated from geographically different buildings, hence more niche variation and thus more diversity is expected. Based on current databases we were able to identify the following non-*pneumophila* species in these samples: *L. bozemanii*, *L. drancourtii*, *L. dumoffii*, *L. gratiana*, *L. saoudiensis*, *L. shakespearei*, *L. quinlivanii*, *L. rubrilucens*, *L. waltersii* and *L. geestiana*, but several sequence variants remained unidentified.



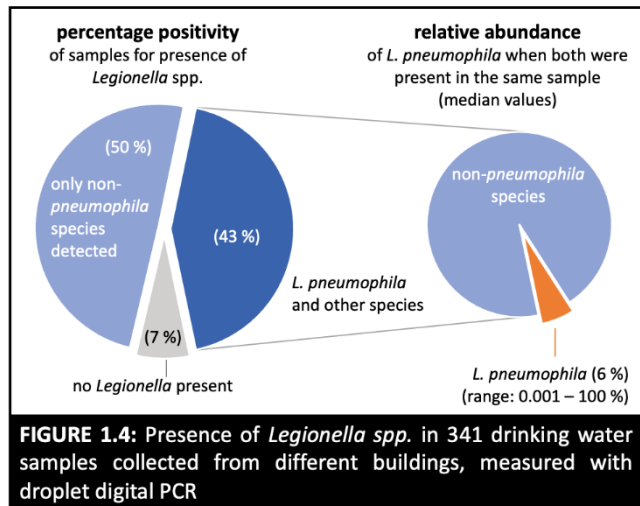
**FIGURE 1.3:** Presence of *Legionella* spp. in 45 shower hose biofilm samples from different buildings, measured with droplet digital PCR

The data suggests a broader distributed and more abundant presence of *L. pneumophila* when multiple buildings are investigated (opposed to only one building in Study-A above). Diversity and co-occurrence of multiple *Legionella* species in the same biofilm samples were also more pronounced than in Study-A; we identified 99 unique sequence variants (average of 13 sequence variants per sample). The higher diversity observed is attributed to the fact that these samples originated from geographically different buildings, hence more niche variation and thus more diversity is expected. Based on current databases we were able to identify the following non-*pneumophila* species in these samples: *L. bozemanii*, *L. drancourtii*, *L. dumoffii*, *L. gratiana*, *L. saoudiensis*, *L. shakespearei*, *L. quinlivanii*, *L. rubrilucens*, *L. waltersii* and *L. geestiana*, but several sequence variants remained unidentified.

**SwissLegio/LeCo case control study (water):**

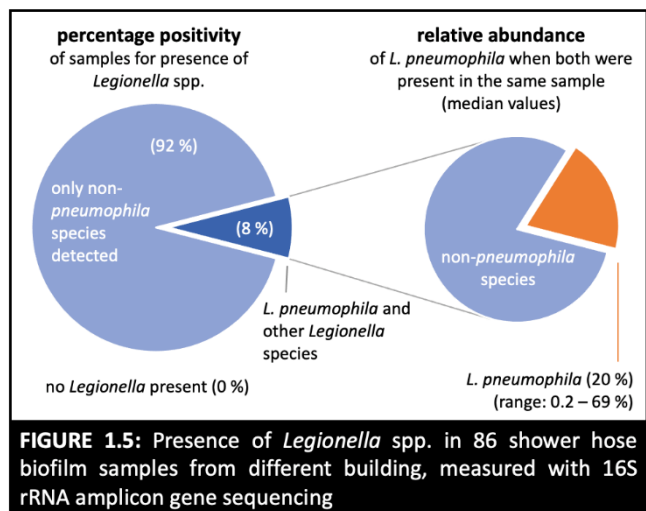
The *SwissLegio* project comprises a separate case-control study that partially overlaps with the LeCo project through the environmental sampling part (CHAPTER 3). These samples were processed first with cultivation-based methods, which has some recognized bias towards *L. pneumophila*. Here, of the 267 isolates (isolated from 23 households) that were tested, 97 % were *L. pneumophila* and the remaining 3 % were *L. anisa*. The dominance of *L. pneumophila* in these samples is notable, but in a similar trend as the German and Spanish cultivation-based studies reported on above (Salinas et al., 2021; Dilger et al., 2018).

However, cultivation-independent analysis of the same samples showed a very different outcome (FIGURE 1.4). ddPCR analysis showed 93 % of all water samples contained *Legionella* spp., while 43 % of the samples also contained *L. pneumophila* (above the detection limit). When *L. pneumophila* was detected, the median abundance of *L. pneumophila* relative to *Legionella* spp. was 6 % (0.001 – 100 %). This large discrepancy between cultivation-based data and PCR data is well-known, and the data point towards considerable broader distribution of *Legionella* spp. and *L. pneumophila* in the environment.



**SwissLegio/LeCo case control study (biofilms):**

The final LeCo study assessed 86 shower hose biofilms from different households from the case control study (above). These samples were assessed through in-depth sequencing but not ddPCR. All samples contained *Legionella* spp., but only 8 % of these samples contained *L. pneumophila*. When *L. pneumophila* was detected, the median abundance of *L. pneumophila* relative to *Legionella* spp. was 20 % (range: 0.2 – 69 %; FIGURE 1.5). In this study, we identified 150 unique sequence variants over the entire study, with a median of five *Legionella* sequence variants per sample (range: 1 – 22). The higher diversity and presence compared to previous studies is likely attributable to the geographical differences of the sampled buildings, but also the higher phylogenetic resolution granted by the use of the full 16S rRNA gene and the higher sequencing depth. Not all sequence variants could be resolved below the genus level, but we identified the following species with varying prevalence (in brackets): *L. waltersii* (56 %), *L. pneumophila* (8 %), *L. geestiana* (5 %), *L. lytica* (3 %), *L. rubrilucens* (3 %), *L. beliardensis* (1 %) and *L. shake-spearei* (1 %).



**1.4 Conclusions and Recommendations**

The vast majority of reported Legionnaires’ disease cases are caused by *L. pneumophila*, although other species can affect particularly immuno-compromised individuals. Molecular data (PCR and sequencing) showed more diversity and broader distribution of *Legionella* species in environmental samples than cultivation data. Based on this molecular data, we conclude that *Legionella* spp. is frequently detected in Swiss water and biofilm samples, with between 80 – 100 % of all samples from the different studies in the project testing positive for *Legionella* spp. It is, however, noted that the molecular data do not

differentiate between viable and non-viable *Legionella*. We found that *L. pneumophila* prevalence varies between studies, with between 8 – 57 % of all samples testing positive (Figure 1.2 – 1.5), depending on the study and the method used. Also, multiple *Legionella* species co-occur in the same samples, with *L. pneumophila* comprising 5-20 % (on study average) of the total *Legionella* population in the shower hose samples tested in this study. Based on molecular data, we argue that *Legionella* spp. presence does not accurately indicate the presence of *L. pneumophila* in samples, and *Legionella* spp. abundance consistently over-estimates the abundance of *L. pneumophila*. These points combined suggest that current legislation based on all *Legionella* species probably overestimates the risk to consumers. Based on this, we recommend the following:

1. That the BAG/BLV *Legionella* and Legionellosis Recommendations consider the lower clinical relevance of *Legionella* non-*pneumophila* species for low-risk users. To this end, one approach would be to develop a risk-based decision guideline for practitioners, considering both the concentration and species of *Legionella*. A proposal for what such an approach may comprise is shown in FIGURE 1.6, which would allow practitioners to apply risk-based resource allocation when dealing with contaminated buildings. In the most basic form, this would entail differentiating between *Legionella* spp. and *L. pneumophila*, with more stringent guidelines for the latter, and more stringent guidelines for buildings with high-risk users.

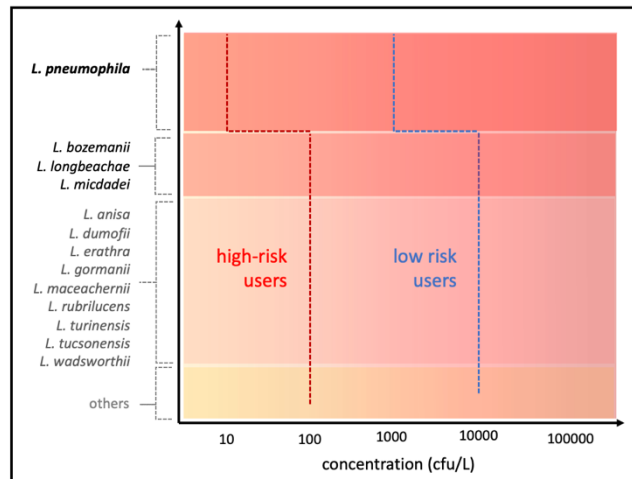


FIGURE 1.6: Suggested risk-based approach to decision-making for *Legionella* monitoring and management in buildings. High-risk users refer to buildings such as hospitals, old-age homes and care facilities. *Legionella* categories are based on the data from section 1.2 and Table 1.1 (above).

2. That a working group of experts consider amendment of the DWBSO;SR817.022.11 (2024) to (1) focus the legislation on *L. pneumophila* (opposed to *Legionella* spp.) in the case of low-risk user buildings, and (2) consider to broaden the legislation to all drinking water samples (i.e. not limited to showers). The first point is strongly supported by several recent publications (Brouwer et al., 2024; Romano Spica et al., 2024; LeChevallier, 2025), although some caution against less stringent monitoring guidelines (Delaney et al., 2022). While multiple factors including both risk and practicality should be considered for revised legislation, we suggest 1'000 CFU/L *L. pneumophila* as the threshold value for buildings with low-risk users. For high-risk user buildings we suggest stringent guidelines for *L. pneumophila* (e.g., 10 CFU/L), as well as guidelines for *Legionella* spp. (e.g., 100 CFU/L)
3. We furthermore recommend that quantitative/digital PCR is considered as an alternative method for rapid screening of samples for *Legionella*, but that at this stage only *L. pneumophila* (opposed to *Legionella* spp.) PCR data is used for the basis of decision making (Sylvestre et al., 2025). In this way, contaminated samples/buildings are rapidly identified, which can then be sampled and processed with routine cultivation-based methods. This recommendation is already progressing towards (1) incorporation in the SVGW method collection, and (2) incorporation in revised versions of the BAG/BLV *Legionella* and Legionellosis Recommendations modules.
4. In support of this approach, we recommend that quantitative/digital multiplex PCR assays for the 3-5 most relevant *Legionella* species and sero-groups (e.g., *L. pneumophila* SG1, *L. pneumophila* SG 2-14, *L. longbeachae*, *L. bozemanii* and *L. micdadei*) are considered and tested extensively in concert with standard cultivation to establish rapid tools to detect potentially problematic species, specifically when considering possible use in high-risk user facilities.

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## 2.

# What is the relative importance of showers as a source for *Legionella* infections?

## 2.1 Background

Legionnaires' disease cases are a consequence of a complex interplay between a person's exposure to *Legionella* spp. contaminated aerosols and their immune status. People with increased exposures or compromised immune systems are most at risk of becoming infected and developing illnesses. Accurate identification of, and effective intervention on, the scenarios that lead to people's exposure to contaminated aerosols will aid in the reduction of *Legionella* spp. infections in Switzerland.

Identifying the sources of *Legionella* spp. that lead to infections is challenging (NASEM, 2020). As discussed in CHAPTER 3, long incubation periods and diverse potential sources of *Legionella* spp. that people encounter in their daily activities, makes it difficult to identify conclusively sources and exposures that drive infections.

In Switzerland, efforts to control *Legionella* spp. infections prioritize reducing exposures in hospitals and publicly accessible baths and showers. A 2018 ordinance (DWBSO;SR817.022.11, 2024) calls for limiting *Legionella* spp. concentrations in aerosol generating baths or whirlpools to below 100 colony forming units (CFU), and from publicly accessible showers to below 1'000 colony forming units (CFU) per litre. Additionally, concentrations below 100 CFU/L are recommended for hospitals and nursing homes (BAG/BLV, 2018). These ordinances and recommendations highlight the perception that showers are an important contributor to *Legionella* spp. infections in Switzerland. Despite the perceived importance of showers in transmission, the specificity of the ordinance leaves gaps in infection control policies targeting showers. First, the overwhelming majority of showers occur in private homes, which are not covered by ordinances limited to publicly accessible locations and hospitals. Second, exposure to potable water supplies through alternative routes beyond showering, such as toilet flushing, faucet aeration, and aspiration have been implicated in *Legionella* spp. transmission.

Here, we discuss the perception of the importance of showers through the lens of contemporary literature on sources of aerosols contributing to *Legionella* spp. infections. We complement this review with directly relevant contributions from the LeCo project. Finally, we discuss the implications on potential legal guidelines for showers in Switzerland, including on the limitations of the guideline values to controlling other routes of *Legionella* spp. exposures through private showers.

## 2.2 Literature review

Showers are perceived to be a risk for Legionnaires' disease due to the prevalence of detectable *Legionella* spp. and *L. pneumophila* in showers combined with the high frequency of exposures to generated aerosols. Indeed, in experimental studies, *Legionella* spp. are detected regularly in water supplies used for showering. In the UK, *Legionella* spp. were detected in 8 % of showers using culture methods and 31 % of showers using qPCR (Collins et al., 2017). High colonisation of shower hoses and shower water was also observed in several LeCo project studies (CHAPTER 1). Culture-based detection methods found *Legionella* spp. in 31 % of the hot water systems of retirement homes in Italy (De Filippis et al., 2018) and 46 % of public bath facilities in Japan (Kanatani et al., 2017). The frequent detection of *Legionella* spp. in water systems is unsurprising, given that *Legionella* spp. and their protozoan hosts may be able to colonize and grow in pipe biofilms, depending on water temperature (CHAPTER 4). Colonization and growth can lead to mobilization when the water is used.

Quantitative microbial risk assessments (QMRA), which are mathematical frameworks to estimate risks of infection for a given pathogen from one or more exposure pathways, also highlight the risks that showers pose for Legionnaires' disease. Hamilton et al. (2019) investigated relative risks of infection

from exposures to aerosol generating fixtures in the households, highlighting that showers are major drivers of infection risk when contaminated with *L. pneumophila*. Risks increase with increasing concentrations of *L. pneumophila*. Critical concentrations for a single sample of a shower are suggested to be as low as 1'400 CFU/L to reach an acceptable threshold of  $<10^{-4}$  infections per person per year (pppy). Using a more conservative disability-adjusted life years (DALY) target of  $<10^{-6}$  DALYs pppy, critical concentrations for a single shower sample are suggested be below 14.4 CFU/L (Hamilton et al., 2019). They note that factors influencing guideline concentrations include factors influencing not only the risk estimate (i.e., choice of target population, disease endpoint, and acceptable disease burden threshold) but also factors beyond risk-based health targets (i.e., feasibility, logistics, and costs). Subsequent QMRA models similarly note that contaminated showers pose infection risks.

In addition to demonstrating that showers pose risks for Legionnaires' disease, QMRA frameworks highlight potentially beneficial interventions. Notably, QMRA frameworks focus on *L. pneumophila* as distinct from the genus level categorization *Legionella* spp., due to the availability of a dose-response model for *L. pneumophila* (Armstrong and Haas, 2007). Overwhelmingly, QMRA studies highlight that the strongest predictor of risks is the concentration of *L. pneumophila* in the water supply (Tang et al., 2024). Concentrations of *L. pneumophila* – and *Legionella* spp. generally – in water supplies are influenced by water temperature, biofilm formation, frequency and duration of periods in which water is stagnant (allowing proliferation of *Legionella* spp.), efficacy of disinfection, and water system design. Although controlling concentrations is the most effective way to reduce risks, reducing aerosol production is also effective. Showerhead type and water pressure both influence aerosolization, but showerhead type has been experimentally suggested to have minimal influence on Legionnaires' disease risks (Niculita-Hirzel et al., 2021).

Epidemiological evidence, including case studies, also points to the role of water supplies including showers in Legionnaires' disease cases. In a review of Legionnaires' disease outbreaks in North America, the U.S. CDC found that gaps in maintenance of water supply management likely contributed to all 23 outbreaks that had occurred on land (Garrison et al., 2016). Matching strains of *L. pneumophila* provides further evidence, including in the U.S. where two strains of *L. pneumophila* found in a hospital's water supply were linked to multiple clusters of nosocomial infections (Rangel-Frausto et al., 1999). Water supply sampling was from faucets, not showers, and one *L. pneumophila* strain from a bathtub was distinct from the strains causing clinical cases. However, in a hospital in Pittsburgh (US), strains responsible for 22 nosocomial cases were found in the potable water supply including in showers, sinks, and a decorative fountain (Demirjian et al., 2015). Bauer et al. (2008) further extended the epidemiological evidencing, highlighting clear increased risk of Pontiac Fever when shower water concentrations exceeded  $10^4$  CFU/L in France (Bauer et al., 2008). In China, two case studies tracked clusters of cases of Legionnaires' disease cases to showers, including one where *L. bozemannii* was implicated (Deng et al., 2001).

In some cases, building water supplies including showers are suspected, but the researchers are unable to provide clear linkages. In New Zealand, for example, Legionnaires' disease cases were linked to *L. pneumophila* found in roof-collected rainwater systems used for showers (Simmons et al., 2008). The bacteria were thought to be seeded by a contaminated nearby water blaster, but whether people were exposed to aerosols from the water blaster or from their own showers remained unclear.

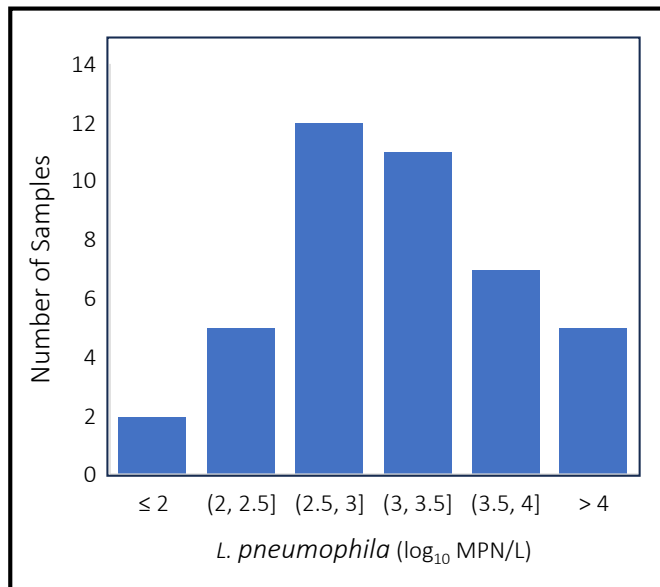
The number of case studies that attribute Legionnaires' disease cases to showers may be low due to the current approaches used for surveillance. Environmental surveillance is more likely to occur following an outbreak than a single sporadic, community-acquired case. In the U.S., cases associated with outbreaks represent only 4 % of all cases (Garrison et al., 2016). Private showers may contribute to sporadic cases, but may be insufficiently investigated as a possible source. Additionally, in Switzerland, case identification primarily occurs for hospitalised, clinically severe Legionnaires' disease infections, which may only represent a small portion of overall *Legionella* infections. Many cases may be asymptomatic or paucisymptomatic, and therefore go unobserved. Pontiac fever reports as a flu-like illness, and may not be severe enough to motivate diagnostics to determine disease etiology. Showers, therefore, may be

acting as a substantial source of sporadic, community-acquired cases that go undetected or unreported. This is particularly relevant when attempting to link risk assessment frameworks to epidemiological data. Risk assessment models may imply a risk of infection from exposures, such as from showers, under conditions in which we do not observe a corresponding level of clinical cases. In such scenarios, it is difficult to distinguish the degree to which this reflects overestimation of risks compared to underreporting of infections.

### 2.3 LeCo project results

The LeCo project provides results that confirm that showers contribute to Legionnaires' disease cases but also note that private showers do not appear to be a major driver of clinically severe infections in Switzerland.

**The LeCo project demonstrates that *Legionella* spp. and *L. pneumophila* are widespread in building systems including showers in Switzerland.** The LeCo project findings confirm that building water systems, including shower-related plumbing, allow proliferation and growth of *Legionella* spp. and *L. pneumophila*. In a meta-analysis of measurement methods for *L. pneumophila* in building water systems, Sylvestre et al. (2025) identified fifteen published studies reporting quantitative estimates of *L. pneumophila* using paired culture and molecular methods. Concentrations of *L. pneumophila* regularly exceeded threshold guidelines of 1'000 CFU or genome copy equivalents per L. Similarly, Cavallaro et al. (2023) demonstrated widespread contamination of shower hoses in a retirement facility in Switzerland, showing that all of the 85 hoses tested were colonized with *Legionella* spp., and approximately 1/3<sup>rd</sup> with *L. pneumophila*. Within the scope of the LeCo project, we also tested 124 private showers for *Legionella* spp. and *L. pneumophila* using culture and molecular methods, representing the households from 74 people with community-acquired Legionnaires' disease and 50 people matched on sex, age, and residential location. Of these households, 91 % of shower first flush samples were colonized by *Legionella* spp. as indicated by molecular methods, whereas only 51 % by *L. pneumophila*. Finally, through a collaboration with a commercial partner in Switzerland, we further assessed *L. pneumophila* concentrations from paired first flush and draw samples from public shower facilities at risk for being colonized by *L. pneumophila*. Approximately half of the samples exceeded concentrations of 10<sup>3</sup> CFU/L *L. pneumophila* (FIGURE 2.1). The work highlights the consensus that building water systems, including showers in Switzerland, are colonized with *Legionella* spp. and *L. pneumophila*, with some buildings having a high proportion of showers colonized at concentrations exceeding current guideline values.



**FIGURE 2.1:** Histogram of *L. pneumophila* concentrations in the showers of a public facility known to have contamination with *L. pneumophila*. Concentrations are measured in log<sub>10</sub> Most Probable Number (MPN) / litre (L). Approximately half of the samples tested exceeded a concentration of 10<sup>3</sup> MPN/L.

**Within the LeCo project, we show that concentrations of *L. pneumophila* observed in building water systems pose a risk of infection from showering that is above generally acceptable thresholds.** In the LeCo project, we applied QMRA frameworks to evaluate the influence of dynamic aerosol generation rates and *L. pneumophila* concentrations in water buildings, on risks of infection from exposures in

showers (FIGURE 2.2). The work allows us to estimate the infection risks associated with shower exposures. We applied this framework to a set of data on concentrations of *L. pneumophila* in public showers. In public showers, we observed that in many locations, risks from showering exceeded a risk of 1 infection per 10'000 people per year. The case study highlights that in Switzerland, concentrations of *L. pneumophila* in showers can pose risks to the exposed population.

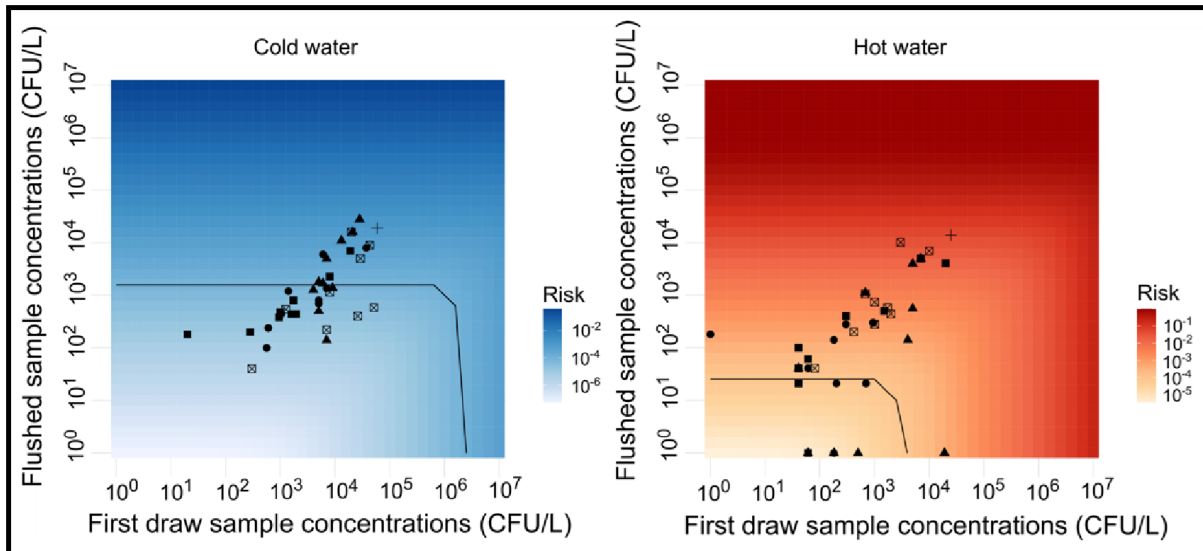


FIGURE 2.2: Heatmap of the risk of infection from showering based on *L. pneumophila* concentrations in the first draw (x-axis) and systemic flushed samples (y-axis), overlaid with observed combinations of first draw and flushed concentrations in showers from public buildings. Factors in the model that are impacted by the water temperature (cold, hot) include the concentrations of *Legionella* spp., which are determined from sampling either cold or hot water composite samples, and the aerosol generation rates, which are derived from empirical data from either cold or hot water showers. Cold water temperature is in the range of 24-26 °C for aerosol generation rates and hot water temperature is in the range of 39-41 °C for aerosol generation rates. The black line reflects a risk of infection of 10<sup>-4</sup> infections per person per year, equivalent to 1 infection per 10,000 people per year.

The LeCo project highlighted that mitigation strategies can help to reduce risk. The QMRA model developed within the LeCo project establishes not only estimates of risks, but also can be used to explore potential mitigation strategies. Indeed, the QMRA model highlights the importance of *L. pneumophila* concentrations in shower water as the most influential factor for infection risk. This finding unsurprisingly reaffirms that reducing *L. pneumophila* concentrations in shower water is the most important mitigation strategy. In addition to this finding, the QMRA also demonstrates that other factors, such as decreasing the shower frequency or length, increasing ventilation rate, and decreasing aerosol generation rates can all help to reduce the risk of infection (FIGURE 2.3). The QMRA also showed that exposures to aerosols are continuous throughout the duration of the shower, showing that reducing the time in the shower or bathroom will also reduce risks. Aerosol generation rates can be decreased both by taking colder showers, which also helps to save energy costs, lowering the flow rate, or using a different showerhead type. The impact of these mitigation strategies is context (shower, user) specific, but nevertheless they provide potentially beneficial behavioural recommendations.

***L. pneumophila* contamination of showers pose an infection risk, but evidence from the LeCo project suggests the relative contributions of showers to Legionnaires' disease is low.** The observed concentrations of *L. pneumophila* in showers in Switzerland, integrated with the risk assessment models, highlights the potential contributions of showers to Legionnaires' disease cases. In the LeCo and *SwissLEGIO* (see CHAPTER 3) projects, however, tracking concentrations of *L. pneumophila* in the first flush of showers in private households revealed that only a portion had detectable *L. pneumophila* in the households of people with clinically severe Legionnaires' disease. Molecular methods using dPCR showed a 51 % rate of detection, whereas culture using Legiolert (IDEXX, USA) showed a 19 % rate of detection. This low

proportion – although not intended to be nationally representative – suggests that many Legionnaires’ disease cases come from sources other than exposures to *L. pneumophila* through showers in Switzerland. Notably, only 11 % of public showers in Graubünden and Glarus contain *Legionella* spp. (Amt für Lebensmittelsicherheit und Tiergesundheit Graubünden, 2024).

Notably, LeCo also showed that the proportion of contaminated showers in private homes was similar to the proportion observed for matched controls, which were people with same sex, similar age, living in geographic proximity who did not have Legionnaires’ disease. Based on this finding, detectable *L. pneumophila* contamination in showers does not appear to be a major risk factor for Legionnaires’ disease in Switzerland. We note some caveats, which include that *L. pneumophila* may have been present but not detectable (due to, for example, temporal variations; limited assay sensitivity). Nevertheless, the best current evidence suggests that private showers pose limited risk of Legionnaires’ disease. Alternative sources are likely responsible for the majority of clinically-severe infections in Switzerland.

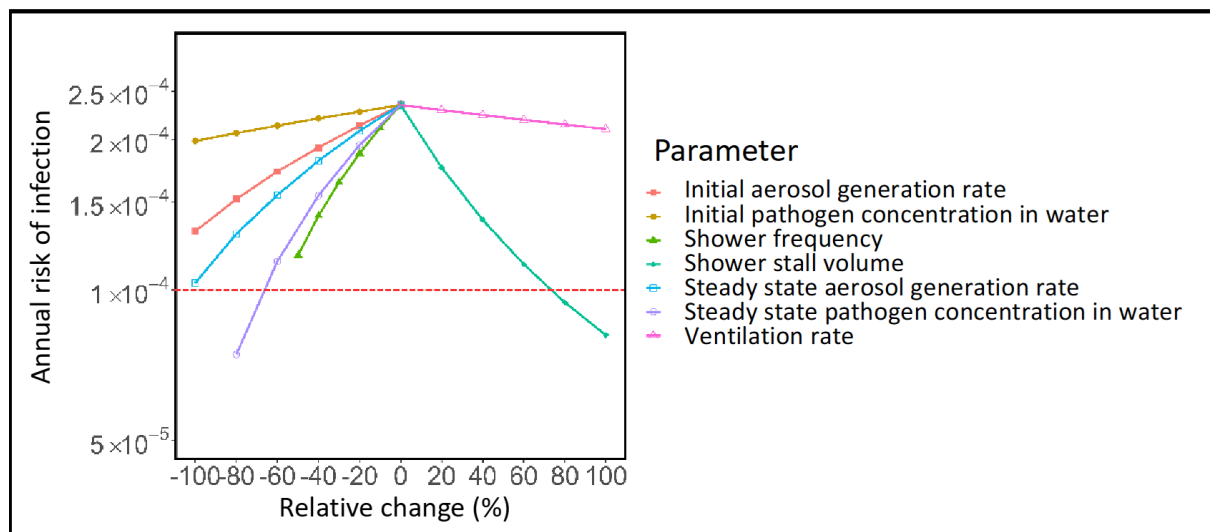


FIGURE 2.3: Reductions in the annual risk of infection from showering achieved by altering modelled conditions of the shower, including aerosol generation rate; pathogen concentrations in the first flush and draw samples; shower frequency; shower stall volume and ventilation rate; and aerosol generation rates. Note that relative changes due to parameters are specific to the initial conditions, and that actual reductions in risks for a given intervention will depend on site-specific conditions. The red horizontal line reflects an annual risk of infection of  $10^{-4}$  infections per person per year, a commonly used threshold for acceptable risk.

## 2.4 Conclusions and Recommendations

Evaluation of published literature combined with the outcomes from the LeCo study affirms a conclusion that showers are potential sources of Legionnaires’ disease in Switzerland, but that their contribution to clinically severe disease appears to be low. In light of this, we make two general recommendations: 1) raising public awareness of Legionnaires’ disease risks from showers and associated mitigation strategies to reduce risks; and 2) better optimizing existing resources focused on reducing risks from showers. We perceive that current evidence supports strengthening existing endeavours, but does not support more stringent regulations focused on controlling Legionnaires’ disease from showers.

### Raising public awareness of Legionnaires’ disease risks from showers and associated mitigation strategies:

- 1. Raising awareness of Legionnaires’ disease amongst the most vulnerable.** The elderly and immunocompromised are most at risk of Legionnaires’ disease infections. Given similar exposures, the elderly will be more likely to become ill due to *L. pneumophila* exposure than other, less vulnerable, populations such as adults and children (Weir et al., 2020). Weir et al. (2020) estimates an approximate 1-log<sub>10</sub> increase in risk of illness for the elderly relative to adults, results that are incorporated

into our own risk model findings. Such a substantial impact would warrant lowering thresholds below 1'000 CFU/L for facilities with vulnerable populations, such as the 100 CFU/L recommended for hospitals and elderly homes by the BAG/BLV (2018). The increased risk also suggests that people responsible for settings such as private homes, elderly homes, and hospitals, in which vulnerable populations are exposed should consider more stringent water management and safety plans. Increased stringency could include more proactive testing with greater frequency than required by law, and proactive management strategies to reduce *L. pneumophila* concentrations or exposures such as ensuring proper temperature control, and incorporating routine flushing. Increasing awareness that this population is at greater risk for Legionnaires' disease may help to prompt or otherwise encourage self-responsibility for risk reduction strategies.

- 2. Advocating for awareness of private testing of showers.** In the context of the risk assessment, reducing *L. pneumophila* concentrations in water is the most effective strategy to reduce risks. However, homeowners may not be aware of the status of *L. pneumophila* contamination in their showers. Under current regulations, *L. pneumophila* contamination within a private home is the responsibility (and liability) of the homeowner. Despite this, very few people are aware of opportunities to assess *L. pneumophila* contamination of their own water supplies and therefore are unable to assess their own risks. Some private labs offer these services, allowing people to identify and mitigate their own risks. Raising awareness of this service and the associated potential benefits of identifying and mitigating *L. pneumophila* contamination in private homes, specifically for the most vulnerable, may better identify households that would most benefit from investment in mitigation strategies. We note the need to design adequate, cost-effective sampling strategies, such as composite sampling. Further, such testing would incur costs to private people, so the decision to test would be based on trade-offs between perceived risks and testing costs. Furthermore, resources would need to be devoted to counsel households on test results, including any potential risk mitigation strategies.
- 3. Promoting simple risk mitigation strategies.** Simple behavioural changes may help to reduce risks from *L. pneumophila* exposures in showers. From our work, we suggest that lowering the aerosol generation rate by reducing flow rate or showering at cooler temperatures can have a large effect on reducing exposures. Opening windows or doors to increase ventilation is also an effective strategy. As the duration of exposure to aerosols also influences risk of infection, reducing the time spent in the shower, reducing shower frequency, or shifting to bathing which generates lower aerosols, if feasible, are also effective interventions. Many of these have the added benefit of helping to also reduce energy and water use and associated costs. However, it is important to note that the relative impact of these simple strategies will be dependent on site-specific conditions. For example, ventilation will be more beneficial in smaller bathrooms or shower stalls in which aerosol concentrations quickly increase than in larger bathrooms or shower stalls in which aerosol concentrations remain low due to dispersion. As such, no universal recommendation for simple risk mitigation strategies is sufficient to reduce risks to safe levels, highlighting the continued need to support testing and water safety management plans.

#### **Better optimizing existing resources focused on water quality testing:**

- 1. Targeting resources to most vulnerable populations.** Actionable concentrations of *L. pneumophila* in building water systems, including in showers, could be lower when the buildings serve the vulnerable such as the elderly than when buildings primarily serve the less vulnerable, such as children and healthy adults. More stringency in acceptable concentrations for the vulnerable may allow for prioritization of resources on control and mitigation strategies to be more effective, and therefore more protective. Such stringency may be prioritized for designated buildings, such as public facilities serving vulnerable populations, hospitals, and elderly or nursing homes (see also CHAPTER 1).
- 2. Better collating and tracking data on *Legionella* spp. in buildings in Switzerland.** Existing regulations mandate water quality testing to help identify Legionnaires' disease risks among public showers.

However, there is currently no infrastructure or resources to allow the collation of this data. Such collation would promote compliance, enable tracking spatial or temporal trends, and help identify clusters or hotspots. Investments in infrastructure, such as a centralized database for reporting, could collate data and also provide tools to simplify reporting, data interpretation, and resources for remediation in the event of problems.

- 3. Optimizing sampling strategies.** Sampling showers for *Legionella* spp. or *L. pneumophila* provides two levels of information. The first is whether or not the shower is contaminated (presence/absence), the second is an estimate of the level of contamination, which can be used to inform risks of infection. Sampling strategies should be better tailored to inform risk. Collecting a first flush sample as well as a composite sample can best inform risk of the system, as proposed in Fischer et al. (2023). However, more efficient sampling strategies may be considered to reduce the number of samples collected (SVGW-MW101, 2021). For example, collecting composite samples only when the first flush sample exceeds, or has a history of exceeding, a specific threshold such as 10 CFU/L (FIGURE 2.2).
- 4. Expanding sampling to other reservoirs.** A major conclusion from the LeCo project is that there is not sufficient evidence to conclude showers are an important source of Legionnaires' disease for the Swiss population, suggesting that other sources play a more important role. Recent outbreaks point to cooling towers (Wüthrich et al., 2019), car washes (Aellig and Bally, 2019), and spas (Leoni et al., 2018) as potential sources. The current framework requiring monitoring of public showers could be expanded to include monitoring other reservoirs, such as cooling towers, in line with regulations from other countries (PSPC, 2022).

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# 3.

## Why is it so challenging to link Legionnaires' diseases cases successfully to infection sources?

### 3.1 Background

Legionnaires' disease (LD) is an atypical form of pneumonia caused by *Legionella* spp. bacteria, which are ubiquitous in water and soil (Cunha et al., 2016). To link LD cases to infection sources, isolates of *Legionella* spp. from clinical samples and from potential environmental reservoirs are compared genotypically and/or phenotypically (Orkis et al., 2018; van Heijnsbergen et al., 2015). To be sure that an environmental reservoir is identified correctly as the source of infection, the clinical and environmental isolates should be highly similar (i.e. they should match). Identifying the source of infection for LD through such matching is important to (1) guide direct mitigations such as decontamination of a building where *Legionella* spp. was detected, and (2) to inform the development of guideline recommendations for *Legionella* control.

In recent years, Whole Genome Sequencing (WGS) has proven helpful for such matching, especially during LD outbreaks. WGS was, for example, used to trace an LD cluster in Basel to cooling towers in 2017 (Wüthrich et al., 2019), to link LD cases in the Netherlands to a wastewater treatment plant in 2022 (Pijnacker et al., 2024), and to attribute LD cases in Finland to tap water in 2021 (Mentula et al., 2023). In other situations, however, linking LD cases to sources of infection remained a challenge, even with WGS (Schjorring et al., 2017; Faccini et al., 2020; Ricci et al., 2022). Reasons included challenges in identifying potential sources of infection, isolating bacteria from both the patient and the environment, and deciding when isolates are considered similar upon analysing the sequencing data. All these challenges are even more pronounced when we try to match sources of infection to sporadic community-acquired LD cases (Den Boer et al., 2015; Schoonmaker-Bopp et al., 2021). Compared to outbreaks, it is more difficult for sporadic cases to narrow down potential infection sources, to decide how extensively potential sources of infection should be sampled, and to get suitable clinical isolates from patients. However, sporadic community-acquired LD cases account for most LD cases notified in Switzerland and other European countries (Fischer et al., 2022).

In this chapter, we highlight challenges (and potential solutions) in comparing isolates using WGS, including those arising from the detection, isolation, sequencing, and genomic analysis of *Legionella* spp. We draw on the existing literature and our experience conducting a national case-control and molecular source attribution study (*SwissLEGIO*) (Fischer et al., 2023a; *SwissLEGIO*, 2024). All project data presented herein are therefore joint findings of the FOPH-funded *SwissLEGIO* study and the LeCo project.

### 3.2 Literature review

**A limited availability of clinical isolates.** In the routine surveillance of LD, clinical *Legionella* spp. isolates are recovered in about 5-10 % of all patients (Fischer et al., 2022; ECDC, 2023). Without a clinical *Legionella* spp. isolate for an LD patient, the source of infection cannot be identified with absolute certainty. Obtaining clinical *Legionella* spp. isolates is, therefore, a bottleneck in environmental source investigations (Den Boer et al., 2015; Petzold et al., 2017). The number of clinical isolates that can be obtained from LD patients is limited for several reasons: Firstly, many LD patients do not have a productive cough, making it difficult to get sputum samples. Secondly, LD patients are often already on antibiotics treatment by the time clinical samples are collected and, therefore, *Legionella* spp. may no longer grow on plates. In addition, the concentration of *Legionella* spp. in clinical samples from milder LD cases can be low (Cunha et al., 2016). Finally, specific culture media and sufficient expertise and manpower in the clinical laboratories are required to culture *Legionella* spp. (Edelstein and Lück, 2015).

Many potential *Legionella* reservoirs can be the source of infection. *Legionella* spp. are ubiquitous in water and soil environments, resulting in a wide range of potential infection sources for LD (FIGURE 3.1). The extent to which these different sources contribute to the overall disease burden of LD remains largely unknown (Fischer et al., 2023a), making it challenging to prioritise different sources of infection in terms of their relevance and subsequently to monitor them at scale.

This said, LD patients may have been exposed to multiple potential *Legionella* reservoirs during the incubation period (i.e. 2-14 days prior to the onset of first symptoms for *L. pneumophila*). In addition, patients may be exposed to sources without being aware, as is the case for outside aerosol-producing sources like car wash stations and cooling towers. Therefore, it is often necessary to investigate multiple potential reservoirs of *Legionella* spp. to identify the source of infection for a particular LD case (Faccini et al., 2020; Pijnacker et al., 2024). This is particularly true for sporadic cases, where – in contrast to outbreaks – GIS analysis/ interviews likely do not point to one common infection source. This consideration of all possible sources of infection for a (sporadic) LD case is resource-intensive, costly and often not feasible as part of the routine surveillance (Den Boer et al., 2007). Currently, source investigations commonly focus on building plumbing systems, potable water, known risk exposures such as cooling towers, and increasingly on wastewater treatment plants (Wüthrich et al., 2019; Buchholz et al., 2020; Pijnacker et al., 2024; Vermeulen et al., 2021; Schoonmaker-Bopp et al., 2021; Scaturro et al., 2015; Faccini et al., 2020). The most comprehensive recommendations for environmental source investigations for *Legionella* in Switzerland focus on shower and bathing water (BAG/BLV, 2018; DWBSO;SR817.022.11, 2024).

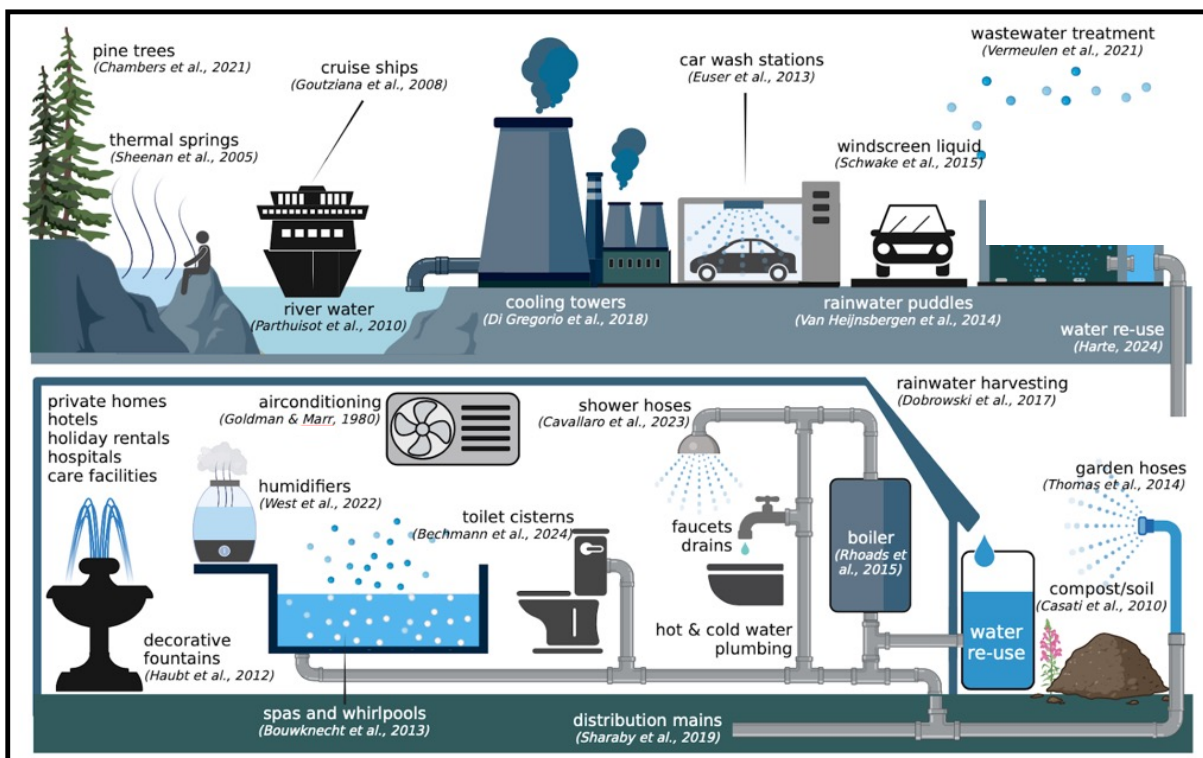


FIGURE 3.1 Environmental sources of Legionnaires' disease (van Heijnsbergen et al., 2015a; Orkis et al., 2018) (Image: biorender.com).

Many different environmental sampling approaches exist. Decisions about how and when to sample environmental *Legionella* reservoirs can affect the detection of an existing *Legionella* contamination. For example, the spatial distribution of *Legionella* spp. in a plumbing system may vary from building to building. This means that decisions about the sample volume, the choice of water outlets (e.g. kitchen, bathroom taps or hot water storage tank outlet), whether to sample from the hot water pipe, cold water pipe or mixed hot/cold water, and whether to take a first flush or a flushed sample can all influence the

chance of isolating *Legionella* spp. (Wang et al., 2017; Logan-Jackson et al., 2021). Appropriate sampling strategies also differ depending on the potential *Legionella* reservoirs to be sampled. Cooling towers, wastewater treatment plants and soil, for example, require other sampling techniques than potable water (CDC, 2024; Casati et al., 2009). Finally, *Legionella* spp. may only be found in the biofilm and not in the water, and the release of *Legionella* spp. from biofilm might fluctuate over time (Wang et al., 2017; Schoen and Ashbolt, 2011), therefore, the detection of *Legionella* spp. may also depend on whether swab samples, water samples or whole biofilm samples are collected.

In addition to the type of sample that is collected, the timing of sampling may also impact on the detection of *Legionella* spp.. A *Legionella* reservoir might only temporally or intermittently act as an infection source (e.g. a cooling tower infected a patient but was cleaned prior to the sampling or hot water temperature is increased prior to sampling). Additionally, studies also suggest that *Legionella* growth and thus, detectable concentrations vary in the environment depending on the season or weather conditions (Fischer et al., 2023b; Logan-Jackson et al., 2021). In concert, this highlights that (1) sampling should occur as soon as possible after an LD case is detected, and (2) many approaches to environmental sampling exist and different types of samples should be collected to reliably detect an existing *Legionella* contamination.

There are different approaches to sampling and different laboratories (cantonal and private) may therefore use different sampling strategies. The LeCo project developed streamlined sampling protocols to address this problem for the sampling of potable water in buildings, which has been added to the SVGW Methodensammlung (SVGW-MW101, 2021). No guidelines for the sampling of other potential environmental *Legionella* reservoirs like cooling towers, soil or wastewater currently exist in Switzerland. Reference documents are, however, available from elsewhere (CDC, 2005).

**Laboratory methods for the isolation of *Legionella* spp. have limitations.** WGS is done on individual *L. pneumophila* isolates. The culturing of *Legionella* spp. from environmental samples is, thus, a mandatory first step. All laboratory methods currently available for the isolation of *Legionella* spp. have limitations that prevent the isolation and sequencing of all *Legionella* spp. in the sample:

- In every sample-processing step (filtration, resuspension, acid/ heat treatment), a proportion of the total *Legionella* spp. is lost (Bridle et al., 2021; Dorrie and Nogueira, 2024).
- Limits of detection on agar plates and in liquid culture may hamper the detection of *Legionella* spp., particularly if *Legionella* spp. is present in low concentrations or is present in a state that is not readily culturable. Enriching the number of *Legionella* cells before plating might facilitate isolation. Possible strategies include enrichment in selective media or culturing with potential hosts (amoeba), which support *Legionella* spp. multiplication and therefore recovery (Moreno et al., 2025). Using different types of culture media (supplemented with different antimicrobials) may be another approach to increase the yield of *Legionella* spp. isolates (CDC, 2005; Ditommaso et al., 2021).
- Agar plates and the liquid culture (e.g. Legiolert) may favour *L. pneumophila* growth and result in an underestimation of the *Legionella* diversity present in the sample (Lee et al., 1993).
- Other microorganisms in the sample may outcompete *Legionella* spp.. This can be partially controlled for by using pre-treatments prior to plating and selective culture medium, whereby heat treatment appears more efficient than acid treatment (Bartie et al., 2003; CDC, 2005).
- Colonies on agar plates are judged to be *Legionella* spp. based on their visual morphology by lab personnel. *Legionella* spp. with atypical morphologies may be misclassified; similarly, multiple distinct strains of *Legionella* spp. with the same morphology may result in inadequately capturing culture diversity.
- As many presumptive *Legionella* spp. colonies as possible should be picked from culture plates to capture the *Legionella* spp. diversity in the sample. This is time and resource-intensive. Additionally, varying concentrations of different *Legionella* spp. strains in samples may lead to a masking of rare strains by predominant *Legionella* spp. strains in the sample (Lecointe et al., 2019).

Ideally, different cultivation approaches (use of different media, different pre-treatments, direct plating) should be combined to optimise culture recovery from environmental samples. In addition, validation of laboratory methods and comparative studies are essential before widespread implementation of laboratory protocols.

**Integration of whole genome sequencing in *Legionella* and LD surveillance.** The current molecular gold standard to compare *L. pneumophila* isolates is sequence-based typing (SBT) (Gaia et al., 2005; Ratzow et al., 2007). In addition, Whole Genome Sequencing (WGS) is increasingly being used and integrated in *Legionella*/LD surveillance. WGS has a higher resolution and thus higher discriminatory power in distinguishing different *Legionella* spp. strains (Petzold et al., 2017; David et al., 2016a). WGS has so far been primarily used for outbreak investigations (Wüthrich et al., 2019; Pijnacker et al., 2024; Mentula et al., 2023; Petzold et al., 2017; Lapierre et al., 2017). The primary aim in outbreaks is to match clinical *L. pneumophila* isolates recovered from patients, and environmental *L. pneumophila* isolates, obtained from common, potential infection sources. In outbreak situations, the chance that both, clinical and environmental *L. pneumophila* isolates are available is considerably higher than in the routine surveillance of sporadic cases (cf. above) (Schoonmaker-Bopp et al., 2021).

Recent WGS studies have also highlighted that some LD-causing *L. pneumophila* strains remain highly conserved across geographical regions and over time. Some strains are further endemic to certain regions and may form complex networks interlinking multiple *L. pneumophila* reservoirs (Ricci et al., 2022; Ricci et al., 2023; David et al., 2016a; Lapierre et al., 2017; Wüthrich et al., 2019; Manageiro et al., 2024). Whilst this can make outbreak investigations more challenging (Lapierre et al., 2017; Ricci et al., 2022; Schjorring et al., 2017; Petzold et al., 2017), it may also open up new avenues for integrating WGS in *Legionella*/LD routine surveillance. Surveillance using WGS could address important questions:

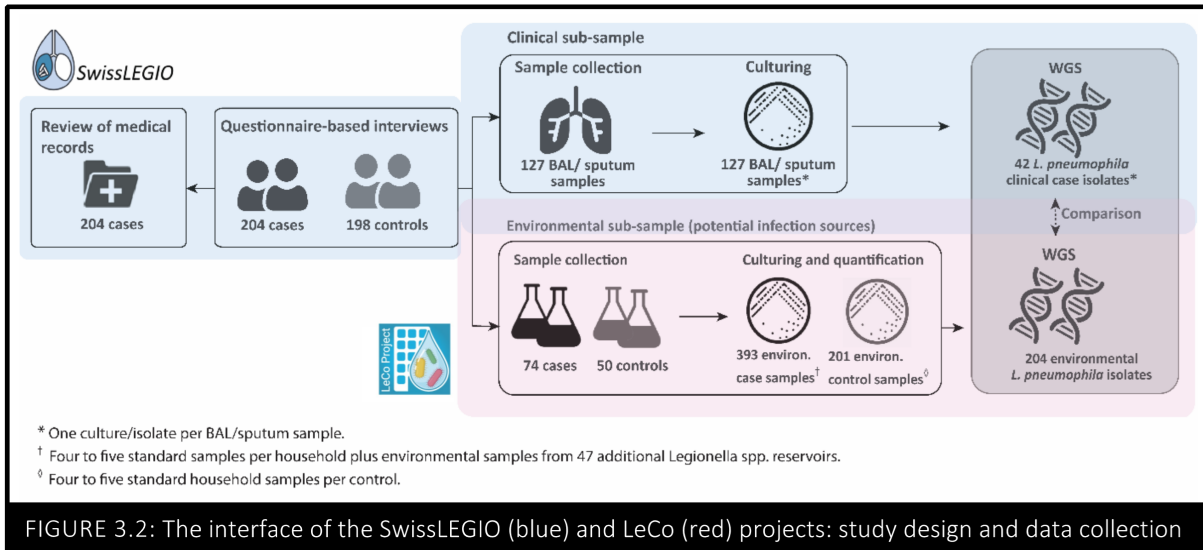
- *Are there regions in Switzerland where there are endemic, pathogenic *L. pneumophila* strains that cause repeated infections (without otherwise common exposures)?* (David et al., 2016b; Ricci et al., 2022; Gorzynski et al., 2022; Ricci et al., 2023; Lapierre et al., 2017)
- *How do pathogenic *L. pneumophila* strains persist and disperse in the environment and in which niches do they grow?* (Manageiro et al., 2024; Lapierre et al., 2017; Wüthrich et al., 2019)
- *Subsequently, is it possible to systematically screen for these endemic and pathogenic *L. pneumophila* strains in the environment to assess the role of potential *Legionella* reservoirs to become infection sources for LD?*

Addressing these questions for surveillance lays an important foundation for regional mapping of predominant strains and the attribution of cases to their likely infection source. It would also support a shift from broad screening for *Legionella* spp. to a more risk-based and targeted screening for pathogenic *L. pneumophila* clones (see CHAPTER 1), but in a wider range of potential *Legionella* reservoirs (and also beyond drinking water) (FIGURE 3.1).

### 3.3 LeCo project results

**Background on the SwissLEGIO/LeCo study.** The FOPH-funded SwissLEGIO study is a national case-control study on LD in Switzerland (Fischer et al., 2023a; SwissLEGIO, 2024). 204 community-acquired LD cases from 20 university and cantonal hospitals and 198 healthy controls from the Swiss general population were enrolled between August 2022 and March 2024. At the interface of SwissLEGIO/LeCo, we specifically investigated the role of potable water from private homes as a source of infection for LD and assessed whether the characterisation of environmental *L. pneumophila* isolates using WGS is useful for *Legionella*/LD surveillance in Switzerland. Therefore, 74 case- and 50 control households were systematically sampled within the LeCo project and tested for *Legionella* contamination after developing a routine sampling protocol. Samples were also collected from other potential *Legionella* reservoirs to which

the LD cases were exposed (FIGURE 3.2). Within the scope of *SwissLEGIO*, we additionally obtained and sequenced *L. pneumophila* isolates from 42 patients (21 % of all enrolled CALD patients).



**Screening potential environmental reservoirs for *L. pneumophila* contamination (focusing on potable water from private buildings).** *Legionella* spp. bacteria are ubiquitous in the environment and patients are often exposed to several potential *Legionella* reservoirs during the period in which they contracted the infection. In the *SwissLEGIO/LeCo* study, we extensively sampled potable water from private homes (kitchen faucets and showers) and, therefore, assessed in-depth if LD cases in Switzerland are linked to this potential infection source (see also CHAPTER 2). We developed standardised protocols for sampling and sample processing (cf. study protocol (Fischer et al., 2023a)). This standardisation made sure that results from household investigations were comparable across Switzerland. We summarise the main lessons learned from this standardised assessment of *Legionella* contamination in private homes below:

- Study participants were instructed to avoid using water taps for four hours prior to sampling. The daytime of sampling was not predefined. To assess peripheral contamination, first flush samples from the kitchen faucet and the two most commonly used showers were collected. To capture *Legionella* spp. in more distal parts of the building’s water installation, two additional composite samples were collected from the hot and cold water lines. Sampling took place between August 2022 and October 2023 across all major regions of Switzerland. Interestingly, no single subset of samples reliably detected *L. pneumophila* contamination across all households (see FIGURE 3.3). This underscores the importance of collecting multiple samples within each household to ensure a *Legionella* contamination is detected with reasonable certainty. This needs to be specifically considered if legislation (e.g. Lebensmittelgesetz) for self-control in buildings is revised.

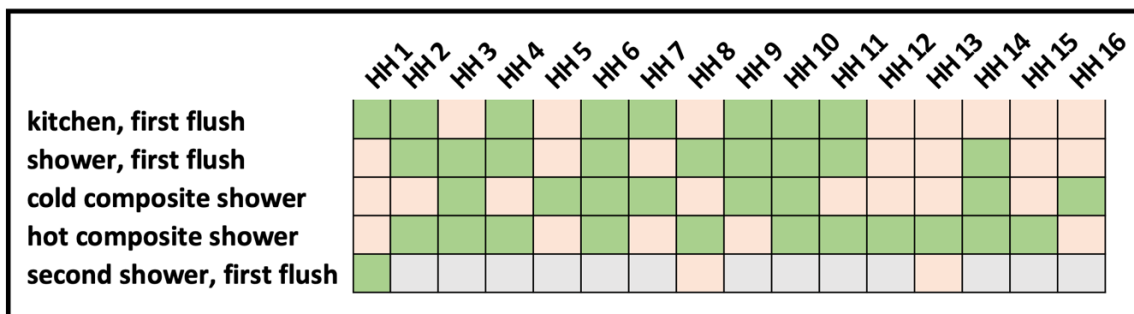


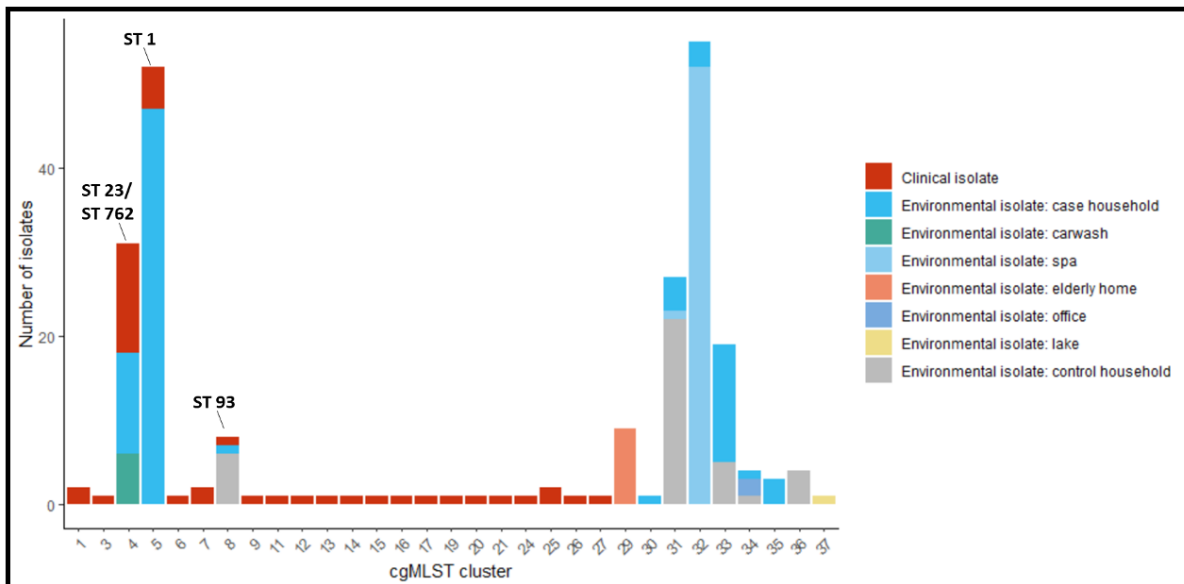
FIGURE 3.3: Summary of positive samples from Legionnaires’ disease case households: 16/74 culture- case households were culture-positive for *L. pneumophila*. The figure illustrates the detection of *L. pneumophila* across different sample types across all positive household. Notably, no subset of samples consistently identified *L. pneumophila* contamination across all households (green= *L.pneumophila* detected, red= no *L. pneumophila* detected, grey= no sample collected, HH= household).

- Household samples were processed according to standardised laboratory procedures. *Legionella* spp. was isolated from water samples according to ISO 11731. Samples were filtered, and concentrated samples were plated on BCYE+AB plates without pre-treatment, with acid pre-treatment and with heat pre-treatment. In addition to the ISO method, we also used the IDEXX Legiolert (liquid culture). Applying this protocol to a large number of water samples, we found that filtration and resuspension resulted in a quantifiable loss of bacteria: the median recovery was 30 % (range: 1 – 90 %). We also observed that the liquid culture (IDEXX Legiolert) was a very simple and efficient method for isolating *L. pneumophila* (70 % of all *L. pneumophila* isolates were obtained by liquid culture).
- Overall, 21.6 % of LD case homes (from eight cantons) and 14.0 % of control homes (from seven cantons) tested culture-positive for *L. pneumophila* by culture. In addition to the private households, we sampled 51 other potential environmental *Legionella* reservoirs were sampled. Of these, eight (15.7 %) were culture positive for *L. pneumophila*.

**Linking *Legionella* reservoirs to LD cases using WGS (focusing on potable water from private buildings).**

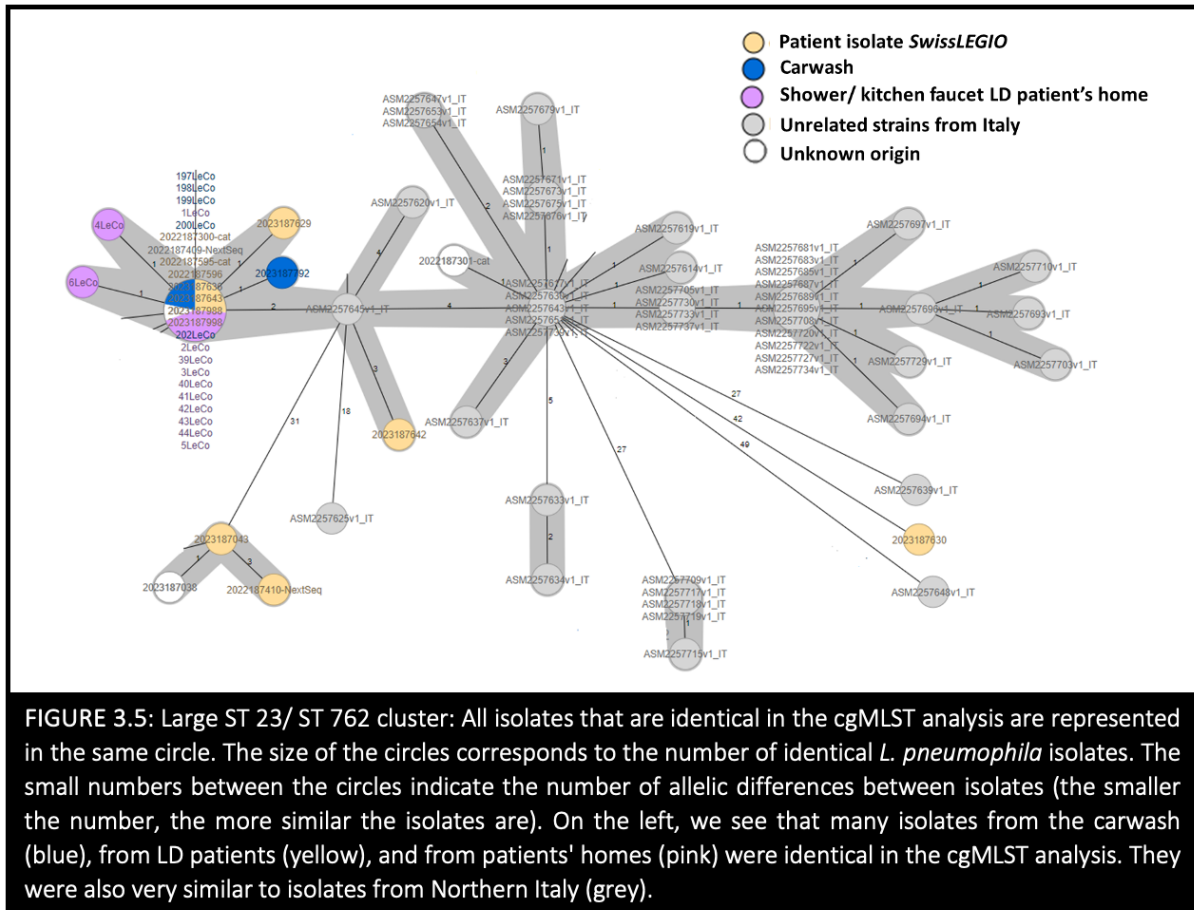
In total 42 clinical *L. pneumophila* isolates and 204 environmental *L. pneumophila* isolates from 15 case households, five control households and eight other potential infection sources were sequenced using WGS. We determined the sequence type (ST) and visualised similarities in minimum spanning trees based on a core genome multi-locus sequence typing (cgMLST) scheme (Moran-Gilad et al., 2015). *L. pneumophila* isolates that were highly similar at this core-genome level were further analysed for differences at the level of single nucleotides across the genome. These single nucleotide polymorphisms (SNPs) represent the highest resolution of genomic analysis.

We had a clinical *L. pneumophila* isolate available for 28 out of the 74 patients for whom we also collected water samples from their homes. Water samples from five out of these 28 case households (18 %) tested positive for *L. pneumophila* by culture. In two households, the clinical *L. pneumophila* isolates genetically matched the isolates from the patient's household water samples (0-1 SNP difference between clinical and closest environmental isolate). No such matches were found with water samples from other environmental reservoirs sampled outside the patients' homes.



**FIGURE 3.4:** Overview of cgMLST clusters showing that clinical and environmental *L. pneumophila* isolates often cluster separately. Clinical and environmental isolates clustered together for ST 1, ST 23, ST 93 and ST 762. A threshold of 60 cgMLST loci was used for clustering.

**The role of WGS beyond matching: Understanding the diversity of *L. pneumophila* and its implications for routine surveillance of LD.** We also examined the overall diversity of *L. pneumophila* strains obtained from clinical and environmental samples using WGS data. FIGURE 3.4 shows that clinical and environmental *L. pneumophila* isolates often clustered separately. Particularly interesting was the large mixed ST 23/ ST 762 cluster containing clinical and environmental isolates. This cluster included seven clinical isolates, environmental isolates from a carwash, and isolates from water samples from two LD patients' homes (FIGURE 3.5). Interestingly, all patients in this large cluster lived in the same neighbourhood and all household and environmental isolates were obtained from this neighbourhood. FIGURE 3.5 also illustrates that the isolates from this cluster were very similar to clinical and environmental isolates that were recovered from northern Italy (Ricci et al., 2022).



In summary, the observed pattern of clustering for *L. pneumophila* isolates highlights some interesting features of the genomic epidemiology of LD in Switzerland:

- We see that clinical and environmental *L. pneumophila* do not always cluster together, aligning with previous finding that not all *L. pneumophila* strains have the same pathogenic potential.
- The large cluster of *L. pneumophila* sequence types suggests that there are pathogenic strains that circulate in certain areas and grow in different environmental niches.
- Although matching is difficult, investigating *L. pneumophila* clusters provides valuable insights into the role and importance of potential *Legionella* reservoirs where pathogenic *L. pneumophila* strains grow and from which they eventually disperse.

### 3.4 Conclusions and Recommendations

The recovery of both clinical and environmental *Legionella* spp. isolates will remain a bottleneck for infection source attribution. Moreover, while showers can be a source of infection for LD (CHAPTER 2), our data suggest that they are unlikely to be the primary source in Switzerland. We argue that if showers are the primary source of infection (i) we would expect higher proportion of case households to test positive for *L. pneumophila*, and (ii) if we have both, clinical isolates from the patient and environmental isolates from showers available, they should match in the vast majority of LD cases. In our nationwide study, only about 20 % (16/74) of case households tested positive for *L. pneumophila* in their potable water by cultivation. We also detected *L. pneumophila* by culture in 14% (7/50) control households. Additionally, even when *L. pneumophila* was detected, only 40 % (2 out of 5) matched the clinical strain. Therefore, to better identify significant infection sources, we suggest broader monitoring efforts. This broader monitoring can be supported through:

1. Rigorous and standardised LD case interviews to determine exposures to potential infection sources (already done to some extent in Swiss routine surveillance and currently also further explored by the *SwissLEGIO* study).
2. Provision of guidelines for cantonal laboratories and cantonal physicians to encourage and support the sampling of potential *Legionella* spp. reservoirs beyond showers.

Finally, the data showed that while matching clinical and environmental *L. pneumophila* for sporadic LD cases may not be expedient, WGS can be a valuable tool for describing the diversity of *Legionella* in Switzerland. This, in turn, could enhance our understanding of the epidemiology of *Legionella*/LD in the Swiss context. Based on these findings, we recommend the following:

- **More guidelines on environmental source investigations are needed.** Current legislation and recommendations on *Legionella* control in Switzerland primarily target drinking water. This may hamper, in practice, infection source investigations of other environmental *Legionella* reservoirs. We recommend:
  1. Developing and publishing guidelines on a central data platform outlining different sampling and laboratory processing methods. Guidelines should be accessible to cantonal authorities and private laboratories. For the laboratory protocols, we concretely suggest that they are developed in close collaboration with the National Reference Centre for *Legionella* (which has the most experience and highest success rate in isolating *L. pneumophila*) and are carefully validated prior to the broader implementation. We also advocate for incorporating Legiolert (IDEXX) or similar methods as part of the standard workflow for isolating *L. pneumophila*, particularly for potable water.
  2. Providing training for cantonal authorities on the importance of efficient and standardized sampling and processing of *Legionella* samples, both from potable water and high-risk sources such as cooling towers, wastewater treatment plants, or soil.
  3. Establishing guidelines that promote WGS as molecular typing methods for both clinical and environmental *L. pneumophila* isolates in decreed/mandated infection source investigations.
- **More harmonization means more efficient resource allocation:** The monitoring of environmental *Legionella* reservoirs is resource-intensive. We, therefore recommend the following actions to improve efficiency:
  1. Enhancing collaboration between private sector institutions (which contribute substantially to *Legionella* control) and authorities, ensuring better resource allocation (e.g. in exchanging sampling data instead of duplicating efforts through repeated sampling by authorities).
  2. Supporting and developing a central platform for standardised reporting on outcomes of monitoring/ infection source investigations by local authorities and private institutions (cf. also above).

3. Increasing efforts to collect, store, and if applicable sequence isolates obtained during source investigations or routine monitoring, and ensuring that characterisation results are reported to cantonal authorities and private labs. This could be facilitated by implementing an interactive dashboard for the WGS data on [spsp.ch](http://spsp.ch). Developing tools that aid in understanding and analysing results may also promote increased use and adoption.

- **The objectives of using WGS data for LD surveillance/ *Legionella* monitoring must be clearly defined.**

We recommend that:

1. As part of the routine surveillance, all clinical *L. pneumophila* isolates collected from LD patients are continuously sequenced (this is already being done). At the same time, we recommend continuing to invest in sensitizing physicians and clinical laboratories to the importance of obtaining such clinical *L. pneumophila* isolates and supporting them in the *Legionella*-specific cultivation of clinical samples as needed.
2. WGS data is used to understand the epidemiology of *L. pneumophila* (i) in areas with high or rapidly increasing notification rates, particularly if they are densely populated, and (ii) in situations where clusters of clinical *L. pneumophila* isolates are temporally and geographically linked. We propose launching pilot projects in densely populated regions such as the Ticino area or Basel-Stadt, where clusters of sporadic LD cases have been observed. These pilot projects should involve broader sequencing of environmental *L. pneumophila* isolates with results being shared with cantonal authorities (i.e. cantonal physicians/ laboratories). Expanding environmental screening could provide valuable insights into which *Legionella* reservoirs act as infection sources and therefore contribute to the disease burden in specific areas. As outlined above, multiple reservoirs likely contribute to cases simultaneously. Broader sequencing would also enhance our understanding of how potentially pathogenic *Legionella* strains spread geographically and over time.

Note - results from the characterization of *L. pneumophila* isolates (clinical and environmental) are currently not shared with cantonal authorities.

3. WGS is used to compare clinical and environmental *Legionella* spp. isolates in situations where vulnerable individuals are exposed (e.g. residents of nursing/ retirement homes, in hospitals). In these cases, matching isolates can contribute to more accurate risk assessment, stronger evidence for source attribution, and enable more targeted decontamination efforts. Without WGS, there is no definitive proof that the environmental strain is responsible for infection, making risk assessment and (outbreak) control less precise.
4. Where WGS is used for surveillance: To maximize the utility of WGS data it must be integrated with high-quality, essential metadata. We recommend that clinical isolates are annotated with the collection date, patient demographics (age, sex, and immune status), the type of LD (community-/hospital-acquired/ travel-associated) and the patient's residence at the district ("Bezirk") level. For environmental isolates, we recommend annotating with the collection date, the type of source (e.g. car wash, private home), and the address of the source at the district level. This metadata will help to anchor genetic data temporally and geographically.

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## 4.

Which pragmatic technical/operational improvements can reduce the risk of *Legionella* growth in buildings?

## 4.1 Background

Building plumbing is a known source of *Legionella* growth and infection (CHAPTER 3; Pedro-Botet et al. (2002); Buchholz et al. (2020)). The reason is that the complexity of building plumbing systems can create environmental conditions that favour *Legionella* growth, including high surface: volume ratios, increased nutrient availability, extended periods of stagnation and warm temperatures. Temperature is considered to be the most critical factor controlling microbial growth, particularly in the absence of disinfectants (Kistemann et al., 2024; Rasheduzzaman et al., 2020). Switzerland has well-developed guidelines with temperature specifications for different areas of the water distribution system, designed to limit *Legionella* growth (TABLE 4.1). However, errors in design, construction, implementation, as well as sub-optimal operation and unforeseen events (e.g. pandemics) can create conditions favourable for *Legionella* growth.

TABLE 4.1: Swiss temperature guidelines for building water distribution systems where the pipes are insulated and kept heated

	SIA (385/1) (2020)	SVGW (W3/E3) (2020)	BLV/BAG (2018)
Hot water storage		60 °C	60 °C
Distribution system	> 55 °C	> 55 °C	> 55 °C
Point of use	> 50 °C	> 50 °C	> 50 °C
Cold water	< 25 °C	< 25 °C	< 25 °C

Here we discuss the responses (survival, growth, death) of *Legionella* to different temperatures relevant to building plumbing systems and focus on where pragmatic and effective improvements can be made to balance consumer safety with energy saving concerns.

## 4.2 Literature review

The general response of *Legionella* to a broad range of temperatures is shown in FIGURE 4.1. These organisms are mesophilic and thermotolerant, which means they are dormant or slow growing in cold water (Wüllings and van der Kooij, 2006; Söderberg et al., 2004), optimally growing in the range of 30 – 42 °C (Wadowsky et al., 1985; Bartram et al., 2008), tolerating moderate heat (43 – 50 °C) (Kustenov et al., 1996) and dying at increasing rates with raising temperatures above 50 °C (Papagianeli et al., 2021; Dennis et al., 1984). There is, to our knowledge, no laboratory study demonstrating any significant *Legionella* growth at temperatures above 50 °C, irrespective of the species (Kusnetsov et al., 1996; Hochstrasser and Hilbi, 2022). However, viable *Legionella* have been detected at water temperatures up to 60 °C (Lesnik et al., 2016), and that repeated exposure to temperature shocks can lead to an increased heat resistance (Liang et al., 2023; Liang and Faucher, 2022). Most of the published data were generated specifically for *L. pneumophila*, and that empirical data for most other *Legionella* species do not exist. What this comes down to, is that every aspect of building plumbing systems should be designed, hydraulically balanced, and operated to avoid *Legionella* growth, which requires keeping both the cold and warm water temperatures outside the critical growth temperature range of 25 – 45 °C. In the following sections, we provide a brief overview of what this means for various components of plumbing installations.

**Hot water storage tank<sup>1</sup>:** With respect to hygiene, the hot water function is two-fold: (1) to supply sufficiently hot water that does not permit *Legionella* growth in either the storage tank or in the distribution

<sup>1</sup> Throughout this document the terminology “hot water storage tank” or “storage tank” is used. Some of the cited references may use the terminology “boiler” in the same context, particularly when referring to smaller systems where the heating and storage units are combined.

system, and (2) to serve as a thermal disinfection barrier to *Legionella* that may have grown in the system (or in the storage tank itself). With respect to the latter, disinfection efficacy increases exponentially between 50 – 60 °C (FIGURE 4.1). Thus, lowering hot water storage tank temperatures to save energy directly compromises efficacy of the thermal barrier. Hence, when optimisation towards energy saving is a goal, it is critical that the hot water storage tank does not become the source of *Legionella* growth, e.g. due to selectively moderate temperatures and lime deposits (Dewailly and Joly, 1991; Cazals et al., 2022).

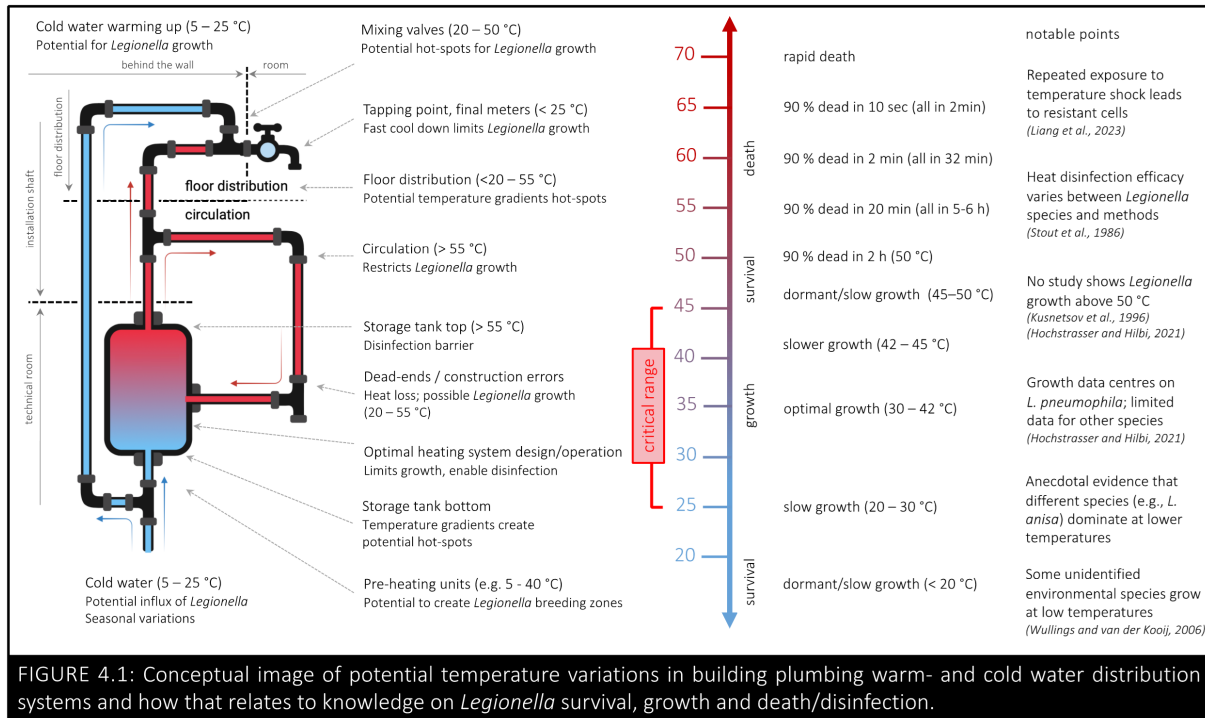


FIGURE 4.1: Conceptual image of potential temperature variations in building plumbing warm- and cold water distribution systems and how that relates to knowledge on *Legionella* survival, growth and death/disinfection.

**Warm water circulation:** The function of circulation systems is to maintain warm water close to the tapping points throughout the building. Even when insulated, circulation systems inevitably suffer temperature loss. With respect to *Legionella*, the goal is to maintain warm water temperatures throughout the entire circulating hot water system that are consistently high enough to limit *Legionella* colonisation and growth (discussed in detail below).

**Floor distribution and fixtures:** According to Swiss regulations up to one meter of the floor distribution can be heated, but the downstream pipes up to and including tapping points must be able to cool down to room temperature (< 25 °C) quickly after use. Accordingly, these installation parts must not be insulated. This approach does not guarantee the absence of *Legionella*; design errors, imperfect hydraulics and/or slow growth at moderate room temperatures can all lead to conditions favouring *Legionella* growth. There is well-documented evidence of *Legionella* growth in these peripheral sections of otherwise properly managed building plumbing systems (Kistemann et al., 2024; Arvand et al., 2011). A simple explanation for the latter is that *Legionella* is fully capable of growing, albeit slowly, at temperatures at or even below 25 °C (Söderberg et al., 2004).

**Limiting or suppressing *Legionella* growth at high water temperatures:** Maintaining high water temperatures throughout a building plumbing system is universally recognized as a strategy for controlling *Legionella* colonization and growth, particularly in the absence of disinfectants. In this regard, there is general consensus that temperatures above 60 °C are effective in disinfecting *Legionella* in the hot water storage tank and also for controlling *Legionella* growth in then network (Mathys et al., 2008; Kistemann et al., 2024). However, maintaining water temperatures above 60 °C is sometimes undesirable and even problematic because of (1) the inherent danger of scalding, (2) the demand for energy savings and efficient heat pump performances, and (3) lime precipitation (Heida et al., 2021; Rasheduzzaman et al., 2020). There is also general consensus that hot water temperatures below 50 °C are insufficient

to control *Legionella* growth in building plumbing systems (Mathys et al., 2008). Thus, the focus with respect to both hygiene and energy saving is the relatively narrow temperature range of 50 – 60 °C. Here, most studies on actual buildings converge on 55 °C (distributed water temperature) as the crucial temperature threshold, above which *Legionella* growth is significantly – but often not completely – inhibited (Darelid et al., 2002). For example, focusing on hotels, Rasheduzzaman et al. (2020) concluded from a meta-analysis that the probability of detecting *Legionella* decreased on average by 60 % when the water temperature was increased from 50 °C to 55 °C, and identified 55 °C as the critical temperature for maintaining acceptably low *Legionella*-positive samples. Similarly, in a particularly large study (292,937 data sets) of German potable water samples, Kistemann et al. (2024) concluded that temperatures above 55 °C in circulation systems are in general sufficient to control *Legionella*. More specifically, these authors calculated “individual tipping point temperatures at which there is a higher risk of *Legionella* spp. growth”, and defined 53 °C as the critical temperature for the hot water return (Kistemann et al., 2024). Importantly, Kistemann et al. (2024) noted that maintaining high temperatures in the circulation system does not necessarily translate to the absence of *Legionella* in peripheral samples. In summary, studies show that from a hygienic perspective, hotter water (> 60 °C) is always better, but that 55 °C is a reasonable compromise for energy saving. Moreover, it is clear that detailed temperature and *Legionella* monitoring is essential in order to prevent and/or quickly correct any system malfunctioning. With these measures and under optimal construction and operation conditions, there may even be opportunities to reduce circulation temperatures to as low as 52 °C (SIA-385/1, 2020; Völker et al., 2016).

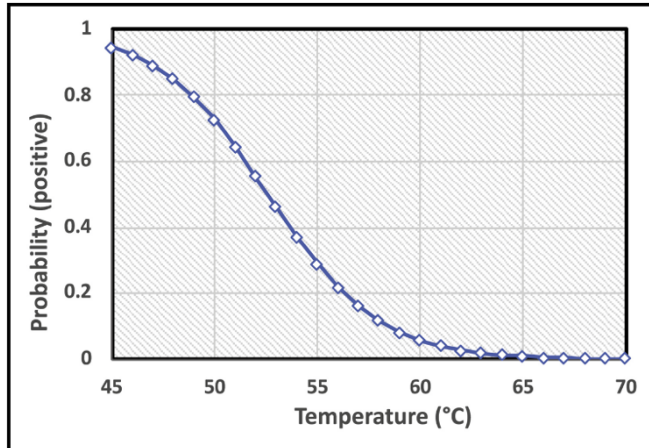


FIGURE 4.2: Probability of *Legionella* positive events at different hot water tap temperatures (Rasheduzzaman et al., 2020)

**A discrepancy between real building data and in vitro studies.** Laboratory studies have found no evidence of *Legionella* growth above 50 °C, and only very limited growth between 45 – 50 °C (Kusnetsov et al., 1996; Hochstrasser and Hilbi, 2022). Yet real-building studies consistently find problematic *Legionella* numbers in buildings with temperatures between 45 – 60 °C (Rasheduzzaman et al., 2020; Lesnik et al., 2016). There are several reasons for this apparent discrepancy, including that intended hot water temperatures are not maintained throughout the entire system, or that the final non-insulated meters do not cool down sufficiently between use, allowing water temperatures in the range favourable for *Legionella* growth.

### 4.3 LeCo project results

A sub-section of the LeCo project focused on building-plumbing related aspects that can affect *Legionella* occurrence such as, (a) microbial growth after first filling of a new building, (b) long-term stagnation and the impact of flushing (Rhoads et al., 2022), (c) temperatures required to disinfect different *Legionella* species, (d) suboptimal design and operational aspects in existing buildings, and (e) optimising water distribution concepts in new buildings. Here we discuss predominantly the latter two, with a broader view taken in the final recommendations.

**Problems in existing buildings:** The purpose of potable water installations in buildings is to provide the user with hygienically safe water in sufficient quantities and appropriate temperatures under optimal technical and economic conditions. Involved stakeholders (e.g. investors, planners, contractors, operators) have different perspectives and priorities, making it difficult to fulfil all these requirements without

compromise. As part of the LeCo project, 15 hot water distribution systems in various building categories (sports facilities, retirement homes, hospitals, residential buildings) were assessed with respect to their hygienic condition and energy efficiency (TABLES 4.2 and 4.3).

**TABLE 4.2:** Commonly-detected design, construction and operational aspects affecting optimal hygienic operation of building plumbing systems

	Problem description	Possible effects	Possible measures
1	The cold-water supply pipe into the hot water tank often has temperatures above 25 °C. This is probably due to turbulences in the bottom of the hot water tank that affects the thermal stratification.	Turbulent inflow and warm, but not hot temperatures in the hot water storage tank promote <i>Legionella</i> growth, detachment of cells from the biofilm and thus increase the microbial load in the hot water tank, challenging the thermal barrier.	(1) Connecting the cold-water supply from below instead of from the side of the storage tank. (2) Ensuring cold water inflow at low velocity. (3) Proper and complete insulation of the cold-water pipes. (4) Maintaining thermal stratification with a permanently cold-water volume at the bottom by placing the OFF sensor at a sufficiently high point.
2	The charging pipe is often drawn in directly via the cold-water pipe, which allows sediments and microorganisms to enter the charging pipe and spread in the upper storage volume.	Sediments can damage pumps and heat exchangers consequently leading to conditions that promote microbial growth. They can also lead to deposits and microbiological contamination in the hot water pipes.	The charging pipe intake should be located on the side of the storage tank in the mixing and cold zone (approx. 30 cm below the OFF-sensor).
3	The charging pipe is often connected directly to the hot water distribution pipe, so that the heated water does not enter the storage tank but goes directly into the hot water supply pipe.	This can lead to <i>Legionella</i> already present in the water not being sufficiently disinfected and/or the temperature in the hot water distribution system being lower than expected, thus increasing the risk of <i>Legionella</i> growth in the distribution system.	The heated water must flow into the hot water storage tank with low pulsation and should not be fed directly into the hot water pipe downstream of the hot water tank. In the case of stratified loading, the heated water should be fed directly into the peak coverage volume, in the case of step loading into the centre of the storage tank. A heat siphon is needed to prevent counterflows and thus undesirable cooling of the storage tank.
4	The circulation system is often not correctly connected to the hot water storage tank. For example: the circulation return is fed directly back into the hot water pipe, or into the thermal barrier volume.	In both cases, there is a risk that any <i>Legionella</i> in the circulation water will not be (sufficiently) disinfected before they re-enter the water distribution system.	The circulation pipe should be connected in the centre of the hot water storage tank. If two tanks are provided, the circulation can be routed to both cylinders depending on the circulation temperature. However, the return to the reheat storage tank must be below the thermal barrier volume.
5	The circulation pump is temporarily switched off in an attempt to save energy (often at night for 2 to 6 hours).	The interruption of the circulation is usually too short for the hot water to cool down to ambient temperature. This means that no energy can be saved, as the heat losses have to be reheated at a 1:1 ratio. Moreover, this means that the circulation water regularly remains at temperatures that allow <i>Legionella</i> growth.	Circulation pumps should be in continuous operation (24/7). Switching off is only meaningful if the water temperature can drop below 25 °C.
6	There is a lack of temperature measurements at critical points in the heating, storage and distribution system	Makes it impossible to check if the hot water heating system is functional and without any significant hygiene risks, either after new construction/conversion or during ongoing operation. Deviations and problems that promote microbial growth	It is essential to implement temperature sensors at the critical points. This is the only way to recognise potential hygiene risks linked to water heating after construction but also during operation, and to resolve them as quickly as possible.

		thus remain undetected and <i>Legionella</i> can spread throughout the entire system. This also makes troubleshooting and successful remediation more difficult in the event of <i>Legionella</i> contamination.	
7	Most water heating systems lack sampling points to check the water quality.	Microbiological testing in accordance with the SVGW guideline W3/E3 is therefore not possible, enhancing the risk that microbiological problems will be recognised too late.	Sampling points must be installed in accordance with SVGW guideline W3/E3.
8	To protect against scalding, the hot water is mixed centrally with cold water and thus distributed at lower temperatures.	The centralised addition of cold water often means that the hot water in the distribution system no longer has sufficiently high temperatures everywhere and microbial growth is encouraged.	If scalding protection is required, this should be implemented at the tapping point instead of centrally. If central mixing is unavoidable, the mixing ratio must be selected so that the hot water temperatures in the distribution system are still high enough to prevent microbial growth.

**TABLE 4.3:** Commonly-detected design, construction and operational aspects affecting optimal energy-efficient operation of building plumbing systems

	Problem description	Possible effects	Possible measures
A	Heated pipes (mainly storage tank connections) are not insulated throughout.	Uninsulated areas cause unnecessary heat loss.	All pipes and components that are kept heated must be insulated in accordance with the regulations.
B	Hot water is often charged with a secondary mixing circuit.	The exergy losses are higher. As a result, energy-efficient heat generation is not possible.	A throttle circuit with speed-controlled circulation pump must be provided in the secondary loading circuit.
C	Higher return temperatures can indicate limescale deposits in the heat exchangers.	Limescale deposits lead to a deterioration in the heat transfer coefficient.	Limescale deposits must be removed regularly.
D	Pressure and thus temperature fluctuations in freshwater stations.	Excessive pressure losses in the heat exchangers of freshwater stations lead to pressure fluctuations. Resulting different volume flows in the cold and hot water pipes further lead to critical temperature fluctuations.	Connect several heat exchangers in a cascade, whereby no heat exchanger has a pressure loss of more than 20 kPa.
E	Control of water heating systems with thermostats.	Depending on the position of the thermostat and the hysteresis setting, the defined standby volume is not fully heated.	Temperature sensors must be installed in the right place so that they can be used as on/off controllers for optimum charging of the hot water storage tank
F	The circulation return has a significantly lower temperature than the storage tank volume into which it is returned	Circulation to the storage tank can cause additional loading times. Recharging takes place at high storage temperatures and therefore high loading temperatures. This prevents energy-efficient charging operation.	Cover circulation heat losses externally with a small heat generator.
G	Water heating systems are often insufficiently documented.	This makes it difficult or even impossible to check whether the system is running perfectly in terms of energy and hygiene or whether corresponding optimisations are necessary and, if so, of what kind.	Up-to-date, complete documentation of the hot water system should be available at all times so that regular and appropriate maintenance and repair can be carried out.

**Floor distribution design and construction:** We focused in the LeCo project specifically on the floor distribution, given the fact that *Legionella* contamination often occur in the peripheral parts of building plumbing systems despite high water temperatures in the circulation (Kistemann et al., 2024). The floor distribution is the section of pipes from the outlet of an actively heated pipe (e.g. by means of circulation or a heat retention bands) that supplies a tapping point with hot water. Here the first meter can be heated passively by means of counterflow circulation (FIGURE 4.3; SIA-385/1 (2020)). This assumes that in the event of water stagnation, the water in the pipe flows in both directions due to temperature or density differences, creating a counterflow. After this passively heated section, a thermal separation takes place using a heat siphon, preventing the formation of a counterflow in the unheated (and thus non-insulated) pipe sections. This non-insulated pipe section thus cools down to ambient temperature during periods of stagnation. It is essential to ensure that the temperatures in the passively heated and non-heated pipe sections of the floor distribution remain outside the microbiologically critical temperature range (25 – 45 °C) during extended or repeated stagnation periods. In the LeCo project we analysed multiple accepted and proposed variations of floor distribution configurations<sup>2</sup>. Below we discuss three configurations in which insulated first meter pipes are compared with non-insulated pipes (FIGURE 4.3), and three configurations in which insulated first meter pipes are compared with and without a 5 % gradient (FIGURE 4.4).

- 1. Insulated vs non-insulated first meter:** The standard design is that the first meter of pipe is insulated to maintain heat (SIA 385/1:2020). Our experimental data showed that when a flow resistance was present in the first meter, both insulated and non-insulated pipes reached (and remained in) temperatures in the microbiologically critical range (25 - 45 °C) for extended periods during stagnation. Only the first 30 cm remain above the critical temperature range, irrespective of whether insulation was present or not. The configuration without flow resistance in the first meter (Variant 3) did not improve the temperature profiles much, with the water temperature prior to the heat siphon remaining in the critical zone during stagnation. After the heat siphon, the temperature dropped below 25 °C after around 120 minutes of stagnation. In short, all three of these configurations, which are standard practice in building plumbing construction, can create situations where optimal temperatures for *Legionella* growth occur.

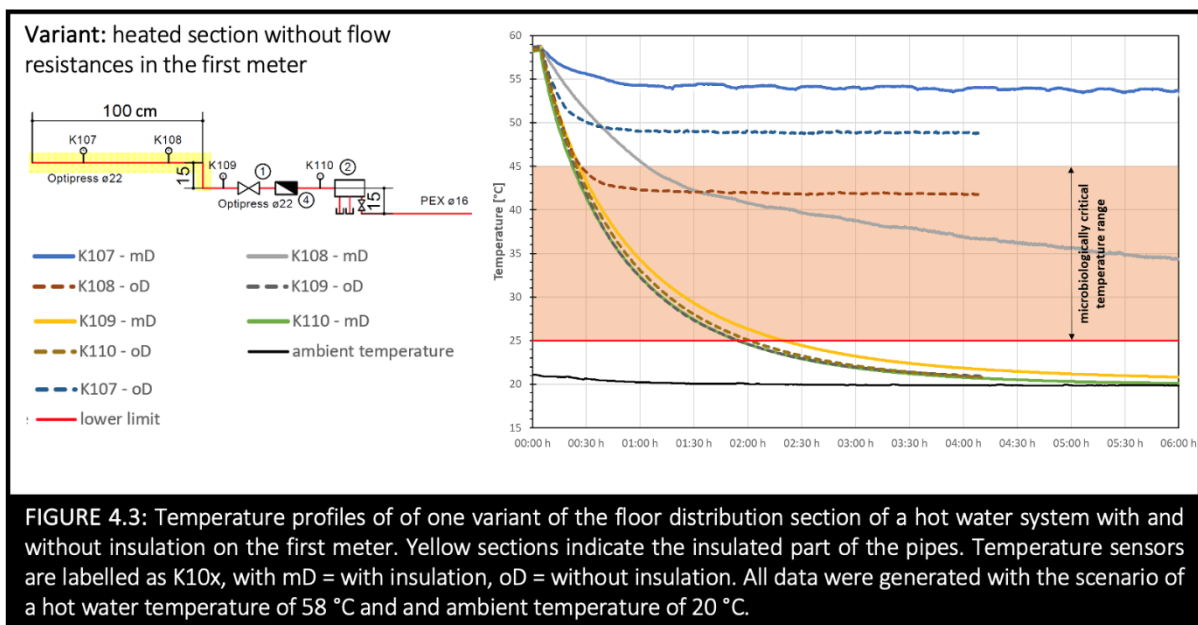
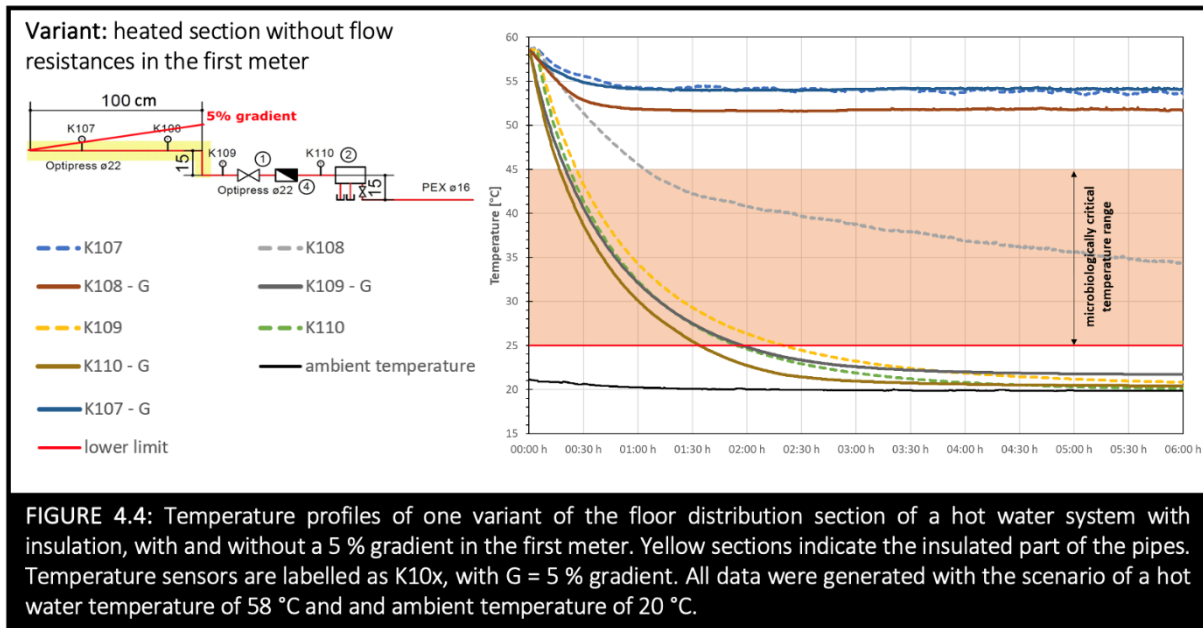


FIGURE 4.3: Temperature profiles of one variant of the floor distribution section of a hot water system with and without insulation on the first meter. Yellow sections indicate the insulated part of the pipes. Temperature sensors are labelled as K10x, with mD = with insulation, oD = without insulation. All data were generated with the scenario of a hot water temperature of 58 °C and an ambient temperature of 20 °C.

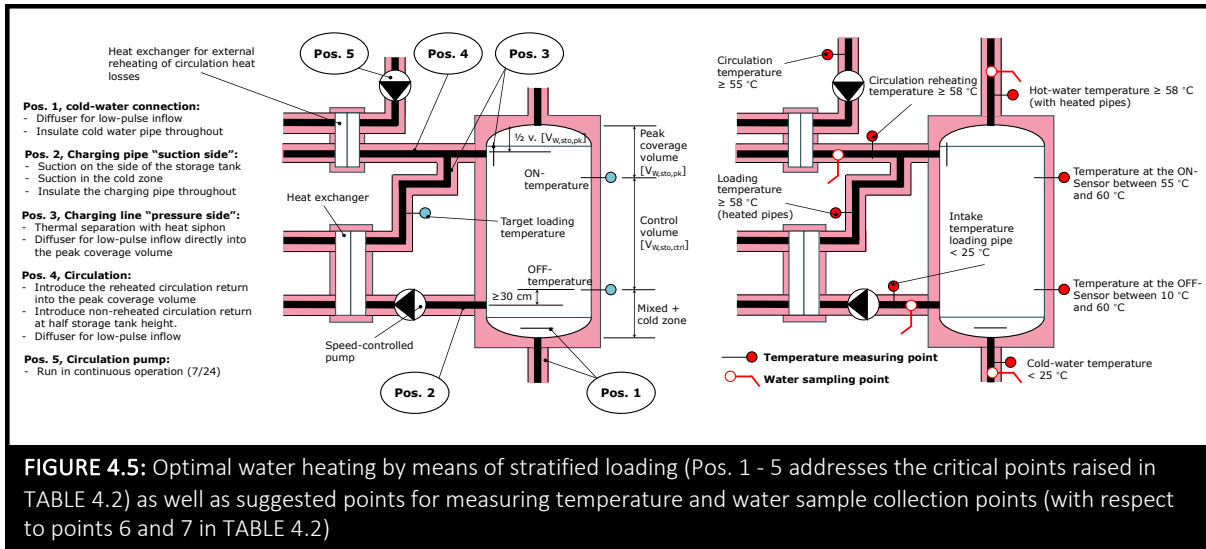
<sup>2</sup> Experimental details from all the different experimental configurations and test conditions are provided in the LeCo Project Report (2024)

2. **Insulated first meter with and without a 5 % gradient:** The data showed that a 5 % gradient sufficed in two of the configurations (with a valve or without any flow resistance) to keep the pipe temperatures either above or below the microbiologically critical range (25 - 45 °C) for extended periods during stagnation. However, with several flow resistances in the first meter (valve and water meter), the counterflow is too weak and the water temperature stagnates in the hygienically critical temperature range for a longer period. It is evident from the data that a relatively minor technical adjustment (5 % gradient) can result in a considerable improvement in the temperature situation of the floor distribution, resulting in both energy saving and a better hygienic situation.

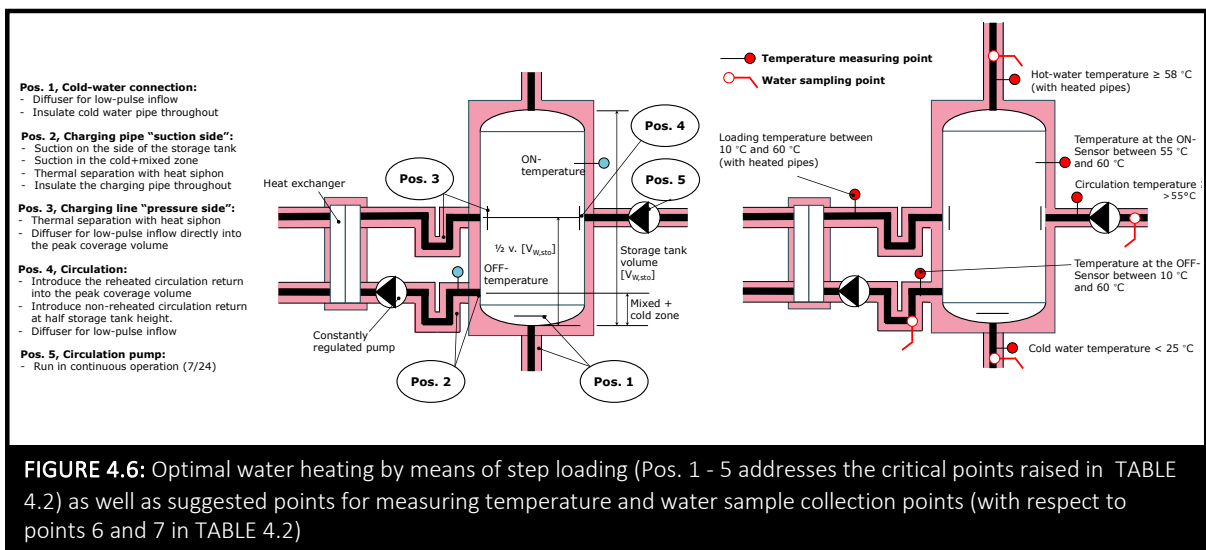


#### 4.4 Conclusions and Recommendations

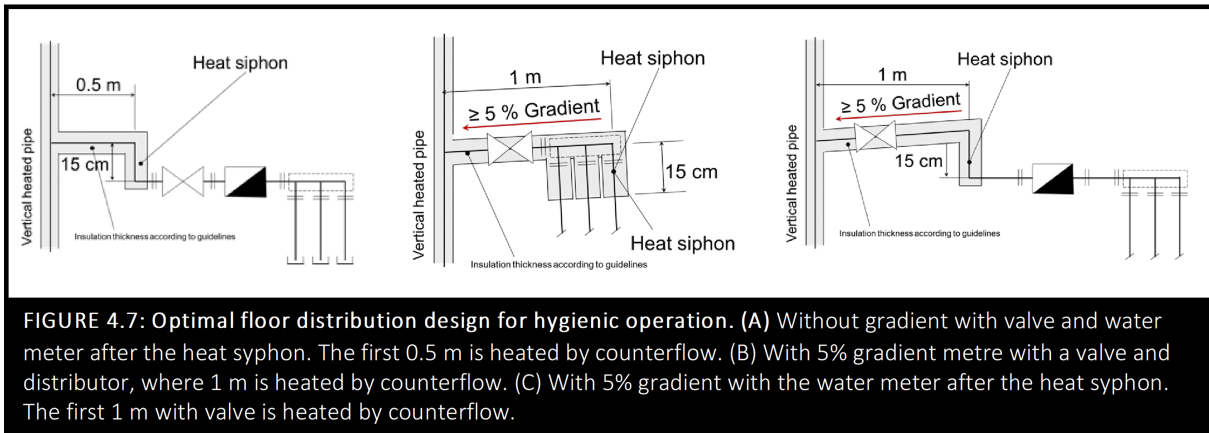
Temperatures in buildings are variable and challenging to maintain due to the complexity of building plumbing systems (FIGURE 4.1). Any possibility for energy saving in combination with maintaining hygienic safety is confined to a relatively narrow working range of about 52 – 60 °C, and is most likely building/situation specific. We argue that a first critical step is to identify and improve frequently-observed problems in existing plumbing systems (TABLES 4.2 and 4.3). In addition, small but pragmatic improvements can be made to system design, both when constructing a new system or renovating and existing one. Based on the above findings, the following two water heating systems and three floor distributions can be presented, which we suggest are optimal from both an energy and a hygiene point of view.



**Optimal water heating with stratified loading.** Stratified loading is often used in buildings where people are present who are sensitive to health issues, such as hospital buildings, retirement homes, sports facilities. During stratified loading, the water is taken from the lower, cold storage tank area (cold zone), heated to the required hot water temperature via the heat exchanger and layered into the hot peak coverage volume as hot water in the upper storage tank area. The tank is heated layer by layer from top to bottom until the target temperature is reached at the OFF-sensor. FIGURE 4.5 shows the optimal configuration for a water heating and storage system with stratified loading, addressing some of the main points raised in TABLE 4.2.



**Optimal water heating with step loading.** Step loading is used primarily in buildings in which people are present who are less sensitive to health risks, such as in single-family houses and apartment houses and in buildings with a low hot water requirement. If the water temperatures within a storage tank are not the same everywhere, local movements (convection currents) occur due to the differences in density. If the water is heated locally, the heated water rises, and circular currents are formed. This flow causes the water in the storage tank to be heated "in stages", which is why such storage tank charges are also referred to as step loading. FIGURE 4.6 shows the optimal configuration for a water heating and storage system with step loading, addressing some of the main points raised in TABLE 4.2.



**Optimised floor distribution with and without gradients and the arrangement of flow resistors.** *Legionella* contamination is known to occur in peripheral parts of building plumbing systems, and the data shown in FIGURES 4.3 and 4.4 highlight potential temperature-critical zones in the floor distribution section. FIGURE 4.7 show the configuration examples that we believe are optimal for maintaining sufficiently hot water in the insulated sections and rapid cool down in the non-insulated sections, in order to avoid the critical temperature range where *Legionella* grows.

**Further recommendations include:**

1. Using the temperature in the heated distribution system (as measured on return to the hot water storage tank), opposed to the temperature leaving the hot water storage tank, as the guidance temperature for *Legionella* control. Here, 55 °C is suggested sufficient to obtain hygienic safety. However, to ensure the required temperature, every riser should be monitored individually.
2. Temperature measurements at critical points within the water heating system are essential for energy-efficient operation and an initial hygienic assessment.
3. Easily accessible water sampling points must be provided for taking hygienic random samples or for sampling the system during temperature-critical operation.
4. In addition, existing regulations such as the SIA 385 series of standards and the SVGW 3 guideline must be reviewed every five years to ensure that they are up to date and, if necessary, adapted to new scientific findings and practical experience. Both theoretical and practice-orientated findings must be considered to ensure practical and scientifically sound application.
5. Finally, it is crucial that these regulations are taught in training and further education programmes. In addition to the correct technical implementation (the “how”), a deep understanding of the background and necessities (the “why”) must also be ensured to guarantee safe and efficient long-term operation.
6. While this project focused on large buildings with complex plumbing systems, a dedicated study on heat pumps would be beneficial for private homeowners. Many private houses use heat pumps, which tend to be less efficient at higher temperatures. Further research on optimizing heat pump performance across different temperature conditions, with a focus on microbiologically optimal temperature levels, could provide valuable insights and practical guidance.

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## 4.5 References

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## Conclusion

Legionnaires' disease incidence has increased steadily worldwide during the last two decades (FIGURE 0.1) despite more than 40 years of excellent basic and applied research and its translation into building codes, operational guidelines and legislation. Apart from increased awareness, testing and reporting, there are two general explanations for this: first, *Legionella* spp. are found practically everywhere in both natural and engineered aquatic ecosystems, while the exact source of contamination is difficult to identify and thus to manage (CHAPTER 3). Second, the environment and exposure dynamics are constantly changing, for example through an aging population (i.e. increased vulnerability), denser population developments (i.e. increased exposure), new personal appliances such as humidifiers (i.e., new sources), different building practices (e.g., blue-green infrastructure), and climate change.

Legionnaires' disease is seasonal, with the highest incidence rates in summer, linked to warm temperatures, high humidity and excessive rainfall events. Current evidence points towards climate change exacerbating all these variables. Following the ecological principle of "*everything is everywhere, but the environment selects*", these changes have the potential to drastically impact Legionnaires' disease cases in Switzerland on multiple levels. It is likely that the potential sources of *Legionella* (FIGURE 3.1) can change through the emergence of new sources (e.g., more cooling towers in operation) or changes in the concentrations of *Legionella* in specific sources. For example, higher ambient temperatures would alter conditions in the peripheral sections of building plumbing systems (FIGURE 4.1), thus changing the temperature profiles (FIGURE 4.2) and potentially creating new niches for *Legionella* growth. The diversity of *Legionella* (FIGURE 1.1) also implies that changing environments may well facilitate growth of different *Legionella* species of which the risks are not properly established (CHAPTER 1, CHAPTER 2).

The observed seasonality in Legionnaires' disease cases has one further implication: it suggests that many sporadic cases are likely the result of infections occurring outside of residential homes, where temperature, humidity and rainfall have a more direct impact on *Legionella* growth and transmission in the environment. The risk assessment (CHAPTER 2) and case-control investigations (CHAPTER 3) seem to confirm that building hot water systems may not necessarily be the primary source of infections in Switzerland. The Swiss building sector has accepted and incorporated meaningful guidelines to safeguard plumbing systems. Rather than imposing additional regulations, we recommend that existing guidelines are incorporated better (CHAPTER 4), and that serious consideration is given to focusing future guidelines only on *L. pneumophila* in the case of low-risk buildings, to facilitate better resource allocation in dealing with contaminated buildings. It is also recommended that more potential sources are considered for routine monitoring, such as cooling towers and wastewater treatment facilities.

It is evident that all these challenges above require ongoing and dedicated interdisciplinary action on multiple stakeholder levels. The research in this project benefitted tremendously from the diverse input of three separate Federal Offices, and from the close collaboration and knowledge exchange between researchers from epidemiology, microbiology, building technology and routine control backgrounds. The outcome of these collaborations is shared through the various project reports, through four PhD theses and 17 master/bachelor projects, and to date 18 publications, with several more in the processing pipeline. Furthermore, the LeCo project brought together *Legionella* experts from around the world in a dedicated scientific symposium (June 2024), and further knowledge sharing is planned through a Swiss stakeholder event (planned for May 2025). It is our hope that this project encourages ongoing interactive collaboration between basic research, applied research, government and industry across diverse disciplines, essential to resolve the challenges posed by *Legionella* in Switzerland.

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## LeCo Publications

- Bigler and Mäusezahl (2025)\*: Die Legionärserkrankung in der Schweiz: Eine nationale Fall-Kontroll-Studie zur Untersuchung von Risikofaktoren und Infektionsquellen (*SwissLEGIO*). *BAG Bulletin*, in press.
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- Eichelberg et al. (2025)\*: Den Legionellen die Stirn bieten. [Aqua & Gas | Plattform für Wasser, Gas und Wärme | 20251111 A&G](#)
- Fischer et al. (2023)\*: 'Legionnaires' disease in Switzerland: rationale and study protocol of a prospective national case-control and molecular source attribution study (*SwissLEGIO*). *Infection* 51: 1467–1479. <https://doi.org/10.1007/s15010-023-02014-x>
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- Gabrielli et al. (2024): Expansion, restructuring and characterization of the *Legionellaceae* family. *bioRxiv*. <https://doi.org/10.1101/2024.10.21.619444>
- Hammes et al. (2025)\*: Foresight 2035: A perspective on the next decade of research on the management of *Legionella* spp. in engineered aquatic environments. *FEMS Microbiology Reviews*, 49:fuaf022. doi: [10.1093/femsre/fuaf022](https://doi.org/10.1093/femsre/fuaf022)
- Margot et al. (2021): Une étude de cas de contrôle des légionelles par la température. *Aqua & Gas*. [Aqua & Gas | Plateforme pour l'eau, le gaz et la chaleur | 20210831 Légionelles et eau potable - étude de cas](#)

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\* Joint LeCo and SwissLEGIO publication

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- Methode MW 101 «Untersuchung von Gebäude-Trinkwasserinstallationen auf *Legionellen* Beprobungsstrategie und Probenahme» (09/2021) *des Schweizerischen Verein des Gas- und Wasserfaches* (SVGW). [Methodenkatalog | SVGW](#)

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\* Joint LeCo and SwissLEGIO publication