Cool ways of using low grade Heat Sources from Cooling and Surplus Heat for heating of Energy Efficient Buildings with new Low Temperature District Heating (LTDH) Solutions.

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Dissemination level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
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Scope of deliverable

This report aims to give an overview over possible different technical solutions to prevent *legionella* growth in domestic hot water system. The report also aims to summarise the prevalence of *legionella* cases in six countries (Sweden, Denmark, Norway, Finland, Germany and France) and compare it with the legislative framework within these countries regarding *Legionella* in domestic hot water systems.

Context of deliverable

The report provides a summary of the research front on what solutions can work for *Legionella* prevention in low-temperature district heating networks and how these solutions relate to today´s legislative rules regarding *Legionella* in domestic hot water systems.

Perspective of deliverable

Low temperatures in domestic hot water systems increases the risk of growth of *Legionella* bacteria which if inhaled can cause Pontiac fever or Legionnaires' disease. As the district heating industry strives to lower the supply temperature in district heating systems in order to achieve higher system efficiency, new solutions might be needed for solving the problems of *Legionella* growth in the customers' domestic hot water systems.

Involved partners

Lund University (the Department of Energy Sciences) was responsible for compiling and authoring this report.

Much of the work with gathering and compiling data for this report has been carried out within the framework of a degree project that resulted in a master's thesis with the title *Overcoming issues with Legionella in DHW in LTDH systems* by Klara Ottosson and Linita Karlsson at the Department of Energy Sciences at Lund University. The degree project was supervised by Kerstin Sernhed and Per-Olof Johansson Kallioniemi at Lund University and Martin Gierow and Markus Falkvall at Kraftringen AB. The master's thesis can be downloaded at the following link: https://lup.lub.lu.se/student-papers/search/publication/8945437

The present report is a processed version of the master's thesis. The content of the thesis has been reviewed, modified and further developed by Janusz Wollerstrand, Kerstin Sernhed and Per-Olof Johansson Kallioniemi at Lund University. EuroHeat & Power has also contributed in the search for relevant literature.

COWI has provided info on the different anti legionella water treatment technologies and has prepared the Technology Sheets appended to the report. Further COWI has carried out quality check on the final document.

Summary

Legionellae are bacteria that naturally exist in freshwater environments, but have also been found in seawater and soils. *Legionella* can cause illnesses such as Legionnaires' disease or Pontiac Fever where the Legionnaires' disease is a severe variant of Pneumonia and Pontiac Fever is a milder influenza like variant. *Legionella* bacteria can grow in domestic hot water systems (DHW systems) and in order to prohibit bacterial growth, national temperature levels on DHW systems have been set.

As the district heating industry strives to lower the supply temperature in district heating systems to achieve higher system efficiency, new solutions might be needed for solving the problems of *Legionella* growth in the customers' domestic hot water systems.

The aim of this report is to:

- give an overview over the regulations in domestic hot water systems in terms of *Legionella* safety in six European countries (Sweden, Denmark, Norway, Finland, Germany and France)
- give an overview on different techniques for *Legionella* prevention.
- make an analysis on the advantages and disadvantages of the different techniques and how these techniques comply with today's regulation of domestic hot water systems as well as to analyse the applicability of the different methods when used within a low temperature district heating context.
- make a statistical outlook on the incidence of Legionnaires disease in the six selected countries and how the incidence levels relate to regulated temperature levels for domestic hot water systems.

The review of national rules regarding *Legionella* safety in DHW systems shows that the legislation in all countries is based on maintaining a sufficient temperature in domestic hot water systems in order to make an unfavourable environment to the *Legionella* bacteria. There are no rules that deal with the control of bacterial levels of *Legionella* in the water. The temperature level requirements in the six different countries differ. For most countries, the DHW temperature requirements are set to minimum 50 °C at the drain point and 60 °C in storage tanks with stagnant water. Some countries have chosen to set the temperature requirements even higher, for example Norway that declares that Legionella should be controlled by keeping the temperature in circulating water systems above 65 °C. Other countries, such as France and Germany, use special legislations for small DHW systems (this special legislation is often referred to as 'the 3-litre-rule'), and in Denmark a DHW temperature of 45 °C is permitted at times of peak flow.

Our overview over feasible technical solutions for preventing *Legionella* growth in domestic hot water systems shows that there are several alternative techniques that theoretically could prevent Legionella growth besides the conventional one based on keeping a high water temperature. Many of these methods, however, come to short because they cannot be viewed as completely safe or as good long-term solutions, or they have not been commercialised and fully tested yet. Because of the legal temperature requirements in domestic hot water systems, the alternative techniques for *Legionella* control could not be used as single methods if ultra-low temperature district heating is used (with a supply temperature of 50 °C), since the legal temperature requirements would then not be met. That means that today's legislation does not support ultra-low supply temperature in district heating grids in most EU countries unless the DHW temperature in the customer installation can be boosted using local heating solutions, such as electric heat tracing, micro heat pumps or instantaneous water heaters. In countries applying the 3-litre-rule, DHW preparation in decentralized DH substations could be a solution. When decentralized DH substations is used, the DHW is heated up instantly in a small heat exchanger with short residence time (seconds). The question arises if such heat-up has a significant influence on Legionella survival dependant on if the set point temperature is 55 or 45 °C. More research is needed to bring clarity if the small DHW systems can be assumed to be *Legionella* safe. If the answer is yes, this could open up for usage of ULTDH for direct preparation of DHW at 45 C° in instantaneous heaters.

According to statistics from the European Working Group for *Legionella* Infections (EWGLI), the countries with the lower temperature requirements actually do show more incidences of Legionnaires' disease. The findings are interesting although it is not possible to establish causal relationship by these variables within the framework of this study - if it is even possible to determine this at all. There may be other, underlying, variables that can explain this relationship. Nevertheless, for health reasons, and for PR reasons, it may be wise to use a precautionary principle for alternative techniques to prevent *Legionella* growth. It would not be fruitful to build a heating system that increases residents' risk of getting *Legionella*; furthermore, such a development could conduce to denigrate district heating reputation.

If the research on *Legionella* safety in small DHW systems can show good results, there will be reason to argue for some legal changes. Today's legal requirements in DHW systems can then be seen to unnecessarily aggravate possible system efficiency in the district heating business that comes with lower supply temperatures.

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1 Introduction

Cool District Heating is a project anchored in two demonstrations of low temperature district heating systems in the cities of Lund in Sweden and Høje-Taastrup in Denmark. Both cities have high ambitions on climate and smart-city policies and want to implement smart system solutions for their fourth generation district heating.

The system efficiency of district heating (DH) can increase by using lower system temperatures. This leads to lower energy losses and enhanced potential to include more waste heat with lower quality into the systems. Depending on what heating production plants are used in the DH system, better operating conditions can also be achieved for example for CHP plants and heat pumps.

To what extent DH temperature can be reduced, is set by the ability to provide good indoor climate and good comfort level on domestic hot water for the connected customers. Within new buildings, with modern low temperature heating system such as under floor heating, the lower limit of supply temperature requirements from the DH supplier is not set by the demand for space heating but by the temperature requirements of domestic hot water systems, in order to prevent *Legionella* growth. The legal requirements for avoiding *Legionella* growth typically involves temperature requirements in tanks and domestic hot water pipes that can kill the *Legionella* bacteria. With ultra-low system temperatures like 50 °C, there is a risk that *Legionella* bacteria will not be sufficiently killed and can then cause illnesses such as Legionnaires' disease, which is a severe variant of Pneumonia, or Pontiac Fever that is a milder influenza like variant. In order to be able to use really low system temperatures in district heating systems, new technical solutions are sought for *Legionella* control in domestic hot water systems.

The aims and methods of this report are:

1. To provide a compilation of the legislation associated with *Legionella* control in domestic hot water systems in Sweden and Denmark as well as in four other European countries (Finland, France, Germany and Norway). The legislation was studied through a literature study of relevant national legislation and or by using second hand sources by referencing a scientific article that mentioned the legislation in question.
2. To give an overview over incidences of Legionnaires’ disease in the six included countries and how the ratio of incidences correlates with the actual legislative rules and requirements of system temperatures in the countries. The material on statistics arises from reports written by international and national authorities, e.g. ELDSNet and Eurostat, Public Health Agency of Sweden or corresponding agency of the other countries.
3. To give an overview over different techniques that could be used for *Legionella* prevention in domestic hot water systems. Information on techniques for *Legionella* control was obtained by a literature study mainly based on known authorities and scientific journals. A large share of the material was found using the Lund University search engine LUB search. It enables finding and accessing published scientific articles from around the globe. Relevant key words used for literature searching was for example: low temperature district heating, *Legionella*, and 4th generation district heating, or a combination of these. In addition to the literature study a focus group interview with five building constructors were held in Lund. The aim of the focus group interview was to discuss attitudes regarding *Legionella* matters with stakeholders.

The collected material provides a basis for actors that are interested in the fourth generation district heating and in finding system solutions that are reliable, *Legionella* safe and cost-effective.

2 Background

2.1 Legionella bacteria

Legionellae are bacteria that naturally exist in freshwater environments but have also been found in seawater and soils (World Health Organization, 2007). The risks for these natural environments to promote high bacterial proliferation are, however, small. Artificial water systems offers a more favorable environment for bacterial growth than natural environments because of the auspicious temperatures, the often stagnant water that exists in tanks and pipes and the favorable circumstances on the coatings on pipes where bacteria can accumulate as well as the oxygen rich environment (Folkhälsomyndigheten, 2015c).

In the Legionellaceae family, there are 59 known species out of which 26 species have been associated with causing diseases (Folkhälsomyndigheten, 2015a). One of these species is *Legionella pneumophila* which causes 80-90% of all diseases associated with the genus *Legionella* (Folkhälsomyndigheten, 2015b). The species *L. pneumophila* in turn is divided into 16 serogroups[1], with bacteria from serogroup 1 being the primary cause of illness.

Figure 1 shows the growth rate for *Legionella* pneumophila in different temperatures.

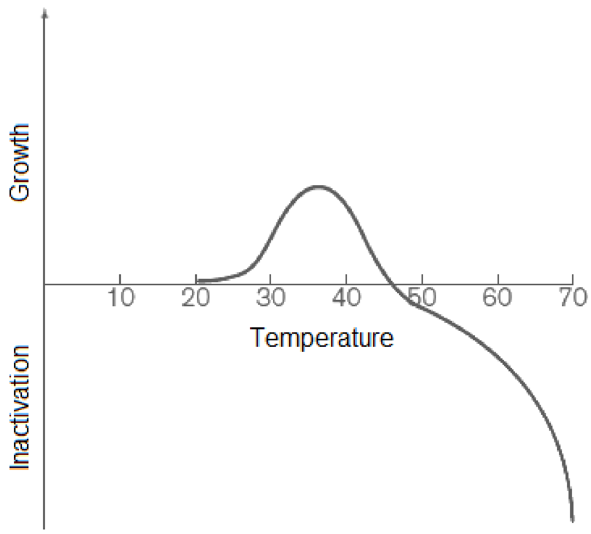

Figure 1. Growth rate for Legionella pneumophila. Source: Stålbom & Kling (2002).

As can be seen in Figure 1, the ideal temperature for *Legionella* growth is between 32 and 42 °C and the bacterial inactivation starts at about 46 °C. Although it is worth noting that there are studies showing that the *Legionella* bacteria are capable of colonizing areas in a temperature range between 6 °C and 63 °C (Yee & Wadowsky, 1982; Dennis, Green & Jones, 1984).

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[1] A serogroup is defined as a group of distinct variations within a species of bacteria that have common cell surface antigens (MediLexicon, n.y.).

The recommended temperature for storage and distribution of cold water to prevent *Legionella* infection is below 25 °C, though preferably below 20 °C, since the reproductive rate of the bacteria is little or none in temperatures below 20 °C (WHO, 2007).

The decimal reduction time is defined as the time required to kill 90% of a population of microorganisms when maintaining a constant temperature (WHO, 2007). For a tested strain of *L. pneumophila* serogroup 1, the decimal reduction time was 111 minutes at 50 °C, 27 minutes at 54 °C and 6 minutes at 58 °C (Dennis et al. 1984). At temperatures above 70 °C, the *Legionella* bacteria are inactivated almost instantaneously (WHO, 2007). A general representation of the decimal reduction time for this strain of *L. pneumophila* can be seen below in Figure 2.

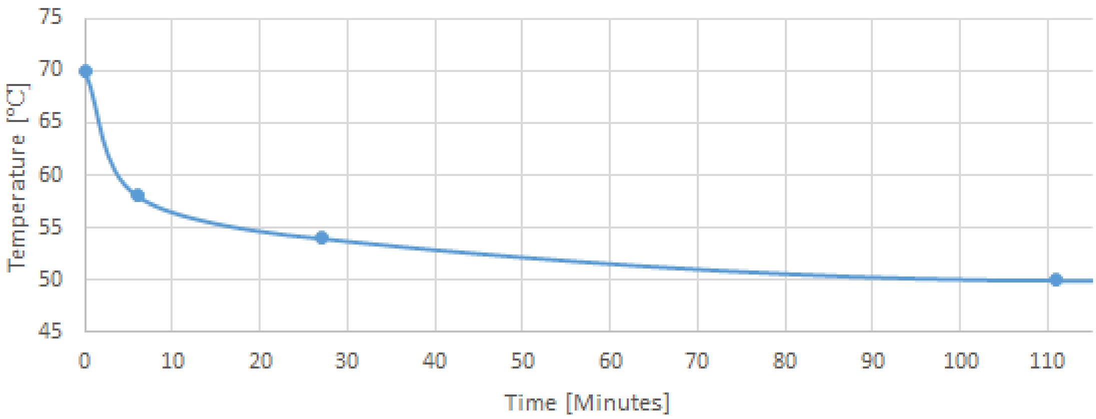

Figure 2. General representation of the decimal reduction time for a strain of Legionella pneumophila serogroup 1. Data: Dennis et al. (1984).

The growth of *Legionella* bacteria is not only dependent on temperature, but also on the availability of nutrients. The bacteria are able to survive in sterile water but they will not multiply in such conditions. The nutrients required for growth are available in common tap water. These nutrients are present in the form of dissolved organic constituents, decay of other microorganisms or excess production of organic nutrients either by other species of bacteria or microorganisms (WHO, 2007).

Another important factor for *Legionella* growth is the presence of biofilms and/or protozoa such as some amoeba. Biofilms and protozoa can provide numerous advantages for the bacteria including structure, stability and nutrients, but also protection from potential toxic effects caused by the medium on which it grows. Biofilm formation occurs when microorganisms attach to a surface where they colonize, multiply and finally form micro colonies or stacks. Formation is more likely to occur in stagnant waters on a surface where the water flow is lower, making the shear stress lower (WHO, 2007). Once a biofilm is formed and colonies or stacks has grown sufficiently, dispersion can occur where bacteria detach from the biofilm and become suspended in the water. These free floating bacteria can then attach to another surface and start a new colonization. The steps of biofilm formation can be seen in Figure 3.

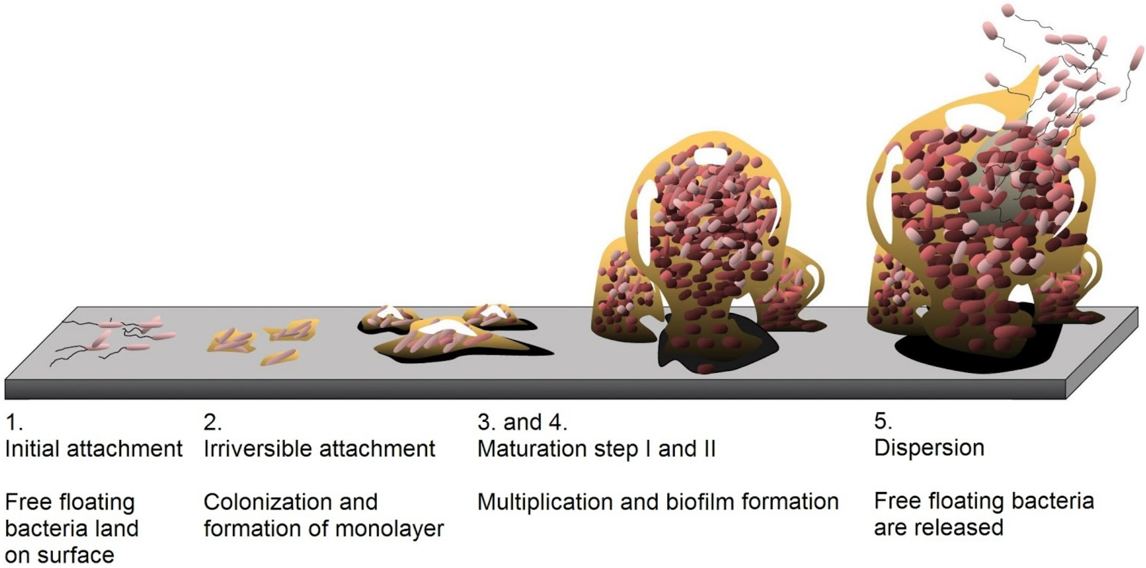

Figure 3. Steps of biofilm formation. Source: Figure modified from original by Monroe (2007).

2.2 Legionellosis

Illness caused by *Legionella* falls under the category of Legionellosis with the subcategories Legionnaires' disease and Pontiac fever. Infection is caused through inhalation of contaminated water in the form of aerosols. These can be produced by various systems such as cooling towers, air conditioning systems, spas and shower heads (Steinert, Hentschel & Hacker, 2002). The reasons why some people that are infected by *Legionella* develops Legionnaires' disease and others Pontiac fever is unclear. The infectious dose is likely to be of relevance, however, there seem to be no documented studies regarding the correlation between number of bacteria and type of illness (Folkhälsomyndigheten, 2015b).

The first case of Pontiac fever was detected in Pontiac, Michigan in 1968. Symptoms are similar to those of a common influenza, including fever, headache and muscle soreness (Steinert et al., 2002). Infected individuals will experience a full recovery in two to five days without any need for treatment resulting in many cases going undetected (Folkhälsomyndigheten, 2015a). Because of this, the focus in this report will mainly be on Legionnaires' disease.

Legionnaires' disease was first detected in 1976 after the American Legion Convention in Philadelphia where 221 of the visitors fell ill in an outbreak of pneumonia which led to the death of 34 legionnaires. The disease appears as a severe form of pneumonia with a fatality rate of 5 – 20% (Folkhälsomyndigheten, 2016a, 2015b). Symptoms are similar to those of a common pneumonia, however, misdiagnosing Legionnaires' disease for a common pneumonia can have dire consequences. This due to *Legionella* infections not being responsive to β-lactam antibiotics like penicillinas and cephalosporins. When treating Legionnaires' disease, other forms of antibiotics of the appropriate range is required (ECDC, 2017a).

The risk of Legionellosis is higher for men than for women, and in more than half of the cases of legionellosis the patient is above 65 years of age (as can be seen in Figure 4). Smoking has also been found to be a risk factor as well as alcoholism, diabetes, impaired kidney functions and lowered immune system (Folkhälsomyndigheten, 2015b).

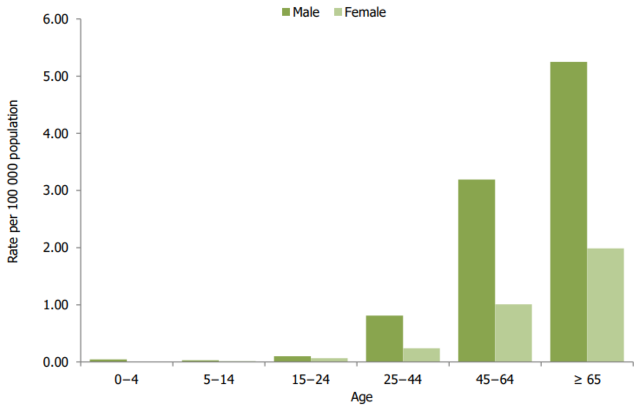

Figure 4. Incidence per 100 000 population by age and gender from all ELDSNet participating countries in 2015. Source: ECDC (2017b).

2.3 Diagnostic methods

Since Legionnaires' disease does not have any clinical features that differentiate the disease from other types of pneumonia, the identification of the disease is dependent on clinicians including the disease in their investigation to determine the cause of illness (ECDC, n.y.). There is thus a risk of under-diagnosing Legionnaires' disease since patients diagnosed with pneumonia typically are treated immediately with antibiotics. If those antibiotics happen to be effective against *Legionella* and the patient recovers, no further investigation regarding the cause of pneumonia is usually performed (ECDC, n.y.). If investigative measures are taken, however, there is still a risk of under-diagnosing Legionnaires' disease. In determining the presence of *Legionella* in a patient, there are several different diagnostic methods available with varying reliability. It is common to use a combination of several methods, the most frequently used primary method being detection of an antigen in a urine specimen. This method along with other frequently used methods will be described in this section followed by a summary of the advantages and disadvantages of each method.

2.3.1 Urinary antigen

Urinary antigen test is a rapid and inexpensive method that has contributed to the increased diagnosing of illness caused by *Legionella* and thus a reduction in the mortality associated thereof. The method mainly detects the most common strain of *Legionella*, that is *L. pneumophila* serogroup 1 (see section 2.1), but fails to detect other species and serogroups. Thus, as many as 20 – 50% of cases might go undiagnosed if only tested through urinary antigen test (Pierre, Baron, Yu & Stout, 2017). It is therefore strongly recommended to also collect a respiratory specimen from sputum or bronchoalveolar lavage to obtain an isolate from the culture to detect less common strains of *Legionella* (ECDC, 2017a).

2.3.2 Culture

Collecting a respiratory specimen from sputum or bronchoalveolar of a patient to cultivate, has shown to be a method able to identify all known *Legionella* species and serogroups. It is therefore the gold standard of diagnosing Legionnaires' disease (Pierreet al., 2017). As this method has such high specificity, it allows for detection of the source through recovering isolates from the culture and matching it with environmental isolates. This method may however be both timely and costly since it might require different pretreatment techniques as well as specific equipment (Pierre et al., 2017).

2.3.3 PCR

Another method of diagnosing *Legionella* is a molecular test through PCR (Polymerase Chain Reaction), a method where a sequence of bacterial DNA can be amplified and the species can be determined. The method has a high sensitivity and a continuous increase in the use of this method has been reported in Europe (Folkhälsomyndigheten, 2015b). The method is rapid, but it can however not identify specific species of serogroups, laboratory expertise is required and false positive results may exist due to detection of non-culturable *Legionella* (Pierre et al., 2017).

2.3.4 Serology

Serological tests (detection of antibodies within a blood sample) can determine if a person has been exposed to *Legionella* to the extent where the immune system has been stimulated and started to produce antibodies. Interpretation of the results can however be uncertain due to a lack of reference populations. Serology is a labor intensive method and is therefore mainly used as a complement. It has also been found that about 25% of patients do not produce antibodies against *Legionella* and results from those serology tests would thus be falsely negative (Folkhälsomyndigheten, 2015b).

2.3.5 DFA

Direct immunofluorescence, or direct fluorescent antibody (DFA), is a rapid test where samples of tissue from the lower respiratory tract is used to detect *Legionella*, however it is a method that requires high expertise and has a low sensitivity and is therefore not widely used (Folkhälsomyndigheten, 2015b).

2.3.6 Overview

An overview of the presented methods of diagnosing Legionnaires' disease can be seen below in Table 1.

Table 1. Advantages and disadvantages with most commonly used methods of Legionella detection.

Diagnostic method	Advantages	Disadvantages
Urinary antigen	Recognizes most *L. pneumophila* serogroup 1 Easy Rapid	Fails to detect other serogroups or other species
Culture	Can identify all known *Legionella* species and serogroups with high specificity	Timely Costly
PCR	Rapid High sensitivity	No identification of specific species of serogroups Laboratory expertise required False positive results may exist
Serology		Uncertain interpretations of results Labor intensive method False negative results may exist
DFA	Rapid	Requires expertise Low sensitivity

As diagnosing *Legionella* can be done in many ways, the most commonly used method will differ between countries. Since no method is completely reliable it is common to complement one method with another. An overview of the most common methods used in Europe in 2015 is showed in Table 2 below.

Table 2. Distribution of methods used in diagnosing Legionnaires' disease in Europe by 2015. Source: personal communication with Dr. Mentula, S. (2018).

Diagnostic method	Europe (2015)
Urinary antigen	89 %
Culture	12 %
PCR	11 %
Serology	3 %

3 Legislation associated with Legionella control

This chapter aims to summarize the *Legionella* related legislation of the six included countries and also the general guidelines and directives provided by the European Union.

The European Union has no specific directive or ordinance regulating *Legionella* levels. However, water quality is mentioned in several directives, e.g. the Directive regarding biological agents at work (Directive 2000/54/EC) and the Directive on the quality of water intended for human consumption (Council Directive 98/83/EC). The legislations do not provide any specific requirements on *Legionella* control, however technical specifications have been developed and determined by EWGLI.

What the national regulations associated with *Legionella* control all have in common is the statement that water systems *should be designed so that microbial growth is minimized*. In section 2.1, describing the optimal growth conditions of *Legionella,* it was mentioned that favourable conditions for the bacteria are in stagnant waters at a temperature between 32 °C and 42 °C in presence of a biofilm. EWGLI writes in their guidelines that there are a number of design features that should be implemented in order to make the water system an inhospitable environment for bacteria. First of all, the system should be kept at a temperature that does not promote microbial growth. Secondly, the system should be designed in such a way that water stagnation does not occur. Finally, the components should be made in materials that do not promote microbial growth, e.g. by limiting the growth of biofilm on the surfaces (EWGLI, 2017). In addition, EWGLI recommends that hot water should be stored at a temperature no less than 60 °C and that the circulating water is kept at a temperature that allows at least 50 °C at the tap within one minute of opening the tap (EWGLI, 2017).

The countries whose legislation will be analysed in this chapter are Sweden, Denmark, Norway, Finland, Germany and France. All countries but Norway have based their guidelines and legislation on EWGLI recommendations (EU OSHA, 2011).

3.1 Sweden

In Sweden, legislation concerning *Legionella* are of either a preventative nature or protocols on how to contain outbreaks. This report will focus on the preventative legislation. General legislation regarding control and prevention of *Legionella* are mainly handled in the Building and Planning Act (in Swedish: Plan- och bygglagen), the Building and Planning Ordinance (in Swedish: Plan- och byggförordningen), the Work Environment Act (in Swedishy: Arbetsmiljölagen) and the Swedish Environmental Code (in Swedish: Miljöbalken). The specific technical regulations are determined by the National Board of Housing, Building and Planning (Folkhälsomyndigheten, 2016b).

The Swedish Environmental Code, chapter 9.9, makes a general statement that buildings meant for public use should be constructed in such a way that there is no or limited risk to human health and well-being (SFS, 1998:808). Similar statements can be found in the Building and Planning Act, chapter 8.4: a construction should be safe with regards to hygiene, health and environment, and in the Building and Planning Ordinance, chapter 3.9: a construction should not expose citizens to unacceptable health risks. This includes, but not is limited to, exposure to polluted or contaminated air or water (SFS 2010:900, SFS 2011:338).

The technical specifications can be found in the regulations developed by the National Board of Housing, Building and Planning (in Swedish: Boverkets byggregler). Regulation 6.622 states that in order to limit and minimize bacterial growth, the hot water temperature should be kept at a minimum of 50 °C at the tap. The same goes for water circulation, the temperature should not be below 50 °C. The system should also be designed in a way so that the cold water isn’t heated unintentionally and never becomes hotter than room temperature. For stagnant water, for example in water tanks, the recommendation is that the water temperature should be over 60 °C. The maximum tap water temperature is also regulated at 60 °C to avoid scalding and at 38 °C if there is significant risk of accidents (BFS 2011:6).

The Work Environment Act dictates that the Swedish Work Environment Authority has the right to regulate the conditions in the workplace. Concerning *Legionella,* it states that showers must be designed to minimize growth and dispersal of the bacteria and as well as carefully considering the placement of cooling towers as these pose a risk of spreading *Legionella* bacteria (AFS 2009:2). To further ensure the well-being of employees the employer is required to perform risk analysis to identify potential sources of threat to human health (AFS, 2005:1).

3.2 Denmark

In Denmark a few different laws and standards address the challenges of *Legionella*. In chapter 21 of the Building and Planning Act (in Danish: Bygningsreglementet) it is stated that water systems should be constructed so that the risk of *Legionella* growth is minimized. This should be achieved by following the guidelines in *Rørcenteranvisning 017 Legionella - Installationsprincipper og bekæmpelsesmetoder* (Bygningsreglementet, 2018).

The guidelines refer to the water standard DS 439 that states that in any water system it should be possible to raise the temperature to 60 °C in case of an increase in bacterial concentration. This temperature should however not be kept at all times since it increases the risk of calcification. In general, the temperature in tanks as well as the flow temperature should be 55 °C. The standard also says that the temperature should be kept above 50 °C in systems with DHW tank or with circulation of domestic hot water - except at peak flows where a temperature of 45 °C at the tap is acceptable (Rørcentret, 2012).

3.3 Norway

Similar to Sweden and Denmark, there are a number of regulations associated with *Legionella* in Norway. Some are very general and others have specific temperature requirements. The regulations on environmental health care (Forskrift om miljørettet helsevern) has a chapter on avoiding the spreading of *Legionella* that concerns commercial properties and activities. It states that the construction and operation of commercial properties should have satisfactory protection of growth and spreading of *Legionella* bacteria (FOR-2003-04-25-486, § 11). In § 13 of the same regulation it is stated that a corporation has an obligation to inform the authorities in case of a health hazard arises, including increased concentrations of *Legionella*.

More specific regulations can be found in the Norwegian equivalent to the Building and Planning Act (in Norweigan: Byggteknisk forskrift). These regulations declare that *Legionella* should be controlled by keeping the temperature in circulating water systems above 65 °C. Other measures that should be taken are to avoid using materials that can release particles that can be used as nutrients by the bacteria and to keep a sufficient water flow in all pipes (TEK 17, §15.5). To avoid scalding there is a limit to the temperature of the water that exits the tap. In locations such as kindergartens and retirement homes the tap water temperature is limited to 38 °C and in all other locations to 55 °C (TEK 17, § 15.5).

3.4 Finland

Finnish legislation is very clear regarding water temperature in tap water systems. In the ordinance regarding water utilities (in Swedish: Miljöministeriets förordning om byggnaders vatten- och avloppsinstallationer), chapter 2, § 6, it is declared that hot water should keep a minimum of 55 °C to inhibit bacterial growth and maximum 65 °C to avoid scalding. Cold water should not be warmer than 20 °C, with the exception of unused water that is allowed to reach 24 °C if it has not been used for 8 hours. To avoid this, the water systems should be constructed in such a way that there is no heat transfer from hot water to cold water pipes (Finlex, 1047/2017).

3.5 Germany

According to the Ordinance on the Quality of Water Intended for Human Consumption (in German: Trinkwasserverordnung), chapter 4, section 17, water installations must be constructed according to the currently valid codes of practice. In the case of *Legionella* the code of practice is Technical Rule W551 (DVGW, 2004). This rule, often referred to as the 3-liter rule, states that in small systems, with storage tank < 400 litres and where the volume between the heater and the furthest tap is less than 3 litres, there is no need for additional treatment methods. These can for example be found in single-family homes with an individual heat exchanger. It is however, recommended to keep the hot water temperature over 50 °C at all times (DVGW, 2004), even though no real temperature requirement is stated.

In larger systems with storage tank >400 litres the temperature must be over 60 °C at the outlet of the tank. The same principle applies in the case of a district heating central shared between multiple households, as would be found in an apartment complex (DVGW, 2004).

3.6 France

Similar to Finland, France has very straightforward regulations regarding hot water temperature. In 2005 the legislation regarding water intended for heating and domestic hot water was updated to include specific temperature requirements (Legifrance, 2005): if the volume between the point of distribution and the furthest tap is larger than three litres, the water temperature in the whole system must be higher than 50 °C. Moreover, if there is a storage tank of more than 400 litres, the temperature at the outlet of the tank must be equal to or higher than 55 °C.

3.7 Summary of temperature requirements

This chapter has presented the temperature requirements for domestic hot water in Sweden, Denmark, Norway, Finland, Germany and France. The temperature requirements refer to either a minimum system temperature, i.e. the minimum temperature permitted in the water circulation system, or a minimum water temperature in the tap. In a few of the countries there is both a minimum system temperature and a minimum tap water temperature. Sweden, Norway and Finland have also set a maximum temperature on the tap water to avoid scalding. Furthermore, four out of the six countries, only Norway and Finland excluded, have a different minimum temperature if there is an accumulation tank installed. A summary of the temperature requirements can be found in the table below.

Table 3. Overview of national legislations for Legionella prevention in domestic hot water systems

Country	Min. system T	Min. tank T	Min. tap T	Max. tap T
Sweden	50 °C	60 °C	50 °C	60 °C/ 38 °C*
Denmark	55 °C (45 °C)**	55 °C (up to 60)		
Norway	65 °C (circulating)			55 °C/38 °C*
Finland			55 °C	65 °C
Germany	50 °C, unless small system	60 °C		
France	50 °C, unless V < 3 liters	55 °C		

* Only for locations with increased risk of scalding

** Exceptions of temperature requirements are made at peak hours

As can be seen in Table 3, all the countries require a minimum temperature of at least 50 °C to avoid *Legionella* growth. There are three exception cases: Denmark, Germany and France. In Denmark, a system temperature of 45 °C is permitted at peak flows and in France and Germany the three-litre rule is applied. This rule states that if the volume between the point of distribution and the tap is less than three litres, the temperature requirement can be neglected.

Four out of six countries also require the temperature in accumulator tanks to be higher than the system or tap temperature. This is most likely to further ensure the inhibition of bacterial growth. In tanks the water is stagnant and bacteria generally have more time to colonize.

In the column furthest to the right it can be seen that Sweden, Norway and Finland not only have a minimum temperature but also a maximum temperature that is allowed for the hot tap water. These limits are set to avoid scalding. In Sweden and Norway the lower limit is specifically for locations where the risk of scalding is higher, such as retirement homes and kindergartens.

4 Incidences of Legionnaires' disease

In order to facilitate the tracking of outbreaks of Legionnaires' disease, a standardized approach of reporting cases was introduced by the European Working Group for *Legionella* Infections (EWGLI) known as ELDSNet (former EWGLINET). This network is since 2010 coordinated by the European Centre for Disease Prevention and Control (ECDC) and participants are as of August 2017, 28 EU member states as well as Iceland, Norway and Switzerland (ECDC, 2017a).

In Figure 5 statistics from EWGLI on cases of illness caused by *Legionella* are presented as reported incidence per 100.000 inhabitants.

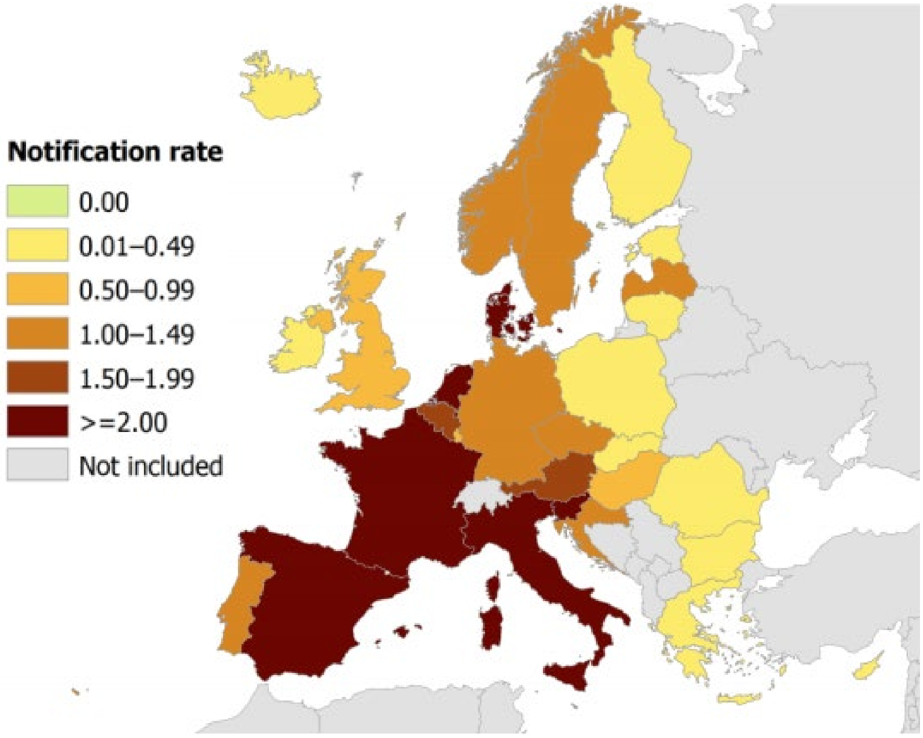

Figure 5. Reported incidence per 100 000 inhabitants of Legionnaires' disease by country in 2015. Source: ECDC (2017b).

The overall incidences in the participating countries in 2015 were the highest ever reported and amounted to 1.4 cases per 100 000 inhabitants. Though their combined population approximately represent only 50% of the EU/EEA population, France, Germany, Italy and Spain accounted for 69% of all notified cases in 2015 (ECDC, 2017b). Altogether there has been a general increase of notified cases in Europe between 2011 and 2015 as can be seen in Figure 6, no apparent reason has been found for this noted increase. However, several factors are suggested to contribute to this increase such as improved surveillance, an aging population, increased travel and climate change (ECDC, 2017b).

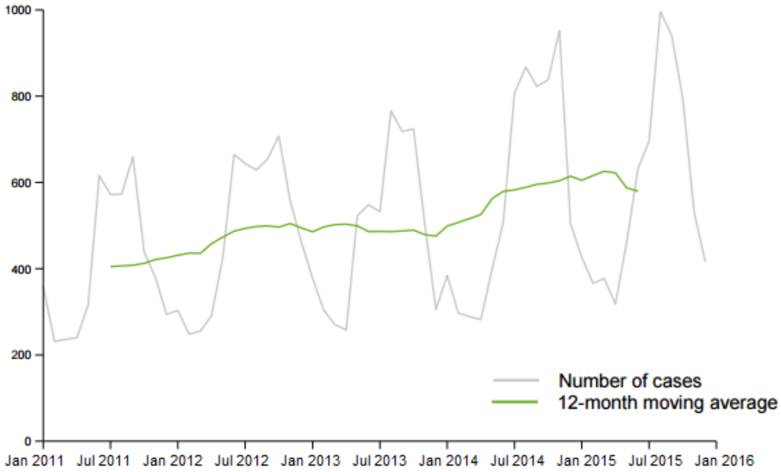

Figure 6. Number of reported cases between 2011 and 2015 from all ELDSNet participating countries. Source: ECDC (2017b).

The number of cases of Legionnaires' disease reported varies seasonally, as can be seen in Figure 6. This might be explained by the more favourable temperatures for *Legionella* growth in the summer months. Not only can the higher temperatures have a direct effect on the bacterial growth, but it can also contribute to the higher incidence through an increased use of cooling towers for comfort cooling in the summer (ECDC, 2017b). Holiday travels to summer houses and the seasonality of holiday venues can also be a risk factor explaining the increased incidences in the summer months. This due to stagnant water in unused pipes which can lead to biofilm formation and increased *Legionella* growth (ECDC, 2017c).

4.1 Sweden

In Sweden, Legionnaires' disease is a notifiable disease which falls under the category of being subject to mandatory contact tracing according to the Communicable Diseases Act (The Public Health Agency of Sweden, 2016). This means that each case of Legionnaires' disease has to be reported to the Public Health Agency of Sweden, where an investigation on the cause should be performed. The incidence of reported cases has been somewhat stable around 1.5 cases per 100 000 inhabitants during the last five years (Folkhälsomyndigheten, 2016b). It has been found that a significant amount of incidences have been related to travel. In Figure 7, the total incidence can be seen in blue (top, bulleted line), and the incidence of cases with Sweden as the origin of infection in orange (bottom, squared line).

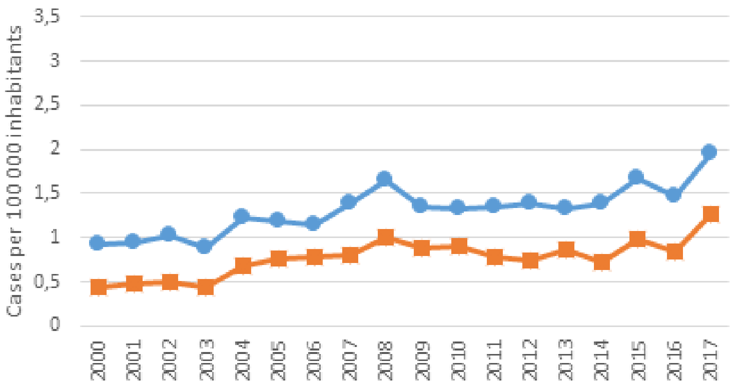

Figure 7. Incidence of Legionnaires' disease 2000-2017 in Sweden. Total incidence in the top line, incidence with Sweden as origin of infection in the bottom line. Source: Folkhälsomyndigheten (2018).

Although Legionnaires' disease is a notifiable disease, it is estimated that the real incidence in Sweden might be ten times higher than reported (Folkhälsomyndigheten, 2015b).

4.2 Denmark

In Denmark Legionnaires' disease falls under the category of individually notifiable diseases. Each case of Legionnaires' disease is therefore to be reported to Statens Serum Institut, which is under the authority of the Danish Ministry of Health, according to national law (Statens Serum Institut, 2018). An increasing trend in illness caused by *Legionella* has been observed where the increase is highest among those who have been infected within the country, although travel related infections has increased as well. No obvious explanation for this increase has been found (Statens Serum Institut, 2017). The incidences reported to ECDC between 2009 and 2015 can be seen below in Figure 8.

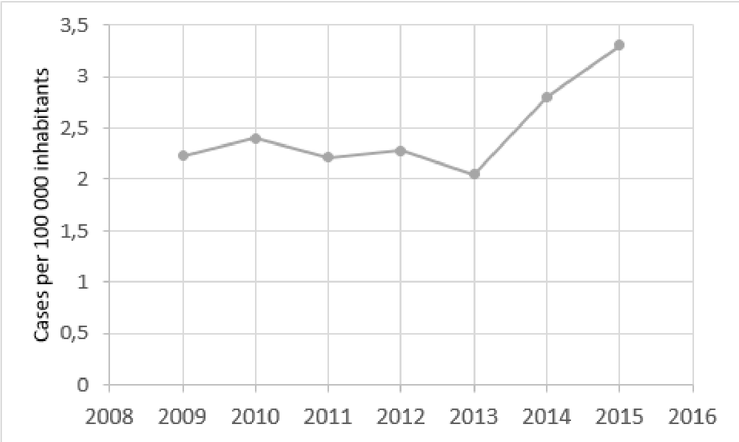

Figure 8. Incidence of Legionnaires' disease 2009-2015 in Denmark. Source: ECDC (2017b).

4.3 Norway

Legionnaires' disease is categorized as a Group A disease in Norway. This means that all clinicians are required by law to report cases of illness caused by *Legionella* to the Norwegian Institute of Public Health through the Surveillance System for Communicable Diseases (MSIS) according to Folkhelseinstituttet (2017). The incidence in Norway has ranged between 0.5 and 1.2 per 100 000 inhabitants from 2009 to 2015 which is shown in Figure 9.

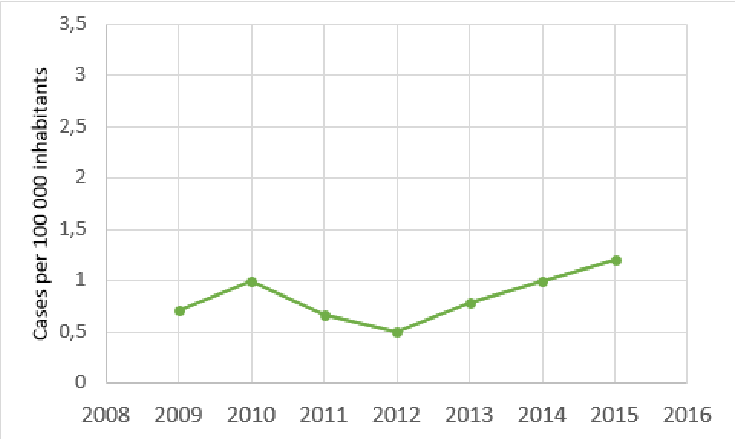

Figure 9. Incidence of Legionnaires' disease 2009-2015 in Norway. Source: ECDC (2017b).

4.4 Finland

Cases of Legionnaires' disease are to be reported to the National Infectious Disease Register maintained by the National Institute for Health and Welfare in Finland (Institutet för Hälsa och Välfärd, 2016). Incidences are relatively low and have not exceeded 0.5 per 100 000 inhabitants between 2009 and 2015 as can be seen in Figure 10 below.

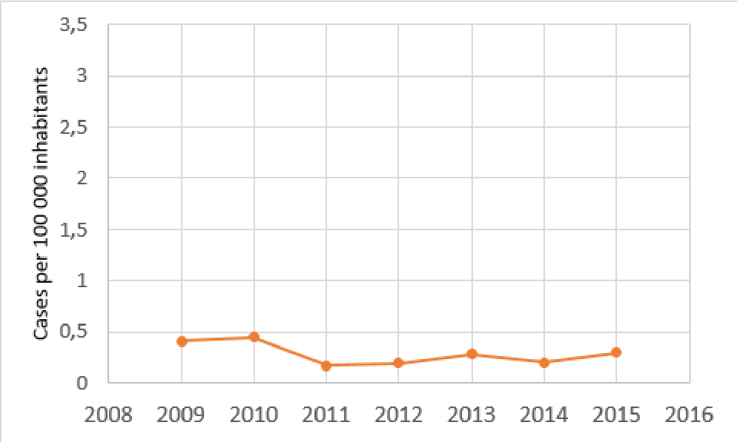

Figure 10. Incidence of Legionnaires' disease 2009-2015 in Finland. Source: ECDC (2017b).

In diagnosing Legionnaires' disease in Finland, serology is the most common method used in Finland, followed by urinary antigen (Dr. Mentula, S., personal communication, 2018-04-05).

4.5 Germany

Outbreaks of Legionnaires' disease are to be reported and analysed by the Robert Koch Institute in accordance with the German Protection against Infection Act. The data is maintained in the database SurvNet Electronic Surveillance System for Infectious Disease Outbreaks (Robert Koch Institut, 2017). A small increase in reported cases between 2009 and 2015 can be seen in Figure 11.

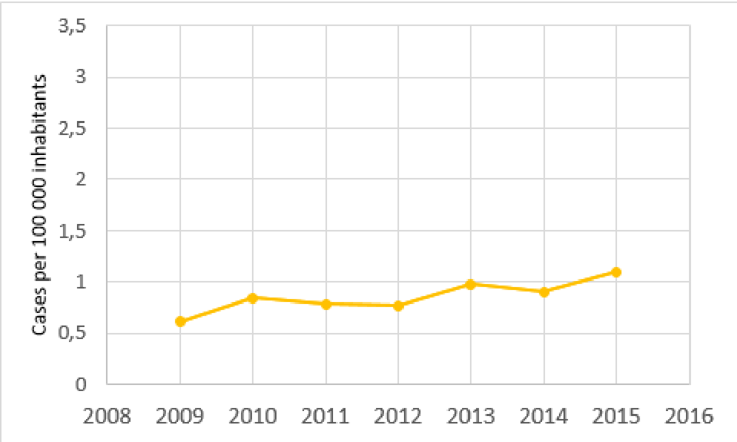

Figure 11. Incidence of Legionnaires' disease 2009-2015 in Germany. Source: ECDC, (2017b).

4.6 France

In France Legionnaires' disease is categorized as a notifiable disease and surveillance is ensured by a mandatory reporting system. A standardized form is to be filled out by physicians and biologists and the data is collected by the Institute for Public Health Surveillance (Santé Publique France, 2017). Data reported to ECDC from 2009 to 2015 can be seen in Figure 12.

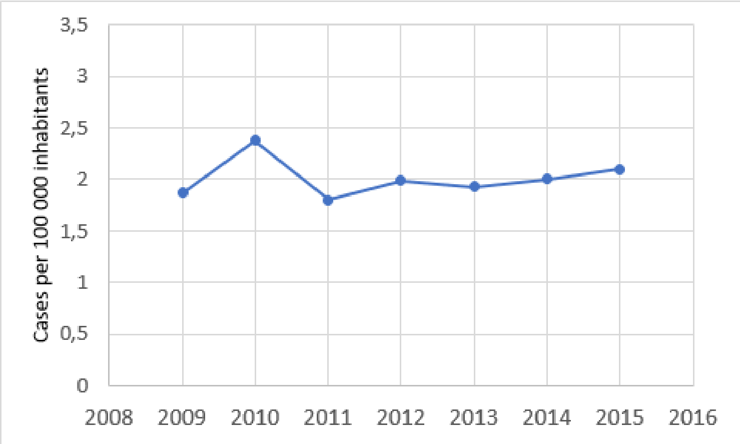

Figure 12. Incidence of Legionnaires' disease 2009-2015 in France. Source: ECDC, (2017b).

A sensitivity analysis of the mandatory notification system through a capture-recapture analysis[2] showed a significant improvement (from 10% in 1995 to 33% in 1998 and 88.5% in 2010). This increase was suggested to be caused by a growing awareness among practitioners and major media attraction during a large outbreak in northern France in 2003-2004 (Campese, Jarraud, Sommen, Maine & Che, 2013). Campese et al. suggest that the present surveillance system does give a representative description of the epidemiology of Legionnaires' disease in France. Aside from the sensitivity analysis reported for France, reports on the sensitivity of the surveillance systems are not common, only reports from Italy, the Netherlands and Belgium have been found in our searches.

4.7 Overview

Since Legionnaires' disease is a notifiable disease in all of the studied countries, statistics regarding reported cases could be obtained from the European Centre for Disease Prevention and Control. Incidences reported from Sweden, Denmark, Norway, Finland, Germany and France for the years 2009 to 2015 differ. A visual representation of incidences in the studied countries is here compiled and shown in Figure 13.

[2] In using a capture-recapture method for estimating true incidences, two independent data sources are required. In the study by Campese et al. (2013) mandatory notifications (source A) and a survey of hospital laboratories (source B) were used as independent sources. The true incidence, N_{est}, is estimated through the number of cases in source A, N_A, multiplied by the number of cases in source B, N_B, divided by the number of cases that appeared in both sources, N_{AB}

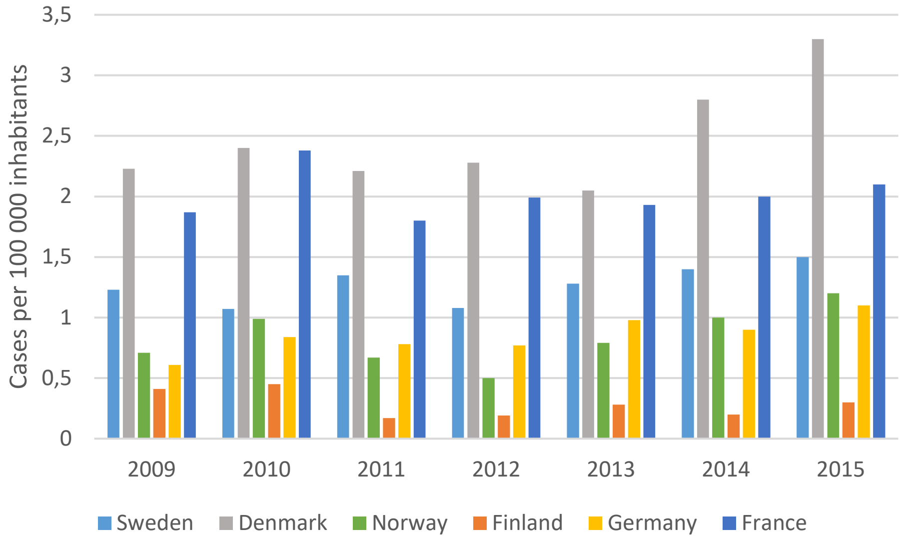

Figure 13. Incidence of Legionnaires' disease 2009-2015 in studied countries. Source: ECDC (2017b).

The incidence varies between the compared countries. There are various possible reasons or combinations of reasons that is not related to the temperature requirements on the domestic hot water systems in the different countries, that might explain this difference. The possible explanations can be divided into three categories: the sensitivity of the surveillance systems, environment-related aspects for *Legionella* growth and susceptibility of the population for the disease.

4.7.1 Differences in methods to detect Legionnaires disease

In order to compare the incidences, it is imperative to have accurate statistics. However, the sensitivity of the surveillance systems has not been documented in many countries. As previously mentioned, besides the one for France in 2010, sensitivity analysis was only found from three other countries: Italy, the Netherlands and Belgium. The study from Italy was conducted in 2002 with a capture-recapture method and showed a 78.6 % sensitivity. The study from the Netherlands reported a 42.1 % sensitivity and was from 2000-2001 (Campese et al., 2013). These might be considered fairly old studies and might no longer be valid. The more recent study in Belgium in 2012 showed a sensitivity of 65 % (Jacquinet, Denis, Valente Soares & Schirvel, 2014). This might be a more valid representation of the current situation; however, it is possible that it has changed as well. The results of the sensitivities were widely spread (88.5 %, 78.6 %, 42.1 % and 65 % for France, Italy, the Netherlands and Belgium respectively), and in Sweden, estimations have been made that the true incidence might even be ten times higher than reported (Folkhälsomyndigheten, 2015b). These few studies and estimations suggests a widely varying sensitivity of the surveillance systems in different countries, thus making the comparisons of statistics very hard to perform in a reliable way. To be able to compare notification rates between countries, more thorough investigations on the performance of the surveillance systems are required.

Apart from the sensitivity in the surveillance systems, there are other uncertainties in the reporting systems that considers the choice of diagnostic method. The diagnostic methods used varies between countries, and each method has their own advantages and disadvantages.

According to Dr. Mentula, microbiologist at the National Institute for Health and Welfare in Finland, Legionnaires' disease is severely underdiagnosed in Finland. Mentula suggests that it is not a case of underreporting or un-treating, but underdiagnosing due to clinicians using broad spectrum antibiotics to treat pneumonia, which results in that no further investigation of the causative pathogen is done (Dr. Mentula, S., personal communication, 2018-04-05).

Furthermore, Mentula suggests that serology, the widely used method of diagnosing Legionnaires' disease in Finland, might provide results that are difficult to interpret and the method should therefore not be encouraged to use. As previously mentioned, about 25 % of patients do not produce antibodies against *Legionella* and serological tests would thus give a negative result even in the presence of *Legionella*. As this method is not commonly used in other European countries, this might be one of the reasons for the low incidence reported in Finland compared to the other investigated countries.

4.7.2 Differences in climate between countries

Legionella is more likely to grow in a warmer environment; therefore, the average annual temperature of the countries might also have an explanatory factor. Since the reported cases of Legionnaires' disease has a clear peak during the summer months, the average temperatures of these months is of special interest. The average high temperatures during those months might have an effect on the *Legionella* growth and the use of cooling towers. The average high temperature in France during summer is about 10 °C higher than the corresponding temperature in Norway (Weatherbase, n.y.). Keeping in mind that the optimum growth temperature for *Legionella* is 32-42 °C, the thermal conditions in France are more compatible for proliferation compared to the conditions in Norway, which might also be an explanation for the higher incidence in France. However, this interpretation does not explain the high incidence in Denmark compared to for example Sweden, where the average high temperatures are similar.

4.7.3 Differences in variables that could affect the population susceptibility of the disease

When investigating the incidences of Legionnaires' disease, it might be of interest to consider the susceptibility of the population to the disease. In an attempt to find correlations between incidence rates and susceptibility of the population, the percentage of the people who are exposed to known risk factors in the studied countries will be analysed here.

Since Legionnaires' disease mainly affects individuals above 65 years of age, differences in the share of the population that are in this age span in each country might be of interest. However, the share of an older population does not differ much between the compared countries (Eurostat, 2017a), suggesting that this is not of high relevance when explaining the different incidence rates.

Another common risk factor for Legionnaires' disease is smoking. The proportion of smokers in each country might therefore also be interesting to look at. Here we find that more than a fifth of the French population are considered smokers (Eurostat, 2017b), a relatively high number that might contribute to the high incidence of Legionnaires' disease in France. However, the percentage of smokers in Denmark is about the same as in Norway, suggesting this is not the reason for the difference in incidences of Legionnaires' disease between these countries.

Alcoholism has also been reported as a risk factor for Legionnaires' disease and France has the highest alcohol consumption per capita of the studied countries; almost twice as much as that of Norway (WHO, n.y.). Germany, however, has almost the same alcohol consumption per capita as France, but much lower incidences of Legionnaires' disease, suggesting that alcohol consumption might not affect the incidence rate significantly. The same comparison can be made between Finland and Denmark where the alcohol consumption does not differ much but the incidences do.

5 Techniques for Legionella control

The conventional treatment technique against *Legionella* in DHW systems is to continuously keep the temperature at a level that inhibits bacterial growth. A reduction in supply temperature when implementing LTDH might result in temperatures that instead favour bacterial growth. It is possible to meet the comfort requirements with a lower supply temperature and the issue that remains is thus how to guarantee the health and hygiene requirements, specifically with regards to *Legionella,* without a continuous high temperature (SP, 2014). There are a number of water treatment techniques, some very mature in conventional water systems and some still in their trial stages. The techniques that will be further described in this chapter can be divided into three main categories: mechanical techniques, sterilization and alternative water system design.

5.1 Mechanical Techniques

Mechanical techniques for removal of *Legionella* do not inhibit bacterial proliferation, but work through discharging of existing bacterial population. The mechanical technique presented in this work is installation of filters on each tap in the water system.

5.1.1 Filters

By using membrane filters installed on each tap, also called point-of-use (POU) water filters, *Legionella* colonization can be prevented as the microorganisms are kept from entering the protected site. This technique is frequently used in high risk facilities where extra precautions should be taken e.g. in hospitals (Baron, Peters, Shafer, MacMurray & Stout, 2014). Filtration is a very effective method of *Legionella* prevention, however the relatively short lifetime of the filter causes the operation cost to be high, since the filters must be replaced frequently (Yang, Li & Svendsen, 2016a).

The lifetime of the filters varies between manufacturers, for example Marchesi et al. (2011) reports a lifetime of one month from their manufacturer and Tandrup Water Solutions report up to 92 days for their T-safe *Legionella* filters (T-safe, n.y.). In a field evaluation conducted by Baron et al. (2014), *Legionella* was successfully removed with POU filters for 12 weeks, thus exceeding this manufacturer's 62 days (almost nine weeks) recommended maximum duration of use with more than three weeks. The actual lifetime of the filters was thus more than 35 % longer than the recommended duration of use.

Evaluation made by Totaro et.al. showed that hollow-fibre filters did not work as good as the published data claims. Membrane filters worked as expected or better. Daily flushing of filters was of great importance to avoid local biofilm/bacterial growth in POU units.

There are several commercial products of this kind on the market, two examples are shown in Figure 14.

Figure 14. Commercial POU microbial filters for tap water systems
a) shower head with T-Safe® filter (to the left). Source: T-Safe (n. y.)
b) faucet with H_2Otap3000 filter (to the right). Source: Biogen Technologies (n. y.)

5.2 Sterilization

Sterilization techniques aim to kill bacteria and thus keep the colonization in check. This can be done either by adding a chemical to the water, that for example destabilizes the bacteria's cell wall, by installing ultraviolet lights, or by using an advanced oxidation process. In this section five sterilization techniques will be covered: chlorination, ultraviolet light, ozone, ionization and photocatalysis.

5.2.1 Chlorination & Electro Chemical Water Treatment

Chlorination is a common sterilization method in potable water treatment in many countries and can also be used for *Legionella* control if sufficient residual concentrations are kept in the water system (Yang et al., 2016a). Chlorine inhibits bacterial growth by having a negative impact on the respiration process and can either be used for continuous control with low dosage over a longer period of time, or as a shock treatment with a high dosage on a single occasion (SP, 2014). A study has shown that a continuous chlorine concentration of 0.5 mg/l is enough to achieve a 5-log reduction of *Legionella* growth (Cervero-Aragó, Rodríguez-Martínez, Puertas-Bennasar & Araujo, 2015) and this is also the concentration used by some commercialized products, such as Krüger Aquacares Bacterminator (Krüger Aquacare), see Figure 15.

Figure 15. Chlorination sterilization method.
a) Electro Chemically Activated Water generator of Krüger Aquacares (to the left. Source: Kruger.
b) Scheme of working principle according to Evershade (to the right). Source: Evershade.

However, if the bacteria have hosts in the form of protozoa, such as amoeba, or are sheltered in biofilm, it is more problematic compared to free *Legionella* in the water and then higher chlorine concentrations will be required for sterilisation. Cervero-Aragó et al. showed that some amoebas are highly resistant to chlorine. Even with a chlorine concentration of 2.5 mg/l, a significant amount of *Legionella* could be found sheltered in amoeba after 30 minutes of exposure.

An important factor to consider when using any type of chemical, is the local water quality legislation (Yang et al., 2016a). Some countries have set very restrictive limits for chlorine making it an unsuitable choice. The World Health Organization (WHO) recommends that the chlorine concentration should be limited to 5 mg/l to avoid any risk to human health (WHO, 2017). The Swedish regulations on the other hand are stricter and only allow a dosage of 1 mg/l of chlorine (LIVSFS 2017:2). Other disadvantages are that chlorine is corrosive and as a result, the pipes dependent on chosen material may need additional treatment or need replacement more often.

Electro Chemical Water Treatment (electrolysis of NaCl containing water) enables a dose of chlorine to the hot domestic water of 0.5-1.0 mg/l which is below smell limit and can be used to maintain the water quality after initial sterilisation.

Chlorine can also be used in the form of chlorine dioxide which is usually a more effective sterilization chemical than pure chlorine. However, it is not as effective as a continuous disinfection as it decomposes quickly and the concentration thus decreases. For continuous control a concentration of 0.5 mg/l is required (Yang et al., 2016a). The maximum allowed dosage for chlorine dioxide in Swedish drinking water is 0.7 mg/l (LIVSFS 2017:2) and the WHO recommends the same levels (WHO, 2017).

It can be questioned if hot shower water is to be considered as drinking water as for the cold water.

5.2.2 Ultraviolet light

Ultraviolet (UV) light disrupts the DNA replication of bacteria and thus inhibits their growth. The effect is instantaneous and does not require any added chemicals to the water. However, since there is no lingering effect it is not suitable for larger systems or systems that have been colonized by biofilm in which bacteria are sheltered. Placing the UV lamps close to the tap is therefore of great importance and it might be more appropriate to use UV as a complement to another disinfection technique compared to using it as a single solution (Yang et al., 2016a). This conclusion is supported by a study performed by Liu et al. on the efficacy of UV treatment in combination with other treatment methods. The study showed that if the system contained *Legionella* and had not been decontaminated before the installation of the UV lamps, they would actually have little effect. However, if the system is pre-treated with for example hypochlorination, UV provides an efficient short-term control of *Legionella,* as well as of other bacterial growth. Another study conducted by Cervero-Argaró, Sommer and Araujo, investigated the efficacy of UV lights on *Legionella* associated with protozoa. Cervero-Argaró et.al. concluded that bacteria hosted by protozoa is up to 100 times more resistant against UV and that it is recommended to install another sterilization method as a complement to UV lamps (Cervero-Argaró, Sommer & Araujo, 2014).

Another factor to consider in regards to UV lamps, is that the lamps will require regular maintenance to clean off scaling (Liu et al., 1995).

A typical technical solution for UV lamp unit is shown below, Figure 16.

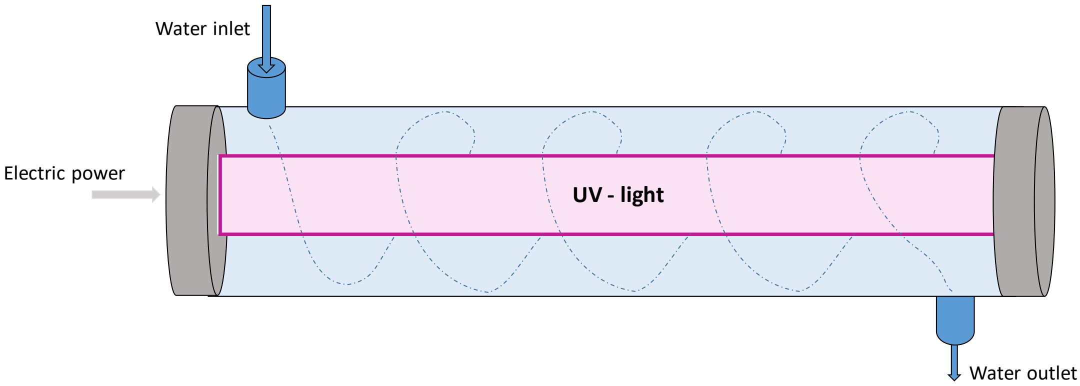

Figure 16. Principle illustration of UV treatment of water. Modified from Alfaa UV (n.y.)

5.2.3 Ozone

Ozone is a powerful oxidizing agent that can be dissolved in the water system. In the past ten years it has become a more common technique in potable water treatment and is starting to replace chlorine in many locations. Not only due to its high efficacy when it comes to sterilization, but it is also less harmful to the environment compared to chlorine (Li et al. 2017). Ozone is effective in low concentrations - 1 to 2 ppm - and inhibits growth by damaging bacterial DNA. Ozone has the drawback of a very short half-life, meaning it is difficult to maintain a high enough concentration for sterilization throughout the whole system. It can also be corrosive to the pipes which increases the need for maintenance (Associated Water Technologies, 2003). Ozone can be produced from air or from pressurized oxygen, and has to be injected into the water, see Figure 17.

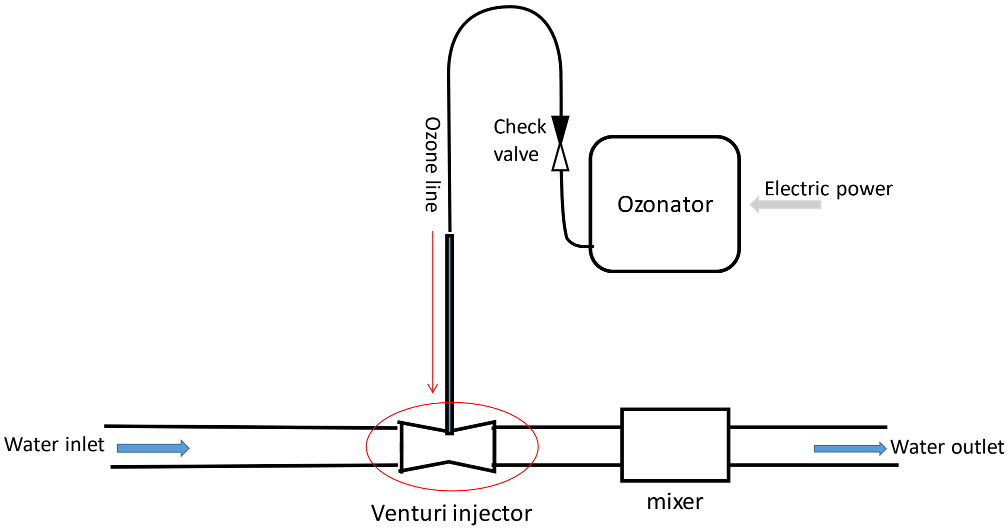

Figure 17. Principle illustration of ozone production and dosing unit. Modified from SpaDepot (n.y.)

5.2.4 Ionization

Like chlorination, ionization is a commonly used technique of sterilization in water systems. Silver and copper electrodes are placed in the system and release ions that disrupt the membranes of the bacteria. The effective dosages range is between 0.02 mg/l to 0.04 mg/l for silver ions and 0.2 mg/l to 0.4 mg/l for copper ions. This technique can be used as a long-term solution, although there are a few drawbacks. Most important is the issue regarding effective dosage and water quality legislation (Yang et al., 2016a). The EU, the World Health Organization or Sweden do not have any specified limits regarding silver ion concentration. WHO states, however, that in situations where silver ions are used as a form of bacterial control, levels up to 0.1 mg/l can be accepted without risk to human health (WHO, 2017). The European Union limits the copper concentration to 2 mg/l (Council Directive 98/83/EC), as does the Swedish National Agency (Livsmedelsverket, LIVSFS 2017:2). The Danish regulations are stricter and limit the copper ion concentration to 0.1 mg/l (Yang et al., 2016a). Moreover, ionization as a sterilization method is prohibited in Germany and only permitted under some circumstances in the Netherlands (Walraven et al., 2016).

Aside from the already mentioned legislative obstacles with using ionization, some water quality aspects will affect the effectiveness. Most importantly the alkalinity of the water will impact the solubility of copper ions in water. The concentration of free copper ions will decrease with increasing pH and a study found that at a pH of over 9, copper was unable to neutralize *Legionella* bacteria (Lin, Vidic, Stout & Yu, 2002).

In a long-term study performed in the Netherlands, copper-silver ionization was proved to be an effective sterilization method against *Legionella.* The study was performed in five different large systems and after three months all but two were clear of *Legionella*. The remaining required six and eighteen months respectively before they were confirmed decontaminated. In the experiment a theoretical copper concentration of 400 +/- 200 µg/l was used and the theoretical silver concentration was 40 +/- 20 µg/l. However, the measured concentrations were often lower and averaged between 317 - 444 µg/l for copper and 18 - 30 µg/l for silver (Walraven, et al., 2016). Some recurrence was found and was assumed to be caused by ion concentrations that were lower than intended. This, in turn, could have been a result from leakage, poor circulation in the system or inadequate flushing. The treatment could thus not reach all parts of the system allowing *Legionella* to grow in some areas. The authors therefore concluded that continuous measurement of the ion concentration is crucial to secure the efficacy of the sterilization (Walraven et al., 2016). A principle of copper-silver ion generator is shown in Figure 18.

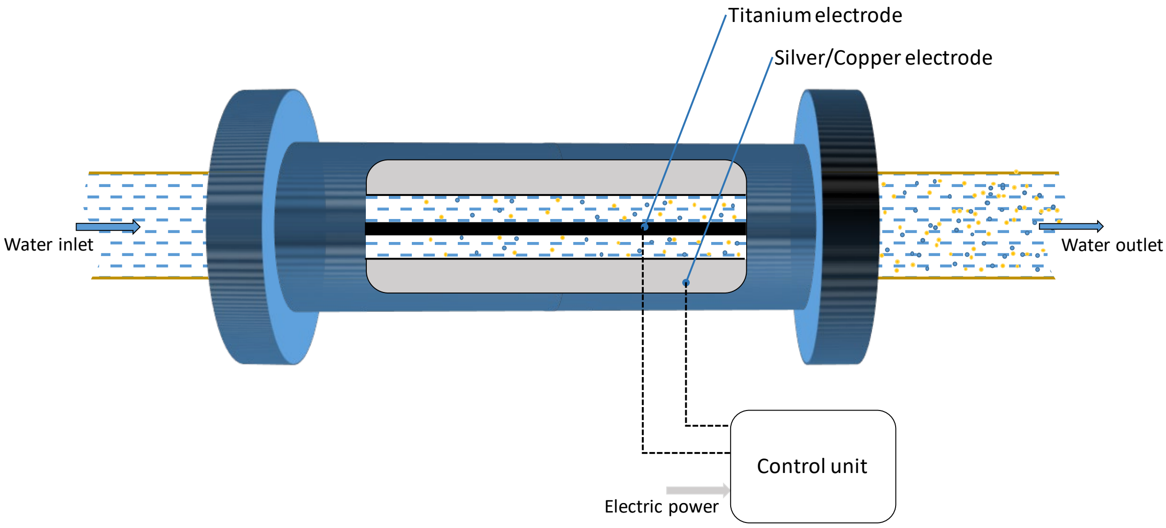

Figure 18. Principle of Copper/Silver ion generator.
Modified from TARN-PURE Ltd., (n. y.)

5.2.5 Photocatalysis

Photocatalysis is a so called advanced oxidation process (AOP). It uses a catalyst, such as titanium dioxide, TiO_2, that produces radicals that react with the bacteria and inactivates them by affecting the respiration process and the disintegration of the cell membrane. It becomes more efficient in the presence of UV light (Cheng, Chan & Wong, 2007). See Figure 19.

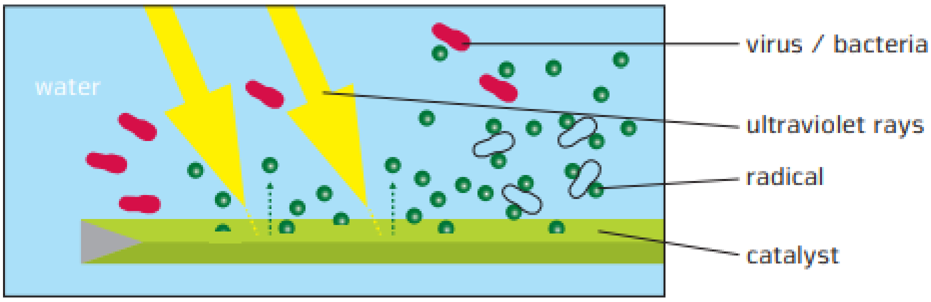

Figure 19. Schematic course of disinfection of the water by AOP.
Source: Boll & Kirch Filterbau GmbH

In a study performed by Cheng et al. photocatalytic oxidation was tested on four strains of *L. pneumophila* serogroup 1. Three strains were obtained from a local water tower, and the last one was an artificially grown ATCC (American Type Culture Collection) strain. Titanium dioxide and UV-light with a wavelength of 365 nm was used in the study. All strains showed significant reductions after 45 minutes, the ATCC strain being more resistant than the other strains. After 90 minutes all strains but the ATCC had achieved a 7-log reduction, the initial concentration being 10^7 cfu/ml (colony-forming units/ml). It was suggested that this was due to the difference in fatty acid profile of the strains. Fatty acids in the cell membrane are an important factor in the resistance to oxidation and bacteria can alter the composition of their fatty acids and thus become more resistance as the membrane becomes more rigid. The study concluded that photocatalysis in the presence of UV can be used as a sterilization method but that the efficacy is highly dependent on the composition of fatty acids in the cell membrane (Cheng et al., 2007).

One of the main benefits of photocatalytic oxidation is that it does not leave any harmful residual compounds in the water. There will therefore not be any problems with drinking water regulations. The majority of the cost for this type of sterilization is the initial investment cost for installation and equipment, the operation cost is small in comparison (Yang et al., 2016a).

Figure 20 shows an example of commercial application using AOP (or AOT, which stands for Advanced Oxidation Technology). The product, called *BOLLFILTER Automatic Type 6.03 AOT* is a combined particle filter and AOP unit.

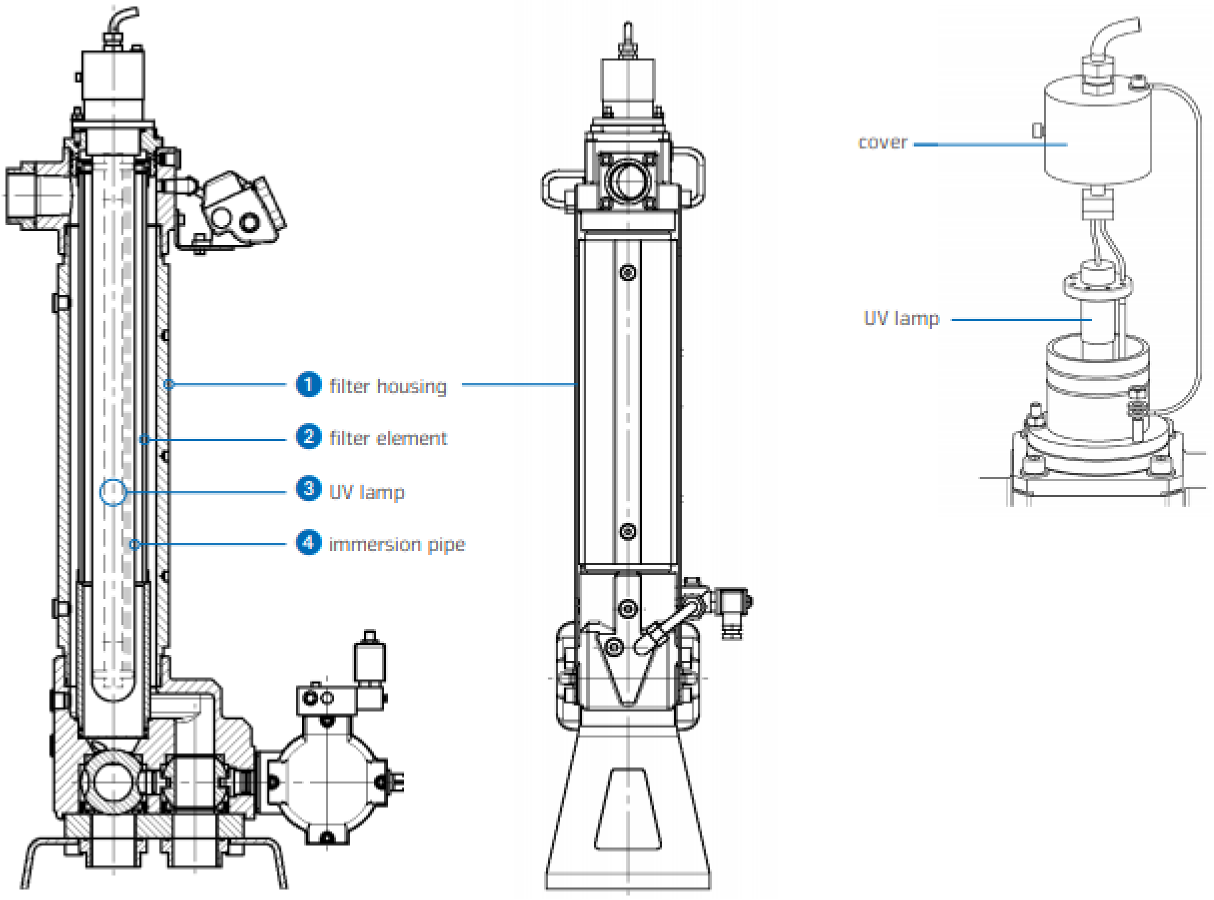

Figure 20. Combined particle filter and AOP unit with automatic backflush cleaning function. Source: Boll & Kirch Filterbau GmbH

5.3 Alternative System Design

Many of the sterilization methods described above include adding chemicals to the water, which may pose problems with local legislation. It would therefore be preferable to find a way to guarantee the water quality with regard to bacteria without compromising other quality aspects. Designing the DHW system, including the substation, in a way that the risk for bacterial growth is minimized might be a good solution. As discussed in section 2.1 about *Legionella* both residence time and temperature are vital for the growth of *Legionella* bacteria. The water systems should thus be designed to make one or both of these factors unfavourable to bacterial growth.

5.3.1 Decentralized substations

The use of decentralized substations (meaning that every flat has its own DH substation) can inhibit growth of *Legionella* by limiting the residence time in what might otherwise be favourable conditions. The idea is based on the German technical rule W551 that says that in systems, where the total volume between the point of distribution and the furthest tap does not exceed three litres, there is no need for additional disinfection techniques (DVGW, 2004). These systems are so called small systems, and are usually only found in single-family homes. The principle could nevertheless be applied in apartment buildings as well. Each apartment would then have its own district heating central - a flat station – with an individual heat exchanger that would heat up water instantaneously when needed (SP, 2014). A sketch of what such a system could look like is shown in Figure 21.

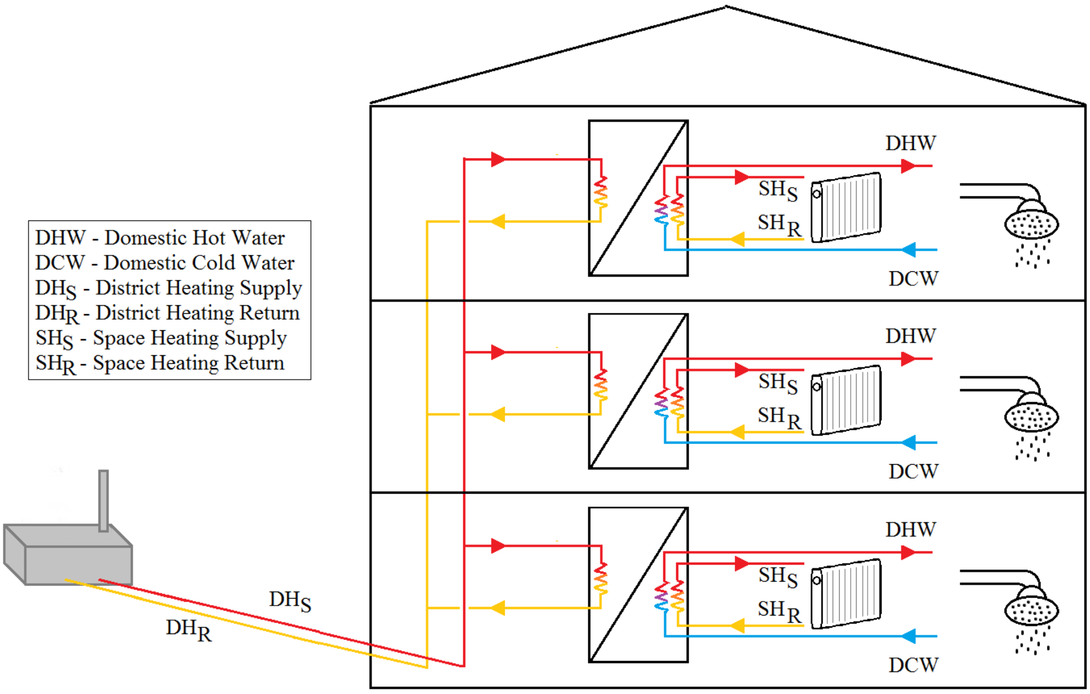

Figure 21. Process diagram of decentralized substations.

Decentralized substations has the potential to limit *Legionella* growth even with the lower supply temperatures from low temperature district heating. Yang, Li and Svendsen performed a study on a six story residential building in Denmark that concluded that an LTDH system with a supply temperature of 55 °C could be operated with decentralized substations while still ensuring the water quality with regards to *Legionella* (Yang, Li & Svendsen, 2016b).

Other advantages that could be seen with flat stations is that there will be no need for water circulation and this can significantly reduce the heat losses (Yang, Li & Svendsen, 2016b). The drawback is that it requires considerable investment costs and can be difficult to implement in existing buildings as the installation would require extensive renovations (SP, 2014).

5.3.2 Temperature increase through an auxiliary heating device

In order to meet temperature requirements for DHW systems when using low temperature district heating, an auxiliary heating device might be installed at the customer after the heat exchanger. In this report, three types of additional heating devices will be investigated: electric heat tracing, micro heat pumps and electric heating elements.

Electric heat tracing

One possible solution is to install electric cables on the DHW pipes (see Figure 22 for a process diagram of the setup). The DHW can thus be heated to the required temperature even if the primary supply water temperature is too low. This also eliminates the need for circulation of hot water since the heating process is nearly instantaneous (Yang, Li & Svendsen, 2016c). Replacing the hot water circulation system with electric heat tracing can lead to large energy savings and economic benefits. A study performed at Aalborg Hospital in Denmark showed that electric heat tracing can save up to 40 % of the energy consumed in a circulation system and that the equipment costs half as much. Another benefit is that it is applicable on existing systems without extensive renovation and in places where space is a limiting factor (Yang et al., 2016c). To make electric heat tracing more efficient it is advised to introduce smart control where the heat load at varying times is considered.

Electric heat tracing is already used in industrial properties but only a few projects (such as the hospital in Aalborg), exist in non-industrial properties and further investigation is required to fully determine the applicability in LTDH systems (Yang et al., 2016c).

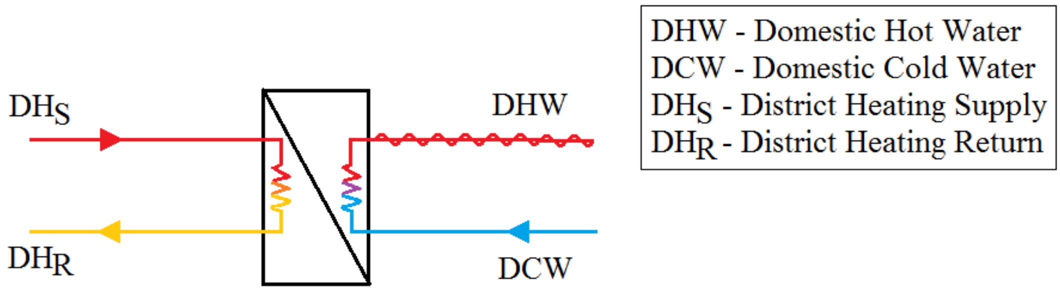

Figure 22. Process diagram of electric heat tracing.

Micro heat pump

Another way to raise the temperature in the domestic hot water system from a too low DH supply temperature is to install a micro-booster heat pump. In a study from 2012 on different micro heat pump designs and placements, it was found that micro heat pumps could be an energy efficient way of boosting the water temperature. Three scenarios were investigated and the most efficient was where the incoming DH water was split into two streams and where the energy from one was used by the heat pump to heat the other. Figure 23 presents the layout of such an installation. The DH water then heats cold tap water through a heat exchanger. Even though there is a storage tank, there is no risk of *Legionella* growth since the storage tank is installed on the primary side of the heat exchanger. Thereby, the tap water (DCW and DHW) and the DH water are hydronic separated and the risk for *Legionella* is eliminated (Zvingilaite, Ommen, Elmegaard & Franck, 2012). One disadvantage is that the investment cost is rather high and accounts for more than half of the annual cost of the micro heat pump over its lifetime.

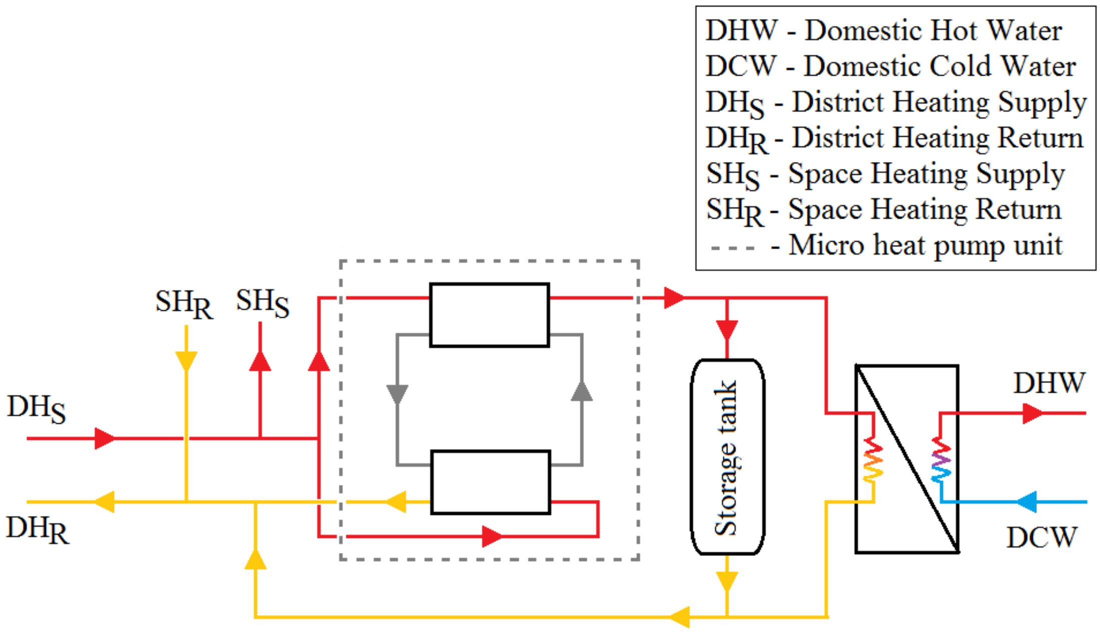

Figure 23. Process diagram of the setup with a micro heat pump.

Instantaneous electric heater

The concept of an electric heater is to have an electric heater in addition to the heat exchanger. This provides instantaneous heating of either the supply stream, i.e. before the heat exchanger or directly of the DHW, i.e. after the heat exchanger.

In 2016 a study was published by Yang, Li and Svendsen comparing five different scenarios of electric heating. The result of the study with regards to energy use can be seen in Figure 24.

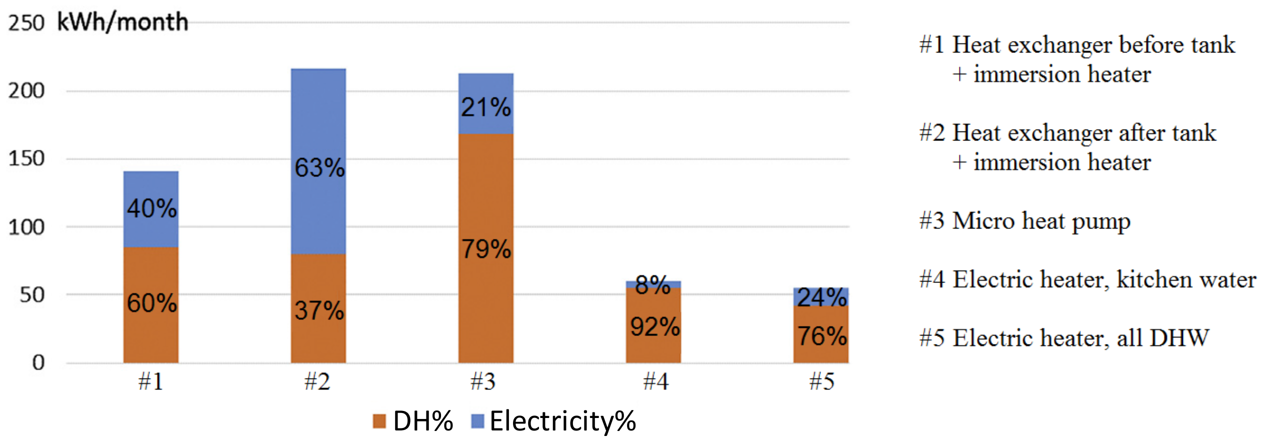

Figure 24. Heat and electricity delivered for DHW preparation. Source: Yang et al. (2016d).

As can be seen in Figure 24, scenario four and five had the highest energy performance and only these two will therefore be further described here (scenario three has been described in previous section). The setup of the fourth and fifth scenario were very similar in their configuration. There was an instantaneous electric heater installed after the heat exchanger and no accumulation tank. In the fourth scenario only the water used in the kitchen for washing purposes was heated, as can be seen in Figure 25. In the fifth scenario on the other hand, all of the DHW was heated as shown in Figure 26 (Yang et al., 2016d).

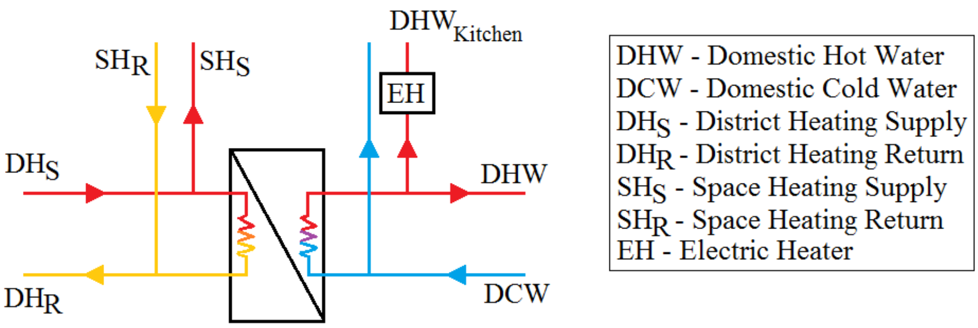

Figure 25. Process diagram of the fourth scenario, where only the hot water for the kitchen is heated.

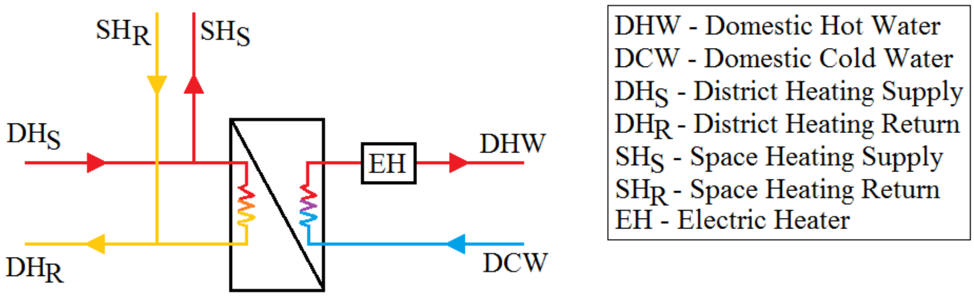

Figure 26. Process diagram of the fifth scenario. All DHW is heated.

Not only did the fourth and fifth scenario require the least amount of total energy but they were also able to use a high percentage of DH energy and required little contribution from electricity relative to the heat demand. This may partly be due to the fact that there is no storage unit since tanks tend to increase the heat losses. The investment cost of scenario 4 and 5 were 11 000 and 16 000 DKK respectively and the levelized cost of energy 1.4 DKK/kWh and 1.9 DKK/kWh (Yang et al., 2016d).

A problem with the electric heaters used in scenario 4 and 5 is that during periods of peak load the required power may be higher than the normal power supply (Yang et al., 2016d). To avoid a power outage, it would be necessary to increase the size of the main fuse. This could in turn become expensive with installation costs and higher electricity bills. As an example from Sweden from current fees at Kraftringen, a 16 ampere fuse, which is common for a single-family house in Sweden, has a subscription fee of 4 140 SEK. To secure the electricity supply with an in-line electric heater an upgrade to a 35 ampere fuse may be necessary. A fuse of this size has a subscription fee of 10 620 SEK, i.e. a yearly increase of almost 6 000 SEK, not including the cost of the upgrade itself (Kraftringen, 2018).

This leads to considering using heat pumps for the temperature topping.

5.3.3 Pipe techniques

Once incorporated into biofilms, bacteria such as *Legionella* are more protected from its surroundings and can survive the action of disinfectants to a higher degree than when suspended in the water (Moritz, Flemming & Wingender, 2010). Therefore, biofilm inhibition is essential when using pipe techniques to prevent *Legionella* growth. This technique can be divided into two subcategories - material selection and surface roughness.

Material selection

Numerous studies have been made on biofilm formation on different materials. The materials of interest in this study are plastic and copper as they are the most commonly used pipe materials in drinking water distribution systems (Lethola et al., 2004). As described in section 5.2.4, copper has been known to have antimicrobial properties against bacteria among other species (Gião, Wilks & Keevil, 2015). Not only can copper inactivate several pathogens when in contact with the surface, but it can also prevent formation of biofilms (Gião et al., 2015). Copper ions can also leach into the water and in that way affect suspended microorganisms as it can be toxic to bacteria through attacking the respiratory enzymes or nucleic acids of the bacteria (Lethola et al., 2004). Pipes made of certain types of plastics can, on the other hand, promote biofilm formation as it can provide nutrients through the release of biodegradable compounds (Moritz et al., 2010). In a study made by Van der Kooij, Veenendaal and Scheffer (2005), an experiment was carried out comparing the effect of copper, stainless steel and cross-linked polyethylene (PEX) on biofilm formation and the growth of *Legionella* in a model drinking water system. Kooij et al. found that there was less cultivable *Legionella pneumophila* on copper pipes compared to pipes made of stainless steel and PEX in accordance with other studies on the subject. However, after about two years of conducting the experiment, the concentration of *Legionella* in the water was the same for all pipe systems which suggest that the inhibitory effect of copper had ceased (Van der Kooij et al., 2005). This result complies with the experiment by Lethola et al., where it was concluded that biofilm formation was slower in copper pipes than in plastic pipes but there was no significant difference in microbial numbers after 200 days (Lethola et al., 2004).

The material selection in pipes is of importance in how fast the biofilm formation initially occurs, however in relation to the life expectancy of the pipe, the choice of material might not be as crucial (SP, 2014). In the experiment of Van der Kooij et al., the researchers also found that although the biofilm formation was initially higher in the PEX pipes than the stainless steel pipes, the concentration of *Legionella* were similar (Van der Kooij et al., 2005). This suggests that there are other factors in determining the microbial composition of a biofilm than pipe material.

Surface roughness

Another method of preventing biofilm formation is pipe coating where a thin layer of antibacterial material is added to the inside surface of the pipe (SP, 2014). With a coated, smooth surface on the inside of the pipe, attachment of biofilm to the pipe surface can decrease which in turn will reduce bacterial proliferation. There are several materials that can be used for antibacterial purposes, often mentioned are metal ions of silver, copper and zinc (Rusin, Bright, & Gerba, 2003). Rusin et al. conducted an experiment that showed a significant effect on *Legionella pneumophila* growth by silver and zinc coating on stainless steel surfaces. However, an issue with coating of antibacterial compounds on metal surfaces is that the release of metal ions decreases over time. The antibacterial effect will thus be reduced significantly and will not be apparent throughout the lifetime of the pipe (SP, 2014). It is suggested that only particularly vulnerable areas could be coated with a material that does not necessarily possess antibacterial characteristics, but can provide a polished surface to reduce colonization and formation of biofilm. Such particularly vulnerable areas could be areas with lower flow, bends and joints (SP, 2014).

5.4 Discussion of techniques for *Legionella* control

In this section the different techniques for *Legionella* control that have been explained in this chapter will be discussed further.

5.4.1 Mechanical Techniques

Using filters for *Legionella* control is a mature method that has been commonly used in locations where extra precautions should be taken, e. g. hospitals, due to its high efficiency. In their experiment, Marchesi et al. ranked the efficiency of different methods to control *Legionella* in the water supply and found that filters were the most efficient method. However, it was also the most expensive method (Marchesi et al., 2010). This raises the question on the feasibility in implementing filters as a technique for *Legionella* control in a wider range. The technique requires frequent maintenance through continuous switching of filters and can thus be seen as an added inconvenience.

5.4.2 Sterilization Techniques

Neutralization of bacteria using chemicals, such as chlorine, or by ionization have the advantage that they are mature methods that commonly used in potable water treatment across the globe. However, using chemicals is not totally without encumbrance. The most important ones may be legislations of water quality for potable drinking water that are in place in order to protect human health, and the attitude of consumers.

Chlorine

There are limit values for the concentration of chlorine and chlorine dioxide regulated by national legislation that need to be taken into account if choosing chlorine as a sterilization method. This legislation differs between countries so it may be difficult to come up with an international standardized procedure for chemical treatment. As mentioned in subsection 5.2.1, high concentrations of chlorine may be required to combat *Legionella* hosted by amoeba and these will likely not comply with regulations. In Sweden, for example, the maximum chlorine dosage is 1 mg/l which would, according to the study mentioned in chapter 5.2.1, not be enough to inhibit *Legionella* in amoeba. For free *Legionella* on the other hand, the chlorine concentrations required are unlikely to have any negative health effects.

UV

The study performed by Liu et al. described in chapter 5.2.2 confirmed that UV can efficiently inhibit *Legionella* growth given that the system had been previously cleaned so that there is no *Legionella* present in biofilm from the beginning. However, it would be difficult to guarantee that all systems where UV were to be used would be free of biofilm, or to guarantee that *Legionella* would not colonize in existing biofilm. Furthermore, UV is a point-of-use technique, implying that for ideal operation the UV lamps would need to be installed as close to the tap as possible. This will likely result in high costs due to need for renovation as well as an additional treatment technique and regular maintenance in cleaning the lamps.

Ozone

The benefits of using ozone are that it is very effective and that it is significantly less harmful to the environment and humans compared to chlorine (Li et al., 2017). Something that may work against it is the fact that ozone has a short half-life. The consequence of this is that the ozone would have to be introduced in the system close to the tap in order to avoid bacterial regrowth. The method could therefore be considered almost as a point-of-use technique, which complicates the process as individual dispersion mechanisms would need to be installed. As far as we could see in our literature review, very little research exists on ozone as a means for *Legionella* control. It is therefore unlikely that the technique could be implemented for this purpose in a near future.

Ionization

The use of ionization is even more problematic as it is prohibited in some countries, for example in Germany, and only allowed in critical situations in others, such as the Netherlands (Walraven et al., 2016). In Denmark it would also be problematic to use as the maximum allowed concentration of copper and silver are lower than the effective concentrations (Yang et al., 2016a). On the other hand, ionization has the benefit that it is effective in the long run and that it offers a residual effect. It can be used in large systems and provide protection against *Legionella* in all parts of the system that could be reached by the water flow.

Sterilization usually involves adding some sort of chemical to the water system and the attitude of consumers in this matter should not be underestimated. Especially in today's society when people are becoming more aware of what they are putting into their bodies and what is being released into the environment. Using additional chemicals as water treatment could be a tough method to sell. This was confirmed at the focus group interview held with building contractors in Lund, Sweden. The participants were asked the question of how they thought their buyers and residents would react to the introduction of a chemical sterilization technique. Most of the participants emphasized the issue of information dissemination, something that becomes increasingly difficult with a second generation of buyers. The participants also brought up the need for the sterilization technique to be nearly undetectable by the residents. Their main concern being that a change in water quality of some sort, for example in taste or temperature, would result in complaints from the residents.

5.4.3 Alternative System Design

Decentralized substations

Decentralized substations, or flat stations, is a hot topic when talking about solutions for *Legionella* control in domestic hot water systems connected to district heating systems. Pilot tests have been performed in Denmark, for example by Yang, Li and Svendsen, concluding that the decentralized substations could be used while still securing the system with regards to *Legionella* (Yang et al., 2016b). However, as mentioned in subsection 5.3.1, this solution also requires invasive renovations that complicates implementing flat stations in existing buildings. This was also a an issue that was brought to light in the focus group interview, where a concern of high costs was expressed. Flat stations would require more space, maintenance and higher investment costs, which would affect the final price or rent of an apartment.

Also, there is still the issue of temperature requirements to consider. The legislations are restricting implementation of many alternative solutions that cannot fulfil the requirements on DHW temperature, including decentralized substations.

Auxiliary heating device

As mentioned in subsection 5.3.2, an auxiliary heating device boosts the DHW temperature and can therefore comply with the current legislation on DHW temperature requirement. This gives it an important competitive advantage over the other available techniques. It uses thermal treatment, which is already established as the primary treatment for *Legionella* control in most, if not all, EU countries today. Other advantages compared to sterilization techniques is that it does not compromise the quality of the water by adding any chemicals. It could therefore be implemented in all countries without having to take any local water quality legislation into account.

The economy is however a downside here. In existing buildings, the installations of an electric heating device or an electric heat tracing would require significant renovations, which would be complicated as well as time consuming and expensive. Auxiliary heating devices to boosts the DHW temperature is therefore more suitable for installation in new buildings where the heating devices could be included in the design from the beginning. The need for an individual device in each household would make the investment cost higher than for current district heating systems when several or all flats in the building share the same district heating substation.

There is also an issue with the electric effect required by the auxiliary heaters at peak hours. Peak loads usually occur in the morning or in the evening when many household appliances are and showers are used simultaneously. Depending on the size of the original fuse it may be necessary to upgrade it to one that can handle a higher peak load. For the customer this may result in an additional connection fee and it will lead to a higher yearly subscription fee.

Pipe techniques

Different materials have different qualities that might affect the bacterial growth. The experiment mentioned in subsection 5.3.3 conducted by Kooij et al. found that the initial bacterial inhibitory effect of copper pipes was larger in comparison to pipes made of PEX and stainless steel. However, this effect declined and was no longer present at all after about two years. The life expectancy of the pipes is much longer than two years which suggests that the choice of pipe material as a control measure for *Legionella* prevention is a feasible solution. In the same way do coating of antibacterial material on the inside of the pipe show bacterial inhibitory qualities initially, but only for a limited amount of time. This suggests that the use of pipe coating is not a viable technique for *Legionella* control.

5.5 Possible developments

5.5.1 Alternative shower head design

There is an obvious relation between shower water droplet size and the risk of *Legionella* infection but according to Aaron et.al. (2017) the mechanism of bacteria transmission is poorly investigated. However, so called aerating shower heads already present on the market, originally developed to reduce water consumption and increase the showering comfort, claims to produce fewer inhalable water particles of the size <10 μm and consequently reduce a risk of the infection (Kelda, n.y). Careful evaluation of this type of point-of-use products and more research within this field would be to recommend.

5.5.2 Ozone POU units

Tap water ozonisers can be applied as point-of-entrance (POE) but also as point-of-use (POU) devices. Commercial units of this kind are available on the market and claims to improve water quality and kill microorganisms “within minutes” (Ozomax, n.y). The efficiency of the latter one devices against *Legionella* in domestic hot water applications has not been investigated yet, however.

5.5.3 Small systems

As already mentioned, in Germany and France there is a special legislation concerning tap water systems where the pipe volume between the entry point and every tap/shower is maximum 3 litres. For these small systems there is no specific demand on the temperature of entering water which can come directly from a heat exchanger or from a mixing valve, as long a consumer comfort is satisfied (about 40 °C at the tap). In practice, small systems like that are present in almost all countries. In small houses tap hot water is often distributed from a mixing valve with a set point of 40-45 °C and there is no hot water circulation. If the house is connected to a district heating system, the DHW is heated up instantly in a small heat exchanger with short residence time (seconds). The question arises if such heat-up has any significant influence on *Legionella* survival dependant on if the set point temperature is 55 or 45 °C. A careful analysis of data concerning DHW related *Legionella* infections depending on kind of accommodation could bring clarity if the small DHW systems can be assumed as *Legionella* safe. If yes, this could open for usage of LTDH for direct preparation of DHW at 45 C° in instantaneous heaters.

5.5.4 DHW circulation

A spectacular hypothesis is whether the DHW circulation concept can ever be *Legionella* safe, not only because of practical imperfections (uneven flow/temperature distribution in the pipe grid) but also because each circulation system consists of a large number of forks where hot circulating water is heating up stagnant or mostly stagnant water in connecting pipes 24 hours a day. The stagnant water has a temperature somewhere between the temperature in the DHW circuit and the ambient temperature, a temperature range suitable for Legionella growth. Distributed instantaneous DHW heaters, like individual gas boilers or flat stations, appear much safer in this aspect, provided that they are heated up only when tapping of domestic hot water occur.

6 Conclusions

In this report the aim has been to gather information about regulations of domestic hot water systems in terms of *Legionella* safety in six countries and to make a literature review on different methods that could be used to keep *Legionella* safety and prohibit *Legionella* growth in domestic hot water systems. An analysis has been done on the advantages and disadvantages of the different methods and how the methods comply with today's regulation of domestic hot water systems and the applicability of the different methods when used within a LTDH district heating system. I addition to this, a statistical outlook has been done on the incidence of Legionnaires disease in the six selected countries and how the incidence levels relate to regulated temperature levels for domestic hot water systems. The conclusions from the overall study is summarised here.

Conclusions on *Legionella* related legislation and temperature requirements in domestic hot water systems:

- The European Union has no specific directive or ordinance regulating the actual concentration of *Legionella* bacteria in domestic hot water systems. Instead, the guidelines require that certain temperature levels are kept in the systems. The European Union guidelines for temperature requirements in the DHW system are 50 °C at the drain point and 60 °C in storage tanks with stagnant water.

- Some countries have chosen to set the temperature requirements even higher, for example Norway, that declares that *Legionella* should be controlled by keeping the temperature in circulating water systems above 65 °C.

- Other countries included in this study, has made exceptions from the EU guidelines in the national regulations that go under the 50 °C at the drain point and 60 °C in storage tanks in some cases and under some circumstances. France and Germany make exceptions for small systems where the pipe volume between the entry point and every tap/shower is maximum 3 litres. There is no specific demand on the temperature of entering water which can come directly from storage tank or heat exchanger or from a mixing valve as long a consumer comfort is satisfied (which means about 40 °C at the tap). In Denmark, a DHW temperature of 45 °C is permitted at times of peak flow.

Conclusions on techniques to prevent *Legionella* growth in domestic hot water systems:

- The conventional treatment technique against *Legionella* in DHW systems is to continuously keep the temperature at a level that inhibits bacterial growth, thereof the EU guidelines. A reduction in supply temperature when implementing LTDH might result in temperatures that instead favour bacterial growth.

- This report has summarized alternative techniques to prevent *Legionella* growth. The different techniques can be divided into three categories: mechanical techniques, sterilization techniques and alternative system design, all with different advantages and disadvantages. In Table 4 we have summarized the advantages and disadvantages of the described techniques. We have also added one column in the table describing if legal temperature requirements in the domestic hot water systems would be fulfilled if low temperature district heating where the supply temperature in the DH system is lower than the required temperatures for DHW systems were to be used.

Table 4. Advantages and disadvantages of the studied techniques for Legionella control in low temperature DH system.

Technique	Advantages	Disadvantages	Fulfils temperature requirements in regulations?
Filters	• Instant effect • Very effective	• Short lifetime; frequent maintenance required • High cost • Local effect, not residual	No
Chlorination	• Mature technology • Residual control	• Less effective on protozoa • Local legislation • Potential health hazard, chemicals added • Can be corrosive for pipes	No
UV	• Instant effect • Mature technology	• Not sufficient on its own • Less effective on protozoa • Local effect, not residual	No
Ozone	• Highly oxidizing, effective in low concentrations	• Corrosive: pipe maintenance required • Local effect, partly residual	No
Ionization	• High efficiency • Mature technology	• Can be prohibited by national legislation because of potential health hazard • Copper and Silver ions added	No
Photocatalysis	• Pilot studies show high efficiency	• Not commercialized for residential properties • Local effect, not residual	No
Decentralized substations	• No need for DHW circulation: reduces heat losses	• Investment cost	No
Electric heat tracing	• No need for DHW circulation: reduces heat losses	• Only partly commercialized for residential properties	Yes
Micro heat pump	• Energy efficient	• Higher investment costs	Yes
Electric heating element	• Compact installation	• High electric effect required at peak times: may need upgrade of main fuse	Yes

- More research on the effectiveness of different techniques to prevent *Legionella* growth is needed.

- The review of different techniques for preventing *Legionella* growth in domestic hot water systems shows that there are several alternative techniques that theoretically could prevent *Legionella* growth besides keeping a high water temperature, although these could not be used as single methods if ultra-low temperature district heating is used, since the legal temperature requirements in some countries would then not be met.

- The only *Legionella* preventing techniques that in fact could be used today together with ULTDH is the ones that raise the temperature up to the level that the temperature requirements for domestic hot water systems can be achieved. Only in countries which use the exception of the three-litre-rule in small systems, the decentralized substations can be used together with ULTDH. In order to be able to use any of the other techniques as a single solution to prevent *Legionella* growth, regulation would have to be altered to focus on the concentration of *Legionella* bacteria instead of certain temperature levels.

Conclusions on disease incidence and temperature requirements:

- The examination of the statistics of the incidence of onset of Legionnaires' disease in six countries show a possible connection between the DHW temperature requirements and reported cases of *Legionella* pneumonia. The countries with higher temperature requirements show fewer cases of illness per capita (Norway and Finland) and the countries with the lowest temperature requirements show higher number of reported cases of Legionnaire's disease (Denmark and France). The findings are interesting although it is not possible to establish causal relationship by these variables within the framework of this study - if it is even possible to determine this at all. There may be other, underlying, variables that can explain this relationship. Nevertheless, for health reasons, and for PR reasons, it may be wise to use a precautionary principle for new solutions to prevent *Legionella* growth. It would not be fruitful to build a heating system that increases residents' risk of getting *Legionella*, further, it could conduce to denigrate district heating reputation.

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Sterilization, Chlorine dioxide

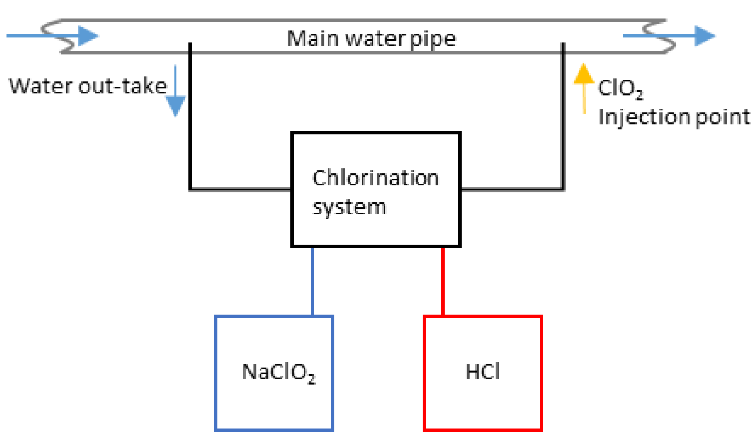
1. Short Description

In order to control legionella bacteria in a domestic hot water system, chlorine dioxide can be added to the cold water inlet before hot water preparation, providing a continuous prevention against legionella in hot water systems.

2. Key words

- Legionella control
- Legionella prevention
- Chlorination
- Chlorine dioxide
- Sterilization
- Low temperature district heating
- Water treatment

3. Illustrations



Chlorine dioxide sterilization method. Scheme of working principle based on Krüger Aquacare Oxiperm Pro

Chlorine dioxide generator by Krüger Aquacare

Source: *Krüger Aquacare Oxiperm Pro* (n. y. b)

4. Technical description

The chlorination using chlorine dioxide is a common sterilization method in potable water treatment used in some countries, used against Legionella proliferation when sufficient residual concentrations is kept in the water system (Yang et al., 2016a).

The system produces chlorine dioxide (ClO_2) using a solution of sodium chlorite ($NaClO_2$) and hydrochloric acid (HCl). The chlorine dioxide can be stored in a small tank and dosed gradually in the water flow. Chlorine inhibits bacterial growth by having a negative impact on the respiration process. It can either be used for continuous control with low dosage over a longer period of time, or as a shock treatment with a high dosage on a single occasion (SP, 2014).

Perspective:

- Effective
- Well established technology for water treatment
- Residual effect, covers the whole DHW system

5. Characteristics

A continuous chlorine dioxide concentration of 0.5 mg/l is enough to achieve a 5-log reduction of Legionella growth (Cervero-Aragó, Rodríguez-Martínez, Puertas-Bennasar & Araujo, 2015).
A shock treatment can be performed maintaining a concentration between 50-80 mg/l for 8 hours, in the system's tank, and for 1 hour at all the outlet. The process show a good inhibiting efficacy of the Legionella bacteria (Yang et al., 2016a).

6. Demands to installation

- Point of use (POU) installation, space for installation at the end user
- It requires maintenance access to refill the chemicals' tanks

7. Pros and cons

Pros	Cons
+ It is mature technology, since it has been used/tested for a long period. + It has a high residual control when a high concentration level is maintained in the system, ensuring the disinfection of the entire system. + It is effective against the biofilms in the water system. + Mostly suited for larger buildings.	- Local legislation can affect the effectiveness of this technology, due to the limitation of the chlorine dioxide concentration. - Potential health hazard, chemicals added to the water. - Can be corrosive for pipes since the high oxidation capacity. - With low chlorine dioxide concentration, the residual effect can be limited, reducing the effectiveness of the solution and leading to a possible growth of bacteria in some points of the water system. - Needs maintenance and a service agreement.

8. Economic data**

Capacity range [m³/day]	Equipment cost ekskl. VAT, [€]	Total cost incl. installation price excl. VAT, [€]	O&M cost [€/m³]
Krüger Aquacare Oxiperm Pro with max capacity of 25 m³/h	8000 €	8000+470 €	Annual service cost: 1450 €* Annual operation cost: 300 €* Total O&M cost: 0.68 €/m³*

* Data based on a plant for:
- 40 apartments
- 3.5 persons per apartment
- 50 l/person*day
- 2555 m³/year
- 7 m³/day

** Prices reference 2018

9. Environmental issues

- Potential health hazard in technical room if chemicals are not handled with care.
- Chemicals are used in the process
- A surveyed non-return valve must be installed on the water supply side
- Alarm when chlorine dioxide level is low

Suggestion: Consider at valve that closes the DHW supply if the low concentration alarm is not reset in connection with maintenance within 5 days.

10. Example of suppliers

- Krüger Aquacare
- Guldager
- Grundfos
- BWT Best Water Technologies

11. References

Yang, X., Li H. & Svendsen, S. (2016a), Alternative solutions for inhibiting Legionella in domestic hot water systems based on low-temperature district heating, Building Services Engineering Research and Technology, 37, 468–478.

Cervero-Argaró, S., Sommer, R. & Araujo, R.M., (2014), Effect of UV irradiation (253.7 nm) on free Legionella and Legionella associated with its amoebae hosts, Water Research 67, 299-309.

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[Retrieved on 2018-08-06]

Sterilization, Electrochemical treatment

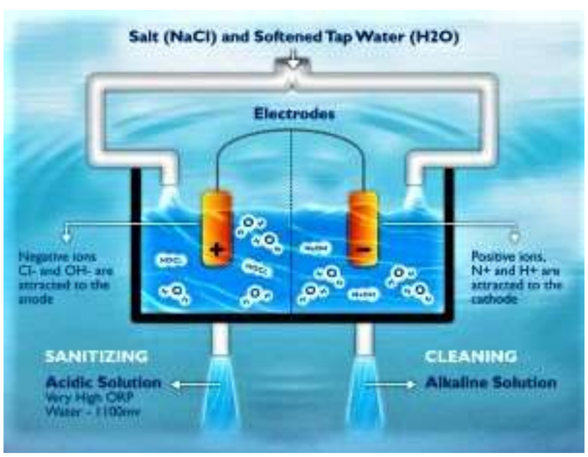
1. Short Description

In order to control legionella bacteria in a domestic hot water system, an electro chemical treatment can be applied to the domestic hot water system, using two electrodes and adding common salt. The process softens water and release chlorine ions in the water.

2. Key words

- Electrochemical treatment
- Legionella prevention
- Legionella control
- Sterilization
- Low temperature district heating
- Water treatment
- Chlorination

3. Illustrations



Chlorination sterilization method. Scheme of working principle according to Evershade

Source: Evershade

Electro Chemically Activated Water generator of Krüger Aquacare

Source: Krüger Aquacare

4. Technical description

Chlorine is a common sterilization method used in many countries in potable water systems. It can also be used for Legionella control if sufficient residual concentrations are kept in the water system (Yang et al., 2016a).
The system for electro chemical treatment of domestic hot water is equipped with two electrodes and electrical current flows through them when placed in the water that have to be treated. Common salt is added to the water in order to create a solution. The reaction with the electrical current produces a hypochlorite solution, which sterilizes the water.
This inhibits bacterial growth by having a negative impact on the respiration process and can either be used for continuous control with low dosage over a longer period of time or as a shock treatment with a high dosage on a single occasion (SP, 2014).

Perspective:

- Effective
- Well established technology for water treatment
- Residual effect, covers the whole DHW system

5. Characteristics

A residual level of chlorine concentration between 1 and 2 mg/l is required for continues control of legionella. If the Legionella bacteria are associated with host protozoa, the chlorine concentration has to be higher (The European Guidelines Working Group, 2017).
Besides the good effectiveness of the treatment, chlorine in higher concentrations is corrosive, which may lead to pipe corrosion if they are not properly treated. Moreover, chlorine residual has the potential to cause carcinogen disease to human beings (Yang et al., 2016a).

6. Demands to installation

- Point of use (POU) installation
- Maintenance, Chemical refill
- Additional chemicals added

7. Pros and cons

Pros	Cons
+ It is a mature technology, widely used in and tested. + It has a high residual control when sufficient concentration level is maintained in the system, ensuring the disinfection of the entire system. + The concentrations in the water at the tab is below smelling limit. + It has low operation costs, since it requires only common salt. + Due to the softening of the water, the deposit on sanitary equipment and in the piping system is reduced. This lead to a lower cost of maintenance and cleaning. + Most suitable for larger buildings.	- Less effective on protozoa. - Local legislation can affect the effectiveness of this technology, due to the limitation of the chlorine concentration in the water in potable water (however domestic hot water is not drinking water). - Can be corrosive for metal pipes since the high oxidation capacity. - The pH of the water can affect the effectiveness. - Needs maintenance and a service agreement.

8. Economic data**

Capacity range [m³/day]	Equipment cost excl. VAT, [€]	Total cost incl. installation price excl. VAT, [€]	O&M cost [€]
E.g. Krüger Aquacare BacTerminator with max capacity of 50 m³/day	6200 €	6200+470 €	Annual service cost: 845 €* Annual operation cost: 420 €* Total O&M cost: 0.50 €/m³*

* Data based on a plant for:
- 40 apartments
- 3.5 persons per apartment
- 50 l/person*day
- 2555 m³/year
- 7 m³/day

**Prices reference 2018

9. Environmental issues

- Potential health hazard if technical room is not vented, due to the chlorine generated
- A surveyed non-return valve must be installed on the water supply side
- Alarm when salt level is low

  Suggestion: Consider at valve that closes the DHW supply if the low level alarm is not reset in connection with salt refill within 5 days.

10. Example of supplier

- Krüger Aquacare
- BWT Best Water Technologies

11. References

Yang, X., Li H. & Svendsen, S. (2016a), Alternative solutions for inhibiting Legionella in domestic hot water systems based on low-temperature district heating, Building Services Engineering Research and Technology, 37, 468–478.

Cervero-Argaró, S., Sommer, R. & Araujo, R.M., (2014), Effect of UV irradiation (253.7 nm) on free Legionella and Legionella associated with its amoebae hosts, Water Research 67, 299-309.

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The European Guidelines Working Group, (2017), *European Technical Guidelines for the Prevention, Control and Investigation, of Infections Caused by Legionella species.*

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[Retrieved on 2018-08-06]

Legionella filter

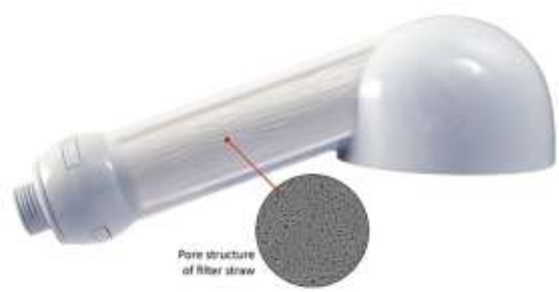
1. Short Description

The Legionella filters are a point of use (POU) technology that allows stopping Legionella bacteria with a mechanic membrane filter ensuring a local Legionella protection.

2. Key words

- Legionella control
- Low temperature district heating
- Disease prevention
- Heat savings on hot tap water
- Point-of-use (POU)
- Water filter
- Mechanic membrane filter

3. Illustrations



Commercial POU microbial filters for tap water systems, shower head with T-Safe® filter.

Source: http://t-safe.co.uk/technology/ ...

Commercial POU microbial filters for tap water systems faucet with H2Otap3000 filter

Source:
http://www.biogenfilters.com/h2otap-3000/
http://www.kruger.dk/Ejendomme/legionella/

4. Technical description

By using membrane filters installed on each tap, also called point-of-use (POU) water filters, Legionella colonization can be prevented as the microorganisms are kept from entering the protected site. This technique is frequently used in high-risk facilities where extra precautions should be taken, e.g. in hospitals (Baron et. al., 2014). Filtration is a very effective method of Legionella prevention, however the relatively short lifetime of the filter causes the operation cost to be high since the filters must be replaced frequently (Yang, Li & Svendsen, 2016a).

Perspective:

- Effective
- Well established technology
- Local protection

5. Characteristics

The filters are applied directly to the tap, which do not require specific experience to perform the installation. The lifetime of a filter is variable, depending on the device producer and on the tapping cycles. It can vary between 2 to 3 months and afterwards the filter has to be replaced. The solution is suggested in retirement homes, hospitals and other buildings with dedicated safety requirements for the occupants.

6. Demands to installation

- Point of use (POU) installation
- Maintenance access
- Regular maintenance / change of filter
- Wide variety of design and use

7. Pros and cons

Pros	Cons
+ It has an instant effect on the water, without any waiting time. + It is highly effective against the bacteria. + There is a wide variety of designs and applications.	- The filters have a short lifetime compared to other water treatment. They require frequent maintenance to replace the filters. - Due to the short lifetime, this technology has high operation costs. - The effect of the filter is locate only at the tap. If the piping system is already infected by Legionella bacteria, the filter cannot act against the contamination and bacteria growing in the pipes. - The pressure drop due to the filter installation requires a minimum pressure level at the tap. - Visually non attractive outside hospital environment. - Expensive.

8. Economic data

Capacity range [m³/day]	Equipment cost ekskl. VAT, [€]	Total cost incl. installation price excl. VAT, [€]	O&M cost [€/m^3]
Biogen Technologies H_2Otap 4000 90 days >15000 liters	28 €** each	-	1.87 €/m³
T-Safe® Hygiene Shower 92 days >5000 liters	56 €** each	-	11.6 €/m³

**Price reference 2018

9. Environmental issues

- Recycling of the exhausted filter

10. Example of suppliers

- Biogen Technologies S.L.
- Tandrup Water Solutions A/S
- T-safe

11. References

Baron, J.L., Peters, T., Shafer, R., MacMurray, B. & Stout, J.E. (2014). *Field evaluation of a new point-of-use faucet filter for preventing exposure to Legionella and other waterborne pathogens in health care facilities*. American Journal of Infection Control 42 (2014) 1193-1196.

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Totaro, M., Valentini, P., Casini, B., Miccoli, M., Costa, A.L., Baggiani, A. (2017). *Experimental comparison of point-of-use filters for drinking water ultrafiltration*. Journal of Hospital Infection 96, 172-176

Internet references:
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T-safe filter price: http://vanlose-vvs-fjernvarme-service.dk/vvs-butik/index.php?id_product=8&id_product_attribute=0&controller=product [retrieved on 2018-08-02]

Sterilization, Ionization

1. Short Description

Silver and copper electrodes are placed in the system and release copper and silver ions in the water flow that disrupt the membranes of the bacteria.

2. Key words

- Legionella control
- Low temperature district heating
- Disease prevention
- Ionization
- Silver ions
- Copper ions

3. Illustrations

Commercial Copper/Silver ion generator.
Source: http://proeconomy.com/the-orca-system/orca-kb3/

4. Technical description

Ionization is a commonly used technique of sterilization in water systems and it specifically identify the electrolytic generation of copper and silver ions for the water treatment. Silver and copper electrodes are placed in the system and when a low electrical current passes through them, they release copper ions (Cu^{2+}) and silver ions (Ag^{+}) that disrupt the membranes of the bacteria. The ions act on the DNA and RNA, on the cellular proteins and the respiratory enzymes of the bacteria. In this way, the cells are immobilized, preventing the bacteria's growth and eventually leading to their death.

The effective dosages range is between 0.02 mg/l to 0.04 mg/l for silver ions and 0.2 mg/l to 0.4 mg/l for copper ions. This technique can be used as a long-term solution but there are a few obstacles. Most important is the issue regarding effective dosage and water quality legislation (Yang et al., 2016a).

Perspective:

- Effective
- Ionization as a sterilization method is prohibited in some EU countries
- Residual effect

5. Characteristics

When silver ions are used as a form of bacterial control, levels up to 0.1 mg/l can be accepted without risk to human health (WHO, 2017). The European Union limits the copper concentration to 2 mg/l, while some countries consider a lower limit or even do not allow the use of this sterilization system.
The silver-copper ionisation system has a limit in relation to the water alkalinity, since it affects the solubility of the copper. For pH over 9, the copper is not able to neutralize the Legionella bacteria (Lin, Vidic, Stout & Yu, 2002).

6. Demands to installation

- Central installation
- Connection to power/water

7. Pros and cons

Pros	Cons
+ It has a high efficiency against the biofilm. + It is a mature technology, since it has been used and tested for a long period. + The technology is effective for the entire domestic hot water system, but the concentration has to be checked constantly in order to ensure full protection. + Potential low treatment costs at high capacities.	- Addition of copper and silver ions in the water system. - The use of this technology can be prohibited by national legislation because of potential health hazard. - The pH of the water can affect the effectiveness of this water treatment. - The technology has a high investing cost and it depends on the size of the system.

8. Economic data**

Capacity range [m³/day]	Equipment cost ekskl. VAT, [€]	Total cost incl. installation price excl. VAT, [€]	O&M cost [Year]
ProEconomy - KB2 Orca Water Ionisation 358 m³/day	21000** €	-	Maintenance: 4500** € + Cathodes replacement 5800** € = 0.08 €/m³

** Prices reference 2018

9. Environmental issues

- Can be prohibited by national legislation because of potential health hazard.

10. Example of suppliers

- ProEconomy - Orca

- TARN-PURE Ltd.

11. References

Yang, X., Li H. & Svendsen, S. (2016a), *Alternative solutions for inhibiting Legionella in domestic hot water systems based on low-temperature district heating*, Building Services Engineering Research and Technology, 37, 468–478.

WHO, World Health Organization (2007). *Legionella and the prevention of legionellosis*. Geneva: Bartram, J., Chartier, Y., Lee, J., Pond, K & Surman-Lee, S.

LIVSFS 2017:2, *Livsmedelsverkets föreskrifter om ändring i Livsmedelsverkets föreskrifter* (SLVFS 2001:30) om dricksvatten.

Walraven, N., Pool, W., & Chapman, C. (2016) *Efficacy of copper-silver ionisation in controlling Legionella in complex water distribution systems and a cooling tower: Over 5 years of practical experience*, Journal of Water Process Engineering 13, 196–205.

Lin, Y.E., Vidic, R.D., Stout, J.E., Yu, V.L., (2002), *Negative Effect of High pH on Biocidal Efficacy of Copper and Silver Ions in Controlling Legionella pneumophila*, Applied and Environmental Microbiology June 2002, 2711-2715.

WHO, World Health Organization (2017). *Guidelines for Drinking water Quality: fourth edition incorporating the first addendum*, Geneva.

Lin, Y.E., Vidic, R.D., Stout, J.E., Yu, V.L., (2002), *Negative Effect of High pH on Biocidal Efficacy of Copper and Silver Ions in Controlling Legionella pneumophila,* Applied and Environmental Microbiology June 2002, 2711-2715.

Internet references:

http://proeconomy.com/the-orca-system/ [retrieved on 2018-08-07]
http://tarn-pure.com/copper-silver-ionisation [retrieved on 2018-06-25]

Silver-copper ionization description https://www.lenntech.com/processes/disinfection/chemical/disinfectants-copper-silver-ionization.htm [retrieved on 2018-08-06]

Sterilization, Ozone

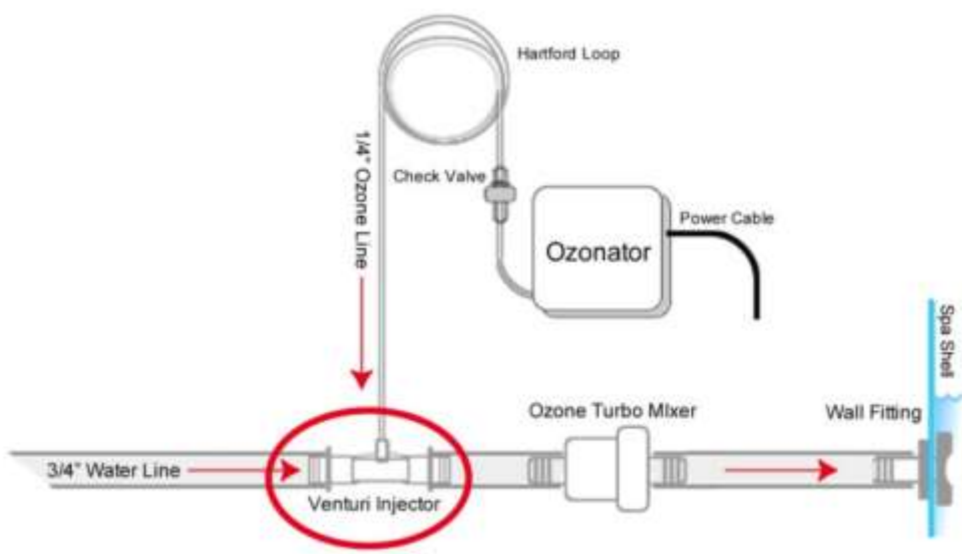
1. Short Description

Ozone is produced in a dedicated system and afterwards is injected into the domestic hot water system. It inhibits the bacteria's growth by damaging the bacteria's DNA. Ozone has the drawback of a very short half-life, meaning it has a limited residual effect. By adding Ozone can be produced from air or from pressurized oxygen.

2. Key words

- Legionella control
- Low temperature district heating
- Legionella prevention
- Ozone
- Water treatment

3. Illustrations



Ozone production and dosing unit.
Source: http://ozonize.co.za/water-purification/

4. Technical description

Ozone is a powerful oxidizing agent that can be dissolved in the water system. It is produced with a dedicated system, which uses air or pressurized oxygen to produce the ozone. Once it is ready, it is injected into the water system.
In the past ten years it has become a more common technique in potable water treatment and it is starting to replace chlorine in many locations, not only due to its high efficacy, when it comes to sterilization, but it is also less harmful to the environment (Li et al. 2017). Ozone is effective already at low concentrations, between 1 and 2 ppm, and inhibits growth by damaging bacterial DNA. Ozone has the drawback of a very short half-life, meaning that it is difficult to maintain a high concentration for sterilization throughout the whole system. It can also be corrosive to the pipes, which increases the need for maintenance (Associated Water Technologies, 2003).

Perspective:

- Effective
- Used for water treatment
- Limited residual effect

5. Characteristics

As mentioned, the ozone has a short half-life time. This time depends by the temperature and the pH of the water. For example, at a temperature about 15 °C and pH equal to 7, the half-life time is 30 minutes. In case of a temperature equal to 25 °C, the half-life time is just 50 % (www.lenntech.com).

6. Demands to installation

- Connection to power
- Space for installation
- Connection to the domestic hot water system

7. Pros and cons

Pros	Cons
+ The technology is highly oxidizing and it is effective at low concentrations. + When the correct concentration is kept for the entire system, thanks to the residual effect, it offers a good protection of the entire water system.	- Due to the high oxidation capacity of the ozone, there is risk of corrosion in the piping system, leading to higher maintenance required - Due to the short life of the ozone molecules, it is possible that in big water systems that are already affected by Legionella bacteria, the ozone cannot disinfect the all system. - Ozone is carcinogenic to inhale.

8. Economic data

Capacity range [m³/day]	Equipment cost ekskl. VAT, [€]	Total cost incl. installation price excl. VAT, [€]	O&M cost [€/m^3]
n.a.	n.a.	n.a.	n.a.

9. Environmental issues

- Potential health hazard
- Residual ozone at the tap results in release of gaseous ozone into the air

10. Example of suppliers

- Absolute Systems Inc. (Absolute Ozone)
- Lenntech BV

11. References

Associated Water Technologies, (2003), *LEGIONELLA 2003: An Update and Statement by the Association of Water Technologies*, http://www.awt.org/pub/035C2942-03BE-3BFF-08C3-4C686FB7395C [Retrieved on 2018-03-12].

Li, J., Li, K., Zhou, Y., Li, X., & Tao, T., (2017), *Kinetic analysis of Legionella inactivation using ozone in wastewater*, Chemosphere 168, 630-637.

Internet references:
http://ozonize.co.za/water-purification/ [retrieved on 2018-06-27]

Ozone decomposition https://www.lenntech.com/library/ozone/decomposition/ozone-decomposition.htm [retrieved on 2018-08-07]

Sterilization, Photocatalysis

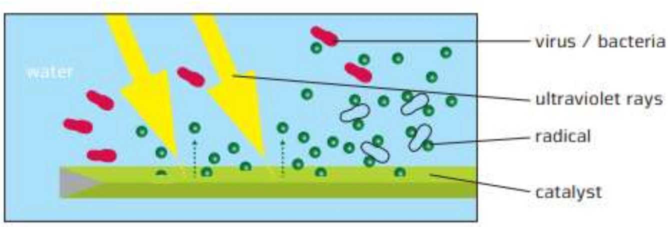
1. Short Description

The technology consists on the projection of UV light on a catalyst, such as titanium oxide, which produces radicals. The radicals react with the bacteria in the water and they inactivate them.

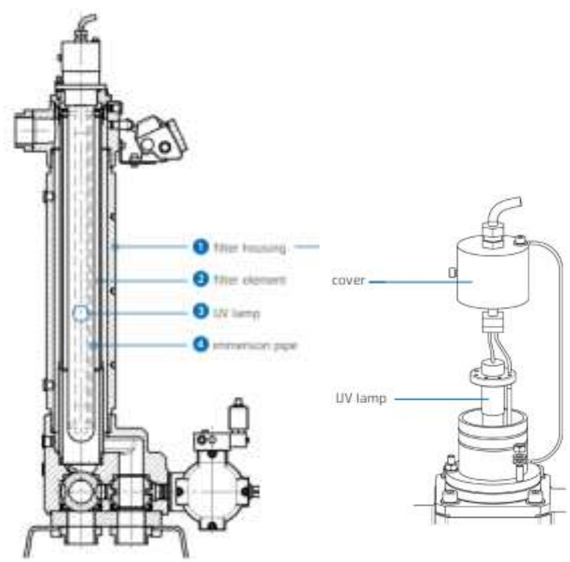
2. Key words

- Legionella control
- Low temperature district heating
- Disease prevention
- Advanced oxidation process (AOP)
- Photocatalytic oxidation
- Titanium dioxide

3. Illustrations



Schematic course of disinfection of the water by AOP
Source: Source: Boll & Kirch Filterbau GmbH



Combined particle filter and AOP unit with automatic backflush cleaning function.
Source: Boll & Kirch Filterbau GmbH

4. Technical description

Photocatalysis is a so called advanced oxidation process (AOP). In the process, a catalyst is used to release radicals in the water that react with the bacteria and inactivates them by affecting the respiration process and the disintegration of the cell membrane. Normally, titanium dioxide (TiO_2) is used as catalyst. The process is more efficient in the presence of UV light, which activates the production of radicals (Cheng, Chan & Wong, 2007). The function of the radicals is to oxidize the impurities contained in the water. More precisely, when a radical hits the microorganism in the water, it removes a hydrogen from the microorganism, and the action of many radicals destroy the microorganism. The radicals turn then back to the water molecules.

Perspective:

- Pilot studies shows high efficiency
- Not commercialized for residential properties

5. Characteristics

The technology works in two steps. The UV light is used directly as disinfectant, as it can inactivate the bacteria itself, and secondly it is used to activate the catalyst, which releases radicals that contribute to the water disinfection.
The inactivated bacteria tend to attach to the catalyst walls, so it has to be cleaned. Therefore, some devices have been developed with a cleaning system that keep the disinfection system cleaned.

6. Demands to installation

- Space for installation
- Connection to the power
- Connection to the water system

7. Pros and cons

Pros	Cons
+ The pilot studies for this technology show high efficiency. + The technology does not release armful residual compounds in the water. + The technology is environmental friendly, since no dangerous products are added to the water. + Chemicals are not used in the process	- The technology is not commercialized for residential properties. - The effect of this solution is applied only locally, where the filter is applied, therefore, if a piping system is already infected by Legionella bacteria, the disinfection system is not enough to consider the water safe.

8. Economic data

Capacity range [m³/day]	Equipment cost ekskl. VAT, [€]	Total cost incl. installation price excl. VAT, [€]	O&M cost [€/m^3]
3 - 15 m³/h	UV lamp: 600 € Filter: 16 000 €		Lifetime, UV lamp: 4 000h O&M: 1 200 €/y + electricity Electricity: 1.7 - 3 kW
...	...	...	...
...	...	...	...

9. Environmental issues

- -

10. Example of suppliers

Not commercialized for residential properties

- Boll & Kirch Filterbau GmbH

11. References

Cheng, Y.W., Chan, R.C.Y., Wong, P.K, (2007), *Disinfection of Legionella pneumophila by photocatalytic oxidation*, Water Research 41, 842-852.

Yang, X., Li H. & Svendsen, S. (2016a), *Alternative solutions for inhibiting Legionella in domestic hot water systems based on low-temperature district heating*, Building Services Engineering Research and Technology, 37, 468–478.

Boll & Kirch Filterbau GmbH, (no year), *BOLLFILTER Automatic TYPE 6.03 AOT*, https://www.bollfilter.com/fileadmin/downloads/prospekte/automatic-filter-type-6.03-AOT-en-BOLLFILTER.pdf, [Retrieved on 2018-06-26]

Internet sources:

ObservatoryNANO (2010), Environment: Photocatalysis for water treatment https://www.sswm.info/sites/default/files/reference_attachments/MULLER%20et%20al%202010%20Photocatalysis%20for%20Water%20Treatment.pdf [Retrieved on 2018-08-07]

Sterilization, Ultraviolet light

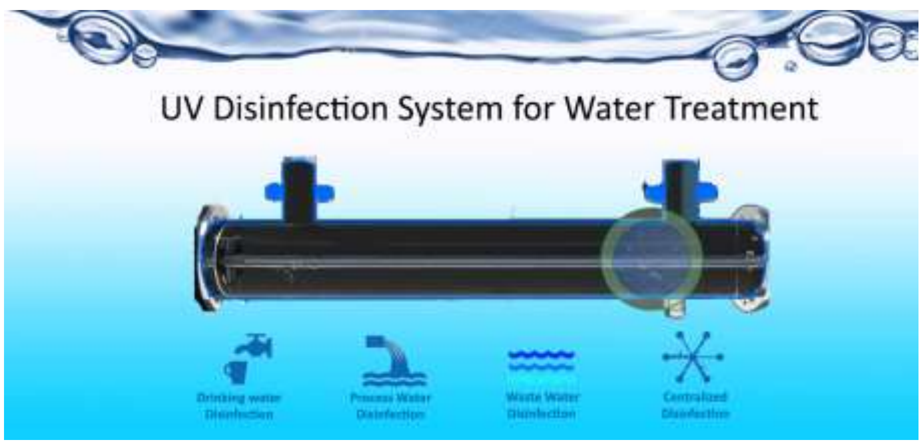
1. Short Description

Ultraviolet (UV) light can be used as treatment against Legionella bacteria. The microorganism are exposed to the UV light, which acts on their DNA, preventing their reproduction or directly destroying the bacteria.

2. Key words

- Legionella control
- Low temperature district heating
- Legionella prevention
- Local sterilization
- Ultraviolet (UV) light

3. Illustrations



An UV lamp unit for water disinfection according.
Source: http://www.alfaauv.com/blog/uv-disinfection-system-water-treatment/

4. Technical description

Ultraviolet (UV) light disrupts the DNA replication of bacteria and thus inhibits their growth. The effect is instantaneous and does not add any chemicals to the water. However, since there is no lingering effect, this technology is not suitable for large systems or systems that have been colonized by biofilms, where the bacteria are sheltered. Placing the UV lamps close to the tap is therefore of great importance and it might be more appropriate to use UV as a complement to another disinfection technique (Yang et al., 2016a).

Perspective:

- Effective
- Well established technology
- Local protection

5. Characteristics

In order to obtain a complete control of the water system, the UV system should be combined with other water treatment, for example hypochlorination. The UV system provides an efficient short-term control of Legionella, as well as other bacterial growth. Another factor to consider is that the lamps will require regular maintenance to clean off scaling (Liu et al., 1995).

6. Demands to installation

- Placement, Point of use (POU) installation
- No lingering effect
- Maintenance access
- Regular maintenance of lamps

7. Pros and cons

Pros	Cons
+ The technology guarantees an instant effect on the bacteria. + It is a mature technology, since it has been used and tested for a long period. + This water treatment does not add chemicals to the water. + Cheap operation.	- The technology does not ensure the disinfection of the entire water system, since the disinfection is located where the UV lamps are located. Therefore, if a piping system is infected by Legionella bacteria, they can continue the growing process and create biofilms. - The UV system should be placed as close as possible to the tap point, if it is the only disinfection system adopted. - The UV system should be used as an extra safety system, together with a disinfection system that guarantees the disinfection of the entire water system. - The water quality can affect the efficacy of the system. In particular, high level of carbonates can limit the intensity of the UV radiation. - A laminar flow in the filter can reduce the efficacy of the UV radiation. The water might not receive a uniform radiation.

8. Economic data

Capacity range [m³/day]	Equipment cost ekskl. VAT, [€]	Total cost incl. installation price excl. VAT, [€]	O&M cost [€/year]
7 m^3/day (max. flow 1 m^3/hour)	430 €	By third party	88.50 € + electricity Electricity: 210 kWh/year
...	...	...	...
...	...	...	...

9. Environmental issues

- -

10. Example of suppliers

- Lenntech BV
- BIO-UV Group
- Ultrafilter Group Danmark

11. References

Cervero-Argaró, S., Sommer, R. & Araujo, R.M., (2014), *Effect of UV irradiation (253.7 nm) on free Legionella and Legionella associated with its amoebae hosts*, Water Research 67, 299-309.

Liu, Z., Stout, J.E., Tedesco, L., Boldin, M., Hwang, C, Yu, V.L. (1995), *Efficacy of Ultraviolet Light in Preventing Legionella Colonisation of a Hospital Water Distribution System*, Water Research 29, 10, 2275-2280.

Yang, X., Li H. & Svendsen, S. (2016a), *Alternative solutions for inhibiting Legionella in domestic hot water systems based on low-temperature district heating*, Building Services Engineering Research and Technology, 37, 468–478.

Internet references:

http://www.alfaauv.com/blog/uv-disinfection-system-water-treatment/ [retrieved on 2018-06-28]

https://www.ultra-filter.dk/ [retrieved on 2018-08-07]