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Overcoming issues with *Legionella* in DHW in LTDH systems

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Thesis for the Degree of Master of Science

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June 2018, Lund

The present thesis for the Degree of Master of Science has been completed at the Division of Efficient Energy Systems, Department of Energy Sciences, Lunds Universitet – LTH and at the company Kraftringen Energi AB in Lund. Supervisors at the company Kraftringen Energi AB: Martin Gierow, Project Manager and Markus Falkvall, Project Engineer; Supervisors at LU-LTH: Assistant Professor Per-Olof Kallioniemi and Assistant Professor Kerstin Sernhed; Examiner at LU-LTH: Associate Professor Marcus Thern.

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Foreword

This Master thesis marks the end of our education in Environmental Engineering at Lunds Tekniska Högskola. The thesis has been written in cooperation with Kraftringen Energi AB during the spring semester of 2018.

We would first of all like to thank our supervisors at Kraftringen, Martin Gierow and Markus Falkvall, for your dedication and all the time you have put in to help us during these past few months! Thanks also to all the wonderful people at Kraftringen who have been so extremely kind to us and expressed interest and curiosity in our work.

Secondly we would like to thank our supervisors at LTH, Per-Olof Kallioniemi and Kerstin Sernhed, not only for helping us find this subject but for all your feedback and for answering all our boring questions on references and layout.

Finally we would like to thank all the people who have helped us survive five years of university and made our time here in Lund so extraordinary!

Thank you!

Linita Karlsson & Klara Ottosson

Lund, June 2018

Abstract

The aim of this master's thesis is to analyze current issues with the bacteria *Legionella* in domestic hot water (DHW) systems and to investigate the possibilities to overcome them as the district heating industry moves towards low temperature district heating (LTDH). The analysis is based on a literature study of reports from authorities and scientific articles, as well as a focus group interview with contractors in Brunnshög.

District heating (DH) is an energy efficient way of supplying densely populated areas with heat for space heating and DHW. In conventional DH systems the supply temperatures usually range between 75 °C and 110 °C, temperatures the DH industry are now working to reduce. This reduction would result in significant energy savings, mainly due to decreased heat losses, which would in turn be economically beneficial. However, decreasing the temperature can cause problems with the water quality, especially with regards to growth of bacteria, such as *Legionella.*

Exposure to *Legionella* bacteria can cause two types of illnesses: Legionnaires' disease and Pontiac fever, Legionnaires' disease being the more serious of the two. Its symptoms are similar to those of a common pneumonia with a mortality rate of 5 – 20%. Legionnaires' disease is a notifiable disease in all of the EU. A general increase has been reported and the average incidence in 2015 was 1.4 per 100 000 inhabitants. It is however likely that the actual incidence is much higher since many cases of Legionnaires' disease are undetected.

The traditional solution to inhibit *Legionella* growth is to keep the DHW above a certain temperature. This temperature varies between countries but is most often above 50 °C. In this thesis the temperature requirements in six countries (Sweden, Denmark, Norway, Finland, Germany and France) are studied and their temperature requirements range from 45 °C to 65 °C. As the industry moves toward LTDH and supply temperatures around 50 °C, alternative techniques need to be implemented for *Legionella* control. There are many techniques that could theoretically be applied. These can be divided into three subcategories: mechanical techniques, sterilization techniques and alternative system design. Although some of the techniques are already commercially available many cannot be implemented since they do not comply with current legislation regarding temperature requirement. The only currently applicable solutions in LTDH systems are those that boost the temperature, i.e. solutions with an auxiliary heating device.

The aim of the focus group interview was to gain insight of the attitude toward LTDH among contractors and to get an idea of their knowledge regarding *Legionella* in DHW systems. The result of the interview was that the participants were mostly positive toward LTDH and district heating in general. It is regarded as a robust and reliable heating system and the favored choice if available. The knowledge on *Legionella* and inhibition techniques varied in the group.

Sammanfattning

Syftet med denna masteruppsats är att analysera problematik med *Legionella* i tappvarmvattensystem och undersöka möjliga lösningar då fjärrvärmebranschen rör sig mot lågtempererad fjärrvärme (LTFV). Analysen är baserad på en litteraturstudie av rapporter från myndigheter och vetenskapliga artiklar. Rapporten innehåller även en fokusgruppsintervju med byggherrar i Brunnshög.

Fjärrvärme är ett energieffektivt sätt att förse tätbefolkade områden med värme för uppvärmning och varmvatten. I traditionella fjärrvärmesystem varierar framledningstemperaturen vanligen mellan 75 °C och 110 °C, temperaturer som fjärrvärmebranschen nu önskar sänka till runt 50 °C. En temperatursänkning skulle medföra stora energibesparingar, framförallt tack vare minskade värmeförluster, vilket i sin tur även skulle vara ekonomiskt lönsamt. Däremot kan en sänkning av temperaturen skapa problem med vattenkvaliteten, framför allt gällande tillväxt av bakterier såsom *Legionella*.

Exponering av *Legionella*-bakterien kan orsaka två olika sjukdomar: Legionärssjuka och Pontiacfeber, där legionärssjuka är den allvarligare av dem. Den yttrar sig som en allvarlig form av lunginflammation och har en dödlighet på 5 – 20%. Legionärssjuka är en anmälningspliktig sjukdom i hela EU. En generell ökning har rapporterats och den genomsnittliga incidensen 2015 var 1,4 per 100 000 invånare. Det är dock troligt att den faktiska siffran är betydligt högre då många fall av legionärssjuka inte diagnostiseras.

Den traditionella lösningen för att hämma tillväxt av *Legionella* är genom att ha ett temperaturkrav på tappvarmvattnet. Detta temperaturkrav varierar mellan länder men är oftast över 50 °C. I den här uppsatsen har temperaturkravet i sex länder studerats (Sverige, Danmark, Norge, Finland, Tyskland och Frankrike) och deras temperaturkrav varierar mellan 50 °C och 65 °C. Allt eftersom fjärrvärmebranschen rör sig mot framledningstemperaturer runt 50 °C behöver alternativa tekniker för att kontrollera bakteriell tillväxt utvecklas. Det finns ett flertal tekniker som teoretiskt kan appliceras. Dessa kan delas in i tre underkategorier: mekaniska tekniker, steriliseringstekniker och alternativ systemdesign. Trots att några av dessa tekniker är kommersialiserade kan de inte implementeras i dagsläget då de inte tar hänsyn till de gällande temperaturkraven. De enda lösningar som kan implementeras för närvarande är de som höjer vattentemperaturen, det vill säga de med en extern värmekälla.

Syftet med fokusgruppsintervjun var att få insikt i byggherrarnas åsikter om LTFV och att få en överblick i kunskapen om *Legionella* i tappvarmvattensystem. Resultatet av intervjun blev att deltagarna var mestadels positiva inställda till LTFV och även fjärrvärme generellt. Det ansågs vara robust och tillförlitligt och som det uppenbara valet om det är tillgängligt. Däremot var kunskapen om *Legionella* och alternativa kontrolltekniker begränsad inom gruppen.

Abbreviations and definitions

4GDH - Fourth Generation District Heating

ATCC - American Type Culture Collection

COOL DH – COOL DH is an abbreviation of 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. The project is partially funded by the EU through Horizon 2020. Other involved parties are COWI, Kraftringen, the city of Høje-Taastrup, the City of Lund, Lund University, Euroheat and Power, Logstor A/S, Høje-Taastrup Fjernvarme amba, Alfa Laval, LKF and KE KELIT.

DH - District Heating

DCW - Domestic Cold Water

DHW - Domestic Hot Water

ECDC - European Centre for Disease Prevention and Control

ESS - European Spallation Source. A high-power neutron spallation source for material research.

EWGLI - The European Working Group for Legionella Infections. Organization with the aim to increase information and knowledge of *Legionella*.

LTDH - Low Temperature District Heating

LTH - Lunds Tekniska Högskola

MAX IV – Research facility in Brunnshög, Lund, with the brightest X-ray in the world.

POU - Point-of-use

SH - Space Heating

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1. Introduction

If all the excess heat produced in Europe was to be used instead of wasted it would be enough to heat every single building on the continent. Using waste heat is one way of achieving a more efficient energy system. The benefits of more efficient energy systems range from economic to environmental and it is a high priority for the European Union (EU) (Heat Roadmap Europe, n.y.). Such energy systems are often referred to as *smart* energy systems and are characterized as being 100 % renewable and based on synergies to streamline the efficiency as well as decrease costs (Energy Plan, n.y.).

In the strive to create smart energy systems, the EU is financing a project to devise a roadmap for decarbonization of the heating and cooling sector; Heat Roadmap Europe (HRE). The HRE concludes that the road to decarbonization is energy efficiency of both the energy demand and the energy supply. Reducing the demand can be done for example by renovating buildings, thus saving heat by decreasing the required energy needed to sustain a comfortable indoor environment. On the supply side heat savings can be made by using the heating system that is most efficient for the local conditions. In rural areas this would be heat pumps as they can use renewable energy in an efficient manner due to their high coefficient of performance. In cities, the simplest way to provide a large population with heat with low-carbon footprint is through district heating as it can make use of lower quality energy, such as excess heat from industries, and thus reduce the dependency on fossil fuels (Heat Roadmap Europe, n.y.).

When using the right energy source, district heating is an environmentally friendly and efficient way to meet the heating and domestic hot water needs of large populations. The system could be made even more efficient by lowering the supply temperature as this would mean reduced energy losses and increased potential use of lower quality energy sources. These systems are often referred to as low temperature district heating - LTDH (Lund et al., 2014).

Implementing LTDH is not without challenges. The temperature cannot be lowered too much as the demands of comfort and hygiene must still be met. LTDH is often associated with fourth generation district heating (4GDH) where the aim is to reach a supply temperature of 50 ºC (Lauenburg, n.y.). This could be possible since studies show that comfortable water temperatures could be obtained with supply temperatures around 45 ºC, the biggest issue lies with hygiene requirements (SP, 2014). The quality of the water must be guaranteed to protect the health of the public. A big risk factor when pushing the district heating supply temperature below 60 ºC is the increased growth of bacteria, such as *Legionella*, in the domestic hot water system. Growth of bacteria is traditionally regulated by keeping the water temperature at levels inhibiting bacterial growth. This temperature is in most European countries defined in legislation or technical guidelines and are thus compulsory to follow. Before LTDH can be properly implemented it is therefore imperative that alternative solutions to combat growth of *Legionella* are developed.

1.1 Background

As a part of the EU financed project COOL DH, the municipalities Lund in Sweden and Høje-Taastrup in Denmark are two of the involved parties that will cooperate to promote more efficient district heating for sustainable cities. The project will develop, demonstrate, analyze and spread technical solutions for LTDH systems (European Commission, 2017).

In the north eastern part of Lund, a new district called Brunnshög is under development and construction started in 2017. Not only does this area already hold one of the world leading research facilities - MAX IV Laboratory, but the European Spallation Source (ESS) is also under construction. When finished, it will be one of the most powerful neutron sources for material research in the world. It is estimated that about 40 000 people will work and/or live in Brunnshög when construction of the area is complete (Lunds kommun, n.y.). The vision for this new residential area is that it will be leading in innovation and sustainability. The area will support the climate agenda of Lund municipality to achieve a 50 % reduction in CO_2 emissions by 2020 compared to 1990 and to approach zero emissions in 2050. This will for example by producing more renewable energy than is needed for the area (Lunds Kommun, 2012).

In the area between MAX IV and ESS, construction of buildings designed for research, businesses and educational purposes will take place, becoming Science Village Scandinavia. The area will include facilities such as guest accommodation, university campuses and research institutes, but also gyms, restaurants and cafés (Science Village Scandinavia, n.y.a).

In making Science Village Scandinavia, and the rest of Brunnshög, a world-class research- and innovation district, one of the projects include connecting to the world's largest low temperature district heating network that is under construction in Brunnshög. By using residual heat available in large quantities in northern Lund, from sources such as MAX IV and ESS, the low temperature network will be an efficient way of heating the district's buildings. It could also be used for ground heating at bus and tram stops and cycle paths during the winter to avoid snow removal and thus favoring an environmentally friendly way of travelling. The construction commenced with the energy company Kraftringen Energi AB as developer in the fall of 2017 and the first hot water deliveries are estimated in September 2019 (Science Village Scandinavia, n.y.b).

1.2 Aim

The aim of this thesis is to analyze the current issues with *Legionella* in domestic hot water systems and investigate the possibilities to overcome them as the district heating industry moves towards low temperature district heating (LTDH). The industry strives to lower the supply temperature to as low as 50 ºC. However, most European Union countries require a domestic hot water temperature that cannot be obtained directly by such a system. District heating becomes more energy efficient as the supply temperature is reduced and it is therefore of great interest to find a solution that will allow this development while still preventing *Legionella* growth.

The focus of this thesis will be on domestic hot water. The thesis will provide a short description of district heating and LTDH followed by a section about the *Legionella* bacteria and its properties. It will then move on to statistics regarding cases of illness caused by *Legionella* in some selected countries. The *Legionella* related legislation of the same countries will then be covered and compared. This will be followed by a presentation of techniques alternative to thermal prevention and control of *Legionella*. Finally, to gain a deeper understanding of what obstacles to implementing LTDH lie ahead, a focus group interview with contractors involved in the Brunnshög project will be conducted.

In order to fulfill the aim of this thesis the following research questions will be addressed:

- *Legionella pneumophila* is a commonly occurring bacteria in fresh water. The reported number of cases of illness caused by *Legionella* in Sweden are in the hundreds. How does this compare to surrounding countries? What is the procedure concerning reporting and keeping statistics?
- To inhibit *Legionella* growth in tap water systems, national regulations are set regarding the hot water temperature. However, the temperature limit differs between countries. What are the existing regulations regarding hot water temperature in Sweden and surrounding countries and how do they differ?
- There are a number of technical solutions that inhibit *Legionella* growth with lower district heating supply temperatures. What techniques are available and what are the advantages and disadvantages of the different methods?
- The possibility to lower grid temperatures in district heating systems is affected by the available techniques for *Legionella* inhibition as well as local regulations regarding domestic hot water temperature. It is also dependent on the willingness of contractors to adapt to a new type of system. What are the attitudes towards implementing LTDH among contractors in the Brunnshög area? And what obstacles do they foresee?

1.3 Limitations

To confine the scope of this thesis, some limitations were set. The study will only investigate the risks of *Legionella* in domestic hot water systems within low temperature district heating systems.

Since conditions and possibilities for district heating are similar in the Nordic countries, the statistics and legislations from Denmark, Norway and Finland, besides Sweden, will also be included in the study. Germany as well as France will also be included due to their different legislative rules.

2. Theory

In this chapter, district heating will be briefly described as well as the development towards the fourth generation district heating where lowering the temperature in the system is in focus to promote energy savings. In lowering the temperature, however, the risk for bacterial growth might increase. The initial section about district heating is therefore followed by a section about the bacteria *Legionella* and what environment it thrives in. It is further described what consequences might be the result of bacterial proliferation - the illness Legionellosis. Risk factors for falling ill and how the disease is diagnosed will also be addressed.

2.1 District Heating

This section will provide a short explanation of the concept of district heating and give an example of conventional supply temperatures. This thesis focuses on LTDH but the definition of LTDH has not been specified. It constitutes of district heating with lower than conventional supply temperatures. The aim of LTDH is to reach supply and return temperatures that are defined as fourth generation district heating (4GDH) and therefore the properties and advantages of 4GDH will be presented in the second subsection.

2.1.1 What is district heating?

Many of the solutions that provide heat for households and buildings are based on individual heat production for each building, for example an oil- or gas-fired burner. District heating on the other hand produces heat in a heating plant and then distributes this heat through a pipe system to its clients, whether they are a single-family house or a hospital. At the heating plant heat is produced by combustion of e.g. biofuels, but the heating plant can also use waste heat from industries (Energiföretagen, 2017). Water is heated in a boiler and then distributed to the clients using pipe systems. The outgoing water temperature varies between supply companies. For Kraftringen it ranges from 76 °C in the summer months to 105 °C in winter time. The specific temperature depends on factors such as outdoor temperature and consumer demand (Gierow, M., personal communication, 2018-04-06). In Sweden, each house or building connected to the district heating grid has a heat exchanger that transfers heat from the district heating water to the water that is then used either for space heating or for domestic use. The district heating water is thus cooled down and then sent back to the plant to be heated again. The general design of a district heating system can be seen in figure 1.

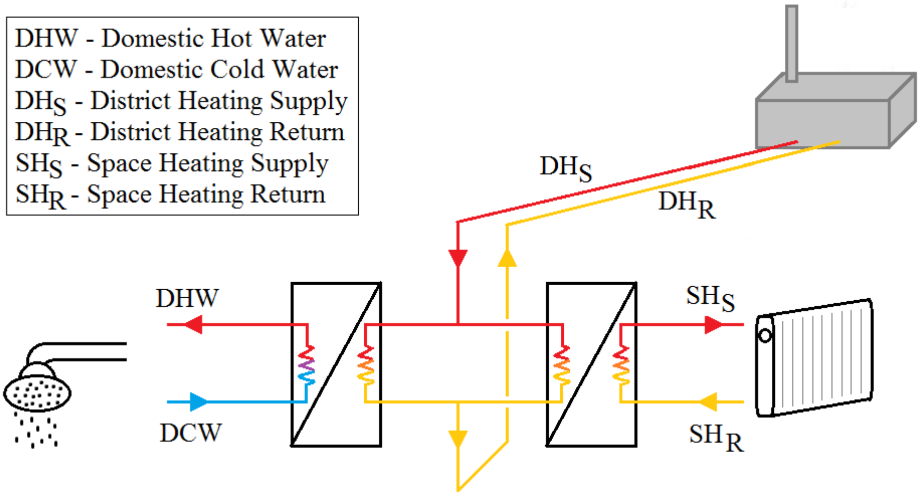

Figure 1. District heating system.

2.1.2 Fourth Generation District Heating

District heating was first introduced in the late 19th century and has since been under constant development. With each new generation of district heating there has been a reduction in the distribution temperature and this is true also for 4GDH. It has been suggested that a supply temperature of 50 °C would be desirable (Lauenburg, n.y.).

The industry can reap several benefits from low temperature district heating; a higher power-to-heat ratio from combined heat power plants and a greater possibility to utilize heat from energy sources of lower quality, for example waste heat from industries and renewables such as solar and geothermal energy to mention a few. These energy sources are often local which gives a high price stability and reduces the need for imported fuel (Averfalk & Werner, 2017). Lowering the system temperatures will also mean reduced heat losses (Averfalk & Werner, 2018). Other advantages of lowering the temperature include lower risks of scalding and the possibility to utilize plastic as the pipe material which can significantly reduce the costs compared to metal pipes (Schmidt et al., 2017).

2.2 The *Legionella* bacterium

The bacterium *Legionella* will be described in this section. Known species and the environment in which they thrive with regards to temperature, nutrients, biofilm and protozoa will be discussed.

2.2.1 Legionellaceae

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, with bacteria from serogroup 1 being the primary cause of illness. A serogroup is defined as a group of distinct variations within a species of bacteria that have common cell surface antigens (MediLexicon, n.y.).

Legionellae are bacteria that naturally exist in freshwater environments but have also been found in seawater and soils (World Health Organization, 2007). However, there is only a small risk for these natural environments to promote high bacterial proliferation. Typically for *Legionella* growth to reach high concentrations, they have to establish in artificial water systems (Folkhälsomyndigheten, 2015c). This may be explained by the more optimal environment provided through temperature, coatings on pipes and oxygen rich as well as stagnant waters.

2.2.2 Temperature Levels

The ideal temperature for *Legionella* growth is 32-42 ºC as can be seen in figure 2 and bacterial inactivation starts at about 46 ºC; however, they have been found to be capable of colonizing areas in a temperature range between 6 ºC and 63 ºC (Yee & Wadowsky, 1982; Dennis, Green & Jones, 1984). The recommended temperature for storage and distribution of cold water to prevent *Legionella* infection is below 25 ºC, though preferably below 20 ºC, since the reproductive rate of the bacteria is little or none in temperatures below 20 ºC (WHO, 2007).

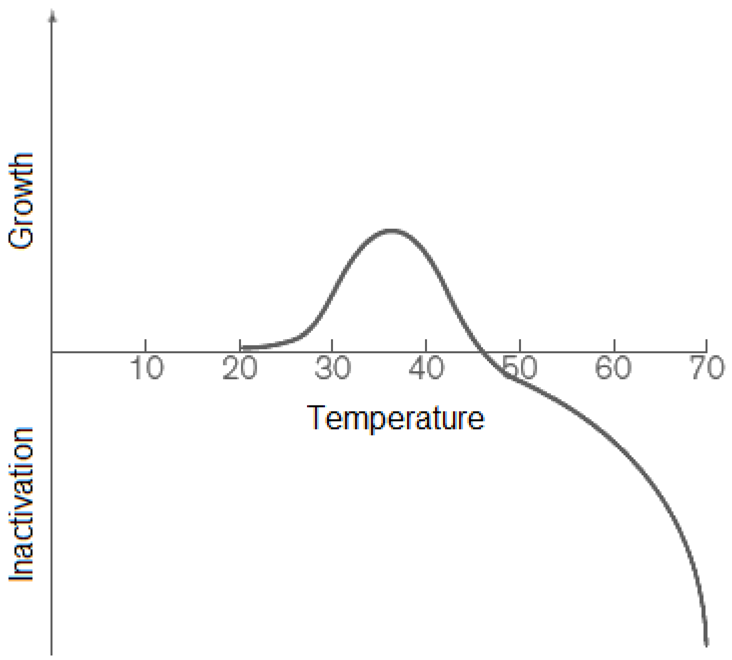

Figure 2. Growth rate for Legionella pneumophila. Source: Stålbom & Kling, (2002).

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 ºC, 27 minutes at 54 ºC and 6 minutes at 58 ºC (Dennis et al. 1984). At temperatures above 70 ºC, 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 3.

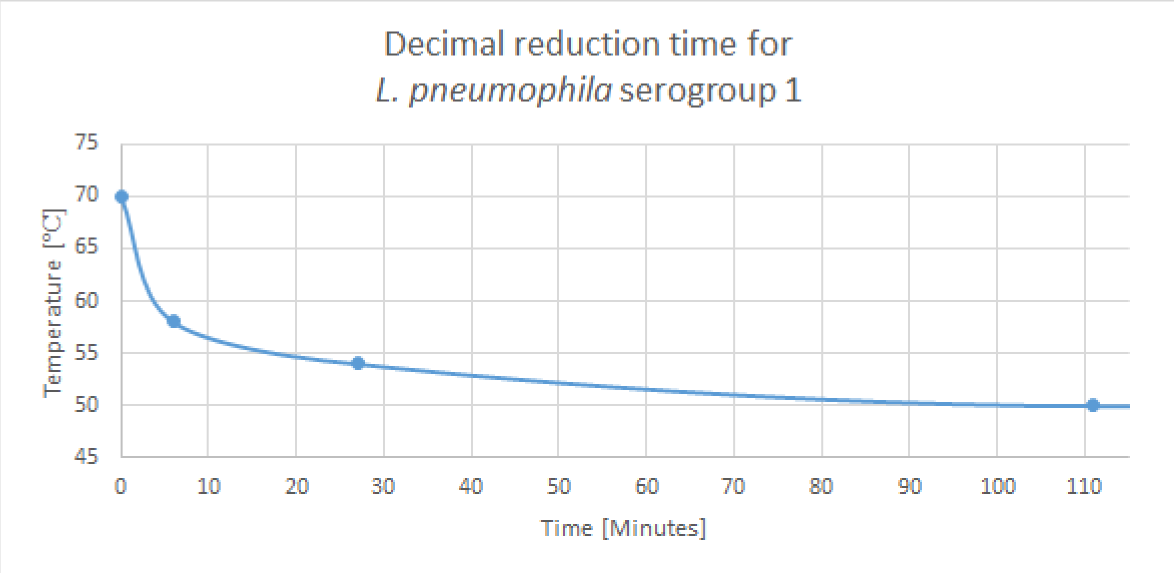

Figure 3. General representation of the decimal reduction time for a strain of Legionella pneumophila serogroup 1. Data: Dennis et al., (1984).

2.2.3 Nutrients

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).

2.2.4 Biofilms and protozoa

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 microcolonies 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 4.

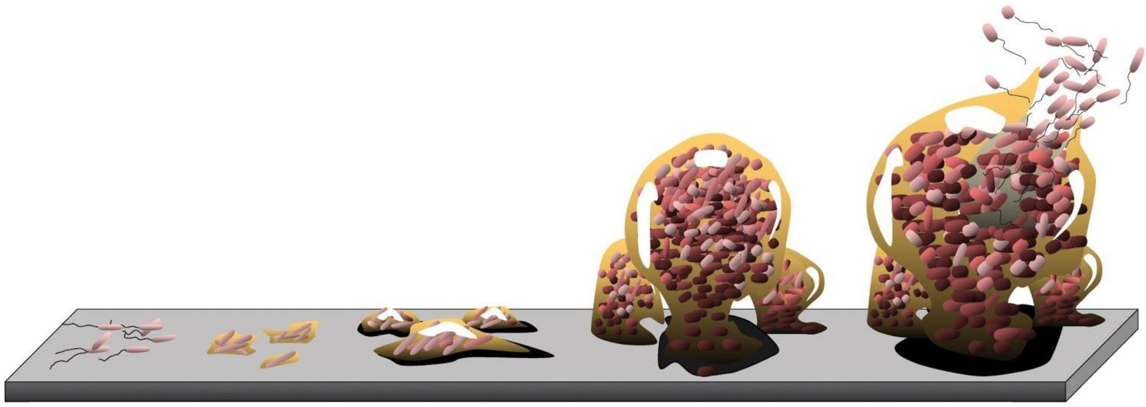

Figure 4. Steps of biofilm formation. Source: figure adapted from original by Monroe, (2007).

2.3 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 infected by *Legionella* develops Legionnaires' disease and others Pontiac fever is unclear. The infectious dose is likely to be of relevance, however, there are no documented studies regarding the correlation between number of bacteria and type of illness (Folkhälsomyndigheten, 2015b). In this section, the two types of illnesses are described followed by information regarding common risk factors as well as diagnostic methods.

2.3.1 Pontiac fever

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, for the continuation of this thesis, the focus will mainly be on Legionnaires' disease.

2.3.2 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).

2.3.3 Risk factors

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 (see figure 5). Smoking has also been found to be a risk factor as well as alcoholism, diabetes, impaired kidney functions and lowered immune system (Folkhälsomyndigheten, 2015b).

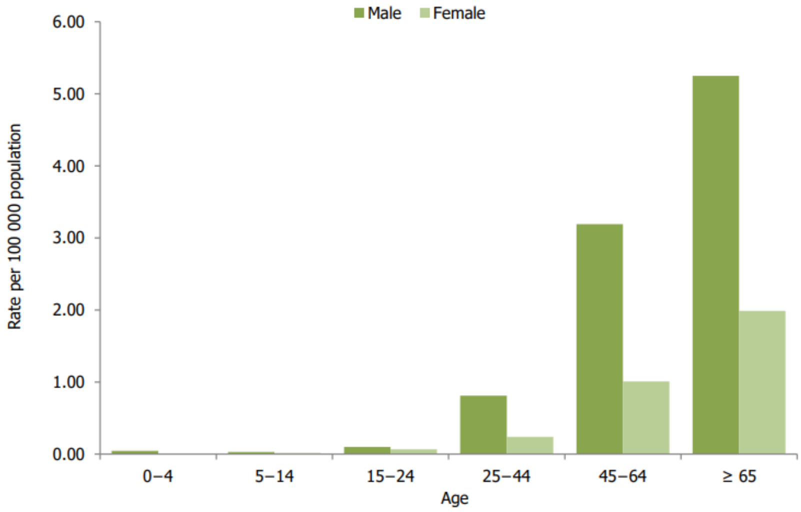

Figure 5. Incidence per 100 000 population by age and gender from all ELDSNet participating countries in 2015. Source: ECDC, (2017b).

2.3.4 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.

Urinary antigen

This 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 subsection 2.2.1), 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).

Culture

Collecting a respiratory specimen from sputum or bronchoalveolar of a patient to cultivate has shown to be 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).

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).

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).

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).

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 dependable it is common to complement one method with another. An overview of the most common methods used in Europe in 2015 can be seen in table 2 below.

Table 2. Methods used in diagnosing Legionnaires' disease in Europe.
Data: personal communication with Dr. Mentula, S. (2018).

Diagnostic method	Europe (2015)
Urinary antigen	89 %
Culture	12 %
PCR	11 %
Serology	2.8 %

3. Method

This chapter describes the method that was used in authoring this thesis. Firstly, the procedure for the literature study is presented, followed by an explanation and description of the focus group interview.

3.1 Literature study

This thesis is based on a literature study of material concerning *Legionella* and associated legislation, low temperature district heating (LTDH) and alternative methods of disinfection that can be used in tap water systems. The material comes from scientific articles, practical studies, national and European legislation, technical guidelines and reports and recommendations from national agencies. The main factor when selecting material was that it would serve a purpose when answering the research questions of the thesis.

The material on statistics came mainly from reports written by international authorities, e.g. ELDSNet and Eurostat, and national authorities, e.g. Public Health Agency of Sweden or corresponding agency of the other countries. If it could be found, data was collected from both sources and then compared as they sometimes differed slightly.

In the chapter on legislation associated with *Legionella* control the laws have been found on the online version of the national legislations. On occasion, where the original couldn't be found, second hand sources were used by referencing a scientific article that mentioned the legislation in question. Some of the laws have been translated by the authors since they could only be found in their original language.

Information on techniques for *Legionella* control was obtained by searching for subject related words. For example: low temperature district heating, *Legionella*, and 4th generation district heating, or a combination of these. The majority of the material is from known authorities and scientific journals since they were assumed to be the most reliable sources. A big part of the material was found using the Lund University search engine LUB search. It enables finding and accessing scientific articles from around the globe. This was especially helpful when trying to find research on the different available techniques for *Legionella* control. Since all the articles that can be obtained from LUB search have been published it can be assumed that these are reliable sources.

3.2 Focus group interview

The thesis includes a focus group interview aimed to get an understanding of the attitudes of stakeholders in Brunnshög towards LTDH and *Legionella* issues. The contractors invited to discuss these matters were those who will be building in central Brunnshög and the Science Village, where the LTDH system will be implemented.

The participants of the focus group interview were contacted on the basis that their companies will be connecting their buildings to the LTDH network and that they therefore should have some previous understanding of the matter, which would lead to an interesting discussion. Contact information was provided by Peter Rodenstam, who is responsible for customer relations at Kraftringen in relation to the Brunnshög project. An invitation was sent via email from Kerstin Sernhed at Lunds Tekniska Högskola (LTH), explaining the basis and aim of the group interview. The invited guests were then contacted by telephone by the authors, Ms. Ottosson and Ms. Karlsson, to confirm their participation and to provide further explanations when needed.

Six representatives from five companies were available on the suggested date. In addition to these six, representatives from Kraftringen and LTH were present as audience. They were not a part of the interview as such and were only allowed to participate in the end to ask and answer questions that may have come up during the interview. The interview was moderated by Ms. Sernhed and the authors of this thesis acted as secretaries and took notes of the discussion.

The aim of the group interview was to generate a discussion around each question and so the questions were very open in their formulation. The moderator, Ms. Sernhed, made sure that the participants stayed on the right track and did not drift off topic but did not lead the participants to any specific answers. The interview lasted for two hours and the questionnaire can be found in the appendix.

4. Statistics on Incidences of Legionnaires' disease

In this chapter, statistics on cases of illness caused by *Legionella* are presented. Firstly, statistics from the countries in the European Union as well as Iceland, Norway and Switzerland are presented regarding incidences, trends and seasonal variations. Secondly, statistics from the six previously stated specifically selected countries (Sweden, Denmark, Norway, Finland, Germany and France) are presented.

4.1 EU

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).

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). The notification rates from the participating countries as presented by EWGLI can be seen in figure 6.

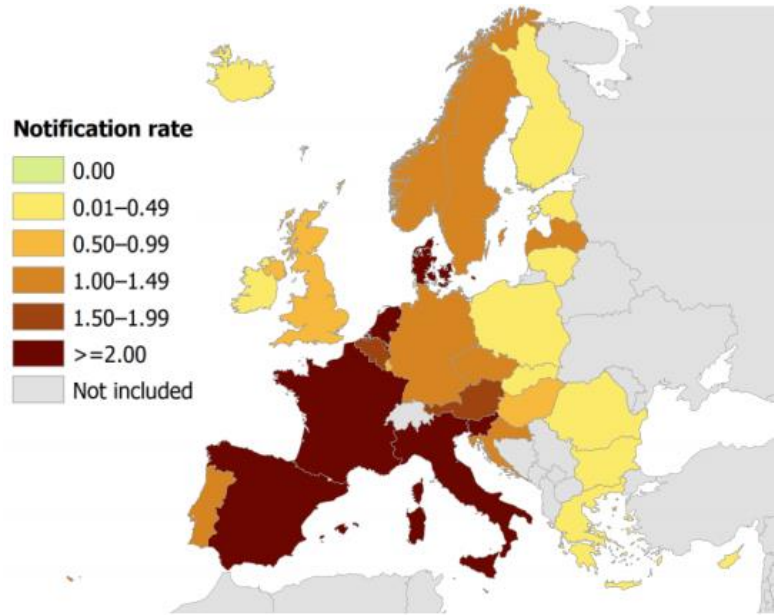

Figure 6. Reported incidence per 100 000 inhabitants of Legionnaires' disease by country in 2015. Source: ECDC, (2017b).

Altogether there has been a general increase of notified cases in Europe between 2011 and 2015 as can be seen in figure 8, 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, increasing travel and climate change (ECDC, 2017b).

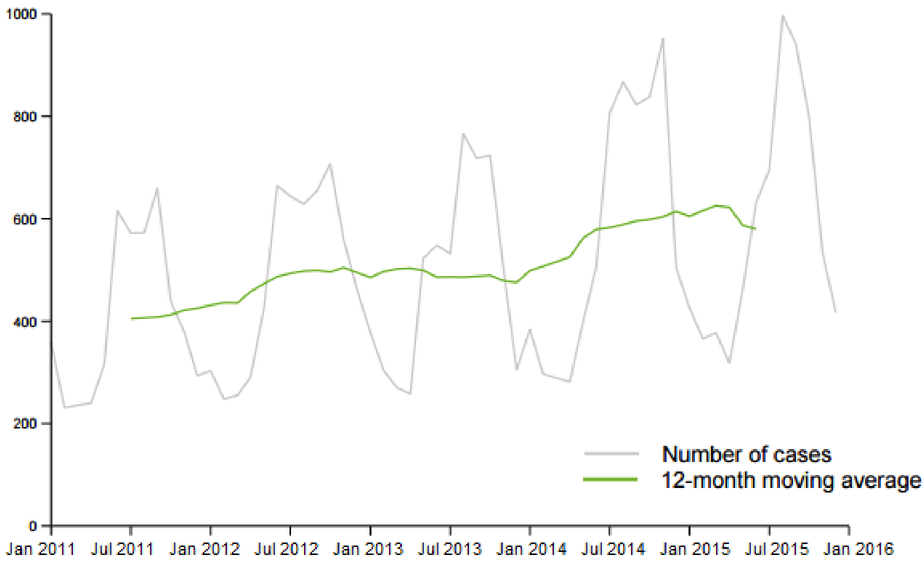

Figure 8. Number of reported cases between 2011 and 2015 from all ELDSNet participating countries. Source: ECDC, (2017b).

The number of cases of Legionnaires' disease reported varies seasonally as can be seen in figure 8. This might be explained by the more favorable 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).

4.2 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 9, 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).

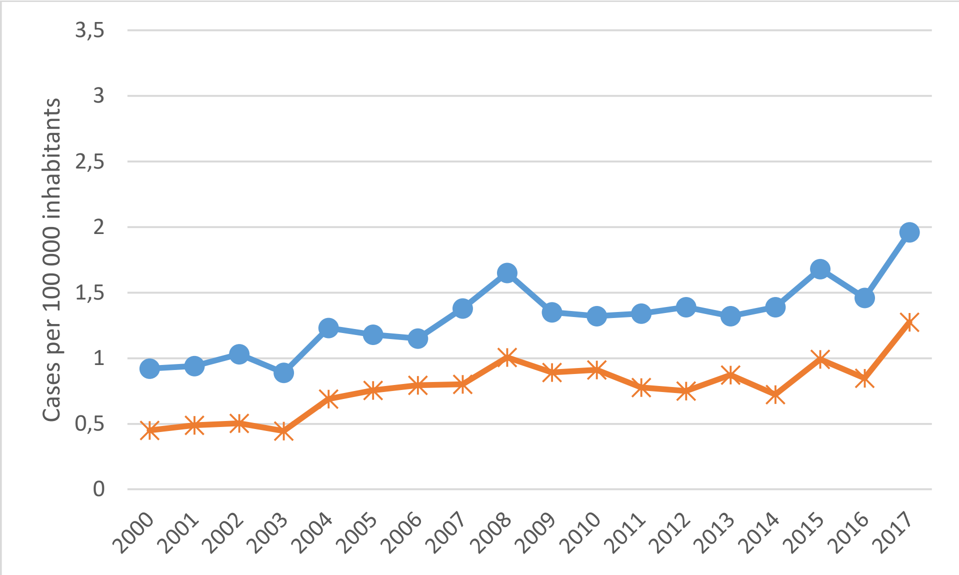

Figure 9. Incidence of Legionnaires' disease 2000-2017 in Sweden. Total incidence in the top line, incidence with Sweden as origin of infection in the bottom line. Data: Folkhälsomyndigheten, (2018).

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).

4.3 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 infected in Denmark 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 10.

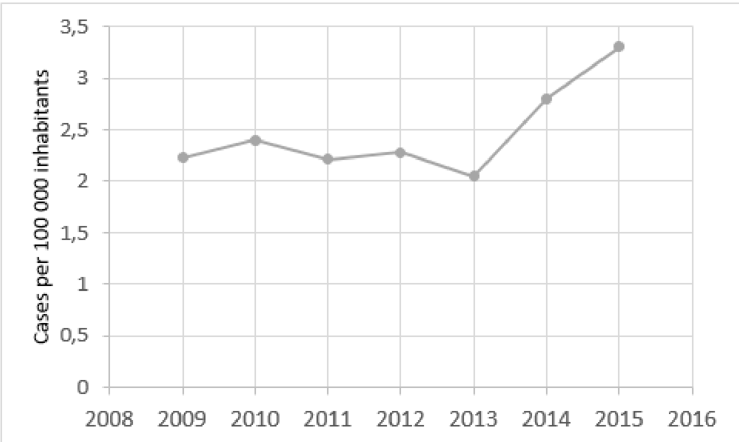

Figure 10. Incidence of Legionnaires' disease 2009-2015 in Denmark. Data: ECDC, (2017b).

4.4 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) (Folkhelseinstituttet, 2017). The incidence in Norway has ranged between 0.5 and 1.2 per 100 000 inhabitants from 2009 to 2015 which can be seen in figure 11.

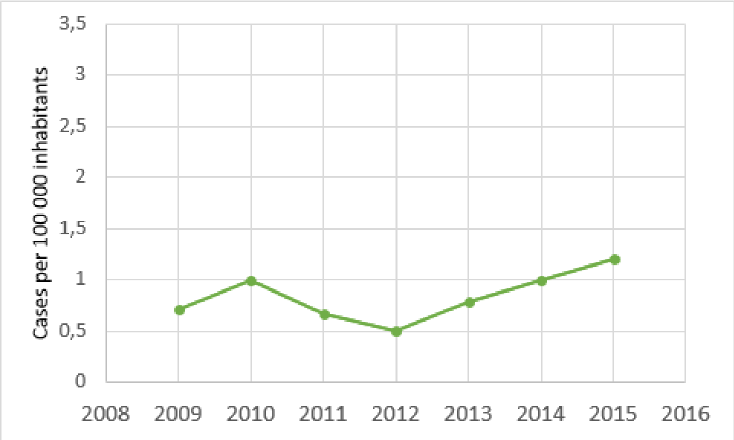

Figure 11. Incidence of Legionnaires' disease 2009-2015 in Norway.
Data: ECDC, (2017b).

4.5 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 12 below

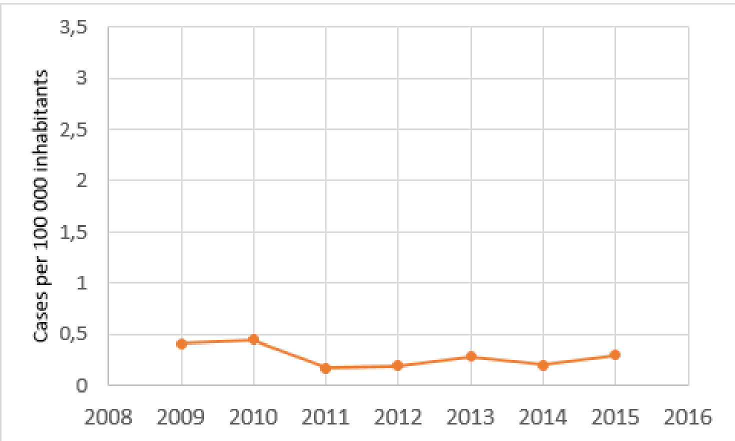

Figure 12. Incidence of Legionnaires' disease 2009-2015 in Finland.
Data: ECDC, (2017b).

In diagnosing Legionnaires’ disease, serology is the most common method used in Finland, followed by urinary antigen (Dr. Mentula, S., personal communication, 2018-04-05). The most commonly used methods can be seen in table 3 below.

Table 3. Methods used in diagnosing Legionnaires’ disease in Finland. Data: personal communication with Dr. Mentula, S. (2018).

Diagnostic method	Finland (2013-2016)
Urinary antigen	45 %
Culture	13 %
PCR	7 %
Serology	48 %

4.6 Germany

Outbreaks of Legionnaires’ disease are to be reported and analyzed 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 below in table 13.

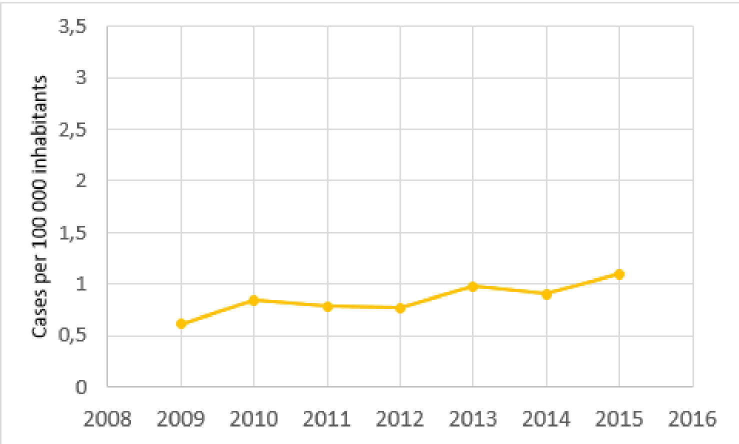

Figure 13. Incidence of Legionnaires’ disease 2009-2015 in Germany. Data: ECDC, (2017b).

4.7 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 14.

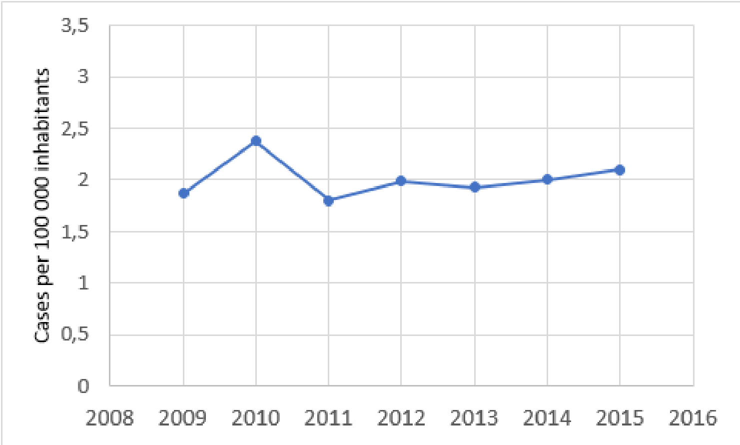

Figure 14. Incidence of Legionnaires' disease 2009-2015 in France. Data: ECDC, (2017b).

A study of the sensitivity of the mandatory notification system through a capture-recapture analysis (see Appendix A1. for definition) 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 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.

4.8 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 did differ and a visual representation of incidences in the studied countries can be seen in figure 15 below.

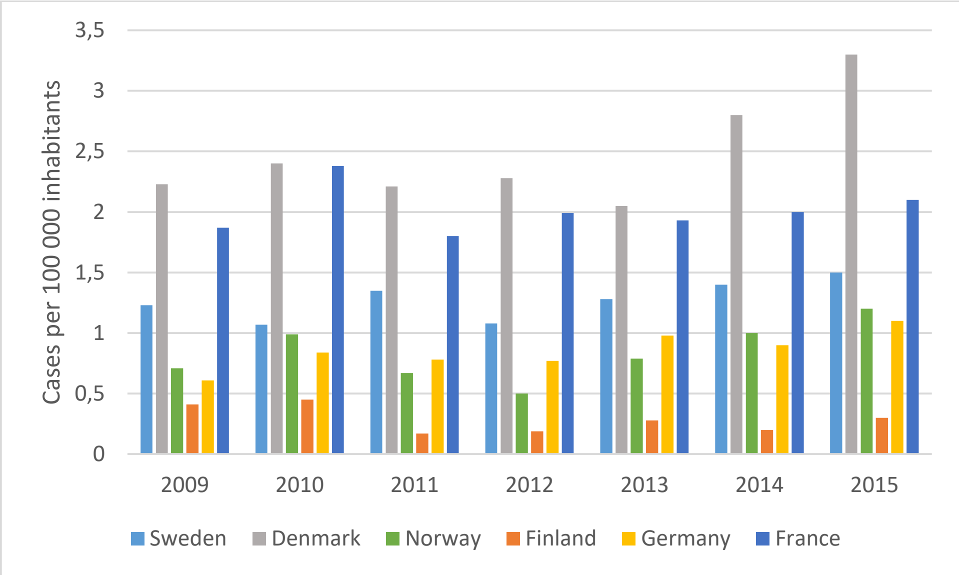

Figure 15. Incidence of Legionnaires' disease 2009-2015 in studied countries. Data: ECDC (2017b).

4.9 Analysis

The incidence varies between the compared countries and the reasons for this are not clear. There are various possible explanations, or a combination thereof, that might be reasons for this difference that are not related to the temperature requirements on the domestic hot water in the different countries. The possible explanations can be divided into three categories: the sensitivity of the surveillance system, environmental aspects for *Legionella* growth and susceptibility of the population.

Sensitivity of surveillance system

In order to compare the incidences, it is imperative to have accurate statistics. However, the sensitivity of the surveillance systems have not been documented in many countries. As previously mentioned, besides from the one for France in 2010, sensitivity analysis were 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 accurate. 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 making comparisons of statistics very hard to perform. 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 considering 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 under reporting or un-treating, but underdiagnosing due to clinicians using broad spectrum antibiotics to treat pneumonia, resulting in no further investigation of the causative pathogen (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 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.

Environmental aspects for Legionella growth

Legionella is more likely to grow in a warmer environment, therefore the average annual temperature of the countries might also be of interest. Since the reported cases of Legionnaires' disease has a clear peak during the summer months, the average temperatures of these months might be of special interest. The average high temperatures during those months for the investigated countries 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.

Susceptibility of the population

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 analyzed.

Since Legionnaires' disease mainly affects individuals above 65 years of age, the percentage of the population that are in this age span in each country might be of interest. However, the percentage does not vary much in compared countries (Eurostat, 2017a), suggesting it 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 of interest. 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. Legislation associated with *Legionella* control

This thesis analyzes the *Legionella* related legislation of six countries and also the general guidelines and directives provided by the European Union. What they all have in common is the statement that water systems should be designed so that microbial growth is minimized. 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.

In section 2.2, describing the optimal growth conditions of *Legionella,* it is mentioned that favorable conditions are in stagnant waters at a temperature between 32 ºC and 42 ºC 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 ºC and that the circulating water is kept at a temperature that allows at least 50 ºC at the tap within one minute of opening the tap (EWGLI, 2017).

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

5.1 Sweden

In Sweden, legislation concerning *Legionella* are of either a preventative nature or protocols on how to contain outbreaks. This thesis will focus on the preventative legislation. General legislation regarding control and prevention of *Legionella* are mainly handled in the Building and Planning Act (Plan- och bygglagen), the Building and Planning Ordinance (Plan- och byggförordningen), the Work Environment Act (Arbetsmiljölagen) and the Swedish Environmental Code (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 (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 ºC at the tap. The same goes for water circulation, the temperature should not be below 50 ºC. The system should also be designed in a way so that the cold water is not 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 ºC. The maximum tap water temperature is also regulated at 60 ºC to avoid scalding and at 38 ºC 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).

5.2 Denmark

In Denmark a few different laws and standards address the challenges of *Legionella*. In chapter 21 of the Building and Planning Act (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 ºC 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 ºC. The standard also says that the temperature should be kept above 50 ºC except at peak flows where a temperature of 45 ºC is acceptable (Rørcentret, 2012).

5.3 Norway

Similarly 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 (Byggteknisk forskrift). These regulations declare that *Legionella* should be controlled by keeping the temperature in circulating water systems above 65 ºC. 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 ºC and in all other locations to 55 ºC (TEK 17, § 15.5).

5.4 Finland

Finnish legislation is very clear regarding water temperature in tap water systems. In the ordinance regarding water utilities (Miljöministeriets förordning om byggnaders vatten- och avloppsinstallationer), chapter 2, § 6, it is declared that hot water should keep a minimum of 55 ºC to inhibit bacterial growth and maximum 65 ºC to avoid scalding. Cold water should not be warmer than 20 ºC, with the exception of unused water that is allowed to reach 24 ºC 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).

5.5 Germany

According to the Ordinance on the Quality of Water Intended for Human Consumption (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, where the volume between the heat exchanger and the furthest tap is less than 3 liters, 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 ºC at all times (DVGW, 2004).

In larger systems with storage tanks the temperature must be over 60 ºC 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).

5.6 France

Similarly 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 liters the water temperature in the whole system must be higher than 50 ºC. Moreover, if there is a storage tank of more than 400 liters the temperature at the outlet of the tank must be equal to or higher than 55 ºC.

5.7 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 4. Overview of national legislations.

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	60 °C		
France	50 °C, unless V < 3 liters	55 °C		

**Only for locations with increased risk of scaldings*

As can be seen in table 4, all the countries require a minimum temperature of at least 50 °C to avoid *Legionella* growth. There are two exception cases: Denmark and France. In Denmark, a system temperature of 45 °C is permitted at peak flows and in France the three-liter rule is applied. This rule states that if the volume between the point of distribution and the tap is less than three liters 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 table 4 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.

6. 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 favor 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.

6.1 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 thesis is installation of filters on each tap in the water system.

6.1.1 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 vary between manufacturers, e.g. 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 (Krüger Aquacare, 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 were thus more than 35 % longer than the recommended duration of use.

6.2 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, or by installation of ultraviolet lights or an advanced oxidation process. In this section five sterilization techniques will be covered: chlorination, ultraviolet light, ozone, ionization and photocatalysis.

6.2.1 Chlorination

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, 2017). 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* and higher concentrations will be required. Cervero-Aragó et al. showed that some amoeba 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 highly corrosive and as a result the pipes may need additional treatment or need replacement more often.

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).

6.2.2 Ultraviolet light

Ultraviolet (UV) light disrupts the DNA replication of bacteria and thus inhibits their growth. The effect is instantaneous and does not add any 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, 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).

This conclusion can be emphasized by a study performed by Liu et al. on the efficacy of UV treatment in combination with other treatment techniques. The study showed that if the system has not been decontaminated before the installation of the UV lamps they will 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 other bacterial growth.

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

Another study was conducted by Cervero-Argaró, Sommer and Araujo, investigating the efficacy of UV lights on *Legionella* associated with protozoa. They concluded that bacteria hosted by protozoa is up to 100 times more resistant against UV and that it was recommended to install another sterilization method as a complement to UV lamps (Cervero-Argaró, Sommer & Araujo, 2014)

6.2.3 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 (Li, Li, Zhou, Li & Tao, 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).

6.2.4 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 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). 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. The measured concentrations were however often lower and averaged between 317 - 444 µg/l for copper and 18 - 30 µg/l for silver (Walraven, Pool & Chapman, 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).

6.2.5 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 disintegration of the cell membrane. It becomes more efficient in the presence of UV light (Cheng, Chan & Wong, 2007).

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. They used titanium dioxide and UV-light with a wavelength of 365 nm. 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).

6.3 Alternative Water System Design

Many of the sterilization methods described above include adding chemicals to the water, which may pose problems with local legislation and 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 water system in a way that the risk for bacterial growth is minimized might be a good solution to this. As discussed in section 2.2 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 unfavorable to bacterial growth.

6.3.1 Decentralized substations

Decentralized substations inhibit growth of *Legionella* by limiting the residence time in what might otherwise be favorable conditions. The idea is based on the German technical rule W551 that in systems where the total volume between the point of distribution and the furthest tap does not exceed three liters there is no need for additional disinfection techniques (DVGW, 2004). These are so called small systems and are usually only found in single-family homes but the principle could 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 would look like can be seen in figure 16.

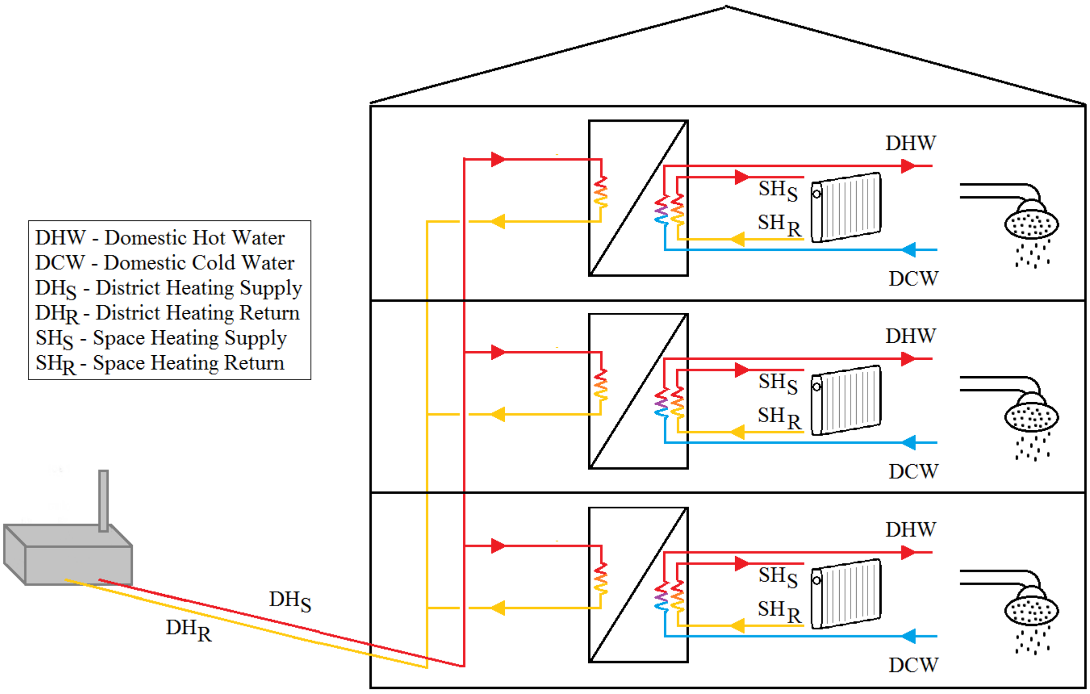

Figure 16. Process diagram of decentralized substations.

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*. Other advantages is that there is no need for water circulation which can significantly reduce the heat losses and that there is no addition of chemicals that may affect the water quality (Yang, Li & Svendsen, 2016b). The drawback is that it requires considerable investments and can be difficult to implement in existing buildings as the installation would require extensive renovations (SP, 2014).

6.3.2 Temperature increase through an auxiliary heating device

The idea of an auxiliary heating device is to boost either the supply temperature or the DHW temperature to be able to meet the required temperatures. There are many types of heating devices but in this thesis only three will be investigated: electric heat tracing, micro heat pumps and electric heating elements.

Electric heat tracing

One of the above mentioned heating techniques is to install electric cables on the DHW pipes (see figure 17 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 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).

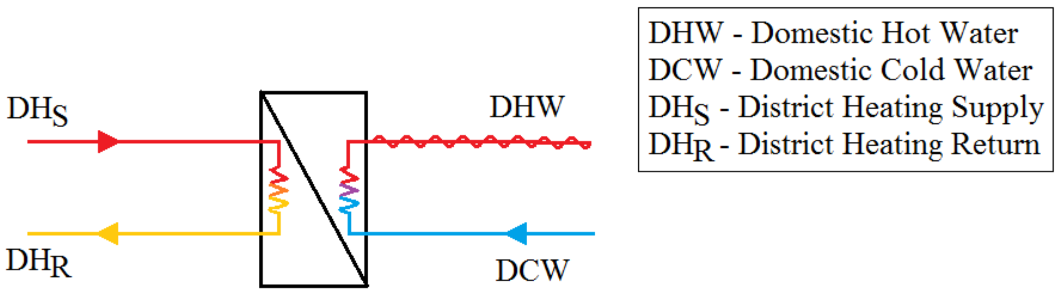

Figure 17. Process diagram of electric heat tracing.

Micro heat pump

Another way to heat up the domestic hot water is to install a microbooster heat pump. It can boost the temperature when the DH water temperature is not high enough, either for comfort reasons or to comply with regulations. 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, where the energy from one was used by the heat pump to heat the other. Figure 18 presents the layout of such an installation. The DH water then heats cold tap water through a heat exchanger. Since the tap water and the DH water are never in contact 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.

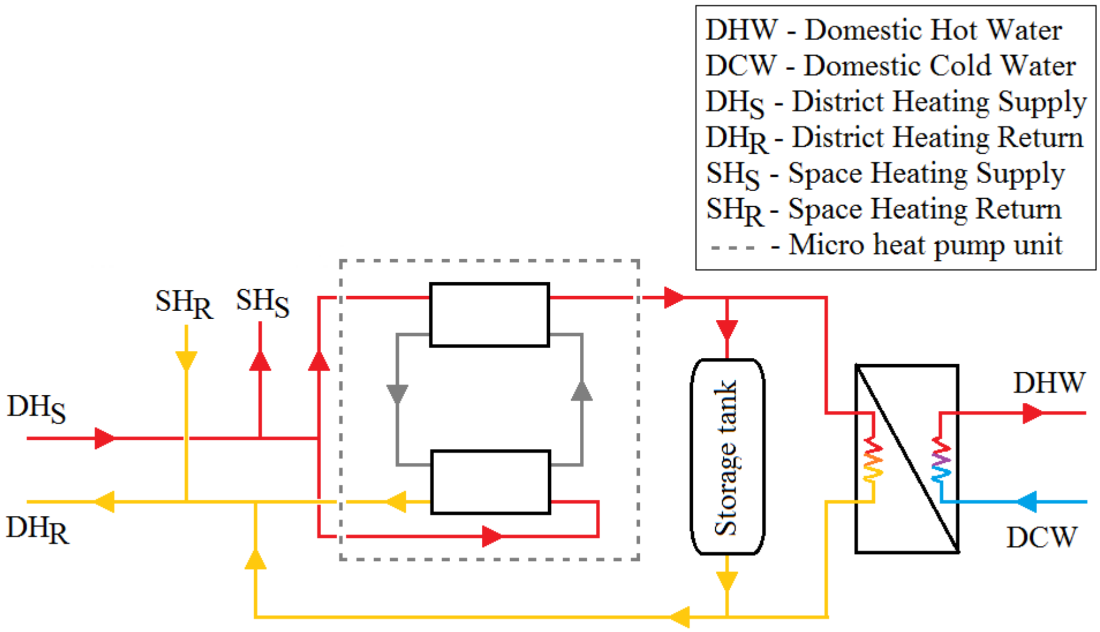

Figure 18. Process diagram of the setup with a micro heat pump.

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 19.

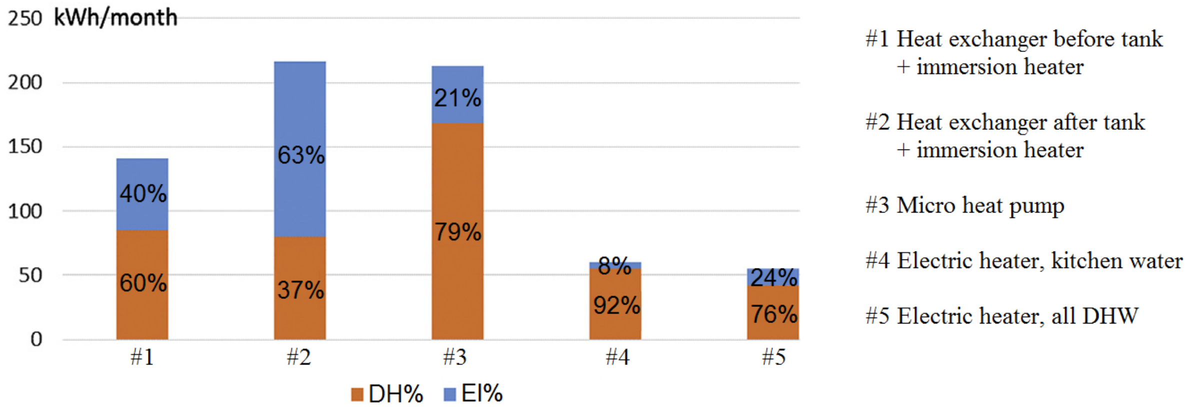

Figure 19. Heat and electricity delivered for DHW preparation. Source: Yang et al., (2016d).

As can be seen in figure 19, scenario four and five had the highest energy performance and only these two will therefore be further described here. 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 20. In the fifth scenario on the other hand, all of the DHW was heated as shown in figure 21 (Yang et al., 2016d).

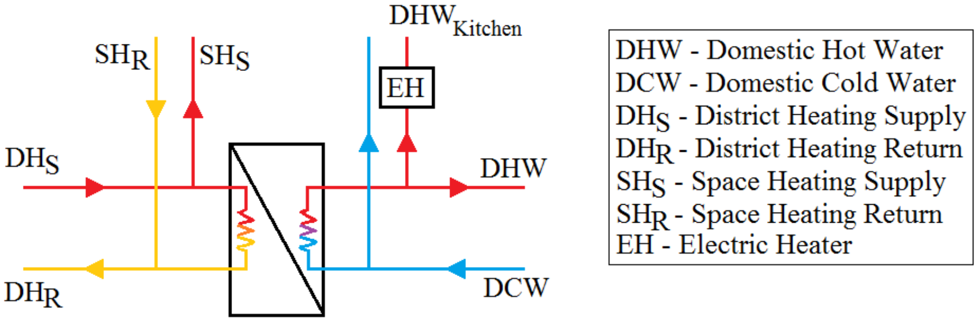

Figure 20. Process diagram of the fourth scenario, where only the hot water for the kitchen is heated.

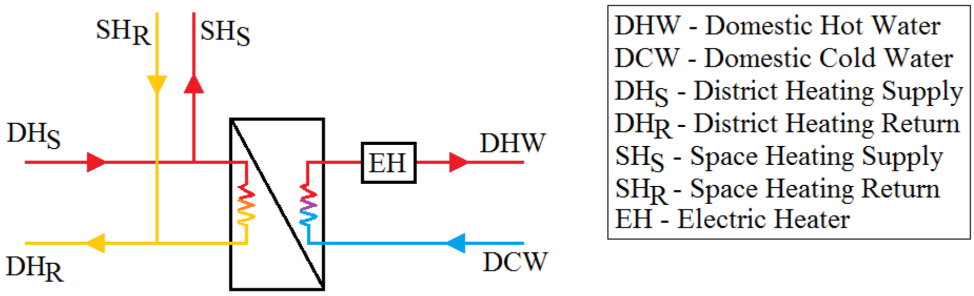

Figure 21. Process diagram of the fifth scenario. All DHW is heated.

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 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 peak loads 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 current fees at Kraftringen, a 16 ampere fuse, which is common for a single-family house in Sweden, has a subscription fee of 4140 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 10620 SEK, i.e. a yearly increase of almost 6000 SEK, not including the cost of the upgrade itself (Kraftringen, 2018).

6.3.3 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 also described in section 6.2.4, 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). On the contrary, pipes made of certain types of plastics can 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 is in agreement 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 their experiment, Van der Kooij et al. 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 decrease 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).

6.4 Analysis of techniques for *Legionella* control

In this section the different techniques for *Legionella* control that have been explained in this chapter will be analyzed. The analysis will start off with a summary of the techniques where the advantages and disadvantages of each technique will be listed. In the following subsections each category of techniques will be analyzed separately.

6.4.1 Summary of techniques for *Legionella* control

Presented in table 5 are the advantages and disadvantages of the described techniques.

Table 5. Advantages and disadvantages of the studied techniques for Legionella control.

Technique	Advantages	Disadvantages	Fulfills temp. requirements
Filters	• Very effective	• Short lifetime: frequent maintenance required • High cost	• No
Chlorination	• Mature technology • Residual control	• Less effective on protozoa • Local legislation • Potential health hazard	• No
UV	• No added chemicals • Instant effect	• Not sufficient on its own • Less effective on protozoa • Dependent on placement: no residual effect	• No
Ozone	• Highly oxidizing, effective in low concentrations • No harmful effects on health and environment	• Short half-life: little residual effect • Corrosive: pipe maintenance required	• No
Ionization	• Mature technology • Study shows high efficiency	• Can be prohibited by national legislation	• No
Photocatalysis	• No harmful residuals • Pilot studies show high efficiency	• Not tested in large scale systems	• No
Decentralized substations	• No added chemicals • No need for circulation: reduces heat losses	• Not tested in large scale systems • Investment cost	• No
Electric heat tracing	• Can be used with low DH supply temperatures • No need for circulation: reduces heat losses	• Not commercialized for residential properties	• Yes
Micro heat pump	• Can be used with low DH supply temperatures	• High investment costs	• Yes
Electric heating element	• Can be used with low DH supply temperatures • Instantaneous heating of DHW	• High electric effect required at peak times: may need upgrade of main fuse	• Yes

6.4.2 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.

6.4.3 Sterilization Techniques

Neutralization of bacteria using chemicals, such as chlorine, or by ionization have the advantage that they are mature methods. They are commonly used in potable water treatment across the globe. However, using chemicals is not without obstacles. The most important may be legislations 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 technique. They can also vary between countries so it may be difficult to come up with an internationally standardized procedure for chemical treatment. As mentioned in subsection 6.2.1 high concentrations of chlorine may be needed to combat *Legionella* hosted by amoeba and these will likely not comply with regulations. For example in Sweden the maximum chlorine dosage is 1 mg/l which would, according to the study mentioned in chapter 6.2.1, 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 6.2.2 confirmed that UV can efficiently inhibit *Legionella* growth given that the system had been previously cleaned so that there was no *Legionella* present in biofilm. 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, meaning 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 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 which would mean that it would need to be introduced in the system close to the tap to avoid bacterial regrowth. It would nearly be a point-of-use technique which complicates the process as individual dispersion mechanisms may need to be installed. In general, very little research exist on ozone as a means for *Legionella* control and so it is unlikely that the technique could be implemented in a near future.

Ionization

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 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 term 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 where the water flow reaches.

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 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 sell. This was confirmed at the focus group interview. 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 pressed the issue of spreading the appropriate information, something that becomes increasingly difficult with a second generation of buyers. The participants also mentioned 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.

6.4.4 Alternative System Design

Decentralized substations

Decentralized substations, or flat stations, is a hot topic when talking about solutions for *Legionella* control. The concept will be tested in the contractor LKF's (Lunds Kommuns Fastigheter) project Xplorion before it is opened for residents and in the focus group interview LKF's representative Dennis Kerkhof expressed high expectations of success. Pilot tests have also been performed in Denmark, for example by Yang, Li and Svendsen, where they concluded 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 6.3.1 this solution also requires invasive renovations that complicates implementing flat stations in existing buildings. This was also brought to light in the focus group interview, where a concern of cost was also expressed. Flat stations would require more space, maintenance and higher investment costs which would affect the final price or rent of an apartment and might make it less attractive to potential residents.

Finally there is still the issue of temperature requirement to consider. These legislations are restricting implementation of many alternative solutions that cannot fulfill the requirements on DHW temperature, including decentralized substations.

Auxiliary heating device

As mentioned in subsection 6.3.2, 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 edge over the other available techniques. It could, theoretically, be implemented straight away as no legislative changes would be necessary. 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.

On the downside however, there is the economic perspective. Installing an electric heating device or electric heat tracing would require significant renovations in existing buildings, which would be complicated as well as time consuming and expensive. It 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. However, it is probable that the investment would pay off as the price per kWh would likely decrease as a result of the reduced heat losses from having a lower temperature in the system.

There is also an issue with the electric effect required by the auxiliary heaters at peak times. Peak times are usually in the morning or in the evening when many household electrics are used simultaneously putting a lot of stress on the main fuse. Depending on the size of the original fuse it may be necessary to upgrade to one that can handle a higher effect. This may result in a connection fee and it will lead to a higher yearly subscription fee.

Pipe techniques

Different material have different qualities that might affect the bacterial growth. The experiment mentioned in subsection 6.3.3 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 was no longer present 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 insufficient. Coating of antibacterial material on the inside of the pipe similarly demonstrates initial bacterial inhibitory qualities, but only for a limited amount of time. This suggests that pipe coating is not either a suitable technique for *Legionella* control.

7. Focus Group Interview

The aim of the focus group interview was to have a discussion about LTDH and *Legionella* with contractors involved in Brunnshög to get an insight of their knowledge level on the subject. It was of interest to discuss their familiarity with the issues that may arise as well as how the construction of a LTDH system would affect them as contractors. The interview began with a short presentation from each participant about their involvement in Brunnshög before moving on to the prepared questions.

The first few questions revolved around knowledge and information about the LTDH network in Brunnshög: *Why do you think Kraftringen is building a LTDH system at Brunnshög?* And *What information have you received about the project?*

The answers for the first questions were quite similar: it is a way to utilize the waste heat from MAX IV and ESS. It was understood that LTDH is more sustainable compared to regular district heating since the temperatures would be lower which would reduce the heat losses. In general the participants seemed to have a high understanding of the concept of LTDH. The opinions on information distribution on the other hand were diverse. One company said they had had multiple meetings with Kraftringen and that they had all the information they needed to proceed with their construction. At the same time another company claimed that they had received too little and too unclear guidelines and were unsure of what the final verdict was regarding who was building where, what, and most importantly, when.

The interview then moved on to the attitudes towards heating systems in general and then more specifically towards LTDH: *What factors do you consider when choosing a heating system?* And *What are your thoughts on connecting to the LTDH system in Brunnshög?*

The participants were encouraged to write down the most important factors on a whiteboard and then they were instructed to rate their top two factors. The results were that the most important one was the security of supply, followed by cost and finally environmental benefits and required maintenance. All the participants seemed to agree that district heating was the clear choice if it is available. Specifically because it offers the stability and security of being able to supply heat to their customers under all conditions. The participants were also mostly positive to a connection to the LTDH network. They claimed to be able to adapt to a new system as long as they have all the necessary information and parameters in good time before they start construction. There was however a big "if" and that was the cost. Some of the participants expressed concern that a connection to the LTDH network might result in an increased investment cost due to the need for installation of individual heat exchangers or auxiliary heating devices. In this case it would be important to perform a long-term economic analysis to determine whether savings could be made at later stages through for example reduced energy costs.

Finally any previous experience and/or knowledge of combating *Legionella* was discussed: *Has your company experienced any problems with Legionella?* And *Have you ever used any additional techniques to inhibit Legionella growth?*

Here the answers differed depending on whether the company builds as well as manages the buildings or if they are only involved in the construction phase. The participants from companies who also manage buildings were more knowledgeable on *Legionella* inhibition and one stated that they flush the water systems every other week with water at 70 ºC for this reason. All the participants were however unanimous in acknowledging that *Legionella* is an important factor that is most definitely considered throughout a construction project. To actually provide a solution, however, is often delegated to a sub-contractor and only one or two of the participants in this interview had any knowledge of available techniques, other than thermal, for *Legionella* control.

Finally the floor was open for additional questions from the audience: *How do you think the residents would react towards a change in Legionella control method and a reduction in supply temperature?*

The opinions here were several. One participant claimed that he thought that residents would accept a lot before bothering to complain and another thought the opposite; that even the slightest reduction in temperature would result in a rapid increase in complaints. On the other hand they were all unanimous in that it would be harder to implement a technique that involves chemicals, as this is a more controversial topic. The general agreement was that the new technique should be as simple to explain and implement as possible and that it should not affect the lives or routines of the residents more than absolutely necessary. It was further discussed that only one of the present companies seemed willing to be the first to try a new solution. This was, according to the group, a common attitude within the construction and water-sanitation industry. It is risky to make a big investment for research for a new solution that might not pay off and it is therefore preferred to use well-established, mature techniques.

Three main things were brought to light in this focus group interview. First of all, *Legionella* control is a very important aspect when designing and constructing a new building. Second of all, implementing a new technique, i.e. a replacement for the current temperature requirement, should be nearly unnoticeable by the residents. Finally, construction companies seem to be reluctant to take the risk of being first with a new solution and hence the question of whose responsibility it is to develop new solutions needs to be answered

8. Conclusions & Discussion

The aim of this thesis was to investigate how to overcome issues with *Legionella* in domestic hot water systems as the district heating industry moves towards low temperature systems. In order to do so, four main questions were formulated. One, how are cases of Legionnaires' disease reported in respective countries? Two, what are the regulations regarding domestic hot water temperature in Sweden, Denmark, Norway, Finland, Germany and France? Three, what solutions, alternative to the conventional temperature control, exist and what are their advantages and disadvantages? And four, what are the attitudes towards LTDH among contractors in Brunnshög?

The study aided in answering these questions with varying success:

1. The statistics from six countries were reviewed in this study. It is clear that the incidence varies between them but it is unclear why. There are many factors that could be contributing to this variation, including sensitivity of the surveillance system, environmental aspects for *Legionella* growth, susceptibility of the population and the temperature requirements of each country. However, it was established that a deeper statistical analysis would be required to draw any reliable conclusions in this matter.

2. With the exception of Denmark and France, all six studied countries require a DHW temperature equal to or above 50 °C at all times. In Denmark, a DHW temperature of 45 °C is permitted at times of peak flow and in France, the three-liter rule is applied.

3. There are several alternative techniques that could theoretically be implemented. These can be divided into three categories: mechanical techniques, sterilization techniques and alternative system design. The implementation of the majority of them are hindered by the current legislation on temperature requirements. At present the only possible solutions are those that boost the DHW temperature, i.e. electric heat tracing, micro heat pump or electric heating element.

4. The result of the focus group interview was that contractors were very positive toward district heating and LTDH. The main concern seemed to be the risk of increased installation costs.

8.1 Statistics

In comparing the statistics regarding incidence rates between the studied countries, a difference could be seen though the reason for this difference is not clear. The temperature requirements vary between countries and a correlation with incidence rates might be seen. Denmark and France both have the most lenient temperature requirements as well as the highest incidence rates compared to the other four countries studied. However, to be able to draw any conclusions regarding the impact of temperature requirements on incidence rates, it is imperative to examine the possibility of other factors playing a significant role.

Many possible explanations were analyzed that were not related to the domestic hot water temperature requirements. The proposed reasons for the difference in incidences were divided into three categories: sensitivity of the surveillance system, environmental aspects for *Legionella* growth and susceptibility of the population. None of the analyzed reasons showed a clear correlation with reports on Legionnaires' disease. A statistical analysis including more countries and more detailed patient information might result in a deeper understanding of the relationships. It is also imperative to further study the impact of a combination of risk factors on the incidence rate. For example the high incidence rates in France might be a consequence of having high ranking in all of the discussed risk factors. They have the highest percentage of the population that are considered smokers as well as the highest alcohol consumption per capita. This in combination with having the highest average temperature and that they therefore might utilize cooling towers more than other countries could have a significant impact on the incidence. However, such conclusions can not be drawn with statistics based on only six countries and without adapting further statistical analysis methods. As this was not possible within the scope of this thesis, a suggestion for further studies is to make a broader analysis based on detailed statistics from more countries.

8.2 Legislation

The aim with LTDH is to reach supply temperatures that approach 50 ºC. Considering heat losses, primarily in the heat exchanger, this means that the temperature of the water when it reaches the tap will be around 45 ºC at the most. As can be read in chapter 5, the countries studied in this thesis all have temperature requirements that cannot be satisfied with these supply temperatures. The threshold for the majority of the countries is 50 ºC, a temperature that has most likely been chosen because it is above the limit for *Legionella* growth (see figure 2, page 7): at temperatures higher than 46 ºC *Legionella* bacteria are inactivated. Some countries, such as Norway, have decided on a higher system temperature to further ensure the absence of *Legionella*. Interestingly the origin country of the three-liter rule, Germany, does not apply it themselves. The recommendation in Germany is that the operation temperature of a DHW system should be at least 50 ºC (DVGW, 2004), whereas the three-liter rule is applied in France.

Of the six countries studied in this thesis there are only two exceptions to a temperature requirement of at least 50 ºC. These are in Denmark at peak flow times, when a temperature of 45 ºC is accepted, and in France that has applied the three-liter rule for small systems. Under other circumstances and in the other countries the minimum temperature in the domestic hot water system varies between 50 ºC and 65 ºC. Hence, as the legislation is today, it would not be possible to reduce the district heating supply temperature without supplementary temperature boosting. It is difficult to say if and how these legislations could be altered. For a change in regulations to occur, it is imperative that a safe solution can be presented, guaranteeing the water quality with regards to *Legionella,* that is also accepted by the general public.

8.3 Techniques

There are a number of techniques that could theoretically be applied as a method of bacterial control in DHW systems. However, from what we could find none of them are at a stage where they could be implemented in a near future. Two main issues remain: first, they have not been tested in real, large-scale systems, as is the case for most of the alternative system design solutions. Second, they do not comply with the national legislation for water quality reasons and/or temperature requirement, which is true for the sterilization techniques but also for decentralized substations.

Unless the legislations regarding temperature requirement are changed, either to a lower temperature requirement or to be based on the concentration of bacteria, the only approved techniques would be those with auxiliary heating devices. The heating devices could boost either the supply water or the DHW to the required temperatures and thus stay within the limit of the law. Even though the concept of high temperature to control bacterial growth is mature, the auxiliary heating devices are not. As was discussed in section 6.3 these solutions have high investment costs which affect the consumers. Furthermore, the installation process may require invasive renovations making the solutions unsuitable for existing buildings. The research in this area is far from finished and there is still a long way to go before a ready solution for *Legionella* control can be presented.

8.4 Focus Group Interview

The attitudes toward LTDH amongst the participating representatives could be concluded as only positive. They did not see any obstacles in connecting to the LTDH network as long as they got clear instructions a long time in advance. District heating, if available, was the only clear choice as it was considered dependable and robust.

The focus group interview made it clear that *Legionella* is an issue that representatives from the construction industry are aware of and that is considered from an early stage. However, it also became clear that the expert knowledge lies elsewhere than with contractors. The actual solutions are typically provided by a subcontractor. The only preventive technique known by all representatives was the temperature requirements set by the National Board of Housing, Building and Planning (Boverkets byggregler). They were all open for new solutions, however, no contractor wants to take the risk of being the first in case of failure.

It is not clear whether the participants were a representative group and thus to make a general conclusion on the knowledge and attitudes amongst stakeholders in Brunnshög, it would have been preferred that representatives from more companies had attended. It is possible that the general positive attitude we concluded from the focus group interview was a result of all participants being representatives from companies that are positive to innovation as they all are building in the new modern area Brunnshög. These results might therefore not reflect the knowledge and attitudes among stakeholders outside of Brunnshög. However, this was not the aim of this thesis, although it might be an interesting topic to investigate in further studies.

8.5 Method

To fulfill the aim of a study it is essential to choose an appropriate method for answering the research questions. In the following section the two methods chosen for this study will be discussed.

8.5.1 Literature study

This thesis is a compilation and analysis of available material regarding *Legionella* control techniques, legislation on DHW temperature and statistics on Legionnaires' disease. We chose to base the majority of the thesis on a literature study since it allowed us to use information and results from studies performed by experts in their respective fields. We believe this gives the thesis a higher credibility and it also allowed us to cover many more techniques compared to if we had performed a practical study on one or two techniques. As has been mentioned before, most of the information for the literature study has been gathered from articles and reports, only a small part has been obtained through personal communication with experts. Including more of this type of knowledge may have given the thesis a greater depth and would have provided an even broader view of the issues at hand.

The chapter on statistics was the most difficult to draw any conclusions from as the accuracy of the statistics was hard to determine and also differed between countries. As was mentioned in section 8.1 a much more extensive statistical analysis, which is not within the scope of this study, would have been required to draw any real conclusions on this matter.

Regarding the chapter on legislation we were confined to the legislation that is currently applied. No information could be found on potential alterations of the temperature requirements that might take place in the future and it is therefore hard to say whether a change is impending.

Low temperature district heating is a relatively new subject and there are a limited number of scientific articles on the subject, especially that also treat issues with *Legionella*. If one were to do a similar compilation in a few years time it is very likely that a number of new studies will have been executed and the conclusion might be different than what we have been able to draw.

8.5.2 Focus group interview

We chose to do a focus group interview for this thesis, rather than for example a survey, for a number of reasons. Firstly, a similar survey was sent out for an essay in a university course that took place in the autumn of 2017 and we believed the participants would be less willing to respond to a survey twice in such a short time. Secondly, we anticipated that a group interview would provide a greater depth to the thesis since the answers would be more detailed. Finally, the aim was that the discussing nature of the interview would allow us to get a broader view of the attitudes and knowledge level since the participants would not be confined to the pre-written answers of a survey.

The verdict after completing the group interview was that it was successful in fulfilling the expectations of the second and third reason listed above. The first one, however, turned out to be more complicated than predicted. Out of the fourteen companies that were contacted only five were able to participate on the given day. This entails that the conclusion from the interview might not be representative of the industry. The attendance might have been higher if there had been more occasions to choose from or if the invitations had been sent out further in advance since there seemed to be an interest in the subject from many of the of the companies that were contacted. There were however representatives from both municipal and private companies present and some distinctions were able to be made in the attitudes between the two which could be interesting to explore further.

8.6 Final words

Lowering the supply temperature of a district heating system to 50 ºC may result in large energy savings as well as economic benefits. However, the time and investment required to build a system with these properties that also guarantees the quality of the water and the safety of consumers makes us ask the question if it is actually worth it? How much greater would the benefits be compared to only reducing the supply temperature to 65 ºC or 60 ºC - a temperature that would enable the DHW to comply with the temperature requirements in most countries? These are questions to be answered by someone else, perhaps in a future master thesis. The concept of LTDH is fairly new and there is much left to be defined, discovered and developed and time will tell how the district heating systems of tomorrow will be formed.

9. References

AFS, Arbetsmiljöverkets författningssamling, 2005:1, *Mikrobiologiska arbetsmiljörisker - Smitta, toxinpåverkan, överkänslighet,* Arbetsmiljöverket.

AFS, Arbetsmiljöverkets författningssamling, 2009:2, *Arbetsplatsens utformning,* Arbetsmiljöverket.

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].

Averfalk, H. & Werner, S. (2017). *Essential improvements in future district heating systems*. Energy Procedia 116 (2017) 217–225.

Averfalk, H., Werner, S., (2018), *Novel low temperature heat distribution technology,* Energy nr 145, p. 526-539.

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.

BFS, Boverkets Författningssamling 2011:6, *Boverkets Byggregler,* Boverket.

Bygningsreglementet Danmark (2018), chapter 21; *Vand.*

Byggteknisk Forskrift - TEK17, § 15.5 *Innvendig vanninstallasjon* (Implemented 15-09-2017).

Campese, C., Jarraud, S., Sommen, C., Maine, C. & Che, D. (2013). *Legionnaires' disease in France: sensitivity of the mandatory notification has improved over the last decade*. Epidemiology & Infection 141, 2644-2649.

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.

Cervero-Aragó, S., Rodríguez-Martínez, S., Puertas-Bennasar, A., & Araujo, R.M., (2015), *Effect of Common Drinking Water Disinfectants, Chlorine and Heat, on Free Legionella and Amoebae-Associated Legionella,* PLoS ONE 10(8): e0134726. doi:10.1371/journal.pone.0134726.

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

Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption.

Dennis P.J., Green D. & Jones B.P. (1984). *A note on the temperature tolerance of Legionella*. Journal of Applied Bacteriology, 56, 349–350.

Directive 2000/54/EC of the European Parliament and of the Council of 18 September 2000 on the protection of workers from risks related to exposure to biological agents at work.

DVGW (2004), Code of Practice W551, *Drinking water heating and drinking water piping systems; technical measures to reduce Legionella growth; design, construction, operation and rehabilitation of drinking water installations.*

ECDC, European Centre for Disease Prevention and Control, (n.y.). *Legionnaires' disease outbreak investigation toolbox*. https://legionnaires.ecdc.europa.eu/?pid=109 [Retrieved on 2018-03-23].

ECDC, European Centre for Disease Prevention and Control, (2017a). *Operating procedures for the surveillance of travel-associated Legionnaires´disease in the EU/EAA.*

ECDC, European Centre for Disease Prevention and Control, (2017b). *Annual Epidemiological Report for 2015 Legionnaires' disease*.

ECDC, European Centre for Disease Prevention and Control, (2017c). *European Technical Guidelines for the Prevention, Control and Investigation, of Infections Caused by Legionella species.*

Energiföretagen (2017). *Fjärrvärme - bekväm och resurseffektiv uppvärmning.* https://www.energiforetagen.se/sa-fungerar-det/fjarrvarme/ [Retrieved on 2018-02-18].

Energy Plan (no year). *Smart Energy Systems.* http://www.energyplan.eu/smartenergysystems/ [Retrieved on 2018-02-05].

European Commission (2017). *COOL DH.* https://cordis.europa.eu/project/rcn/212356_en.html [Retrieved on 2018-02-19].

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

Eurostat (2017a). *Population age structure by major age groups, 2006 and 2016*.

Eurostat (2017b). *Proportion of daily smokers of cigarettes, 2014.*

EU OSHA - European Agency for Safety and Health at Work (2011). *Legionella* and *Legionnaires' Disease: A Policy Overview.*

Finlex 1047/2017, *Miljöministeriets förordning om byggnaders vatten- och avloppsinstallationer*, (22-12-2017).

Folkhelseinstituttet (2017). *Legionellose.* https://www.fhi.no/nettpub/smittevernveilederen/sykdommer-a-a/legionellose/#meldings-og-varslingsplikt [Retrieved on 2018-02-20].

Folkhälsomyndigheten (2015a). *Inledning: Ett kapitel i kunskapssammanställningen Legionella i miljön - hantering av smittrisker.*

Folkhälsomyndigheten (2015b). *Epidemiologi och övervakning: Ett kapitel i kunskapssammanställningen Legionella i miljön - hantering av smittrisker.*

Folkhälsomyndigheten (2015c). *Förekomst i miljön och olika vattensystem: Ett kapitel i kunskapssammanställningen Legionella i miljön - hantering av smittrisker.*

Folkhälsomyndigheten (2016a). *Historik och tidiga svenska insatser: Ett kapitel i kunskapssammanställningen Legionella i miljön - hantering av smittrisker.*

Folkhälsomyndigheten (2016b). *Nationell lagstiftning relaterad till legionella, Ett kapitel i kunskapssammanställningen Legionella i miljön – hantering av smittrisker.*

Folkhälsomyndigheten (2018). *Samtliga fall av Legonellainfektion*. https://www.folkhalsomyndigheten.se/folkhalsorapportering-statistik/statistikdatabaser-och-visualisering/sjukdomsstatistik/legionellainfektion/?t=county [Retrieved on 2018-02-19].

FOR-2003-04-25-486, *Forskrift om miljørettet helsevern,* (2003).

Gião, M. S., Wilks, S. A. & Keevil, C. W. (2015). *Influence of copper on biofilm formation by Legionella pneumophila in potable water.* Biometals 28, 329-339.

Heat Roadmap Europe (no year). *A low-carbon heating and cooling strategy for Europe* http://www.heatroadmap.eu/ [Retrieved on 2018-02-05].

Institutet för hälsa och välfärd (2016). *Anmälningspliktiga sjukdomar.* https://www.thl.fi/fi/web/infektionssjukdomar/overvakning-och-epidemier/registret-over-smittsamma-sjukdomar/anmalan-om-smittsam-sjukdom/anmalspliktiga-sjukdomar [Retrieved on 2018-02-20].

Jacquinet, S., Denis, O., Valente Soares, F. & Schirvel, C., 2014. *Legionnaires' disease: overview of the situation concerning notification in Wallonia (Belgium) in 2012, a retrospective descriptive study based on a capture-recapture method.* Archives of Public Health, 72, 2.

Kraftringen (2018), *Elnätsavgifter fr.o.m 2018-05-01.*

Krüger Aquacare (no year). *Bekæmpelse af legionella i ejendomme*. http://www.kruger.dk/Ejendomme/legionella/ [Retrieved on 2018-04-04].

Krüger Aquacare (2017), *Technical Data for BacTerminator Safe.*

Lauenburg, P. (no year). *Teknik och forskningsöversikt över fjärde generationens fjärrvärmeteknik,* Institutionen för Energivetenskaper, LTH.

Legifrance,(2005) *Arrêté du 30 novembre 2005 modifiant l'arrêté du 23 juin 1978 relatif aux installations fixes destinées au chauffage et à l'alimentation en eau chaude sanitaire des bâtiments d'habitation, des locaux de travail ou des locaux recevant du public*, JORF n°291 du 15 décembre 2005 page 19295 texte n° 36.

Lethola, M. J., Miettinen, I. T., Keinänen, M. M., Kekki, T. K., Laine, O., Hirvonen, A., Vartiainen, T. & Martikainen, P. J. (2004). *Microbiology, chemistry and biofilm development in a pilot drinking water distribution system with copper and plastic pipes*. Water Research 38, 3769-3779.

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

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.

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.

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

Lund, H., Werner, S., Wiltshire, R., Svendsen, S., Thorsen, J.E., Hvelplund, F. & Vad Mathiesen, B. (2014). 4*th Generation District Heating (4GDH) - Integrating smart thermal grids into future sustainable energy systems,* Energy 68, p. 1-11.

Lunds kommun (2012), *Lund NE/Brunnshög Vision och Mål.*

Lunds kommun (no year). *Brunnshög*. https://www.lund.se/brunnshog [Retrieved on 2018-02-15].

Marchesi, I., Marchegiano, P., Bargellini, A., Cencetti, S., Frezza, G., Miselli, M. & Borella, P. (2010). *Effectiveness of different methods to control legionella in the water supply: ten-year experience in an Italian university hospital*. Journal of Hospital Infection 77, 47–51.

MediLexicon (no year). *Serogroup*. http://www.medilexicon.com/dictionary/81202 [Retrieved on 2018-05-11].

Moritz, M., Flemming, H-C. & Wingender, J. (2010). *Integration of Pseudomonas aeruginosa and Legionella pneumophila in drinking water biofilms grown on domestic plumbing materials*. International Journal of Hygiene and Environmental Health 213, 190-197.

Pierre, D., Baron, J., Yu, V. & Stout, J, (2017). *Diagnostic testing for Legionnaires' disease*. Annals of Clinical Microbiology and Antimicrobials 16, 59.

The Public Health Agency of Sweden (2016). *Notifiable diseases*. https://www.folkhalsomyndigheten.se/the-public-health-agency-of-sweden/communicable-disease-control/surveillance-of-communicable-diseases/notifiable-diseases/ [Retrieved on 2018-02-19].

Robert Koch Institut (2017). *Infectious Disease Epidemiology Annual Report.* https://www.rki.de/EN/Content/infections/epidemiology/inf_dis_Germany/yearbook/Yearbook_inhalt.html [Retrieved on 2018-02-21].

Rusin, P., Bright, K. & Gerba, C. (2003). *Rapid reduction of Legionella pneumophila on stainless steel with zeolite coatings containing silver and zinc ions*. Letters in Applied Microbiology 36, 69-72.

Rørcentret (2012). *Legionella - Installationsprincipper og bekæmpelsesmetoder,* Teknologisk Institut, ISBN 87-991239-8-3.

Santé Publique France (2017). *Légionellose*. http://invs.santepubliquefrance.fr//fr/Dossiers-thematiques/Maladies-infectieuses/Infections-respiratoires/Legionellose [Retrieved on 2018-02-26].

Science Village Scandinavia (no year, a). *Science Village - a part of Brunnshög.* https://sciencevillage.com/en/science-village-2/science-village-a-part-of-brunnshog/ [Retrieved on 2018-02-15].

Science Village Scandinavia (no year, b). *Low temperature district heating network.* https://sciencevillage.com/en/projekt/low-temperature-district-heating-network/ [Retrieved on 2018-02-15].

Schmidt, D., Kallert, A., Blesl, M., Svendsen, S., Li, H., Nord, N., Sipilä, K., (2017) *Low Temperature District Heating for Future Energy Systems,* Energy Procedia 116, 26-38.

SFS 1998:808, *The Swedish Environmental Code,* Miljö- och energidepartementet.

SFS 2010:900, *The Buliding and Planning Act,* Näringsdepartementet.

SFS 2011:338, *The Building and Planning Ordinance,* Näringsdepartementet.

SP (2014), *Säkerställa vattenkvalitet vid 45˚C med avseende på Legionella – En förstudie för innovationsupphandling.* SP Rapport 2014:65.

Statens Serum Institut (2017). *Substantial increase in the number of legionella cases.* https://www.ssi.dk/English/News/News/2017/2017%20-%2011%20-%20EPI-NEWS%2045%20Legionella.aspx [Retrieved on 2018-03-14].

Statens Serum Institut (2018). *Individuelt anmeldelsespligtige sygdomme.* https://www.ssi.dk/Smitteberedskab/Om%20overvaagning/Lovpligtige%20meldesystemer/Individ_anmeldelses_sygdomme.aspx [Retrieved on 2018-02-20].

Steinert, M., Hentschel, U. & Hacker, J. (2002). *Legionella pneumophila: an aquatic microbe goes astray.* Federation of European Microbiological Societies 26, 151.

Van der Kooij, D., Veenendaal, H. R. & Scheffer, W.J.H. (2005). *Biofilm formation and multiplication of Legionella in a model warm water system with pipes of copper, stainless steel and cross-linked polyethylene.* Water Research 39, 2789-2798.

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.

Weatherbase (no year). *Europe*. http://www.weatherbase.com/weather/country.php3?r=EUR&regionname=Europe [Retrieved on 2018-04-19].

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

WHO, World Health Organization, (no year). *European Health Information Gateway*. *Pure alcohol consumption, age 15+ (litres per capita)*. https://gateway.euro.who.int/en/hfa-explorer/ [Retrieved on 2018-04-25].

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

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.

Yang, X., Li H. & Svendsen, S. (2016b), *Decentralized substations for low-temperature district heating with no Legionella risk, and low return temperatures,* Energy 110, 65-74.

Yang, X., Li H. & Svendsen, S. (2016c), *Modelling and multi-scenario analysis for electric heat tracing system combined with low temperature district heating for domestic hot water supply*, Building Simulation 9, 141-151.

Yang, X., Li H. & Svendsen, S. (2016d), *Evaluations of different domestic hot water reparing methods with ultra-low-temperature district heating,* Energy 109, 248-259.

Yee, R.B. & Wadowsky, R.M. (1982). *Multiplication of Legionella pneumophila in unsterilized tap water*. Applied and Environmental Microbiology, 43, 1330–1334.

Zvingilaite, E., Ommen, T.S.,; Elmegaard, B., Franck, M.L., (2012), *Low Temperature District Heating Consumer Unit with Micro Heat Pump for Domestic Hot Water Preparation,* Proceedings of the 13th International Symposium on District Heating and Cooling.

Figures

Monroe, D. (2007) *Looking for Chinks in the Armor of Bacterial Biofilms.* PLoS Biol 5(11): e307. https://doi.org/10.1371/journal.pbio.0050307 [Retrieved on 2018-04-09].

Stålbom, G. & Kling, R. (2002). *Legionella: Risker i VVS-installationer.* VVS-Installatörerna.

Appendix

A1. Capture-recapture

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}. This can be seen below in equation A1.

$$N_{est} = \frac{N_A \cdot N_B}{N_{AB}}$$ *Equation A1.*

A2. Question guide for focus group interview with contractors in Brunnshög regarding low temperature district heating

Hi and welcome to this group discussion.

We have invited you to this interview as contractors in the Brunnshög area for us to get an insight in your reflections and concerns regarding low temperature district heating systems.

Kraftringen is constructing a LTDH network in Brunnshög and we would like to hear your thoughts on this and how (or if) it affects you as contractors.

The method used in this interview is called focus group interview because it focuses on one question, namely *low temperature systems for heating.* The discussion will last until 13.00.

You are here as an expert, so please don’t hesitate to talk about what is important to You, from your experience. Don’t be afraid to elaborate on what is said by other participants.

In the room you can see a number of people who are here as audience - they are here to listen to you, to gain a deeper understanding of what you know and your reflections. They will be invited into the discussion at a later stage and will be able to either ask you questions or to answer any questions you might have.

11.05 Presentation of participants

All the participants write their names on a name tag and present themselves with their name and the company they represent.

What is your role as contractor/property owner - do you own and manage the properties that you build?

11.15 Knowledge and information

Now we will talk a little about what is happening in Brunnshög.

Why do you think Kraftringen is building a LTDH system in Brunnshög?

What information have you received about it?

How do you view the information you have received? (From whom did you receive the information, in what way, was it relevant?) If you were able to change something in the information that you were given, what would it be?

11.30 Choosing the heating system

In general, what are the most important factors when choosing which heating system to use in the properies you build?

What are your thoughts on connecting to the LTDH grid?

11.50 Heating systems and LTDH

Have you considered how you, as contractors and consultants, are affected by implementing heating systems that are adapted to low temperatures?

Do you see any negative aspects or obstacles with connecting to the LTDH grid?

Do you see any positive aspects or obstacles with connecting to the LTDH grid?

Kraftringen will keep the supply temperature in the LT grid at 65 ºC. There is however, a theoretical possibility to decrease the supply temperature to 50 ºC. This would entail that the heating systems would need to be dimensioned to cope with such a change and the conventional way of ensuring water quality, with regards to *Legionella*, would no longer be possible since the temperature would be too low. What would be required for you, as contractors, to be able to provide solutions that can provide heating and domestic hot water needs with a supply temperature of 50 ºC?

12.20 Previous experiences

Do you have any previous experiences building properties with low temperature systems?

Have you ever experienced any problems with *Legionella* in tap water systems? What solutions have you used in this case?

Have you used any additional solutions (other than the required temperature) to control *Legionella* in domestic hot water systems? Or do you know of such techniques even though you have never used them?

The district heating industry intends to lower the system temperatures. How do you, as contractors, address this matter?

If Kraftringen was to present a ready solution to combat *Legionella*, would this be helpful and interesting for you?

12.40 Questions from the secretaries and audience