Technology Collaboration Programme
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Technology Collaboration Program on Heat Pumping Technologies (TCP-HPT)

HPT-Annex 46
Domestic Hot Water Heat Pumps

IEA HPT

Annex 46

Legionella
and
Heat Pump Water Heaters

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Preface

This project was carried out within the International Energy Agency Technology Collaboration Program on Heat Pumping Technologies (HPT TCP).

The IEA

The IEA was established in 1974 within the framework of the Organization for Economic Cooperation and Development (OECD) to implement an International Energy Program. A basic aim of the IEA is to foster cooperation among the IEA participating countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology and research and development (R&D). This is achieved, in part, through a Program of energy technology and R&D collaboration, currently within the framework of over 40 Implementing Agreements.

Disclaimer

The HPT TCP is part of a network of autonomous collaborative partnerships focused on a wide range of energy technologies known as Technology Collaboration Programs or TCPs. The TCPs are organized under the auspices of the International Energy Agency (IEA), but the TCPs are functionally and legally autonomous. Views, findings and publications of the HPT TCP do not necessarily represent the views or policies of the IEA Secretariat or its individual member countries.

The Technology Collaboration Program on Heat Pumping Technologies (HPT TCP)

The Technology Collaboration Program on Heat Pumping Technologies (HPT TCP) forms the legal basis for a Program of research, development, demonstration and promotion of heat pumping technologies. Signatories of the TCP, called participating countries, are either governments or organizations designated by their respective governments to conduct. The Program is governed by an Executive Committee (ExCo), which monitors existing projects and identifies new areas where collaborative effort may be beneficial.

Annexes

The core of the TCP are the "Annexes". Annexes are collaborative tasks conducted on a cost-sharing and/or task-sharing basis by experts from the participating countries. Annexes have specific topics and work plans and operate for a specified period, usually a number of years. The objectives range from information exchange to the development and implementation of heat pumping technologies. An Annex is in general coordinated by an expert from one country, acting as the Operating Agent (manager). This report presents the results of one Annex.

Triennial Heat Pump Conference

The IEA Heat Pump Conference is one of the three major products of the Technology Collaboration Program on Heat Pumping Technologies. The Executive Committee supervises the overall organization and its quality and selects from a tender procedure the host country to organize the Conference and establishes an International Organization Committee (IOC) to support the host country and the ExCo.

The Heat Pump Centre

The Heat Pump Centre (HPC) offers information services to support all those who can play a part in the implementation of heat pumping technologies. Activities of the HPC include the publication of the quarterly Heat Pumping Technologies Magazine and an additional newsletter three times per year, the HPT TCP website, the organization of workshops, an inquiry service and a promotion Program.
The HPC also publishes results from the Annexes under the TCP-HPT.

For further information about the Technology Collaboration Program on Heat Pumping Technologies (HPT TCP) and for inquiries on heat pump issues in general contact the Heat Pump Centre at the following address:
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Disclaimer

The information and analysis contained within this summary document is developed to broadly inform on world-wide developments. Whilst the information analysed was supplied by representatives of National Governments, a number of assumptions, simplifications and transformations have been made in order to present information that is easily understood. Therefore, information should only be used as guidance.

The market is developing fast and at the moment of publication some information can already be overtaken by new developments. There are some websites listed at the reference pages of the report.

In compiling, editing and writing this report I would like to thank Kashif Nawaz (Oak Ridge National Laboratories – USA), Cordin Arpagaus (NTB-Interstaatliche Hochschule für Technik Buchs - CH), Roberto Sunyé (CanmetÉNERGIE/CanmetENERGY – Can), the Japanese National Team under Kyioshi Saito (Waseda University – Japan) and Neil Hewitt (Ulster University – UK).

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The views expressed in this report do not necessarily reflect those of the individual project participants.

Summary

The relative importance of the production of domestic hot water (DHW) rises in the total energy demand of buildings compared to space heating. One of the main reasons for the higher energy demand is that DHW is produced, stored and distributed at temperatures above 55 to 60°C to avoid the risk of infecting the DHW system with Legionella bacteria. The desired usage temperature at the tap water with the highest risk (i.e. shower head) is however only 30 to 40°C. This means that the temperature difference between hot water outlet and the cold water inlet almost doubles, which has a negative effect on the energy efficiency.

The risks of Legionella infection exists in locations of stored (stagnant) hot water at relatively low temperatures and in collective systems. The bigger and more complicated a water distribution network is, the greater the risk for the growth of Legionella bacteria. By taking advantage of the knowledge of how water- and heating installations ought to be designed, the growth of Legionella bacteria can be prevented. It is basically a question of keeping installations clean, the cold water cold and the hot water hot. The risks for single family houses are much smaller compared to bigger houses and buildings, so that it can be debated if there is any risk at all as the piping systems, towards the tap with the highest risk, rarely contain more than 3 litres of stagnant water and the water in the system is refreshed regularly.

This report gives an overview of the legislation in the participating Annex 46 countries and some other countries, which shows that there are a number of differences and that there is a lack in harmonisation in the approach of dealing with legionella in HPWHs. Harmonization is needed when the demands in legislation differ too much there will be no equal markets as the demands have consequences for the test procedures as well.

Calculations suggest that increasing hot water storage temperatures to 60°C recommended for Legionella control would increase CO_2 emissions. It is not suggested to take a slack attitude to the problem, but the broad-brush turn-up-the-thermostat approach, given the energy penalty involved, can be debated. Further study in this area is justified.

Heat pumping technologies for single-family buildings as well as in collective systems for multi-family buildings, sports centres, hospitals, etc. are well fitted and capable to deliver the required temperatures to fight Legionella.

Contents

1. Introduction

This report has been compiled and edited from a number of existing reports and gives an overview of a landscape of legionella in Sanitary Hot Water Systems. Special focus is on HPWHs.

In the first paragraph, an overview is given of what Legionella disease is and how serious the problem is with increasing numbers of registered cases worldwide. Then an overview is given of the various legislative measures to avoid a further growth of the disease through contamination from hot water systems.

There are adequate measures, which can be undertaken in the design and management of a DHW systems. Especially large collective systems with hot water distribution systems are vulnerable, which is often the case for hospitals, sports centres and care homes for the elderly people and less in the domestic area where circulation systems are used.

A number of technical measures for small collective systems is discussed, for a large part investigated in the developments toward low temperature District Heating (4th Generation).

The energy penalty for a number of measures on the performance of heat pumps is severe, but heat pumps are well able to deliver the required temperatures.

2. Legionnaires' disease

Legionnaires' disease, also known as legionellosis, is a form of serious pneumonic infection caused by inhaling (and in rare cases aspiration of) the bacterium *Legionella pneumophila* or other *Legionella* species. Legionellosis is the term used for all forms of infections caused by *Legionella* and includes not only Legionnaires' disease but also a milder flu-like infection, commonly known as Pontiac fever. After the first recognition of Legionnaires' disease occurring in people attending a hotel conference in the USA in 1976 ("Epidemiologic Notes and Reports: Respiratory Infection – Pennsylvania", 1997) (add lit to Reference list), surveillance for the disease began in several countries and is now recognized as an infection which can be acquired worldwide wherever conditions allow legionellae to proliferate.

Community-acquired outbreaks of Legionnaires' disease are most commonly associated with aerosols generated by evaporative cooling towers. Wet cooling towers and evaporative condensers are used for comfort cooling in commercial buildings, hotels, etc., and for cooling industrial processes.

Legionella are also frequently found in building water systems, particularly in hot and cold distribution systems in large and complex buildings such as hotels, hospitals, office blocks, multi-occupancy accommodation buildings, commercial buildings, shopping malls and passenger vessels.

Legionella are also associated with causing infections from other systems such as spa pools and hot tubs including those on display. However, any system or equipment, which contains, stores or recirculates non-sterile water[1] and has the potential to be aerosolized is a potential source of legionellosis. In rare cases, legionellosis may also be acquired by aspiration.

Legionnaires' disease principally affects older adults. Those with risk factors including increasing age, smoking, and immunosuppression and underlying diseases such as diabetes are at increased risk from the disease. The case fatality rate for community-acquired cases is currently around 10% and despite the availability of appropriate antibiotic treatment, a certain number of deaths are recorded each year in otherwise healthy persons with no known underlying risk factors.

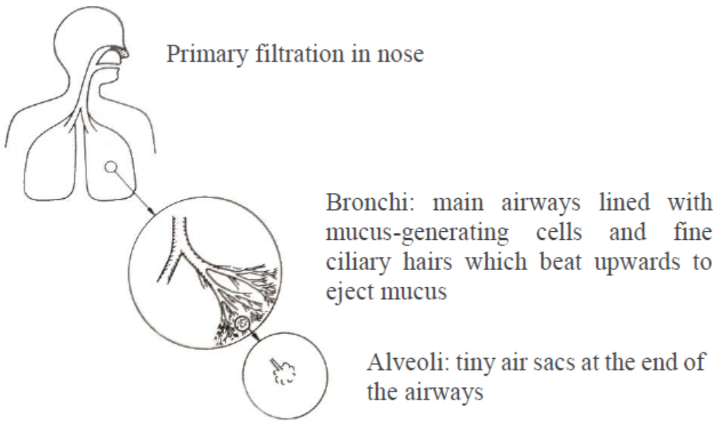


Fig 2.1 – Legionella disease is a lung disease and not caused by drinking water

[1] Disinfected water is not sterile; disinfection reduces the number of microorganisms but does not eliminate them

2.1 Number of reported cases

The number of people suffering from Legionnaires' Disease (Legionellosis) has risen across Europe in recent years: in 2016, according to the European Center for Disease Prevention and Control (ECDC), 7,069 cases were reported in Europe (in 2013) 5,830 reported cases).

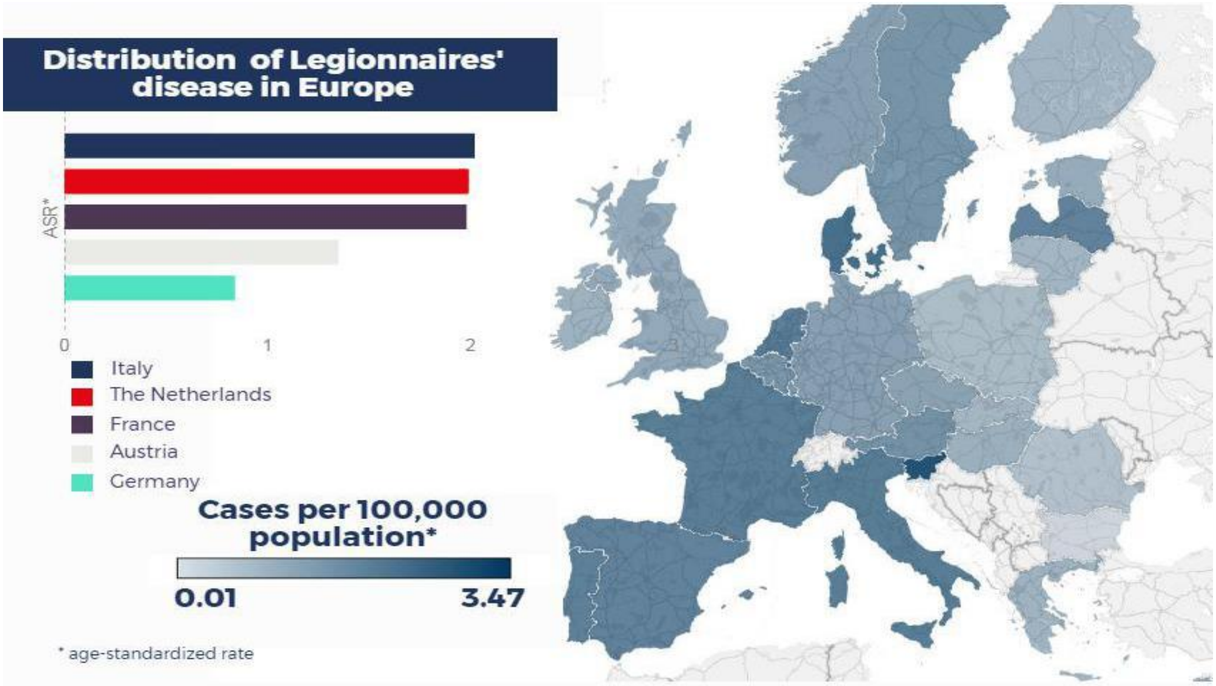


Fig 2.2 Legionella disease in Europe (ECDC).

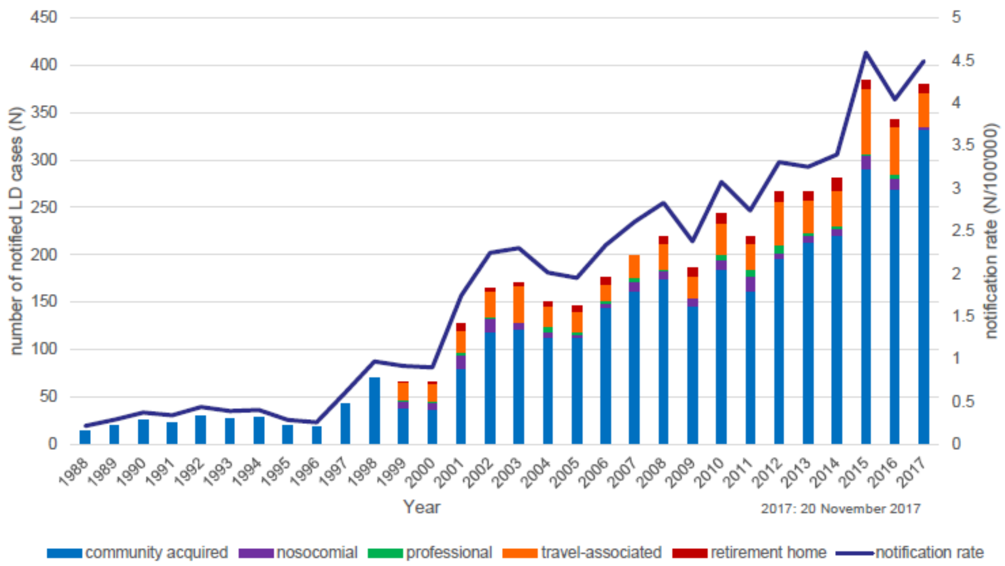


Fig 2.3 Number of notified Legionnaire's Disease cases in Switzerland (Division of Communicable Diseases, Nicole Gysin, 2017) (add literature ref to References list)

As shown in Fig 2.3, the number of Legionnaire's Disease cases in Switzerland has been steadily increasing. The total number of cases has more than doubled in the last ten years from about 200 registered cases in 2008 to 400 in 2017. The reporting rate for the observed period ranges from 2.8 cases per 100'000 inhabitants in 2008 to 5 in 2017.

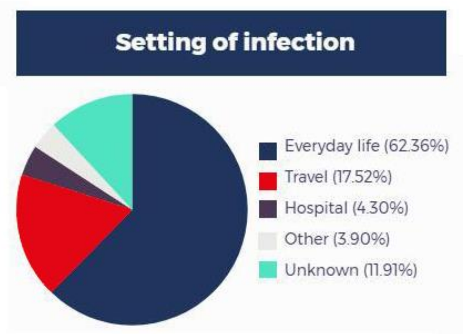


Fig 2.4 Source of infection in Europe (ECDC)

The same development is noticeable in other European countries as in Switzerland. Although the main source of Legionellosis in Europe is in everyday life at the home water distribution systems, several additional factors are likely to be responsible for the increase in case numbers:

- Increase of the detection rate of cases of Legionnaire's disease in patients with pneumonia by the increased use of rapid tests (qualitative detection of Legionella pneumophila antigen in urine samples of patients)
- Increase in the reporting rate of cases of Legionnaires' disease due to the electronic laboratory reporting obligation since the beginning of 2014
- An actual increase in legionellosis cases as a result of global climate change is being discussed: a link between a particularly warm, wet summer and an increased number of cases was found in 2014 in the Netherlands and England. In the spring and summer of 2017, a number of reported cases of legionnaires' disease were observed in many European countries, including Austria, up to 40% above the expected number of cases

In The Netherlands there have been between 300 and 400 reports of patients with legionella inflammation over the years 2017 to 2016. In the summer, legionella inflammation occurs more often than in winter. In some years, the number of reports is somewhat higher than usual, which depends on certain weather conditions. Especially in heavy rainfall after a relatively warm period, there is an increase in the number of patients. The actual number of patients is probably somewhat higher than the number of reports. Due to limitations in diagnostics, not all patients may be diagnosed.

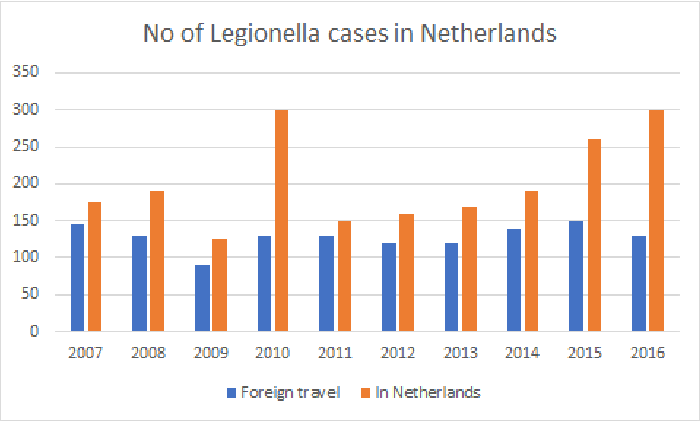
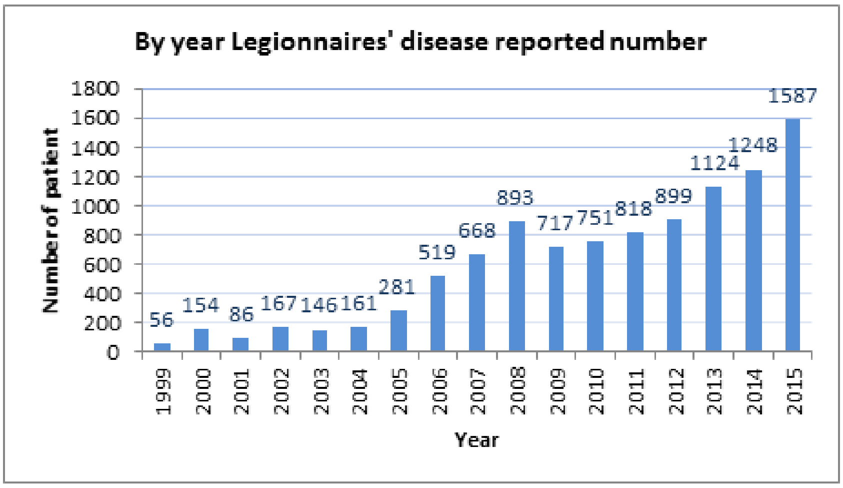


Fig 2.5 Legionella cases in The Netherlands

Case numbers have also risen in Austria: in 2013, there were 100 cases documented, while in 2017 there were already 218 cases of Legionnaires 'disease (with a population of 8.772 million, compared to 490 in Switzerland in 2017 in terms of population size) registered by 8.372 million). While the number of Legionella outbreaks has remained constant over the years, the number of single diseases has risen sharply. More information in Legionella in Europe can be found on Eurosurveillance[2] 2017 Jul 6; 22(27): 30566.

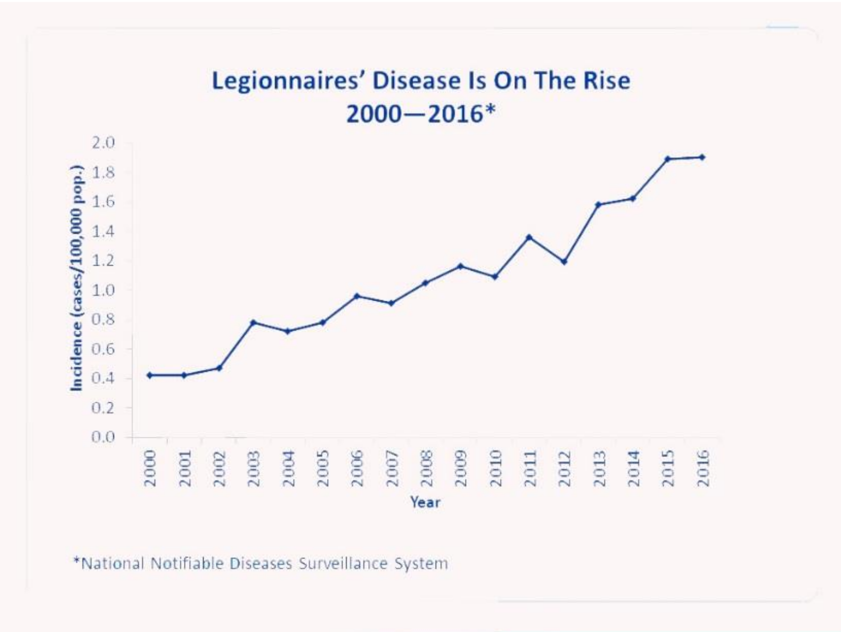
A search for Canadian national statistics for Legionnaires disease or *Legionella* did not show any records but according to Health Canada, the average number of reported cases of Legionnaires' disease is generally less than 100 per year. However the actual number of cases is thought to be much higher, as many people with pneumonia may not be tested for infection with *Legionella* (Public Health Agency of Canada, May 2015).

[2] Eurosurveillance is a European peer-reviewed scientific journal devoted to the epidemiology, surveillance, prevention and control of communicable diseases, with a focus on such topics that are of relevance to Europe.



In Japan, according to Infection Disease Surveillance started in April 1999 pursuant to the Infection Disease Law, the number of outbreaks of Legionnaires' disease in Japan exceeded 1,000 cases in 2013 and is still on the increase.

Fig 2.6: Number of Reported Cases in Japan for each Fiscal Year[3]



In the United States, the number of cases reported to CDC has been on the rise since 2000. Health departments reported about 6,100 cases of Legionnaires' disease in the United States in 2016. However, because Legionnaires' disease is likely underdiagnosed, this number may underestimate the true incidence. More illness is usually found in the summer and early fall, but it can happen any time of year.

Fig 2.7 Reported cases in USA (Centers for Disease Control and Prevention (CDC)).

Overall, worldwide the number of reported cases is increasing. However, it is unclear whether this increase represents artefact (due to increased awareness and testing), increased susceptibility of the population, increased Legionella in the environment, or some combination of factors.

[3] Prepared based on Data from Infectious Disease Weekly Report (IDWR) published by National Institute of Infectious Diseases (NIID)

2.2 Facts about Legionella

Where and when is there risk of Legionella in hot water systems in buildings?

In the past, Legionella prevention in sanitary hot water systems has been built on a number of assumptions, which - under the light of evidence from field studies – cannot be confirmed. Furthermore, new evidence has come into light that needs to be included into Legionella safety considerations.

For a number of reasons people travelling to holiday destinations are particularly at risk of Legionnaires disease, and such cases account for up to half of the cases reported from some European countries. Through extensive media coverage, the public has become increasingly aware of Legionnaires' disease and the specific risks associated with travel, cruise ships and hotel stays. However, the acquisition of legionellosis is not limited to travel-associated buildings, but may be acquired from arguably any water system in buildings, which is not maintained and controlled to minimize the risk of infection. After Legionella grows and multiplies in a building water system, water-containing Legionella then has to spread in droplets small enough for people to breathe in. It can become a health concern when it grows and spreads in human-made building water systems like:

- Showerheads and sink faucets
- Hot water storage tanks and heaters
- Large plumbing systems in collective sanitary hot water systems
- Hot tubs that aren't drained after each use
- Cooling towers
- Decorative fountains and water features

It is often assumed that any water system that has the right environmental conditions potentially can be a source for legionella bacteria growth. There is a reasonably foreseeable legionella risk in a water system if:

- hot and cold water storage tanks have water temperatures between 20°C and 45°C;
- in any part of the hot water system where water temperatures are between 20°C and 45°C, which can occur in distribution pipes and heat exchangers with little or no water flow;
- there are deposits that can support bacterial growth, such as rust, sludge, scale and organic matter in pipes, showers and taps.

Larger collective hot water systems, varying from district heating, multi-family buildings, hospitals, health care centres, homes for the elderly and sport centres run a relatively high risk of legionella contamination when no proper precautionary measures have been taken.

Systems with low risk situation are found:

- in a small domestic buildings without individuals especially 'at risk' from legionella bacteria;
- where daily water usage is inevitable and sufficient to turn over the entire system;
- where cold water is directly from a wholesome mains supply (no stored water tanks[4] (example), or borehole groundwater);
- where hot water is fed from instantaneous heaters or low volume water heaters (supplying outlets at 50°C);
- where the only outlets are toilets and wash hand basins (no showers).

[4] Little attention is given to open heater tanks in lofts (a UK habit also seen in Japan and other countries) these open-top tanks (hopefully with cover) sit in warm lofts in summer. One might expect that if a cylinder is fed from one of these, it might require a different sterilisation regime to a mains fed cylinder, and surely, there should be at least as much concern from the loft tank that there should be from the hot cylinder kept at only 50°C for example.

Thermal disinfection is the most common method in terms of controlling Legionella in hot and cold water systems.

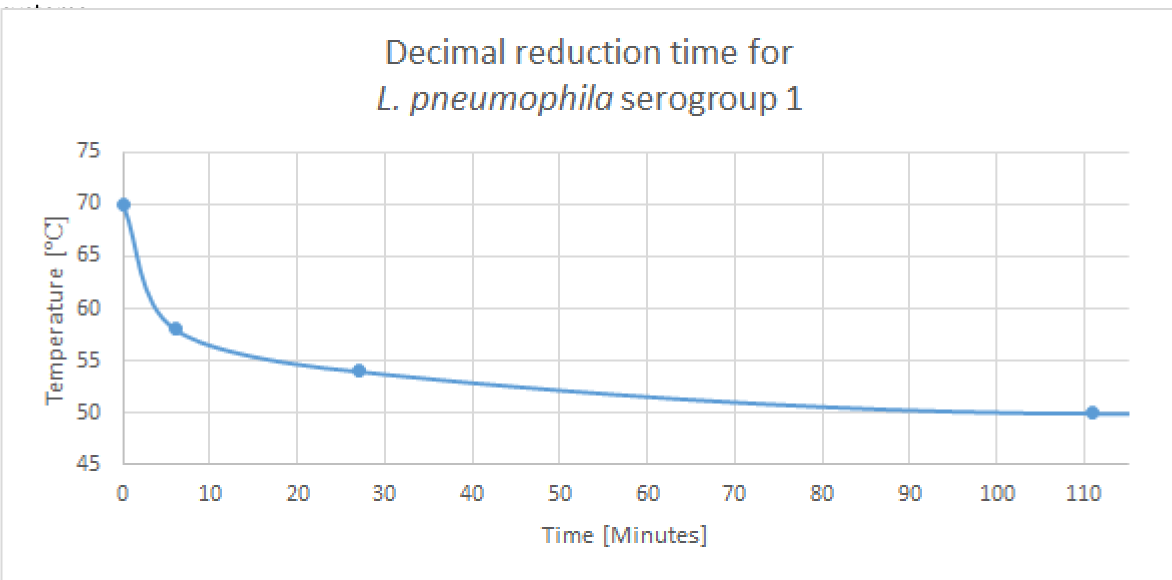
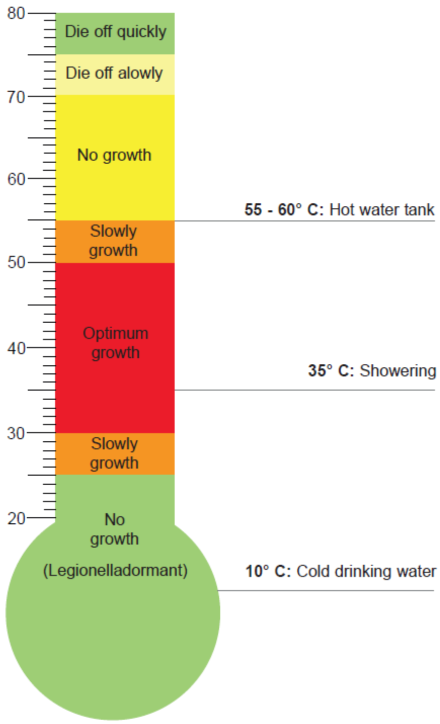


Fig. 4.1. General representation of the decimal reduction time for a strain of Legionella pneumophila [02]

Fig. 4.1 shows the decimal reduction time for a strain of Legionella pneumophilia. The decimal reduction time is the time required, at a given condition (e.g. temperature) or set of conditions, to achieve a log reduction, that is, to kill 90% (or 1 log) of relevant microorganisms. The curve shows that the time necessary to kill Legionella is reduced by increasing temperature. Elevation of water temperature to 70 to 80°C kills off Legionella within seconds.



Legionella can thus be safely and easily controlled with good design, engineering and management protocols. The most effective treatment against Legionella is to keep cold water cold under 20 to 25°C and hot water, above 55°C, as there is no growth. A benefit of thermal treatment is that it there are no additives required into the water. This makes it the preferred method in countries that have strict limits on water quality. An alternative for water disinfection are UV radiation or the addition of chlorine.

For instance raising the temperature of water heaters once a day or even once every few days to 55°C (131 °F) at the coldest part of the water heater for 30 minutes effectively controls legionella check ref. In all cases and in particular energy efficient applications, Legionnaires' disease is often the result of engineering design issues not taking into consideration the impact of stratification or low flow.

Fig. 4.2.

The threshold for the water temperature when reaching the tap point is for the legislation in the majority of countries 50°C. That is because it is above the limit for Legionella growth as at > 46°C Legionella bacteria are inactivated. Some countries, such as Norway, have decided on a higher system temperature to further ensure the absence of Legionella.

The traditional solution to inhibit Legionella growth is to keep the DHW above a certain temperature. There is a number of other technologies that can be applied, divided into three subcategories: mechanical technologies, sterilization and alternative system design. Although some of the technologies is already commercially, available many cannot directly be implemented.

In accordance with the German Standard W551 [S 16} is that, if controlled properly, a system with a total volume (from hot water production to end use) of less than 3 litres can eliminate the risk of Legionella. The advantages of alternative design are numerous.

2.3 Myths about Legionella

A number of publications that are cited are referring to measurements that were performed on single and double family homes. Although these have a considerably smaller risk for Legionella infection than larger systems, much can be learnt from these smaller systems since the influencing variables are fewer and the situation is most of times clearer. In addition, the role that hot water distribution plays in Legionella infections can be studied better since there are also small systems that do not maintain the drinking water distribution lines hot at all times (no DHW recirculation or heat-ribbons), a configuration that is virtually inexistent in large systems for obvious reasons [32].

Heating up once a day or once a week

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

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

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

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

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

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

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

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

Supply temperature and delta-T of return for DHW recirculation

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

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

Limits for volumes of stored hot water

A limit of hot water storage volume above which the risk for Legionella increases does not exist. Large volumes are problematic if they are at a temperature at which Legionella can grow, but if their temperature is > 50 °C, they effectively protect from contamination out of the hot water re-circulation or from pre-heating volumes by decimating the load of active1 Legionella.

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

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

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

Legionella also grows above 50°C.

Growth has been clearly demonstrated at 25 – 45°C, with a rate of doubling within six hours under ideal conditions between 35 - 40 °C. From 45 - 50 °C the concentration of cultivable legionella decreases. This decrease is strongly dependent on the temperature, i.e. 90% harmless in 100 minutes at 50°C and in 2 minutes at 60°C.

Viable but not culturable corms of Legionella pneumophila occur in higher temperatures. However, in the past two decades, the relevance of such viable but non-culturable (VBNC) legionellae has been controversially discussed, and whether VBNC legionellae can directly infect human macrophages, the primary targets of

Legionella infections, remains unclear. Seemingly these are no direct health threat.

The risks in single family houses are the same as in MFB

In general legionella has never been found in single family buildings without a hot water circulation system if the storage temperature has been set >50^{o}C.

The multiplication potential for Legionella in drinking water piping systems of one and two-family houses is low compared to large buildings such as Hospitals or hotels. This can be explained by the shorter pipes or smaller pipe diameters and the resulting small populated surfaces. [...] Systems with circulation and continuous operation of the pump or with a timer and operation for longer periods were free of Legionella. Two systems [Haller note: which have Legionella] operated the pump only once a day for half an hour, others were natural circulation systems.

In Fresh Water Systems, there is no danger to Legionella

This is not true because the flow time of the water flowing through the storage vessel with a return temperature of about 55C is too short to thermally kill of legionella which origins from the piping system.

2.4 Collective system configurations

The provision of collective domestic hot water in multi-family buildings is a complex issue. In collective systems hot water is pumped through a distribution system, which for domestic hot water is either:

- A system where the distributed water is directly used for showers and other applications. This type of system is mainly applied in hotels, hospitals, health care centres, homes for the elderly, office blocks, commercial buildings, shopping malls and passenger ships. These systems always have a piping separated from the piping for space heating and the risks of legionella without adequate measures are relatively high.
- A circulation systems in which the hot water is circulated as energy bearer and not used as domestic hot water for shower, bath or consumption by the individual end user. The heat exchanger between the collective system and the individual end user is substation generating instantaneous hot water in a small self-sufficient hot water system.
- A circulation system for space heating/cooling only where the domestic hot water is generated by an individual water heater fed by the collective system for space heating.

Any attempt at energetic optimization of water heating requires an overall view of the areas of deployment - distribution - use. In addition, there are - under given boundary conditions - also within each system, possibilities for improvement. However, it should be noted that there is no blanket statement about the "best system", as this depends on the local conditions (i.e. connection to the district heating network, possibility of using geothermal or groundwater) but also on the actual operation or user behaviour. Overall, it is necessary to consider the efficiency of the hot water preparation together with that of the building heating, as this is solved in many cases together or at least affect the systems.

In the market there are two types of collective systems, being:

- An individual collective system in one block of apartments. This can be a small block of apartments up to high-rise buildings. This type of distribution system can be of all three above mentioned types.
- A district heating system serving a large number of houses, offices, etc.. In DH-systems the end user is always separated from the circulation system by heat exchanger.

In any collective distribution system for sanitary/domestic hot water there is an increased risk of Legionella, which is in multifamily buildings and other buildings like hotels, hospitals, health care centres and homes for the elderly almost always treated by thermal disinfection, delivering high temperatures. This is demanded by legislative procedures in all the participating countries in the Annex. Heat pumping technologies for single-family buildings as well as in collective systems for multi-family buildings, sports centres, hospitals, etc. are well fitted and capable to deliver these required high temperatures according to general legislation dominant in the participating countries, to fight Legionella.

The main question however is if these high temperatures are needed. Based upon literature studies it is concluded that the domestic hot water temperatures can be below 60°C without increased risk of Legionella if the overall volume of domestic hot water in the system behind the heat exchanger is below three litres or is boosted. This finding sets the rule for designing the domestic hot water systems supplied by low-temperature collective distribution systems in multifamily buildings, as well as for district heating systems [29]. However this is not the case if the distributed water is directly used by end user.

It is important for the development of low temperature collective systems in multifamily buildings and the 4th generation district heating systems for as the system heat losses can be reduced to one quarter of the value for traditional systems designed and operated at temperatures of 80°C/40°C.. This low temperatures transform to a new concept reflecting the requirement for lower heat loss from networks required by the reduced heating demand of low-energy and refurbished buildings combined with the lower supply temperatures. These needs meet in the recently developed concept of low-temperature distribution systems designed with supply/return temperatures as low as 50°C/25°C. However, such low temperatures bring challenges for domestic hot water as the individual end user is requiring a certain level of comfort where DHW should be delivered in reasonable time, without unwanted changes in desired temperatures (comfort) and without increased risk of bacterial growth (hygiene). While the comfort requirements set the minimum DHW temperature to 45°C, the legislative hygiene requirements set it to 60°C, which is simply not reachable for low-temperature distribution system.

The main challenge for DHW in a collective system is that DHW has to be delivered in reasonable time, without unwanted changes in desired temperatures. As the demand is of a high capacity (25 – 35 kW's) for a short time during the day it still has to be available 24/7.

There is a distinction between instantaneous (i.e. tankless) systems and storage systems. Instantaneous systems require high capacity heat exchangers, either by getting a high temperature as input from the distribution system in a relatively small heat exchanger, or by low temperature input and a large heat exchanger. To reduce such short capacity peaks and obtain a more homogeneous demand, storage systems can be introduced in the system to store hot water and flatten the power demand. Both instantaneous and storage systems are common nowadays. These storage tanks can be on the side distribution system before the individual substation or on the side of the individual end user after the substation.

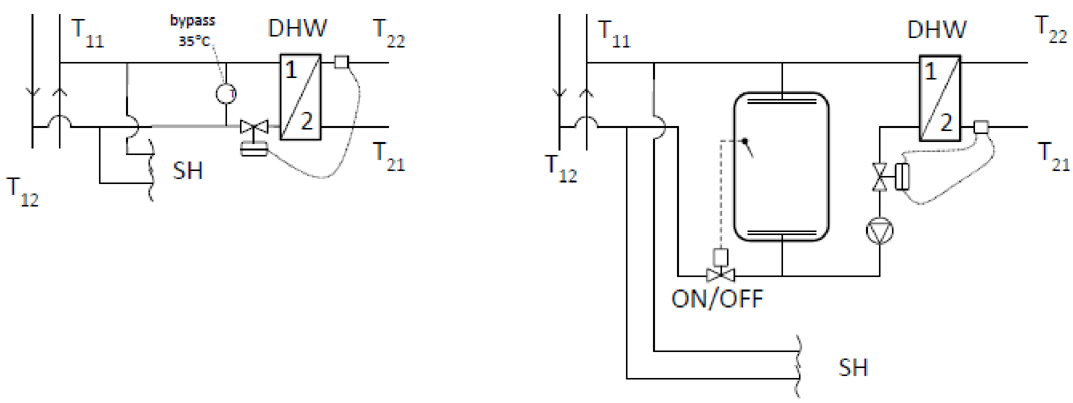


Fig. 2.12 Low-temperature substations; left: instantaneous DHW principle, right: storage tank for collective system water [29]

The DHW HEX in traditional substations are designed for minimum supply/return temperatures of 60/30°C (summer conditions of medium temperature), whereas a low-temperature substation should work at the temperature levels of 50/25°C and produce DHW of at least 45°C.

Thus the key component of a low-temperature collective system substation is a highly efficient HEX as an example the Micro Plate™ design of plates, specially developed for low supply temperatures by Danfoss.

Fig. 2.13 – The new Micro Plate™ design compared with the traditionally used fish bone design (courtesy of Danfoss A/S) [29]

Compared to traditional HEX for high and medium temperatures, the HEX for low-temperature should be more efficient because the temperature difference between the system water supplied and the DHW produced is for design conditions only about 3°C (50°C/47°C) while in traditional HEX it is as much as 10°C (60°C/50°C). Such a low temperature difference in the case of low-temperature HEX is possible thanks to the special “dimpled” pattern of the HEX’s plates, which in comparison with traditional fishbone corrugated plates increases the heat transfer area and the overall heat transfer coefficient while maintaining high cooling of primary water (i.e. low return temperature).

The performance of a low-temperature substation with instantaneous DHW preparation was evaluated based on the results from laboratory measurements supplemented with results from the verified numerical model developed in MATLAB-Simulink [29]. The laboratory measurements showed that the low-temperature substation can heat the required flow of DHW to 47°C with 50°C DH water while keeping the return temperature as low as 20°C. The results of numerical simulations considering the influence of the distribution network, represented by a 10 m long service pipe connection for the substation equipped with an external bypass with a set-point temperature of 35°C, showed that the time needed to produce 40°C DHW was 11s with and 15s without the external bypass, respectively. DS 439 suggests 10 s as the reasonable waiting time for DHW, so a low-temperature DH substation based on the instantaneous principle of DHW preparation should be equipped with bypass solution keeping the service pipe warm and reducing the waiting time.

2.5 Bypass solutions

Based upon the goal to introduce the 4th generation of district heating in Denmark DTU has studied the alternatives for domestic hot water, whereas it is of importance to reduce the heat losses as much as possible without losing comfort for the end user, by guaranteeing a short waiting time and the right temperatures. In this creating the optimal bypass solutions are of importance. Dietrich Schmidt et.al. (Fraunhofer) has studied and published on that topic (Low Temperature District Heating for Future Energy Systems [14]), see addendum 3.

The waiting time for DHW delivery consists of time needed for the DHW substation to produce DHW water (known as recovery time) and the transportation time needed to transport the DHW produced by DHW pipes to the tap. The recovery time depends not only on the physical properties of the DHW HEX (heat transfer properties, volume of water, the HEX’s mass), but also on the DHW controller steering the flow of DH water, on the temperature of the circulated system water (CS water) entering the substation, and on the history of DHW tapping. The bigger the HEX, the longer the waiting time, because CS water needs to heat up more thermal capacity (water and the HEX’s mass) before DHW with the desired temperature is produced. Similarly, the longer the time since the previous DHW tapping, the more time is needed because the HEX has cooled down. To speed up the heat flow from the DH at the beginning of tapping, the state-of-the-art proportional-thermostatic DHW controller opens the DH flow to the maximum, until the desired DHW temperature is reached, and then throttles down just to maintain the desired DHW temperature.

However, this description is fully valid only for a house substation with a buffer tank for CS water, where the temperature of CS water supplied to the DHW HEX is expected from the very first moment to be 50°C, because the CS water is stored in the buffer tank. The situation is different for the substation with instantaneous DHW preparation (IHEU), because the HEX is supplied by CS water taken directly from the system network. During the non-heating season, the CS water standing in the supply service pipe can cool down as a result of there being no heat demand in the building. This will extend the recovery time of the substation. To prevent the cooling down of the supply service pipe, the traditional solution is to maintain a small flow of CS water and “bypass” (see Figure 2.11) it back to the system network just on the border of the substation (external bypass) or to let the CS water flow through the DHW HEX (internal bypass) by installing the bypass valve in the house substation. Having a bypass valve installed in each house substation is a better solution than having a bypass valve installed only at the end of each street pipe, because it keeps the supply service pipe warm for each customer.

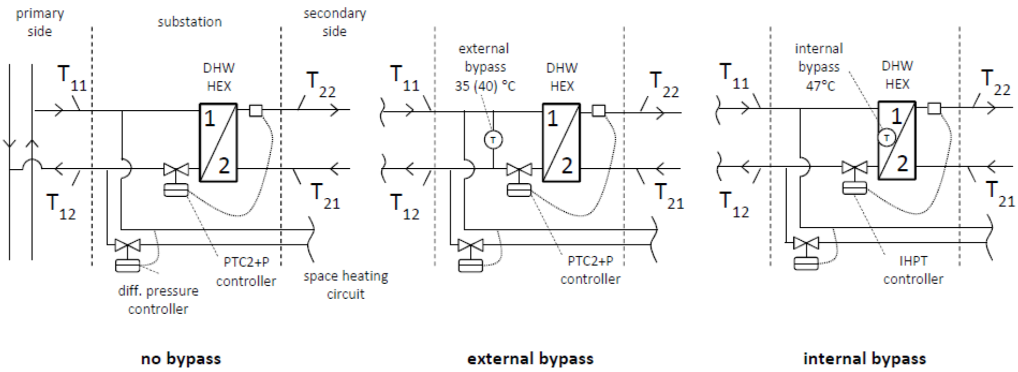


Fig. 2.14 Various bypass strategies for IHEU; left: no bypass; middle: external bypass (cold HEX) with set-point temperature 35°C; right: internal bypass (warm HEX) with set-point temperature 47°C (defined by DHW set-point 45°C) [29]

Both types of bypass reduce the waiting time for DHW, but bypassing CS water back to the system network without proper cooling increases the heat loss from the distribution network. The typical set-point temperature used for the external bypass in a low- temperature distribution network is 35°C except for the buildings at the end of the streets, where the set-point temperature is increased to 40°C required by missing subsequent customers. The internal by-pass offers shorter waiting time for DHW after idling of substation, but this is paid for by higher heat consumption for its operation and greater heat loss from the HEX which is kept always warm. Furthermore, in some countries keeping the DHW HEX warm is seen as a solution that increases the risk of Legionella growth, so it is not very much used. Another disadvantage in using an internal bypass is reduction in efficiency of the HEX developing in time in medium distribution network by sedimentation on the DHW side from maintaining the HEX at higher temperature.

However, the temperature of circulated water supplied to the house substation in the very first moments after a period without heat demand or during bypass operation is also influenced by the thermal capacity and transportation time in the service pipe. Looking at a substation based on the instantaneous DHW principle without an external bypass just after DHW tapping performed during a non-heating period. There is no flow and the supply service pipe (SP) is full of 50°C CS water, which means that the CS water in the service pipe will cool homogenously over the whole length in accordance with the cooling curves presented in Figure 2.12. It can be seen that, for example an AluFlex 20/20/110 pipe surrounded by soil with a temperature of 8°C, the CS water standing in the service pipe will homogenously cool down to 20°C in 180 minutes.

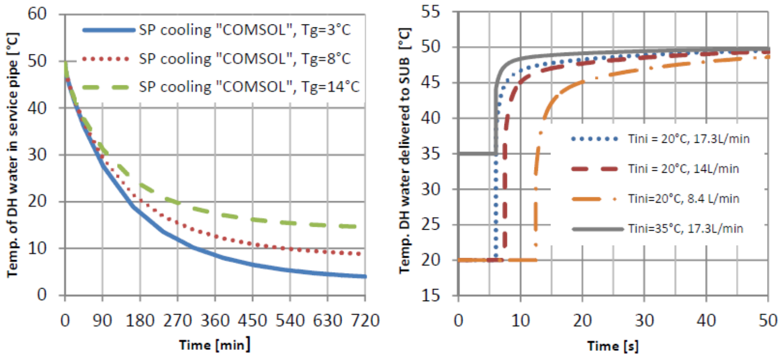


Fig. 2.15 left: Cooling down of DH water standing in an AluFlex 20/20/110 service pipe during idling. The initial temperature of water in pipe is 50°C, and the initial temperature of the insulation is 15°C ; right: Effect of the thermal capacity of an AluFlex 20/20/110 service pipe during reheating of the pipe

After 180 minutes, the customer opens the DHW tap again and "fresh" CS water at 50°C starts to flow to the 10 m long service pipe from the distribution pipe in the street while the cooled CS water standing in the supply service pipe will enter the substation. It means that the delivery of fresh CS water in the substation will be postponed by a transportation delay. Furthermore, thanks to the thermal capacity of the service pipe wall, being at the initial moment at 20°C, the CS water supplied will be cooled down for some period at the beginning of tapping. Therefore, depending on the flow rate of the CS water (defined by DHW controller) and the initial temperature of the service pipe, it will take some time before the CS water with a temperature of 50°C reaches the inlet to the substation, as can be seen in Figure 2.12-(right), showing results based on code of Dalla Rosa reported in [30]. During this period the substation will be supplied with CS water cooled by standing in the supply service pipe, increasing the recovery time of the substation. For the AluFlex 20/20/110 service pipe 10 m long and IHEU controlled with combined proportional-temperature DHW controller the initial distribution flow rate is 17.3 L/min and it will take almost 7.5 s to deliver hot water at 45°C and roughly another 20s to deliver 50°C warm water to the substation. The influence of service pipe thermal capacity on the bypass operation is similar.

3. Legislation in various countries

Legionella can be safely and easily controlled with good design, engineering and management protocols. This knowledge has led to regulatory measures, information campaigns, plumber schooling programs, certification and management programs and inspections in a large number of countries. Underneath the IEA Annex 46 participating countries the policies are discussed, as well as a small number of other countries.

3.1 ASIA

The main Asian countries which have taken a number of measures against Legionella prevention are Japan, South Korea, Australia and New Zealand. In Australia, a Series of National Guidelines have been developed in consultation with the Communicable Diseases Network Australia and endorsed by the Australian Health Protection Committee. Their purpose is to provide nationally consistent advice and guidance to public health units in responding to a notifiable disease event. These guidelines capture the knowledge of experienced professionals, built on past research efforts, and provide advice on best practice based upon the best available evidence at the time of completion. One of these guidelines published is the Code of practice on the 'Prevention and control of Legionnaires disease' [S09]. New Zealand has a similar approach and published: The Prevention of Legionellosis in New Zealand; Guidelines for the Control of Legionella Bacteria [11].

The measures in Singapore are described by Lam, Meng Chon et al. [12].

3.1.1 Japan

In Japan, Legionnaires' disease is defined as a bacterial infectious disease caused by Legionella bacteria (such as Legionella pneumophila) and has been designated as a class 4 infectious disease by the "Act on Prevention of Infectious Diseases and Medical Care for Patients of Infectious Diseases" enforced on April 1, 1999 (Infectious Disease Law, Act No. 114 of October 2, 1998). There are two types of this disease: fulminant pneumonia and transient Pontiac fever, and complete reports on both of them are mandated by the Infectious Disease Law, which means the doctor who diagnosed the disease must report to the nearest public health department.

Hot water supply equipment is divided into three large categories:

- Instantaneous type such as instantaneous water heaters installed in kitchens of standard households,
- Hot-water reservoir type such as electric water heaters, and
- Circulation type that boils water at a centralized location in buildings such as office buildings to supply hot-water to each floor.

Typical heat pump water heaters for residential use in standard households in Japan fall under the classification of the hot-water reservoir type. In the case of the hot-water reservoir type, there were cases where Legionella had been detected due to dissipation of chlorine residual, long residence time, temperature decrease, and the like. Thus, measures against Legionella-related problems have been an issue that needs to be addressed during determination of product specification by Japanese manufacturers of heat pump water heaters.

In Japan, the Ministry of Health, Labour and Welfare announced "Technical Guidelines Concerning Necessary Measures to Prevent Legionnaires' Disease" (July 25, 2003 Ministerial Notification No. 264 of the Ministry of Health, Labour and Welfare) to show the hygienic measures to be taken in the facilities that become an infection source of Legionnaires' disease, and is making efforts to prevent this disease.

These guidelines mention:

Basic Concept for Hygienic Measures for Hot-Water Supply Facilities

With regard to Legionnaires' disease originated from hot-water facilities, cases of hospital-acquired infection of which the origin was supposed to be hot-water supply equipment were reported in Japan, and there were some cases of group infection in foreign countries. Therefore, such facilities need to be paid due attention.

In the case of hot-water supply equipment, the control of the hot-water temperature is most important for prevention of bacterial contamination.

Stagnation of hot-water in a hot-water reservoir or hot-water supply piping helps microorganisms including Legionella bacteria to breed. Therefore, it is important to take measures to prevent stagnation of hot water within the equipment especially for the circulation-type centralized hot-water supply facility.

- *Facility-Related Measures*; for installation of hot-water reservoir-type hot-water supply equipment and circulation-type centralized hot-water supply equipment, it is necessary to install a heating device to keep the water temperature at 60 °C or higher inside the hot-water reservoir or 55°C or higher at the faucet at the end of hot-water piping. It is also necessary to provide a drain valve in the hot-water reservoir and others to drain stagnated water, and for circulation-type centralized hot-water supply equipment, it is additionally necessary to provide a flow valve to make the hot-water circulation constant throughout the equipment.
- *Measures to be taken during Maintenance*; the hot-water reservoir must be cleaned at least once a year, in addition to regular drainage of water stagnating in the hot-water reservoir. Proper adjustment of the circulation pump and flow valve is also necessary to secure a constant and even circulation of hot water throughout the equipment in the case of the circulation-type centralized hot-water supply equipment.

Temperature Conditions Required for Hot-Water Reservoir and Hot-Water Supply Equipment

The Ministry of Health, Labour and Welfare specifies the hot-water supply temperature for hot-water supply equipment of the hot-water reservoir type and the circulation-type centralized hot-water supply equipment in the "Maintenance Manual for Buildings" (January 25, 2008, Notification No. 125001, Environmental Health Division, Health Service Bureau) as follows. These specifications have been considered as one of the standards for the design of the hot-water reservoir and hot-water supply equipment.

(1) Concept for Temperature Control

As preventive measures against Legionella contamination, it is important to discharge initial flowing water and to keep the water temperature at 55 °C or higher at hot-water supply taps and others of all sections of hot-water supply equipment after the water temperature has become constant. Therefore, it is necessary to arrange the preset temperature in the hot-water reservoir and others to be adequately high for such temperature at all taps and others. In the case of installation of hot-water reservoir-type hot-water supply equipment and circulation-type centralized hot-water supply equipment, the water temperature in the hot-water reservoir and at taps at the end of piping shall be maintained at 60 °C or higher and 55 °C or higher, respectively.

(2) Point to Consider

Attention shall be paid to heat burn in relation to the hot-water supply temperature. A higher temperature hot-water supply is more effective for prevention of Legionella contamination but, at the same time, has a higher risk of heat burn. Therefore, preventive measures for heat burn become necessary.

It is advisable not to set the hot-water supply temperature higher than necessary from an energy and resource saving point of view. On the other hand, however, it is still important to keep the hot-water supply temperature not dropping beyond 55 °C.

Regarding preventive measures against other bacteria, the measures for Legionella bacteria can also be valid for other bacteria.

The safety standards for these kinds of Legionella contamination have been determined with reference to the ASHRAE evaluation test.

3.1.2 South Korea

In South Korea, statistics showed that the patients with legionellosis have been steadily increasing since its first outbreak in 1984 (Kim et al, 1985 [24]). Legionellosis occurs throughout the year regardless of season. Thus, surveillance of water supply systems having the potential of being contaminated, as well as cooling water towers, at various public facilities should be performed all year round. Recently, Legionella has been isolated from environmental sources in South Korea and the distribution of Legionella was different depending on geographical region, with 10.9% in Seoul, 2.5% in Gyeonggi, 20.0% in Chungcheong, and 2.0% in Jeju (Lee et al, 2010). Accordingly, studies on the regional distribution of Legionella isolated from the environment are warranted

The Ministry of Health and Welfare is the government agency responsible for responding to health crises in South Korea. The Korea Centers for Disease Control and Prevention (KCDC) was established by the relevant Minister who delegated certain powers to the KCDC to address infectious disease emergencies.

The aims of the Infectious Diseases Control and Prevention Act include preventing the occurrence and prevalence of infectious diseases and prescribing the necessary measures for their prevention and control. The Quarantine Act provides measures for preventing infectious diseases from spreading inside South Korea and outside its borders.

South Korea has an infectious disease surveillance system. When a person is infected with a specified infectious disease, the person may be treated and hospitalized in designated hospitals.

3.2 North America

Canada and the United States are participating in the Annex, whereas not much information is available from Mexico.

3.2.2 United States

The June 2015 release of the final version of ANSI/ASHRAE 188-2015 was a giant step for Legionella prevention in the United States in part because it represented agreement among government agencies and industry groups—not only about the need for Legionella prevention in building water systems—but also about the approach to it.

To comply with ASHRAE 188, building operators must implement a water management program (WMP) for water systems that can harbour and transmit Legionella bacteria. The essential components ASHRAE 188 requires for a WMP are almost identical to those the World Health Organization recommended in 2007 (WHO 2007) and the United States Veterans Health Administration (VHA) has required since 2014 (VHA 2014).

ASHRAE 188 has received more attention and support than any government or industry Legionella document released in the United States to date:

Just a few weeks after its June 2015 release, because of the tragic Legionnaires' outbreak that sickened more than 120 people and caused 12 deaths, New York City and State adopted emergency ASHRAE 188-related regulations for minimizing Legionella risk associated with cooling towers. In 2016, the regulations were updated and made permanent.

- In June 2016, the CDC issued three publications emphasizing the need to comply with ASHRAE 188:
  The CDC report in Morbidity and Mortality Weekly Report (MMWR) about a rise in Legionnaires' disease cases and the need for better building water management caught the attention of the mainstream media, which immediately published stories highlighting the responsibility of building owners and managers.
  The CDC provided "Developing a Water Management Program to Reduce Legionella Growth & Spread in Buildings: A Practical Guide to Implementing Industry Standards" to help facility operators "develop and implement a water management program to reduce your building's risk for growing and spreading Legionella." Referencing ANSI/ASHRAE Standard 188-2015, the CDC emphasized "Legionella water management programs are now an industry standard for large buildings in the United States."
  In the Vital Signs article "Legionnaires' disease: Use water management programs in buildings to help prevent outbreaks," the CDC told building owners and managers to "develop and use a Legionella water management program" and state and local officials to "consider changing building and public health codes to include Legionella water management programs."
- The Building Owners and Managers Association International (BOMA) posted an announcement on boma.org that the CDC "asks building owners and managers to adopt newly published standards that promote *Legionella* water management."
- In July 2016, law.com issued a report concluding, "Compliance with the new ASHRAE standard likely will be viewed by courts as the standard of care in personal injury lawsuits involving exposure to *Legionella*. Adopting industry standard practices and complying with applicable law is the best defence. Conversely, failure to follow such standards and legal requirements could expose building owners and operators to potentially significant liability."
- The U.S. EPA, in its September 2016 document, "Technologies for *Legionella* Control in Premise Plumbing Systems: Scientific Literature Review," referenced an ASHRAE 188 water management program as a risk management approach that can be beneficial for managing plumbing systems to protect water quality and public health.

Although agreement among government agencies, experts, and professional societies about the need and approach to *Legionella* prevention in the United States is a huge step, it is not enough.

Talking about *Legionella* control measures, writing about them in articles, and even agreeing on an industry standard won't keep people from getting sick and dying from *Legionella* infections.

Prevention will happen only to the extent that operators of hotels, hospitals, office buildings, apartment and condominium buildings, nursing homes, industrial facilities, and schools implement comprehensive and effective *Legionella* control measures in the management of their water systems. The responsibility lies with them, and perhaps with the health departments that advise and regulate them.

3.2.3 Canada

A search for Canadian national statistics for Legionnaires disease or Legionella did not show any records but according to Health Canada, the average number of reported cases of Legionnaires' disease is generally less than 100 per year. However, the actual number of cases is thought to be much higher, as many people with pneumonia may not be tested for infection with Legionella.

The Canada Occupational Health and Safety Regulations (COHSR), Part II, Division III entitled 'HVAC Systems' contains requirements in respect of HVAC systems, such as standards, records, operation, inspection, cleaning, testing, maintenance, and investigations.

Some highlights include:

- Instructions for operation, inspection, testing, cleaning and maintenance of HVAC systems must be written and reviewed by a qualified person who shall take into account CSA Guideline Z204-94, entitled Guideline for Managing Air Quality in Office Buildings, dated June 1994.
- The employer must then appoint a qualified person to put the instructions into action and to complete a written report about each inspection, cleaning, testing, and maintenance event.
- Employers must have a qualified person develop an investigation procedure for events where a worker's health or safety may be harmed by the air quality, such as an exposure to Legionella.
- The qualified person shall take into account the Health Canada publication 93-EHD-166, Indoor air quality in office buildings: A technical guide when writing an investigation procedure.

"MD 15161 – 2013 Control of Legionella in Mechanical Systems" is the standard for the control of legionella published by Public Works and Government Services Canada (PWGSC). MD 15161 was developed for building owners, design professionals, and maintenance personnel and was first published in 1986. Its first edition reflected many of the requirements for the control of Legionella in mechanical systems, based on an exhaustive study of the subject.

The document was revised in 2006 considering the latest research in the field, including the development of new ASHRAE guidelines. Subsequently, there was an outbreak of Legionnaires' disease in Quebec City in 2012 that led to several fatalities; the source of this outbreak was traced to a cooling tower in a downtown Quebec City building. Following this outbreak, PWGSC carried out an extensive review of building maintenance programs as well as testing protocols for control of Legionella bacteria. It also reviewed current industry practices for Legionella control, with assistance from private sector consultants. This standard is the result of this extensive effort.

The standard states that hot water shall be maintained or stored above 60°C, distributed to each outlet at a minimum of 50 °C, and reduced to below 43 °C at the point of use. More often than not, however, visual inspections find that there is no thermostat on the hot water tank, or that the hot water tank temperature is kept as low as 45°C to save energy and to prevent scalding.

Cold water systems are generally not a problem for Legionella growth since the water is usually stored below 20 °C. However, the water in "point of use" systems such as irregularly used spigots, drinking fountains, emergency eyewash stations, etc. can be found at higher temperatures. These systems often have minimum maintenance performed on them to limit bacterial growth.

The water distribution system should be designed to minimize "dead legs" (sections of pipe that are no longer in use but continue to contain stagnant water) and to reduce the water residence time with the use of recirculating pumps.

MD 15161 targets cooling towers and evaporative condensers, open water systems, HVAC systems and components and domestic hot water (DHW) systems.

3.3 Europe

In most European countries there is national legislation concerning the design of DHW preparation systems in residential and commercial buildings. There are no EN Standards or EC-regulations dealing with temperature levels for DHW preparation concerning legionella treatment.

'The European Technical Guidelines for the Prevention, Control and Investigation, of Infections Caused by Legionella species' have been developed by members of the European Surveillance Scheme for Travel Associated Legionnaires' Disease (EWGLINET) and the European Working Group for Legionella Infections (EWGLI). The Network Committee endorsed them in 2003 for the Epidemiological Surveillance and Control of Communicable Diseases in the Community, instituted by Decision No 2119/98/EC of the European Parliament and the Council of 24 September 1998 on setting up a network for the epidemiological surveillance and control of communicable diseases in the Community.

The original goal was to harmonize legislation and standards in Europe, however that is not yet the case for the European Member States as national laws apply where advice on specific aspects of control and prevention differs between these European guidelines and regulations in force in Member States. Underneath the countries in focus are the participating countries in the IEA Annex 46 and some other large countries.

3.3.1 Switzerland

The Swiss Society of Engineers and Architects (SIA[5]) is Switzerland's leading professional association for construction, technology and environment specialists. With 16,000 members from the fields of engineering and architecture, the SIA is a professional and interdisciplinary network whose central aim is to promote sustainable and high-quality design of the built environment in Switzerland. The building industry in Switzerland typically follows the standards SIA 385/1 (SIA, 2011) and SIA 385/2 (SIA, 2013a) for designing domestic hot water systems.

The following topics are of major interest:

- legionella prevention
- heat losses (of tubes and storage tank)
- domestic hot water demand
- tapping time
- heat tracing

Legionella: The standard SIA 385/1 [S11] defines the basic requirements for domestic hot water systems. SIA

[5] www.sia.ch

385/2 [S11] describes the calculation methods for the planning of domestic hot water systems. The following topics are of major interest:

- legionella prevention
- heat losses (of tubes and storage tank)
- domestic hot water demand
- tapping time
- heat tracing

The temperature of the hot water is directly related to legionella. According to the Swiss Federal Office of Public Health (BAG) there were 275 cases of legionella in 2014, about 10% ending deadly [26, 27]. Based on these facts there are many guidelines and instructions published by different institutions in Switzerland regarding legionella prevention. The content is mostly redundant. The SIA 385 systematically implemented the guidelines set by the BAG. There are 3 different risk classes of buildings [28]:

- Low risk: single family houses, multifamily houses without central hot water supply
- Medium risk: multifamily houses with central hot water supply (also schools with showers, hotels, sports facilities, etc.)
- High risk: hospitals with intensive care and/or special departments (e.g. oncology, neonatology)

The temperature of the hot water is directly related to the legionella. According to the Federal Office of Public Health (BAG[6]) there were 275 cases of legionella in 2014, about 10% ending deadly (Lippuner, 2015a, 2015b). Based on these facts there are many guidelines and instructions published by different institutions in Switzerland regarding legionella prevention. The content is mostly redundant. The SIA 385 systematically implemented the guidelines set by BAG. The major requirements can be summarized as follows:

- Single family and multiple family buildings are classified as "low risk"
- Unused pipes must be renovated
- Domestic hot water of 25 °C to 50 °C that has not been used during the last 24 hours must be thermally disinfected (Recommendation for low risk class: 1 hour at 60 °C (Suter et al., 2010)
- The design of the domestic hot water system requires:
    - 60 °C at the storage tank outlet
    - 55 °C at the heat traced pipes
    - 50 °C at the tapping point
- The amount of water to be stored is determined according to SIA 385/2
- Periodical cleaning of domestic hot water storage tank from lime scale
- Avoidance of parallel installed and thermally connected hot and cold water pipes
- Periodical flushing of rarely used tapping points

According to BAG (2009) [29], there are various measures for the elimination of legionella:

- Mechanical measures:
    - Cleaning (decalcification, removal of encrustations and biofilms)
    - Renovation (replacement of corroded parts, lifting of deadlines and water days)
- Physical measures:
    - Thermal shock (>70°C, superheat and flush)
    - Emergency procedures for legonellosis and routine maintenance procedures
- Ultraviolet radiation (UV-C, 220-280 nm)
- Chemical measures:
    - Chlorination (sodium hypochlorite, NaClO)
    - Chlorine shock (15-50 mg/L) or continuous (gaseous Chlorine (Cl2), Javel water (NaClO), 2-3 mg/L)

[6] www.bag.admin.ch, Bundesamt für Gesundheit

- Ozone treatment (O3): The effective ozone concentration to prevent legionella propagation is 1-2 mg/L [11]. However, such high values are not compatible with the Swiss drinking water regulation which defines an ozone tolerance limit of 0.05 mg/L.

System temperatures: There are two major reasons for having high system temperatures in a domestic hot water system:

1. Legionella prevention
2. Comfort

The legionella prevention has already been mentioned above. In addition, the time until the water reaches a certain temperature at the tapping point outlet is a comfort criterion and is specified in the SIA 385/1 standard (SIA, 2013b, 2011).

Table 3.1: Specifications of the output time at the water tapping point according to SIA 385/1 standard (SIA, 2013b, 2011).

Output time in distribution networks - fully opened tap armature - output time until the water reaches 40°C	
without heat tracing (e.g. without recirculation loop)	with heat tracing (e.g. with recirculation loop)
15 s	10 s

3.3.2 United Kingdom

A guide 'The control of legionella bacteria in hot and cold water systems', issued by the British Health and Safety Executive, gives guidance and practical advice on the legal requirements of the Health and Safety at Work Act 1974, the Control of Substances Hazardous to Health Regulations 2002 concerning the risk from exposure to Legionella and guidance on compliance with the relevant parts of the Management of Health and Safety at Work Regulations 1999. More information can be found on the HSE website.

The control of legionella bacteria in water systems. Approved Code of Practice gives specific information on the health and safety law that applies. In brief, general duties under the Health and Safety at Work Act 1974 (the HSW Act) extend to risks from legionella bacteria, which may arise from work activities. The Management of Health and Safety at Work Regulations 1999 provide a broad framework for controlling health and safety at work (see www.hse. gov.uk/risk for more information). More specifically, the Control of Substances Hazardous to Health Regulations 2002 (COSHH)3 provide a framework of duties designed to assess, prevent or control the risks from hazardous substances, including biological agents such as legionella, and take suitable precautions.

The essential elements of COSHH are:

- risk assessment;
- prevention of exposure or substitution with a less hazardous substance if this is possible, or substitute a process or method with a less hazardous one;
- control of exposure where prevention or substitution is not reasonably practicable;
- maintenance, examination and testing of control measures, automatic dosing equipment for delivery of biocides and other treatment chemicals;
- provision of information, instruction and training for employees;
- Health surveillance of employees (where appropriate, and if there are valid techniques for detecting indications of disease) where exposure may result in an identifiable disease or adverse health effect.

Under general health and safety law, duty holders including employers or those in control of premises, must ensure the health and safety of their employees or others who may be affected by their undertaking. They must take suitable precautions to prevent or control the risk of exposure to legionella. They also need to either understand, or appoint somebody competent who knows how to identify and assess sources of risk, manage those risks, prevent or control any risks, keep records and carry out any other legal duties they may have. An overview is give in a brochure by the Health and Safety Executive.

This standard BS 8580:2010 on water quality, gives recommendations and guidance on the assessment of the risk of legionellosis presented by artificial water systems. It is applicable to any undertaking involving a work activity or premises controlled in connection with a trade, business or other undertaking where water is used or stored in circumstances that could cause a reasonably foreseeable risk of exposure to legionellae and contracting legionellosis.

The standard is applicable to risk assessments being undertaken on premises, plant and systems for the first time, and to review and audit where a previous assessment has been undertaken and where control measures might have been implemented.

Suitable and sufficient assessment of risks allows appropriate control measures to be put in place to protect the health and safety of employees and members of the public who could be affected by work activities.

Legionella risk assessment is no different, and is a legal requirement under the Health and Safety at Work Act 1974. The Management of Health and Safety at Work Regulations 1999 and the Control of Substances Hazardous to Health Regulations 2002, make specific requirements for risk assessment. These regulations apply to the control of Legionella and are embodied in the Approved Code of Practice and guidance document, "Legionnaires' disease: The control of Legionella bacteria in water systems", otherwise known as ACoP L8.

A risk assessment is a live document, not a one-off exercise, and needs to be reviewed regularly, ideally in anticipation of changes. For example, the risk assessment for a new construction ought to be performed before commissioning, but then reviewed when the system has been operating normally for several weeks or months.

It is the responsibility of the duty holder to ensure that an assessment is carried out to identify and assess the risk of exposure to Legionella from work activities and water systems and to put in place any necessary precautions. The duty holder appoints a person to take day-to-day responsibility for controlling any identified risk from Legionella bacteria. The appointed "responsible person" needs to have:

a) Sufficient standing and authority within the organization (e.g. a manager or director) and competence and knowledge of the system to ensure that all operational procedures are carried out in a timely and effective manner
b) A clear understanding of their duties and the overall health and safety management structure and policy in the organization.

If the duty holder is competent, they may appoint themselves responsible person.

A person is identified to carry out the risk assessment. This person can be an employee of the duty holder or an external contractor. This standard gives recommendations for how such a person conducts a risk assessment for Legionella, though the duty holder remains accountable for implementing the recommendations.
The national surveillance scheme for Legionnaires' disease in residents of England and Wales is co-ordinated by Public Health England (PHE). The main objectives of the scheme are to:

- detect clusters and outbreaks of Legionella in England and Wales or abroad through the surveillance of all reported cases
- identify sources of infection so that control measures can be assessed and where necessary improved upon, to prevent further cases

- as a member state, collaborate with the European Legionnaires' disease Surveillance Network (ELDSNet) in the detection, control and prevention of cases, clusters and outbreaks within European countries through the reporting of travel associated cases of Legionnaires' disease

3.3.3 Netherlands

Strict rules for legionella prevention apply to a number of companies and institutions. For example, for places where many people come, or where people come with less resistance. Examples of these risk locations are hospitals and nursing homes. However, there are rules for hotels, campsites and truck stops with a public shower. These are institutions where people run a great risk of becoming infected with legionella. The owners of these institutions must take measures to prevent legionella. For example, they have to find out where the legionella bacteria can grow in the water supply.

The Dutch laws and regulations for legionella prevention in drinking water and hot water are described under:

- Drinkwaterwet (2009);
- Drinkwaterbesluit (2011): an order in Council based on the Drinkwaterwet;
- Regulation on Legionella prevention in drinking water and hot water (2011):

All building owners with a collective hot water installation, have a 'duty of care for proper hot water', not endangering the occupant of the building. A special website 'Drinkwater Installaties' is giving information on how to design and manage hot water systems preventing legionella

In accordance with the Building Decree, the Drinking Water Decree and the connection conditions of the drinking water companies in the Netherlands, drinking water installations must comply with NEN 1006 "General regulations for tap water installations". This standard is issued by the Netherlands Standardization Institute (NEN).

The standard is generally held for a number of reasons, among other things with regard to the various conditions under which drinking water companies supply drinking water and the differences in composition. In order to achieve good harmonization in the implementation of drinking water installations, the Water Works Sheets provide a further elaboration of what is stated in the standard in a general sense. Both provisions and guidelines are included in the Water Worksheets.

In addition, instructions for implementation have also been given for certain situations. The set in the Work Sheets must be regarded as standard conditions that a drinking water installation must meet in order to be in accordance with NEN 1006.

The NEN 1006 was completely revised in 2015 and published in the autumn of 2015. As a result, all Water Worksheets will also be revised. A special Water Worksheet is being developed on DHW Heat Pumps, differing clearly from solar thermal.

Thermal management is seen as the main principle for preventing legionella. In collective domestic systems this is based upon four criteria:

- Temperature of cold water is lower than 25^{o}C
- Hot water temperature is at least 60^{o}C
- There are no unused pipes in the systems
- There is a weekly use of the taps

3.3.4 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 litres the water temperature in the whole system must be higher than 50°C. This rule is often referred to as the 3-liter rule and states that in small systems, where the volume between the heat exchanger and the furthest tap is less than 3 litres, there is no need for additional treatment methods. These can for example be found in single-family homes with an individual heat exchanger. It is however, recommended to keep the hot water temperature over 50°C at all times. Moreover, if there is a storage tank of more than 400 litres the temperature at the outlet of the tank must be equal to or higher than 55°C.

3.3.5 Austria

The valid standard in Austria concerning the planning, installing, operation, control and restoration of centralized DHW systems is the ÖNORM B 5019:2017. Its aim is the prevention of infections caused by contaminated DHW. Beside other building types, this standard applies for multi-family buildings, but not for single-family houses and semi-detached houses. The ÖNORM B 5019:2017 refers to centralized DHW preparation systems that contain several taps where the water volume between the heater and the remotest tap of are more than 3 Litres.

These centralized DHW systems have to constantly maintain a water temperature of 60°C or above after the heating facility and of 55°C or above in all pipes.

One way to avoid these restrictions is to use so called “fresh water stations” in each dwelling. This way, the individual systems have no DHW storage and the volume of water between the heater (fresh water station) and the remotest tap usually can be maintained below 3 Litres. The DHW tubing inside a dwelling is usually smaller, therefore the usage of fresh water stations avoids the restrictions imposed by the ÖNORM B 5019:2017.

In order to maintain the piping’s required minimum temperature of 55°C at all times, centralized DHW systems must contain

- circulation piping with constantly working circulation pump
- electrical trace heating (required temperature: 60°C)

The standard defines 4 risk groups. Risk group 1 refers to public buildings (1a) and multi-family buildings (1b), risk group 4 refers to hospitals or areas of hospitals where persons with suppressed immune system reside. The strictness of the required safety measures depend on the risk group of the persons that may reside in the building. Safety measures concerning water temperature measurement and water quality examination apply in the commissioning phase (initial examination) and during the operations phase of the building (continuous examination). In multi-family buildings (risk group 1b), the temperatures in the circulation system and the total DHW consumption must be monitored at least annually, if necessary, the taps’ frequency of use may be monitored as well.

If the Legionella concentration, measured during the initial or any continuous examination, exceeds the value of 100 colony-forming units, restoration is required, the measures are categorized in (Austrian Standards 2017):

1. Installation-related measures: maintaining required operation temperatures, replacement of shower heads, removing dead pipes, using decentralized DHW heaters
2. Process-related measures: thermal disinfection at 70°C (preferred), chemical disinfection e.g. with chlorine dioxide (only if other measures are not possible), UV disinfection (not recommended), filters in taps (only temporarily)

3.3.6 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 litres, there is no need for additional treatment methods. These can for example be found in single-family homes with an individual heat exchanger. It is however, recommended to keep the hot water temperature over 50°C at all times (DVGW, 2004).

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

Every household should always make sure that the tap water is free from contamination. From a hot water installation with more than 400 litres of hot water and for water pipes whose content exceeds 3 litres up to the point of extraction, an annual water test for Legionella must be carried out. Basically, this concerns any multi-family dwelling in which a duty of investigation would exist.

The responsibility lies with the operator of the respective plant. If Legionella are detected, there are orders to be followed. The higher the proven concentration of Legionella, the more drastic the measures you have to take.

One of the many worksheets for new installations of central domestic hot water heaters requires, in addition to improved construction, an operating temperature of 60°C and regulates the temperature for the subsequent distribution system. In 2001, a regulation was added to amend the Drinking Water Ordinance. It regulates the quality of the water for human use.

3.3.7 Sweden

Requirements regarding water supply systems are given in Boverket's Building Regulations Clauses 6:61 and 8:42. Requirements regarding the quality of drinking water are set out in the Ordonance on Drinking water from the National Food Administration, SLV FS 1989:30, H318.

In Sweden, legislation concerning Legionella are of either a preventative nature or protocols on how to contain outbreaks. 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°C at the tap. The same goes for water circulation, the temperature should not be below 50°C. The system should also be designed in a way so that the cold water 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°C. The maximum tap water temperature is also regulated at 60°C to avoid scalding and at 38°C if there is significant risk of accidents (BFS 2011:6). The Work Environment Act dictates that the Swedish Work Environment Authority has the right to regulate the conditions in the workplace. Concerning Legionella it states that showers must be designed to minimize growth and dispersal of the bacteria and as well as carefully considering the placement of cooling towers as these pose a risk of spreading Legionella bacteria (AFS 2009:2). To further ensure the well-being of employees the employer is required to perform risk analysis to identify potential sources of threat to human health (AFS, 2005:1).

3.3.8 Harmonisation in Europe

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 European Working Group for Legionella Infections (EWGLI).

Describing the optimal growth conditions of *Legionella,* it is mentioned that favourable conditions are in stagnant waters at a temperature between 32°C and 42°C in presence of a biofilm. EWGLI writes in their guidelines that there are a number of design features that should be implemented in order to make the water system an inhospitable environment for bacteria. First, 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 in their guidance document 'European Guidelines for Control and Prevention of Travel Associated Legionnaires' Disease' recommends that hot water should be stored at 60°C (140°F) and distributed such that a temperature of at least 50 °C (122°F) within one minute of opening the tap and preferably 55 °C (131°F).

The European Working Group for Legionella Infections (EWGLI) was formed in 1986 and members of this group established a European surveillance scheme for travel- associated infections in 1987 (World Health Organization, 1990). In 2012 EWGLI was affiliated to the European Society for Clinical Microbiology and Infectious Diseases ESCMID and as a result the name changed to the ESCMID Study Group for Legionella Infections (ESGLI)

The European surveillance scheme for Travel Associated Legionnaires' Disease, which was named EWGLINET in 2002, has grown in size and complexity since 1987, and now functions under an official EU Control of Communicable Disease programme with the name of European Legionnaires' Disease Surveillance Network (ELDSNet) (Commission Decision 2000/96/EC).

The first edition of the guidance document was produced in 2002 to describe the procedures for control and prevention of travel-associated Legionnaires' disease for participants in EWGLINET. It was produced by a small team from the surveillance scheme and the European Working Group for Legionella Infections and agreed by all collaborators in EWGLINET. The guidelines were submitted to the Network Committee for the Epidemiological Surveillance and Control of Communicable Diseases in the Community that operated under Decision No 2119/98/EC and Commission Decision 2000/96/EC. After some modifications, the EU Network Committee officially endorsed the document in June 2003. In 2005 the European Centre for Disease Prevention and Control (ECDC) was established through Regulation (EC) No 851/2004. As a disease-specific network, ECDC funded EWGLINET from January 2007 until April 2010.

Since 2010, the European surveillance of Legionnaires' disease has been carried out by ELDSNet and coordinated by ECDC in Stockholm. Data are collected by nominated ELDSNet experts for each European country and electronically reported to The European Surveillance System (TESSy) database. The surveillance data are from two different schemes: the first scheme covers all cases reported from EU Member States, Iceland and Norway; the second scheme covers all travel-associated cases of Legionnaires' disease, including reports from countries outside the EU/EEA.

The aims of these two schemes differ. The main objectives of collecting annual data on all nationally reported cases of Legionnaires' disease are:

- to monitor trends over time and to compare them across Member States;
- to provide evidence-based data for public health decisions and actions at EU and/or Member State level;
- to monitor and evaluate prevention and control programmes targeting Legionnaires' disease at national and European level;
- to identify population groups at risk and in need of targeted preventive measures.

The original goal was to harmonize legislation and standards in Europe, however that is not yet the case for the European Member States as national laws apply where advice on specific aspects of control and prevention differs between these European guidelines and regulations in force in Member States.

Table 3.2 summarizes the temperature levels at various locations of a hot water preparation system for Legionella prevention in different European countries.

Country	Cold water T	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)	> 50 °C	
Finland	<20 °C		60 - 65 °C	55 °C	65 °C
Germany		50 °C	60 °C	> 45 °C	
France		50 °C, unless V < 3 liters	55 °C		
Netherlands	≤ 25 °C	60 °C	60 °C (55°C*)	60 °C (55°C*)	65 °C
United Kingdom	<20 °C		60 °C	> 50 °C	
Switzerland	≤ 25 °C	55 °C	60 (≥ 55 °C)	55 °C	65 °C
Spain	<20 °C		55 °C	55 °C	
Belgium	<25 °C		60 °C	55 °C	
Italy			60 °C	45 - 48 °C	

* In Netherlands higher temperatures are required for collective circulation systems than for individual systems

4. Heat Pump Systems and Legionnaires disease

The question to be answered is if there are heat pumping technologies available that can deliver the high temperatures required by legislation in many countries in order to thermally kill of legionella? High temperatures which often are not needed as the legislation fails to recognize the alternatives, and the question can be asked whether the legislator knows the alternatives at all.

There is a number of heat pump designs capable of achieving high temperature outputs, including:

- Use of natural refrigerants and sorption products, especially CO_2 and Propane
- Cascade systems with two separate refrigeration cycles.
- Enhanced Vapour Injection (EVI).
- Gas Driven Heat Pumps

Whilst these products have been specifically designed for high temperature operation, the designs of "conventional" domestic heat pumps are increasingly being improved to reach 60 to 65°C at reasonable efficiency [10]. For comparison, high temperature heat pumps with heat supply temperatures of 100 to 160°C will increasingly become commercialize in the coming years, especially for industrial drying, sterilization and evaporation processes in the food, paper, metal and chemical industries (Arpagaus et al., 2018).

High temperature heat pumps for domestic hot water heating are suitable for retrofit to existing properties as they can be used with existing, high temperature distribution systems (e.g. existing radiators) and are also capable of meeting hot water demand. However, as the performance of heat pumps reduces with increasing output temperature, most suppliers will first try to specify systems that can run at lower temperatures for increased efficiency (even where that requires some heat emitters to be upgraded). Especially in collective systems, alternatives are being developed and getting into the market.

For the heat pump water heater there obviously is a clear difference in solutions for individual systems in single family buildings and collective hot water systems in multi-family buildings or district heating systems.

4.1 Individual systems

Individual systems are stand-alone DHW Heat Pumps or double function heat pumps for space heating and hot water generation. In principle both concepts have storage tanks:

- Domestic hot water is stored for direct consumption, i.e. shower, bath, kitchen etc.
- Hot water is stored and consumption water flows through a heat exchanger in the tank to be heated for use. This is a so-called 'fresh water system'.

Preferably, the temperature inside the hot water tank is higher than 55°C to kill off Legionella bacteria, but the temperatures probably can be lower as the flow of the hot water through the tank is semi continuous with regular domestic demand. In addition, the time the water stays in the tank is too short to grow bacteria. As this is not guaranteed the standards for hot water storage tanks are on the 'safe side' avoiding any health risks. It is therefore considered desirable / necessary within the norms to keep any margin in the minimum temperature in order to avoid dangerous situations in case of malfunction.

The option particularly in residential installations to apply thermal disinfection weekly at a lower temperature is not recommended. This cannot be realized. When the thermal disinfection does not take place automatically, the chance is too great that it will not be carried out.

For individual standalone DHW Heat Pumps or double function Heat Pumps a higher temperature can be realized by:

- An immersion electrical heater which arranges for the domestic hot water according to legislative requirements to be heated to 60 to 65°C. By using a timer this can be done once a day/week or at other desired time intervals. As ‘standard’ heat pumps can run up to 55°C the DHW only needs to be increased by 5 to 10°C by the electrical heater. This is not an enormous amount of additional energy. For a 150 litres storage tank this amounts up to 0.8 – 1.0 kWh per week.
- Heat Pump Water Heaters with alternative natural refrigerants, like CO2 and Propane, can easily reach higher temperatures. Especially air source heat pumps in cold climates are the challenge, which has been described extensively under HPT-Annex 42.

There is a number of heat pump system designs that are capable of achieving high supply temperatures. Techniques include dual refrigeration cycle cascade products, products with optimised design for specific refrigerants, Enhanced Vapour Injection (EVI), use of natural refrigerants and sorption products. Whilst these products have been specifically designed for high temperature operation, the designs of “standard” heat pumps are being optimised to reach 60 to 65°C at reasonable efficiency.

An important point of attention is the Heat Pump Water Heater with an outside plate heat exchanger where the tank water flows in counter flow through the condenser. This outside plate exchanger is standard in HPWH saving CO_2 as refrigerant and it is becoming more and more common in other HPWHs as well.

As long as the regulatory demands do not change towards higher temperatures there does not seem to be a great problem in the market.

4.2 Collective systems

Most of the collective systems in housing blocks are circulation systems. The water, which is circulated as energy bearer in the system, is not used as domestic hot water for shower, bath or consumption by the individual end user. The heat exchanger between the collective system and the individual end user system is for the domestic water use fed with cold water to be heated and used as domestic hot water. In principle, thus the end user side can be regarded as an individual system with short pipe length and a content much smaller than 3 litres, as long as the cold water fed in for domestic use has a temperature lower than 20°C.

The current guidelines for legionella in collective systems seem contradictory to this, because they generally require thermal control of legionella in a distribution system in multi-family buildings. Thus for smaller collective systems, i.e. blocks of Multi Family buildings not connected to the district heating grid increasing the temperature of the distributed water to a level of 65 to 70°C is the standard solution.

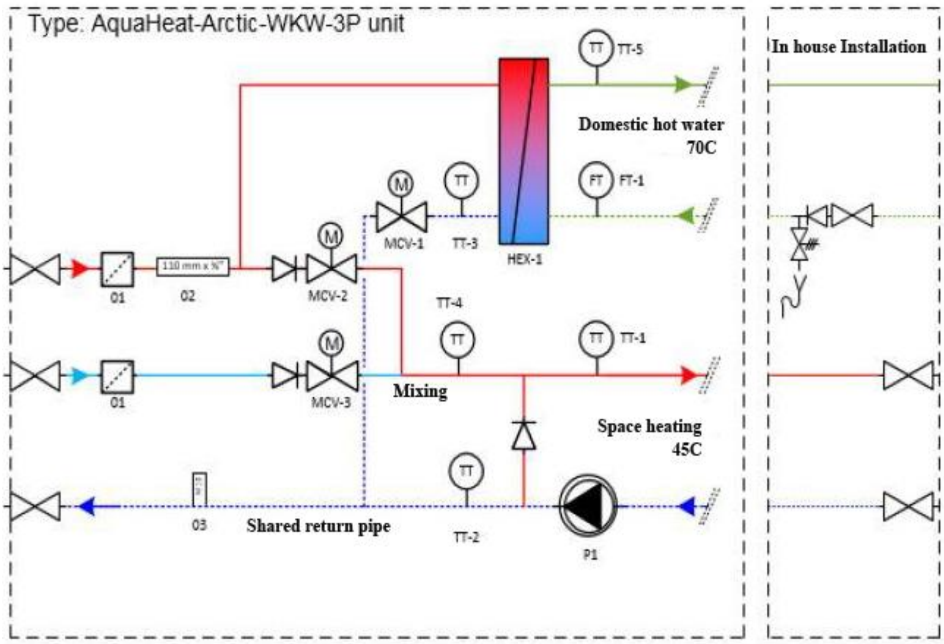


Fig 4.2 Three and half pipe distribution system

Since insufficiently high temperatures and long-term stagnancy are the main risk factors for Legionella proliferation in collective hot water systems, Xiaochen Yang et.al. [03] proposed alternative designs that can eliminate those factors. The basic concepts behind such designs are temperature boosting and volume limitation. Temperature boosting can be achieved using local supplementary heating devices. It is clear that mostly in new systems the DHW and space heating systems are split in three, four and five pipe systems, where in the separate DHW distribution temperatures are raised to 70°C.

Temperature control is still the most widely used method for preventing Legionella in hot water systems. In Denmark, for example, the standard regulates that the circulation pipe should be kept at 55°C all the time, and it should be possible to heat the storage tank up to 60°C on a regular basis. Some Scandinavian countries are currently planning to operate District Heating (DH) networks at lower temperatures (around 30 to 70°C) to reduce fossil fuel consumption and improve energy efficiency. The aim with Low Temperature DH is to reach supply temperatures that approach 50°C. 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°C at the most. With the legislative demand in a majority of the countries that the temperature of the water should be a minimum of 50°C when it reaches the tap, the feed temperature in the distribution system should be at least 10 K higher.

The volume limitation concept Linita Karlsson et.al. [02], in accordance with the German Standard W551 [S 16} is that, if controlled properly, a system with a total volume (from hot water production to end use) of less than 3 L can eliminate the risk of Legionella. The advantages of alternative design are numerous. With a central heat pump in the basement a decentralized substation can be used where the feed is 55ºC. Decentralized substations inhibit growth of Legionella by limiting the residence time in what might otherwise be favourable conditions. The idea is based on the German Standard W551 that in systems where the total volume between the point of distribution and the furthest tap does not exceed 3 L 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.

Decentralized substations have the potential to limit Legionella growth even with the lower supply temperatures from low temperature district heating. Yang et al [03] performed a study on a six story residential building in Denmark and 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 are 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. The drawback is that it requires considerable investments (number of substations) and can be difficult to implement in existing buildings, as the installation would require extensive renovations.

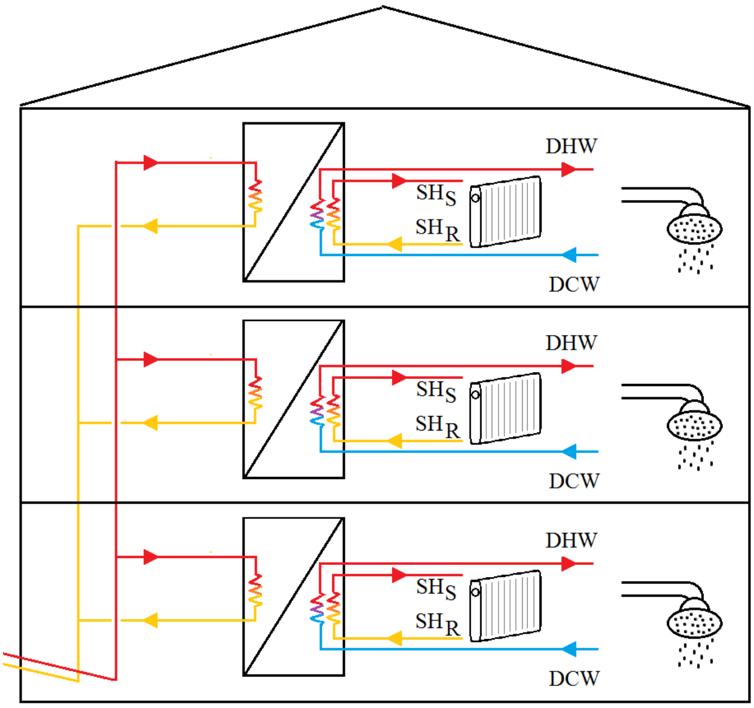


Fig 4.3 Process diagram of decentralized substations [02].

Boosting the temperature, 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 and three will be presented here: 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 (Vetsch [01], Yang et al [03]). Replacing the hot water circulation system with electric heat tracing can lead to large energy savings and economic benefits. To make electric heat tracing more efficient it is advised to introduce smart control where the heat load at varying times is considered.

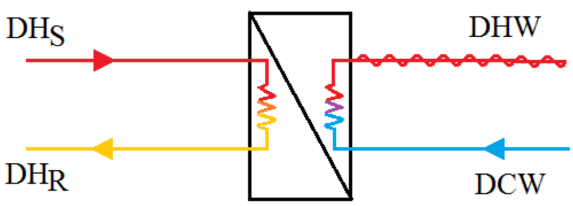


Fig 4.4 Process diagram of electric heat tracing [02]

- **(Micro)-Booster Heat Pumps**: Another way to heat up the domestic hot water is to install a microbooster heat pump. The central LT heat pump feeds the floor heating in the houses, but at the same time the low temperature heat serves as a source for the booster heat pumps, which make hot water decentrally per apartment and store them in a tank. An advantage of this 'semi-central' system, the less complex distribution system, being a two-pipe system.

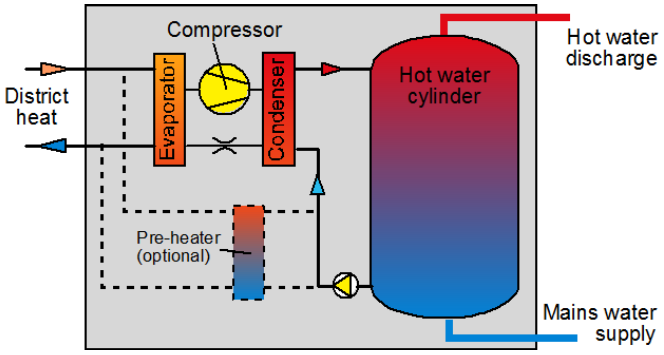


Figure 4.5 Basic layout of a booster heat pump.

- **Individual Domestic Hot Water Heat Pump**, which can be installed separately of the two-pipe distribution system in the individual apartments. This seems to be a good solution for renovation of existing distribution systems to lower temperatures [07]
- **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.

There are several alternative techniques than thermal management 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.

In collective systems, especially the larger district heating systems sterilization is an option to fight potential legionella infection. 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. Five sterilization techniques can be observed in the market: chlorination, ultraviolet light, ozone, ionization and photocatalysis.

4.3 Heat Pumping Technologies

Other than individual domestic hot water heat pumps which are often monobloc air to water heat pumps or part of an double function heat pump, collective heat pumps for multifamily buildings and for other applications are of a larger capacity and often fit to deliver high temperatures.

The most common refrigerants used in heat pumps today are R410A, R134a and R407C. Until recently the maximum output temperature for domestic heat pumps using these refrigerants was about 55°C with R134a achieving slightly higher temperatures, however now temperatures above 60°C can be achieved. By using slightly different temperature and pressure characteristics the refrigerant can be flashed off at a higher temperature, increasing the output temperature, although this can reduce the overall thermal output. High temperature heat pumps are considered to be products capable of producing an output temperature of at least 65°C and higher. There is a number of heat pump designs capable of achieving high temperature outputs, including:

- Cascade systems with two separate refrigeration cycles.
- Enhanced Vapour Injection (EVI).
- Products with optimised design for specific refrigerants such as natural refrigerants.
- Absorption heat pumps
- Gas engine driven heat pumps

Whilst these products have been specifically designed for high temperature operation, the designs of "conventional" heat pumps are increasingly being improved to reach 60-65°C at reasonable efficiency.

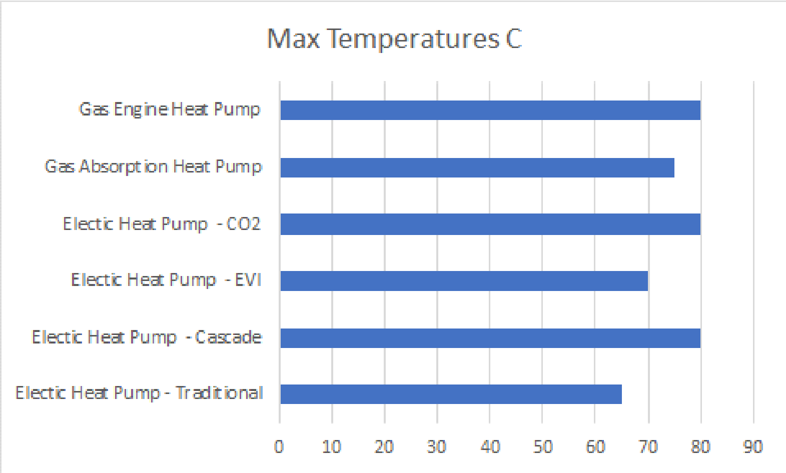


Fig 4.6 Maximum temperatures per heat pump type

High temperature heat pumps are suitable for retrofit to existing properties as they can be used with existing, high temperature collective distribution systems capable of meeting hot water demand at the high temperatures as required by legislation and comfort demands. Traditionally heat pumps are electric driven, while gas driven heat pumps are a niche market, but can be very important in renovation projects. Gas heat pump technology can be split into sorption heat pumps and gas engine driven heat pumps. Sorption heat pumps can be split into two types – adsorption and absorption. Sorption units use a thermal compressor to heat the refrigerant, whereas gas engine driven heat pumps use a mechanical compressor (similar to electric heat pumps) but where the energy source is gas. Gas driven heat pumps still use some electricity, although this is a small amount in comparison to electric heat pumps.

4.3.1 Electric driven heat pumps

Three types of electric drive heat pumps are discussed with only two having example projects.

Cascade Heat Pumps

Producing domestic hot water (DHW) in collective systems with a ground source heat pump (GSHP) is challenging due to the high temperature of DHW, especially for air source heat pumps in colder climates. With the simple cycle system it is not possible to reach temperatures above 65°C as reaching the outlet water temperature at 80°C would require theoretically a compression ratio of about 7 and the coolant temperature (R134a) of 140°C. In order to overcome these problems the only feasible solution is to split the temperature difference in a cascade of two cycles. The use of two different refrigerants allows to exploit the best performance of each refrigerant combining a wide scale of advantages.

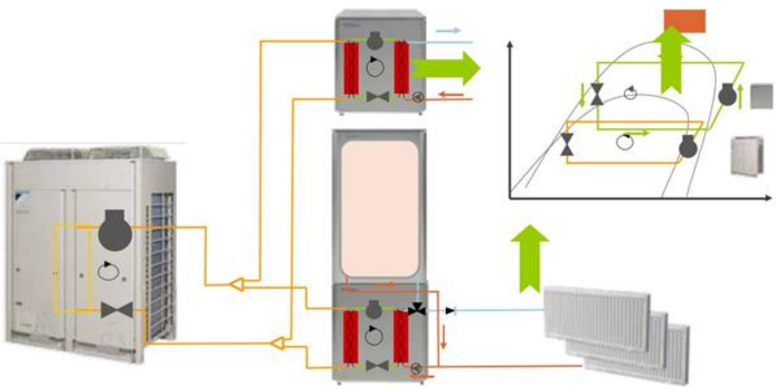


Fig 4.7 Cascade heat pump (source AFPAC)

A cascade system consists of two single-stage cycles (a low temperature and a high temperature cycle using different refrigerants) which are thermally connected by an intermediate heat exchanger or a storage tank. The low temperature cycle uses the refrigerant R-410a which is able to evaporate at a very low air temperature and condenses in the intermediate heat exchanger at a relatively low pressure and a temperature of about 45°C. This process transfers heat to the evaporator of the high temperature cycle which induces the evaporation of the second refrigerant R-134a. This refrigerant is then able to condense at a pressure that is not too high to affect performance. Cascade systems are capable of reaching temperatures of up to 80°C. Some systems are able to fluctuate between using both cycles together, and using just a single-stage cycle to optimise performance.

At first the developments and installation concepts were based upon two separate heat pumps installed in cascade. A number of projects are still installed in that way. In fact these can be considered as booster heat pumps of considerable size, up to 260kW. A number of projects can be named.

Netherlands - Collective HT HP – Jacques Urlusplantsoen – Leiden – Renovation of privately owned flats with a central heating system new type cascade ground source heat pump developed under the Dutch TKI-program Urban Energy. Linthorst Techniek developed under the governmental TKI Urban Energy Program a high-temperature heat pump for existing buildings. The TT68/80 heat pump can replace the central heating boiler without have to change the infrastructure of the building. The development of the high temperature heat pump started in 2010. The focus of building constructors for renovation is on insulation with a big impact for residents and not needed for relatively new buildings. This is a good option for 50% of the Multifamily buildings owned by housing corporations, but not so much for the buildings owned by VVE's. Thus the goal for Linthorst was to develop a high-efficiency and high temperature heat pump with the challenge to deliver safe domestic hot water at a temperature of 65°C. The multistage heat pump the water temperature boosts up to 70 or 80°C from a ground source of 10°C.

Fig 4.8 Installation at Jacques Urlusplantsoen

- In the Suurstoffi project a number of alternatives have been installed. Site 5 was commissioned in early 2013. It consists of three buildings that contain the uses residential, office, sales, commercial and fitness. In construction area 5, the heat exchange between the energy network and buildings takes place centrally, in House B via a low-temperature heat pump, which converts the energy to 35°C for space heating.

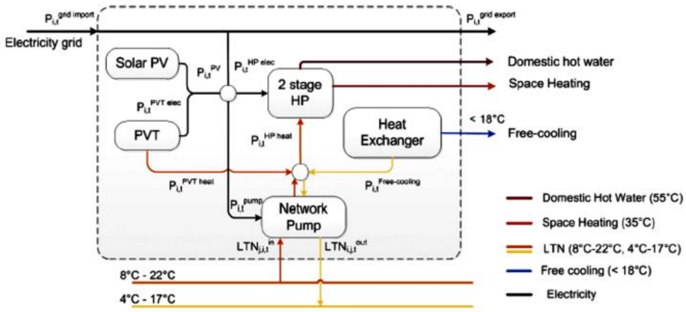


Fig 4.9 Technical diagram at Block 5 in Suurstoffi

  In addition, part of the heat produced from the low-temperature heat pump is then converted into hot water (60°C) by a high-temperature heat pump. The hot water consumption was 11% below the planned value, which corresponds to the expected deviations of +/- 10% from the planned demand values to the measured consumption values. The reasons for the lower hot water consumption can presumably be attributed to lower occupancy rates and careful assumptions when planning. Due to the lower hot water production, the heat pumps had to work less in the higher temperature range (60°C for hot water instead of 35°C for room heating) than planned. The annual performance figure of the heat pumps (4.4 in the last evaluation period) is 6% higher than the planning expectations.
- Netherlands - YOTEL Hotel – Amsterdam. - New BREEAM Excellent certified hotel built applying modular construction with prefabricated hotel rooms and technical system, with ground source heat pump.
  Three types of heat pumps have been installed:

Enhanced Vapour Injection (EVI).

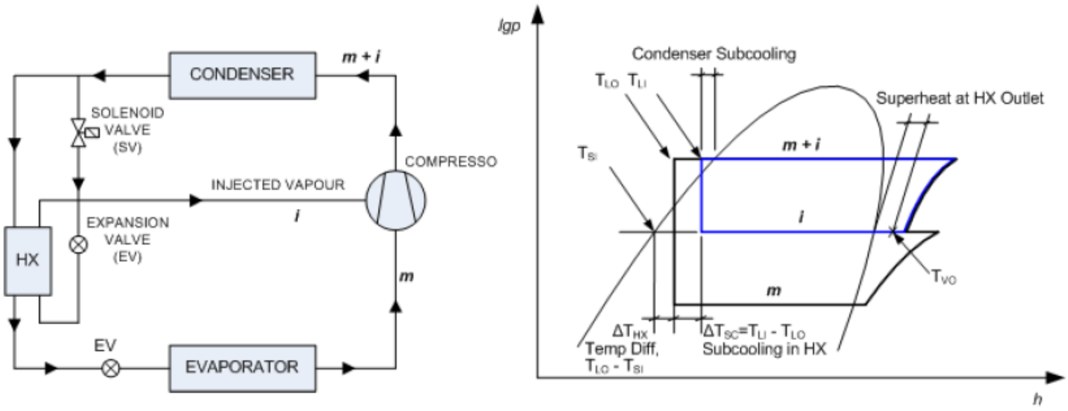
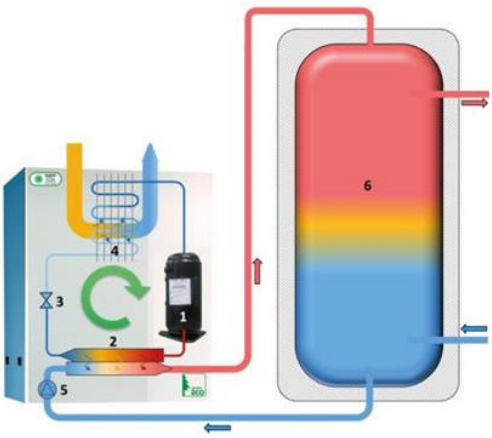


Fig 4.10 EVI technology (source Emerson)

The EVI technology requires an additional loop to be added to the standard heat pump cycle. This loop enables a small proportion of the condensed refrigerant to be extracted and expanded through an expansion valve and into a counter flow heat exchanger which acts as a subcooler. The additional subcooling increases the evaporator capacity. The resulting superheated vapour is then injected into the compressor part way through the compression process as shown in Figure 7. The result is a significant gain in heating capacity due to the increased refrigerant mass flowing through the condenser for the same size of compressor. There is also an increase in power use, but the overall effect is to increase the COP. The cooling provided by the gas injection allows the operation of the compressor over a larger envelope compared to a conventional single stage cycle, providing higher output temperatures at low evaporating temperatures.

CO2 Cycle heat Pumps



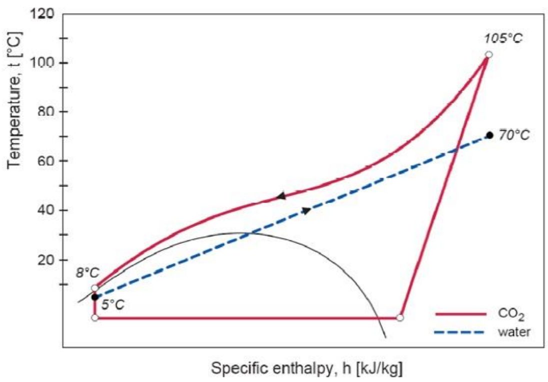


Fig. 4.11 CO2 heat Pump Configuration (source AFPAC) *Fig 4.12 – CO2 cycle (source Strathclyde University)*

This technology, originally from Japan, uses R744 or CO2 as the refrigerant. This system implements a transcritical Heat pump cycle. This results in a replacement of the condensation phase of the conventional refrigerant by a substantial cooling phase of the CO2 fluid within an exchanger called here gascooler. CO2 transcritical cycle is used for the production of hot water in water heaters due to its high efficiency. It can supply high temperature hot water varying from 60 to 95°C. so it therefore requires no supplementary heating. At optimum gas cooler pressures, the cycle of the heat pump water heater in a T-H diagram is shown in figure 1 where city water is at 5 degrees and domestic hot water (DWH) is at 70°C.

This type of cycle is very suitable for DHW production, particularly at high temperatures. Especially in Japan and China the monobloc heat pumps for single family houses is very popular. For larger systems the technology using CO2 as refrigerant is also available.

- France – Eco-Cute – Villa Plaisance du Touch in a suburb of Toulouse – New built low energy luxury apartment building with a collective hot water circulation on air source heat pump with CO2 as refrigerant. This type of CO2 system, in the deployment phase in France and in Europe, can be applied to capacities below 3kW and up to several tens of kW. This allows broad coverage on applications where DHW consumption is high, such as collective residential applications.

4.3.2 Gas driven heat pumps

Gas driven heat pump technologies can be split into sorption heat pumps and gas engine driven heat pumps. Efficient, gas driven heat pumps can reach high temperatures and therefore be used with existing distribution systems especially fit to produce domestic hot water in collective open systems.

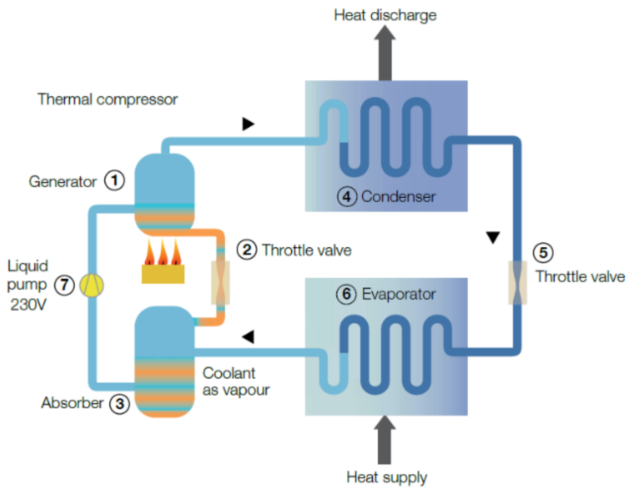
- Absorption heat pumps can reach higher temperatures than standard electric heat pumps, typically up to 65˚C.
- Adsorption heat pumps can reach high temperatures of up to 75˚C. However, it is recommended that they operate at a flow temperature of 40-45˚C.
- Gas engine driven heat pumps can reach temperatures above 65˚C.

The main advantage of gas heat pumps in many markets is that, even if deployed widely, they would not constitute a significant burden on the electricity grid. If the scenario of heat pump uptake in a large number of countries was realised through electric heat pumps, generation and grid network capacity would need to increase significantly. The wider deployment of GHPs offer the advantage of reducing the peak demand by 80% compared to electric counterpart. From the point of view of utilities, this eliminates the need for lower-efficiency peaking power plants and over-expansion only to cover maximum peak times. This reduction not only saves on utility bills, but can also in some cases eliminate the need for costly electrical infrastructure upgrades; panels, breakers, etc. besides electric power demand reduction [47]. An extensive gas infrastructure is already in place in many of these countries and gas driven heat pumps have an important role to play. For single family buildings the hybrid heat pump has been developed for that course (HPT-Annex 42), for larger building projects larger capacities are needed. More and more it seems that for the smaller applications the developments in Europe of sorption heat pumps has come to a halt in favour of the hybrid system, although some manufacturers, like ROBUR are offering these type of heat pumps. For larger projects in multifamily buildings, hotels and hospitals there is still a considerable market.

Sorption technologies

Sorption units use a thermal compressor to heat the refrigerant, whereas gas engine driven heat pumps use a mechanical compressor (similar to electric heat pumps) but where the energy source is gas. Gas driven heat pumps still use some electricity, although this is a small amount in comparison to electric heat pumps.

The market for the gas absorption heat pumps in the built environment in Europe nowadays is dominated by this Italian company. Its heat pumps are sold in Europe under the names Robur, Buderus, Xinoé, and Remeha. In the USA and Canada there is growing interest for this type of heat pumps. The capacities of a single unit go up to about 40 kW, depending on the heat source used.



A gas-fired heat pump is not fitted with an electrical compressor, like an electric heat pump. Instead, it works on a second loop process, using ammonia dissolved in water, with ammonia acting as the refrigerant and water as the absorbent. The mixture is heated by the gas burner in the generator (1). Th e refrigerant evaporates and is separated from the water. The water is transferred to the absorber (3) via the throttle valve (2). The ammonia vapour is directed to the condenser (4), where it condenses and transfers the condensing heat to the central heating water. The liquid goes to the evaporator (6) via the throttle valve (5), where it evaporates while absorbing heat from the outside air. The vapour then goes to the absorber and comes into contact with the water, which has low levels of ammonia. This is where the refrigerant is absorbed into the solution. The vapour is absorbed by the water, resulting in a solution that's rich in ammonia. The heat released during this process is transferred to the central heating water with the residual heat from the generator, which increases the efficiency of the heat pump. The rich solution is taken by the liquid pump (7) to the generator (1) and the process starts again from the beginning. (source REMEHA).

- France - Dinetard student residence - Toulouse - A new student residential building heated by air source gas absorption heat pumps for space heating and solar support for domestic hot water. The project is monitored for a number years. Three different configurations were studied by the Atmosphere fluids BE, in comparison with a reference solution with an efficiency of 95% PCI (excluding DHW), which would have been composed of two condensing boilers with a power of 110 kW, of which one exclusively dedicated to domestic hot water. By adding one, then two and then three absorption heat pumps, these simulations made it possible to show that the technical and economic optimum for this residence was a solution composed of two heat pumps.
- France - Residence 9 Town - Lyon - New luxury housing project in the private sector for which the heat for space heating and domestic hot water is produced by a set of 4 gas absorption heat pumps. Three different configurations were studied by the Atmosphere fluids BE, in comparison with a reference solution with an efficiency of 95% PCI (excluding DHW), which would have been composed of two condensing boilers with a power of 110 kW, of which one exclusively dedicated to domestic hot water. By adding one, then two and then three absorption heat pumps, these simulations made it possible to show that the technical and economic optimum for this residence was a solution composed of two heat pumps.

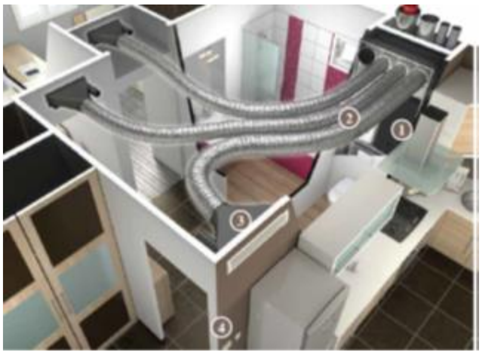
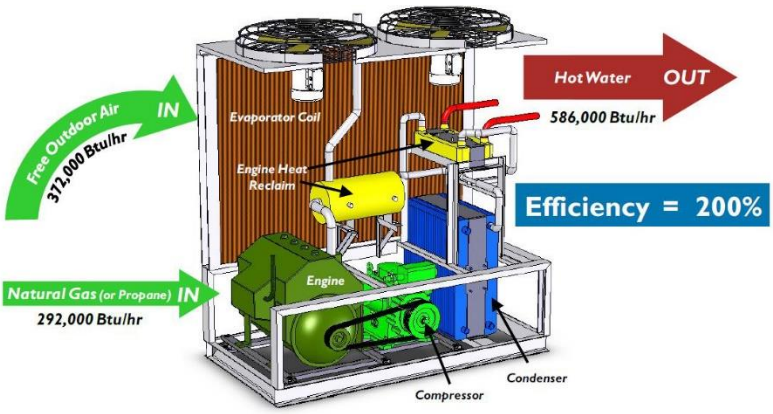


Fig.4.13 - air vector system (source AIR France)

Gas Engine driven heat pumps

One advantage of using an internal combustion engine to drive the compressor in a heat pump system is the ability to use the excess heat of combustion generated by the engine. The excess heat is available for wintertime heat augmentation, thereby reducing or eliminating the need for auxiliary heaters. It has been a common practice with combustion engine heat pump systems to recover the excess heat from the engine by conveying a working fluid (e.g., water and ethylene glycol antifreeze) through the coolant and sometimes the exhaust system such that waste heat from the engine is absorbed by the working fluid. The heated working fluid is then pumped to a heat exchanger or radiator located in the air flow leading to the air-conditioned space. In the RGHP, the heat is added directly to the refrigerant via a heat recovery heat exchanger. The excess heat of combustion generated by the engine could also be used for domestic water heating, thus further reducing energy costs and peak electricity demand for electric water heaters. Temperatures up to 80°C can be reached at a high efficiency.



Gas engine driven heat pumps (GHP) currently hold a small share of the U.S. and European HVAC market. This share is considerably smaller than what the full potential of GHP technology can realize. However, development and market penetration of GHP technology have been challenged by various market and technical barriers. The main barriers are high initial cost, low awareness of the technology, and poor perception.

Fig 4.14 Gas engine principle (Source: Ilios Data Sheet)

A monitoring study has been done by ENERGY 350 for NEEA and reported upon in 'Natural Gas Internal Combustion Engine Heat Pump Field Trial' - Final Report . This pilot with a Tecogen-Ilios gas engine heat pump has a rated capacity range of 117 – 175 kW, and is fired with propane. The Capital Manor Retirement Community in Salem, OR was selected as an ideal site with a large DHW load, significant DHW storage capacity and reasonable installation logistics. Typically these gas engine heat pumps are air source heat pumps. The development of smaller gas engine driven heat pumps was presented by Abuheiba et.al [47] and Vineyard [48] a an opportunity in the domestic market downsizing from 45 kWs to 20 kWs. Since 2010, a total of 70 units have been installed and operated. These 70 units have aggregated over 400,000 hours of running time. One of the installations was fuelled by propane and the rest were fuelled by natural gas. Currently there are 32 field installations. More than half of them have accumulated more than 10,000 hours of runtime. One unit has accumulated 29,000 hours. In addition to the 32 field installations, one unit served an office building in Las Vegas, NV for 6 years during which it accumulated 27,000 hours. Overall, the units operated satisfactorily. There were no major reliability issues even with the units with the highest runtimes. Of the smaller units twenty-two units have been installed since May 2014. Twenty-one units have accumulated over 23,000 run hours. The collected field data provided valuable information on the performance of the unit [47].

There is also a Dutch company that produces gas engine driven heat pumps. The company is called Reduses and it produces gas engine heat pumps of reasonable sizes, ranging from 137 to 280 kW for low temperature heating and from 57 to 99 kW for high temperature heating. Stepless part-load operation from 25 to 100 % is possible for these systems.

An important advantage is the lower load on the ground source system as less heat is extracted from the source This helps to maintain a balance in the aquifer for residential buildings with a relatively large heat demand and a small demand for cooling.

Fig. 4.15 – Reduses heat pump in the Tergooi Blaricum Hospital (Netherlands)

The source of an electric heat pump quickly becomes unbalanced and usually, heat is loaded with dry coolers or solar collectors to regenerate the source. With the gas engine-driven heat pump this is not or much less needed. This fact has been one of the main drivers behind the development of the Reduses heat pump technology. A number of projects have been realized in domestic multifamily buildings, nursing homes for the elderly, hotels and hospitals.

Two well-known gas engine driven heat pump manufacturers are Aisin-Toyota and Sanyo. Both companies are Japanese. Capacities are about 80 kW for heating and 60 kW for cooling, depending on the gas engine used. Units are placed in parallel if larger capacities are required. Part-load is also possible. This is done by reducing the engine rotational speed at constant torque. Multiple compressors are driven by the same engine, making it possible to switch off one or more compressors during part-load operation.

4.3.3 Fresh Water Systems

A fresh water station (FWS) produces domestic hot water, transferring heat energy from a buffer tank directly to incoming domestic water from the mains water supply. The FWS only heats up in the continuous flow when the tap is turned on, thus being in fact instantaneous water heater using the heat from the storage tank. Systems can have a capacity to supply larger multifamily buildings, but are also available in smaller sizes with capacities down to 24kW's for single family buildings. The storage tank of the FWS can be connected to any heat generator. Originating in solar thermal applications these FWS are an excellent storage system to combine renewable technologies. But they also are installed with only a heat pump as generator. To transfer the heat from the storage tank to the domestic water:

- A finned in tank spiral heat exchanger can be used, which is the traditional type.
- A small volume high capacity external counterflow plate heat exchanger can be used. This type of heat exchanger is in fact similar to the heat exchangers used as substation in collective systems and district heating

The claim that fresh water modules have no risk of legionella contamination as the domestic hot water flowing through the storage tank is 'fresh' cold water and in smaller systems less than 3 litres cannot be confirmed in literature [Haller, 52, 52].

The requirements for the planning and execution of drinking water systems (except for the design of the buffer tank and the fresh water station) do not differ from those of conventional heating systems. The dimensioning of the pipes and fittings as well as the design of the circulation system also remain the same. Since the bulk capacity of individual fresh water stations is limited, several stations can be cascaded if there is a higher demand for hot water. The bulk capacity also increases by the sum of the corresponding individual stations, for example from 25 liters per minute - depending on the buffer tank and desired domestic hot water temperature, among others - for a single system to up to 100 liters per minute with a fourfold cascade.

Fig. 4.16 Typical installation of fresh water system with heat pump (source Heliotherm)

5. Conclusions

Legionella bacteria occur naturally and are ubiquitous in freshwater, including groundwater, and soil. They become a human health risk when allowed to multiply rapidly due to warm water temperatures between 25 to 45°C and are a particular hazard in manufactured environments where aerosolization may occur. The number of reported Legionnaires' disease cases in Europe is about 1 to 2 per 100'000 inhabitants. Maintaining the temperature of hot and cold-water systems to prevent or minimize the growth of Legionella is an important control measure to prevent the risk of Legionella infection. Water systems should thus avoid temperatures between 25 to 45°C, by:

- Maintaining cold water below 20°C.
- Maintaining hot water above 50°C.

According to the German Standard W551 the system is safe with temperature below 50°C if the total volume of the DHW system excluding HEX is less than 3 L ("3 L rule"). This is based upon the experience that in small DHW system, when there is no circulation the water in the system cools down to room temperatures. These findings are not taken over by a number of standards in other European countries. Thus, it seems also possible that in large collective systems with low temperature distribution systems DHW is made through a small local heat exchanger, if that is refreshed regularly. A competing alternative are (Micro)-Booster Heat Pumps and high temperature collective heat pumps.

The worldwide legislation is not harmonized. Reviews of current literature and recent guidelines have substantiated that, in order to stifle the culture ability of legionella and colonization of the electric hot water distribution system, consistently maintaining water stored in an electric hot tank at ≥60°C and at above 50°C across the distribution networks are no negotiable options

The consequences for energy efficiency are significant, especially for heat pumping technologies. Preliminary calculations suggest that increasing the hot water storage temperatures from 50°C measured in previous studies to 60°C recommended for legionella control would increase CO_2 emissions from hot water. The COP decreases roughly about 2% with every °C higher supply temperature. Whilst the risks to human health should clearly remain a priority when setting regulations in this area, the impact on CO_2 emissions of an over-conservative approach suggest that further study in this area is justified.

Interestingly the origin country of the "3 L rule", Germany, is not applying it. Germany recommends an operation temperature of a DHW system to be at least 50°C (DVGW, 2004), whereas the 3 L rule is applied in France. There are only two exceptions to a temperature requirement of at least 50°C. These are in Denmark at peak flow times, when a temperature of 45°C is accepted, and in France that has applied the 3 L rule for small systems. Under other circumstances and in the other countries the minimum temperature in the domestic hot water system varies between 50°C and 65°C. It is difficult to say if and how these legislations could be altered. To change regulations, it is imperative to present a safe solution, guaranteeing the water quality with regards to Legionella that is also accepted by the general public.

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[S16] - DVGW W 551:2004-04 - Trinkwassererwärmungs- und Trinkwasserleitungsanlagen - Technische Maßnahmen zur Verminderung des Legionellenwachstums - Planung, Errichtung, Betrieb und Sanierung von Trinkwasser-Installationen

Websites

European Legionnaires' disease Surveillance Network (ELDSNet)
Centers for Disease Control and Prevention (CDC)

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