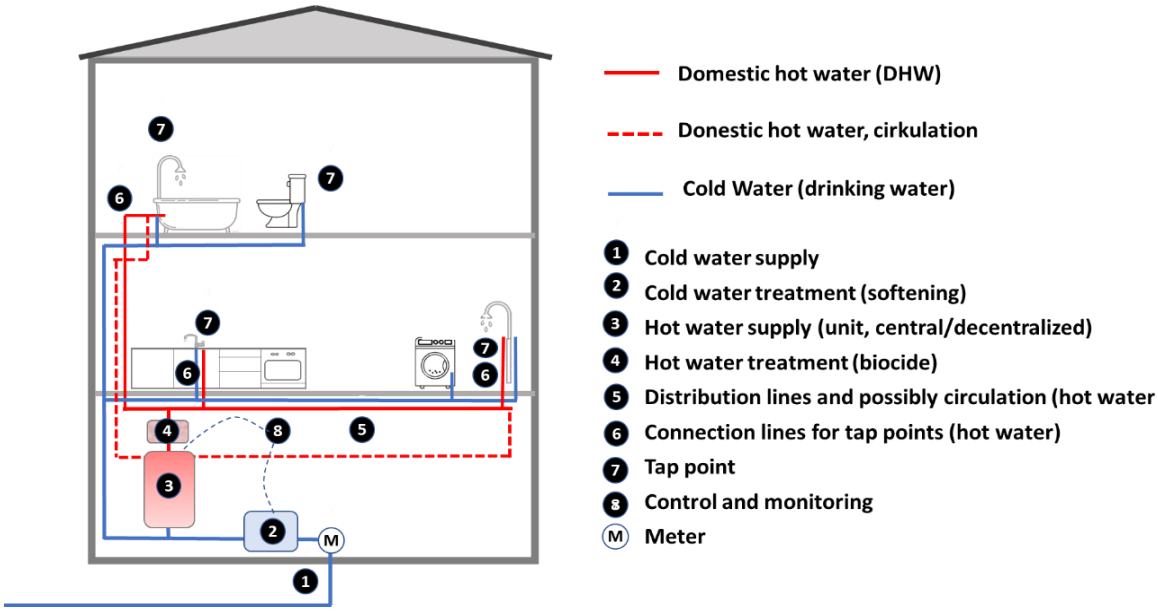
Final report

1. Project details

Project title	Legionella protection and energy efficiency for installations and supply Legionellasikring og energieffektivisering for installationer og forsyning
File no.	J.nr. 64020-1099
Name of the funding scheme	EUDP
Project managing company / institution	Danish Technological Institute Kongsvang Allé 29 DK 8000 Aarhus C
CVR number (central business register)	5697 6116
Project partners	Danish Clean Water (DCW) METRO THERM A/S (METRO THERM) Statens Serum Institut (SSI) VIA University College (VIA) Fredericia Fjernvarme (FF) KAB Projektkontoret - Region Sjælland (PRS) Teknologisk Institut/ Danish Technological Institute (DTI)
Submission date	24 January 2023

Domestic water installations and *Legionella*



2. Summary

2.1 Summary

Domestic hot water constitutes an increasing proportion of energy consumption and climate footprint regarding buildings, i.a. because *Legionella* requires a higher temperature than is needed in terms of comfort. At the same time, *Legionella* has become a growing challenge with several cases of illness and a number of deaths as a result of legionnaire's disease. Denmark has a relatively high incidence ratio but also other countries are challenged. In the project, a major investigation was carried out, as well as the development and demonstration of three measures for protection against *Legionella*.

The investigation included study on the spread, growth, and reduction of *Legionella* in domestic hot water systems as well as of authority requirements, standards, and research studies. This showed that due to biofilm the temperature requirements for treatment against *Legionella* are underestimated, just as the Danish temperature requirements are on the low end.

A risk assessment tool has been developed based on a recognized method and through adaptation of the found influence parameters with a view to making it usable in practice. The tool will contribute to a better clarification of both existing and new domestic water installations.

An electric booster unit ensures temperature monitoring and optimal control of the domestic water installation based on knowledge of *Legionella* growth and reduction. The solution will be able to support future adaptation and development of products for the temperature challenge for protection against *Legionella*.

Use of the relatively environmentally friendly hypochlorous acid allows for lower water temperatures according to those required for comfort. The project has showed that it is possible to bring high *Legionella* germ counts down to a tolerable level, which combined with the possibilities in relation to reducing energy and climate footprint makes it relevant to include it in the Danish building regulations.

2.2 Dansk resumé

Varmt brugsvand udgør en stigende andel af energiforbrug og klimaaftryk for bygninger, bl.a. fordi *Legionella* fordrer højere temperatur end der komfortmæssigt er behov for. Samtidig er *Legionella* blevet en voksende udfordring med flere sygdomstilfælde og en række dødsfald som følge af legionærsygdom. Danmark har en relativt høj forekomst, men også i udlandet er udfordringen stor. I projektet er gennemført en større udredning, samt udvikling og demonstration af tre foranstaltninger vedr. beskyttelse mod *Legionella*.

Udredningen omfattede undersøgelse af spredning, vækst og reduktion af *Legionella* i varmtvandssystemer samt af myndighedskrav, standarder og forskningsundersøgelser. Denne viste bl.a., at på grund af biofilm er temperaturkravene til bekæmpelse mod *Legionella* undervurderet, ligesom de danske temperaturkrav er i den lave ende.

Der er udviklet et risikovurderingsværktøj baseret på en anerkendt metode og gennem tilpasning af de fundne influensparametre med henblik på at gøre det brugbart i praksis. Værktøjet skal bidrage til en bedre afklaring af såvel eksisterende som nye brugsvandsinstallationer.

En elektrisk booster-enhed sikrer temperaturovervågning og optimal kontrol af brugsvandsinstallationen baseret på viden om *Legionellas* vækst og reduktion. Løsningen vil kunne understøtte fremtidig tilpasning og udvikling af produkter til temperaturudfordringen for beskyttelse mod *Legionella.*

Anvendelse af det relativt miljøvenlige hypoklorsyre giver mulighed for legionellasikring ved lavere vandtemperatur, dvs. svarende til det komfortmæssige behov, uden forøget legionellarisiko. Projektet har vist, at det er muligt at bringe høje legionella-kimtal ned til et tolerabelt niveau og at kunne fastholde det. Løsningen vil derfor kunne give klare fordele med hensyn til at reducere energi- og klimaaftryk og foreslås inddraget formelt i det danske bygningsreglement, såfremt specifikke dokumentationskrav opfyldes.

3. Project objectives

3.1 The objectives of the Project

The main objectives of the project:

- Development of a risk assessment tool for *Legionella*[1] in domestic water installations based on the utilization of existing knowledge and insight regarding the influence parameters.
- Development and demonstration of two solutions for prevention and control of *Legionella* in domestic hot water installations, respectively by temperature adaptation and use of biocide.

As a basis for fulfilling the stated objectives, an investigation of documentation and authority requirements regarding *Legionella*'s dependence on the influence parameters occurring in domestic hot water, including the temperature, had initially to be carried out.

3.2 The addressed and developed energy technology areas

The main technological area of the project is illustrated in Figure 1 and includes *Legionella* challenges in the domestic water installation itself.

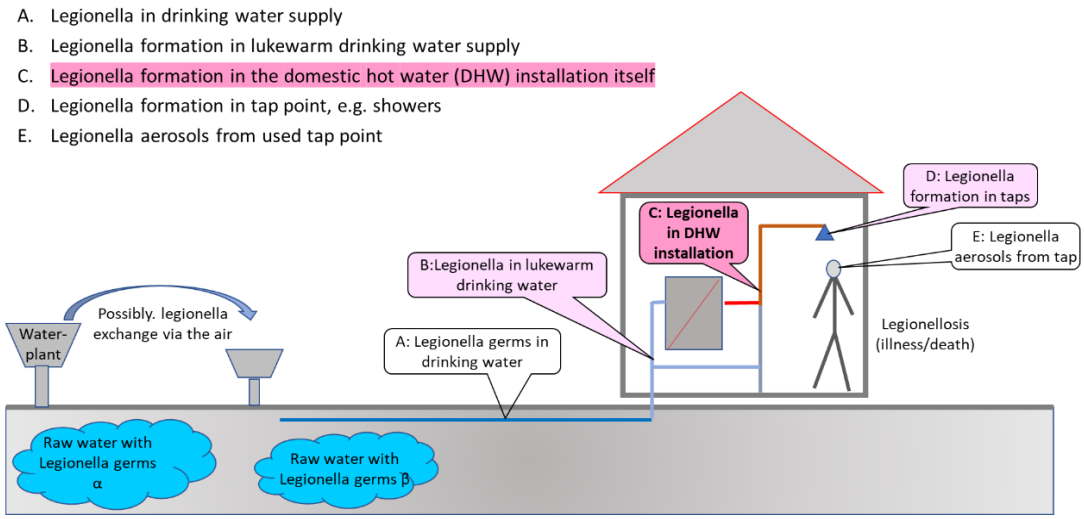


Figure 1 *Legionella* might occur in several stages on its way from water extraction to use, but the project's focus area is on the domestic hot water installation.

The developed and demonstrated technologies cover:

- a tool for risk assessment for *Legionella* in domestic hot water installation, to be used by technical building managers, as well as by servicing and controlling parties to identify and improve existing installations, or to support the design of new installations.
- a power heated unit connected to an existing heating system for domestic hot water and for controlling the temperature to fulfill the *Legionella* requirements.
- a biocide generator connected to an existing heating system for domestic hot water and for dosing the domestic hot water installation with a sufficient amount of hypochlorous acid (Neuthox) for necessary reduction of *Legionella*.

The project does not in detail concern with what happens at the tap points, e.g. a shower, even though this is ultimately of decisive importance for growth and aerosol formation and thus spreading and infection with *Legionella*.

[1] The spelling "*Legionella*" is used in the following corresponding to that used in the specialist literature.

4. Project implementation

4.1 Conducting of the project

The project was carried out based on the seven work packages including partners and tasks defined in the application and after evaluation with the following content (partners mentioned in brackets):

- WP1: Establishment of a basic for assessment (*Legionella* and resources), partly for *Legionella* influence parameters in water (DTI in collaboration with primarily SSI and VIA but also DCW and METRO THERM)
- WP2: Initial product solutions and the relationship and challenges to installation including to risk analyzes (Input from manufacturers (DCW and METRO THERM) and users (KAB, FF and PRS) coordinated by DTI)
- WP3: Development of risk assessment methods plus assessment of consequences for energy savings, climate impact and other resources (DTI in collaboration with primarily SSI and VIA and with input from DCW and METRO THERM)
- WP4: Product solutions development for specific installation types (On the producer and user side, respectively DCW, METRO THERM and KAB, FF and PRS, but overall coordinated by DTI and with supplementary input from VIA)
- WP5: Validation and improvement of methods for specific installation types (DTI in collaboration with primarily SSI and VIA and with input from others including demo, WP6)
- WP6: Demonstration of improved product solutions for specific installation types (Manufacturers, DTI and users, and with SSI responsible for *Legionella* tests and analysis)
- WP7: Project management and general communication - incl. final reporting (DTI in collaboration with the steering group and partners).

The interaction between the work packages is illustrated in Figure 2.

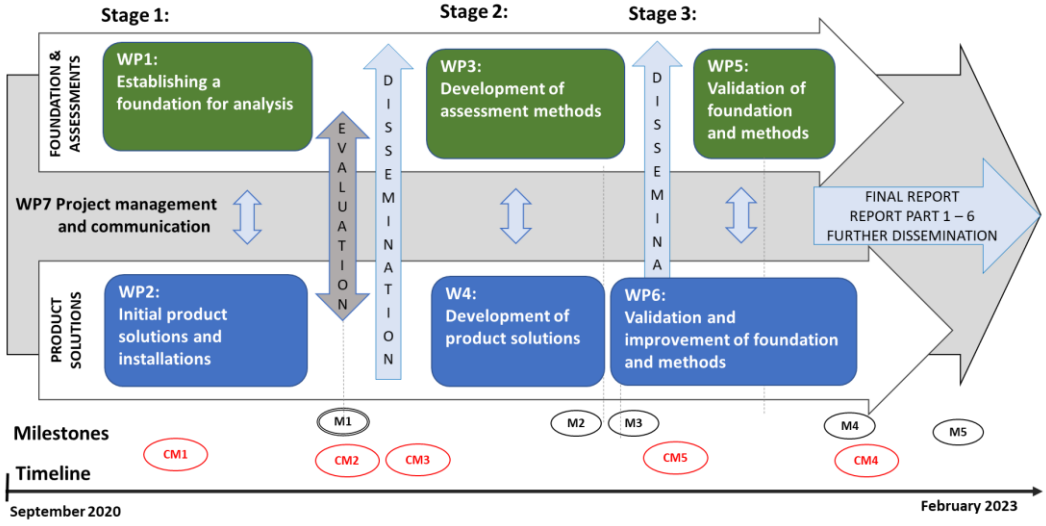


Figure 2 The division of the project into two tracks and 7 work packages (WP's).

The project schedule was extended by 4 months, especially due to challenges regarding agreements on demonstrations of the two developed product solutions. With starting on 1 September 2020, the project thus continued until 28 February 2023. The revised schedule corresponding to the implementation appears in Figure 3. The milestones have been followed with a few minor overruns and adaptation to the revised timetable.

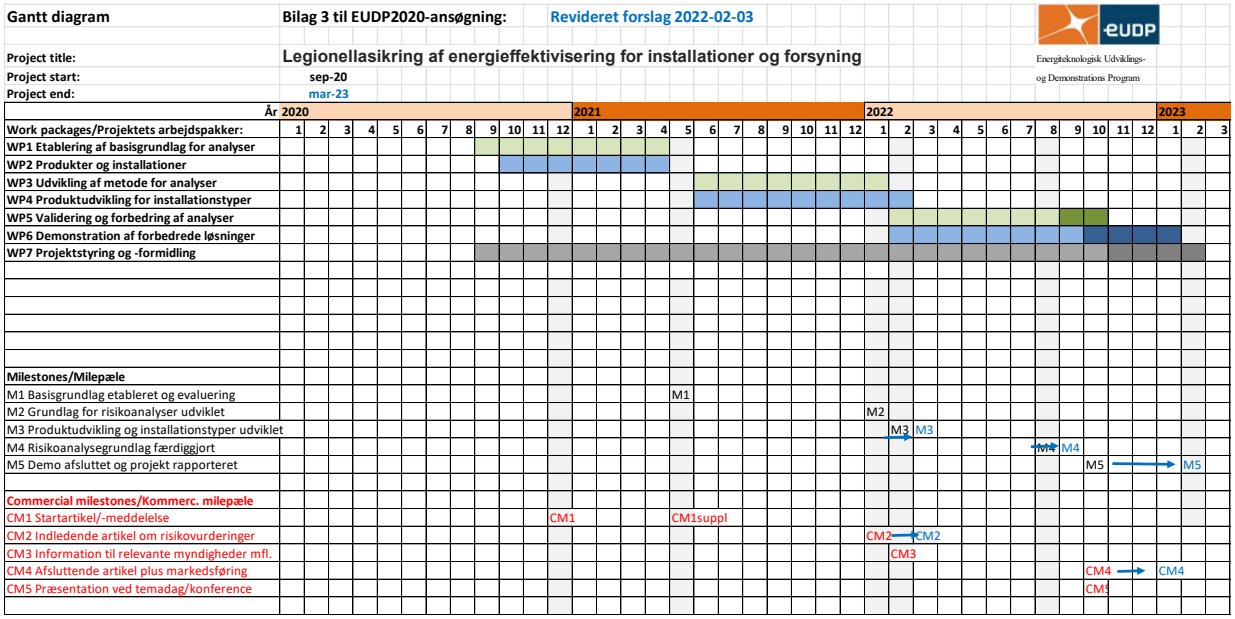


Figure 3 Gantt-diagram showing the time schedule for the work packages (WP) and milestones.

An evaluation meeting with participation of EUDP as well as the Danish Housing and Planning Authority (Bolig- og Planstyrelsen) was held 8 June 2021 after carrying out WP1 and WP2. During the course of the project several presentations have been given and articles published, see section 5.5 of this report.

The results of the relatively extensive work, including a major investigation of relevant Danish and foreign literature, were originally planned to be documented through internal notes and presentations. However, along the way there was a desire to summarize it in a more in-depth documentation, which resulted in the preparation of six published in-depth reports (part 1 to 6) in Danish. These reports are listed in section 5.5 of this report. This documentation also covers two conducted pilot studies about a possible influence on the large Danish geographical variation in *Legionella* regarding the importance of groundwater quality and district heating temperature, respectively. The latter also included a student project initiated by VIA.

The project group met twice a year for joint project meetings, where the overall project progress was presented and discussed, as well as plans for further work were made. In connection to this, meetings were held in the steering group and for discussion and decision regarding central and particularly important topics. The steering group included the corresponding representatives as the project group, but was supplemented by DTI with a chairman. In addition to the project meetings, many working group meetings have been held with parts of or the entire project group. Most joint meetings were from the very beginning held as virtual meetings due to Covid-19 (see Section 4.2). Virtual meetings have also been held with external parties, including external Danish experts and The University of Ghent.

4.2 Risks and other barriers including impact on the schedule

The most important barriers identified initially – and followed up in the project - were as follows:

1) Complexity due to the combined theoretical and practical aim: The research initiatives have been based on established collaborations, and with regard to the participants there have been great motivation and at the same time highly complementary and limited overlapping interests.
2) Lack of expert resources due to the need of expertise both in the installation side and on the microbiological side: There has been a great deal of stability in the project staff with only very few personnel changes. Engagement in other activities has in some cases caused delays which, however, have later been able to be caught up.

3) Collaborative challenges due to a relatively complex group with different interests and purposes: The activities have in general been based on established collaborations, and the participants have had great motivation and at the same time largely complementary and limited overlapping interests.
4) Overlapping measures in other projects/countries: The research and development in the area have been followed closely including in, what is going on in other countries. Several activities are going on internationally regarding *Legionella* in domestic hot water installations, but not with a great overlap.
5) Too close to practice in relation to the research and development-based, or vice versa: This has generally not been problematic.

Regarding the technological risks identified and followed up in the project:

- Basic technological challenges: The developed solutions have built on technologies that the companies each have experience with and insight into. For thermal compensation, it has been particularly challenging that the investigation showed a need for stricter temperature requirements, including for both compensation and disinfection. For the biocide solution (use of hypochlorous acid), the lack of official knowledge and acceptance is a particular challenge, as this is a relatively new technology.
- Risk assessments that are not sufficiently reflected in the product solutions: There has been ongoing interaction concerning the two product solutions, and for both a systematic analysis has been carried out, just as the importance of ensuring impact to the critical points of failure has been made clear.
- Statistical basis of the risk analyzes weak: The investigation showed and emphasized that the documentation base regarding the influence parameters was weak. The developed method has been adapted based on this, and with an increased focus on use as a practical tool.

Regarding the marketing risks identified and followed up in the project:

- Markets need for technology for *Legionella* protection of domestic hot water installations is uncertain: There has been a great deal of awareness of the need - and currently it is increasing due to the increasing extent of legionnaires' disease and an increased focus on energy savings and reduced climate footprint through reduced domestic water temperature.
- Markets needs covered by other solutions: Alternative solutions are offered, but there is nothing that has changed the competition and that makes utilization of the developed knowledge and technology less likely.
- Skepticism from environmental authorities regarding biocide solution in hot water: This is a challenge and there is still a lack of a Danish official position, but the increasing attention to energy savings and climate improvements has improved attention and expectation of a more positive future position. Furthermore, there is a realization that hypochlorous acid is relative harmless for the environment and could contribute with CO_2 and energy reduction.

The study showed that biofilms are often not sufficiently taken into account in terms of temperature protection against *Legionella*. This has affected the project and its implementation in different ways. Furthermore, it had to be noted that the available basis for documentation of the influence parameters that affect *Legionella* growth and reduction is relatively weak, which has also affected the development activities, including the developed risk assessment tool.

Already at the start of the project, Covid-19 gave rise to particular problems, as it proved difficult to hold physical meetings. However, this was compensated from the start by holding virtual meetings using Teams. Based on the fact that several of the partners knew each other in advance, the virtual meeting succeeded beyond all expectations and at the same time supported intensive holding of working group meetings.

Regarding demonstration of the developed product solutions, it proved somewhat more difficult than expected to arrange agreements with end users. This was mainly due to apprehension on the part of users about engaging in measures that could link users with *Legionella*-infected domestic water installations. At the same time, due to the high level of activity during the period, it was also difficult to get installers and others involved. As a result, a postponement of the project by 4 months was applied for and granted. Except this postponement the project has largely been carried out with the scheduled dismantling of milestones.

5. Project results

The results of the three main objectives are summarized in section 5.1 – 5.3 while section 5.4 covers the main results from the preceding investigation. The reporting through six in-depth reports (part 1 to 6) which are referred to in section 5.1 to 5.4, as well as the carried-out dissemination of the project's results, are described in section 5.5.

5.1 The risk assessment tool

A pilot tool for risk assessment of domestic water installations has been developed and is based on a systematic review of the domestic hot water installation and its components, as illustrated in Figure 4.

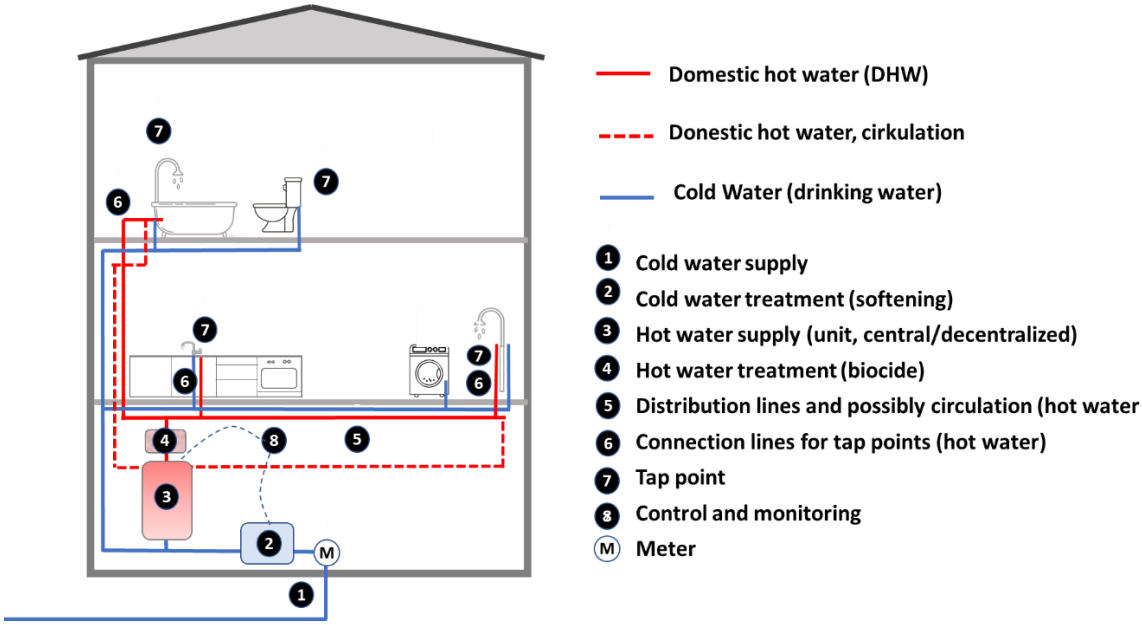


Figure 4 Figure 4 Risk assessment for Legionella via review of the domestic water installation.

The tool called *LegionellaRisk* is based on the use of Failure Modes and Effects Analysis (FMEA).

This basis was chosen as it provides a simplified approach when reviewing the installation and thus with the possibility of being used for the main target group consisting of those technically responsible and servicing building installations. At the same time, it is a relatively affordable method in terms of resources. An in-depth statistical analysis did not prove realistic due to lack of input data regarding the central influence parameters and their importance for *Legionella* growth/reduction, including the influence of temperature. Further, there is a geographical variation in the incidence of legionnaires' disease in Denmark of the order of magnitude of a factor 5, which currently cannot fully be explained.

For each component, risk factors are included with associated questions and ratings according to the influence parameters that may have a significant impact on the occurrence of *Legionella*. This is illustrated in Figure 5. Based on an overall review of the domestic water installation, an overall risk is determined through a simple addition of the risk factors. The assessment covers hot water installation with any circulation but also the water supply itself with possible *Legionella* growth due to pipes with lukewarm water, this is to say above 20 °C.

The risk assessment shows where there are particular risks and opportunities for improving the installations, as well as it includes considerations of supplementary temperature and biocide treatment. Through subsequent activation of these options, the overall risk can be reduced. The risk for the domestic hot water installation can be compared with the risk of similar installations via a review of all listed risks.

Delsystem	Influensparameter		Konsekvens		Sandsyn./frekvens/antal		Kontrol		Risiko-bidrag
System/ komponent	Parameter (vælg fra liste)	Værdi (vælg fra liste)	Potentiel effekt (kan overskrives)	KONS	Mulig årsag (vælg eller skriv)	SAN	Procedure (vælg eller skriv)	DET	RIS
	Hvilken parameter undersøges?	Hvilken værdi antage parameteren? (husk at angive konsekvens, hvis liste ikke benyttes)	Her angives effekt (autoudfyldes - kan overskrives)	Konse-kvens (auto-udfyldes)	Årsag: Vælg fra liste eller skriv alternativ årsag Tilføj evt. forklaring	Hvor ofte sker det? (100 % = altid)	Er der en procedure til at undgå konsekvensen?	Effektivitet	Risiko-bidrag
				0		100%		0%	0
Vandforsyning	Legionella	Legionella.spp; Der er foretaget målnger og konstanteret Legionella	Legionella spp. observeres næsten altid	5		100%		0%	31
	Temperatur	0 - 20 °C; Temperaturen OK	Ingen vækst af farlige bakterier	0		100%		0%	0
				0		100%		0%	0
Koldtvandsrør	Temperatur	0 - 20 °C; Temperaturen OK	Ingen vækst af farlige bakterier	0		100%		0%	0
	Temperatur	20 - 25 °C; Temperaturen på det kolde vand er for høj	Risiko for vækst af Legionella	5	Dårlig isolering	100%		0%	31
	Døde_ender	Død ende (kold); Død ende tilsluttet koldt vand, < 20 °C	0	0	24 stk. sjældent benyttede tappesteder ved skraldeskate	100%		0%	0

Figure 5 The risk assessment tool illustrating initial risk factor screening.

In addition to the risk from the review of the domestic water installation, parallel assessments can be included, e.g. based on real *Legionella* test and measurement or via determining the risk based on experiences according to the age and immediate condition of the installation.

At the same time, it must be stated that it is essential that the *Legionella* protection covers all dead ends and that rarely used tapping points are taken into account. Furthermore, the risk assessment does not include the effect of the tap location itself, including its possible breeding ground for local *Legionella* and spread via aerosols, e.g. in a shower, because this was not within the project's scope.

The pilot tool has been developed and adapted based on practical domestic water installations at KAB. The tool is intended for carrying out risk assessments for larger, new, and existing domestic hot water installations as well as for principle assessments for smaller installations. The purpose of the tool is to achieve sufficient protection against *Legionella* in the installation.

Through continuous iteration, the tool is assessed to be able to form the basis for a systematic review of domestic water installations with the possibility of subsequent improvements. This could hopefully lead to a reduction of the risk of *Legionella*, and a de crease of the Danish incidence of legionnaires' disease. At the same time, account must be taken of any clarifications determined by the upcoming implementation of the new EU drinking water directive (on the quality of water intended for human consumption).

Regarding the consequences for energy consumption, climate footprint, environment and economy of different solutions for better protection against *Legionella* were, among other things, identified:

- The necessary higher temperatures for the domestic hot water installation, than what the comfort needs require, have a considerable price in the form of increased energy consumption, increased climate footprint, environmental impact and costs, which strongly challenges society's energy and climate wishes.
- There are alternative solutions for temperature protection, including the use of a biocide, for example the hypochlorous acid referred to in the project (Neuthox), but here, among other things, authority instructions regarding documentation requirements for design and use, need to be adjusted to get all benefits.

Finally, it is concluded that an objective assessment of the consequences of various solutions for energy consumption, climate footprint, environment and economy must most appropriately be carried out through the work that is currently underway regarding life cycle analyzes (LCA) and which, according to the authorities, must be in place by 2029 at the latest.

For further details, see in-depth report part 4.

5.2 Electric booster unit for monitoring and protection domestic hot water

METRO THERM A/S has developed an electric booster unit (El-booster) which can be connected to the existing domestic hot water system.

The El-booster has the function of both monitoring the domestic hot water system by continuously measuring the temperature in the hot water producer, and in the return of the circulation line. At the same time, it also measures, how cold the cold water is that flows into the hot water producer, as well as how often the water is changed, and the velocity of the water in the circulation line. In this way, the control in the booster can monitor the most important influence parameters from the risk assessment, and thus continuously check whether the water complies with the current Danish requirements. Further it can give an alarm if any of these are below the limit values, and thus reduce the risk of the use of the hot water installation.

The electric booster can also carry out a thermal heat treatment comprising a thermal compensation and a disinfection of the producer at 60 – 65 °C (see the concepts for protection against *Legionella* in section 5.4), when the control has calculated that there is a possibility that the *Legionella* count has doubled. This is done by heating the hot water via an electric water heater to a minimum of 65 °C in the hot water producer, and a minimum of 60°C on the return from the circulation circuit. Further it can keep each of these minimum temperatures for at least 30 minutes, so that most *Legionella* bacteria die. The thermal disinfection is most effective on systems with circulation, as the entire domestic hot water system is heated to at least 60°C. However, not the actual tapping points and coupling pipes for these, unless they are you manually opened.

The booster with circulation is illustrated in Figure 6.

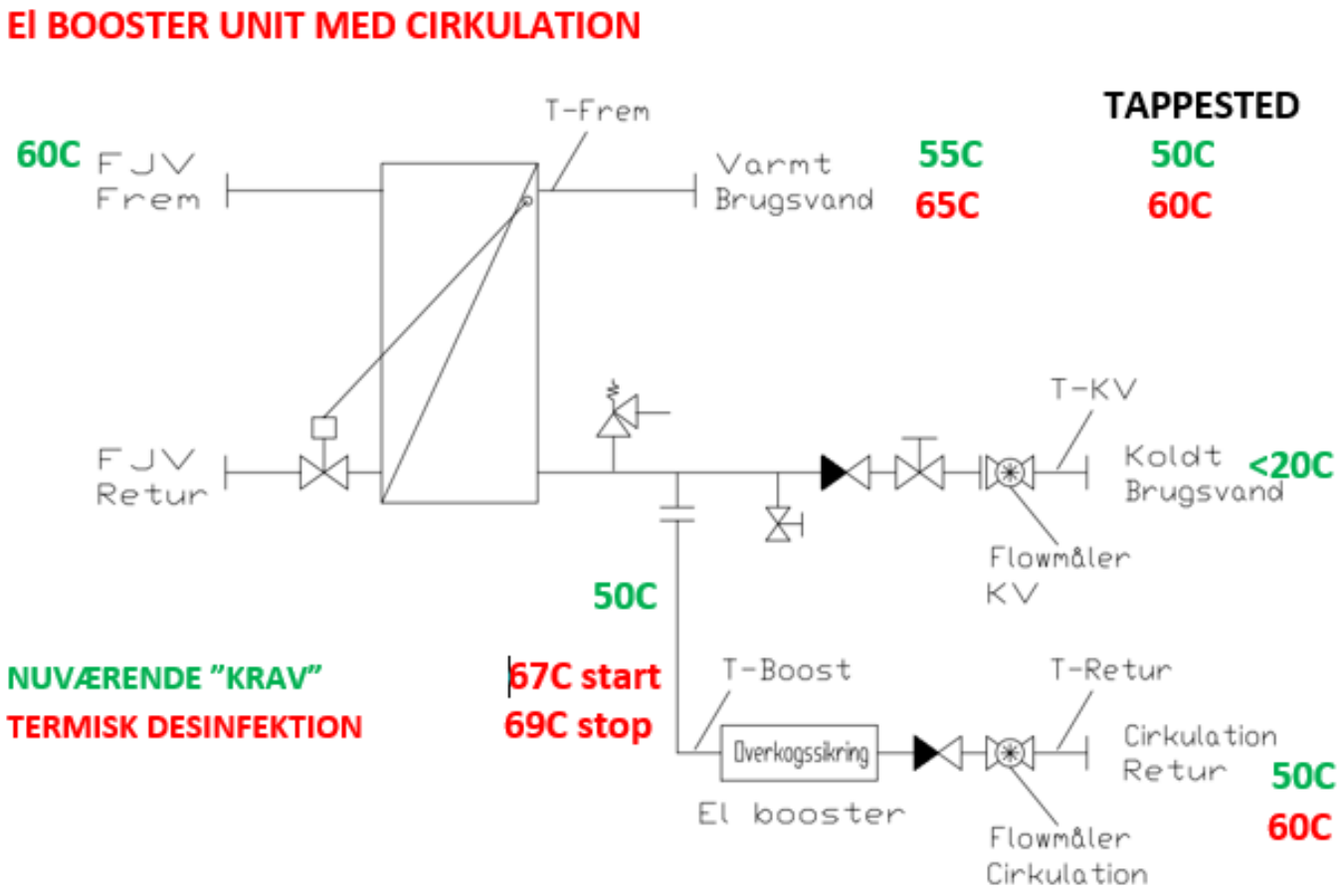


Figure 6 Electric booster unit (El-booster) with circulation of domestic hot water.

For systems without circulation, our field test, which has been running for nine months (see later), has shown that it is necessary to open the tapping points at the end of the thermal disinfection. As otherwise it will only be the domestic hot water producer that is heated, and any biofilm and *Legionella* that may be found in the pipe system will not be killed. In the long term, therefore, automatic tapping points can be developed with great advantage, which cooperate with the control of the El booster. It can thus open for a small flow through the tapping point, when the EL-booster control during the thermal disinfection gives a signal for this.

Laboratory test

To ensure that the system with El-booster, and the control of this, works as intended, extensive tests have been carried out in the METRO THERM laboratory, where both types of El-booster units, with and without circulation, have been tested. The laboratory tests are illustrated in Figure 7, and the tests ensures that the various control functions, as well as alarms, work as they should.

Complete control with attached sensors and cables

Figure 7 El-booster with circulation of domestic hot water.

Field test / demonstration

The selected experimental site was a single-family house with district heating, where the heating of the domestic hot water takes place in a plate heat exchanger, and where the system is without circulation.

The temperature of the domestic hot water from the plate heat exchanger, is controlled by the built-in control valve in the district heating unit. This had a standby function which means that the water in the plate heat exchanger is kept at 44 °C during stand by, and only during tapping the temperature is raised to 53 °C.

This has resulted in the El-booster carrying out a thermal disinfection of the domestic hot water producer every night, as the doubling time for the number of *Legionella* has already been reached after 18 hours. However, it was ascertained that the daily thermal disinfection of the domestic hot water producer alone, had no effect on the *Legionella* count at the two tapping points, the first four months. In fact, there was a sharp increase in the number of *Legionella* during the four-week summer holiday without water consumption. This, however, returned to normal after two weeks of normal water consumption.

Only when a thermal disinfection of the entire system was carried out (exchanger + pipe system + all tapping points) the *Legionella* counts dropped down completely, so that no *Legionella* counts could be measured the day after the thermal treatment. The thermal disinfection was carried out by first activating the El-booster, and then continuing the thermal treatment with a small flow of approx. 1 L/minute in each of the tapping points, one by one. The duration of the thermal disinfection of each tapping points was approx. 20 minutes,

and with a temperature of 63°C. With the continued daily thermal disinfection of the domestic hot water producer alone, the count has remained at this unmeasurable 0 CFU/L for the next 125 days.

Through the project, an El-booster solution has thus been developed and tested which works as intended, by continuously monitoring the domestic hot water system, and which gives an alarm if the important influence parameters fall outside the limit values. This will help to increase safety against *Legionella*, as well as there will be a focus on any problematic operation of the domestic hot water system.

The thermal disinfection that the El-booster carries out on domestic hot water systems, with circulation, will be most effective, as almost the entire system (apart from tapping points and dead legs) is heat-treated. However, the thermal treatment in a domestic hot water system, without circulation, is only really effective as disinfection when the flow is also opened all the way to the tapping points, resulting in the entire system to be heated to a minimum of 60°C.

Furthermore, the El-booster also provides a better overview of the operation of the domestic hot water system, and thus also the opportunity to reduce temperatures if they are too high. And thereby achieve energy savings.

For further details, see in-depth report part 5.

5.3 Biocid (hypochlorous acid) protection against *Legionella*

With a new concept/set up and two field tests having successfully proved the effectiveness of the technology the original project objective set by DCW was achieved. After activating the generator a drastic reduction in the number of cultivable *Legionella* bacteria was achieved, although the temperature in both cases was lower than permitted in Denmark.

Many buildings in Denmark have difficulty maintaining a constant temperature of 50°C in their hot water systems and lack the resources to upgrade these systems. However, one could solve these problems, if tackled correctly, by legalizing the installation of hypochlorous acid (HOCL) units and thus eliminating reliance on high temperatures to combat bacteria.

With the completion of a thorough risk analysis and two field studies as well as the installation of over 250 generators throughout Denmark to treat *Legionella*, a basis for concluding that the technology works has been established. Furthermore, the field studies show that the technology is also efficient at lower temperatures than those currently permitted.

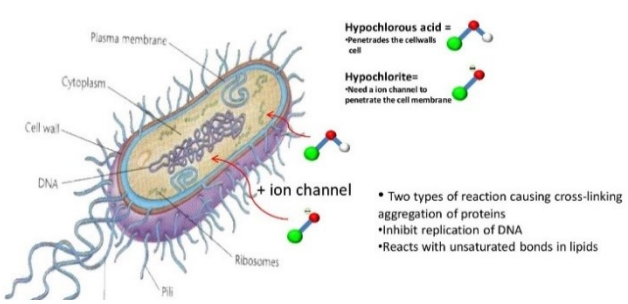
If legislation makes the use of NEUTHOX® technology to compensate for high temperatures possible, substantial benefits could be achieved. Denmark alone can save DKK 1 -2 billion every year if this solution were widely implemented as standard. Countries whose district heating systems operate at temperatures of 55°C rather than the 50°C stipulated in Denmark could save even more.

The implementation of lower-temperature district heating requires technologies that can treat hot water systems for *Legionella* bacteria without using heat (because sufficient heat is not present). This is the missing piece that district heating companies need to achieve a cost-efficient solution that is safe to use. To date, end-users have had to install energy-intensive booster units in order to run the systems according to the regulations. This technology could be the last piece of the puzzle.

How is it done?

An electrolysis generator converts salt, water and electricity into a mild but highly effective disinfectant solution known as hypochlorous acid (HOCL). This has proven far more reactive than chlorine when the same concentrations are compared. The human immune system uses HOCL as one of its most effective ways of combatting infections.

Both field studies clearly show a drastic reduction of viable *Legionella pneumophila* after generator dosing was activated. In both cases the temperature at the end of the system was below the permitted 50°C, yet the water continued to be treated against *Legionella* bacteria with high efficiency.

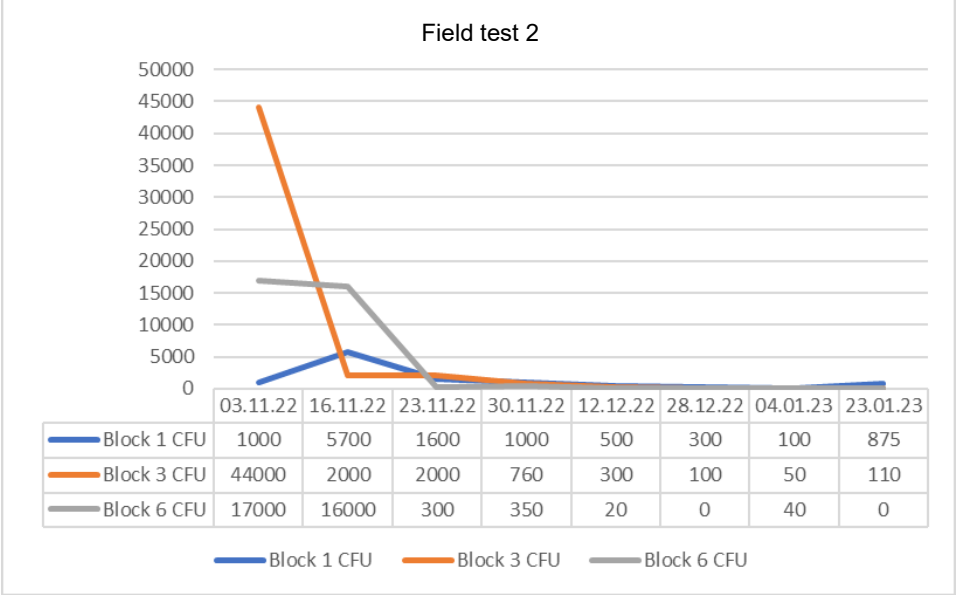


The neutral charge of HOCL enables it to easily penetrate the cell wall of any bacteria. This also disables bacterial ability to generate resistance, if the HOCL concentration is high enough as nothing will survive.

Figure 8 Hypochlorous acid

The risk analysis shows that the generator must be capable of emitting alarm signals and of regularly sending a signal to show it is active. An alternative is to have manual checking routines in place and to keep a logbook to validate that the generator is running as intended. The installation of a connection to the generator is recommended to eliminate human errors.

The results for the field tests are described in graphs in Figure 9.

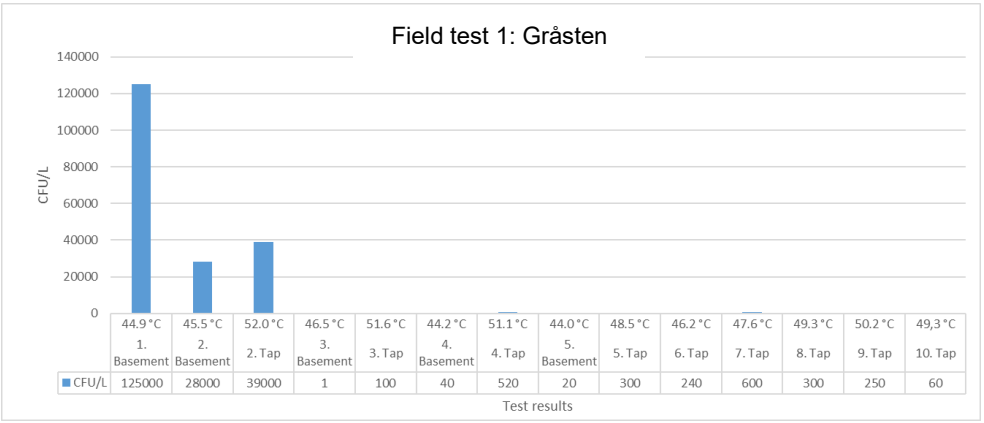


	03.11.22	16.11.22	23.11.22	30.11.22	12.12.22	28.12.22	04.01.23	23.01.23
Block 1 CFU	1000	5700	1600	1000	500	300	100	875
Block 3 CFU	44000	2000	2000	760	300	100	50	110
Block 6 CFU	17000	16000	300	350	20	0	40	0

Field test 2 shows that we commissioned the DCW NEUTHOX® generator on 10 November 2022.

A general reduction is then seen, with small deviations caused by the release of biofilm.

The general tendency is a reduction followed by the maintenance of a low *Legionella* level.



	44.9 °C 1. Basement	45.5 °C 2. Basement	52.0 °C 2. Tap	46.5 °C 3. Basement	51.6 °C 3. Tap	44.2 °C 4. Basement	51.1 °C 4. Tap	44.0 °C 5. Basement	48.5 °C 5. Tap	46.2 °C 6. Tap	47.6 °C 7. Tap	49.3 °C 8. Tap	50.2 °C 9. Tap	49,3 °C 10. Tap
CFU/L	125000	28000	39000	1	100	40	520	20	300	240	600	300	250	60

Field test 1 shows that we commissioned the DCW NEUTHOX® generator between samples 2 and 3.

A drastic reduction is then seen, which is continuously maintained below the threshold value.

Figure 9 Demonstration of the DCW solution using hypochlorous acid (NEUTHOX®).

For realizing the full potential of the technology, legislation must be amended to take new technologies into account. Updating the legislation will lead to numerous benefits such as energy savings, CO_2 reductions, fewer complications, less risk of human errors, elimination of scalding risk, and ultimately cost savings.

Further to the conclusion of this EUDP report, DCW will open a dialogue with the authorities about the options for incorporating its results in future legislation. Among the proposed topics is an exemption from the temperature requirements when HOCL is used to suppress bacteria in water systems:

- Exemption from the 50°C requirement if a generator providing permanent preventive *Legionella* treatment, such as DCW's NEUTHOX® generator, is installed.
- Exemption from the requirement of a system's having the capacity to boost to 60°C if it provides permanent preventive *Legionella* treatment. This should apply both when existing buildings are retrofitted and when new ones are constructed.

For further details, see in-depth report part 6.

5.4 Results from the basic investigations

***Legionella* occurrence and the significance for energy, climate, environment and economy**

- The Danish incidence of legionnaires' disease is among the highest in Europe and colonized DHW systems are probably the main source and is increasing with approximately 300 cases of disease and 30-40 deaths annually. The most widespread and most dangerous species of *Legionella* in domestic hot water installations is *Legionella pneumophila*, which is estimated to cause more than 90% of the Danish cases of legionnaires' disease.
- In Denmark and abroad, *Legionella* prevention is primarily handled by using an appropriate temperature for the domestic hot water. However, this is challenging for energy and climate as the necessary water temperature to avoid *Legionella* must be 50 °C or above, while the comfort requirement is only 45°C. The reasons for this are greater heat loss and poorer opportunities to utilize waste heat and renewable energy with low temperatures. The costs in Denmark for the extra heat loss have been estimated to an expense of 1 – 2 billion DKK annually.
- Due to increased interest and plans in Denmark and abroad, especially in the EU, in using district heating and heat pumps based on waste heat and renewable energy with low temperatures, the temperature challenge is gaining increasing importance.

Causes of and combating *Legionella* in domestic water installations

- The temperature is the most important influencing parameter for the development and reduction of *Legionella* in the installations, but several other parameters come into play, including the water flow conditions, the water quality, the pressure, the affected materials, and the presence of biofilms. However, the investigation has shown that the knowledge of the conditions that influence the growth and reduction of *Legionella* is often poorly founded or unclear documented, i.e., it has not been clarified how temperature and flow conditions play a role together.
- It is generally agreed that *Legionella pneumophila* develops at temperatures higher than 20 – 25 °C and lower than 45 - 50 °C. On the other hand, due to e.g. biofilm formation, there is a considerable uncertainty when it comes to the temperatures required for the reduction of *Legionella* – and for how long the temperatures must be present. It is the biofilm that provides fertile ground for the growth of *Legionella* and which affects the reduction of *Legionella*. Due to biofilm, higher temperatures are often needed than previously recognized and used. This is very unfortunate, since at the same time the energy and climate needs, as stated earlier, are moving in the direction of lower temperatures.
- If the water temperatures for the total installation are kept at 50 °C and higher, the investigations indicate that the domestic hot water installation will normally lie within the recommended max. 1000 CFU/L. At a water temperature of 55 °C and higher, the risk of *Legionella* is very low.

- When lower temperatures then 50 °C are compensated by increased temperatures over a suitable period of time (periodic heat treatment), the current standards and guidelines generally require too low temperatures / short periods of time to break down the *Legionella*. However, no clear basis has been found for establishing these relationships. The best basis therefore seems to be to start from some test results which have been used by Ghent University in connection with their work with thermal/hydraulic simulation models in the effort to find optimal solutions in the interaction between *Legionella* protection and energy efficiency.
- Temperature disinfection requires according to a number of recent studies a temperature of 65 – 70 °C or more to ensure the reduction of *Legionella* against previously often used 60 – 65 °C - and further it must be with the tap point activated. These temperatures are particularly challenging due to potential scalding when opening the tap, and furthermore, in Denmark, it is very unfavorable for the cleanliness of the pipes due to the high lime content in the water.
- Disinfection through elevated temperature is often used in combination with thermal compensation as a preventive measure and using 60 - 65 °C for the heating system itself. However as mentioned above it seems that 65 °C or more is necessary to combat an established biofilm. Further a cyclic operation with high temperatures can lead to thermotolerant *Legionella*.
- The flow conditions are also very important, and particularly a specific challenge is dead ends, but documentation of the required water speed and water replacement is extremely sparsely elucidated through laboratory tests and often with conflicting results.
- In Denmark, there is a significant geographic variation in the incidence – over a factor of 5 – in legionnaires´ disease, this might be associated with different levels of *L. pneumophila* and occurrence of strains with different virulence in the domestic water installations among the Danish cities and provinces. The conducted pilot studies on the potential influence by the water quality, indicate that there may be a correlation, so that an increased content of lime in the groundwater may cause a higher content of *Legionella*. However, the variation also shows that a number of other influence parameters probably play a role. Comparing the historical temperature data from reported district heating supplies with the incidence of legionnaire's disease, there is no direct indication that a reduced district heating temperature (which as mentioned is highly desirable in terms of energy and climate) has led to an increasing incidence at the specific location.
- Especially due to the challenges with the necessary hot water temperatures, the use of biocides, microfilters, ultraviolet light (UV), ozone and others are often listed as alternatives. Due to the aim of the project particular focus in the investigation has been on the use of hypochlorous acid, which was not previously used to such a large extent, but in recent years it has become more relevant because of its relatively low environmental impact, high efficiency and that it is safe to handle.

Various authority requirements and instructions regarding *Legionella* in water installations

- There are significant differences in the *Legionella* related temperature requirements for domestic water installations in the various countries, despite several coordination measures. The current Danish authority requirements for temperatures of 50 °C at the tapping point and 55 °C in the heating part are considered acceptable but are on the lower side compared to the temperature requirements in several other countries.
- The biggest Danish challenge is assessed to be that the requirements are often not complied with in practice, which applies to both old and new facilities. For the small facilities this may be due to a misconception, as previously the perception was that small installations were not as critical as large installations. Non-compliance with the temperature requirements for old installations is often due to the system not being properly regulated or equipped with circulation valves ensuring the correct temperature in the entire circulation circuit. Other reasons can be, for example, that there is insufficient heat capacity available for the whole system.
- The current Danish requirements, which are laid down through the Building Regulations ("Bygningsreglement") and the related instructions ("Rørcenter anvisninger"), partly include the common European standards that exist in the area, but the Danish requirement for a maximum temperature of

65 °C deviates, as it was added because of the high lime content in the Danish groundwater, and since corrosion can play a role.

- Biocides or other alternatives to temperature treatment are often mentioned in the instructions, but like abroad they are in the Danish authorities' guidelines only explicitly mentioned. Based on the instructions, the importance of being able to document the effect of the biocide all the way to the tap point is generally emphasized. To implement the benefits of this technology, it needs to be a priority to move it from instructions to optional alternative in legislation.
- The new EU drinking water directive from 2020 (Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption), which among others is based input from WHO, will sharpen attention and demands both regarding *Legionella* in domestic water and risk assessment as a preventive element.

Conclusions regarding concepts for protection against *Legionella* in domestic water installations:

Based on the completed study and the other research, the following terms are defined and used in the project:

- "Thermal maintenance" based on a temperature throughout the installation of a minimum of 50 °C or 55 °C, resulting respectively in good and high protection against *Legionella* if outlets are used frequently etc.
- "Thermal compensation" where periodic lower temperatures of 45 - 50 °C are compensated by generally higher temperatures according to usual growth/reduction *Legionella* curves, but with careful consideration of the presence of biofilm and that taps and water outlets not necessarily are treated with the hot water.
- "Thermal disinfection" at temperatures of 60 - 65 °C, which typically results in the removal of 90% of cultivable *Legionella*, or at 65 - 70 °C, which typically results in the removal of almost all cultivable *Legionella* and biofilm. The disinfection of the whole installation can however only be achieved if dead legs are removed and all taps and water outlets are treated in an appropriate period with the given temperatures.
- "Periodic heat treatment", which covers a combination of thermal compensation and thermal disinfection, but often carried out at 60 - 65 °C, which typically results in the removal of 90% of cultivable *Legionella*, and further often only covering the heating unit, which can give a false sense of protection if it is not combined with open taps.
- "Biocide compensation", where a biocide such as hypochlorous acid in a suitable concentration protects against *Legionella* formation.
- "Biocid disinfection", where a biocide is used in a sufficient concentration to remove biofilm and *Legionella*.

For further details, see in-depth Part 3, Section 5.7

Proposed developments regarding prevention and control of *Legionella* and resources optimization

In addition to the measures described in sections 5.1 - 5.3, the following development measures with future significance must be listed:

- Official clarification of documentation requirements regarding alternative solutions for temperature treatment including in particular the use of biocides, i.e. hypochlorous acid/Neuthox.
- Official clarification of the potential savings in money, energy and CO_2 by introducing alternatives to temperature.
- On line/in line measurement methods, i.e. where, via lab-on-a-chip, *Legionella* is measured directly in pipes, containers, etc. and with a fast response time will in the long run provide the opportunity for continuous demand management, but the work with this seems currently in a waiting position.
- Other new technology in addition, including interaction between treatment and site of tap, and heating closer to the place of domestic water demand.Teaching and follow-up control in order to ensure compliance with the Danish requirements regarding *Legionella* and domestic water installations, including possible involvement in energy labeling and energy audits.

- Well-documented simulation model for determining the relationship between temperature, flow conditions for *Legionella* growth/death and with a view to supporting energy and climate-optimal dimensioning of domestic water installations, cf. the simulations model from Ghent University and REHVA (The Federation of European Heating, Ventilation and Air Conditioning associations).
- Initiatives with a view to strengthening knowledge about the influence parameters that are important for the growth and reduction of *Legionella* in water installations. This certainly also applies to a clarification of the significant difference of a factor 5, which applies to the geographical variation of legionnaire's disease in Denmark.

For further details, see in-depth report part 1 to 3, including part 3, section 5.7 that clarifies the established concepts regarding Legionella protection of domestic hot water installations.

5.5 Dissemination of results including six in-depth sub-reports

Dissemination by conferences, standardization, articles etc.:

An evaluation meeting after carrying out WP1 and WP2 was held 8 June 2021 and with participation of the Danish Housing and Planning Authority (Bolig- og Planstyrelsen) as well as the EUDP secretary. During the further course of the project, the results have been disseminated via 12 presentations and published presentations at thematic days at DTI covering domestic hot water installations and *Legionella*. The days which were held in Taastrup on October 12, 2021 and September 27, 2022. For links see Section 8 Appendices.

The results of the project have also been disseminated to varying degrees via project partners' participation in standardization, including in DS S314 "Water supply" and DS S316 "Heating and cooling systems in buildings", as well as in advisory tasks for Danish authorities.

The project has been presented in the following articles, for links see Section 8 Appendices:

- Nye veje til bekæmpelse af *Legionella*, Tekniq, Dansk VVS, november 2020
- Lavtemperatur og legionellarisiko – et udfordrende dilemma (Eng: *Low temperature and Legionella risk – a challenging dilemma*), Teknologisk Institut, 15. marts 2022,
- Teknologisk Institut og SSI advarer: Sætter vi temperaturen ned på det varme vand øges risikoen for *Legionella*, Ingeniøren, 14. marts 2022
- *Legionella i brugsvand øger behovet for nye løsninger*, HVAC, april 2023.

The six published in-depth reports (part 1 to 6) and other information from the project:

1. *Lokale influensparametre for Legionella i brugsvandsinstallationer*, dealing with the different influence parameters and their specific significance for the development of *Legionella.*
2. *Incidens af legionærsygdom og mulig geografisk influens,* which sheds light on the geographically distributed incidence and examines possible causes for the very significant Danish variation.
3. *Myndighedskrav samt undersøgelser.* Authority requirements as well as studies that investigate authority requirements, instructions, guidelines and R&D studies with a focus on domestic water installations, *Legionella* and energy conditions*. Furthermore, the results are summarized with input from parts 1 and 2 and for use in parts 4 – 6.*
4. *Legionella risiko- og ressourcevurderinger,* which deal with the development of a tool for assessing the risk of *Legionella* in domestic water installations and state consequences for energy, climate, environment and economy, as well as provide suggestions for improvement.
5. *Legionellabekæmpelse i brugsvand gennem temperaturbehandling*, which deals with the development and demonstration of a solution for temperature control and management.
6. *Legionellabekæmpelse i brugsvand ved anvendelse af biocid*, which deals with the development and demonstration of an improved solution for biocide dosing.

Project Web page and other Web pages: Information about the project, its course and the resulted six in-depth sub-reports are published on a project website in the domain of DTI. This page as well as the pages for the other dissemination activities follows from section 8.

6. Utilisation of project results

6.1 Utilisation of the project results by the partners

Subsequently, it is described how the project's technological results as well as the knowledge gained from the completed investigation are used by the individual partners.

METRO THERM A/S:
Through the project METRO THERM has acquired significant knowledge about *Legionella* and protection against it. In addition to the developed El-booster, this knowledge will also be used in our existing products, such as heat pumps, district heating units and electric water heaters. As well as in the development of future products.
It is currently unclear whether we will market the El-booster as a separate product, or whether we will instead incorporate its functions into new combined products. At present, this has meant that we have changed our standard settings, of the domestic water temperature, in our heat pumps. And thus made these products more *Legionella*-proof.
Finally the knowledge provided through the project should also be used/clarified in standards, guidelines and in the Building Regulations. It will therefore be natural that this knowledge is taken into account in the current work, with the revision of the Danish Water Standard DS439.

Danish Clean Water (DCW):
We have since 2015 shown the effect of the technology, with more than 250 generators installed as a barrier against *Legionella*. With this new angle, that it also is possible in lower temperatures, it opens for energy savings, cost savings, CO_2 reductions, energy renovations, but most important, increased safety for the users.
DCW will with the evidence from the field tests in this EUDP report, prove that there is an untouched energy reduction potential. With an integration of this new technology in the legislation, the reduction potential is around 4 billion each year in Denmark.
We will navigate in the slipstream of the district heating companies, that have big interest in making low temperatures safe. If legislation is changed as proposed, we anticipate to double the turnover every year for at least the next 3 years.

Teknologisk Institut/ Danish Technological Institute (DTI):
DTI will as a GTS (approved technological service institute) use the strengthened knowledge regarding *Legionella* in water installations achieved from the extensive investigative work and the interaction with the other partners. Development of the risk assessment tool has brought increased knowledge of risk assessment as well as increased knowledge of the conditions that have the greatest importance for the development and prevention of *Legionella* in domestic water installations.
With this as a background, two theme days have been held during the project period with a total of over 150 participants. Furthermore, the developed knowledge is included in connection with the Institute's consultancy and courses within domestic water installations.
In addition to being part of the Institute's commercial activities, the accumulated knowledge about *Legionella* and hot and cold water installations will be included in connection with the Institute's consultancy and activities for Danish authorities as well as in standardization work, including the revision of the Danish Water Standard DS439.

Statens Serum Institut (SSI):
Through the project and its collaborations, SSI has gained an increased insight into the overall knowledge picture regarding *Legionella* in domestic water installations, which will be beneficial both in connection with its Danish work and in interaction with corresponding foreign bodies. Among other things will it be able to contribute to a strengthened effort in relation to the local follow-up in connection with confirmed cases of legionnaire’s disease derived from legionella-contaminated water installations.

VIA University College
VIA Built Environment, Energy, Water & Climate covers, among other things, teaching and research regarding energy efficiency and drinking water treatment and finds that the project's results and cooperation will be able to strengthen these areas. In connection with the project, a student project connected to the Climate and Supply Engineering education has already been completed, where specific knowledge has been able to be utilized. Project findings of the connection of water quality with risk of *Legionella*-growth has also been included in a 3rd semester course in Water Quality – chemistry and microbiology. Similarly, it will be possible in the future to further utilize knowledge gained and relationships with regard to studies within *Legionella* and domestic water installations.

Fredericia Fjernvarme
Fredericia Fjernvarme pays close attention to the *Legionella* problem and its negative consequences for a continued reduction of temperatures in the district heating system, just as it plays into Dansk Fjernvarme's interests. The knowledge and experience gained will be of considerable use in further work, including achieving the best solutions in terms of energy, climate and environment, such as regarding the special issues regarding low-temperature district heating and how the bill for *Legionella* control is fairly distributed.

KAB
With 65,000 tenancies - including nursing homes - KAB has had a significant interest in the project and the opportunities to utilize the knowledge gained, as the *Legionella* problem occupies a significant place in the day-to-day work with the installations. At the same time, KAB believes that considerable knowledge and experience have been gained through the project regarding both risk assessment and various technical solution options which will presumably be utilized in the further work.

Projektkontoret - Region Sjælland:
As office for the design of the new university hospital in Køge ("Universitetshospital Køge") there is a lot of focus on the *Legionella* challenge, and the knowledge gathered from investigative work and the interaction with a number of relevant actors in the field will be beneficial in future work.
With the background of participation in the European standardization work regarding heat pumps, it has also been able to provide relevant input for this work.

6.2 The future market and the further exploitation

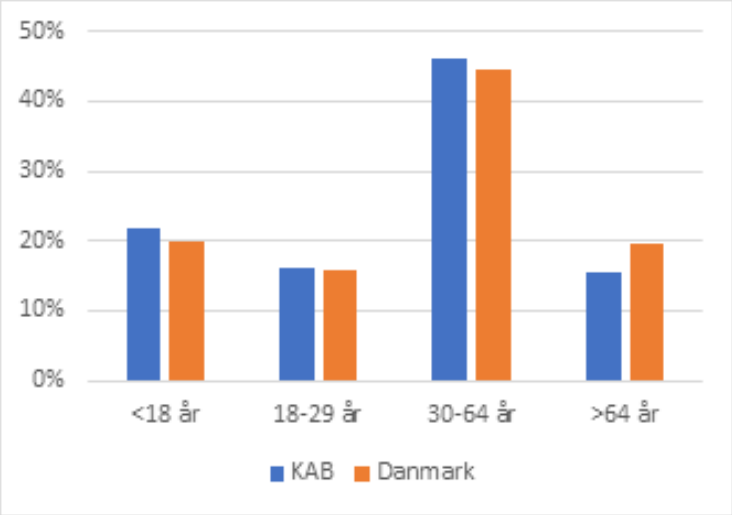
An increasing focus on finding solutions regarding *Legionella* in domestic water installations

The project aims at domestic hot water systems based on heating via district heating or local heating systems, i.e heat pumps. Climate challenges and the increasing need to save energy cause increased requests for lower supply temperatures for these systems. The increased challenges identified in the project regarding *Legionella* in the hot domestic water point to a need for higher water temperatures in the domestic water installations. This dilemma has greatly intensified the need to find optimal or alternative solutions for protection against *Legionella* in the installations.

With the desire to be able to use lower temperatures, the need for knowledge on how to do this best and safely in relation to *Legionella,* and with reliable documentation, is essential. Whether the solution is based on thermal treatment or biocid (e.g. Neuthox), a knowledge of and not least a solution to this challenge will open up great opportunities.
Implementation of the new EU drinking water directive requires increased *Legionella* protection and execution of risk assessments. This will undoubtedly encourage the need for *Legionella* protection solutions and risk assessment tools. For the participating manufacturers, there is further potential for exploitation of being a "first mover".

A growing market for low-temperature solutions both nationally and internationally

Based on Figure 10, it can be stated that over 70% of the installations in Danish rental properties are over 30 years old, and that only 20% are under 20 years old. Compared to the increasing energy and climate focus, it must be expected that a large number of the old installations will have to be replaced over the coming years. In Denmark, there are over 1.7 million households that are heated by district heating. Increased distribution of district heating and heat pumps in the coming years will further strengthen this market.



Source: KAB statistics, 2020

Figure 10 Relative age distribution of rental housing at KAB and in Denmark.

A much larger and very relevant market for the participating producers is the European district heating market, although it is significant that chlorine is often added to the drinking water abroad, which also inhibits *Legionella* growth in the hot domestic water. Denmark already has a significant export for district heating as illustrated in Figure 11 from the Danish export statistics. Solutions for protection against *Legionella* include, among other things under the items ”Energisparende produkter” (Energy-saving products) and “Diverse komponenter” (Miscellaneous components), which amount to just over 50 billion DKK.

Mia. kr.	2019	2020	2021	2020-2021
Teknologi til produktion af energi	42,5	33,1	31,5	-4,7%
Distribution af energi	3,1	3,0	3,4	11,1%
Energilagring	1,0	1,0	1,3	25,7%
Energibesparende produkter	29,6	28,6	31,3	9,5%
Diverse komponenter	21,5	19,5	21,6	10,9%
Samlet eksport af energiteknologi	**97,7**	**85,2**	**89,1**	**4,6%**

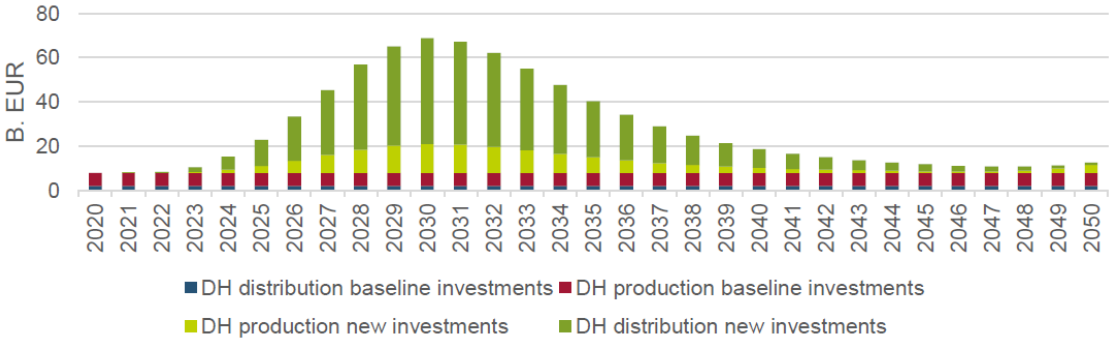
Source: DI Energi et al [2]

Comments:
”Mia. kr”. = billion DKK
”Energisparende produkter” = Energy-saving products
“Diverse komponenter” = Miscellaneous components

Figure 11 The Danish export of energy technology, including energy-saving products.

The future district heating market is i.a. highlighted in the report “Towards a decarbonised heating and cooling sector in Europe” from 2019. The *Legionella* problem is mentioned countless times in the report, and at the same time it shows a very large future market, as shown in Figure 12.

[2] Eksport af energiteknologi og -service, DI Energi, Energistyrelsen, Green Power Denmark og Dansk Fjernvarme, 2021



Source: Towards a decarbonised heating and cooling sector in Europe, 2019[3]

Heat Roadmap Europe 4 represents the most recent iteration in the Heat Roadmap Europe project series

Figure 12 District Heating investments for the Heat Roadmap Europe 4 scenario.

In the European report "Advancing District Heating & Cooling Solutions and Uptake in European Cities" from 2022[4] it is among others stated:

- *The tendency of the evolution of district heating so far has been towards lower distribution temperatures,reducing heat losses and allowing for the integration of sustainable heat sources. These systems operate at temperatures at or just above the limit set by domestic hot water temperature requirements, i.e. the network supply temperature is reduced down to approximately 50°C or even less. These systems are still novel and need further research activities, including innovative business models and regulatory frameworks. The development of low-temperature networks will promote a cost efficient and technically viable decarbonisation of the European DHC sector. There are currently six EU-funded projects focussing on these solutions.*
- *District heating currently accounts for around 12% of heating in Europe. With the right investments, this share could grow to 50% by 2050. In the face of rising energy prices and reduced energy security due to geopolitical developments, modern district heating and cooling networks offer a solution that can be fuelled by a wide range of locally available resources.*

The conclusion is that solving the *Legionella* problem with as low temperatures as possible is very crucial for energy savings and climate improvements. The need for risk assessment is further clarified through the requirements of the new EU drinking water directive, which is being implemented, and which also applies to domestic hot water.

In the further utilization of the results, the manufacturers and the other partners will take these market opportunities as a starting point and see a clear further potential for both the developed products and the developed knowledge.

[3] Towards a decarbonised heating and cooling sector in Europe - Unlocking the potential of energy efficiency and district energy.; Mathiesen, B. V., Bertelsen, N., Schneider, N. C. A., García, L. S., Paardekooper, S., Thellufsen, J. Z., & Djørup, S. R. Aalborg Universitet. 2019

[4] Advancing District Heating & Cooling Solutions and Uptake in European Cities, D2.1 Overview of Support Activities and Projects of the European Commission on District Heating & Cooling; Sofia Lettenbichler, Jack Corscadden and Aksana Krasatsenka (Euroheat & Power); July 2022

7. Project conclusion and perspective

The completed investigation regarding *Legionella* in domestic hot water installations showed:

1) *Legionella* from domestic hot water seem to be growing problem in Denmark, with more patients and deaths due to legionnaire's disease, and relatively speaking, it is among the highest in Europe.
2) If the service water temperature is always 50 °C or above, *Legionella* will not normally occur, and at temperatures of 55 °C and above, the probability of *Legionella* should be very small.
3) In order to remove emerging *Legionella* in domestic hot water, higher temperatures than previously assumed are necessary. This is because it must be taken into account that the biofilm protects *Legionella*, which causes the need for higher temperature/longer activation time than before recommended to break it down. If the domestic water is to be almost disinfected, the temperature must be raised to 65 – 70 °C or above, compared to the previously expected 60 – 65 °C.
4) The necessary water temperatures to avoid *Legionella* are significantly above the required service water temperatures of 45 °C based on the comfort needs. This leads to considerable extra energy consumption and climate footprint.
5) The Danish authority requirements are among the least restrictive, but if they are followed to the letter they are considered satisfactory. However, practice has shown that this often does not happen. In particular, the requirements for temperature compensation and disinfection should be increased in relation to the identified needs.

The above-mentioned temperature conditions have caused considerable attention towards finding alternative methods for *Legionella* protection. In the project the focus is particularly on the possibilities of adding biocide, which can compensate for the temperature requirements, but in general it is a challenge that they are not specifically included in the authorities' instructions regarding *Legionella* control. The technology is used to reduce *Legionella* at problematic levels, but without taking advantage of the potential for energy savings.

In relation to the above-mentioned challenges, the project has developed and in part demonstrated a risk assessment method with a view to a practical review of both existing and planned domestic hot water installations, in part two solutions for better protection against *Legionella*. They concern respectively about an electric booster unit (El-booster) for monitoring and compensating the water temperature, including with the possibility of following the stricter requirements, partly an improved plant for treatment with the relatively environmentally friendly hypochlorous acid (Neuthox). The latter, through the possibility of reducing the water temperature, could at the same time provide an actual paradigm shift regarding the dilemma between better *Legionella* control and increased energy consumption/climate impact.

8. Appendices

Description of the project and reference to the six published in-depth reports (part 1 to 6): EUDP2020-projekt 'Legionellasikring af energieffektivisering for installationer og forsyning' - Projekter - Teknologisk Institut

The relevant theme day papers (see section 5.5) appears from: https://www.teknologisk.dk/ydelser/legionella-temadag/2021/40905,2 and https://www.teknologisk.dk/ydelser/legionella-temadag/2022/40905.

The relevant articles (eee section 5.5), appears from:

- https://www.tekniq.dk/nyheder/nye-veje-til-bekaempelse-af-legionella/
- https://www.teknologisk.dk/ydelser/lavtemperatur-og-legionella-risiko-og-8211-et-udfordrende-dilemma/43880
- https://ing.dk/artikel/teknologisk-institut-seruminstituttet-advarer-saetter-vi-temperaturen-ned-paa-varme-vand?utm_source=nyhedsbrev&utm_medium=email&utm_campaign=ing_daglig.