BSAM Data-Driven Proactive Maintenance Handbook

- *Smart maintenance of district heating networks*

BSAM Baltic Smart Asset Management

Interreg South Baltic

EUROPEAN UNION

European Regional Development Fund

BSAM Data Driven Proactive Maintenance Handbook

- Smart maintenance of district heating networks

BSAM: **B**altic **S**mart **A**sset **M**anagement (EU-Interreg project)

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2023

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Design and Layout:
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Linnaeus University, Department of Biology and Environmental Science, Kalmar, 2023
ISBN: 978-91-8082-036-3

Contract:
Refers to Interreg South Baltic project, STHB.02.02.00-SE-0149/18

Title:
BSAM– Baltic Smart Asset Management

https://lnu.se/en/bsam

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Foreword

This handbook is a result of project partners' reports of their case studies, illustrating field applications of condition monitoring devices for data-driven, predictive maintenance, through the Smart Asset Management (SAM) process, to meet future challenges that district heating (DH) operators are facing due to the trend of decentralised energy production.

The handbook should be useful for people working in the DH companies, and for students looking for a career in thermal engineering.

The BSAM Handbook has been produced as one of the main outputs of the Baltic Smart Asset Management (BSAM) EU project (contract STBH.02.02.00-SE-0149/18). It will be published and made available on the project website https://lnu.se/en/bsam

Additional reports/materials related to the project's main outputs are also available on the project website including:

» **Risks analysis guidance and methods/tools (how to use the data collection for analysis in BSAM)**

» **Training module** (includes educational elements as well as online tools through the website/link)

This book shares the experiences gained during the project activities. To help achieve the goal of creating this BSAM Handbook, other advisors, consultants, companies and institutions were included in the work to promote and offer advice about Smart Asset Management relating to district heating in the South Baltic.

(Lead Partner on behalf of the BSAM partnership)

Contents

Introduction

About the project

There is a rapidly growing interest in modern maintenance and monitoring methods of district heating to lower CO_2 emissions, increase energy efficiency, and maintain a high reliability of heat supply.

The main purpose of the Baltic Smart Asset Management (BSAM), a European Union project, is to create environmental benefits for District Heating (DH) in the Baltic Sea region and deliver cheaper heating and cooling, based on better applications of assets and a more efficient use of the existing and future resources, as well as improved energy savings within DH systems. The project methods comprise development and transnational exchange of knowledge and cooperation about improvement of DH processes and the grids' operations and maintenance. In the long term, the dependence of coal and gas will be reduced in the Baltic Sea region and across the entire European Union, while employing a green energy approach. The big 2020 challenge in Europe is to increase energy efficiency by 20% and decrease CO_2 emissions. The DH fuels will be exchanged, and the efficiency of the entire system will be improved, from production of heat, through to the end-users. These efforts will promote the European goal to reduce dependency on fossil fuels and realise a circular economy.

In many countries, the grid systems need to be modernised, renewed, and examined to identify weak DH lines and detect small leaks. Thus, a major project goal is to implement methods for reinvestment in the correct lines at the right time and enhance the digitalisation of DH distribution networks.

The project was carried out by partners from the South Baltic Sea Region.

Project partners are:

1. Linnaeus University, Sweden (lead partner)
2. SweHeat & Cooling (the Swedish Council for District Heating), Sweden
3. Öresundskraft AB, Sweden
4. Opec Gdynia, Poland
5. Gdańsk University of Technology, Poland
6. Lithuanian District Heating Association, Lithuania
7. Klaipeda University, Lithuania

Associated partners are:

1. Swedenergy, Sweden
2. Energiforsk, Sweden
3. Nybro Energi, Sweden
4. The Swedish Embassy in Warsaw, Poland
5. Roskilde University, Denmark

The guide in **Appendix A** explains how external communications have been used from the time the Subsidy Contract was signed, December 2019.

The main purpose of this handbook, according to the BSAM application form, is to create a common interpretation of the concept of district heating smart asset management (SAM) between partners, especially in terms of DH companies, through smart preventive and proactive maintenance.

Project objectives

The BSAM project raises cross-border awareness of preventive data-driven maintenance methods for energy companies and delivers this BSAM handbook for educational purposes to decrease CO_2 emissions and increase energy efficiency by involving stakeholders through new arenas of cooperation that focus on proactivity.

One of the main project outputs is two pilot cases for smart data-driven maintenance methods with an emphasis on green proactive and preventive solutions.

Chapter 1: District Heating in the different countries: historical perspective, current situation, and statistics

1.1 Lithuania

District heating (DH) in Lithuania traces its history back to June 1939 when this energy technology was put into service in the largest interwar construction project completed in Lithuania at the time – the building complex of the Vytautas Magnus University. The boiler-house generated thermal energy for heating, hot domestic water and process steam for laundries, disinfection chambers, kitchen facilities used in operating rooms, etc.

For more than 80 years, the Lithuanian DH sector faced numerous changes and transformations. Cities and towns destroyed during World War II were rebuilt and developed, mainly from 1960 to 1990. Most of the DH systems in Lithuania were installed during the Soviet (USSR) period, when cities were built in a planned manner and even the smallest towns used district heating and hot water supply. In the period of centrally the planned economy (1929-1992), there was predominance of typical technological solutions, consumers paid based on the set norms, energy was relatively cheap, and energy saving was not an issue. After the Second World War, the Lithuanian DH sector mainly used peat, coal, and fuel oils for heat production. Later, with the installation of a gas pipeline system, most boiler-houses and power plants started using Russian natural gas, and fuel oils served as the back-up fuel.

During its period of independence (after 11 March 1990), Lithuania managed to preserve its larger size DH systems, but they had to be adapted to new and altered working conditions. Today, the Lithuanian DH sector supplies a relatively high share of heat for consumption compared to other EU countries – more than 50% of total heat consumption. Only Finland, Sweden and Estonia have similar shares provided by the DH sector to their heat markets. In Lithuania, district heat is supplied to more than 700,000 apartments. District heating is also available for most education and health institutions, other public establishments, and commercial buildings in the cities; it is a very important energy infrastructure for the country.

After the restoration of Lithuania's independence and the transition to free market relations, the district heating sector was viewed controversially due to the surge in heating prices and the poor economic power of consumers. Lithuania was dependent on a sole supplier of natural gas, the Russian concern Gazprom, and the conditions it dictated. The public has realised the need to modernise district heating systems, to make them more efficient and to adapt them to a different type of fuel. It was a unique task, requiring the incorporation of new modern technologies and new business models into the post-Soviet system.

In 1997, building-level inlet heat meters were already in place in all buildings served by the Lithuanian DH sector. This allowed measuring of consumption of thermal energy, and consumers were billed for their actual consumption. The level of energy efficiency in individual buildings determines building prices and motivates investments into energy saving. Measurements have shown that the relative heat consumption (kWh/m²) in different buildings can vary up to a factor of 10, with the difference in heat prices (ct/kWh) in different cities not exceeding a factor of two.

Another major stage of modernisation, which has proven itself, was completed in 2004 and involved the replacement of group substations with individual automated heat substations in buildings. This not only saved about 15% of heat, but also significantly reduced pipeline maintenance costs, improved heating regulation and service quality. This is related to the dismantling of regional domestic hot water pipelines and instead preparing hot water inside buildings using individual heat substations.

Even more rapid modernisation of DH systems began after 2004, when Lithuania joined the European Union and had the opportunity to use EU aid for the renewal of energy infrastructure. This period was marked by significant new pipeline installations and replacement works, including accelerated renewal of the preserved DH systems with modern pipelines. These enabled reductions of heat transfer losses, leading to fuel savings, as well as reduced environmental impacts.

The peak in prices for natural gas in 2007-2012 and the EU's policy of greater use of renewables have led to the rapid construction of biomass-fired boilers and cogeneration plants in Lithuania. The result of state aid and incentive regulation was that by 2017 about 70% of the total district heat production came from renewables – wood chips. In 2020, the DH sector reached another record with 75% of fuel used to produce heat being renewable. Biomass, together with local municipal waste fuels, has now reached about 79% of total heat production. Meanwhile, the share of imported natural gas has reduced by up to 19%. Thus, district heating is not only "green", but also largely energy independent. Even in the event of an interruption in the supply of imported fuel from any country, all necessary heat could be produced from indigenous or diversified sources. It was mainly on account of decarbonisation of the DH sector that Lithuania has long achieved the EU's target of reducing carbon emissions by 20% by 2020 (see Figure 1.1). Additionally, saved quantities of CO_2 emissions are sold to other countries. Annual CO_2 emissions have been reduced from 260 t CO_2/GWh to 70 t CO_2/GWh through replacement of fossil fuels by renewable energy sources (RES) in the Lithuanian DH sector in the period 2005-2022.

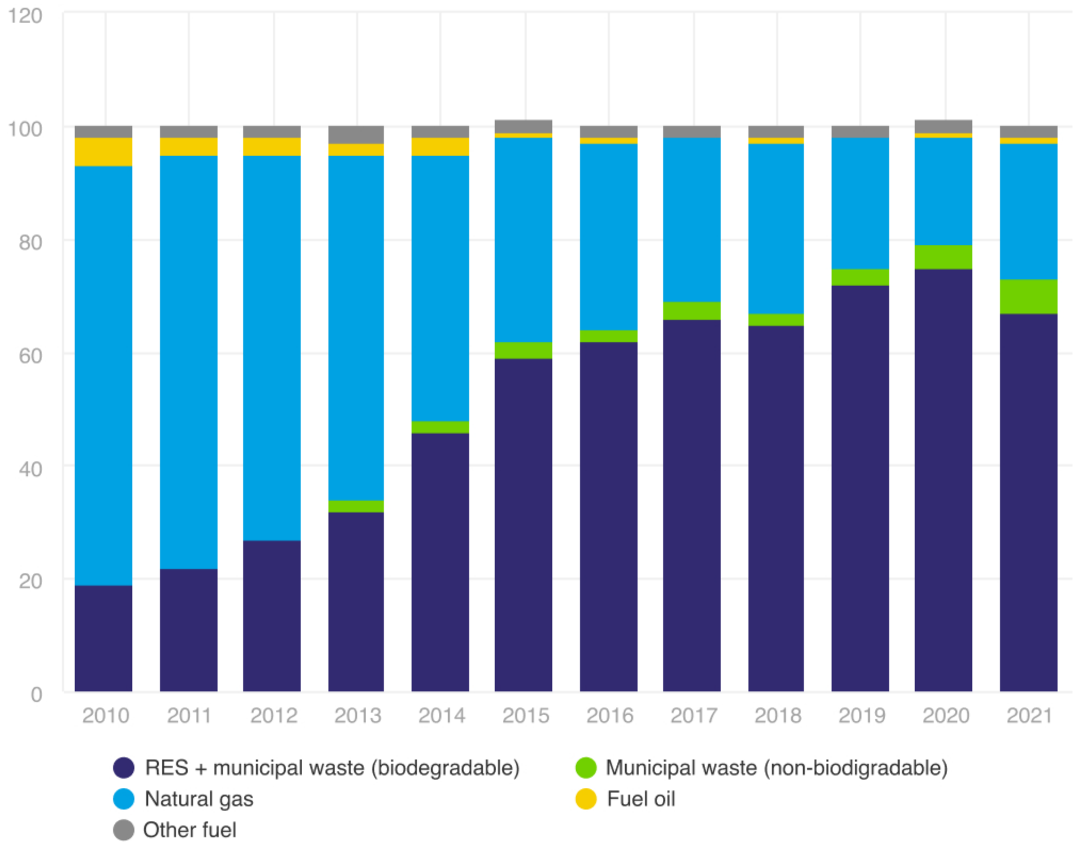


Figure 1.1. Structure of primary fuel in Lithuanian DH production, 2010-2021
(data from LDHA)

A considerable contribution here was made not only by heat suppliers, but also by independent heat producers who built about one-third of the plants using biomass. Competition among heat producers is organised based on monthly heat sale auctions. There is a national fuel and energy exchange in Lithuania, BALTPOOL, where all heat producers are required to buy fuel and sell heat in individual municipalities. Utilisation of solar, ambient, or waste thermal energy are among the priorities in further development of DH in Lithuania. Biomass firing boilers will be gradually replaced by cogeneration plants. Significant attention is paid to energy efficiency and the reliability of DH facilities. Statistics on Lithuanian DH trenches are presented in Figure 1.2.

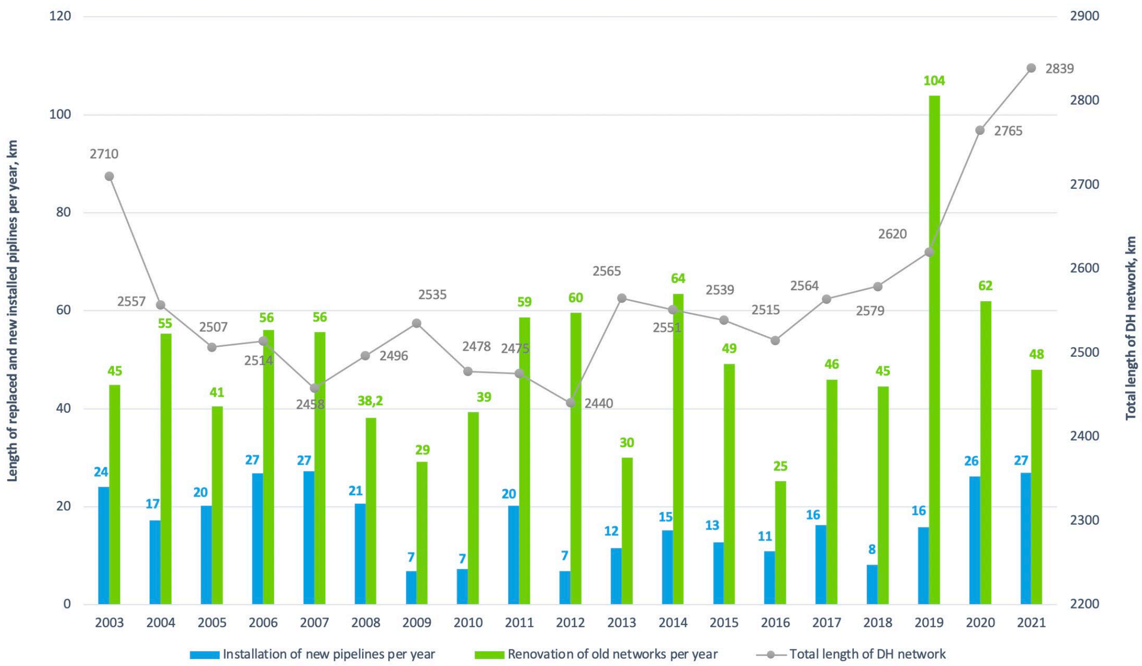


Figure 1.2. Overall length of DH trenches in Lithuania
(data of LDHA)

Significant disconnections from DH networks were seen until 2007 due to attractive prices of natural gas. However, this process was later stabilised and the overall length of DH pipelines in operation has recently grown to reach almost 2,800 km. Annually, about 50 km of pipes were replaced and about 10 km of new pipes were installed, mainly to connect new consumers or optimise the configuration of the networks. Currently about 42% of piping is being changed to industrially pre-insulated ductless pipes; however, there are still about 41% of old pipes installed in concrete duct channels. Considering that in the new EU funding period of 2021-2027 support for the replacement and installation of new pipelines is no longer planned, DH companies will have to find ways to introduce other technologies to ensure the longevity and reliability of the pipelines. District heating, based on renewable energy sources together with cogeneration plants, is considered a priority of Lithuania's energy strategy.

Most Lithuanian DH systems operate with supply temperatures lower 100°C, therefore corresponding to third generation of DH supply mode. Smaller DH systems often supply net water at the temperature level of 70-90 °C, which makes these systems more efficient and reliable.

1.2 Poland

District heating (DH) in Poland is as old as independent Poland. After more than 100 years of heating development, every second household now uses district heat. In 1841, the first DH installation was built in Warsaw, which was used to heat individual buildings, established at Jan Mitkiewicz Avenue. Then, representative buildings such as the European Hotel or Zachęta exhibition were heated. The first heat and power plant, as well as the heating system, were installed in the Infant Jesus hospital complex at Lindley Street, Warsaw, built in the beginning of the 1900s. In 1901, the Warsaw University of Technology was founded, which had its own centralised heating system. Kazimierz Obrębowicz, considered the father of Polish district heating, designed, and developed several district heating systems in Poland.

In the 1920s and 1930s, a workers' housing estate was built in Żoliborz, Warsaw, with a central boiler house to heat the blocks. The expansion of district heating systems gained momentum during the reconstruction of the city after World War II. Currently, the heating network managed by Veolia is the largest system of its type in the entire European Union. It has about 1,800 km of network, thanks to which it supplies heat to 19,000 facilities in Warsaw, thus covering 80% of the heat demand.

In the case of Cracow, one of the largest cities in Poland, citizens used stoves located in apartments for heating. It was very rare for them to be heated by boiler rooms. Municipal Heating Plants were established in 1953; there were 12 in total, and the district heating networks were only 30 kilometres long. By 1962, the Municipal Heating Plants were transformed into the Municipal Heat Energy Company. At the beginning of the 1960s, Cracow was heated mainly from heat obtained from the Lenin ironworks. And in 1970, a heat and power plant were launched in Łęg, which already supplied heat to new housing estates. In the mid-80s, it underwent significant changes and improvements when it was connected by the main line with the Skawina Power Plant.

In the case of Łódź, on the other hand, power plants were built for the needs of industrial plants. It was not until 1953 that the power plant started to produce steam for industry, and two years later the construction of the first combined heat and power (CHP) plant was established. The development of the heating system in Łódź took place in the 1960s and 1970s, when tens of kilometres of the heating network were built, and two more CHPs were constructed. In 1989, there was a breakthrough in the heating industry, because the CHP plant merged with district heating facilities, and today it is operated by Veolia. Pro-environmental investments and modernisation of basic processing equipment, as well as expansion and modernisation of heating networks, are still being carried out. Currently, the system is based on two combined heat and power plants and has over 820 km of district heating network.

In Szczecin, a city in north-western Poland, local coal-fired plants were operating in the mid-1900s. In the mid-1970s, by decision of the voivode, a company was established that managed networks in the entire Szczecin Voivodship. It was only in 1997 that district heating systems became the property of municipalities.

In Poznań, the first power plant was built in 1904. The Poznań II Karolin Heat and Power Plant, built in the 1970s, allowed for further expansion of district heating, supplying heat to new housing estates. The city of Poznań is supplied with electricity, heat, media, and technical maintenance of installations by Veolia.

The beginnings of the Lublin district heating sector date back to the 1950s and 1960s. Lubelskie Przedsiebiorstwo Energetyki Cieplnej (LPEC) has been operating since 1974. In the 1980s, the company tried to connect as many facilities as possible and create the so-called ring heating system. Then, LPEC became one of the pioneers of automation of transmission processes, and processing of thermal energy.

In Wrocław, the decision to build a power plant for municipal purposes was made in the 1890s. Electricity had been produced there since 1901, then the plant was taken over by the Soviet army, and in 1947 was transferred back to Poland. At that time, the power plant was expanded after the war, and in the 1950s was transformed into a combined heat and power plant, and heat production started in 1959.

After Germany, Poland is currently the second largest district heat producer in the European Union. In 2017, the DH system satisfied over 40% of residential heat demand. Polish DH networks provide space heating for at least six months per year, depending on weather conditions. The data of the Energy Regulatory Office show that about 400 entities on the Polish market are active in the field of generation, transmission, distribution, and trading of heat (as at the end of 2020). These entities generate over 53,000 MWt of installed capacity in generating equipment and provide almost 35,000 MWt of power ordered by customers. The total length of the heating network is over 22,000 km.

Enterprises generate heat from sources of various sizes, with a predominance of small sources – up to 50 MW (44.6% of generation enterprises in 2020). Only 10 licensed enterprises have the generation capacity of sources exceeding 1,000 MW, and their total available capacity constitutes over one-third of the generation capacity of all licensed sources. These entities also operate in electricity generation.

In 2020, over 90% of all heating companies in Poland were involved in heat generation. Together with the heat recovered from technological processes (heat recovery), they generated 393,800 TJ of heat. Ultimately, 57% of the heat produced by licensed heating companies went to recipients connected to the network – after satisfying the companies' own thermal needs and considering transmission losses. In 2020, the share of heat from cogeneration amounted to 65.2% of the total heat production.

Nowadays, the highest share in DH is covered by hard coal and coal product cogeneration plants. In 2015, the share of RES in district heating systems reached only about 7.4%. Many Polish citizens still use individual coal-fired boilers and stoves, which are being systematically modernised or replaced with e.g. gas boilers, according to the Clean Air Program, implemented by the Polish Government. The act assumed thermal modernisation of Polish households with the simultaneous replacement of heat sources during the period 2018-2029 to enhance energy efficiency and diminish the emission of dust and other pollutants related to the problem of smog.

It should be emphasised that coal is still used mainly to produce district heat, the share of which in 2020 accounted for 68.9% of fuels used in heat sources. The diversification of fuels used for heat production is slow (in 2019 coal accounted for 71%, in 2018 – 72.5%, and in 2017 – 74%).

The structure of fuels used for heat production in Poland is shown in Figure 1.3.

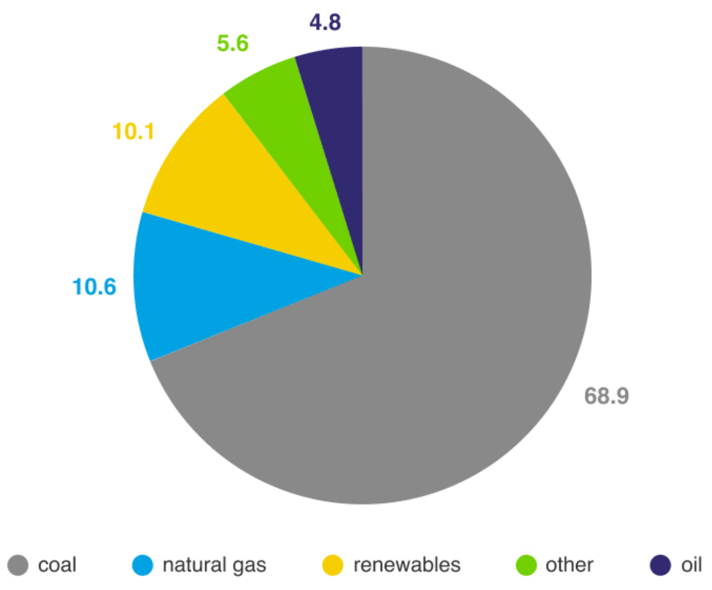


Figure 1.3. Structure of fuels used in the heat production in Poland, 2020
(based on data from the Energy Regulatory Office)

Nowadays, the major challenge for Polish DH is a step-by-step transformation into modern third-generation systems (3GDH), with temperature supply below 100°C. The typical DH network supply temperature is 135°C, while the return is 70°C for a large district heating system. An important element in Polish DH systems is thermal energy storage (TES) tanks that support 10 Polish CHP plants, providing heat source load-levelling for variable heat demand periods.

One of the directions of DH development in Poland is the use of geothermal energy as a heat source. Poland is one of the richest countries in Europe in terms of low-temperature geothermal resources; four geothermal areas are distinguished: Polish Lowlands, Carpathian Province, Carpathian Foredeep, and Sudety Region. The most valuable, from a heating point of view, are the areas of Carpathian Province, as well as the Lower Cretaceous and Lower Jurassic reservoirs in the Polish Lowlands. The total installed capacity from six geothermal DH plants is 76.2 MWth. The outflow water temperatures vary from 20 to 97°C.

The major Polish DH goals assume two-time limits, the first by the year 2030, with a reduction of CO_2 emissions by 42% (compared to levels from 2016) and a share of 40% RES. The second limit is set for the year 2050, with the reduction of CO_2 emissions by 100% (compared to levels from 2016) and utilisation of 100% renewable energy.

1.3 Sweden

District heating is one of the youngest urban utility infrastructures in Sweden, with the youngest being district cooling. Water, sewage, electric power, gas, telecom are other older utility infrastructures have national coverage. District heating is also the youngest and least established utility infrastructure (see Figure 1.4). In Sweden, district heating supplies 98% of urban buildings and has a 60% share of the total heat supply market in Sweden. So far, district heating has not been included in the large research programs that water and wastewater have.[6] This might be seen as a serious weakness from a sustainability perspective.

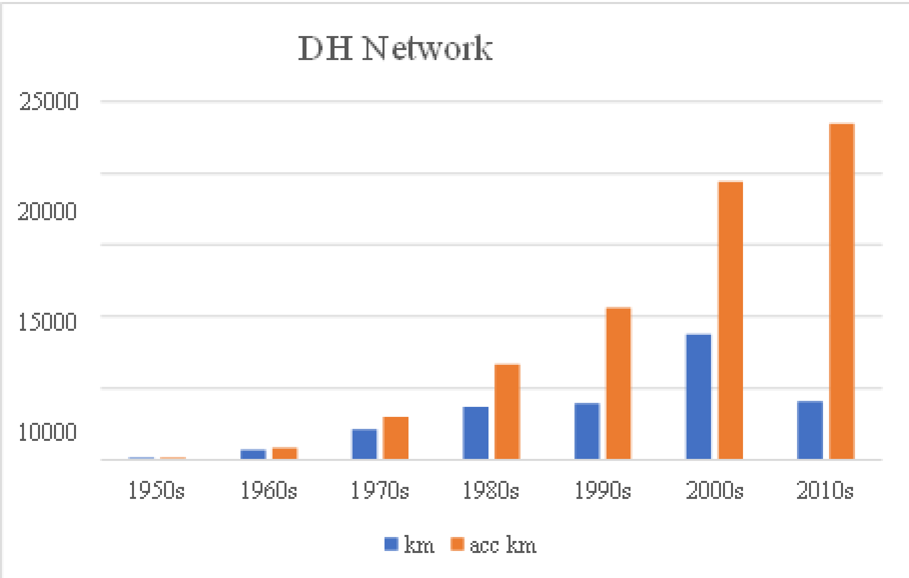


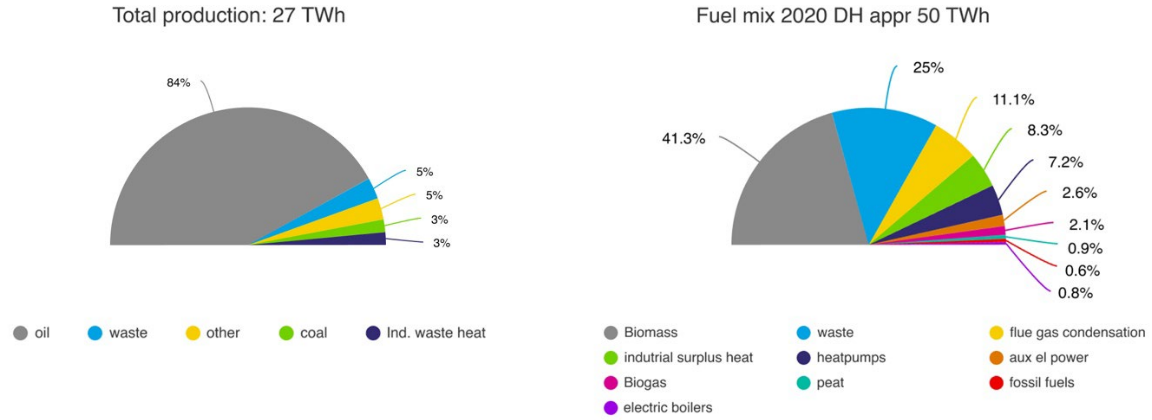
Figure 1.4. Growth of DH network (in km) by decade
(data from SweHeat & Cooling)

Until quite recently, there has been a lack of attention on district heating regarding the challenges associated with the maintenance of Swedish infrastructure.

An important question is why it is important to preserve district heating and make it more efficient. District heating provides 60% of the heating to buildings in Sweden, and today is virtually 100% fossil fuel free,

[6] https://mistrainframaint.se/

and independent from imported gas, oil or coal (see Figure 1.5). Buildings in urban areas are about 98% connected to district heating.



Fuel mix DH in **1981** Fuel mix DH in **2020**

Figure 1.5. Sustainable conversion of DH fuel mix in Sweden, 1981-2020
(data of SweHeat & Cooling)

Within modern district heating, hot water distribution systems expanded after the Second World War. This is called second-generation district heating (2GDH) and comprises the distribution of high temperature hot water in concrete ducts, transferred to the customer via tailor-made substations at site. A predecessor was district heating with steam, the so-called first-generation district heating (1GDH). Third-generation district heating (3GDH) was introduced in the 1970 and 1980s, with lower temperatures, pre-insulated and pre-fabricated pipes and pre-assembled heat exchange substations. Construction of DH systems began in the 1950 and 1960s and accelerated after the oil crisis of 1973, when Sweden decided to phase out oil for heating purposes (see Figure 1.4). A significant expansion occurred during the first decade of the 2000s, driven by long city-interconnections, city growth and connection of areas with single-family houses. In 2020, the estimated length of DH network was over 25,000 km.

District cooling has expanded in the past 20-30 years with a coverage which amounts to about 1% of the DH market in Sweden.

In 2019, 63 km of pipes were replaced, and 220 km of new construction (expansion or new systems) took place. The pipe network was designed for a life of 20-30 years, but most of the installations from 1960s are still in operation. In fact, with the replacement rate of 2019, it will take 373 years to renew the entire network. That could be defined as a “maintenance debt” unless methods are developed to ensure longer lifetime of the pipe networks.

Type of pipes and ducts

The most common type of pipe is pre-insulated with PUR-foam (polyurethane) and PE-shield (polyethylene), which was introduced at the end of the 1970s and in the 1980s (see Figure 1.6; note that this data covers 60% of the total length in Sweden. ACE is an asbestosis cement type of duct around the steel pipes. Concrete is a duct with steel pipes with a concrete box and lid around).

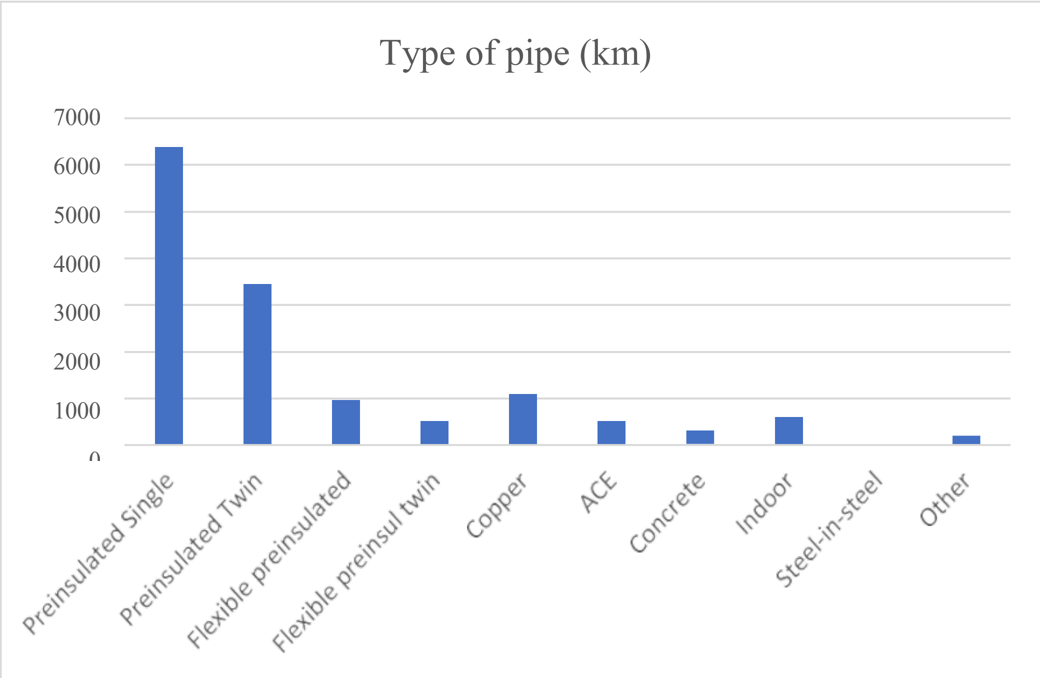


Figure 1.6. Most common types of DH trenches
(data from SweHeat & Cooling)

Water losses

An important indication of performance is water losses in the distribution system, usually measured as Lost Volume (m^3) divided by Total System Volume (m^3), called Turnover Losses. A good system has a turnover loss of less than 1 per year. Reported data include small systems, typically 1,000 m^3, up to very large systems, from 50,000 m^3 up to more than 130,000 m^3 total system volume. The database lacks information from many DH companies, and a conclusion is that typical turnover loss is 0.8 to 3 per year, where 3 means losses that are three times greater than the system volume.

Distribution temperatures and delta T heat exchange

Supply net water temperature (the delivered temperature) and the return temperature have decreased over past decades, which is good because heat losses will also decrease with lower distribution temperatures. The reported data show average forward temperatures of between 80 and 100°C, with maximum forward temperatures (coldest days) at 100-115°C.

The difference between forward temperature and return temperature is called Delta-t method and is an indication of exchange efficiency of the connected substations and buildings. The statistics show Delta-t method from 30 up to 50°C.

Faults

Data on numbers of leakages and interruption time is available, but incomplete. The highest number of faults/leakages is 128 at one company. Among the companies that have reported total interruption times (minutes/year), time periods from 10 minutes to 50,760 minutes per year are reported by some district heating (DH) enterprises (SweHeat & Cooling).

Monitoring

From the interviews and the reported data, with many gaps, a best practice pattern can be discerned. The best practice can, to a certain degree, be distinguished by the mode of operation & maintenance. Many DH companies use moisture alarm wires and thermography to detect degradation or hot water leakages in pre-insulated pipes. It is common to use concrete chamber monitoring devices for air temperature and humidity, and flooding measurement. Around 10 companies measure the remaining strength of the steel.

The share of district heating in most countries of the Baltic Sea region covers about 50% of the total heat demand and supplies heat to most multi-family apartment buildings. Therefore, the DH sector is important for society in general and must be carefully operated. This is explained by the extremely high capital costs of DH production and transmission facilities. Heating quality is vital to countries in the north part of Europe, and the repairing or replacement of DH tubes can cause inconvenience. Thus, reliability, efficiency and lifetime of DH assets are extremely important. The latest monitoring technologies and means for prevention of failures must be introduced. International cooperation in development of these technologies thus becomes increasingly important.

Chapter 2: Challenges related to DH production and transmission facilities

The district heating sector constitutes an important segment of the energy complex in northern situated countries. The history of district heating (DH) systems starts in the 19th century when so-called first-generation DH systems were introduced, based on combustion of coal for steam generation. Together with industrial devolvement, district heating systems have been undergoing a transition from using fossil fuels as heat sources towards a continuously rising share of renewable, solar, and geothermal energy sources. Parallel to the development of heat generation systems, heat distribution systems, as well as their maintenance techniques, have been modernised and improved. One of the most important milestones in the management of DH systems was the introduction of pre-insulated pipelines coupled with electric wires connected to alarm systems, which enabled the monitoring of damages in the DH system. In fact, the damage to heat distribution systems, related mainly to the ageing of the infrastructure and external impacts, poses the biggest social and economic threat related to the exploitation of DH systems. Old infrastructure, e.g. channels and pipes with damaged insulation, leads to water leakages and heat losses, affecting the economy and efficiency of heat distribution. Thus, further development of modern and reliable management systems, allowing for the prediction of possible failures as well as the application of novel durable materials and solutions during the installation of new DH networks, are crucial factors determining their safe, reliable, and long-term exploitation. Assuring the safety of heat distribution is a legal requirement resulting from energy policies in all modern countries. Safe and reliable usage of such networks, from the perspective of the consumer, means the lowest possible number of incidents leading to interruption in the heat supply process.

2.1 Heat production facilities and assets management

Recently, traditional primary energy sources for district heat production fossil fuels (coal, heavy oil, natural gas) are gradually being replaced by renewable biomass in a large scale. For example, biomass share in fuel structure reached 75% in Lithuania (Energies 2021, 14(2), 314; https://doi.org/10.3390/en14020314). Together with three large city waste to energy CHP plants, solid fuels supply about 80% of the overall heat demand. The share of natural gas dropped to 19% (see Figure 1.1).

In the DH sector of Sweden, a wider variety of renewable energy is employed for heat production – over 70% (see Figure 1.4).

In Poland, a significant share of coal is still utilised for DH production (see Figure 1.3). Gradually, coal will be replaced by sustainable biomass or other renewable heat sources. Recently, modular small-sized nuclear reactors have also been considered as solutions for heating large Polish cities.

When considering asset management issues in heat production phases, specificity of solid fuels combustion and impact on boiler plant facilities are among the priorities, and special attention should be paid to the use of biofuels, which are a somewhat new type of fuel in the DH systems of many countries. As forest residual biomass is the main type of biofuel employed in DH boiler plants and CHP plants most problems arise due to the composition of primary fuels. Some typical risks associated with use of this type of biofuel will now be described further.

The high percentage of minerals in biofuels could lead to intensive formation of various deposits on heating surfaces. Usually, it increases mechanical erosion and destruction of boiler elements, etc. The primary risk occurs in the furnace due to alkali bursting. Chemical compounds of potassium penetrate the walls of furnaces and destroy bricks or create layers on heat-resistant concrete because of different temperature expansion rates.

Figure 2.1. Furnace damaged by alkali bursting

To reduce the risk of alkaline corrosion (see Figure 2.1) of the refractory materials used in the furnaces, these recommendations could be followed:

1. Surfaces of the firebox liner must be cleaned of ash and slag.
2. Thermal seams in the firebox lining and cracks ≥8 mm wide should be filled with kaolin wool.
3. When using aluminosilicate (chamotte, mullite, anduluzite, etc.) materials (bricks or concrete), it is recommended that they be dense (> 2,200 kg/m^3), have a compressive strength >50 MPa, thermal resistance >30 cycles (according to DIN 51068 -1: 1976), and iron oxide content <1%.
4. The resistance of aluminosilicates to alkali corrosion can be increased by using impregnation suspensions or special refractory mastic coatings.
5. The combustion of biofuels with an increased alkali content or with an operating temperature of ≥1,200^{o}C requires the use of special refractory materials that are more resistant to alkaline effects.
6. Frequent and sudden stops and starts of the boiler should be avoided to increase the longevity of the liner.

If there is some fertile soil mixed with biomass, a significant quantity of sulphur could be delivered to a furnace. During the fuel oxidation process, sulphur converts into oxides which react with water vapour and form a certain volume of sulphur acid. Condensation of sulphur acids (dew point at the temperature range 70-110^{o}C) could cause intensive corrosion of steel tubes in heating-only boilers.

Corrosion can have many causes. High temperature corrosion may occur in tubes located in the furnace, e.g. steam superheaters. However, corrosion of hot water boilers using wet biofuels is usually classified as low-temperature corrosion. It occurs mainly due to the following reasons:

1. condensation of sulphuric acid (H_2SO_4) on the metal surfaces of the boiler and reaction of the acid with the metal, causing the formation of iron oxides, e.g. Fe_2O_3 (hematite) and/or Fe_3O_4 (magnetite).
2. deposition of various chlorine salts on pipes and reaction with metal.

The nature of the corrosion can be distinguished by traces in the pipes – acid corrosion evenly thins the wall of the pipe to 0 in certain areas, although nearby (2-3 m away) the pipe can be completely healthy and of the original wall thickness (see ~~F~~figure 2.2). This is related to wall temperature regime being below or above acid dew point. The surface is smooth with no clear changes in metal thickness.

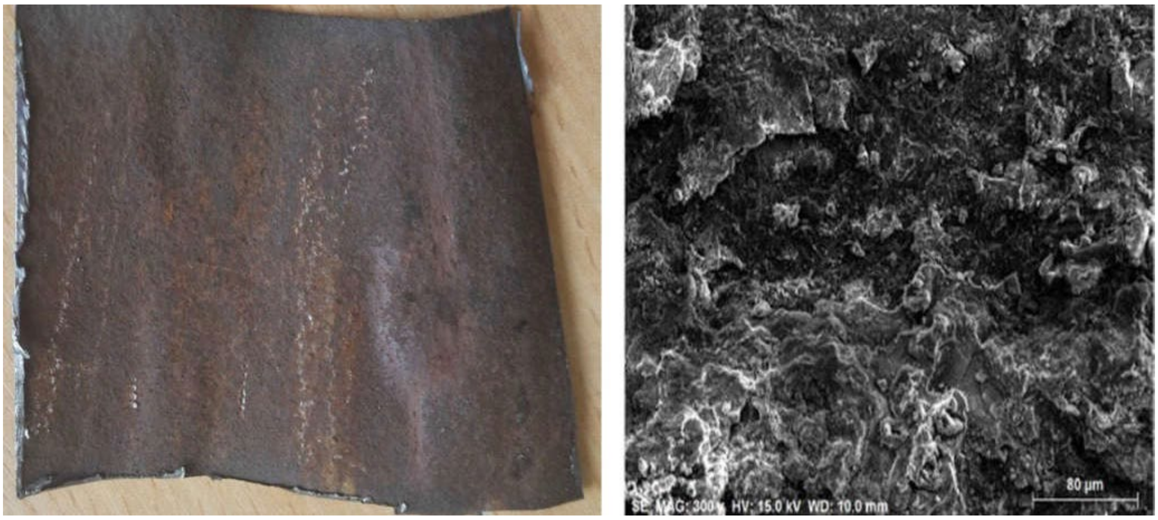


Fig 2.2. Signs of acid corrosion, usually H_2SO_4 sulphuric acid.
On the right – view from electron microscope surface photos, scale 80 m/km

Corrosion of chlorine salts (see Figure 2.3) erodes pits – holes/pits 1-3 mm in diameter can form sizable craters, which can cover a large area. Their edges are usually sharp borders.

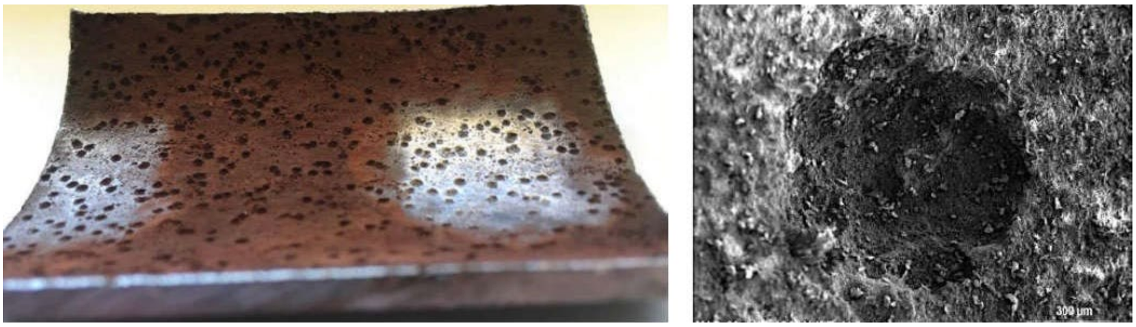


Fig 2.3. Chlorine salts leave traces of corrosion. Damaged areas of salts are clearly visible, corrosion has a point effect. On the right: photograph of the surface taken with an electron microscope, scale 300 µm (Photo by dr. K. Buinevicius, Kaunas University of Technology)

Basic recommendations (dr. K. Buinevicius, Kaunas University of Technology) to prevent corrosion include the following:

1. Boilers must be monitored for timely detection of corrosion processes and, where possible, measures taken to decrease the intensity of the corrosion.
2. Boiler pipe thickness measurements should be made on several sides of the heat transfer surface.

3. Periodically check the sulphur and chlorine content of the fuel by sampling. If an increased amount is detected, the fuel supplier should be informed.
4. Keep the water temperature in the boiler as high as possible. If steel surface temperatures are maintained above acid dew point, corrosion risk should be greatly reduced.
5. The condensation temperature of acid also depends on water vapour concentration in the flue gas. The higher the fuel humidity, the higher the water temperature in the boiler must be maintained.
6. The temperature of the water supplied to the boiler is limited by the boiler's technical parameters, which are related to its specification. So, the fuel type must be adjusted to the boiler construction and design parameters. A temperature regime of 120-140ºC is usually sufficient to prevent low temperature corrosion in boilers or flue gas ducts.
7. When planning the purchase of new boilers, it is recommended to focus on the possibility, during operation, to maintain higher water temperature limits, or other corrosion prevention means must be sought.
8. When unloading the boiler to minimum loads, flue gas temperature is significantly decreased, and the intense absorption of hygroscopic salts can appear. This greatly promotes corrosion by chlorine salts. Therefore, flue gas temperatures in any mode should not be lower than 120-130ºC at the "dry" heating surfaces.
9. Wet sulphur and chlorine-containing fuels present the highest risk of corrosion. Conversely, relatively dry biofuels (W <20%) cause no significant acid corrosion, even if water temperature in the boiler is near to 80ºC, as long as the fuel is free from chlorine.
10. Wet washing of boiler surfaces could remove salt deposits, but only if a boiler is dried quickly and thoroughly, otherwise moisture will activate corrosion in poorly washed areas. Otherwise, it is better to use dry mechanical pipe cleaning.
11. A number of anti-corrosion measures can be applied at the boiler construction stage, for example, increased water recirculation capacity; internal water circulation should avoid a situation whereby the coldest water meets the coldest flue gas flow; use corrosion-resistant steels and other means.

Usually, heat productions assets are easily accessible, therefore they could be properly monitored and risks avoided if the boiler specification is adequate for the fuel composition. Management of assets should ensure correct and timely procedures in this case.

Recently, biomass firing heating-only boilers typically consist of a furnace and separate heat transfer surfaces (as in Figure 2.4).

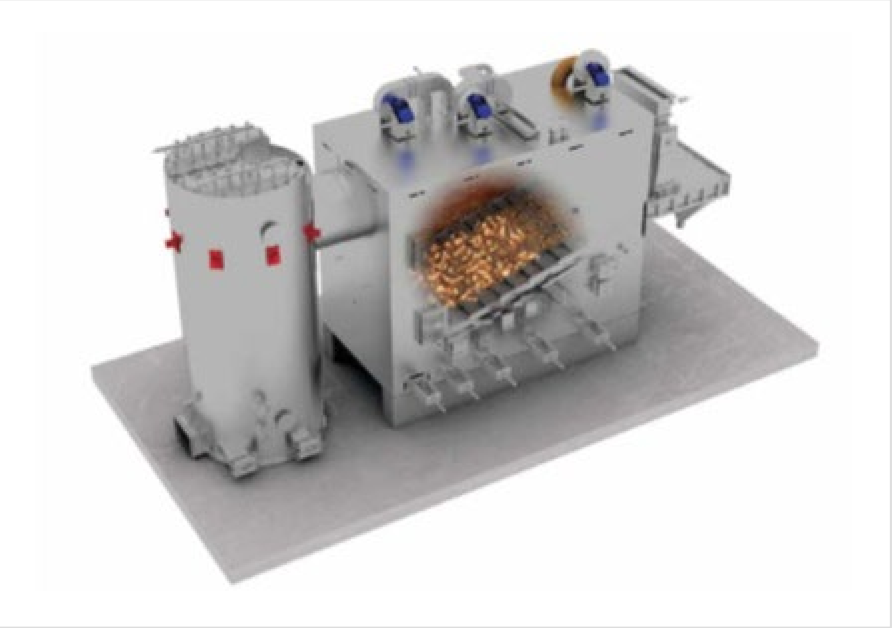


Figure 2.4. Typical wood chips firing hot water boiler
(data from Enerstena UAB)

Risks described above relate to the main facilities of the boiler plant. However, modern boiler plants usually have various additional heating surfaces installed, where flue gas is cooled down below water vapour dew point temperature. Physical and condensing (latent) heat is utilised in this way. One such option – the condensing economiser – is presented in Figure 2.5.

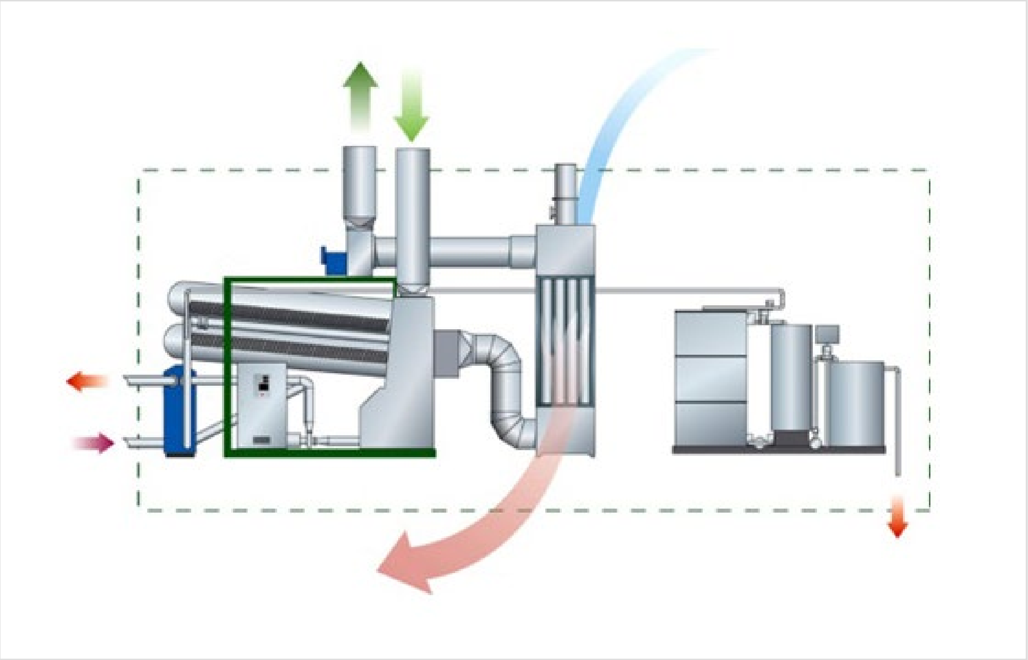


Figure 2.5. Condensing economiser for deep recovery of flue gas thermal energy
(data from AXIS Tech UAB**)**

These installations, utilising water vapour latent heat, recover and produce an additional 20-25% of heat from flue gas leaving a wet biomass firing boiler plant. It must be pointed out that condensate produced during deep cooling of flue gas is aggressive, and special steel protection means must be applied, and condensate must be neutralised before discharging into drains.

As a result of the number of new biomass firing and efficient installations introduced to the Lithuanian DH sector, overall relative consumption of primary fuel per unit of produced energy has decreased. This not only reduces heat prices, but also significantly improves the overall energy efficiency of the DH systems. The newest large biomass firing boiler-plants are equipped with heat pumps which allow an additional 5-7% utilisation of biomass energy potential to be achieved due to very deep flue gas cooling. However, with deeper cooling of flue gas, more aggressive condensate must be collected and properly utilised. Materials resistant to corrosion and specific facilities for “wet” flue gas management must be applied in this case.

Management of boiler plants is not difficult due to the fact all elements are easily accessible. Visual, ultrasonic monitoring or thermography could be applied, and repair works carried out if necessary. Much more complicated is the monitoring and status evaluation of the pipelines laid underground, where physical access is not possible.

The main task of the BSAM project is to overview and test new, mainly indirect physical, methods of DH network management.

2.2 Heat transmission pipelines: laid technologies, risks, and traditional assets management

Investment in the modernisation and development of pipelines generates significant indirect socio-economic benefits in terms of reduced local air pollution and increased local fuel usage, while replacing imported fossil fuels, eliminating polluting individual heating boilers, etc.

If a tube is damaged locally by some external mechanical, it can easily be repaired or partly replaced. Much more expensive and complicated is the replacement of large pieces of piping system when tubes are corroded systematically (wall thickness become critical) and need to be replaced in large volumes. In such situations the question always arises about whether it’s time to replace the tube or if it could still operate if given some additional attention. Statistics on tube replacement (mainly) in the entire Lithuanian DH sector is presented in Figure 2.6, illustrating volumes of pipelines replaced annually. This process not only causes higher prices for heat consumers but also creates inconvenience in the cities where the construction work takes place.

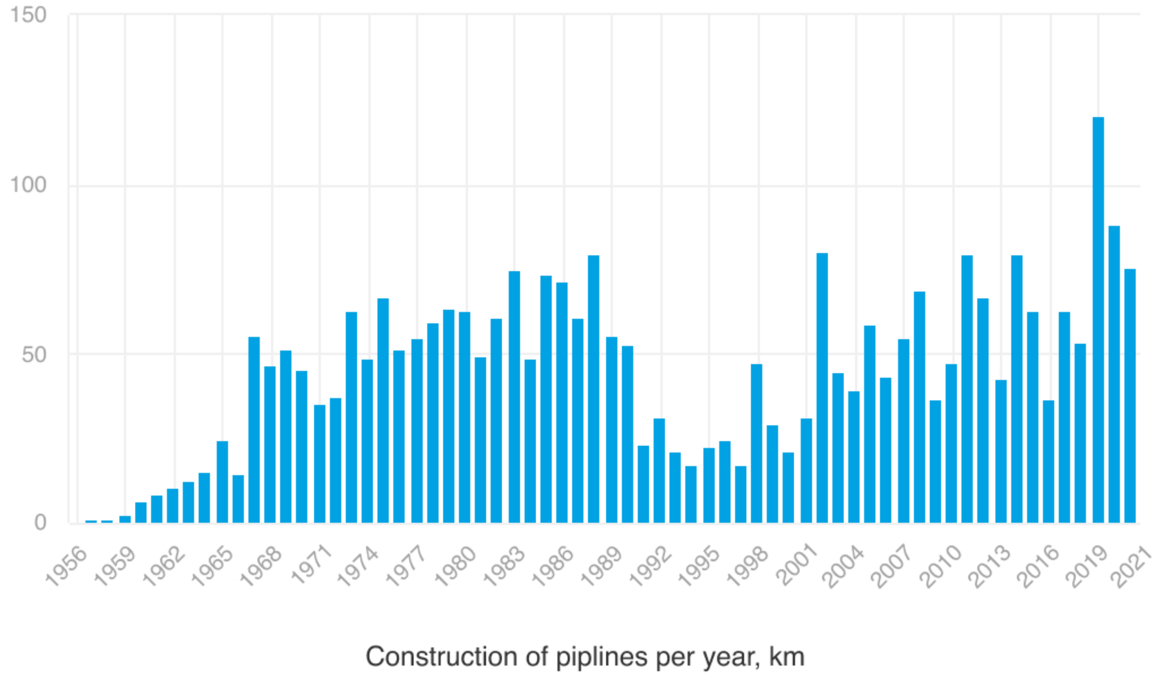


Figure 2.6. Annual volumes of new pipes installed and replaced in the Lithuanian DH sector
(data from LDHA, Lithuania District Heating Association)

Installation and replacement of DH tubes is often a complicated and expensive process. Overall volume of newly installed tubes reached approximate 40% in Lithuania's DH sector. So, there exists some mixture of various tube construction technologies in most DH systems. This situation requires different diagnostic methods for leakages, searches, or failure prevention.

2.2.1 Types of pipelines applied in DH networks

Construction of DH systems in the Baltic Sea region at a large scale began just after the Second World War. The extensive construction of multi-floor apartment buildings began together with construction of DH networks connecting large boiler plants and CHP plants with consumer systems in the planned economy countries. In most cities, a four-pipe route system with hot water preparation in group heat exchangers were used. In post-planned economy countries, during last two-decades, hot water preparation has been reallocated to buildings, which removed short-lived circulating pipelines, reduced heat transfer losses and repair costs. This process finished in the DH sector of Lithuania and significantly increased reliability of district heating and domestic hot water supply processes.

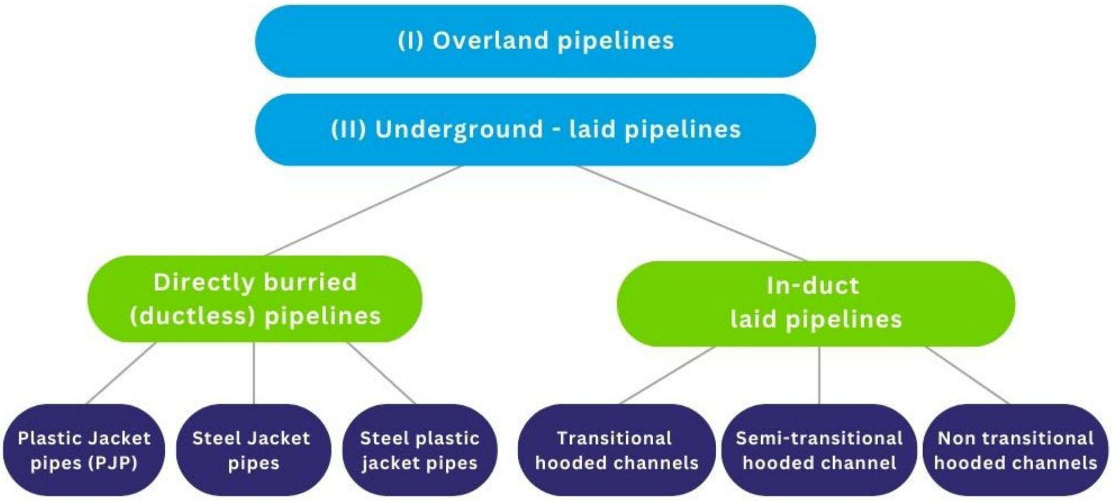


Figure 2.7. Simple classification of most common pipeline construction types

Several different methods of laying heat supply pipelines are used, i.e. overland networks, accessible and inaccessible ducts, and ductless piping systems (see Figure 2.7). Overland networks were laid in areas with high groundwater levels and difficult terrain, usually. Such pipelines (see Figure 2.8) are easy to service, they are not degraded by groundwater, but pipelines laid in this way significantly increase heat loss during the winter, and are more affected by environmental factors (rain or snow) compared to pipelines laid on the ground. Improper operation or poor insulation significantly shortens the life of these pipelines.

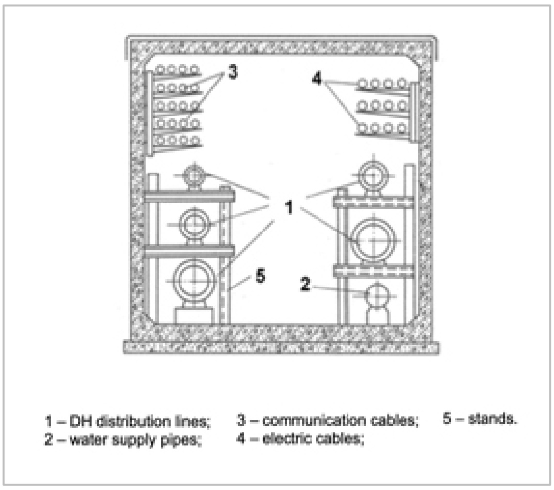
Overland pipeline in Radviliškis city, Lithuania

16 km length overland pipeline built from theformer Ignalina nuclear power plant to the city of Visaginas, Lithuanian

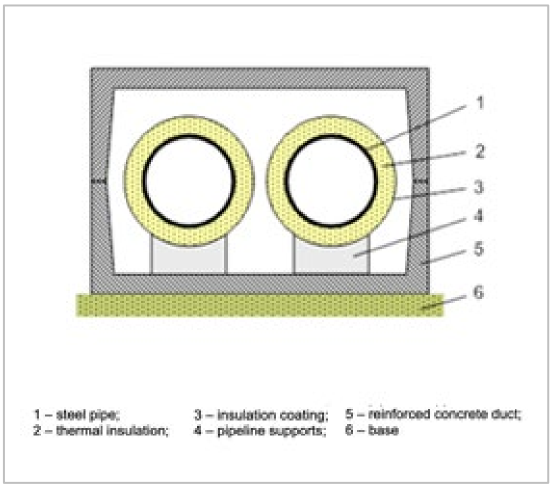
Figure 2.8. Examples of above ground and overhead pipelines (photos by LDHA)

Accessible ducts are not widespread; currently there are only a few cities with pipelines laid in this way. Their advantage is that the pipelines can be accessed directly without additional equipment. Although good operation of the pipelines is ensured, the installation of such ducts is expensive; therefore, this method was not popular.

Most of the heat supply pipelines were laid as inaccessible concrete ducts (see Figure 2.9). The dimensions of these ducts depend on the diameter of the pipelines and the construction of the duct. This type of channel is assembled from tough reinforced concrete. As practice shows, the most common cause of failure of pipelines laid in this way is failure of waterproofing of reinforced concrete beds, which results in corrosion of the external surfaces of the pipelines.



Pipes in transitional hooded channels



Pipes in non-transitional hooded channels

Figure 2.9. Accessible and inaccessible hooded concrete ducts (data from LDHA)

Concrete ducts are so-called hollow ducts, with steel pipes in a hollow space with a fixed external cover. The function of the external casing is to form the hollow space, enabling free ventilation, and to protect this space and the steel pipes from intruding moisture and water. The length extension of the steel pipes caused by high temperatures is absorbed by various compensators mounted in the chambers or directly in the trenches. The steel pipes are attached to fixtures in certain positions and the length extension (caused by thermal variation) are directed by guides.

The concrete ducts usually have two steel pipes, heat insulation of mineral wool and an outer casing of a concrete box, casted at site or prefabricated modules.

2.2.2 Risks in the DH networks

Generally, failures of district heating tubes can be divided into internal and external (see Figure 2.10). The external damage of pipelines is more local in nature and can be repaired in small segments. The pipelines that are damaged by internal corrosion must usually be replaced in large sections, which requires significant investment funds. External impact on pipelines can be caused by local corrosion or mechanical damage at a short section of DH trench. With external corrosion it is difficult to notice and predict possible failures in the operated pipelines. They can be caused by net water leakages, by ground water penetration and poorly functioning drainage systems, or a defect could be made during the installation of pipelines, due to mechanical destructions from outside impact, etc.

Internal corrosion

External corrosion

Figure 2.10. Illustration of damaged DH pipelines
(photo by AB Vilniaus šilumos tinklai)

Internal corrosion of tubes could be monitored and controlled by management of net water, by suitable water treatment processes and similar. Conversely, there are many factors causing external tube corrosion (usually local oxidation of steel pieces), among them:

- Net water leakage (penetration inside insulation)
- High groundwater and poor hydraulic insulation
- Drainage system problems
- Outdated compensation equipment
- Others

Often, some of the reasons for mechanical damage of tubes can be identified. Among them are destroyed expansion compensators, supports, drilling during construction works, etc. Local mechanical defects could be easily repaired if they are quickly identified and the tube itself is still healthy. However, if water leaks have long lasting contact with a steel tube, corrosion may damage large piece of pipeline, and replacement of long lengths of tube might be unavoidable. So, prevention and fast identification of leakage sites in the DH network is an extremely important factor for avoiding high operational expenses.

According to the experiences of Lithuanian DH companies, the greatest number of accidents take place in the pipelines laid in the non-transitional hooded channels. The main causes, according to LDHA information (see Figure 2.11), are:

- Water enters and contacts a pipeline through the concrete duct joints due to worn out hydraulic insulation
- Mechanically broken ducts through external impact (oversized load on the surface, digging, drilling etc.)
- Water enters the attachment points of the underground ducts through a stationary support
- The connection between the duct and the foundation of the building is non-hermetic
- Very often duct-type pipe systems are flooded when high groundwater or rainwater enters the channel.

Poor waterproofing

Broken channels

Water enters the attachment points of the underground channels through a stationary support

The connection between the duct and the foundation of the building is non-hermetic

Figure 2.11. Identified water leakages and opened concrete ducts
(photo by AB Vilniaus šilumos tinklai)

Local water leakages caused by external impact could rarely be found in old non-transitional duct-type pipelines. Even a little water contact with the steel tube in the oxygen ambience could cause increasing corrosion and significant failure of the tube after a certain time (see Figure 2.12). Such sites are rarely identified as water could flow far from inlet site. Noise is very low in the beginning phase, and is difficult to locate using acoustic mobile devices.

Figure 2.12. Examples of high rainwater and drainage system caused defects
(photo by AB Vilniaus šilumos tinklai)

Inaccessible underground pipelines mounted in small concrete ducts are still in operation in large volumes in many countries. Therefore, fast localisation of leakages, corrosion prevention and correct forecasting of tube perishing are extremely important targets of DH assets management.

Water intrusion in the duct causes humidity and accelerated corrosion on steel pipes and steel reinforcements in the concrete. The preventive action is to keep ducts watertight and chambers dry, below 60% air humidity. Corrosion of steel pipes, water intrusion, air humidity and ventilation capacity should be monitored.

Internal corrosion defects are found less often in Vilnius heating networks, for example, but they still occur. The reason for their occurrence is usually poor-quality net water, in which high concentrations of oxygen and CO_2 accumulate and cause corrosion of inside of the pipe. Often, such sections of pipelines are located where previously there was a higher consumption of thermal energy, but over time it decreased, the diameter of the pipes remained old, and the average speed of net water also decreased. Looking at past decades in Vilnius DH networks there was a period when river water was purified only from mechanical impurities and was used for direct filling into heat networks. Because of these simplified technical solutions, internal corrosion occurs. Recently, excessive oxygen sometimes enters net water through cracked heat exchangers at the heat substations if the pressure of cold water is higher than the pressure of DH net water at this point.

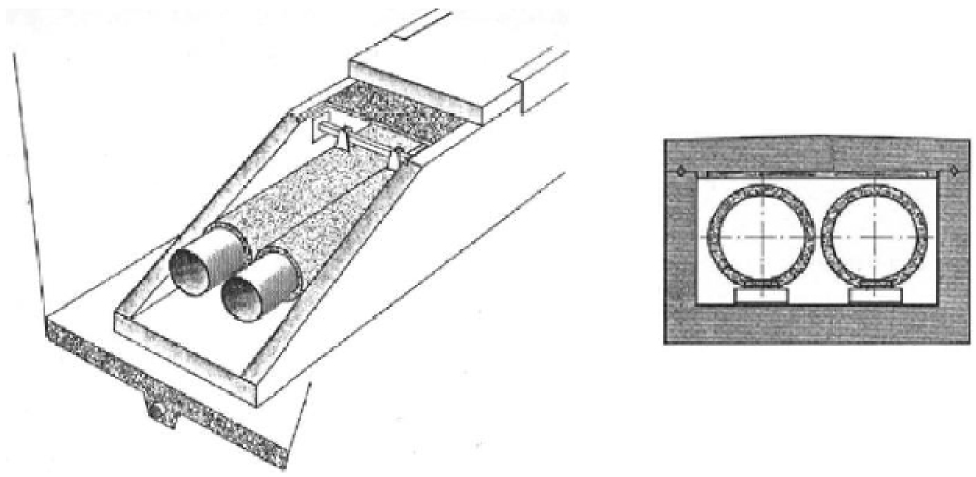


Figure. 2.13. Construction of typical DH trenches laid in 1950-1980
(data from Öresundskraft)

Another type of DH trench, so called ACE (*Asbestosis Cement Culvert*), was constructed from 1964 to 1982 (see Figure 2.13). There is 58.4 km ACE duct remaining in Helsingborg. In 1982, use of asbestosis was forbidden. Design and construction of ACE is a so-called hollow duct/culvert, where the steel pipes can move in a hollow space, with a fixed outer casing. The casing creates the hollow space that enables free ventilation and protects the pipes from external water intrusion.

The ACE duct consists of single or twin steel pipes, heat insulation by mineral wool, polyurethane (PUR) foam or aerated concrete, and a 5 m-long asbestosis pipe. Examples presented in Figures 2.14 and 2.15 were submitted by Öresundskraft.

Figure 2.14. Example of ACE type pipeline (data from Öresundskraft AB)

Fig 2.15. PVC type pipeline (photo by Öresundskraft AB)

The ducts are of a relatively short length but are vital transmission lines situated in densely populated city centre locations. It is of societal interest to preserve them as long as possible.

PVC-pipes are prefabricated and used for DN20-DN125, between 1969 and 1990. A 9.3 km PVC pipe remains in Helsingborg, for example. This was one of the first pipe designs with an outer casing of PVC plastic and insulation of polyurethane foam. The pipe could have single or twin steel pipes in the same duct. The steel pipes were pushed into the casing after the foam was applied. In bends, branches, and joints, two halves of insulation were applied. Thermal length expansion is absorbed in the pipe curves.

The outer casing is delicate and can be deformed due to porous. Because of an elevated risk of water intrusion and leakage, a major part of this type of pipeline has been replaced.

2.2.3 Pre-insulated pipes with steel tubes

Since 1975, pre-insulated water pipelines have been introduced into the DH networks, which are laid in a trenchless manner or installed in existing concrete beds. Pre-insulated pipes have a particularly good quality of thermal insulation and low heat loss during operation. Their initial construction costs and labour costs are lower than the pipes that are laid in concrete channels, and their durability and reliability are not inferior to the latter if the installation work is carried out correctly and the proper temperature is maintained during operation. Pre-insulated pipelines are well constructed, so the heat loss in them is insignificant and averages 7-12% (see Figure 2.16).

Figure 2.16. Example of pre-insulated pipeline
(photo by AB Klaipėdos energija)

DH companies are increasingly installing various systems that monitor the condition of the pipelines and detect early degradation of pipes or water ingression into the thermal insulation, etc. In this way, even small faults can be rectified more effectively to prevent large-scale accidents in pipelines and prolong their lifespan.

The pre-insulated pipe is the most common recent design (see Figure 2.16). It is available in all dimensions; for example, it was introduced in 1972, with 207.4 km length of trench in Helsingborg, and 89.4 km in Ängelholm.

The pipe could contain single or twin steel pipes. Two or multiple copper wires are embedded in the PUR foam. Pipes from 1972-1978 do not have wires. The wires are connected to moisture (in the foam) for surveillance (alarm) and localisation.

Pipes are welded together, filled with foam, and covered by a PE joint. Over the years, there have been several types of joints. Most common today are shrink-joints and electro-welded joints. The latter can be applied while repairing a damaged pipe (PE case or joint) online, with the pipe in operation.

The plastic casing (PE) is robust to mechanical wear but can be damaged. If the pre-insulated pipe has been manufactured according to quality standards, assembled correctly (regarding welding, alarm wires and joints), it can be used for up to 100 years according to suppliers.

Alarm wire circuits are effective in detecting hot water leakage, as well as damaged casing and water intrusion. It is vital that the wire circuits are properly connected and documented. As mentioned, pre-insulated pipes from 1972-1978 did not have embedded wires and pipes installed up to 1980 had unreliable wires.

The ageing phenomena in pre-insulated pipes has recently been a subject of research. It is a well-known fact that water will destroy the PUR foam. High temperature or variations in temperature may also degrade the foam or the adhesion between foam and steel pipe. This may cause movement of the steel pipes and eventually cracks may form. Detailed investigation of various factors affecting ageing of pre-insulated pipelines are presented in Figure 2.17.

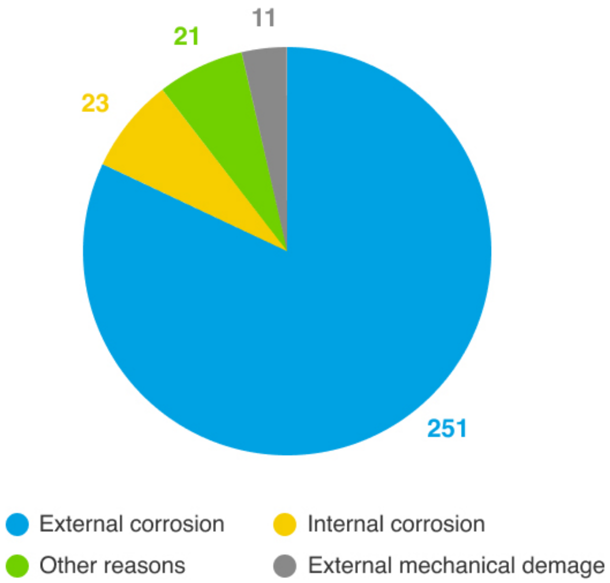


Figure 2.17. Types and statistics on reasons for tube failures in 2020
(data from LDHA)

Annual statistics of the identified ruptures in Vilnius DH system (in the period 2016-2018) show a number of cases in different types of DH trenches. Two-hundred and twelve ruptures were found in the underground inaccessible ducts and 10 cases were located in the trenchless pre-insulated tubes. The total number of failures was 277. General statistic on reasons for ruptures from the most Lithuanian DH systems (year 2020) shows that the main reason for tube ruptures is external corrosion, accounting for more than 80% of cases (see Figure 2.17).

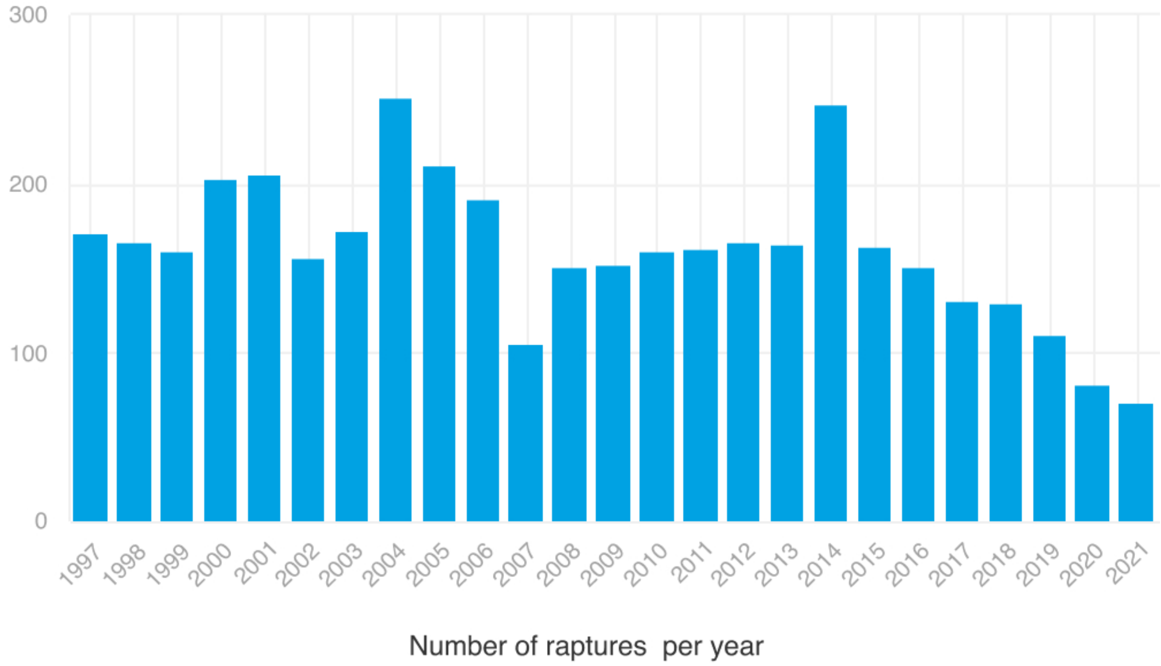


Figure 2.18. Number of annual tube failure cases in the Vilnius DH network
(data from AB Vilniaus šilumos tinklai)

From 1997 to 2022, a total of 1,929 pipeline failures in Vilnius, which appeared during hydraulic tests, were caused by external and internal determining factors (see Figure 2.18).

2.2.4 Pre-insulated pipes with copper tube

The Aquawarm system's unique construction is used on pipes up to a diameter 50 mm and occasional for larger dimensions. It consists of one or two copper pipes with a plastic outer casing and insulation between. The cord is easy to handle and can therefore be used more easily for, e.g. obstacles and difficult passages.

Aquawarm (see Figure 2.19) is a flexible pipe constructed with sinus curves, which allow for thermal expansion.

Figure 2.19. Aquawarm

Figure 2.20. Copperflex

Because of its flexibility, the pipe is easy to use when there are obstacles in the pipe shaft, and it can be used advantageously in narrow passages where space is limited. Muffling of the pipe is easier to perform compared to pre-insulated pipe with steel tubes. It is tempting to have the pipe contractor perform the sleeve coating instead of the personnel soldering the line directly on site.

Experience has shown that this becomes more expensive in the long run because the work is not carried out with sufficient quality and therefore often needs to be redone later.

The plastic casing is durable and resistant to mechanical impact. It is important that the plastic casing is not subjected to abnormal wear before the pipes are put into operation, because it is relatively thin and can easily be damaged.

Copperflex (see Figure 2.20) is a material used on pipes up to a diameter of 50 mm. It consists of one or two copper pipes with a plastic outer casing with insulation between. The pipes are delivered on rolls. The cable lengths are longer than Aquawarm, which results in fewer joints, meaning there are fewer places that can break.

The plastic casing works in the same way as the Aquawarm.

Hard foam between the plastic cover and the copper tube makes the pipe much stiffer than Aquawarm. Because of this, the Copperflex needs to be placed in the ground with bends that take up the expansion.

If water intrudes, it doesn't go far due to the hard foam but if the leakage is continuous the hot water will melt down the foam and damage will occur along the pipe. Leakage can be traced by a combination of thermography, acoustic listening, and correlation.

Recently, plastic pre-insulated tubes have sometimes been used for construction of DH networks. This type of tube still has some limitations of usage due to limited operational pressure and temperature range. Plastic tubes are typically manufactured up to 200 mm diameter and delivered in long rolls. Installation of the pipelines is quite simple, and many DH operators use their own staff to install them. The popularity of plastic pipelines should grow in relation to the lowering temperature regimes in DH networks.

Chapter 3: Circulating water, quality and operational conditions of DH networks

The net water of district heating systems affects many components of the system: heating surfaces of boilers, large amounts of transmission pipelines, heating systems inside of buildings, etc. Therefore, it's extremely important to maintain water conditions to minimise the aggressiveness of water against various types of steel, copper, rubber elements, plastics, and other materials.

Unfortunately, untreated water contains various insoluble and soluble substances, including gas, which can damage district heating facilities and communication lines. There are various forms of impact, but most dangerous are the adhesive deposits of salts and the resulting corrosion process. Initially, it may cause overheating of high temperature elements in the boilers, blockage of tubes and similar. If intensive corrosion takes place, it can lead to malfunctions, lost tightness, ruptures, and similar failures of the DH system.

Composition and substances in untreated water depend on the primary water source but mostly present in the form of inorganic salts (especially undesirable calcium, magnesium, and sodium salts) and organic substances. The soluble gases are mostly oxygen, nitrogen dissolved from the air, and carbon dioxide. Before of the water can be used in the district heating facilities, these water constituents must be removed, or their concentration reduced to a safe level.

The use of insufficiently treated net water, or additional water inflow from cold drinking systems, for example, can lead to system malfunctions due to deposits and corrosion. Under certain circumstances, damage leads to considerable costs that cannot be calculated in advance. If the standard values are complied with, the alkalinisation of the water on metallic surfaces furthers the formation of homogeneous oxidic covering layers, which are highly resistant against corrosion.

3.1 Effects of water substances

Gases, biological and organic elements, insoluble and soluble substances, oils or greases and similar elements typically present in raw water. Additionally, gases can enter into circulating net water due to air leakage into the system in the event of low pressure (e.g. insufficient pressure maintenance). Air inclusion can also occur during the initial, partial filling, or new filling of the system. The reason could be external water inflow, diffusion through permeable components, etc.

Oxygen (O_2) usually causes corrosion of ferrous materials. Therefore, oxygen concentration has to be minimised as far as technically justifiable. Damage directly due to corrosion can present in the form of perforations in heat generators, pipes and radiators made of unalloyed or low-alloy ferrous materials. The blinding of sieves, measuring equipment and filters due to corrosion products is considered to be an indirect consequence of corrosion.

Nitrogen (N_2) is an inert gas and, as a water constituent, only causes problems when its concentration is so high that free nitrogen fractions (gas bubbles) form inside the system. Gas bubbles may occur as the solubility of gases decreases with increasing temperature and decreasing pressure. Circulation faults, disturbing noises, and erosion of protection layers (erosion corrosion) are the consequences. However, system malfunctions due to nitrogen bubbles are not to be expected if the nitrogen content of water is maintained at ≤10 mg/l at a positive excess pressure of min. 0.5 bar (at the highest point of the system).

Carbon dioxide (CO_2) can present in net water if is not sufficiently alkalinised. Water-soluble carbon dioxide (CO_2) influences pH value, which drops with increasing CO_2 concentrations. Due to the increasing solubility of iron hydroxide occurring with decreasing pH values, deposited corrosion products can be partially dissolved by water having a relatively low pH value (<8). The increased iron ion concentration can lead to an increased formation of magnetite (Fe_3O_4) in the form of hard, black deposits on the hot side of heat exchanger surfaces. This causes the increase of the overall heat transfer resistance and, thus, decreased thermal performance. In particularly critical cases, this may even lead to overheating which, in turn, may lead to crack formation.

Hardness components (alkaline earth) exist when using unsoftened make-up water. The alkaline earth ions contained in the water can lead to the formation of hard deposits, mainly containing calcium carbonate (limescale, boiler scale). This causes the increase of the overall heat transfer resistance and, thus, the thermal performance to decrease. In particularly critical cases, this may even lead to overheating which, in turn, may lead to crack formation in heat generators (e.g. heat exchanger, pressure vessels, etc.).

Soluble anions of chloride and sulphate in the presence of oxygen intensify local corrosion (e.g. crevice corrosion) in unalloyed ferrous materials. Under critical conditions (e.g. concentration under deposits or in crevices), chloride ions can lead to pitting corrosion or stress-corrosion cracking in non-corroding steels. In addition, chlorides can cause corrosion in aluminium materials.

The contamination of circulation water by oils or greases – for example due to the inflow of operating fluids or due to valves, pipes, heating surfaces, etc. that have been treated with a temporary corrosion protection and with processing aids – can cause massive malfunctions. As a film or coating on heated surfaces, oils and greases hamper heat transfer and can, alone or in connection with other substances, cause malfunctions of the regulation and safety devices. Oils and greases are nutrients for microorganisms and therefore increase the probability of microbiologically influenced corrosion processes. Insoluble and soluble organic substances can affect the water treatment techniques and further promote microbiological reactions in the circulation water.

3.2 Water treatment techniques

Typically, primary raw water enters the mechanical self-cleaning filters at the water treatment plant. The largest particles up to 150 microns are retained in these filters and cleaned from the raw water. For larger size dirt particles, mud flaps/filters are typically applied. When water is supplied to ultrafiltration, a coagulant is dosed to bind the finer particles before ultrafiltration. In ultrafiltration, an alkali-acid is also often used to clean the water from finer particles. A disinfectant is additionally dosed to remove bacteria. After this process, water must be transparent with minimal concentration of floating solid particles. For removal of water-insoluble substances, various mechanical processes are typically applied: candle cartridge filters, bag filters, or similar.

After ultrafiltration, water usually enters softening cation filters or demineralisation facilities. In softening filters, salt is used to replace K, Mg ions in net water by Na ions during the softening process. Softening is necessary to prevent fouling, which may subsequently clog boilers' heat transfer surfaces, heat exchangers etc. Even a thin layer of lime decoctions can reduce cooling of steel, and it could be overheated by high temperature flue gas flow. After a certain period, cation exchangers must be regenerated with common salt (NaCl), to replace hardness components (calcium and magnesium ions) with sodium ions. Net water free from hardness components can no longer cause deposits and limescale. This type of water treatment is commonly used in salty operations.

During demineralisation, salts (cations and anions) dissolved in the water are removed using ion exchanging processes to reduce electrical conductivity. For this purpose, strongly acidic cation exchangers are normally used in connection with strongly alkaline anion exchangers. Demineralisation can be attained with the aid of nano level diaphragms (in general, using reverse osmosis). Under the influence of pressure, the ionogenic substances are separated from the water by semi-permeable diaphragms. The water is generally softened upstream in order to protect the diaphragm.

After softening or mineralisation, water usually enters the vacuum, atmospheric or membrane deaerators, where dissolved gases are removed from the water. It is particularly important to carefully remove oxygen, which acts as an oxidiser and can cause corrosion of boiler tubes and DH network pipelines.

Established methods for removing soluble gases (such as O_2, N_2 and CO_2) are thermal degassing and vacuum degassing. Diaphragm degassing can also be applied under certain conditions. The procedure of catalytic oxygen scavenging is implemented by converting soluble oxygen presenting in water with added hydrogen using the catalytic effect of certain noble metals.

Generally, water entering the DH systems should be properly treated and monitored according to recommendations and instructions of boiler or tube manufactures. In Sweden and Denmark, for example, certain quality parameters for circulating net water are recommended by the branch organisations or associations. In Lithuania, though, only minimal DH water quality requirements are fixed in the national regulatory documents.

The quality of the circulating water can be affected by external water inflow, gas inflow, corrosion processes, etc. For this reason, a partial flow treatment unit is often integrated into the bypass line. This subsystem contains filtering, degassing and ion exchange, which continuously removes suspended and dissolved substances contained in the water.

Partial flow treatment facilities should treat 1-3% of the circulation water volume daily. The supplementary make-up water volume must be considered when designing and dimensioning the facility.

Finally, make-up water is supplied to DH networks by pressure maintaining pumps. Small DH networks with very little make-up water usage inject some chemicals for O_2 absorption instead of deaeration. Additionally, the injection of chemicals for the final absorption of oxygen and for further improvement of net water quality are typical procedures applied in DH systems.

Increasingly, new methods, such as reverse osmosis or nanomembrane technologies, are applied for reduction of corrosion aggressiveness of net water.

Galvanic procedures are preferably performed in set-ups where the sacrificial anodes, which are normally used to protect the cathodes, are made of magnesium or zinc, and are mounted in a steel vessel for them to be metallically conductive. Electrolytic procedures are preferably performed in set-ups where anodes, made of aluminium, magnesium, zinc, or iron, are insulated and electricity is pulsed through the walls of the vessel, with a dc voltage passing between the vessel and the anode.

The iron, zinc or magnesium hydroxides react in an alkalescent manner, leading to a (desired) pH value increase. Aluminium hydroxide, occurring due to the electrolysis of aluminium anodes, leads to the formation of protective layers on ferrous materials. The slurry caused by this process must be regularly removed from the vessel. The efficiency of an electrochemical procedure, characterised by the oxygen removal rate (preferably expressed in g/h), depends mainly on the cathodic surface (size of the vessel) and on the exposure time of the water in the vessel.

Correct water treatment is important for the normal operation of DH supply systems, as the long-term cost-effectiveness and life span of the system depends on it.

3.3 Operational aspects

Typically, heat transfer surfaces in the heat generators are heated directly, therefore deposits (boiler scale and limescale) may form on the water side and corrosion may occur, which might cause damage to the boiler. For flawless operation of DH systems in practice, the pressure maintenance system, including the expansion vessels and their integration into the system, must be properly designed and operated.

Some other factors, such as insufficient filling of make-up water, external water inflow, under pressure, wrong start-up and shut-down procedures, etc., could be responsible for gas inflow (O_2, N_2, CO_2) into the DH system and, as potential sources of malfunctions, must be checked during operation.

Supplementary water is required to compensate for water losses which may occur due to volume variation, evaporation, clarifying or small leakages in the district heating facility. Also, the supplementary water can be loaded with oxygen and other gases. Insufficient pressure maintenance or untreated supplementary water can lead to an increased gas content in the circulation water.

Fundamentally, losses due to leakage should be kept as low as possible (localising the leakage as quickly as possible).

If the pressure of the district heating network is locally lower than that of the potable drinking water network, faulty heat exchangers for the heating of potable drinking water may lead to external water inflow. Increased hardness levels of the circulation water can suggest such an external water inflow. The increased hardness can lead to the formation of deposits on the surfaces of the heat exchanger which, in turn, leads to an increase of the overall heat transfer resistance.

Under pressure occurs, for example, when temperature variations lead to volume contractions of the circulation water, so that volume exchange in a closed circuit is insufficient. Air tends to penetrate the piping, especially at seals and automatic bleeders. The nitrogen remaining after the oxygen has been consumed by the process of corrosion can lead to malfunctions in the system due to the formation of free gas bubbles.

The pressure-control pipe may be connected to the pressure or the suction side of the network circulation pump. If the pressure-control pipe is connected to the pressure side of the network circulation pump, insufficient at-rest pressure in the highest radiator can lead to dropping below the atmospheric pressure, which would cause air to be sucked in through packed valves and bleeders.

Sufficient dimensioning of the expansion vessels can account for leakage loss and of volume variations of the network's content. Correspondingly, in the case of diaphragm expansion vessels, the upstream pressure must be adapted to the volume variations of the network's content. Consequently, the operability of the diaphragm must be checked regularly.

In the presence of overflow valves, the predefined upstream pressure must be continuously checked. If the upstream pressure is regulated using air, its temperature dependence must be considered.

In domestic heat substations with direct connection, care must be taken that the differential pressure regulators are functional. If the potable drinking water heating system is connected directly, a combined regulator in the inlet could, in the event of a malfunction, cause under pressure.

In district heating facilities with discontinuous operations (e.g. weekend shutdown, annual closing or summer shutdown) and where oxygen inflow is not expected during shutdown, particular measures to stabilise the system are not necessary. In facilities where oxygen inflow is expected, it might be necessary – especially in facilities operated under salty conditions – to condition the circulation water with corrosion inhibitors and/or an oxygen scavenger. Circulating the network's water volume weekly is recommended, and the water quality must be checked at regular intervals.

In any case, the at-rest pressure of the DH facility must be ensured. To ensure the at-rest temperature, the pressure maintenance facility must not be shut down. However, when individual heat generators are shut down, care must be taken that they remain connected to the network via a circulation pipe. This reduces corrosion probability in the water circuit and prevents corrosion due to humidity rejection through the flue gas system.

The pressure test with filling water should be performed immediately after scavenging. A repeated purging of the system prior to start-up should, as far as possible, be avoided. Even if net water is properly treated and maintained, it can cause serious problems when it leaks, and affects steel pipes from outside. In this case, atmospheric oxygen dissolves again, water surrounds the tube, and external corrosion occurs. To prevent such situations or to locate them at an early stage is one of the main tasks of a DH network management system.

The appropriate selection and dimensioning, as well as the correct integration of pressure maintenance and the circulation pumps in DH facilities have a decisive influence on the inflow of gases, especially oxygen and nitrogen. Attention must be paid to always ensuring a positive excess pressure at the high point of the system (recommendation: 0.5 bar positive excess pressure).

Chapter 4: Methods for monitoring DH networks and leak detection

4.1. Monitoring of DH system tightness by make-up water flow rate

With extremely long district heating pipelines operated in large cities, it is almost impossible to avoid some net water leakages. Net water can escape from network pipelines, could be lost inside buildings, during drain processing, etc. There are many cases of and reasons for loss of net water. To maintain proper pressure in the DH network, it is necessary to replace escaped water. So, the overall volume of filled chemically treated net (make-up) water must be continuously measured in each DH system. This water flow is the first and main indicator of tightness and possible new leakages. DH operators can monitor make-up water flow "online" using models that allow them to follow and evaluate the situation in their DH network. Net water leakages are not just lost resources, but are also of great risk to pipelines due to tube corrosion and ruptures, and can indicate the necessity for additional repair works, shut-downs, etc.

Generally, overall tightness of DH piping system could be estimated by criteria, i.e. annual usage of make-up water (refilled into the DH system); high figures could be evidence of significant leakages. On the other hand, leakages can cause intensive corrosion of certain tubes, and it's interesting to note large differences in Lithuania's various DH systems (Figure 4.1).

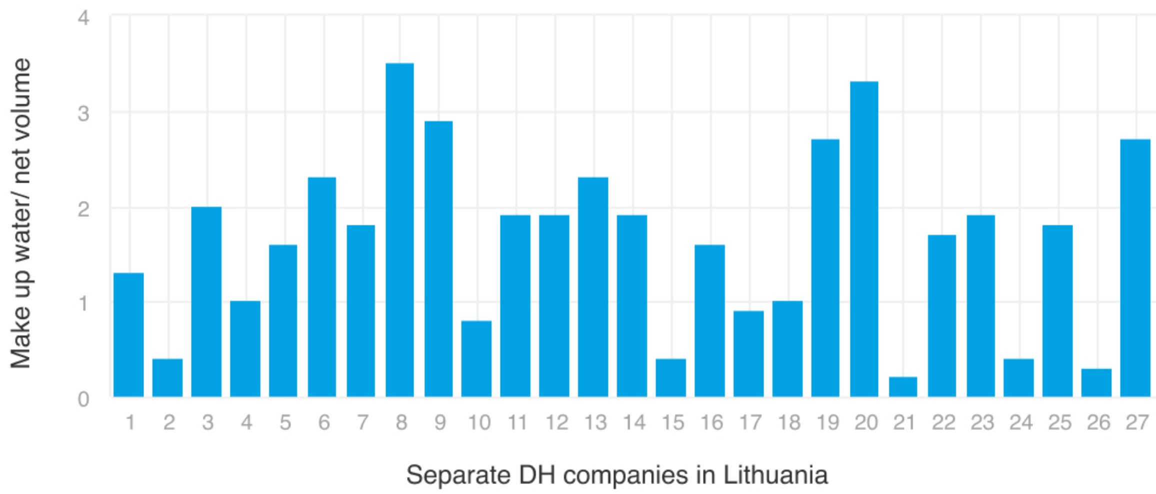


Figure 4.1. Annual replacement of net water volume in a selected number of DH systems (Data from LDHA)

More detailed statistical analysis shows a general trend in Lithuania – the larger the city, the higher relative consumption of make-up water (m^3) per volume of DH pipeline system (m^3) required. This might be explained by the difficulties in finding net water leakages in a large sized city.

In some Lithuania cities still operate direct type heat substations, where net water directly circulates inside buildings as well. In such situations it is not possible to separate where net water disappears: is it in the DH piping system or inside the buildings? Search for leakages in such cases becomes more challenging.

Employees working in the network management system are the first to notice faults in DH water supply and other malfunctions (see Figure 4.2). The digitised operational system gives them wider control possibilities to improve data exchange with other systems, and to see a greater number of network parameters, with deviations from the set parameters displayed on the video screen in real-time.

Figure 4.2. Modern network control panel installed in the Vilnius DH network dispatch centre (photo by LDHA)

Pressure gauges, flow rate meters and other measurement devices in a DH network assist operators to find some faults and leakages in the piping system. Valuable information could be provided by remote sensors installed in heat substations or at the critical points of the DH piping system.

4.2. Monitoring and control of internal corrosion of steel tubes

The main internal factors that influence the lifetime of DH pipelines are water quality, pressure, temperature regime, and velocity of net water. Hardness of water, low water pH-value, oxygen content or bacteria can be the cause of fouling and corrosion (see Figure 4.3). Another cause of internal corrosion is untreated water entering the systems through leaking heat exchangers where domestic hot water is preheated.

Figure 4.3. Example of internal tube corrosion and leakages
(photo by AB Vilniaus šilumos tinklai)

The internal rate of wear of the pipeline is mainly determined by the maintenance of make-up water and the continuous monitoring of net water quality. The quality of the water is usually controlled by the DH staff.

DH companies usually control more water quality indicators than is required by current standards. Unfortunately, the current rules for the operation of networks are outdated and do not consider the application of new technologies. The main purpose of network water treatment in accordance with the normative indicators is to prevent corrosion and formation of scum on the surfaces of heat exchangers.

The main factors affecting the entire wear of pipelines are the quality of net water, the chemical preparation of make-up water, and the velocity of water flow. For example, according to instructions of Vilnius DH networks, the oxygen concentration in the supply net water cannot exceed 0.05 mg/l, and in the return water the oxygen value should not exceed 0.02 mg/l. Another important indicator of the water quality of DH is the concentration of dissolved CO_2 (carbon dioxide); there should be no CO_2 at all. The rate of steel corrosion decreases at higher pH values of net water. The minimal rate of corrosion of steel is when the pH = 8.5 ÷ 10.5.

Another important factor that can promote internal corrosion of pipes is the speed of water below 0.5 m/s. At such water velocity, accumulations of deposits are formed in some parts of the pipeline, and at low (about 40°C) temperatures, biological-bacterial corrosion may begin to develop. Low water speed was identified as a problem in the last decade of the 20th century when the sudden disconnection of some industrial enterprises reduced the purchase of district heat. However, changes in the network configuration and temperature schedule resolved the problem quite quickly.

Another important indicator is the hardness of the water. The total hardness of water is the sum of the concentrations of calcium and magnesium ions in water. Hardness of water greatly affects the formation of deposits on the surfaces of heat exchangers and pipes.

Regarding chemical preparation of network water, various materials are used to prevent corrosion and extend the service life of the heat supply pipes. Currently, Vilnius DH company uses a caustic soda (NaOH) to increase the pH of net water to the required value of 9.0-9.8. Raising the pH of net water to the specified value binds all the free carbon dioxide and thus stops the carbonic acid corrosion of the steel pipes. Corrosion indicators are used to monitor its intensity (see Figure 4.4).

The new indicator

The indicator was removed from the pipeline after three years of use

Figure 4.4. Example of corrosion indicators used to determine the corrosion intensity of steel pipes (photo by AB Vilniaus šilumos tinklai)

As corrosion of tubes in DH facilities can be caused by various factors, an important indicator for quality of water treatment is the average corrosion rate. Corrosion rate of the internal surfaces of the DH pipelines should be constantly monitored by conducting a network water test and installing internal corrosion indicators in the most places most likely to provide useful readings.

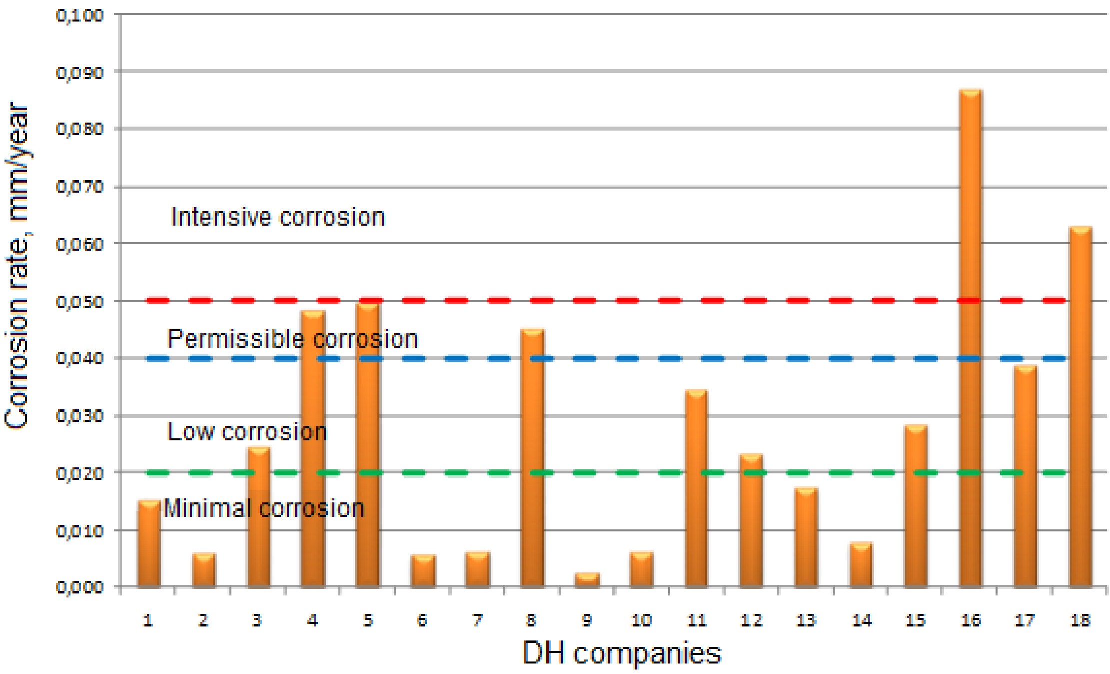


Figure 4.5. Corrosion rate of tubes in the selected DH systems in Lithuania

Based on the long-term corrosion rate measurements provided by Lithuanian DH companies, a corrosion rate is shown in Figure 4.5. The corrosion rates observed in Lithuanian DH systems range widely from

0.002 to 0.087 mm/year (see Table 4.1). DH systems with a corrosion rate higher than 0.05 mm/year urgently need to improve the quality of water treatment and ensure better quality of make-up and net water. It is obvious that the corrosion intensity of pipelines is quite different across DH systems, which reflects the quality of net water treatment and operations of DH networks in general.

Table 4.1. Inner tubes corrosion intensity

Corrosion rate	Corrosion velocity, mm/year
None	0-0.02
Low	0.02-0.04
Medium	0.04-0.05
High	0.05-0.2
Emergency	>0.2

There were several cases in Lithuania with high corrosion rates (>0.05 mm/year).

The main factors influencing corrosion rate could be:

1. High oxygen concentration in the net water, exceeding allowed limits
2. Acidity and alkalinity (pH). At pH >7, the process of reduced oxygen reduction and hydroxyl formation occurs. When pH <7, hydrogen gas begins to form, which, like hydrogen ions, is much more permeable (more intense diffusion into the metal takes place), resulting in a significantly faster corrosion process
3. Temperature (the higher the temperature, the more intensive the corrosion)
4. Electrical conductivity of the net water
5. Type of ions; chloride ions in water intensively decompose the layer of rust formed on the metal surface, thus preventing the formation of a protective layer. Sulphur-containing ions are involved in additional electron-generating reactions in the rust itself, thus supporting the self-regenerative rusting process
6. The electrochemical potential, depending on the chemical composition of the metal, directly determines the speed at which the electrochemical corrosion reactions will take place
7. Surface mechanical stress (the higher the mechanical stress formed in the metal, the faster the local corrosion progress).

4.3. Pressure tests of piping system

In Lithuania, as well as in other Baltic countries, every year at the end of the heating season, mandatory hydraulic tests and scheduled repairs are carried out according to legal regulations. The weakest pieces of the piping system are usually determined in this way. However, in most Western European countries, pressure testing of DH tubes is carried out just after installation or repair works.

Hydraulic test areas in large cities are normally divided into areas (zones) to facilitate servicing and to speed up fault detection in cases of rupture. The test is usually conducted using a mobile pump that raises the network pressure up to 20% higher than operational pressure and keeps it there for half an hour. If the pressure does not drop sharply during this time, the heat networks are considered to have passed the hydraulic test and, after examining the condition of the networks, technicians inform building administrators that hot water supply to residents can be resumed.

If the pressure is not maintained for half an hour, then the section of the network that has cracked is disconnected and the pressure in the remaining part of the network is tested further. The search for a defect in the damaged section of the network is done, and, when it is detected, that section is disconnected from the entire network. Building administrators are informed that heat supply will not be renewed as scheduled, and the duration of repairs will depend on the complexity of the defect. When the defect and the scheme at that location is complicated, the DH company can connect them to a mobile boiler-house. The average time consumers are left without hot water supply is approximately one to four days.

In recent years, the decrease in the number of defects during both summer and the heating season leads to the conclusion that maintenance and hydraulic testing are efficient, but all the methods have already been used and it is no longer possible to improve operation of the heat networks any further by existing means.

In Vilnius' case, hydraulic tests are carried out with parameters of the network: P=16 bar, T=60°C. Duration of the tests is 30 minutes. For example, in Vilnius, from 1997 to 2022, a total of 1929 pipeline ruptures appeared during hydraulic tests, caused by a variety of external and internal reasons. In the same period, there were a total of 2173 additional ruptures of tubes that occurred during routine operation. Therefore, it's evident that pressure testing cannot eliminate the risk of new ruptures during normal operational periods.

The Vilnius DH company ordered a feasibility study on the impact of hydraulic tests on heating networks in general. The study examined various scenarios relating to the influence of temperature on pipes, and several incidences were found where the mechanical impact of temperature to specific parts of the pipelines was greater, in comparison, than the influence of pressure induced during hydraulic tests. According to scientists from Lithuanian Energy Institute, hydraulic tests can be effective in straight sections of pipes and in sections of pipes remote from the elbows or if the pipelines are operated at a relatively low pressure.

Figure 4.6. Example of soil collapse due to large rupture during pressure test
(data from Quest Integrity)

Pressure testing of DH pipelines is also related to some risk of soil being washed out, e.g. the collapse of the ground layer due to a large rupture of a tested tube (see Figure 4.6). An operator was carrying out a pressure test on a district heating line, whereby it leaked and caused a sink hole.

In small DH networks, pressure tests are usually carried out across the entire network at the same time by raising pressure in the boiler plant. Of course, interruptions of hot water supply during pressure tests and repairs cause inconvenience for consumers and citizens.

Full-scale annual pressure tests of DH pipelines are mandatory in the post-planned economy countries, where state regulation in the DH sector is wide and deep. However, theory and practice obtained in Western European countries shows pressure testing does not indicate all sites of potential ruptures. Additionally, some pieces of pipelines could even be damaged by overpressure. Hydraulic pressure testing is not rational in pre-insulated pipelines that have electrical wires for indicating water penetration into the tube insulation. Due to these and similar reasons, the necessity for overall regular pressure testing now is under discussion in the post-planned economy countries.

4.4. Electrical wires for indication of water presence inside insulation

The increasing use of district heating increases the requirements for effective, affordable, and comprehensive monitoring of the corresponding pipe network. Undetected leaks mean loss of performance, as well as heat loss and reduced earnings of the supplier. The early detection and localisation of leaks and sheath damage increases the efficiency of the pipe network. The repair of faults in the early stages keeps costs and downtime to a minimum.

Recently, pre-insulated tubes are manufactured with fault control system wiring, which is connected to the detectors. In case of a certain violation, the detector is triggered and sends a signal to the dispatch centre. In order to detect leaks and damage in district heating pipes early and reliably, the insulation and loop resistance of a measuring pair in the insulation layer of the pipe is monitored. Moisture penetrating the insulation layer or faulty joints changes the measured insulation resistance. This is detected and reported by the LANCIER monitoring system; for example, see Figure 4.7.

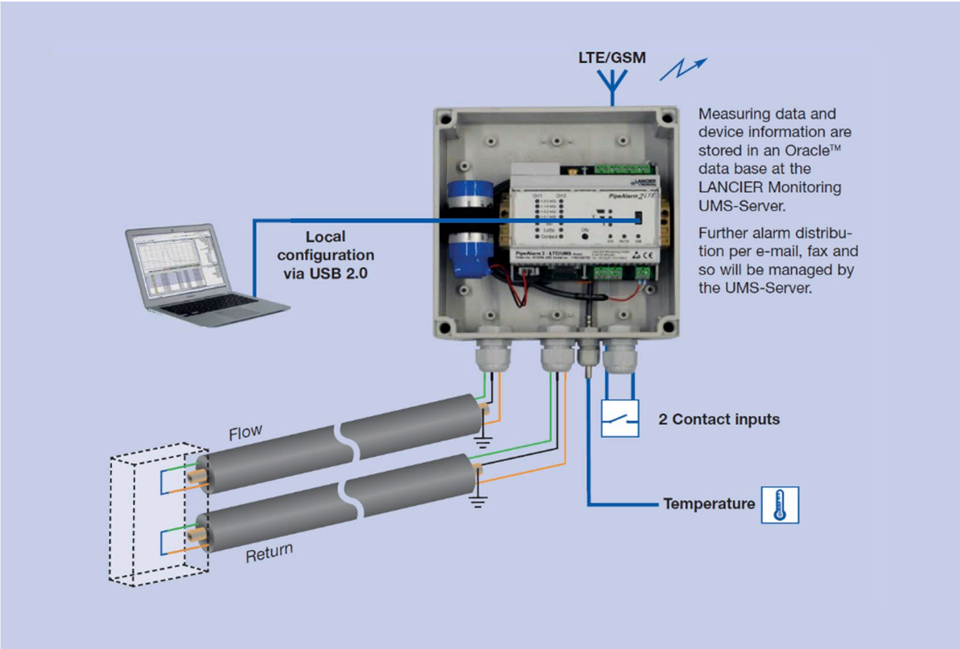


Figure 4.7. Example of the leakages monitoring system
(data from LANCIER)

With the NiCr system, the leak can be located exactly. Likewise, breaks in the measuring wires and manually inserted bridges (e.g. after maintenance work) are reliably detected. Depending on the structure of the network to be monitored and the available signal paths, there are various system options that can be combined with each other (see Figure 4.8). The monitoring stations record all measurement parameters and evaluate the measurement results according to determined, programmed threshold values. A central server permanently calls up alarms and status information via the network. Usage of remote data transmission systems in the DH networks provides the opportunity to include further measuring tasks (e.g. temperature, humidity, pressure, contacts, etc.).

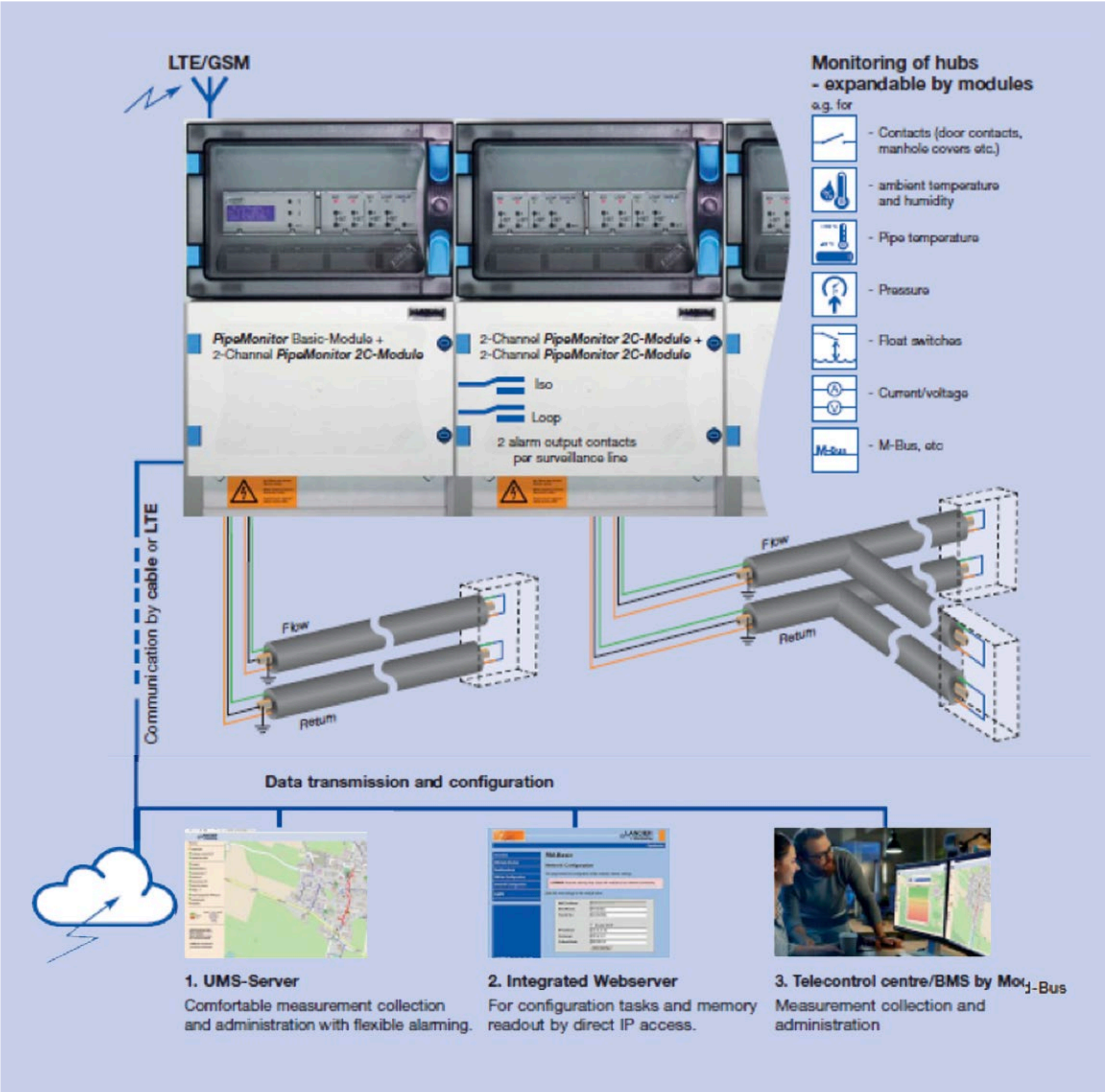


Figure 4.8. Example of the DH system monitoring complex
(data from LANCIER)

Similar technology using electrical tapes could be applied for detection of water spillages in the DH trenches installed in the impassable reinforced concrete channels. Special facilities should be applied for pushing or attraction of electrical tapes inside existing channels (see Figure 4.9).

Figure 4.9. Electric tapes laid down in the impassable reinforced concrete channel

If net water leaks or ground water penetrates inside the concrete channel, an electric alarm signal (because of short circuit) is sent to the DH operator dispatch centre. The next step could be more accurate problem analysis carried out using mobile devices on the site. Of course, stretching of electrical tapes inside existing impassable channels is rather difficult task in certain DH trenches, and is not always possible. Mobile devices for leak detection or site clarification are more commonly used by the DH operators.

4.5. The Nordic system for leak detection in the DH pipe networks

District heating networks built using the so-called Nordic system have been in use for over 70 years.

With a developed standard alarm wire of 1.5 mm^2 of uninsulated, soft-annealed, single-strand copper wire inside PUR foam at fixed distance, along the length of the steel pipe, there are two levels of monitoring, **Level 1** and **2**, like those supplied by Wideco Sweden AB (see Figures 4.10 and 4.11).

Figure 4.10. WiDetect X1, Level 1 unit
(Wideco Sweden AB)

Figure 4.11. WiDetect X6, Level 2 unit
(Wideco Sweden AB)

Level 1 monitoring of a district heating system requires that the alarm wire is looped to ensure that the whole length of the system is being monitored. The system reveals three electrical values for the total length of the looped alarm wire: isolation resistance, loop resistance and galvanic voltage. It does not reveal the location of the issue or issues.

Insulation resistance is the resistivity between the copper wire and the steel pipe. Dry PUR foam is a perfect electrical isolator and will not allow electric current to pass through it. A decrease of electric resistivity between wire and tube could therefore be an indication of moisture, lack of PUR material between the wire and pipe, or a change in distance between them.

Loop resistance is the total resistance of the alarm wire in a loop, calculated 1.3 ohm for each 100 metres of wire; resistivity increases by about 0.4% per degree. Other factors that affect the loop resistivity are the quality of the joints, improper handling, incorrect tools, or built-in moisture.

Galvanic voltage is the electrical voltage between the electrodes, in this case copper wire to steel pipe. Ions pass between the copper alarm wire and the steel pipe via a medium other than PUR foam; moisture from the outside of the pipe has a greater content of minerals and other pollutants leading to a greater galvanic voltage than that of the deionised district heating water.

All three electrical values reveal parts of the line’s status, but it is only together that you can specify the cause of the fault. Interpretation of the values is an exclusion process.

Level 2 monitoring removes the requirement of an alarm wire loop to function, keeps the measurement of electrical values and adds the ability to find where the fault is located by using a TDR pulse. A time domain reflectometer (TDR) – also referred to as a cable radar – measures the time between the output pulse and the reflected pulse and, using data on the electrical properties of the cable, calculates the distance to the fault location. The individual reflexes can be enlarged and studied in detail. Interruptions, short circuits, joint problems, and impedance changes can all be studied and located.

Fixed alarm installation on walls or pipe-mounted units for small spaces are great tools to ensure a pipe system is built correctly, identifies issues during warranty, and extends the lifetime of the network, therefore maximising both up-time and profitability.

Figure 4.12. Portable XPM with computer for field measurements
(data from Wideco Sweden AB**)**

Portable measurement devices like the XPM (see Figure 4.12) give the user a level two capable unit to any site with the Nordic system or any other measuring cables for district cooling, water pipes or multi-zone moisture detector cables. All measurement data is saved and synchronised to the cloud, as well on the local device.

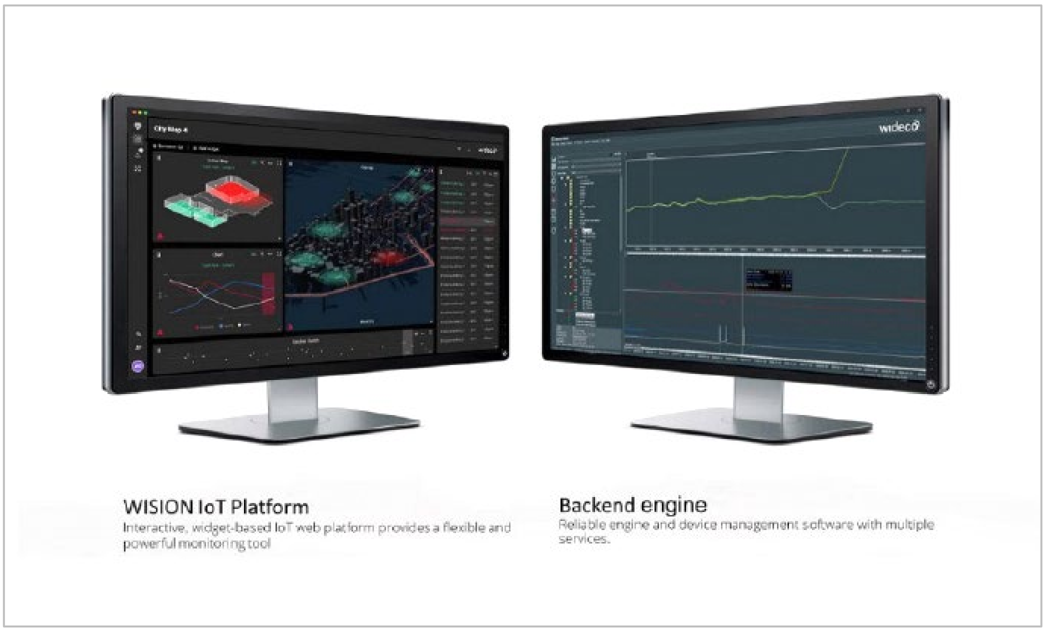


Figure 4.13. Wision and XTool monitoring software
(data from Wideco Sweden AB)

The XTool v5 (Figure 4.13) is the latest backend system from Wideco. It handles all the data provided from company´s third-party sensors, alarm actions, user administrators and more.

Wision is the latest frontend system from Wideco, a user-friendly system and built to be used on mobile devices. A flexible visualisation tool, it gives the user control of what is displayed, and how to display it.

4.6. Mobile devices for leak detection

In parallel to the stationary monitoring systems, mobile devices are often applied for detection of net water leakages. If stationary monitoring systems are more feasible for use in large DH systems, mobile devices are a cheaper version and typically applied in small DH systems, where it's possible to walk along all existing pipelines.

An acoustic device can be applied to check the location of the defect (see Figure 4.14). A detector is used to go along the pipe and search for the location where the noise level is at its highest, i.e. where there is a suspected leak.

Figure 4.14. Acoustic leakages localisation using Hydrolux HLE 5000
(data from AB Vilniaus šilumos tinklai)

Hydrolux HLE 5000 (see Figure 4.14) is designed to determine the location of drains in DH tubes laid in the concrete ducts directly from the ground surface. Acoustic drain finder Hydrolux HLE 5000, with the assistance of piezomicrophones, amplifies the sound of the resulting leak, automatically selecting filters for eliminating extraneous sounds.

A correlator consists of two sensors (see Figure 4.15) and the main device. At the bottom of the sensors there is a magnet that sticks to the pipe; one sensor is fixed in one chamber, the second in the other. When the sensors and the device are activated, the type of pipeline (metal), diameter, and distance between the sensors are determined. The device display shows the location of the crack.

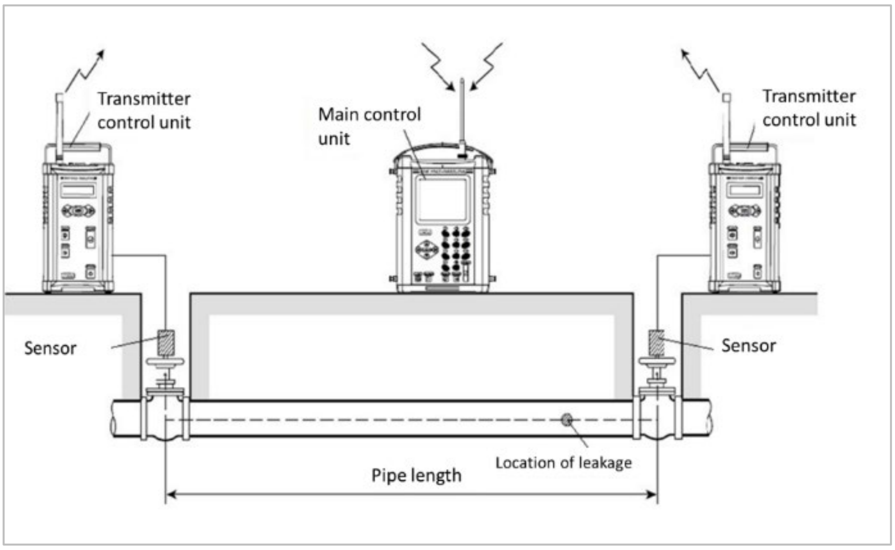


Figure 4.15. Acoustic correlator for localisation of water leakages
(data from AB Vilniaus šilumos tinklai)

To detect defects in channel-type trenches (without fault control system wiring), portable acoustic and ultrasonic devices are usually applied. Because of leakages, pressure drops in certain zones, which is indicated by the available pressure sensors at certain points of the DH network. Certain zones of the DH network are checked using water flow meters, where they are installed. When a leakage has been identified, a more accurate location is identified using drain outflow finders, e.g. the reflector Riser Bond 1205 CXA (see Figure 4.16). This is a device for monitoring pre-insulated pipes with a fault control system. It identifies the following defects: a broken measured circuit and the concentration of moisture in the insulation, and the exact distance to a certain defect. Using this device, the exact length of newly installed heat supply pipelines can be determined to an accuracy of +/- 0.03 m (+/- 0.01%) from the measured section.

Figure 4.16. Reflectometer Riser Bond 1205 CXA
(data from AB Vilniaus šilumos tinklai)

There are two main steps for monitoring of pre-insulated pipelines. The circuit of the control system for malfunctions is checked by connecting the device simultaneously to the sensor wires. If, after connecting the device in this way, a corresponding icon appears, this means that the wires are not broken, and a circuit has been formed.

The next step is to check that wires do not shorten into the housing, the purpose of which is to detect moisture in non-canonical pipelines and to stop pipe corrosion in a timely manner. Verification is carried out by connecting the device to one of the wires and the pipe (mass). If the device connected in this way displays corresponding icon, this means that there is moisture in the shell of the non-canonical pipeline, or that the wire is in contact with the pipe or the metal sleeve.

Often used is the Fuji Leak Noise Correlator LC2500 leak finder (see Figure 4.15), which is designed to determine the location of leaks in channel-based pipelines. A correlator is a device that deducts the correlation coefficient of the signals received by two sensors. Transmitters transmit the received signal from the sensors to the main unit (correlation). The main block calculates the correlation coefficient of the received transmitter signals and the time delay range and determines the exact location of the leak.

To diagnose the location of the leak, it is necessary to know at least one of four main points about the diagnostic section of the heat supply pipeline:

1. That the main unit of the correlator can simultaneously receive constant signals sent by two transmitters.
2. From what material the section of the heat supply pipeline that is being diagnosed is made.
3. The exact diameter of the section of the diagnosed heat supply pipeline and the thickness of the walls.
4. The exact length of the section of the diagnosed heat supply pipeline.

In the diagnose process, without knowing at least one of the above points, it will not be possible to determine the place of leakage in the heat supply pipeline.

An increase in the amount of make-up water refilled into the networks indicates the appearance of new ruptures in the DH piping system, which need to be detected and eliminated. If the DH system is formed with pre-insulated pipes, then the ruptures will be well indicated by the wires installed in the pipe insulation, localising the problem area. Mobile acoustic and ultrasonic devices are applied mainly to check and clarify the location of the fracture.

There are still many old-type DH tubes installed in various reinforced concrete channels (ducts), in which the detection and elimination of ruptures is quite difficult. This is typical in large-scale aged DH systems dominated by unpassable concrete ducts. Visiting all the heating chambers and finding water leakages in large-scale DH networks requires a lot of time and resources, especially if there are few or no suitable primary devices and no remote reading systems installed. Even if the heat boxes are equipped with humidity indicators with remote data transfer, accurate information is not always obtained, since network water can leak into drainage systems or similar. Moreover, these methods only show the consequences of problems, e.g. ruptured pipes, but do not indicate the poor condition of channels or pipelines, the loss of thermal insulation, or pipes covered with water, but which are not yet torn.

The status of large-scale DH systems (quality of thermal insulation, net water leaks, etc.) has recently been controlled with the help of infrared cameras installed on airplanes, drones, or a car, etc.

4.7. Infrared thermography

Infrared thermography is an efficient way of detecting and localising leakages in the DH network. In the case of a media leakage, hot media will heat the surrounding ground and eventually also the ground surface. This, sometimes minor, difference in temperature at the ground surface can, in most cases, be visualised by a thermal camera. An example is provided in Figure 4.17. Left, a thermal infrared image depicting a potential leakage, here marked in yellow. Right, the actual leakage after excavating the pipe.

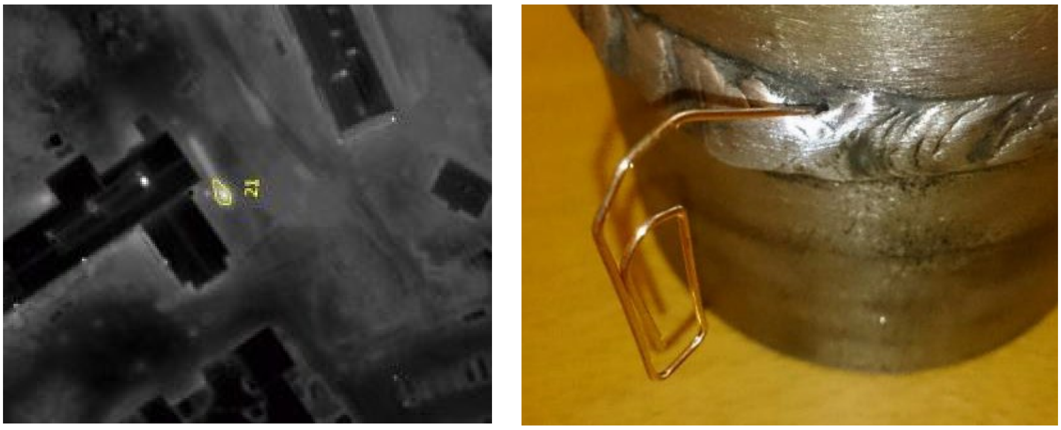


Figure 4.17. Finding a leakage with thermovision
(data from Termisk)

When searching for leakages in a DH network using a thermal camera, the camera can be mounted on a car, a drone, a helicopter, or an aircraft. The benefits of using an airborne platform compared to a car is that areas that might be inaccessible for a car can also be examined. Below, an example of such an existing system for automatic detection, classification, and visualisation of leakages provided by Termisk Systemteknik AB[7] (Termisk) in Sweden, is described. In this case, thermal infrared images are either acquired by drone or by aircraft.

Large-scale mapping of entire DH networks is, in most cases, cost-effectively performed from the air using an aircraft. In the specific case of the system provided by Termisk, the aircraft maintains an altitude of 800 m which yields a pixel footprint at the ground of around 24 cm. The sensor is a radiometric, cooled, mid-wave (3-5µm) thermal infrared camera that has a temperature sensitivity of <18mK. The aircraft flies back and forth over the network in order to cover the whole area. The duration varies depending on the shape of the network, but as an example, a mid-size Swedish city/network (Örnsköldsvik) takes around five hours by aircraft. That is, data collection is completed in one night.

If the network is small, or if only a small section of the network is to be examined, a drone might be a better option. The approach is similar to the one described above, except for a lower flying altitude and an extended collection time to cover the same area. As an example, collection of images for the same city as in the example above would take more than a week.

When images have been collected, they are used to build a large georeferenced mosaic of the examined area. Automatic image analysis is used to detect and classify (using deep learning) potential leakages. The mosaic, DH network, and potential leakages are visualised in a visualisation software in order to get an

[7] https://www.termisk.se

overview of the status of the network, see example in Figure 4.18. Purple lines represent the DH network and potential leakages are marked in yellow.

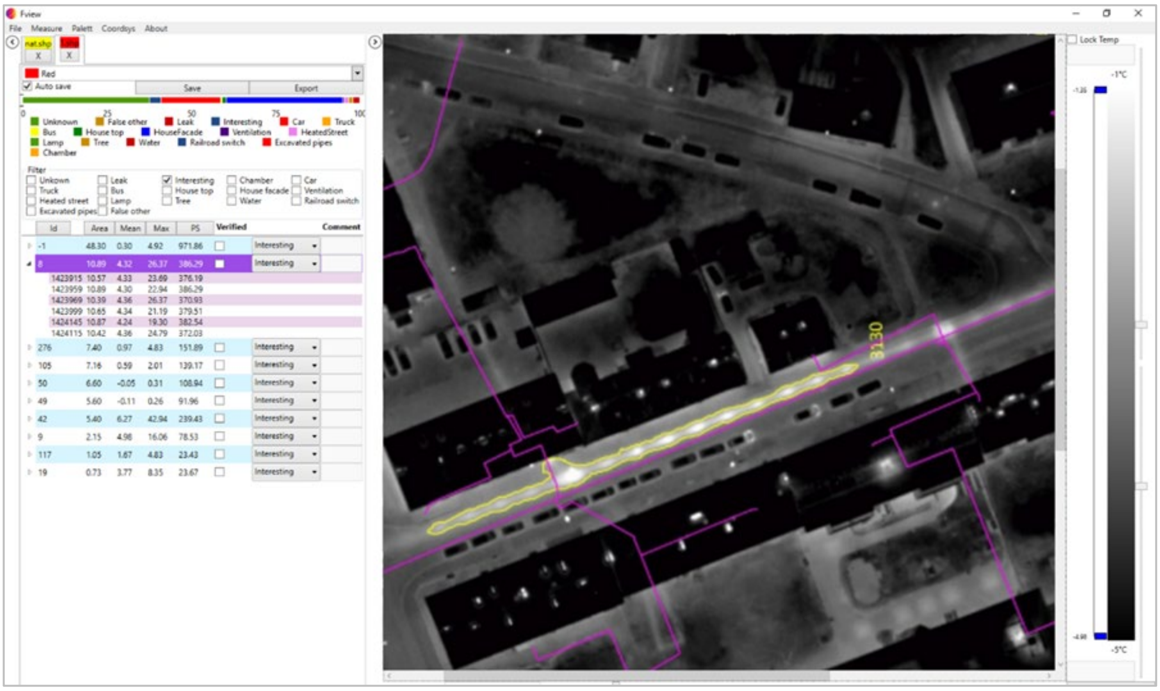


Figure 4.18. A visualisation software used to get an overview of the status of the network (data from Termisk)

In summary, the major benefit of using airborne thermography to search for leakages in the DH network is that leakages cannot only be detected but also quite accurately localised. Modern image analysis methods and available visualisation tools provide the user with an invaluable overview of the status of the network and GPS-coordinates, as well as ratings of potential leakages. On the downside, the acquisition of images and analysis provide information about the network status at a given point in time and, therefore, must be repeated at a regular time interval.

A drone with an additional thermal imaging camera can assess the condition of pipelines and search for emergency sections of pipelines and leaks. Thermographic control is used to plan the renovation of old pipelines. This ensures that the worst pipes are replaced first, which will significantly reduce heat losses and make heat supply more reliable.

A thermovisor is widely used in the wintertime. DH companies provide their customers with a service to assess the thermal insulation status of buildings, as well as to check the insulation status of the heating pipelines themselves, which is especially evident in winter with large temperature differences. It could be used to assess the condition of boilers, turbines, and all other thermal equipment.

4.8. Georadar technology for underground investigations

Georadar technology (see Figure 4.19) has recently been applied for underground investigations, particularly for mapping DH pipelines and trenches, for assessing the status of concrete ducts and channels, and similar. An antenna sends EM signals into the ground and receives them back with changes, depending on soil characteristics, pipes, or other structures in the soil. They can be one-channel or multi-channel type devices.

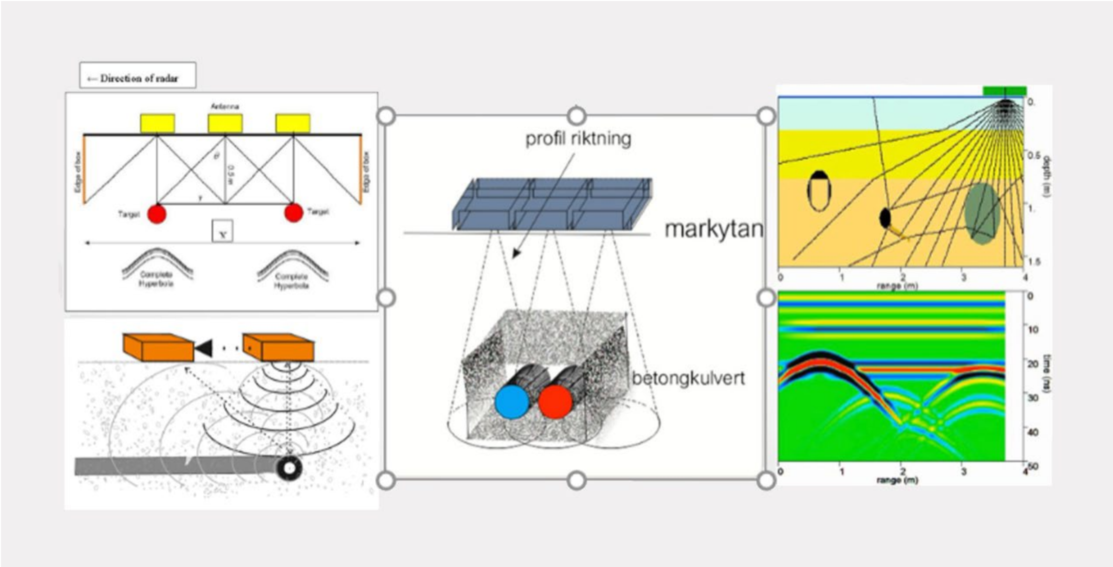


Figure 4.19. Principles of georadar technology for underground investigations

As well as being applied for mapping, georadar technology could also be used to check the humidity of the soil (see Figure 4.20). Visual images of humidity allow identification of water leakages from pipes due to cracks or failed joints (see Figure 4.21). Collapse of soil or changes in soil density helps to identify underground events, cracks, or holes.

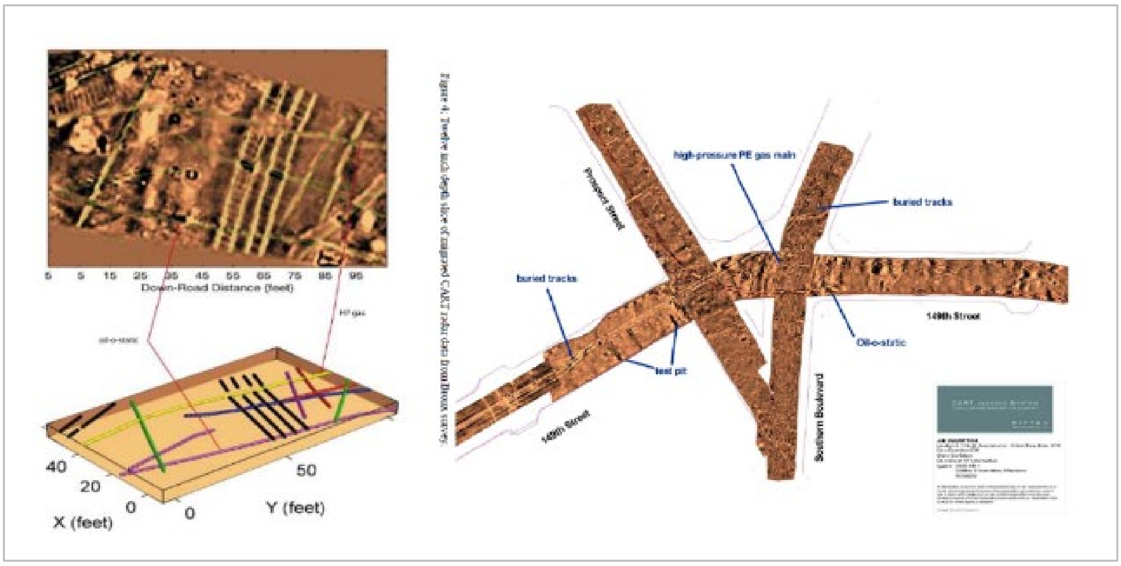


Figure 4.20. Examples of mapping using geo radar multi-channel technology

Georadar, as an on-invasive testing method, is a somewhat new technology to district heating practices, and thus requires further research and experience.

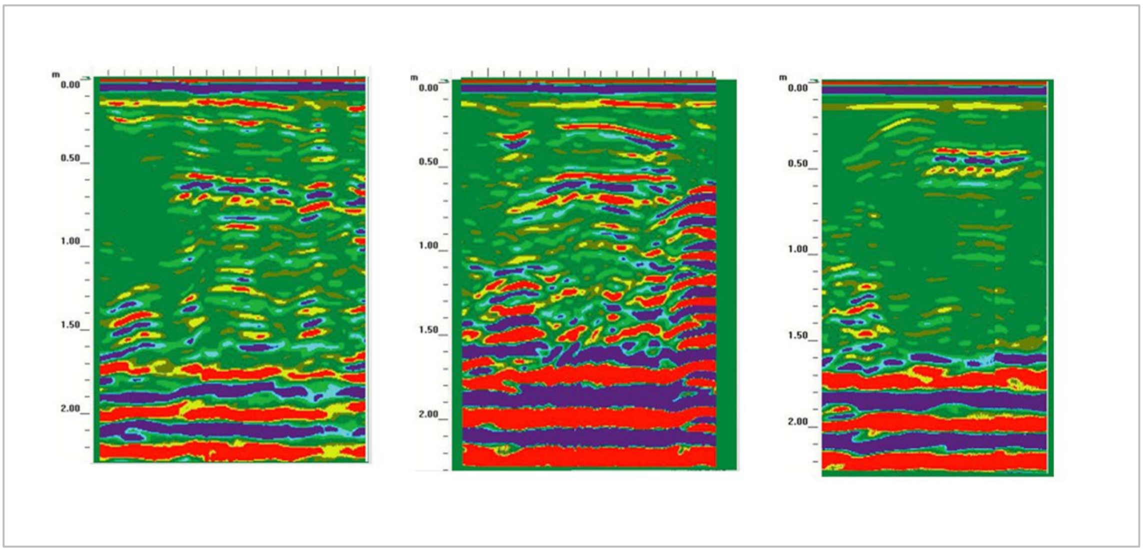


Figure 4.21. Checking concrete culvert; assessment of humidity and insulation state

Additionally, georadar technology and device operation requires that operators have specific competence and experience of working with it.

4.9. Tracer gas leak detection with helium

Tracer gas leakage search with helium as a method should be applied to those areas of the DH pipeline where the suspected leak has already been detected using production test methods. Costs related to the introduction of tracer gas into water should be assessed separately.

This leak detection method allows searching for leaks in pipelines without any interruption to normal operations. For this purpose, helium is dissolved in the water of the heating system, with the concentration kept so low that there is no possibility of gas escaping into the pipeline network. Water containing helium escapes at the leakage points, the helium is desorbed from the water and diffuses to the surface. Using a sensitive measuring device, concentrations exceeding the natural amount of helium in the air (approximately 5 ppm) can be detected on the surface.

The medium (net water) is enriched with helium (He) in a special loading station, which is connected to the network via a bypass line (see Figure 4.22). For better mixing, the loading station should be connected to the return line of the heat carrier. For this purpose, the network operator installs two closed outlets on the equipment side, if necessary, with corresponding hoses. The network pressure must not exceed 9 bars and the temperature of the return heat carrier in the network must not exceed 90°C.

A part of the flow is taken from the network, charged with helium, then returned to the network. Network pumps ensure intensive mixing and distribution throughout the network. It is important here that there are no hydraulically blocked zones throughout the network. The increasing concentration of helium in the network is checked using measurement controls. When using this helium method, all gas release systems that may be in the network must be turned off for the duration of the leak search.

Figure 4.22. Mobile helium (He) injection plant
(by AGFW)

In the indicative loading time, with a network volume of 1,000 m^3 and a return heat carrier pressure of 4 bars, the helium can be stored for four to five days. The lower the pressure of the return heat carrier, the longer the charging takes.

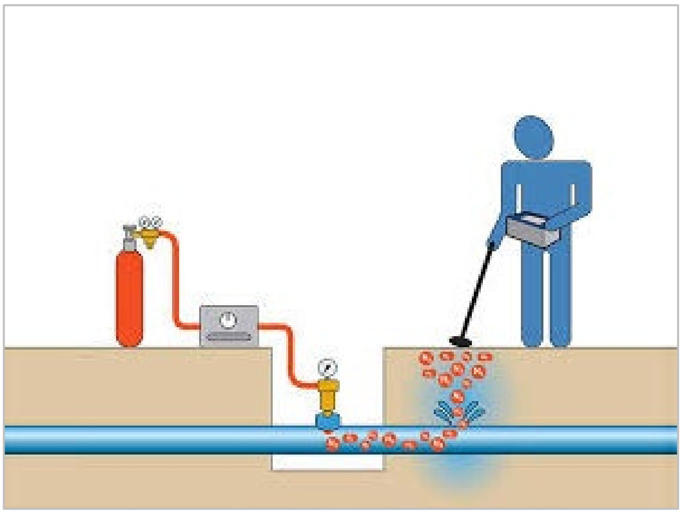


Figure 4.23. Search of water leakage measuring He concentration in the air
(by AGFW)

Helium desorbs from the heat carrier in the medium that has flowed through the leak site and reaches the surface through the ground layer. Using mobile measuring devices (see Figure 4.23), helium concentrations above the normal amount of helium in the air can be detected in wells, house connections, and near-surface air above pipe runs. Knowing where the pipeline route passes is a prerequisite. Measurements in near-ground air should only be made in dry weather and as dry soil conditions as possible (no continuous rain). If the ground surface has a sealed cover, holes (approximately 12 mm in diameter) can be drilled in any joints (e.g. street rain drains) to pinpoint the damaged area. Later, the holes can be sealed with corks.

4.10. Uranine staining of central heating system water to locate leaks

Uranine (40% fluorescein sodium solution) and similar substances colour the central heating system water so characteristically that it can easily be distinguished from drinking water and surface, stratified or underground water. One of its possible uses is the localisation of the defect in heat exchangers intended for heating drinking water. Through the leakage point, depending on the pressure difference between the potable water and the district heating network, the potable water will enter the district heating network, or the coloured district heating water will enter the potable water heater. If the pressure of the district heating return line is higher than the water pressure on the drinking water side, the coloured district heating water at the leakage point will enter the drinking water, it will be recognised as green water at a customer's water consumption point (sink, bathtub, etc.) and the customer will report it to their water supplier.

Drinking hot water preparation systems tested by colouring and, if necessary, by increasing the pressure of the district heating return lines, then repaired, significantly improve the quality of water in the district heating supply network.

Figure 4.24. Dye added for tracing leakage in DH system
(photo from Kalmar local newspaper *Barometern*).

Figure 4.24 illustrates a case of miscolouring a wetland.[8] Uranine is a yellow-green dye that is widely used and fluoresces green under UV and daylight. In aqueous solution it has significant colouring power. The uranine solution in heating system water is considered biologically and food safe. When diluted in water at a ratio of 1:107, the dye can still be identified visually, using UV if necessary. Paints are chemically very stable at normal circulating water temperatures.

However, before applying this method, it is necessary to obtain permits from the relevant authorities (e.g. Department of Health, Department of Environmental Protection, Fire Service, etc.). Customers also need to be informed in time.

When determining the amount of uranine to be dosed, the following points should be considered. As the water of the heat supply system in households will be diluted with drinking water, the concentration in the water of the heat supply system must be higher than the visibility limit. Experience has shown that a

[8] District heating system water quality "District heating substations design and installation", Energiföretagen, 2016.

concentration of about 0.6 mg/l uranine is sufficient to visually perceive the colour. If necessary and appropriate, this amount should be further increased to find smaller leaks. In order to trace the colour, even if the infiltrating district heating water is mixed with drinking water at a ratio of 1:107, the concentration of uranium in the district heating water must be approximately 0.1-1 mg/l.

The dosing time must be managed in such a way that the entire amount of water in the heat supply system can be coloured as evenly as possible. Resin exchangers in partial flow desalination units must be bypassed until the metering process is complete.

Uranine concentration in district heating water is determined by sampling. This must be done by a water chemistry laboratory. After about 10 days, the desired concentration should be established. The ‘dyeing’ process is considered complete when the dye is removed from the district heating water. This is done by continuously replenishing the system with prepared district heating water or by separating the dyes in the resin exchangers of a partial flow desalination plant, which can take several months.

Figure 4.25. Bottles with metal from corrosion
(photo by Prof. William Hogland, Linnaeus University, Kalmar)

Corrosion must be avoided in the entire DH system and optimum conditions for low internal corrosion are if water has 1) a pH value within a suitable interval, 2) low dissolved oxygen content, 3) low conductivity. There are mainly three types of water systems related to DH for a) cold water system, b) domestic hot water for sanitary use, and c) radiator and ventilation systems waters (see Figure 4.25)

4.11. Wall thickness measurement using moving probes

Wall thickness can be measured by ultrasound when only one side of the test object is accessible. During an ultrasound examination, sound waves are transmitted to the object under examination with the help of a transmitter. When passing through an object, sound can be reflected in inhomogeneous areas, e.g. in pores and cavities, as well as in changed seams (corrosion) and the back wall of the object. The reflected sound waves are received by the receiver and imaged in the ultrasound device. The wall thickness of an object or the depth of inhomogeneity can be determined by measuring the propagation time of sound waves.

Waves with a frequency greater than 20 kHz are called ultrasound. The frequencies used in ultrasound technology range from 0.5 MHz to 15 MHz.

Normally, it would only be possible to check the condition of underground district heating pipes from the outside, with high associated costs. However, so-called intelligent probes can be used to obtain information about the condition of pipelines. Depending on the diameter of the pipes, they are equipped with many test heads, which allow information about the condition of the pipe, both on the entire circumference and on the examined length, to be obtained.

A probe is usually composed of many elements. In addition to the drive mechanism, it requires spacers with rollers to keep the distance between the tube and the test sensors as uniform as possible. Sensors in the test probe continuously send a signal to the pipe wall. The propagation time of the received signal is measured, which proportionally reflects the corresponding wall thickness.

The entire measuring technique consists of the device described above and other components such as a cable for supplying power to the drive unit or probe and transmitting the measured values. Measurement results are constantly checked, evaluated, and recorded in the control unit.

To check the corresponding section of the line, it must be disconnected. Depending on the diameter, a correspondingly large piece of pipe must be separated from the network. Then a sluice must be attached to the test piece. Depending on the type of operation, this gateway performs the following tasks. A watertight lock must be made. The cable must also be routed through the appropriate adapter in a pressure-tight manner. In addition, the sluice must have connectors to accept hose connections. In this way, for example, the required amount of water can be supplied from the hydrant, with the required water pressure to ensure the propulsion of the probe. At the same time, water provides the coupling medium necessary for the ultrasonic measurement.

An ultrasonic measurement always requires a coupling medium. Therefore, with the help of a sluice, it is necessary to ensure that the entire pipeline is filled with water (without air). Before the actual measurement, as a rule, the pipelines must first be cleaned. This is done with foam cleaning probes. Depending on the type of drive, and therefore the design of the sluice and the diameter of the test pipe, as well as the number of elbows, the sections that can be traversed can be of different lengths.

During the measurement, it is possible to immediately observe on screen whether there are any serious changes in the wall thickness. A detailed evaluation of the results will be performed by properly qualified service provider employees based on the recorded data.

The international company Quest Integrity has developed an ultrasonic inline inspection tool, known as InVista™, which can collect readings from inside the pipework (see Figure 4.26). The special tool must run within the pipework once and it will gather and provide data on the internal wall loss, the external wall loss and the geometry of the line with extremely high accuracy. This technology is now available for tubes with diameters of between 2 and 48 inches (5.08-121.92 cm). It provides data on combined absolute wall loss and full geometry dimensions with 100% coverage in a single pass, as well as circumferential, longitudinal and ID/OD location of defects with referencing. High-density direct measurement ultrasonic technology provides accurate, repeatable results measured to 0.127 mm precision on wall thicknesses up to 50 mm.

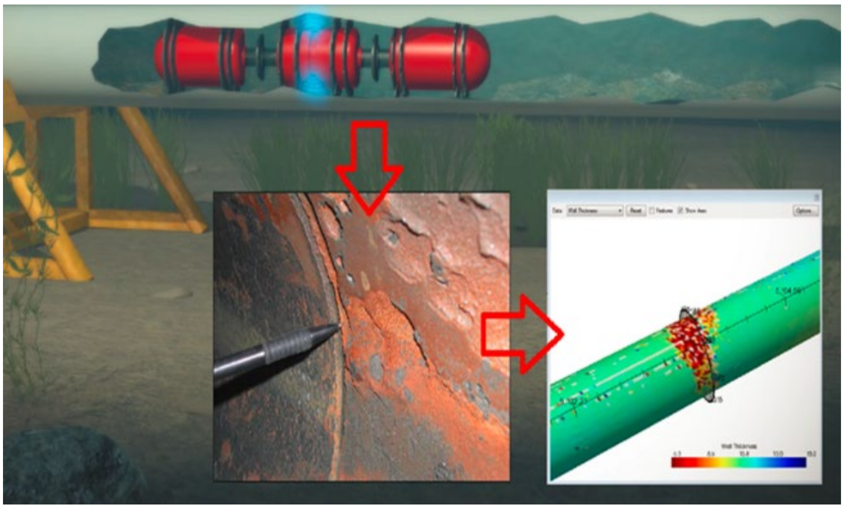


Figure 4.26. Ultrasonic inline inspection of unpiggable and difficult pipelines
(data from Quest Integrity)

The InVista inspection tool utilises ultrasonic technology to gather information from inside the pipe. It emits a signal every 6 mm^2 proving data on the inner radius, the wall thickness and geometry (see Figure 4.26). It's important to note that the tool must be run in a liquid for the ultrasonic technology to be effective. First, the line should be cleaned, any loose debris/scale must be removed, and the line proved suitable for inspection tool. The inspection tool gathers 360° data inside the line along its total length. When the data is downloaded onto the viewer software, internal and external metal loss can be identified.

A more detailed report supported by a software package allows the client to review the pipework digitally. The software could show any point within the pipework and the operator can review an area or detected defect. Some features of the technology include:

- Ultrasonic inline inspection of unpiggable and difficult pipelines/pipework 2"-48" (5.08-121.92 cm)in diameter
- Combined absolute wall loss and full geometry dimensions with 100% coverage in a single pass
- Circumferential, longitudinal and ID/OD location of defects with referencing
- High-density direct measurement ultrasonic technology provides accurate, repeatable results measured to 0.127 mm precision on wall thicknesses up to 50 mm

4.12. Stationary acoustic monitoring of leakages

One example of a stationary acoustic leakage detection system is the moisture detection system provided by PG Monitoring System AB (see Figure 4.27). The system is able to find the beginning of a leak in its very early stages. It will create an alarm to raise awareness of a fault that is occurring and locate the fault to within meters. It can measure distances of up to 4,000 m of pipe. The level of sound is easy to view in the map, clearly indicating if it is too high, and send alarm if required.

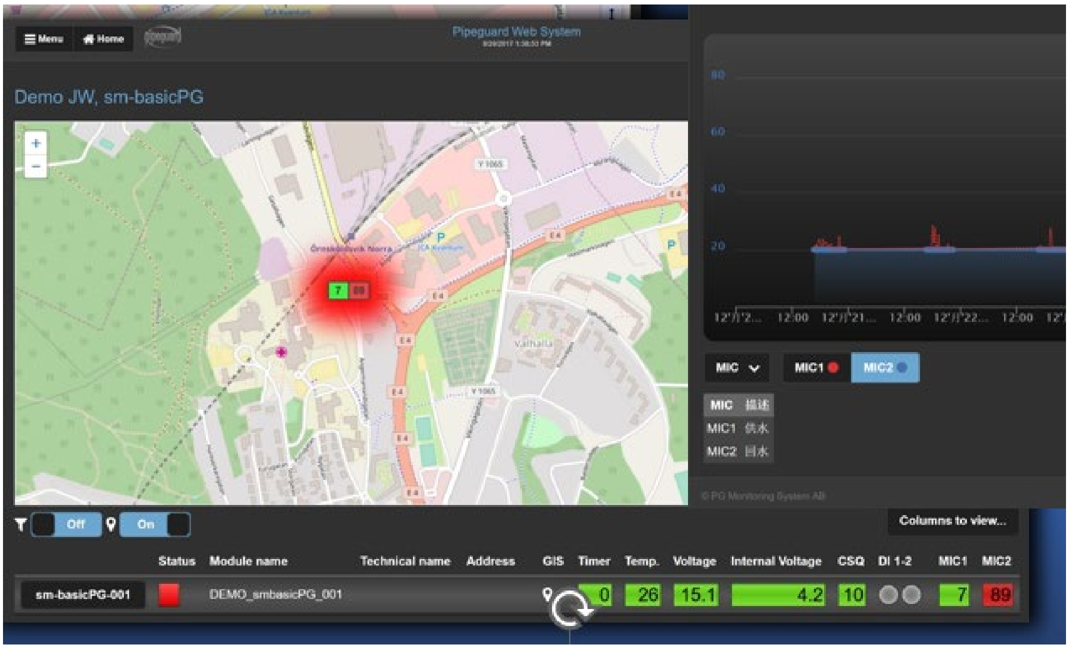


Figure 4.27. Indication of leakage on the map, Pipeguard example
(data from PG Monitoring System AB)

This is a fully automatic monitoring system for surveillance in district heating networks pipes without alarm wires. The module searches for leak sounds and presents values in a map image, from which the size of the leak can be judged.

An example of a surveillance monitoring system for district heating chambers is shown in Figure 4.28. This unit can be lowered down into non-accessible chambers; however, there is another version can be installed in accessible chambers. Apart from water level surveillance, it can measure chamber air temperature and humidity level. It can also be equipped with special microphone to record audio files, and detect water leakage noise (using a special fast Fourier transform filter). Recorded audio files from two units can be used to locate a leakage along the pipe. The battery life of the unit is five years.

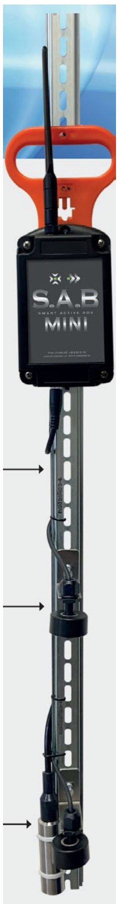


Figure 4.28. Surveillance unit, for non-accessible chambers
(data from Arne Jensen AB)

In the diagram, the top arrow shows the metal frame to be fixed in the chamber. The middle arrow shows a float sensor for detecting flood water levels, and the bottom arrow shows a float sensor for flood alarm and an optional sensor for water level measurement.

4.13. Control of tube wall thickness and steel composition

There are several new technological solutions that can be practically applied for monitoring of tubes and joints status in DH piping systems. Among them, ultrasonic technology seems particularly promising.

Ultrasonic devices

An ultrasonic device is designed to measure the welding seams and the metal itself. With the piezo element, the ultrasonic signal is sent through the entire thickness of the metal; the returning signal shows all the internal defects and the thickness of the metal on a visual display. Currently, it is widely used instead of X-rays.

An ultrasonic metal thickness gauge: contact gel is applied on the piezo head, which is then attached to the pipe, and the screen shows the thickness of the metal pipe wall. If corrosion is detected, its extent at that point in the pipeline is shown.

A manual portable metal composition analyser is convenient and compact but does not show the carbon content of steel. It can show how many alloying elements are present in the steel at any specific location. These devices are mobile and could mainly be applied episodically for steel control during repair work or at the installation phase, but do not provide a systematic overview of pipeline status over a certain period.

Acoustic analysis

The SAB condition monitoring system is an advanced and flexible measurement platform. It has its own power supply, an energy harvesting unit that transforms heat from the district heating pipe to an electrical current. The system has two electronic boxes, as seen in Figure 4.29. The left box (JAM) is an audio amplifier unit that creates audio pulses (vibrations) in the actuator seen in the very front of picture. Special microphones on another SAB unit (installed about 100 m away) will pick up the vibration that is propagating through the water column in the pressurised steel pipe. An audio file is recorded in the right box (SAB), transferred via a mobile data network to a database. From the database, audio files are selected and analysed using smart algorithms that calculate the remaining strength of the DH steel pipes. This is a predictive condition monitoring method that can find the remaining lifetime of a steel pipe that has been degraded by corrosion or thermal wear. The acoustic system can also detect and locate water leakage noise. Special filters are designed to ignore noise unrelated to leakage.

The SAB unit has a powerful micro-computer and can measure anything via connected sensors, including:

- Temperature, humidity, and air quality (CO) in chamber
- Water level, alarm, and range measurement
- Temperature, flow (optional), pressure (optional) in pipes

Figure 4.29. The SAB condition monitoring system
(data from SweHeat and Öresundskraft)

The above described technologies and devices for DH assets management are mainly orientated to find leakages and potentially risky sites (water penetration into pipelines, for instance). Such approaches provide the possibility to identify problems to prevent them becoming worse but do not provide complex and systematic information about the status of certain tubes, pipelines, or an entire DH network. Separate methods or their combinations employed in DH assets management assist in the location of the weakest sites of a network but are not particularly effective for the prognosis of tube reliability, deterioration, and the necessity for replacement. For this purpose, new approaches and additional technologies must be involved. A new philosophy, based on data-driven systematic information and smart assets management methods, will be discussed in the next chapter.

Chapter 5: Proactive data-driven (smart) assets management

Typical network challenges are related to the fact that there is a leakage in the network, but locating it takes long time. Usually, leakages are recognised only when they occur; very few preventive tools are available. Proactive data-driven methodology is based on stationary and periodical measurements when many parameters and indicators are available, and which reflect the status of certain pipelines and particular tubes. It allows the risk of failures to be estimated and predicts the operational lifetime of the assets. Traditional approaches to maintenance of DH pipes can be illustrated ~~by~~ as the following sketch in Figure 5.1:

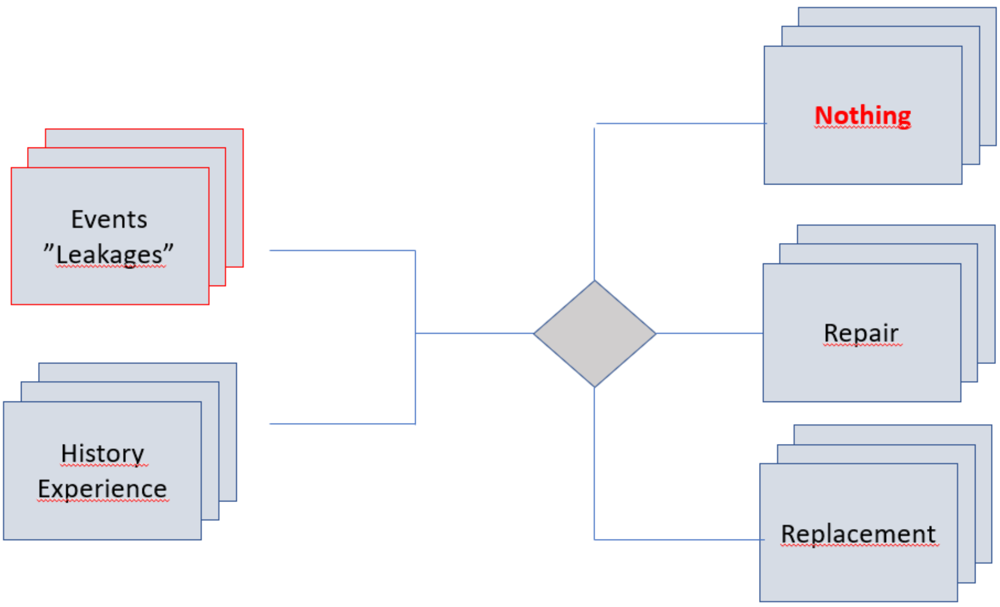


Figure 5.1. Traditional approach to maintenance of DH pipes
(data from SweHeat)

New smarter approaches to DH piping system management could be applied if – in addition to the above mentioned methods of periodical or continuous measurements (monitoring) of water leakages (water penetration|) and pipe strength – continuous measurements of certain tubes (pipeline parameters or such) were introduced, and extensive and comprehensive data collection and analysis was used. Such systematic evaluation of data using state-of-art software, helps not only in the prevention of accidents, but also allows planning of pipeline repair and replacement works. As a result, reliability of DH network is significantly increased, the operation of DH trenches is prolonged, and the cost of heat transmission is reduced (Grzegórska et al., 2021). Data-driven methodology, which includes stationary measurement equipment, with many parameters measured and analysed, is illustrated in Figure 5.2:

Pipe Maintenance Methods - Predictive

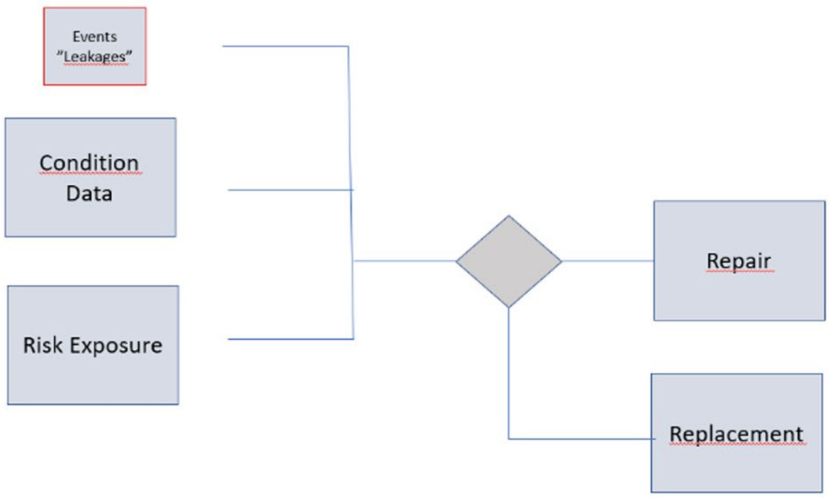


Figure 5.2. Predictive management of DH pipelines
(data from SweHeat)

Data-driven maintenance methodology for DH distribution means that asset owners get better information upon which to base their decisions. The assets, the DH pipes, can be used for their full lifetime, before repair/replacement/relining, without additional risk of pipe-burst and leakage. The positive economic impact is significant if assets are used for their full lifetimes. Less capital is used, improving ROCE (Return On Capital Employed). The direct replacement cost of old pipe networks in city centres can be 5,000-10,000 EUR per metre of new pipe. The added value of new pipes compared to the old pipes is typically only 20-30% of the total investment. A major part is non-added value, excavation, welding, etc. Experience shows that 80-90% of replaced steel pipes are in good condition, not in need of the entire length to be replaced. Replacement is usually due to several identified leakages at a certain segment of the DH pipeline. A failure could be very local but it's not possible to evaluate the status of the entire pipeline without excavation and opening of tubes.

It is becoming more important in our society to preserve assets and infrastructure. It is good for the economy, as shown above, and it is good for the environment, because typically 80% of a construction's emission of CO_2 is related to the construction phase. It is also good for the city, because of the reduction of excavations, open trenches, and blocked streets. Finally, it is good for the DH company because replacement projects require intensive project management.

In summary, the data-driven maintenance system can:

a) detect leakages (online)

b) locate leakages (online)

c) detect and locate weakness in the steel pipes.

The sensor boxes can also detect anomalies and operational data in the DH chambers and ducts, such as: flooding, humidity, space temperature, pipe temperatures, etc.

Acoustic sensors and algorithms of analyses allow the detection and location of corrosion and thermal wear in steel pipes before the pipe bursts. This reduces hot water losses and risks of accidents, utilise the full lifetime of the pipes, and requires less reinvestment. Additionally, it helps to detect and locate weak customer connections, causing high return temperatures and enabling a reduction in average system temperatures and reduced losses, etc.

5.1 Pilot case Poland: Gdansk University of Technology/OPEC

5.1.1. Monitoring of DH grid status, examination, and refurbishment in OPEC Gdynia

DH company OPEC Gdynia has a highly efficient heat transmission system with insulated steel pipes placed in a concrete channel and a very small amount of low-parameter (low-temperature) pre-insulated pipe system. In addition, it has local group stations that can exchange high-temperature to low-temperature, with water going directly to the recipients.

The **main challenges and problems** faced by the DH network in practice are (information provided by OPEC):

- insulation or replacement of the existing insulation of channel pipelines or their replacement with pre-insulated networks in order to reduce transmission losses
- control of the heating system operation (ensuring appropriate pressure and temperature parameters for each recipient)
- forecasting the demand for thermal energy considering weather forecasts
- system operation control in emergency situations
- flooding the heating chambers with groundwater and rainwater
- wear of individual system components
- corrosion of pipelines
- mechanical damage of infrastructure (on construction sites)
- high renovation costs
- changing the power supply system from group stations to individual heating substations
- installation of devices for remote data reading
- replacement of mechanical water meters with ultrasonic ones
- installation of PV installations on buildings
- replacement of obsolete heat valves in heating chambers with fully regulated valves (controlled from the control room) for more effective regulation of pressures and flows

System risks considered by the DH company:

- development of the system related to the capabilities of the source
- reduction of heat demand in buildings as a result of thermal modernisation
- need to increase the efficiency of the system (renewable energy sources, elimination of high-emission sources)
- increasing outlays for the development of the system

When **analysing the risk factors** related to the DH system, following elements considered:

- unsealing of pipelines due to corrosion or failures caused by improper service work
- possibility of high pressure and high temperature in the chambers and heating substations
- risk of toxic gases in the heating chambers
- threats to infrastructure from rodents and insects

Additional risks occurring during the pipeline renovation estimated, such as:

- work in places with heavy pedestrian and road traffic (the need to properly secure the workplace)
- need to move in tight spaces
- working at height

Monitoring measurement frequency on the DH network:
Brandes impulse alarm systems, monitored by the built-in RATMON system, have been applied. These are systems specially designed to monitor DH networks. Monitoring is carried out continuously (24/7). Additionally, measurements of the alarm system are performed once a month.

Smart Assets Management applied for risk analysis. The risk is analysed mainly using the VISTA program, which provides following options:

- visualisation of selected parameters measured in the heating chambers
- visualisation of the work of heating substations and chambers
- ability of remote control of selected devices
- registration of selected data (pressure, temperature, basic data from meters, heat valve operation, etc.)
- signalling of alarms
- changing the configuration of the operation of selected devices (shutdown temperatures, work schedules, lowering the temperature at night, etc.)
- observation of the system operation in selected places (main chambers, heating substations at the end of the network)

Additionally, when assessing the risk of pipeline failure, the company has recently introduced a thermovision map. A system for remote reading of data from heat and water meters has been installed, instead of the usual data transfer needed for billing (GJ and m^3 states). This enables the analysis of the building and network operation (based on the collected data from meters collected every hour (technological measurements – temperature, flows, power). Data and analyses are presented graphically based on GIS maps (buildings, networks, topography, thermovision); additionally, there is the ability to build charts from the required data or tabular summaries.

It is planned to build a supervision system over the pre-insulated networks with the use of RATMON switchgears. The data collected in this way is to be sent to the GIS system, which is constantly being improved. Networks, with so-called impulse installations and Brandes installations, will be connected to this system for the purpose of comprehensive monitoring of the entire DH system.

5.1.2 Purpose of the Gdansk pilot case

The Gdansk pilot case in the BSAM project, was launched in early 2022 based on the decision of the project partners and budget reallocation. The pilot case contains two parts, i.e. 20 devices for data-driven proactive maintenance of a district heating pipelines mounted on OPEC DH grid in Wejherowo, Gdynia (see Figure 5.5) (approx. 35 km north-west of the regional metropole of Gdańsk), and a laboratory installation at the university for model investigations of pre-insulated pipeline degradation (see Figure 5.6). The main goal of the pilot case is to assist digitisation of analogue data needed in smart asset management of district heating systems, resulting in a decrease of carbon footprint of DH systems. This will be achieved by providing a central data storage and analysis system, which can be implemented as in independent server and application in the cloud and on the supplied control unit. The system must ensure digital security of data collection and allow further advanced processing of data. Data from the DH grid will be measured and collected using sensor stations (see Figure 5.3), developed specifically for the BSAM project. The system based on sensor stations enables control and analysis of a thermal stability of DH pipelines for the supply and return lines, and the coupling of this data with temperature and humidity in DH chambers (see Figure 5.4). The data collection system is based on the MQTT protocol and data is saved in the GSM network. Sensor stations send encrypted data to an external broker with a public address on the network. The data from the broker is retrieved and archived on the local server.

Features of the BSAM pilot case:

Sensor station

The BSAM system is based on collecting data from sensor stations, mounted in selected locations of DH grid. Each sensor station contains:

- Four temperature sensors for measuring the temperatures at the supply and return pipes
- One temperature and humidity sensor for monitoring environmental conditions in the DH chamber
- One sensor for detecting a water leak, based on the water-level principle
- Four sensors for ultrasonic testing of the pipe condition, allowing for detection of a pipe rapture.

Principle of ultrasound detection of a pipe rapture

Ultrasound in air and liquid pressure systems arises because of turbulence in the flow in a given part of the installation and its components (valves, orifices, gate valves). Leakage of a fluid from the installation causes the formation of local turbulence during the fluid flow. Generated waves bounce against solid elements while losing strength. A measuring device picks up short blows and transforms them into a signal indicating a pipe fault. Due to defined locations of sensor stations, it is possible to localise a pipe rapture since the damage is located within the distances between the ultrasonic sensors. Detection of damage is based on comparing states.

System server and communication

As a part of a local server, node red software was launched. This software allows for data visualisation using a dashboard. The data is archived in the form of CSV files, ready for further analysis.

Measuring sensor stations are mounted in scattered, but fixed locations on the DH grid. Each station requires an independent power supply because a connection to the electric grid in a DH chamber would be complex and expensive. Thus, a battery power supply was installed in sensor stations; the battery requires charging/exchange every 30 days and its condition is monitored constantly. A GSM network was chosen to serve for communication purposes, since implementation of typical solutions for radio networks (e.g. LoRaWan) is costly and not suitable for this system, mainly due to expected interferences from the large number of similar objects in the cities.

Figure 5.3. Installation of sensor stations in Wejherowo (OPEC DH grid)
(photo by Gdańsk University of Technology)

Figure 5.4. Sensor station on the DH grid (OPEC, Wejherowo)
(photo by Gdańsk University of Technology)

Figure 5.5. Locations of sensor stations (boxes) in Wejherowo, OPEC DH grid
(photo by Gdańsk University of Technology)

Sensor stations on the DH grid and laboratory test installation

Twenty sensor stations have been installed on the OPEC DH grid in Wejherowo. The data have been collected since September 2022 and data analysis is planned in early spring 2023 to investigate the system behaviour during the heating period 2022/23.

A laboratory test installation contains an electrical water boiler coupled with typical DH pre-insulatedpipes (see Figure 5.6). The control stations in the laboratory installation includes sensors (see Figure 5.7) that allow for monitoring of temperature distribution for the supply and return pipelines because of heat transfer in the plate heat exchanger:

- internal diameter of a pipe: 50 mm
- length of a supply: 12 m
- length of a return: 12 m
- plate heat exchanger
- water meters (max flow rate 160 dm min^{-3})
- 24 meters of pre-insulated pipes in reserve
- device for measuring pipe thickness
- control system coupled with a sensor station.

Figure 5.6. Construction of a laboratory test installation at Gdańsk University of Technology

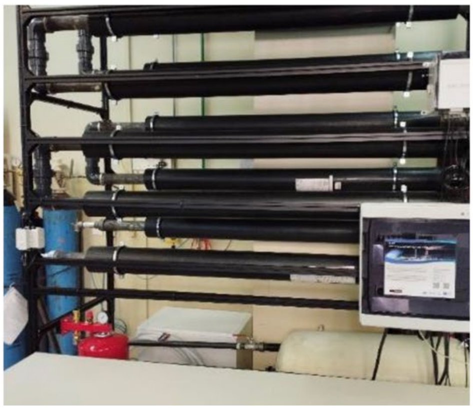


Figure 5.7. Control stations in the laboratory installation
(photo by Gdańsk University of Technology).

Figures 5.8 and 5.9 show read-outs from a single sensor station.

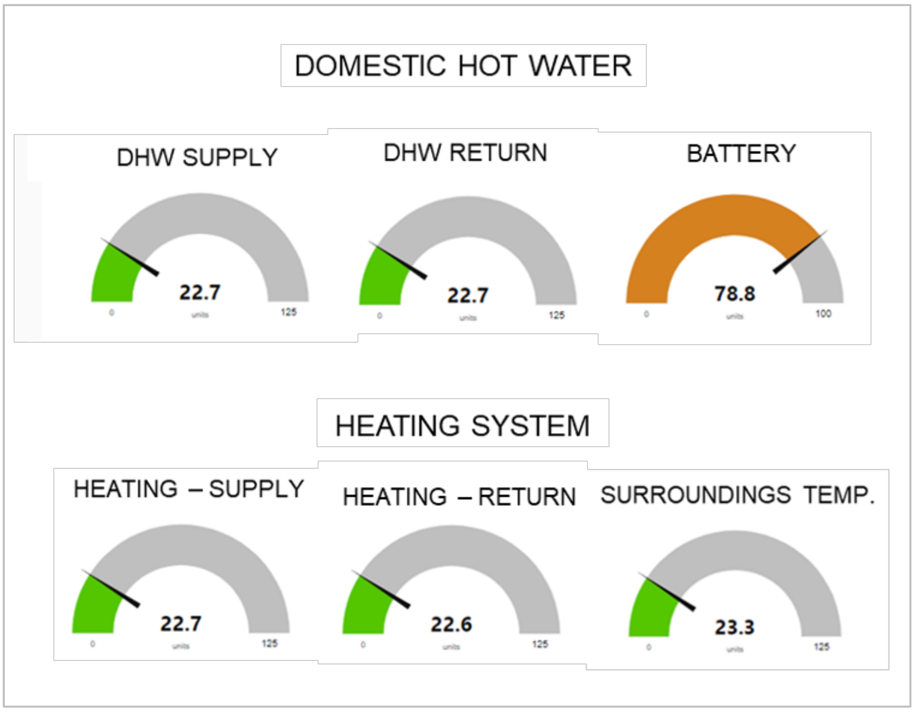


Figure 5.8. Visualisation of read-outs from a single sensor station
(data from Gdańsk University of Technology)

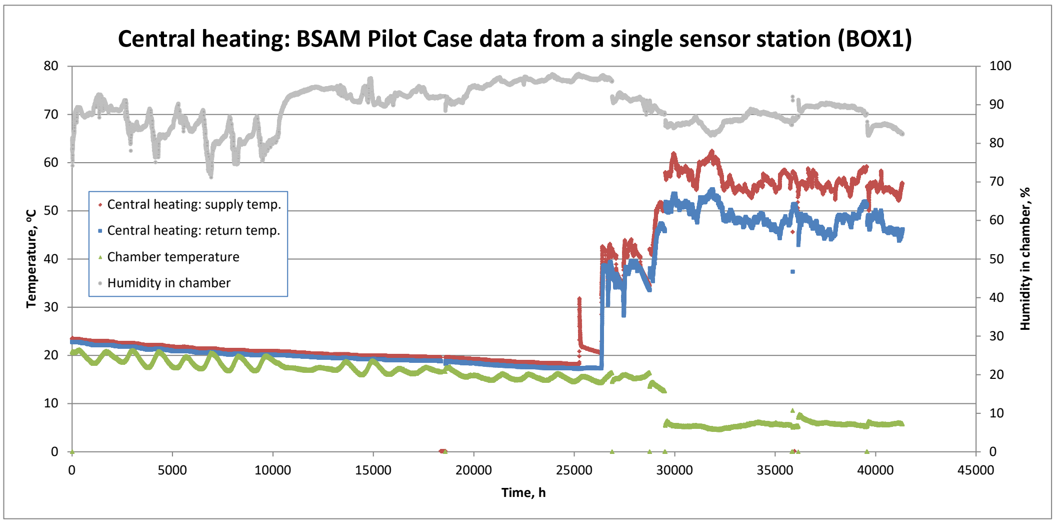


Figure 5.9. Data visualisation from a single sensor station
(data by Gdańsk University of Technology)

5.1.3 Pilot case Poland – conclusions

The pilot case developed in Poland shows good potential for monitoring of selected parameters of a DH system – temperature, humidity, alarm for pipe rupture, all of which confirm the stability of a system – and allows for very fast detection and localisation of a pipe rupture. This was provided at a relatively low price and proved to work reliably for over nine months. Advantages also include ease of installation of devices (fast, non-invasive) and real-time online data visualisation. An important aspect of the implemented system is related to acoustic signals that can be obtained. However, as is the case in the Swedish pilot, valuable use of the results would require years of experience to relate the changes in signal to the condition of the pipes.

Installation of the sensor stations on the grid was not complicated and it is non-invasive of DH assets. Practical installation of the smart assets management facilities at OPEC's DH network should raise staff interest and awareness in the new possibilities of tube maintenance and planning of replacements. The test set-up at Gdansk Tech University provides good potential for further investigation of technical aspects of smart assets management and in development of new hardware and software in this field.

The carbon footprint reduction due to installation of a single sensor station was assessed. Taking into consideration specific assumptions, i.e. BOX (sensor station) devices are supplied from electrical grid and the power consumption is compensated by renewable energy from photovoltaics; leak detection flow rate using hydrophones of 100 l/h and similar was assumed during the occurrence of a single pipe rapture; 1 km of district heating network is considered; localisation of pipe rupture by traditional method takes 36 h; localisation of a rapture using a BOX device takes 1 h; DEFRA coefficients (2022) were used for calculations; carbon footprint assessment is for a period of one year with one accident of water leak due to pipe rupture both for domestic hot water and heating system hot water), it was found that the carbon footprint can be reduced by 44.85 kg eCO_2 compared to using traditional methods of failure detection.

In summary, this pilot case implemented in Gdansk Tech University, with laboratory and field installations, could be the beginning of a new DH management school directed to the further improvement of district heating technology in Poland, as well as in other countries.

5.2 Pilot case Sweden: Öresundskraft

Technological solutions for continuous measurements of certain physical parameters of tubes have been developed by several Swedish companies and tested in Swedish DH networks. In particular, Öresundskraft DH company has implemented a so-called smart assets management (SAM) methodology, where in addition to traditional leakage monitoring methods, continuous measurement of steel tube wall thickness as well as other parameters of DH pipelines, which are important for assets management, have been implemented. Continuous measurement of physical characteristics and risk identification by continuous data analysis allows the company to identify leakages or other existing or potential problems in the DH network, as well as to plan tube repairing or necessary replacement. A large amount of data received from the DH network has been analysed using specialised software and has provided important information for the DH network's management team.

As an example, the City of Helsingborg is going to rebuild Furutorpsgatan, in central Helsingborg, providing a new pavement and bicycle lane. Ahead of the roadworks, Öresundskraft AB examined 500 m of concrete culvert below the street, which was built 1976 (see Figure 5.10). Furutorps street is a central and very busy street, and the street work could limit public access to city buses, schools, restaurants, stores, and apartment buildings.

In order to keep workers and public safe, the repairs of the street need to be prepared with a specific focus on safety according to general public safety legislation.

Figure 5.10. Furutorpsgatan in Helsingborg with 500 m of concrete culvert chosen for a pilot case of 10 chambers
(photo by Öresundskraft)

Figure 5.11. Arrangement of devices for measurement of tube wall thickness in the DH chamber
(photo by Öresundskraft)

A key element of the system is Smart Active Box (SAB) (see Figure 5.11), a sensor platform for measuring water flooding, water level, water temperature, pipe temperature (forward, return), air humidity, CO-level, temperature. It also provides condition monitoring of the remaining strength of the steel pipes (prediction of end-of-life/replacement before failure). Hot water leakages can be detected and located online, using acoustic correlation. Mechanical stresses (fatigue) from temperature variation in pipes can be logged.

Sensor boxes are installed in all concrete duct chambers. A sensor box type SAB (see Figure 5.11) is equipped with sensors for measuring flooding, humidity, space temperature, pipe temperatures, etc. The box is also equipped with microphones (accelerometer) and a pulse generator (actuator). The system is self-power supplied, harvesting heat from the forward flow pipe, and transforming it to electricity.

Measurement data is transferred over mobile data network (IoT), stored in the cloud or physical databases, and presented to the users in a SCADA-system. An analytical service is also provided.

Through continuous monitoring, the remaining strength of the steel pipes that have been degraded by corrosion can be monitored between the measurement points. This is done by injecting acoustic pulses in the pipes containing the pressurised water volume. This predictive maintenance monitoring enables prediction of the condition and lifetime of the steel pipes. During repeated online measurements, weak (corroded) sections of the steel pipelines will be revealed, singling out the 10-20% of pipe sections that are typically degraded. The remaining 80-90% can be used for many more years, until degraded by corrosion.

The sensor box has many other functions, as mentioned. The same microphones can also detect leakages in the pipes and by correlation locate the leakage in semi-real time. This function will drastically reduce leaked water volumes and reduce the risk of consequential damages. The SAB sensor box can also be upgraded with more sensors to further analyse and exactly locate corroded spots along the steel pipe.

The SAB box can also prevent corrosion by preventing moisture and condensation on metal surfaces. It measures humidity level and water flooding in the ducts and chambers. A fan, power supplied by the SAB-system, can be installed to ventilate humid air out through the ventilation towers.

Data-driven maintenance methodology requires a new procedure of work for the DH companies' operation and maintenance and asset management teams. While the upside is to utilise assets over a longer life period, prevent pipe bursts and leakages and reduce unplanned emergency field work, the requirement for the companies is to spend more time on analytics and planned decision making.

Work environment rules are changed regularly and there are special requirements for district heating distribution where work is carried out in chambers below ground level (see Figure 5.12). The SAB (Smart Asset Box) solution, which controls both the climate in the chamber and the status of the pipes, makes the working environment safer because it determines what condition the pipes are in and ensures that the air in the chambers has the right levels of, for example, O_2 and CO.

The solution includes moisture alarm wires for alarm and fault location of moisture in pre-insulated pipes, hot water leakage through steel pipe into PUR foam, or intrusion of water from damaged PE shield into PUR foam. Moisture alarm tapes for water intrusion in ducts/culverts have been installed, and alarm and location measurements provided as well.

A more detailed description of technologies and data-driven smart management of the network at Öresundskraft DH company is presented in **Annex 1**.

Figure 5.12. Inspection of DH network chambers
(photo by Öresundskraft AB)

Continuous monitoring of the remaining strength of steel pipes (prediction of end-of-life/replacement before failure) is carried out by acoustic signal analysis. Sensor boxes with remote communication installed in most of the DH chambers and online, continuously provide data, including alarm signals, to the analytical centre. Data are collected, transferred via API, and logged in Power BI, a data analytics tool and user interface that receives the measurement data. The Network Information System (NIS) is based on Geographic Information System (GIS) coordinates. All reports and planning of maintenance are made in the NIS. By the beginning of year 2025, the entire network will be continuously condition monitored using this technology. Details on the Smart Active Box technology in Helsingborg is provided in **Annex 2.**

The process of data-driven assets management methodology, developed in the Öresundskraft district heating company, as a "Technical Feasibility report, Smart Active Box" is presented in **Annex 3**. The report demonstrates how to increase the service time of pipes in the DH network by assessing the status of the steel pipes and the chambers.

Recommended process:

1. Define the most critical pipe sections that should be monitored online. Work stepwise, starting with 5-10 sections.
2. Install the online sensor box system, SAB. During the installation process, specialist engineers will make advanced manual measurements to establish a baseline. Each pipeline section that is monitored will be classified as Good (Green), To-be-extra-observed (Yellow), Risk-to-be-replaced (Red). This analysis will be repeated on a regular basis, finding trend changes, pointing to a sign of degradation.
3. Organise the analysis. The SAB supplier will provide analytical services, user-interface and customised report. Align the new information and data with existing systems, such as Network Information Systems. A recommended maintenance plan can be provided by the product service system supplier. The new system will require more in-house engineering capacity, but less fieldwork.
4. Implement new maintenance work based on predictive data. Be proactive, prevent degradation and leakages by knowing your network better.

Predictive maintenance techniques are designed to help determine the condition of in-service equipment to estimate when maintenance should be performed. This approach promises cost savings over routine or time-based preventive maintenance because tasks are performed only when warranted. Thus, it is regarded that condition-based maintenance is carried out as suggested by making estimations of the degradation state of the pipes.

To build a new pipeline could cost approximately 6-8 million EUR. It is a complex project, and a lot of infrastructure is needed in the streets. The technical lifetime for pipes could be expected to last more than 80-100 years.

Repairing the concrete culvert will cost approximately 2.5 million EUR and its new technical life should be around 50-100 years. It is a more sustainable method for the climate and environment. The reparation work is described below:

1. Excavate along the culvert.
2. Scan the culvert to detect any rusty reinforcement steel.
3. Remove cracked concrete and rusty reinforcement steel.
4. Repair the concrete culvert.
5. Add sensor cable for detecting moisture in culvert.
6. Repair the chambers.
7. Seal the culvert and chambers with new sealing.
8. Restore the street.

The SAB sensor box system continuously measures the steel pipes integrity and its strength to withstand pressurised hot water. This predictive maintenance strategy will improve work conditions. There will be less emergency work and less corrective repair work to manage leakages. The economic benefits of the SAB technology are presented in **Annex 4**.

Examples of data provided by the SAM system and their interpretations (discussions) are illustrated in **Annex 5.**

The goal for Öresundskraft AB is to change the right pipe at the right time. This requires that the status of pipes and culverts is known. SAB, with the Delta thickness method, is currently the main technology available. Delta thickness gives an average value of the steel's strength thickness between two SAB boxes and since these are located in each descendible chamber (see Figure 5.11), it gives very accurate information about the quality of the steel. The chambers are built with a space of 40 to 190 m between them. As the SAB continuously measures from the same point, all external factors are removed and the changes in the measurement depend only on the strength thickness of the steel.

5.2.1 Pilot case Sweden – conclusions

There are three things that make SAB unique in comparison with other similar equipment:

- A sound pulse is applied through the steel from one SAB, passes through the water and is received and recorded by another SAB. The method is called Delta thickness (Delta-t). This provides a status assessment of the steel's strength thickness in the pipe network. Strength here relates to fresh steel condition without corrosion.
- The SAB does not need batteries because the current is the difference between the heat in the network and the ambient air temperature.
- The water level in the chamber is measured continuously.

These three things were realised during the project and worked successfully.

Measuring the strength of the steel in DH culverts and pipes is extremely important because it indicates how long the steel will remain functional. If the steel has a sufficiently high strength, it makes sense to also check that the outer casing and insulation are in good condition.

Next year, a 500-meter culvert will be repaired as a comparison to replacing the same culvert with a new pipeline. It is presumed that the repair cost will be half of what it would be to replace it. At the same time, there will be an investigation of the sustainability that describes the difference between replacing the culvert or repairing it. If this project turns out successfully, Delta-t will have enabled a new way of repairing this type of culvert and extending its service life.

The solution to charge the battery with the heat difference between the pipeline and the ambient air enables continuous measurement without having to change batteries. With the same measuring range using regular batteries, the batteries will often discharge and therefore need to be frequently replaced; this would be both economically and technically unprofitable, requiring resources in both batteries and personnel to replace them.

When the water level is measured continuously, pumping can be done to reduce the amount of rainwater in the chamber and measures can be taken to stop or reduce the water supply. The moisture content of the air in the chamber is also measured and when the water supply has been stopped or reduced, the measures to reduce the moisture content can begin. Keeping the moisture content below 60% causes the corrosion rate to stop or decrease significantly.

6. Project summary and conclusions

1. The Baltic Smart Assets Management (BSAM) project revealed large scale and complicated exploitation issues in the district heating systems, related to ageing of pipelines and the impact of external factors.

2. Practical technologies applied for leak detection and prevention in district heating systems have been reviewed, and their features and applicability analysed.

3. A variety of monitoring and management techniques are available on the market but all of them have essential limitations and can't solve the main assets management task: to prevent tubes failures and to optimise the operational lifetime of tubes.

4. The BSAM project made it possible to exchange knowledge among partners and stakeholders related to DH management techniques, approaches, and perspectives.

5. Two pilot cases with practical applications of new Smart Assets Management (SAM) technology for DH pipes operation and maintenance clearly demonstrated the possibility and usefulness of systematic and continuous measurements of the physical tube and pipeline parameters, enabling tube failure prevention and replacement planning.

6. The Swedish example of DH pipelines monitoring using the SAB system in Helsingborg is outstanding comparing to similar techniques applied in Poland and Lithuania. However, installation and results processing of this system is based on years of experience and goes way beyond the scope and budget of the BSAM project.

7. BSAM revealed and showed the necessity, importance, and profitability of using the SAM approach towards monitoring DH systems for prolonged exploitation periods, as well as the elimination of unexpected pipe raptures and the need for urgent system repairs due to accidental failures.

8. The BSAM project has produced three important outcomes:

- A network for co-operation between project partners and related stakeholders has been formed. This may prove of benefit in the future, both in terms of common project applications, as well as co-operation in the BSAM-related issues and cross-border consultations.
- The BSAM Handbook, as one of the main project outputs, is an overview of problems and novel solutions to monitor and manage DH systems assets. This piece of work is a unique handbook for professionals, as well as for teaching and training purposes.
- The BSAM training module, the other main output of the project, consists of a set of logically categorised presentations of high potential for teaching, both for BSc and MSc student courses, as well as for professionals from the DH sector. Additionally, the module presents selected SAM methods and materials related to the pilot cases and discussions developed in the BSAM project.

9. Generally, further development of already obtained experience and knowledge of data-driven smart assets management based on the large scope of physical data and qualitative analysis could herald a new era in operation and development of district heating technology.

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Appendices

Annex 1

Introduction

This is a translation of the handbook, where experience and the more comprehensive Maintenance Handbook of Öresundskraft District Heating Company in Sweden, is summarised. The Handbook was first published in Swedish.

1. Background

Öresundskraft has two DH (District Heating) networks, in Helsingborg (dated 1964 and onwards) and in Ängelholm (dated 1977 and onwards). The two networks are very different from a construction point of view, implying different monitoring methods.

A fault on a pipe or outer casing is caused by long-term degradation by humidity, water or other external impingements.

Experience from maintenance work:

- A fault usually starts small, while after days or a month increasing and becoming critical.
- A degradation will become more costly to resolve the longer time elapses before repair.
- There are causes other than corrosion which lead to degradation and faults.

To discover degradation and to prevent faults, maintenance measures and improvements are executed in the networks according to this handbook. In order to maximize data collection and improve probability to discover weaknesses in their early phase, a variety of maintenance methods are used.

2. Purpose

The purpose of maintenance and condition monitoring of DH networks is to secure reliable operation, good working environment, high reliability of heat delivery, sustainable use of resources and a long-term focus to maintain the value of the assets by improvements and maintenance methods.

An active maintenance work schedule enables a DH company to identify, localise and remedy faults and degradation and identify root-causes that can directly or indirectly shorten an asset's lifetime.

3. Goals and performance indicators

The goals with the maintenance work are:

1. Maximise the pipe network lifetime.
2. Postpone replacement investment as long as possible.

Performance indicators:

- By the beginning of 2025, the entire network shall be continuously condition monitored.
- Chambers and ducts/culverts shall be dry, with no water flooding.
- Chambers and ducts/culverts shall have an air humidity lower than 60% as an average over a month.

4. Definitions

Definitions used in this handbook are based on SS-EN 13306:2017 Maintenance – maintenance terminology:

Basic definitions

Operation – combinations of technical, administrative, and managerial activities – other than maintenance measures – resulting in a unit that is working and in use.
Operations reliability – ability to perform what is needed when it is needed.
Maintenance – combination of all technical, administrative, and managerial actions during a unit's life cycle with the purpose to keep it or restore it in such a condition that required and expected functions can be performed.

Faults and incidents

Degradation – harmful change of physical condition caused by time, wear, or other external influence. Degradation can cause faults. In a systems perspective, degradation can also cause system faults.
Fault – interruption of a unit's ability to perform required and expected functions.

Types of maintenance

Corrective Maintenance – maintenance after a fault, aiming to repair and get a function as before the fault.
Improvement/improved operation reliability – combination of all technical, administrative, and managerial actions related to improvements of the internal functional reliability and/or access to maintain the reliability for a unit, without any changes of the original function.
Preventive maintenance – maintenance actions with the purpose to assess and or prevent degradation and reduce the risk probability for a fault on a unit.

Predictive maintenance techniques are designed to help determine the condition of in-service equipment to estimate when maintenance should be performed. This approach promises cost savings over routine or time-based preventive maintenance, because tasks are performed only when warranted. Thus, it is regarded as condition-based maintenance carried out as suggested by estimations of the degradation state of an item.[1][2]

The main promise of predictive maintenance is to allow convenient scheduling of corrective maintenance, and to prevent unexpected equipment failures.

Predictive maintenance differs from preventive maintenance because it relies on the actual condition of equipment, rather than average or expected life statistics, to predict when maintenance will be required.

Some of the main components that are necessary for implementing predictive maintenance are data collection and pre-processing, early fault detection, fault detection, time to failure prediction, maintenance scheduling and resource optimisation.

5. Condition monitoring methods

This chapter describes the methods to assess status, through condition monitoring of the pipe network. Status assessment can be followed by maintenance and repair.

5.1 Scheduled inspections on own assets

What: Manual inspection of condition, lubrication, repair, scheduled replacement of smaller details, lids, gaskets etc. Locations: All chambers, valves and inspection points. How: Visual, manual inspection. When: At schedule or at suspected problem.
Report to NIS (5.16).

5.2 Scheduled Inspection on assets owned by others

Same as 5.1.

5.3 Observations

What: Observation of faults, for instance moisture or water leakage. Locations: The entire distribution network. How: Visual, manual inspection. When: Any employee or citizen is encouraged to report anomalies.
Log incident and observation in NIS (5.16).

5.4 Assessment of concrete

What: Condition assessment of concrete and steel reinforcement. Locations: Chambers and ducts/culvert. How: Visual and if required technical sample test. When: Suspicion of corrosion and degradation. Log incident, test result and observation in NIS (5.16).

5.5 Sensor boxes for chambers with limited access

What: Condition monitoring, measurement, alarm of water flooding, water level and temperature. Locations: Chambers. How: Sensor box, remote communication. When: Online, continuously, alarm.
Data logged in Power BI (5.16).

5.6 Sensor boxes for accessible chambers or other space

What: Smart Active Box (SAB), sensor platform measuring water flooding, water level, water temperature, pipe temperature (forward, return), air humidity, CO-level, temperature. Condition monitoring of remaining strength of the steel pipes (prediction of end-of-life/replacement before failure). Hot water leakages can be online detected and located (acoustic correlation). Mechanical stresses (fatigue) from temperature variation in pipes can be logged. Locations: Chambers. How: Sensor box, remote communication. When: Online, continuously, alarm, analytics.
Data collected, transferred via API and logged in Power BI (5.16).

5.7 Moisture alarm wires in pre-insulated pipes

What: Moisture alarm wires for alarm and fault location of moisture in pre-insulated pipes; hot water leakage through steel pipe into PUR foam or intrusion of water from damaged PE shield into PUR foam. Locations: Pre-insulated pipes, measurement points. How: Manually and online. When: Online, continuously, alarm, scheduled inspections.
Data reported into Alarm Wire user interface and in NIS (5.16).

5.8 Moisture alarm tapes in hollow ducts/culverts

What: Moisture alarm tapes for water intrusion, in ducts/culvert, alarm and location. Locations: Hollow ducts. Measurement in chambers. How: Manually and online. When: Online, continuously, alarm, scheduled inspections.
Data reported into Alarm Wire user interface and in NIS (5.16).

5.9 Thermography

What: Hand-held, car-held, aerial thermography of directly buried pipes. Locations: Entire network of directly buried pipes. How: Manually. When: According to schedule or at suspicion of hot water leakage or excessive heat loss.
Data reported in NIS (5.16).

5.10 Melting snow inspections

What: Observation of melting snow along pre-insulated pipes (directly buried). Locations: Entire network of directly buried pipes. How: Manually. When: According to schedule or at suspicion of hot water leakage or excessive heat loss.
Data reported in NIS (5.16).

5.11 Condition assessment with ground penetrating radar

What: Scanning of distribution network by radar from ground surface level, analysis of water intrusion in joints, degraded concrete. Locations: Entire network of pipes. How: Manually. When: According to schedule or at suspicion of degradation.
Data reported in NIS (5.16).

5.12 Acoustic listening for leakages

What: Acoustic listening for leakages. Locations: Entire network of pipes, especially near valves, flow through closed valves. How: Manually or by SAB (5.6). When: Automatic or manually at suspicion of leakage.
Data reported in NIS (5.16).

5.13 Leakage location with acoustic correlation

What: Acoustic correlation to find location of hot water leakage. Locations: Entire network of pipes. How: Manually or remotely by SAB (5.6). When: After indication of leakage or suspicion of leakage.
Data reported in NIS (5.16).

Annex 2

SAB Smart Active Box in Helsingborg

Background

In an increasingly tough heat market, new ways of thinking and new approaches are required to remain competitive.

The function and status of the networks need to be checked continuously in order to continue to supply uninterrupted and functional district heating at a competitive price for a long time to come.

In addition to good delivery quality, methods are also required to be able to reinvest in the right pipes at the right time.

Leakage control is done with the current system nine times/year. The check is manual and is performed by personnel driving around by car and collecting measured value from the system that indicates whether there is water or not in the chamber. The system must be replaced with a new one that provides continuous monitoring with more functions than just leakage. The person who manufactured the system has retired and no new person wants, or has the knowledge, to take over, which will mean that the system finally stops working.

What is SAB Smart Active Box

Smart Active Box (SAB) (see Figure 1) has been developed in a collaboration between Öresundskraft and Arne Jensen AB. The goal of the product is to be able to digitise and build the smart district heating network. One of the development criteria has been that the product would be cost-effective and with more functions than the sensor boxes on the market today.

The Smart Active Box measures various parameters in the district heating network and its surroundings, such as temperatures and humidity levels. It must be placed in a district heating chamber, see picture below. Some will be placed in customer facilities or other accessible spaces to get a comprehensive picture of the steel pipes in the district heating network in Helsingborg.

Figure 1. Installation of SAB in a chamber

There are three things that make SAB unique in comparison with other similar equipment:

- A sound pulse is applied through the steel from one SAB, passes through the water and is received and recorded by another SAB. The method is called Delta thickness (Delta-t). This provides a status assessment of the steel's strength thickness in the pipe network. Strength here refers only to fresh steel without corrosion.
- The SAB does not need batteries because the current is the difference between the heat in the network and the ambient air temperature.
- The water level in the chamber is measured continuously.

Through the sound method (Delta thickness), the average thickness of the steel strength can be measured over a distance between the SAB units. The further development of this method is currently being carried out in a test facility at the Åkerslundsverket area. The goal is to be able to measure the lead conduct with a meter by meter accuracy introduced by the SAB method. This method is called the pin point method because it points out exactly where the weak points are. Both of these methods are world-unique.

SAB also provides a series of other measurements: water flooding, water level, chamber temperatures (floor, room), pipe temperature (forward, return), air- humidity, CO- and O_2-levels. Hot water leakages can be detected and located online (acoustic correlation).

The power supply without battery (power unit) is made by taking the difference between the outer temperature of the pipe and the ambient air temperature. This energy difference is then converted into voltage. This technology can, if necessary, be combined with solar cells to achieve sufficient voltage. This technology is superior to what is currently on the market and means that no battery replacement will be necessary. Continuous two-way communication is possible because the power supply is constant. A database for Big Data and a graphic interface means that communication between users and SAB takes place without the need for field visits. There are currently about 550 SABs installed in Helsingborg's district heating network, see Figure 2 below. These have been evaluated with good results over a period of two years.

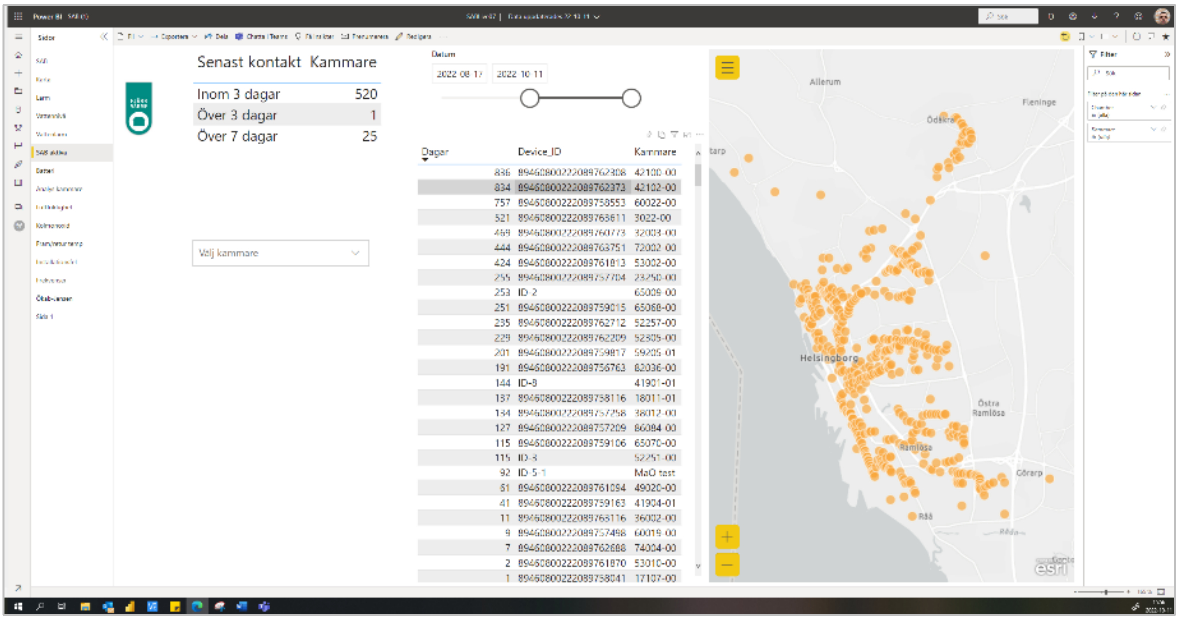

Figure 2. 550 Smart Active Boxes set up today

Performance

The measure proposed is to install 580 SABs, primarily in chambers but also indoors in properties over a three-year period. The installation means that the supplier assembles the equipment and ensures that it is functional and that it communicates with the supplier's data server. The installations begin in chambers with pipes that are particularly important for delivery to customers, and end in chambers with pipes that are of less importance for delivery.

The Delta thickness method has been used in a real case. On Furutorpsgatan in Helsingborg, the city has to rebuild the entire street, and where the district heating culvert is built, a pedestrian and bicycle path is to be constructed. The culvert, which was built in 1976, is one of the largest in Helsingborg's district heating network with a diameter of 600 mm. The goal that Öresundskraft AB has is that the right pipe must be replaced at the right time, regardless of age, and thus it was required that this culvert be measured with the delta thickness method to assess its status.

A decision support system has been used to visualise the delta thickness measurements.

According to the status picture on Furutorpsgatan (see Figure 3), after 46 years of use, the steel pipe has between 50% and >75% strength thickness remaining. The result means that no measures need to be carried out on the pipe, so it will remain in its entirety.

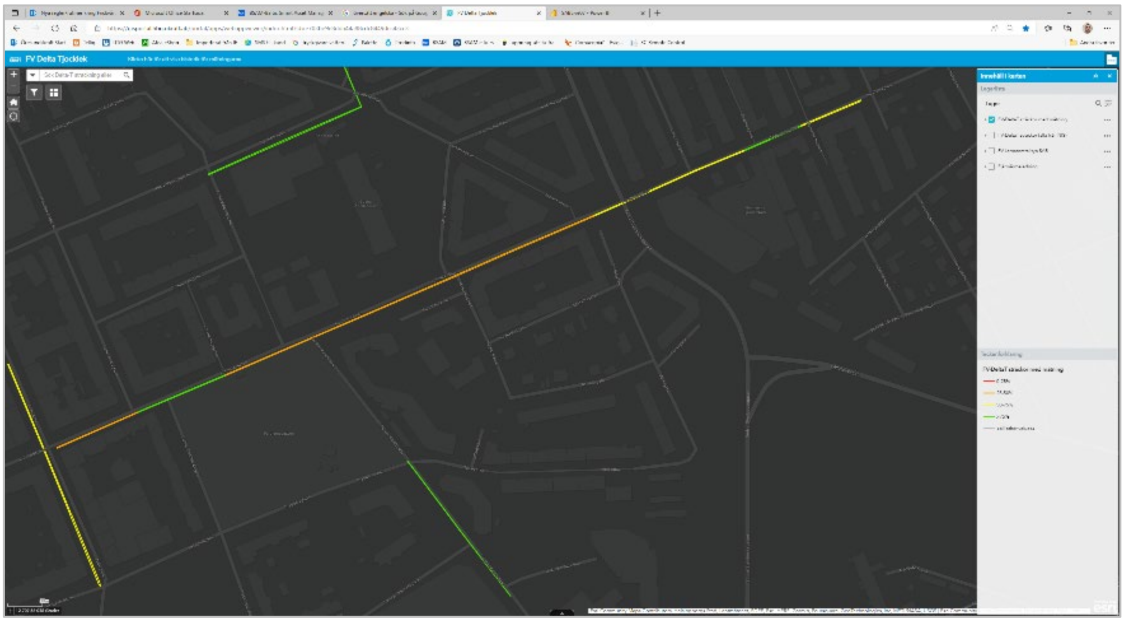

Figure 3. Status at Furutorpsgatan (Furutorps street in Helsingborg)

However, measurements were made with ground radar and test pits in the street to be able to see the condition of the concrete casing around the steel pipes. The result from these was that the concrete was partially split and in poor condition. It was decided that a test section of 45 m should be carried out, with repair of the concrete casing. Repair work involved removing bad concrete and reinforcements and replacing them with new.

To prevent the reinforcement from rusting, an active cathodic protection is applied, and shotcrete is applied on top to protect the entire structure and the cathodic protection. The concrete also prevents leakage currents from spreading into the ground from the cathodic protection.

The economic benefits of carrying out renovation work on the culvert instead of replacing it with new pipes are extremely large, even if the repair work also entails significant costs.

The renovation work is estimated to cost 50% of what a replacement would cost, which in value corresponds to €3,000,000 on a pipe length of 500 m. If the same approach were then used on the other concrete culverts in Helsingborg, it would be a cost reduction of €66,000,000.

From a sustainability point of view and Öresundskraft's goal to be ecologically sustainable, it is not compatible with removing and placing concrete that is fully functional on the tip and scrapping steel pipes that are in good condition.

It should be added that when culverts of this large dimension are replaced, a temporary delivery to the customers must be arranged. In this case and many others, it is very difficult and costly to perform.

If this project turns out successfully, Delta thickness has enabled a new way to repair this type of culvert and extend its life.

The cathodic protection is digitally monitored, and will show whether the concrete is protected over time. The monitoring will be evaluated, and the results will be shown in 2023/2024.

For district heating as a product, it is vital that the right efforts are made on the right pipes and at the right time, meaning that if a pipe or culvert needs to be replaced, this must be measured, ascertained and proven. It is also vital that different kinds of repair methods are developed for each construction type within the entire network.

Motive

In order for delivery security and, thus, customer satisfaction to remain at the high level it has today, it is necessary that the district heating network becomes more intelligent, and that continuous monitoring of the steel pipes is carried out. Lost customer satisfaction due to reduced delivery security must not occur; however, this is difficult to measure in costs.

Customers' experience today is that DH provides 100% delivery, particularly important for sensitive customers who use district heating in their businesses, and not just for heating and hot water. Customers have said that no back-up is needed for district heating because it is always "there". To maintain this experience, continuous monitoring and continuous improvements are required, of which pipe status assessments play a significant part.

Work environment rules are changed regularly and there are special requirements for district heating distribution where work is carried out in chambers below ground level. The SAB solution, which controls both the climate in the chamber and the status of the pipes, makes the working environment safer because it determines what condition the pipes are in, and ensures that the air in the chambers has the right levels of, for example, O_2 and CO. When new work requirements emerge, there is technology and measurement data that can be used to meet these requirements.

There are many advantages to installing a system of devices over having no system at all. The system will determine the service life of steel pipes through Delta thickness and, in the future, the Salami method (Salami slicing tactics), and thus pipes will be replaced at the right time, not prematurely.

The system must also be active and give alarms when events happen, e.g. leakage of rainwater into the chamber, leakage of FV water or abnormal temperature changes.

Receiving alarms at an early stage is important because water on the outside of the pipe causes corrosion, which in turn leads to leakage of district heating water. In this way, the service life of the pipes is optimised because the cause of the error can be found before pipe corrosion occurs.

SAB uses two-way communication, which means that it can actively provide desired measurements, e.g. moisture content in a chamber with a high resolution of six minutes, which is more than enough with a sluggish medium such as FV water. This would not have been possible with a battery connection, without the batteries having to be frequently replaced.

The SAB enables functions that are not currently available on the market. Its measurements enable pinpoint accuracy when it comes to commercial use.

All other boxes on the market today use a battery or are connected to the mains. SAB is the only one that has continuous charging.

The potential to be able to participate in and influence the development of SAB in the future is significant, and is made possible by a supplier that is the most innovation-oriented within district heating today, and a product that is highly adaptable.

Annex 3

Executive summary

This Social Impact study concludes that a system for predictive maintenance will improve the service to the end-users on low income and of course to other users. The predictive maintenance strategy also improves working safety and condition for employees and contractors.

Introduction

Social Impact report of pilot case SAB Smart Active Box.

How to increase the service time of pipes in the district heating network by assessing the status of the steel pipes and the chambers.

Administrative numbers are listed below:

Project	BSAM Baltic Smart Asset Management Interreg South Baltic Programme
Project Partner	Öresundskraft AB, project partner (PP3) registration no 556089-7851
Address:	Västra Sandgatan Helsingborg
Project manager	Technical manager, Magnus Ohlsson
Project members	Operations manager, Tony Stegroth
	Operation engineer, Niklas Stensson
	Maintenance engineer, Lars Istrell

Heating as a social right

Comfort heating, space heating of homes, should provide an indoor temperature not lower than 20°C. Warm tap water must be heated to above 60°C to prevent legionella.

Fuel poverty – the inability to afford to heat their homes – is a reality for many people in Western and Eastern Europe, and something we must avoid in Helsingborg.

Critical areas

Almost 100% of all multi-family houses in Helsingborg are connected to district heating. Many people with low incomes live in these houses.

District heating was connected to these building in the 1960-1980s, the oldest sections of the network.

Price and availability

The price and availability of heating is critical for people on low incomes. Öresundskraft AB aims to maintain a reasonable and low price on district heating using smart asset management, which includes preservation of pipelines as long as their maximum service life. Through online condition monitoring we can minimise the risk of pipe ruptures and consequential loss of heat delivery.

Safe work environment

The SAB sensor box system continuously measures the steel pipe integrity – the strength to withstand pressurised hot water. This predictive maintenance strategy will improve the work conditions; there will be less emergency work and corrective repair work to handle leakages.

Inspire others

About 150 energy companies are operating district heating networks in Sweden. Even more property companies own and operate their own pipe network links between buildings and central district heating block. Many of these networks are in very poor condition, leading to heat and hot water losses. Our work can support and inspire them.

Annex 4

Economic feasibility report on Smart Active Box

This economic feasibility study compares two alternatives: a) the standard mode of maintenance and asset management, reliant on corrective maintenance and pipe replacement based on age, risk and previous failure history, and b) modern predictive maintenance using sensor boxes and condition monitoring.

The second alternative is highly profitable, with a ROI payback period of less than one year.

Economic feasibility report of pilot case Smart Active Box (SAB).

How to increase the service life of pipes in the district heating network by assessing the status of the steel pipes and the chambers.

Case pilot City Network

	Network										
	Fictive "South Baltic City" with 100 000 inhabitants.										
500	km DH pipes, built in stages from 1960, whereof 100 km hollow/asbestosis and 10 km concrete.										
	Cost to replace old pipes EUR 300 up to 5 000 per m.										
2 000	EUR in average cost per m to replace pipe.										
1000	**sections of pipes must be replaced**				**totally**	**100**	**km**				
20	years to replace pipes							Cost hot process water		11	EUR/m3
5000	m of pipes per year to be replaced.							Cost cold water		5	EUR/m3
100 000 000	**EUR total investment**							Start Cost Coorective Repair		10 000	EUR/m3

Alternative strategies

								Result			
								Annual costs, incl annuities EUR			
	Strategy							OPEX	CAPEX	Totalt	
Alt Min	Minimum maintenance. Corrective maintenance and repairs.							1 150 000	8 882 743	10 032 743	
	Replacement based on age, risk, history.										
Alt Max	Monitoring of chambers, pumping/ventilation of humid chambers,							487 500	2 360 696	2 848 196	
	condition monitoring of steel pipes, Predictive Maintenance										

Alternative minimum (Alt Min)

Alt Min	Minimum maintenance. Corrective maintenance and repairs. Replacement based on age, risk, history.										
	Leakage per year										
		30%	risk large leakage, cost		500 000	EUR				150 000	
		3	mid size leakages per year		200 000	EUR				600 000	
		20	small leakages per year		20 000	EUR				400 000	
		Annual cost for preventive maintenance								0	
		Average cost per year, corrective repairs, incl hot water losses								1 150 000	EUR
		(Capital cost of spares not incl)									
	Annuity of re-investment (if done year 0)				100 000 000	internal interest	8%	depreciation (years)	30	8 882 743	EUR

Alternative maximum (Alt Max)

Alt Max	Monitoring of chambers, pumping/ventilation of humid chambers, condition monitoring of steel pipes, Predictive										
	Leakage per year										
		8%	risk large leakage, cost		500 000	EUR				37 500	EUR
		0,75	mid size leakages per year		200 000	EUR				150 000	EUR
		5	small leakages per year		20 000	EUR				100 000	EUR
		Annual cost maintenance			200 000	EUR				200 000	EUR
		Average cost per year, corrective repairs, incl hot water losses								487 500	EUR
	20%	of initial reinvestment, due to selective replacement									
	Annuity of re-investment (if done year 0)				20 000 000	EUR	8%	deprec (years)	30	1 776 549	EUR
	Annuity of investment in predictive monitoring				5 000 000	EUR	8%	deprec (years)	15	584 148	EUR
										2 360 696	EUR

Result

		Result			
		Annual costs, incl annuities EUR			
	Strategy	OPEX	CAPEX	Totalt	
Alt Min	Minimum maintenance. Corrective maintenance and repairs.	1 150 000	8 882 743	10 032 743	
	Replacement based on age, risk, history.				
Alt Max	Monitoring of chambers, pumping/ventilation of humid chambers,	487 500	2 360 696	2 848 196	
	condition monitoring of steel pipes, Predictive Maintenance				

The results show a big difference in the two alternatives:

Alt Min: Minimum maintenance, corrective maintenance and repair. Replacement of pipes based on age, risk and failure history. Total cost per year (30 years annuities) is EUR 10 million.

Alt Max: Monitoring of chambers, pumping/ventilation of humid chambers, condition monitoring of steel pipes, predictive maintenance with sensor boxes. Total Cost per year (30 years annuities) is EUR 2.8 million.

The investment cost for the sensor boxes for predictive maintenance is EUR 5 million. A simplified calculation shows that this total investment will have Return On Investment with a payback period of less than one (1) year.

Validating the feasibility study

The general study above can be validated with a specific case. Under a busy street, Furutorpsvägen, is a concrete duct district heating pipeline. The total cost for replacement of this pipeline has been calculated at EUR 60-80 million. The investment in sensor boxes is below EUR 0.25 million. We assume that the pipeline can be used for 10 or even 30 years more; 30 years is a typical economic depreciation period.

Annex 5

Results delivered by SAM system and interpretations (discussions)

The values from Delta thickness are presented in Arc Gis and the others are presented in Power BI. The image in Figure 1 shows a piece of the network and the colours green and orange show that the thickness is 80% or better compared to the original thickness. So far, the lines are divided into whether they are 80% or better. A finer division will be performed later.

A great deal of work has been put into automating the entire process, which means that the actuators add a sound from one SAB, the sound is transported in the line that is picked up by the microphones, through another SAB. The audio file ends up in a database, from where it is processed automatically, and the result is an average value of the steel's strength thickness. This is then delivered to Öresundskraft, which enters the values in its own database and on to Arc Gis. In Arc Gis, different time intervals can then be selected and thus a trend is given to the quality of the steel over time.

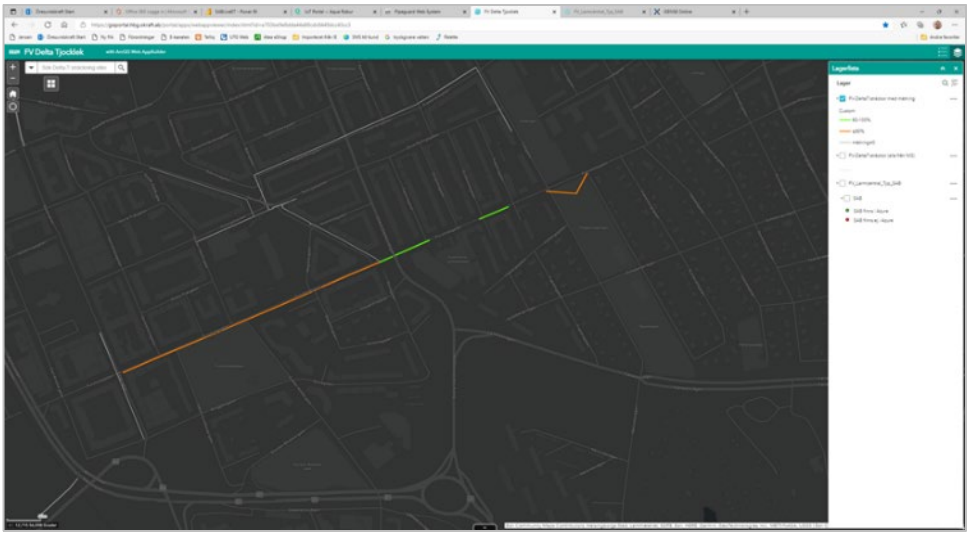

Figure 1. Arc Gis programme

The Delta thickness method has been used in a real case. On Furutorpsgatan in Helsingborg, the city has to rebuild the entire street, and where the district heating culvert is built, a pedestrian and bicycle path is to be constructed. The culvert, which was built in 1976, is one of the largest in Helsingborg's district heating network with a diameter of 600 mm. The goal that Öresundskraft AB has is that the right pipe must be replaced at the right time, regardless of age, and thus it was required that this culvert be measured with the delta thickness method in order to assess its status. The decision support system, Arc Gis, has been used to visualise the Delta thickness measurements. According to the Arc Gis image, the steel pipe has at least 80% strength thickness after 45 years of use. The result is that no measures need to be performed on the pipe; it can remain in its entirety.

On the other hand, measurements and test pits were made in the street to be able to see the condition of the concrete casing around the steel pipes. The result of these was that the concrete was partly split and in poor condition. In a renovation work next year, bad concrete and reinforcements will be removed and replaced with new. The renovation work has been prepared by Öresundskraft AB, together with contractors and consultants. The work means that any bad concrete and reinforcements are removed and replaced with new. To prevent the reinforcement from rusting, an active cathodic protection is applied, and shotcrete is used to grind and set a shape for the casting of the concrete. If the work is successful, it will be of considerable financial benefit to carry out renovation work instead of the alternative, which is to change the culvert to new pipes. The economic difference between these options is highly significant. The renovation work is estimated to cost 40% of what a replacement would cost, which in money corresponds to SEK 30 million on a pipeline of 500 m. Should the same approach be used on the other concrete culverts in Helsingborg, there would be a cost reduction of approximately SEK 660 million. A sustainability study will be performed to compare the climate impact between a renovation and a replacement. It should be added that when culverts in this large dimension are replaced, a temporary delivery to customers must be arranged, which is difficult and costly to perform. If this project is successful, Delta thickness has enabled a new way of repairing this type of culvert and extending its service life.

In Power BI, different environments have been built up to display and interpret the various measured values that are collected. The images below show these with the functions that have been selected. At Öresundskraft AB, Power BI has been selected to test and see if the desired functions can be performed. It is not clear which program will be used as a decision support system, but the market will be examined to see which would be the most effective.

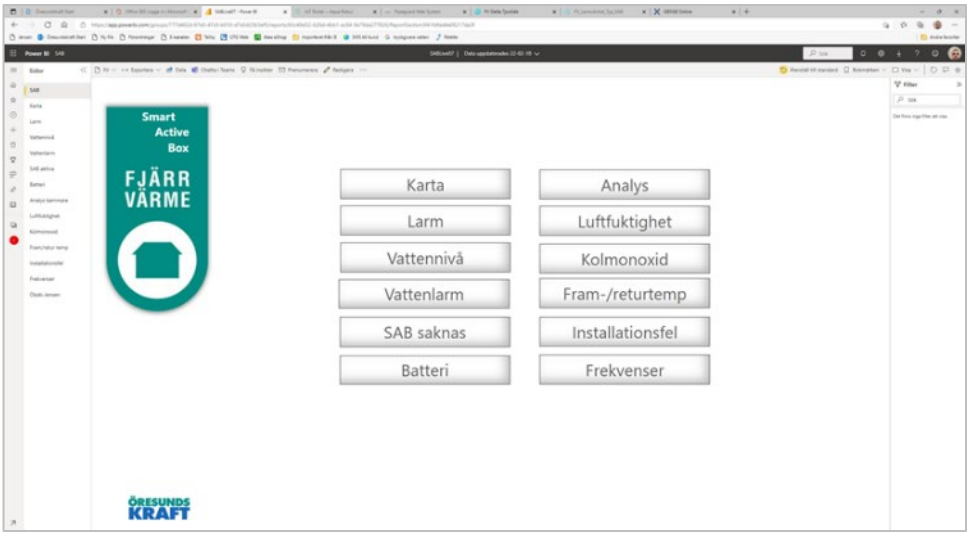

Figure 2. *Power BI navigation page overview*

Figure 2 shows an overview of the pages that can be selected in Power BI. A significant advantage of Power BI is that pages can be added and subtracted or easily changed, and it is user-friendly. There is a link between the pages that allows a device to be selected and then the user can jump to another page to see another desired parameter. On all pages, date ranges can be selected and data from the last three months stored.

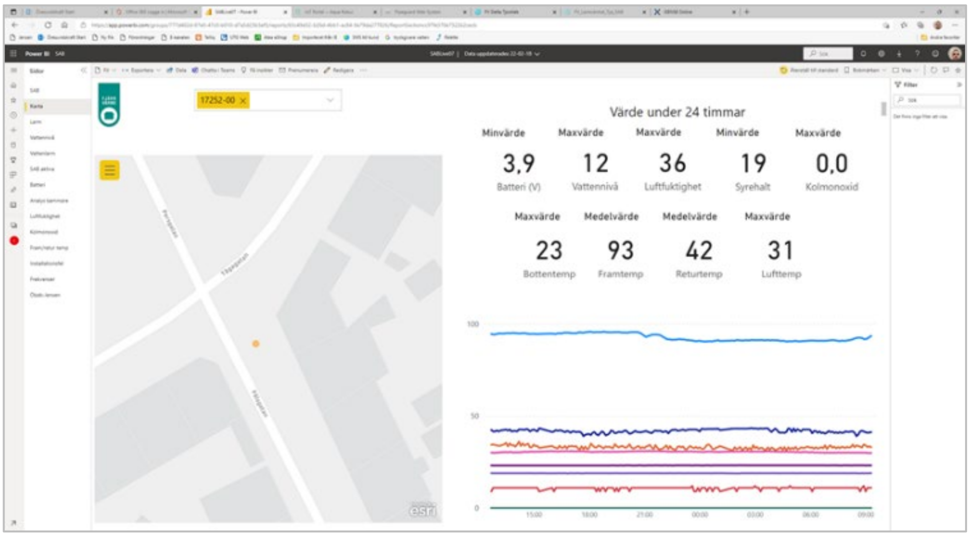

Figure 3. The last 24 h values of a chamber are displayed

In Figure 3 the desired chamber is selected, and the values of the last 24 hours are displayed. This page is used to see a chamber with its current value. A good area of use is a customer reporting that they have no heat; the nearest SAB is then searched, and a check can be made on whether the water heat is being transferred, quickly identifying if there is a problem online or at the customer's exchange.

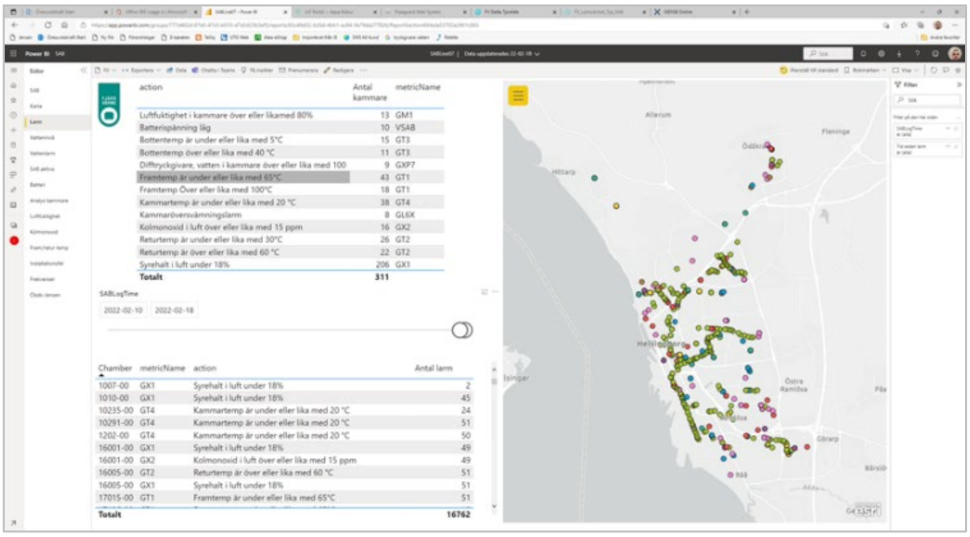

Figure 4. Alarm limits parameters and locations of alarms in Helsingborg

In the Figure 4, different alarms are set up with selected alarm limits on all available parameters. Alarm limits can be changed and thus monitoring of desired parameters and intervals can be performed.

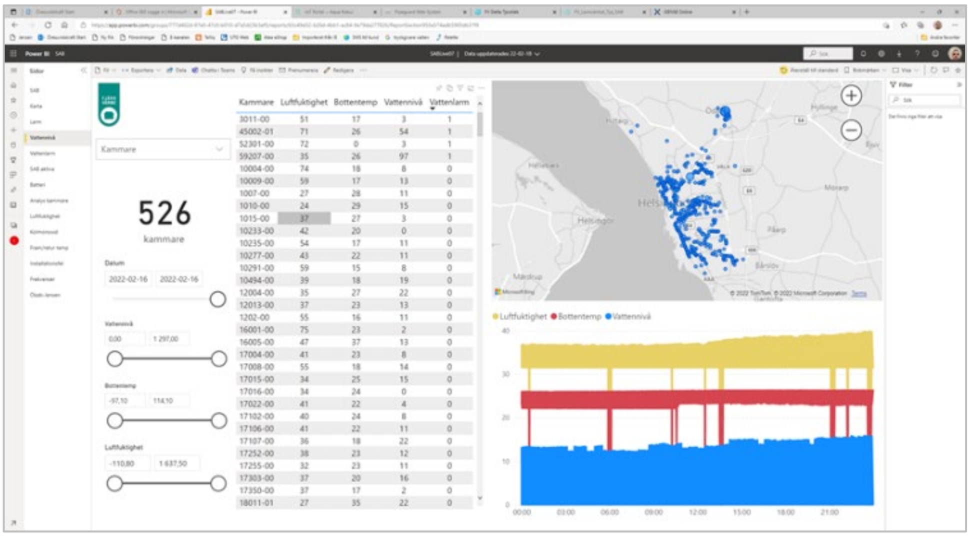

Figure 5 Parameters of water level in a chamber

Figure 5 shows the level of water presence in the chambers. Water in the chambers causes corrosion and it is therefore crucial that the chambers are pumped free of water. By showing the level, a decision can be made on which chambers contain the most water and need to be prioritised.

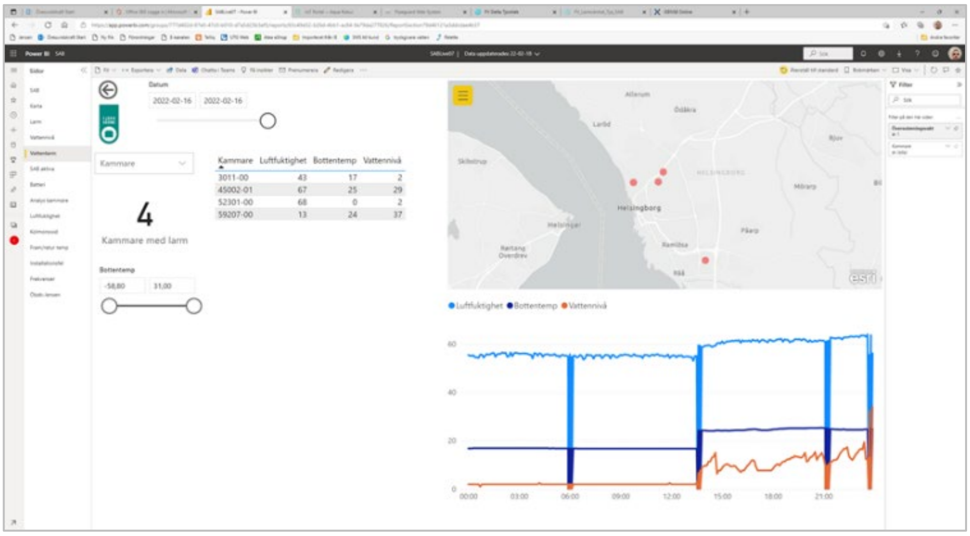

Figure 6 Parameters of the presence of water in a chamber without level display

Figure 6 also shows the presence of water in the chambers but without level display. By going out and inspecting the chambers, it is possible at an early stage to see where the water enters the chamber and thus the right remedial measures can be quickly taken.

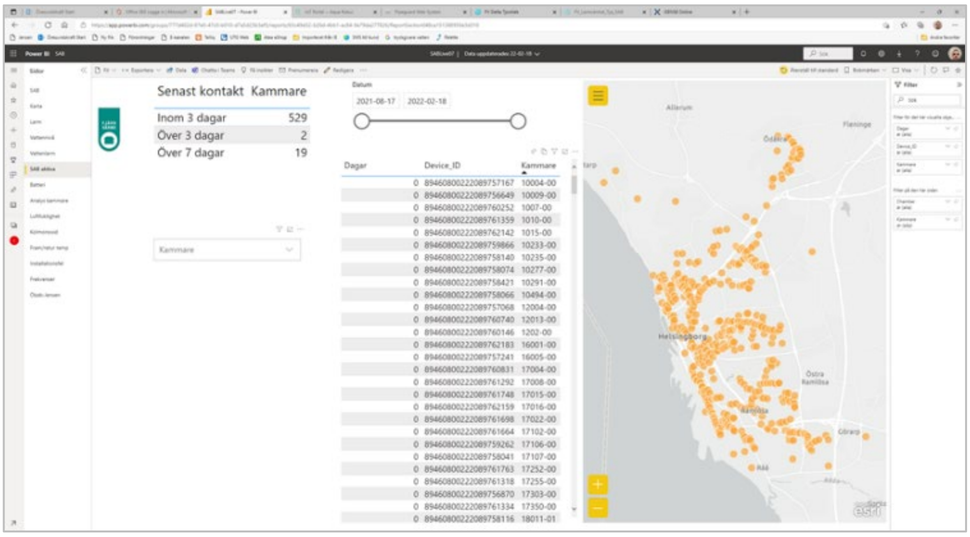

Figure 7. Device values report for time period of three to seven days

Figure 7 shows which units have provided value within three days, over three days, and more than seven days. This is important for knowing if there is any device that does not provide value for any reason.

Figure 8. The battery level in a device

Figure 8 shows the battery level in the devices. This page shows if the power supply is not sufficient for the units, and measures to improve this need to be put in place.

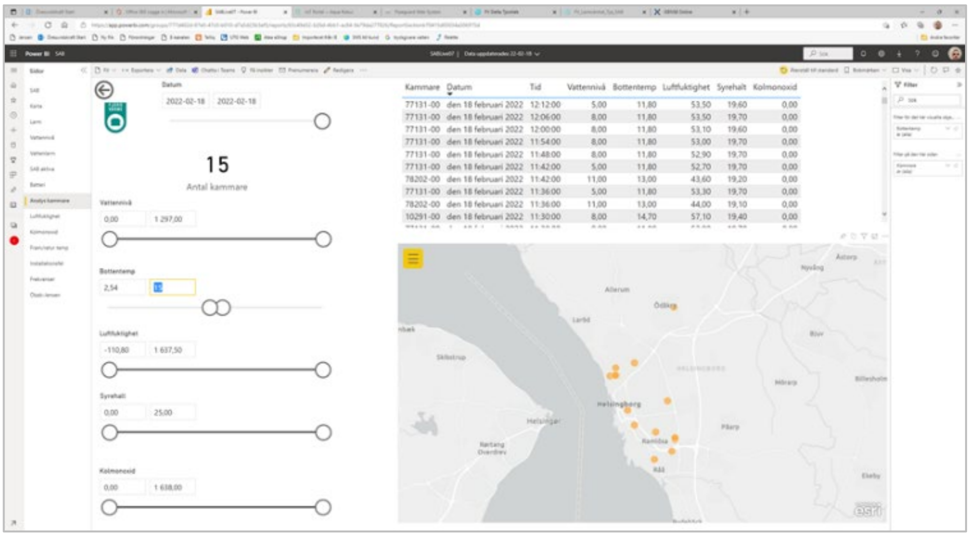

Figure 9 Tracking of the values of different parameters

Figure 9 shows data collected from 15 chambers in order to be able to track different parameters of water level, bottom temperature, humidity, oxygen content and carbon monoxide. For example, setting the oxygen content in the range from 0 to 16%, and other measured values to the minimum or maximum value, it will be possible to ascertain if there is insufficient oxygen in any chamber.

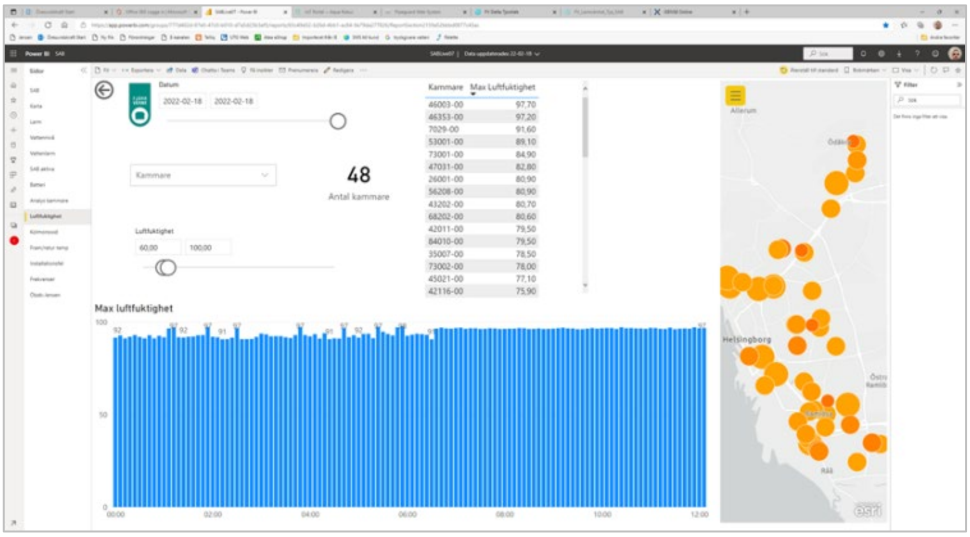

Figure 10 Visualisation of humidity in the chambers

Figure 10 shows the humidity in each chamber, which is important because a humidity above 60% provides a corrosive environment. A limit on humidity can be selected and then remedial measures can be taken to reduce the humidity.

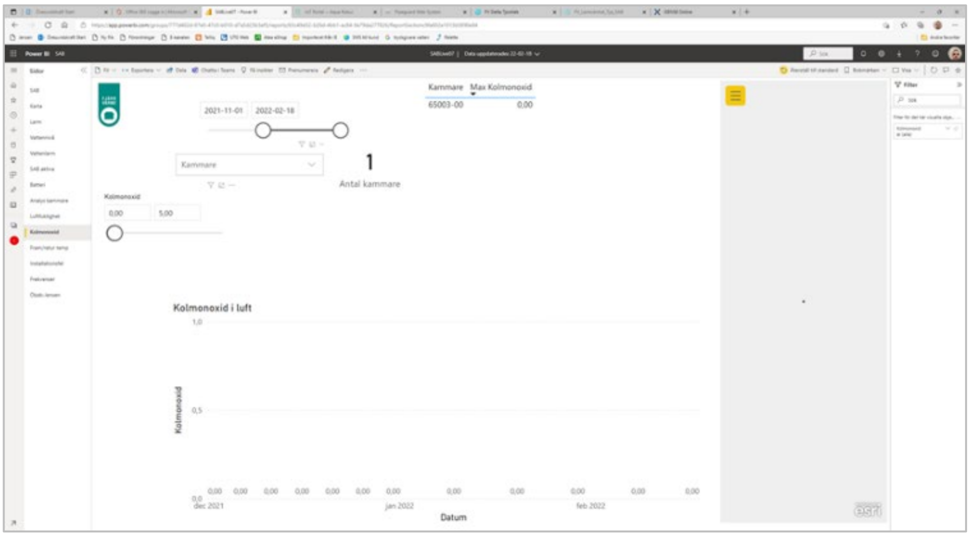

Figure 11. The contents of carbon monoxide in a chamber

Figure 11 shows the content of carbon monoxide in each chamber, which is important because this is a highly toxic gas. Historically, no chamber has ever had problems with carbon monoxide, but with continuous measurement it can be more certain that it is not present.

There are three things that make SAB unique in comparison with other similar equipment:

- A sound pulse is applied through the steel from one SAB, passes through the water and is received and recorded by another SAB. The method is called Delta thickness (Delta-t). This provides a status assessment of the steel's strength thickness in the pipe network.
- The SAB does not need batteries because the current is the difference between the heat in the network and the ambient air temperature.
- The water level in the chamber is measured continuously.

Using the sound method (Delta-t), the average steel strength between two SAB units can be measured. The method makes it possible to predict the service life of the network for the first time. This is completely world-unique.

The power supply, without mains connection, is made by taking the difference between the pipe temperature and the ambient air temperature. This energy difference is converted into a current stored in a battery. The method is patent protected. If necessary, the technology can be supplemented with solar cells. It is superior to any other technology currently on the market, and means that the battery is always charged and functional, and does not have to be replaced.

Continuous measurement of the water level in the chamber makes it possible to continuously pump the chambers free from rainwater, ensuring a lower moisture content. As the moisture content lowers, the corrosion on the pipes and metal parts of the chambers also decreases.

A database for storage of Big Data, receives the data through a mobile data network and a graphical user interface, meaning that communication between users and SAB takes place without the need for field visits. There are currently about 550 SABs installed in Helsingborg's district heating network. These have been evaluated with good results over a period of one year in this system.

Delta thickness today gives the average thickness between two units. This needs to be developed to become even more specific and thus provide strength on shorter distances than between two units.

In a world where sustainability is soon to be a ‘hygiene factor’ to be able to operate in industry, solutions must be developed to ensure that materials which have already been refined and used in, for example, district heating culverts and district heating pipes, are really used throughout their service life.

For delivery security and, thus, customer satisfaction to remain at the high level it is at today, the district heating network must become more intelligent and there must be continuous monitoring of the steel pipes. Lost customer satisfaction due to reduced delivery security must not occur. The customers’ experience today is that we have 100% delivery availability. This applies to sensitive customers who use district heating in their businesses and not just for heating and hot water. Customers have said that no back-up is needed for district heating because it is “always there”. To be able to maintain this experience, continuous improvements are required, where status assessments of the network are a significant part.

Work environment rules change regularly and there are special requirements when work is performed in chambers below ground level. The SAB solution, which measures both the climate in the chamber and the status of the pipes, makes that working environment safer because the status of the pipes and the chamber is continuously known before staff go down into the chambers. Today, O_2 and CO are measured with the help of SAB. When new work requirements emerge, there is technology and measurement data that can be used to meet these requirements.

There are many advantages to installing a system of devices over having no system at all. The system will determine the service life of steel pipes using Delta thickness, and thus pipes will be replaced at the right time and not prematurely.

The system is active and provides alarms when events happen, e.g. leakage of rainwater into the chamber or leakage of FV water, as well as abnormal temperature changes. Receiving alarms at an early stage is important because water outside the pipe causes corrosion which in turn leads to leakage of district heating water. SAB enables functions for preventive maintenance that are not currently on the market. All boxes on the market today use a battery or are connected to the mains; SAB is the only one that has continuous charging.

The potential to be able to participate in, and influence the development of SAB in the future is significant, and is made possible by a supplier that is highly innovation-oriented, and a product that is adaptable. This project, with installations by SAB, has made it possible for Öresundskraft to have sufficient measurement data in two years’ time to be able to determine the service life of all steel pipes in culverts, and pipes where SAB is installed.

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Appendix A:

Brand and promotional items

Contents

1 LOGO AND INDENTIFICATION

From the moment of signing the Subsidy Contract, each project partner is obliged to inform the general public about the project and that it is co-financed by the European Union within the South Baltic Programme.

Documents and materials drawn up for the project purposes should be correctly labelled. Full information can be found on www.southbaltic.eu/communication

1. BSAM identity

2. A key colour card for logo

C 100	C 100
M 100	M 0
Y 0	Y 0
K 0	K 0
R 50	R 0
G 42	G 162
B 113	B 227

3. The Programme's logo, the European Union symbol, and ERDF

The Programme's logo and EU emblem are available on the programme website: https://southbaltic.eu/programme-logo-and-eu-emblem

4. The BSAM logo together with the Programme logo: logo versions should have a white background.

In case of space limitations, use the Programme and the EU logos only.

Logos are available in png, eps and pdf formats in the BOX (BSAM folder/logotype & emblem).

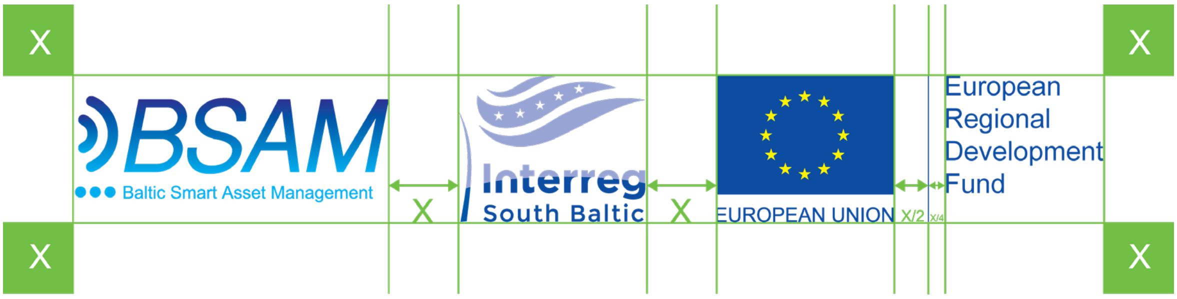
2 BASIC RULES

The project logo should always be next to the Programme logo, on its left-hand side and on the same line with it. The project logo and the Programme logo are treated as a "set of logos" – in these cases they are separated from the partner logo by a line.

See the Programme's www.southbaltic.eu/communication, page 9 below.

The Project partners' logos may be placed next to the Programme logo, on its right-hand side as shown below.

Refer to the Programme guidelines www.southbaltic.eu/communication to ensure the logo is created with the recommended sizes. Clear space refers to a distance of “X”, as a unit of measurement surrounding each side of the compound logo. “X” equals the distance between the programme logo and the EU emblem.



Logo formatting, as shown below, is absolutely forbidden!

No other logos or objects can be positioned between the project and Interreg logos.

3 EXAMPLE, PROMOTIONAL MATERIAL

1. Examples of use the Programme´s logo with the project´s logo

2. Promotional material

4 POSTER

5 ROLL UP

Posters should have a minimum format size of A3 and be visible to the public (e.g. entrance area of a building).

6 PRESENTATIONS TEMPLATES

Logos must be visible on all materials used.

7 A4 DOCUMENT TEMPLATE

AGENDA [Main title]

Date: [2020-00-00]
Place, address: [place, address]

[Title]

[00.00–00.00]	[Title], *by [name, organisation]*
[00.00–00.00]	[Title], *by [name, organisation]*
[00.00–00.00]	[Title], *by [name, organisation]*
[00.00–00.00]	[Coffee break / Lunch]
[00.00–00.00]	[Title], *by [name, organisation]*

https://lnu.se/en/bsam

1 (1)

[Title]

[Place and date]

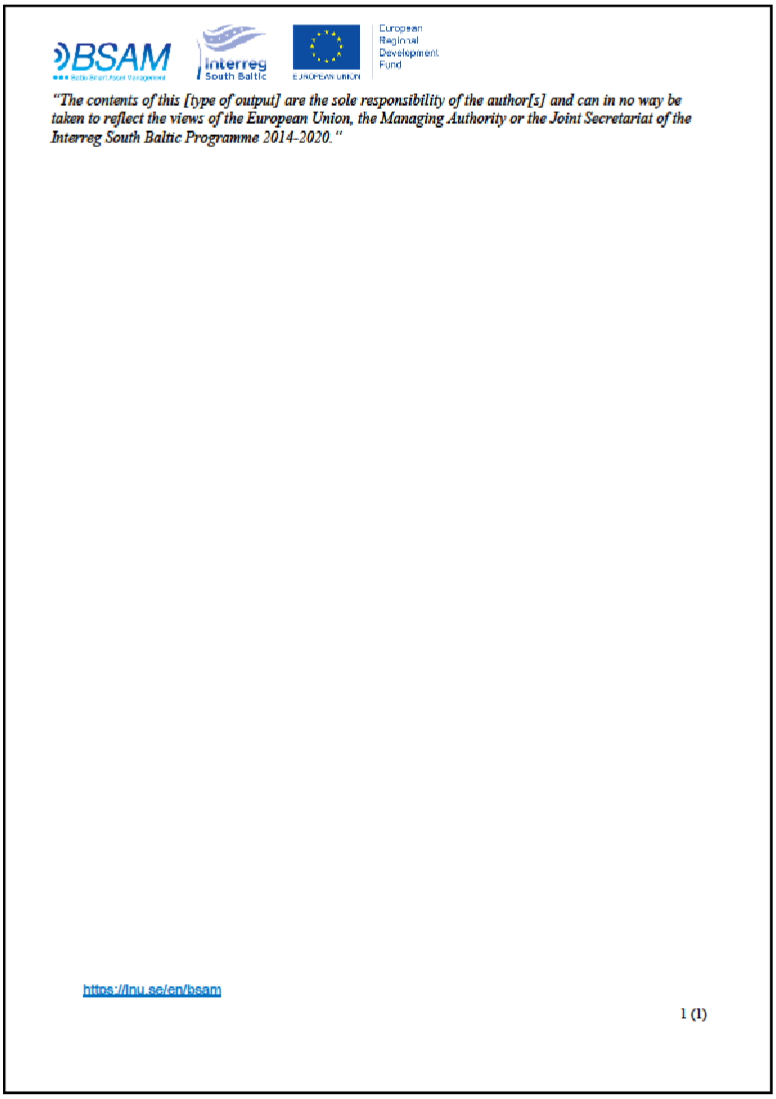
Participants

No	First name	Last Name	Organization	Position	Signature
1					
2					
3					
4					
5					
6					

All written outputs developed by the project must include the following disclaimer:

"The contents of this [type of output] are the sole responsibility of the author[s] and can in no way be taken to reflect the views of the European Union, the Managing Authority or the Joint Secretariat of the Interreg South Baltic Programme 2014-2020."

See example below.



"The contents of this [type of output] are the sole responsibility of the author[s] and can in no way be taken to reflect the views of the European Union, the Managing Authority or the Joint Secretariat of the Interreg South Baltic Programme 2014-2020."

https://lnu.se/en/bsam

1 (1)

BSAM Baltic Smart Asset Management

Interreg South Baltic

EUROPEAN UNION European Regional Development Fund

All partners

Linnæus University

SweHeat & Cooling

Öresunds Kraft

opec

Gdańsk University of Technology

LŠTA Lithuanian District Heating Association

Klaipeda University

Swedenergy Energiföretagen Sverige

Energiforsk

Embassy of Sweden Warsaw

ISM

Nybro Energi ditt lokala energibolag

RUC Roskilde University