DISTRICT ENERGY BY SWEDEN

Best Practice Guide

The Swedish “Systems Approach”

The desire to create an efficient community has in Sweden resulted in the integration of different functions and that household waste produces bio-gas and remaining combustible waste is used as fuel in waste-to-energy combined Heat & Power Plants. The waste heat from that process is used for District Heating and via absorption chillers District Cooling is produced. Compression Heat Pumps are using treated sewage water to produce both District Heating & District Cooling and the sewage treatment plant produces bio-gas. The bio-gas is then used in buses and taxis in the cities. Sweden has large forest areas and the waste from forest industry and from the forest is used in bio-mass fired boilers and Combined Heat & Power Plants to produce Electricity and District Heating. As a result of the “System Approach” Sweden is toady a world leader in efficient Energy utilisation.

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Best Practice Guide

This Best Practice Guide has been prepared with the aim to introduce the Swedish knowledge and expertise within the areas of Production, Distribution and Consumption of District Heating and District Cooling, covering technology, business concepts and operations.

Executive Summary

Sweden is a pioneer when it comes to sustainable energy solutions. With winter temperatures dropping as low as -35°C and summer temperatures peaking at over +30°C, setting the right indoor-temperature is vital.

Today, 55% of all homes and commercial buildings in Sweden are heated by District Heating and the Swedish model is being successfully implemented in many countries all over the world. District Heating and District Cooling makes the most of energy that would otherwise have been lost and is a main driver of sustainable and eco-efficient city development.

The Swedish model sets focus on end-user demands, independence of fuels and the interaction of multiple heat sources. Residents actual demand of heating and cooling is dimensioning the heat production and the system is changed from being production-driven towards demand-driven. Only the heating or cooling needed will be accepted by the system and the residents will only pay for the energy they have used.

The most cost efficient solution for District Heating is based on a two-pipe network system, a substation in every building and individual metering building by building. It is important that both radiator systems and tap-water systems are in balance and that buildings have acceptable insulation. Consequently, functionality and performance for components in the system are key issues. The whole system must be considered and products and components working together in an optimal way as well as with optimal individual function.

District heating is supplied by a central plant which can use advanced methods to run on many different fuels or recover heat from different sources, such as surplus energy and waste-energy from industries, treated sewage water etc.. Regardless of what type of furnace, boiler or heating technology that will be used, it is important to include a Combined Heat & Power plant to ensure high efficiency and fuel utilization and to avoid energy being wasted. The fundamental idea behind modern district heating is to use this surplus heat which otherwise would be wasted- from electricity production, from fuel- and biofuel-refining, and from different industrial processes. Another resource that in many countries are neglected for Energy Production is Household and Industrial Waste that are put on landfills or marginally used for Energy Production. In Sweden the sorting of Waste is extensive, organic materials like food waste are collected separately and used for bio-gas production, metals, cardboard, glass, paper and other recoverable fractions are separately collected and the remainder is going to the Waste to Energy Plant for production of electricity and District Heating. This approach has developed over the last 25 years to a point where less then 1% of the waste now is going to landfills. Furthermore district heating can make use of many kinds of renewables such as biomass, geothermal, solar thermal etc.

District cooling is based on the same clever concept as district heating. Instead of each building having its own cooling plant, the cooling is supplied by a central unit which can be operated using lots of different resources and effective methods. The cooling plant is often run by the same company as the one producing district heating in the region. Free cooling involves utilizing cold water from nearby lakes and waterways. Absorption cooling is a technology that utilize the thermal energy generated in the production of district heating and can as well use waste heat from Combined Heat & Power Plants, industry or waste incineration, for the production of chilled water. Heat pumps are able to produce both heating and cooling at the same time and currently this is together with free cooling from lakes and rivers the most common way of producing district cooling in Sweden.

History of District Heating

District Heating in Europe started in 1950's with hot water district heating systems, in contrast to the older technology from USA that use steam as energy transfer media.

The first steam system was developed by Birdsill Holly in Lockport, New York and provided steam for heating of his house and some neighbouring buildings. Mr. Holly formed Holly Steam Combination Company in 1877. Mr. Holly was a good engineer and inventor, among other things he invented a steam meter and he held over 50 patents in relation to steam heating systems. The New York Steam Company was formed in 1881 and the system went into operation on March 3, 1882 and by 1886 the Company had 350 customers. The first facility had 48 boilers and 8 km of main steam lines. More pipes and plants were added and by 1932 the Company supplied 2,500 buildings. Today there are 538 District Heating systems in the USA of which 330 in college/university areas, 123 in hospital complexes and 85 in down town locations. Almost all systems are provided with steam at 6.9 to 10.4 bar (100 to 150 psi). Some of the oldest systems do not have condensate return pipes but the condensate is cooled as low as possible in domestic hot water heat exchangers and then dumped in the sewer lines.

When District Heating started in Sweden in the 1950's the selected media for distribution of heating energy was 120 degree C hot water. Swedish District heating systems provide both heating and domestic hot tap water to consumers. Of Sweden's 290 municipalities 270 have District Heating systems. About 58% of the heating requirements in Sweden are provided by DH. Total length of culvert is over 23 400 km (2014). The buildings area heated by DH is about 730 million m2. The energy consumption for connected buildings are between 116 - 138 kWh/m2. As one example in the city of Västerås (150 000 inhabitants) District Heating started in 1954 and early 1960's a CHP plant was added, the system is today integrated with other smaller surrounding communities and the distance from one end to the other is approximately 70 km. From the start the District Heating plants were based on coal firing but as cheap heavy fuel oil became readily available, new plants in the 1960's and 70's were mostly based on this fuel. As a result of the oil crises in late 1970's District Heating companies, during the 80's shifted fuel and started to once again use coal as the main fuel. Environmental concerns were at this time limited to emission of particles and sulphur, heavy fuel oil was limited to 1% sulphur, this was later reduced to 0.3%.

Electricity was cheap especially during the summer, and as a result many electrical boilers were installed. Thermal storage tanks were built to even out the load between low load periods at night and peaks during the day. In mid 80's concerns about sulphur content and NOx emissions resulted in installations of de-sulphurization equipment and catalysts in coal fired plants. In the 70's garbage burning started in a few locations, and in the last 15 years plants has been built in many cities to a point where DH-companies now import garbage from other EU countries. In the 80's District Heating companies introduced large Heat Pumps in their systems, using sea/lake water or treated sewage water as the heat source. Many of these Heat Pumps were later converted to provide both heating and cooling to newly constructed District Cooling systems. As global warming became an issue in the early 90's once again companies shifted fuels. A Carbon Dioxide Tax was introduced in Sweden in the early 1990's that forced companies to look for alternatives to fossil fuels. Sweden has a lot of forest and waste material from the forest industry is readily available which resulted in a rapid conversion towards bio-fuels, as well a new era for combustion of garbage. The older systems were designed for 120 degrees Celsius supply temperature and 70 degrees C return temperature and a design pressure of 16 bar. New systems are designed for 80 or 100 degrees C with return temperatures of between 33 and 53 degrees C. The design temperatures have been reduced to allow for a lower backpressure for CHP units and thereby higher production of electricity. In summer the supply temperature is reduced to 65 to 70 degrees C. Piping network heat losses are in the range of 3 to 8% of delivered energy for new systems. Water losses from network equal to one change of water in the network per year or less. Energy consumption for heating and hot tap water has from 1985 => 2009 been reduced by 27% with maintained comfort level in buildings as a result of energy efficiency improvements and upgrades of buildings. Heat energy meters are installed in every building and billing is based on consumption.

Best Practices for Design of District Heating and District Cooling systems

When designing a new or updating an existing District Heating system the design approach should always be to start in the buildings to determine their load, energy and temperature requirements. Followed by sizing of the network, hydraulic modelling and in large networks transient analysis to prevent water hammers. Last the design and sizing of the plant, selection of fuel source, boiler technology and/or CHP technology. The Swedish Best Practice experience can be discussed at length but some of the most important points are presented in this Best Practice Guide.

General Design criteria’s

* Keep the District Heating supply temperature level as low as economically justifiable from a piping cost point of view, thereby maximizing electrical generation in CHP’s and heat generation by heat pumps;

* Keep the District Cooling return temperature as high as possible to reduce costs for piping networks, pumps sizes and electrical consumption;

* Building installations for heating can be radiators, under floor heating or fan coil units, for cooling, fan coil units or “cooling baffles” is an alternative, the approach is to select a system that require low supply temperatures and provides a high differential temperature for the District Energy system;

* New Swedish District Heating systems are designed for 80 or 100 degrees C supply temperatures resulting in return temperatures of between 33 and 53 degrees C;

* The standard design pressure for District Heating systems are 16 bar (g);

* There is no standard approach with regard to maximum distance from plants to consumers or how large a District Heating system becomes. It is not unusual with long distances from one end of a network to the other. A distance of 100 km between the outer ends of the network exists and systems are continuously expanding. It is all judged on economic basis as the technical issues transporting hot water over long distances are possible to solve.

Substations (Energy transfer stations, ETS’s)

* Design the system with individual heat exchanger stations (ETS’s) for each building, alternatively for a few buildings that are located close together;

* Use brazed plate heat exchangers for building heat exchanger stations (ETS’s) as long as water quality is not a concern. Mostly it is feasible to arrange the water cleaning in a way so that brazed plate heat exchangers are feasible. For large stations plate and frame heat exchangers can be used;

* Use ”intelligent” control equipment that can communicate with the central plants SCADA system;

* Use high quality two way control valves that are sized to take absolute minimum 50% of the total pressure drop across the ETS;

* Use ultrasonic energy meters;

* For larger buildings, use circulation pumps on the secondary side that have variable speed control;

* In existing buildings all three way valves on the building side of the heating system should be replaced by modulating two way valves;

* In new buildings only modulating two-way valves should be installed;

* All equipment shut off valves, strainers, etc. should be of the welded type, flanges only on control valves, energy flow meters and connections to heat exchangers!

Piping Networks

* Use prefabricated, pre-insulated pipes with steel pipes as media carrier pipes and high density polyurethane foam as insulation with an outer jacket of HDPE;

* Always use pipes with leak detection copper wires with a working principle of frequency change of the pulse not the change of resistance in the insulation and install a leak detection monitoring system that communicates with the central SCADA system; this system is integrated with valves. Leakage information is transferred to SCADA system by using LPWAN technology;

* Use welded HDPE joints that can be pressure tested with compressed air before injection of polyurethane foam insulation;

* For drainage and air vents, use prefabricated, pre-insulated direct buried valves;

* Cleaning of the inside of the pipe by ”pigging” before initial fill up of the piping system is recommended;

* All equipment in piping networks should be of the welded type! No flanges!

* For valve selection. If pipe DN size smaller than DN 400, use reduced bore ball valves with PTFE sealing. If pipe DN size from range DN 400-DN800, use full bore triple off- set metal seal butterfly valves. If pipe DN size is bigger than DN 800, use reduced bore triple off- set metal seal butterfly valves.

* Basic approach when designing networks are to avoid underground chambers in the network to the largest degree possible by using long-stem ball valves. Plastic valve chamber which is made from polyethylene can be also an alternative.

*In some challenging situation, hydraulic actuator is used as there is no electric involved while operating the valve.

* Avoid all kinds of compensators;

* Focus on Quality control during installation, drainage, bedding material quality, welds to be X-rayed, filling material and compression of bedding and backfilling;

* Prepare leak alarm drawings and monitor continuously the status;

* If these guidelines are followed the expected technical lifetime for the piping network is at least 50 years;

Plants

* In Sweden all of the following solutions have over the years been integrated in District Heating and District Cooling systems and the questions asked each time, when looking at a new or further developing an existing scheme are typically:

* Is waste heat recovery from industrial processes available within a reasonable distance from the district heating system and the consumers;

* Is there a power plant within acceptable distance that can be converted for steam extraction?

* Can Heat Pumps be installed to recover energy from sewage water or other heat source?

* Heat Pump / Chiller’s that operate to supply heating in the winter and cooling in the summer is a very efficient solution where the same investment is utilised “twice”.

* Can landfill gas be part of the solution?

* Can Bio-gas from digesters at a sewage water treatment plant be utilized;

* Is garbage/house hold waste or industrial waste available at a quantity and quality to justify the installation of garbage burning CHP-plant?

* Is some kind of biomass available that is of quality and quantity to justify installation of a CHP or heating only boiler?

* What other fuel,and energy sources are available, electricity, natural gas, fuel oil, coal? How do I deal with the CO2 problem generated by these fuels?

* For larger plants, CFB-boilers are used for combustion of household and industrial waste and biomass;

* For smaller plants sloping moving grate boilers are used and designed for the specific fuel;

* In combination with bio-mass fired boilers flue gas condensing with humidification of combustion air has become a standard;

* Electrical Boilers can be very attractive especially when electricity demand from other users are low and renewable energy resources like wind power and solar power are available;

* When natural gas is the fuel, gas turbine combined cycles are typically used, alternatively spark ignited gas engines;

* What flue gas treatment arrangements are required to deal with emissions of particulates, sulphur dioxide and nitrogen oxide?

* What combination of energy supply provides the lowest emissions of carbon dioxide?

* In all plants advanced control equipment and SCADA systems are installed;

The described criteria's are widely accepted be Swedish Energy Companies and design engineers and it is SweHeat & Cooling's recommendation and experience that when these Best Practices are implemented it will result in long lasting sustainable energy systems that are economically viable.

CHP & Tri-Gen

Swedish energy companies are widely using Combined Heat and Power (CHP) for production of electricity and heating energy for the supply to district heating systems and their consumers. The technology used is in many cases traditional steam boilers of which some are of the CFB type alternatively sloping moving grates, in combination with steam turbines. The older plants, built before 1990, were originally built for coal firing many of these has been converted to alternative fuels like peat, wood powder or other renewable fuels. Newer CHP plants are now built for utilisation of bio-mass fuels like wood chips or wood powder and household and industrial waste.

The use of Tri-generation for supply of power, heating and cooling energy to consumer buildings and developments, is one of the most efficient and environmentally friendly solutions commercially available today. This type of system can when properly configured, also when utilising fossil fuels such as natural gas, provide considerable reductions of Carbon dioxide emissions compared to conventional schemes. The best approach for such cases is the combination of Tri-generation with Heat Pumps/Chillers that will utilise the locally produced electricity for the generation of heating and cooling. The basic sizing for Tri-generation alternatives is that the Electricity generating unit should be able to provide a part of the plants internal electrical consumption at peak electrical demand, i.e. when the chillers and/or heat pumps are running at peak load on the thermal side. In the case where the heating/cooling loads are low, and thereby the internal electrical consumption is low, the tri-generation unit can deliver electricity to the national grid.

Thermal Energy Storage (TES)

Hot Water TES and Chilled Water TES

The best concept and the lowest cost for storing thermal energy in District Heating systems are open large district heating water thermal storage tanks connected directly to the district heating network. This technology has been used in many installations in Sweden for over 40 years, and thermal storage tanks from a few hundred cubic meters too many thousands of cubic meters are installed. In many cases the tank is providing the static pressure for the district heating systems, in those cases the tanks are typically between 25 and 40 meters high. As an example a tank for the capacity of 800 MWh that would store water up to 98 degree C and with a district heating return temperature of 45 degree C will have a volume of approximately 15 500 cubic meters, with a height of 35 meters the diameter would be 23.7 m. The tank would be well insulated to minimize heat losses.

It is very important to do a proper concept evaluation of thermal storage tank alternatives, optimization of tank sizes in relation to district heating and district cooling loads and a process optimization for proper integration of the thermal storage tank operation with other production resources. When performing the detail design it is extremely important to consider the arrangement of the tank's internal nozzles to guarantee the proper stratification in the tank and the design of other internal tank features.

District Cooling Plants with Ice Thermal Energy Storage

The central plant for a District cooling system has to be configured and optimised to provide the system with the lowest cost of energy. To achieve this the optimal relation between single duty chillers, dual duty chillers and ice Thermal Energy Storage (ice TES), has to be found. This optimisation has to take into consideration both initial capital costs as well as operating cost over the life-time of the plant (Life Cycle Cost analysis).

The single duty chillers will be sized to provide the night time demand from the cooling consumers and be of single duty – single evaporator type. The chillers that are to provide chilled water during the day time and make ice at night should be dual duty – dual evaporator type. The ice TES should be of the type ice on coil external melt and connected in series with the different chillers chilled water evaporators and directly connected to the piping network i.e. no heat exchangers between ice TES and piping network. This type of ice TES, when directly connected to the piping network provide a very constant supply of cold water, between 0.3 degree C and 1.0 degree C during most of the discharge cycle and it is only at the end of the day when the storage has less then 5% of ice remaining that the supply temperature goes slightly over 1.0 degree C. At that time the load from the systems has decreased so it is less important that the supply temperature increases slightly.

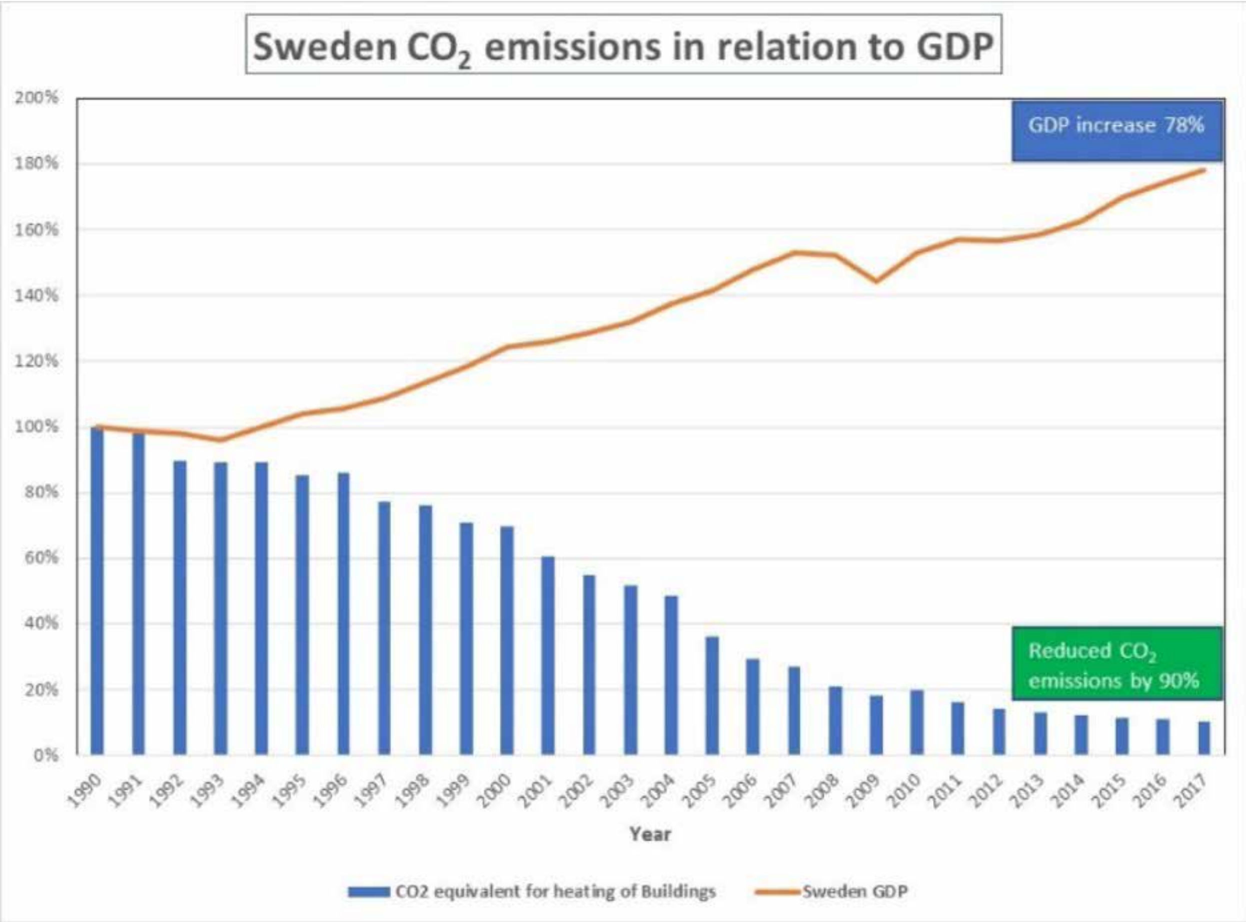
With this configuration it is possible to provide 1.0 degree C water to the system during peak hours and thereby considerably reduce the sizes in the piping network compared to traditional design. The return temperature from consumers are typically in the range of 11 to 12 degree C, but it would be advantageous in new developments both for the building owners and the District Cooling Company to design and install larger cooling coils in the HVAC system to further increase the return temperature. The District Cooling Company can in such case reduce the pipe sizes in the distribution network, install smaller distribution pumps and the electrical consumption will be less. The Building Owner will have to install a bit larger and slightly more expensive cooling coils in the HVAC unit, but can reduce pipe sizes, install smaller circulation pumps and will reduce the electrical costs for pumping. I.e. reduce life cycle cost for both Building Owners and District Cooling Company.

Environmental Performance

In the 70's, Sweden was the most oil dependent country in the industrialized part of the world. Since then, oil dependence for heating and electricity production has gone down by 96.5%. When it comes to sulphur emissions we are back at levels before world war one! How is that possible? You may think that Sweden as a sparsely populated developed country had been spared from environmental problem! The truth is we have had our share of irresponsible exploitation of nature and environment. In the 70's even the water in central Stockholm was heavily polluted. Swimming and fishing was of course forbidden. Today, lake water in the city is even drinkable and people are swimming in these waters and enjoy the nice Swedish summer. The 70's also saw numerous environmental scandals which triggered political action and tougher legislation. The first UN conference on the environment was held in Stockholm 1972.

Also due to the oil crisis, large efforts were made in the 70's and 80's, to find new ways to treat water, to insulate buildings, develop automatic energy saving systems and alternative sources of fuel. In the past decade these findings have been put into practice in a larger scale. Strict environmental legislation has pushed the development of: new public/private partnerships, fruitful exchange between industry and universities, as well as pioneering entrepreneurship in new industries. This influenced of course also the District Heating industry to become much more environmentally aware and to focus not only on efficiency but also on the environment. A district heating system, compared to individual heating, can easily cut the fuel consumption in half when the plants also provide electricity in a combined heat and power plant configuration. The high efficiency, over 90% for a CHP plant using a steam turbine cycle, in combination with electrostatic precipitators and/or textile filters to reduce emission of particles, scrubbers to reduce sulphur dioxide emissions and catalyst to reduce emission of NOx result in plants with minimal impact on the environment. The remaining problem is then Carbon dioxide. The Swedish approach was to already early 1990's put a carbon tax on carbon dioxide emissions, this has reduced the usage of fossil fuels and promoted renewable energy solutions.

The question that is asked by many is of course, "does not environmental legislation and care for the environment only cost the country much of its growth potential"? For Sweden, district heating has enabled us to slash CO2 emissions while still enjoying stable economic growth. Take a look at the graph. The orange line shows how the Swedish GDP has grown with 78% from 1990 to 2017. At the same time the Swedish Carbon dioxide emissions for heating of buildings has decreased with 90% as presented by the blue bars in the chart.



Thanks to efficiency measures, transition to new energy sources and combined heat and power plants and district heating this has been achieved.

Business Environment

Swedish district heating – whether publicly or privately owned – is a profitable business with clear economic and environmental benefits for all concerned.

District Energy is however not only technical solutions and products! There is as well a requirement for a business environment that promote efficient, cost effective and environmentally friendly concepts. The situation in Sweden has been that Government have supported the development of District Energy by creating a levelled playing field where different centralized and individual solutions have competed on equal terms and in most cases District Energy has been the consumers preferred choice. District Energy in Sweden is existing in a competitive environment and is a profitable and viable business.

The Management of District Energy Companies is a complex process with many stakeholders including customers, equipment suppliers, fuel suppliers, suppliers of consumables, municipal and national Government etc. In cases where local fuels are utilised it can include to build a local fuel market by giving long-term contracts for fuel supply, so that local entrepreneurs are prepared to invest in required machinery and vehicles for transportation of the fuel to the plant. This all requires clear long-term strategic goals including both technical and economic analysis and business plans as well as tools to measure the outcome.

Successful District Energy Companies requires well trained knowledgeable Managers, operations and maintenance staff and District Energy Companies are continuously providing advanced training to their staff that is resulting in well optimised operations and high efficiencies.

The competence level in Swedish District Energy Companies are as a result high and in cooperation with Universities, Equipment Manufacturers and Consultants we can offer training courses in all aspects of Operating a District Energy Company including Management, Best Practice Design and Operation & Maintenance.

Concluding Remarks

This Best Practice guide is an attempt to share Swedish experience from over 65 years for how to design and implement district heating systems. The history of district cooling in Sweden is shorter about 25 years but the experience from distribution of district heating water, substations and heat pump technology made the step to District Cooling much “shorter” as both District Heating and District Cooling shares many components and engineering practices.

SweHeat & Cooling stands behind our member companies who will all make their outmost effort to provide the best management and engineering advice and provide the latest most modern advanced products to all Customers and Colleges in the District Energy Business and Industry.

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SWEHEAT & COOLING

City of Stockholm

Supplied with Heating and Cooling from CHP and Heat Pump/Chillers

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