BASREC

Best Practice Sharing
Municipal Energy Integration

Booklet 3 - District Cooling

July 2015

Foreword

District cooling (DC) is a new and developing market complementing traditional district heating (DH) and cogeneration of heat and power (CHP). Obviously in the future due to the two trends of both global warming and constantly improving energy efficiency of buildings, DC will be an important new business area to the current DH companies. Both trends reduce the need of heating, but increase cooling as the excess heat inside the buildings has to be ventilated out anyway. In as North as Helsinki for instance, there are already buildings in which the cooling load is higher than the heating load. In southern regions the cooling load must be even more dominant to heating compared to Helsinki.

The DC in Europe started in the countries where there is little or no regulation of the energy sector. The energy companies have been required, and they have also been able, to flexibly respond to the changing and constantly demanding needs of the cooling market. For instance, as an example from the transportation sector, there are hardly any cars or vehicles anymore on the market without air conditioning facilities, and thus buildings without appropriate cooling systems no longer have good market value. DC offers a more economic, environmentally sound and financially viable option to the customers compared to the traditional individual cooling.

The booklet at hand offers descriptions of processes on how DC was established, examples on how DC is run and further developed today, and some statistics from four capitals of BSR with DC facilities commissioned already. From the capitals, the DC is already expanding to other cities of the region. However, in order to fight the Climate Change and to improve the overall energy efficiency of municipalities, much stronger expansion is needed.

The booklet has been issued with an objective to:

Provide guidance to cities, regions and energy companies in the Baltic Sea Region (BSR) in their process of accelerating conversion from fossil fuels, improving energy efficiency, and extending the use of renewable energy sources.

BASREC has initiated a project on Best Practice sharing within Municipal Energy Integration. The project scope included the following 3 main topics:

- Integral Urban and Energy Planning
- Planning and Integral Operation
- District Cooling

Relevant stakeholders in a number of selected Cities have been interviewed and based on these three booklets (1,2,3) have been issued, one on each topic. The present booklet presents the concept of DC as it has been applied in some major Cities in the BSR. Based on the interviews in the selected Cities (Helsinki, Stockholm, Copenhagen and Berlin) an overview of the main features and driving forces drawn from the questions below is included for the individual cities in chapter 5 of this booklet:

- *The rational of choosing the technologies to deliver DC*
- *The incentives and challenges to attract other stakeholders to DC: waste heat sources, environmental authorities, etc.*

- *The ownership border of DC facilities between the customer and utility*
- *The financing scheme: own sources, investment subsidies, development loans, commercial loans*
- *Tariff setting and customer contracting*
    - *The incentives and challenges to attract the first customers to the brand new DC system*
    - *The ways to integrate to the existing energy system as tri-generation: power, heat and cold.*

Finally, the authors of the booklet hope that the stories and examples presented in the booklet will contribute to a strengthened development of DC in the BSR in particular, but elsewhere as well.

Contents

Abbreviations

BASREC	Baltic Sea Region Energy Co-operation
BSR	Baltic Sea Region
CHP	Combined heat and power plant
DC	District cooling
DHC	District heating and cooling
DH	District heating
DHW	Domestic hot water
EU	European Union
HP	Heat pump
HVAC	Heating, ventilation, air-conditioning
SH	Space heating
O&M	Operation and maintenance
CFC	Chlorofluorocarbon.
HCFC	Hydrochlorofluorocarbon
PEF	Primary energy factor

1 District Cooling – Concept and Main Features

Cooling makes our urban environments more productive and comfortable and is not needed only on a summer day. Cooling is critical for the correct functioning of computers and manufacturing equipment, and vital for industrial processes. Moreover, the comfort requirements of people have increased in past years as neither cars nor building spaces without comfort cooling are desired anymore. Therefore, we may take it for granted that our offices, the local shopping centres, hospitals, many other facilities, as well as local industry all require cooling. In fact, cooling has become as important as a heating system. Today, 40% of commercial and institutional buildings in Europe have cooling systems, and demand is set to grow substantially.

Traditionally, comfort cooling is based on electricity to run the individual appliances. Consequently, electricity demand grows with the expansion of traditional air-conditioning.

Until recently, peak loads of electricity in many European countries have typically occurred during winters, but lately the highest peaks in many regions and countries have been registered during summer periods - in many cases touching capacity limits with risks of outages. The reason for this trend is often the increased need for comfort cooling.

A potential threat to the environment and to electricity supply infrastructure can be converted into great opportunities for the energy business, its customers and society, if the cooling is approached in parallel with the electricity market, CHP, the heat market and the availability of waste heat resources to be used in combination with natural resources in future DC systems.

Development of the major DC systems in Europe shows that the application of the technology is not directly linked to climate conditions. Some most advanced and expanded DC systems locate in the north, namely in Scandinavia rather than in the central and southern Europe. This is very much because of free energy markets that encourage energy companies to develop new products and services, as well as strong tradition of centralized energy systems and mature infrastructure of CHP and DH.

DC is an environmentally optimized cooling solution, using local, natural resources to produce cooling where and when it is needed.

The DC customer is connected to the cooling production via a pipe network. Chilled water is distributed to the buildings where it loses its cold content, thus cooling down the building temperature.

DC makes the most of local resources and can combine different cooling sources, depending on local conditions and tailored to the users' needs:

- *Heat pumps:* heat pumps chill the buildings through DC network and deliver the waste heat to the DH system.
- *Free cooling:* Cold water is directly extracted from oceans, lakes, rivers or ground water, and its coldness is used for chilling buildings. Electricity is needed for water circulation pumping only.
- *Use of surplus heat*: In many processes, for example when electricity is generated or waste is burned, large parts of energy are set free in form of surplus heat. This heat can be converted into cooling and thereby be recycled in DC networks. Absorption chillers are used in conversion as "chemical" heat pumps having the waste heat instead of electricity as driving force of the chiller to produce cold water.
- *High-efficiency chillers:* These are compressor driven chillers that require significantly less electricity

than the individual chillers due to economies of scale.

The heat pumps can be used to integrate DH and DC and waste heat sources in a flexible and efficient way.

Primary energy factors (PEF) and specific CO_2 emissions make it possible to compare cooling solutions with regard to their contribution to reducing the use of fossil fuels.

PEF measures the combined effect of efficiency and the use of renewable and recycled energy sources. The assessment encompasses the whole energy cycle – from conversion to delivery to the customer. The lower the PEF value of a technology, the more fossil energy is being saved. Operational data confirms that DC schemes are far less energy-consuming than conventional air conditioning systems. Moreover, central production of cooling is environmentally and operationally superior to individual cooling in each building based on electricity.

In Figure. 1, an example of PEF related various cooling options is presented. The benefits of cooling options in terms of PEF would be similar to those of CO_2.

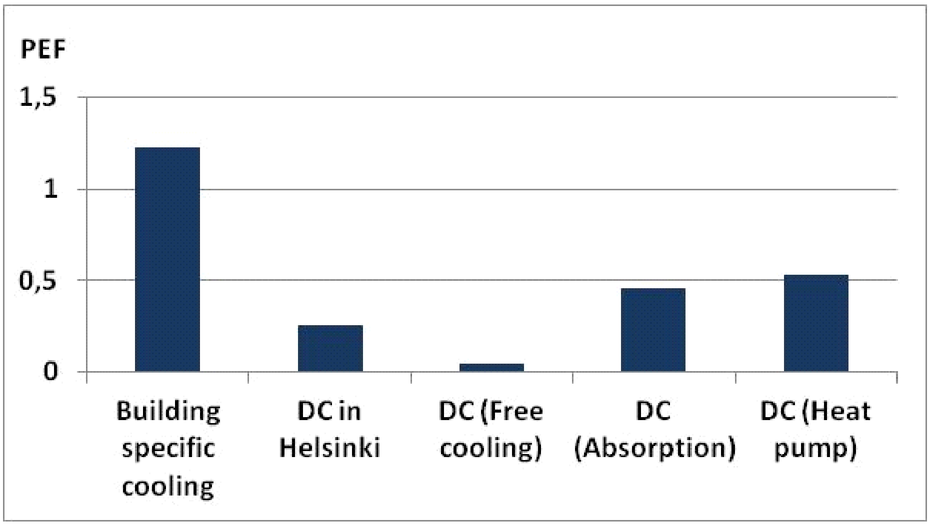

Figure 1: An example of primary energy factor (PEF) associated to various cooling options in Helsinki (source HELEN Ltd.)

It is very common to meet the supposition that DC systems must be based on absorption chillers, and those located in the end-user buildings. This is definitely not the case as there is no such building specific absorption system competitive to the centralized DC available. DC systems can just as well be based on electric driven chillers such as centrifugal compressors or screw compressors. The concept of centralizing chilled water production in high-efficiency state-of-the-art plants based on electric-driven chillers has proven feasible in many applications.

Compressor driven cooling as a means of DC, where waste heat from the cooled buildings can be used to warm up either the make-up or the return water of the DH system, can be developed as a complementary product to CHP and DH. Using heat pumps for combining DH and DC is a good idea that has been adopted in some cities already. Moreover, free cooling can be used as complementary when cold sea or lake water is available nearby. Thus, PEF of cooling can be substantially low.

The choice of concept shall be based on a feasibility analysis and possibly general environmental considerations. Often, the use of absorption chillers is not economically feasible due to energy price structures. At the same time, absorption chillers may be superior with regard to carbon emissions if based on waste heat.

DC can be developed as a complementary product to CHP and DH as the cooling demand will increase both due to climate change and the energy efficient buildings, and perhaps even more due to increasing indoor air quality requirements that have a big impact on human health and comfort. The modern energy efficient buildings have substantial indoor heating sources as both the increasing number of electric appliances, even though the new ones being more energy efficient than the old ones, and the inhabitants emit heat. Therefore, heating needs tend to decline while the cooling increase. Using heat pumps for combining DH and DC is a good idea that has been adopted already successfully in many cities in BSR, for instance, in 8 cities in Finland (Helsinki, Espoo, Vantaa, Turku, Heinola, Lahti, Tampere, Kuopio), and in as many as 35 cities in Sweden. The largest DC suppliers are FORTUM in Stockholm, the Tekniska Verken (Technical Works) in Linköping and HELEN in Helsinki.

In year 2014, for instance, the DC sales in Sweden and Finland exceeded 1 000 and 190 GWh already with the network lengths amounting to 500 km and about 100 km, respectively.

Integration of DH, DC and CHP creates **tri-generation** in which heating, cooling and electricity are provided at high overall efficiency and with only low flue gas emissions (and low carbon emissions in particular).

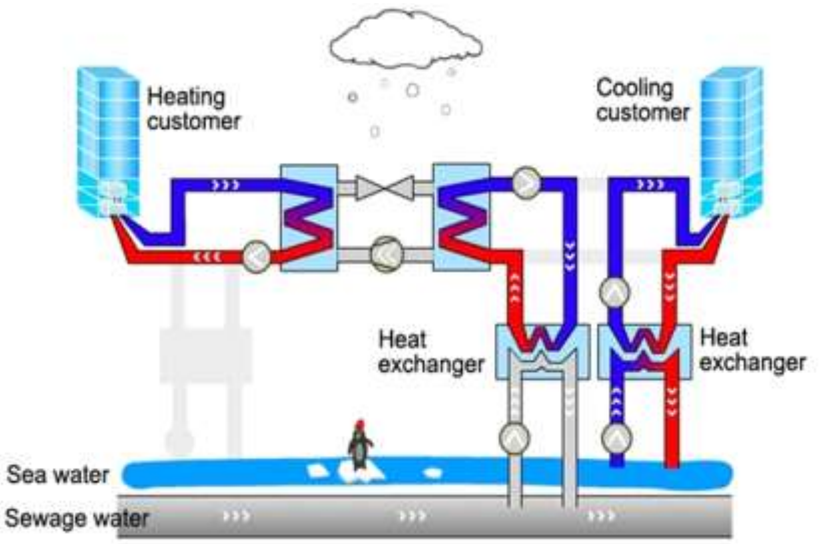

Figure 2: Combined DHC plant: Cleaned sewage water heat is converted to DH by means of a heat pump. Water heat from the DC system can be converted to DH by means of the same heat pump, Additionally free cooling can be used to chill buildings. (Source: HELEN Ltd)

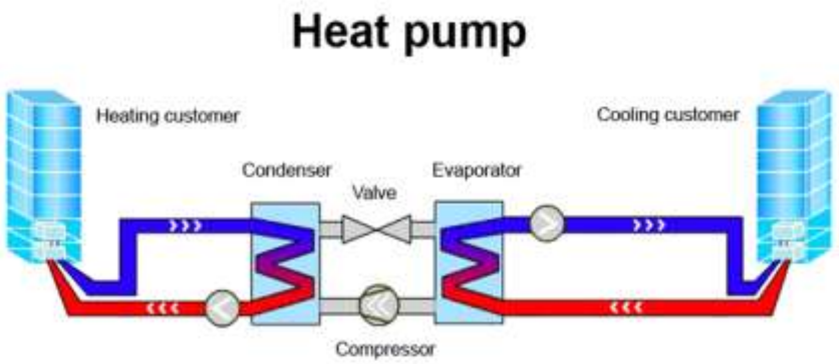

Figure 3: A compressor driven heat pump converting the waste heat from the chilled buildings to DH. (Source: HELEN Ltd)

2 District Cooling – Driving Forces and Motivation

Traditionally, the individual electric compressor driven heat pumps are installed in buildings and apartments. Such individual cooling systems using small compressors are extensive electricity consumers at low overall efficiency, and require either room space or outdoor surface of the particular building.

Advanced use of waste heat and cooling sources with heat pumps and integration of DH and DC systems increase the overall efficiency and reduce emissions. The optimum temperature level of the heat source will depend on the actual conditions at the power plant, and consequently, a feasibility analysis is required in each individual case to determine the optimum plant configuration.

Many customers having both DH and DC use both products in parallel around the year: DH to deliver DHW in summer and DC to chill IT server rooms in winter time. In future, due to global warming and highly energy efficient buildings, the cooling needs may increase whereas the heating needs will decline. Today in the office buildings the need of cooling is already higher than the need of heating. Surprisingly, in many modern buildings even as north as in Finland, the cooling peak load is already higher than the heating peak load.

DC integrated to DH is the only way to use solar energy in densely built urban centers to produce DHW. Integration of solar to DC proceeds in three steps is as follows:

- In summer time, the buildings are naturally heated by solar radiation.
- The DC system absorbs the excess heat from the buildings and transfers the waste heat to the DH system by means of heat pumps.
- In DH, the waste heat recovered from the DC system is used for DHW heating to substitute fossil fuels. Thus, the solar radiation in the 1st step was converted to DHW heating in the 3rd step.

Let us imagine that in case the DHC system would not exist at all but the DHW should be produced with individual solar collectors. In Helsinki, for instance, the capacity of the solar collectors would require a surface area equivalent to the size of 30 football courts to be located in the already densely built Helsinki peninsula. It is obvious that it would be difficult if not impossible to find such a large surface available for solar collectors in a densely built city center, but the integral DHC solves the surface problem in an optimal way.

The capital investment required for DC systems is substantial. The DC systems are best suited, where primarily the thermal load density is high. Also the annual load factor should be rather high as well. The high heat load density is important but can be easily achieved in many BSR cities. Helsinki with 0,6 million population, for instance, is not exceptionally densely built at all, but DC has become financially and economically viable.

The load pattern and a long annual operation time are important to economy of both DH and DC. This requires a proper planning and market survey as basis for designing and developing the integrated schemes. Business cases need to be set up taking into account the need for oversizing costs to be dealt with during the initial development phases.

High load density is needed to offset the high capital investment for the distribution system that constitutes 25-50% of the capital costs of the overall DC system. High load densities are normally found in industrial complexes, densely populated urban areas and high-density building clusters such as tall buildings. A high annual load factor is required to ensure a reasonable payback time.

The main advantages related to DC are:

- Low operating costs and competitive capital investment compared to traditional individual cooling
- Sustainable to environment
- High operational safety, flexibility and availability
- Architectural and practical benefits as both construction space and surface is released by DC for other use.

In general, the DC business is easier to start in a large than a small city due to the economy of scale associated with the investments and benefits.

Best practice examples for development and optimization of DC exist in BSR to be learned of, and replicated in other cities.

In Helsinki, for instance, the incentive to consider DC was caused by the CHP heat wasted in summer time due to lack of adequate heat load of customers as only DHW was needed. The overall efficiency of energy production needed to be further improved. In other words, the question was: What to do with the CHP heat in the summer? Delivering the CHP heat to the Baltic Sea or to find some other use for it? Here DC came in as an option. In the DH system in summer, at least 80^{o}C supply temperature had to be kept anyway due to optimal heat load dispatch between the various heat sources.

On the other hand in Copenhagen, there was steam available for industrial customers that could be used as the driving force of the absorption chillers in the DH system.

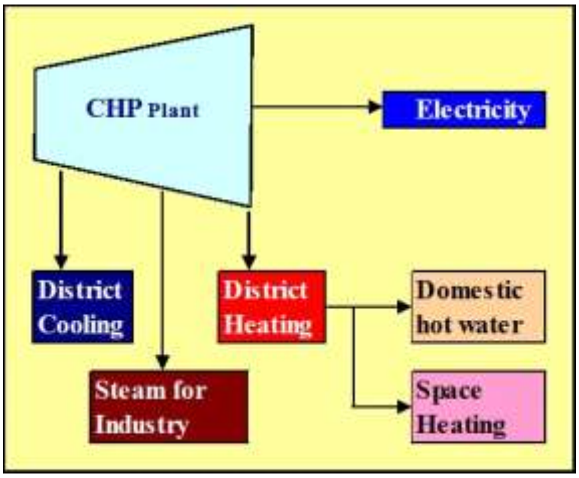

Figure 4: District cooling as a new product to integrate heating and electricity services in the city.

CHP is the most efficient way to generate electric energy from any fuel at 90+ percent efficiency. As other products, CHP offers DH to be used for DHW and SH, steam for industry, and as a new product, DC to the surrounding community.

3 District Cooling – Barriers and Competitive Solutions

The barrier assessment is based on the interviews of experts in the capitals of four BSR countries covering customer attraction, product pricing, the institutional capacity, system sizing, etc.

Attraction of customers is challenging as the DC product is new and not generally known. The potential customers typically are not aware of their existing cooling cost as the costs have been hiding in the building O&M cost. Based on experience it is common that a half or even more of the building energy balance is related to cooling but this is not known by the building owner. Therefore, comparison is often difficult due to lack of data.

One of the barriers is definitely the high investment costs as the pipelines are large due to small temperature difference in cooling, only about 10^{o}C. In Berlin, for instance, some €46 million has been invested in DC development since the year 1996 including the cooling sources and DC network. In Helsinki and Stockholm, the investments have ranged probably from three to ten times the investments made in Berlin as their DH systems are much larger (see table 1 on page 12)The other identified barriers for DC were:

- Hesitation of the HVAC engineers and potential clients towards the suggested new DC product.
- High investment needs, due to large size piping and oversizing needed in the beginning.
- No public subsidies available for initiating and extending the DC. The company's own resources had to be adequate. Therefore, either the company or its owner has to be financially strong.
- Cross-subsidizing of different products, DH and DC, is not allowed. Both products have to live on their own, and the DC costs have to be covered by DC revenues. This also requires financial resources from the company to start a new business that has to run on its own.
- Sometimes, private ownership of the DH company may hinder co-operation with the municipality in DHC development. If so, development of DC becomes overly challenging.

Ways to phase out the above barriers are based on the results of the interviews i.e. based on real experience from the best practice implementation cases.

The arguments towards potential customers of DC are that:

- DC is reliable and releases O&M resources of the customers to the core business as the service provider takes over the cooling service.
- Costs of cooling are competitive to the existing individual electricity drive cooling.
- Price of DC is predictable compared to price of electricity and O&M associated with previous individual cooling.
- DC needs less room space with heat exchanger than the individual cooling systems with compressors and heat exchangers.

Figure 1: A DC substation with heat exchangers and expansion tank (Source: HELEN Ltd.)

Critical issues to help initiate and develop DC systems are as follows:

- The customers have to be bound to DC with expressions of interests or draft contracts before large investments will be done.
- The plans for DC must be done some 10 or more years ahead in order to oversize the pipelines to the current load but to meet the cooling load needs of the future.
- In order the DC load expansion to materialize in the future, close co-operation with the city planning is vital. The city master plan shows how much, where and when both new buildings will be constructed and existing buildings will be renovated (heating, cooling, water, sewage, thermal insulation). The plan shall be the basis for DC planning as well.
- Good reputation of the DH/DC company and its product is important as the potential customers must have trust in the suggested new DC product. The level of trust is very much based on the existing reputation, whether good or poor.
    - Courage and strong resources (financial, institutional) are necessary to investments that are required to start the new business activity in a comprehensive and convincing way.
    - Co-working in combining the energy and city development plans is vital. This requires open and close co-operation amongst the energy planners at DH/DC company and the urban planners in the municipality.

The DH company knows the buildings quite well already and this can support the development of DC as well. The DH customer database includes data of the particular building such as construction year, building volume, type of building and DH consumption, which are most useful when designing the new DC connection as well.

The financial competitiveness is to be based on cost comparisons and environmental benefits presented based on real examples from best practice cases.

The various benefits from the point of view of (a) the energy company, (b) the customer and (c) the city are as follows:

a) For Energy company:
    - DC offers a new business to the DH company as the heat load will decline in the future but the cooling needs may increase
    - DC offers a new business area with positive net cash flow
    - The peak load duration times of DC have been actually higher, ranging from 700 to 1000 h a year compared to 400 to 500 h initially estimated. Longer peak load duration improved the DC economy.
    - Improved overall efficiency while integrating DC to DH
    - Adding the DC to the existing product mix of DH and electricity provides synergy benefits in billing and collecting, network construction and maintenance, and in energy production.
    - DC is based mainly on low value energy cooling sources (DH outside the heating season, sea or lake water) compared to electricity used in individual cooling machines.

b) For Customers:
    - Reliable cooling services
    - Predicable costs of cooling
    - Free room space in the building, avoided growth (increase) of piping and free roof area as not individual cooling equipment are needed anymore

- Better outlook of the building as the individual coolers can be removed/avoided on/from the out walls.
- Lower cooling costs to the customers compared to the traditional technology
- DC is based mainly on low value energy cooling sources (DH outside the heating season, sea or lake water) compared to electricity used in individual cooling machines, which makes the DC more acceptable to customers that are becoming increasingly conscious of sustainability

c) For City:

- Increased attractiveness due to DC (lower costs to customers, lower emissions in the city, better comfort to customers, sometimes better outlook of buildings)

Consistent co-operation with the city planning authority is vital to have the integral energy and city planning, both progressing in parallel.

4 Examples from DC Market

The below table shows general data about the extent of the DC systems in four Baltic capitals, namely Berlin, Copenhagen, Helsinki and Stockholm. In Stockholm the DC system is the largest. Three of the capitals are located on the coast of the Baltic Sea, which makes it possible to use sea water as a free cooling source, which however is not a necessity to successful DC.

	Berlin	*Copenhagen*	*Helsinki*	*Stockholm*	*Unit*
Number of buildings	70	40	300	600	#
Network length	14	12	60	200	km
Connected load	44	18	170	350	MW
Cooling sources:	60	13	130	370	GWh
From DH to DC with heat pump		3	90	200	GWh
Free cooling		3	15	100	GWh
Absorption cooling	18	3	25	50	GWh
Compressor cooling	42	7		20	GWh

Table 1: Summary of DC in four Baltic capitals (2015) with rounded numbers.

As presented in Table 1 above, the free cooling using the Baltic Sea as the cooling source is rather minor: 5% and 27% in Helsinki and Stockholm, respectively, for instance. Therefore, the free cooling is not critical to develop DC. The Finnish Fortum Ltd, for instance using their vast DC experience from Stockholm is initiating DC in Tarto, Estonia, where there is no chance for free cooling at all.

5 Best Practices on DC

5.1 Berlin

Vattenfall operates the largest DC system in Germany located in the new city centre of Berlin around Potsdamer Platz and Leipziger Platz. The Vattenfall central cooling station in Stresemannstraße supplies approximately 10 000 offices and about 1 000 apartments with DC. It cools the national library, philharmonic orchestra, picture gallery, Sony Center, for example, as well as the Potsdamer Platz Arcades, the headquarters of Deutsche Bahn AG, the Bundesrat parliament building, the Federal Environment Ministry (BMU) and the Berlin House of Representatives.

Since 1996 the company has invested approximately € 46 million on DC technology including the central cooling station and the network. There are two sources for DC in Berlin such as:

- A large amount of the cooling energy has been generated by absorption chillers driven by district heat coming from the CHP plant *Mitte*. At present, however, the CHP has been stopped for the summer time, which has reduced the share of absorption chilling in the DC production mix.
- Compressor chillers refrigerating machines meet the remaining demand for cooling while putting the waste heat to the atmosphere through the traditional cooling towers. By means of the compressor heat pumps, the heat from the return line with temperature ranging from 12 to 16^{o}C will be transferred to 32^{o}C as the supply to the cooling tower. The cooling tower returns the water as 27^{o}C to the heat pump. The DC supply will be 6^{o}C, after the excess heat was transferred to the cooling tower.

At times of peak demand 5 300 m^3/h of water at a temperature of 6°C flows through the DC network to the customers. After the local cooling process in the buildings has warmed up the water to around 12°C then he water is returned to the central cooling station where it is cooled down again.

In the past years, the DH system has expanded in four periods of time steps, and the 5th period currently being under development. The customers are willing to be connected to DC as the centralized cooling is safe, cost competitive, provides constant room temperatures and saves expensive room space compared to the traditional individual cooling.

The DC construction became actual as the previous old buildings were falling apart and the entire district had to be re-developed. As alternatives both DC and electricity driven cooling were considered. Finally, DC was chosen as a more cost effective and environmentally sound solution.

The DC system of Berlin ventilates the excess heat received from the cooled buildings to the atmosphere through the cooling towers. Therefore, a lot of water is needed and has to be pumped out from the underground well owned by Vattenfall. When producing heat from the compressor and the absorption plants, the excess heat to be ventilated amounts to 1,2 MW and 2,5 MW, regarding the compressor and absorption chilling, respectively.

The pipelines of DH and DC are installed in common channels having the DC pipes under and DH pipes above each other.

Figure 6: DC facility n Berlin (Source: Vattenfall Europe).

5.2 Copenhagen

HOFOR is responsible for DC in Copenhagen after having had established the first DC system in Denmark in spring 2010, when a cooling plant, with the capacity of 15 MW, was put into operation. HOFOR produces and distributes DC to customers in Copenhagen.

The first plant was built in Copenhagen City Centre, and the second plant is in operation close to the City Hall. The DC plants use seawater and surplus heat from the power plants to produce cooling for a number of large customers. A number of owners of commercial and office buildings have shown strong interest in having access to DC, and for the Kongens Nytorv project, seventeen potential customers were identified, having in total cooling demand of 15,3 MW. The major customers all have existing individual central cooling plants whereas most of the minor customers do not have a central cooling plant in place and will thus need to establish such.

The pilot DC system was fully implemented in 2013. High priority has been given to design the production in the most sustainable way. Therefore, the system uses approx. 22% free cooling, absorption chillers based on surplus heat from CHP plants covers approx. 25% and central electric chillers cover 53%. Out of the total cooling approx. 45% is CO_2 neutral.

The absorption chillers have been established in connection with the steam part of the Copenhagen District Heating system. A quarter of the total heat requirement in HOFOR's supply area is distributed as steam. The steam network was originally established in order to supply hospitals and industries in need of high temperature process energy and once a steam pipeline was established, nearby offices, institutions and blocks of flats were also connected.

Over the next decade, HOFOR will convert the network in order to abolish steam. By 2021,all customers are to be supplied with district heating based on hot water. This development has been taken into consideration in connection with the DC development planning.

A second DC project for the area around the Town Hall Square has started operation in 2014.

The DC market in Copenhagen is not a monopoly but based on free market mechanisms. Thus the DC part of HOFOR is organised in a separate company with separate economy and balance sheets. The municipality has established the initial shareholder capital for the DC part of HOFOR.

Only natural refrigerates are allowed in Denmark. The system operates at supply temperature of 6 ^{0}C and a return temperature of 16 ^{0}C under normal conditions. The pipes are with approx. 600 mm diameter.

The project stands upon a survey, mapping potential customers including investigations of existing air-conditioning systems, need for renovation taking into account the age of the system, technology, maintenance level and subsequently the prevailing cooling costs.

Only customers with existing cooling demands are approached. The policy is not to "create" new cooling demands.

According to calculations made by HOFOR the CO_2 reductions are up to 70%compared to traditional cooling. A centralized DC production increases efficiency 5-10 times compared to decentralized electrical driven cooling solutions.

Future DC plants are to be established throughout Copenhagen. Within the next 2-3 years this will go up to 30-35 MW installed capacity in central Copenhagen. New parts of Copenhagen like Kalvebod Brygge, Islands Brygge, Sydhavn and Nordhavn (all areas along the harbour) are the next in line to receive cooling through newly installed DC pipelines. Development of these areas takes place in a close cooperation between the municipal planners and HOFOR.

As a utility company, HOFOR has existed under different names for more than 150 years. It was founded in 1857 when the first gas supply plant was built in Copenhagen. At the time, gas was used for lighting. Two years later, the first water works was established, and in the 1860-80s, a sewer system was established in order to improve hygiene conditions in the city. The first electricity production plant was put into operation in 1892, and in 1925, HOFOR started district heating supply based on CHP. Today, HOFOR is a multi-utility company for the entire metropolitan area. HOFOR as it is today was formed in 2012 in a merger between Copenhagen Energy and the water supply companies in the municipalities of Albertslund, Brøndby, Dragør, Herlev, Hvidovre, Rødovre and Vallensbæk.

HOFOR can deliver 40 MW of cooling to 40 DC consumers. Copenhagen's newly opened DC plant will be supplying sustainable air conditioning to Copenhagen City Hall and several large companies nearby. Department stores, museums, hotels, and offices had to cool off their buildings, and server rooms by means of their own electric cooling system, whereas they now have the option of choosing climate-friendly DC which means fewer expenses and a cleaner Copenhagen.

In the winter months, cooling is solely produced by means of seawater. In summer months, steam is bought from CHP production, as heating consumption in the summer is very low. Electricity compressors are used in the summer months; seawater is used to remove surplus heat from the compressor machines.

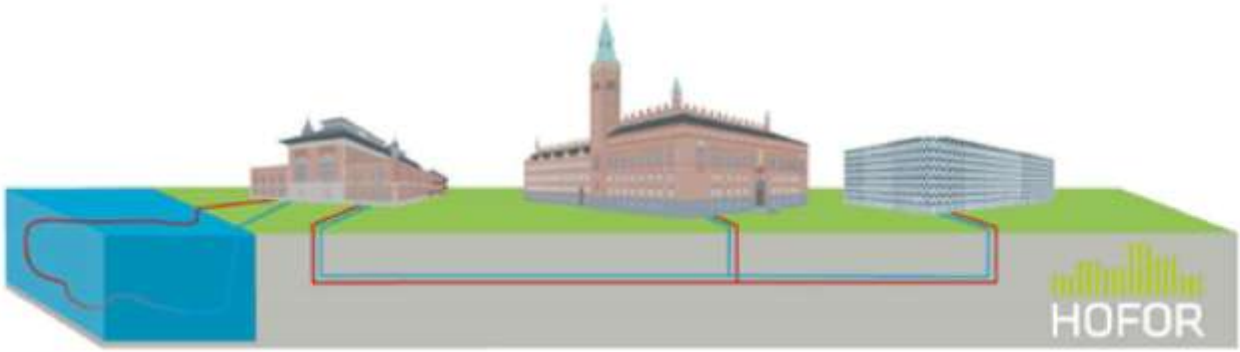

Figure 2: District cooling in Copenhagen. Source: HOFOR

The DC network in Copenhagen is expected to deliver cooling for approximately 1400 full load hours per year.

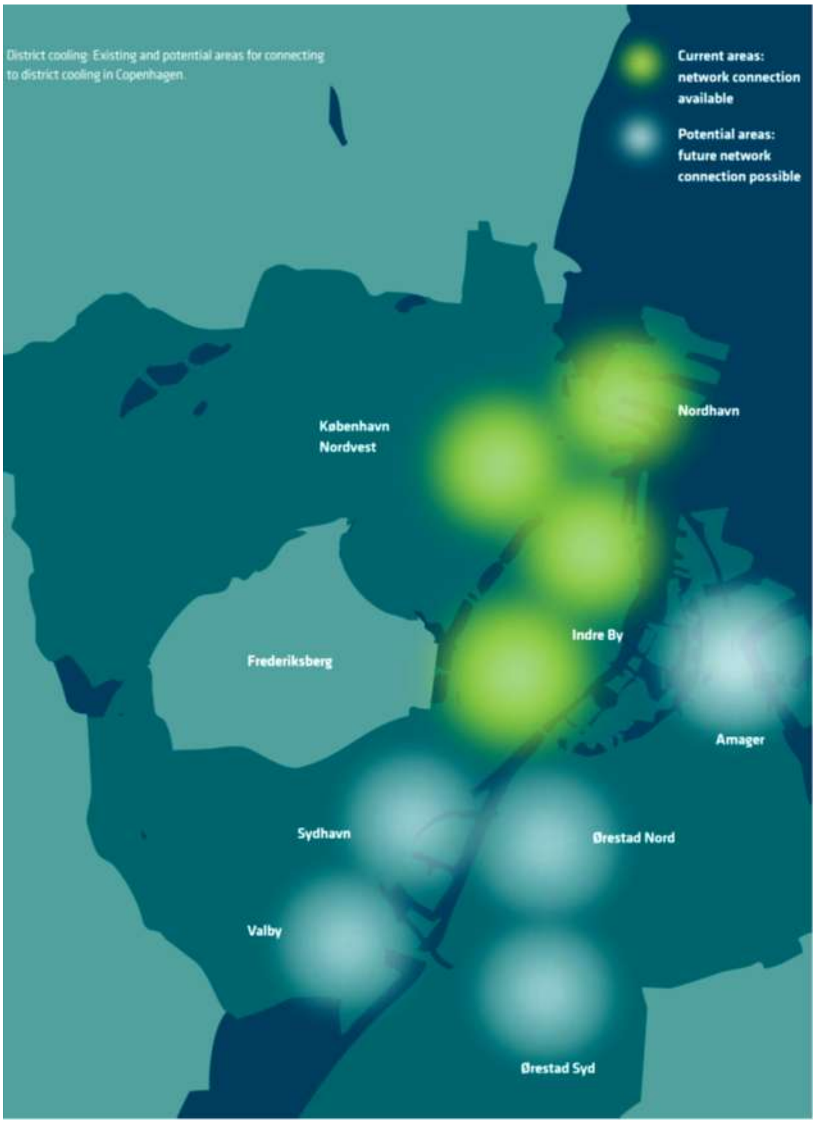

Figure 8:District cooling in Copenhagen. (Source: HOFOR)

5.3 Helsinki

The DC system in Helsinki has been established and been constantly expanding on free market basis under operation and ownership of HELEN Ltd, the successor of Helsinki Energy valid since January 1, 2015. At present the DC system in Helsinki with 170 MW cooling load is the 3rd largest in Europe after Paris and Stockholm,

The DC system of Helsinki as an integral part of CHP, DH, solar heat recovery and cold storing has been several times awarded by the international organizations such as Euroheat&Power, International Energy Agency (IEA) and International District Energy Association (IDEA) due to its high level of innovations and system integration, the latest award dating April 2015 titled *Global District Energy Climate Awards*.

As an innovative approach in Helsinki, the DH and DC systems have been integrated by using the waste heat from the chilled buildings to warm up the DH return water. Thus, solar heating was indirectly used for DHW heating in large scale but without solar collectors, as demonstrated in Chapter 2 already. In summer 2014 on one day a record was achieved according to which waste heat was recovered from the buildings by means of DC and transferred further to the DH system in amount that covered 50% of the DH production of that day. At that moment, the DHW of 250 000 inhabitants of Helsinki was produced by solar waste heat.

Figure 9: Katri Vala HP plant in Helsinki for combined DHC with five heat pumps for heating (60 MW) and cooling (90 MW) as the largest of its kind in the world, awarded as best practice by the International Energy Agency (IEA) and the Euroheat & Power in 2009.(Source: HELEN)

In Helsinki, the DC development has proceeded in the following 15 steps, first a small demo, then the pilot and finally the large scale system:

1) In year 1995, a DC demo plant was installed to the industrial complex (ABB factory) with 2 small absorption machines, 300 and 900 kW each, and 3 cold water storage tanks were installed and commissioned. The tanks were needed as accumulators and peak shavers.

2) The demo appeared successful in operation, and therefore, the lessons learned and operation experience was gained to DC company. As a result, it became obvious as well that the cooling machines at the customer premises work, but cannot be optimal. Multiplying small machines from customer to customer does not bring the economy of scale that is necessary to make DC a commercial business. Moreover, condensing capacity required to ventilate out the waste heat from the buildings is higher with absorption than compressor chillers, which would require additional space in the customer premises. Therefore, planning of a centralized DC was started.

3) Survey was done in the city areas in which starting of DC might be most attractive. For attractiveness, the following parameters are important: new construction, types of buildings, existing CHP and HP infrastructure. To support the survey work, the general plan of the city was vital as it showed where the expansion and complementary construction will take place, when, and how.

4) Ruoholahti district adjacent to the Salmisaari CHP plant appeared to be the best pilot candidate to start with DC: a complex of large and new official and commercial buildings. Many of the new buildings were still under construction, and no final decision was made about the cooling system yet. It was certain, however, that the new buildings will need some cooling systems anyway. Excess heat from the CHP plant was available outside the winter season. Moreover, the Baltic Sea with seasonally cold water was near to consider the sea as another and natural cooling source. The land area of the CHP plant could be used for the cooling source installations. Therefore, DC was suggested to the building owners as an alternative cooling method for consideration.

5) All residential buildings were excluded in the initial stage due to challenging contracting of many apartment owners. Therefore, only sport centers, hotels, office and business buildings were attracted. The Ruoholahti pilot for DC amounted to 10 -15 MW cooling peak load.

6) Interviews were carried out with potential customers to understand the current situation and possibilities to improve the cooling economy and performance.

7) Financial analyses were carried out comparing the planned DC and the traditional individual cooling systems both from the customers and the DC company's point of view. In the analyses, the experience collected from the Demo plant was valuable.

8) Individual customer (building) specific contracts were designed that share the benefits of DC in a way being attractive both to the customer and the DC company. No overall tariff system is made publically available but the DC contracts remain individual for the time being.

9) The customer contracts are signed by the end-user, not the real estate developer. The allocation between the one-time (down payment) in the commissioning stage and the annual payments was designed individually to meet the wishes of the customer.

10) The customer contract may be valid for a certain period or for the time being. In case the ending date is set, there is a possibility to adjust contract conditions or even terminate the contract if either party is disappointed to the service/business.

11) After a satisfactory confidence about customer connections to materialize was available, the investment decision could be done and the implementation could start.

12) Thereafter, another construction area, Hermanni, close to Hanasaari CHP plant started as a large area to develop. For the new buildings, DC services were offered. As a new approach, smaller compressor driven DC units were installed in to containers, and the containers were located near to the new buildings to produce DC. There was not a centralized large cooling source or DC network available yet, so the containers were used as a temporary solution. While selling DC services to the potential customers, one has to be able deliver as well.

13) For Hermanni district, the network was built and the new cooling source established. As the source, Katri Vala heat pump station, as largest of its kind, was implemented. The station is connected to the channel which leads purified sewage water to the sea, out of which the heat pump transfers the heat energy to the DH system. The heat pump station also chills the buildings Hermanni district that is now connected to the new DC system, where the heat pump transfers the waste heat received from the DC to the DH system.

14) The DC systems of Hermanni and Ruoholahti were later interconnected with a DN600 pipeline, which created the basis for a large scale expansion of the DC system in Helsinki.

15) Today, the DC system is expanding to the north, covering the district of Töölö already.

In addition to chilling sources, network and substation, two large cold water storages, both located underground in rock with volumes 38 500 m^3 and 11 500 m^3, have been built in order to reduce the need of machinery and to shave the cooling peak. The cooling loads of the customers are not simultaneous, but the DC load amongst the customers is even less simultaneous than in DH. Therefore, the cold water storages as accumulators are very important in optimal DC.

As the pipelines were oversized in the beginning, now more new customers can be connected to the DC system with relatively low incremental investments.

Some 15 years ago, chilling systems were not that common in the buildings in Helsinki and the customers were not aware to require either. Today, there are hardly any new buildings in Helsinki which will be built without cooling, as the customers' expectations on living and working comfort have arisen substantially. Therefore, the DC market awareness is strengthening. Now in Helsinki, also residential buildings are being increasingly connected to DC.

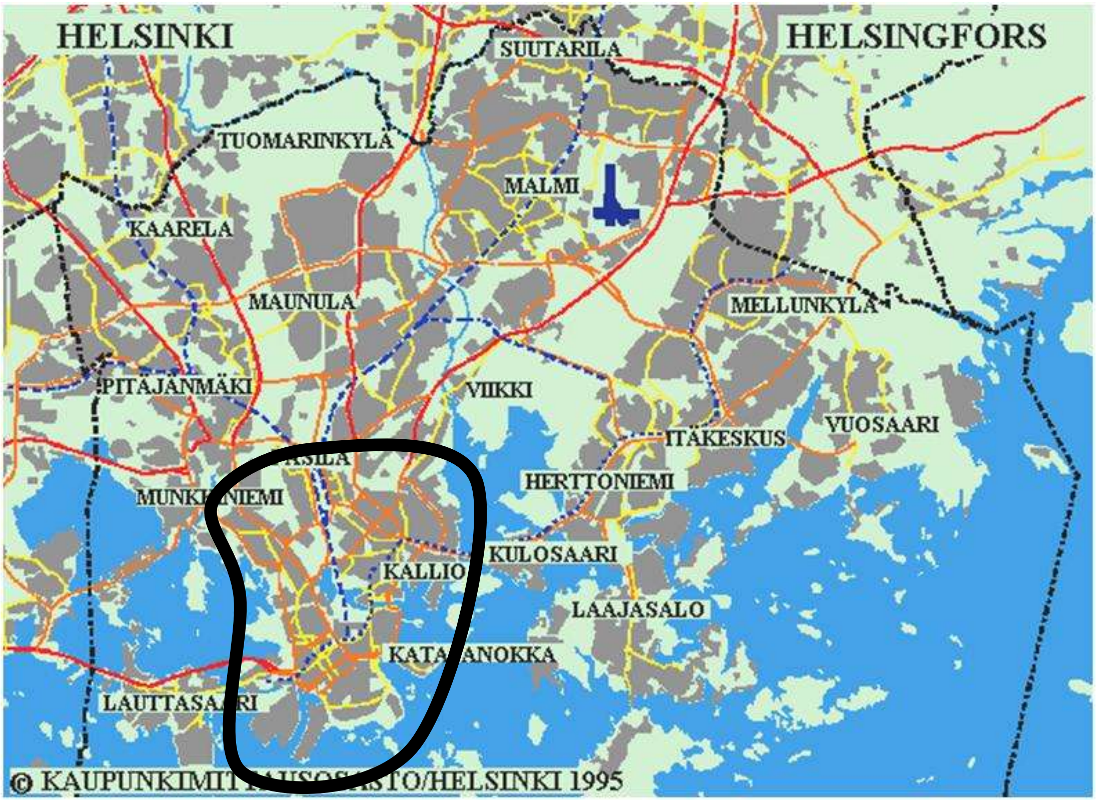

Figure 10: Scheme of DC in Helsinki circulated with black line but entire city is covered with DH already.

5.4 Stockholm

At present (2015) the DC system in Stockholm is the largest in the world both in terms of the number of customers and the extent of the network. (source: http://svenskfjarrvarme.se/Nyheter/Nyhetsarkiv/2015/Fler-vill-ha-fjarrkyla/)

The development of DC in Stockholm started with an inquiry from a shopping mall in 1992, which lead to a feasibility study in 1993 and the first delivery of cooling to downtown Stockholm in 1995. DC had a very positive response from the market. It was partly due to a political decision to phase out harmful CFC and HCFC refrigerants because they caused major damage to the ozone layer.

- The drivers for the DC market are a combination of many things.
- Outsourcing of Cooling (as of Heating) and the already established commercial relations.
- Valuable building space released for other use.
- Reduced investments, predictable costs and reduced risks.
- The political decision of phasing out CFC and HCFC.

The first driver means that the building owner can outsource the cooling service to a professional partner at lower costs, clear responsibilities, lower environmental impacts, and good service quality, the factors that all raise the value of the building of the owner.

The market has developed from the initially large customers where small costumers have followed, and consists mostly of commercial buildings such as public buildings, office buildings, hotels etc. DH was established 40 years ago and customers are used to buy from the energy supplier. The DC consists of fully commercial relations between customer and supplier. Other market drivers are shifts in comfort culture, behavioural patterns, increase in internal loads (computers etc.), affordability and consumer expectation and the perception that air condition contributes to higher productivity. The green profile of DC is also sold based on a common wish to improve the environment.

Today DC is a part of city infrastructure and in some cases DH tunnelling could be used. The city is used to accepting digging to improve infrastructure and the city recognizes the synergies in production, distribution and marketing.

Figure 11: The DC areas in Stockholm. Source: http://www.fortum.com/countries/se/foretag/fjarrkyla/fjarrkyla-i-stockholm/pages/default.aspx

Today, the use of DC is widespread in Stockholm. Approximately 7 million m² of commercial space in Stockholm are connected to the DC. Stockholm's DC network currently consists of different systems with capacities between 3 MW and 228 MW. The largest system is the one supplying the central parts of Stockholm. Today, approximately 135 customers and 600 buildings are supplied with DC. This makes a total capacity of 330 MW in the ca 500 km long DC grid. The customers range from 8 to 7 000 kW, where the average customer is about 500 kW. In total, 530 GWh cooling is sold in Stockholm.

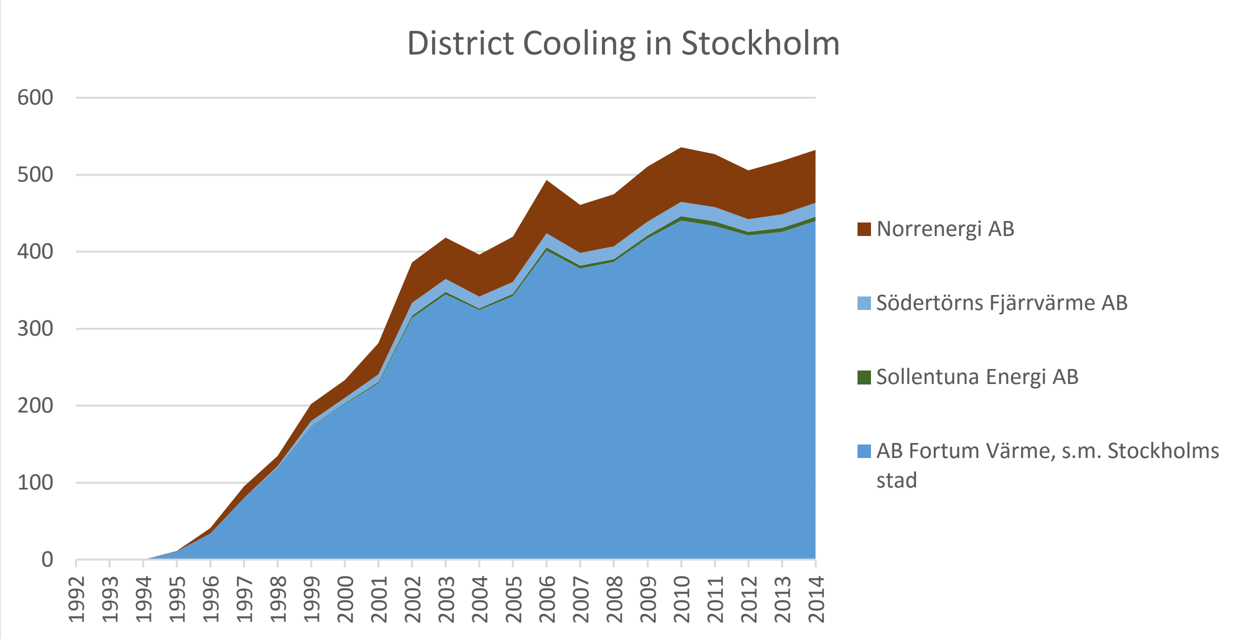

Figure 12: DC Production Stockholm 1992-2014. Source: http://www.svenskfjarrvarme.se/Statistik--Pris/Fjarrkyla/

The biggest DC company in Stockholm is conducted by the energy company Fortum. Fortum sells about 500 GWh of DC in Sweden each year. Fortum accounts for about half of the supply of cooling in Sweden. Fortum soon discovered that cooling was used during a greater part of the year than initially expected. This is because the demand for cooling is not only based on hot weather, but also on the need to cool electronic equipment in combination with chillers, commercial and industrial requirements, etc. If corresponded cooling effect would be produced by traditional methods, five times as much electricity would be required. DC reduces the electricity demand on from cooling by 80%. In systems with electricity peaks during the summer, the DC contributes to reduced demand peaks caused by individual air conditioning.

Cold water from the bottom of the sea is used to cool down the DC water that circulates in a closed loop. The seawater is then returned to the sea. The heat in the warmer water in the DC return pipe can be recovered to the DH system via heat pumps. During the nights when there is excess capacity from free or waste cooling production, a day-to-day storage is utilized.

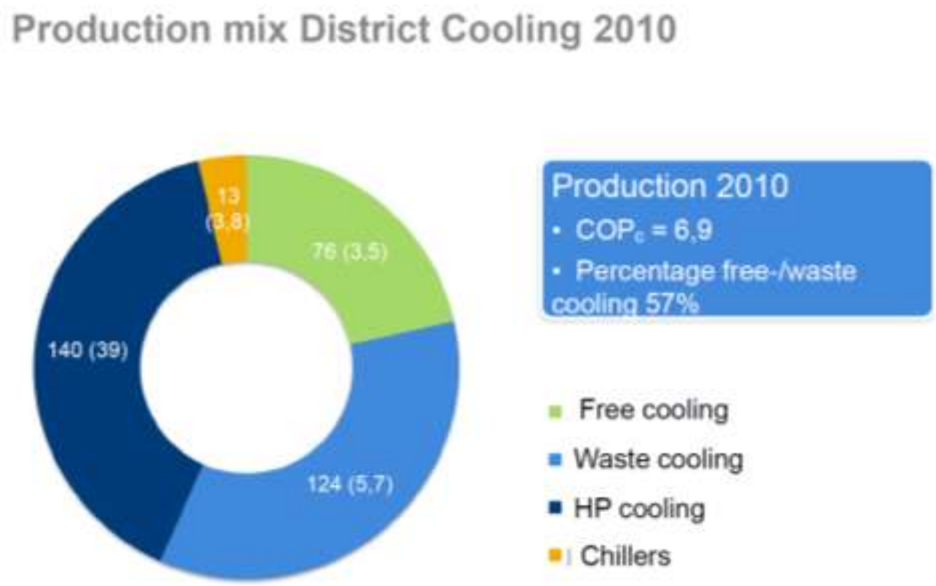

Figure 13: Production mix DC Stockholm 2010. Source: Anders Hill, Fortum

Fortum has 6 bigger heat pump plants in Stockholm; most of them are designed to produce heat and cooling simultaneously. District cooling means that excess energy is diverted from real estate. From this waste heat some 35% (157 GWh) is recovered for and sold as DH. For day to day optimization of production a storage unit about the size of ca. 12 full load hours is utilized.

DC is expected to expand in the industrial areas of Stockholm and in data hubs, as most consumers with individual cooling units in the city are already connected to the DC grid. In many cases the expansion of the DC grid is made from a central point close to the DC production, as opposed to making expansions in the periphery.

6 Conclusions

The four capitals of the BSR are forerunners of DC expansion in their respective countries, and many other cities in Finland and Sweden, for instance, run DC systems already on fully commercial basis.

As the main success factors of the DC development the following should be emphasized:

- Good co-operation between the city (urban) and the energy planning as outlined in booklet 1 is essential, as the DC initiation and development should be consistent with the city development. Based on the interviewed experts, it is hard to believe that a large and sustainable DC system could be established without close and fluent co-operation between the city and the DH company.

- Good reputation of the DH company amongst the customers to introduce a new DC product in large scale is vital. It would be highly challenging to convince the customers with a new DC product if there is no complete trust with the existing DH product.

- Integration of the new DC to the existing DH will provide synergy and energy benefits, thus complementing the DH/CHP schemes presented in booklet 2.

- Strong financial resources of the DH company are needed as the DC is highly capital intensive and has to start in rather large scale in the beginning already.

- DC should start with commercial and public buildings in which one owner is to be convinced compared to a number of apartment owners.

- Both the cooling market analysis and the cooling system piloting in small scale are important to gain knowledge to the DH company before introducing the new DC product on the market.

The DC services are provided all year round, not only during the warmest seasons, which is essential to the economy in a capital intensive business. Many buildings already need more cooling than heating, and this trend is expected to strengthen in the future, which makes DC a growing business area.

As the demands of the customers constantly increase in terms of comfort and sustainability, the room space cooling based on renewable sources becomes increasingly important when assessing the value of a building. To meet the cooling demand and to increase the flexible use of renewable resources, DC offers an important opportunity to the future.