ULOGA DALJINSKOG HLAĐENJA U BUDUĆIM PAMETNIM ENEGETSKIM SISTEMIMA

THE ROLE OF DISTRICT COOLING IN THE FUTURE SMART ENERGY SYSTEMS

Oddgeir GUDMUNDSSON¹,
Peter KAARUP Olsen², Jan Eric THORSEN¹

¹ Danfoss A/S, Heating Segment, Application and Technology,
Nordborg, Denmark.
² Ramboll A/S, Energy, Copenhagen S, Denmark
¹og@danfoss.com, ²pko@ramboll.com

The role of district heating in future smart energy infrastructure has been fairly well discussed but its counterpart, district cooling has as well a large role to play. District cooling is a centralized solution for providing cost efficient and environment friendly cooling to buildings. When considering district cooling one normally thinks that it is a solution for the warm climates. It might therefore come as a surprise that the Europe’s largest district cooling market is found in a Scandinavian country, Sweden. The second biggest district cooling market is in France. Even with the difference in the climate both countries have identified the significant benefits district cooling can bring, both from an economic and environmental perspective. The purpose of this paper is to; a) underline the benefits district cooling can bring to cities and their inhabitants, b) identify few of the potential cooling sources and c) discuss common challenges and best practices to ensure stable and economic operation of the system.

Key words: (English) district energy; cooling; controls; efficiency
1 Introduction

Cooling energy demand within Europe is today low compared to countries like U.S. and Japan. In U.S. the commercial and residential cooling saturation is 80% and 65% respectively, in Japan it is 100% and 85% respectively. Europe on the other hand has cooling saturation of only 27% and 5% respectively [1]. The cooling demand in Europe is therefore expected to rise significantly. Key parameters that influence the cooling demand are building design, internal heat loads, heat island effects, and comfort reasons. Given the current low cooling energy demand saturation in Europe gives the perfect opportunity for establishing district cooling system and avoiding investment in conventionally small scale and decentralized electric driven compressor chillers. By avoiding the decentralized approach significant primary energy usage greenhouse gas emissions and peak electricity demand can be avoided. Experience in the U.S. shows that fouling is a common problem in chillers, according to the HPAC Engineering webpage the average fouling in water-cooled chillers creates a 17% increase in energy consumption. This is not a surprise as a biofilm of only 150 microns (0,15 mm), which is so small that it is typically overlooked, causes 5.3% increased energy consumption in cooling tower based chillers [2].

District cooling is about outsourcing of cooling units in buildings to an external cooling utility which has high focus on the performance and efficiency of the cooling plants. Once the cooling utility has been formed it will establish a pipe network for connecting multiple buildings to one or more cooling sources using various resources for generating the cooling. Cooled water is circulated from the cooling sources to the buildings, where heat exchangers are used to extract heat from its cooling system, and then back again to the cooling sources to be cooled again. Both the property owner and the environment benefit from this. In addition to monetary and environment benefits there is an added supply security for the building owners.

Although the first district cooling systems were introduced in the 1930’s for cooling of the Rockefeller Center in New York and U.S. Capital Buildings in Washington DC district cooling in Europe took its first steps in 1990s. In Europe district cooling has shown an exponential growth where it has been established, until the local market has been saturated. Even though district cooling is reaching its 30 years anniversary in Europe it is still a rather unknown solution and has a market share of about 1% or 3 TWh/year [3]. Considering that Swedish district cooling system alone delivers almost 1 TWh/year [4] the growth potential is enormous.

There are many reasons why municipalities and energy companies have started up District Cooling schemes. Reasons that are commonly named are a) synergies with existing district heating systems, b) increased utilization of existing combined heat and power (CHP) plants during the summer, c) new development on the market, d) existing high cooling demand and e) demand for more green energy profiles, both at the utility and potential consumers. Almost all energy companies that have district cooling systems mention these points which imply that there is a business and market driven approach.
Currently the main markets for district cooling in Europe are commercial buildings, which typically need large connection capacities and cooling throughout the year.

2 District cooling

2.1 Arguments for district cooling

Urbanisation, globalisation and rising cooling demands have led to an increased interest in the environmental and economic benefits of district cooling. Similarly as with district heating the main driving power of district cooling comes through economy of scale, its indifference on the origin of the cooling and its ability to maximize the operational efficiency across multiple cooling sources by taking advantages of simultaneity of demands, which would be impossible on a building level. This makes it more cost effective than locally based cooling such as central air conditioning.

Besides the above mentioned power drivers there are multiple alternative benefits, the frequently mentioned are:

- District cooling substations require significantly smaller space than building level chillers and thus frees up valuable space in the building. Further, cooling towers can be removed from from example rooftops.
- District cooling typically results in significantly higher energy efficiency through greater flexibility of optimizing cooling production over time and cooling sources.
- District cooling substations are relatively simple and well proven technology through decades of usage in district heating systems, thus resulting in lower maintenance costs than building level cooling units.
- District cooling both reduces and optimizes electrical loads over the day, leading to significantly reduced electrical peaks. Reduction through greater efficiency and possibility of utilizing free cooling or heat driven cooling units and optimized by decoupling demand and production by utilizing large scale thermal storage. For example is seasonal storage with ATES (Aquifer Thermal Energy Storage) a possibility for both free cooling and utilisation stored cooling / heating energy in peak demand periods.
- District cooling reduces HFC handling.
- District cooling is a silent system - no noise at the building which increases the comfort for users.
- District cooling has architectural advantages, i.e. no need to consider cooling fans, chillers and other auxiliary systems.
- District cooling has been shown to contribute to higher building value through its multiple benefits.
- District cooling has less demand for technical staff on building level (building owners / operators)
- District cooling is environmental beneficial
• District cooling increases energy security by utilizing local sources and maximizing efficiency of all cooling units.
• District cooling is a very resilient technology. The system can be operated from all cooling sources. The system can quickly adapt to fuel price pressure through pooled cooling sources and multi-fuel plants.
• With co-production of district heating with heat pumps, it can be possible to achieve very compatible heating and cooling tariffs.

2.2 Benefits of district cooling in terms of savings for Europe

District cooling can greatly reduce the peak power demand during the cooling season. A great example was documented in Cleveland in 1994/95, see Figure 1.

![District Cooling Customer Electric Demand Profile](image)

**Figure 1. Example of how district cooling could change the electrical demand profile across the year [5].**

District cooling could avoid electrical capacity requirements of 50 GWe and investments of 30 billion Euro or 30-40% of the investment for new district cooling infrastructure. District cooling would save 50-60 TWh per year, equivalent to power consumption of Greece. District cooling would save 40-60 million tons of CO2 per year (15% of Europe's share in the Kyoto protocol) [1].

On country level can as an example be mentioned Cooling Plan Denmark [6], which states that the potential for district cooling in the country of Denmark is estimated to be about 2.4 GW cooling. This would result in an enormous socio-economic saving of approx. 1.3 billion EUR.
3 Cooling sources

District cooling can be produced using a range of very different techniques which are often combined in order to utilise local conditions as efficiently as possible and provide security of supply and very stable cooling prices. Producing district cooling in conjunction with district heating is especially smart, because we often need cooling when we least need heating, which ensures high utilization of combined heat and power plants throughout the year.

For direct use of cooling sources they typically need to have temperatures below 6°C. Higher temperature cooling sources can be used in combination with heat pumps. The typical supply temperature of the district cooling water is 4-6°C, can be higher in certain cooling processes. The typical return temperature is 12-16°C.

There are number of free cooling sources, the most common ones involves utilising cold water from ground water (aquifers), seas, lakes or other waterways. Other free cooling sources are outdoor air or even snow collected during the winter and stored in large storages.

Absorption cooling is a technique utilising the thermal energy generated in combined heat and power plants, waste incinerations or surplus heat from industry to drive an absorption heat pump for cooling down the district cooling water. The absorption heat pump would generally be located centrally but in case of a high temperature district heating system the absorption heat pumps could be located de-centrally and fed by the district heating system.

Electrically driven heat pumps are able to produce both heating and cooling at the same time. These heat pumps are currently the most common way of producing district cooling in Sweden, due to the very good economy when both the heat and cool can used. Already today there are many district heating utilities using heat pumps using various heat sources, for example sea water and waste water, it could therefore be cost efficient for these utilities to start running district cooling systems.

3.1 Practical example of utilization of pooled cooling sources

When pooling together various cooling sources significant economic benefits can be achieved. If free cooling sources are available, such as sea, lakes or rivers they can provide the majority of cooling demand during the colder months of the year. During the summer these cooling sources tend to warm up and therefore other and more expensive cooling sources need to be operated. In case there is a power plant nearby it would be natural to use absorption chillers, which can utilize the waste heat from the power production. This would of course also apply to existing CHP plants, which typically have over capacity of heat during the summer months. On top of these electrical chillers, the most expensive units to operate, can be used to provide peak capacity.

For determining where district cooling is applicable Ramboll has developed a unique tool, DCmapper, which is able to identify areas with district cooling potential, by gathering information regarding the cooling demand and geographical location of buildings. These pieces of information are then measured against the differ-
ence between the preliminary expenses of a local cooling facility and a district cooling system, respectively.

![Distribution of production graph](image)

**Figure 2.** Example of utilization of different cooling source in a pooled district cooling network. The figure is from Stockholm, Sweden [3].

### 4 Distribution network

A district energy system could look like shown below.

![Supply concept for combined district cooling and heating](image)

**Figure 3.** Supply concept for combined district cooling and heating.

Figure 4 shows the approach existing buildings are marked with green and circles are drawn around the buildings with estimated cooling demand. Then as long as the circles intersect each other it could be economical to build the district cooling network. This could be a simple way to assess the cooling density in different areas and cover the network size.
Figure 4. Example of mapping potential district cooling areas.

Figure 5 shows how district cooling system could look like once the initial mapping has been performed and the most economically feasible area has been chosen.

Figure 5. Example of a district cooling pipe network. Cooling capacity / demand of building areas are mapped.

Hydraulic/thermal analysis of district cooling networks is carried out to find the right pipe dimensions in the district cooling network. This includes steady-state and dynamic modelling, with focus on surge analysis. The hydraulic analysis is also a very important part of feasibility studies for investigating the potential for district cooling in different areas.

Different pipe types can be used for district cooling pipe network. It could be HDPE pipes or pre-insulated steel pipes similar as used for district heating.
insulated pipes ensure low energy increase and low temperature increase, which could be of large significance in some projects / climate zones.

5 Substations

District cooling substations are from the conceptual layout very similar to indirect DH substations for heating, see Figure 6. The difference is mainly that due to the lower dT between flow and return, typically a factor 4, the diameters of e.g. pipes and valve sizes are typically double for the same capacity. Special focus has to be put on the design of the heat exchanger regarding temperature sets. It’s common to specify heat exchangers with temperature difference from primary to secondary side of 1.0 to 2.0°C. A typical temperature set could be 8/16°C – 17/9°C, giving a dT of 8°C for primary and secondary side.

The substations are industrial prefabricated and typically offered on a frame in one or multiple sections depending on the size.

![Figure 6. Typical prefabricated indirect substation for district cooling.](image)

Figure 7 shows a one circuit substation. The substations can be of multiple circuits either due to different secondary temperature demands or due to capacity.

To avoid condensate on the surfaces of the substation it’s recommended to apply airtight insulation.

A difference compared to a substation for district heating systems is the freezing protection bypass. This bypass is relevant to activate in the case of low ambient temperatures in combination with no cooling demand. Optionally are parallel coupled control valves. If they are with integrated dP controllers, one control valve is sufficient for providing the needed range ability and control performance.
6 Building installations

District cooling systems as such are invariant about the building installation. The only requirement to the building installation is that the cooling within the building originates from a central place, where the district cooling system can be connected to the district cooling system via heat exchanger.

To ensure efficient operation of the district cooling system it is necessary to run the building cooling installation so that sufficient heating of the district cooling water supply can be achieved, i.e. to ensure as high temperature difference as possible between the supply and the return.

7 Common challenges

There are number of common challenges when running district cooling systems, below are few of the most common ones.

- Large upfront investments when few cooling costumer agreements are made / few cooling customers connected
- Finding space for the district cooling facilities: Technical components (in a building), thermal storage, pipe tracing (large dimensions) especially in city centre areas
- Ensuring noise reduction of very large chillers / heat pumps, but it is a challenge that can be solved with sufficient insulation components
- Low temperature difference between the supply and return, commonly known as low dT syndrome.

All of those challenges can be overcome by sticking to good preparation work, known solutions and focused operation.
8 Driving factors for district cooling

A common nominator for district cooling system is the strong growth once it is started, the growth typically continues until the market is fully saturated few years later. Great examples can be seen in Stockholm and Helsinki, see figure

![Image: DC sales Stockholm](image)

**Figure 8. District cooling growth in Stockholm [3].**

![Image: District cooling growth in Helsinki from 1998 to 2012 and project growth to 2030 [3].](image)

**Figure 9. District cooling growth in Helsinki from 1998 to 2012 and project growth to 2030 [3].**
Driving factors behind the general strong growth seen when district cooling systems are constructed are:

- Increasing affordability
- Shifts in comfort culture, behavioural patterns and consumer expectation
- Increase in internal heat loads (computers etc.)
- Increase in urban heat island phenomenon and a general trend towards higher temperatures
- Perception that comfort cooling contribute to higher productivity
- Movement to universal building designs which are poorly adapted to the local climatic conditions

Market experience from US shows that once 20% of the office space in a city is air conditioned it sets the rental value and un-cooled space can only be rented out at discount price.

9 Conclusions

It is a fact already today more energy is used to cool buildings then heating buildings. The energy need for cooling is also expected to grow in the future along with higher comfort requirements from emerging markets. To fulfil the growing cooling demand more and more countries are realizing the district cooling provides a simple, easy and cost efficient way to provide cooling with high quality and consistent comfort. Further benefits of district cooling are that it provides the ultimate means to take advantage of renewable energy sources in a cost and environmentally efficient way.

In cases where an existing district heating system has been in a city it has proven to be rather simple to start district cooling systems because the consumers then know the technology and the benefits it brings. It has further been shown that even in colder regions, like Sweden and Finland, district cooling has been shown to be very economically attractive, which should give a good indication on the attractiveness in warmer regions.

When planning, building and operating the district cooling systems it is very important to do it right to avoid running into a situation that can greatly impact the cost efficiency of the whole system. By adhering to best practices the future of district cooling is bright.

10 References