EUROHEAT & POWER

May 2006

DISTRICT COOLING

COOLING MORE WITH LESS

1. INTRODUCTION

A major objective of the European Union's energy policy is to develop the efficiency of energy production and end-use in the framework of a free market. The recent "GREEN PAPER on Energy efficiency or Doing More With Less" (COM (2005) 265 final) estimates that a cost-effective reduction of 20% of energy consumption is within reach by 2020 compared to 1990 levels. Developing efficiency will enable to decrease the dependency on imported fuels; it will also logically reduce noxious emissions and thereby participate to climate change mitigation.

Within this policy frame, the CHP (combined heat and power) and DHC (district heating and cooling) sector plays a significant role today in a responsible use of energy and intends to further contribute.

Additional to the traditional need for heating, the demand for cooling has recently emerged. Although this development came later in Europe than in America and Japan, Europe is rapidly closing the gap as almost all new commercial and institutional buildings are equipped with comfort cooling. The growth of comfort cooling is today very high all over Europe. If met exclusively with electricity and building-bound appliances, it will require huge extra investments in power generation, electricity grids and will increase noxious emissions.

In this context, developing an integrated approach to energy demand and meeting the cooling demand with district cooling entails significant benefits and will enable to "*do more with less*".

The purpose of this paper is to shed light on district cooling, its technologies, market position, and its role in the framework of more energy-efficient energy systems.

The paper also formulates recommendations on policy and measures to ensure that district cooling will further contribute to the goals of the European energy policy.

2. WHAT IS DISTRICT COOLING?

District cooling refers to cooling that is commercially supplied through a cold/heat carrier medium against payment on the basis of a contract. District cooling can be a network serving several customers; it can also refer to the local production and distribution of cooling to supply the needs of an institution - business centers, airports, hospitals, universities and public buildings. Experiences demonstrate that this type of block cooling can be the starting point of a district-cooling network when new users are added.

The centrally-produced district cooling can reach an efficiency rate often 5 or even 10 times higher than traditional local electricity-driven equipments. It also opens a great flexibility, tailored to users' needs, to combine cooling production with different possibilities such as:

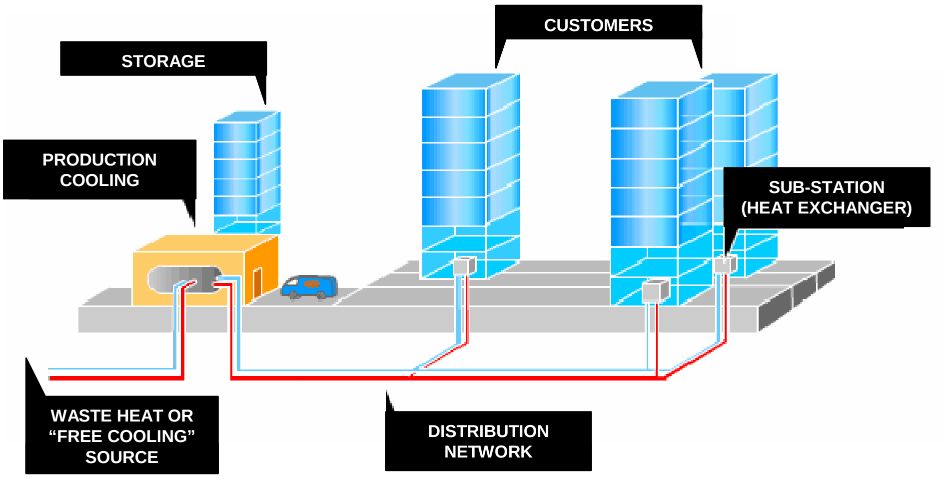
- Deep sea or deep lake water "free cooling"
- Absorption chillers (in combination with surplus heat production from industrial sources, waste burning plants or cogeneration production plants)
- Heat pumps in combination with heat demand (i.e. district heating systems)

To increase the efficiency and reliability, these cooling sources and production techniques are often combined with different kinds of storage solutions, such as:

- Seasonal storage where free cooling in winter is stored for use during the summer period
- Night-to-day storage facilities where overcapacity during the night is stored for use during daytime.

The centralisation of cooling production is a prerequisite to reach a high efficiency insofar as it makes possible to use "free cooling" or surplus heat sources, and thereby reap benefits brought by a large-scale production of energy. A distribution network is therefore necessary to enable the cooling supply to the customers.

Figure 1: District-cooling system

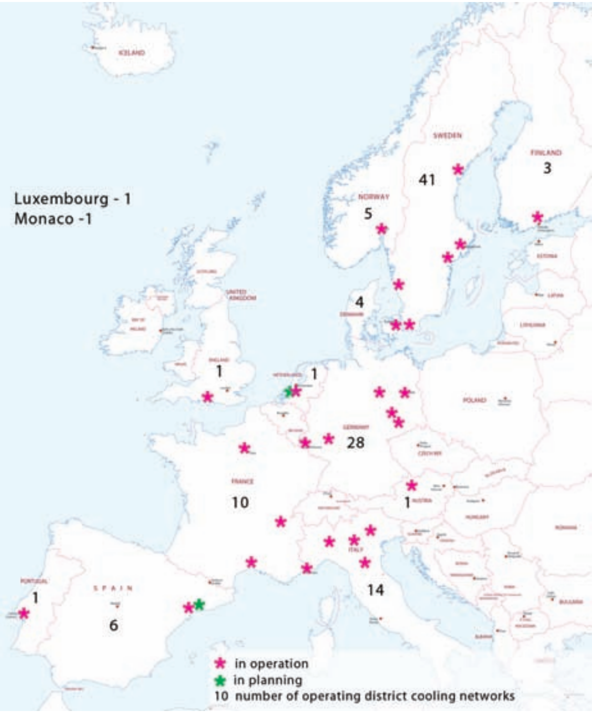


- **An overview of district cooling production technologies can be found in annex 1.**
- **The delivery of district cooling is an energy service insofar as it brings substantial benefits in terms of comfort and energy savings to the customer – cf annex 5 "the benefits for the customers".**

3. DISTRICT COOLING IN EUROPE

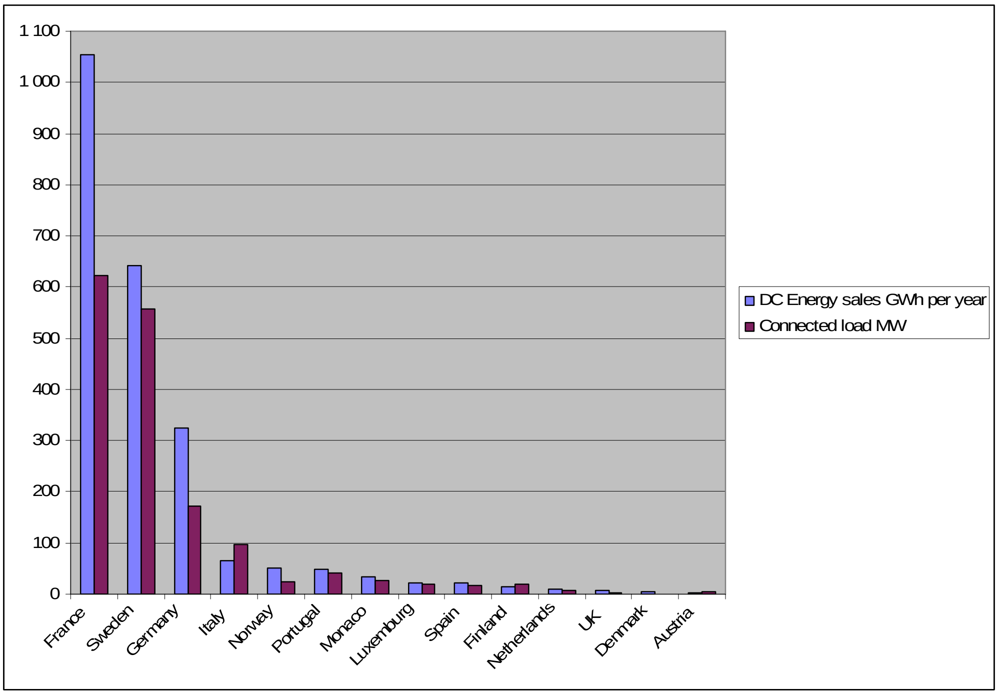
District cooling has successfully developed in densely populated areas in Europe in service industries, public buildings and, in some cases, in residential sector. District-cooling networks are operated in several countries – as illustrated below, and many new systems are under development or in the feasibility study phase. On-site block cooling are operated in all the countries of the European Union in order to meet energy needs of big buildings – airports, or industries.

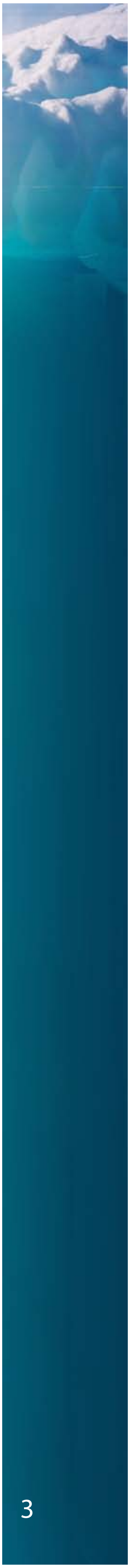
Figure 2: Indicative mapping of cooling networks and on-site cooling installations (5 biggest indicated per country)



The market share of district cooling is today about 1-2%, or between 2 to 3 TWh cooling. District cooling should be able to take a 25% share of the rapidly expanding cooling market, which can be between 500 and 700 TWh already 2012 according to the preliminary findings from the on-going Ecoheatcool study (www.euroheat.org/ecoheatcool/).

Figure 3: District cooling – 2003 statistics





There are different reasons behind the development of district cooling. The development of a district-cooling network is always a win-win process for a range of different players. On the customers' side, buildings owners are increasingly keen on outsourcing operations to external companies with a view to developing productivity and gain on optimisation of energy use. For energy companies, the development of a district-cooling offer is an attractive choice to enter new markets and get closer to end-users. For a city, the district-cooling option enables a sustainable supply of cooling with the ensuing environmental and economic advantages in terms of quality of life, attractiveness of the city and a better urban design.
If in some Member States, the development of district cooling could rely on experience in district heating like for instance in Helsinki, Paris and Stockholm. In other cases, the development is more recent and embedded in innovative local urban projects like in Barcelona and Lisbon.

The choice to manage energy in a more rational way systematically lies in the background of all projects. Different factors have played a role in the development of district cooling such as the priorities laid down in the respective national or regional regulatory frameworks, and the investment climate. Last but not least, the influence of climatic conditions and the design of local demands play a role and impact on the choice of technologies in district cooling networks.

- **A showcase of district-cooling networks can be found in annex 2.**

4. CONTRIBUTION OF DISTRICT COOLING TO THE EUROPEAN ENERGY POLICY

4.1. DISTRICT COOLING'S CONTRIBUTION TO INCREASE ENERGY EFFICIENCY

The integrated approach of district cooling opens the possibility to use fossil resources in an efficient way, and resources that would otherwise be wasted such as surplus heat from a wide range of sources. Centralising the production enables to '*Do More with Less*' as illustrated in the table below on the performance of different cooling solutions. If for instance conventional chillers achieve an energy efficiency ratio (EER) of 1.5-3, a district cooling network with free cooling or using waste heat/absorption chillers reaches a ratio of 25-40.

In all cases, district cooling achieves higher results than conventional appliances.

Figure 4: Performance of different cooling solutions

Solution	EER	PRF
Conventional building-bound solution Conventional RAC and CAC	1,5 – 3,5	1,7 – 0,7
Conventional chillers combined with aquifers	3 -6	0,8 –0,4
District-cooling solution Industrial chillers with efficient condenser cooling and/or recovered heat to DH	5 - 8	0,5 – 0,3
Free cooling / industrial chillers	8 -25	0,3 – 0,1
Free cooling	25 -40	0,1 – 0,06
Absorption chiller driven from surplus heat or renewable source	20 - 35	,13 – 0,07

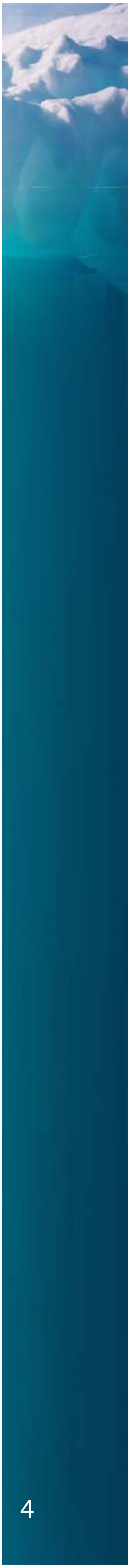
EER = (Seasonal System) Energy Efficiency Ratio. This states the output of yearly useful cooling energy per unit of yearly energy input in the system.

PRF = Primary Resource Factor that relate to the environmental impact. See §5.3

4.2. DISTRICT COOLING'S CONTRIBUTION TO REDUCE EMISSIONS

The efficiency of district cooling leads to emission reductions.

District cooling is instrumental in the phasing out of refrigerants such as CFCs (chlorofluorocarbons) and HCFCs (hydrochlorofluorocarbons) that is due in 2010. Electricity-driven compression chillers use these refrigerants whose release in the air participates to the destruction of the environment – i.e. depletion of the ozone layer that accelerates the phenomenon of global warming.



Additional to refrigerants, district cooling enables CO_2 reductions and will therefore play a role in meeting the Kyoto objectives. Based on preliminary estimations from the ecoheatcool project the potential in CO_2 savings of district cooling in the European Union represents from 20 and 40 million tons annually. For comparison this is between 5 and 10% of the European share of the CO_2 savings in the Kyoto protocol[1].

4.3. DISTRICT COOLING'S CONTRIBUTION TO THE SECURITY OF ENERGY SUPPLY

Between 1990 and 2002 the average peak loads in the European Union have increased by 20 %. In a southern member state like Greece, the corresponding increase was 54 % during the same period. The average peak-load increase is expected to continue at the same rate - at least. In Mediterranean countries, the forecasted increase is even higher. In the years between 1990 and 2020 generation capacity in Spain and Italy is expected to double. In Greece and Portugal capacity is forecasted to increase three times during the same period.

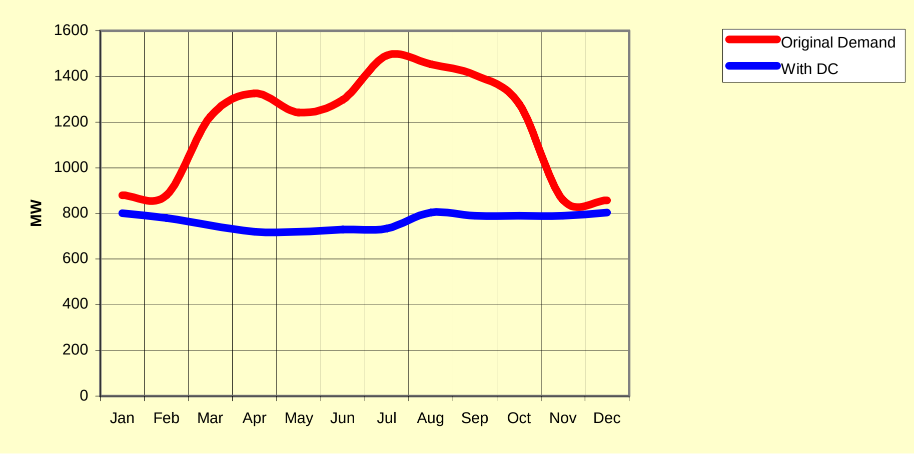
In the frame of this general trend a significant development happened recently with regards to peak loads. If they traditionally occurred during wintertime, latest peaks were recorded during the summer, and some cases touching capacity limits with resulting risks of outages.

An increase demand for cooling, if met by traditional electricity devices, will worsen the situation. Between 1990 and 2002, the annual electricity consumption in EU15 rose by 30 %, while the increase for July was 38 %. If a heat wave similar to that of 2003 were to occur again, it would be a potential problem limiting electricity production when the need for cooling is peaking up.

This development of cooling is happening in a context when Europe is to invest massively in order to both renew its electricity generating capacity and meet the growing demand. According to a report from the IEA (World Energy Outlook 2003), the electricity generation in the European Union is projected to increase at an average rate of 1.3% between 2002 and 2030. Forecast investment represents $788 billion in electricity generation, $121 billion into transmission grids and $423 billion into distribution networks.

In this perspective, policy-making needs to go further than replacing old generation facilities with new ones.
Current investment needs in energy generation offers a historic opportunity window to generate energy more efficiently and give more room for an integrated approach to energy needs. In this context, district cooling provides a working alternative to meet the growing cooling demand.

Figure 5: The contribution of district cooling to the reduction of peak demand (example)



Where applied, district cooling takes away the summer peak demand in electricity. Although district cooling needs electricity as a driving force itself, the demand for electricity per unit cooling delivered is much lower than with traditional local cooling production.

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[1] Pursuant to the Kyoto protocol, the EU is committed to an 8% reduction of greenhouse gas emissions by 2008-2012 compared to 1990 levels. It means a total reduction of 340 million tonnes greenhouse gas emissions in CO_2 equivalent.

Areas with district cooling are much less likely to be confronted with shortages in power supply.

4.4. DISTRICT COOLING'S CONTRIBUTION TO THE INNOVATIVENESS AND COMPETITIVENESS OF EUROPE'S ECONOMY

District cooling competes against other alternatives on the cooling market and must be a competitive option with attractive pricing and a high quality of supply and service.
The technologies that are used in the district cooling system are state of the art. Because the grids and the cooling production facilities take a huge share in the investments, much emphasis is placed on energy efficiency, cost savings, investment optimisation and quality improving innovations. Because the providers of alternative solutions are also innovative, this competition in innovativeness drives the business to continuously create added value for the customers and investors.

- **Annexes 3 and 4 show how both customers and energy companies can benefit from the development of district cooling systems[2].**

5. RECOMMENDATIONS REGARDING THE REGULATORY FRAMEWORK

5.1. BETTER STATISTICS

Cooling supplies are characterised by a lack of information in Europe. The total weigh of cooling in energy consumption is much higher than estimated in the Commission's green paper on 'Energy Efficiency or Doing More with Less'. Statistics on cooling supplies should therefore be collected at European level with a view to facilitate the policy process. The same can be said about energy scenarios and modelling that lack the cold dimension.
The on-going Ecoheatcool project will provide information on the real situation of the cooling market.

5. 2. STABILITY OF LEGISLATION

In the current situation of liberalised energy markets, emphasis is put on short-term return on investments, and on low prices. This context is not favourable to energy-efficient technologies, which are more capital-intensive and need a longer return on investments. It is therefore important for operators that the regulatory framework aiming at developing energy efficiency is stable, coherent and predictable.

5. 3. GENERAL: USE OF PRIMARY RESOURCE FACTORS

Besides a stable framework, legislation should provide tools to evaluate the different market options available to produce cooling. In order to reach EU objectives, it is necessary that identical calculation, measurements and evaluation methods are used to cover all cooling options, not based on theoretical models but on operational data.

If, for instance, building-bound technologies are evaluated on theoretical values, while district cooling is evaluated by its operational figures, then most of the benefits are not taken into consideration. There is tremendous evidence that, especially for small-scale technical systems, there is a huge gap between theoretical values and the operational outcome. In this respect the use of operation-based primary resource factors (PRF) will represent a breakthrough to benchmark different cooling technologies available on the market, and enable a fair comparison of their respective energy efficiency - individual electric chillers included.

The primary resource factor[3] expresses the relation between the non-regenerative primary energy input compared to the final energy delivered to the buildings, taking into account all losses which may occur from energy extraction, transformation and transport. The advantage of such a methodology is that it takes into account all savings, and tackles the risk of measuring them only at the building level, or end-users' level. Determining the primary resource factors for different heating/cooling options implies fixed values for the different fuels and calculations based on input energy and output figures. The final results can be less than one when CHP and renewable energy are used.

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[2] Interested readers are also invited to read the position papers specifically designed for customers and energy companies.

[3] A more thorough description of how PEF work will soon be available with workpackage 3 of the ecoheatcool project that is dealing with the question of "*Guidelines for assessing the efficiency of district heating and district cooling systems*".

The Commission has mandated CEN to draft a standard on the 'performance of quality district-heating and large volume systems' in order to implement the Directive on energy performance of buildings. The standard, under approval in national bodies, foresees the use of primary energy factors and should be used for implementing all energy efficiency-related legislation.

5. 4. LABELING OF HEATING AND COOLING SYSTEMS

Recently the European Union Eco-labelling Board has undertaken activities to label water-heating systems and will start with a first product group (i.e. heat pumps). Euroheat & Power has welcomed this initiative assuming that the largest possible number of heating and cooling technologies available on the market will be covered. Such labelling will offer opportunities to promote efficient technologies if it addresses all products on the market and uses a methodology clearly measuring all savings from production to delivery to the building. In this respect, Euroheat & Power recommends the use of primary energy factors – see above.

5. 5. DIRECTIVE 2002/91/EC ON ENERGY PERFORMANCE OF BUILDINGS

The EPB Directive aims at reducing the environmental impact of the energy use for buildings. It foresees different instruments such as the setting of minimum requirements on the energy performance of new buildings and for large existing buildings that are subject to renovation (Articles 4.5 and 6); energy certification of buildings (Article 7) and inspection of boilers and air conditioning systems (Articles 8 and 9).

Article 5 sets out that for new buildings above 1000 m^2 the technical, environmental and economic feasibility of connection to a district cooling should be investigated. As above-written, Euroheat & Power deems that the standard being developed in the framework of CEN and using PEF will enable a fair assessment of the respective performance of cooling options on the market.

5.6. DRAFT DIRECTIVE ON ENERGY SERVICES

The proposal intends to promote energy efficiency through the development of a market for energy services. The Proposal's annex III gives an indicative list of energy services among which district cooling is eligible.

In the framework of this proposal, Member States will be assigned objectives in terms of reductions, likely to be measured on a project basis. The key question is how to measures these savings. If their determination is limited to the end-user level (building), a large amount of the energy chain is neglected and all savings are not factored in.

In this case, the Directive would not reap all the benefits carried out by energy-efficient solutions like district cooling. Its savings occurred well in the upstream of the delivery to the buildings and are based on efficient centralised production and use of renewables/valorisation of free inputs.

To be effective the Directive needs to be complemented by tools allowing quantifying and comparing the energy savings potential of different options. The methodology used in the EPB Directive provides a relevant and effective tool.

5. 7. SEVENTH FRAMEWORK PROGRAMME FOR RESEARCH AND TECHNOLOGICAL DEVELOPMENT

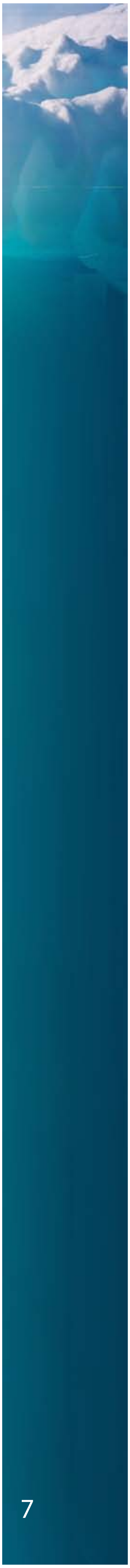
A European/international approach on research enables synergies and economy of scale. The CHP/DHC sector is acting at both international (through the electricity market) and national/local level (heat and cool market), while its societal and environmental benefits contribute to the welfare of society as a whole. However, given the local specificity of the sector, only very limited funds have been made available for research in CHP/DHC so far, although the applicability of results is, in most cases, very similar among European countries.

A proactive approach at European level would allow a faster implementation of the European Union strategies and a deeper cooperation between manufacturers acting at the European level, research institutes/universities acting at the national level and utilities at the local/municipal level.

Euroheat & Power would therefore welcome the creation of a dedicated CHP/DHC research area - tailored to the needs and possibilities of the sector - in the context of the 7th Framework Programme.

5. 8. REMOVAL OF ADMINISTRATIVE BARRIERS

Barriers exist that prevent the development of infrastructures. The development of a district network to supply cooling not only implies major investments but also authorization and licenses from public authorities to buy land, and dig pipes in the ground. These obligations do not exist for individual



technologies. Long and uncertain negotiations with authorities can prove a clear barrier for district projects. At national levels, procedure to develop infrastructure should therefore be clear, transparent and quick enough to facilitate the emergence of ambitious projects.

6. SOURCES

LEGISLATION QUOTED

- Directive 2004/8/EC on the promotion of cogeneration based on a useful heat demand in the internal energy market
- Proposal COM/2003/0739 final for a Directive on energy end-use efficiency and energy services
- Directive 2002/91/EC on the energy performance of buildings
- Directive 2003/96/EC restructuring the Community framework for the taxation of energy products and electricity
- Community guidelines on State aid for environmental protection (2001/C37/03)
- Second progress report (April 2003) "Can we meet our Kyoto targets?" on the Commission's communication COM (2001) 580 European Climate Change Programme
- Green paper COM (2005) 265 on Energy Efficiency or Doing More with Less
- Green paper COM (2000) 769 Towards a European strategy for the security of energy supply
- CEN prEN 15316-4-5 Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies - Part 4-5: Space heating generation systems, the performance and quality of district heating and large volume systems

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- www.euroheat.org/ecoheatcool/

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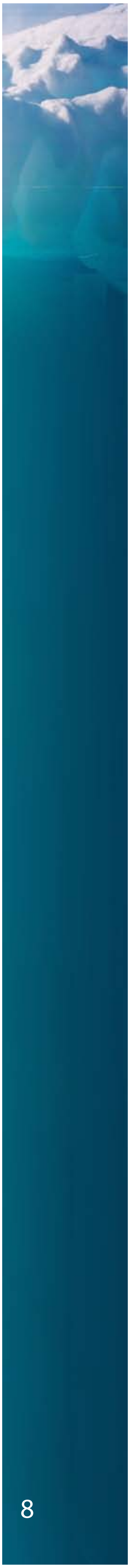
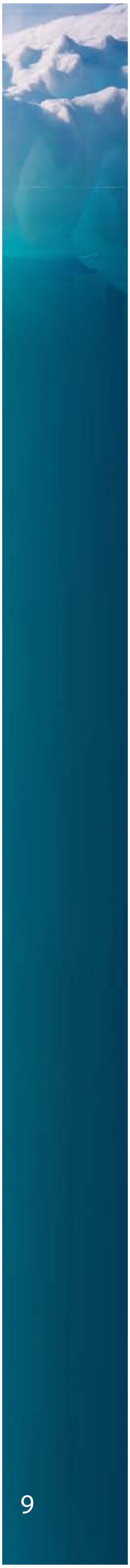




ANNEX 1 OVERVIEW OF DISTRICT COOLING TECHNOLOGIES

District cooling can be produced in different ways. The technology chosen depends on a range of parameters such as economical factors, local energy systems, natural resources available and strategy to develop the urban.

A1: 1 PRODUCTION

In the production plant, one of or a combination of the following production and storage techniques are the most common.

Combining district Heating/Cooling

"Surplus cooling" can be used from heat pumps that are originally intended for production of district heat, operating on, for instance, seawater or waste water. By connecting the cold side of the heat pumps to a district-cooling system, the heat pumps can be used for simultaneous production of heat and cold.

Absorption chillers

Absorption chillers use heat as primary energy and not electrical power as is the case for conventional compression chillers. The benefits of this technology compared to conventional chillers are that the electrical power consumption is dramatically reduced and primary energy is used more efficiently. Surplus heat from, among others, municipal waste incineration, industrial processes and power production may be used for cooling production by integration of an absorption chiller to the plant.

The cooling production can also be distributed out in local areas or buildings using the district heating system as the distributor of the waste heat to the local absorption chiller. This dependency can imply higher distribution temperatures on the district heating system during the summer. This consequence has to be deeply analysed before entering into this distributed solution.

As the heat demand is seasonal and low during summer time, cooling production through an absorption chiller enable to increase the efficiency of the plant by using excess heat that is available while displacing less environmentally friendly alternatives.

"Free cooling"

The concept refers to the extraction of available cold water. It can be compared to the use of geothermal energy in district heating systems. The cold water required to cool down buildings can be found in oceans, lakes or rivers, aquifers.

Via heat exchangers the cold is transferred to the distribution network and delivered to the customers where the cold is used in the cooling infrastructure of the building. The maximum cooling temperature delivered to customers can be guaranteed with - if needed - additional cold added from different sources.

Such a system can be developed when the water temperature is cold enough and when the plant is close to the buildings where the water is carried. The advantage of free cooling is that it offers cooling on a renewable basis.

Such schemes exist in Europe (Stockholm, Helsinki) and North America (Toronto).

Industrial chillers

High efficient industrial chillers can be added as a part of the production mix to secure outgoing temperatures and redundancy and/or for peak capacity.

A1: 2 STORAGE

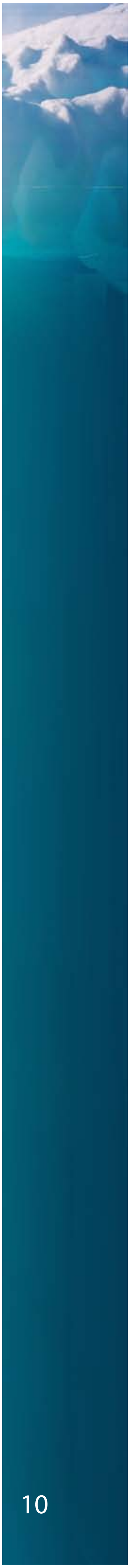
To increase the efficiency and reliability, these cooling sources and production techniques are often combined with different kinds of storage solutions, such as:

Seasonal storage

Seasonal storage, often performed as an aquifer solution, where free cooling in winter is stores for use during the summer period

Night to day storage

Night to day storage, often performed as ice or water storage solutions. Overcapacity during the night is stored for use during daytime.

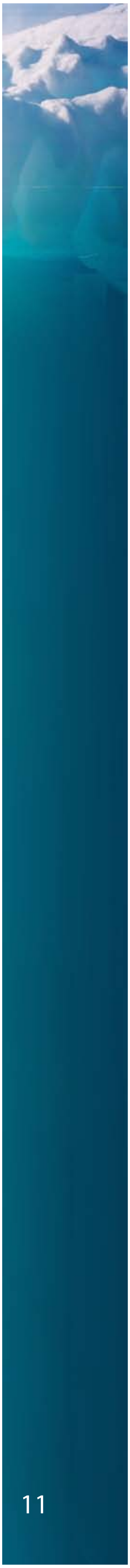


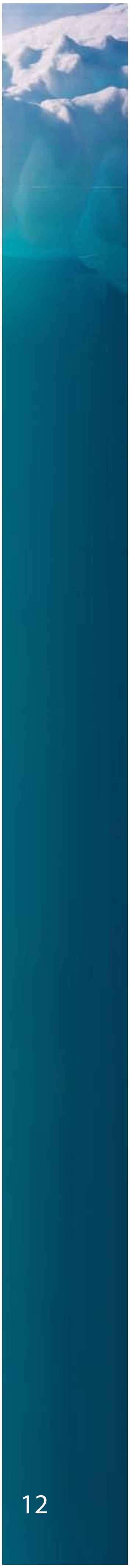
A1: 3 DISTRIBUTION

In a district-cooling network, the chilled water is distributed to buildings where it loses its cold content, thus cooling down the building temperature; the warmed up water is then returned to the central production facility. The supply temperature is normally between 6 and 7°C, but an ice mixture of 0°C is used in some cases. The typical temperature in the return pipe is 12 °C -17 °C. The supply of cooling to the user can also be done through a district heating systems coupled to absorption chillers at the user's location.

A1: 4 SUBSTATION

The customer interface or the "substation" is usually an indirect connection via a heat exchanger - the same technology as for district heating. The substation is not only the connection point and the contract boundary between the supplier and the customer but also a digital connection for measurements of the cooling delivery. This information is also used for energy services to the customer such as energy declarations, alarms and benchmarking information.





ANNEX 2 SHOWCASE OF DISTRICT COOLING SYSTEMS IN EUROPE

As described in the Position Paper there are a number of District Cooling (DC) systems. Depending on local conditions different technical solutions are used. Described below are the examples in Amsterdam, Barcelona, Helsinki, Lisbon and Stockholm. In many countries there are a number of systems. Some other good examples that are not more described in the following pages, but can be mentioned are:

- **Paris**

In Paris some of the first and also the largest European DC systems exist. In the area of La Défense, a system is operated by CPCU. In the Paris City center Climaspace operates the other large system. The technical solutions for the DC production are chiller/heat pumps and a cold water distribution network. Operation started in 1991. The sales of district cooling for these two systems are estimated to be 350 GWh each.

- **Berlin**

In Berlin, Bewag's Energy Center close to the Potsdamer Platz is serving the area with District Cooling. The chilled water is produced with 3 absorption chillers and 7 compression chillers. DC operation started in 1997. The production capacity for this plant is now 38 MW$_c$ and the DC energy sales are estimated to be 36 GWh in 2005.

For some more detailed examples see the following pages on.

A.2.1 AMSTERDAM
A.2.2 BARCELONA
A.2.3 HELSINKI
A.2.4 LISBON
A.2.5 STOCKHOLM

ANNEX 2.1 SHOWCASE OF DISTRICT COOLING SYSTEMS IN EUROPE: AMSTERDAM

Until recently District Cooling has been a well hidden secret in the Netherlands. There are at present a number of small institutional cooling systems in the Netherlands. Most of these systems are aquifer/heat-pump solutions supplying one or a few buildings but to small to be defined as large scale District Cooling. In 2003 Nuon took the decision to establish Netherlands first real large scale commercial District Cooling system in Amsterdam, in a partnership with the Swedish management company, Capital Cooling Europe (CCE). The CCE staff has earlier developed the DC business in Stockholm.

The system is under realisation in the Zuidas area. Zuidas is located along the highway A10 between Shiphol Airport and the City of Amsterdam. Zuidas is Amsterdam's International Business Hub where commercial buildings dominate the prospected areas. The largest finance corporations, international hotels, the RAI exhibition halls, VU university hospital, law firms, IT companies and WTC are among the contracted and potential customers.

An outline of the planned system that now is under construction is shown in picture A4.1.2. About 2,5 million square meters of office area is planned for in this area and is one of the most intense building areas in the Netherlands.

The first delivery of District Cooling will commence in May 2006. Nuon's first contracted District Cooling customer was ABN Amro head office, which has a peak cooling demand of 9.6 MW. The existing aquifer cooling system, which is only three years old, will now be replaced by district cooling.

Figure A2.1.1: View over the Zuidas area with ABM Amro on the left

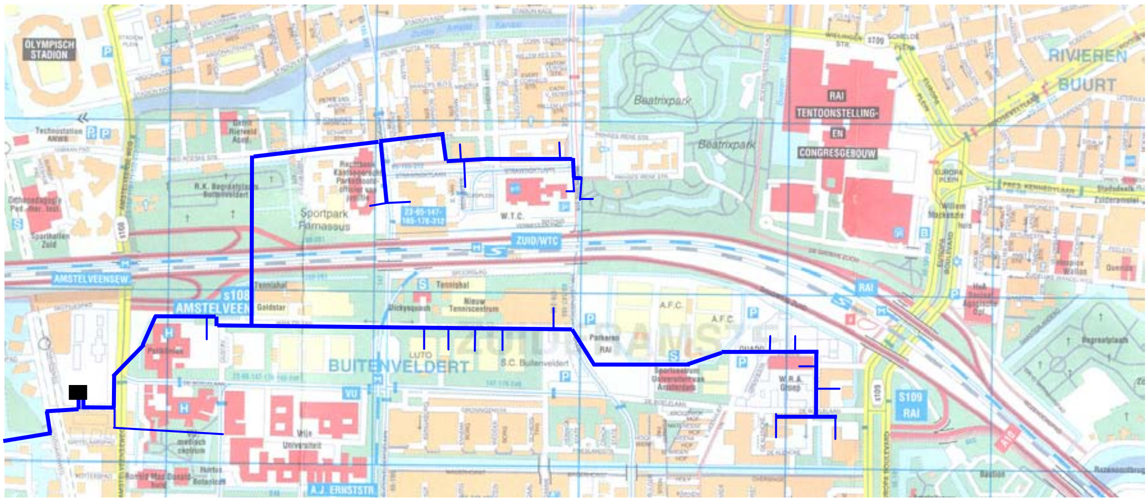
The District Cooling systems capacity is designed for a peak demand of 76 MW, which is planned to be reached 2012. The DC production will then reach 100 GWh and will be a mixture of free cooling from the bottom of Lake Neiuwe Meer and chillers.

Separate traditional chiller installations in buildings generally has a low EER (seasonal system energy efficiency ratio) of 2,5 where 1 kWh of electricity to produce 2.5 kWh of cooling and aquifer solutions can reach twice that figure. With the planned production of District Cooling in Zuidas only 1 kWh of electricity is needed for producing 10 kWh of cooling. The District Cooling will reduce 75% of the CO_2 emissions compared to conventional chillers.

The free cooling implies that cold bottom water from the Lake Neiuwe Meer will be used. The temperature at a depth of 30 m is about 5-7°C, and can be used for district cooling production. At periods when the temperature in the lake is to high chillers will adjust the distribution systems forward supply temperature to 6 °C. The return temperature from the customers will be 16°C.

Also a second District Cooling system is now also planned for in Amsterdam in the area of Bullewijk, located between Schiphol Airport and the City of Amsterdam. Here cold lake water from the Lake Ouderkerkerplas is planned for as the free cooling source. This system will be almost the equal size as the Zuidas system. This area also consists of commercial buildings such as investment banks, IT-companies, AJAX Arena and the AMC hospital. The Bullewijk system is planned to have its first DC delivery in 2007.

Figure A2.1.2: The DC system in Zuidas, Amsterdam



All district cooling customer contracts are individually negotiated. Pricing is always based on the customers alternative cost. The benefit with this market pricing is that it will only be a contract if a win-win situation is created.

ANNEX 2.2 SHOWCASE OF DISTRICT COOLING SYSTEMS IN EUROPE: BARCELONA

Over the last decade in Spain, the growth of individual systems for cooling has been very high leading to additional demand for peak electricity capacity and deterioration of urban environment. The city of Barcelona has taken the lead in the supply of an efficient supply of cooling.

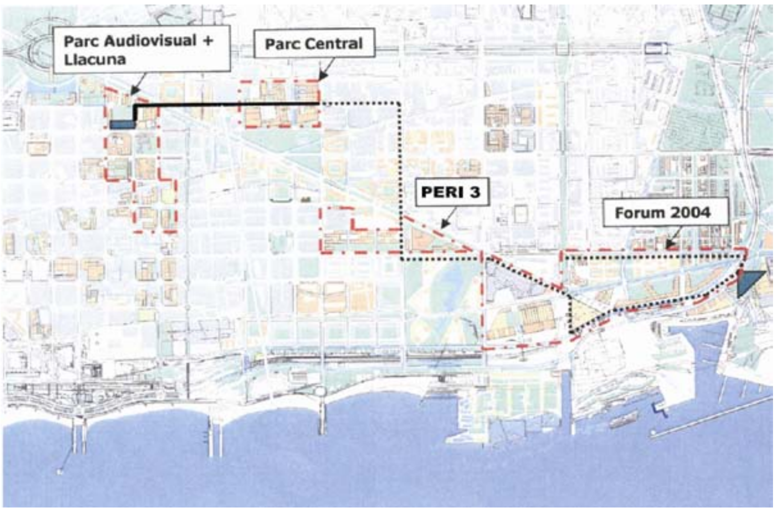
In 2002 a first system started operations in Spain, and now three successful systems are delivering cooling on a commercial basis to customers.

The biggest Spanish system is operating in Barcelona, and covers the new urban centre called Forum area, where a major international event – Universal Forum of Cultures - was held in 2004. In 1999, the City Council of Barcelona, in the frame of a strategy on urban development, realized that district heating and in particular cooling systems present important advantages:

- Improved **energy efficiency** with possible use of renewables and waste energy in district systems
- **Reduction of environmental impact** as compared to conventional air-conditioning systems. The district-cooling system enables to decrease GHG emissions, and also it improves significantly environmental and health conditions
- Creation of **added value** in terms of new services developed for modern tertiary activities (offices, hotels, information technology and other knowledge-based business) - increasing the attractiveness of the city for investors

After five years of careful planning, the first system started in 2004 to supply clients in the newly reconstructed area called Forum.

Figure A2.2: Expansion of the district-cooling system from Forum area to the new 22@ technological district in Barcelona



The system, initially formed by a 5-km network, 17 MW cooling production capacity and 5000 m3 storage, started to supply 5 clients who contracted around 16,5 MW. The main source of energy is steam generated in the solid urban waste treatment plant, located next to the installations. The cooling business is run by Districlima whose main shareholders are ELIO IBERICA-SUEZ, AGBAR and TERSA.

After the start of commercial operation in March 2004, the system supplied 16.018 MWh cooling and 5.345 MWh heating energy, cutting primary energy consumption by 30% and GHG emissions by 31% (more than 1.400 t CO_{2eq} in 2004).

Several factors influenced the positive development of district cooling in Barcelona, but the most important ones were:

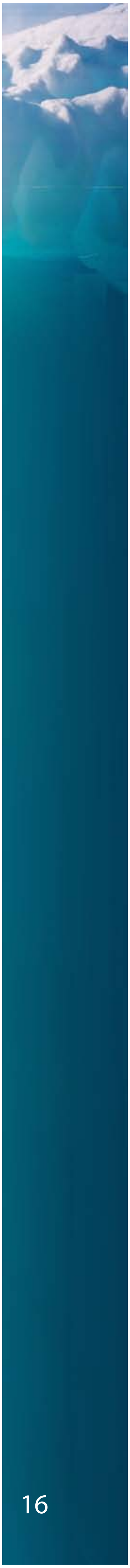
- Commitment of the local authorities for the creation of a completely new market - decisive to convince the first new customers to connect
- Comprehensive city planning, to integrate energy infrastructure in the design of new city areas
- Dense area with a lot of new tertiary buildings with an important cooling demand forming the 'critical mass' for the project
- Public-private partnership formed around the project. Good coordination of the planning process between all involved parties

It did not take long for building managers to understand the numerous advantages of DC. New clients joined just after the launch of the system. In late 2004 the network began to expand to the Forum neighbourhoods, mainly to the new technological district called 22@. Furthermore, the district system for 22@ was the object of deep analysis and negotiations between public and private parties from year 1999. So, after the initial success of the Forum DC system, the City Council decided to speed up the implementation of the DC in 22@ technological district.

In spring 2005, Districlima won the concession to supply the whole district 22@. As a result, the new production capacity already under construction is expected to reach 50 MW plus an equivalent of 26 MW in storage capacity in 2010. The expansion is based on the growth of the capacity in Forum DC central, but soon also in a new satellite central within 22@ district. The expected demand for 2010 is over 100 MW contracted capacity.

Spin-off effects of the first big DC system built in Spain:

- One of the biggest Spanish energy utilities, Gas Natural, is presently projecting a DHC system for a tertiary area in the Barceloneta district, in Barcelona
- A huge project in the South-West part of the city of Barcelona is under evaluation by the City Council. This project is linked to the use of a great amount of low temperature waste energy presently dissipated to the sea by the liquid natural gas re-gasing plant in the Barcelona Harbour. Within a radius of 4 km there is an industrial area and tertiary sector with a great number of potential consumers
- DHC system integrated in the new urban development in EXPO 2008 site in Zaragoza
- Studies for new developments in Sagrera area in Barcelona



ANNEX 2.3 SHOWCASE OF DISTRICT COOLING SYSTEMS IN EUROPE: HELSINKI

District Cooling (DC) customers in Helsinki include business- and office buildings, hotels and shopping centers. The first residential buildings will also be connected to the DC network in a few years. Both existing and new buildings are district cooling customers. When delivered to the customers, the DC water temperature is +8°C. The temperature of returning cooling water is +16°C.

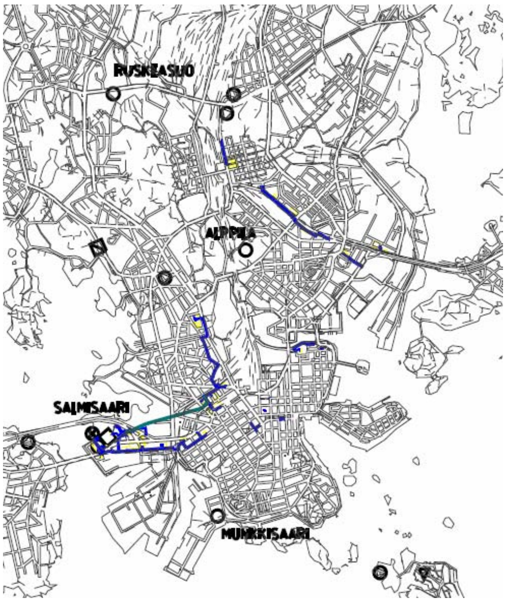
An ever-increasing number of business buildings need District Cooling all year round. Powerful lighting, people and ADP equipment as well as solar heat all increase the indoor temperature. Cooling has become all year round even in the Finnish climate.

Figure A2.3.1: View of Helsinki center

Building owners also recognise the effect of indoor air quality on working efficiency and comfort e.g. in offices and shops. Cooling of ventilation air has become frequent so that cooling is automatically being installed to nearly all new business premises. Furthermore, ventilation air cooling is usually installed to existing buildings in connection with larger renovations.

As compared to building-specific solutions, District Cooling has proved to be a competitive alternative to compressor chillers and cooling towers by its price and technical solutions. Building owners in Helsinki want to concentrate on their core business areas, which do not include investing in individual energy production or continuous maintenance of such equipment. Changes in the electricity market prices, restrictions to the use of cooling refrigerants, uncertainties about future taxes and other legislation factors make District Cooling an attractive alternative. With District Cooling the long term cooling costs are predictable and stable, which is also an important asset.

Figure A2.3.2: Map of network



By the end of 2005, the total connection power of buildings in the district-cooling network will be approx. 32 MW and the number of connections about 37. The connected customer load of DC varies between 25-3400 kW. The annual energy consumption of Helsinki Energy's DC customers is divided so that 1/3 of the total consumption is during the six coldest months of the year and 2/3 during the six warmest months. The peak load of District Cooling consumption is normally between 1:00-4:00 pm.

District Cooling customers typically choose their cooling capacity 15-25% lower compared to the defined capacity of alternative building specific cooling systems. If more cooling energy is later needed, increasing the capacity is agreed upon between the customer and Helsinki Energy.
The District Cooling is distributed from Salmisaari cooling centres to the customers in Ruoholahti, Kamppi and Töölö

suburbs via underground pipelines built under streets and in tunnels. In summer 2006, also the District Cooling customers (office- and business buildings, hotels) in Kaartinkaupunki and Kluuvi areas will be connected to the new distribution network. Since the beginning of 2003 District Cooling has been distributed to office buildings in Hermanni, Vallila, Sörnäinen and Pasila areas by using transportable cooling units. In summer 2006 these areas will be connected through distribution network to the large cooling centres.

The DC grid have large diameters; the inner diameter of the network main pipelines is between 400-800 mm. Implementing such pipelines under streets is challenging, slow and expensive. Building is especially difficult in the Kaartinkaupunki, Kluuvi and Kruununhaka areas. A new four-kilometre Kamppi-Erottaja-Kruununhaka multi-utility service tunnel is being built at the moment. When it is ready, it will enable the building of District Cooling distribution network all the way to the business- and office building quarters in the city centre.

The DC centres operate 24 hours a day and 365 days a year. Cooling energy production reliability has been ensured by using different, alternative production methods and by making the network looped. According to gained experiences, the distribution reliability of District Cooling equals the reliability of district heating. A centralised production method brings operational reliability with the expanding distribution network and several production units located around the city

Helsinki Energy's primary method of producing cooling energy is with seawater. During a period of about six months the sea water is cold enough to directly provide the needed cooling energy through heat exchangers and pumps. Sea water is a renewable source of cooling energy. When the sea- water temperature rises in the spring, District Cooling is produced mechanically.

Figure A2.3.3: Installations of Helsinki Energy

Helsinki Energy produces electricity by combined production. In the winter, all the heat gained from electricity production is used as district heating. In the summer, this heat is not entirely needed for district heating. By using absorption technique, this excess heat can be used for producing cooling energy. In the absorption processes, sea water is used for re-cooling. Helsinki Energy now has three absorption chiller centres for District Cooling production. The first DC pilot plant was established in 1998 and is located in Pitäjänmäki, and has a cooling capacity of 1.2 MW. A 10 MW cooling centre was established in 2001 and is located in Salmisaari, where also a new 35 MW plant will be fully taken into operation in spring 2006. The Salmisaari cooling plant has in total ten 3.5 MW absorption chillers and two compressor chillers. The heat source for the absorption technique is +85°C district heating water.

Helsinki Energy also has nine transportable cooling units, which enable a quick launch of cooling services in a totally new customer area. As soon as the final pipe connection is built from the district cooling centre to the customer, the cooling unit is moved to a new location. The cooling units that Helsinki Energy has have a cooling capacity between 400-1500 kW. At the moment, Helsinki Energy is building the world's largest combined district heating and -cooling production facility using cleaned waste water as heat source. The district cooling capacity of the facility is 60 MW and district heating capacity 90 MW. This heat pump facility is located underneath Katri Vala Park and it will be taken into commercial use in summer 2006. The facility will be mainly in district heating production, and in summertime it is used in normal load District Cooling production together with the absorption chiller centres. In the future, cooling energy will also be produced in large compressor chiller centres. The technique is at its best in peak load and backup power production. The centres will be operated to cut down the peak load energy demand and to re-cool the cooling water reserves. Cooling water reserves provide flexibility for cooling energy production. At the moment, Helsinki Energy has one 1000 m3 cooling water storage in Salmisaari and in total 300 m3 storage in Pitäjänmäki. New 10000 m3 cooling water storage are planned to be built in Salmisaari, Hanasaari and in connection to the shared use service tunnels. The water storage is cooled during the night when the cooling consumption is lower. The stotragees enable operating the coolers at maximum effective 100% drive. The stored water cooling energy is then used during the next day peak load hours.

The interest of building owners towards District Cooling has increased steadily. The reason behind the popularity is the ecological friendliness and cost-effectiveness of the system as compared to conventional compressor technique. District Cooling will be the primary cooling solution in Helsinki Energy's customer areas.

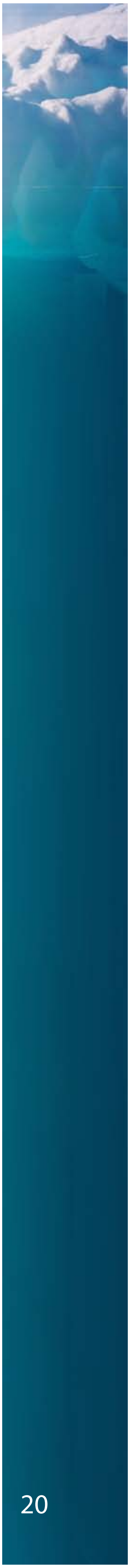
According to future plans, the total connection capacity of district cooled buildings is estimated to exceed 100 MW by 2010 and 250 MW by 2020. By then the number of DC customers will exceed 300. At the moment, contracts are being made with customers to be connected to the DC network in 2007-2010. In 2020, the length of DC network in operation will be about 100 km. During the next few years, building the distribution networks will be visible in the street scene as the cooling centres will mainly be located in underground premises excavated in the bedrock. During 2005, the DC distribution network will expand in total by 8 kilometres, half of which is located in shared use service tunnels. By the end of the year the total length of the DC network will be 16 km. During the following 2-3 years, the network will expand by 7-10 km per year. Building the DC network is based on a detailed general plan of future situations in 2010, 2015 and 2020. The distribution network is dimensioned and built according to this general plan.

Compared to conventional building-specific solutions, environmental friendliness is the most important trend steering Helsinki Energy's development of District Cooling. Providing DC increases the ecological efficiency of Helsinki Energy's combined heat and power production. Until recent years, there was no alternative to the conventional building-specific cooling solutions, but now, District Cooling now can provide one alternative to those areas where construction is feasible. Due to the costs of first investments, building cooling centres and the continuous expanding of district cooling network the payback time of investments is fairly long.

ANNEX 2.4 SHOWCASE OF DISTRICT COOLING SYSTEMS IN EUROPE: LISBON

In 1998, the main city of Portugal was hosting the World Expo. It was an opportunity for the country to modernise the main infrastructures of Lisbon and develop a project of urban regeneration. A new area was created to host the exhibition and then to serve as a new business area covering 500.000 m2. The area was designed to reach a balance between offices, residential buildings, and tertiary activities; parks and modern public means of transportation were also designed.

Figure A2.4: World Expo area in Lisbon. (Photo by Anders Tvärne, Capital Cooling Europe)



For energy supplies, the ambition was to cover the thermal needs of the exhibition site with intelligent and efficient technologies. Climaespaco won a call for tender to develop a project and exploit energy installations for a period of 25 years under a concession contract with the city of Lisbon.

The production plant is a trigeneration plant. This means that heat, cold and electricity. The absorption chillers are driven by waste heat from the electricity production in the gas turbine.

In 1998, the installed capacity was 40 MW cooling, 23 MW heat and 5 MW electricity. A foreseen expansion to 60 MW district cooling and 44 MW district heating.

The trigeneration plant is composed of the following items:
- A 4.8 MW_e gas turbine
- Two absorption chillers of 2x5.1 MW_c
- Two compressor chillers with ammonia as refrigerant of 2x5.8 MW_c
- A heat recovery boiler 12 MW_{th} and an auxiliary boiler 15 MW_{th}
- A cold water storage tank 15 000 m^3,
- Plus a district heating network
- Plus a district cooling network.

The network supplies an area of 330 ha at the south-east of the city, along the river Tagus. Around 70 buildings are connected to the network and supplied with cooling and heating.

The trigeneration expects to reach a saving of annual 6000 tonnes equivalent oil. This is representing a 45% reduction compared to separate productions of electricity, heat and cooling. In terms of emissions, 20.000 tonnes CO2 a year, 250 tons of NOx and 300 tons of SO2 will be avoided annually. In comparison with offices using a conventional system, energy consumption for heating, cooling and electricity for lighting and equipment needs is expected to be reduced from 248KWh/m2 to 51 KWh/m2. The total reduction of CO2 is about 70%. It should be mentioned that the refrigerants, CFC and HCFC are now also are phased out.

ANNEX 2.5 SHOWCASE OF DISTRICT COOLING SYTEMS IN EUROPE: STOCKHOLM

Starting in Sweden in the early 1990's, District Cooling (DC) has had a rapid development. Today, District Cooling production in Sweden has grown to the same size as the production of the much older product wind power. But there is a very important difference: Unlike wind power, District Cooling has been successfully established without any subsidies! The cooling business in Stockholm is run by the energy corporation Fortum and alone accounts for about half of the national supply. 7 000 000 square meters of commercial area in the Swedish Capital are supplied with District Cooling via the cooling distribution network, that is currently 76 kilometer-long.

Figure A2.5.1: Stockholm City

DC operations in Stockholm started in 1994. The market responded positively - partly because of the political decision to phase out CFC and HCFC-based products that are extremely aggressive to the ozone layer. It may appear strange that large-scale District Cooling has had a flying start in northern Europe, where the need for cooling reasonably is less than on the southern Europe. One conceivable explanation is that property owners are used, since 50 years back, to buying heat from large District Heating systems.

When launching a new product, the paramount achievement is to create confidence among customers - actual and potential. Market success is founded on a couple of very clear advantages for District Cooling:

- new price products and services based on customer demand and willingness to pay
- District Cooling has been presented to - and appreciated by - customers as easy to operate, reliable, economical and environmentally friendly
- it is an uncomplicated and easily maintained product - property owners just purchase cooling instead of being responsible for complicated machinery
- over its total operating time, District Cooling has reached a reliability level exceeding 99.7 per cent
- advantage of economy with competitive market prices free from public interventions, long contract periods and reduced investments for customers. Individual contracts are based on alternative prices and are often combined with District Heating contracts.
- system flexibility makes it possible to adjust cooling capacity to varying demands without having to invest in over-dimensioned equipment.
- fast adjustments of delivery capacity facilitates keeping and/or acquiring tenants
- the environmental superiority is a good door-opener to customers and the media. During the decade of District Cooling's existence in Stockholm, emissions of CFC and HCFC have dropped by more than 60 metric tons. CO_2-emissions from conventional cooling is 280 g/kWh as compared to 60 g/kWh from Stockholm District Cooling
- noise is radically reduced when individual cooling equipment is removed and releases space in customer property. One brilliant example is the recent development project for commercial real estate in downtown Stockholm. By connecting to District Cooling and removing large cooling

installations on the flat roofs, space was created for constructing the City's most central, attractive apartments as penthouses with an excellent view!

- public economy benefits from more efficient use of especially the electricity supply infrastructure. As shown above, there are great economic advantages in avoiding additional electricity supply for cooling, which is ensured by District Cooling.

When District Cooling in Stockholm was launched, strong demand was expected. Indeed, growth has been faster than expected, which led to a temporary stop in sales last year due to the lack of production capacity. Fortum has now resolved that situation by connecting two DC systems and building new production capacity.

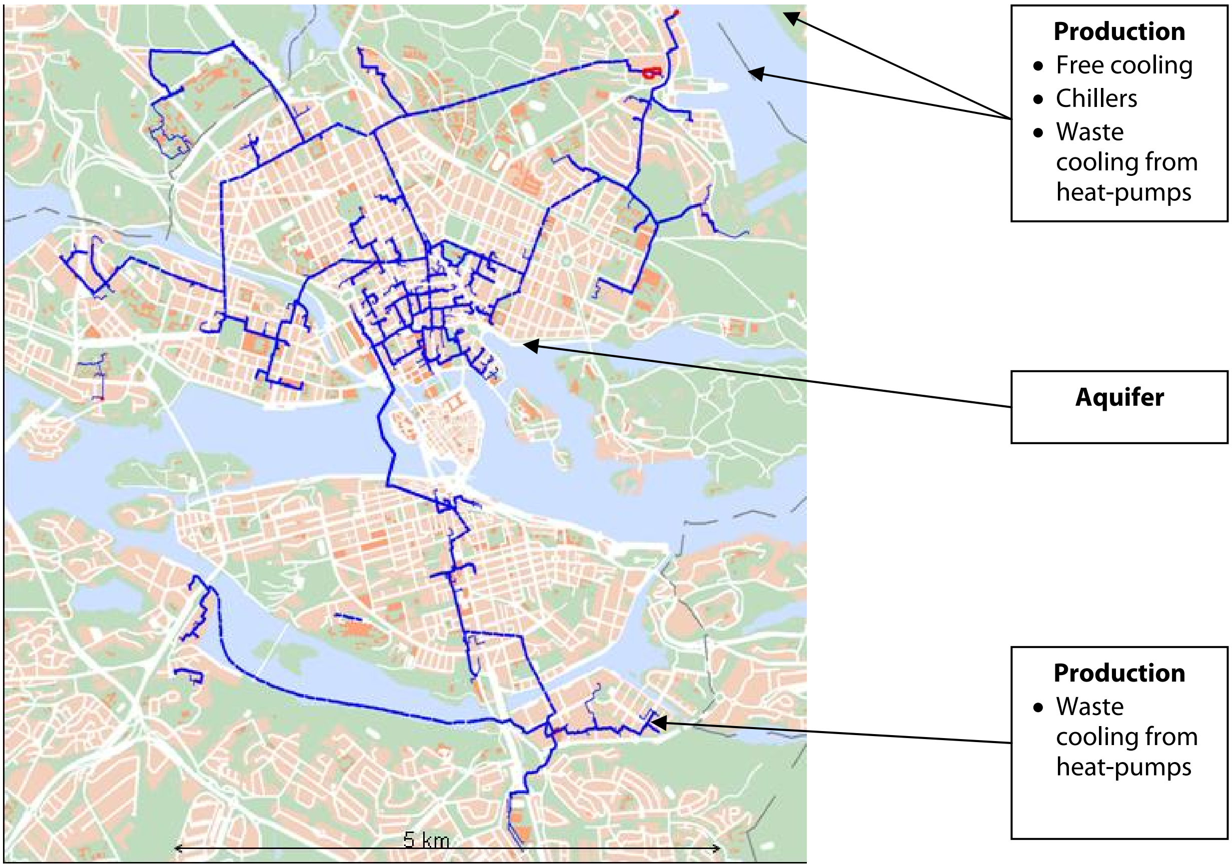
One pleasing surprise is that the utilization period has turned out to be significantly longer than expected. Cooling is necessary not only because of warm weather, but to approximately 50 % due to the all year round need for process cooling of computers, refrigerating/freezing equipments etcetera.

In systems with summer electricity peaks, the electricity savings provided by District Cooling have full impact. The Stockholm example shows that also in systems with winter electricity peaks, District Cooling gives a sizable reduction.

Fortum presently sells 500 GWh of district cooling per annum. If that cooling had been produced conventionally, it had required five times more electric energy. That is to say that District Cooling means an 80 % reduction of the electricity requirement for cooling.

The Stockholm scheme consists of today of different systems raging from 3 MW to 228 MW.
The largest system is today the DC system for the central parts of Stockholm. 228MW of DC in customer connections is now integrated from earlier several smaller and temporary systems.

Figure A2.5.2: The Stockholm City DC system

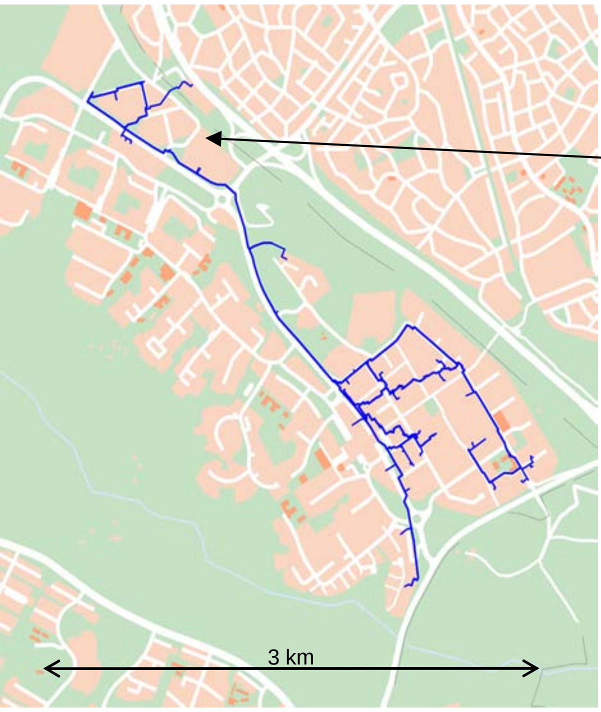


Production
- Free cooling
- Chillers
- Waste cooling from heat-pumps

Aquifer

Production
- Waste cooling from heat-pumps

Figure A2.5.3: The second largest Stockholm system, the Kista system, designed for 50 MW



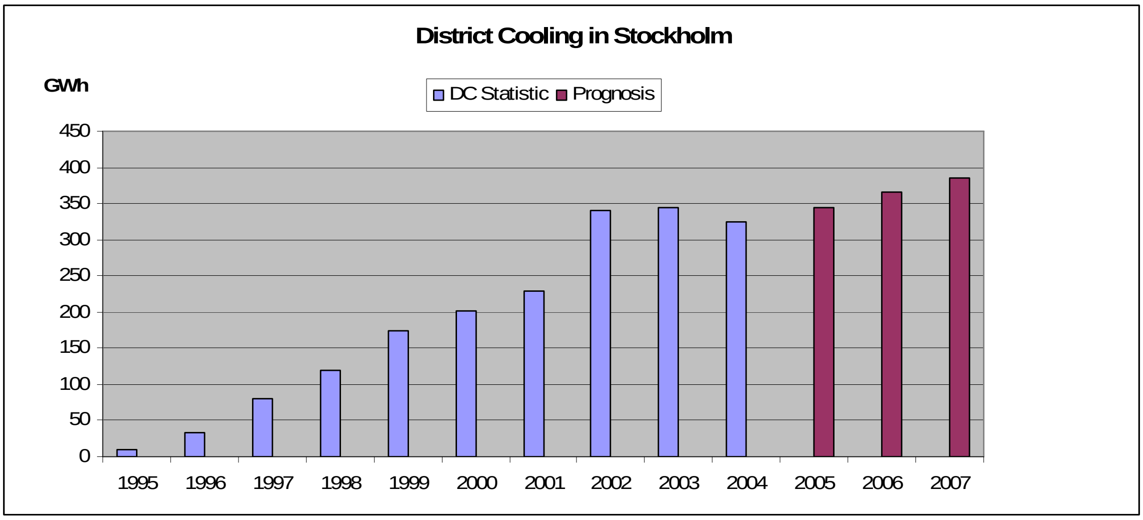
Production
- Chiller
- Heat-pumps
- Option free cooling

DATA :

Production capacity in:
The Central network: 188 MW
The Kista network: 41 MW
Skärholmen Mall: 10 MW
Infra City: 9 MW
Danderyd Mall: 3MW
Farsta Mall: 3 MW
Älvsjö: 5 MW
Marieberg: 4 MW
Nacka Forum: 3,5 MW

- Number of customers exceeds 500.
- DC grid, pipe length: 76 km.
- Supplied commercial area 7 000 000 square meter.

Figure A2.5.4: Development of the DC systems in Stockholm.



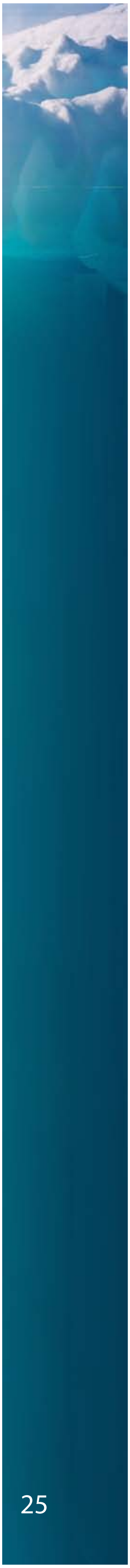
ANNEX 3 DISTRICT COOLING AS AN ENERGY SERVICE: BENEFITS FOR CUSTOMERS

District cooling has some selling points that are of great interest to propriety owners:

Examples are:
- **More economical way of cooling due to:**
  - Less expensive in exploitation than alternatives, like compression cooling
  - Less price risks compared to alternatives.
  - Clear cost profile, no 'hidden costs'
  - Care free service with a very high reliability
- **Fits well into Corporate Social Responsibility (CSR) policy:**
  - Highly energy efficient cooling production
  - Often cooling from sustainable sources
  - Contributes to improved local environment: Architectural freedom and quality; taking away noise from cooling towers; no use of cooling agents (chemicals) at the premises); contribute to lower the urban heat island effect.
  - No sanitary risk – e.g. legionella.
- **Improved value for the cooled building:**
  - Flexible adjustment of supply to demand, both comfort cooling and process cooling
  - Floor-space saving
  - No use of cooling agents (chemicals) at the customers' site and thereby giving a solution for replacement of phased-out CFC/HCFC in cooling systems.
  - No noise and water consumption, lower electrical transformer.
  - Respect of the integrity of the building (historical architecture)

ANNEX 4 DISTRICT COOLING AS AN ENERGY SERVICE: BENEFITS FOR ENERGY COMPANIES

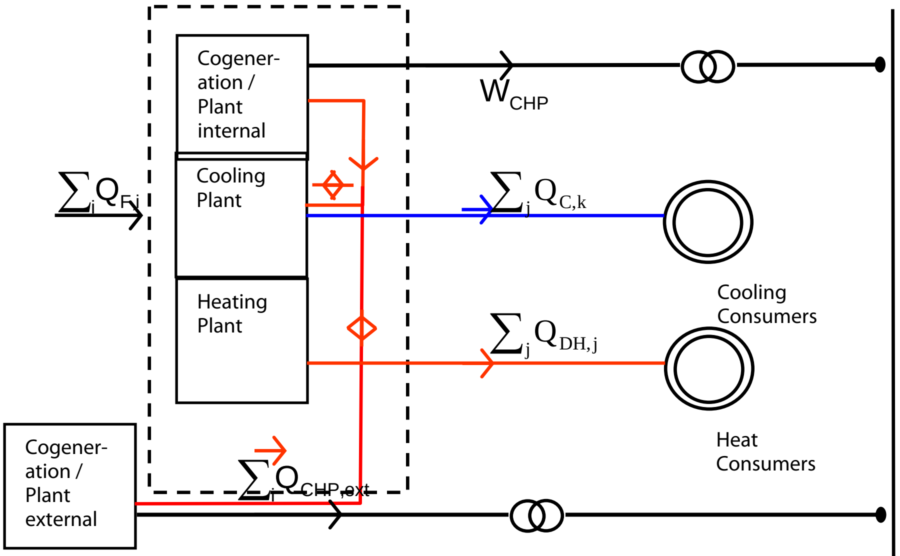
Attractive features of district cooling for companies are:
- **Good business from a economic approach, especially for companies that operate** electrical grids as well as it is reducing electrical power needs
- **Fits perfectly into Corporate Social Responsibility (CSR) policy:**
  - Highly energy efficient cooling production
  - Link to use of sustainable sources
  - Contribute to improved local environment (architectural freedom and quality; taking away noise from cooling towers; No use of cooling refrigerants (chemicals) at the premises).
- **An innovative service to attract an bind new and existing customers:**
  - Flexible adjustment of supply to demand, both comfort cooling and process cooling
  - Lowering the risks that are involved in the electricity price
  - Care free service with a very high reliability



ANNEX 5 PRIMARY RESOURCE FACTORS FOR DISTRICT-COOLING SYSTEM

The calculations for the production of cooling are done in a similar way to that of heating. The same system borders apply for the three products that are cooling, heating and electricity.

Picture A2.1: System borders for the different products



Both district heating and cooling products have their own primary energy factors. Before the calculation of primary resource factor for district cooling system, the fuels of district heating shall be determined. The formula of PRF for district heating system is the following:

$$f_{P,DH} = \frac{\sum_i Q_{F,DH} \cdot f_{P,f} - W_{CHP} \cdot f_{P,elt}}{\sum_j Q_{DH,j}}$$

$f_{P,f}$ = Primary resource factor of the fuel input to the district-heating system

$f_{P,elt}$ = Primary resource factor for electricity

W_{CHP} = Electricity production of the cogeneration plants of the considered system

$\sum_i Q_{F,DH}$ = Fuels of district heating system (including fuels of district heat and CHP electricity)

$\sum_j Q_{DH,j}$ = Heat energy consumption measured at the primary side of customer's substations

W_{CHP} = Electricity production of the cogeneration plants of the considered system.

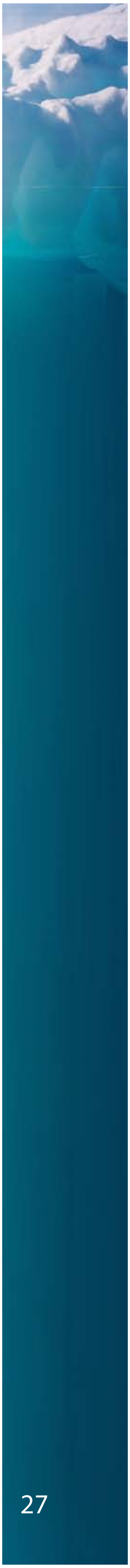
All the fuels that are not specifically used for district cooling production are the fuels of district heating. Absorption chillers are using as input energy the heat produced in the installations. The formula needed for the calculation of district cooling system is therefore the following:

$$f_{P,DC} = \frac{\sum_i Q_{F,i} \cdot f_{P,f} - W_{CHP} \cdot f_{P,elt} - \sum_j Q_{DH,j} \cdot f_{P,DH}}{\sum_k Q_{DC,k}}$$

$\sum_i Q_{F,i}$ = Total fuel input to considered system (Including fuels of DH, DC and CHP electricity)

$\sum_j Q_{DC,k}$ = Cooling energy consumption measured at the primary side of customer's substations

For the production of cooling based on a sustainable use of natural resources such as deep cold sea/lake water, a value of 0.07 should apply to reflect the renewable feature of the supply.



ANNEX 6 ANALYSING COOLING MACHINES IN BUILDINGS

Cooling machines in buildings are analysed in four real case studies. COP (Coefficient of Performance) of chillers and total COP with auxiliary devices are analysed as well as COP as a function of load factor. The efficiency of cooling process, running time of the chiller and nominal consumption of the building during annual cooling period was also analysed. Designed cooling capacity in buildings varied 5 – 20 W/m^3. Lack of the cooling capacity existed in buildings with the lowest designed cooling capacity during two years period 2002 – 2003. COP of the cooling machines varied 2.1 – 5.6 and the total COP (or seasonal system energy efficiency ration, EER) of the cooling system were 0.7 – 2.4.

A cooling machine process consists of a compressor, expansion valve, evaporator and condenser, through which a working fluid runs. Evaporating is endothermic and condensing exothermic process. HCF, CFC and HCFC are used in working fluid as well as hydrocarbon, ammonium and carbon dioxide.

Cooling machines work round the year in office and business buildings. The temperature of condensed liquid is 35 – 45 °C. COP for the cooling machine is defined

$$COP = \frac{\Phi}{P},$$

where Φ is a cooling effect and P is a needed power.

The condensed thermal energy from compressor machine is transported through liquid circle and cooled with outdoor temperature air. Thermal effect in condenser circle can be written

$$\Phi_l = \frac{(1 + COP) \cdot \Phi}{COP},$$

The theoretical efficiency of the cooling machine is described with Carnot efficiency

$$\eta = \frac{T_h}{T_l - T_h} \quad ,$$

where T_h is a temperature in evaporator and T_l is a temperature in condenser. Increasing temperature in condenser and decreasing temperature in evaporator will decrease the efficiency of the cooling machine.

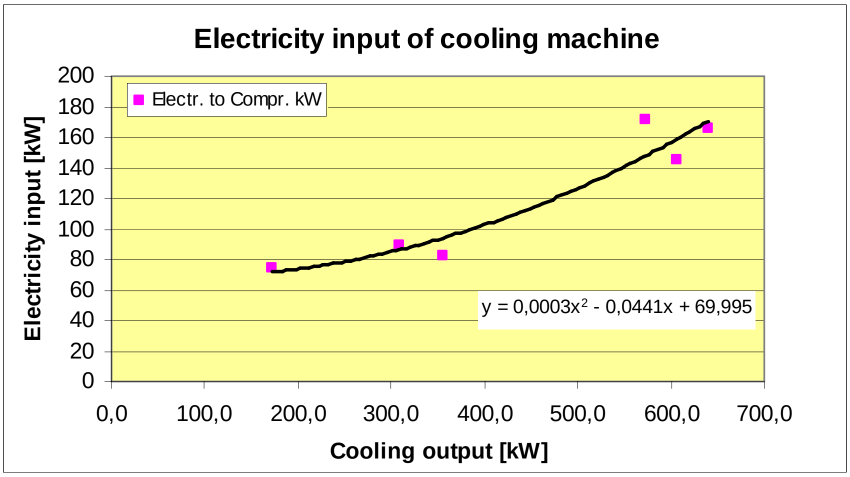
Driving and energy cost

Input power as a function of cooling effect for the compressor machine is shown in picture A3.1. The values are informed by manufactures. Annual consumption of electricity can be evaluated based on annual utilisation time with maximum peak load.

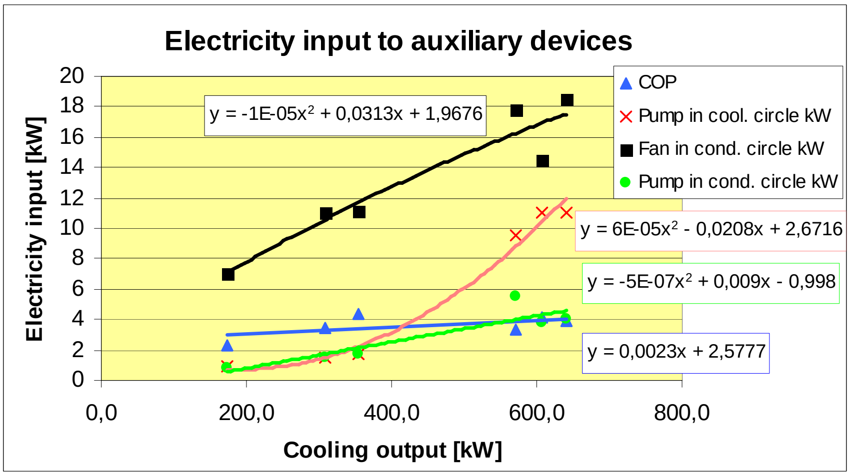
Power of auxiliary devices is shown as a function of cooling effect in

Picture **A3.2**. Input power for fans in cooling radiators is changing compared to cooling capacity of the chiller. COP varies 3 – 4 in the figure.

The total COP of the cooling system is evaluated when electric input to all the auxiliary devices are taken account in addition to input electricity of the chiller. The total COP is net output cooling effect divided by total electricity input of chiller with auxiliary devices. In case studies the total COP seems to be much less than COP of the chiller itself.



Picture A3.1. Power in cooling compressor.



Picture A3.2. Auxiliary devices of cooling machine as a function of output cooling effect.

Input power for fans in air-cooled radiator is about 0.03 kW_e/kW_c in liquid circle. A wet surface radiator can be designed about half of that size compared to the air-cooled radiator. The wet surface radiator cannot be used in winter. Used amount of water is 4 – 5 l/h, kW_c. Water spray cooled radiator is used when the cooling capacity is increased during peak cooling load. Used amount of water is 2 – 3 l/h,kW_c and the increased cooling effect is 15 – 20 %.

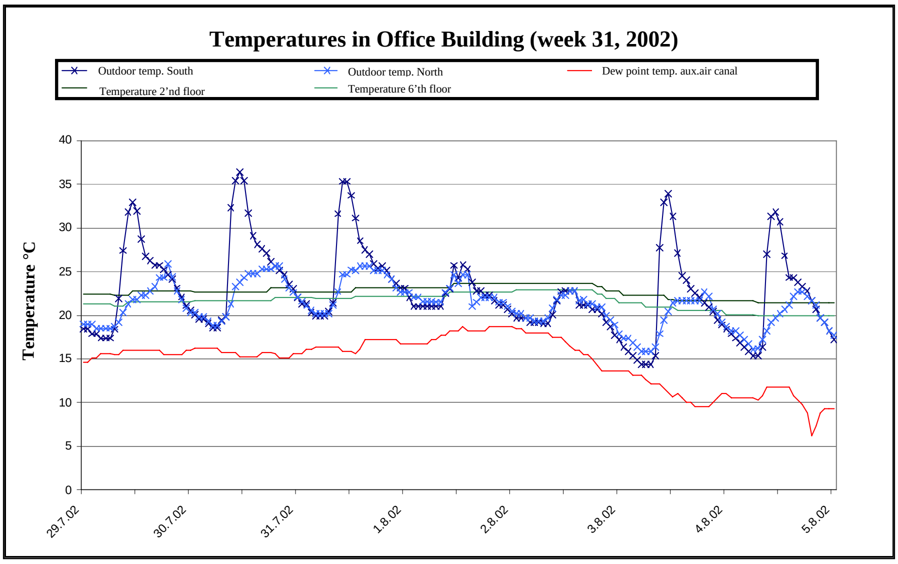
Measurements in case studies

Cooling systems in buildings are not normally equipped with the measurement system, which could be make possible to analyse effectiveness of the cooling energy production. Case study cooling systems were equipped with instruments for measuring and collecting data to analyse the cooling systems by VTT. The measuring period was two years without any remarkable disturbances.

Case study measurements of the cooling system in an office building

The office building had one of the best running cooling system. A week period in 2002 is presented and analysed as an example. The week 31 was warm and outdoor temperature was more 20°C in several days.

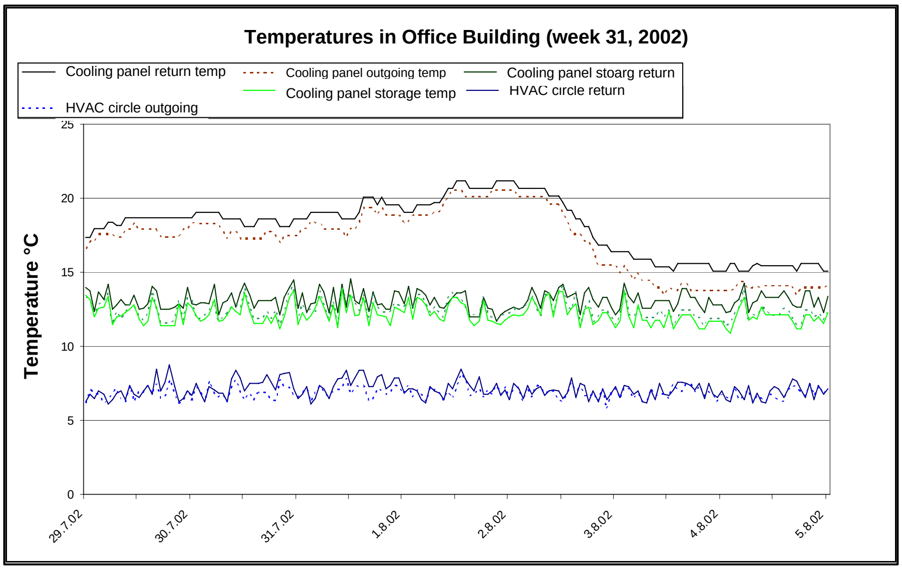
The hot weather limit was reached during three days. The outdoor temperatures in northern and southern side of the building are shown in Picture A3.3. Indoor temperatures in the 2'nd and 6'th floor are presented also in the figure. We see that the cooling system has worked well. A dew point temperature is measured to be 7 – 18°C in exhaust air canal and is also presented in the figure.



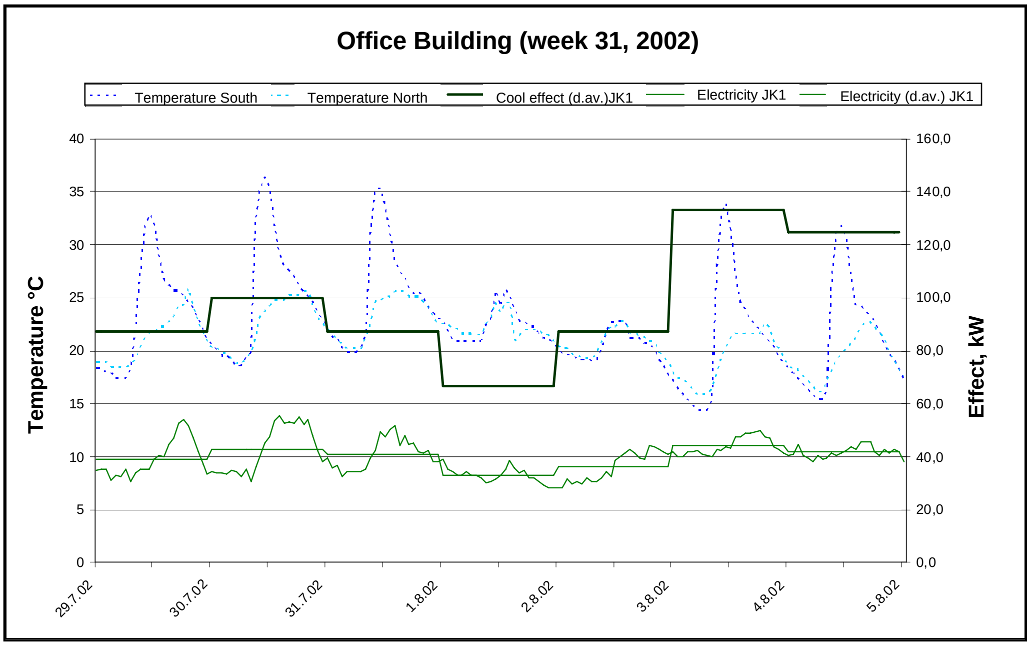
Picture A3.3. Indoor and outdoor temperatures and dew point temperature of the office building during the week 31 in 2002.

Outgoing and return temperatures in the cooling panel network are presented in Figure A3.4. The temperatures before and after the accumulator tank and HVAC system circle are presented also. The cooling machine 1 (JK1) supplies the cooling panel circle. The outgoing temperature varies 12 – 14 °C and return temperature rises 0 – 2 °C. The cooling machine 2 (JK2) supplies the HVAC circle and outgoing temperature is 6 – 8°C and the return temperature rises 0 – 2°C.

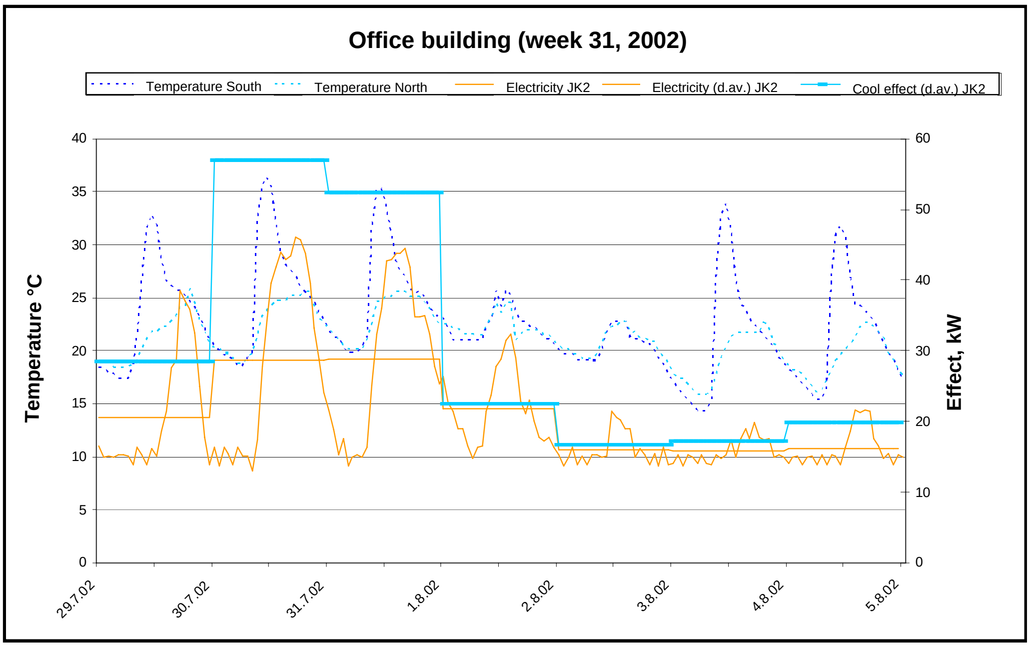
Picture A3.4: Temperatures in cooled element circle (JK1) and in HVAC circle (JK2)



The output cooling energy and supplied electricity were measured in both cooling circles. Hourly input electric power, daily average electric power and cooling output are presented in picture A3.5. The values of JK2 are presented in picture 6.

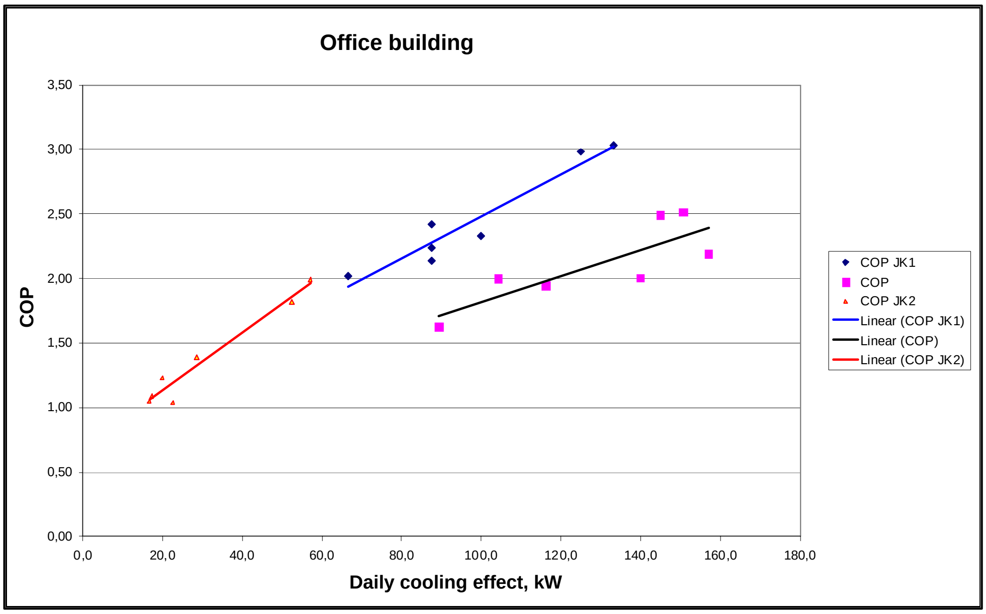


Picture A3.5: Cooling from JK1 in the week 31.

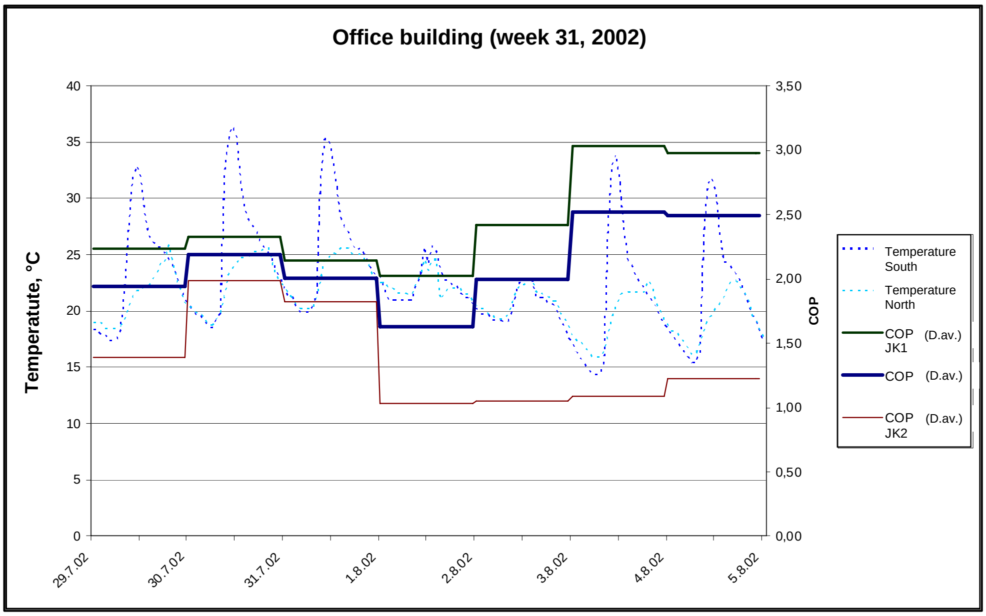


Picture A3.6: Cooling from JK2 in the week 31

Daily values of COP to both the machines are presented in Picture A3.7. COP for the whole cooling system varies 1.6 – 2.5 and weekly average value is 2.12. The lowest value appears on Thursday, when both the machines were in low load. The highest COP appears when most of the cooling can be produced in cooling panel circle. COP values are presented also as a function of cooling output in Picture 8. As a result of the case studies it was noticed that the COP of the cooling machines are less than expected. Total COP of the cooling system including also auxiliary devices of the cooling machine are about 30 – 50 % less than COP of the compressor itself. Also temperature difference ΔT between outgoing and return pipes in cooling circle might be only 0 – 2°C instead of ΔT 5 – 8°C, which it is expected to be. These facts mean that cooling energy cost is higher than expected based on COP of the cooling compressor.



Picture A3.7: COP of the machines JK1 and JK2



Picture A3.8: COP as a function of output from JK1 and JK2 and also total COP of JK1+JK2

References

Kari Sipilä, Aulis Ranne, Juhani Aaltonen. 2004. Kiinteistökohtaisen jäähdytyksen tuotanto kustannukset (Analysing Cooling Production Cost in Buildings), Osat 1 - 3 (in Finnish).126 s. total