

DISTRICT HEAT DRIVEN ABSORPTION COOLING OF DISTRICT COOLING PLANTS IN TRONDHEIM, NORWAY

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Abstract: In 2003, Trondheim Energi Fjernvarme AS started to deliver district cooling at St. Olavs Hospital, which is a new University hospital in Mid Norway. Stage one of the district cooling plant consists of one 3 MW absorption chiller and two compressor chillers. The total cooling capacity is 7 MW.

In 2007, the new hospital buildings covered 100 000 m² floor area. The annual cooling load was 6 600 MWh, where 67% was covered by "free cooling" from river water, and 30% was covered by the absorption chiller. During this summer, the compressor chillers covered only 3% of the cooling demand. Hence, this is a cooling system with little environmental impact.

In 2009, the new hospital buildings approached 200 000 m² floor area, and during the warmest summer days the chiller plant operated at 100% capacity. The annual cooling load had increased to 10 000 MWh. About 70% of the cooling was covered by "free cooling", while the absorption chiller covered about 20% and the compressor chillers 10% of the cooling demand.

In order to reduce the use of the electrically driven compressor chillers, a new 3 MW absorption chiller will be installed prior to the 2011 summer cooling season.

Key Words: district cooling, absorption chiller, hospital

1 INTRODUCTION

Trondheim Energi Fjernvarme AS has delivered district heat to the city of Trondheim since 1982. Today the system covers more than 30% of the heating demand in the city. The base heat production is from a waste incineration plant. During summer, there is a surplus of heat from the waste incineration in the district heating system.

When Trondheim Energi Fjernvarme AS started to build district cooling plants, it was a goal to minimize the use of electric energy. Therefore the production of chilled water is based on "free cooling" from river water or sea water, and district heat driven absorption chillers in summer when the river and sea water temperatures are too high to cover the cooling demands. To date, Trondheim Energi Fjernvarme AS has built two district cooling plants in Trondheim, and the third one is under construction.

2 DISTRICT HEATING AND COOLING IN TRONDHEIM

Figure 1 presents a map of Trondheim showing the district heating system. The figure also shows where the district cooling plants are located.

The base heat production plant is a waste incineration plant located about 10 km from the city. The first incineration plant was established in 1982, and the second one in 2007. The total heating capacity for the plant is about 70 MW. In addition to waste incineration, additional heat is produced from eight different energy sources at nine different energy plants in Trondheim. Figure 1 shows the district heating grid with the 10 heating plants. The total length of the district heating grid is 180 km, and the grid is continuously extended.

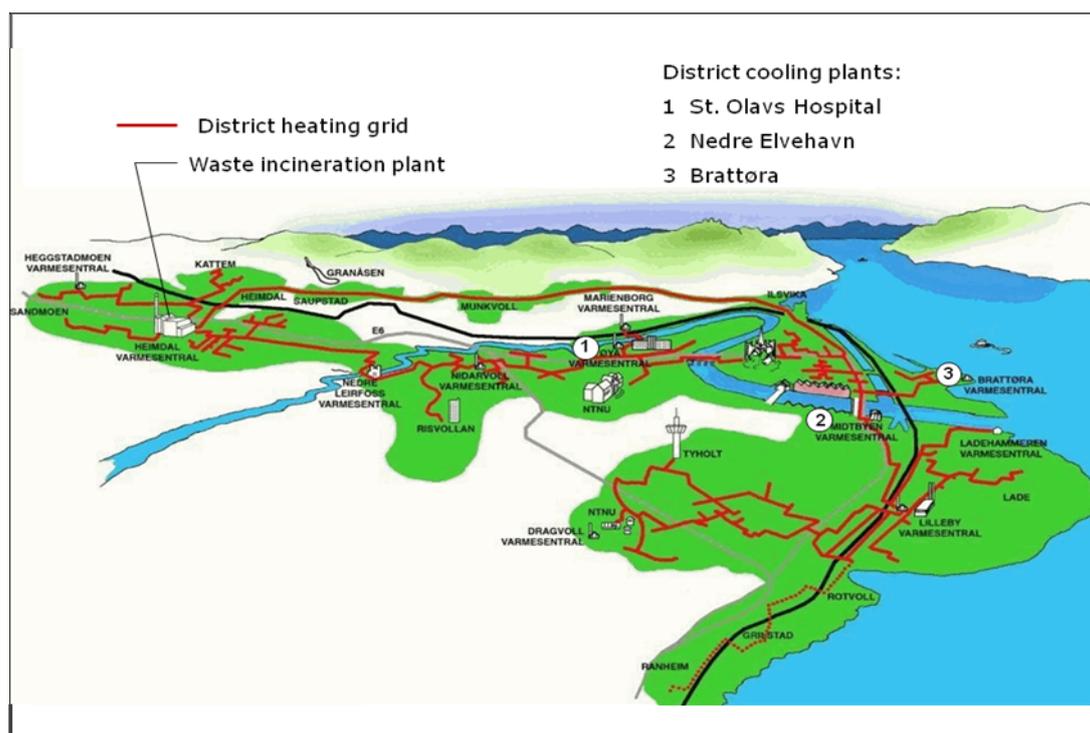


Figure 1: District heating and cooling plants in Trondheim.

Figure 1 also shows three district cooling plants which are connected to the district heating system. Two utilize river water as the primary cooling source, and district heat driven absorption cooling or compressor cooling as auxiliary cooling sources. The third district cooling plant is under construction at Brattøra, close to the Trondheim fjord, and this plant will utilize sea water as the primary cooling source.

3 DESCRIPTION OF THE DISTRICT COOLING PLANT AT ST. OLAVS HOSPITAL

St. Olavs Hospital is the regional hospital for the Mid-Norway health region. The new University Hospital is being built in the central part of Trondheim. The first clinical centres were completed in 2006, and the entire project will be completed in 2014.

Trondheim Energi Fjernvarme AS has delivered district heat to the existing hospital in Trondheim since 1982. The base heat production is from a waste incineration plant. The new hospital also requires cooling. The first part of the central cooling plant at St. Olavs Hospital was built in 2004, and it consists of one absorption chiller with 3 MW cooling capacity, one 3 MW centrifugal chiller and one screw compressor chiller with 1.3 MW cooling capacity. River wa-

ter is used for cooling the district cooling water when the river water temperature is sufficiently low, and for condenser cooling when the water temperature is high.

Due to increased cooling demands, a second absorption chiller will be installed in May 2011, in order to contribute with environmental friendly cooling when the large summer cooling demands occur. This new absorption chiller is also a part of the ECO-City project. ECO-City is a CONCERTO project funded by the European Union, where the goal is to demonstrate innovative integrated energy concepts in the supply and demand side in three successful communities in Denmark/Sweden, Spain and Norway (ECO-City 2005-2011).

Figure 2 shows the pipe diagram of the district cooling plant at St. Olavs Hospital. The plant comprises two absorption chillers and two compressor chillers. Each of the chillers is equipped with a circulating pump for chilled water which preferably will operate at constant speed when the chiller operation is needed. These pumps will provide water circulation in the machinery room, and this water will either circulate out to the cooling water customers or it will circulate back to the chillers through an accumulation tank. The district cooling network is separated from the chillers by the accumulator as shown in Figure 2, and in this way, the district cooling distribution pumps may be frequency controlled while the chiller pumps operate at constant speed.

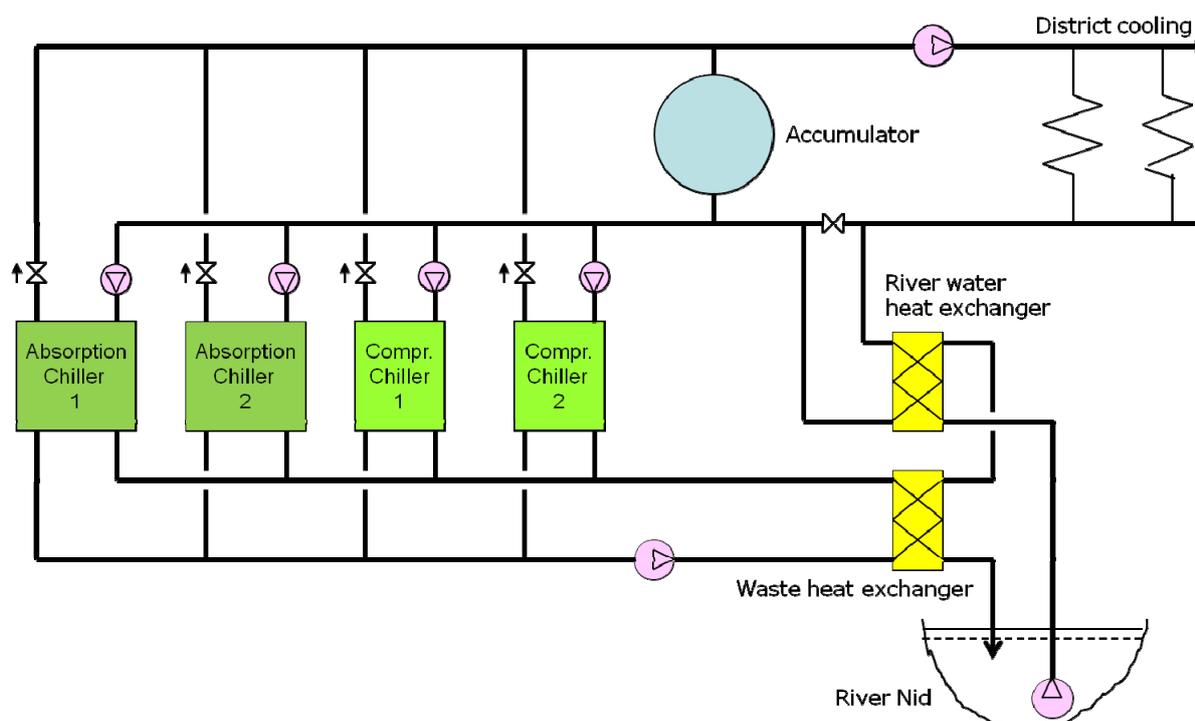


Figure 2: Principle pipe diagram of the district cooling plant at St. Olavs Hospital, Trondheim

4 EXPERIENCES FROM THE ST. OLAVS HOSPITAL DISTRICT COOLING PLANT

St. Olavs Hospital is built in several phases:

Phase 1:	2003 – 2006:	100 000 m ² total floor area
Phase 2:	2006 – 2009:	200 000 m ² total floor area
Phase 3:	2009 – 2014:	220 000 m ² total floor area

The cooling demand increases with increasing floor area. In this paper we compare the cold energy production from the district cooling plant for the two years 2007 and 2009, when the building floor areas were 100 000 and 200 000 m², respectively.

4.1 Cold Production

The district cooling is used to cool computer and communication rooms, medical technical equipment, condenser cooling of local refrigeration equipment, and ventilation cooling. Figure 3 shows the daily mean ambient air temperatures, and Figure 4 shows the daily mean cooling demands during 2007 and 2009. The measured temperatures and cooling production is registered every 10 minutes.

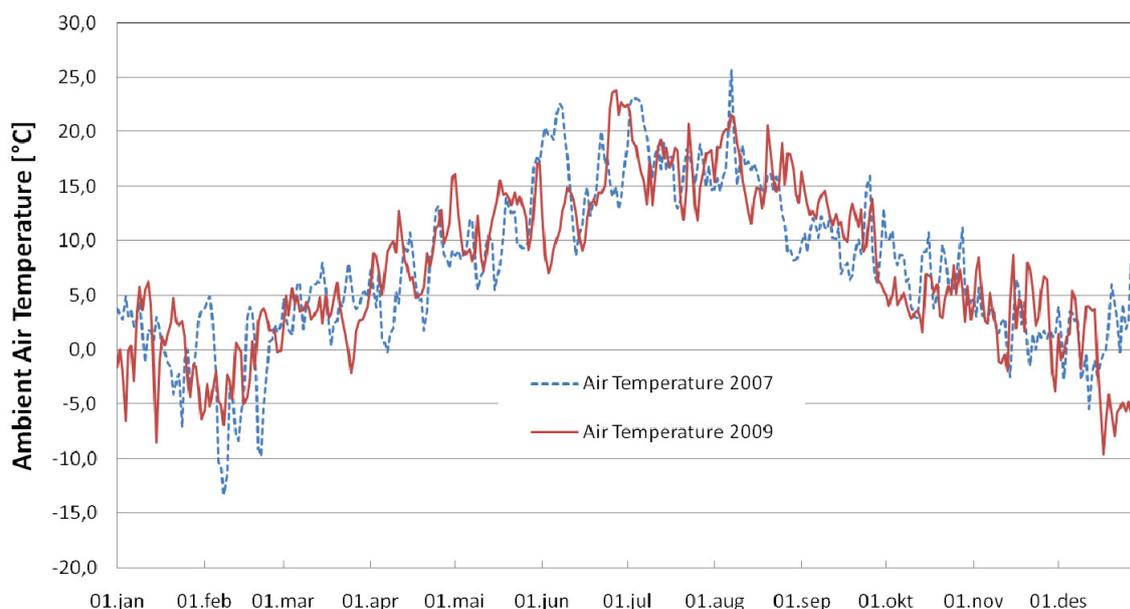


Figure 3: Daily mean ambient air temperatures in Trondheim in 2007 and 2009.

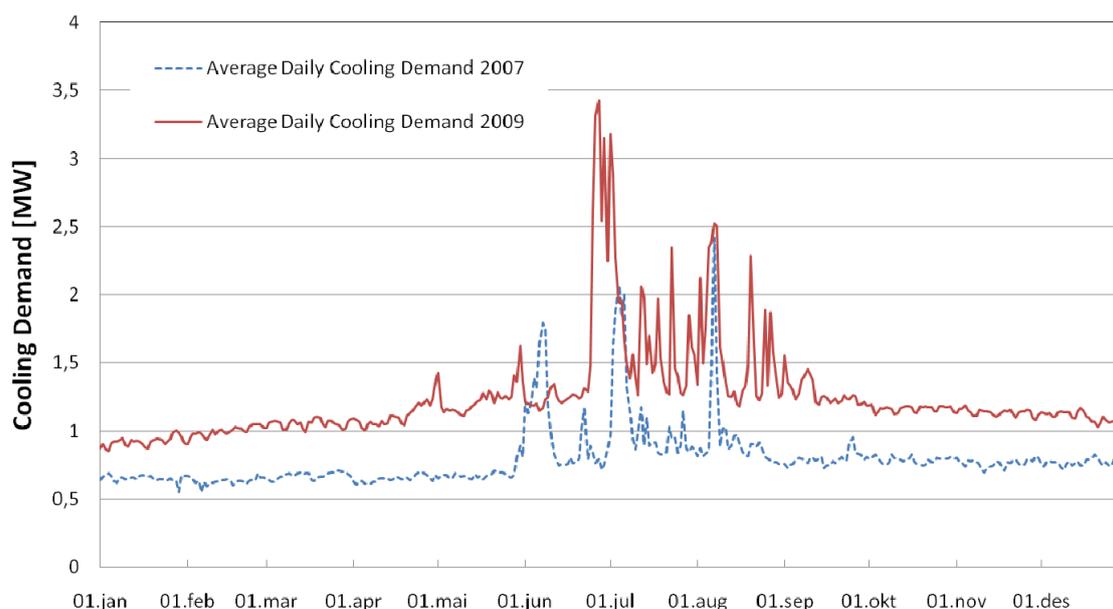


Figure 4: Daily mean cooling demands at St. Olavs hospital in 2007 and 2009.

In 2007, the cooling demand was approximately 600 - 700 kW for most of the year, and this seems to be quite constant at ambient temperatures below 17°C (Eggen and Utne 2007). At ambient air temperatures above 17°C, the district cooling is also used to cool the ventilation air and to provide some local comfort cooling, and the cooling demand increases correspondingly.

In 2009, the cooling demand at ambient temperatures below 17°C had increased by about 400 kW from approximately 700 kW to 1 100 kW.

In 2007, the maximum cooling peak load was 4.6 MW, and the total cooling demand was 6 600 MWh/year. Two years later, the building floor area had increased from 100 000 m² to 200 000 m². The maximum cooling peak load had increased to 6.9 MW, and the total cooling demand was 10 000 MWh/year.

Figure 5 shows the variation of cooling production during a hot day and on a winter day in Trondheim in 2009, with 26°C as the maximum temperature, and 18°C as the minimum temperature at night.

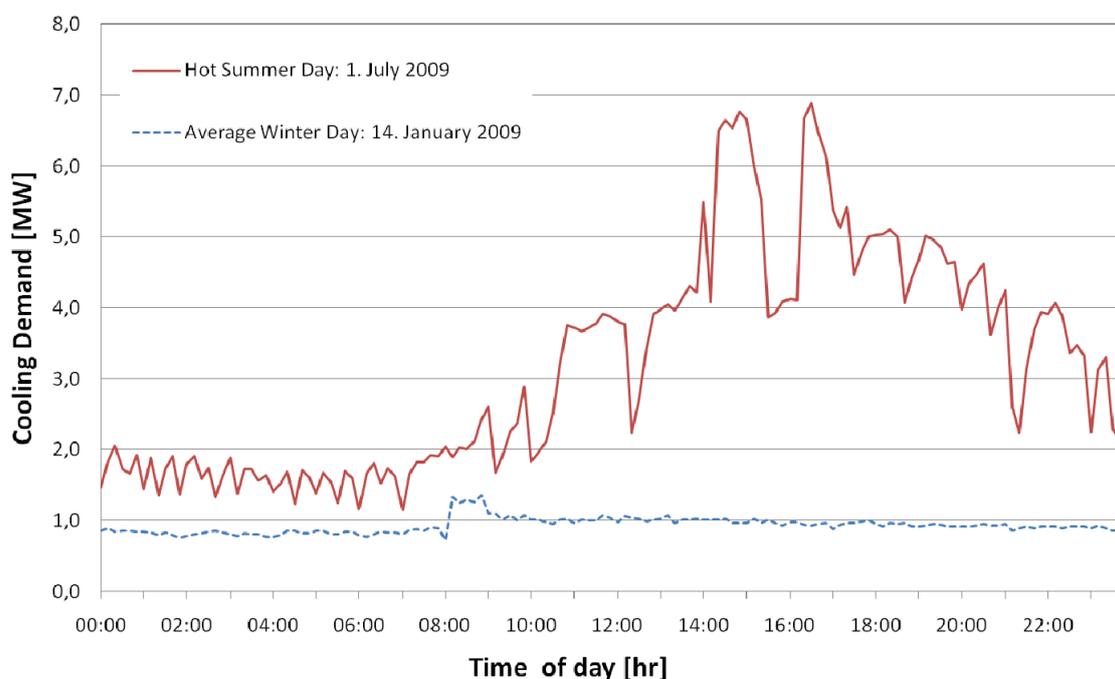


Figure 5: Cooling demand variations through a hot and a cool day at St. Olavs hospital.

The maximum cooling load registered during summer 2009 occurred on July 1st and was 6.9 MW at 16:30, and almost as high at 14:30. The drop in cooling demand between these highs could be due to cloud cover or different use of medical equipment. Figure 5 shows that the average cooling load during hotter daytime period was approximately 5 MW, and this complies with the calculated cooling demands at design conditions. During an average winter day, the cooling production was approximately 1 MW with small variations from day to night.

4.2 District Cooling Production from Different Cooling Sources

Figure 6 shows the monthly cooling production from different cooling sources in 2007 and 2009. During the 8 coldest months, the entire cooling demand was covered by "free cooling" from river water (Nidelven).

The total cooling production during 2007 was 6 600 MWh including 4 400 MWh "free" cooling from river water and 2 200 MWh by the chiller plant. Thus, nearly 67% of the cooling demand was covered by direct heat exchange with river water, and 33% was covered by the chiller plant. Most of the district cooling from the chillers was produced by the absorption chiller. Only 3% was produced by the compressor chillers.

In 2009, the new hospital building approached 200 000 m² floor area, and during the warmest summer days the chiller plant operated at 100% capacity. The annual cooling demand had increased to 10 000 MWh. About 70% of the cooling demand was covered by "free cooling", while the absorption chiller covered about 20% and the compressor chillers 10% of the cooling demand. In order to reduce the use of the electrically driven compressor chillers, a new 3 MW absorption chiller will be installed prior to the 2011 summer cooling season. The absorption chiller operates on district heat with a minimum temperature of 80°C and has a COP of 0.7.

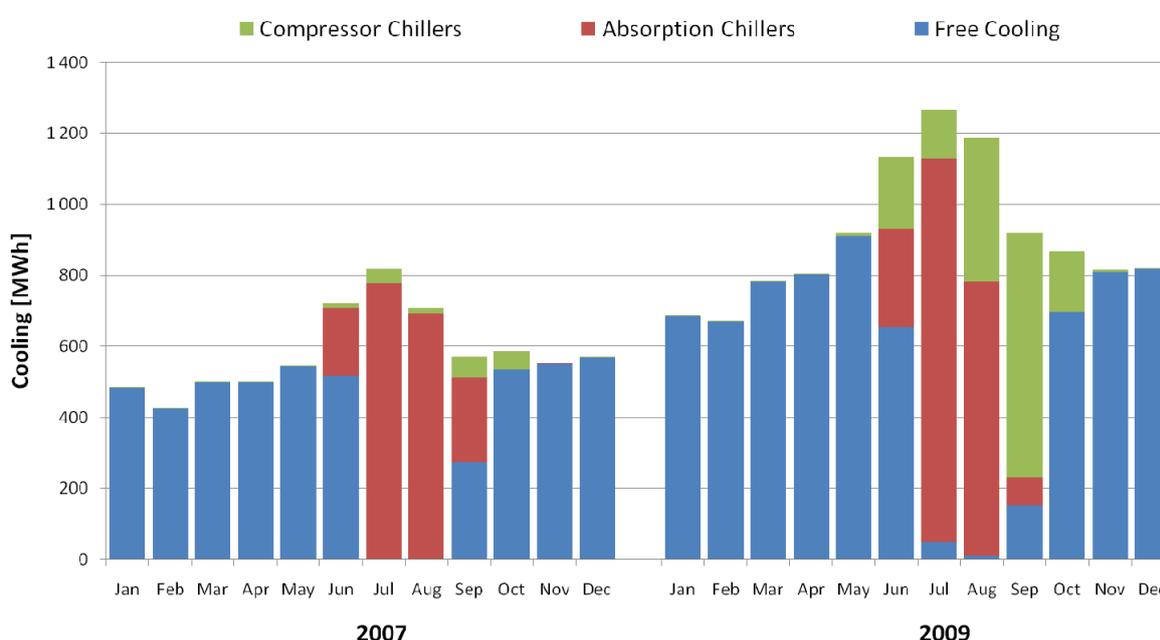


Figure 6: Cold production from different cooling sources at St. Olavs hospital in 2007 and 2009.

4.3 Operating experiences

When the chiller plant was commissioned in 2004, the cooling demand was too small for the 3 MW absorption chiller, and cooling from the chiller plant was mainly covered by the screw compressor chiller. The cooling demand has increased with the development of the new hospital, and since 2006, there has not been any severe problems connected to the absorption chiller nor the river water supply system. At the smallest capacities, the absorption chiller is operated on/off.

The only problem encountered with the absorption chiller is that the district heating control valve was too big. Now, it has been replaced by a smaller valve, and the operation of the absorption chiller has improved.

5 FURTHER DEVELOPMENT OF THE DISTRICT COOLING SYSTEM

A new district cooling plant is under construction at Brattøra, which is located at the seaside of the city as shown in Figure 1. This location offers better design and operational conditions for the district cooling plant because the sea water has a higher cooling potential during the summer season than the river water.

Figure 7 shows the monthly mean temperature of the river water which is used for cooling in the two existing district cooling plants. The figure also shows the sea water temperature at 80 m depth outside Brattøra.

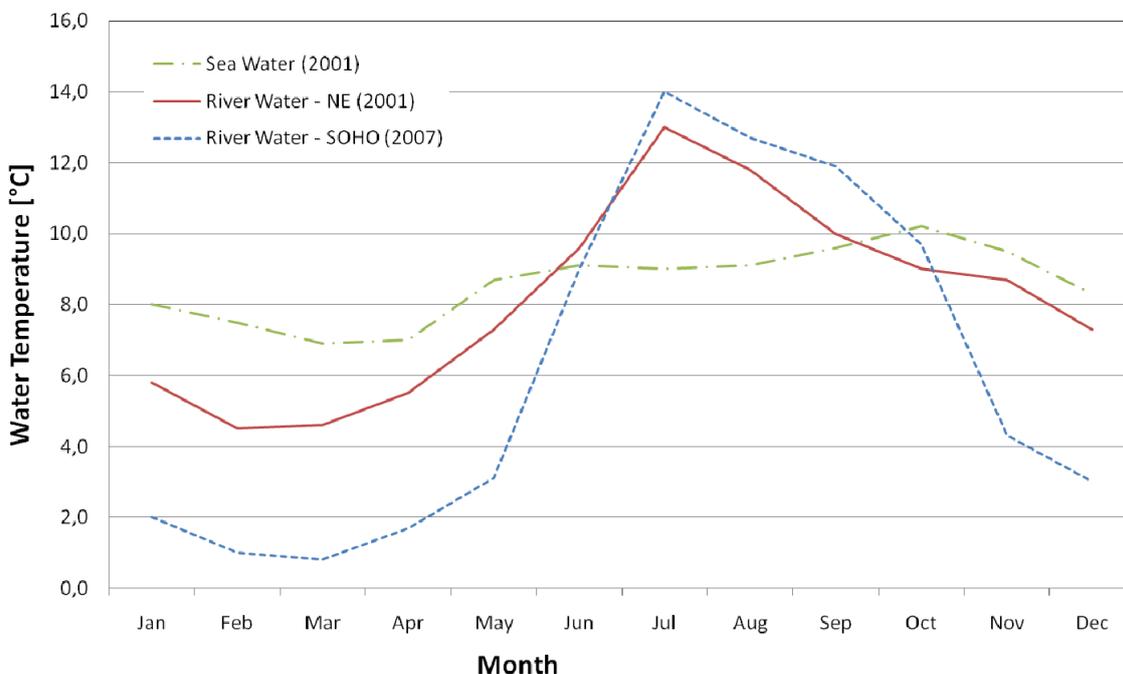


Figure 7: Comparison of river and sea water temperatures for the three district cooling plants

Sea water is a better cooling source for district cooling water than river water since the temperature is considerably lower during the summer. The maximum cooling demands normally occur in June, July and August. During this period, the sea water temperature rarely exceeds 10°C. Since the design forward/return temperatures of the district cooling water are 7/15°C, the district cooling water can be pre-cooled from 15 to 11°C by heat exchange with sea water, and post-cooled down to 7°C by an absorption or mechanical chiller. In this way, 50% of the maximum cooling demand can be covered by direct heat exchange with sea water. Thus, the absorption and/or compressor chillers may be dimensioned for only 50% of the maximum cooling capacity when sea water is the primary cooling source while the chillers must be designed for 100% capacity when only river water is available. Figure 7 shows that the maximum river water temperatures are 13 and 14°C for the Nedre Elvehavn (NE) and St. Olavs Hospital district cooling plant, respectively.

During the winter, the sea water temperature is considerably higher than the river water temperature. Therefore, sea water is also an excellent heat source for heat pumps.

Regarding the river water temperature, Figure 7 shows that the water temperature at St. Olavs Hospital is lower than the water temperature at Nedre Elvehavn. The reason for that is that the river outside St. Olavs Hospital contains pure fresh water, while it is brackish water outside Nedre Elvehavn, which is close to the Trondheim fjord as shown in Figure 1. The brackish water is a mixture of fresh water and sea water. When the fresh water is flowing with the river out to the sea, it has nearly the same temperature in the river surface as meas-

ured at St. Olavs Hospital. Heavier and warmer sea water will flow from the Trondheim fjord into the bottom of the river outlet, and it will stream up the river in counter current flow with the fresh water. It will gradually mix with fresh water on its way upstream, and from Figure 7, it can be assumed that the water at the bottom of the river at Nedre Elvehavn contains approximately 50% each of fresh and salt water.

Due to this increase of temperature at the bottom of the river, the brackish water may be used as heat source for heat pumps. This have been done at hotels about 1 km from the river outlet in Trondheim, e.g. at Radisson SAS Royal Garden Hotel which was built in 1983.



Figure 8: Radisson SAS Royal Garden Hotel is heated and cooled by means of the river.

5.1 New district cooling plant at Brattøra

Brattøra is a new urban area in the city of Trondheim, with a new Rock Museum, railway station, swimming pool (aqualand), hotels and lot of office buildings. A new district cooling plant is under construction for this area. The machinery room for the district cooling plant will be located in the basement of a new hotel which is also under construction. The district cooling plant will be built in a similar way as shown in Figure 2 for St. Olavs Hospital. The main cooling source will be sea water, but in summer and autumn, additional cooling will be supplemented by absorption and compressor chillers. Both heating and cooling of most of the buildings at Brattøra will be performed by district heating and district cooling from Trondheim Energi Fjernvarme.

In this case, the compressor chiller will also be used as heat pump for heating of the hotel. This is a huge hotel with 400 rooms, and with a large congress hall. The heated floor area is 25 000 m². The hotel is built with a low-temperature heating system (60°C/40°C). About one third of the heating demand is hot tap water, which according to the Norwegian regulations has to be heated to 70°C.

In order to achieve the highest degree of building energy saving certificate (Energy label A), the heat pump must cover at least 75% of the heating demand of hot tap water. Since the average fresh water temperature is 7°C, the heat pump must heat the water up to at least

55°C. This is a challenge since the heating system of the hotel is a low-temperature system with forward temperatures normally varying between 40 and 50°C.

This challenge may be solved in several ways:

1. *Separate CO₂ heat pump for hot tap water*
This high-efficiency solution is not suitable since the heat pump is too small to serve as an auxiliary chiller for the district cooling plant.
2. *Heat pump with two temperature set points at the high temperature side*
In this case, the heat pump can normally operate with 40 - 50°C forward water temperature at day time. During the night, it may switch to e.g. 60°C forward temperature for an hour or two in order to heat a large accumulation system with tap water of at least 55°C
3. *Heat pump with liquid subcooler and desuperheater*
This is a common way of improving the efficiency of heat pump water heaters. As an example, the heat pump at Royal Garden Hotel (Figure 8) is built in this way.

Figure 9 shows the principle piping diagram for a heat pump with a liquid subcooler for pre-heating the water, a condenser for both space and tap water, and a desuperheater for re-heating. Whenever necessary, the sanitary water will be reheated to the required temperature by the district heating heat exchanger.

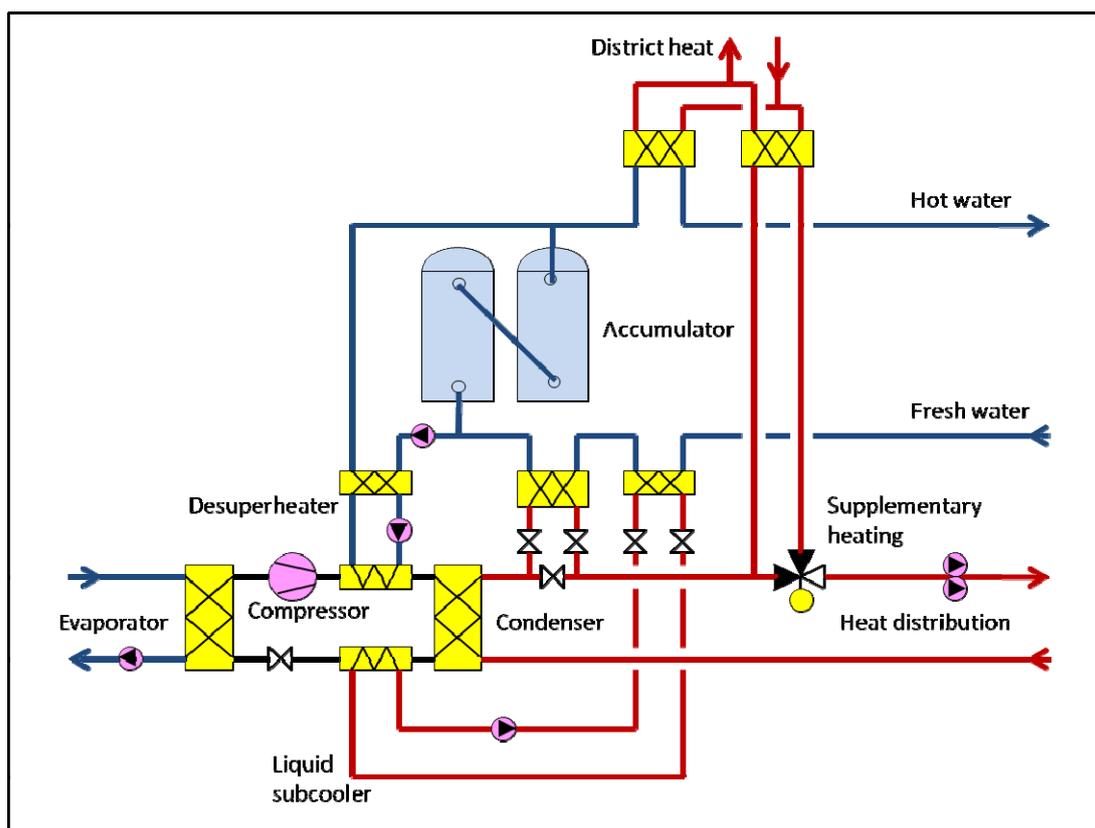


Figure 9: Principle piping diagram for a heat pump with liquid subcooler and desuperheater

Figure 10 shows the p-h diagram for R134a illustrating theoretical effects of sanitary water heating from the three different heat exchangers. The evaporation temperature is 0°C and the condensing temperature is 50°C, resulting in a forward water temperature of approximately 48°C.

The average fresh water temperature is 7°C, and the liquid subcooler has the potential to cover about 25% of the heating demand when the heat pump is operating for hot sanitary water production only. When the heat pump is operating at high capacity for cooling or space heating, the liquid subcooling will diminish. Nevertheless, the subcooler is probably the most effective heat exchanger since it is producing useful heat without increasing the power demand for the compressor.

The desuperheater has a relatively small heating capacity for an efficient R134a heat pump. Theoretically, the desuperheater covers only 10% of the heat output from the heat pump. However, by connecting a hot water accumulation system to the desuperheater, it can increase the hot water temperature for the hotel up to at least 65°C during the night as shown to the right in Figure 10. This accumulator heating curve is calculated for a heat pump with a desuperheater heating capacity of 40 kW, and a 10 m³ accumulation system. The high temperature refrigerant gas from the compressor into the desuperheater is 70°C.

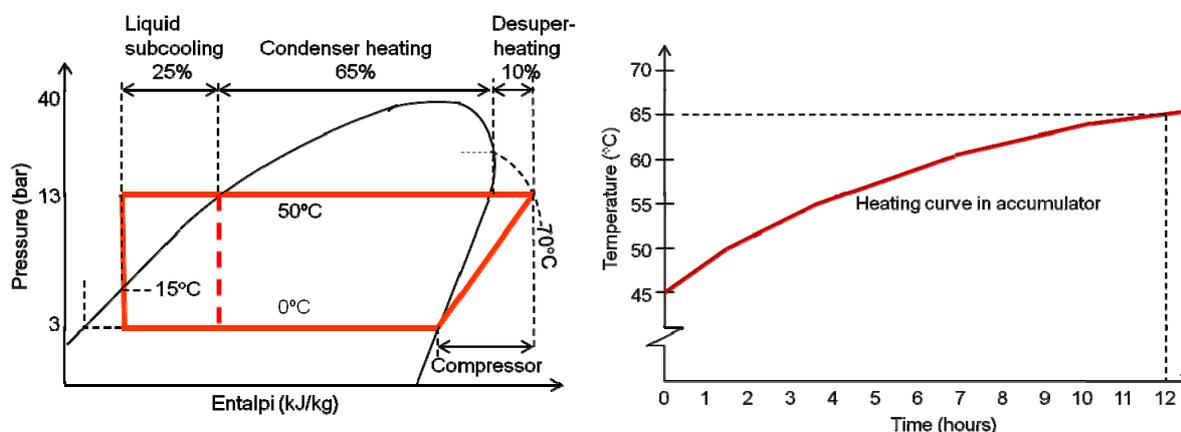


Figure 10: Heat pump water heater cycle in a p-h diagram (left), and the desuperheated heating curve in the accumulator system (right).

In hotels, most of the hot tap water is used between seven and nine o'clock in the morning, and between 17 and 19 o'clock in the evening. During the night, the hot water consumption is relatively small. Therefore, it can be very profitable to connect the hot water accumulation system to a desuperheater. The heating capacity of the desuperheater will diminish as the temperature in the accumulation tank increases, as shown to the right in Figure 10.

There are great possibilities for saving energy in the new hotel at Brattøra by efficient heat pumps. However, in this case, Trondheim Energi Fjernvarme runs a waste incineration plant for district heat production. During summer, there are excess heat available from waste incineration, and of course, this excess heat will be used for heating purposes and cooling purposes through absorption chillers. The heat pump will mainly be used during Winter, but also in Summer if there is no waste heat available.

6 CONCLUSION

In 2007, the new hospital buildings included 100 000 m² floor area. The total cooling demand was 6 600 MWh, and 67% was covered by "free cooling" from river water, while 30% was covered by the absorption chiller. During this summer, the compressor chillers covered only 3% of the cooling demand. Hence, this is a cooling system with little environmental impact.

In 2009 the new hospital buildings approached 200 000 m² floor area, and during the warmest summer days the chiller plant operated at nearly 100% capacity. The annual cooling de-

mand had increased to 10 000 MWh. About 70% of the cooling demand was covered by "free cooling", while the absorption chiller covered about 20% and the compressor chillers 10% of the cooling demand. In order to reduce the use of electrically driven compressor chillers, a new 3 MW absorption chiller will be installed prior to the 2011 summer cooling season.

Trondheim Energi Fjernvarme AS has very good experiences with absorption chillers. Therefore, a new district cooling plant at Brattøra will be built in a similar way as the two existing district cooling plants, with free cooling from sea water as the primary cooling source, and with a mix of absorption and compressor chillers for auxiliary cooling. The machinery room is located in the basement of a new hotel, and one compressor chiller will be used as heat pump for heating purposes in the hotel.

7 REFERENCES

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