District Cooling, Balancing the Production and Demand in CHP (1999: T2)

Purpose of the Report

The main objectives of the research project were to

- Produce information on integrating heating and cooling with combined heat and power (CHP), focusing on district-heat-driven absorption cooling
- Investigate the possibility of balancing the production and demand with the means of heat-driven cooling in connection to CHP
- Collect systematic information and operating experiences of existing district cooling systems connected to CHP
- Collect information on new promising heat-driven cooling techniques

The report is not a complete guide to district cooling or CHP, but it concentrates on some specific issues which had not been investigated before and which were of special interest. The report continues the work that was published in 1996 with the title "Integrating District Cooling with Combined Heat and Power"which gives a broad picture of the field.

Briefly, the main emphasis in the report is put on cooling technologies, integrating cooling with CHP and cooling with district heating networks. In the following the main topics and findings of the report are summarized.

Cooling Technology

The main objective of the Cooling Technology section was to introduce alternatives to one-stage water/LiBr absorption process, which is the most common heat-driven cooling technique today. Namely, the present absorption chillers are not very well suited to be driven with district heating or other relatively low-temperature heat.

The report introduces the principles of refrigeration and cooling and presents a number of water chilling and cooling technologies. The purpose is to present a comprehensive list of heat-driven cooling technologies available today or in the near future. The described features include the working principle of each technique, temperature ranges, energy efficiency, capacity questions, applicability in different conditions and economy.

Energy Efficiency of CHP Connected Heat-driven Cooling

There has been a lot of debate, which is more energy efficient: to extract steam from a steam turbine to drive heat-driven chillers or to produce electricity as much as possible from the steam and use the electricity to drive electric vapor compression chillers. This question was answered by developing a method suitable for comprehensive comparison of heat- and electric-driven cooling in connection to steam turbine CHP. In the method the efficiency of heat-driven cooling is measured in electricity lost due to heat generation for cooling duty, and COPe,Abs is used to denote the total "electric" efficiency of absorption cooling. In addition, all the auxiliary electricity consumption is taken into account. The method requires simulation of a CHP plant and information on the COPs and internal auxiliary electricity consumptions of heat- and electric-driven cooling plants.

Balancing the Production and Demand

In a warm climate the annual electric power peak occurs in summer partly due to electric air-conditioning and refrigeration. If a part of the air-conditioning cooling demand was covered with heat-driven cooling machines, the power peak would be shaved off. If balancing the production and demand was possible by this means, constructing new power capacity for increasing peak demand could be avoided. An essential question is, whether existing CHP plants could be used more effectively than today for cooling production employing heat-driven cooling processes.

To answer this question a problem of maximum cooling output from a CHP plant was studied for condensing and back-pressure steam turbines. All the electric power output of a CHP plant was imagined to be converted to cooling with electric vapor compression chillers. A possible increase to this reference cooling output by using heat-driven absorption chillers is referred to as a “balancing effect”. The results of simulated cases showed that the capacity balancing effect in the condensing CHP is practically zero, unless the electricity production in the condensing tail is very inefficient.

The balancing potential in back-pressure facilities seems to be substantial (up to 180 MWch with a plant of 45 MWe/90 MWth), which is mainly due to increased power production with the aid of increased heat load required by absorption chillers. Namely, the electric com pression chillers were responsible for more than 70% of the balancing effect in the example cases. The excess power production in summer could be used for any other purpose than cooling as well. For example, using absorption chillers with backpressure CHP could reduce the electric power demand by reducing the number of electrical chillers, and at the same time the CHP plant would provide additional power producing capacity to help cover the electric power peak.

The results are also applicable to gas turbine combined cycle or similar cases with heat recovery from flue gases. In such a case a part of the heat is obtained from “waste heat” and it does not affect the power production in any way. Thus, using waste heat for heat-driven cooling can increase the balancing effect considerably.

If constructing a new power plant becomes necessary to cover the peak power demand caused by cooling need, it cannot be called “balancing the production and demand” anymore. When considering a new CHP plant for maximizing the cooling output, the question is, how much cooling output per fuel input the plant produces. The choice is no longer between cooling techniques but also CHP plant types. This problem is addressed in this report.

Absorption Chillers Driven with District Heating

CHP and district heating is commonly used in countries with a cold winter. In some countries where district heating is used, there is also considerably great cooling demand in summer. Heat-driven cooling techniques make it possible to use the heat portion of the CHP production for cooling duty in summer. A logical idea is to take the advantage of the energy transmission capacity in the existing district heating networks. Today the most common district-heat-driven cooling technique is the single-effect water/lithium bromide absorption chiller. District-heat-driven absorption chillers could be installed in individual buildings instead of electric compression chillers. Using district heating networks for cooling in summer could improve the economy of district heating in warm climates.

The possibility of driving absorption chillers with district heating hot water was investigated. Chiller connections to the district heating network are presented and their characteristics are listed in the report. The supply temperatures in hot water networks are usually below 100°C or even 80°C in summer, which may cause some problems for heat-driven cooling applications.

There are two main problems related to district-heat-driven absorption cooling. The first is choosing the optimal district heat supply temperature for the absorption chiller design point in summer to minimize the total costs of cooling. This design problem can be solved by optimization and an example of this is provided in the report. However, the problem is very case-specific and no generalizations of the results can be made.

The second problem is the hydraulic restriction of maximum water flow in existing district heating transmission pipelines. The existing transmission pipes designed for wintertime heating demand limit the cooling load served by absorption chillers to about 20% of the maximum wintertime heating load. The problem has its basis on the small hot water temperature difference and the low COP of the absorption chiller. The only solutions to this problem are developing better heat-driven cooling machines and possibly laying additional district heating network capacity. Nevertheless, as shown elsewhere in the report, this 20% could be enough to see significant effects on the capacity balancing, economy and energy efficiency of existing backpressure steam turbine CHP. In the existing systems re-building the district heating house connection lines for the water demand of absorption chillers is often necessary, but this is surprisingly small component in the cooling plant total costs. If some of the branch lines have to be re-built, the costs become easily too great.

New district heating networks can be designed to meet the maximum flow rates, which may occur in summer or winter. The allocation of costs between the heating and the cooling then becomes an issue.

Economy of District-Heat-Driven Cooling

The economy of district-heat-driven absorption cooling with condensing and backpressure CHP was studied from the viewpoint of the energy producer. Absorption chillers were imagined to be installed in individual buildings instead of electric compression chillers, which they were also compared to. The CHP plant and the district heating network were assumed existing, hence none of their costs were allocated for cooling production, except for the district heating house connection line that was assumed to be re-built. Some factors, including absorption chiller plant design and driving temperature profile over the cooling season, were optimized.

The economy of integrating district-heat-driven absorption cooling with condensing CHP does not look very promising compared to the same size of electric compression chillers. However, the situation is very case-specific and depends mainly on the relative prices of electricity and heat. The makeup water costs are highly important in the total annual costs of cooling. The lower the costs of water, the better are the chances of absorption cooling. In the case of natural heat rejection, e.g. river, lake or sea, absorption cooling can be very competitive with electric compression cooling.

The backpressure steam turbine CHP shows a substantial potential for integrating district-heat-driven absorption cooling with it. The costs in all calculated absorption cases were over 60% less than those in the electric cooling case. This is due to increased production of electricity with the heat load caused by the absorption chillers.

Examples of optimized absorption chiller plant design parameters and heat supply temperature profiles can be found in the report. However, the latter ones are very case-specific and should be treated as examples only.

Summarizing, the following aspects in local conditions improve the competitiveness of heat-driven cooling in relation to electric compression cooling:

- The ratio of electricity price to heat price is high
- Makeup water costs are low (or condenser cooling is achieved by lake/river/sea water or other means without a wet cooling tower)
- Normal summertime heat supply temperature is high

- Number of equivalent full-load hours for cooling is great
- Electric transmission losses are high
- Heat transmission losses are low
- Maintenance costs of heat-driven chillers are lower than those of electric chillers and the lifetime is longer
- Distance between the chiller and the cooling tower is short
- (In the case of district-heat-driven cooling) District heating house connection line is short or it does not have to be re-built for the heat-driven cooling application

In the case of steam turbine CHP, if the heat supply temperature has to be raised above the normal summertime temperature for a long period of time only because of heat-driven cooling, the economic feasibility of heat-driven cooling reduces considerably.

Operating Experiences

Within the project three series of measurements on a district-heat-driven one-stage water/LiBr absorption chiller were performed in Seoul, Korea at the end of summer 1997. The purposes of the measurements were to record normal operation and to experiment the effects of applying relatively low-temperature driving hot water.

Unfortunately, the measured data was highly transient and no far-going conclusions on the chiller steady-state performance could be drawn. However, the results show that trying to force the chiller to work with a lower hot water temperature than normally causes strong transients and oscillation as the chiller tries to find an equilibrium. The physical laws governing the chiller make the cooling water temperatures low and/or chilled water temperatures high to compensate lowering of the hot water temperature.

The report introduces three realized cooling cases in Germany. More extensive operating experiences from Germany were collected with a survey, and some statistics of the survey are presented. There is practical, cooling market and cost information on the German situation of district cooling in the report.

Cooling and the Environment

Most of the air-conditioning cooling demand in the world today is covered by electric vapor compression chillers. The refrigerant fluids employed in vapor compression chillers have been found to contribute to ozone depletion and global warming. The decomposers of ozone, CFCs and HCFCs, are subjected to phase-out by international agreement. This development has already resulted in promising alternatives for the old refrigerants. A major improvement is that the HFCs do not deplete the ozone layer and they really can replace the old refrigerants in a number of applications. Today many new vapor compression chillers employ HFCs, but as the ozone depleting HCFCs are still being used to some degree, heat-driven cooling processes can be supported with the fact that their working fluids do not contribute to the ozone depletion at all.

In the future, when the refrigerants of vapor compression applications become totally harmless to the ozone layer, the only impact to the global environment will be the greenhouse gas emissions. A greater quantity of greenhouse gases is released into the atmosphere from energy consumption for cooling duty than from refrigerant discharge. This fact makes the energy efficiency very important in analyzing the global environmental impacts of cooling, which are mainly caused by CO2 emissions. However, it is important to notice that in respect to the global warming the amount of gas emission does not give the total picture, but the characteristics of the gas in the atmosphere have also to be taken into account.

Summarizing Conclusions

On the basis of the findings in this report the following summarizing conclusions can be drawn:

The energy efficiencies of large-scale electric compression chillers and single-effect water/LiBr absorption chillers driven with steam turbine CHP are roughly in the same order of magnitude. They both depend on the conditions to a great extent. Often a case-specific analysis must be provided to find the most fuel saving cooling concept between heat- and electric-driven ones, and the whole energy conversion chain must be included in the analysis. Using “waste” heat (the production of which does not reduce the electric output of CHP) for driving heat-driven cooling processes can save considerable amounts of primary energy.

Existing CHP:
If the electric power demand peak occurs in summer due to electric cooling, it is possible to achieve substantial peak shaving by using heat-driven cooling units with existing backpressure steam turbine CHP. In this case also, heat-driven cooling would be very profitable business for the energy producer, if the excess backpressure electricity was sold at a good price. Power peak shaving is also possible by exploiting suitable heat sources for heat-driven cooling, e.g. “waste” heat recovery from gas turbines or CHP engines, process waste heat, etc. Steam turbine CHP equipped with a condensing tail cannot provide any substantial power peak shaving by using the heat-driven cooling processes available today, unless the condensing tail is very inefficient or the condensing pressure high.

If there is an existing district heating network, its energy transmission capacity can be exploited for heat-driven cooling if it is economically feasible. With today’s single-effect water/LiBr absorption chillers district-heat-driven cooling can be feasible depending on the local conditions. Especially in the cases of existing backpressure steam turbine CHP or “waste” heat recovery the economy seems viable. The existing transmission pipes designed for wintertime heating demand limit the cooling load served by absorption chillers to about 20% of the maximum wintertime heating load. Re-building the district heating house connection pipes is often necessary for the water demand of the absorption chillers, but if the re-built pipe length is short, this does not reduce the feasibility considerably.

New CHP:
If a new CHP plant is designed in the conditions in which the electric power peak takes place in summer due to increasing electric cooling demand, it is wise to choose such a CHP concept which provides the maximum cooling output per fuel input. This problem has been addressed in “Integrating District Cooling with Combined Heat and Power” by Spurr and Larsson and the CHP technologies rank as follows, from highest to lowest cooling output per unit fuel input:
- Gas turbine combined cycle
- Engine CHP
- Gas turbine
- Steam turbine

This ranking holds true regardless of the chiller technologies employed. For the steam turbine options the condensing turbine results in higher cooling output than the backpressure turbine (with the present commercial cooling techniques available).

Although not considered in detail in this report, the engine CHP has proven to be feasible for combined power, heating and cooling production. It is very energy efficient and has potential for smaller district energy systems. Absorption chillers have been successfully integrated with the engine CHP, because the heat recovery does not affect the power production and the temperatures of produced heat are suitable for the driving heat.

A great question mark remains, to what extent, if at all, heat-driven cooling could improve the chances of CHP and district heating in relatively warm climates. There are well-known advantages related to CHP: energy efficiency, effective pollution control in centralized production and benefits in load diversification. Heat-driven cooling does balance the heat demand over the year, but if separate pipe networks have to be constructed for cooling (chilled water) and heating (hot water), the first costs of the system obviously become high. Furthermore, this does not necessarily improve the economy of district heating. A great drawback in this respect is the fact that the cooling load that can be served by district-heat-driven applications is rather small, if the district heating transmission pipes are dimensioned according to wintertime heating demand. Extensive district-heat-driven absorption cooling requires larger pipe diameters than wintertime heating, and thus the costs increase and the allocation of costs between the heating and the cooling becomes an issue.

The nature of all the different products of cogeneration must be understood. District heating and cooling must have a local demand, whereas electricity is a global product on the deregulated market. With heat-driven chillers cooling can be transformed from electricity demand into heat demand, from global market into local market. Local district energy demands must be fulfilled by local suppliers. Producing district thermal energy may or may not affect the power production, depending on the CHP technology used.

The local conditions will have the deciding impact on the feasibility of any design. In some cases, it could be preferable to have both condensing and backpressure CHP plant types, or maybe other such as engine CHP plants, connected to the same district energy system. The cooling plants, for their part, could consist of combinations of heat- and electric-driven units.

The delivery of district cooling could be provided with a district heating network to the degree it is possible and feasible. Chilled water network gives a possibility to use electric chillers for district cooling. Despite the cooling technique (electric or CHP-integrated heat-driven) or the distribution technique, cooling production in units of sufficient size guarantees higher energy efficiency than production in small-scale individual units. It must be emphasized that district heating and cooling systems also provide reliability and comfort to customers, the value of which is difficult to estimate.