

Integrating District Cooling with Combined Heat and Power (1996 N1)

SCOPE AND PURPOSE

This report describes the energy efficiency, economic and environmental implications of alternatives for integrating district cooling with Combined Heat and Power (CHP). The purpose of the report is to provide guidance to designers of district cooling systems to identify the best options for integrating district cooling with CHP in new plant facilities.

Each case will have its own particular technical and economic parameters, and this report is intended to aid in structuring the essential case-specific analysis, rather than substituting for such an analysis. Capital and operating costs for CHP and chiller technologies are presented, but significant variations in costs can occur due to currency values and other case-specific factors

For the purposes of this report, district cooling is defined as any system which provides building cooling through the distribution of chilled water, hot water or steam from a central plant. Thus, cooling achieved through distribution of district hot water or steam to drive absorption chillers located in buildings is also considered district cooling.

The report addresses:

- the thermodynamic fundamentals of CHP and cooling, providing a conceptual foundation for later quantification of the efficiency of alternative cooling/CHP options;
- the efficiency, air emissions and economics of alternative CHP technologies (gas turbine, reciprocating engine, steam turbine and gas turbine combined cycle);
- the efficiency, refrigerant environmental impacts and economics of alternative cooling technologies (electric centrifugal,

steam turbine centrifugal, one-stage steam absorption, two-stage steam absorption and hot water absorption);

- review of fundamental aspects of district heating and cooling systems which are relevant to integrating district cooling with CHP;
- the efficiency and economics of integrated cooling/CHP technology alternatives, including presentation of economic formulas, discussion of key economic variables and calculation of cooling costs for illustrative hypothetical scenarios; and
- case study examples of integrating district cooling/CHP.

ENERGY EFFICIENCY

Basis for Efficiency Comparisons

A consistent “figure of merit” for comparing the energy efficiencies of different options for combining CHP and cooling is problematic because each option, employed in a given circumstance, will produce different annual quantities of electricity, heating and cooling. Efficiency comparisons based on summing these three types of energy outputs will be misleading because they ignore the differing exergy qualities of electricity, heating and cooling.

Consequently, comparisons of the efficiencies of alternative CHP/chiller options were made on the basis of maximizing chilled water production. Heat-driven chillers were supplemented with electric-drive chillers using available electric output from CHP.

Findings Regarding Efficiency

1. If the goal is maximum cooling output per unit of fuel used, the CHP technologies rank as follows, from highest to lowest output:

- Gas turbine combined cycle
- Diesel engine
- Gas turbine
- Steam turbine

This ranking holds true regardless of the chiller technologies employed, although the extent of differences between the CHP types varied depending on the chiller technologies.

2. With a simple cycle gas turbine, the higher-temperature heat-driven chillers (supplemented by electric drive chillers) provide more cooling output than the lower-temperature options, with the electric-chiller-only option providing the lowest cooling output. This is also roughly true with a diesel engine, although the lower-temperature heat-driven options compare more favorably because the temperature of the useful thermal output of diesel engines is more limited compared to the gas turbine.
3. With steam turbine and gas turbine combined cycle CHP, the electric drive chiller provides the highest cooling output, followed by hot water absorption and other heat-driven options, roughly in order of increasing driving temperature. The differences between chiller types with gas turbine combined cycle are less than those for steam turbine CHP.
4. When combining cooling with CHP in new gas turbine combined cycle facilities, there are only small differences in overall efficiency between maximizing electric production and using electric drive chillers compared to extracting some of the thermal energy and using it to operate absorption chillers. The differences in practical efficiencies are within the range where specific equipment selection and design conditions will determine which alternative is most efficient.
5. Simple cycle gas turbine CHP can appear attractive from an efficiency standpoint when the thermal output is viewed as “waste heat.” However, it can be argued that this is because, from the standpoint of new plant design, total efficiency has not really been optimized with a simple cycle, i.e., generally there is the capability to generate additional electricity in a combined cycle.
6. For a new CHP facility, there is not a compelling argument for using heat generated through CHP to drive chillers as opposed to installing a condensing tail to drive electric chillers. However, this argument does not hold for the smaller end of the scale of CHP facilities (e.g. 5 MWe), where due to economies of scale it is generally not cost-effective to install a steam turbine to drive a generator in a combined cycle.

ECONOMICS

This report addresses the costs of generating cooling energy using CHP. However, distribution costs can be a significant part of the total cost of district cooling. Where a district heating system is well developed, distribution of “cooling energy” via the district heating loop for conversion with absorption chillers has the potential to be the most cost-effective option considering both plant and distribution costs.

The economics of integrated cooling/CHP options are highly dependent on many case-specific factors. The following discussion summarizes the results of the illustrative scenarios presented in the report for new CHP systems in the 20-25 MW_e size range under stated load and economic assumptions.

CHP options

1. In the illustrative scenarios, simple cycle gas turbine CHP provides the lowest cooling

cost at low values of electricity (3 cents/kWh_e), due in large part to its low investment cost.

2. Combined cycle gas turbine CHP provides the lowest cooling cost at higher electricity values (above 5 cents/kWh_e) as a result of its high electric efficiency. As electricity value rises, the competitiveness of the gas turbine combined cycle increases faster than the other CHP options.
3. With the potential for steam turbine CHP to be fired with lower-cost fuel, this CHP option has the potential to be the most cost-effective option depending on specific fuel costs.
4. In CHP plants under 20 MW_e, reciprocating engine CHP can become more competitive than indicated in the illustrative scenarios, and in CHP plants above 50 MW_e, steam turbine CHP has the potential to be more competitive than indicated.
5. Sensitivity of cooling costs to changes in fuel cost, heat value and electricity value is lowest in the warm climate because net CHP costs are spread over a relatively large number of cooling utilization hours. Conversely, sensitivity of cooling costs to these factors is highest in the cold climate because net CHP costs are spread over a relatively small number of cooling utilization hours.

Chiller options

1. Based on the illustrative scenarios, electric drive chillers combined with gas turbine CHP (at low electric values) and gas turbine combined cycle CHP (at high electric values) provided the lowest cooling costs for centralized chilled water district cooling. However, in many scenarios the cost differences between electric drive cooling and heat-driven options (supplemented with

electric drive) were quite small and can be considered insignificant in view of the many case-specific variables which can affect the calculations. In general, the costs of the CHP are more significant than the costs of the chiller equipment.

2. Generally, cost differences between the cooling technologies combined with simple cycle gas turbine and diesel engine CHP are very small because the electric output of these CHP technologies is not affected by thermal extraction. In contrast, with steam turbine CHP and to a lesser extent gas turbine combined cycle CHP, cost differences between chiller technologies are more significant because with the steam cycle the electric output decreases when thermal energy is extracted, and this derate increases with increasing thermal extraction temperature.
3. Aside from direct economic considerations, the value of flexibility and reliability may lead the system designer to install heat-driven chillers. For example, heat-driven cooling can help protect against penalties associated with a loss of power generation capacity at peak, since with heat-driven chillers the system operator can fire up relatively inexpensive standby boiler capacity.
4. For all CHP types, the economic differences between the heat-driven chiller options were relatively small, with costs slightly higher for chillers requiring higher-temperature driving energy. In essence, the higher investment costs for higher-temperature heat-driven options was to a large extent offset by their higher efficiencies.