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Performance Assessment of District Cooling System Coupled with Different Energy Technologies in Subtropical Area

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Abstract

In the subtropical urban area with a high density of buildings, district cooling system is regarded as an efficient alternative to supply cooling to a group of buildings with high efficiency and low cost. Appropriate design can render the district cooling system to achieve good performance. This paper attempts to study the performance of the district cooling system integrated with different energy technologies in a new development area. Performance of district cooling system with thermal storage system is calculated to level the energy consumption and reduce monthly bill. Results are compared with that of hydro pumped storage system and recommendations are given about the design and control the thermal storage system under current local tariff. The performance of district cooling system integrated with the combined cooling, heating and power system is also investigated to make full use of the primary energy. Performance of the system designed based on two ways are studied. Results show that the cogeneration system is beneficial for both the investors and users. Suggestions are given to help improve the performance of the district cooling system in the new development area by coupling with different energy technologies.

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*Keywords:*District cooling system; Thermal storage system; Cogeneration system; CCHP

1. Introduction

District cooling systems (DCSs) have been widely used for its high efficiency. The users can be commercial buildings, industrial buildings and residential buildings [1]. Sufficient studies have been done in the district cooling and heating systems including the design, operation and optimization. Sakawa [2] tried to predict the cooling and heating load of a district cooling and heating system with artificial neural

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network. A district heating and cooling system integrated with a thermal solar plant was studied by Pedro [3]. An operational optimization study of a trig-generation system coupled with DCS was conducted by Jordi [4]. A district cooling and heating system in Japan was studied by cooperating the operation of the central plant and the air conditioning system of end-user buildings [5].

In subtropical areas DCSs can be used, especially in the urban area with high density of buildings, like Hong Kong. However, few studies have studied the application of DCS in such area. To support the development of the city, Hong Kong government reclaims land from the mountain area and plans to develop a new district. By adding a new district accompanying with increasing population, the electricity demand of the entire city will be largely increased. It definitely will increase the load of the existing power station. DCS is proposed to supply cooling for this new district. To reduce the peak demand of the grid and meet the cooling and electricity demand simultaneously, three ways can be used:

1) The first is to couple DCS with energy storage system at user side. Energy is stored during off-peak time and released during peak time to reduce the peak energy consumption, such as thermal storage system.
2) The second is to couple DCS with hydro pumped storage system at the power supply side. During off-peak time, water is pumped from a lower reservoir to a higher reservoir and energy is stored in the form of potential energy. During peak time when the electricity demand is high, power is generated by releasing the water through the turbines[6].
3) The third one is to couple DCS with combined cooling, heating and power (CCHP) system, which is to install a local power generation system to meet the cooling, heating and power demand of buildings simultaneously. In the subtropical area where the heating is not required and the cooling is dominated, the study of DCS with CCHP is not sufficient yet.

To reduce the peak electricity demand and apply DCS in this new district, it is necessary to conduct a feasibility study by integrating DCS with different energy technologies. Initial optimization of the integrated system is conducted. The energy performance of DCS coupled with ice storage system based on different methods is studied and compared with that of hydro pumped storage system. The performance of the DCS coupled with CCHP system based on two design methods is investigated and discussed.

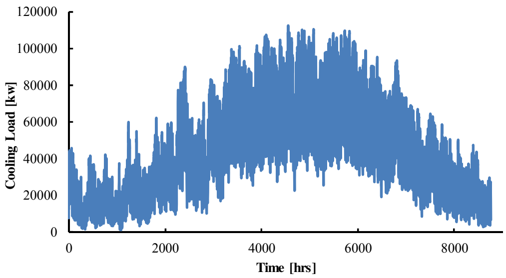

Fig.1 Annual hourly cooling load of the district

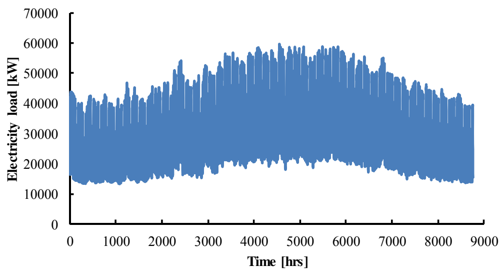

Fig.2 Annual hourly electricity load of the district

2. Method

2.1. System description

DCS is planned to supply cooling for commercial and public buildings in the new development area. Cooling loads are calculated based on the preliminary plan of the government. Totally 37 buildings are involved. The cooling loads and electricity loads are calculated and the results are shown in Fig. 1 and Fig.2. The DCS is designed based on the cooling load. 10 identical chillers with a capacity of 3400 tons are selected, together with 10 groups of chilled water pumps and cooling water pumps.

2.2. Models used in the study

Three kinds of chillers are used in the system: basic electrical compressor chillers to cool the chilled water, double-effect chillers to make ice for the ice storage system, and the absorption chiller used in the CCHP system. Detailed introduction for the chillers can be obtained from the reference [7]. Parameters for other components are listed in the Table 1.

Table.1 Parameters for models used in the simulation

Parameter	Value
Pump head for the chilled water pump	55m
Pump head for the cooling water pump	23m
COP for the entire ice charging system	3
COP for the absorption chiller	0.8
Efficiency for the power generation	0.3
Efficiency for the cooling	0.4
Efficiency for hot water	0.1

Table 2 Tariff in Guangzhou

Limitation		Price(USD/kwh)				
		Base Price	City construction surcharge	Large water conservation project fund	Reservoir tranfer fund	Total
Time of use	Peak time	0.16	0.00	0.00	0.00	0.16
	Normal time	0.09	0.00	0.00	0.00	0.10
	Base time	0.05	0.00	0.00	0.00	0.05

Note: Peak time: 14:00-17:00, 19:0-22:00; Normal time: 8:00-14:00, 17:00-19:00, 22:00-24:00; Base time: 0:00-8:00

Table 3 Tariff in in Hong Kong

Tariff type	Item				
	Demand charge (USD/kVA)		Energy charge(USD/kWh)		Fuel clause(USD/kWh)
	peak period	off-peakperiod	peak period	off-peakperiod	all the time
Large Power Tariff	14.7 (first 5000)	0.0 (less than the on-peak peak)	0.065(first 200 kWh/kVA)	0.053	0.029
	14 (Exceeding part)	4.14 (Exceeding part)	0.062 (Exceeding part)		
Ice-Storage Air-conditioning Tariff	8.36 (first 650)	0 (less than the on-peak peak)	0.086 (first 200,000)	0.076	0.029
	8 (exceeding part)	3.27 (lager than the on-peak peak)	0.084 (exceeding part)		

3. DCS with Thermal Storage System

Ice storage system is used in this study. Three methods can be used to size and control the ice storage system: full storage, partial storage based on load levelling and partial storage based on demand limiting. In this paper, two methods are tested: full storage and partial storage based on load levelling. The government of Hong Kong gives special tariff for users using ice storage system. Guangzhou is a city close to Hong Kong with similar climate but the tariff is very different as shown in Table 2. To compare the performance of DCS with ice storage system under different tariffs, cost under Guangzhou Tariff is also calculated. The tariff of Hong Kong is shown in Table 3.

3.1. Results of DCS with thermal storage system based on full storage

Full storage means that the cooling during peak time is totally met by ice storage system. The electricity cost under Hong Kong tariff is shown in Table 4. It can be seen that DCS with full ice storage system under Hong Kong tariff is not feasible. With the ice storage system, the annual operation cost is increased by 27.4%. The extra capital cost for the storage system cannot be paid back under such tariff. It demonstrates that DCS with full ice storage system is not efficient in Hong Kong.

Table 4 Cost for DCS with and without ice storage in Hong Kong

	Demand bill($)	Energy bill($)	Fuel bill($)	Total bill($)	Average($/kwh)
DCS without ice storage	3253931.108	5091913.943	2463672.493	10809517.54	0.126814716
DCS with ice storage	1492824.7	8931363.513	3347391.205	13771579.42	0.118911428

The operation cost under Guangzhou tariff is shown in Table 5. It shows that the cost for DCS with ice storage system can be largely reduced. When the cooling during the peak time is met by the ice storage system, the operation cost can be reduced by 18%. If the cooling at both the peak time and normal time is met by the ice storage system, the annual cost can be reduced by 22%. It shows that the tariff incitement is very important for the use of ice storage system. If the Hong Kong government wants to reduce the peak demand largely, current tariff has to be revised and enlarges the electricity price difference between the peak time and the off-peak time.

Table 5 Cost for DCS with and without ice storage system under Guangzhou tariff

	Peak time ($)	Normal time ($)	Valley time($)	Total($)	Average($/kwh)
No storage	803849.5	3850193.1	4168010.8	8822053.4	0.1
ice storage for peak time	2646871.9	3850193.1	750150.3	7247215.3	0.07
ice storage for peak and normal time	5426898.3	691822	750150.3	6868870.7	0.05

3.2. Results of DCS with thermal storage system based on load levelling

Based on the load levelling method, several chillers can be shut down during the peak time to reduce the peak demand. Detailed chiller numbers to be shut down can be determined by checking the load profile of the month. The best is to reduce the peak demand largely without consuming too much extra energy. Results are shown in Fig.3, which shows that larger percent of cost can be saved during January, February, March, April, October and December. All these months are the cooler time of the year such as winter, the beginning of spring and the end of autumn, when the cooling load is lower. During the hot summer, the saving percent is not very high. That's because the cooling load keeps high constantly all the summer. The lasting period when all the chillers are turned on is long. The annual average cost saving of the DCS with ice storage based on load levelling is about 4%, which is very promising.

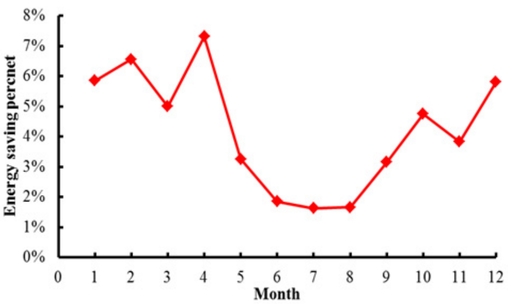

Fig.3 Operational cost saving of DCS with ice storage system based on load levelling

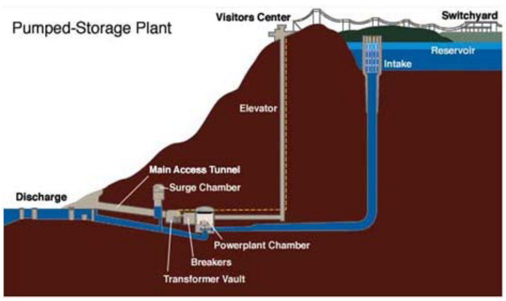

Fig. 4 Schematic diagram of a hydro pumped storage system

4. DCS with Hydro Pumped Storage System

Hydro pumped storage systems are usually used at the power plant side to help balance the electricity demand and supply. The system is consisted of two reservoirs at different heights. The schematic diagram of a hydro pumped storage system is shown in Fig.4 [8]. To meet the peak electricity and cooling demand of the district, the performance of DCS with hydro pumped storage system is calculated in this section. The results are compared with the DCS integrated with thermal storage system.

The performance of hydro pumped storage system and thermal storage system was compared by the paper [9]. It concluded that ice storage system was much more efficient than the hydro pumped storage system. The energy flow is shown in Fig.5. However, three parameters are vital to determine the final results: the pumped storage efficiency, the COP of the ice storage system and the COP of the basic cooling system. The cooling produced by unitary primary energy at different COPs and efficiencies of hydro pumped storage system is shown in Fig.6. It shows that if the COP for the thermal storage system is lower than 2.3, the hydro pump storage system will always be more efficient. It can be seen that the advantage for thermal storage system is not so apparent. One character of hydro pumped storage systems is that the capital cost is very high. If no such system exists, thermal storage can be a good choice to reduce the peak load of local grid. If the existing hydro pumped storage system can accommodate the increased electricity demand, it is recommend to be used to reduce the peak demand. The decision may be made based on the local policy and electricity tariff.

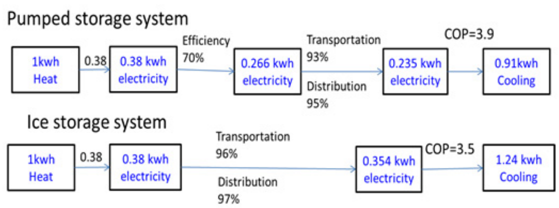

Fig.5 Energy flow of hydro pumped storage system and thermal storage system in the reference [9]

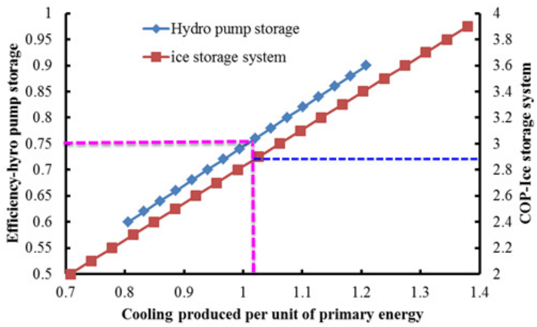

Fig.6 Cooling production by hydro pumped storage system and ice storage system

5. DCS with CCHP System

When DCS couples with CCHP system and is used in this new district, it supplies cooling, electricity and hot water simultaneously. The hot water is supplied to hospitals or residential buildings of this district. When designing a CCHP system, there are two ways to determine how large the plant should be built. One is based on the thermal demand, which means the capacity of the plant should supply sufficient heating/cooling to the users. In this paper, it means the cooling demand should be met firstly. Surplus electricity will be sent to the grid. If the electricity production cannot meet the demand, it has to take from the grid. The other is based on the electricity demand, which is to size the system to meet the electricity demand of the district. Both methods are tested and compared with the system that depends on the grid.

The DCS coupled with CCHP system can be sized based on the Fig.1 and Fig.2. Results of the integrated systems based on both methods are shown in Table 6. From Table 6 it can be seen that the DCS coupled with CCHP consumes much less gas than totally taking from the grid. When the system is sized based on the thermal demand, DCS with CCHP system consumes 30% less natural gas than the grid when producing the same amount of electricity, cooling and hot water. When the system is sized based on the electricity demand, DCS with CCHP system can save 21% of gas. However, the capital cost is not calculated here because the cost may differ largely from project to project.

Table 6 Energy consumption of DCS with CCHP vs. DCS with grid

	Design basis	Surplus electricity (kwh)	Electricity from grid(kwh)	Hot water(kwh)	Gas used by CCHP(kwh)	Gas used by grid (kwh)	Total Gas (m3)
DCS with CCHP	Thermal demand	79307089.5	49272559.3	76261749.7	762617497.4	140778740.9	91385479.88
	Electricity demand	0	51901827.7	66250239.7	662502396.9	148290936.2	82017983.6
DCS with local grid	Thermal demand	79307089.5	293033012.9	76261749.7	0	448601852.1	129655796.4
	Electricity demand	0	293033012.9	66250239.7	0	359283252.6	103840757.7

6. Conclusions

Performance of the DCS with different energy systems is calculated and compared in subtropical area. After all the discussions, the following conclusions can be obtained:

1) Full ice storage system is not feasible under current Hong Kong tariff. The tariff must be changed and the difference of electricity prices between peak time and off peak time should be enlarged.
2) DCS with ice storage system based on the load levelling method can save around 4% of the annual operation cost, which is recommended in the design of DCS.
3) The performance difference of hydro pumped storage system and thermal storage system depends on the equipment and efficiency of the system. Detailed comparison and check is strongly recommended before the decision is made.
4) DCS with CCHP is very beneficial than just taking electricity from the grid. It can save around 30% primary energy than the traditional DCS system.

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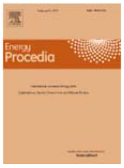

Biography

The corresponding author is Chair Professor of Department of Building Services Engineering in the Hong Kong Polytechnic University. Research interests include building energy management, optimal and robust control of air-conditioning systems, dynamic simulation of building systems, etc.