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Optimization of ice making period for ice storage system with flake ice maker

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ABSTRACT

Ice storage system can be used to shift electrical load from on-peak hours to off-peak hours, which can bring mutual benefits to power supplier and consumers. But if it does not operate properly the economic benefit will not be achieved. There is an ice storage system with flake ice maker that have been installed in Donghua University. In this paper, the characteristics of phase-change heat transfer of flake ice maker is studied. According to the different temperature of water washing the plate of evaporator and air conditioning load characteristic, the operation parameters are optimized. The optimized operation strategy of this ice storage system is presented according to its heat transfer characteristic.

1. Introduction

With the development of economy of China, the consumption of electricity improves greater and greater, and the peak load and the peak to valley ratio have both been increasing fast. For example, the consumption of electricity of Shanghai city is shown in Fig. 1, Ref. [1], the peak load has reached more than 1000MW and the peak to valley ratio has exceeded 60%. According to the latest data from Shanghai municipal electric power company, the last year's maximum load of Shanghai is 19,543 MW and this year is up to 21,208 MW. More than 40% of the consumption of electricity of Shanghai city is due to the utility of air condition, and this ratio is below the number of developed countries above 60% [2]. So the consumption of electricity and the electric power shortage due to air condition will become more seriously in future. The ice storage air condition (ISAC) system has been used more and more due to its super capability for peak load shifting and leveling, which can bring mutual benefits to power supplier and consumers.

In this paper, an ice storage system with flake ice maker which is installed in Donghua University is introduced. The phase-change heat transfer characteristics of flake ice maker is studied and the optimization of operating strategy is presented.

2. The ice storage system with flake ice maker

Donghua University is located at Songjiang University City of Shanghai, and its supply of cooling energy is from a district cooling plant installed at the basement of the library and information centre. The total air condition area is more than 52,000 m^2 including 5 office buildings and the library and information centre. The per-hour cooling load of design day of Donghua University is shown in Fig. 2, and the cooling load during 0:00–8:00 and 22:00–0:00 are close to zero. The ice storage district cooling plant with flake ice maker is shown in Fig. 3. There are four screw chillers with flake ice maker which total cooling capacity is 8970 kW (2500RT).

The plant is a storage-led arrangement. The ice storage tank is located downstream of the evaporator of the chiller. The chiller can be run at full load with the highest operating temperature and the best COP is possible in this arrangement. A bypass line carrying a three-way valve is provided across the chilled water supply and the load to moderate the release rate of the stored cooling energy [3,4] pointed out that larger chilled water temperature differential can be achieved and more energy saving can be provided in storage-led arrangement.

The plant is a partial storage system that a portion of the on-peak cooling load is provided by the storage and the remaining portion is by the chillers. The control strategy of the plant is storage-priority that the release of the cooling energy from the ice storage is given over the use of the chiller. The major advantage of storage-priority is that it makes more use and operation of the chillers at night for ice making so that both the energy cost and demand charge can be reduced through load shifting [6].

3. Heat transfer characteristics of flake ice maker

The ice making process of flake ice maker is shown in Fig. 4. Each screw chiller has 8 sets of vertical plate of evaporator. The liquid of

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Nomenclature

A	area of the plate of evaporator (m)
c	specific heat (kJ/(kg K))
E	total energy consumed (kJ)
h	enthalpy (kJ/kg)
L	latent heat of phase change (kJ/kg)
P	power capacity of chiller (kW)
q	heat flux (kW)
s	thickness of ice layer (mm)
t	temperature (K)
v	velocity relevant to interface (m/s)
Greek letters	
α	coefficient of heat convection (kW/(m^2 K))
η	efficiency of ice making
λ	coefficient of heat conduction (kW/(m K))
μ	efficiency of heat pump
ρ	density (kg/m^3)
τ	time (s)
Subscripts	
d	dumping ice layer
l	liquid
op	optimum
p	phase change
ps	pressure constant
s	solid
t	ice storage tank
w	the plate of evaporator
∞	main flow
1	inside of the plate of evaporator
2	outside of the plate of evaporator

refrigerant flows and evaporates in the plate of the evaporator. The chilled water drawn from the ice storage tank washes the two outside surface of it. One part of the chilled water is frozen on the surface and the other part flows down back into the ice storage tank. Then the thickness of the ice layer grows. It is convection that heat is transferred from chilled water to ice layer. Then the heat is conducted through ice layer to plate of evaporator. Last the heat is transferred to refrigerant by convection from plate of evaporation, which provides the energy for refrigerant to evaporate. When the thickness of ice layer grows to some extent (3–6 mm generally [7]), then the chiller is operated in process of ice dumping, which the four-way valve is adjusted then the chiller is operated as heat pump and high temperature vapor is introduced into plate of evaporator to melt the ice layer. After a little of ice layer is melted, the ice layer is fallen into ice storage tank by gravity. Then a period of ice making is over.

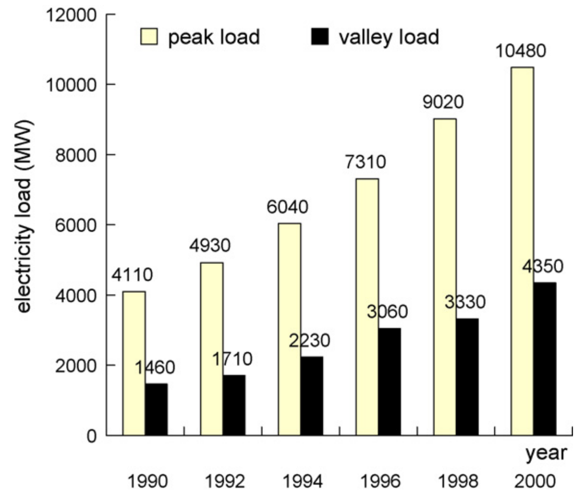

Fig. 1. The growth of electricity power load of Shanghai city during the past decade.

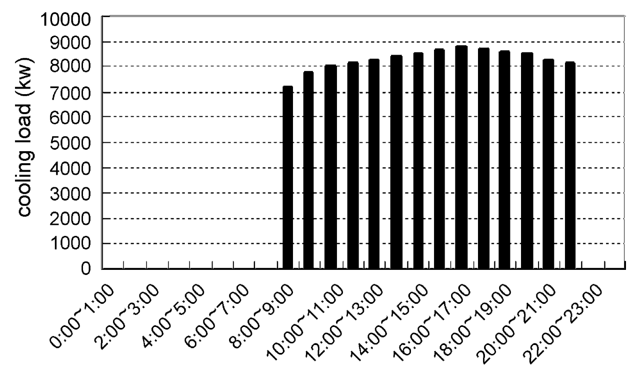

Fig. 2. Per-hour cooling load of design day of Donghua University.

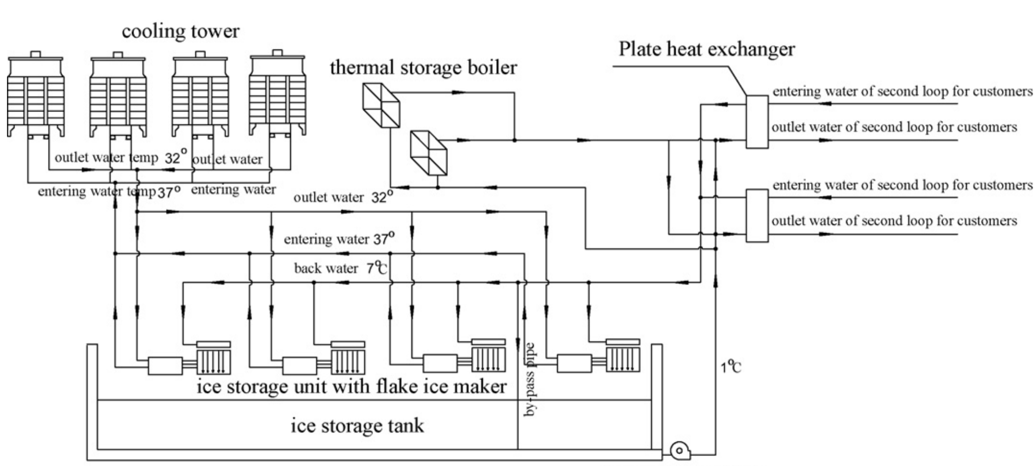

Fig. 3. The schematic diagram of the ice storage district cooling plant of Donghua University.