

Economic Analysis of Ice Storage Air Conditioning System of Chao Yang Plaza in Beijing

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Abstract: In this paper, an economic mathematics model was founded to analyze the economic technology properties of an ice storage air conditioning system of Chao Yang plaza at Beijing. The Power input of the ice storage system of Beijing Chao Yang Plaza air conditioning engineering was compared with that of a conventional air conditioning system if it used for the engineering. The impactation of the operation strategy to the economic technology properties of the ice storage air conditioning system was also investigated. The operating cost of ice storage system is lower than that of an ordinary air conditioning system, and the difference of time-shared electrovalence is bigger, the profit is more. The operating strategy of a priority of release cold quantity is should be adopted in order to reduce the operating cost.

Keywords: ice storage air conditioning system, operating strategy, time-shared electrovalence

NOMENCLATURE

A	transport cost [yuan]
B	Installation/debugging cost [yuan]
C	total cost [yuan·kW/h]
D	power rate per day [yuan/day]
d	days of air conditioning in summer [day]
E	total electrovalence [yuan]
E _d	power rate per year [yuan/year]
E _j	basic power rate [yuan/year]
F	total maintenance and repair cost [yuan]
J	basic electrovalence [yuan/kW·Month]
L	increased capacity cost of power [yuan]
M	first cost of air conditioning system [yuan]
Ms	first cost of equipments [yuan]
n	operational life of system [year]
P	distribution capacity of system [kW]
P _x	demand of electricity in the peak period [kW]
P _y	demand of electricity in the flat period [kW]
P _z	demand of electricity in the valley period [kW]
Q ₁	total cooling load per year [kW/h/year]
W	lifetime-average total operating cost [yuan]
X, Y, Z	electrovalence in the peak, flat, valley period, [yuan/kW]

1. INTRODUCTION

The technology of ice storage is that it adopts electric refrigerating engine to refrigerate and uses sensible heat or latent heat of cool-storage mediator to store cold quantity in one method during the nighttimes when the electrical load is very low and it yet release the stored cold quantity to meet the need of structure's air conditioning or production technology in the daytime when the electrical load is higher^[1]. Because of the increasing of the peak-to-valley difference in municipal electric power in China, on the one hand, the investment of power

construction is more and more growing to meet the demand of electricity during the peak; on the other hand, the electric load during the valley is increasing slowly, or even falling. One of the mayor reasons of the increasing of the peak-to-valley difference in municipal electric power is the prevalent of air conditioning, and the technology of ice storage is an effective method to solve the problem^[2].

Comparing with the conventional air conditioning system, refrigeration plants capacity and installed power of ice storage system are less by 30%~50%; their one-off investment is higher. However, their investment is probably equivalence or increases few; their operating cost is lower because electric power department performs time-shared electrovalence policy, and the difference of time-shared electrovalence is bigger, the profit is more^[1]. The operating strategy of ice storage system has two kinds, including total storage and component storage. The total storage is that the cooling load in the daytime is provided completely by the cold quantity stored in the nighttimes. Compared with other ice storage scheme, refrigeration plants' capacity of total storage is biggest and the first cost is relatively most, but the power rate is lowest due to using the night low cost electricity. However, in the component storage, one part of the cooling load in the daytime is the cold quantity stored in the nighttimes; another part cold is provided by refrigeration plants. The characteristics of component storage are that the utilization ratio of refrigeration plants is high and storage plants capacity is less than that of total storage, but the operating cost grows^[1-3].

Due to these characteristics of ice storage system, people have more and more focused its economic problem. In this paper, the model for economic analysis of ice storage system was established. Using this model an analysis of an existing ice storage air

conditioning system was carried out, and the results were compared with those of a conventional air conditioning system. And the economy of ice storage systems under different operating strategies was analyzed.

2. ECONOMIC MODELS

Assumed:

(1) Except the water chilling units and ice storage units, other equipments are identical between conventional and ice storage air conditioning system;

(2) The electrovalence is unchanged in the operational life;

(3) The cooling load is unchanged in the operational life.

2.1 The Index of Overall Cost

The lifetime-average total cost per unit cooling load is adopted to evaluate the economy of ice storage air conditioning system. The index of overall cost is [4]:

$$C = \frac{M + W}{n \cdot Q_1} \quad (1)$$

The total cost of conventional and ice storage air conditioning system are respectively computed, and then the difference of them is compared. If the difference is positive, it may show that ice storage system is more economic than conventional air conditioning system; if the difference is negative, the cause is opposite.

2.2 The Calculation of First Cost

The first cost includes the investment of building projects and equipments, transport cost of equipments, installation and debugging cost of equipments, increased capacity cost of electric power, tools and reserve parts cost, other cost and so on. The difference in building projects of ice storage and conventional air conditioning system is very little [1]. The first cost is only accounted the investment of equipments, transport cost of equipments, installation and debugging cost and increased capacity cost of electric power[4]. If calculated other cost, the cost may be added into the model. The first cost is:

$$M = M_s + A + B + L \quad (2)$$

The basic parameters of transport cost and installation and debugging cost of equipments are shown in the table 1[1].

Increased capacity cost of electric power is

$$L = mP \quad (3)$$

2.3 The Calculation of Operating Cost

Operating cost includes power rate, maintenance and repair cost of equipments, labour cost, management cost and so on. However, because the economic level of different area is different, the operating cost is only accounted power rate and maintenance and repair cost of equipments. The total operating cost of air conditioning system in the operational life is given by:

$$W = E + F \quad (4)$$

The lifetime-average total power rate is the summation that basic power rate plus kilowatt-hour meter power rate in the operational life. The basic electrovalence per year may be given by:

$$E_j = 12JP \quad (5)$$

The kilowatt-hour meter power rate per year is:

$$E_d = dD \quad (6)$$

The kilowatt-hour meter power rate per day is:

$$D = XP_x + YP_y + ZP_z \quad (7)$$

The lifetime-average total maintenance and repair cost is calculated by 5 % of the first cost of equipments.

3. THE ANALYSIS OF EXAMPLE

3.1 Building General Situation

Beijing Chao Yang Plaza is about 210 thousand square-meter and the area of air conditioning is 150 thousand square-meters. The highest designed cooling load is 19980kW and the total cooling load is 67681kWh. The hour-by-hour load is shown in the Fig. 1.

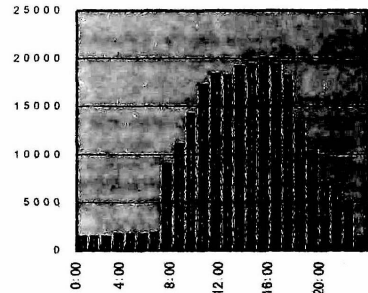


Figure 1: Distribution of hour-by-hour load

The number of days of summer air conditioning is 180 days and the designed operating time of air conditioning is from 0:00 to 23:00. The equipments list of ice storage and conventional air conditioning system is demonstrated in the table 1.

Table1: The equipments list of air conditioning system

model number and specification	number	capacity (KW)
refrigerating output:1170RT	3	748
refrigerating output:757RT		687
refrigerating output:500RT	1	323
HX-12 heat exchange area:29.4m ²	735pieces	0
heat exchange output:1170RT	3	0
heat exchange output:1671RT	1	
refrigerating utput:1400RT*	4	898
refrigerating output:500RT*	1	323

3.2 The Operating Strategy

In this ice storage air-conditioning system, the component storage strategies, which load equalization, is adopted and the load in the nighttimes is provided by base-loaded host machine. Based on this strategy, the system has four operating modes, such as making ice of host machine, refrigerating of melting ice and host machine, refrigerating of melting ice, and refrigerating of electric refrigerators. The ice storage operating strategy figures under different loads are depicted in the Fig 2- Fig 5.

3.3 The First Cost

The comparison with the first cost of ice storage and conventional air conditioning system of Beijing Chao Yang Plaza is shown in the table 2. The increased capacity cost of electric power may equal to 450 yuan/kW.

Table 2: The first cost of ice storage and conventional air conditioning system (thousand yuan)

item	ice storage system	conventional system
refrigeration equipments	8819	13420
ice storage equipments	5733	0
heat exchanger	1801	0
transport cost	1145	939
installation cost	3532	403
increased capacity cost	1155	1762
the total cost	22185	16524
the difference	5661	

3.4 The Operating Cost

The time-share electrovalence in Beijing is demonstrated in the table 3.

Table 3: The time-share electrovalence in Beijing

time-interval	the start time and end time		electrovalence (yuan.kWh ⁻¹)
peak	8:00	11:00	1.064
	18:00	23:00	
flat	7:00	8:00	0.713
	0:00	0:00	
	11:00	18:00	
valley	23:00	7:00	0.26

The operational life of equipments is 15 years and the number of days of summer air conditioning is 180 days in a year. In the 180 days, the number of days of 100% cooling load is 2 days; the number of days of 80% cooling load is 60 days; the number of days of 60% cooling load is 75 days; the number of days of

30% cooling load is 43 days. Including to the operating strategies of different loads and the time-share electrovalence, the operating cost per day of different loads may be calculated. Then the operating cost per year may be calculated based on the number of days of different loads in a year. The operating cost of ice storage air conditioning system is shown in the table 4.

Table 4: The operating cost of ice storage system (thousand yuan)

operation cost per year	the total power rate	the total maintainan cost	the total operating cost
2586.5	38797.5	110.9	38908.4

Table 5: The operating cost of conventional air conditioning system (thousand yuan)

operation cost per year	the total power rate	the total maintainan cost	the total operating cost
3819.3	57289.5	82.6	57372.1

The operating cost of conventional air conditioning system is shown in the table 5. The comparison with the operating cost of ice storage and conventional air conditioning system is demonstrated in the table 6.

Table 6: Comparison of the operating cost of ice storage and conventional air conditioning system (thousand yuan)

system	operating cost per year	difference of operating cost per year	the total operating cost	the difference of total operating cost
ice storage system	2586.5	-1232.8	38908.4	-18463.7
Non ice storage system	3819.3		57372.1	

As is shown in the table 6, compared with the conventional air-conditioning system, the operating cost per year of ice storage system is less by 1232.8 thousand yuan and the lifetime-average total operating cost of ice storage system is less by 18463.7 thousand yuan.

3.5 The Comparison of The Index of Total Cost

Based on the calculated results of ice storage and conventional air conditioning system, the total cost can be calculated through the mathematic mode, and then the results are shown in the table 7.

Table 7: Comparison of the he index of total cost of ice storage and conventional air conditioning system (thousand yuan)

system	the total first cost	the total operating cost	the index of total cost	the difference of index of total cost (yuan/kW h ⁻¹)
ice storage system	22185	38908.4	5.577	-1.169
Non ice storage system	16524	57372.1	6.746	

As shown in the table 7, the lifetime-average total cost per unit cooling load of ice storage system is 0.1169 yuan.kWh⁻¹ less than that of conventional air conditioning system. From the results, we can see that ice storage air conditioning system is more economic than the conventional air conditioning system based on the time-shared electrovalence.

3.6 The Comparison of Different Operating Strategies

The operating strategy above is a priority of release cold quantity, and the following strategy is a priority of refrigeration units. The operating strategy figures of ice storage system under different loads are depicted in the Fig. 6~Fig. 8. The operating cost of ice storage air conditioning system under this strategy is shown in the table 8. The comparison with the operating cost under the strategy of a priority of release cold quantity and refrigeration units is demonstrated in the table 9.

Shown as in the table 9, the operating cost under the strategy of a priority of release cold quantity is less than that under the strategy of a priority of refrigeration units.

4. CONCLUSIONS

(1) The total first cost of an ice storage system is more than that of a conventional system;

(2) The operating cost of an ice storage system would be lower than that of a conventional system when the electric power department performs time-shared electrovalence policy;

(3) The economy of ice storage and conventional air conditioning system has been compared by the index of lifetime-average total cost per unit cooling load. The difference (ΔC) can reflect in straight the economic returns of ice storage air conditioning system. Through calculated, the ΔC of Beijing Chao Yang Plaza is negative. Therefore, the project, which adopts ice storage system, may have good economic returns;

(4) The ice storage air conditioning system has good economic returns by using the difference of time-shared electrovalence. Therefore, the operating strategy of a priority of release cold quantity is should be adopted in order to reduce the operating cost.

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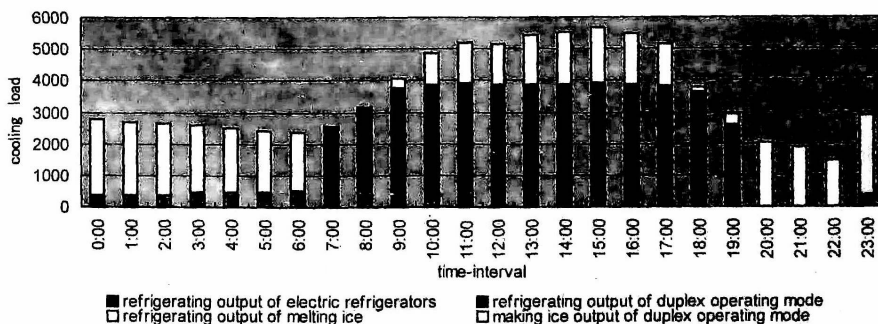


Figure 2: Ice storage system operating strategy under 100% load

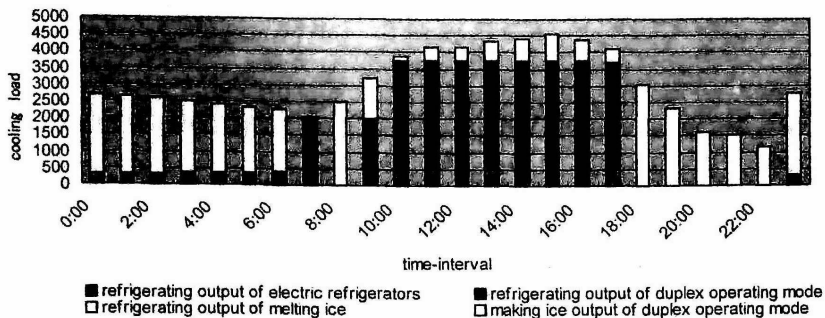


Figure 3: Ice storage system operating strategy under 80% load

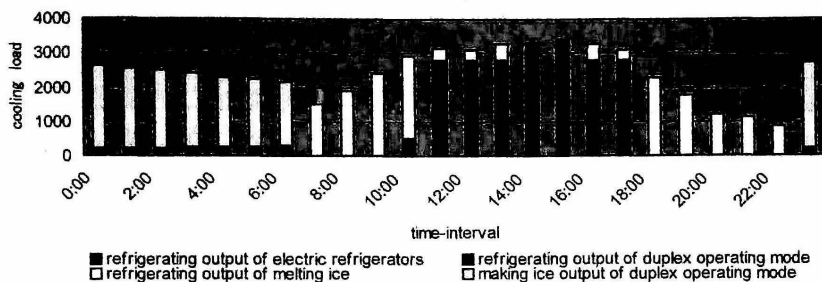


Figure 4: Ice storage system operating strategy under 60% load

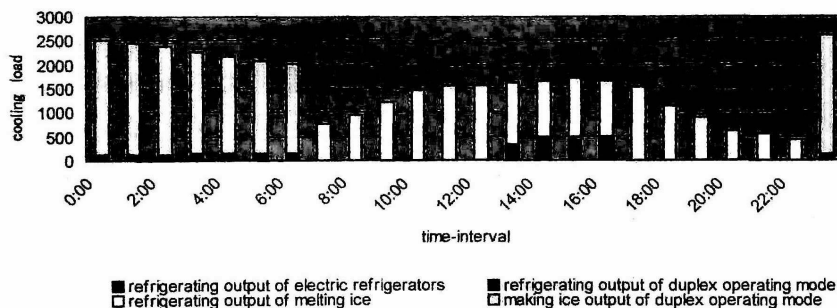


Figure 5: Ice storage system operating strategy under 30% load

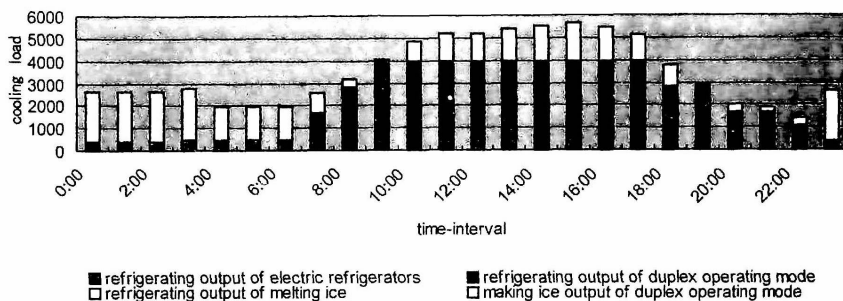


Figure 6: Ice storage system operating strategy under 100% load

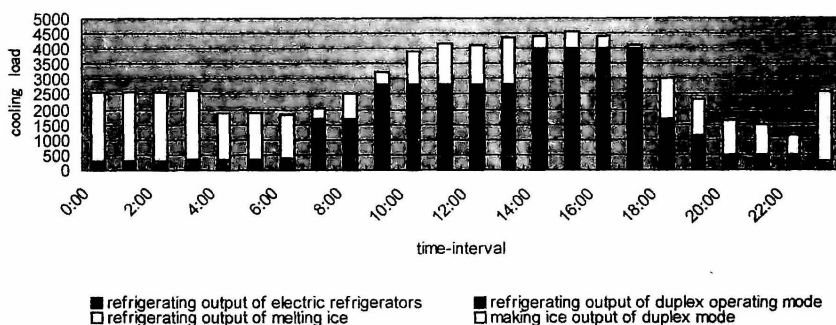


Figure 7: Ice storage system operating strategy under 80% load

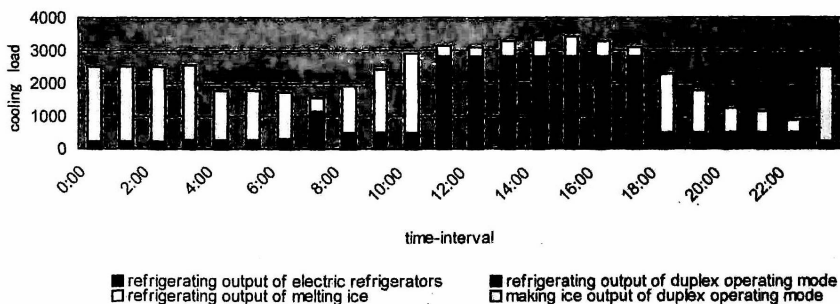


Figure 8: Ice storage system operating strategy under 60% load