

Economical Analysis of an Air-Conditioning System with Ice Storage Refrigeration in Civil High Rise Residential Buildings

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Abstract: Compared with the public constructions having only diurnal cooling load, the air-conditioning system with ice storage refrigeration in civil high rise building has its particularity in refrigeration, that is, the cooling capacity must be supplied at night for the common public construction that has very small load difference between day and night. So the basic refrigerating unit must be equipped to meet the requirement of cooling load at night. Usually, the basic refrigerating unit should vary its refrigeration capacity with diurnal load to get a balance of cooling capacity, but this method can't exert the proper potential ability of the refrigeration supplied by melting ice stored. Therefore, the proportion of the load supplied by the basic refrigerating unit must be adjusted to a proper value to utilize the advantages of ice storage system, which can store ice by means of refrigeration powering the unit by low price of electricity at night and provide cooling capacity during the daytime. It could decrease the maintaining cost and increase the economical benefits. Based on a design of an air-conditioning system with ice storage refrigeration in a civil high rise residential constructions of 30000 square meters, the relationship between the operating cost in summer and the cooling capacity of the main refrigerating unit under basic load will be established, and the ratio of cooling capacity provided by the main refrigerating unit will be optimized to meet the amount of melting ice and cooling capacity supplied by the basic refrigerating unit under the working condition of non-design diurnal load.

Keywords: ice storage, civil construction, basic load, optimization

NOMENCLATURE

D — hours for refrigeration unit running during day (h);

M_n — annual operating cost of concentrated air-conditioning (Yuan);

M_{nc} — original cost of concentrated air-conditioning (Yuan);

M_x — annual operating cost of ACSISR (Yuan)

M_{xc} — original cost of the ACSISR (Yuan);

M_z — price of the main refrigerating unit (Yuan);

N — hours for making ice by refrigeration unit at night (h);

N_h — reclaiming period of the ACSISR (year);

Q_{max} — maximal cooling load designed in peak hours (kW);

R_1 — cooling load of refrigeration unit at ice making state (kW);

R_2 — cooling load of refrigeration unit at refrigeration state (kW);

R_3 — capacity of the main refrigerating unit at different value of

T_{cc} — difference of original cost without main refrigerating unit (Yuan);

η — change rate of compressor capacity, $\eta = 0.7$ for screw compressor;

η_b — ratio of basic load during daytime;

$\triangle$ — main refrigerating unit making ice;

$\square$ — main refrigerating unit refrigerating;

$\bigcirc$ — equipment of accumulating ice melting ice.

1 INTRODUCTION

The conflict between supply and demand in electric energy is growing more seriously at the rush hour of using electricity for resident air-conditioning. In recent years, the electricity used of urban air-conditioning has gotten overload of 40% of the total power-net load during the period of rush hour.^[1] It is indicated based on a research that the central air-conditioning mode will save more energy than the separated air-conditioning mode when the number of air-conditioners used approaches a limited value^[1]. However, an air-condition system with ice storage

Table 1 The electrovalence at different time in Beijing

Peak hours and valley hours for electric energy in Beijing			
Time	Peak hours	Normal hours	Valley hours
	8: 00: 00~12: 00: 00	6: 00: 00~8: 00: 00	23: 00: 00~6: 00: 00
	18: 00: 00~23: 00: 00	12: 00: 00~18: 00: 00	
Electrovalence	0.9550Yuan/kWh	0.6150Yuan/kWh	0.2960Yuan/kWh

Table 2 The running state of the ACSISR at different time

Working time	Work modes of equipments			Electric status	Electrovalence	Coefficient of cooling load	Cooling load (kW)
1: 00~2: 00	△			Valley	0.2960	0.16	272
2: 00~3: 00	△			Valley	0.2960	0.16	272
3: 00~4: 00	△			Valley	0.2960	0.25	425
4: 00~5: 00	△			Valley	0.2960	0.25	425
5: 00~6: 00	△			Valley	0.2960	0.25	425
6: 00~7: 00		□		Normal	0.6150	0.50	850
7: 00~8: 00		□		Normal	0.6150	0.59	1003
8: 00~9: 00		□	○	Peak	0.9550	0.67	1139
9: 00~10: 00		□	○	Peak	0.9550	0.67	1139
10: 00~11: 00		□	○	Peak	0.9550	0.75	1275
11: 00~12: 00		□	○	Peak	0.9550	0.84	1428
12: 00~13: 00		□	○	Normal	0.6150	0.90	1530
13: 00~14: 00		□	○	Normal	0.6150	1.00	1700
14: 00~15: 00		□	○	Normal	0.6150	1.00	1700
15: 00~16: 00		□	○	Normal	0.6150	0.92	1564
16: 00~17: 00		□	○	Normal	0.6150	0.84	1428
17: 00~18: 00		□	○	Normal	0.6150	0.84	1428
18: 00~19: 00		□	○	Peak	0.9550	0.74	1258
19: 00~20: 00		□	○	Peak	0.9550	0.74	1258
20: 00~21: 00		□	○	Peak	0.9550	0.50	850
21: 00~22: 00		□	○	Peak	0.9550	0.50	850
22: 00~23: 00		□	○	Peak	0.9550	0.33	561
23: 00~24: 00	△			Valley	0.2960	0.16	272
00: 00~1: 00	△			Valley	0.2960	0.16	272
总计						13.72	23324

Table 3 The operating cost of the basic refrigerating unit under different loads during daytime in summer

The load rate of the basic refrigerating unit during daytime	0%	20%	40%	60%	80%	100%
Operating cost within 24 hours under the 100% load (Yuan)	3622.79	3679.78	3738.30	3801.00	3868.00	3933.59
Operating cost within 24 hours under the 80% load (Yuan)	2782.68	2840.15	2907.14	2974.14	3041.14	3122.53
Operating cost within 24 hours under the 60% load (Yuan)	1947.69	2013.29	2084.57	2172.63	2238.99	2351.59
Total operating cost in summer (Yuan)	384104.80	393203.50	403340.00	414567.60	424579.20	438344.30

refrigeration (ACSISR) is playing an important role in

the central air-conditioning mode. The temperature of chilled water that from an ACSISR is lower than that from an ordinary air-conditioning system, and could decrease the amount of wind supplied because of low temperature. At same time, big temperature difference between chilled water and cooling air leads to small flux of the water, and relative facilities such as water circulation pump, ventilator and the air-conditioning box with small capacity and low prices can be chosen. Therefore, it will be a reasonable option for the energy saving and the cost-minimum to employ the concentrated ACSISR in civil high rise residential buildings. A central ACSISR could compensate some cooling capacity in rush hours and exert great ability of moving "the peak" of electricity, and it will take up a great proportion in residential buildings in the future.

2. THE TECHNOLOGICAL AND ECONOMICAL ANALYSIS OF AN AIR-CONDITIONING SYSTEM WITH ACSISR

It is easy for traditional air-conditioning system to form the partial heat island within the small range of the buildings. However, It can effectively decrease the need of the electric power in rush hours and reduce the cooling capacity of air-conditioning if the ACSISR technology is applied. It is more expensive at original cost in ACSISR than in separated air-conditioning system equipped in civil high rise buildings, but the running cost of separated air-conditioning system is far more expensive than that of the concentrated cooling system because the work efficiency of separated air-conditioning system is lower, and separated air-conditioning system with non-frequency variety will consume more electric energy during starting and stopping than normal time.^[1] It needs to be indicated that the ACSISR doesn't save electric energy, but it can decrease the capacitor equipped and the adjusted capacity in rush hours by means of moving peak electricity, make the refrigeration unit be in high efficient working condition. In this way, it can decrease the use of electric power and increase the utilization ratio of energy sources.^[2]

It is the peak moving effect of the ACSISR that avoids building new electric plant for several hours' electric peakload. Along with some buildings work of Olympic Game, large quantities of relative air-conditioning facilities will be established, and the requirement for electric power will be increased continually. According to statistics, when inputting the limited money to set up the ACSISR, the peak moving effect will obtain more benefit than that of building electrical power plants.^[2]

In our country at current, the average electrovalence of low load ratio is high, and the average electrovalence of high load ratio is low. So it takes users to control the electric load in rush hours and increase load ratio.^[3] Electrical policy encourages residents use power energy as much as possible at valley hours, which not only gives some profit to users but also equalizes the load of the electric network. Since 2000, National Project Committee canceled the regulation that imposes from some big projects which consume exceed electric power, the situation of unbalance of the network load was aggravated further.

It shows that the ACSISR will be playing an important regulating role in the fields of refrigeration and air-conditioning in summer in two aspects: the economic efficiency and social management macro-regulation.

3. THE CHARACTERISTIC OF ACSISR

It is known from research that the different building structures have different cooling loads. Generally, the cooling loads of air-conditioning can be classified as three types, that is, the mode with large basic load, the mode with little basic load and the mode without basic load.^[4] As far as the commercial and office buildings, the main cooling loads are accumulated during the daytime because of the high temperature, high density of staffers and central activity during the time. For the hotels, restaurants and residents houses, besides the cooling loads in daytime there is still large basic load at night as the heat transfer continually from the body of people, the electrical appliances during the nighttime. Accordingly, it should be taken into consideration for factors above when designing the ACSISR refrigeration for these buildings. The cooling ability of the ACSISR includes that supplied by the main refrigerating unit, the basic refrigerating unit and the equipment of ice storage refrigeration. It could approach an optimized situation between the requirement of cooling load and the supplement of that for each kind of building according to themselves air-conditioning characteristics of all kinds of buildings, and obtain the best economic benefits and social effects.

4. ANALYZING AN ACSISR IN HIGH RISE RESIDENTIAL BUILDING

A high rise tower residential building was chosen as the target to be analyzed in the paper according to new resident building criterion, the building has 27 floors with structural area about 30,000 square meters, the highness at 2.9 meter for each floor and 120~150 square meters for every apartment. Its concentrated air-conditioning facilities use the combination of the characteristic of the ACSISR with the technique of supplying wind under low temperature. It employed part ice-accumulating mode since the original cost is cheaper and it can exert all of the equipments' ability. The strategy adopted is melting ice to provide cooling load firstly that can decrease the operating cost and take full advantages of the low-cost electrovalence at night (see Table 1). The screw-refrigerating unit was selected because it can make sure that the COP will be keeping at a high status at the time of refrigerating and accumulating ice. Housed equipment was selected, which is the most widely used equipment for accumulating ice in domestic market and for choosing the ice ball as the accumulating medium with the character of running reliably, high ratio of getting cold per unit, low flow resistance and large capacity for filling refrigerant. In this system, the refrigerating unit is in series with the equipment for accumulating ice, cold water with large temperature difference can be supplied, and the refrigeration efficiency is high because the refrigeration unit is located at the high

temperature side in the refrigeration loop. The related parameters for the system are shown in Table 2.

It should note that the operating time calculated for air-conditioning annually is 150 days, included 20 days running at the 100% of cooling load, 60 days running at the 80% of cooling load, 80 days running at the 60% of cooling load. The basic refrigerating unit is selected according to the largest cooling load at night and the main refrigerating unit is selected according to the formulae as follows.

$$R_2 = Q_{\max} \cdot D / (D + N \cdot \eta) \quad (1)$$

$$R_1 = R_2 \cdot N \cdot \eta / D \quad (2)$$

It can be seen from Table 3 that the operating cost of air-conditioning in summer increases along with the rise of cooling load of the basic refrigerating unit during the daytime, so this situation for the air-condition unit should be avoided as much as possible. It can be known from formula (1), the item $Q_{\max}$ is the total amount of cooling load but. The increase of basic cooling load can reduce the capacity of the ice accumulating equipment. The basic refrigerating unit will consume electric energy in normal hours and peak hours same as the main refrigerating unit does during the daytime. Therefore, the most of the cooling load for the building is provided by the refrigeration unit, and the advantages of "moving peak to valley" the ice storage refrigeration couldn't be well exerted. On the other hand, the rising of the basic cooling load means that the main refrigerating unit with less refrigerating capacity can be employed. It means that the original cost for this mode could be reduced, and the larger the basic cooling load is, the less the capacity of the main refrigerating unit is, the lower the original cost is (shown in Table 4).

Table 4 The capacity of the main refrigerating unit needed under different basic cooling loads

The load rate of the basic refrigerating unit	0%	20%	40%	60%	80%	100%
the capacity of the main refrigerating unit (KW)	1320	1248	1176	1104	1032	960

The capacity of the main refrigerating unit at different ratio of basic loads during day is determined by formula (3) as follows

$$R_3 = (Q_{\max} - R_b \cdot \eta_b) \cdot D / (D + N \cdot \eta) \quad (3)$$

It can be known from the method of the static reclaiming benefit in ACSISR that the reclaiming period can be determined according to the formula as follows

$$N_n = (M_{xc} - M_{nc}) / (M_n - M_x) = (T_{cc} + M_z) / (M_n - M_x) \quad (4)$$

According to Table 4, the relationship between the operating ratio of the basic refrigerating unit during daytime and the capacity of the main refrigerating unit can be concluded as follows. The relationship between the operating cost for air-conditioning in summer and the price of main refrigerating unit with the ratio of basic load during day is shown in Fig. 1

$$R_3 = 1319.63 - 360.18 \cdot \eta_b \quad (5)$$

The original cost per kW quantity of cold provided by refrigeration unit is about 800 Yuan in ACSISR. Formula (5) can be converted to formula (6) as follows according to the relationship between the cooling load ratio and the price of the main refrigerating unit.

$$M_z = 1055704 - 288144 \cdot \eta_b \quad (6)$$

The relationship between the total operation cost in summer and the cooling load rate of the basic refrigerating unit during daytime can be concluded as well according to Table 3. Formula (7) can be concluded after the regressing analysis is made according to the parameters in Table 3.

$$M_x = 382793.31 + 53793.17 \cdot \eta_b \quad (7)$$

Formula (8) can be gotten from formula (6), (7) and (4), that is

$$N_n = (T_{cc} + 1055704 - 288144 \cdot \eta_b) / (M_n - 382793.31 - 53793.17 \cdot \eta_b) = (A - 288144 \cdot \eta_b) / (B - 53793.17 \cdot \eta_b) \quad (8)$$

The original cost is 2.54 million Yuan in ordinary concentrated air-conditioning system and 3.98 million Yuan in concentrated ACSISR. The price of the main refrigerating unit is 1.056 million Yuan.

$$T_{cc} = 38.4 \times 10^4 \quad (9)$$

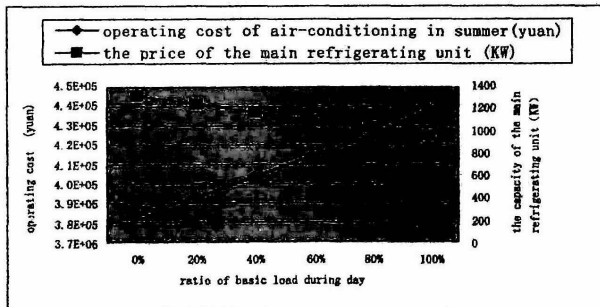


Figure 1 Comparison of original cost and operating cost with basic loads

The operating cost in general air-conditioning is 690 thousand Yuan, that is $M_n = 69 \times 10^4$, then

$$N_h = (T_{cc} + 1056 - 288 \cdot \eta_b) / (M_n - 383 - 538 \cdot \eta_b) \\ = (144 - 288 \cdot \eta_b) / (307 - 538 \cdot \eta_b) \quad (10)$$

Table 5 the reclaiming period of the air-conditioning with ACSISR

The basic ratio during The daytime η_b	0%	20%	40%	60%	80%	100%
The reclaiming time (year) N_h	4.69	6.93	14.43	-80.20	-9.80	-4.99

It can be seen from the formula (8) and the Table 5 that the value of parameter N_h will rise as the value of parameter η_b does. The increasing rate of the operating cost is greater than the decreasing rate of the original cost along with the increasing of the cooling load rate of the basic refrigerating unit. As a result, the reclaiming period will be extended. The operating cost of concentrated ACSISR will be greater than that of the ordinary concentrated air-conditioning and the reclaiming period will be a negative number when the cooling load rate of the basic refrigerating unit increases to a definite degree.

5. CONCLUSIONS

The operating optimization idea of this kind of ACSISR should be: if the operating time of the basic refrigerating unit is shortened during day or the cooling load of building is supplied only by the main refrigerating unit plus the ice accumulating equipment, the ability of the ACSISR will fully be exerted, moreover, both the operating cost and the reclaiming time will be decreased. For large basic cooling load ACSISR if the basic refrigerating unit runs only at night, the shortening the reclaiming period will be gotten. On

the condition of units' operating at the time of non-designed day, the ice-accumulating equipment should be utilized as much as possibly and the main refrigerating unit should share much less load to exert the ability of the ice accumulating equipment. The results of the project, in the paper, have laid a base for further analyzing other cases in future.

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