The Technical and Economical Analysis of a Centralized Air-Conditioning System with Cold Storage Refrigeration in High-Rise Residential Buildings[1]

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Abstract: In recent years, the application of a centralized air-conditioning system (CACS) with cold storage refrigeration in high-rise residential buildings has gradually increased. Due to the large difference between civil residential buildings and commercial buildings, characteristics such as the cooling load in summer and the storey height must be considered in the design of the air-conditioning system, and the cold storage equipment and the cold supplying means must be properly selected. The option of establishing centralized air-conditioning equipment with cold storage and supplying unified cold in high-rise residential buildings is analyzed objectively with technical and economical methods in this paper. It is not true that the option of supplying unified cold can save energy all the time. CACS with cold storage will not always be economical. Based on a 27-floor building, the running costs in summer and the first costs are both compared between CACS with and without cold storage refrigeration. The cold storage method selected will significantly impact the residents.

Key words: cold storage refrigeration; centralized air-conditioning system, technical and economical analysis, high-rise buildings

1. INTRODUCTION

Along with the vast use of the air conditioners, the peak to valley difference on urban electric network load increased gradually. On the one hand, electric power is not sufficient at peak hours. Moreover, the electricity must be restricted in some area at special time. However, excess electric power couldn't be consumed at valley hours. Due to the characteristic that it could barely be stored for the electric power, vast energy was wasted every year. As people's living standard grows, quite a lot of residents could purchase air conditioners. People nowadays are trying to employ CACS with or without cold storage refrigeration in some areas. CACS with cold storage refrigeration could decrease the peak to valley difference and stabilize network load. However, the feasibility-analysis about whether it is proper to employ CACS with cold storage refrigeration (CSR) in high-rise buildings should be done.

A high-rise residential building with 27 storeys was studied and the application of CACS with CSR is analyzed in this paper. The new feature appeared after the combination of the high-rise residential buildings and CACS is studied and their respective characteristics are introduced simply. The first cost of CACS for three different kinds, and the running cost in summer together with the payback period are calculated. In addition, the optimum option is selected and some suggestions are given at the last part.

2. THE TECHNICAL CHARACTERISTICS OF CACS WITH COLD STORAGE REFRIGERATION IN HIGH-RISE RESIDENTIAL BUILDINGS

2.1 The Architectural Characteristics of High-Rise Residential Buildings

The low storey height about 2.8m is a significant characteristic of high-rise residential buildings. Generally speaking, CACS adopts single-line air

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supply system, and then, the influence in the room caused by the dimension of the wind duct must be considered when designing CACS as the restriction of storey height. Therefore, the cross-section area and the height of the wind duct must be decreased as much as possible.

2.2 The Cooling Load Characteristic in High-Rise Residential Buildings In Summer

Compared with huge commercial constructions, high-rise residential buildings need cold supply around the clock. It has more features such as the cooling load being dispersed, the load difference between day and night being little, and the cold supply need when storing cold. The maximum cooling load during the day and night, as a reference to determine the capacity of the double operating mode refrigerating unit and the base-load refrigerating unit, should be known. As an example in Beijing, the cooling load hour by hour of high-rise residential buildings in summer could be seen in Tab.1. As is seen in the table, the maximum cooling load difference between the day and the night, together with the capacity difference between the base-loaded refrigerating unit and the double operating mode refrigerating unit are both little.

Tab.1 Designed cooling load hour by hour in Beijing

Time interval	0:00	1:00	2:00	3:00	4:00	5:00
Cooling load hour by hour（*KW*）	1713	1661	1615	1569	1530	1481
Time interval	6:00	7:00	8:00	9:00	10:00	11:00
Cooling load hour by hour（*KW*）	1574	1663	1742	1846	1947	2036
Time interval	12:00	13:00	14:00	15:00	16:00	17:00
Cooling load hour by hour（*KW*）	2102	2177	2258	**2295**	2289	2265
Time interval	18:00	19:00	20:00	21:00	22:00	23:00
Cooling load hour by hour（*KW*）	2224	2031	1930	1873	1815	**1767**

2.3 The Characteristics of CACS

CACS can be divided into CACS with CSR and CACS without CSR, and the constructions studied locate in Beijing, Shanghai and Guangzhou, as three representative areas of North China, Middle China and South China, in this paper.

CACS without CSR can supply real-time cold according to the change of cooling load in summer. Therefore, excess or insufficient supply of cold will not appear in most cases. CACS of this kind can be controlled intensively and it can solve many problems of the individual air conditioners, while, actually, it supplies cold that individual units offered intensively. The cold supply curve hour by hour is according with the changing trend of the network load; hence, CACS without CSR can't improve the load characteristic of the electric network ultimately.

At the same time, CACS with CSR employed widely in huge commercial constructions has been applying in civil residential buildings for its marked characteristic of cutting the electric peak to fill the electric valley, as is seen in domestic project. CACS with CSR comprises CACS with ice cold storage refrigeration (CACS with ICSR) and CACS with water cold storage refrigeration (CACS with WCSR), which is often found in some commercial buildings.

The characteristics of CACS with WCSR: It can utilize the sensible heat of water to accumulate cold, usually, water of 4~7 ℃ is adopted. The simple system, the little investment and the convenient maintenance repair make it possible to employ conventional air-conditioning units. Nevertheless the density of water is little, the specific heat can only attain 4.2*KJ/*（*kg*℃）. Besides, both the volume for storing cold and the cold loss are large.

The characteristics of CACS with ICSR: It can utilize the hidden heat when phase changing to accumulate cold. The cold storage tank, together with the cold loss, is much less than that of the CACS with WCSR because the cold storage density of water of 0 ℃ can reach 334*kj/kg*. Compared with the conventional CACS, the amount of wind of CACS with ICSR can be saved by 40%. [1] Generally, CACS with ICSR is combined with the technology of low temperature blast, for the latter can fully utilize the low temperature water generated by CACS with ICSR. Thus, it can offset the increased first cost caused by CACS with ICSR. Generally speaking, the first cost of wind system with the combination of CSR and cryogenic blast is lower than conventional air-conditioning system (CACS without CSR) when the construction area exceeds 14,000 m^2. [2] The area of the selected construction is about 30000m^3, so the technology of low temperature blast can be adopted. Moreover, the coefficient of performance (*COP)* of the compressor drops as the evaporating temperature of the refrigerating unit does, so the efficiency will decrease a lot.

3. A REAL PROJECT WITH CSR IN HIGH-RISE RESIDENTIAL BUILDINGS

The total construction area is 27,100 m^2, and the respective designed maximum load hour by hour of three regions(Beijing, Shanghai, Guangzhou) are 2295KW、2454KW and 2318KW, and the calculation is based on it.

3.1 The Type Selection of Refrigerating Unit

The rotary screw compressor chiller has the feature of low exhaust temperature, high thermal efficiency, even running, tiny vibration and wide application. The infinitive variable control of the refrigerating output can be adjusted from 10%~100% and the *COP* at the air-conditioning work condition can vary from 4.1 to 5.4. In addition, the lowest temperature of the evaporator outlet can fall to -7 ℃～-13 ℃ and the *COP* can still be maintained from 2.9～3.9 when making ice. Consequently, the rotary screw compressor chiller is selected.

3.2 The Selection of Refrigerating Unit

As the requirement of supplying cold at night, the base-loaded refrigerating unit must operate when the double-working-condition refrigerating unit storing cold during the night. The capacity of the base-loaded refrigerating unit can be determined according to the maximum cooling load at night, however, the cooling load the base-loaded refrigerating unit faced needs to be further discussed. If the base-loaded refrigerating unit takes more cooling load, then the accumulating facilities and the main refrigerating unit will take less, vice versa. Hence, the running cost rises and the advantage of storing cold won't be displayed if the base-load refrigerating unit takes more cooling load. To utilize the cheap electricity at night, the base-loaded refrigeration should stop running when cold needed during the day, and the main refrigerating unit together with the accumulating facilities takes the cooling load. The capacity of the main refrigerating unit on condition that the accumulating facilities supplying cold first can be determined by the formula below [2].

$$R2=Qmax \cdot D/(D+N \cdot \eta) \quad (1)$$

Qmax, designed cooling load of constructions at peak hour（*k*W）

D, hours of the main refrigerating unit supplying cold during the day（*h*）

N, hours of the main refrigerating unit refrigerating at night （*h*）

R2, the refrigerating output of the refrigerating unit when storing cold（*kW*）

η, the rate of compressor capacity, η of the rotary screw compressor chiller should be fixed at 0.95 for CACS with WCSR, 0.7 for CACS with ICSR.

3.3 The Selection of the Terminal of CACS with CSR

It adopts the special terminal of low temperature blast. The primary low temperature wind is sent to inner room, and the wind is mixed with the air of air-conditioning area near the air outlet, thus, the air fluxion can be reinforced and the commixture can be finished before the wind arrives at the working area.

3.4 The Insulation of the Air Supply System of CACS with CSR

Single-line air supply system is adopted. Compared with conventional CACS, it still adopts zinc-coated steel as the duct material in CACS with ICSR and CACS with WCSR, but the duct insulation of CACS with ICSR must be done strictly in order to prevent moisture condensation.

3.5 The Running Control Strategy of CACS with CSR

The running program is very important in the design of CACS with CSR, and it determines whether a design could be successful. Compared with other option, the capacity of the cold storage facilities and the main refrigerating unit on the running strategy of fully cold storage is much larger, however, its running cost is much fewer. This project of CACS with CSR in residential buildings has the 24-hour cooling load, which is not fit to adopt the running strategy of fully cold storage. In addition, it can't acquire economical effect until the cold storage amount takes 30%～70% of the total cooling load[1]. Therefore, the running strategy of partly cold storage is selected. It will utilize the valley electricity and decrease the running cost when adopting the strategy of cold storage facilities supplying cold first. Therefore, the control strategy of partly cold storage and cold storage facilities supplying cold first is preferred.

4. THE FIRST COST AND RUNNING COST

For conventional CACS, first cost comprises two parts, part of air supply system and part of water supply system. The first cost of CACS with CSR and CACS without CSR in three regions (Beijing, Shanghai, Guangzhou) is shown in Tab.3. The running cost of CACS with CSR includes systematic running cost at certain time and certain places.

Tab.2 The electric peak hour and valley hour and its relative electric price in Beijing, Shanghai and Guangzhou

		Peak hour	Even hour	Valley hour
Beijing	Period	8：00～12：00 18：00～23：00	6：00～8：00 12：00～18：00	23：00～6：00
	Electric price	0.955(Yuan)	0.615(Yuan)	0.296(Yuan)
Shanghai	Period	8：00～11：00 18：00～21：00	6：00～8：00 11：00～18：00	21：00～6：00
	Electric price	0.871(Yuan)	0.568(Yuan)	0.295(Yuan)
Guangzhou	Period	7：00～12：00 19：00～22：00	12：00～19：00 22：00～23：00	23：00～7：00
	Electric price	0.681(*Yuan*)	0.570(*Yuan*)	0.403(*Yuan*)

The running cost has a direct relationship with the structure of the electric price. The price of different period is displayed in Tab.2. The capacity of the pump, together with capacity of the fan and other accessory equipment in CACS with ICSR, is not so large, and so is the running cost. Whereas, the *COP* of the double-working-condition refrigerating unit in CACS with ICSR is much little than that in CACS with WCSR during the period of cold storage at night. Besides, It adopts the strategy of cold storage facilities supplying cold first. Accordingly, the total running cost of CACS with ICSR is a little higher than that of CACS with WCSR.

5. THE ECONOMICAL ASSESSMENT OF CACS WITH CSR

It adopts the dynamic economical assessment in this paper.

5.1 The Increased First Cost of CACS with CSR

The increased first cost of CACS with CSR can be calculated according to the formula as is shown below.

$$\varDelta I=I_s-I_c \qquad (2)$$

$\varDelta I$, the increased first cost of CACS with CSR (*Yuan*)

I_s, the first cost of CACS with CSR (*Yuan*)

I_c, the first cost of CACS without CSR (*Yuan*)

5.2 The Annual Saved Fund of CACS with CSR

The saved fund can be calculated as the formula as below.

$$\varDelta P=P_c-P_s \qquad (3)$$

$\varDelta P$, the saved running cost of CACS with CSR (*Yuan*)

P_c, the annual electric fund of CACS without CSR (*Yuan*)

P_s, the annual electric fund of CACS with CSR

(*Yuan*)

5.3 The Calculation of Payback Period of the Investment

The payback period of the investment can be fixed according to the formula shown below.

$$\Delta P = \frac{\Delta I \cdot (1+i)^n \cdot i}{(1+i)^n - 1} \qquad (4)$$

i, the discount ratio, which is not lower than the interest of the bank, can be fixed to 0.06.

Tab. 3 Comparison of the costs and the payback period between CACS with CSR and CACS without CSR

Item / Region	First cost (10,000 *Yuan*)			Annual running cost (10,000 *Yuan*)			Payback period (10,000 *Yuan*)	
	ICSR	WCSR	CCACS	ICSR	WCSR	CCACS	ICSR	WCSR
Beijing	704.04	549.53	412.49	55.58	51.31	79.55	22	6
Shanghai	770.59	590.98	447.91	55.15	50.9	77.56	34	7
Guangzhou	742.74	563.38	427.23	62.79	56.91	85.43	31	6

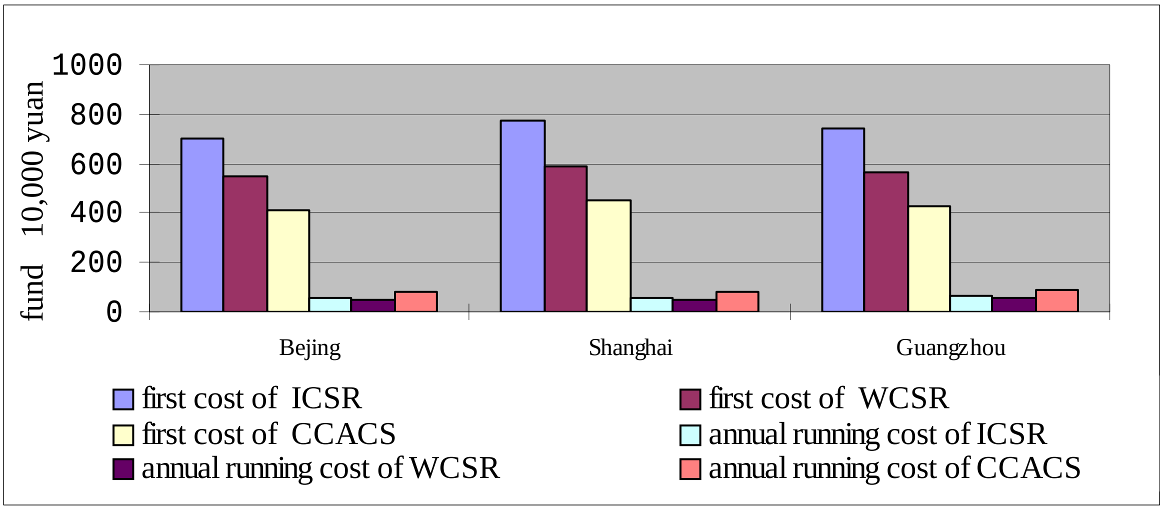

Fig. 1 Comparison between CACS with CSR and CACS without CSR

$$C = \frac{\Delta P}{\Delta I} \qquad (5)$$

The payback period is

$$n = \frac{\ln C - \ln(C-i)}{\ln(1+i)} \qquad (6)$$

The data in Tab.3 and Fig.1 are the results based on the cold supply period of 90 days in Beijing. According to the practical situation, the respective ratio of cold supply period in Shanghai and Guangzhou is 1.089148 and 1.257147 against that in Beijing. Consequently, the cold supply period is 98 days in Shanghai, 113 days in Guangzhou. It can be seen from the table and the figure that the investment has an intimate relationship with the cooling load. As a standard of cold supply period in Beijing and according to the three regions' respective demand for cold, the relative polygon figure will be obtained if the cold supply period in Beijing changes from 90 days to 105 days and to 120 days, as is shown in Fig.2 and Fig.3.

It can be seen from the figures below, the payback period of CACS with ICSR will be shortened dramatically along with the increasing of the cold supply period. However, it is not so apparent for CACS with WCSR.

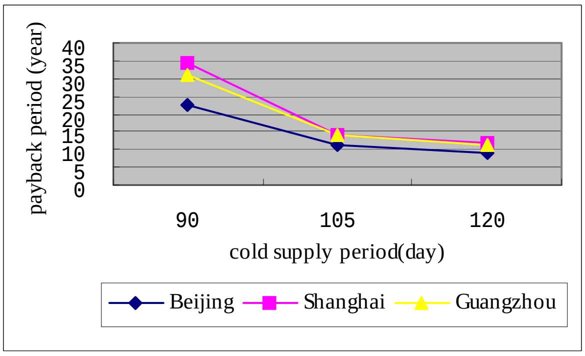

Fig. 2 Payback period of CACS with ICSR

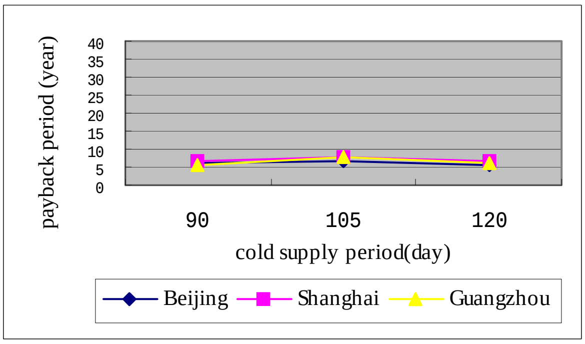

Fig. 3 Payback period of CACS with WCSR

6. CONCLUSIONS

1. It can be concluded from the calculation above that the payback period of CACS with ICSR is much longer than that of CACS with WCSR. The payback period of CACS with WCSR, compared with CACS with ICSR, changes a little.

2. The electric price influences CACS with CSR a lot. It benefits to cold accumulation if the difference of the electric price between the peak and valley is lager enough. The peak to valley difference of the electric price is so little that CACS with CSR in Guangzhou can't be applied.

3. The capacity of the base-loaded refrigerating unit will be determined by the maximum cooling load at the cold storage time, and the first cost will change with it too.

4. The difference of the first cost between CACS with CSR and CACS without CSR in our country will be enlarged if the electric capacity enhancement fee will be canceled, which goes against the popularization of CACS with CSR.

5. The change rate of the compressor capacity is larger in CACS with ICSR than that of CACS with WCSR, and then the refrigerating unit in CACS with ICSR that is in the double working condition must bear more cold load. As a result, the running cost of CACS with ICSR is higher than that of CACS with WCSR. It is suggested that the double-working-condition refrigerating unit with low change rate of compressor capacity would be employed in practical projects.

6. Compared with the constructions such as hotel, the cooling load of residential buildings in summer changes a little. If CACS with CSR is adopted, the base-loaded refrigerating unit must supply cold when storing cold, and the capacity of the based-loaded unit may exceed that of the main refrigerating unit. Accordingly, the capacity of relative accessory facilities such as pump rises rapidly, and so does the investment of the system.

7. The first cost of CACS with ICSR in the three regions is high, and the payback period is long. The advantage of CACS with ICSR is much apparent as the cold supply period extends. The payback period will not exceed 12 years if the cold supply period in Beijing is fixed on 120 days. Therefore, CACS with ICSR could be adopted if the area of the refrigerating unit room is limited and the cold supply period is long in summer. On the condition that the commercial area under the constructions is big enough, CACS with WCSR could be taken in account, which could be used for accumulating heat in winter and storing cold in summer.

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