Scheme design and economic analysis of an office building's cold and heat source system in hot-summer and cold-winter zone

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Abstract. In the context of green development and sustainable development, in response to the national policy of “carbon neutrality and peak carbon dioxide emissions”, we will fully implement clean energy heating and reduce air pollution. Air energy is the representative, bringing the comfortable, efficient, safe and energy-saving environment to people. For an office building in Nanjing, which is located in hot-summer and cold-winter zone, an air source heat pump unit is designed as a cold and heat source system to meet the demand for heating in winter and cooling in summer. At the same time, compared with the traditional cold and heat source system which is designed central heating in winter and multi-line refrigeration in summer, the result of economic analysis shows that the use of air source heat pump as the cold and heat source system of office buildings is more economical and energy-saving. It is suitable to popularize and apply in China's hot-summer and cold-winter zone.

1 Introduction

The air source heat pump unit uses the energy in the air as the main power. It has the characteristics of simple system structure, convenient installation, high degree of automation and utilization of renewable energy. And it is widely used at home and abroad. In the actual application process, with its high work efficiency, it gradually reduces the large amount of pollutant emissions brought by traditional heating methods to the atmosphere, which has been recognized by many people in the industry. Nanjing is located in China's hot-summer and cold-winter zone. There is no central heating in winter, so air source heat pump is a better option. In this paper, the air source heat pump is used as the cold and heat source system to conduct HVAC design and economic analysis for an office building in Nanjing.

2 Project Overview

This project is an energy-saving office building located in Nanjing, Jiangsu Province. The building area is 6000m², designed according to the building energy saving 65%. The office hours of the office building are from 9:00 to 20:00. The calculation parameters of outdoor air in Nanjing are shown in Table 1 [1].

Table1. The calculation parameters of outdoor air in Nanjing.

The outdoor design temperature for heating (°C)	-1.8
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The outdoor design dry-bulb temperature for summer air conditioning (°C)	34.8
The extreme minimum temperature (°C)	-13.1
The number of days when the average daily temperature is $\leq 8^{\circ}\text{C}$ (d)	109

3 Design Calculation Of Air Source Heat Pump System

3.1 Estimating heating load in winter and cooling load in summer

According to Table 3.1.2-1 in "Design code for city heating network"(CJJ34-2010), the recommended value range of heating index for office buildings with energy-saving measures is 50~70 W/m², and the recommended value range of cooling index is 80~110 W/m² [2]. Therefore, for an energy-saving office building in Hefei, Anhui Province, the heating index in winter is 50 W/m², and the cooling index in summer is 90W/m². Since the building area is 6000m², the heating load in winter is $Q_1=6\ 000\times 50\ \text{W/m}^2=300\ \text{kW}$, and the cooling load in summer is $Q_2=6\ 000\times 90\ \text{W/m}^2=540\ \text{kW}$.

3.2 Using existing heat pump samples to select models

The heating effect of the air source heat pump unit is given priority. The outdoor design temperature for heating in Nanjing is -1.8°C. According to the sample of Mcquay MHS F ST2 large air cooled with heat pumps (single

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screw), the winter units are selected. Considering that the ambient temperature is -4°C and the outlet water temperature of the unit is 45°C , the MHS FST2 060.1 unit is selected, and the heating capacity of the unit is 156.0kW. Since the heating load in winter(Q_1) of the office building is 300kW, the selected air source heat pump unit has a heating capacity of 156.0kW, and the number of units is $1.92(=300/156)$, so 2 MHS F ST2 060.1 air source heat pump units are selected.

According to the outdoor design dry-bulb temperature in Nanjing is 34.8°C , and the summer units are selected. Considering that the ambient temperature is 35°C and the outlet water temperature is 7°C , the MHS F ST2 060.1 unit is selected, and the unit's cooling capacity is 205.0kW. Since the cooling load in summer(Q_2) of the office building is 540kW, the selected air source heat pump unit has a heating capacity of 205.0kW, and the number of units is $2.63(=540/205)$. Therefore, in summer, it is based on 2 MHS F ST2 060.1 units and another MHS F ST2 060.1 unit is selected. The air source heat pump unit selection is shown in Table 2.

Table2. Design selection table.

Working condition	In winter	In summer
Unit Type	MHS F ST2 060.1	MHS F ST2 060.1
Outlet water temperature ($^{\circ}\text{C}$)	45	7
Aambient temperature ($^{\circ}\text{C}$)	-4	35
Heating capacity/ cooling capacity (kW)	156	205
Power (kW)	69	74
Number of units	2	3

3.3 Selecting auxiliary heat source

In extreme weather, the heating capacity of the air source heat pump unit will be affected, and an auxiliary heat source should be provided. The capacity of the auxiliary heating device is determined according to the difference between the effective heat generated by the air source heat pump unit and the heat consumption of the building under extreme weather conditions in winter. In order to ensure that the transformer installed capacity of the entire building does not increase due to the use of electric heating in winter, it is required that the direct electrical heating load in winter does not exceed 20% of the cooling load in summer, and the total installed direct electrical heating capacity per unit building area does not exceed $20\text{W}/\text{m}^2$ [3].

The auxiliary heat source of this design adopts electric heating boiler. As the extreme minimum temperature below -10°C rarely occurs in Nanjing, and the low temperature weather events in winter show a significant downward trend [4], the number of days when the extreme

minimum temperature is considered according to the most unfavourable conditions should not exceed 2 days.

Since the unit selection in winter is based on the ambient temperature of -4°C , the total heating capacity of the two units is $196(=98 \times 2)$ kW in the case of reduced efficiency in extreme weather, which cannot meet the building's heat consumption of 300kW. It can be calculated that the difference between the effective heat generated by the air source heat pump unit and the heat consumption of the building under extreme weather conditions in winter is $104(=300-196)$ kW.

Therefore, when running 2 air source heat pump units, 104kW electric heating boiler is equipped. 20% of the building cooling load in summer is 108kW, and the total installed capacity of direct electrical heating per unit building area is $17.3\text{W}/\text{m}^2$. Equipped with a 104kW electric heating boiler, it can not only meet the requirements of the specification that the direct electrical heating load in winter does not exceed 20% of the building cooling load in summer, but also meet the requirement that the total installed capacity of direct electrical heating per unit building area does not exceed $20\text{W}/\text{m}^2$.

Calculation formula for power consumption of electric auxiliary heating:

$$W = Q/h \quad (1)$$

W is power consumption (kW). h is the thermal efficiency of water heating equipment ($90\% \sim 95\%$). Then $W=104/95\%=109.5$ kW.

Therefore, during the extreme weather period (usually calculated as 2days, 11h per day), the total power consumption that needs electric assistance is $Q=109.5 \times 2 \times 11=2409$ kW·h.

4 Economic Analysis

4.1 Initial investment of unit

The model parameters of the air source heat pump unit selected in this office building are shown in Table 3.

Table3. The model parameters.

Unit Type	MHS F ST2 060.1	
Rated working condition	Heating	Cooling
Outlet water temperature ($^{\circ}\text{C}$)	45	7
Aambient temperature ($^{\circ}\text{C}$)	7	35
Heating capacity/ cooling capacity (kW)	156	205
Power (kW)	69	74

The cost of the air source heat pump unit is 1.5 yuan/W, so the initial investment of the selected MHS F ST2 060.1 units is 92.25 (ten thousand yuan).

The cost of the electric-assisted boiler is 0.35 yuan/W, so the initial investment of the electric-assisted boiler is 3.64 (ten thousand yuan).

In summary, the initial investment is 95.89 (ten thousand yuan).

4.2 Economic analysis in winter

4.2.1 Operating costs of heat pumps in winter

According to the office hours of the office building, the operating time of the unit in winter is 11h (8:00-19:00). Considering the number of days when the average daily temperature $\leq +8^{\circ}\text{C}$ is 109 days, the heating period is 109 days. According to the electricity price list of Jiangsu Electricity Grid, the electricity price for general industrial and commercial use is 0.6414 yuan/kWh. According to the time-sharing sales of electric boilers in Jiangsu Province, the electricity price of electric boilers in general industrial and commercial sectors (8:00-24:00) is 0.6414 yuan/kWh^[5].

See Table 4 for the calculation results of heat pump operating costs in winter.

Table4. Heat pump operating costs in winter.

	Calculation formula	Result
Single-day unit power consumption in winter (kW·h)	$69\text{kW} \times 11\text{h} \times 2$	1518
Unit power consumption during heating period in winter (kW·h)	$1518\text{ kW} \cdot \text{h} \times 109$	165 462
Total operating cost in winter (yuan)	$0.6414 \times (165\ 462 + 2409)$	107 672.5
Electricity cost per unit area in winter heating period (yuan/m ²)	$0.6414 \times (165\ 462 + 2409) / 6000$	17.95

4.2.2 Total cost of central heating

At present, there is no urban central heating in Nanjing. Refer to Zhengzhou urban infrastructure supporting fee collection management method, the heating pipe network construction fee is 60 yuan/m²^[6], the initial investment cost of central heating is the product of the unit area heating pipe network construction fee and building area, 36 (ten thousand yuan).

With reference to the "Administrative Measures for Urban Heat Supply and Heat Consumption of Zhengzhou" and the relevant documents of Zhengzhou City Price Bureau, the unit price of central heating in winter is 0.19 yuan/m²·day^[7]. Since the heating period is 109 days and the unit price of central heating in winter is 20.71 yuan/m². The total cost of central heating in winter is 12.4 (ten thousand yuan).

In summary, the calculation results are summarized in Table 5.

Table5. Economic analysis in winter.

Heating method	Air source heat pump	Central heating
Initial investment (ten thousand yuan)	95.89	36
Total operating cost (ten thousand yuan·a-1)	10.8	12.4
Operating cost (yuan·m-2)	17.95	20.71

It can be seen from Table 5 that the operating cost of air source heat pumps is lower than that of central heating.

4.3 Economic analysis in summer

According to the office hours of the office building, the number of cooling days is 135 days.

4.3.1 Operating costs of heat pumps in summer

See Table 6 for the calculation results of heat pump operating costs in summer.

Table6. Heat pump operating costs in summer.

	Calculation formula	Result
Single-day unit power consumption in summer (kW·h)	$74\text{ kW} \times 11\text{ h} \times 3$	2442
Unit power consumption during heating period in summer (kW·h)	$2442\text{ kW} \cdot \text{h} \times 135$	329 670
Total operating cost in summer (yuan)	$0.6414 \times 329\ 670$	211 450.3
Electricity cost per unit area in summer heating period (yuan/m ²)	$(0.6414 \times 329\ 670) / 6000$	35.2

4.3.2 Total cost for varied refrigerant volume

The initial investment per unit area of varied refrigerant volume is about 200 yuan/m², and the construction area of this office building is 6000 m². So the initial investment of the multi-line is 120 (ten thousand yuan).

See Table 7 for the calculation results of the total summer cost for varied refrigerant volume.

Table7. Total cost for varied refrigerant volume.

	Calculation formula	Result
Single-day unit power consumption in summer (kW·h)	$540/3 \times 11\text{ h}$	1 980
Unit power consumption during cooling period in summer (kW·h)	$1\ 980\text{ kW} \cdot \text{h} \times 135$	267 300

Total operating cost in summer (yuan)	$0.6414 \times 267\ 300$	171446.2
Electricity cost per unit area in summer cooling period (yuan/m ²)	$(0.6414 \times 267\ 300) / 6000$	28.57

In summary, the calculation results are summarized in Table 8.

Table8. Economic analysis in summer.

Cooling method	Air source heat pump	Varied refrigerant volume
Initial investment (ten thousand yuan)	/	120
Total operating cost (ten thousand yuan·a ⁻¹)	19.3	17.1
Operating cost (yuan·m ⁻²)	35.20	28.57

4.4 Comparative economic analysis

The air source heat pump unit is used as the cold and heat source system, and the central heating and varied refrigerant volume are used as the cold and heat source system for comparative analysis. The data results are summarized in Table 9.

Table9. Economic analysis.

Method	Air source heat pump	central heating & Varied refrigerant volume
Initial investment (ten thousand yuan)	95.89	156
Operating cost (yuan·m ⁻²)	30.1	29.5

It can be seen from the data that the initial investment cost of central heating in winter and varied refrigerant volume in summer is 601,000 yuan more than that of air source heat pumps. Although the operating cost of the air source heat pump unit is extra 6,000 yuan per year, the initial investment of central heating and varied refrigerant volume cannot be fully covered within the service life of varied refrigerant volume for 20 years. If combined with Jiangsu Province's air source heat pump promotion policy, the operating cost of air source heat pump units will be lower.

5 Conclusion

Air source heat pump units are used as the cold and heat source system for office buildings in Nanjing, which is located in China's hot-summer and cold-winter zone, which can meet its needs with heating in winter and cooling in summer.

Comparing the traditional central heating in winter and the varied refrigerant volume cooling mode in summer with the air source heat pump unit as the cold and

heat source system, it is found that the air source heat pump unit is a more economical and energy-saving choice. In winter, the outdoor design temperature for heating is used as the basis for selection of air source heat pump units, and the initial investment of the unit is only 958,900 yuan. Although it is necessary to add an electric auxiliary heating boiler, compared with the use of extreme minimum temperature as the basis for unit selection, it avoids the choice of oversized units, saves energy and reduces initial investment. Therefore, the use of air source heat pumps as the cold and heat source system of office buildings is more economical and energy-saving, and it is suitable for popularization and application in China's hot-summer and cold-winter zone.

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