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Design and Performance Analysis of a Combined Heat Source for Data Center Waste Heat and Solar Energy Applied to Evaporative Cooling System

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Abstract. To address the problem that indirect evaporative cooling technology is limited in high humidity areas, this paper establishes an evaporative cooling system with dehumidification system, which uses the waste heat of data center and solar energy as the regenerative heat source of dehumidification bed, and introduces the selection method of the main equipment of this system; the performance of data center using this system in Guangzhou is analyzed and compared with the conventional mechanical refrigeration system. The results show that the PUE of the conventional mechanical cooling system is 1.4, and the PUE of the combined heat source system is 1.21, which is better than that of the conventional mechanical cooling system; the power consumption and carbon emission of the combined heat source system are much lower than that of the conventional cooling system, which shows a superior energy saving level.

Keywords. Data center, indirect evaporative cooling, system design, performance analysis, energy saving

1. Introduction

With the rapid development of 5G, cloud computing, artificial intelligence and other new generation information technologies, data centers as the infrastructure of the information industry, are indispensable platforms in the era of digital economy, and with them comes a huge power consumption. At the global level, data centers accounted for 0.9% of global energy consumption in 2015 and are expected to account for 4.5% in 2025 and 8% in 2030 [1]. China's data centers accounted for 2.71% of the national electricity consumption in 2020 and are expected to reach 4.05% in 2025 [2]. The power consumption of data centers includes IT equipment, cooling system, power supply and distribution system, lighting, etc., among which the cooling system accounts for 30% to 60% of the total energy consumption [3, 4]. It can be seen that the cooling system is the

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core task of data center to reduce energy consumption, so in this paper, we choose indirect evaporative cooling technology, which can obtain cold from the natural environment, and compared with conventional mechanical compression refrigeration technology, the energy efficiency of indirect evaporative cooling technology can be increased by more than two times [5], with significant energy saving effect [6, 7].

However, the indirect evaporative cooling technology is limited by the technical principle, which has high performance only in hot and dry regions and is not applicable to regions with high relative humidity [8, 9], limiting its widespread use. Therefore, this paper proposes the addition of a solid dehumidification bed in front of the dew point evaporative cooler to reduce the moisture content of outdoor air and achieve energy-efficient application of this system in high humidity regions. In order to make full use of the data center waste heat resources and solar energy resources to improve the energy utilization efficiency, the system uses solar energy and data center waste heat as the combined heat source for the desorption and regeneration of the solid dehumidification bed, and combines the phase change energy storage technology so that it can continuously provide heat at night and reduce the use of auxiliary heat sources.

There are many studies on waste heat recycling technology [10-12] and combined application of solar energy and phase change energy storage technology [13-15] at home and abroad, but there are few engineering cases of practical application in data centers. Therefore, this paper integrates waste heat recovery and utilization technology, solar energy technology and phase change energy storage technology into data centers, and constructs a "combined heat source of data center waste heat and solar energy" system, which provides a new direction for realizing low energy consumption data centers.

2. System Integration of Data Center Waste Heat and Solar Energy Combined Heat Source

The data center combined heat source system is composed of air filtration unit, dew point evaporative cooler, dehumidification unit, solar hot air unit, phase change heat storage unit, and microwave generator. Figure 1 shows the schematic diagram of the integration of the combined heat source system in the data center.

The air purification device is used to provide clean air; the dew point evaporative cooler is a component to provide cooling for the system, and the cooling system composed of it is called the dew point evaporative cooling system; dehumidifying device, whose inlet is communicated with ambient air and outlet is communicated with dew point evaporation cooling system of data center, which can send the produced cold air into data center. The dehumidification device is composed of two adsorption beds, one for use and one for standby, are used alternately; the solar hot air device can use solar energy to heat air, its downstream is connected to the dehumidifying device, and its upstream is connected to the hot air outlet of the data center; there is also a phase change heat storage device between the solar hot air device and the dehumidifying device, which uses the phase change energy storage technology to store the heat of the solar hot air for desorption auxiliary heat source at night or when there is no continuous solar energy utilization condition; the adsorption bed is also integrated with a microwave dehumidification device, which can regenerate the adsorption material by using the principle of microwave oscillation and is used as one of the regeneration heat sources under extreme conditions.

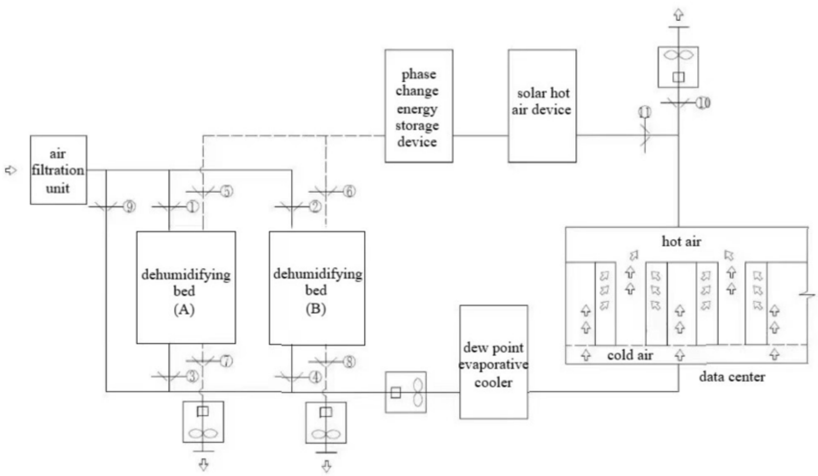

Figure 1. Schematic diagram of data center waste heat and solar combined heat source system integration.

3. Integrated Design Method of Data Center Waste Heat and Solar Energy Combined Heat Source System

3.1. Dew Point Evaporative Cooler Selection Calculation

3.1.1. Air Supply Volume of Data Center

$$q_m = \frac{Q}{[(1.01 + 0.00184d_o)(t_N - t_o)]} \tag{1}$$

where, d_o is the moisture content of the cold channel air supply state point, g/kg; t_o is the dry bulb temperature of the cold channel air supply state point, °C;

3.1.2. Cooling Capacity Required by Data Center

The calculation equation for the required cooling capacity of the data center is given separately according to whether a dehumidification system is required, as equations (2) and (3):

$$Q_z = \begin{cases} q_m(h_w - h_o), d_w \leq d_o & (2) \\ q_m(1.01 + 0.00184d_o)(t_{wd} - t_o), d_w > d_o & (3) \end{cases}$$

where, Q_z is the total cooling capacity of the dew point evaporative cooler air supply required by the system, kW; h_w is the outdoor design state point specific enthalpy, kJ/kg; d_w is the outdoor design state point moisture content, g/kg; h_o is the cold channel air supply state point specific enthalpy, kJ/kg; t_{wd} is the outdoor state point dry bulb temperature after dehumidification, °C.

3.2. Selection and Calculation of Adsorption/Desorption Cycle System

According to the requirement of dehumidification volume, several dehumidification bed modules are connected in series to form a dehumidification bed unit; according to the requirement of air volume, several dehumidification bed units are connected in parallel to form a complete dehumidification bed.

3.2.1. Dehumidification Bed Design Calculation

(1) Calculation of the number of dehumidification bed modules in series

$$N_{series} = \frac{d_w - d_o}{D} \tag{4}$$

where, N_{series} is the number of dehumidification modules in series (rounded to the nearest whole); D is the average dehumidification capacity of dehumidification modules, g/kg.

(2) Calculation of the number of dehumidification bed modules connected in parallel

$$N_{parallel} = \frac{q_m}{(1-k)q_s} \tag{5}$$

where, $N_{parallel}$ is the number of dehumidification modules in parallel (rounded to the nearest whole); q_s is the rated air volume of dehumidification module, m³/h; q_m is the air supply volume of data center, m³/h; k is the ratio of secondary air to primary air of dew point cooler.

3.2.2. Dehumidification Bed Resistance Calculation and Fan Selection Principles

According to the number of dehumidification modules in series combination, determine the resistance of dehumidification modules after series combination as equation (6):

$$Z_{series} = N_{series} Z_s \tag{6}$$

where, Z_{series} is the resistance of dehumidification module in series combination, Pa; Z_s is the rated resistance of dehumidification module, Pa.

For the dehumidification bed part of the fan selection should be a comprehensive consideration of the dehumidification module parallel combination of air volume, resistance and system resistance and other selection of fans.

3.2.3. Regeneration Air Volume and Fan Selection Principle

$$q_r = k q_s N_{series} N_{parallel} \tag{7}$$

where, q_r is the total regenerative air volume of the dehumidification system, m³/h.; *k* is the regeneration airflow coefficient of the dehumidification module. The experimental test shows that *k* takes 0.3-0.5 when the regeneration temperature is 80°C.

In order to ensure the regeneration air volume, the regeneration fan can be selected according to the fan air volume and resistance parameters of the dehumidification working conditions, and the use of variable frequency fans.

3.2.4. Microwave Generator Selection

Each dehumidifying bed module has two microwave generators. When the dehumidifying bed is desorbed by microwave, the microwave generators run intermittently, that is the microwave generators run for 2 minutes and stop for 3 minutes, so as to circulate. The total microwave power is equation (8):

$$P_{wbz} = N_{series} N_{parallel} P_{wb} \tag{8}$$

where, P_{wbz} is the total microwave power of the dehumidification bed, W; P_{wb} is the microwave power of the dehumidification module configuration, W.

3.3. Calculation of Solar Collector Sizing Based on Phase Change Energy Storage

The selection of solar collectors is based on the air volume required for the desorption and regeneration process of the dehumidification system and the rated air volume of the solar collectors, as shown in equation (9):

$$n = \frac{q_r}{q_f} \tag{9}$$

where, q_r is the total regenerative air volume of the dehumidification system, m³/h; q_f is the rated design air volume of the solar collector, m³/h.

The installation area of the heat collection and storage unit is equation (10):

$$A_t = A_c \cdot n \tag{10}$$

where, A_c is the collector heat collection area, m^2; *n* is the number of collector tubes.

4. Case Studies

4.1. Overview and Design Parameters of Data Center

4.1.1. Data Center Overview

This case is a one-storey storage data center with a total construction area of 6500 m^2, of which the area of the server room is 4000 m^2 and the area of the support area is 2500 m^2. The building adopts modularized server room, there are 4 server room modules, the total IT load is 8236.8kW. The total cooling load of server room area is 8800kW; the total cooling load of support area is 920kW; the total cooling load of data center is 9720kW. The air supply form of data center cooling system is under the movable floor, and the measure of cold and hot channel isolation is adopted.

4.1.2. Design Parameters

(1) Data center environment design parameters

When designing and calculating the case, it is calculated according to the supply air temperature of the cold aisle 25°C, the relative humidity of the supply air 50%, and the temperature difference between the cold aisle and the hot aisle 12°C (the side of the hot aisle is 37℃).

(2) Outdoor design parameters

The trial location of the case is selected in Guangzhou, which is hot in summer and warm in winter. In summer, the outdoor dry bulb temperature is 34.2℃ and the moisture content is 21.31 g/kg.

4.2. Mechanical Refrigeration System Selection

In this case, the natural cooling type air-cooled screw chiller is selected, in winter and transitional season, when the outdoor air temperature reaches the set temperature, the natural cooling function is turned on, so that the unit gives priority to using the natural cold source to directly cool the circulating chilled water, minimizing the energy consumption of the compressor operation.

4.3. Combined Heat Source System Selection

4.3.1. Dew Point Evaporative Cooler Selection

A total of 48 dew point evaporative coolers are used in this case data center, the power of a single unit is 5.55kW, so the total power is 266.4kW.

4.3.2. Dehumidification System Selection

By calculating the dehumidification module series, parallel and the total number of modules, the dehumidification fan, regeneration fan and microwave operating power can be obtained, the results are shown in Table 1.

Table 1. Dehumidification system power calculation results.

Total number of dehumidificatio-n modules in series (number)	**Number of parallel groups of dehumidific-ation modules**	**Number of dehumidific-ation modules per group (number)**	**Total number of dehumidification modules (number)**	**Total power of dehumidifier fan (kW)**	**Total power of regenerative fans (kW)**	**Microwave generator power (kW)**
2	1383	10	13830	1077.12	694.56	8298

4.3.3. Thermal Storage Solar System Selection

According to the calculation, the total regenerated air volume is 2073600 m^3/h, and the number of collector units is 9654.

4.4. Performance Calculations and Comparisons

By consulting “Special Meteorological Data Set for Thermal Environment Analysis of Buildings in China”, the hours of meteorological conditions of two systems with different operation strategies in typical meteorological years in Guangzhou were obtained, and the performance indexes such as annual system operation energy consumption, PUE and carbon reduction were calculated.

4.4.1. Data Center PUE Calculations

The PUE value is commonly used in data centers to measure the effective energy utilization efficiency, and its value is the ratio of the total energy consumption of data centers to the energy consumption of IT equipment. The total energy consumption of data center of conventional cooling system and combined heat source system is 11531.6kW and 9927.88kW respectively. So the PUE is 1.4 and 1.21 respectively.

4.4.2. Analysis of Power Saving and Carbon Reduction

In this case, the annual power consumption of mechanical refrigeration system and combined heat source system is 24900300kWh, 11335070kWh respectively. For Guangzhou with high humidity, the power saving is 13565230kWh.

According to the standard "Carbon Emission Calculation Standard for Buildings" GB/T51366-2019, the carbon emission factor of southern regional power grid is 0.5271 $kgCO_2/kWh$. Therefore, the system can reduce CO_2 emissions by 8000 t per year.

5. Conclusion and Prospect

In this paper, under the background of limited use of indirect evaporative cooling technology, an evaporative cooling system with dehumidification system is designed, including the calculation of system main equipment selection, and analyzes the performance of data centers using this system in Guangzhou, and it is compared with conventional mechanical cooling system, and the results are as follows:

(1) In terms of data center PUE, the combined heat source system has a better PUE level, for Guangzhou, the dehumidification system needs to be turned on nearly 40% of the time, which increases the power consumption, but its PUE value is still lower than that of the mechanical cooling system.

(2) In terms of electricity saving, for Guangzhou with high humidity, the power saving ratio can still reach 54%. In terms of carbon emissions, the combined heat source system can reduce CO_2 emissions by 8000 t annually.

It can be seen that the combined heat source system has a better level of energy saving and efficiency. However, it should be noted that the design and calculation of the system in this paper are all in an ideal state. This system still has a wide research direction in the follow-up development, such as studying the optimal combination ratio of waste heat and solar energy in data center, improving the dehumidification capacity of dehumidification bed as well as the carrying out the optimal system configuration.

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