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An energy efficiency measurement and calculation method and its application in data center

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ABSTRACT

Data centers are energy-intensive buildings. Energy efficiency is an important indicator for data center energy consumption. The energy consumption of the data center needs to be measured under full load conditions. However, the data center cannot achieve full load generally. Therefore, it is necessary to open the dummy load equipment. The measurement takes long enough to get the energy efficiency value, which wastes a lot of energy. This paper introduces a new energy efficiency method of measurement and calculation. First, some temperature points are selected to measure the corresponding energy efficiency values. Then the energy efficiency-temperature model is obtained. Based on the imported annual meteorological data where the data center is located, the energy efficiency is finally calculated. Compared with the traditional method, this method takes less time and consumes less energy.

Keywords: Data center, cooling system, energy efficiency

NONMENCLATURE

Abbreviations	
PUE CLF IT	Power Usage Effectiveness Cooling Load Factor Information Technology
Symbols	
CLF_{hour} CLF_{DC} t_{stable} $t_{measure}$	CLF of each hour CLF of the cooling system in data center temperature stabilization time measuring time

1. INTRODUCTION

In recent years, the number of newly built data centers has increased rapidly. Data centers have gradually become the foundation for the development of various Internet industries. In 2017, the total energy consumption of global data centers accounted for about 2%, and it is expected that this energy consumption will reach 5% by 2024 [1]. The energy consumption of the data center mainly includes IT equipment, cooling system, power supply and distribution system, lighting system, etc. IT equipment and cooling system consume 90% of the energy in the data center [2].

Due to the uninterrupted operation of the data center, the cooling system must provide cooling throughout the year to meet the heat dissipation requirements of IT equipment. Therefore, the cooling system consumes a lot of power. And the overall power distribution of the data center is unreasonable. In order to evaluate the power consumption efficiency of the data center, The Green Grid introduced PUE in 2007, which is defined as follow [3]:

$$PUE = \frac{Total\ facility\ power}{IT\ Equipment\ power} \tag{1}$$

For PUE, the data center generally adopts its design value. However, the value is calculated based on the assumption that the data center is fully loaded. If the operation PUE after the completion of the data center needs to be checked, actual testing is required. But a new data center is not put into full load operation immediately when it is built in actual operation. It usually takes 1 to 3 years for IT equipment in large data centers to run from empty load to full load [4]. If the testing time is required short, dummy load equipment in the rack is

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needed. It can be installed to conduct a one-year energy consumption test. For the data center, IT equipment cannot operate during this period. Therefore, this year's electric energy is consumed without output effect, which does not meet the energy-saving goals.

In this paper, a method to quickly measure the energy efficiency of the data center cooling system is proposed. Dummy load equipment is installed to test the energy efficiency of the cooling system in the data center under different climatic conditions in a short time. Then, the energy efficiency of the data center throughout the year is calculated. Furthermore, the annual average energy efficiency of the cooling system in the data center is obtained. Compared with traditional energy efficiency measurement methods, it can save time and energy at the same time.

2. ENERGY EFFICIENCY MEASUREMENT SYSTEM

For the components of the total energy consumption of the data center, IT equipment, UPS systems and lighting equipment do not change with the outside climate. In order to analyze the cooling system conveniently, CLF is introduced here[5]:

$$CLF = \frac{Cooling\ system\ power}{IT\ Equipment\ power} \quad (2)$$

CLF and PUE satisfy the following relationship:

$$PUE = CLF + 1 + \frac{Other\ power}{IT\ Equipment\ power} \quad (3)$$

At different ambient temperature, only the power consumption of the cooling system in the data center changes, and the others remain unchanged. That is, in the formula (3), only CLF changes with temperature. Therefore, CLF is used in the following part to analyze energy efficiency. Combining the corresponding relationship between the CLF and the outdoor air temperature, a cooling system energy efficiency measurement method can be designed to obtain the energy efficiency of the cooling system quickly.

First, determine the geographic location of the data center tested, and measure the CLF value of the data center in the largest possible temperature range. Then, the dummy load equipment only needs to be turned on for each measurement. And after the temperature stabilization time t_{stable} and the measuring time $t_{measure}$ under each temperature condition, CLF at each temperature is measured. Perform data processing on each temperature and the corresponding CLF value, and the functional relation between the two is obtained:

$$CLF = f(T) \quad (4)$$

In order to simplify the formula, the corresponding relationship between CLF and temperature is expressed in the following polynomial fitting form:

$$CLF = aT^3 + bT^2 + cT + d \quad (5)$$

a, b, c, d are model coefficients

In actual operation, considering the use of natural cooling sources in the data center, different cooling forms are generally adopted according to different climatic conditions. For example, when the outdoor temperature is high, mechanical cooling is adopted. And when the outdoor temperature is moderate, the integrated cooling mode of mechanical cooling and natural cooling is adopted. When the outdoor temperature is low, the data center only uses natural cooling sources to save energy. The corresponding relationship between CLF and temperature is different under different cooling modes. Therefore, a piecewise curve fitting model can be used to express the relationship between CLF and temperature:

$$CLF = \begin{cases} A_1T^3 + A_2T^2 + A_3T + A_4 & T \le T_1 \\ B_1T^3 + B_2T^2 + B_3T + B_4 & T_1 < T \le T_2 \\ C_1T^3 + C_2T^2 + C_3T + C_4 & T > T_2 \end{cases} \quad (6)$$

Where T_1 is the temperature at which the natural cooling is completely adopted, T_2 is the temperature at which the mechanical cooling system is completely adopted. And $A_1, A_2, A_3, A_4, B_1, B_2, B_3, B_4, C_1, C_2, C_3, C_4$ are the different coefficients of the model.

From the above functional relation, the standard CLF value at any temperature can be obtained when the data center adopts this cooling system. Based on the city's 8760 hours of weather data throughout the year, the CLF of the cooling system in the data center can be calculated according to the corresponding relationship between CLF and temperature. Taking the average of the annual energy efficiency, the energy efficiency of the cooling system in the local data center is obtained. The calculation formula is as follow:

$$CLF_{DC} = \frac{\sum_{hour=1}^{8760} CLF_{hour}}{8760} \quad (7)$$

Where CLF_{hour} is the calculated CLF corresponding to the temperature of each hour, and CLF_{DC} is the average energy efficiency level of the data center cooling system in a year.

Compared with the traditional method, the measurement of this method takes less time and consumes less energy. Therefore, this measurement method is quite efficient. Take any data center as an

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example, turn on the dummy load equipment at each temperature point, set the temperature stabilization time t_{stable} to 1 hour, and set the measuring time $t_{measure}$ to 2 hours. That is, the dummy load equipment needs to be activated for 3 hours under each temperature condition. Set the temperature range of the data center area in a year from -10℃ to 35℃, and select 45 temperature points for testing. In this way, the dummy load equipment only needs to be activated for 135 hours to accurately measure the energy efficiency of the data center cooling system. This basically achieved the effect of saving time and energy at the same time.

3. APPLICATION OF COOLING SYSTEM ENERGY EFFICIENCY CALCULATION

3.1 Introduction of the cooling system

Combined with the energy efficiency calculation method of the cooling system introduced above, this paper selects a data center in Jilin City, Jilin Province as an analysis example. The data center has no raised floor, and the cooling form is the integrated heat pipe cooling system based on the rack-level and row-level. The evaporator of the integrated heat pipe cooling system is built into the rack door, which is rack-level cooling. And the evaporator is placed between the rows of racks, which is row-level cooling.

As shown in Fig 1, the integrated heat pipe cooling system consists of two heat pipe cycles and one vapor compression cycle [6]. There are three operating modes under different outdoor environmental conditions. When the outdoor temperature is too low, the mechanical compression refrigeration system is turned off, and only the separate heat pipe is used for heat exchange. When the outdoor temperature is too high, the natural cooling cycle of the heat pipe cannot work, and the compressor is turned on at this time. The heat of the working fluid of the evaporator in the data center is taken away by the intermediate heat exchanger, and then the heat is discharged outside through circulation. When the outdoor temperature is moderate, the natural cooling of the heat pipe can work. But because the outdoor temperature is not low enough, the cooling capacity does not meet the cooling requirements of the data center. Therefore, the compressor needs to be turned on at the same time, and heat exchange is performed in the integrated cooling mode of series and parallel.

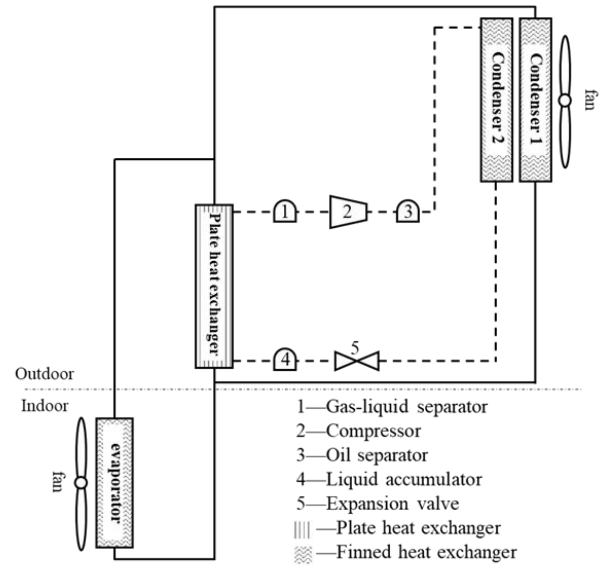

Fig 1 Schematic of the integrated heat pipe cooling system

3.2 Application of the energy efficiency method

A dummy load test was performed on the above data center, and CLF of the cooling system was measured and recorded at each temperature point. In this way, CLF values corresponding to different outdoor ambient temperature were obtained, as shown in Fig 2.

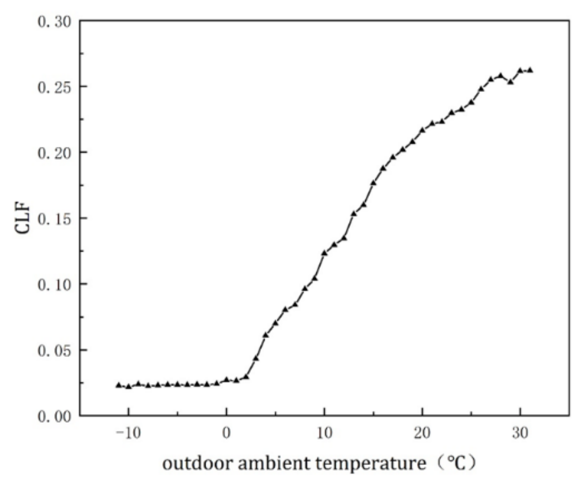

Fig 2 CLF with outdoor ambient temperature

According to the weather conditions in Jilin City, the outdoor ambient temperature tested ranges from -11℃ to 31℃. In order to make the measurement results more accurate, each meteorological temperature point was measured three times. That is, for each meteorological temperature point, it takes 9 hours to get the standard CLF value. Therefore, in order to get an accurate CLF value, the total time that the dummy load equipment needs to be activated is 387 hours.

From the test data, when the outdoor ambient temperature is above 0℃, CLF fluctuates and rises with

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temperature. When the outdoor ambient temperature is below 0℃, CLF basically remains constant. Therefore, the functional relation between CLF and T (℃) was obtained by data segmentation fitting:

$$CLF = \begin{cases} 0.02323064 & T \le 0 \\ -6.756e-6T^3 + 1.598e-4T^2 + 0.009T + 0.018 & T > 0 \end{cases} \quad (8)$$

Then, the annual meteorological data of Jilin City was introduced, as shown in Fig 3. Based on the above CLF-temperature functional relation (8), introduce each temperature point in a year into the calculation model. And the corresponding CLF of the data center in each operation hour could be calculated. The calculation results are shown in Fig 4.

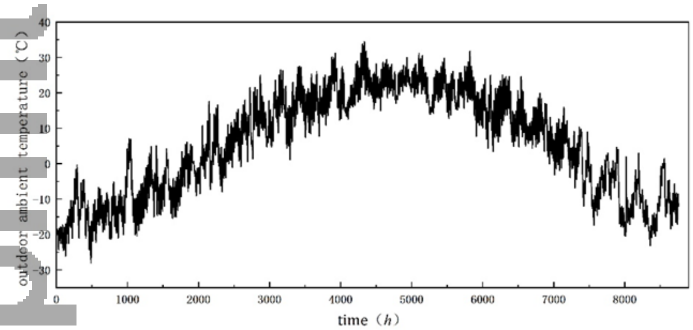

Fig 3 Outdoor ambient temperature of Jilin City

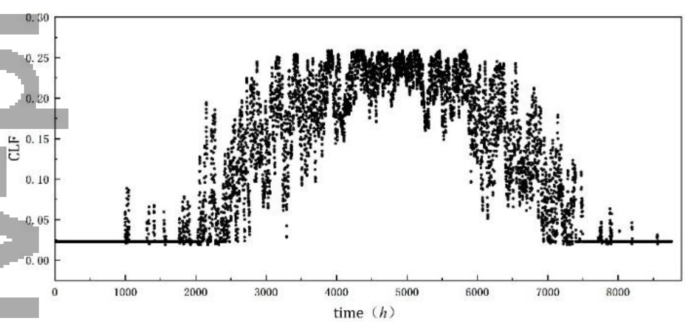

Fig 4 CLF of the data center cooling system in a year

In this way, 8760 CLF values throughout the year in the data center cooling system were presented. And according to formula (7), the annual average CLF of the data center cooling system could be obtained as 0.110637.

4. CONCLUSION

This paper introduces a convenient calculation method for the energy efficiency of the data center cooling system. Compared with traditional measurement methods, it has the advantage of saving time and reducing consumption simultaneously. In terms of application of this method, a data center with the integrated heat pipe cooling system in Jilin City was as the calculation example. CLF values under different temperature were measured in a short time in the dummy load operation mode. According to the functional relation between CLF and temperature, the hourly CLF value under the temperature range throughout the year was calculated. Based on the calculated CLF values, the energy efficiency of the data center cooling system could be finally obtained.

In theory, this energy efficiency measurement and calculation method of data center can be extended to various regions. According to the energy efficiency of the data center cooling system in certain region, the relationship model between CLF and temperature can be calculated. In this way, as long as the annual meteorological data of the measurement area is provided, the energy efficiency of the cooling system installed in the data center of any measurement area can be obtained. Therefore, this method has a huge application potential.

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