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Optimization of server water cooling system operating conditions based on minimum energy consumption analysis

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ABSTRACT

To improve data center thermal management, a water cooling system based on the cooling tower of data center with thermal power of 4.8 kW is introduced. A fin-type water-cooled heat sink is taken to cool chip in the server cabinet. Aiming to realize the minimum energy consumption of the water cooling system, and the optimization analysis on the cooling water working condition is carried under different safe chip temperature with aid of TRNSYS software. The results show that when taking safe chip temperature of 70°C, the minimum power usage effectiveness (PUE) value of approximately 1.097 is yielded at these optimal case: inlet temperature of secondary cooling water of 20°C, and the primary and secondary cooling water flow rates of 9.207 L/min and 6.108 L/min, respectively. Finally, the fitting correlation equations of optimal parameters for different safe chip temperature are given to guide cooling system design.

Keywords: cooling tower, energy consumption, TRNSYS, water-cooled heat sink

1. INTRODUCTION

With the advent of 5G internet services and the big data era, the data center industry is developing rapidly, which drives the continuous improvement of data center information technology (IT) equipment performance. During the operation of a data center, the heat load generated by its IT equipment is 100 times that generated in an ordinary office [1]. The most effective way to reduce the energy consumption of a data center is to reduce the energy consumption of the cooling system in the data center.

In recent years, researchers have begun to analyze and study the energy consumption and economy of data center cooling systems. Endo et al. [2] conducted a one-year operation test. This data center uses a fresh air cooling system that can yield energy saving rates of up to 20.8% per year when compared with a data center using traditional air conditioners. Kim et al. [3] proposed a feasible multi-stage outdoor air cooling system to achieve energy savings in data centers. This system achieved an energy saving rate of up to 18.4% when compared with the traditional mechanical refrigeration system. Zhang et al. [4] established a data center energy consumption model with distributed air flow control, and they concluded that this method can significantly reduce the cooling energy consumption of the traditional data center ventilation system.However, with the transistor density doubling every two years, the heat flux density of IT equipment is increasing exponentially [5]. At present, an increasing number of scholars have begun to investigate liquid cooling, which will become a trend in the field of data center cooling [6]. I. I. Levin et al. [7] considered the structure, layout, and technical characteristics of a liquid immersion cooling system, and a liquid immersion server was designed. Whelan et al. [8] designed a water-cooled heat dissipation system for chip cooling. This system can cool the chip with a heating capacity of 200 W and maintain the chip temperature at 65 °C. Zimmermann et al. [9] proposed using 60 °C cooling water to cool the system. They found that data centers with traditional air-cooled systems can save up to 40% on energy consumption.

However, the aforementioned research did not comprehensively consider the thermal management of the system. For example, the research of I. I. Levin et al. [7] only considered the structural optimization of the server cabinet side, and the research of Severin Zimmermann et al. [9] only considered the influence of the cooling water temperature of the refrigeration system on the system energy consumption. In this study, using the fin-type water-cooled heat sinks to solve the heat dissipation of the chips in the server cabinet, and optimization the working condition parameters of the cooling system of date center based on the cooling tower, and analyzes the energy consumption of the system under each operating condition.

2. METHODOLOGY

To evaluate the energy efficiency of the data center, a 22u cabinet server water cooling system was established. The total power of the cabinet server is 4.8 kW. As shown in Fig. 1, the data center consists of cabinet server and a water cooling system. The cabinet server is divided into 12 layers, and each layer has a heat dissipation structure unit, which is composed of a fin-type water-cooled heat sink and a chip. The water circulated through the water-cooled heat sink of the cabinet server is called secondary cooling water. The temperature of the secondary cooling water flowing into the server is referred to as the inlet water temperature. The water cooling system mainly includes two pumps, a heat exchanger and a

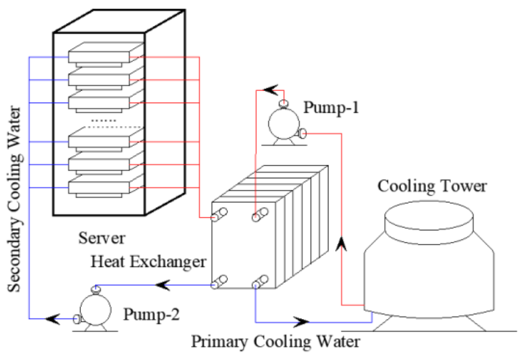

Fig. 1 Data center cabinet server and water cooling system

cooling tower. The closed cooling tower is used to provide primary cooling water. The primary cooling water and secondary cooling water exchange heat through the plate heat exchanger.

2.1 Heat dissipation structure unit

To satisfy the heat dissipation of the cabinet server with high heat flux, a fin-type water-cooled heat sink adopts.The structural unit is shown in Fig. 2 (a). Shown in order from bottom to top are the chip, bottom plate of the heat sink, top lid, and inlet and outlet provided on the top lid. To reduce the thermal contact resistance between the chip and the bottom plate of the heat sink, a thin layer of thermal grease was applied between the two [10]. Fig. 2(b) shows the bottom fin structure of the water-cooled heat sink. W_b, L_b, and H_b represent the length, width, and height of the bottom of the heat sink respectively; L_f represents the length of the fin; and H_f, W_f, and S_f represent the height, width, and spacing of the fins respectively. Fig. 2(c) shows an enlarged partial view of the fin. The structural dimensions of the heat sink are listed in Table 1, where m and k_{gr} [11] stand for the number of fins and conductivity of thermal grease, respectively.

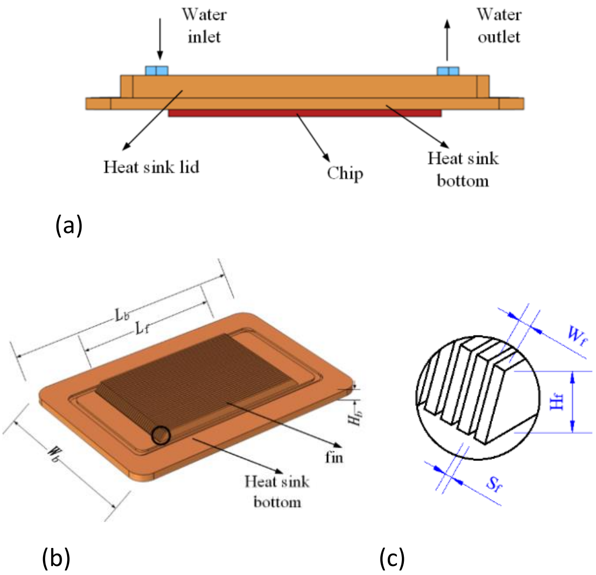

Fig. 2 Geometric model, (a)Heat dissipation structure unit, (b)Heat sink bottom plate, (c)Partially enlarged view of fin

Table 1 Parameters of fin-type heat sink

Parameter	Value	Parameter	Value	Parameter	Value
L_b (mm)	115	W_b(mm)	78	H_b(mm)	3
L_f(mm)	72.6	W_f(mm)	0.8	H_f(mm)	3.5
S_f(mm)	0.45	m	38	k_{gr}(W/m·K)	4.5

2.2 Water cooling system

The transient simulation software TRNSYS was used to establish the water cooling system model. As shown in Fig. 3, the entire model includes a cooling tower module, two cooling water pump modules, a plate heat exchanger module, a server module, three result display modules, and two power calculation modules. The model parameters are listed in Table 2.

The power usage effectiveness (PUE) is currently a more general index used for evaluating air conditioning systems in data centers. It was first proposed by Malone [12] in 2006 to be the ratio of total electrical power to IT equipment power.It can be calculated using

$$PUE=\frac{P_{total}}{P_{IT}}=\frac{P_{IT}+P_{tower}+P_{pump-1}+P_{pump-2}}{P_{IT}} \quad (1)$$

where P_{total} is the total power consumption of the data center; P_{IT} is the power consumption of the IT equipment; P_{tower} is the power consumption of the cooling tower; P_{pump-1} is the power consumption of the primary cooling water pump; and P_{pump-2} is the power consumption of the secondary cooling water pump.

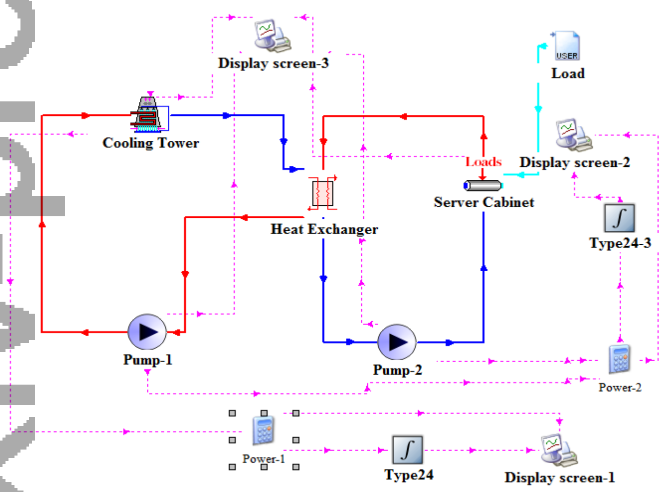

Fig. 3 Water cooling system model of data center

Table 2 Parameters of equipment

Equipment	Model	Specific parameter value
Cooling tower	BST-3	Rated Flow:3 m^3/h ; Rated air quantity:2200 m^3/h ; Motor power:0.12 kW Wet bulb temperature:28℃; Dry bulb temperature:31.5℃ ; Atmospheric pressure:9.94×10^4 Pa
Water pump	BW2-6	Rated flow:2 m^3/h; Rated power:750 W
Plate heat exchanger	B3-32A-30-3.0	Heat transfer coefficient:2025 W/K; Heat exchange area:0.81 m^2

3. RESULTS AND DISCUSSIONS

3.1 Optimization of cooling water flow on server side

By calculating the heat dissipation structure unit, the relationship among the water inlet temperature, secondary cooling water flow and chip temperature is obtained, as shown in Fig. 4. It can be seen that the chip temperature decreased with the increase in the flow rate of secondary cooling water, and the decrease in the chip temperature became smaller and smaller, after which it finally stabilized. The chip temperature decreased with the decrease in water inlet temperature, and the decrease range was essentially the same. Usually, there is a safe chip temperature to ensure the safe operation of the CPU.When the temperature is higher than that safe value,the chip will work in a low efficiency or be broken. Taking the safe temperature of 70 °C as case, there is a minimum secondary water flow rate for each water inlet temperature to maintain this safety temperature, and as the water inlet temperature rises, the minimum water flow required increases continuously. But when the inlet water temperature rises above 26℃, no matter how much the water flow is increased, the safety chip temperature requirements cannot be met. Therefore, corresponding to the determined safety chip temperature, there is a limit on the available highest water inlet temperature. Besides, there is a minimum cooling water flow rate corresponds to each available water inlet temperature.The smaller the flow rate, the smaller the pump power consumption, and the more energy-saving. Therefore, when other parameters are determined, the minimum flow rate is the optimal secondary water flow.Fig.5 shows the relationship between the water inlet temperature and the corresponding optimal secondary cooling water flow when the safe chip temperature was maintained at 65 °C, 70 °C, 75 °C, and 80 °C. It can be seen that, for a constant chip temperature, as the water inlet temperature increased, the optimal secondary cooling water flow rate increased, and the increased range becomes more obvious. Moreover, the available highest water inlet temperature decreased as the safety chip temperature decreased.

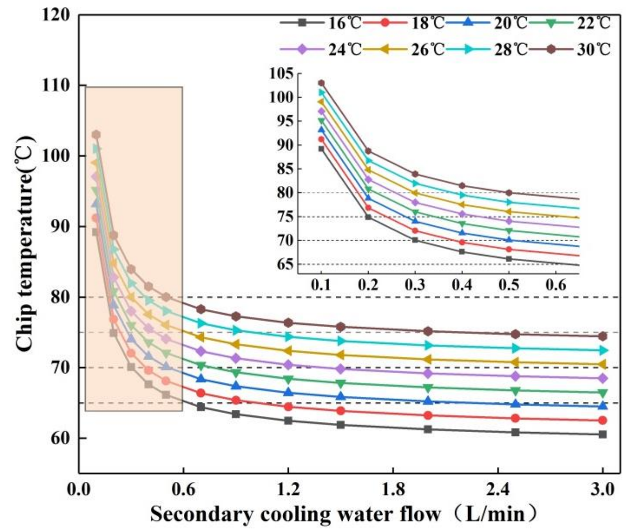

Fig. 4 Change in chip temperature with flow rate of secondary cooling water

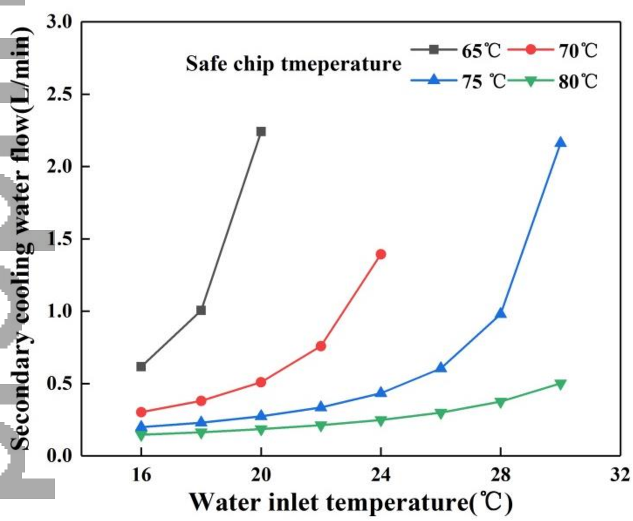

Fig. 5 Relationship between water inlet temperature and optimal flow rate of secondary cooling water

3.2 Optimization of cooling water flow at cooling tower side

When the optimal flow rate of secondary cooling water is taken referring to Fig. 5, the Fig.6 shows the changes in water inlet and oulet temperature, chip temperature with primary cooling water flow. It can be seen that with an increase in the primary cooling water flow, the water inlet temperature, water outlet temperature, and chips temperature decreased and finally gradually stabilized, and the change trends of the three were essentially the same. When the chip temperature does not exceed 70℃, the minimum primary water flow required is 9.207 L/min, which is the optimal primary water flow under this condition. Therefore, there is an optimal primary water flow for each safety chip temperature.

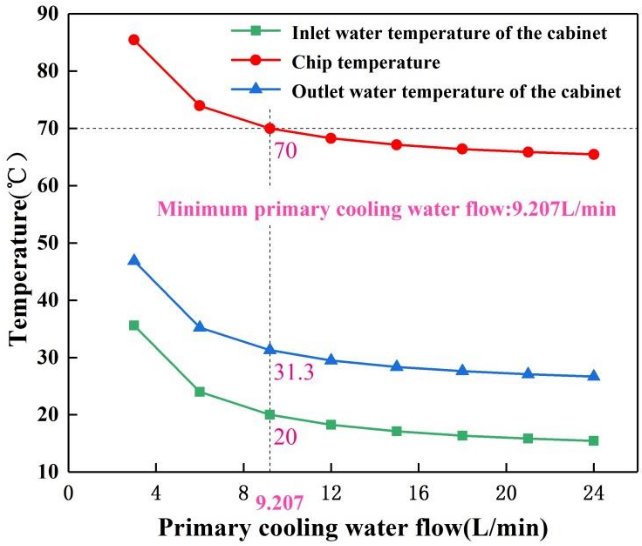

Fig. 6 Change in water inlet and outlet temperature of secondary cooling water temperature, chip temperature with flow rate of primary cooling water

Fig. 7 shows the relationship between the optimal flow rate of primary cooling water and that of optimal secondary cooling water with water inlet temperature at different safe chip temperatures. It can be seen that for a chosen safe chip temperature, the optimal secondary cooling water flow decreased with the decrease in water inlet temperature and the optimal primary cooling water flow rate gradually increased. When the safe chip temperature is different, the optimal flow rate of the primary water has little change, while the optimal flow rate of the secondary water decreases significantly as the safe chip temperature increases. The water inlet temperature drops from 30°C to 16°C, the maximum and minimum increases in the primary cooling water flow rate were 4% and 57.4%, respectively.

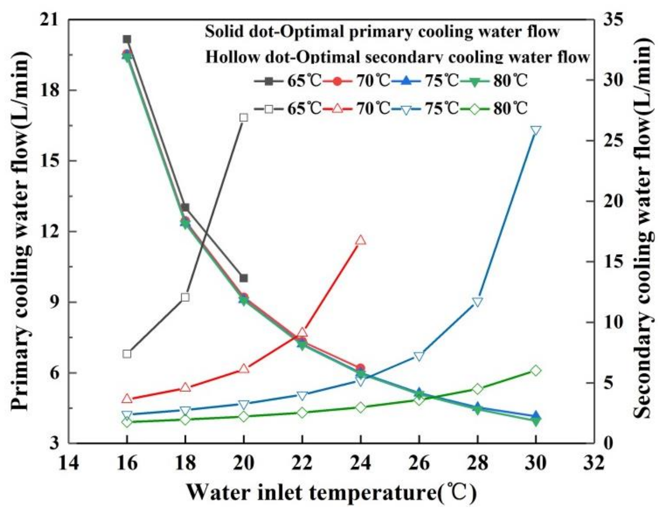

Fig. 7 Change in optimal flow rate of cooling water with water

inlet temperature

3.3 Parameter optimization based on minimum power consumption

Fig.8 shows the power consumption of each configuration of the cooling system, and the PUE varies with the water inlet temperature when taking safe chip temperature of 70℃. It can be seen that the power consumption of the secondary cooling water pump increased and that of the primary cooling water pump decreased with an increase in the water inlet temperature. It can also be seen that when the water inlet temperature was 20 °C, the PUE reached its minimum value, which is approximately 1.097, with corresponding primary and secondary cooling water flow rates of 9.207 L/min and 6.108 L/min, respectively. Therefore, an optimal water inlet temperature exits in water cooling system.

Fig. 9 shows the variation in the optimal water inlet temperature and the optimal primary and secondary cooling water flows under different safe chip temperatures. It can be seen that, with the safe chip temperature increase, the optimal cooling water flow almost decrease linearly, and the optimal water inlet temperature almost increase linearly. The fitting correlation equations are given in Fig. 9, which can provide a guide to optimize the working conditions of water cooling system with low system energy consumption.

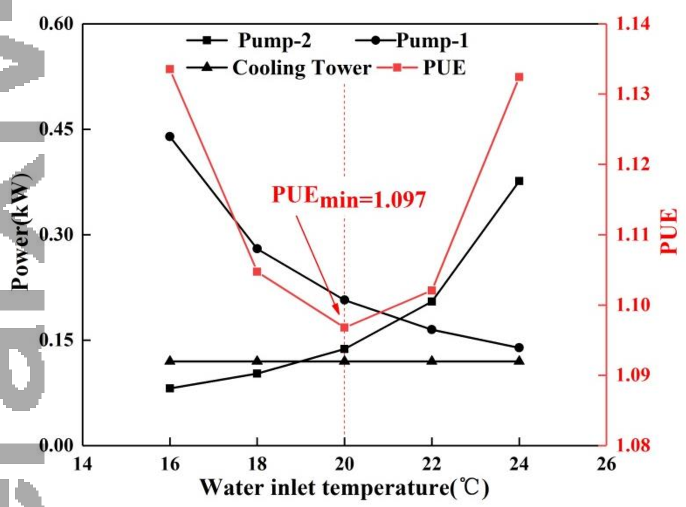

Fig. 8 Change in power consumption and PUE with water inlet temperature

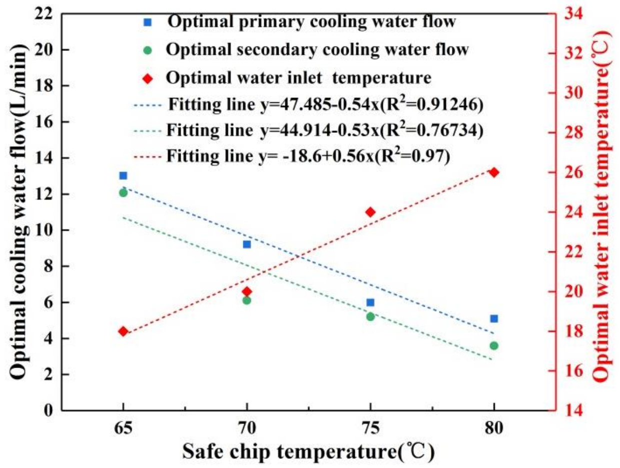

Fig. 9 Optimal cooling water flow and optimal water inlet temperature versus safe chip temperature

4. CONCLUSIONS

This study investigates a cooling system based on the cooling tower of data center with the thermal power of 4.8kW, which uses a fin-type water-cooled heat sink. Aiming at the minimum energy consumption of the system, the optimal operating conditions of the cooling water are analyzed, and the following conclusions are obtained:

(1)The CPU needs to control its working temperature not to exceed its safe value. For each safe chip temperature, there exists an optimal operating condition to realize the minimum system energy consumption, including the optimal secondary water flow on the side of the cabinet, the optimal primary water flow on the side of the cooling tower, and the optimal water inlet temperature. Taking safe chip temperature of 70℃ as case, the optimal water inlet temperature, primary cooling water flow rate and secondary cooling water flow rate are 20 °C, , 9.207 L/min and 6.108 L/min, respectively, and the minimum PUE is approximately 1.097.

(2) With the safety chip temperature increases, the optimal secondary water flow and the optimal primary water flow almost decrease linearly, while the optimal water inlet temperature increases linearly.The corresponding fitting correlation equations are given, which can guide the optimal working condition parameter setting of the cooling system for different safe chip temperature requirements.

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REFERENCE

[1] Long Phan, Cheng-Xian Lin. A multi-zone building energy simulation of a data center model with hot and cold aisles [J]. Energy & Buildings, 2014, (77): 364-376.

[2] Endo H, Kodama H, Fukuda H, et al. Effect of climatic conditions on energy consumption in direct fresh-air container data centers [J]. Sustainable Computing: Informatics and Systems, 2015, 6:17-25.

[3] Je-Yong Kim, Hyun-Jae Chang, Yong-Ho Jung, et al. Energy conservation effects of a multi-stage outdoor air enabled cooling system in a data center [J]. Energy and Buildings, 2017, 138: 257-270.

[4] Zhang X, Lindberg T, Xiong N, et al. Cooling Energy Consumption Investigation of Data Center IT Room with Vertical Placed Server [J]. Energy Procedia, 2017, 105: 2047-2052.

[5] T.J. Breen, E.J. Walsh, J. Punch, et al. From chip to cooling tower data center modeling: part I influence of server inlet temperature and temperature rise across cabinet [C].Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm), 2010 12th IEEE Intersociety Conference ,2010.

[6] T. Cader, L. Westra, V. Sorel, A. Marquez Liquid cooling in data centers [J]. ASHRAE Trans, 2009, 115: 231-241.

[7] Levin I I, Dordopulo A I, Doroncheenko Y I, et al. Immersion liquid cooling FPGA-based reconfigurable computer system[J]. IFAC-PapersOnLine,2016,49(25):366-371

[8] B.P. Whelan, R. Kempers, A.J. Robinson. A liquid-based system for CPU cooling implementing a jet array impingement water block and a tube array remote heat exchanger [J]. Applied Thermal Engineering, 2012, (1): 86-94.

[9] Zimmermann S, Meijer I, Tiwari M K. Aquasar: A hot water cooled data center with direct energy reuse [J]. Energy, 2012, 43(1): 237-245.

[10] J.P. Gwinn, R.L. Web. Performance and testing of thermal interface materials[J]. Microelectronics Journal, 2003, (34): 215–222.

[11] J.P. Gwinn, R.L. Web. Performance and testing of thermal interface materials[J]. Microelectronics Journal, 2003, (34): 215–222.

[12] Malone C, Belady C. Metrics to characterize data center & IT equipment energy use[C]. Proceesdings of 2006 Digital Power Forum: Richardson TX, 2006:1941-5923.