Advances in Applied Mathematics and Mechanics
Adv. Appl. Math. Mech., Vol. **11**, No. 1, pp. 91-107

DOI: 10.4208/aamm.OA-2018-0139
February 2019

Numerical Investigation into the Air Flow Distributions of the Air Conditioning System in the Modular Data Center

Hao Dong[1], Ziqiang Qin[2], Shicheng Liu[1], Yao Li[2], Yingying Shen[2], Haibo Wang[2], Yitong Zong[2], Xiaojun Wu[3] and Haiqing Si[2,*]

[1] *College of Aerospace Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China*
[2] *College of Civil Aviation and Flight, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China*
[3] *China Aerodynamics Research and Development Center, Mianyang 621000, China*

Received 6 June 2018, Accepted (in revised version) 4 July 2018

Abstract. Data center plays an increasingly important role in everyday life. As data center is becoming more and more powerful, energy consumption is also increasing dramatically. The air conditioning system occupies at least 50 percent of the total energy consumption. Therefore, delicate analysis on the air conditioning system could help to reduce energy consumption in data center. An advanced Finite Volume Method with RNG $k-\varepsilon$ model and convective heat exchange model is used in this paper to study the airflow and the temperature distribution of modular data center under different arrangements. Specifically, the calculation formula of convective heat transfer coefficient for plate flow is adopted to simplify analysis; and fans on the back of racks are simplified to be walls with a certain pressure jump. Simulations reveal that, in the case where air conditioners are arranged face-to-face, the temperature distribution on the back of racks is not uniform, and local high temperature points emerge near the side wall of air conditioners. By analyzing the distribution of air flow and temperature, geometric model is optimized by using a diagonal rack arrangement and drilling holes on the side wall. In the same energy consumption situation, the overall maximum temperature of the optimized model is reduced by 2.3°C compared with that of the original one, and the maximum temperature on the server surface is reduced by 1°C. Based on the optimized model, the effect of the hot aisle distance on the temperature distribution is studied. By simulating four different cases with various distances of hot aisle of 100cm, 120cm, 130cm and 150cm, it is found that the temperature is generally lower and distributed more evenly in the case with 120cm hot aisle distance. This demonstrates that the distance of hot aisle has an effect on temperature.

AMS subject classifications: 58D30, 76N15, 76N25, 76B47

Key words: Modular data center, air conditioning, temperature distribution, hot/cold aisle, CFD.

---

*Corresponding author.
Email: sihaiqing@126.com (H. Q. Si)

1 Introduction

Data center is the physical space for centralized processing, storage, transmission, exchange, and management of information. Continuous developments of micro-electronic technology and chip integration enable significant improvements in packaging density and operating frequency, which is also accompanied by rapid increase in the heat flux density. In cloud computing data center, power consumption can reach 10kW for a single rack. The reliability and service time of a server largely depend on its operating temperature. Overheating of the device can seriously affect its stability and reliability [1]. Due to that, effective and efficient air conditioning system is an essential part of the data center. Scientific organization of air flow in the air conditioning system not only fulfills temperature requirements of data center [2], but also reduces energy consumption. Data center is one of the largest energy-consuming facilities mainly in many developed countries. Traditional temperature control solution accounts for 30% to 50% [3–5] of the total power consumption of the data center. Therefore, exploration in reducing PUE value (a ratio of air conditioning system energy consumption to the total energy consumption) and creating an energy-saving and environmentally friendly data center would be a very interesting research topic academically and economically.

The servers used in high-density data centers are generally blade severs, the size and power consumption of each sever are fixed. The cold air supplying from the air-conditioning flows over the sever surface which brings away heat through the convection effect. Therefore, studying and understanding the distribution of airflow could favor improving the cooling efficiency of air conditioning. Yang et al. simulated the temperature field of air-cooled radiator [6]. According to the theory of thermal convection [7], a physical model was established and formulas of calculating the convective heat transfer coefficient were given. Through comparing with the results of simulation and experiments, the correctness of the calculation method for convective heat transfer coefficient was verified. Since the heat dissipation process of blade sever is similar to that of the air-cooled radiator, the same formula will be utilized in this work to quantify the convective heat transfer coefficient.

The widespread use of data centers and the drastic increase of power consumption have made the thermal management of data center more difficult. Most computer servers are air-cooled in typical data centers. Cho and Kim [8] pointed that coolant air mixing with heated air exhausted from equipments would lower the efficiency of the air conditioning system. Vaibhav et al. [9] carried out some experiments about the inlet temperature of racks in both open and contained aisle conditions. Hot air will mix with cold air in open cold aisle. Even if over-providing cold air, hot air still exists on the top of cold aisle. Nada et al. [10] investigated, compared and evaluated three different thermal management solutions of data center. In their experiments, the hot aisle and the cold aisle are in different sides of the rack. They found that the rack inlet air temperature was reduced by 3-13% for aisle partition configuration, while the reduction reaches 13-15.5% for aisle containment configuration. Apart from establishing the hot and the cold aisles, many