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Experimental and numerical study of airflow distribution optimisation in high-density data centre with flexible baffles

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A R T I C L E I N F O

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A B S T R A C T

In this paper, an innovative airflow optimisation method applying flexible baffles (FBs) set in an air inlet of racks is proposed to improve the airflow distribution in a data centre during the later maintenance and optimisation phase for existing data centres. Two models (i.e. without FBs and with FBs) are developed and compared by numerical simulations in Airpak 3.0 packages. An on-site experiment is conducted to validate these two models. Both the simulation and experimental results show that the use of FBs can effectively improve the thermal environment in the data centre. To optimise the effectiveness of FBs, a series of scenarios (i.e. FBs with different sizes and angles) is analysed and compared, based on which an optimisation method of the data centre with FBs is developed. The optimum thermal environment appears when 20-cm FBs with a 75° angle in the vertical direction of the rack are applied. The temperature drop of the hotspot in the racks reaches about 1.5 °C, which can effectively weaken the rack hotspots. In addition, the results demonstrate that the temperature drop at a certain point on the rack is related to the corresponding point temperature and the size of the FBs. The higher the temperature of the point, or the wider the width of the baffle, the greater the temperature drop.

1. Introduction

Data centres serve as locations for both data storage and data processing and circulation. During the past several decades, with the rapid development of information and communication technology, the demand for larger storage capacity and faster data processing speed in data centres has contributed to a significant increase in their energy consumption. The energy consumption of data centres has doubled quadrennially over the last 20 years, and data centres were responsible for approximately 1.3% of the worldwide total electricity consumption in 2010. In addition, the demand for data processing will double biennially until 2020 [1,2]. As the augmentation of data processing is inevitable, energy conservation strategies are going to be applied in data centres [3]. Cho et al. [4] mentioned that cooling energy consumption accounted for around 38% of the total energy use within data centres, second only to demand-side systems composed of processors, server power supplies, storage, and other servers. Thus, there is an extreme need to use energy-efficient cooling strategies to lower the energy consumption in high-density data centres.

There are many ways to improve the efficiency of the cooling supply and reduce energy consumption in data centres, including free cooling strategy, airflow management, higher allowable IT temperatures, and cooling management. Among them, free cooling and air management are used more often as energy efficiency strategies in actual data centres [5]. According to Zhang et al. [6], free cooling is an ideal energy conservation strategy which uses natural cold sources to cool data centres in the case of relatively low outdoor temperatures. According to Ma et al. [7], free cooling technology performs better than conventional cooling systems, which reduces a data centre's energy consumption when the outdoor air temperature is relatively low. However, the application of free cooling strategy should meet the following conditions: sufficiently dry and cool outside air, acceptable enthalpy number in the air, and no additional conditioning [3]. Compared to free cooling strategy, airflow management strategies are convenient to operate and fulfil. Airflow management strategy is devoted to changing the data centre's configuration and CRACs air supply state to improve cooling efficiency and the thermal environment [8].

Airflow management, aimed at consuming the minimum energy to keep intake conditions (IT equipment) within the recommended ranges [9], is a promising and manoeuvrable energy-saving approach. Good airflow distribution can not only decrease energy consumption in data centres, but it can also avoid the appearance of overheating servers bringing catastrophic data losses and extend the service life of the servers [10]. Cho et al. [8] evaluated an air distribution system's airflow performance for cooling energy conservation in high-density data centres. The results demonstrated that five criteria in total were

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defined: supply air temperature (SAT), ceiling height, raised floor height, air distribution type (supply/return air location), and zoning regarding aisle containment configuration. These criteria help to evaluate the data centre's general thermal airflow and cooling efficiency. Also used in this evaluation were the design factors for cooling system conditions and alternative approaches to optimise airflow organisation.

Efforts have been conducted by many researchers to cut down the cooling energy consumption in data centres with airflow organisation optimisation. Ham et al. [11] studied the optimum SAT ranges of various air-side economisers in a modular data centre. The results demonstrated that cooling energy consumption was at a minimum when the SAT of CRACs was between 18 °C and 23 °C. The higher the SAT conditions, the greater the cooling energy consumption. Oró et al. [12] performed numerical and experimental analyses of air management in a data centre in Spain and concluded that the cooling energy consumption could be reduced significantly by reducing the air flow rate and increasing the SAT at the same time. Sorell et al. [13] analysed the impacts of ceiling height on the air distribution in data centres. The results showed that increasing the space height improved the overall performance of the air distribution system, but the space height was no more than it needed to be. However, underfloor air distribution systems with ceiling plenum returns need to be taken into consideration since nothing indicated that this air distribution mode could improve air distribution systems' thermal performance.

Sorell et al. [14] used Computational Fluid Dynamics (CFD) modelling to compare underfloor and overhead air supply systems in a data centre. They found that underfloor air distribution performed better when the airflow for the underflow system was beyond 15% of the total racks' airflow, while the overhead system was considered acceptable in the case of a lesser airflow. Schmidt & Lyengar [15] evaluated the suitability of a raised floor air supply and overhead air supply design in very high-density data centres by CFD modelling. Conclusions were drawn that underfloor air supply design was appropriate for higher chilled-air supply cases to produce cooler rack intake air, while overhead air supply design was suitable for lower chilled-air supply cases to yield a cooled rack intake temperature. Cho et al. [16] simulated a high-density data centre with six different air distribution systems to evaluate the thermal performance of the data centre. The results demonstrated that underfloor air supply design performed better in optimising the airflow and thermal performance in data centres.

S.A. Nada and his research team made many efforts to study the thermal and energy impacts concerning aisle containment configuration. In 2015, Nada et al. [17] built CFD models to investigate the thermal performance of different CRAC configurations and aisle separation. One of the results showed that the thermal performance of the data centre was improved by the application of cold aisle containment (CACs). Then, Nada & Elfeky [18] experimentally investigated the thermal management methods in data centres for different arrangements of CACs. The results indicated that the application of semi-enclosed cold aisles enhanced the data centres' thermal performance, while the use of fully enclosed cold aisles exhibited an important thermal performance improvement with the rise in power density. In 2016, Nada et al. [19] performed a numerical and parametric study for the improvement of energy and thermal management in data centres. They found that the application of appropriate CACs enhanced the performance of cooling in data centres, especially in data centres with high power density.

The previous researchers considered all five criteria to optimise a data centre's airflow and thermal distribution. However, as mentioned in Cho et al. [8], it was during the early design phase that these works cut down the energy consumption and improved the cooling efficiency by considering the configuration of the IT server room. However, these airflow management methods cannot be applicable in the energy conservation improvement of existing data centres for the enhancement of airflow and thermal distribution. Therefore, in this paper, an innovative airflow optimisation method that applies variable-angle flexible baffles (FBs) set in the air inlet of racks is proposed to improve the airflow and thermal distribution in data centres during the later maintenance and optimisation phase.

The organisation of this study is as follows. Section 1 summarises the research on the development of data centres and the application of efficient cooling strategies in recent years, and puts forward the innovations of this study. Section 2 introduces the studied data centre and the experimental setup, while section 3 describes the numerical simulation part including the data centre model, relevant parameter settings, simulation conditions, and grid independent test. In section 4, the experimental results and simulation results are analysed and discussed, and then the simulation results are validated using the experimental results. Finally, the conclusions are given in section 5.

2. Methodology

2.1. Data centre description

The data centre analysed in this study is an operative facility which is used to provide computing and information services for a university in Nanjing, China. The specification of the physical model and the distribution of racks are provided by the Facility Management department. The dimensions of the data centre are 11.0 m (L) × 8 m (W) × 4 m (H). Fig. 1 shows the layout and specification of the data centre with a total of 18 server racks which are divided into two rows (rack A and rack B). The data centre incorporates a raised floor plenum that is 0.45 m above the floor. Two CRAC units are used to generate the cooling air, and these CRACs are located at one side of the data centre. The cool air maintained by the CRACs enters the data centre through the floor vents to the underfloor plenum. Then, the air rises to the CACs, which are between rack A and rack B, and is drawn via the servers in the racks. The cool air is heated by the IT loads of the servers, and then enters the hot aisles behind the two rows of racks. Finally, the hot air returns through the hot aisles to the CRACs.

Table 1 lists the parameters of the data centre and equipment. The 18 servers are positioned on either side of a CAC that contained 27

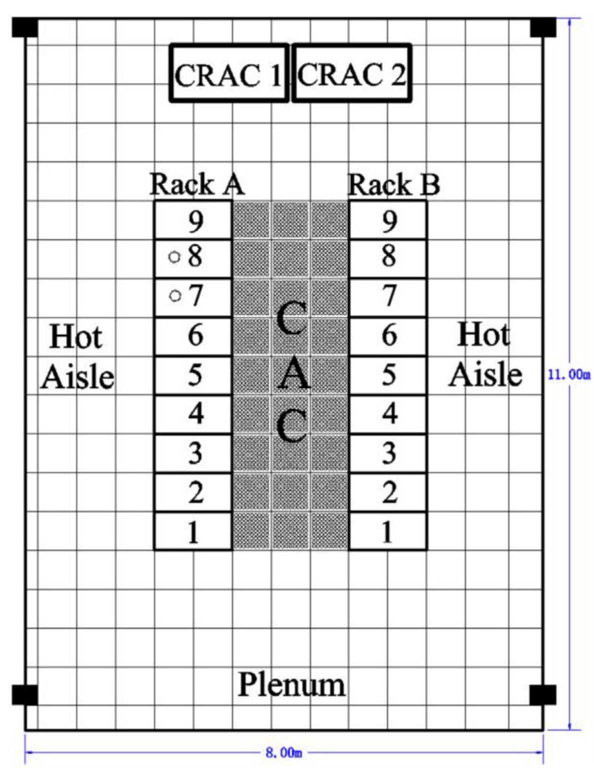

Fig. 1. Data centre layout and specifications (top view).