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Application of the combined air-conditioning systems for energy conservation in data center

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ABSTRACT

The dissipation of heat from the server racks is continuously increasing. For this reason, a raised floor cooling system is important to keep the computer system operating to be effective and long lasting. Thus the proper design air conditioning system in data center is concerned in order to avoid disruption that caused by overheat. Nowadays it is not only a raised-floor cooling system that has been used in data center but also a new cooling system called "In-row" has been introduced into the market. This research presents a simulation of cool air flow generated by 3 different air conditioning systems in data center, which are raised floor air conditioning system, In-row air conditioning system and the combined of them, for giving some appropriate guidelines to help the designer to achieve a better and more efficient cooling system. Dimensionless parameters in the form of supply heat index (SHI), heat load of server racks and the volume flow rate from perforated tile were carried out by considering the rack inlet temperature compared with the standard air temperature of ASHRAE. The results show that these parameters provide an effective tool to the improvement of energy efficiency in the data center.

1. Introduction

A data center is a facility used to house computer systems and associated components, such as telecommunications and storage systems. It generally includes backup power supplies, redundant data communications connection, environmental controls (e.g., air conditioning and fire suppression) and security devices. The data center is used to house large quantities of computer systems. It normally contains the electronic equipments such as server computer, main frame, data storage, network switch, data cabling system and communication networking. These computer systems are deployed in a typical 19 inch rack. A raised-floor air conditioning system is often used to cool all these equipments while they are operating.

Fig. 1 shows a schematic diagram of a data center where computer room air conditioning (CRAC) unit delivers cool air into the space of raised floor. This cool air enters the data center room through perforated tiles and passes through a front face of rack and hot air exits from a rear face of rack. Finally this hot air returns to CRAC unit. However it is usually found that this cool air cannot effectively remove a heat dissipation at the top of server racks. Therefore, the environmental condition in data center must be designed strictly to avoid disruption that caused by overheat. Thus, the solution to this problem is to use a new air conditioning system in data center called "In-row" as shown in Fig. 2. This cooling system is used to deliver cool air at the top, middle and bottom of server rack.

This paper presents a simulation of cool air flow generated by 3 different air conditioning systems in data center which are raised floor air conditioning system, In-row air conditioning system and the combined of air conditioning system (between raised-floor and In-row air conditioning systems). The results of simulations were presented using Commercial Computational Fluid Dynamics (CFD) program. As a result, dimensionless parameters in the form of supply heat index (SHI), heat load of server racks and the volume flow rate from perforated tile were carried out by considering the rack inlet temperature compared with the standard air temperature of ASHRAE. It gives the correlation of all important parameters used for a design of combined air conditioning system in data center. This correlation can be used as a tool to improve the efficiency of the cooling system.

2. Theory

The CFD simulation can provide detailed distributions of air flow and temperature within data center. Ref. [1] applied CFD analysis to show rack inlet temperature and flow distributions for a different height of data center. Ref. [2] compared CFD results of two different perforated tile layouts, a traditional and a guard tile arrangements. Ref. [3] compared CFD results with measurements of rack inlet

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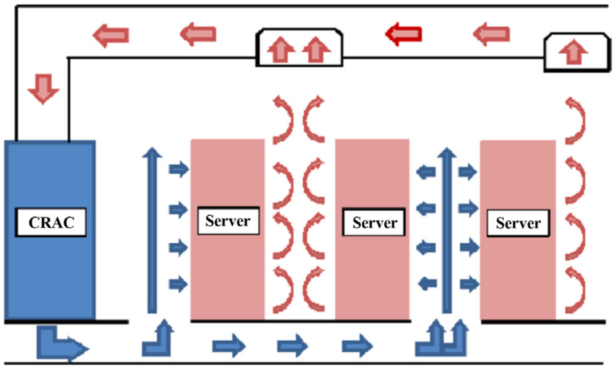

Fig. 1. A raised floor air conditioning system in data center.

temperature using fan boundary conditions at the rear of racks. Ref. [4] presented results of a CFD analysis of the combination of overhead airflow distribution and raised floor distribution. The previous studies [5–8] have utilized numerical codes using k–ε turbulence model to solve data center problems.

The numerical methods and algorithms to solve and analyze problems that involve in fluid flows are known as computational fluid dynamics (CFD). The CFD simulation is used to provide a complete three-dimensional profile of the temperature and flow within the system. The fundamental basis of any CFD problems is the Navier–Stokes equations (conservation law). The four terms in the general differential equation are the unsteady term (transient), the convection term, the diffusion term, and the source term as shown in Eq. (1):

$$\frac{\partial}{\partial T}(\rho\phi) + \mathrm{div}(\rho u\phi) = \mathrm{div}(\Gamma\,\mathrm{grad}\,\phi) + S \quad (1)$$

The flow resistance of perforated tiles can be obtained from pressure drop for such tiles. The pressure drop ΔP across a perforated tile can be calculated from

$$\Delta P = RQ^2 \quad (2)$$

where Q is the air flow rate. R is the flow resistance of perforated tiles and can be obtained from

$$R = \frac{1}{2}\frac{p}{A^2}K \quad (3)$$

where ρ is the density of air and A is the open area of perforated tile. K is the flow resistance factor (the "K factor") based on a large number of measurements and is given by Idelchik [8].

$$K = \frac{1}{f^2}[1 + 0.5(1-f)^{0.75}] + 1.414(1-f)^{0.376} \quad (4)$$

Fig. 2. An In-row air conditioning system in data center.

Table 1
ASHRAE recommended environmental envelope for class 1 environments [10].

	2004 version	2008 version
Low end temperature	20 °C (68 °F)	18 °C (64.4 °F)
High end temperature	25 °C (77 °F)	27 °C (80.6 °F)
Low end moisture	40%RH	5.5 °C DP (41.9 °F)
High end moisture	50%RH	60%RH and 15 °C DP (59 °C DP)

where f is the fractional open area of the perforated tile.

2.1. ASHRAE data center environmental specifications

Maintaining temperature and humidity design conditions is critical to the operation of an IT server room. Design conditions for temperature within the room should be in the range of 18–27 °C. The higher ambient conditions can cause damage and rapid temperature swings can also have a negative effect on facility operation. Table 1 shows temperature and humidity design conditions recommended by ASHRAE.

3. Methods

3.1. Validation

3.1.1. Detailed field measurement

Temperature measurements were carried out in a data center to be used for validation with the computational results. The layout of the data center is depicted in the plan view shown in Fig. 3, measuring 25.2 m^2 with a 3.1 m ceiling height.

There are two server racks and one empty rack, each dissipates heat at the rate of 3 kW, and two computer room air conditioning (CRAC) units, each unit consumes 26 kW. Moreover, there are two 15 kVA uninterruptible power supply (UPS) and seven 25% open perforated tiles.

Detailed measurements were taken in this data center. The airflow through the perforated tiles was measured by using flow measurement hood (Fig. 4). The temperatures were measured with a type K thermocouple. The air temperature was measured at the center of each tile located at the height of 1 m, 1.5 m and 2 m above the floor and spreaded over the room.

3.1.2. CFD model construction

Computational fluid dynamics model of the data center was generated using the commercially available CFD software Fluent. The three-dimensional model was solved using the standard k–ε turbulence model (turbulent kinetic energy k, dissipation ε).

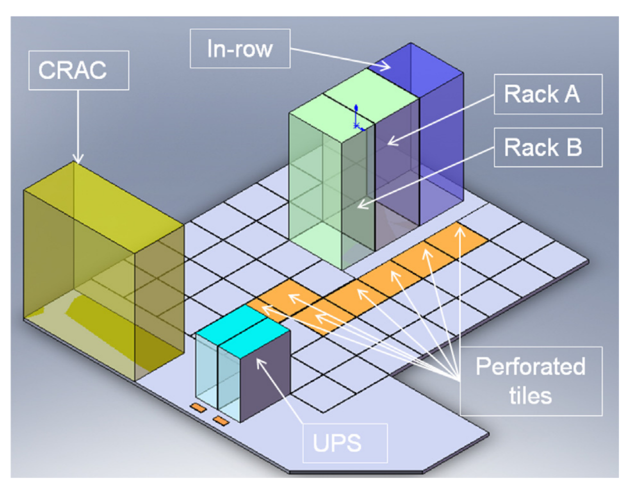

Fig. 3. A raised floor air conditioning system.