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Evaluation of air management system's thermal performance for superior cooling efficiency in high-density data centers

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ABSTRACT

In a typical data center, large numbers of IT sever racks are arranged in multiple rows. In IT environments, in which extensive electronic hardware is air-cooled, cooling system inefficiencies result when heated exhaust air from equipment prematurely mixes with chilled coolant air before it is used for cooling. Mixing of chilled air before it is used with heated exhaust air results in significant cooling inefficiencies in many systems. Over-temperatures may not only harm expensive electronic equipment but also interrupt critical and revenue generating services. The cool shield is a cost effective aisle partition system used to contain the air in cold aisles and hot aisles of an IT server room. This paper focuses on the use of performance metrics for analyzing a vertical aisle partition system in high-density data centers. Performance metrics provide a great opportunity for the data center industry at large. They could form the foundation for a standardized way of specifying and reporting various cooling solutions. The Rack Cooling Index (RCI) is a measure of how well the system cools the IT servers within the manufacturers' specifications, and the Return Temperature Index (RTI) is a measure of the energy performance of the air-management system. Combined, they provide an opportunity to judge the performance of the aisle partition system in an objective way subsequent to comprehensive CFD modeling.

1. Introduction

A data center is a centralized repository, either physical or virtual, for the storage, management, and dissemination of data and information organized around a particular body of knowledge or pertaining to a particular business. The air-conditioning system in today's data center must be capable of supporting on a 24/7, 365 days/year [1]. With the rapid growth of the information-based industry, data centers have become a prevalent phenomenon in both the public and private sectors. Such facilities are widely used for web-hosting, central depository information bases of governmental organizations and research units, intranet, financial transaction processing, and other activities [2]. Data centers are facilities that house IT servers and data storage systems. To ensure that these computer systems function reliably, they must be adequately cooled. Each IT server must receive a certain minimum amount of cooling air, determined by its heat generation rate. Thus, the key to guarantee equipment reliability is to ensure that the cooling air distributes properly throughout the data center, that is, that the supplied airflow meets the airflow demand at each location [3]. Average power densities in data centers are rapidly increasing and are expected to reach up to 3000 W/m^2 in the next 5 years [4]. During the last few years, data centers have increasingly drawn much concern from utilities, building owners, facility managers, and IT equipment manufacturers. This can be attributed to some of the findings as follows; at these heat dissipation levels, the inefficiencies of state-of-the-art data centers are intensifying. These inefficiencies include re-circulation of warm air into the cold aisle, short-circuiting (or by-pass) of the cold air back into the computer room air conditioning (CRAC) unit, lack of information about local conditions which could lead to hot spots, mal-provisioning of cooling resources that leads to inefficient system operation, and inefficient workload placement [5,6].

Thermal management of IT equipment relies heavily on how well cool air is distributed in the equipment room. Data centers need a tool for evaluating and designing the thermal environment to ensure effective equipment cooling without excessive energy usage [7]. Telcordia [8] was developed to update historical environmental criteria in telecom facilities. It introduced a common language and new concepts, requirements, and objectives for designing and operating equipment facilities. Data centers thermal guidelines produced by ASHRAE Technical Committee 9.9 [9] adopted several of the ideas that were introduced by Telcordia [8]. The document provides equipment manufacturers and facility operations personnel with a common set of guidelines for

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Nomenclature

Q	total dissipation from data center components (W)
C_p	specific heat of air at constant pressure (Pa)
m	mass flow rate of air through a rack (CMH)
T	temperature (°C)
n	total number of intakes
x	intake x

Superscripts

r	rack
c	CRAC

Subscripts

in	inlet
out	outlet
ref	CRAC supply
i,j	Cartesian direction
max-rec	maximum recommended/some guideline or standard
max-all	maximum allowable/some guideline or standard
min-rec	minimum recommended/some guideline or standard
min-all	minimum allowable/some guideline or standard
Return	return air (weighted average)
Supply	supply air (weighted average)
Equip	rise across the electronic equipment (weighted average)

environmental conditions in data centers. Sharma et al. [10] introduced two dimensionless parameters as the Supply Heat Index (SHI) and the Return Heat Index (RHI) for evaluation of the thermal performance of data centers. These indices provide a way of understanding the convective heat transfer in equipment rooms with raised floors. Energy efficiency can be impacted not only by inadequate cooling systems but also equipment room configurations that allow hot and cold air to mix. Herrlin [11] studied rack cooling effectiveness in data centers. The Rack Cooling Index (RCI) is a measure of how effectively equipment racks are cooled and maintained within industry temperature guidelines and standards. It is also well suited as a design specification for new data centers. An example with under-floor versus overhead cooling is included in the reference above to demonstrate the use of the index. VanGilder and Shrivastava [12] introduced the dimensionless Capture Index (CI), which is a cooling performance metric at the equipment rack level. The CI is also typically computed by CFD modeling.

Cho et al. [13] verified through CFD simulation the thermal performances of 6 types of air distribution systems generally applicable for high-density data centers. But only a relative evaluation based on the temperature and airflow distribution of the IT server room was performed without using evaluation indices. Of the various systems, the under-floor system showed the most stable indoor environment distribution, but even in this system, the air re-circulation or air bypass continued to occur.

Herrlin [14,15] carried out a study on the Return Temperature Index (RTI) which is a measure of the net level of by-pass air or net level of recirculation air in the data center. Both effects are detrimental to the overall energy and thermal performance of the space.

The main task for a data center facility is to provide an adequate equipment environment, and a relevant metric for equipment intake temperatures should be used to gauge the thermal environment. RCI is a measure of how effectively equipment racks are cooled and maintained within industry temperature guidelines and standards [11]. RTI is a measure of the level of by-pass air or re-circulation air in the equipment room. By-pass air does not contribute to the cooling of the electronic equipment, and it depresses the return air temperature. Recirculation, on the other hand, is one of the main reasons for hot spots or areas significantly hotter than the ambient temperature [14]. A successful design of the air distribution system (ADS) requires an understanding of the fundamental mechanisms governing the distribution of chilled air in data centers. The aim of this study is to propose the vertical aisle partition system for increasing the cooling efficiency related to the IT server heat removal in a data center and objectively analyzing its performance. This paper proposed additional measures to improve the thermal performance of the under-floor system, which is most ubiquitously applied in current data centers, and verified the results by utilizing quantitative evaluation indices. An aisle partition system is important for adequately cooling the IT equipment and controlling the associated energy costs. Computational Fluid Dynamics (CFD) modeling has the capacity to help understand how a cooling solution will perform prior to being built. However, modeling also has the capacity to generate an unwieldy amount of data. The crux of the matter is to know what to look for and then objectively characterize and report the performance.

2. Data centers' thermal management

2.1. Importance of thermal management in the server rooms

From the composition of the server room which is the core element in a data center, as shown in Fig. 1, it can be seen that the IT server that processes and saves data takes up the largest portion, and the other components are the data cables that can be interconnected, the power cables and the rack for the server installation. In general data centers, cooling designs utilize CRAC units along the perimeter of the room and perforated tiles in the raised floor – these designs are not capable of cooling higher density cabinet loads. Since the main function of the data center ADS is to prevent overheating of IT equipment, it is important to make sure the air is not intermixed at the air inlet and outlet installed on the equipment. Many data center operators take a relaxed attitude toward by-pass air, which is produced by the CRACs and returns directly without cooling servers. By-pass air causes a gap between the temperature of air produced by the CRAC units and the temperature of the air at the inlet to the server. CRAC units are designed to produce lower temperatures for the sole reason of offsetting the re-circulation of air from the outlet of the server to its inlet. Air by-pass also starves the servers of air, which increases re-circulation. The goal of air management is to minimize re-circulation of hot air and minimize by-pass of cold air in the data center. Successfully implemented, both measures result in energy savings and better thermal conditions. Furthermore, improved air management is essential to maximizing data center free cooling opportunities. When the IT server rooms' airflows are efficiently maintained, the greatest effect can be obtained with the smallest effort. However, because there is still a lack of understanding on this matter, most data centers fail to seize the opportunity of improving cooling efficiency and energy performance, and despite having enough cooling capacity, they install additional cooling equipment to resolve the problem of local temperature rise. The server room air management basically involves all the air supplied by the CRAC unit flowing into the IT server, and after the heat removal, it involves the return of hot air to the CRAC unit. However, in reality, factors that obstruct airstreams, such as air re-circulation, or by-pass, as shown in Fig. 2, lower the cooling efficiency and a vicious cycle of rising local temperature occurs [16]. By measuring the temperature at the front and rear of an IT server, Cho et al. [17] examined the distribution of air temperature after heat is actually removed from the server.