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Studying the fan-assisted cooling using the Taguchi approach in open and closed data centers ☆

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ABSTRACT

This research examined the application of fan-assisted cooling within open and contained raised-floor data centers with the intention of assessing the effectiveness of the system's cooling method. A computational fluid dynamics (CFD) approach that incorporated both airflow and thermal analysis was employed to examine the detailed effectiveness of fan-assisted air-cooling in a data center that exhibited the behavior of under-cabinet leakage. The CFD technique was also used to assess the impact that three distinct aspects had on the performance of the fan-assisted air-cooling system: cold aisle containment, straightened air flow and fan-to-tile distance. In addition, the mixed-level Taguchi statistical approach was applied to understand how variations in these parameters directly and interactively modified the heat transfer in the surroundings of the inlets of the server racks. The results of the research reveal that fan-assisted perforations, taking the combination of the key factors (the main and interact effects) into account, would represent a viable means through which the cooling systems employed in both open and closed aisle data centers can be enhanced. The well-constructed CFD-based Taguchi methodology might yield a good level of validity for use in substantial and timely optimization procedures to further improve the cooling effectiveness and efficiencies of data centers.

1. Introduction

A major source of the world's waste energy results from the energy required to cool data centers, which often reach high temperatures. Cooling technologies are critical for controlling the heat output of data centers and ensuring energy consumption is kept as low as possible. Researchers have placed a significant focus on the development of cooling systems that can minimize energy consumption while also effectively keeping data centers at a reasonable temperature level. One solution that has attracted a large amount of interest is the raised-floor model, which integrates a cold/hot aisle section above the floor of the data center. Fig. 1 presents an overview of the cooling system that is typically employed in such a configuration.

Within this arrangement, an under-floor plenum sits between the bottom of the data center and the raised-floor (filled with tile perforations) upon which the server racks are positioned. A computer room air-conditioning unit (CRAC) is usually positioned at one side of the room, and this unit emits cooled air into the under-floor plenum. By locating the server racks in strategic locations throughout the data center in accordance with the air flow, an effective inlet/outlet cooling system can be achieved. If available, cold aisle containment is an effective solution that acts as a pressurized cavity that separates the cold air supplied from the tile perforations and the hot air produced by the electrical equipment and, therefore, keeps the server inlet airflow cool. The hot air emitted from the server cabinet is eventually drawn into an extraction system positioned at the top of the CRAC. The rejected heat can then be removed from the data center environment to the outside atmosphere through a chilled water system (framed in the dashed line of Fig. 1)

In recent years, significant exploration has focused on the improvement of new strategies that can effectively determine the methods by which airflow and thermal management can be optimized in commercial buildings and data centers that incorporate a raised floor scheme. Bauman et al. [1] performed a modeling study to investigate the heat transfer pathways and cooling efficiency of an underfloor-air-distribution system (UFAD). One study described the use of an UFAD system to determine the savings of energy compared to the way in which the air flowed through the ceiling-based air distribution system (CBAD) [2]. Paust et al. [3] carried out a number of experiments and CFD simulations to examine how temperature rise in raised-floor systems can be addressed

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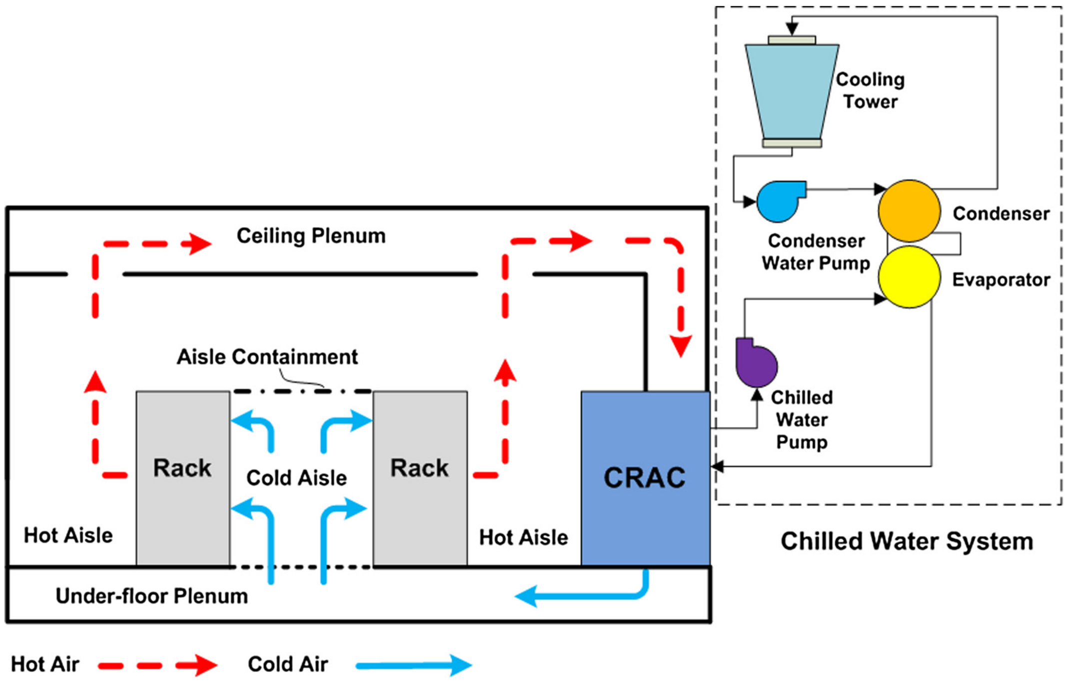

Fig. 1. Raised-floor data center cooling configuration.

using the design of the ductwork. Zhang et al. [4] reviewed the models for calculations of cooling load and energy consumption, and discussed the advantages and disadvantages on the use of the raised-floor system. In a related study [5], they proposed simplified linear models for the impacts the previous models had on the predictions of airflow and pressure distributions in the under-floor plenum. Within their study, they considered a number of factors, including the loss coefficient of the raised-floor leakage and the velocity ratio of the plenum inlets and outlets. A double cold aisle raised-floor configuration was partitioned into multiple zones and the inter-zonal airflow boundary conditions were analyzed for applying compact models to more complicated data center geometries [6]. The use of a simplified physics model, coupled with real-time sensor measurements, was studied by Lopez and Hamann [7] to predict the temperature distributions in data centers. Using a raised-floor data center model, the simulation-based Artificial Neural Network (ANN) and Genetic Algorithm (GA) approaches were applied in order to achieve an optimal prediction of the thermal operating conditions [8]. The method of non-linear principle component analysis (NLPCA) was implemented for better characterizing the cold aisle flow structure over a set of transient air-supply conditions within the under-floor plenum [9]. The Srinarayana et al. [10] discussed the strategies that incorporated a ceiling exhaust air return designed to enhance the effectiveness of the cooling system in various environments including raised-floor and non-raised-floor configurations. Fulpagare et al. [11] have quantitatively examined how plenum pipes and the ratio of open area perforation influence the efficiency of a cooling system that incorporates a CRAC unit. In a review study by Fulpagare and Bhargav [12], rack layout, efficiencies and energy performance metrics for raised-floor data centers were summarized. A CFD modeling approach was employed in research by Cho et al. [13] that examined how heat and cooling indices could be utilized to assess the performance of air management systems. Fakhim et al. [14] employed numerical studies to develop an understanding of the thermal performance of a raised-floor server room that could be subsequently used to identify a model by which the cooling system could be optimized. The outputs of the research indicated that raised-floor systems are highly sensitive to both variations in air pressure between the under- and over-floor voids and the method by which the air flowed through the server racks. As such, their work indicated that the use of an efficiently optimized perforated tile system in a raised-floor cooling system could successfully accommodate the cooling demands of a data center while also improving the independency of the local tile airflow that was the consequence of the global under-floor pressure. However, available research in this specific domain is limited. While existing research is generally in agreement that a fan-assisted tile structure represents an advanced cooling system that is capable of meeting the cooling needs of an open-aisle data center and effectively managing thermal flow [15], there is still a lack of understanding regarding the systematic nature of the active tile flow in open and closed aisle configurations that have a leakage effect, and it is not yet understood how fan unit positioning can be comprehensively managed to enhance the effectiveness and control of these layouts. Thus, this research aims to bridge this gap by incorporating a mixed-level Taguchi design approach and by considering how the main effects and factor interactions of flow straightening, fan-to-tile distance as well as the addition of cold-aisle containment influence the tile flow and temperature patterns. This mixed-level Taguchi systematic design approach was also under investigation to more efficiently visualize and characterize the key raised-floor cooling properties of the data center and to enhance its performance.

2. Geometries and modeling strategies

The research described in this paper involved an assessment of a data center of 8.75 m × 6.4 m × 5.15 m. Fig. 2 presents an overview of the geometric setup. This single-cold-aisle data center facilitated a CRAC unit positioned at the left end of the room, and a raised-floor layout (positioned 0.914 m above the room bottom) The CRAC operated at an air temperature of 19 °C and at a flow rate of 5.3 m^3/s. The server racks (dimensions of 0.61 m × 1.067 m × 2.13 m) in the data center were positioned in two rows on either side of the cold aisle, consisting of five racks in each row. The cold