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Numerical investigation of inter-zonal boundary conditions for data center thermal analysis

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ABSTRACT

The computation time for predicting optimum thermal operating conditions in data center facilities using compact thermal modeling tools is significantly reduced compared to a three dimensional, simulation-based optimization methodology. However, applying compact models to configurations outside of the geometry and operating conditions used for model development often results in inaccurate predictions. In order to model a complicated geometry, a potential remedy is to partition the room layout into a finite number of characteristic zones to which the compact models readily apply. Here, a multiple hot aisle/cold aisle data center configuration was analyzed using CFD simulations of the entire room. The room was then partitioned into two zones and the full room simulations were used to quantify the air flow across the inter-zonal partitions. The inter-zonal conditions are then used to extend the solution results from a single zone to a multiple zone configuration. Two specific room configurations are considered where the computer room air conditioning units (CRACs) are located either at the same end or opposite ends of the cold aisle. The method is found to work well when the CRACs are located at opposite ends of the cold aisles.

1. Introduction

The energy cost for cooling data centers has led to a substantial research effort in developing improved means of thermal management. For both existing and newly designed data centers, effective optimization and control of the cooling system operating conditions requires real-time prediction of the temperature and air flow, and the predictive capabilities must be accurate for a wide variety of configurations. The development of most compact thermal models requires the use of fully three-dimensional, physics-based flow and temperature modeling or experimental data. The Proper Orthogonal Decomposition (POD) method has been used to optimize data center cooling and to provide real-time predictive capabilities for thermal analysis [1–4]. Simulation-based Artificial Neural Networks (ANNs) that have been integrated with a Genetic Algorithm (GA) optimization procedure have been developed to provide real time capabilities for predicting optimized data center operating conditions [5]. However, the performance of these techniques (both ANN and POD methods) still relies on the data obtained from observations. In order to achieve a reasonable predictive capability, the methods must be applied to the operating conditions and geometry within the realm of the observed data from the CFD simulations or experimental measurements. For example, in [5], a basic data center configuration was used to develop the ANN-GA methodology for a range of operating conditions. It was shown that the ANN-based model, as applied to a basic hot aisle/cold aisle data center configuration, works quite well due to its nonlinear and multivariate learning capabilities. However, significant deviation from the basic physical structure of the data center challenges the ANN's performance and limits it's generality. Here, we investigate a methodology that partitions the data center configuration into a number of characteristic zones where the ANN-GA model readily applies. The primary issue in such an approach is the understanding of the inter-zonal boundary flow conditions. Many efforts have been made by researchers in the heat transfer community to investigate the flow structures of non-partitioned and/or partitioned enclosures and their influence on thermal management using experimental, analytical or numerical methods. For example, a numerical investigation of convective thermal behavior was implemented for both undivided rectangular enclosures and those divided into two zones by a vertical partition [6]. The numerical study on laminar natural convection in [7] demonstrated that the presence of a vertical partition in an enclosure considerably affected the circulation intensity and the heat transfer characteristics across the enclosure. The laminar natural convection in an air-filled square cavity with a partition on the top wall was experimentally investigated with heated and cooled vertical walls [8]. Natural convection in

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partitioned square enclosures filled with air was numerically studied for different thermal conductivities of the walls and partitions and for different thermal boundary conditions in order to characterize the overall thermal performance of the enclosure [9]. A top-down strategy was proposed in [10] to detect faulty HVAC units at different levels, which led to more appropriate thresholds for fault detection. In the research community on data centers, the idea of partitioning a more complex configuration was also employed previously. VanGilder and Shrivastava [11,12] utilized a physics-based partial decoupling aisle (PDA) method to evaluate the cooling performance in a cold aisle by isolating the aisle from the surrounding larger environment in order to achieve near real time computations. In this approach, the cold aisle has to be bounded by a symmetric cluster of equipment. Also, the approach is somewhat sensitive to the end airflow boundary conditions of the cold aisle. The nature of the flow in this region is sensitive and dependent on the operating conditions and thus is difficult to predict without extensive CFD calculations. The present study proposes a different methodology to partition a data center into zones and to utilize the CRAC flow rate as a means of effectively controlling the airflow conditions that bound the decoupled computational domain. The approach can be used to analyze the thermal transport and cooling performance in conjunction with different types of compact models (e.g., POD and ANNs).

2. Data center computational model

The computational fluid dynamics (CFD) model used here is a basic raised floor, two cold aisle data center configuration. The flow field and temperature distribution were computed using the commercial finite volume software package FloTHERM. Fig. 1 illustrates the two different configurations for the CRAC locations. Fig. 1(a) and (c) present different views (side view and top view, respectively) of the first layout with the CRACs located at the same end of the room (referred to as the aligned CRAC layout). In the second configuration, shown in Fig. 1(b) and (d), the CRACs are located at opposite ends of the cold aisles (referred to as the anti-aligned CRAC layout). The cooling air from the CRACs is delivered through the plenum. A dashed plane located in the middle of the hot aisle was created to virtually partition the total above-floor space into two characteristic zones, zone 1 and zone 2, and there is an adiabatic solid partition separating the plenum, shown in Fig. 1(a) and (b). For the present study, the plenum height was taken to be 0.67 m. The width (in the y direction) of the hot aisle is 1.2 m, and the length (in the x direction) of the virtual partition is 11 m (the same as the room length). The virtual plane between the two zones was subdivided into 18 vertical finite flow measuring panels (individually 2.67 m high and 0.61 m wide), as shown in Fig. 1(e). Note that the height of each flow measuring panel is the distance from the raised floor to the ceiling, and the panel

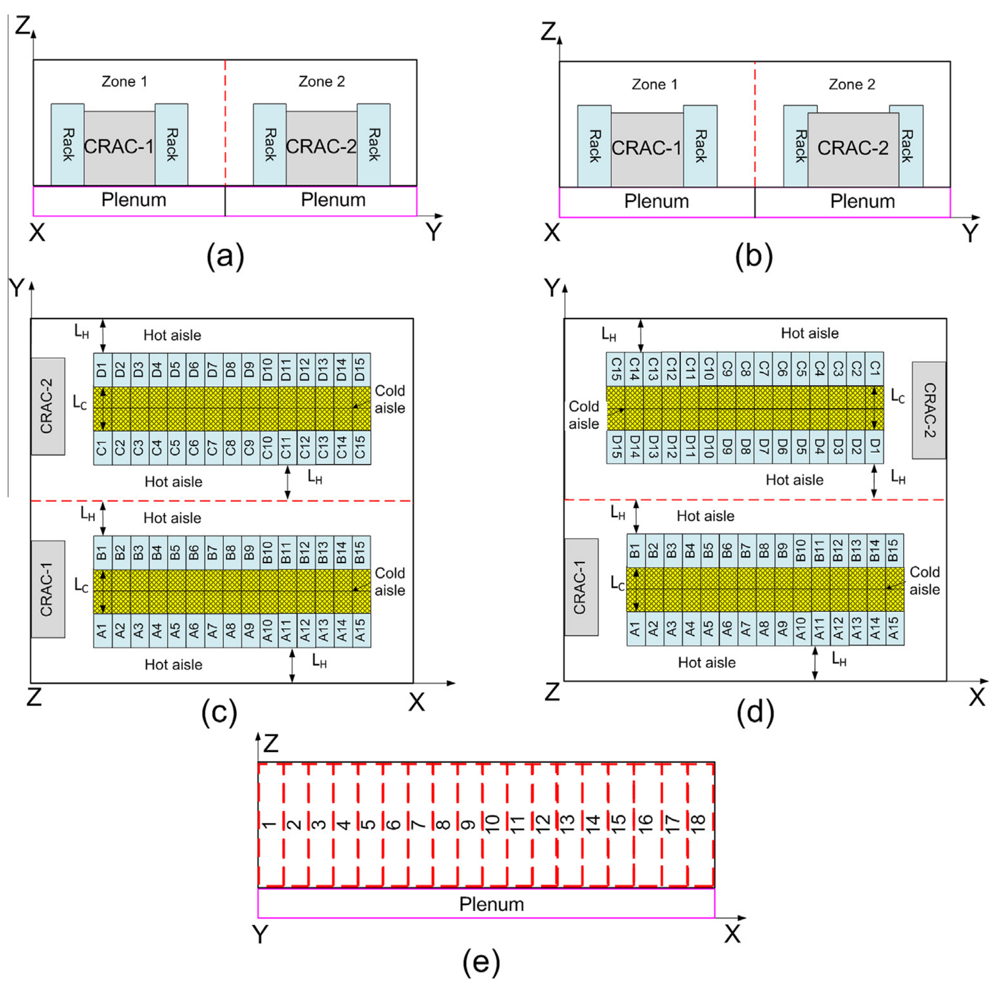

Fig. 1. Double cold aisle data center configurations: (a) side view of the aligned CRAC layout; (b) side view of the anti-aligned CRAC layout; (c) top view of the aligned CRAC layout; (d) top view of the anti-aligned CRAC layout; (e) subdivided inter-zonal partition.