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Effects of Servers' Rack Location and Power Loading Configurations on the Thermal Management of Data Center Racks' Array

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Effects of server/rack locations and server loading configurations on the thermal performance of data center racks' array are experimentally investigated using a scaled physical model simulating real data. Front and rear rack temperatures profiles, server temperatures, and performance indices supply/return heat index (SHI/RHI) are used to evaluate the thermal management of the racks' array. The results showed that (i) servers located in high level rack cabinet have the worst thermal performance, (ii) middle racks of the rack row showed optimum thermal performance and energy efficiency, and (iii) locating the servers of high power densities in the middle of the racks row improves the thermal performance and energy efficiency of the racks array.

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Keywords: data center, racks position, thermal management, performance indices, power loading

1 Introduction

Data centers are commonly used in banks, telecommunications, mobile phone companies, market transactions, universities, and other private applications for data storage and processing. Typically, data center racks accommodate servers of different power densities. Literature review revealed that the data center thermal performance depends on the power density distributions through the servers' racks and location of servers; however, this has not been investigated. The aim of the present technical study is to conduct an experimental work to study the thermal management around different racks in a rack array under different power density distributions at different locations and different power loading conditions. A scale physical model which was used in our previous study [1] will be used to conduct this study.

Data center servers' racks are arranged in a hot/cold-aisle configuration [2]. Cold air is supplied from the raised floor plenum through perforated tiles located in the cold aisles. Server fans suck this cold air to cool the server and discharge it in the hot aisle. This hot air is extracted from the top of the data centers by the computer room air conditioning unit (CRAC) to recool and supply it again to the data center plenum. Performance indices' parameters SHI and RHI are introduced in the literature to predict hot air recirculation, cold air bypass, and the thermal performance/effectiveness of data centers [1,3]. Data center performance under different air circulation configurations was previously investigated [4–6]. The effect of power density, perforated tiles opening ratios, racks' server loading conditions, and CRACs unit locations on the thermal management of the data center racks were investigated [7–12].

To minimize and avoid cold air bypass and hot air recirculation, different physical separations and containments' configurations of the hot and cold aisles have been suggested in modern energy efficient data centers [13–18].

The literature review reveals that most of the studies conducted for evaluating data center thermal performance were conducted under uniform servers' power density which is not the actual case. In the present technical investigation, the thermal performance of data centers of different servers' power densities and servers' loading conditions are experimentally investigated.

2 Experimental Facility and Procedure

A scale modeling theory [1] is used to achieve a physical scale modeling of real data centers for the purpose of testing. Figure 1

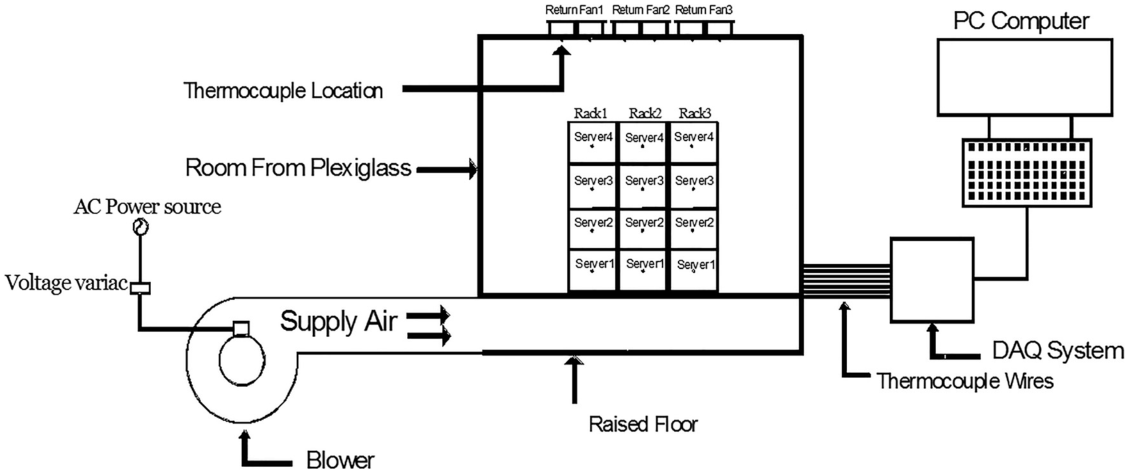

Fig. 1 Schematic diagram of the experimental setup

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shows a schematic diagram of the test facility. A blower delivers air into the plenum of the data center through perforated tiles to cool their servers. The hot air exits from the rear face of the racks and is discharged to the atmosphere using discharging fan. Three sets of 12 thermocouples (T-type) were used to measure the intakes, discharge air, and servers' surface temperatures. Plastic frames were used to fix the thermocouples to measure air temperatures. Each frame contains four thermocouples distributed at the servers' heights. All the thermocouples' readings were recorded and corrected using data acquisition calibrated system.

The scaled data center room was designed based on a 1/6 length-scale ratio. It is made from Plexiglas wall of thickness 1 cm. The room dimensions are $700 \times 329.2 \times 500$ mm. The raised floor thickness of the room is 100 mm. The cold and hot aisles' dimensions are 101.6 and 75 mm, respectively. A row of three racks, each rack dimensions $101.6 \times 152.6 \times 334$ mm, is used to simulate a rack row of racks' matrix of real data center. Each rack was designed to house four servers' cabinets of dimensions $101.6 \times 152.6 \times 80$ to accommodate the servers' simulators [1]. Each server has a variable speed fan (up to $\sim$0.45 m^3 /min) and electric heater of variable heating power (up to $\sim$150 W) simulating the fan and heat generation of actual servers. The air flow rates are measured by using hot wire anemometer (measuring range 0 to +20 m/s). The most recommended opening ratio of the perforated plate, 25% opening ratio [4], is used in this study. The uncertainties in measuring air flow rate, air temperatures, input voltage, and input current were evaluated to be ±2%, ±0.2 °C, ±0.25%, and ±0.25%, respectively. The experiments were conducted at different data center power densities (W/m^2) of 379, 759, 1139, 1518, and 1898 for the following three arrangements of racks' power loading:

Case A: uniform power loading of the three racks;
Case B: side racks at low power density and middle rack at high power density; and
Case C: middle rack at low power density and side racks at high power densities.

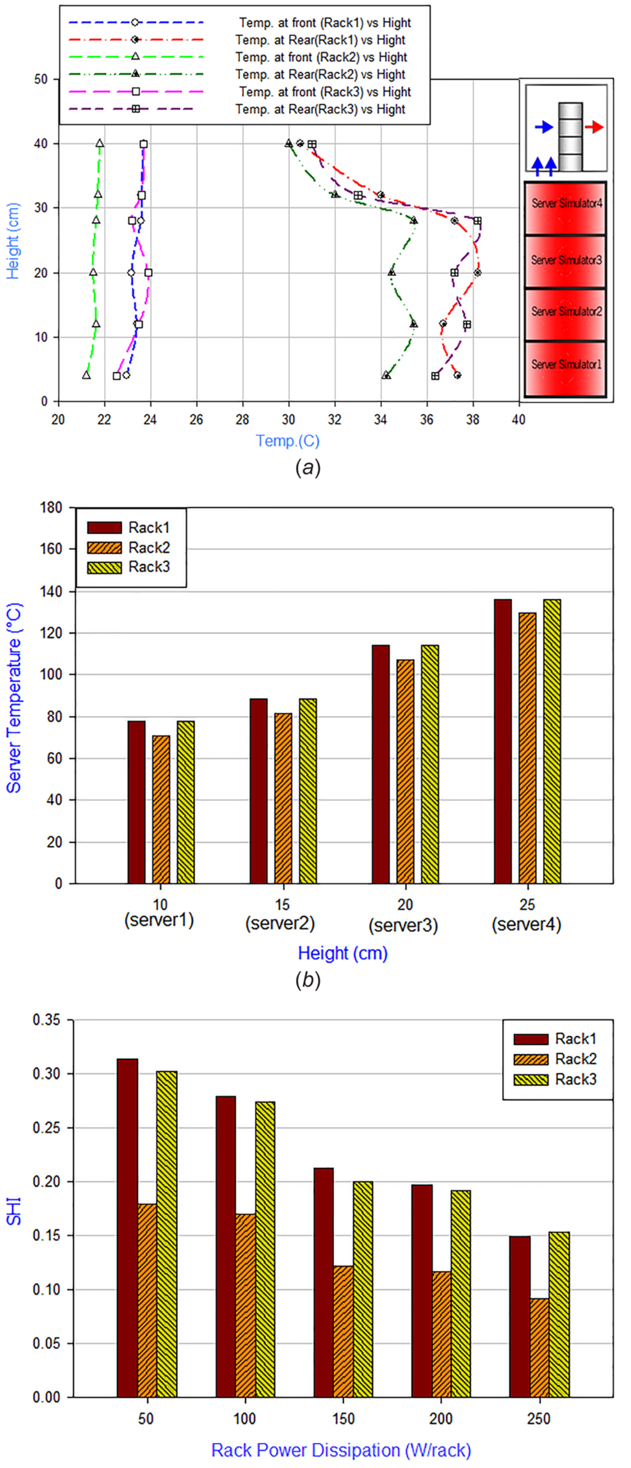
3 Results and Discussion

3.1 Effects of Rack Location. Figure 2(*a*) shows that the temperature profiles at the front and rear of side racks (racks 1 and 3) are always higher than the temperature profile of the middle rack (rack 2). The trend is the same for any power density. This can be attributed to the hot air recirculation that may have occurred around the sides of racks 1 and 3. It was noticed that at low power densities, the increase in temperature along the rack height (from bottom rack to top) is relatively high as compared to that at high power density. This can be attributed to that at low power densities, the air flow velocity is low to reach the top of rack.

Figure 2(*b*) shows the server temperature distributions of the three. The figure shows that the servers located at the rack bottom cabinet always have lower temperature compared to the upper servers. The trend was the same for any power density. This can be attributed to the increase of the intake and rare air temperature with increasing the height.

The effect of the rack location on SHI is shown in Fig. 2(*c*). The figure shows that the middle rack (rack 2) always has a bitter (lower) value of SHI as compared to the side racks (racks 1 and 3). This can be attributed to the expected hot air recirculation from the side edges of the side racks. It was also noticed that a steady reduction in SHI with increasing the rack power density was previously reported [1,14].

3.2 Effects of Racks' Power Workload Conditions. Figure 3 shows the temperature profiles along the rack height at the racks' front and rear for the three workload schemes. Figure 3 shows that (i) the middle rack intake air temperature in case B is higher than those in cases A and C, (ii) the side racks' air intake temperature in case C is higher than those in cases A and B, (iii) the middle rack discharge temperature is approximately the same for three cases A, B, and C, and (iv) the air discharge temperature of the side racks in case C is higher than those in cases A and B. This temperature profiles lead to that (i) the temperature of the middle rack servers' temperatures in case B is approximately the same as those of cases A and C, while the side racks' server temperatures in case C are dramatically increased over those of cases A and B and (ii) the increase of the servers' temperature increases its



(*a*)

(*b*)

(*c*)

Fig. 2 Effect of racks location on temperature profiles and SHI: (*a*) temperature profile at front and rear of the three racks, (*b*) server temperatures, and (*c*) SHI

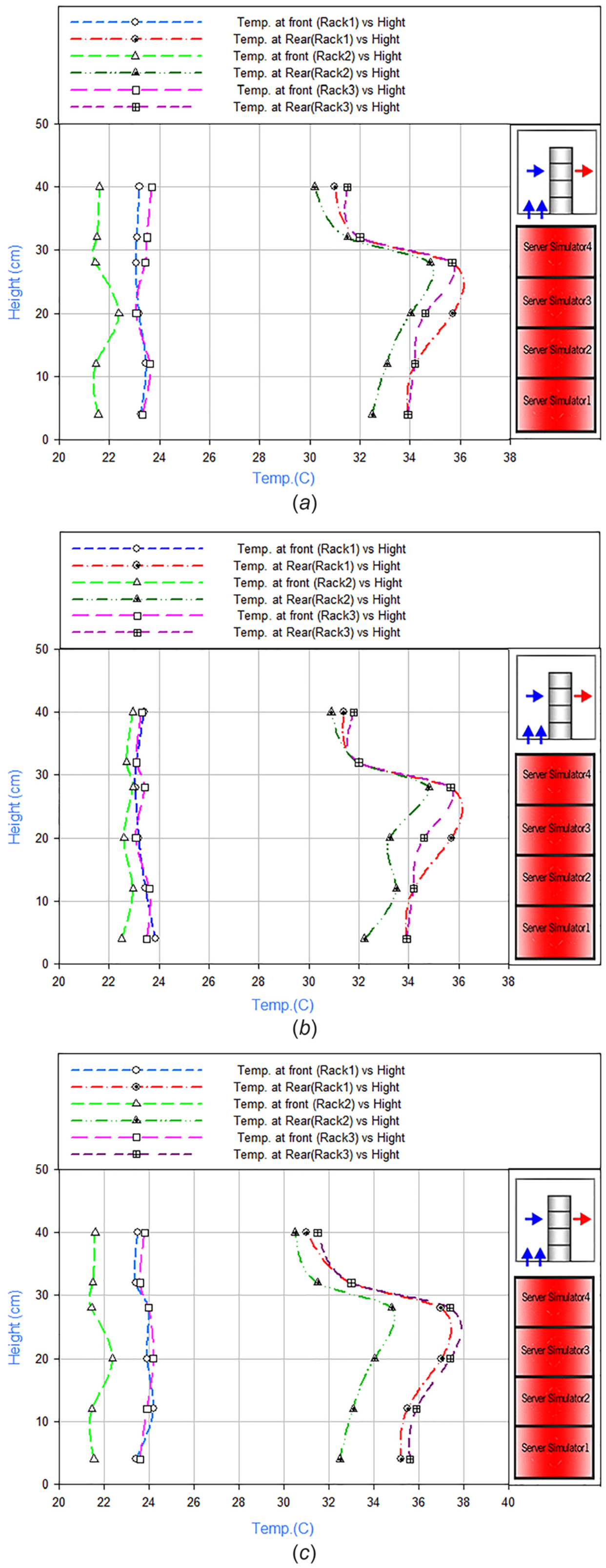


Fig. 3 Temperature profile at racks' front and rear for different power loadings: (*a*) case A, (*b*) case B, and (*c*) case C

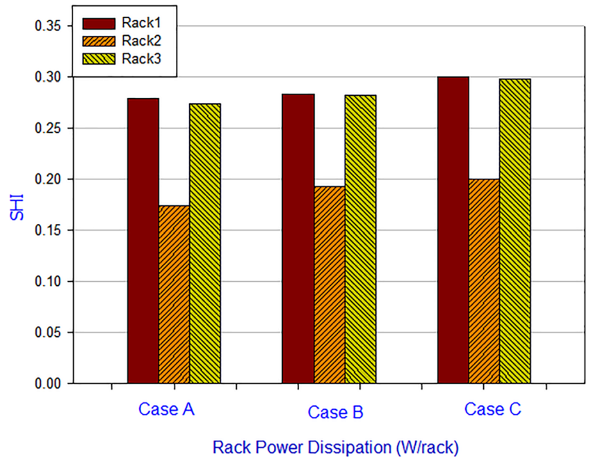


Fig. 4 Variation of SHI for different power loading configurations

height in the rack location for the three cases of workload schemes where the temperature of server 4 (located at height 25 cm) is higher than the temperature of server 3 (located at height 20 cm) and so on. This reveals to that placing the servers of high power density in the middle of the racks row gives the lowest server surface temperature and the lowest rack rare air temperatures as compared to the case of placing them on the ends of the racks row. This can be attributed to hot air recirculation that occurs at the side racks.

Figure 4 shows the effects of the power loading configurations on SHI. The figures show that SHI for case C is relatively higher than that of case B. This can be attributed to the more hot air recirculation from the sides of the racks row mixing with supplied cold air and rises the air temperature at the servers' intake of the side racks. However, in the case of placing the servers of high power density in the middle rack (case B): (i) the hot air recirculation at the side racks will be lower than those in case C and this reduces the servers' intake temperatures of the side racks and consequently causes reduction of SHI and (ii) more cold air is pushed to the middle perforated tiles and this may cause cold air bypass to slightly increase SHI as shown in Fig. 4.

4 Conclusions

The effects of rack location in the racks' array and servers' power loading configurations on data center thermal performance have been experimentally investigated. The results showed the following:

- The middle racks of the racks row showed lower servers' air intake temperatures, servers' surface temperatures, and servers' discharge temperatures as compared to the servers at the side racks.
- The side racks of the racks row have bad thermal performance indices as compared to the middle racks.

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