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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 13 (11): 1825-1830, 2014
ISSN 1812-5638 / DOI: 10.3923/itj.2014.1825.1830

Airflow Simulation and Improvement for an Internet Data Center

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Abstract: Due to the rapid development of the Information Technology (IT) industry, Internet Data Centers (IDC) are applied increasingly in a wide range of applications. However the highly centralized management of electronic equipment produce dramatic sensible heat load, which makes air conditioning systems of the data center encounter a great deal of energy consumption. This study focuses on airflow simulation and performance improvement of an IDE facility. The Computational Fluid Dynamics (CFD) simulation of airflow distribution were conducted to evaluate the different layout of supply and return air arrangement. Simulation results revealed that the methods of raised floor supply and ceiling return system along with the hot aisles and cold aisles approach can reduce bypass recirculation airflow. It will improve significantly the cooling performance of the data center. The assessment of rack cooling index has been proposed to evaluate the performance of the data center. Through the study of CFD simulation and analysis, it is expected to develop the energy-efficient and cost-efficient system specific for IDC facilities.

Key words: Internet data center, airflow simulation, performance improvement

INTRODUCTION

The heat dissipation soaring has made the internet service providers and Information Technology (IT) manufactures difficult to provide proper equipment cooling (Malone and Belady, 2008). The energy consumption of data centers is expected to increase dramatically in the next coming years (Cho *et al.*, 2009). It is vital to investigate the best airflow distribution for the performance improvement for the data center facility. Computational Fluid Dynamics (CFD) simulation is a scientific technique that can be applied to improve the data center performance without interfering the function of IDC. The airflow distribution through perforated floor tiles in a computer room has been investigated extensively and successfully by using CFD simulation (Rambo *et al.*, 2007). Furthermore, the height and the opening percentage of the raised floor in a data center have been studied to examine the influence of air flow distribution by the application of numerical simulation using CFD code (Karki and Patankar, 2006). The rack intake temperature can be determined by CFD modeling and the Rack Cooling Index (RCI) can be defined accordingly (Herrlin, 2008). They also investigated the method for optimizing cooling effectiveness by using RCI through CFD simulation (Herrlin and Khankari, 2008). CFD simulation makes three-dimensional analyses of temperature and airflow distribution feasible.

Some worst case practices in data centers have been presented to examine the best practices opportunity through field study (Sullivan, 2008). The designing and managing data including the challenges for IDC has been investigated comprehensively to explore the energy-efficient data centers (Kant, 2009). Besides, Khattar (2010) presented the existing data center retrofit project and demonstrated its applicability by improving the heat containment and airflow management by field measurement. ASHRAE TC 9.9 (2009) also provides thermal guidelines for data processing environments. The design specification and operating conditions of data centers were presented comprehensively. Moreover, Tozer and Salim (2010) conducted the practical approach of air management metrics in the data center. The airflow distribution and performance between raised floor and non-raised floor for data center systems were compared and evaluated comprehensively.

MATERIALS AND METHODS

System description: The investigated data center with the dimension of 23.4 m (length) ×12.6 m (width) ×2.6 m (height) belongs to the TELCOM company of Taiwan for

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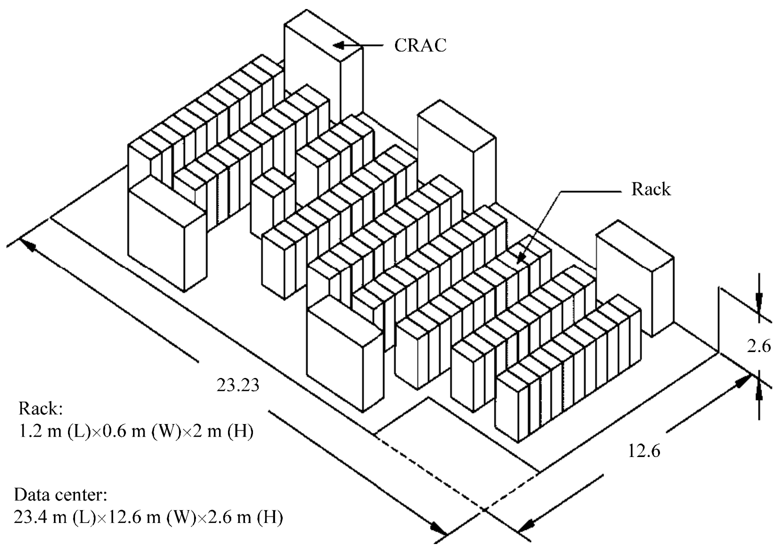

Fig. 1: Geometric model of the investigated data center

internet service. The schematic diagram and layout of the investigated data center is shown in Fig. 1. There are 95 racks with hot-aisle and cold-aisle in alternating arrangements. The rack-mounted servers are arranged to draw air in at the front and exhaust air out at the back. The supply air from Computer Room Air Conditioning (CRAC) units was distributed to cold-aisle through the raised floor with a height of 0.6 m and then passed through the server and returned back to CRAC unit from the hot-aisle. The hot air of the hot-aisles was discharged via returning air grilles at the ceiling and circulated back to CRAC unit of the data center. Different arrangement was shown in Fig. 2a including raised floor and non-raised floor supply air systems along with direct return and ceiling return approach was proposed and compared through CFD simulation to achieve better airflow distribution and energy-efficient data center.

Numerical simulation: A commercial CFD code (Fluent Inc, 2006) was used to simulate the temperature and air distribution of the data center. The geometric model of the investigated data center is displayed in Fig. 1. Five CRAC units and nine racks with hot-aisle and cold-aisle alternating arrangement were arranged evenly in the data center. There are 4 heating blocks (500 W) inside each rack with 2kW loading were assumed as the heating load of the data center. To cool down the cooling load of the data center, the supply airflow rate of 300 m^3 min^{-1} for each rack was provided. The boundary conditions have been defined according to the field test data with the study air temperature of 16°C and air velocity at 2.7 m sec, respectively. The opening percentage of perforated tiles is kept at 25% in the data center.

Rack cooling index: Rack Cooling Index (RCI) has been adopted as a measure of how efficiently racks are cooled under thermal guidelines and standards. It can provide an effective measure for rack cooling performance. The RCI is defined as:

$$RCI_{HI} = \left[1 - \frac{\text{Total over Temp}}{\text{Max.allowable over Temp}}\right] \times 100\% \quad (1)$$

$$RCI_{LO} = \left[1 - \frac{\text{Total under Temp}}{\text{Max. allowable under Temp}}\right] \times 100\% \quad (2)$$

where, HI and LO represents the measures of data centers at the high end and low end of temperature range, respectively. RCI_{HI} is a measure of the absence of over-temperatures, RCI_{HI} is 100% means no over-temperature exists.

RESULTS AND DISCUSSION

Figure 2a depicts four cases of alternative layout for simulation including raised floor and non-raised floor supply air system along with direct return and ceiling return air arrangement. Figure 2b presents the temperature

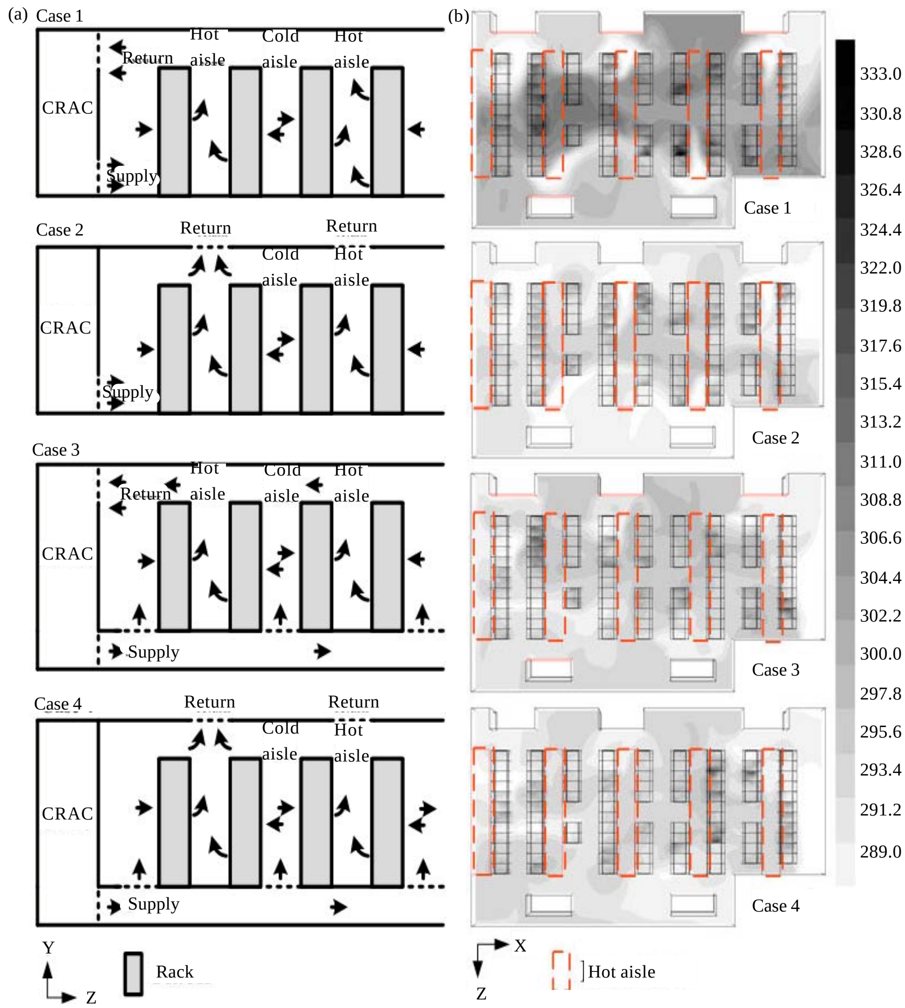

Fig. 2(a-b): Schematic arrangement and temperature profile of different improvement alternatives in the data center, (a) Alternative and (b) Temperature profile

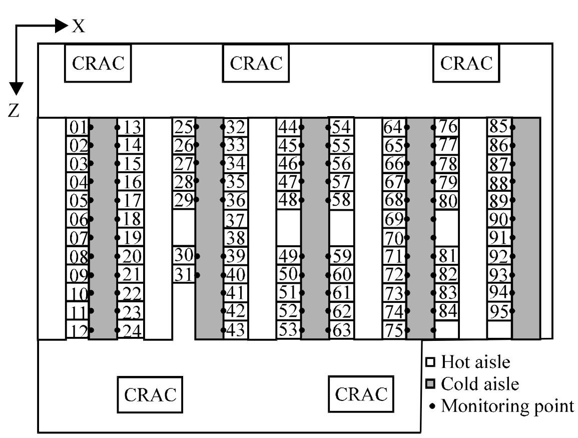

Fig. 3: Layout plan for rack intake temperature recording of the investigated data center

distribution of different supply and return arrangement. As shown in Fig. 2b, most of the temperature of the data center is above 35 °C. For some area, it is even higher than 50°C for many racks.

To examine the rack intake temperature for each rack inside this data center, the layout of the racks along with the numbers is presented in Fig. 3. Even though half of racks presents ideal (or good) cooling performance through RCIs analysis, there exists recirculation airflow at the vicinity of rack number 14 to 17. Detail airflow distribution for case 1 can be identified from Fig. 4. It will result in by-pass airflow near the return air of CRACs.

As shown in Fig. 5, the uprising recirculation air flow occurs near the supply air outlet of CRAC. It will induce the airflow to block the cooling stream flow into the racks

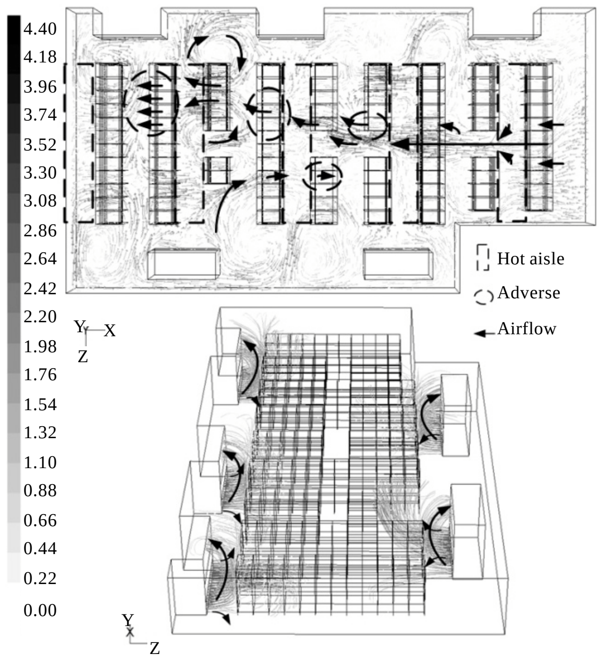

Fig. 4: Airflow distribution for the layout of case 1 in the data center (at Y = 1 m)

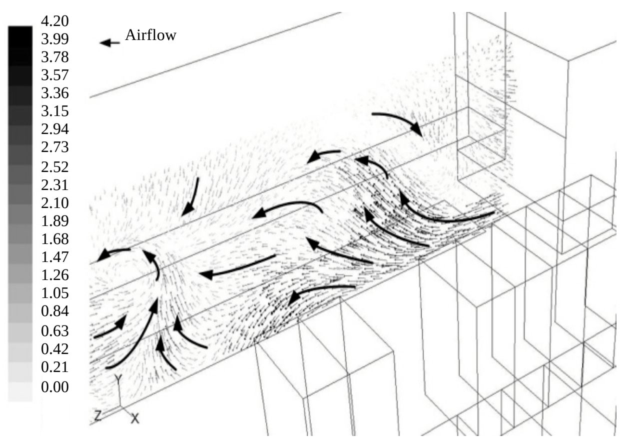

Fig. 5: Uprising recirculation airflow for the layout of case 3 in the data center

and it will result in hot spots (high temperature) on the racks for the arrangement of case 3. To improve the above mentioned situation, case 2 and case 4 with the ceiling return air system approaches were simulated Fig. 6a presents the intake temperature distribution for four cases at different rack of the data center. Only the case 2 and case 4 represent favorable temperature distribution under the allowable temperature limit (15 to 32°C). Case 1 and case 3 present higher temperature due to short cycle for returning air to CRAC. To examine the case 4 precisely, the rack intake temperature distribution for is shown in Fig. 6b. It reveals the arrangement of ceiling-returned system with raised floor arrangement can provide satisfactory temperature profile and better cooling performance. Figure 7 presents the rack cooling index RCI_{LO} for all racks in the data center for case 4, there are still 39 racks present the RCI_{LO} lower than 91%, which represents too low temperature then it is needed.

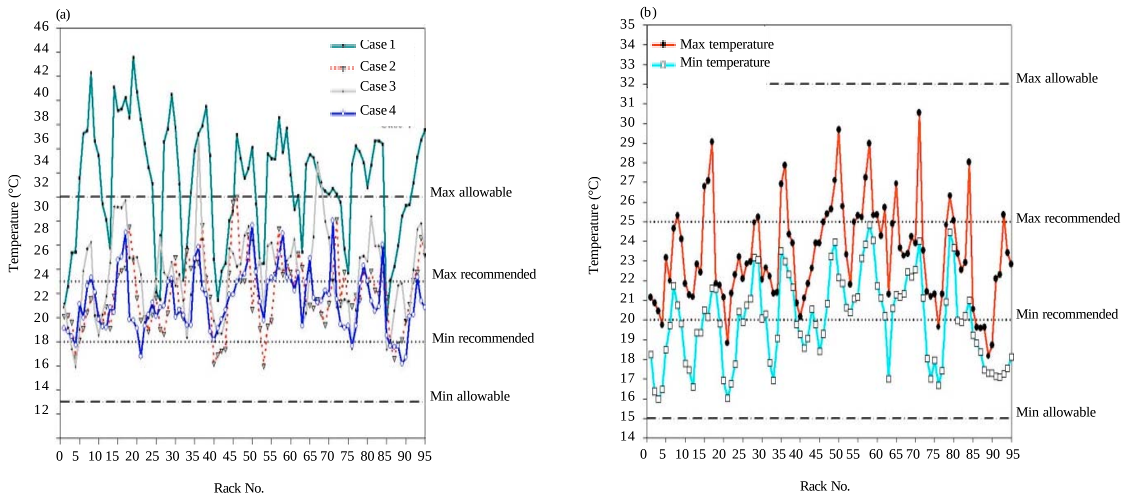

Fig. 6(a-b): Rack intake temperature distribution for different case arrangement (a) Different cases and (b) Case 4

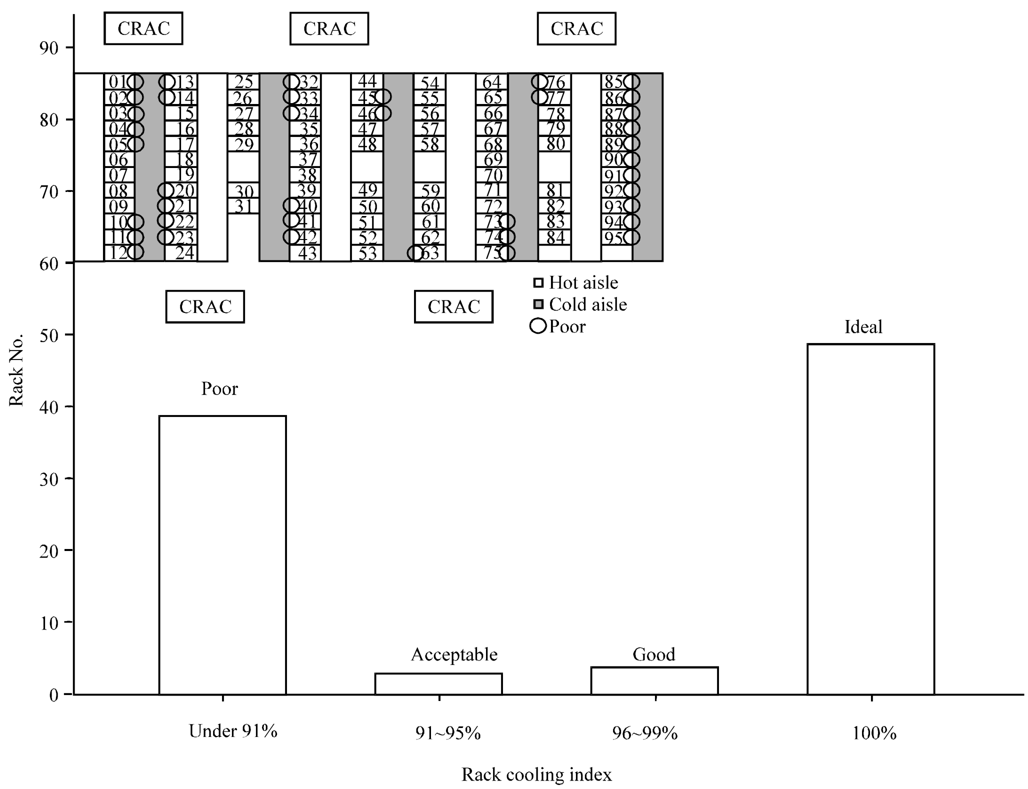

Fig. 7: Rack cooling index for all racks in the data center in case 4

CONCLUSION

The best practice for airflow distribution can be identified through the simulation of alternative layouts for the data center without increasing the cooling capacity of CRAC unit. The arrangement of raised floor supply air and ceiling return distribution system with hot and cold aisle approach presented the best performance for airflow distribution and cooling effectiveness of the data center. It can provide better performance to reduce energy consumption in the data center. The application of RCIs is performed to validate that the indices provide meaningful information that help to evaluate the performance of data centers. By comparison of RCIs of different arrangement, the cooling performance of data center can be evaluated accordingly. It is expected that the best practice for data center can be identified easily through analyzing the rack cooling effectiveness.

ACKNOWLEDGMENT

The authors would like to express their great appreciation to the financial support by the National Science Council under the grant No. NSC 100-2221-E-167-023-MY3.

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