Comparative analysis of thermal environment between raised-floor and row-based cooling in a campus data center

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Abstract. In recent years, the modular data center, which adopts row-based cooling strategy, is becoming popular and widely applied. Also, cold aisle containment is integrated to reduce the mixing of hot and cold air. Even so, similar to the raised-floor cooling, the cold air bypass and hot air recirculation still affect the thermal environment. This paper presents the comparison of thermal environment between raised-floor and row-based cooling, through changing the factors of servers’ arrangement, aisle containment and blanking panel. Experiment and simulation were employed to investigate the inlet air temperature of racks and thermal environment of the data room, and a total of 15 models were simulated. The results showed that combining the cold aisle containment with blanking panels can bring uniform airflow, and the servers installed in the upper part of the rack was the best choice for the both cooling strategies. Especially, the blanking panels could further improve the airflow for all servers’ arrangement using row-based cooling strategy, which can reduce the mean inlet air temperature by 16.7 °C, and the minimum SHI value can reach to 0.089. These results could guide the thermal environment management to guarantee the effective utilization of cooling capacity in data centers.

Keywords. thermal environment, raised-floor cooling, row-based cooling, aisle containment, blanking panel

1. Introduction

Data centers consume enormous electricity[1], and energy-saving technologies and thermal management methods are more and more concerned by industry delegates[2, 3]. Raised-floor (RF) and row-based (RB) cooling are the widely used cooling strategies. The earlier research focused on the energy efficiency and thermal environment[4, 5]. A few recent studies were investigated the thermal environment by integrating RF and RB cooling[6]. While it is unknown that the application characteristics of these two cooling strategies with airflow distribution measures. This paper comparatively analyses the thermal environment between RF and RB cooling in a campus data center by considering three factors of servers’ arrangement, aisle containment and blanking panel. Field measurement and simulation study are employed, and a total of 15 models were simulated. The inlet air temperature of racks and Supply Heat Index (SHI) value are regarded as the criteria for thermal environment.

2. Field experiments

2.1. Data room description

In field experiments, a campus data room was employed in Chongqing, the southwest of China. And the data room was divided into two spaces, with the area of 102m\textsuperscript{2} and 63m\textsuperscript{2} respectively, before its transformation. The predominant cooling scheme for the data room is to use the Computer Room Air Conditioning (CRAC) units to supply a raised floor plenum underneath the racks with cold air. Then the
cool supply air is delivered through perforated tiles located near the racks, and the hot exhaust air from
the racks is collected from the upper portion of the facility by the CRAC units. The height of the room
is 3m, which includes 0.3m-height of the raised floor plenum, 2.7m-height between the raised floor and
ceiling. After retrofitting, there are 3 modules of racks in the data room, and each of them adopts the RB
cooling scheme, and the cold aisle is contained. The room layout of before and after refurbishment is
shown in figure 1.

![Figure 1. The room layout of before and after refurbishment](image)

2.2. Experimental study
In order to compare the cooling effect before and after the transformation of the data room, experiments
were conducted in 27th–29th, October, 2015 and 20th–23th, January, 2018. The main experimental
parameters are racks’ inlet and outlet temperature, CRACs’ inlet and outlet temperature and perforated
tiles’ outlet temperature. As for the racks, the measurement points were arranged at the height of 1U,
21U, and 42U away from the front and rear doors with 5cm and the parameters were recorded by using
Intelligent Environment Tester. The inlet air temperature of the CRACs was read from their panels. And
the outlet was recorded by using Automatic Temperature and Humidity Recorder. Especially, module 1
was the main experimental object owning to the servers’ installation. The main experimental equipment
and parameters are given in table 1.

| Experimental equipment | Model               | Measuring range | Accuracy                      | Resolution          |
|------------------------|---------------------|-----------------|-------------------------------|---------------------|
| Intelligent Environment Tester | KANOMAXA531 | 0~100% RH, -20~70°C | ±3% RH, ±0.5°C | 0.01 m/s, 0.1°C, 0.1% RH |
| Temperature-Humidity Recorder | Testo 174H | 0.01~30.0 m/s, 2.0~98.0% RH, -20~70°C | ±2% measurement value, ±2% RH, ±0.5°C | 0.1°C, 0.1% RH |

SHI is given by the ratio between the enthalpy rise and the total heat power rise from supply to
exhaust from the rack, which indicates the mixing degree of the airflow. The formula is shown below.

\[
SHI = \frac{\sum_i \sum_j (T_{in,i,j} - T_s)}{\sum_i \sum_j (T_{out,i,j} - T_s)}
\]  

(1)

Where \( T_{in} \) is the rack inlet air temperature, \( T_{out} \) is the outlet air temperature, and \( T_s \) is the supply air
temperature from CRAC unit. The subscript \( i \) represents the \( i \)th rack, while \( j \) the \( j \)th row within a data center.
A value of 0 for SHI means that there is no recirculation of hot air, and the air inlet temperature of the
racks is equal to the air supply temperature from the CRACs. Usually, the value of of SHI<0.2 can be regarded as the good airflow distribution. Through testing and calculation, the SHI value before and after refurbishment was 0.79 and 0.31, respectively. Though, the values were all larger than 0.2, the airflow distribution was improved by the RB cooling with cold aisle containment. But here, it is unknown that this improvement should attribute to aisle containment or RB cooling strategy. Maybe, the RF cooling with cold aisle containment also performs good thermal environment. To solve this problem, the numerical simulation will be adopted to investigate the application condition of these two strategies.

3. Numerical study

3.1. model description

6SigmaDCX is committed to the data center design, management and thermal analysis[7, 8]. And it solves full-level of thermal issues including room level-6 SigmaRoom/RoomLite, rack level-6 SigmaRack, and electronic level-6 SimgaET[9]. And in this paper, 6SigmaRoom Version R12 was employed to compare the benefits of RF and RB cooling strategies with cold aisle containment. In this paper, 6SigmaRoom was verified by comparing the inlet and outlet air temperature of racks between simulation and measurement. The model was established according to the actual situation and the parameters such as server power, CRACs cooling capacity were based on the field measurement. Table 2 presented the deviation of the inlet and outlet air temperature of the racks between simulation and measurement, whose value were within 15%. It can be concluded that 6SigmaRoom is an effective tool for thermal environment of data centers. And the simulation results of it can be acceptable.

| Rack No. | Measurement air temperature | Simulation air temperature | Deviation |
|----------|-----------------------------|---------------------------|-----------|
|          | Inlet                       | Outlet                    | Inlet     | Outlet |
| A02      | 19.43 °C                    | 21.53 °C                  | 19.31 °C  | 21.74 °C | 0.62%    | -0.95%  |
| A07      | 18.59 °C                    | 27.16 °C                  | 16.55 °C  | 25.84 °C | 10.96%   | 4.86%    |
| A11      | 24.08 °C                    | 30.70 °C                  | 23.68 °C  | 31.99 °C | 1.66%    | -4.20%   |
| A13      | 20.16 °C                    | 29.28 °C                  | 19.35 °C  | 28.91 °C | 4.02%    | -4.20%   |
| B02      | 20.13 °C                    | 25.28 °C                  | 22.43 °C  | 25.85 °C | -11.41%  | -2.26%   |
| B07      | 19.06 °C                    | 24.60 °C                  | 21.87 °C  | 26.16 °C | -14.74%  | -6.31%   |
| B13      | 22.23 °C                    | 24.45 °C                  | 24.48 °C  | 27.53 °C | -10.14%  | -12.57%  |

Table 2. A summary of the deviation between simulation and measurement results

Based on that, a model of post-retrofit data room only contained module 1 was simulated (see figure 2(a)). The benefits analysis on inlet air temperature of racks were carried out by varying the factors such as the cooling strategy (RF or RB), aisle containment (cold aisle containment or none), servers’ arrangement (see figure 2(b)) and air distribution strategy (install blanking panels or none). A total of 15 models were simulated, which were shown in table 3.

![Figure 2. The model layout and servers’ arrangement](image)
Table 3. A summary of the study cases

| Case | Simulation type | Case | Simulation type | Case | Simulation type |
|------|----------------|------|----------------|------|----------------|
| 1    | RF-1-U         | 6    | RF-2-C-B       | 11   | RB-1-C-B       |
| 2    | RF-1-C         | 7    | RF-3-U         | 12   | RB-2-C         |
| 3    | RF-1-C-B       | 8    | RF-3-C         | 13   | RB-2-C-B       |
| 4    | RF-2-U         | 9    | RF-3-C-B       | 14   | RB-3-C         |
| 5    | RF-2-C         | 10   | RB-1-C         | 15   | RB-3-C-B       |

Note: 1, 2 and 3 represent three servers’ arrangement (see figure 2(b)); C and U means the cold aisle contained or not; B is short for blanking panel.

3.2. Settings and data inputs

In the simulation, the main input parameters were the power density, cooling capacity and air flow rate per CRAC, and the opening rate of perforated tiles. In order to simplify the numerical simulation, only HUA WEI RH2288 V3 was selected in the model, whose rated power is 750 W, and every server load rate was 56%. And it was the same that the servers were installed in every rack, whose power density is 4.2 kW. As for the RF cooling strategy, the size of perforated tiles is 0.6m × 0.6m. The open free area of the pore plate and damper is 40% and 50%, respectively. The size of the rack is 1.2m (depth) × 0.6m (width) × 2.05m (height). And the opening rate of front and rear door is 64%. The parameters of CRAC for these two cooling strategies were presented in table 4, as well as the total airflow rate of CRACs was equal to that of servers. Besides, all the simulations adopted the standard k-epsilon turbulence model, and the obstruction in the raised plenum was not considered in the simulation. In addition, according to ASHRAE TC 9.9, the recommended air temperature is 18 °C~27 °C, and the acceptable air temperature is 10 °C ~35 °C for Class A2.

Table 4. The main setting parameters of CRACs

|                  | RF cooling | RB cooling |
|------------------|------------|------------|
| Rated cooling capacity (kW) | 70         | 35         |
| Rated airflow rate (m³/h) | 13000      | 6500       |
| Return air temperature (°C) | 28         |            |
| Minimum supply air temperature (°C) | 13         |            |
| Percentage of fan speed (%)  | 70         |            |

4. Result and discussion

Figure 3 depicted the mean inlet air temperature of every rack for 15 simulation cases. From that, it can be easily found the mean inlet air temperature of side racks performed higher than that of middle for RF cooling strategy in general, without cold aisle containment in particular. And the inlet air temperature of the racks on both sides of CRACs is higher than that of the others for RB cooling with cold aisle containment. The mean inlet air temperature can be as high as 32.29 °C for the uniform arrangement of servers using RB cooling. And the cold aisle containment with blanking panels plays an important role on uniform inlet air temperature, which reduced the mean inlet air temperature by 16.7 °C. As for RF cooling, from figure 3(a), the mean inlet air temperature of the racks had little difference among “Case 1”, “Case 2” and “Case 3”. It can be concluded that the cold aisle with or without blanking panels has less effect on the inlet air temperature for servers clustered in the lower portion of the rack. This is because the hot air can easily recirculate through the upper portion of racks, and there has little cold air to mix. On the contrary, when the servers were cluster in the upper part of the rack, the hot air recirculated from the lower portion, and mixed with the cold air, which resulted in the inlet air of the rack slightly higher than the outlet temperature of the perforated tile (see figure 3(b)). As shown in figure 3(c), the cold aisle containment was not an efficient method to improve the inlet air temperature of the rack for the arrangement of one server with double voids. The uniform arrangement of servers in a rack made the uniform airflow flowing through every server, whatever the cold aisle was contained or not.
Figure 3. The mean inlet air temperature of every rack for 15 simulation cases

Figure 4 presented the inlet air temperature distribution of rack row A for every cases. By comparison the strategies of RF and RB cooling with cold aisle containment of three servers’ arrangement, note that the servers installed in the upper part of the rack was the best choice for the both strategies. But for the RB cooling, the upper arrangement may lead to the hot spot for the bottom server, as shown in figure 4 “Case 5”. Besides, comparing “Case 8” and “Case 14”, the uniform arrangement of servers was not suit for RB cooling. This is because the cross-section of supply air was relatively decreased and the air kinetic energy increased, which easily results in the negative pressure for the cold aisle, and then the hot air will be mixed with the cold air by going through voids between the servers. Especially, owning to the mixed hot air flowing up gradually, the inlet air temperature of servers will increase vertically. Unlike that, the hot air only presented in the top inlet of the rack for RF cooling. However, the hot air recirculation will be avoided by installing the blanking panels in the voids between servers for these two cooling strategies. And this method seems to have no effect on the arrangement that clustering the servers in the lower part of the rack, owning to the hot air also recirculating through the gap between the blanking panels.

Figure 4. The inlet air temperature distribution of racks in row A
According to the equation (1), the SHI value of every case was summarized in Table 5. In the term of the thermal environment, the cold aisle containment with blanking panels can efficiently reduce the hot air recirculation or cold air bypass. Especially, the blanking panels could further improve the airflow for all servers’ arrangement with RB cooling strategy only with cold aisle containment, and the minimum SHI value can reach to 0.089.

Table 5. A summary of the SHI value

| Case | SHI  | Case | SHI  | Case | SHI  | Case | SHI  | Case | SHI  |
|------|------|------|------|------|------|------|------|------|------|
| 1    | 0.166| 4    | 0.290| 7    | 0.266| 10   | 0.201| 13   | 0.099|
| 2    | 0.148| 5    | 0.201| 8    | 0.265| 11   | 0.089| 14   | 0.386|
| 3    | 0.121| 6    | 0.136| 9    | 0.130| 12   | 0.264| 15   | 0.098|

5. Conclusion

This paper investigates the thermal environment between RF and RB cooling in the condition that the total airflow rate of CRACs equals to that of servers, through changing the factors of servers’ arrangement, aisle containment and blanking panel. The conclusions are as follows:

1. Cold aisle containment is not an efficient way to improve the thermal environment for RF cooling with servers clustered in the lower part of racks or uniform arranged in racks.

2. The servers installed in the upper part of the rack is the best choice for both RF and RB cooling strategies with cold aisle contained. And the thermal environment will be further improved by installing the blanking panels in the voids of racks.

3. Blanking panels are the necessaries of RB cooling strategy to avoid large difference in inlet air temperature between racks in a row. And this method can reduce the mean inlet air temperature by 16.7 °C, and make the SHI value less than 0.1.

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