Optimizing Thermal Performance of Data Centers with Novel Local Partition Configurations

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Abstract. The indoor environment of data center today has differed from the legacy data centers from the heat density to the air distribution. The energy consumption of cooling system has been taking up a large percent of the total energy of data centers. The reliability problem caused by local overheating and economic problem by undercooling attract the attention. novel local partition configurations are proposed in this paper to optimizing the air distribution and thermal performance of data centers. A basic model and 6 partition models have been simulated to analyze the effectiveness of the novel configurations. The result proves that the configurations with local enclosed partition at tile No.2 show great performance in eliminating the hot spots and undercooling problems.

1. Introduction
The energy consumption of data center is consisted of IT equipment energy consumption, cooling system energy consumption, power supply and lighting energy consumption. The consumption of cooling system has been taking up approximately 40% of the total energy consumption, which is one of the main sources of energy consumption in the data center [1]. Due to the high heat dissipation of IT equipment in the data center, the cooling system is requested to operate without stopping. The air conditioning system is facing severe challenges, not only in order to meet the reliability requirement of data center, but also to achieve the purpose of energy saving [2]. Air distribution have great influences on the thermal performance of data centers which has close relation with the energy consumption of cooling system [3]. Overheating and subcooling should be eliminated when a good air distribution solution is applied [4]. Optimizing the uniformity of airflow along the cold aisle is considered to be an effective solution to improve the air distribution and thermal performance [5]. In this paper, an novel local partition configuration is proposed. And a series of derived models have be simulated to prove the effectiveness for improving the thermal performance and to investigate the optimal configuration with local partitions.

2. Physical model and working condition
The basic physical model is a simulated data center computer room with a size of 10900mm (D)×7300mm(W)×3000mm(H) using underfloor air distribution(UFAD) system. There are 44 server racks arranged in the room divided into 4 rows equally. The rack rows are arrangement in the form of hot aisle/ cold aisle (HA/CA). The distance between each row is 1200mm. The computer room air conditioners (CRACs) are arranged at in the line of cold aisles against the wall.
Some parameters of the simulations are as follows in Table 1. There are numbers of investigations working on the geometry configurations of underfloor plenum [6], [7]. Perforated tiles with the
Porosity of 20~30% are considered as the optimal for the thermal performance [8], [9]. And 600~800mm is thought to be the ideal height for underfloor plenum to obtain the most uniform airflow distribution [10], [11]. According to the previous investigations and reference, the plenum height is set to be 600mm and the porosity of perforated tiles is set to be 20% in this investigation.

| Table 1. Parameters of the basic model |
|----------------------------------------|
| Parameter                         | Value                     |
| Room size                         | 10900mm×7300mm×3000mm     |
| Rack size                         | 2000mm×1100mm×600mm       |
| Tile size                         | 600mm×600mm×10mm          |
| Plenum height                     | 600mm                     |
| Porosity of perforated tiles      | 20%                       |
| Porosity of rack outlet           | 60%                       |
| Supply air temperature            | 18°C                      |
| Volume of supply air              | 7.008 m³/s                |

The plan of models are shown in Figure 1. Model (a) is the basic model without any partition in the plenum. (b) and (c) use partitions to create two independent air distribution room in the underfloor plenum. With this configuration, one CRAC serves the corresponding one cold aisle. The novel partition configurations are meant to improve the uniformity of the airflow and to eliminate the hot spots that emerge at the racks close to the CRACs. Hence, local partitions are added to increase the pressure at the near tiles and to distribute the right amount of air to the far points [12]. The local partitions perpendicular to the cold aisle are perforated with the porosity of 0%, 20% and 80%. All the other partitions are enclosed and not perforated.

![Figure 1. Plans of simulation models](image)

3. Results

The rack surface temperature distribution and airflow temperature distribution results obtained from numerical simulations are shown in Table 2. The plate contours of airflow temperature distribution at the height of 1500mm and 500mm are selected to investigate the effects of different configurations have on the outflow distribution and the thermal performance.
Table 2. Numerical simulation results

| Model | Rack surface temperature distribution | Airflow temperature distribution | Airflow temperature distribution |
|-------|----------------------------------------|---------------------------------|---------------------------------|
| 01#   | Standard model                         | Z=1500mm                        | Z=500mm                         |
|       | No partitions                          |                                 |                                 |
| 02#   | Enclosed partition at tile No.2        |                                 |                                 |
| 03#   | Perforated partition at tile No.2      |                                 |                                 |
|       | Perforation rate 20%                   |                                 |                                 |
| 04#   | Perforated partition at tile No.2      |                                 |                                 |
|       | Perforation rate 80%                   |                                 |                                 |
| 05#   | Enclosed partition at tile No.5        |                                 |                                 |
| 06#   | Perforated partition at tile No.5      |                                 |                                 |
|       | Perforation rate 20%                   |                                 |                                 |
4. Discussion

According to the rack surface temperature results, models 1#, 4#, 6#, 7# can obviously noticed that the hot spots emerge at the top parts of the racks close to the CRACs. This phenomenon is caused by the pressure distribution in the plenum. The flow rate of the outflow of perforated tile depends on the pressure drop between pressure of the room and the static pressure under the tile. When it gets closer to the CRAC, the flow rate will gets higher which leads to a high dynamic pressure and the corresponding lower static pressure. That makes the outflow rate of close tiles lower than others. At the mean time, the hot spots emerge at the close racks normally.

The rack surface temperature results also indicated that models 2#, 3#, 5# have eliminated the hot spots. From the temperature distribution at the cold aisle side surface of the rack rows, the airflow uniformity of model 2# shows the best thermal performance. However, comparing the airflow temperature at the height of 1500mm where the top part of racks are, the hot spots still exist except for model 2# and 3#. The model 4# & 7# with 80% perforated partitions even make the local overheating problem worse. The result shows that the maximum temperature has increase 2.1℃ than that in the basic case. The model 5# & 6# shows great nonuniformity in air distribution. A large amount of chilled air was supplied to the 4th ~6th racks which also leads to the undercooling. Overall, the 20% perforated partition at tile No.2 and the enclosed partition at the tile No.2 are effective improving configurations to optimize the thermal performance and air distribution of the data centers.

The airflow temperature distribution at the height of 500mm is close to the tiles which makes it capable to reflect the air distribution of different models. The enclosed partition models 2# and 5# indicated that the enclosed partitions are able to increase the local static pressure to increase the airflow volume so that the local thermal environment can be improved. But it also need to be mentioned that an obvious temperature rise appears after the local enclosed partition. It is reckoned that the enclosed partition leads to a pressure drop behind it and create a low pressure area. So it is proposed that the perforation design is necessary for the local partition if the more uniform airflow is needed to be achieved. The local partitions at tile No.5 do show the influence on the air distribution, but it affects the racks in the middle part rather than those at the close part near the CRACs. The model 2# with enclosed partition at tile No.2 eliminates the hot spots completely, while the enclosed partition causes an obvious nonuniformity airflow which would increase the reliability of the system when the working condition is changed. The model 3# with 20% perforated partition at tile No.2 eliminates most of the hot spots and shows great uniformity. The partition configuration is also found to be capable to improve the thermal performance of airflow at the local tiles and the nearest two tiles. The influence of partition configuration on the airflow at the local tile is greater than that at the surrounding tiles. And the overheating problem is worst at the first rack at the tile No.1 closest to the CRACs. Therefore, it should be considered that arrange the partition configuration at tile No.1 to make the improvement match the racks with overheating problems of different severity.

5. Conclusions

This work proposed novel underfloor air distribution configurations with local partitions to improve the air distribution and the thermal performance of data centers. Simulations on different models with different partition configurations have been investigated and analyzed. The results are as follows:
(1) This novel underfloor air distribution configuration with local partitions are proved to be effective in improving the air distribution and thermal performance of data centers.
(2) The configuration with local enclosed partition at tile No.2 eliminates the hot spots completely; The configuration with 20% perforated partition at tile No.2 achieves the most uniformity airflow.
3) The configurations with local partitions at tile No.2 shows better improvement than those at tile No.5. It does not improve the overheating problem at the racks closed to the CRACs obviously when the partitions are arranged at tile No.5.

4) The local partition could be arranged at tile No.1 to match the improvement with the severity of overheating in the future works.

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7. References
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