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Effect of under-floor blockages and perforated tile openings on the performance of raised-floor data centres

B. Fakhim, N. Srinarayana, M. Behnia and S. W. Armfield

School of Aerospace, Mechanical and Mechatronic Engineering
University of Sydney, New South Wales 2006, Australia

Abstract

Computer and telecommunication equipment are most commonly housed in raised-floor data centre facilities. Cold air is delivered into the facility via perforated tiles and air must be distributed properly to adequately cool the equipment. The airflow distribution depends mainly on the pressure distribution or the flow field in the space under the raised-floor which again depends on many other factors such as the plenum size, percentage opening of perforated tiles, the locations and flow rates of the computer room air conditioner (CRAC) units, and the size and location of the under-floor obstructions like cables and pipes.

In this article, the effect of position of the under-floor blockages and percentage opening of perforated tile are studied using computational fluid dynamics (CFD). The results provide an understanding of the fundamental fluid mechanical processes controlling the airflow distribution through the perforated tiles and help the facility designer to rearrange the blockages and improve the thermal performance without altering the layout or cold air supply.

Introduction

Data centres usually consist of processing servers, networking switch devices and mass storage arrays. The demand for increased computers and servers performance has led to very high power-density cabinet designs, with a single cabinet dissipating up to 30 kW. This increased density results in significantly increased performance, but at the cost of unprecedented power consumption and heat loads at both cabinet and facility levels [1]. Therefore, data centres require dedicated cooling systems for thermal management; the state-of-the-art is computer room air conditioning (CRAC) units that deliver cold air to the cabinets through perforated tiles placed over an under-floor plenum. To dissipate the large heating loads, a system of distributing the cooling air to the cabinets is employed. This system typically consists of an under-floor plenum, commonly varying in depth from 0.3–1.2 m, under grid floor tiles. CRAC units are essentially industrial air-conditioning units, which pump air into the plenum. By replacing solid floor tiles with perforated units, a jet of cold air is emitted, enabling the distribution of cooling air within the room. The region where perforated tiles are placed is called cold aisle. On each side of cold aisle, computer racks are placed with their intake sides facing the cold aisle. This cold air is drawn by the computer racks and the hot air is exhausted in the region between back ends of two rows of racks. This region is called hot aisle. Hot air rises from the hot aisle, into the ceiling space and flows back into the CRAC units. The recommended arrangement for the perforated tiles and the equipment racks on the raised-floor is the so-called ‘cold aisle–hot aisle’ arrangement [2], shown in figure 1.

In raised-floor data centers, the perforated tile flow rate distribution is fundamentally a fluid mechanics problem. The lateral flow rates are proportional to the local pressure drop (pressure in the plenum minus pressure above the raised-floor) across the tiles. In real-life data centers, the pressure variations above the raised-floor are small compared to the pressure differentials across the perforated tiles and can be neglected; that is, the pressure above the raised-floor is nearly uniform [3,4]. Thus, the lateral flow rates depend directly on the local pressure in the plenum and are, therefore, controlled by the same parameters that govern the plenum flow field such as the plenum size, percentage opening of perforated tiles, the locations and flow rates of the CRAC units, and the size and location of the under-floor obstructions like cables and pipes [5]. An understanding of the effect of these parameters on the lateral flow rates is essential for achieving the desired airflow distribution.

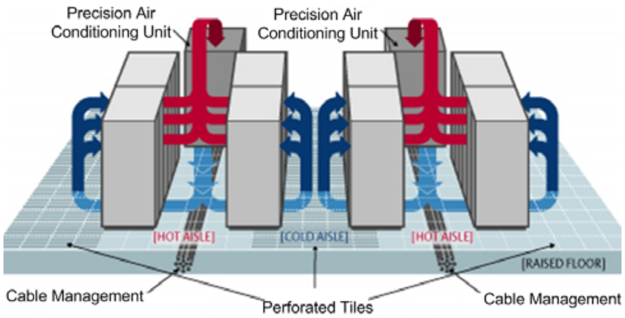


Figure 1. Hot aisle/cold aisle configuration.

Under-floor plenums are also used to route piping, conduit and cables that bring power, network connections to the racks and supply coolant to the CRAC units [6]. Under-floor blockages make the airflow pattern highly unpredictable. This leads to highly non-uniform tile flow rates. Non-uniformity in tile flow rates eventually increases infiltration of hot air in cold aisles leading to hot spots in cold aisles.

The aim of this study is to investigate the effect of position of the under-floor blockages and percentage opening of perforated tile, on the thermal performance of data center. This is achieved through the use of CFD.

Computational model

The top view of data centre layout is shown in figure 2. It is a raised-floor data center with alternating hot and cold aisle arrangement and room return infrastructure with a size of 12.2 m × 11 m × 2.76 m. The data centre consists of 80 racks with a density of 2.5 kW each. The racks are modelled with cuboids in conjunction with recirculation devices defined by characteristic heat load and flow rate, representing rack inlet and server fans respectively. There are four CRACs with a capacity of 54 kW each and the flow rate for each CRAC is 5522 L/s. CRACs are modelled with solid cuboids characterising coils and fans and recirculation devices detailing the CRAC’s supply and extract areas, as well as turning vanes in the plenum to direct the CRAC exhaust in the perpendicular direction.

The under-floor plenum is 60 cm high and a constant supply temperature of 16^{o}C is used. Obstructions (cable trays, piping) are modelled with cuboids located under the floor.

The simulations are conducted using FloVENT V8.2 by Mentor Graphics Mechanical Analysis [7], employing a Cartesian grid. Because of the typical flow rates and the sizes involved, mixing of hot and cold air, use of ventilation systems and server fans the flow is turbulent and the effect of turbulent mixing is modeled using the standard k–ε turbulence model. The k–ε model is the most appropriate for large, open spaces because of the way it calculates the turbulent viscosity and conductivity.

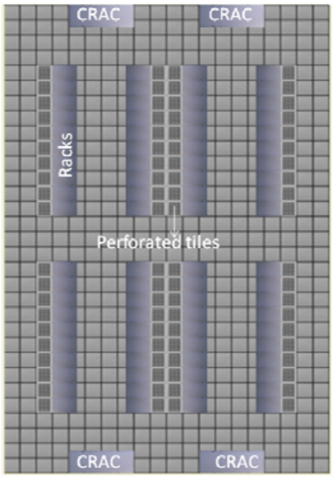


Figure 2. Data centre layout.

Results and discussions

Cable positioning

The data centre layouts with cable positioning (blue lines) under cold aisle alone and hot aisle alone are shown in figure 3.

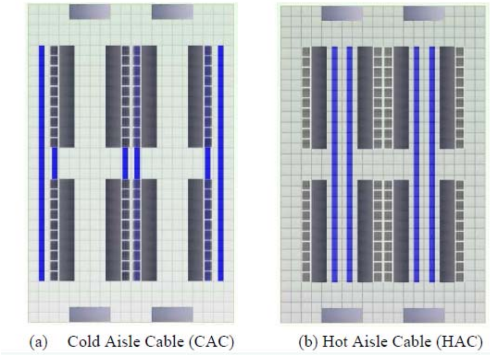


Figure 3. Cable positions.

The flow rates have been obtained for each individual perforated tile. The average flow rate through the perforated tile is 0.27. The normal distributions of perforated tile flow rates for both the scenarios are shown in figures 4 and 5. The standard deviation for the cables positioned under the hot aisle case is 0.02 m^3/s, while for the cables under cold aisle case is 0.022 m^3/s. Smaller the standard deviation, better is the uniformity of flow through perforated tiles. This means that cables and other obstructions should be placed under the hot aisle. This result agrees well with the investigation of Schmidt et al. [9]. It is, however, noted that the standard deviation is small in this study because of symmetry in heat distribution and geometry, and few underfloor blockages considered. In practise the layout and heat distribution may not be symmetrical and might lead to higher standard deviation.

Vertical location of cables and obstructions from floor

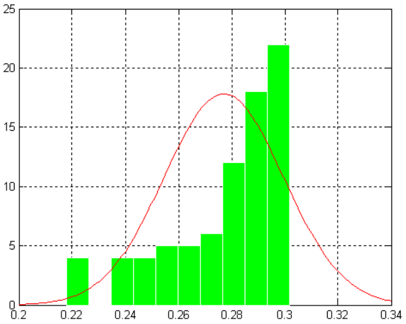


Figure 4. Normal distribution of perforated tile flow rate for cables under cold aisle.

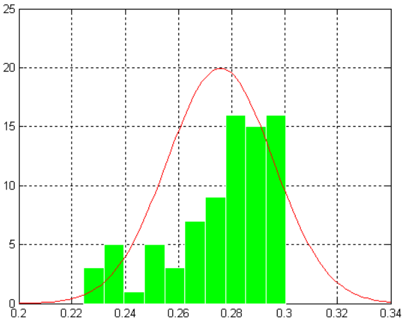


Figure 5. Normal distribution of perforated tile flow rate for cables under hot aisle.

Using the result from previous section (cables under hot aisle), the vertical location of cables is investigated here. Four different locations have been chosen, that is, 15 cm, 30 cm, 45 cm and 60 cm from raised-floor. In this case, the standard deviation (not shown in this paper) was lesser for the heights 45 cm and 60 cm. The closeness of cables position (15 cm, 30 cm) to perforated tile meant that most of the airflow was obstructed and there was non-uniform flow though the tiles. Both 45 cm and 60 cm gave same results and the choice of better one depends on the accessibility of cable trays from raised-floor for maintenance purposes, etc., which would be 45 cm from raised-floor.

Percentage opening of perforated tiles

Here the effect of percentage opening of perforated tiles on airflow uniformity and thermal performance of data centre are examined. Four different configurations of perforated tile openings, that is, 25%, 50%, 75% and fully opened are analysed.

Figures 6, 7, 8 and 9 show the normal distribution of perforated tile flow rates. Clearly, the normal distribution curve is narrower in 25% open case indicating that the standard deviation of perforated flow rate from the mean flow rate is very less and thus the airflow through the perforated tiles is more uniform compared to the other cases considered here. This result is in good agreement with the investigations of VanGilder and Schmidt [4] who obtained similar result of 25% opening on a different data centre layout study. This generalises that 25% perforated tile opening can be applicable to any layout.

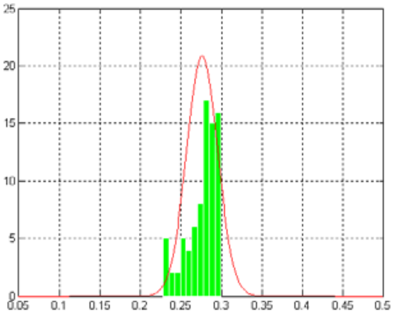


Figure 6. Normal distribution of perforated tile flow rate for 25% open.

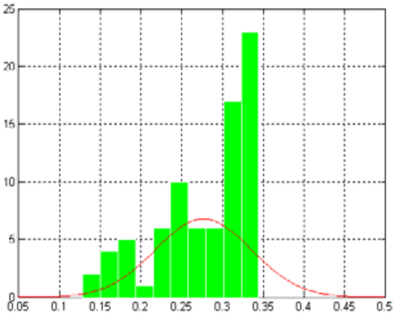


Figure 7. Normal distribution of perforated tile flow rate for 50% open.

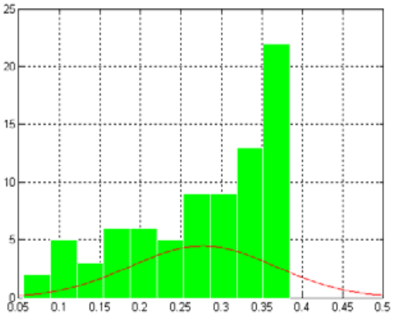


Figure 8. Normal distribution of perforated tile flow rate for 75% open.

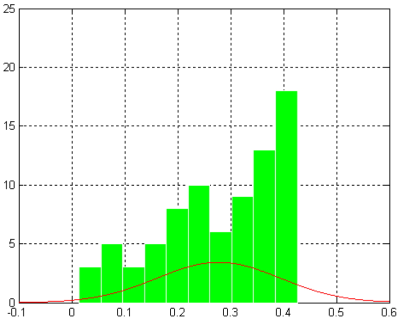


Figure 9. Normal distribution of perforated tile flow rate for fully open.

The data centre thermal performance in the current work is assessed using the supply heat index (SHI) [8], defined as,

$$SHI = \frac{\text{Enthalpy rise due to infiltration in cold aisle}}{\text{Total enthalpy rise at the rack inlet}} = \frac{T_{in,rack} - T_{ref}}{T_{out,rack} - T_{ref}} \qquad (1)$$

where $T_{in,rack}$ and $T_{out,rack}$ are average inlet and outlet temperature from a rack, respectively and T_{ref} is the CRAC supply temperature. The lower the SHI, the better the performance of the data centres. SHI can be predicted for individual cabinet units as well as the whole of data centre.

SHI of data centre for the four different perforated tile opening is shown in table 1.

% opening	SHI
25	0.033
50	0.053
75	0.086
Full	0.112

Table 1. SHI for different perforated tile openings.

From table 2, it is clear that 25% perforated tile opening performs better than other cases considered here, and thus reinforcing the statement made earlier that 25% perforated tile opening can be used in any data centre.

Perforated tiles with flow deflectors

In this paper, preliminary results are presented for perforated tiles with flow deflectors, that is, variations in angle of incidence of air onto racks coming out of perforated tiles. The data centre layout is shown in figure 10. It has eight high density rack of each 4 kW (red colour) and 32 other racks (grey colour) with 2.5 kW each. There are four CRACs with a capacity of 54 kW and a flow rate of 5522 L/s each. The under-floor plenum is 60 cm high and a constant supply temperature of 16°C is used.

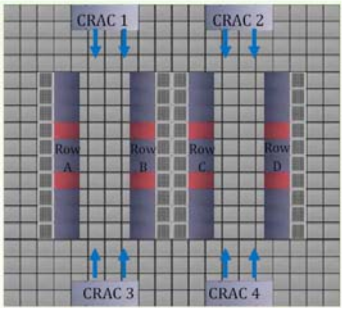


Figure 10. Data centre layout for angle of incidence of air stream from perforated tiles study.

Table 2 shows SHI, the maximum and mean temperature of data centre for different angles of flow deflectors.

Angle (°)	SHI	Maximum temperature (°C)	Mean temperature (°C)
45	0.042	32.2	23.7
65	0.134	30.6	22.85
85	0.013	26.5	20.75
90	0.009	26.4	20.70
No deflector	0.027	26.7	20.9

Table 2. SHI, the maximum and mean temperature of data centre for different angles of flow deflectors.

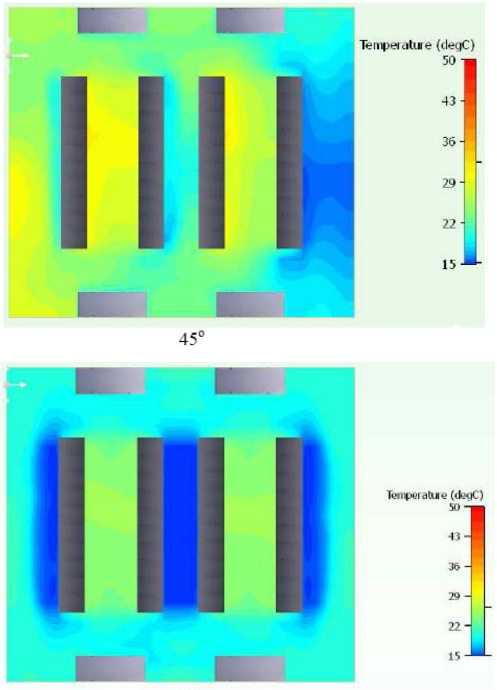
From table 2, with 90° deflection (flow coming straight out of perforated tile) gives the best solution with lower SHI, maximum and mean temperatures. There is hot air recirculation from hot aisle to cold aisle from the top and sides of racks. The recirculation from the top has more detrimental effects compared to recirculation from the sides. In the 90^o deflector case, the cold air from perforated tile, in addition to being taken into the racks, flows upward and counters the hot ait recirculation from top more efficiently compared to other deflection angles considered here. Both 45^o and 60^o perform poorly and the maximum and mean temperatures are high due to hot air recirculation and top racks receiving less cold air. Figure 11 shows the temperature profile for 45^o and 90^o flow deflections at a height of 1 m from raised-floor. In the 45^o deflection case, there is high amount of hot air recirculation leading to a hotter cold aisle, while in the 90^o deflection case the cold aisle is kept much cooler.

Conclusions

In this paper, the effect of location of under-floor obstructions, and percentage opening of perforated tiles on the flow uniformity and thermal management of data centre is presented. In addition, preliminary results have been presented for perforated tiles with flow deflectors. A numerical analysis has been conducted using FloVENT.

It is observed that placing cable trays and obstructions under hot aisle instead of cold aisle leads to better flow uniformity through perforated tiles. Among the four positions of perforated tiles under the raised-floor, both 45 m and 60 cm gave better flow uniformity. The effect of flow uniformity for four different percentage opening of perforated tiles is examined and it is found that 25% opening is better compared to 50%, 75% and fully opened perforated tiles.

The data centre performance is analysed using supply heat index. The 25% open perforated tile gave the best SHI of 0.033 among the other openings considered in this paper. The effect of having perforated tiles with flow deflectors on performance of data centre is also analysed and it is found that flow coming straight out of perforated tiles (90^o deflection) gives better SHI and lower maximum and mean temperatures in the data centre.



45^o

90^o

Figure 11. Temperature field for 45^o and 90^o flow deflection through perforated tiles at a height of 1 m from raised-floor.

Acknowledgements

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