the axial velocity is small (i.e., small dynamic pressure). Consequently, the rear side of the data center (tile rows greater than 6) has a high mass flow rate compared to the front side. At an open area ratio of 60%, backflow occurs due to the Venturi effect.

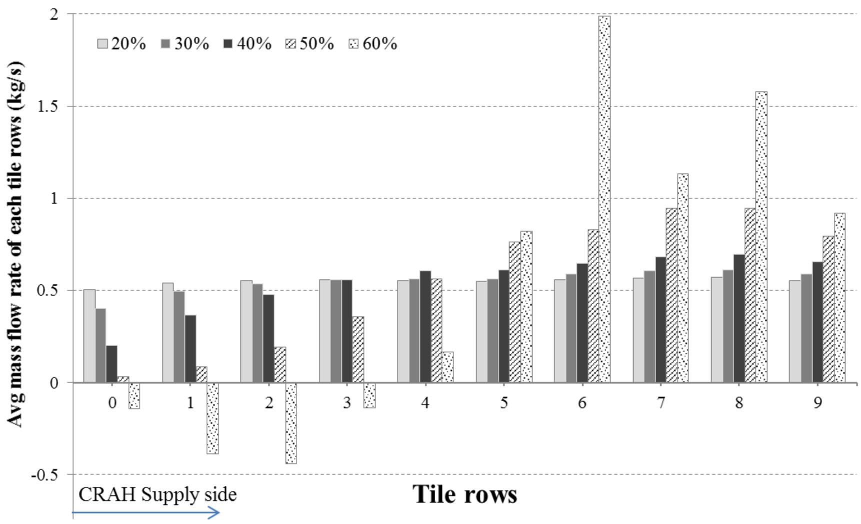

Figure 4. *Average mass flow rate of tiles in each row*

(2) Temperature distribution

The paramount issue of data center cooling is the supply air temperature of each rack. These temperatures of 11 right side racks (i.e., Rack number 10 to 19 and UPS Rack) are shown in Figure 5 for open area ratios of 20%, 40%, and 60%. As shown in Figure 4, when the airflow of each tile is uniform (i.e., 20%, 40%), there is no significant temperature fluctuation in any rack. However, as the tile open area is 60%, which shows severely non-uniform airflow in Figure 4, there is a significant fluctuation in temperature distribution.

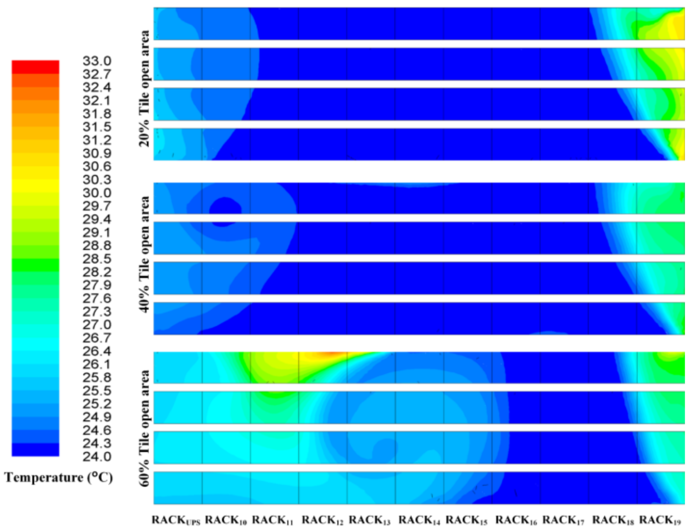

Figure 5. *Temperature distribution of the rack inlet area at a CRAH supply air temperature of 24℃*

(3) Air management performance

Estimated air management metrics (i.e., RTI and RCI) are shown in Figure 6. In Figure 6 (a), when the CRAH supply air temperature is 24℃, both RTI and RCI are close to their ideal value (i.e., 100%) regardless of the tile open area ratio. However, when the supply air temperature is increased to 27℃ (Figure 6(b)), RCI_{HI} decreases significantly in cases of 50% and 60% open area, which indicates that the rack inlet temperature is greater than high-limit of the recommended range at many servers. This result suggests that the air management performance is still acceptable regardless of tile open area when CRAH supply air temperature is lower than the upper-limit of the recommended range (i.e., 27℃). However, when the CRAH supply air temperature is increased to the upper-limit temperature, if the airflow of tiles is non-uniform, there might be reliability problems in some racks due to high rack inlet air temperature.

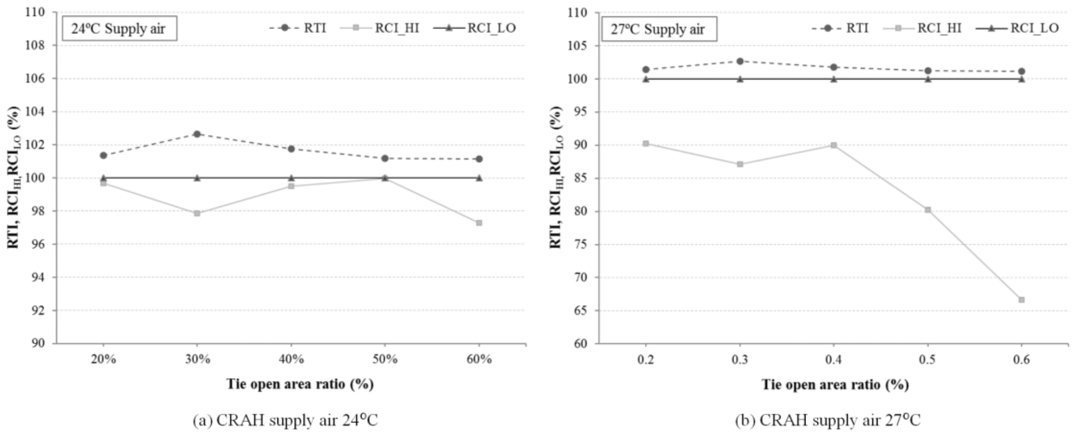

Figure 6. *RTI and RCI values with tile open area ratios at CRAH supply air temperatures of 24℃ and 27℃*

CONCLUSION

In this paper, the relationship among open area ratio and airflow uniformity of tiles, and air management performance is analyzed in a modular data center via CFD simulation. The results shows that an decrease in tile open area leads to an increase in airflow uniformity, but the air management performance is affected by airflow uniformity as well as CRAH supply air temperature. The simulation results show that tiles with open area of 40% show both good air management performance and acceptable airflow uniformity.

Recently, pressure distribution of aisles and raised-floor has been important to control airflow in containment architecture (Moss and Steinbrecher 2012). In addition, to reduce fan static pressure drop and unwanted leakage flow, a large open area of tile would be preferred although this might yield severe non-uniform airflow. Thus, it is expected that CFD modeling strategy used in this study could be beneficial for proper data center thermal design.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (No. 2012001927), and the Korea Evaluation Institute of Industrial Technology grant funded by the Korean Government (No. 10045236)

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