A numerical airflow pattern study of a floor swirl diffuser for UFAD system

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ABSTRACT

Floor swirl diffuser is one of the commonly used diffusers in underfloor air distribution (UFAD) system. Geometrical design of the floor swirl diffuser will affect the airflow pattern of the indoor environment. Thus, the purpose of this study is to examine the effect of geometrical design of a floor swirl diffuser on the aspects of airflow rate, number of diffuser blades, angle of attack of diffuser blades, and the grille thickness. Laboratory experiment was carried out to validate CFD simulation results. The results of this study have shown that diffuser blades have an important role in the airflow pattern. The grille thickness, which is required to withstand the impact and the load of human and furniture, needs to be minimized as the thickness is detrimental to the function of diffuser blades. Besides, airflow rate per diffuser is studied in UFAD system in order to achieve thermal stratification. The air throw is lower compared to a high angle of attack at the low angles of attack of 30° and 45°. The optimum number of diffuser blades to create the swirl effect is 18 blades with a free area of 18.86%.

1. Introduction

UFAD diffusers are used to deliver conditioned air from the floor plenum to the occupants’ space for human comfort in UFAD system. Generally, UFAD diffusers are categorized into six types: round omni-directional diffusers, selective directional diffusers, displacement flow diffusers, linear diffusers, ducted diffusers and terminal units [1]. Although there are various UFAD diffusers available in the market since the emerging of underfloor air distribution technology in 1990s, there is limited research work carried out on the geometry of UFAD diffusers. The present study examines the geometrical effect of the floor swirl diffuser in terms of the airflow pattern.

A well-designed UFAD system can have a potential to reduce energy consumption, reduce floor to floor height, improve thermal comfort, improve ventilation efficiency and provide flexibility in reconfiguring the interior layout of the building [2]. The performance of UFAD system has been examined from the aspects of fluid dynamics, energy performance, temperature distribution and thermal stratification [3–6]. However, one of the most crucial factors that will influence the thermal comfort and ventilation effectiveness of the indoor environment is the airflow pattern of UFAD diffusers.

ASHRAE Standard 62.1-2013 awards the highest ventilation effectiveness of 1.2 to UFAD system that achieves thermal stratification or the vertical throw is less than or equal to 0.25 m/s at the height of 1.4 m above the floor [7]. Both displacement ventilation and underfloor air distribution (UFAD) systems can have the potential to achieve values greater than 1.0 [8]. Thermal stratification is defined by the stratification level that divides the room into upper and lower zones. Lower zone has a relatively well mixed air due to the turbulence created by high velocity jets of the floor supply air outlets. Upper zone has a warm and contaminated air rising by the heat plumes. The average air velocity at upper zone is relatively low [9]. The ventilation effectiveness of UFAD system will be downgraded to 1.0 if the system does not achieve the thermal stratification or the required air throw, and thus the ventilation effectiveness will be similar to the conventional overhead air distribution (OHAD) system. The potential to achieve higher ventilation effectiveness means a reduction on the required minimum outdoor air rates. There will be a significant reduction on the cooling energy consumption for cases with high ventilation effectiveness.

Based on study conducted by Lin and Tsai [10], the supply airflow rate is found to have a strong connection with the supply air momentum flux and thus affects the gradient of the vertical temperature profiles of the indoor environment. The study describes the throw height as the level where the temperature at the supply air outlet area is equal to the temperature of that height in the

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Fig. 7. The center plane air temperature profiles for airflow rates of (a) 100 CMH; (b) 195 CMH; (c) 290 CMH.

Fig. 8. Diffuser’s swirl mechanism with (a) 12 blades, (b) 18 blades and (c) 24 blades.

Fig. 9. The center plane air velocity profiles for (a) 12-blades; (b) 18-blades; (c) 24-blades swirl mechanism.

Fig. 10. Plane air velocity profiles for diffuser blades at the angles of (a) 30°; (b) 45°; (c) 60°.

details can be found in references [28,29]. As the grille thickness increases, it is observed that the primary air is delivered into the space vertically upwards with a higher air throw and velocities. The primary air jet has induced a secondary air flow near to the jet. However, the room temperature becomes uneven as the cold air is delivered straight to the return air grille on the ceiling. The results in the case of no swirl diffuser blade have shown similarity to cases as the grille thickness increases such as 10 mm and 20 mm grille thickness. The thickness of the grille has proven to be detrimental to the function of diffuser blades.

4.5. The centerline velocity, $v_c$

The case on 195 CMH is the base model used to study the geometrical design changes. The simulation result suggests a good agreement with the experimental measurement. Fig. 13 shows the centerline velocity of all models through experimental measurement and simulation. Among all the comparisons, the centerline velocity graph shows that the grille thickness has a major impact on the airflow from the floor swirl diffuser. The cases with 10 mm and 20 mm thick grilles have resulted in high air velocities near the air outlet at 1.91 ms$^{-1}$ and 2.06 ms$^{-1}$ respectively. The case without
diffuser achieves a similar result of high centerline air velocity near the air outlet at 1.88 ms⁻¹. This has proven that the air is delivered into the space without a proper swirling effect. For the cases with no grille and 3 mm grille thicknesses, the centerline air velocities are greatly reduced to maximum values of 0.57 ms⁻¹ and 0.77 ms⁻¹ respectively. Therefore, having a thick grille is equal to not having diffuser blades, and the air will be delivered to the space without creating the swirling effect.

5. Conclusions

In the present study, a comprehensive investigation has been successfully conducted on the airflow pattern of a floor swirl diffuser through various aspects, including the airflow rate, number of diffuser blades, the angle of attack of diffuser blades and grille thickness. The results can be used as an important guide to design an optimised UFAD system. Based on the results obtained, there are several major conclusions made as follows:

1) In the airflow rate study, a 250 mm nominal diameter floor swirl diffuser with an airflow rate of 100 CMH and below can be awarded with a ventilation effectiveness of 1.2 according to ASHRAE Standard 62.1:2013. The minimum outdoor airflow rate can be reduced by dividing it with a factor of 1.2 if the design is in accordance to this flowrate or below. The momentum flux of the diffuser is directly proportional to the supply air velocity. Thus, the equivalent supply air velocity of 1.73 ms⁻¹ is acceptable. An airflow rate of 195 CMH and above supplied using this diffuser will not obtain this better ventilation effectiveness at 1.2 because a higher air throw will cause the low and high stratification layers to be mixed by the turbulences of the flow. The diffuser performance will then be identical to an OHAD mixing system of 1.0. The future research on thermal stratification is recommended to include heat load profiles of the room in order to have a complete understanding on thermal stratification.

2) It is suggested that the optimum number of diffuser blades to create a swirl effect is 18 blades, which has a free area of 18.86%. The airflow of this case shows a well-developed plume air development (Fig. 9). The air plume developed is the largest among the three cases. A large free area in the case of 12 blades or a small free area in the case of 24 blades could lead to a direct air jet flow into the space, and thus ineffective in the air plume development, which is similar to the case without diffuser blades.

3) The swirl blades are important in rotating the discharged air to improve the mixing effect. At the low angles of attack of 30° and 45°, the air throw is lower compared to a high angle of attack. The primary air is established and expanded by entraining room
Fig. 13. The centerline velocity (m/s) for all the geometrical variation of floor swirl diffuser from the floor level of 0 m to 3 m above floor level.

4) A thicker grille leads to air delivered as a straightened air jet into the space. The swirl effect from the diffuser blades is eliminated. Thus, a minimum grille thickness should be developed without detrimental effect to the strength to withstand the impact and load of people and furniture.

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