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Numerical Study on the Effect of Air Diffuser Angle on the Flow Field and Contaminant Dispersion in a Ventilated Room

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ABSTRACT: Due to increasing application of air conditioning systems in various industries including cleanrooms, the optimized use of the applied equipment for less energy consumption and better contaminant distribution is essential. This paper investigates the effect of four-way ceiling diffuser angle effect on the ventilation system performance numerically using Eulerian-Lagrangian approach. In this study, the initial contaminant distribution is assumed to be uniform in the ventilated space and the room assumed to be without diffuser and with diffusers of 30, 90 and 30-90 blade angles is investigated. This work shows that the diffuser with 30 and 30-90 blade angles decrease the contaminant faster than 90° and without blade configurations. It is also shown that the 90° diffuser and without diffuser cases which shoot air vertically leads to less deposition and higher exit to deposition ratio. Based on flow field pattern, the flow field of cases with 30 and 30-90 degree could sweep particles from corners of the room better than W/O diffuser and 90° cases while their flow field role is less in sweeping corners and the main role is on central locations.

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1- Introduction

Four-way ceiling diffusers are known as mechanical devices to control the inlet air and contaminant distribution in the ventilated systems. There are many numerical and experimental studies on Heating, Ventilation, and Air Conditioning (HVAC) systems including cleanrooms focusing on flow field and contaminant motion. Computational Fluid Dynamics (CFD) is an appropriate method for such purpose which needs to be verified with experimental results.

Among CFD studies on diffuser effect some works could be noticed. Sajadi et al. [1] investigated geometrical parameters such as blade angle and aspect ratio of a kind of swirl diffusers and showed higher effect for a range of angles. Djunaedy and Cheong [2] found better modeling of RNG than standard k- ε and also showed that diffuser modeling method has a distinct effect on the obtained results. Tavakolli and Hosseini [3] studied swirl diffuser angle effect on the turbulent properties of the flow field and mass transfer using large eddy simulation to reach a better air quality. Chen et al. [4] compared different opening ratio of multi-slot diffusers which used in vehicles and found decreased particle deposition for angles higher than 45°.

In spite of previous studies on geometric effect of diffusers, there is not any work on flow field and contaminant distribution of a room equipped with variable four-way ceiling diffuser angle. The novelty of present study is focusing on this issue using computational fluid dynamics which has a potential to be used in higher performance air diffusers.

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2- Governing Equations

The flow field in the ventilated space is assumed as a three-dimensional turbulent flow which is not affected by particle motion. The general form of governing equation for gas phase is:S

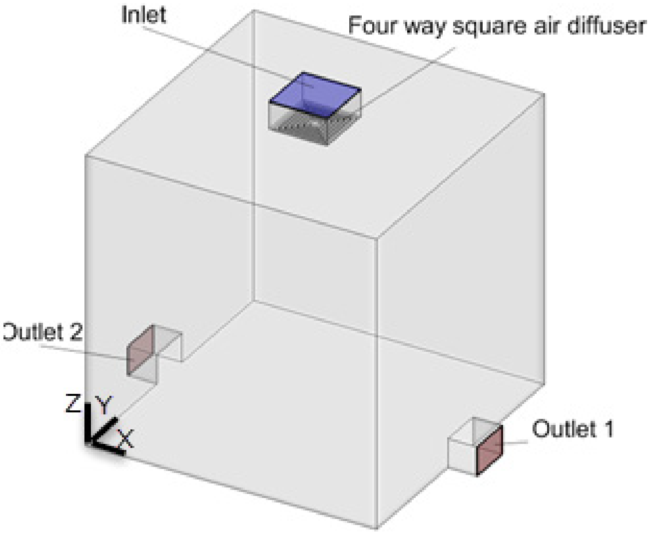
$$\frac{\partial}{\partial t}(\rho\varphi)+div\left(\rho\vec{V}\varphi-\Gamma_{\varphi} grad\,\varphi\right)=S_{\varphi} \qquad (1)$$

which φ could be 1, V, k and ε to show continuity, momentum conservation, turbulent kinetic energy and turbulent kinetic energy dissipation equations. Γ_{φ} and S_{φ} represent effective diffusion and source term, respectively. The contaminant is assumed as particles and tracked using Eulerian-Lagrangian approach as follows:

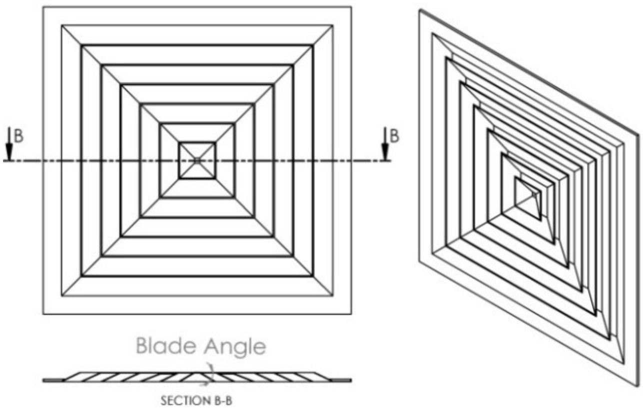
$$\frac{du_p}{dt}=\frac{\left(u_f-u_p\right)}{\tau_{relax}}+\frac{g\left(\rho_p-\rho_f\right)}{\rho_p} \qquad (2)$$

3- Numerical Conditions

Fig. 1a shows the schematic of the ventilated room (3 m cube) which includes a ceiling diffuser and two exhausts. The four-way ceiling diffuser configuration which is showed in Fig. 1b has been studied by considering different configurations including 30° and 90° and a novel designed configuration with variable angle from 30° to 90°. There is a pelenum box above 60 cm ×60 cm diffuser with 30 cm height. Exhaust grills are 45 cm × 30 cm. Inlet velocity is assumed 0.21 m/s. Particle diameters which has been studied are 1, 5 and 10 micron which are positioned in the domain with equal distance to each other initially. Their boundary conditions are deposition for floor and reflect for ceiling and other walls. The number of CFD cells is 1 million which is acceptable in mesh independency point of view based on previous study [5]. The verification of numerical results has been performed with a test case [6].



(a)



(b)

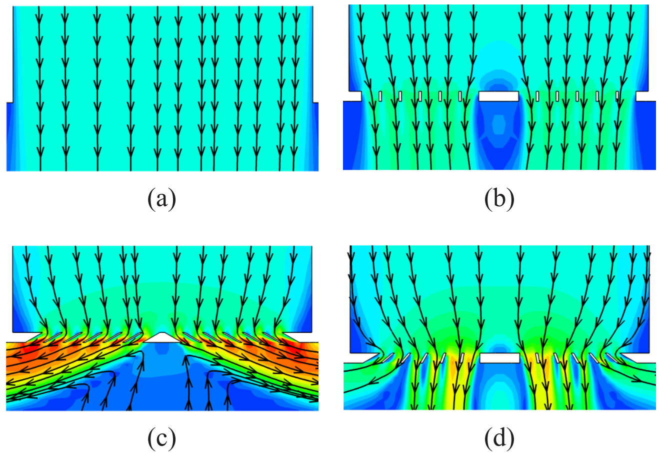
Fig. 1. Geometry of (a) ventilated room (b) Four way ceiling diffuser

4- Results and Discussion

Streamlines showed in Fig. 2 present the air flow passing through diffusers in four studied configurations of without diffuser, 90°, 30°, and 30-90 degree. In the case without diffuser, there is not any resistance and the air flow enters the room vertically with 90° angle. The diffuser angle in other configurations plays important role in changing the flow field in the room.

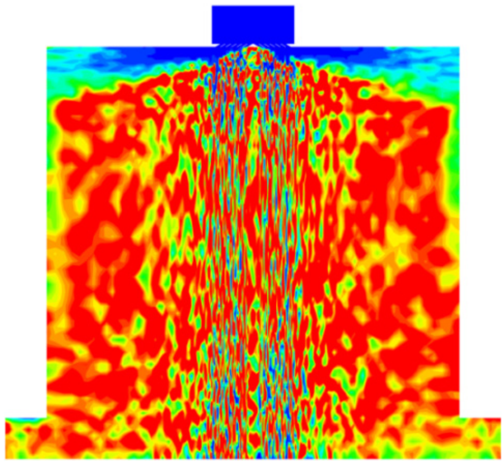
The airflow pushes the particles and makes the initially contaminated room clean, as seen in Fig. 3 which is contaminant contour for the 30° and 30-90 degree configurations after 10s. It was observed that the W/O and 90° configurations affect below the diffuser, 30° configuration affects near walls and ceiling regions and 30-90 degree configuration affects both regions.

According to findings of this research including Fig. 4, decrease rate of greater particles is faster than smaller particles. It is also concluded that 30° and 30-90 degree leads to higher rate of decreasing contaminants than 90° and without diffuser configurations with higher exhaust to deposition ratio.

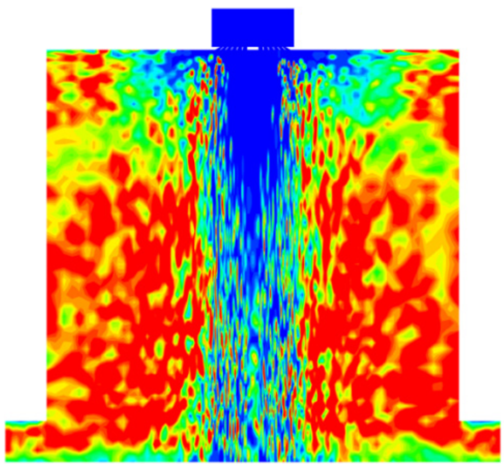


(a) (b) (c) (d)

Fig. 2. Streamline and contour of entering air velocity to the ventilated room of a) W/O diffuser, b) 90°, c) 30° and d) 30-90 degree diffuser angle

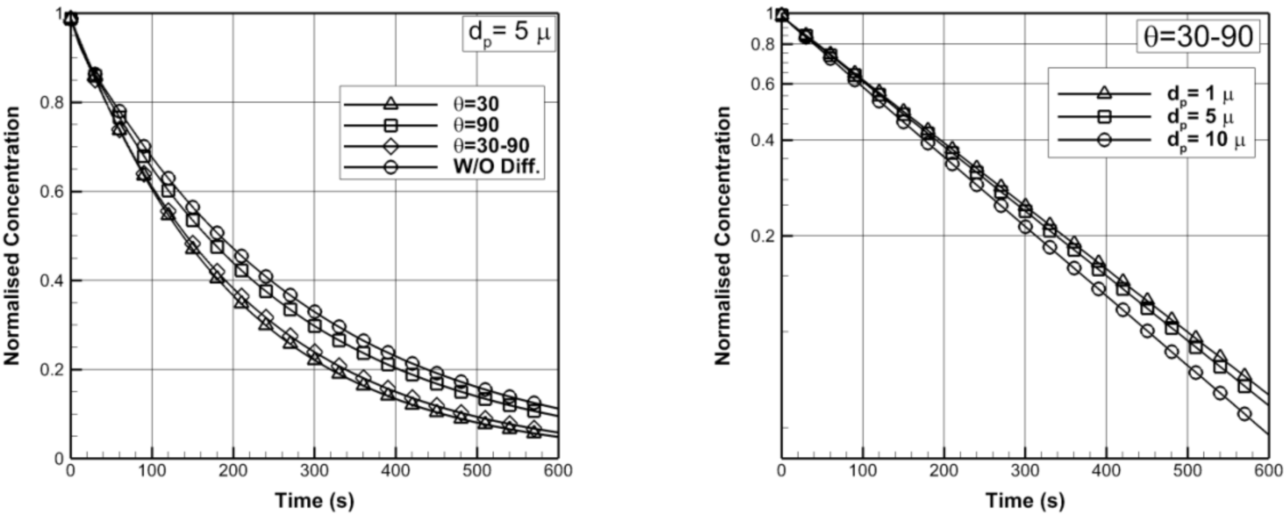


(a)



(b)

Fig. 3. Contaminant concentration contour at time 10s in the configuration of a) 30° and b) 30-90 degree diffuser angle.



(a) (b)

Fig. 4. Normalized concentration versus time of (a) different configurations; (b) different particle diameters

Higher exhaust to deposition ratio is seen in 30-90 degree configuration in comparison to 30° configuration.

5- Conclusions

This study showed the importance of diffuser angle on two aspects of decrease rate and exhaust to deposition ratio which could be used by HVAC designers.

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