EFFECT OF DIFFERENT VENTILATION SYSTEMS ON CONCENTRATIONS OF INDOOR PARTICLE EMITTED FROM FLOOR OF THE OFFICE

Linlin Li[1], Yifeng Yao[1], Yang Luo[1,], Yuandong Huang[1]*
[1] College of Environment and Architecture, University of Shanghai for Science and Technology, Shanghai, China

Abstract. A three-dimensional numerical simulation of airflow, temperature, and pollutant concentration distributions with underfloor air distribution (UFAD) system and displacement ventilation (DV) systems are presented for different operating conditions. Since the particles deposited on the floors can be re-introduced into the air through re-suspension and then constitute a threat to human's health, an optimal ventilation system is required to reduce the indoor air particle concentrations. In the present study, the effects of different systems on the concentrations of indoor particles are numerically investigated by an Eulerian-Lagrangian method, and the RNG k-ε model is adopted for the simulation. Three different supply air velocities (0.2-0.4 m/s) and different supply air temperatures (20 ℃, 22 ℃ and 24 ℃) are considered in the simulation. Meanwhile, the thermal effect of the human body on the micro-environment and its interaction with the surrounding environment are comprehensively evaluated. The simulation results shows that for the UFAD and DV systems, good performance of particle removal is obtained with the high air supply speed for the DV system, while under larger temperature gradient of the indoor environment, the UFAD system is capable of reducing the concentration of the particles emitted from the floors with lower air supply speed.

Keywords: Underfloor Air Distribution, Displacement Ventilation, Thermal plume, Particle Concentration, Human micro-environment

1 Introduction

Epidemiological studies have shown that exposure to aerosol particles may have harmful effects on human health [1,2]. The particulate matter may come from indoor sources such as construction materials, plants and equipment, residents and human activities [3], and from the outdoor sources such as activities of industrial centers and vehicles [4]. The generated particles have a mutual interaction with the airflow in ventilated rooms, and the features of particle transport are influenced by the support air velocity and temperature. Therefore, itis necessary to investigate the effects of ventilation systems on the distribution of particles.

Numerous experimental and computational studies have shown that indoor ventilation mode, air supply temperature and human body surface temperature are important factors affecting air quality and pollutant diffusion. In terms of the comparative study on the performance of different air supply modes. Ho et al. [5] found that under the same thermal comfort conditions, the floor air supply mode is conductive to pollutant elimination and is better on energy saving than upper air supply modes. Moreover, the study of Alajmi [6] showed that floor air supply system has significant energy saving effect as compared with ceiling-based air distribution (CBAD). Z. Zhang, et al. [7] used the Lagrange particle tracking method to predict the dispersion and concentration distribution of particles in ventilated rooms with three different ventilation systems, and the study found that the UFAD systems have better particle removal performance than the ceiling and side wall ventilation systems. In the performance study of UFAD single air supply system, Lin and Tsai[8] showed that the temperature stratification of UFAD systems decreases as the inlet air flow rate increases. Meanwhile, the vertical temperature difference is strongly dependent on the distance to the inlet diffusers. Zhang et. al [9] and Fong et. al [10] also found that the well-designed UFAD systems could provide a good thermal environment. Furthermore, the influence of air inlet angle in swirl diffusers of UFAD system on distribution and deposition of indoor particles was investigated by M. Taheri et al. [11], and they found that for the particles with different sizes, the pollutant concentration is different with the increasing of the inlet air angle.

Meanwhile, S. Alotaibi et al. [12] numerically studied the influence of mixed and displacement air distribution systems on concentrations of micro-particles emitted from floor or generated by breathing, and the results showed that the performance of DV in particle removal is largely dependent on particle generation location. Furthermore, the study also found that the reversed displacement ventilation presented the best performance in case of floor generation, while DV provided the worst performance.

Xu et al. [13] conducted a simulation study on particulate matter generated by staff activities and office conditions under displacement ventilation system. Here, the distribution of five different particulate matter with different pollution source locations was analysed. The outcomes showed that the lower location of the pollution source generated lower concentration of particulate matter in the respiratory zone.

* Corresponding author: luoyang@usst.edu.cn

Based on the previous researches, it can be found that different ventilation modes showed large discrepancy on the performance of particle removal. Meanwhile, the influence of ventilation systems on the particle removal performance should be with considering the location of the pollutant source and on the operation conditions. Here, due to the effect of air flow, the particles deposited on the floors can be re-introduced into the air through re-suspension, and then constitute a threat to human's health, especially in small office with densely populated settings. Thus, this study is to investigate whether the application of different air supply systems can improve the thermal comfort and indoor air quality satisfaction of occupants under the optimal air supply volume control in a specific small office situation,

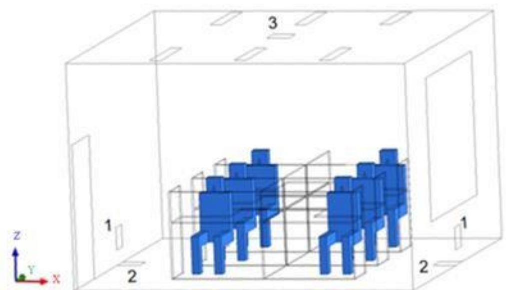

Fig.1. Schematic diagram of modelling room: 1-DV system air inlet; 2-UFAD system air inlet; 3-outlet..

2 Model description and research method

The geometry considered in the present study is an office room with 4.5 m in length, 4.66 m in width, and 3 m in height. Here, six human bodies with a surface temperature of 31℃ and six desk are arranged in the office room (see Fig, 1), and the performances of the two different ventilation systems are evaluated and compared in this study, as illustrated in Table.1. The airflow inside the room was assumed to be steady-state, three-dimensional, incompressible and turbulent flow. The Boussinesq assumption is adopted to demonstrate the buoyancy force caused by cooled jet flow and thermal upward plume generated by manikin. The walls, ceiling, and floor of the chamber are insulated. Also, an exhaust diffuser with an area of 0.09 m2 is mounted on the ceiling, and two vortex inlet diffusers are placed in different locations to performed as different ventilation system. Furthermore, in order to simulate indoor dust accumulation effect, it is assumed that indoor dust particles with a particle size of 1μm are evenly distributed under different wind speeds, and the ground is selected as the dispersion source of indoor particles with the emission rate of 2.26μg/s.

In the current study, commercial software FLUENT 18.0 is used to simulate the airflow, temperature, and pollutant concentration distributions with UFAD and DV systems. The RNG k-ε model is adopted for the simulation after the validation test, and a good agreement is achieved between the simulation and experimental results of the normalized particle concentration at different locations with a maximum relative error in the order of 10%. The Euler-Lagrange method is adopted in this paper for the calculation of indoor particles distribution and deposition. The second-order upwind scheme is used for discretized convection, and a staggered scheme called PRESTO! is selected for pressure term. Meanwhile, the SIMPLE algorithm is adopted for the pressure and velocity coupling. In order to discuss the influence of air supply conditions on the indoor airflow and pollutant diffusion, different speed and temperature conditions under two air supply systems are considered in this study. The simulation conditions are shown in Table 1.

Table 1. Simulation conditions.

Case	Ventilation systems	Air supply velocity	Air Supply temperatures (℃)
U1		0.2	20
U2			20
U3	UFAD	0.3	22
U4			24
U5		0.4	20
D1		0.2	20
D2			20
D3	DV	0.3	22
D4			24
D5		0.4	20

3 Results and discussion

3.1 Effect of supply air velocity on particle concentration distribution

In this paper, three different air supply speeds (0.2, 0.3 and 0.4m/s) at the same temperature (20℃) are considered to analyze the distribution of indoor particulate matter under two different ventilation modes. Since the office staff are basically sitting in a fixed position, the height of the breathing zone is about z = 1.1 m. The concentration of fine particles at the z = 1.1 m plane is mainly analyzed in this study.

Fig. 2 illustrates the comparison of normalized particle concentration contours at the breathing level (at z = 1.1m) with different air supply systems. It is found that the particle concentration is higher when the air supply with the speed of 0.3 m/s under UFAD system, while the worse condition is obtained with air velocity of 0.2m/s under the DV system. Furthermore, as compared the performance of particle removal of the two ventilation systems, the results show that average concentration of fine particles at the breathing level of the UFAD system is relatively lower than that of the DV system. Meanwhile, it can be obtained that the concentration decreases with the increase of the supply air velocity under the DV system, which is relate to the fact that large air supply speed induces high frequency of air change and ventilation efficiency in the room. Here, it can be noted that the particle concentration at the breathing level under the UFAD system is higher when the air supply with speed of 0.3 m/s. The results show that the concentration under the UFAD system is not

 https://doi.org/10.1051/e3sconf/202235605062

linearly varied with the increase of the supply air velocity.

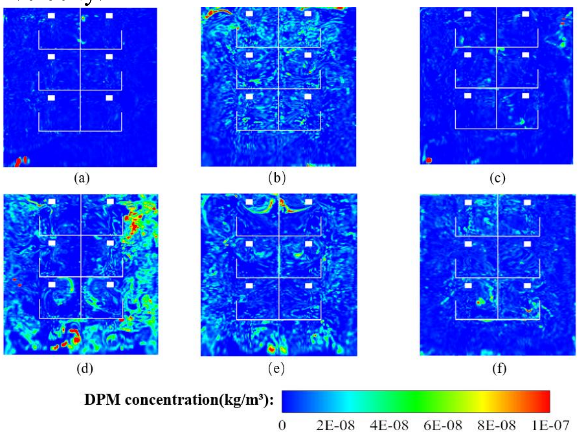

Fig.2. Particle concentration distributions under different supply air conditions at the z = 1.1m plane: (a) U1; (b) U2; (c) U5; (d) D1; (e) D2; (f) D5.

3.2 Effect of temperature on particle concentration distribution

In this study, in order to investigate the effect of the air supply temperature on the airflow, temperature and particle concentration distributions, different air supply temperature (20°C, 22°C, 24°C) is considered with a fixed air supply speed (0.3 m/s). Fig. 3 and Fig. 4 show the temperature field, normalized velocity and particle concentration contours at the vertical central plane (at y = 2m) under UFAD and DV systems, respectively. As observed in Fig. 3 and Fig. 4, the air in the lower part of the room travels to upper part mainly by upward air supply injection and human-generated heat plumes, and the flow is generally dominated by the human thermal plume in the human micro environment.

In the UFAD system, a pronounced thermal stratification effect is manifested due to the set of air supply outlet on the ground floor. The cold air is supplied from the ground, and because the mass of the cold air is significantly greater than that of the hot air, and after reaching a certain height, it will no longer diffuse upward, resulting in a stable thermal stratification phenomenon. Specifically, when the supply air temperature is 20 °C, the gap with the background temperature of the room is larger, and the temperature gradient of thermal stratification also becomes larger. Meanwhile, larger velocity with lower temperature is obtained in the low region near the vertical walls, thus the particle generated from the floor is accumulated in the region under the desk due to the velocity recirculation therein. As the supply air temperature increased, the slight decrease of the air density with the slight increase in buoyancy, which results in the lower particle concentration around the human. However, as the supply air temperature close to the room temperature, the thermal plume upward obliquely with larger air velocity, while the particle concentrated at the central region below the desk due to the large velocity below the human body. Moreover, the thermal stratification creates the accumulation of fine particles towards the higher levels of the room. At the same time, due to the blocking effect of indoor staff and desks, the distribution of particles in the lower level becomes uneven.

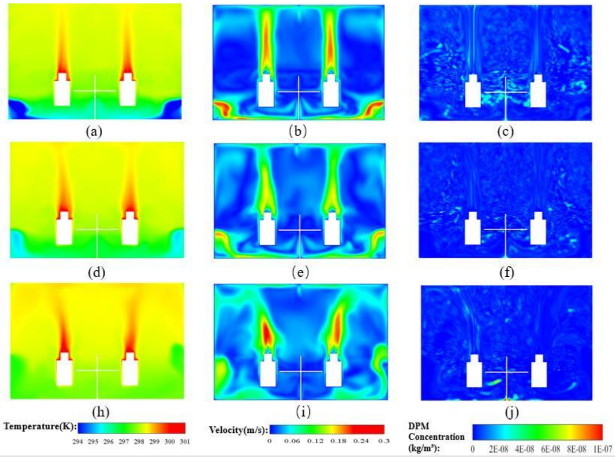

Fig.3. Temperature, velocity and particle concentration distributions at Y= 2 m plane in the UFAD system: U2 (a), (b) and (c); U3 (d), (e) and (f)U3; U4 (h), (i) and (j).

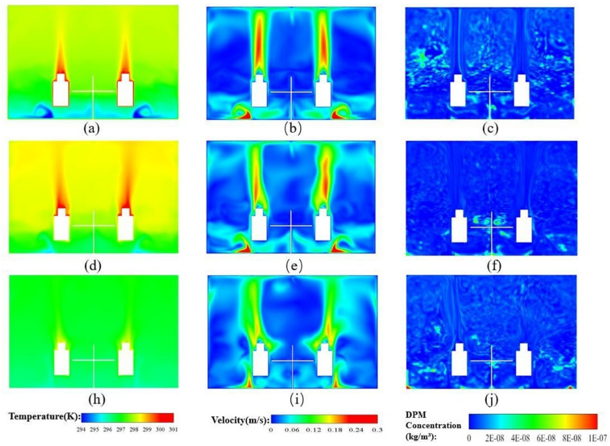

Fig.4. Temperature, velocity and particle concentration distributions at y = 2m plane in the DV system: D2 (a), (b) and(c); D3 (d), (e)and(f); D4 (h), (i) and (j).

Likewise, for the DV system (see Fig. 4), the effect of different supply air temperatures on particle distribution is also discussed. The air flow is sent at a low speed through the supply port, and the supply temperature is lower than the background temperature. Under the condition of bottom air supply, the human body temperature is significantly higher than the surrounding air. The air around the human body is heated, becomes less dense and spreads upward. A pronounced upwardly spreading thermal plume can be observed above the body. For particle distribution, the formation of indoor temperature stratification results in a non-uniform distribution of particle concentration in the vertical direction. The thermal plume around the human body also has an important impact on the distribution of particulate matter. For the case where the supply air temperature is 20°C, the larger gap from the background temperature results in more pronounced temperature stratification. The convective flow caused by the temperature difference between the human body and the surrounding allows more cold air at the lower level to be lifted to the upper level. The thermal plume is more pronounced above the human body, which also results in less particle accumulation at the breath height. Fig. 4 presents that when the supply air temperature is the lowest (20℃ in the present study), the thermal plume above the human upward due to strong buoyancy, which induces upward velocity flow above the human body. It can be obtained that the upward thermal plume is destroyed when the supply air temperature reached 24℃, which results in the particles deposited on the floors be re-introduced into the air surrounding the human through re-suspension.

4 Conclusion

Different ventilation modes profoundly affect the indoor airflow and particle accumulation, while different supply air speed and temperature also influence the airflow patterns in a room, which in turn have an impact on thermal plumes and particle concentration around the body. This paper mainly considers the influence of different ventilation modes and human thermal plume on the indoor micro-environment, and draws the following conclusions:

1) When the supply air temperature is the same, reducing the supply air speed of the DV systems will lead to an increase in the concentration of particulate matter in the breathing zone, resulting in the deterioration of the indoor air environment.

2) With the larger temperature difference of the indoor environment, the lower supply air speed may support clear air quality for the human inside the narrow office.

3) For UFAD and DV systems, different supply air temperatures will lead to the generation of temperature vertical stratification with different human thermal plume phenomena, which further affect the pollutant concentration distribution pattern.

4) Comparing the particle removal performance of the two ventilation system, the DV system is found to be more sensitive to the temperature variation, and the performance is linearly related to the supply air velocity, while the influence of supply air velocity on the performance of the UFAD system is more complicate. The further study will considered numerous case analysis to identify the effect of the supply air velocity on the performance of UFAD system.

This work was sponsored by Shanghai Sailing Program of China (Grant No. 20YF1432900).

References

1. M. Pirani, N. Best, M. Blangiardo, S. Liverani, R.W. Atkinson, G.W. Fuller, Environ. Int., **79**, 56-64 (2015)
2. R. Chen, B. Hu, Y. Liu, et al., Biochim. Biophys. Acta Gen. Subj, **1860**, 2844-2855 (2016)
3. D. Ciuzas, T. Prasauskasa, E. Krugly, et al., Atmos. Environ., **118**, 107-117 (2015)
4. Y. Lv, H. Wang, Y. Zhou, et al., Build. Environ., **149**, 582-591 (2019)
5. S. H. Ho, L. Rosario, M. M. Rahman, Build. Environ., **46**, 415-1427 (2011).
6. A. Alajmi, R. El-Amer, Energy Convers Manage, **51**, 1637-1642 (2010)
7. Z. Zhang, Q. Chen, Atmos Environ, **40**, 3396-3408 (2006)
8. Y.J.P. Lin, T.Y. Tsai, Energy Build, **80**, 321-330 (2014)
9. L. Zhang, T.T. Chow, K.F. Fong, et al., Int. J. Refrig., **28**, 288-305 (2005)
10. M.L. Fong, Z. Lin, K.F. Fong, et al., Indoor Air ., **21**, 231-239 (2011)
11. M. Taheri, S. A. Zolfaghari, M. Afzalian, et al., Build. Environ., **191**, 107613 (2021)
12. S. Alotaibia, W. Chakroun, C. Habchi, Build. Environ., **26**, 100855 (2019)
13. J. Xv, Y. M. Zhong, K. Zhong, Cleaning and Air Conditioning Technology, **1** (2008)