E3S Web of Conferences **356**, 05045 (2022) https://doi.org/10.1051/e3sconf/202235605045
ROOMVENT 2022

Investigation on the Contaminant Distribution with Dedicated Outdoor Air System in Restaurant

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Abstract: The continual transmission of epidemics makes health workers aware of the importance of airborne transmission in special cases. The well-known equation Wells-Riley highlights the importance of ventilation to dilution of infectious aerosol as well. And the airborne transmission of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has been confirmed. The main problem of the coronavirus disease 2019 (COVID-19) epidemic of three families in a restaurant in Guangzhou lies in unreasonable ventilation. An air-conditioning system of Ceiling radiant cooling plate (CRCP) combined with a dedicated outdoor air system (DOAS) has been proposed in this paper. The simulation of the diffusion of tiny exhaled droplets is carried out through SF_6 tracer gas. A numerical simulation of the original indoor air distribution of the restaurant and that of the new air-conditioning system has been conducted. Pollutant concentrations of different indoor locations and exposure indexes under four working conditions of ventilation rates 3, 6, 9, and 12 ACH are calculated. The results suggest that the air supply mode of air conditioners put forward in this paper can decrease the risk of indoor infection to a large extent. When the ventilation rate is 1L/s, the probability of infection is very high. With the increase in ventilation times, the risk of infection gradually decreases. Offering suitable ventilation in crowded spaces can greatly prevent and control the air transmission of coronavirus.

1 Introduction

An article in Science magazine used big data analysis that showed that severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) will go with humanity until 2025, so understanding the transmission of SARS-CoV-2 and effectively protecting against it will be extremely important to stop the widespread disease from worsening [1]. China's National Health Commission pointed out the possibility of aerosol transmission in a relatively closed environment for a long time exposed to high concentrations of aerosols, ASHRAE also issued a statement that the SARS-CoV-2 is likely to be transmitted by air, and airborne transmission of this virus should be controlled [2]. Over the last few years, domestic and foreign researchers have also conducted more and more academic research on coronavirus airborne transmission [3,4]. Miller, S. L et al analyzed the super transmission event of COVID-19 that broke out in a weekly choir rehearsal in Skagit County, Washington, and finally determined that the super transmission event was aerosol transmission [5]. Hua Q et al. studied a transmission event that broke out during lunch at a restaurant in Guangzhou and figured out that the cause of the mass infection came from lower fresh air and crowded spaces, as well as circulating air from the air conditioning system [6]. A ceiling radiant cooling plate (CRCP) combined with a dedicated outdoor air system (DOAS) can provide better indoor comfort and also exclude indoor odors, harmful gases, and particulate contaminants such as aerosols. In this paper, the restaurant will be modeled and numerical calculation of whether the indoor contaminants can be effectively eliminated by a dedicated outdoor air system (DOAS) in the same outdoor environment and under the same conditions of human activity to reduce the risk of infection.

2 Model

2.1 Restaurant model

The volume of the restaurant is 456m^3 (length 17.5m, width 8.3m, height 3.14m). There are 18 large and small tables in the restaurant, among which the pathogenic sitting table is marked AS TA, and the total number of diners in the restaurant is 89. The air conditioning of the restaurant mainly relies on 5 fan-coil air conditioning units for circulating air supply, without outdoor air supply. Bidirectional ventilation can be achieved through infiltration and the temporary opening of fire doors and elevators. More architectural information about the restaurant is available in reference [6,7]. In this paper, DOAS will set up a separate fresh air outlet of the same size as the original air conditioning air supply outlet, exhaust vents will be set on the other side of the

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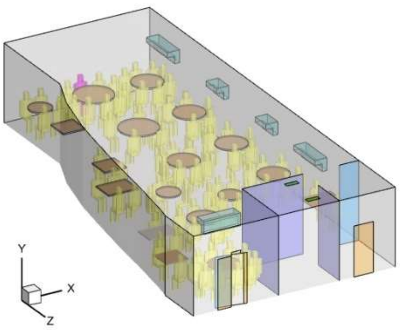
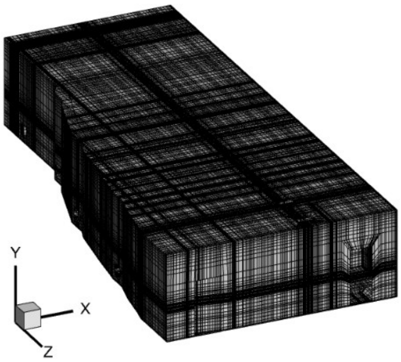
wall, and the radiant cold supply plate will be arranged on the roof of the restaurant. The 3D model of the room is shown in Fig. 1, with a total of 1535880 meshes.



(a) Physical model



(b) Grid division

Fig.1. Physical model and grid division.

2.2 Governing equations

We used the widely used CFD software package (Ansys Fluent, USA) for modeling calculations, using the Basic Reformation Group (RNG) k-ε turbulence model and component transport model to simulate the effect of turbulence on airflow and pollutant diffusion [8]. Its basic control equations can be described as:

$$\frac{\partial}{\partial t}(\rho\varphi) + div(\rho\bar{V}\varphi) = div\left(\Gamma_\varphi \nabla\varphi\right) + S_\varphi \quad (1)$$

Here ρ represents the density, φ the dependent variables, Γ_φ the effective exchange coefficient for the dependent variable φ, and S_φ the source term. See the reference for more details on formulas.

2.3 Ventilation performance indices

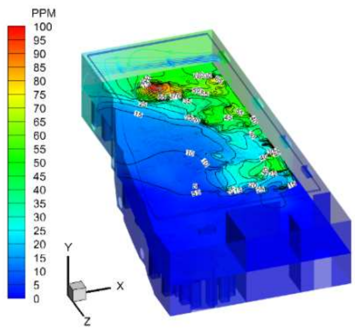
The tracer gas SF_6 is used to simulate the pollutant exhaled by novel coronavirus infected persons, and the exhaled gas concentration is 7382 PPM [9]. To evaluate the exposure of people at various locations in the restaurant to the exhaled air of the infected person, the exposure index e_p^c was established, and its calculation formula was as follows:

$$e_p^c = \frac{\bar{c_p} - \bar{c_s}}{\bar{c_e} - \bar{c_s}} \quad (2)$$

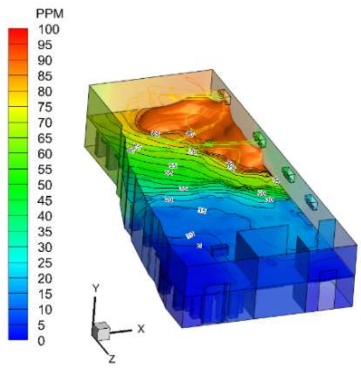
Where e_p^c represents the mean concentration of contaminant of the restaurant and $\bar{c_e}$ and $\bar{c_s}$ represents the mean contaminant concentration in the exhaust and in the supply respectively. The value of $\bar{c_p}$ is obtained immediately after the stationary experiment.

3 Result and discussion

The fan coil and the DOAS air supply speed are both 1m/s, The indoor contaminants distribution cloud diagram under the two air conditioning modes is shown in Fig. 2. In both cases, the area with the largest contaminants concentration is generated in the area where the infected person is located. When the air conditioner uses fan-coil units (FCU) to provide circulating air, a recirculation area with serious contaminants accumulation is formed in the two adjacent areas of the infected person due to the airflow organization and the thermal plume effect of food and human body. The ventilation rate is 1L/s, and the probability of infection is very high. When using DOAS, the air in the corresponding treatment area of each air supply outlet enters the restaurant from the upper part, the clean air and indoor air are fully mixed, part of the contaminants are diluted and the heat is taken away from the exhaust port of the opposite sidewall, and the contaminants are only large in a small range of infected people, mainly because the personnel and tables obstruct the air flow and lead to the accumulation of contaminants.



(a) DOAS



(b) FCU

Fig.2. Simulation results of DOAS and FCU.

In order to more clearly analyze the removal effect of independent fresh air on indoor contaminants, sections were taken at Y=1.2m, 1.5m, and 1.8m, respectively, and the indoor contaminants concentration distribution cloud diagrams were calculated when the fan coil supply air supply is calculated by 1m/s, and the DOAS air supply was 0.5-1.5m /s, as shown in Fig. 3:

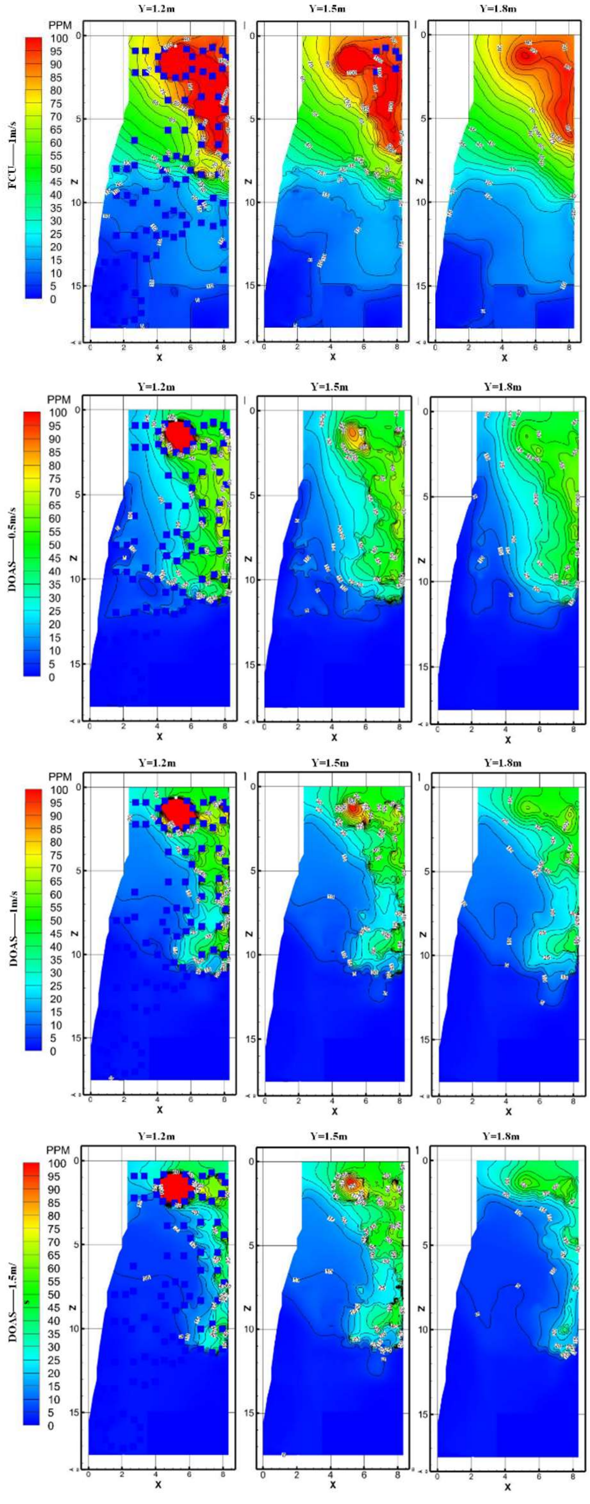


Fig.3. Cloud diagrams of concentration distribution at different sections.

From Fig. 3, it can be seen that the concentration of contaminants in the height Y direction gradually decreases, this is because the oral height of the infected person is about 1.4m, and the exhaled SF_6 gas is gradually affected by gravity after exhalation, so the concentration of pollutants near the height of the table is higher, and the influence of the airflow tissue will rise with the flow of air to the entire height. Compared with the fan coil, the indoor pollutant concentration of DOAS is much smaller overall, and with the increase of the air supply speed, the concentration of indoor pollutants is smaller, the area of small concentration of pollutants becomes larger and larger.

At the height of room Y=1.5m, take the concentration distribution of X=2.9m, X=5.1m, X=7.3m along Z from 0 to 17m, and the results of DOAS at 3~12ACH and the results of fan coil 6ACH are counted respectively. As can be seen from Fig. 4, when the air volume of DOAS reaches 9ACH, it has little influence on the improvement of indoor pollutant removal effect. Therefore, the air volume of independent fresh air should be less than 9ACH as far as possible.

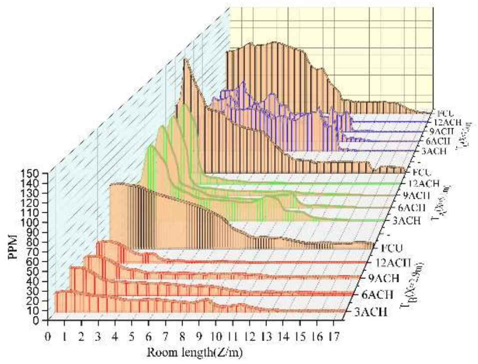


Fig.4. SF_6 concentration distribution along the three horizontal directions of the room.

Change the return air mode of DOAS, one adopts the air distribution form of up-send and up-return (SS), the other adopts the air distribution form of up-send and down-return (SX), and compares the pollutant removal effect of the two forms of air flow tissue, and the results are shown in Fig. 5. The supply air speed is set to 1m/s for both air distribution modes, and the pollutant concentration data from 0 to 17m are plotted along Z at Y=1.2m, Y=1.5m, Y=1.8m, and X=2.9m, X=5.1m and X=7.3m. It can be seen from the graph that up-send and down-return (SX) is more conducive to dilution of indoor pollutants than up-send and up-return (SS), with a lower pollutant concentration.

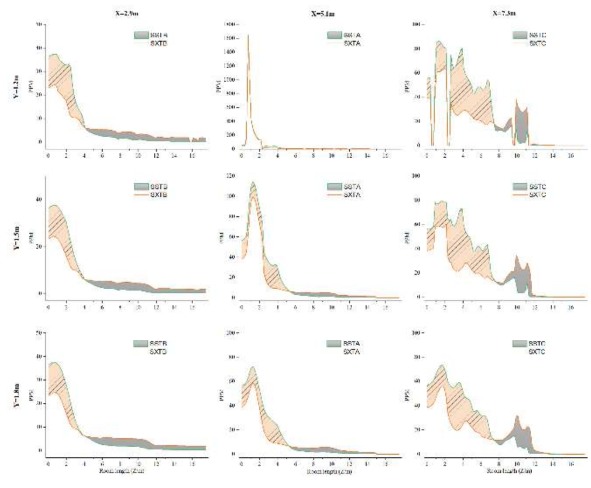
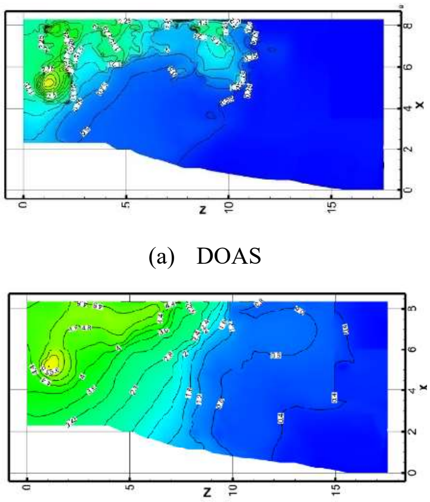


Fig.5. SF_6 concentration comparison between SS and SD at different positions.

Chose up-send and up-return (SS), the air supply speed is 1m/s to calculate the contaminants exposure index of the restaurant at the height of Y = 1.5m, from the exposure index distribution fig. 6(a) can be seen, maximum 3 near the infection, the smaller the farther from infected people value, due to the elevator and the effect of the exhaust air of toilet airflow, As a result, SF_6 tends to move along Z, leading to a higher exposure index of pollutants in this region than the rest. The pollutant exposure index at the height of y = 1.5m when the air supply speed of the fan coil is 1m / S is shown in Fig. 6 (b). The pollutant exposure index at the height of 5m near the table where the infected person is located is greater than 3. Compared with DOAS at the same location, the indoor personnel infection risk is greater.



(a) DOAS

(b) FCU

Fig.6. Exposure index of DOAS at Y=1.5m.

4 Conclusion

In this paper, a numerical simulation method was used to numerically calculate the indoor air distribution of a restaurant with Ceiling radiant cooling plate (CRCP) combined with a dedicated outdoor air system (DOAS). The distribution and removal efficiency of indoor pollutants were mainly discussed. The research results showed that: The airflow organization of DOAS has more advantages than the fan coil in the elimination of indoor contaminants. When the load distribution of the Ceiling radiant cooling plate (CRCP) and dedicated outdoor air system (DOAS) is satisfied, the larger the air volume of DOAS fresh air, the better the elimination effect of indoor pollutants. When the air volume is 9ACH, the improvement of air volume has less influence on the improvement of pollutant removal effect. DOAS adopts up-send and down-return (SX) is more conducive to dilution of indoor contaminants than up-send and up-return (SS).

Acknowledgments
The work was financially supported by Guangzhou Science and Technology Program key project (No.202206010132).

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