

A review of different ventilation methods for controlling the transmission of the virus during the COVID-19 pandemic

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Abstract. With the COVID-19 pandemic sweeping worldwide, much attention has been paid to infectious viruses. Because of the different sizes of pathogen-carrying droplets exhaled by individuals infected with COVID-19, the influence of gravity and inertia on the droplets varies, which leads to different modes of transmission of the virus. Ventilation changes the air distribution in a room, and affects virus transmission. An appropriate ventilation method that reduces the floating time of viruses and the exposure rate of the human body should be selected. Although previous studies have extensively reviewed methods to reduce the airborne transmission of viruses, research on ventilation methods remain limited. This review aimed to explore a ventilation mode that could ensure the thermal comfort and maintain low exposure and infection rates in the human body. This study investigated the transmission modes of the virus and the importance of particle size. The effects of mixing ventilation, displacement ventilation, impinging jet ventilation, and stratum ventilation on the removal of different particle sizes and applications at various locations were compared. The results of this study can contribute to reducing the indoor virus concentrations during the COVID-19 pandemic.

1 Introduction

At the end of December 2019, the COVID-19 epidemic in Wuhan, China and rapidly spread worldwide. According to the World Health Organization (WHO), by December 27, 2021, 279,114,972 cases were confirmed worldwide, of which 5,397,580 cases resulted in death. Although a vaccine has been developed, the SARS-CoV-2 virus has mutated with further transmission. They might exhibit a robust ability for transmission and infection. According to the Centers for Disease Control and Prevention, from January 9 to January 15, 2022, 99.5% of newly confirmed cases in the United States were caused by the Omicron variant. In addition, COVID-19 has caused global economic recession, factory closures, unemployment, and other inevitable situations. The annual percentage change in the global gross domestic product (GDP) decreased from 2.8% in 2019 to -3.1% in 2020, and the annual percentage change in China's GDP decreased from 6% in 2019 to 2.3% in 2020.

Humans release many droplets during exhalation, speaking, and coughing. The diameter of the COVID-19 virus was 60–140 nm under a transmission electron microscope [1]. When an infected individual releases droplets, they may entrap the virus. Owing to their different sizes and initial velocities, these droplets would develop different motion trajectories indoors [2]. Tiny particles of 1–2 μm produced during sneezing could remain airborne for up to 30 h without settling [3]. As the floating time of the virus increases, the contact

time between the human body and virus, as well as the risk of infection increase. During the COVID-19 pandemic, the importance of indoor ventilation has been clearly demonstrated. The conclusions drawn from this study may be a basis for improving indoor air quality, which is conducive to minimizing the transmission of the virus while maintaining human comfort during the COVID-19 pandemic.

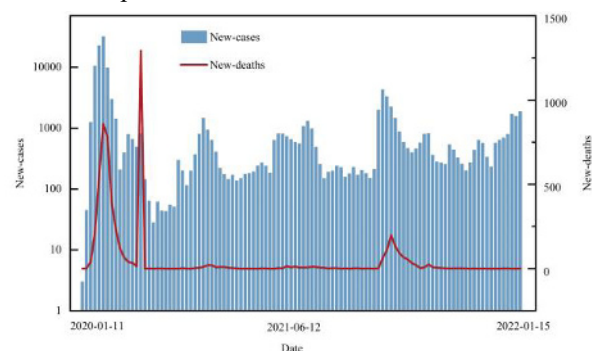


Fig. 1. Viral transmission mode.

2 Indoor transmission of particles

Infectious viruses can be entrapped and transmitted through the droplets released by humans [4]. The transmission routes of most viruses include contact, droplet, and airborne transmission [5]. However, Chen [6] and Zhang [7] showed that the transmission routes of viruses can be classified according to distance: short-

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range transmission (short-range droplet, airborne, and contact transmission) and long-range transmission (long-range air and surface contact transmission). Because the distance between human bodies during short-range airborne and droplet transmission is short, distinguishing the two modes of transmission is difficult, and short-range airborne transmission is often ignored. The mode of transmission is shown in Figure 2.

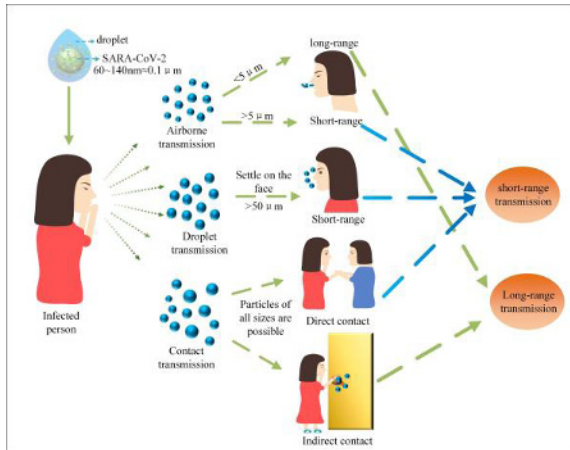


Fig. 2. Viral transmission mode.

3 Ventilation modes

3.1 Mixing ventilation

The fresh air with MV entered the room at an initial speed from the air supply outlet, the pollutants rapidly mixed with the air, and the jet exhaled by the human body was short[8,9]. The ventilation effect was stable in other locations, except for the pollution sources. Because the air supply outlets of MV were located at the upper part of the room. When heating in winter, fresh air accumulates in the upper part of the room owing to thermal buoyancy and the indoor airflow distribution is not as uniform as that in summer. As the room height increased, the non-homogeneity of indoor airflow became more distinct [10].

3.2 Displacement ventilation

The working principle of the DV is rising hot air and sinking cold air based on the air density difference. Fresh air is sent indoors at low wind speeds. Under the action of the indoor thermal plume, the cold air gradually moves upward. Thermal stratification occurs across two areas in a room [9]. The upper part of the room is polluted with uniform airflow, and the lower part is a clean area with unidirectional airflow. Moreover, owing to thermal stratification, the airflow exhaled by the human body develops a locking phenomenon [8], and a high-concentration area of pollutants appears. Compared with MV, a high-concentration area of DV often occurs above the working area of the human body, and the quality of indoor air formed near the human body is improved. When heating in winter, owing to the low air supply speed and low hot air density, the fresh air directly

moves upward, resulting in poor indoor air quality. DV is usually not used individually during heating, and the combination of DV and floor heating or movable vertical radiant heating panels is more effective in removing particulate matter than DV alone [11, 12].

3.3 Impinging jet ventilation

The air supply outlets of the IJV system were arranged vertically at some distance from the floor. Fresh air reached the floor at a certain momentum and was diffused. The IJV combines the advantages of DV and MV [13]. The momentum of the IJV system on the ground was higher than that of the DV; therefore, the IJV overcame the disadvantage that the DV was not suitable for use in winter [10]. However, when the IJV was used for heating, thermal buoyancy is the main driving force at a position far away from the air supply outlets; thus, the propagation distance of the air supply jet was also limited [14]. When the room was too large, a heating blank area developed that the supply air could not reach. In addition, the stratification height affects indoor air quality. The factors affecting the jet propagation distance and stratification height were related to the air supply parameters[10].

3.4 Stratum ventilation

The air supply outlets of the SV were located on the sidewall and were slightly higher than the breathing area of the human body. Fresh air was supplied to the human working area, which enhanced the airflow intensity in the working area and improved the air quality in the human breathing area. The airflow is divided into two parts at the heat source of the human body. A portion of the airflow moved upward to remove the pollutants produced by the human body, while the other part of the air flowed downward to eliminate the residual heat of the human body. In summer, the entire room presented the phenomenon of “cold head and warm feet.” When heating during winter, the supply airflow also increases under thermal buoyancy. Reducing the supply van angle [15] and optimizing the air supply temperature and air volume [16] can alleviate suspension due to air supply.

4 Impacts of different ventilation modes on air transmission

4.1 Impacts on different particle sizes

Because of the different sizes of the particles, resulting in different propagation modes under the same air distribution [10]. Large particles primarily settled by gravity, and small particles were transported under the influence of airflow. MV facilitated the uniform mixing of indoor air, and small particles were suspended indoors for a longer time. The concentration gradually decreased with increasing particle size[17]. Owing to the stratification phenomenon of DV, small particles are transported to the upper part of the room and discharged out of the chamber, which maintains good air quality in

the lower part of the room [18,19]. However, DV increases the risk of cross-infection with large particles [20]. For the small particles resuspended on the floor, because of the low wind speed of MV near the ground, tiny particles could not be discharged and were primarily distributed in the lower part of the room. In comparison, the ventilation effect of IJV on particles resuspended from the ground was better than that of MV [10]. Owing to the high momentum of SV, the particles might possibly collide with the surrounding wall and settle. Compared with the other ventilation modes, SV was more effective for the deposition of $50\ \mu\text{m}$ particles in the breathing area [21].

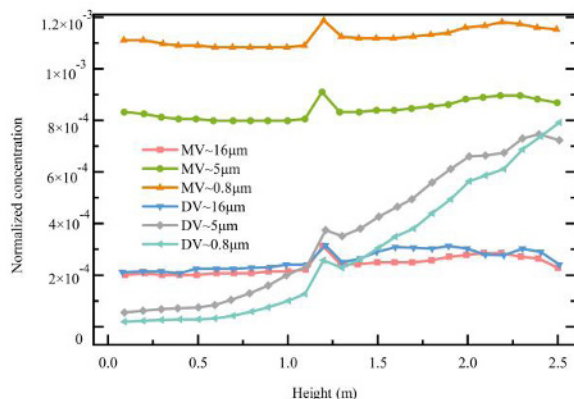


Fig 3. A chart comparing the removal of indoor particulate matter by MV and DV. The data was extracted from literature [18].

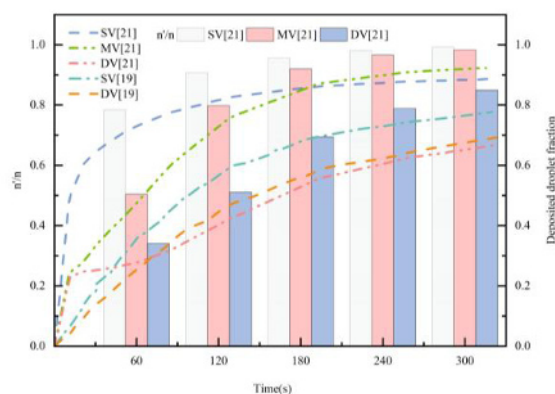


Fig. 4. Efficiency of MV, SV, and DV in removing indoor pollutant particles. The data were extracted from literature.

4.2 Impacts on different locations

On different occasions, the location and concentration of pollutants and the areas where good air quality have to be maintained were different. To ensure that the indoor air quality meets the requirements, selecting an appropriate airflow mode is necessary. The MV formed a uniform indoor environment with no high-risk areas, which is recommended in hospital wards [22]. For infectious viruses, even if the concentration of MV was reduced in the isolation room, the risk of infection among the medical staff remained considerably high. Because SV directly supplies fresh air to the human

breathing area and pollutants are rapidly diluted. SV provides the lowest infection rate for healthcare workers compared to MV, and DV[23]. Therefore, when the pollutants are located near residents [24], the use of SV could achieve a good ventilation effect.

The stratification principle of DV maintained the cleanliness of the lower part of the room and saved energy [25]. For locations without special requirements, such as offices, tall factories, and excavated sites, DV is an effective ventilation method to keep staff working areas clean [25]. In concert halls and orchestra rehearsal rooms, the local removal rates of CO₂ by DV were as high as 1.2 and 1.7 [26]. The IJV system primarily compensated for the shortcomings of other ventilation modes in which hot air rose during heating in winter. For the heating of large plants in winter, the air age of the IJV in the human breathing area was approximately 37–47% less than that of the MV [10]. Simultaneously, the airflow direction of the IJV was the same as that of the human thermal plume, which was conducive to removing pollutants in the upper part of the room and reducing the risk of cross-infection [27]. Although human thermal comfort improved and energy is used efficiently, IJV also improved indoor air quality [13].

5 Conclusion

During the prevalence of COVID-19, prompt vaccination, wearing masks, washing hands frequently, and maintaining good indoor ventilation were found to be effective methods to alleviate the transmission of SARS-CoV-2. Infections in French choirs and restaurants in Guangzhou, China suggest that COVID-19 was more prevalent in crowded or poorly ventilated environments. This paper discusses the effects of different ventilation methods on removing particles to ensure human thermal comfort.

When heating during winter, hot air supplied into the room remains suspended. The heating effects of MV and DV are poor. Because the initial momentum of the IJV was large, the air supply position of SV was located near the breathing area of the human body, and the air supply angle of SV was adjusted, the effects of IJV and SV in heating were better than those of MV and DV.

For the two traditional ventilation methods, MV is more suitable for removing large particles, whereas DV is more suitable for removing fine particles in typical offices. Moreover, in locations with low cleanliness requirements, DV can reduce usage costs, while meeting air quality requirements due to the principle of stratification. In the infectious ward, pollutants are released by the human body, and the SV supplies fresh air directly to the human breathing area, which can maintain the air quality in the room and human breathing area.

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