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Evaluating risk of SARS-CoV-2 infection of the elderly in the public bus under personalized air supply

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Abstract

In developing countries, public transportation is the first choice for the elderly because of its convenience and cheapness. The high density population of public transportation increases the risk of passengers contracting infectious diseases, so it is extremely critical to determine healthy transportation systems to safeguard the health of passengers. The propagation characteristics of droplets in the ZK-type public bus were studied by computational fluid simulation employing the Realizable k-ε turbulence model and discrete phase model. The modified Wells-Riley model was used to quantitatively assess the infection risk of SARS-CoV-2 spread by droplets on the elderly. The risk assessment shows that when the personalized air supply angle is 30°, the number of infected passengers is the least, reaching 14, which shows that the infection risk of passengers can be reduced through the design of personalized air supply angle. Regardless of the angle of the personalized air supply, the rear seats are in a low-risk area. Therefore, it’s recommended that elderly passengers choose the rear seats of the public bus during the epidemic to prevent being infected. This study can provide a reference for healthy transportation systems to construct a healthy environment inside the public bus.

1. Introduction

The new coronavirus pneumonia is an acute infectious disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (Holshue et al., 2020; Huang et al., 2020). As of June 1, 2022, more than 532.09 million people worldwide have been diagnosed with the new coronavirus pneumonia, and the death toll has exceeded 6.31 million (National Health Commission of the People’s Republic of China, 2022). The use of public transportation has been identified as high risk due to the transfer of virus-carrying droplets from the infected passenger to others (Ahmadzadeh & Shams, 2021). The large passenger flow and high passenger density of the public bus increase the infection risk of respiratory infectious diseases such as SARS-CoV-2 among passengers (Duan et al., 2021; National Bureau of Statistics, 2021). In developing countries, most of the elderly will choose public transportation because of their own experience and living habits. However, researchers have found that the risk of death of people infected with SARS-CoV-2 increases with age (Dutch National Institute for Public Health and the Environment 2020; Zhou et al., 2020), and the spread of new coronavirus pneumonia in elderly patients may increase (Bonafe et al., 2020; Smorenberg et al., 2021; Zhang et al., 2020). The fatality rate for SARS-CoV-2 in the general population was 2.3%, rising to 14.8% in patients over 80 years old (Wu & McGoogar, 2020). It can be seen that the elderly with low immunity are at a higher risk of contracting SARS-CoV-2, which makes the elderly more important to be the target of attention. Therefore, it is necessary to assess the infection risk of SARS-CoV-2 of elderly passengers in the public bus.

The "New Coronavirus Pneumonia Diagnosis and Treatment Plan (Trial Version 7)" pointed out that the main route of SARS-CoV-2 transmission includes respiratory droplet transmission and close contact transmission (General Office of the National Health Commission 2020; Jin et al., 2021). Significantly, there are many studies that provide strong evidence for airborne transmission of SARS-CoV-2 (Allen & Marr, 2020; Baboli et al., 2021; Morawska et al., 2020; Noorimotlagh et al., 2021; Robotto et al., 2021; Stern et al., 2021). The transmission of virus-carrying droplets in the public bus is a dynamic process, and the suspension, deposition and escape of droplets are unsteady, leading to a change in the infection risk for passengers over time. The research on the
transmission of virus-carrying droplets and the dynamic change of infection risk is indispensable for investigating close contacts in time and carrying out precise epidemic prevention and control.

Currently, researchers mostly use the Wells-Riley model to evaluate the infection risk of personnel to SARS-CoV-2 based on the calculation of the quanta value of SARS-CoV-2 (Dai & Zhao, 2020; Sun & Zhai, 2020). Dai and Zhao (2020) collected known quanta values and \( R_0 \) (the average number of infected individuals produced by a single infected person in a susceptible population) related to other airborne infectious diseases in previous studies, and the correctness of the calculated quanta value of SARS-CoV-2 between 14 and 48 quanta/h was confirmed through a practical cases. Sun and Zhai (2020) modified the Wells-Riley equation by introducing the social distancing index \( P_s \) and the ventilation index \( E_v \) based on an actual case. The air in the public bus is not evenly mixed with personalized ventilation, and the ventilation efficiency of the local seat is different. Consequently, the indoor air supply rate in the Wells-Riley model is redefined as the air supply rate of the local seat to determine the infection risk temporal characteristics of elderly passengers. Based on calculation of the risk of SARS-CoV-2 infection of passengers, low-risk areas and high-risk areas in the public bus, it can provide safer seat selection recommendations for preventing elderly passengers from contracting SARS-CoV-2 during the epidemic.

Ventilating can dilute the concentration of indoor pathogens and is considered to be one of the important measures for the prevention and control of the SARS-CoV-2 epidemic (Aghalari et al., 2021; Correia et al., 2021; Xu et al., 2020a). Different ventilation patterns lead to different risks of cross-infection among occupants in indoor environments (Pei et al., 2021). Ahmadzadeh and Shams (2021) indicated that the shelf ventilation aims to dilute the concentration of pathogens in the entire room, but personalized ventilation, and ultimately leading to discrepancies in the infection risk. Hence, the results of Xu et al. (2020b) showed that when personalized ventilation was used, the overall ventilation aims to dilute the concentration of pathogens, and the ventilation index \( E_v \) shown in Appendix A.

2. Methodology

2.1. Geometric model

The public bus with the commonly used type ZK was used as the research object, establishing a proportional geometric model. The model size is 9.996 m × 2.3 m × 2.5 m (L × W × H), the size of the air inlet is 0.4 m × 0.8 m (L × W), the size of the return air outlet is 2.4 m × 0.4 m (L × W), and the size of the personalized air supply is 0.08 m × 0.04 m (L × W). The structure diagram and seat arrangement are shown in Fig. 1, and the passenger model is derived from a simplified mannequin of Bjorn’s (2000) research. The detailed geometric model dimensions are shown in Appendix A.

2.2. Mathematical physical model

2.2.1. Governing equations

The transmission and distribution of droplets with SARS-CoV-2 in a closed public bus are studied, and the influence of personalized air supply angles on the risk of passenger infection is determined. Because the air density changes very little at room temperature, it can be assumed that the indoor air density in the public bus is constant, so that the air is an incompressible fluid. And the indoor air is turbulent, fluid flow is governed by Navier-Stokes equations. The Realizable k-ε model can be applied to indoor flow simulations with good convergence and accuracy (Lateb et al., 2013), so the Realizable k-ε model is adopted in this study.

The governing equations are as follows:

Conservation of mass:

$$\frac{\partial u_i}{\partial x_i} = 0$$

(1)

Conservation of momentum:

$$\frac{\partial (pu_i)}{\partial x_i} = \mu \frac{\partial^2 u_i}{\partial x_i^2} + \frac{\partial p}{\partial x_i} + \rho g_i$$

(2)

Conservation of energy:

$$\frac{\partial (\rho T)}{\partial t} + \frac{\partial (pu_i T)}{\partial x_i} = \frac{\partial}{\partial x_i} \left( k \frac{\partial T}{\partial x_i} \right) + S_i$$

(3)

where \( u_i \) is the component of velocity in the i direction (m/s), \( \rho \) is the fluid density (kg/m³), \( \beta \) is the thermal expansion coefficient which is 0.00341 K⁻¹, \( T \) is the operating temperature, which is 288.16 K; and \( \beta \) is the thermal expansion coefficient which is 0.00341 K⁻¹.

The Boussinesq model treats density as a constant value in all solved equations, except for the buoyancy term in the momentum equation:

$$\langle p - p_0 \rangle |_{g_i} \approx -\rho \beta (T - T_0) |_{g_i}$$

(4)

where \( p_0 \) is the constant density of the flow, which is 1.225 kg/m³; \( T_0 \) is the operating temperature, which is 288.16 K; and \( \beta \) is the thermal expansion coefficient which is 0.00341 K⁻¹.

The turbulent kinetic energy, \( k \), and dissipation rate, \( \varepsilon \):

$$\frac{\partial (\rho k)}{\partial t} + \frac{\partial (\rho u_i k)}{\partial x_i} = \left( \mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial^2 k}{\partial x_i^2} + G_k - \rho \varepsilon$$

(5)

$$\frac{\partial (\rho \varepsilon)}{\partial t} + \frac{\partial (\rho u_i \varepsilon)}{\partial x_i} = \left( \mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \frac{\partial^2 \varepsilon}{\partial x_i^2} + \rho C_1 \varepsilon \frac{k}{\varepsilon} - \rho C_2 \frac{\varepsilon^3}{k}$$

(6)

where \( \sigma_k=1.0, \sigma_\varepsilon=1.2, C_2=1.9, C_1 = \max(0.43, \frac{1}{\sqrt{E}}), \eta = E_0^2, E = \sqrt{2E_0E_\eta}, G_k \) is the turbulent kinetic energy due to the mean velocity
The droplets can be regarded as discrete particles, so the discrete phase model is used to simulate the movement of the droplets (Lin et al., 2021). The forces of the droplet include gravity, drag force, Saffman lift force, and thermophoretic force (Liu, 2007). The orbital motion equation of the droplet is:

\[
\frac{d(m_d u_d)}{dt} = F_g + F_d + F_s + F_t
\]

where \(m_d\) is the mass of the droplet (kg), \(u_{d,i}\) is the velocity component of the droplet in the i direction (m/s), \(F_g\), \(F_d\), \(F_s\), and \(F_t\) are the components of gravity, drag force, Saffman lift force and thermophoretic force on the droplet in the i direction, respectively (N). And the equations of gravity \((F_g)\), drag force \((F_d)\), Saffman lift force \((F_s)\) and thermophoretic force \((F_t)\) on the droplet are as follows:

\[
F_g = \frac{m_d g}{8 C_v}
\]

\[
F_d = \frac{\pi d^2 \rho_d (u_d - u_0)(u_0 - u_d) C_d}{8 C_v}
\]

\[
F_s = \frac{1.62 \pi d^2 (du/dz)(u - v_d)}{\sqrt{r} d u / dz}
\]

\[
F_t = \frac{3 \pi d^4 H d u_{th}}{\rho_d F} \frac{dT}{dz}
\]

where \(d_d\) is the droplet diameter (m), \(\rho_d\) is the air density (kg/m\(^3\)), \(u_0\) is the air velocity (m/s), \(C_d\) is the drag coefficient with a value of 18.034, and \(C_v\) is the Saffman sliding constant with a value of 1.175, \(v_d\) is the force exerted by the droplet in the axial movement, \(H_d\) is thermophoretic force coefficient with a value of 0.496.

**2.2.2. Boundary conditions**

1) **Velocity boundary conditions**

The air inlet and the personalized air supply are the velocity inlet with the velocity of 0.56 m/s. And when the infected passenger 3D coughs (cough pattern with a horizontal planar jet), the mouth is the velocity inlet with the velocity of 20 m/s (Zhao et al., 2005).

2) **Pressure boundary conditions**

The return air inlet and the door gap are the pressure outlet, and the relative pressure is -0.1 Pa and 0 Pa, respectively.

3) **Thermal boundary conditions**

The temperature of the air supply is 293 K, and the temperature of the return air inlet and the door gap are both 308 K. When the infected passenger 3D coughs, the temperature of the mouth is 310 K. When the infected passenger stops coughing, the mouth is set as the wall with the heat flux of 26 W/m\(^2\) like other human bodies. The roof, walls, windows, windshield and doors of the public bus are treated with the constant heat flow boundary. The heat transfer coefficient of the roof and walls is set to 1.3 W/(m\(^2\)K), and the heat transfer coefficients of the windows, windshield and doors are respectively 3 W/(m\(^2\)K), 5 W/(m\(^2\)K), 5 W/(m\(^2\)K). Taking into account the heat dissipation of the engine, the heat flux of the seats 8A-8E is 4 W/m\(^2\), and the rest of the seats and the floor are treated as adiabatic boundary.

4) **Droplet physical parameters**

All droplets are spherical smooth droplets. Since large-sized droplets will quickly split into 1μm sized droplets (Zhao et al., 2003), the time that the droplets remain in large size is very short and difficult to determine, so the diameter of the droplets produced by coughing is set to 1 μm, the density is 600 kg/m\(^3\), the temperature is 310 K, and the length of coughing is 0.5 s (Zhao et al., 2005; Zhao et al., 2003).

**2.3. Validation of numerical simulations**

In order to verify the correctness and feasibility of the turbulence model and the droplet transport model, it needs to be compared with experimental results for verification. The applicability of the turbulence model has been verified\(^{(4)}\), so the experiment is needed to prove the feasibility of the droplet transport model. The experimental object is the chamber with a size of 0.6 m × 0.5 m × 0.35 m (L × W × H), which is based on the principle of geometrical similarity from a room at Wuhan University of Science and Technology with a size of 7.2 m × 6 m × 4.2 m (L × W × H). According to the principle of dynamic similarity, the air velocity at the entrance of the chamber is determined to be 2.4 m/s, which is derived from the wind speed at the window measured by Anemomaster KA23.

The system diagram and experimental device of the experiment process are shown in Figs. 2 and 3, respectively. The chamber is installed at the tail outlet of the bag filter. After starting the experiment, first, the draught fan and the cyclone dust collector were turned on, and the draught fan was adjusted until the air velocity at the entrance of the chamber was 2.4 m/s.
chamber reaches 2.4 m/s. At the same time, the pressure at the exit of the chamber was measured. Then, the particle was released at the particle generating position. When the particle release rate was stable, the DUSTMATE dust detector was used to measure the change in the concentration of PM$_{10}$ at the entrance of the chamber within one minute. Finally, the change in the concentration of PM$_{10}$ in the chamber was measured.

After the experiment is completed, ICEM is used to establish a geometric model of the same size according to the chamber and divide unstructured grids, as shown in Fig. 4. According to the inlet air velocity (2.4 m/s), the relative pressure at the outlet (-4 Pa) and the average concentration of PM$_{10}$ at the inlet (13.95 $\times$ 10$^{-9}$ kg/m$^3$) measured by the experiment, the discrete phase model is used to simulate the transmission of PM$_{10}$ with ANSYS Fluent, the solution method adopts the SIMPLE algorithm, and the discrete format of the convection term is the second-order upwind style. The numerical simulation results are taken from the average concentration of PM$_{10}$ on the monitoring surface. Finally, the numerical simulation results are compared with the experimental results, and the comparison results are shown in Fig. 5.

The comparison between the experimental results and the simulation results can verify whether the discrete phase model used in the simulation calculation is applicable for simulating the transmission of particles. It can be seen from Fig. 5 that the calculation using the discrete phase model can better simulate the experimental results. The deviations between experimental results and simulated results are within 6%. The reasons for the deviation include model errors and systematic errors. The model errors come from the turbulence model which relies on the combination of theory and experience to introduce a series of model assumptions, and the random orbit model in the discrete phase model considers the effect of instantaneous turbulence velocity on the particle trajectory by applying stochastic methods. These assumptions will lead to certain errors in the calculation model itself, coupled with systematic errors in the experiment process, which result in the deviation between the simulated data and the experimental data. However, the error between simulation and experiment is considered acceptable within 6% in practical applications, which shows that the discrete phase model used is suitable for simulating the transmission of droplets indoors.

2.4. Grid independence verification

In the process of numerical simulation, the density of the grid will affect the numerical simulation results. In order to reduce the influence of the grid density on the numerical simulation results, it is necessary to verify the independence of the grid. By increasing the grid density, the number of grids was divided into 1.56 million, 1.75 million, 2.31 million, 2.62 million and 4.01 million. Finally, under the condition of the air inlet velocity of 0.6 m/s, five models with different grid numbers were simulated.

The door gap is selected as the monitoring surface, and the two points (3.332, 1.15, 1.25) and (2, 2, 1.5) are chosen for monitoring point...
1 and monitoring point 2. By comparing the average speed of the monitoring surface and the temperature of two monitoring points under different grid numbers, the influence of the grid number on the simulation results is determined. It can be seen from Figs. 6 and 7 that when the number of grids reaches 2.31 million, the average speed of the door gap gradually stabilizes, and the temperature of the two monitoring points no longer fluctuates. Continuing to increase the number of grids has little effect on the calculation results. Hence, considering the calculation accuracy and calculation time, the simulation calculation selects the grid model with a grid number of 2.31 million, and the average speed of the door gap gradually stabilizes, and the temperature of two monitoring points no longer fluctuates. Continuing to increase the number of grids has little effect on the calculation results. Hence, considering the calculation accuracy and calculation time, the simulation calculation selects the grid model with a grid number of 2.31 million, and the residual values for energy are below 10^{-6}, and the residual values for all variables except energy are below 10^{-4}, indicating that the CFD simulations reach the convergence.

### 2.5. Wells-Riley model correction (Risk evaluation model)

Riley et al. (1978) established a Wells-Riley model that can be used to evaluate the risk of viral particle infection based on the concept of "quanta" proposed by Wells, as shown in Eq. (8).

\[
P = \frac{C}{S} = 1 - e^{-\frac{Q_{t'}}{q}}
\]

(8)

where \( P \) is the probability of infection of susceptible persons, \( C \) is the number of infected persons, \( S \) is the number of susceptible persons, \( I \) is the number of infected persons, \( p \) is the respiration rate of susceptible persons (m/s), \( q \) is the quantum production rate of the infected person (quanta/s), \( t \) is the exposure time (s), \( Q \) is the air supply rate (m³/s).

The Wells-Riley model is based on the assumption that the air in the room is fully mixed, but the air in the public bus is not evenly mixed with personalized ventilation, and the ventilation efficiency of the seat is different and is related to time. Therefore, for the infection risk of passengers at different seats, \( Q \) should be the seat air supply rate \( Q(t') \), namely:

\[
P = \frac{C}{S} = 1 - e^{-\frac{Q(t')}{q}}
\]

(9)

where \( Q(t') \) refers to the air supply rate of the local seat at moment \( t' \).

The exposure time \( t \) is corrected to the residence time of droplets on passengers, that is:

\[
t = \int_{t_0}^{t} dt
\]

(10)

where \( t_0 \) is one second before the moment when the droplets are deposited on the passenger.

### 3. Results and discussion

The flow field in the public bus under four personalized air supply angles was studied, and the diffusion and distribution characteristics of cough droplets were obtained. The time characteristics of infection risk of elderly passengers are quantitatively analyzed based on the modified Wells-Riley model, determining the infection risk of the elderly passengers sitting in the caring seats, and providing suggestions for the selection of seats for the elderly during the epidemic.

#### 3.1. Droplet diffusion characteristics under different personalized air supply angles

It is well known that the droplet transmission process after one single cough by a source of infection can be displayed by plotting the locations of all droplets in the public bus. Fig. 8 shows the temporal and spatial distribution of droplets in the public bus. The spatial distribution of droplets in 0–120.5 s is obtained by the simulation calculation, and only the distribution characteristics of droplets at four moments are listed.

Fig. 8 clearly show that the droplets produced by an infected passenger 3D are presented in the shape of a stick at \( t = 0.5 \) s. Afterwards, the droplets gradually move upward due to the buoyancy force and the thermal plume generated by passengers. At \( t = 2.5 s \), the droplets are mainly suspended in the upper space of the public bus in the form of a whale. Meanwhile, part of the droplets are gradually transferred to the area of elderly passengers due to the influence of the airflow at the return air inlet. At \( t = 5.5 s \), most of the droplets gather around passengers 1A, 1B, and 1C, and then spread to the front door and passengers 2A, 2B, and 2C. At \( t = 10.5 s \), the droplets are mainly suspended between passengers 1A, 1B, 1C, and 2A, 2B, 2C. As time goes by, when \( t = 20.5 s \), droplets are scattered in the public bus. Finally, when \( t = 120.5 s \), there is no droplet floating in the public bus.

In order to better reveal the impact of personalized air supply angle on the infection risk of elderly passengers, the following subsections focus on the analysis of the flow field and droplet distribution at elderly passengers. Fig. 9 shows the personalized air supply angle in the Y direction, and the air supply angles are 90° (Case 1), 60° (Case 2), 45° (Case 3), 30° (Case 4), and 0° (Case 5).
Fig. 9 illustrates the flow field distribution of 4A, 4B, 4C and 4D elderly passengers under different personalized air supply angles.

Notably, it can be seen from Fig. 10 that in different air supply angles, the streamlines at the elderly passengers 4B are the densest, and the streamlines at the elderly passengers 4A, 4C, and 4D are gradually sparse. This is attributed to the fact that the elderly passenger 4B is closest to the return air inlet, and there is strong upward airflow from the return air inlet. Then a strong counterclockwise vortex is formed in front of the elderly passenger 4B. While the elderly passenger 4A is located at the left front of the return air inlet, which is farther away from the return air inlet than 4B, so a weaker clockwise vortex is formed in front of the elderly passenger 4A. The elderly passenger 4C is located at the left rear of the return air inlet, so the air flows to the return air inlet. The elderly
passenger 4D is located to the left between the return air inlet and the air inlet, which leads to the heat plume generated by the elderly passenger 4D to be dominant over the airflow pattern, causing the air to flow upward.

The distribution characteristics of droplets among the four elderly passengers can be represented by the droplet deposition percentage, which is defined as Eq. (12).

\[ D_{p,i}(t') = \frac{S_i(t')}{S} \]  

(12)

where \( D_{p,i}(t') \) is the percentage of droplets deposited on passenger \( i \) at time \( t' \), \( S_i(t') \) is the number of droplets deposited on passenger \( i \) at time \( t' \), and \( S \) is the total number of droplets produced by the infected passenger in one cough.

Fig. 11 shows the percentage of droplets deposited on elderly passengers at 120.5s. Obviously, it can be seen that droplets are deposited on the elderly passengers 4A, 4B, and 4C in the four cases, and only in Case 2 droplets are deposited on the elderly passenger 4D. This is mainly because the personalized air supply angle is 60°, which causes the airflow at the personalized air supply above the back door to flow to the elderly passenger 4D, resulting in 0.005% droplets deposited on the elderly passenger 4D. Notably, as can be seen from Fig. 11, except for Case 3, elderly passengers 4B in Cases 1, 2, and 4 have the largest droplet deposition percentage, which are 0.037%, 0.051%, and 0.042%, respectively. This is attributed to the dense streamlines and high flow velocity at the elderly passengers 4B. While in Case 3, the droplets will first suspend in the upper space and then gradually move toward the front of the public bus, making the percentage of droplets deposited on the elderly passenger 4A 20% higher than that on 4B and 4C.

To sum up, when the personalized air supply angle is 90°, 60°, 30°, the air mobility at the elderly passenger 4B is stronger than that of other elderly passengers, so the droplet deposition percentage on the elderly
passenger 4B is significantly higher than that of other elderly passengers. And the deposition percentage on the elderly passenger 4B can be up to 10 times that of other elderly passengers. When the air supply angle is 45°, the air mobility at the elderly passenger 4A is strongest, so the droplet deposition percentage of the elderly passenger 4A is 20% higher than that of 4B and 4C. It can be seen that the high percentage of droplet deposition of the passenger is attributed to the strong air mobility at the passenger.

3.2. Infection risk of elderly passengers in the public bus

The infection risk of elderly passengers largely depends on the deposition of droplets coughed up by the infected person on the elderly passengers, and the air supply rate of the local seat determines the amount of droplets deposited on the elderly passengers. The infection risk temporal characteristics of elderly passengers are given based on Eq. (11), as shown in Fig. 12. The locations of elderly passengers 4A, 4B, 4C, and 4D in Fig. 1 are shown in Fig. 11.

Fig. 12 shows the changing trend of the risk of SARS-COV-2 infection of elderly passengers 4A, 4B, 4C, and 4D under different personalized air supply angles over time. Regardless of the personalized air supply angle, the elderly passenger 4B is always the first to be exposed to droplets with SARS-COV-2. And in addition to Fig. 12a (Case 1), the elderly passengers 4C are exposed to droplets carrying SARS-COV-2 earlier than the elderly passengers 4A in Fig. 12c-d (Cases 2, 3, and 4), which is attributed to the fact that the air flow at the elderly passengers 4C is stronger than that of 4A.
As can be seen from Fig. 12a, the personalized air supply angle is 90°, the airflow is vertical downwards and the elderly passenger 4A is closer to the return air inlet, leading to strong air flow at the elderly passenger 4A, which precedes the elderly passenger 4C being exposed to the droplets with SARS-COV-2.

Furthermore, it can be seen from Fig. 12b that due to the longest exposure time (up to 116s) and the highest percentage of droplet deposition (up to 0.051%) make the infection risk of SARS-COV-2 of elderly passengers 4B significantly higher than that of other elderly passengers, with the highest infection risk reaching $3.28 \times 10^{-7}$.

Fig. 12c shows the change process of the infection risk of elderly passengers with time when the air supply angle is 45°. Before 30.5s, the infection risk of the elderly passengers 4B is the highest, mainly because the elderly passenger 4B is exposed to droplets before other elderly passengers. As time goes by, the elderly passenger 4C has the highest risk of infection. The reason is that in this time period (34.5s-37.5s), although the exposure time of elderly passenger 4C is shorter than that of 4B, the droplet deposition percentage of elderly passenger 4C is significantly higher than that of elderly passengers 4A and 4B, so the risk of infection is the highest. After 40.5s, the elderly passenger 4A has the highest droplet deposition percentage, leading to the highest risk of infection.

The infection risk temporal characteristics of elderly passengers in Fig. 12d is the same as that of Fig. 12b, and the infection risk of elderly passengers is 4B, 4C, 4A, and 4D from high to low. In summary, the risk of SARS-COV-2 infection of elderly passengers in the public bus depends not only on the exposure time, but also on the deposition percentage of droplets by elderly passengers, of which the percentage of droplet deposition is the dominant factor.

3.3. Spatial distribution of the infection risk of passengers in the public bus

Fig. 13 shows the risk of SARS-COV-2 infection of passengers within one stop of the public bus being driven. Conspicuously, regardless of the angle of the personalized air supply, the passengers in the front and middle compartment of the public bus are in a high-risk area, and the space behind the compartment is in a low-risk area. Meanwhile, the risk of SARS-COV-2 infection of passenger 3B is the highest, up to $1.57 \times 10^{6}$, which is 73 times higher than other passengers. This is due to the fact that the passenger 3B is located in front of the infected passenger 3D.
and is close to the return air inlet, which results in strong air mobility and leads to the highest risk of SARS-COV-2 infection. In addition, the infection risks of passengers 2A, 2B, and 2C are generally high, with the highest being $3.98 \times 10^{-7}$, $4.59 \times 10^{-7}$, and $4.51 \times 10^{-7}$, respectively.

Importantly, Fig. 13 illustrates that the risk of SARS-COV-2 infection for elderly passengers in caring seats is not the lowest, and the passengers in the rear seats have the lowest risk of infection. This is because the air flow pattern in the public bus is approximately fixed when the locations of the return air outlet and air inlet are fixed. When the droplets move to the vicinity of the return air outlet, they will escape due to the action of the air flow at the return air outlet. As the droplets move backward to the vicinity of the air inlet, they will move down with the air flow and deposit. Therefore, when the infected passenger is located at the back door of the public bus, only a few virus-carrying droplets will move to the rear compartment, which results in passengers in rear seats hardly being exposed to virus-carrying droplets, so the rear seats belong to the low-risk area. It follows that the setting of caring seats in the public bus at this stage is not suitable for epidemics, and the rear seats of the public bus are more suitable for elderly passengers with low immunity.

The main consideration for the setting of caring seats in the public bus at this stage is the inconvenience of elderly passengers. However, in view of the fact that the caring seats are close to the return air inlet and the air inlet, the air mobility at the caring seat is stronger than other seats, which makes the risk of infection generally higher, and it is not applicable for the epidemic period of infectious diseases. Therefore, it is recommended that elderly passengers with low immunity choose the rear seats of the public bus to reduce the risk of SARS-COV-2 infection.

4. Conclusions

Most elderly people choose public transportation because of their own experience and living habits. Elderly people with low immunity are at a higher risk of contracting the SARS-COV-2 and should be regarded as the focus of attention. The mathematical and physical model of the transmission of droplets in the public bus was established to analyze the impact of four personalized air supply angles ($90^\circ$, $60^\circ$, $45^\circ$, and $30^\circ$) on the transmission of droplets and the infection risk of elderly passengers. The modified Wells-Riley model was used to quantitatively assess the infection risk of SARS-CoV-2 spread by droplets on the elderly with low immunity, providing advice on seat selection for the elderly during the epidemic and a reference for healthy transportation systems to construct a healthy environment inside the public bus. The conclusions are as follows:

1. Under the four personalized air supply angles, when the air supply angle is $60^\circ$, all four elderly passengers at the caring seats are affected by SARS-CoV-2-carrying droplets. When the air supply angle is $90^\circ$, $45^\circ$, and $30^\circ$, the deposition range of droplets in the elderly passengers is reduced to three elderly passengers.

2. By calculating the infection risk temporal characteristics of elderly passengers under four personalized air supply angles, it is observed that when the air supply angle is $60^\circ$, the longest exposure time (up to 116s) and the highest droplet deposition percentage (up to 0.051%) make the elderly passengers 4B have the highest infection risk, which is $3.28 \times 10^{-7}$.

3. Comparing the risk of SARS-COV-2 infection of all passengers in the bus, it can be found that when the personalized air supply angle is $30^\circ$, the number of infected passengers in the public bus is the least, which is 14. When the air supply angle is $45^\circ$ and $60^\circ$, the number of infected passengers is the largest, both of which are 16.

4. Based on the spatial distribution of the infection risk of passengers, it can be concluded that the rear seats of the public bus are relatively isolated, which can be less affected by droplets with viruses, which makes the setting of caring seats in the middle compartment of the bus not suitable for epidemics. The rear seats are more suitable for elderly passengers with low immunity, which is dependent on the locations of the infected passenger, return air outlet and air inlet of the public bus.

This study presents a promising predictive model for SARS-CoV-2 transmission in the public bus that quantifies the impact of personalized ventilation and exposure time on passengers’ infection risk.

Since there are differences in the respiration rate of each person, and in order to highlight the role of the personalized air supply angle on the spatiotemporal distribution of cough droplets in the public bus, this study made appropriate simplifications and assumptions, neglecting the breath airflow. Our research considered the case where the source of infection coughed once, but in fact, the infected passenger may cough more than once, so the actual risk of infection for passengers will be greater, but the relative relationship of infection risks between passengers remains unchanged. Additionally, the location and number of infected passengers can affect the risk distribution of passengers in the public bus, and there are many cases, we will use the matrix method for classification research in the follow-up research.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data used to support the findings of this study are included within the article.

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Appendix A. The detailed geometric model dimensions of the public bus

| Name          | Number | X(m) | Y(m) | Z(m) | yoz(m) |
|---------------|--------|------|------|------|--------|
| public bus    | 1      | 9.996| 2.3  | 2.5  | /      |
| 1A-2C’s seat  | 6      | 0.42 | 0.502| 0.45 | /      |
| 1A-2C’s seat back | 6    | 0.42 | 0.05 | 0.67 | /      |
| 3A-8E’s seat | 24     | 0.502| 0.42 | 0.45 | /      |
| 3A-8E’s seat back | 24   | 0.05 | 0.42 | 0.67 | /      |
| driver’s seat | 1      | 0.57 | 0.57 | 0.55 | /      |
| driver’s seat back | 1    | 0.05 | 0.57 | 0.67 | /      |
| air inlet     | 1      | 0.4  | 0.8  | /    | /      |

(continued on next page)
