Simulation Study on Aerosol Diffusion of Bioterrorism Factors in Port Passenger Station

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Abstract—Among the bioterrorism threat factors, airborne bacteria or viruses are more harmful, and exist in the form of aerosols in port passenger stations, which have the characteristics of transmitting viruses, the characteristics of aerosol diffusion in indoor space are of great significance for preventing bioterrorism events. Under the conditions of micro-negative pressure at the bottom of the space in the passenger station, natural ventilation with doors and windows open on one side, mechanical ventilation with top air supply on one side, etc., the Realizable k-ε turbulence model was used to study the transient diffusion. The temperature of human body is higher than the indoor environment temperature, the phenomenon of thermal plume will appear near the body surface, the local airflow disturbance aerosol particles will move down with the circulation, there will be reflux vortex, at 60 seconds, the residual rate of particulate matter is 15% in the bottom micro-negative pressure ventilation, 20% in the door-window one-side natural ventilation, and 30% in the top-supply one-side exhaust mechanical ventilation, when people are indoors, the use of low-negative-pressure ventilation is conducive to the reduction of aerosol particles.

Keywords-component; Port passenger station, bioterrorism factor, numerical simulation and simulation, aerosols

1 INTRODUCTION

Ports, especially passenger stations, are important public places and crowded places. Once a bioterrorism attack occurs, the consequences will be very serious. Bioterrorism factors mainly include bacteria, viruses, and biological toxins, including Class A terrorist pathogens, smallpox virus, Ebola virus, and Bacillus anthracis (anthrax), which are very harmful when transmitted through air or aerosols.

Research on bioterrorism factors is the basis for hazard assessment and emergency response. China has a large population and a relatively weak medical and health foundation. If a certain biological agent is used to launch a terrorist attack against a city or region in a certain way, how many casualties will be caused, and how much vaccine or drug reserves will be needed for emergency response. There is no quantitative research report on what control measures can be taken to reduce casualties more effectively. Focusing on the field of port and shipping, Zheng et

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al. [1] assessed the risk of disease infection in cruise ships in combination with several models, pointing out that living quarters and restaurants are high-risk areas, and adopting ventilation, installing efficient particulate air purifiers and wearing surgical masks are more effective measures to reduce infection. For the study of virus transmission in the air, Li et al. [2] developed the EITS model and assessed the infection risk of direct and indirect exposure; Wells Riley (W-R) [3] and Dose response (D-R) models [4] are also widely used in the prediction and risk assessment of airborne infectious diseases.

This paper mainly focuses on the bacterial or viral droplets that may be transmitted through the air, mouth and respiratory tract as the research object, combined with the scene of the spread of suspended biological aerosols with viruses in the air in the waiting hall of a northern passenger station, and through computational fluid dynamics methods and software, respectively studies the air flow, the range of droplet diffusion direction Calculation results of residue rate, etc. to select a better transformation scheme. In the study, the conditional assumptions ignored the following factors: the self decay of biological factors, the friction of the surface of the medium material and other factors.

Assuming that the spray aerosol triggered by the local spray diffuses locally, using Fluent software, the numerical simulation is carried out, the scene was calculated by using discrete phase model (DPM) and Realiza-ble model (Realiza-ble model) [5-6] , Coupled algorithm and second-order upwind scheme, the variation of aerosol particle residual rate was simulated for 1 min with a single time step internal convergence error less than 1×10^{-6} order of magnitude.

2 THE CALCULATION MODEL

The air flow velocity in the port passenger station is low and the change of gas density can be ignored. The air in the passenger station is regarded as incompressible viscous fluid. The air density in the passenger station is 1.185kg/m3 and the viscosity coefficient is 1.7894 × 10-5kg/m · s, so the fluid in the passenger station can be set as incompressible fluid, Newtonian fluid, steady flow, viscous fluid, and the air flow is in a state of low speed and high turbulence intensity. Aerosol fluid was studied by CFD technology.

The air flow in the passenger station follows the laws of physical conservation, which usually include the laws of mass conservation (also known as continuity equation), momentum conservation and energy conservation. If the fluid composition is multiple or interacts, there is also the law of component conservation. If there is turbulence transport equation in the turbulent state, the mathematical description of these conservation laws is the control equation. Under the control of these control equations, the fluid flow process is numerically simulated and analyzed to obtain the distribution of basic physical quantities (such as temperature, velocity, pressure, etc.) at various locations in the complex flow field and their changes with time.

Establishes a 1: 1 scale model of the waiting room (Figure 1) . The dimension of the indoor space is 8m × 6m × 5m, including doors, windows, chairs, bodies and vents. The mannequin uses a simplified square model, which sits on a chair and indicates that the person is sitting on the chair. The population is a locally triggered aerosol source for a simulated cough, and the nozzle location is shown in Figure 2, with a nozzle radius of 30 mm. The lower part of the chair is provided with a micro negative pressure air inlet.

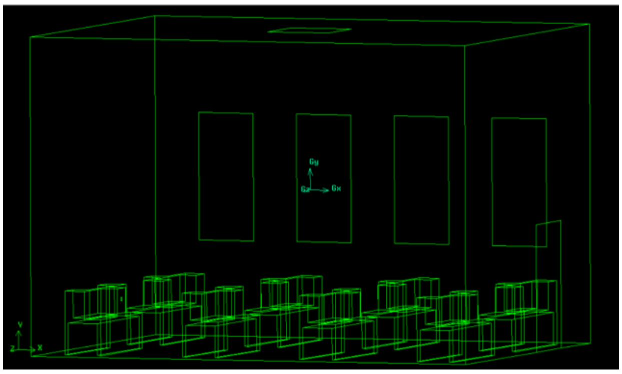

Fig. 1 model and general grid of the waiting hall

3 MESHING AND BOUNDARY CONDITION

3.1 Meshing

Software is used to create unstructured meshes for the calculation area, and the meshes are encrypted near the nozzle of the particle source, as shown in Figure 3. Due to the non-steady state calculation method used in numerical simulation, the calculation speed is guaranteed under the condition of limited calculation resources, the mesh numbers of 770,000,101,106,000 and 201,000,000 are established to verify the grid independence. A straight line passing through the center of the injection source and perpendicular to the plane of the injection source is taken in the indoor space to obtain the velocity distribution at 1s time. Finally, 760,000 meshes are selected as the parameters of the global mesh generation scheme. 2.2 the numerical simulation of boundary conditions is carried out to study the dispersion characteristics of aerosols triggered by local conditions, and the information of the position and residual rate of aerosols at a specific time is obtained. The breathing mode of the model is simplified, and the air inlet condition is set to simulate the airflow of cough-producing particles in the exhalation. The aerosol spray conditions triggered by cough were set up within 1 s, and the particles were calculated using the discrete phase model (DPM). The physical parameters of the particles were set as shown in Table 1, the physical parameters of the particles are: 1-100 μm in diameter, 10 μm in average diameter. The initial velocity of the particles was 10 m/s and the temperature was 310 K (37° C). Realizable K-E model was used to calculate the turbulence model, and Coupled algorithm was adopted. The discrete scheme was a second-order upwind scheme, and the convergence residuals in a single time step were less than 1 × 10-6 orders of magnitude, the time step of unsteady numerical simulation is 0.2 s and the steps are 3000, which is to simulate the change of aerosol residual rate for 10 min. The operation condition settings are shown in Table 2.

Table 1 physical parameters of particulate matter

Property	Units	Method	Value(s)
Density	kg/m^3	constant	1000
Cp	j/kg.k	constant	1680
Thermal Conductivity	w/m.k	constant	0.0242

Table 2 operation condition settings

Conditions	Set value
Operating pressure /pascal	101325
Operating temperature /K	9.81
gravity $/(m/s^2)$	293

3.2 The boundary conditions

Aerosols diffusion with micro-negative pressure at the bottom, due to the different sizes of gas particles and the greater influence of gravity on the mass particles, the computational domain sets up the necessary gravity environment conditions. The specific boundary conditions are shown in table 3. The normal body temperature is about 310K (37 ° C), but the simulated normal body surface temperature is 304K (31 ° C), and the indoor ambient temperature is 293K (20 ° C). Set the surrounding seat as the particle trap boundary condition, the wall and the ground as the particle trap boundary condition, and adiabatic no slip.

Table 3. Setting of boundary conditions at low negative pressure

Boundaries	boundary type	Temperature/K	flow rate/(m/s^{-1})	pressure/ Pa	DPM
The human mouth	velocity-inlet	308	1.3	——	Escape
The aerosol	——	310	10	——	——
seats	wall	304	——	-10	Trap
wall	wall	293	——	——	Trap
floor	wall	293	——	——	Trap
four windows	velocity-inlet	290	0.2	——	Escape
door	pressure-out	293	——	101325	Escape
air intakes	velocity-inlet	293	1.3	——	Escape

The boundary condition of one-side ventilation: 4 windows and 1 door are set as return air outlet, the outlet pressure is atmosphere, the ventilation main one-side window flows in, the entrance exit flows out, the boundary condition of single side exhaust with top air supply: except the top air supply condition, the boundary condition is the same as the first two conditions. Under the condition of ensuring the same ventilation flow, a single side door is arranged for the return air outlet to be a pressure outlet, and the outlet pressure is atmospheric pressure,

4 ANALYSIS OF THE SIMULATION RESULTS

4.1 The results of Bottom micro negative pressure

The micro-negative pressure at the bottom are shown in fig. 2 and Fig. 3. It can be seen that most of the particles move up first at 10 s after ejection and then at 60 s, moving to a certain height of space particles scattered, and then in the 180s and 300s forward motion, and gradually falling. The variation of the farthest propagation distance and the residual rate over time is shown in Figure 4. The particles spread farther and farther in the 60s, reaching a propagation distance of 4.2 m when the residual rate is 15%. Figure 5 shows the human body showing the effect of a nearby thermal plume, which forms a circulation.

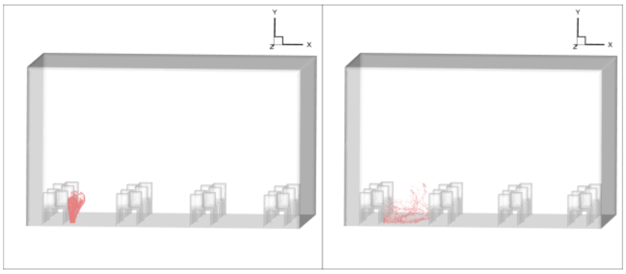

Fig2. 10s (left) and 60s (right)

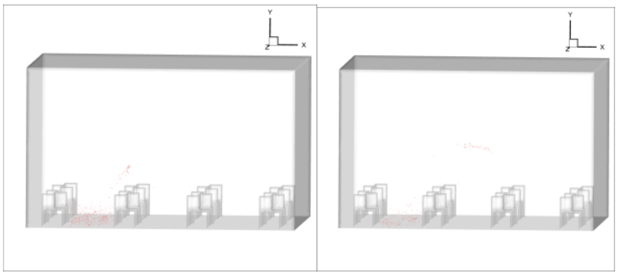

Fig3. 180s (left) and 300s (right)

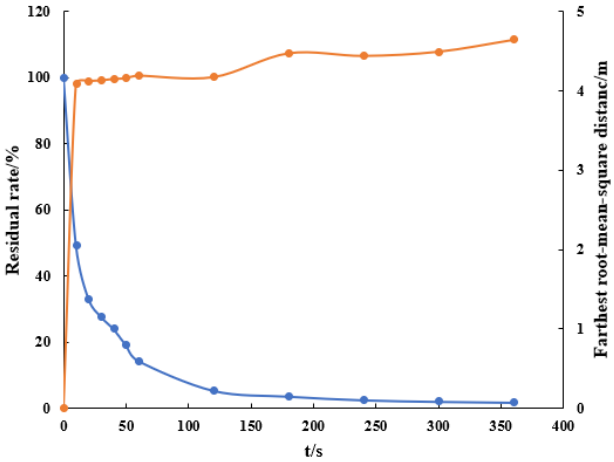

Fig4. particle movement characteristics

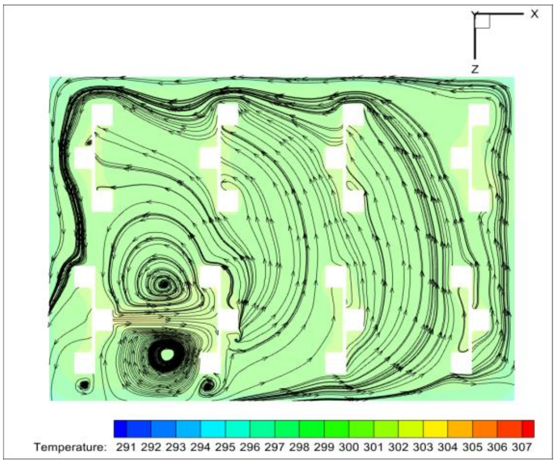

Fig5. (a)60s temperature distribution in y plane

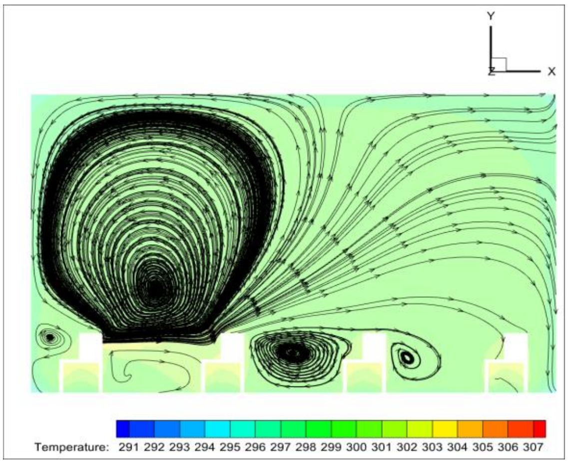

Fig5. (b) 60s temperature distribution in z plane

4.2 The results of one-side ventilation simulation

It shows that the particles move laterally for the most part at 10 s after ejection, and disperse and fall gradually at 60 s, as shown in Fig. 6 and Fig. 7, after the 180s and 300s continued lateral movement, and gradually fell to the ground. The changes in the maximum propagation distance and the residual rate over time are shown in Figure 8, where the particles spread farther and farther within 60 s, reaching a propagation distance of 4.2m when the residual rate is 20% . Figure 9 shows that ventilated air drives a one-way flow, creating small air swirls just below the seat.

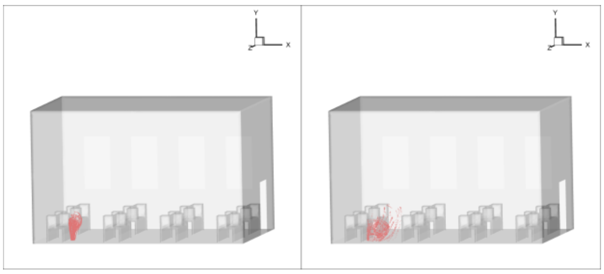

Fig6. 10s (left) and 60s (right)

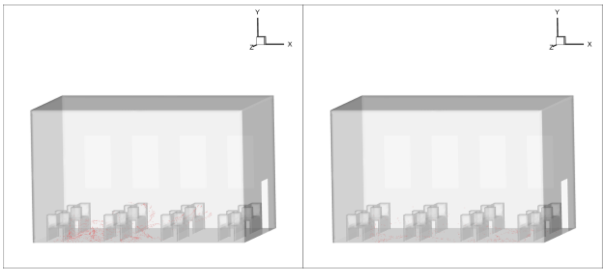

Fig7. 180s (left) and 300s (right)

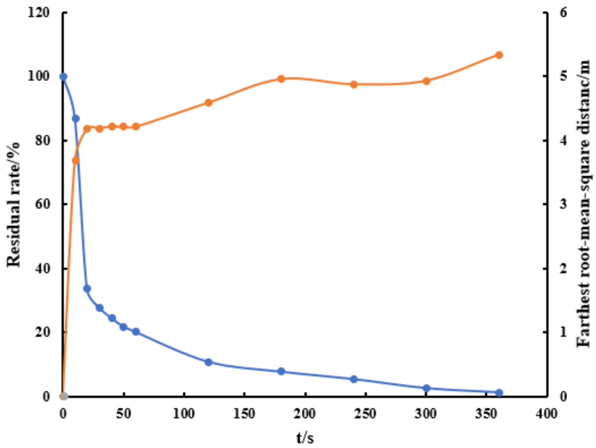

Fig8. particle movement characteristics

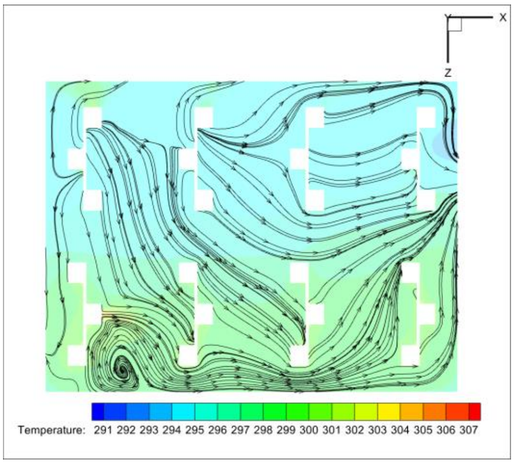

Fig9. (a)60s temperature distribution in y plane

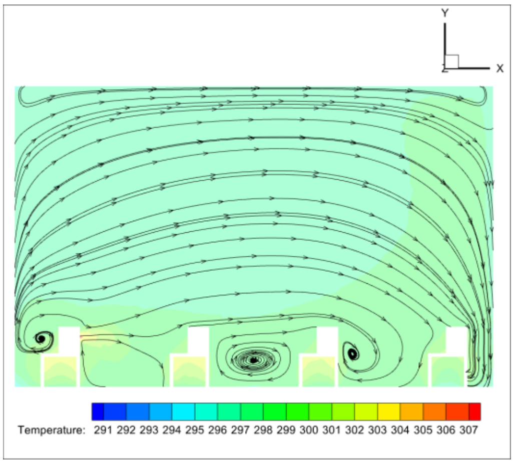

Fig9. (b)60s temperature distribution in z plane

4.3 The simulation results of the top-air supply and one-side exhaust conditions

Fig.10 and Fig.11 show that the particle clusters move most laterally to the top at 10 s after ejection, and disperse and rise up by disturbance at 60 s, it continued to spread throughout space in the 180s and 300s. The changes in the maximum propagation distance and the residual rate over time are shown in figure 12, where the particles spread farther and farther within 60 s, reaching a propagation distance of 5.2m when the residual rate is 30% . Figure 13 shows that the ventilated air leads to two large air vortices.

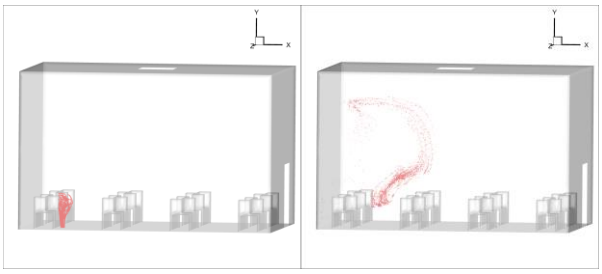

Fig10. 10s (left) and 60s (right)

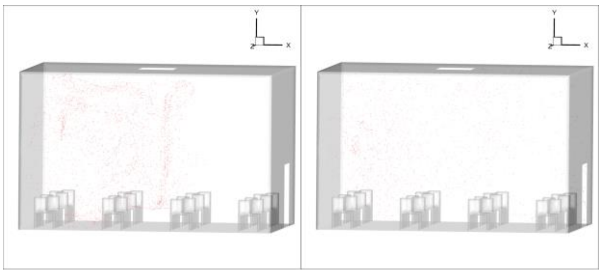

Fig11. 180s (left) and 300s (right)

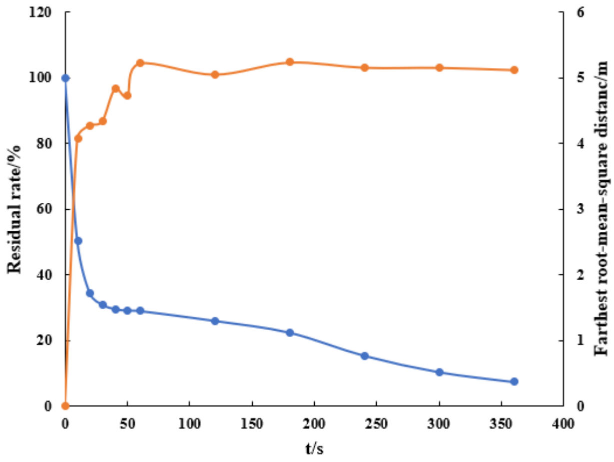

Fig12. particle movement characteristics

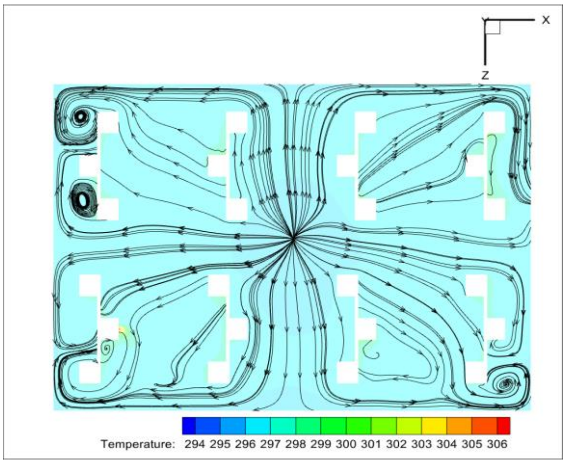

Fig13.(a)60s temperature distribution in y plane

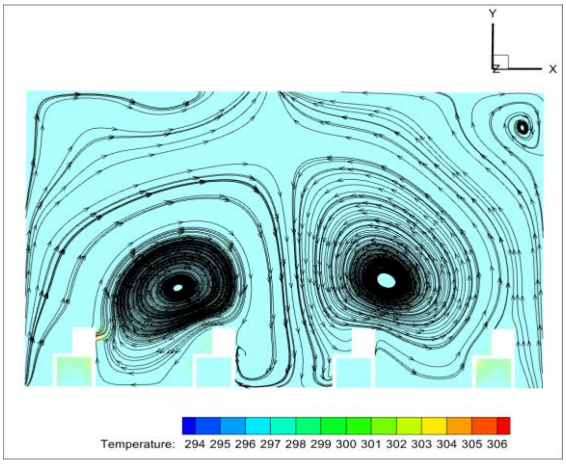

Fig13.(b)60s temperature distribution in z plane

5 COMPARISON AND ANALYSIS

The particle capture/escape percentages at different locations of the waiting room under the three different ventilation schemes when Fig. 14 is 60s, it can be seen that the percentage of relative capture/escape rate is the largest at ground locations and the percentage is the smallest at wall locations, indicating that the dispersion of such particles is strongly influenced by gravity and that micro-negative pressure ventilation may be relatively more applicable.

Through the software numerical simulation, we have carried on the aerosol diffusion scene analysis in the partial space of the waiting room. From Fig. 15, we can see that the large aerosol particles fall to the ground under the influence of gravity, small particles in the room by the influence of airflow larger and diffuse distribution. About 20% of the particles remain in the indoor air 60 seconds after they are ejected. Such pathogenic aerosols that remain in local spaces may pose a risk of infection. Under the condition of the same air flow rate, the mechanical ventilation scheme of micro-negative pressure ventilation at the bottom, one-side natural ventilation with opening doors and windows, and one-side exhaust ventilation with top air supply is proposed in this study, at 60 seconds, the residual rate of particulate matter is 15% in the bottom micro-negative pressure ventilation, 20% in the door-window one-side natural ventilation, and 30% in the top-supply one-side exhaust mechanical ventilation, the bottom micro-negative pressure ventilation can ensure that the aerosol residue rate is gradually reduced, and the airflow turbulence degree is low, and the ventilation under the seat feels better, so it is the preferred scheme to be adopted.

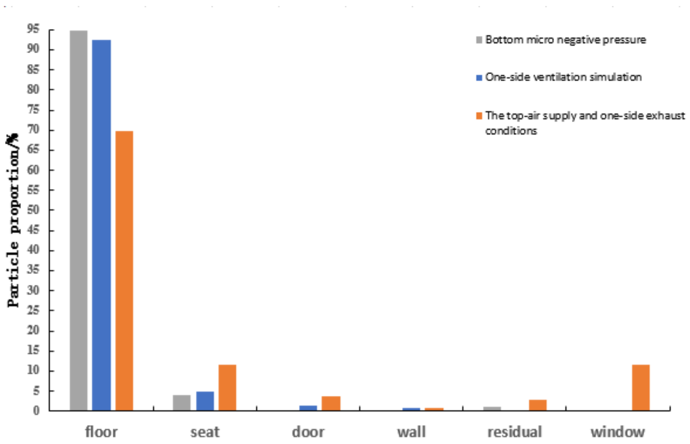

Figure 14: 60s percentage of capture/escape at each location

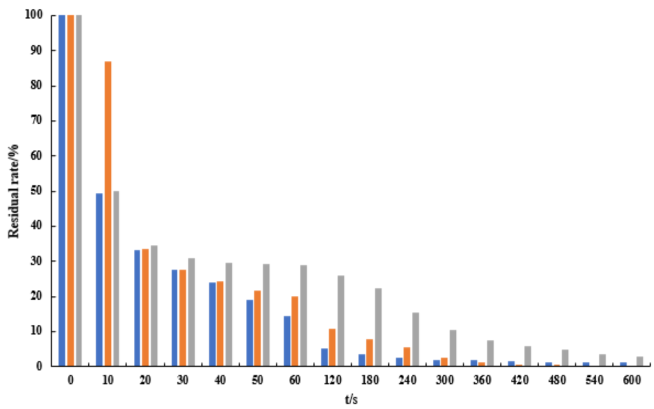

Figure 15: The change of the residual rate of particulate matter in air with time under three operating conditions

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