Study on acquired infection of patients in waiting space of fever clinic

Shuo Liu [1]*, Ying Wang*[2]*, Yiran Lu*[3]*, Yifan Li*[3]*, Yi Wang*[1]*, Li Liu*[1,3]*

[1] Xi'an University of Architecture and Technology, China.
[2] Zhongnan Hospital of Wuhan University, China
[3] Tsinghua University, China

Abstract. Since the COVID-19 outbreak, high numbers of patients with respiratory symptoms flock to fever clinic, cause overcrowding. Due to relatively densely populated space and the existing ventilation strategy, lead to space environment bearing capacity lose efficacy. The patients in waiting space are faced a high risk of cross infection. Thus, it must be strictly controlling the personnel density and fresh air dilution level, prevent SARS-COV-2 transmission though aerosols. This study takes the fever clinic of 3A Grade Hospital case, based on the monitoring results of CO_2 concentration and the transport of exhaled pathogenic aerosols, predict the waiting patient's cross infection risk in crowded space. Computational fluid dynamics simulations and agent social force behaviour model were used. When the number of fever clinic reaches the upper limit of theoretical capacity, under the three ventilation types, average exposure risk in different areas of waiting space were studied. Results show that when the infector is located at the front of the waiting corridor (upwind direction of natural ventilation), when there is only natural ventilation, the difference of average intake fraction in the three areas of waiting space is small, that is, the correlation between distance and exposure is small. Our results also show that when ceiling air conditioner ventilation and natural ventilation are coupled, the dilution effect is significantly lower than that of natural ventilation in the front and rear area, and higher than only run mechanical ventilation.

1 Introduction

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is a highly transmissible and pathogenic coronavirus that emerged in late 2019 and has caused a pandemic of acute respiratory disease, named 'coronavirus disease 2019' (COVID-19), which threatens human health and public safety[1]. Typical symptoms of the coronavirus disease 2019 (COVID-19) are fever and dry cough[2], since the COVID-19 outbreak, high numbers of patients with similar symptoms flock to fever clinic, cause overcrowding in fever clinics, due to relatively densely populated space and the existing ventilation system, lead to space environment bearing capacity lose efficacy. Cause nosocomial infection aggregation epidemic situation.

As evidence has accumulated over the course of the pandemic, scientific understanding about the virus has changed. Studies and investigations of outbreaks all point to a infector can release a large number of respiratory aerosol particles when breathing, speaking or coughing normally, and virus particles are mainly concentrated in small particles($<5\mu m$[3]), which are suspended in the air for a long time, causing long-distance propagation, research shows that patients release SARS-Cov-2 can reach millions of copies per hour[4]. Therefore, waiting patients are exposed to the environment containing virus aerosol for a long time, and there is a high risk of infection.

Studies conducted in isolation ward[4], in a restaurant[5], in a courtroom[6], in public transport[7], in typical classroom[8].
all demonstrated a correlation between the ventilation rate and the infection rate for respiratory infections[9] Good ventilation in populated public spaces will dilute and clear out potentially infectious aerosols[10], is a primary infectious disease control strategy in hospitals and other facilities[11] However, the relationship between ventilation and the exposure risk of patients waiting in a narrow space is affected by many factors, such as ventilation, personnel density, location of infection source and so on.

In this study, taking the aerosol concentration inhaled by waiting patients as an indicator to measure the risk of infection and ventilation performance, restores the typical scene of the waiting space of 3A Grade hospital in Wuhan in the early stage of the epidemic. To explore the influence mechanism of ventilation strategy of fever outpatient waiting space with natural ventilation on airborne diseases. The results can provide a basis for the scientific ventilation design of fever clinic, to reduce the incidence of nosocomial infection in crowded space.

---

* liuli_archi@tsinghua.edu.cn

2 Method

This study takes the fever clinic of 3A Grade Hospital case, numerical simulations applying the actual size of the fever clinic are conducted. Considering the room function, this paper focuses on the areas where patients often stay. Thus, the physical model of fever clinic includes three consulting rooms and waiting corridor. Air distribution systems, ceiling air conditioner are installed, air supply all around, return air in the middle. However, in the early stage of the COVID-19, the ceiling air conditioner is not used, the required air flows only depend on natural ventilation between external doors and windows, the opening position and size are shown in Fig 1(Top), the two external windows are high windows, and the lower edge of the window is 2m high.

The crowd control method and space usage mode of Consulting room and Patient Waiting Area are different, requires adopting different selection method of patients' number limit. To reduce nosocomial infection risk, strictly limit the number of people in the fever clinic and only one doctor and one patient are allowed in each Consulting room. The user of the Patient Waiting Area are only patients, the number of patients varies widely, and the risk of cross infection of patients mainly comes from the close contact caused by the gathering of patients. By controlling the interpersonal distance, the theoretical upper limit of the patient waiting area can be calculated. For waiting space, $N=int[A/d^2]$, where int $[A/d^2]$ indicates that the calculation result is rounded down and d is the recommended interpersonal distance, which is 1.5m[12]. See Table 1 for the upper limit of capacity in each region.

Table 1. Information on the fever clinic

Site	Area type	Area (m^2)	Upper limit of occupants N (person)
Consulting room 1	Consulting	9.45	2
Consulting room 2	Consulting	9.8	2
Consulting room 3	Consulting	9.45	2
Registration	register	-	1
Corridor	Waiting	54	24

Analyse the medical process and time-consuming situation of medical links in fever clinic, use agent social force model[13], the pedestrian path and interaction characteristics of entering fever patients are simulated, coupling the computational fluid dynamics is used for modelling. If the interpersonal spacing is 1.5m, there is no queuing constraint, when the occupants reach theoretical upper limit, the physical model of fever clinic is shown in Fig 1.

Euler- Lagrange approach is adopted to simulate the airflow and droplets/particles. A no-slip boundary condition is applied for all the surfaces. The heat dissipation capacity of a body is about 70W/m²[14], only considered heat dissipation via convection, Corresponding heat dissipation capacity is 23.6 W/m²[15]. Fever clinic patients release droplets from mouth, which is a complex process, thus, the breathing process is simplified to a constant speed [16]. The infected person is located at the beginning of the waiting corridor (Fig 1,

red patient), exhaled at a constant rate, while other patients inhaled at a constant rate. The SIMPLE algorithm is used. Other setups are listed in Table 2.

To validate the accuracy of the numerical set-up, five CO_2 concentration monitoring sites are set in fever clinic, an additional case is provided to make a comparison with the experimental data. As shown in Table 3, despite the differences, the CO_2 concentration in simulation generally agree well with the experimental data, which shows that the numerical set-up is reliable.
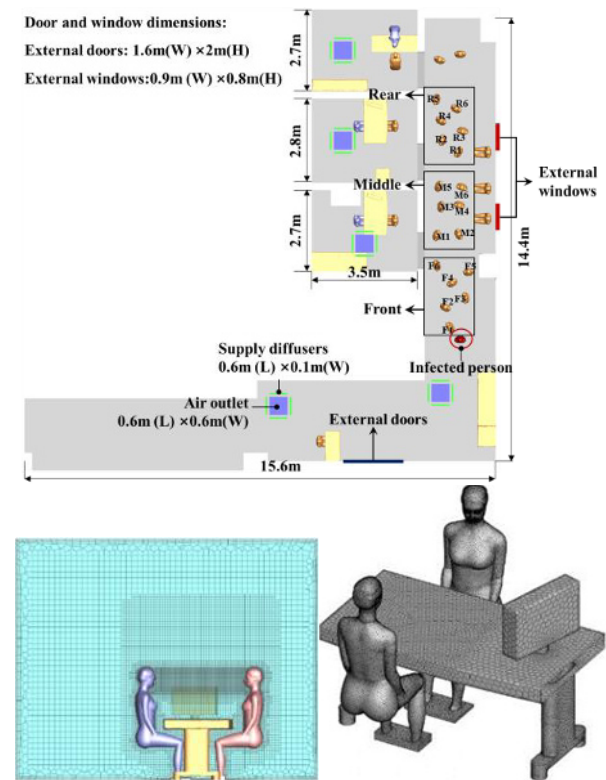

Fig.1. a) The layout of the fever clinic (top); b) volume mesh (low left); c) surface mesh (lower right)

Table 2. CFD numerical and boundary conditions.

Turbulence model	Realizable k-ε turbulence
Mesh	~6720,000 Poly-hexcore (y^+=2~3)
Scheme	Convection term: 2nd order upwind
Droplet turbulence dispersion	Discrete Random Walk (DRW) model
Droplet wall boundary condition	Openings: escape Walls: trap
Droplets initial diameter	5μm
Volatile component	93.6% (v/v)

Table3 Comparison of experimental data and numerical calculation results: relative error of CO_2 concentration and temperature

Measure point	CO_2 concentration (%)	Temperature (%)
Consulting room 1	1.9	6
Consulting room 2	4	1.7
Lobby	2	3.4
Corridor1	2	1.7
Corridor2	1.6	1.3

In the simulation of fever clinic, air distribution and aerosol dispersion by CFD. During natural ventilation, the air supply speed is 0.14m/s, the temperature is 5.4°C, and the relative humidity is 75%; during mechanical ventilation, the air supply speed is 0.43m/s, the temperature is 20°C, and the relative humidity is 60%. All cases are divided into three cases and listed in Table 4.

Table 4 List of simulation tests.

Case	Ventilation mode
1	Only NV(6ACH) Inlet: external doors Outlet: windows
2	NV(6ACH) and MV (6ACH)
3	MV (6ACH)

Abbreviation: NV, Natural ventilation; MV, Mechanical ventilation; ACH, Air changes per hour.

3 Result and Discussions

3.1 Fate of droplets with different ventilation

After released from infector, aerosols gradually diffusion under the action of gravity, buoyancy and airflow. In the process of diffusion, some aerosol particles settle on the human surface, furniture and wall; some particles are inhaled by susceptible or removed through the air outlet, and other particles will continue to be suspended in the indoor space until they settle on the surface or inhaled by the human.

There are three fates for particles released from infector: escape, trap, and suspended. In this paper, "escape" includes inhalation by susceptible and escape through air outlet. Fig 2 shows the final state of aerosols under three ventilation types.

Comparing the removal efficiency of aerosols under the three ventilation modes, results show that the removal efficiency of natural ventilation, natural ventilation and mechanical ventilation coupled, are much higher than those when only mechanical ventilation is considered, among them, natural ventilation has the best removal efficiency，and the risk

of inhalation exposure of susceptible persons is also the smallest. Therefore, natural ventilation should be given priority in this fever clinics with natural ventilation conditions. When there is only mechanical ventilation, the most particles settle on the object surface. In this state, the object surface should be disinfected in time.
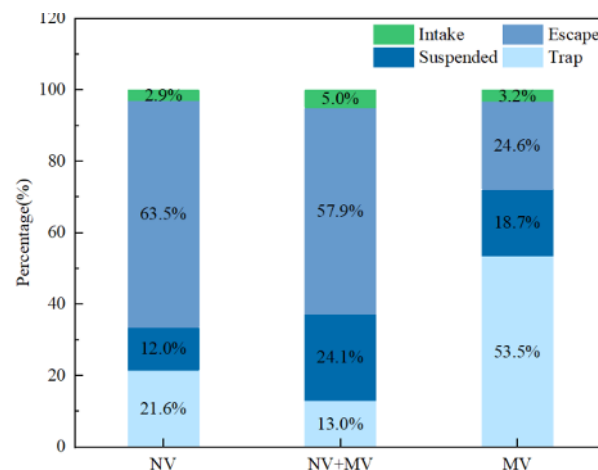

Fig.2. Intake fraction of each region under three types of ventilation conditions

3.2 Intake fraction

To discuss the intervention effect of ventilation on the inhalation exposure of susceptible person caused by aerosol transmission in waiting space, 18 patients in the waiting space were selected and divided into three groups with six people in each group. Their layout and number are shown in the Fig 1(Top).

To quantify the relative inhalation of aerosols released by susceptible patients, intake fraction was defined as:

$$iF = \frac{Number\ of\ particles\ inhaled\ by\ susceptible\ patient}{Number\ of\ particles\ released\ by\ source\ patient} \quad (1)$$

Fig 3 shows that under the three ventilation types，the average intake fraction of six patients in the front, middle and rear areas of the waiting space. Under the three ventilation types, the areas with the highest exposure risk are in the front area, which is 1.8‰(NV), 4.1‰(NV+MV), 4.7‰ (MV) respectively. When there is only natural ventilation, the difference of average intake fraction in the three areas of waiting space is small, that is, the correlation between distance and exposure is small. When natural ventilation is coupled with mechanical ventilation, the middle area presents a high intake fraction, which may be because the area is close to the doors of consulting rooms 1 and 2. After mechanical ventilation is coupled, the polluted air is restrained from being discharged through the window to a certain extent, resulting in the increase of intake fraction of susceptible people in this area. Therefore, the correct air distribution is very important. If the naturally ventilated air room is to operate as expected, it needs to be properly designed. When we talk about ventilation performance, it is generally considered that ventilation is more effective for long-distance propagation of aerosol propagation. According to the results of middle

area and rear area, MV shows better ventilation dilution effect. Especially under MV, the average intake fraction of rear area decreased to a very low level of 1.8‰.
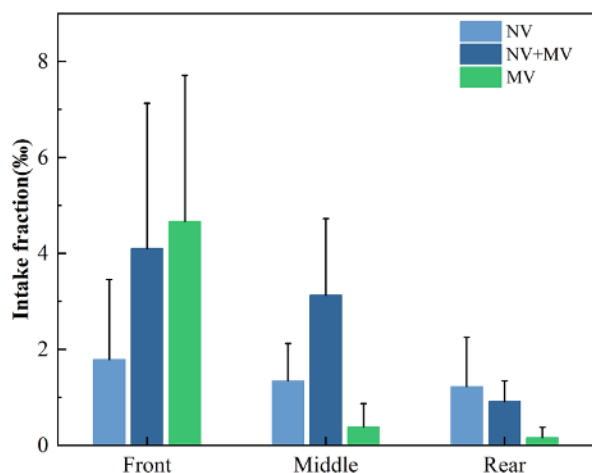

Fig.3. Intake fraction of each region under four types of ventilation conditions

4 Conclusion

In this study, we used CFD to compare the performances of three types of ventilation (NV, NV+MV, MV) in a fever clinic of 3A Grade Hospital. In terms of pollutant removal efficiency, only natural ventilation has the highest removal efficiency. When there is only mechanical ventilation, strengthen the daily disinfection of indoor surface. When natural ventilation is coupled with mechanical ventilation, since the air conditioner is located in the consulting room and close to the air inlet of natural ventilation, the diffusion degree of indoor particulate matter is strengthened to a certain extent, and the removal efficiency of particulate matter is reduced, resulting in more particulate matter suspended in the fever clinic. Patients are exposed for a long time, which may eventually lead to high exposure.

References

[1] B Hu, H Guo, P Zhou, et al. Characteristics of SARS-CoV-2 and COVID-19[J]. Nat Rev Microbiol, **19**,3 (2021)

[2] N Chen, M Zhou, X Dong, et al. Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: a descriptive study[J]. Lancet, **395**,10223 (2020)

[3] Y Zhan、Y Lin、K Yang, et al. Research progress on the spread and diffusion of SARS-CoV-2 aerosol [J]. Lab. Med, **35**, 11 (2020)

[4] M K Satheesan, K W Mui, L T Wong. A numerical study of ventilation strategies for infection risk mitigation in general inpatient wards. Build Simul, **13**, 887–896 (2020)

[5] Y Li, H Qian, J Hang, et al. Probable airborne transmission of SARS-CoV-2 in a poorly ventilated restaurant. Build Environ. **196**, 107788 (2021).

[6] D Vernez, S Schwarz, J J Sauvain, C Petignat, et al . Probable aerosol transmission of SARS-CoV-2 in a poorly ventilated courtroom. Indoor air, **31,** 6 (2021)

[7] X Yang, C Ou, H Yang, L Liu, et al. Transmission of pathogen-laden expiratory droplets in a coach bus. J Hazard Mater, **397**, (2020)

[8] M I Farouk, A F Nassar, M H Elgamal. Numerical Study of the Transmission of Exhaled Droplets between the Instructor and Students in a Typical Classroom[J]. Appl Sci, **11**, (2021)

[9] J Ma, X Qi, H Chen, et al. COVID-19 patients in earlier stages exhaled millions of SARS-CoV-2 per hour[J]. Clin Infect Dis, **72**,10 (2021)

[10] W Chen, H Qian, N Zhang, et al. Extended short-range airborne transmission of respiratory infections[J]. J Hazard Mater, **422**, 126837 (2022)

[11] G A Somsen, C Van Rijn, S Kooij, et al. Small droplet aerosols in poorly ventilated spaces and SARS-CoV-2 transmission[J]. Lancet Respir Med, **8**, 7, (2020)

[12] Y Lu, Y Li, H Zhou, et al. Affordable measures to monitor and alarm nosocomial SARS-CoV-2 infection due to poor ventilation[J]. Indoor Air, **31**,6(2021)

[13] J Li, J Wang, B Jin, et al. Evacuation of Nursing Home Based on Massmotion: Effect of the Distribution of Dependent Elderly[J]. KSCE J Civ Eng, **24**, 4 (2020)

[14] H Zhao, B Stephens, W Ji, et al. Ventilation procedures to minimize the airborne transmission of viruses in classrooms[J]. Build Environ, **10**, (2021)

[15] Y Fan, L Liu, H Zhang, et al. Exposure of Ophthalmologists to Patients' Exhaled Droplets in Clinical Practice: A Numerical Simulation of SARS-CoV-2 Exposure Risk[J]. Front Public Heal, **9**, (2021)

[16] L Wang, X Dai, J Wei, et al. Numerical comparison of the efficiency of mixing ventilation and impinging jet ventilation for exhaled particle removal in a model intensive care unit[J]. Build Environ, **200**, (2021)