Study on Ventilation Efficiency and Infection Probability in the Outbreak at Restaurant

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Abstract. With the spread of the coronavirus infection, ventilation efficiency, new design styles, air conditioning and ventilation operation methods, existing building improvement plans, and other building infection risk reduction methods need to be systematized. This study used computational fluid dynamics (CFD) to recreate a series of cases in which nine out of 89 people were infected at a restaurant in Guangzhou, China. Although the importance of ventilation has been reaffirmed, when making a general ventilation plan, ignore the pollutant concentration distribution in the room and calculate the required ventilation volume assuming complete ventilation in the room. In a real space, the generation of pollution sources are local, and the airflow properties in the room, arrival/distribution of fresh air, and discharge properties of the generated pollutants differ greatly; thus, non-uniform concentration fields, ventilation efficiency distributions, and infection probability distributions also occur. A series of cases infected at a restaurant in Guangzhou was evaluated by Scale for Ventilation Efficiency 3,4 (SVE3, SVE4). SVE3 is corresponding to the traveling time of air from the supply outlet to each point. SVE4 indicates the contribution ratio of a supply opening to air at a point in a room.

In addition, the Wells–Riley model (WRM) is a typical model for quantitatively evaluating the risk of airborne infections, and cases of numerical analysis have been reported in various countries worldwide.

However, WRM assumes that the distribution of indoor droplets is uniform and the droplet concentration is stable, and that floating fine particles with a nonuniform concentration field from the active state of the virus, gravity sedimentation, and a non-uniformly distributed pollution source. A diffusion phenomenon is possible, but there is a problem that has not been addressed. Previous studies have excluded diffusion phenomena from their evaluation because gravity sedimentation is significantly less than inactivation, and the cause of local cluster formation is inadequate.This study aims to establish a predictive flow for infection control using CFD.

Keywords. Airborne transmission, Coronavirus, COVID-19, Room air distribution, Transient analysis, Ventilation efficiency
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1. Introduction

Currently, owing to the influence of COVID19, there is a need for a method to accurately confirm the distribution of indoor air. In this study, the infections were reproduced using computational fluid dynamics (CFD) simulation (**Fig. 1**) of a restaurant in Guangzhou, China, where a local cluster was generated. A series of cases infected was evaluated by SVE3, SVE4.

Therefore, considering the spillover effect, we will demonstrate the effects of each factor of ventilation efficiency evaluation and inactivation, gravity sedimentation, and collection rate to construct an infection control prediction flow.

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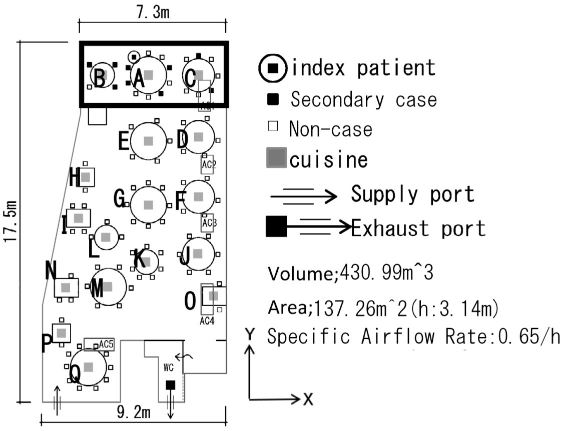
Fig. 1 - Plan of Guangzhou Restaurant



2. Methods

The research methods and procedures of this study are as follows:

1) To clarify the cause of cluster formation, ventilation efficiency indices (SVE3 and SVE4) were evaluated using CFD simulations.
2) Using CFD simulations, we examined the concentration decay due to inactivation, along with the concentration transition due to gravity sedimentation and collection rate.
   Through unsteady CFD analysis, the concentration increase and transition were clarified, and the amount of quanta produced in each case determined. In this study, the exhalation of a primary infected person was modeled using a passive scalar. The gravity sedimentation rate was determined as 8E-04 m s^{-1} by Buonanno et al. , the inactivation rate was 0.63h-1 by Li et al. , and the collection rate was 20%.

3. Results and discussion

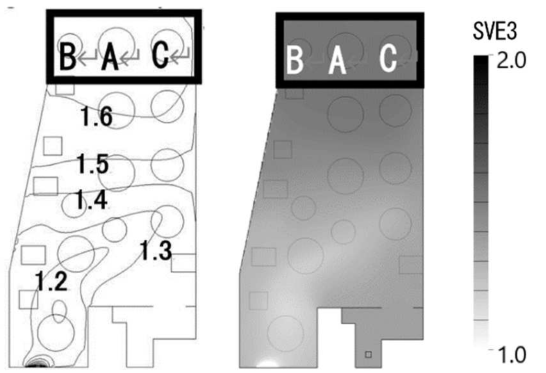
3.1 Assessment of ventilation efficiency sections and subsections

It is presumed that the cause of the occurrence of local clusters is a small ventilation volume ranging from 2.7 to 3.7 $m^3 h^{-1}$, a short circuit of ventilation by the air supply port and the exhaust port of the toilet by the fire door, and the generation of the retention area by the air conditioning airflow. **Tab. 1** shows the analysis cases of SVE3 defined by the average arrival time of the outlet air to a specific area based on the discharge concentration of the suction port and SVE4 defined by the range of force of each outlet. **Fig. 2** shows the distribution of SVE3 when Z = 1.1 m, and the analysis results with poor ventilation efficiency are shown in the local cluster generation space region. To rationally control the indoor air environment locally, it is necessary to specifically evaluate the force range of the blown airflow, which is a control factor. **Tab. 2** shows the contribution rate of each air conditioner, air supply port, and exhaust port to the space. In the area where regional clusters occurred, 42.43% of the air conditioning airflow became circulating airflow, and it was confirmed that a flow field with less air exchange was formed. **Fig. 3** shows the distribution of SVE4 in the horizontal cross-section with respect to the center of the height direction of the air outlet and air supply port of each air conditioner. It is a distribution map based on each outlet. **Fig. 4-7** show contour maps of the vertical section of SVE4. This indicates that the local cluster was created by the airflow properties in the room where it was generated.In order to control the indoor air environment locally and rationally, it is necessary to specifically evaluate the range of force of the blowing airflow, which is the control element.

Tab. 1 – Types of ventilation efficiency (SVE3, SVE4), types of air supply / exhaust ports and air conditioning outlets, its amount.

Case	Ventilation efficiency	3. Mask
1.	SVE3	Supply :280$m^3 h^{-1}$ Exhaust:280$m^3 h^{-1}$ AC1-5 :4080$m^3 h^{-1}$
2－1.	SVE4	AC1 :960$m^3 h^{-1}$
2－2.		AC2 :600$m^3 h^{-1}$
2－3.		AC3 :600$m^3 h^{-1}$
2－4.		AC4 :960$m^3 h^{-1}$
2－5.		AC5 :960$m^3 h^{-1}$
2－6.		Supply :280$m^3 h^{-1}$

Fig. 2 - Contour diagram for SVE3 [h](Z = 1.1 m)



Tab. 2 - Percentage of power range for each SVE4 analysis case.

	Case2-1	Case2-2	Case2-3	Case2-4	Case2-5	Case2-6
AC1	42.43	23.09	11.99	5.68	6.35	3.85
AC2	23.71	27.59	19.62	9.87	11.01	6.68
AC3	13.87	20.04	22.73	15.05	16.63	10.38
AC4	7.92	11.67	17.92	21.15	22.02	18.81
AC5	4.70	6.86	10.95	26.29	21.63	38.84
Exhaust	7.38	10.74	16.79	21.96	22.36	21.44
Total[%]	100	100	100	100	100	100

Fig. 3 - Contour diagram for each SVE4 case.

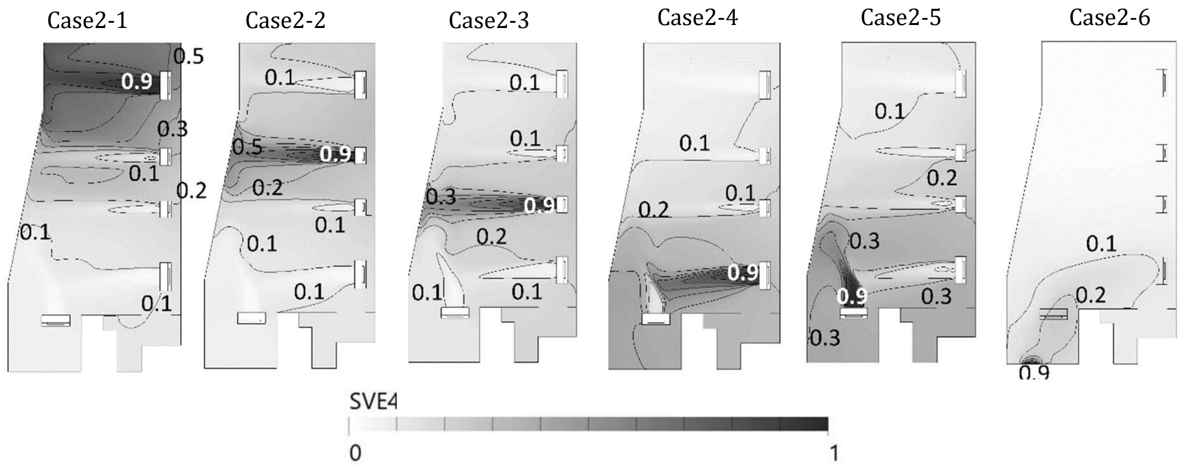


Fig. 4 - Target diagram

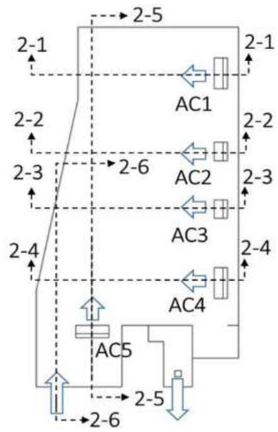


Fig. 5 - Case2-1 section

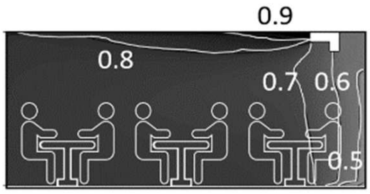


Fig. 6 - Case2-2 section

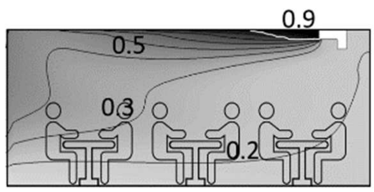
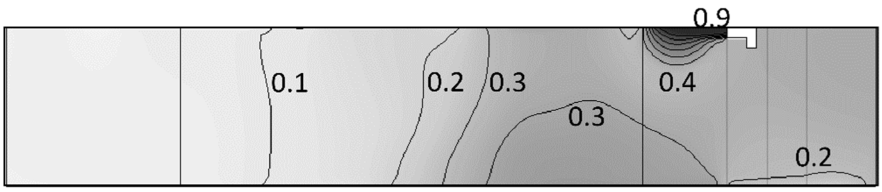


Fig. 7 - Case2-5 section



3.2 Changes in the concentration of each Table standardized by A1

The turbulence model was the standard k–ε model; The scheme is Quick and the exhalation model is a passive scalar. The number and duration of exposures were reported in primary infected individuals and in Tables A, B, C, and other tables in which secondary infections occurred. Tables A, B, C and other tables in **Fig. 8** show the same monitoring points as in the experiment. **Fig. 9** shows the effects of all elements standardized by A1 and the concentration transitions in each table. Table A shows the decay tendency and damping effect of each element after the concentration increases until the visit to the store for 82 minutes. The dotted line shows the case where the concentration transition is compared with the collection rate and gravity sedimentation to investigate the effect of inactivation. Since there are temporary infected persons in Table A, it was confirmed that Table B and Table C showed the maximum attenuation effect and were affected by inactivation. The other tables also aimed to reduce the inactivated concentration and had no effect. Including the analysis results of SVE3 and SVE4 above, Tables A, B, and C show that when the ventilation efficiency decreases, the formation of a non-uniform concentration field and the circulation airflow of the air conditioner occur.

Fig. 8 - Monitoring points for tables A, B, C, and other tables

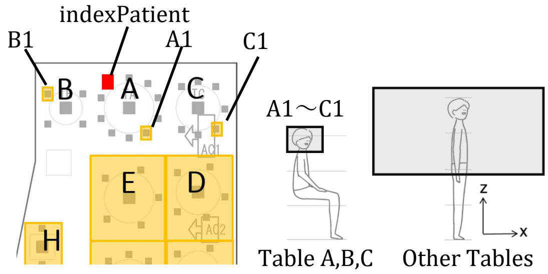
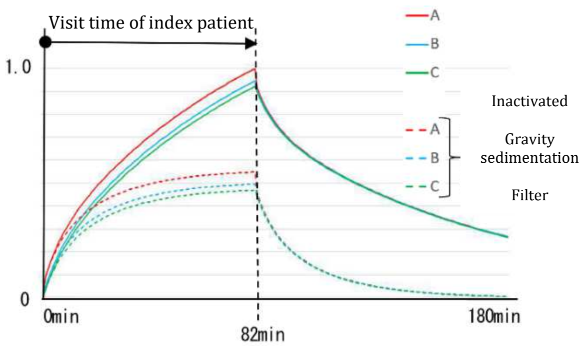


Fig. 9 - Changes in the concentration of each Table standardized by A1



4. Conclusions

In real space, the analysis result of ventilation efficiency by SVE3 was effective because it is displayed in the local cluster generation space area. SVE4 shows the contribution rate of each air conditioner, air supply port, and exhaust port to the space. In order to control the indoor air environment locally and rationally, it was effective to specifically evaluate the range of the force of the blowing airflow. These ventilation efficiency assessments are useful for planning layout plans, suggestions for improving existing buildings, and suggestions for air conditioning and ventilation. Assuming a practical level, we adopted the Euler method passive scalar in consideration of its spread. The difference from previous studies was the difference in Quanta concentration. In the future, we believe that it will be necessary to compare the passive scalar method of the Euler method, which is a respiratory model approach, with the Lagrange method in the infection control flow. In addition, it is confirmed in Tables D to Q that no secondary infection has occurred.

5. References

[1] Riley EC, Murphy G, Riley RL. Airborne spread of measles in a suburban elementary school. Am. J. Epidemiol. 1978; 107: 421-432

[2] REHVA COVID-19 Ventilation Calculator for estimation of ventilation effect on COVID-19 airborne infection, https://www.rehva.eu/covid19-ventilation-calculator,2022

[3] This is not a citation, it is a comment. It seems that two papers are referenced ("2020a, b") Possibly, these are:
Buonanno, G., Stabile, L. and Morawska, L., 2020. Estimation of airborne viral emission: Quanta emission rate of SARS-CoV-2 for infection risk assessment. Environment international, 141, p.105794.
Buonanno, G., Morawska, L. and Stabile, L., 2020. Quantitative assessment of the risk of airborne transmission of SARS-CoV-2 infection: prospective and retrospective applications. Environment international, 145, p.106112.

[4] Lu et al.: COVID-19 Outbreak Associated with Air Conditioning in Restaurant, Guangzhou, China, 2020, Emerging Infectious Diseases, Vol/26, No.7 July 2020 Research Letter