E3S Web of Conferences 356, 04040 (2022) https://doi.org/10.1051/e3sconf/202235604040
ROOMVENT 2022

Simulation Research on Ventilation Control of Gaseous Pollutants in Urban Sentry Boxes

Yanyan Li[1,2], *Haiguo* Yin[1,*], *Xin* Deng[1], *Linfeng* Liang[1] and *Yongchao* Zhai[2]

[1]School of Building Services Science and Engineering, Xi'an University of Architecture and Technology, Xi'an 710055, Shaanxi, China
[2]College of Architecture, Xi'an University of Architecture and Technology, Xi'an, Shaanxi, 710055, China

Abstract. The tiny spaces of sentry boxes in cities, such as mobile security guards, highway toll booths, etc., are mostly located beside roads with harsh outdoor environments. Due to office demands, work windows often need to be kept or frequently opened. The intrusion of outdoor pollutants through the windows leads to the deterioration of the indoor air quality, and threatens the health of employees. This paper takes the gaseous pollutant NO_2 as the representative and discusses the effective ventilation design scheme for improving the air quality in the sentry box with openings using two attached ventilation modes as the carrier. Taking the vertical wall-attached ventilation as an example, the formation of the air curtain at the window hole and its barrier performance to outdoor pollutants were studied. The conclusion is that when the air supply velocity is sufficient to form a complete air curtain at the window hole, it can effectively block the pollutants. The horizontal wall-attached ventilation shows that clean air is delivered to the space with openings, and the indoor air quality can also be well improved due to the dilution effect, but the effect of positive pressure control is not obvious due to the large opening. The conclusions can provide guidance for the ventilation design of sentry boxes with openings.

1 Introduction

Sentry boxes in cities, such as mobile security guards, highway toll booths, and mini convenience stores[1], play an important role in maintaining social security and sorting out social order. With the continuous updating and upgrading of various software and hardware, the urban sentry box is more and more like a mini multi-functional office. But the special thing is that these spaces are located independently on both sides of the road. To realize the corresponding office functions, openable work windows are designed. The dust carried by the vehicle and the exhaust gas generated by the engine movement is driven by the outdoor natural wind to form the air environment around the road. Obviously, the outdoor environment where the sentry building is located is harsh, and pollutants can easily intrude into the room through the work window under the flow of wind, posing a threat to workers' health[2].

At present, more attention is paid to the thermal environment in the sentry box. Generally, there are split air conditioners, but they cannot solve occupants' needs for fresh air, while the way of opening windows to form natural ventilation[3] cannot prevent the intrusion of pollutants. Sapkota et al.[4] tried to use positive pressure control for the entire space to curb the entry of pollutants, but the problem is that when the doors and windows are opened, it is difficult to ensure the positive pressure in the room and does not save energy. The method of personalized ventilation has also been discussed by researchers[5], but due to various reasons such as implementation, there is no systematic design and application method.

As a special air supply method, the air curtain can effectively block the interference of polluted gases and harmful gases to the target zone[6]. In the early days, Hayes et al.[7] studied air curtain exhaust and dust isolation. Later, Afterwards, Havet[8] studied the influence of external disturbance on the air curtain flow field by visualization method and obtained relevant theories such as air curtain mass transfer mechanism and jet velocity. At present, air curtains' dust-proof and heat-proof functions have been widely used in industrial buildings and clean hospital rooms [9,10]. Liu et al.[11] proposed an air-conditioning system with an air curtain. Li et al.[12] and Yin et al.[13] pointed out in the study of wall attachment ventilation that the airflow attached to the building wall forms a flow characteristic similar to an air curtain.

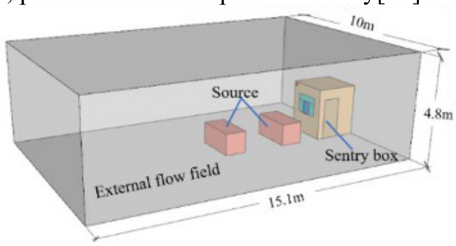
This paper draws on the dust control principle of the air curtain and uses the attached ventilation as the carrier to carry out a CFD simulation study on the ventilation in the sentry box with openings. The purpose is to discuss how to design the ventilation device in such a tiny space with openings and the critical air supply velocity value when an air curtain is used to isolate the outdoor wind.

2 Methodology

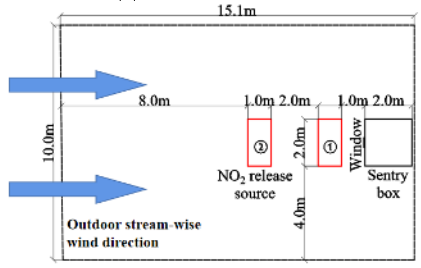
* Corresponding author:yinhaiguo@xauat.edu.cn

2.1 Flow field model

The research in this paper includes two flow areas, the sentry box and the external flow field. To simulate the flow process of outdoor gaseous pollutants entering the room with natural wind, a physical model as shown in Fig.1(a) was established. The dimensions of the sentry box model are 2.0m × 2.0m × 2.4m, and there is an openable working window (width × height, 0.35m × 0.55m). The size of the external flow field was 15.1m × 10m × 4.8m; both the height and width directions were twice the size of the sentry box space model. The length direction of the external flow field was defined as the incoming flow direction of the natural wind. The NO_2 volume emission source with a dimension of 2.0m × 1.0m × 1.0m was set up at 1.0 m and 4.0 m from the window, respectively, as shown in Fig.1(b). Therefore, the length of the outland was set to 15.1m. Even if the emission location of the pollution source was at ②, there was still a distance of 8.0m to ensure the uniformity of the upstream wind. For the elaboration of the setting of the air supply device and the two attached ventilation modes, please refer to our previous study[14].



(a) Geometric model



(b) Top view of the geometric model

Fig. 1. Physical models Cof the flow field.

The ANSYS ICEM™ program was used to establish a three-dimensional geometric model and mesh the model. Due to the regular geometric shape of the model, a structured mesh was selected and generated, as shown in Fig.2. To better capture the flow characteristics of the airflow, local mesh refinements with different densities were carried out on the sentry box, the slit air outlet, the source of pollutants, and the vertically attached walls where the windows are located.

2.2 Numerical details and boundary conditions

Simulations were performed using the ANSYS FLUENT™ (version 19.0) program based on the finite volume method. Because the gaseous pollutant NO_2 can be well mixed with the air and migrate with the air flow, it is reasonable to carry out the experimental verification of the simulated flow field. We have demonstrated in a previous study[14] that the Realizable k-ε turbulence model is in good agreement with the experiments, so it is adopted. NO_2 can exist stably in the air, so the species transport model was adopted.

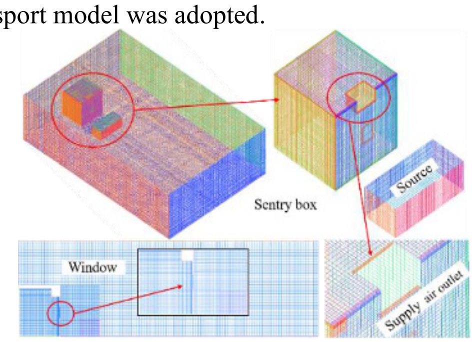


Fig. 2. Grid details of sentry box space model.

The boundary conditions are slightly complicated since the flow field model includes two areas. The front side walls of the external flow field were set as velocity inlets to simulate upstream wind. Because the height of the sentry box is very small (2.5-2.8m above the ground), the simulated natural wind was set as a uniform incoming wind, and the wind speed was set as the average wind speed of the atmosphere in Xi'an, Shaanxi Province (1.7m/s). Taking NO_2 as the representative of gaseous pollutants, set the volume release source in the external flow field. Referring to the current vehicle emission standards stipulated in China, the emission intensity was set as the emission threshold value of one vehicle (0.035mg/m^3). The simulated boundary conditions are summarized in Table 1.

Table 1. Boundary conditions for CFD simulations.

Domain	Boundary	Conditions
Sentry box	Supply outlet (slotted-outlet)	Velocity inlet
	Return outlet	Velocity outlet
	walls	Adiabatic wall
	Window hole	Interface (interior)
External flow field	Front wall	Velocity inlet (1.7 m/s)
	Two sidewalls	symmetry
	Top wall	Moving wall (moving velocity is 1.7 m/s)
	Posterior wall	Pressure outlet
	Floor	Adiabatic wall

The parameters of calculation cases designed for different purposes are summarized in Table 2.

Table 2. Parameter design for simulation cases.

Case	Working mode	U_s (m/s)	T_s (°C)	Q_s (L/s)	Source
N-1	No ventilation	——	——	——	1
N-2		——	——	——	2
V-1	Vertical wall-attached Ventilation	0.5	Isothermal (27°C)	15	1
V-2		0.7		21	
V-3		1.0		30	
V-4		1.5		45	
V-5		2.0		60	
H-1	Horizontal wall-attached Ventilation	0.5	Isothermal (27°C)	15	1
H-2		0.7		21	
H-3		1.0		30	
H-4		1.5		45	
H-5		2.0		60	

3 Result and discussion

3.1 Natural intrusion of pollutants without indoor ventilation

Fig.3 shows the migration of NO_2 released by the outdoor emission source with the natural wind and the invasion of the sentry box through the window without indoor ventilation. It can be seen that the contribution levels of the emission sources at the two locations to the indoor pollutant concentration are equivalent in the steady-state. Indicating that if the outdoor pollution sources continue to emit pollutants, under the action of natural wind, a stable pollutant concentration level will eventually be formed in the sentry box over time. In this paper, only the emission of one vehicle is considered, the release rate of NO_2 source is only 35μg/m^3, but the average concentration of indoor NO_2 reaches 21μg/m^3 in the end. This means that for sentry box spaces, if there is no indoor air purification or ventilation device, the indoor air will be seriously polluted, threatening employees' health.

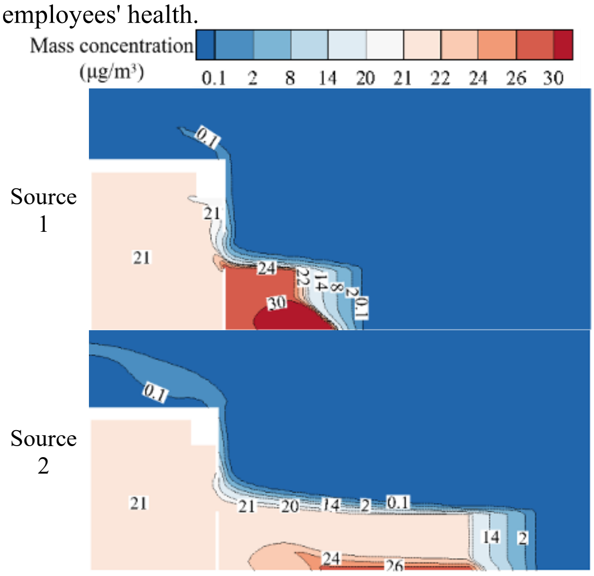


Fig. 3. NO_2 migration and intrusion without ventilation.

3.2 Inhibition of pollutants by ventilation

3.2.1 Vertical wall attachment - air curtain isolation

Considering the recovery and utilization of cooling and heating in practical applications, this paper simulates the situation with a return air treatment device, that is, the clean air after treatment is sent into the room. Fig. 4 shows the indoor velocity field and pollutant concentration field of the vertical wall-attached ventilation at different air supply velocities. After the flow is stable, compared with no ventilation, even with a small supply airflow rate (Q_s=15 L/s), the indoor air quality can be greatly improved. The concentration distribution of NO_2 shows that when the U_s is 0.5 m/s, the outdoor pollutants will still float into the sentry box with the natural wind and mainly enter from the lower edge of the window. Analysing the corresponding flow field, the possible reason is that the air supply velocity is too small. And with the attenuation of momentum, it gradually cannot compete with the interference of outdoor wind.

When the U_s was increased to 1.0 m/s and 2.0 m/s, the flow field distribution showed that the airflow could cover the window hole smoothly, and after passing the window, it was attached to the wall again, so the indoor NO_2 concentration was further reduced. However, the concentration of indoor NO_2 is not zero as imagined. The reason is that the attached jet will entrain the air outside the window at the window hole, causing part of the NO_2 to be drawn into the room. Although the air curtain formed by the vertical wall attached can cover the window; because the clean air is supplied, it may be inaccurate to attribute the improvement of the indoor environment to the air curtain, and more information is needed.

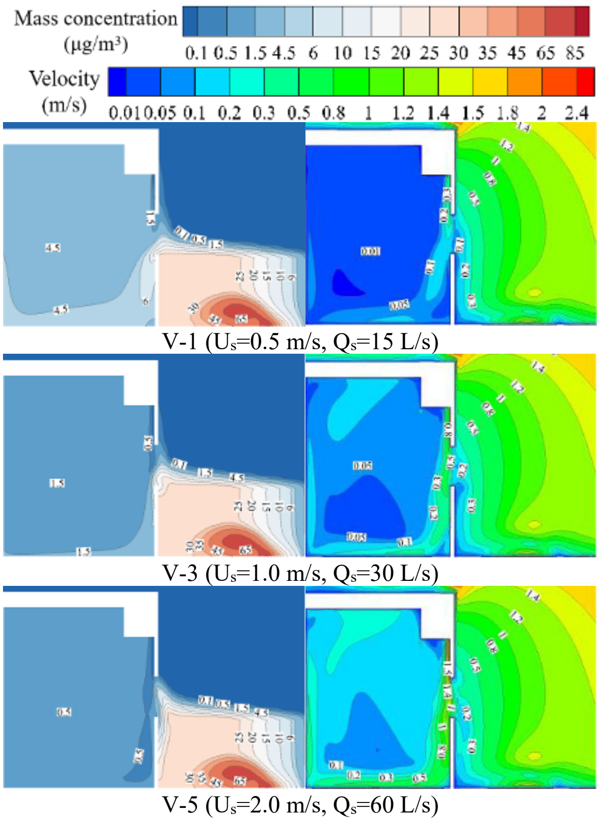


Fig. 4. Pollutant and flow field distribution in vertical wall-attached ventilation mode.

3.2.2 Horizontal wall attachment - fresh air dilution

The horizontal wall-attached ventilation mode is used to explore the reasons for indoor air quality improvement. Fig. 5 shows the indoor flow field and pollutant distribution formed by the horizontal wall-attached ventilation. Consistent with the vertical wall-attached mode, it can still improve the indoor environment even under a small supply airflow rate. But the inhibition mechanism of pollutants may be different. Outdoor pollutants can intrude into the sentry box through windows, and indoors have higher NO_2 concentration distribution near the windows, as shown in Fig.5. It shows that supplying air to the room to form positive pressure to control pollutants does not play a good role in low air supply (Q_s<30 L/s). The main reason for the lower indoor NO_2 concentration is the dilution of clean air, and the distribution of the velocity field also shows this.

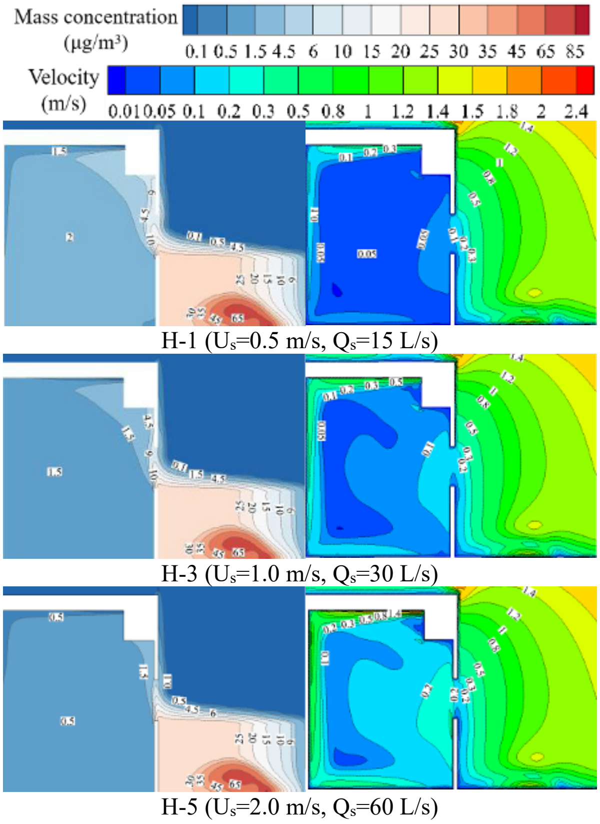


Fig. 5. Pollutant and flow field distribution in horizontal wall-attached ventilation mode.

3.3 Discussion on airflow distribution design

The above analysis shows that the two ventilation mods are not the same as the reasons for indoor air quality improvement. Fig. 6 summarizes the variation of NO_2 concentration in the room and window face with the supply airflow rates. The dimensionless concentration, C_n, is equal to the measured concentration divided by the source release rate.

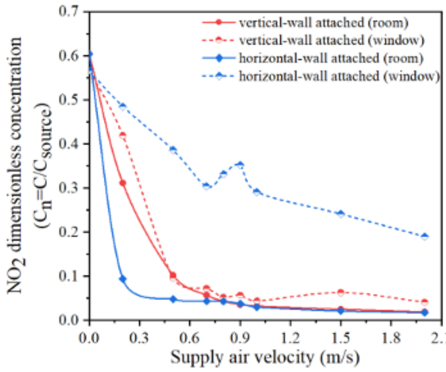


Fig. 6. Variation of NO_2 concentration in indoor and window with supply airflow rates under two air supply modes.

It can be seen from Fig. 6 that when U_s is less than 1.0 m/s, the vertical wall-attached mode is slightly less effective in inhibiting NO_2 than the horizontal wall-attached due to slight entrainment. After increasing U_s, a complete air curtain can be formed to block the intrusion of pollutants. Setting an air curtain is a good solution if the clean air cannot be continuously supplied to the room. By comparing the indoor NO_2 concentration, it can also be found that there is an upper limit for the dilution effect. When the supply airflow rate exceeds 15 L/s, it is almost useless even if the supply airflow rate is increased. The comparison of NO_2 concentration at the window shows that the air curtain formed by the vertical wall-attached model does have a blocking effect. In the horizontal wall-attached mode, the window has a higher concentration, which proves that only maintaining the positive indoor pressure to inhibit the intrusion of pollutants is limited.

4 Conclusions

This paper uses two attached ventilation modes to explore the ventilation design scheme for air quality improvement in the sentry box with openings. The conclusions are as follows:

(1) If clean air can be continuously supplied to the room, a small supply airflow rate can improve the indoor air quality very well. For the sentry box model in this paper, only Q_s>15 L/s are required.

(2) The air curtain formed by the vertical wall attached ventilation at the window hole can block the intrusion of pollutants, but the premise is that the air supply momentum is sufficient to form the attached flow of the airflow.

(3) Compared with vertical wall-attached, the mechanism of horizontal wall-attached ventilation to improve indoor air quality is dilution and positive pressure control, but positive pressure control depends on the air supply volume, and its effect may be limited in the case of large openings.

References

1. Z. Luo, Z. Wang, H. Wang, H. He, Z. Peng, Build Environ. **199**, 107933 (2021)
2. P. Tsai, T. Shih, H. Chen, W. Lee, C. Lai, S. Liou, Atmospheric Environ. **38**, 333-343 (2004)
3. R. Diab, S. Foster, K. François, B. Martincigh, L. Salter, Environ Chem Lett. **3**, 91-94 (2005)
4. A. Sapkota, D. Williams, T.J. Buckley, Environ. Sci. Technol. **39**, 2936-2943 (2005)
5. H. Yang, C. Qi, L. Liu, F. Jin, B. Yan, Journal of Southeast University. **26**, 307-310 (2010)
6. S. Chong, N. Gao, T. Wang, Build Environ. **63**, 69-78(2013)
7. F.C. Hayes, W.F. Stoecker, Y. Kim, Magazine of the Sarek. **11**, 40-45(1972)
8. M. Havet, O. Rouaud, C. Solliec, International Journal of Heat & Fluid Flow. **24**, 928-930 (2003)
9. S. Yang, H. Alrawashdeh, C. Zhang, D. Qi, L. Wang, Build Environ. **151**, 75-87 (2019)
10. C. Shu, L. Wang, C. Zhang, D. Qi, Build Environ. **169**, 106582.1-106582.11 (2020)
11. S. Liu, Q. Cao, X. Zhao, Z. Lu, Z. Deng, J. Dong, X. Lin, K. Qing, W. Zhang, Q. Chen, Build Environ. **180**, 107016 (2020)
12. A. Li, Indoor Built Environ. **28**, 437-442 (2019)
13. H. Yin, W. Zhang, A. Li, Int. J. Vent. **10**, 383-390 (2012)
14. H. Yin, Y. Li, D. Zhang, Y. Han, J. Wang, Y. Zhang, A. Li, Build Simul. (2022)