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Experimental study on indoor environment improvement in toll booth by personalized ventilation technology

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Abstract: The necessity and feasibility of the use of the personalized ventilation (PV) technology in a toll booth is described. First, the indoor environment of the toll booth equipped with a PV system is analyzed. Based on the analysis results, a set of equipment for controlling the indoor air quality (IAQ) of the toll booth is devised. Then, a full-scale model of the toll booth is set up in the laboratory. The airflow organization, the optimum operation parameters, and the restraint effects of the PV system on pollution are also experimentally studied. The experimental results on the air supply characteristics show that the PV system can effectively reduce the air age, improve the ventilation efficiency, and enhance the comfort and acceptability of human beings. In addition, this system plays a significant role in preventing pollution.

Key words: personalized ventilation (PV); indoor air quality (IAQ); toll booth; pollution

In recent years, along with the great development of highway construction in China, the increase in vehicle exhaust pollution has become a serious problem, especially to those working in highway toll booths with poor ventilation. These workers inhale large amounts of harmful vehicle exhaust, road dust and other toxic substances in the surroundings[1-2]. At present, fans or split air conditioners are the most popularly used equipment to regulate air temperature in most highway toll booths. However, the improvement of the indoor air quality (IAQ) has not yet been taken into account[3-4]. Air supply is polluted by toxic materials and effluents before being inhaled by the workers in toll booths. Therefore, it is necessary to improve the working environments in toll booths. As a newly developed technology, the personalized ventilation (PV) technology, in which air inlets are placed near the location of the staff, has been paid much attention to. The PV technology can reduce the interior cold/heat load to save energy and improve the inhaled air quality and the local thermal environment[5]. It is verified that the PV technology has good application prospects in highway toll booths. This work attempts to improve the indoor air quality of toll booths by adopting a PV system.

1 Experiment System

In order to study the effects of the PV technology on the improvement of human thermal comfort and the control of pollution, a full-scale model of a toll booth is set up in the School of Energy and Environment of Hebei University of Technology (see Fig. 1).

Fig. 1 Full-scale model of toll booth

The experiment is carried out in a steel frame structure with a size of 2.2 m × 1.5 m × 2.2 m. The wall consists of two layers of wood-based panels, and the interlayer between the two layers is filled with a kind of foam-insulating material. Tempered glass is used in the upper part of the wall to facilitate observation. A wood desk, a chair and a computer are arranged in the experimental chamber. A split air-conditioner, whose input power is 1.5 horsepower (1.1 kW), is placed near the left wall facing the desk, and the personalized air inlet is installed on the desk. The layout of the toll booth model is shown in Fig. 2.

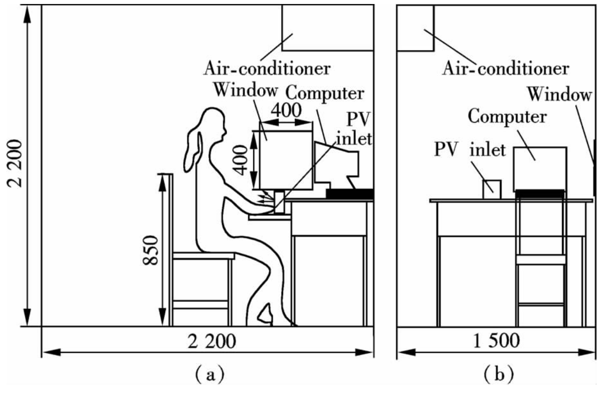

Fig. 2 Layout of toll booth model (unit: mm). (a) Front view; (b) Side view

According to the actual characteristics of the highway toll booth, the indoor environment of the toll booth is regulated and controlled by the PV system and the air conditioning system. The air handling system can be divided into two independent ones: the internal circulation system and the fresh air supply system. The indoor air is handled by the split air-conditioner in the internal circulation system. The internal circulation system can compensate for the cold load and the moisture load of the heat losses from the surrounding protec-

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tion structures, indoor occupants, apparatus and lighting. The internal circulation system guarantees low indoor air temperature and humidity. On the other hand, the PV technology is introduced into the fresh air supply system including fresh air handling units, fans, air ducts and indoor outlets. Through the filtration process and the temperature and humidity treatment of the outdoor air, fresh air can be supplied directly to the breathing zone by an air terminal device (ATD). This system is used to save energy and improve the quality of the inhaled air and the individual's microenvironment.

2 Air Supply Characteristics

2.1 Experimental environment

A personalized fresh air supply can drive away harmful gases and reduce the cold load and the moisture load. Hence, the scientific rationality of the design of the ATD has a great impact on the reasonable distribution of the air supply and the effective control of parameters in any fixed zone. Besides the air supply characteristics of the ATD, the air temperature and the wind velocity around a human body, especially in the breathing zone, are measured to test the system performance.

The experimental study is carried out in the neutral-hot environment. In the neutral-cold environment, the air flow can lower the environmental assessments of the users and may cause a sensation of dryness. Based on the ASHRAE 55—1992, the temperature at the starting point is set to 26 ℃ to offset the temperature rise effects. Taking the habits of the majority of users into account, the background temperature is set to 24 ℃ under the experimental conditions. In addition, in a normal working environment, a higher background temperature may cause a higher air velocity or a lower air temperature. The difference between the local environmental temperature and the background temperature is great, which can reduce the overall environmental assessment of the occupants. Hence, the maximum background environment temperature is set to 28 ℃. To study the PV technology, experiments are carried out when the background temperatures are 24, 26, 28 ℃, respectively [6-8]. The air supply temperature should not be lower than 18 ℃ to prevent an uncomfortable sensation of dryness. Accordingly, the minimum air supply temperature is set to 20 ℃. Considering the narrow interior space, a large design air supply volume can sharply increase the energy consumption of fresh air handling and reduce the system operation costs. Therefore, the maximum air flow in this experiment is set to 50 m^3/h. The test conditions are listed in Tab. 1.

Tab. 1 Test conditions

Condition	Background temperature/℃	Fresh air temperature/℃	Outdoor air volume/($m^3 \cdot h^{-1}$)
1	28	24	30
2	24	21	50
3	28	24	50

The air temperatures and the air velocities around the human body and the window are tested under the three test conditions. The layout of the testing points is shown in Fig. 3.

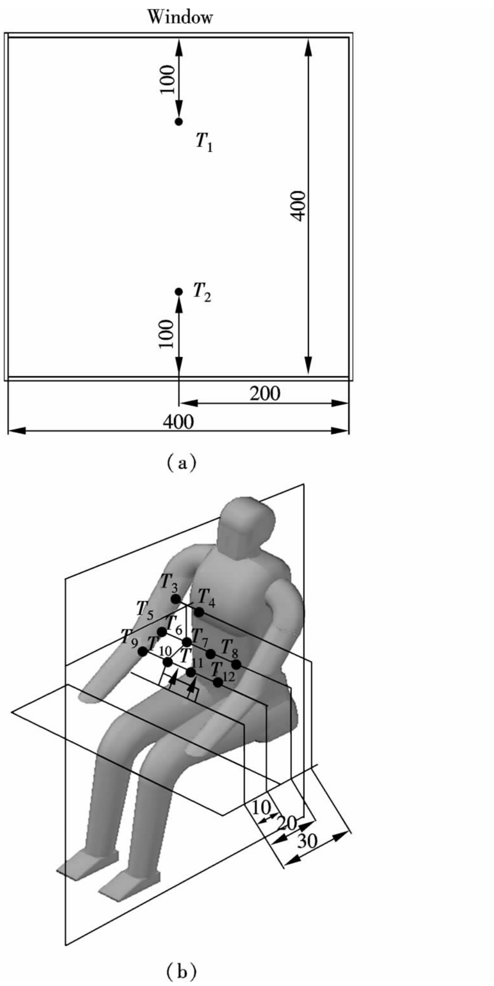

Fig. 3 Layout of testing points (unit: mm). (a) Near the window; (b) Near the human body

2.2 Results and analysis

The results of the air temperatures and the air velocities under the three test conditions are shown in Fig. 4. It can be seen that the background temperature and the fresh air temperature have a great impact on the temperature distribution around the human body. In addition, when the difference between the background temperature and the fresh air temperature is great, the temperature distribution around the human body is uneven. Such an uneven temperature distribution is mainly caused by the inaccessible air flow. And the maximum velocity difference is 0.5 m/s.

The system can supply fresh air directly to the breathing zone of the staff. The maximum velocity near the front of the human body is about 0.5 m/s. The air velocity around the face ranges from 0.15 to 0.2 m/s if the air outlet valve is adjusted properly. Furthermore, a direct supply of the fresh air in the front of the human body can help improve the air exchange rate and reduce the air age. Based on this design, the PV system ensures a direct and effective delivery of chilled fresh air to the breathing zone while maintaining a uniform temperature field distribution.

3 Air Quality Measurement

In order to understand the effects of the PV system on the indoor air quality of the toll booth, the air quality is meas-

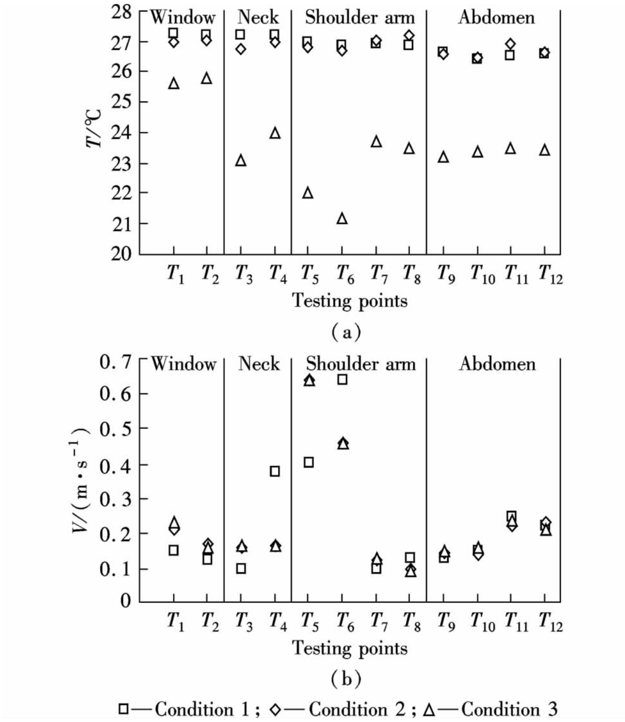

Fig. 4 Experimental results of temperature and velocity. (a) Temperature; (b) Velocity

ured in the toll booth from two aspects as follows [9-11].

3.1 Effect of PV system on volume fraction distribution of pollutant

Take CO as a sample. The volume fraction of CO is maintained at a specific value before the PV system works. By measuring the volume fraction of CO in typical locations, the effect of the PV system on the volume fraction distribution of the pollutant is identified. The typical measuring points shown in Fig. 5 are used to investigate the air velocities in the working zone (near the human body) and the breathing zone. The Q-TRAK plus IAQ monitor is used to measure the indoor air quality and the volume fraction of CO at the measuring points. Two sets of experiments are carried out separately to study the variations in the volume fraction distribution of the pollutant at the typical measuring points.

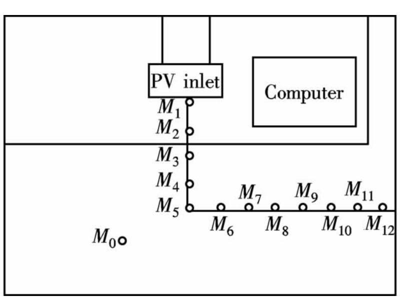

Fig. 5 Typical measuring points

In the first set of experiments, the results show that when the initial volume fraction of CO is about 0.004%, the volume fraction decreases to 0.001% after 15 min, which is lower than the value of the national standards. The volume fraction curve is shown in Fig. 6.

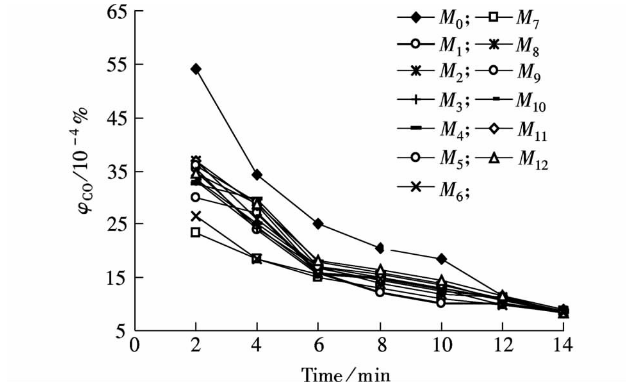

Fig. 6 Volume fraction curves of CO at different measuring points

In the second set of experiments, the volume fractions of CO at the first measuring point with different air volumes (30 and 50 m^3/h) are tested. The results shown in Fig. 7 demonstrate that the air age is relatively small when the air supply volume is large. Moreover, it is shown that the effect of the air supply volume is obvious during the initial 8-min period. With the decrease in the volume fraction of CO, the slope of the curve decreases, indicating that the dilution effects of the PV system becomes increasingly saturated in the breathing zone. When the volume fraction of CO reaches the average level in the room, the fresh air plays a role in inducing the indoor air into the circulation.

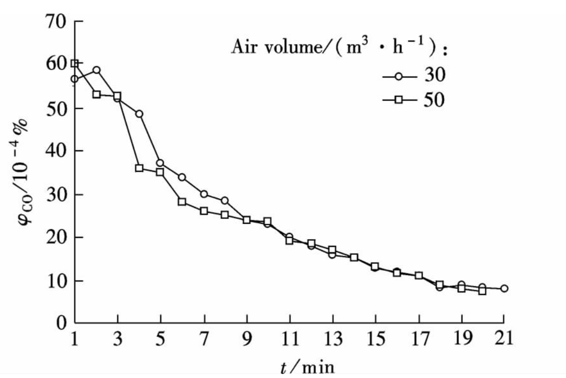

Fig. 7 Volume fraction curves of CO with different air volumes

3.2 Inhibition effect of PV system against pollution

To demonstrate the inhibition effect of the PV system on the intrusion of external pollutants through the windows, a tracer gas method is used to observe the air flow pattern in the toll booth under two different conditions, the steady running condition and the off-state condition (see Fig. 8). The air supply volume is set at 30 m^3/h, and the outlet location is fixed. The air current is in a disorderly flow condition when the PV system is under the off-state condition, which causes a mass transfer in the window section and inevitably induces polluted air into the toll booth. While the PV system is running, the air flow gradually disperses outside the toll booth through the window because of the slightly positive pressure, which can help prevent the polluted outdoor air from entering the toll booth. When the PV system does not work, the tracer gas from the source always enters the toll booth through the window within a certain depth. Nevertheless, while the PV system is running, the tracer gas spreads out through the window. The experimental results qualitatively show that the PV system can impact the air near the inside and the outside of the window. In addition, the air supply volume plays a good role in inhibiting the intrusion of outside pollutants through the window.

(a) (b)

Fig. 8 Air flow under different conditions. (a) Under off-state condition; (b) Under running condition

4 Conclusion

The improvement of the IAQ and human comfort in a highway toll booth model by the PV technology is experimentally studied in this paper. The influence factors on human comfort, such as the background temperature and the air supply temperature, are investigated. In addition, the objective evaluation and the subjective evaluation of the improvement effects of the PV technology on the IAQ of the toll booth are carried out. The results show that the PV technology can prevent outdoor pollutants from entering the toll booth. Furthermore, it can also significantly improve the IAQ in the breathing zone and the working zone.

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PV 技术改善收费亭室内环境的实验研究

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摘要:阐述了特定的公路收费亭环境下应用个性化通风(PV)技术的必要性和可行性.首先,分析了加装个性化通风系统的公路收费亭的室内环境,并基于分析结果,开发设计了一种收费亭内空气品质控制装置.然后,在实验室搭建了等尺度的模拟收费岗亭,研究了亭内气流分布状况、设备最佳运行参数以及个性化通风系统对污染物的抑制效果.系统送风特性的实验研究结果表明,个性化送风系统可以有效缩短空气龄,提高送风效率,提升人体舒适性和用户接受程度.此外,该系统还能有效抑制污染物的侵入.

关键词:个性化通风(PV);室内空气品质(IAQ);收费亭;污染

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