Analyzing the energy-saving effect of the low-level wall-exhaust ventilation system in restroom

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Abstract. For responding the policy call of building a green and low-carbon society and meeting the goal of economizing energy and reducing emission in the process of construct. The troditional ceiling-exhaust ventilation system in restroom should be replaced by the new low-level wall-exhaust ventilation system for better exhaust effect and less air changes per hour which help in solving the existing problems, such as excessive design value of air changes per hour, serious heating/cooling loss and so on.

The optimal interval of air change rate corresponding to the low-level ventilation system is analysed here based on the national health standards. The models of restroom with the new low-level wall-exhaust ventilation system are established by SketchUp software, and the air distribution in the restroom is simulated by Computational Fluid Dynamics software. The analyses of simulation results show the new prefabricated underneath ventilation system can display competently when the air change rate between 10 and 15 times, which reduce about 50% energy compared with 20 air change times in the traditional ventilation system design.

Keywords: low-level wall-exhaust ventilation system, air changes per hour, CFD simulation, low-carbon

1 Introduction

The conventional ventilation system of the restroom mostly adopts the full ceiling-exhaust system, that is, an exhaust fan or air outlet is set on the top of the restroom to exhaust odor in the toilet, but the effect of this exhaust system is often unsatisfactory.

To make the air quality in the toilet meet the national first-class health standard, the ceiling-exhaust ventilation system needs to be designed with 20 air changes per hour, which causes a great waste of heat and cooling capacity inside the building. This practice is not conducive to energy conservation and emission reduction in the building operation, and does not meet the policy call of building a green and low-carbon society.

In addition, the air inlet volume and the wind speed at the door is too high by the negative pressure between the toilet and the building inside, which is easy to make restroom users feel uncomfortable.

In the existing patents, there are also some inventions to discharge the odor in or near the toilet which propose to set vent holes and ventilation channels inside the toilet and squatting toilet, connect the fan to discharge the gas, and control the fan switch through the human body sensor to deodorize from the source. However, these inventions bind the toilet ventilation system with the toilet utensils in the toilet, which limits the selection of products in the process of toilet design, but is not conducive to the wide application of this exhaust concept, [1-6].

Therefore, this paper innovates and optimizes the air outlet position, exhaust mode, system installation and other aspects from the perspective of reforming the toilet ventilation system. so that the traditional toilet can be easily transformed into a sanitary room with low-level exhaust ventilation system with better ventilation effect and less energy consumption.

2 Model establishment and simulation preparation

2.1 Basic physical model

1). The model size of the toilet is 5.35mx6.05mx3.0m, and the size of the door is 1.8mx3.0m. The size of single compartment is 1.2mx1.8mx2.1m (actual size of restroom in Xianyang International Airport Terminal T5).

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2). Exhaust air vents: one air vent at the ceiling and nine air vents at the low-level place. The size of the air vents is 0.2mx0.2m. The bottom of the air vents at the urinal is 1.45m away from the ground and 0.35m away from the water tank in the toilet compartment.
3). The partition of squatting positions is 0.15m away from the ground base plate (taken from the previous reference), and the base plate is 0.1m high.
4). The size of the pollution source inlet of the urinal is simplified to 0.25mx0.25m; The size of the pollution source inlet of the toilet is simplified to 0.5mx0.2m.

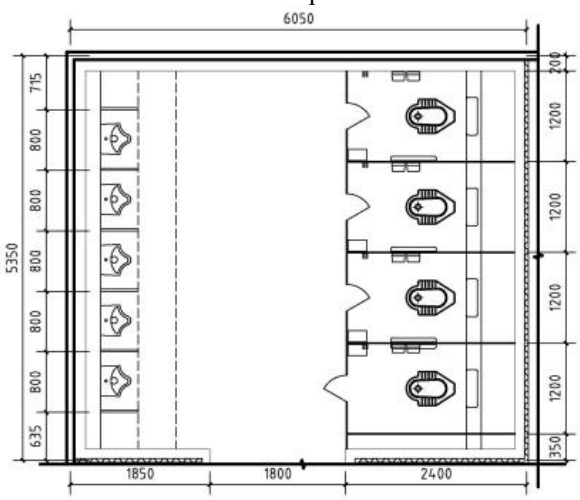


Fig. 1. physical model of restroom.

2.2 CFD Model establishment

2.2.1 Analog parameter setting

In this paper, it is assumed that all sanitary appliances emit polluted gas at the same time (the most unfavorable situation), the implicit solver based on pressure based is selected, and the selection standard of turbulence model is k-ε.
At the same time, open the component transport model. The standard numerical solution method adopts the finite volume method, the simple algorithm and the second-order upwind discrete scheme.
It is assumed that the pollutant gas is a constant physical property and incompressible gas. Natural convection is mainly caused by buoyancy. Select the full buoyancy option and ignore the influence of radiation heat transfer in restroom.

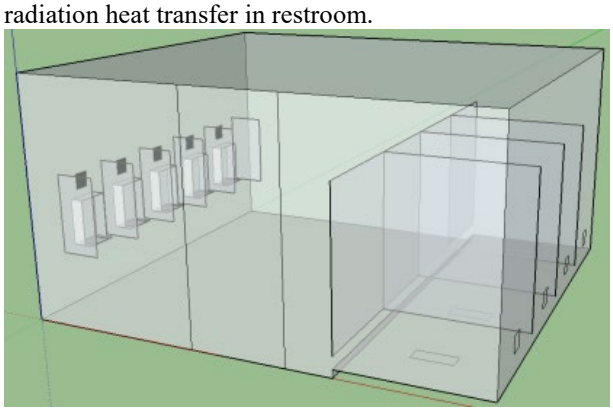


Fig. 2. The restroom picture of simulation model.

2.2.2 Boundary condition setting

1). speed boundary condition: set the air supply outlet as the speed inlet boundary condition, and the exhaust outlet as the speed outlet boundary condition.
2). free outflow: set the door opening as the free outflow boundary.
3). wall boundary conditions: set the walls and partitions around the room as wall boundary conditions
4). Boundary conditions of pollution source release: set the pollution source as the velocity inlet, the ammonia release rate of the toilet is 0.1m/s, the ammonia concentration is 0.000005kg/m^3, the hydrogen sulfide release rate is 0.1m/s, and the hydrogen sulfide concentration is 0.00002kg/m^3, the ammonia release rate of urinal is 0.1m/s, and the ammonia concentration is 0.000005kg/m^3.
5). The supply air volume is 85% of the exhaust air volume, 10% of the ceiling exhaust vent and 90% of the low-level wall-exhaust vent. The exhaust air volume at the urinal accounts for 20% of the lower exhaust air volume.

3 Simulation results and discussion

3.1 Effect of ventilation times on the overall concentration of pollutants

1). Change diagram of pollutant gas average concentration with ventilation times at respiratory plane (z = 0.9m, z = 1.5m) in restroom:

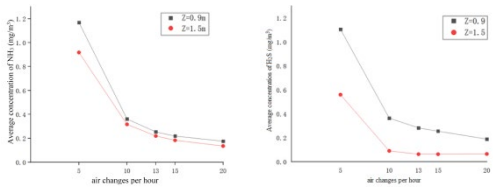


Fig. 3. Schematic diagram of concentration change .

Analysis: as shown in the figure, when the times of air changes increases, the average concentration of NH_3 and H_2S at the respiratory plane is decreasing, and the decreasing range is decreasing. Therefore, it is not economical to blindly pursue the ventilation method of increasing the number of air changes. Taking a value in 10-15 times can bring satisfied air quality.
2). Average concentration of pollutants in the restroom:

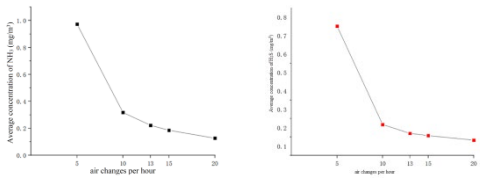


Fig. 4. Schematic diagram of concentration change.

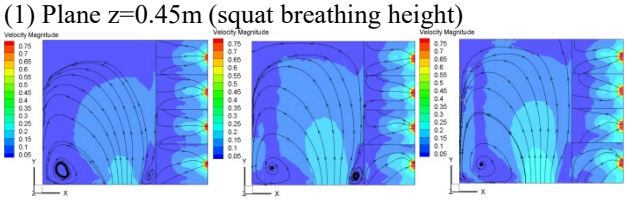
Analysis: as shown in the figure, when the times of air changes increases, the average concentration of NH_3 and H_2S in the whole restroom is decreasing, and the decreasing range is shrinking. Therefore, it is also proved that we cannot blindly pursue increasing the number of air changes, and the value can be taken in 10-15 times.

3.2 Analysis of simulation results under different air change rate

3.2.1 Velocity cloud chart

Analyzing the influence of air change rate on gas flow velocity in different height planes, so as to preliminarily understand the air distribution in the toilet.

(1) Plane z=0.45m (squat breathing height)

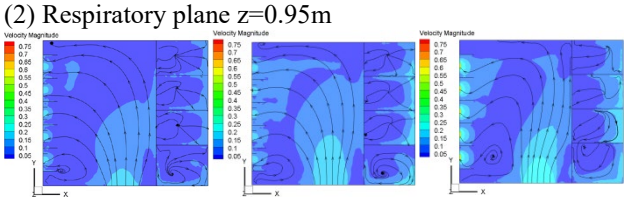


(a) 10 times (b) 13 times (c) 15 times

Fig. 5. Velocity cloud chart on plane z=0.45m.

Analysis: with the increase of ventilation times, the wind speed of door opening make-up air increases, and the flow velocity on this plane increases obviously. With the increase of air velocity at the exhaust port, the control effect of pollutants increases.

(2) Respiratory plane z=0.95m

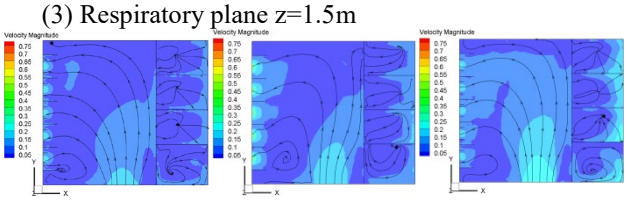


(a) 10 times (b) 13 times (c) 15 times

Fig. 6. Velocity cloud chart on plane z=0.95m.

Analysis: with the increase of ventilation times, the wind speed of make-up air in the door opening increases, the jet distance of make-up air flow increases, and the flow velocity on this plane increases obviously.

(3) Respiratory plane z=1.5m

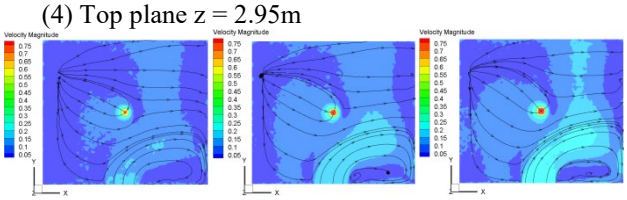


(a) 10 times (b) 13 times (c) 15 times

Fig. 7. Velocity cloud chart on plane z=1.5m.

Analysis: with the increase of ventilation times, the wind speed of door opening make-up air increases. The flow velocity on the whole plane increases obviously, the flow velocity at the urinal increases obviously, and the control effect on pollutants is strengthened.

(4) Top plane z = 2.95m



(a) 10 times (b) 13 times (c) 15 times

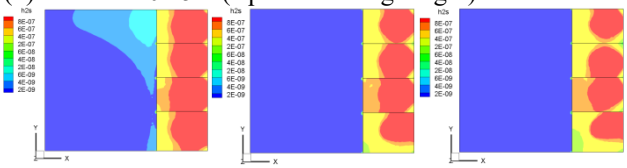
Fig. 8. Velocity cloud chart on plane z=2.95m.

Analysis: the top space on the right side of the door opening intersects with the air flow flowing in the positive x direction at the top, resulting in eddy current. And with the increase of ventilation times, the wind speed of door opening make-up air increases. The velocity increases obviously on the whole plane. And with the increase of exhaust wind speed at the top exhaust outlet, the control effect on the top pollutants is also enhanced.

3.2.2 H_2S mass fraction cloud chart:

Analyzing the influence of ventilation times on H_2S concentration distribution on each height plane, so as to determine the minimum ventilation times under sanitary standards.

(1) Plane z = 0.45m (squat breathing height)

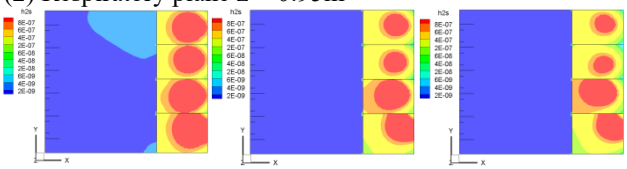


(a) 10 times (b) 13 times (c) 15 times

Fig. 9. H_2S mass fraction cloud chart on plane z=0.45m.

Analysis: at this height, H_2S has just entered the toilet from the toilet, so the concentration is very high, and it can be seen that H_2S flows to the back wall of the compartment under the action of the exhaust outlet at the toilet. With the increase of ventilation times, H_2S concentration also decreases significantly.

(2) Respiratory plane z = 0.95m

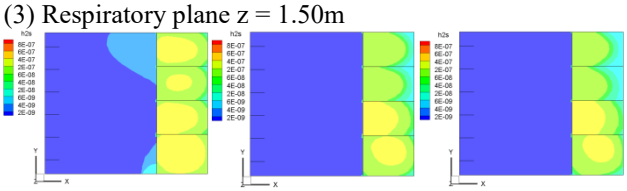


(a) 10 times (b) 13 times (c) 15 times

Fig. 10. H_2S mass fraction cloud chart on plane z=0.95m.

Analysis: with the increase of ventilation times, the H_2S concentration on this plane decreases, and the H_2S concentration outside the compartment is small. It can also be seen that under the action of the exhaust outlet under the toilet, H_2S gas flows to the back wall and flows to the exhaust outlet. From the mass fraction distribution of H_2S gas in different compartments, the two compartments close to the door opening are more obviously affected by the make-up air flow.

(3) Respiratory plane z = 1.50m



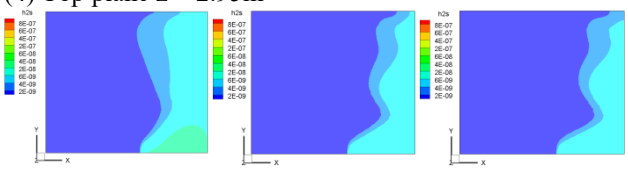
(a) 10 times (b) 13 times (c) 15 times

Fig. 11. H_2S mass fraction cloud chart on plane z=1.50m.

Analysis: with the increase of ventilation times, the H_2S concentration on this plane decreases, and the H_2S concentration outside the compartment is small. It can also be seen that compared with the plane of Z = 0.9m, since z = 1.5m is far from the lower exhaust outlet of

the toilet, the H_2S concentration decreases significantly; H_2S not discharged from the lower air outlet of the toilet accumulates on this side of the compartment door.

(4) Top plane z = 2.95m



(a) 10 times (b) 13 times (c) 15 times

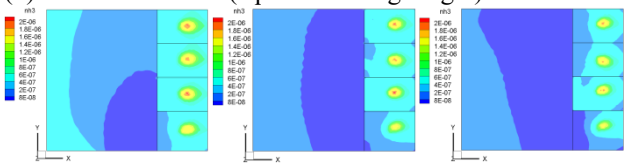
Fig. 12. H_2S mass fraction cloud chart on plane z=2.95m.

Analysis: even if H_2S diffuses to the top of the toilet, the H_2S concentration distribution at this height will decrease with the increase of ventilation times.

3.2.3 NH_3 mass fraction cloud chart:

Analyzing the influence of ventilation times on NH_3 concentration distribution on each height plane, so as to determine the minimum ventilation times under sanitary standards.

(1) Plane z = 0.45 m (squat breathing height)

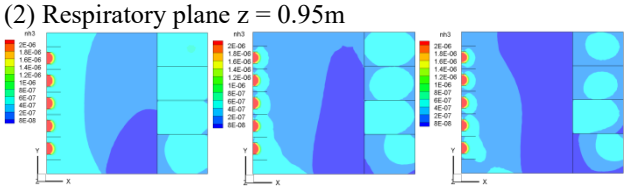


(a) 10 times (b) 13 times (c) 15 times

Fig. 13. NH_3 mass fraction cloud chart on plane z=0.45m.

Analysis: at this plane, NH_3 is mainly distributed in the compartment, and a small part is distributed on one side of the urinal (gradually decreasing with the increase of ventilation times). The NH_3 concentration in the compartment decreases with the increase of ventilation times, and flows to the back wall side of the compartment and is discharged by the exhaust outlet at the toilet.

(2) Respiratory plane z = 0.95m

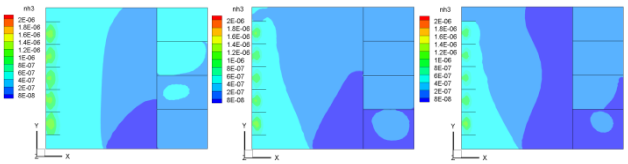


(a) 10 times (b) 13 times (c) 15 times

Fig. 14. NH_3 mass fraction cloud chart on plane z=0.95m.

Analysis: on the side of the urinal, NH_3 has just entered the toilet from the urinal, so the concentration is very large. It can be seen that when the ventilation times increase, the NH_3 concentration also decreases significantly, and at this height, NH_3 is controlled near the urinal. The greater the ventilation times, the better the control effect. On the side of the toilet, when the ventilation times increase, the NH_3 concentration also decreases significantly, and presents a circular diffusion from the central area to the outside.

(3) Respiratory plane z = 1.50m

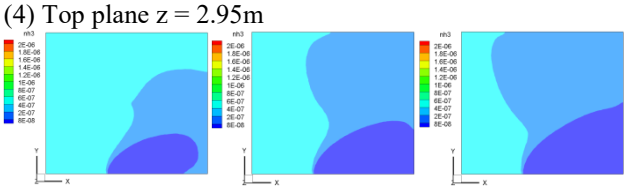


(a) 10 times (b) 13 times (c) 15 times

Fig. 15. NH_3 mass fraction cloud chart on plane z=1.50m.

Analysis: on the side of the urinal, NH_3 flows into the exhaust outlet of the urinal, so the concentration is large. It can be seen that when the ventilation times increase, the NH_3 concentration also decreases significantly. The greater the ventilation times, the better the control effect. NH_3 on the side of the toilet is small and is affected by the make-up air flow in the door opening. The concentration of polluted gas in the two compartments close to the door opening is less than that in the two compartments away from the door opening.

(4) Top plane z = 2.95m



(a) 10 times (b) 13 times (c) 15 times

Fig. 16. NH_3 mass fraction cloud chart on plane z=2.95m.

Analysis: at the top of the toilet, NH_3 concentration decreases significantly with the increase of ventilation times, and is mainly concentrated at the top of the toilet on one side of the toilet urinal by buoyancy force and mechanical force act together.

4 Conclusions

1). Through simulation and data analysis, it can be found that the wall-exhaust system proposed in this paper has better ventilation effect than the traditional ceiling-exhaust system.

2). It can be seen from the H_2S cloud chart that with the increase of height, the gas concentration gradually decreases, under 13 air change rate, the H_2S concentration at 1.5m, the standing breathing height, can be reduced to less than 0.01mg/m^3 specified in the standard.

3). From the NH_3 cloud chart. We can see the NH_3 concentration at 0.9m in the squatting position and at 1.5m at the urinal can be reduced to less than 0.3 specified in the standard at under 13 air change rate.

The effective air change rate of the wall-exhaust system can be preliminarily set as 13 times, which can effectively reduce the exhaust energy loss by about 50%.

4). With the increase of ventilation times, the wind speed of door opening make-up air increases. The flow velocity on the whole plane increases obviously, the flow velocity at the urinal increases, and the control effect on pollutants is enhanceed.

5). The wall-exhaust technology has been applied in terminal T5 of Xianyang International Airport, and the actual application effect brought by 13 air changes will be measured in the follow-up field.

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