Preplanned Studies

Neglected Aspects of SARS-CoV-2 Aerosol Transmission in Bathrooms of Multistory and High-Rise Buildings — Beijing Municipality, China, October 2022

Keyang Lyu[1]; Qin Wang[1]; Xia Li[1]; Zhuona Zhang[1]; Xiaoning Zhao[2]; Yunpu Li[1]; Zhigang Tang[1]; Longjian Li[3]; Fuchang Deng[1]; Xiaoyu Zhang[1]; Kaiqiang Xu[1]; Rong Zhao[4,#]; Dongqun Xu[1,#]

Summary

What is already known about this topic?

There is a toilet flush-soil stack-floor drain pathway of aerosol transmission in multistory and high-rise buildings, but the influencing factors are not completely clear.

What is added by this report?

The poor airtightness of the connecting parts of the floor drain, as well as pressure fluctuations in the sewage pipe during toilet flushing caused by blockage of the soil stack vent, may lead to the cross-floor transmission of viral aerosols through the soil stack and floor drains.

What are the implications for public health practice?

In multistory and high-rise buildings, the bathroom floor drains should be kept sealed, and floor drain connecting parts should be airtight. Furthermore, the soil stack vent should not be blocked. In this way, the cross-floor transmission of viral aerosols can be effectively reduced.

The vertical transmission of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) aerosols between building floors through the toilet flush-soil stack-floor drain route has been confirmed, but it is not fully understood (*1*–*3*). In a centralized quarantine apartment in Beijing, people with a positive SARS-CoV-2 nucleic acid test between September 29 and October 8, 2020 were quarantined in unit 02 and housed on multiple floors. The epidemiological investigation showed consistent genetic sequencing for all cases but ruled out the possibility of contact transmission during isolation and speculated that vertical transmission through the toilet flush-soil stack-floor drain route was possible. The field simulation experiment using fluorescent polystyrene microspheres as simulants found that the poor airtightness of the floor drain components, as well as the pressure fluctuation in the sewage pipe during toilet flushing caused by blockage of the soil stack vent, may have led to the cross-floor transmission of viral aerosols through the soil stack and floor drains in unit 02. During the coronavirus disease 2019 (COVID-19) pandemic, it is recommended that multistory and high-rise buildings maintain the water seals and ensure airtightness between the floor drain components. Furthermore, the soil stack vent should not be blocked. This will ensure pressure balance between the pipe and the atmosphere during toilet flushing and reduce pressure fluctuations in the pipe, in turn effectively eliminating cross-floor aerosol transmission.

The water traps were first removed from the floor drains to observe the pressure changed in the pipe. Experimental scenarios were set up to simulate viruses expelled in exhaled breath and in feces and urine. The bathroom fan was either turned on or off to simulate the situation of some individuals occasionally turning the exhaust fan off. Fluorescent polystyrene microspheres with aerodynamics similar to those of SARS-CoV-2 spike pseudoviruses were used to simulate the virus. Two scenarios, breathing and breathing with defecation with toilet flushing, were simulated in the bathroom of room 402. At the same time, monitoring and sample collection were conducted in bathrooms 502, 1002, 1902, and 2702, and experimenters were assigned to each bathroom to avoid personnel movement affecting the results. Both scenarios included two periods — when the bathroom exhaust fan was either on or off. Changes in the wind speed of the exhaust fan and floor drain, as well as the aerosol particle size spectrum (0.3–10 μm), were monitored in the bathrooms. PM_{10} filter membrane samples collected by medium flow PM_{10} samplers (100 L/min) and smear swab samples of the exhaust fan and floor drain were analyzed. The state of the exhaust fan and the arrangement of the toilet flushing in the two

scenarios are shown in Supplementary Tables S1–S3 (available in http://weekly.chinacdc.cn/). The experimental method was previously published (*4*–*5*).

The bathroom exhaust fans were connected to the exhaust duct through the exhaust branch pipe, and the exhaust gas was discharged through a centrifugal fan on the roof. Therefore, the wind speed could be measured without turning on the exhaust fan. The wind speed in the bathroom floor drain was significantly affected by toilet flushing. Compared with scenario 1, it significantly increased after toilet flushing (scenario 2) and decreased with fewer simultaneously flushed toilets. Representative changes in wind speed are shown in Supplementary Figures S1 and S2 (available in http://weekly.chinacdc.cn/).

In all bathrooms, with the increase of simulated breathing time and the number of toilet flushes, the concentration of the different particle sizes increased (Supplementary Figure S3, available in http://weekly.chinacdc.cn/). The simulants were observed in the filter membrane samples collected from room 502 in scenario 1 period 2 and scenario 2 period 1 and from all rooms in scenario 2 period 2. No simulant was observed in the other filter membrane samples or in the exhaust fan or floor drain samples (Table 1 and Figure 1).

DISCUSSION

The onsite investigation found that bathroom floor drains were connected with the horizontal wastewater branch, and the sewage and branches led to the soil stack. The floor drains were equipped with removable water traps, but all connecting parts were metal-to-metal contacts with a poor sealing effect (Supplementary Figures S4 and S5, available in http://weekly.chinacdc.cn/). In addition, there was a cavity between the trap, the outside pipe, and the horizontal wastewater branch. Therefore, the water trap in the floor drain was removed during the experiment. The exhaust fan was turned on and off in scenario 1. However, regardless of the use of the exhaust fan, the bathroom exhaust pipe on the roof continued to discharge strongly through the centrifugal

TABLE 1. The observation results of fluorescent polystyrene microspheres of samples collected in different rooms in 2 scenarios.

Room number	Scenario 1		Scenario 2	
	Period 1	Period 2	Period 1	Period 2
502	Not observed	Observed (filter membrane samples)	Observed (filter membrane samples)	Observed (filter membrane samples)
1002	Not observed	Not observed	Not observed	Observed (filter membrane samples)
1902	Not observed	Not observed	Not observed	Observed (filter membrane samples)
2702	Not observed	Not observed	Not observed	Observed (filter membrane samples)

Note: Two scenarios, breathing (scenario 1) and breathing with defecation with toilet flushing (scenario 2), were simulated in the bathroom of room 402. Both scenarios included two periods, only turn off the exhaust fans in rooms 1002 and 1902 during period 1, and turn on all exhaust fans during period 2. PM_{10} filter membrane samples [collected by medium flow PM_{10} samplers (100 L/min)], smear swab samples of exhaust fan and floor drain were collected from each room in each period.

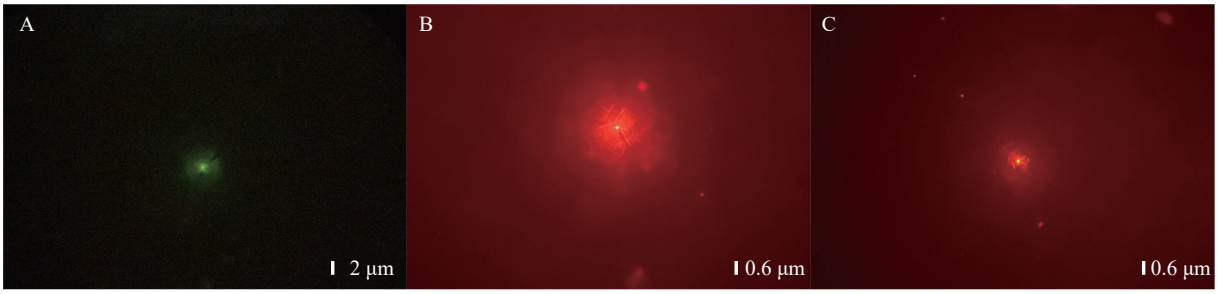

FIGURE 1. Representative photos of fluorescent microspheres collected by air samplers in different rooms in 2 scenarios. (A) room 502 during scenario 1-period 2, (B) room 502 during scenario 2-period 1, and (C) room 2702 during scenario 2-period 2.
Note: After simulating breath, defecation, and toilet flushing in room 402, fluorescent microspheres in filter membranes collected from experimental rooms were observed using fluorescent microscopy. Microspheres with different sizes are indicated in the photos.

fan. Even if the toilet was not flushed, aerosols could enter room 502, which was the closest to room 402, through the unsealed floor drain in the bathroom. However, owing to the increase in floor number and the relatively short experiment time (2 hours), the simulants were not able to enter bathrooms on higher floors.

The soil stack vent on the roof was equipped with filtration and disinfection devices and a centrifugal fan, making it impossible for air to move through the soil stack vent, which resulted in air pressure fluctuations when a toilet was flushed. When a toilet is flushed, there will be pressure fluctuations in the floor drains on all floors that are connected to the same soil stack (*3*,*6*). The use of a centrifugal fan to draw air upward increases the risk of damage to the floor drain water seal. When the toilet was flushed in room 402, simulants were observed in filter membrane samples collected in rooms 502, 1002, 1902, and 2702. This indicates that there is an aerosol transmission pathway from the toilet flush to soil stack to the floor drain.

Furthermore, even if the removable water trap is full in the unused floor drain that is reserved for the washing machine, pressure fluctuations that occur with the toilet flushing could make the viral aerosols turbulent within the soil stack, sewage pipe, and waste pipe. The aerosols could then accumulate in the cavity and spread to the bathroom through non-airtight floor drains. In the field experiment, simulants were found in all rooms that housed positive cases. This indicated that the poor sealing of the connecting parts of the floor drain and the pressure fluctuation in the sewage pipe during toilet flushing caused by blockage of the soil stack vent may have led to the cross-floor transmission of viral aerosols through the soil stack and floor drains, leading to cross-floor disease transmission.

In addition, although the centrifugal fan installed in the bathroom exhaust duct on the roof of the centralized quarantine apartment was kept on, it could only weakly discharge exhaust gas from bathrooms on the lower floors unless the exhaust fans were on. The weak discharge of exhaust gas was supported by the changes in the exhaust fan speeds and the aerosol particles still present in the air. The epidemiological investigation showed that some of the isolated individuals turned off the exhaust fan due to the noise. There was only one window close to the elevator in the corridor. When the window was not opened, the ventilation in the corridor was poor. The bathroom was close to the door of the room; if the exhaust fan was off, the viral aerosols in the bathroom could easily diffuse into the corridor and other rooms when the door was opened and closed for necessities such as nucleic acid testing, food delivery, and garbage removal, resulting in viral spread to adjacent rooms on the same floor. This possibility cannot be ruled out, and there have been previous reports of this phenomenon (*6*–*7*).

This field simulation study has some limitations. It was a qualitative study that only aimed to confirm the existence of an aerosol transmission pathway and did not investigate the risk of infection.

As more COVID-19 patients are quarantined at home, the following points are recommended for multistory and high-rise buildings: 1) In the bathroom, the floor drain reserved for the washing machine should be sealed with waterproof sealant. To ensure a water seal, a plastic bag filled with water needs to cover it, and another one should cover the floor drain of the shower area when not in use. 2) The soil stack vent should not be blocked; this will ensure pressure balance between the pipe and the atmosphere during toilet flushing, reduce pressure fluctuations in the pipe, and prevent damage to the floor drain water seal. If it is necessary to purify the exhaust gas, an electrostatic disinfection device can be installed at the exhaust port. 3) Ensure that the fresh air ventilation system of rooms without external windows is not blocked or closed, and do not block the bathroom exhaust duct or close the exhaust fan. 4) Strengthen health education for isolated individuals. They should open the windows regularly every day for proper ventilation and leave the bathroom exhaust fan on throughout their stay in quarantine. The toilet lid should be closed before flushing, and the water-filled plastic bag on the shower floor drain should be removed only when taking a shower. Management personnel should open the corridor windows regularly every day for ventilation.

Conflicts of interest: No conflicts of interest.

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[#] Corresponding authors: Rong Zhao, zhaorongbj@sina.com; Dongqun Xu, xudq@chinacdc.cn.

[1] Key Laboratory of Environment and Population Health, National Institute of Environmental Health, Chinese Center for Disease Control and Prevention, Beijing, China; [2] Division of Chemical Analysis, Biology and Medicine, Beijing Institute of Metrology, Beijing, China;

[3] Mentougou District Center for Disease Control and Prevention, Beijing, China; [4] Beijing Center for Disease Control and Prevention, Beijing, China.

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SUPPLEMENTARY TABLE S1. The scenarios and time periods in the simulation experiment.

Scenario	Period	Time (min)
1	1	0–60
1	2	70–130
2	1	140–200
2	1	210–270

Note: Two scenarios, breathing (scenario 1) and breathing with defecation with toilet flushing (scenario 2), were simulated in the bathroom of room 402. Both scenarios included two periods, only turn off the exhaust fans in rooms 1002 and 1902 during period 1, and turn on all exhaust fans during period 2.

SUPPLEMENTARY TABLE S2. The arrangements of breathing simulation and defecation simulation with toilet flushing in two scenarios.

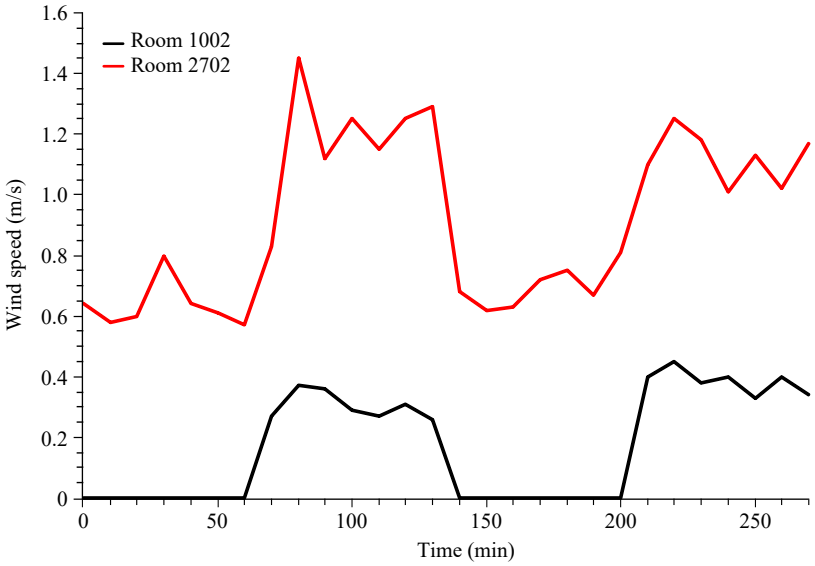
Time (min)	Room number				
	402	502	1002	1902	2702
0–60	B				
70–130	B				
140	B + D, F	F	F	F	F
150	B + D, F	F	F		F
160	B + D, F	F		F	F
170	B + D, F	F			F
180	B + D, F		F	F	
190	B + D, F		F		
200					
210	B + D, F	F	F	F	F
220	B + D, F	F	F		F
230	B + D, F	F		F	F
240	B + D, F	F			F
250	B + D, F		F	F	
260	B + D, F		F		
270					

Note: B means simulating breathing; D means simulating defecation; F means flushing the toilet.

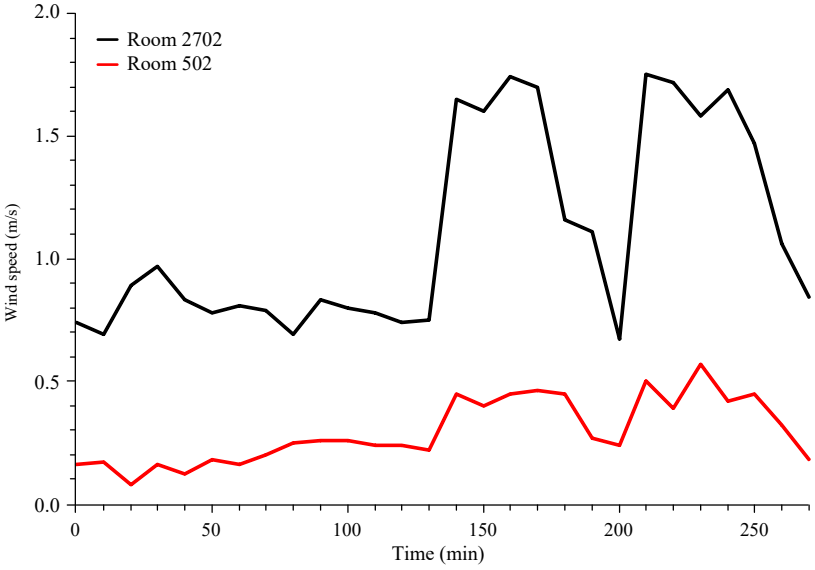
SUPPLEMENTARY TABLE S3. The states of exhaust fans of different rooms in different time periods in two scenarios.

Room number	Scenario 1		Scenario 2	
	Period 1	Period 2	Period 1	Period 2
402	On	On	On	On
502	On	On	On	On
1002	Off	On	Off	On
1902	On	On	On	On
2702	Off	On	Off	On

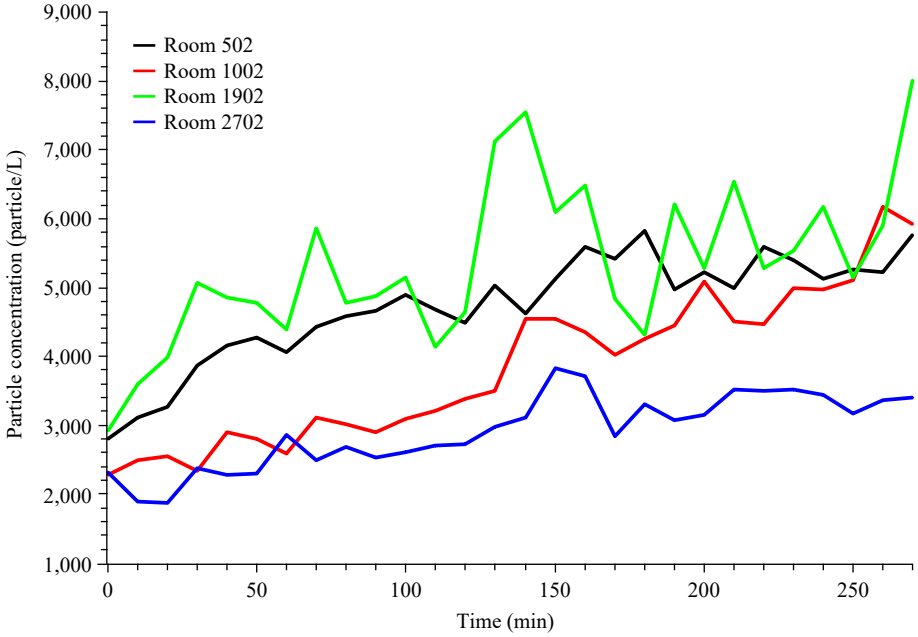
Note: Two scenarios, breathing (scenario 1) and breathing with defecation with toilet flushing (scenario 2), were simulated in the bathroom of room 402. Both scenarios included two periods, only turn off the exhaust fans in rooms 1002 and 1902 during period 1, and turn on all exhaust fans during period 2. On/Off indicates turn on/off the exhaust fan during this period.



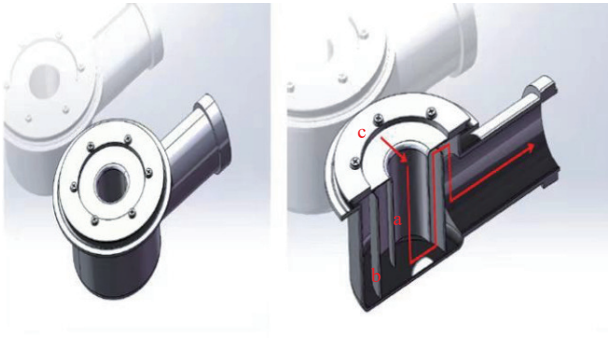
SUPPLEMENTARY FIGURE S1. Representative variations of the wind speed in the bathroom exhaust fans of rooms 1002 and 2702 during 2 scenarios.
Note: Two scenarios, breathing (scenario 1, 0-130 min) and breathing with defecation with toilet flushing (scenario 2, 140-270 min). In all the experimental rooms, the exhaust fans of bathrooms 1002 and 2702 were turned off only during 0–60 min and 140–200 min, and the exhaust fans were turned on in all bathrooms during the rest of the time.



SUPPLEMENTARY FIGURE S2. Representative variations of the wind speed in the bathroom floor drain of rooms 502 and 2702 during 2 scenarios.
Note: Two scenarios, breathing (scenario 1, 0–130 min) and breathing with defecation with toilet flushing (scenario 2, 140–270 min), Only the toilet flushing in scenario 2 was simulated by changing the flushing bathroom arrangement every ten minutes, and the number of flushing bathrooms decreased over time.



SUPPLEMENTARY FIGURE S3. The changes of particle concentration over time at 1 μm in 2 scenarios in different rooms.
Note: Two scenarios, breathing (scenario 1, 0–130 min) and breathing with defecation with toilet flushing (scenario 2, 140–270 min), were simulated in bathroom 402. Changes in particle number concentrations were monitored in bathrooms 502, 1002, 1902, and 2702.



SUPPLEMENTARY FIGURE S4. Model diagram of a bathroom floor drain and schematic diagram of water flow direction of a centralized quarantine apartment in Beijing.
Note: a: The removable water trap in the floor drain; b: The cavity between the water trap, the outside pipe and the horizontal wastewater branch; c: The water flow direction.

SUPPLEMENTARY FIGURE S5. The figure of the floor drains and removable water trap in a centralized quarantine apartment in Beijing.