Preplanned Studies

SARS-CoV-2 Aerosol Transmission Through Vertical Sanitary Drains in High-Rise Buildings — Shenzhen, Guangdong Province, China, March 2022

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Summary

What is already known about this topic?

Aerosol transmission of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) via sanitary pipelines in high-rise buildings is possible, however, there is a lack of experimental evidence.

What is added by this report?

The field simulation experiment confirmed the existence of a vertical aerosol transmission pathway from toilet flush-soil stack-floor drains without water seal. This report provided experimental evidence for vertical aerosol transmission of clustered outbreaks on 18 floors of a 33-story residential building.

What are the implications for public health practice?

The water seal on floor drains is a necessary barrier to prevent the risk of vertical aerosol transmission of infectious disease pathogens in buildings. It is necessary not only to have a U-shaped trap in the drainage pipe, but also to be filled with water regularly.

In several epidemiological reports, clustered outbreaks of coronavirus disease 2019 (COVID-19) in residential buildings show vertical distribution (*1*–*2*). Some research suggested that the negative pressure caused by the exhaust fan in bathrooms or the stronger chimney effect during non-toilet flushing periods drives virus aerosols into soil stacks entering from the floor drains or pipe leaks (*2*–*4*). Another study, which excluded the effects of exhaust fans and assumed that toilet flushing-floor drains without water seal were the primary contributor to aerosolization lacked experimental evidence (*1*). In addition, the aerodynamic characteristics of tracer gases used in field simulation experiments cannot be used to make meaningful conclusions about aerosols (*5*). In our previous research the aerosol simulants were used to confirm the viral aerosols generated by toilet flushing in the sewage pipe. The results showed that under certain conditions, it caused cross-floor non-vertical aerosol transmission between 3 floors in a quarantined hotel (*6*).

A recent COVID-19 clustered outbreak occurred in a 33-story building in Shenzhen City, Guangdong Province in March 2022. In total, 62.9% (39/62) of the confirmed cases lived in a vertical building layout on 18 different floors (room 707, room 907, ... room 3007). According to the epidemiological investigation, those cases were not close contacts. Therefore, it is presumed that cross-floor vertical transmission of the viral aerosols occurred. The onsite investigation found that there were no U-shaped traps in the drainage pipe and the floor drains had no water seals in the building (Figure 1). Polystyrene fluorescent microspheres with similar aerodynamic characteristics to the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) spike pseudovirus were used as simulants to explore the path of the viral aerosols in this building through field simulation experiments. The fluorescent microspheres were observed in samples from every site. This showed that there was a clear transmission path from toilet flush to soil stacks and floor drains without water seal in the high-rise building.

The COVID-19 outbreak in clusters in high-rise buildings through the path of toilet flush-soil stack-floor drains without water seal occurs. This experiment not only confirmed the vertical aerosol transmission pathway, but also had important public health significance for the prevention and control of COVID-19 in residential buildings, hotels, and other buildings, where the U-shaped trap must be designed in the drainage pipe. In addition, the floor drain should be regularly checked and filled with water to reduce the possibility of vertical aerosol transmission of infectious disease pathogens in buildings.

According to the daily habits of residents, combined

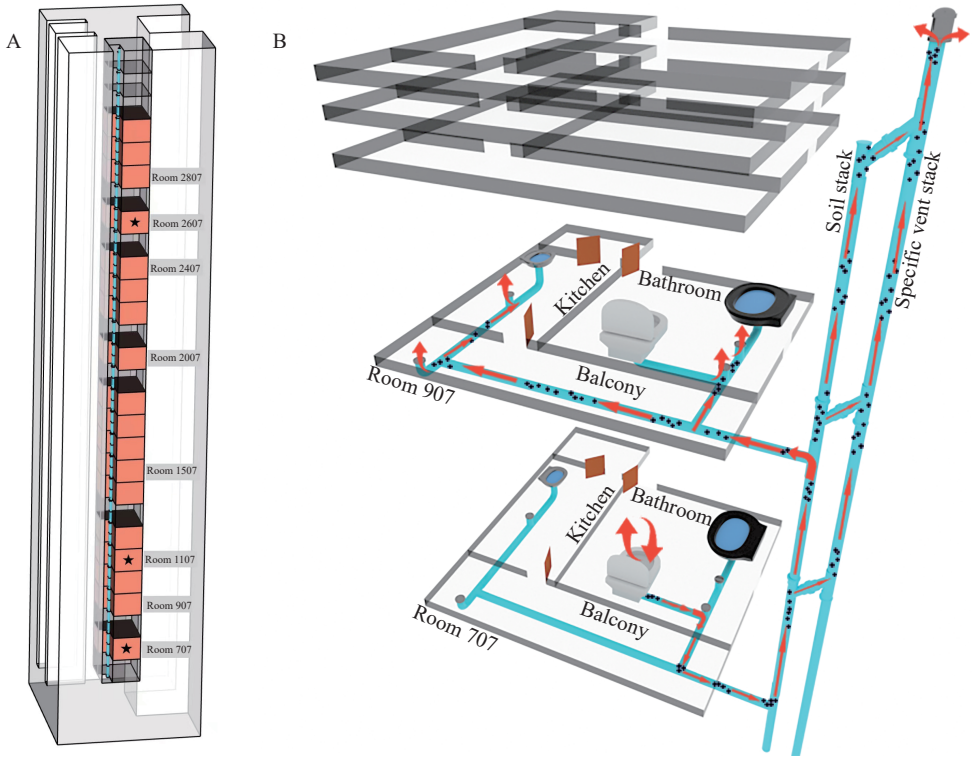

FIGURE 1. Diagram of positive case distribution and cross-layer vertical aerosol transmission of the 7th house layout in the high-rise building. (A) The diagram of the positive cases distributed in the 7th layout across 18 floors and rooms of field simulation experiment in the 33-story building. (B) The diagram of the drainage pipelines and soil stack system in the 7th house layout.

Notes: In the diagram of positive cases distributed in the building, the orange blocks indicate the rooms of confirmed positive cases in the 7th house layout, the black stars indicate the rooms of simulating defecation and toilet flushing (room 707 in scenario 1, rooms 707, 1107, and 2607 in scenario 2), and the sampling room are also noted with room numbers. In the diagram of drainage pipelines and soil stack systems, the black particles indicate the viral aerosol simulant generated by defecation and toilet flushing and the red arrows indicate the transmission pathway of the viral aerosols.

with the epidemiological investigation information, the time of detection of positive nucleic acid tests, and considering the neutral pressure plane and the chimney effect, the field simulation experiment was carried out with the bathroom window and exhaust fan closed. Two scenarios were designed using polystyrene fluorescent microspheres as the simulants. The method of preparation of simulants, as well as the sampling, field monitoring and laboratory analysis methods after toilet flushing were detailed in a previous research (*7*). Room 707, where the index patient lived, was selected to simulate defecation in the first scenario. Before patients in room 707 were transferred to the designated hospital, there was a risk of vertical aerosol transmission to the upper floors, so rooms 707, 1107, and 2607 were selected to simulate defecation in the second scenario. In the two scenarios, when the simulated bathroom toilet flushed, the rest of other bathrooms' toilets flushed at the same time with different arrangements of the combination (Supplementary Table S1, available in https://weekly.chinacdc.cn/).

The change of wind speed of floor drain, taking room 707 as an example, the wind speed of the floor drains varied with the number of toilet flushing, and the peak value was prolonged with an increase in the number of toilet flushing. Except for room 1507, which was located on the neutral pressure plane, the wind speed of the floor drains in all other rooms changed (Supplementary Figure S1, available in https://weekly.chinacdc.cn/).

As the number of toilet flushing increased along with the extension of the simulation time, the number of small particle-size aerosols trended upward, with a few exceptions. Within the same room, the trend of different particle sizes was relatively the same at different times (Supplementary Figure S2, available in https://weekly.chinacdc.cn/). The trend of large particle-size aerosols had no obvious regularity which had fewer total particles and were easily affected by

various factors.

Except for the first scenario in room 1507, the fluorescent microspheres were observed in all filter membrane samples. The fluorescent microspheres were also observed on smear swab samples from the floor drains of the kitchens except room 1507. No smear swab samples were collected from the kitchen of rooms 1107 and 2607 because the floor drains were hidden in the cupboards. In addition, the fluorescent microspheres were observed on the smear swab samples from the bathroom floor drain in room 1507 in the second scenario (Table 1, Figure 2).

DISCUSSION

In our research at a quarantined hotel, the stack exhaust channel was arbitrarily changed. The viral aerosols generated by toilet flushing in the sewage pipe could not be discharged from the exhaust port, and therefore entered the cross-floor vertical units through the floor drains without water seal (*6*). The aerosols in the bathroom entered via the exhaust fan connected to the exhaust air shaft. This pushed aerosols across vertical units of the hotel, across the floor under specific meteorological conditions, resulting in vertical transmission across the 5th through 7th floor. In addition, the hotel rooms adopted a mix of fresh air and recycled air, resulting in non-vertical transmission on the same floor. The combination of the above three effects resulted in the cross-floor non-vertical aerosol transmission of SARS-CoV-2. However, this outbreak occurred in clusters on 18 floors with the 7th vertical house layout (Figure 1). The bathroom exhaust fan and windows of this unit faced the balcony and were connected to the kitchen. The windows of balcony remained open at all times. No matter whether the bathroom exhaust fan or the kitchen ventilator were turned on, negative pressure could not be formed. Therefore, the exhaust fans and the kitchen ventilators were not opened during the simulation. Flushing the

TABLE 1. The observation results of fluorescent microspheres of filter membrane sample and smear swab sample.

No. of rooms	Scenario 1	Scenario 2	
	Filter membrane sample	Filter membrane sample	Smear swab sample
907	●	●	●
1107	●	●	
1507	●	●	
2007	●	●	●
2407	●	●	●
2607	●	●	
2807	●	●	●

Note: The aerosol filter membrane samples collected by medium flow PM_{10} samplers (100 L/min) in the bathroom of each room. The smear swab samples were collected from the floor drain of the kitchen with cotton swab. No smear swab samples were collected from the kitchen of rooms 1107 and 2607 because the floor drains were hidden in the cupboards. The smear swab samples of room 1507 were not observed. The green dots (●) showed where simulants were observed in samples.

FIGURE 2. Representative photos of fluorescent microspheres tracked by different sampling methods at different rooms in 2 scenarios. (A) the aerosol filter membrane sample of room 2807 during scenario 1; (B) the aerosol filter membrane sample of room 1107 during scenario 2; (C) smear swab sample from the floor drain of the kitchen of room 1107 during scenario 2.
Note: After simulating defecation and toilet flushing, fluorescent microspheres (green) were observed using fluorescent microscopy.

toilet in other vertical units directly affected the wind speed of the floor drain in room 707, while the wind speed of the floor drains in room 1507 had no significant change. The wind speed in the floor drain could partly indicate the pressure changes during toilet flushing. Similar pressure changes due to flushing were shown in previous studies (*8*), while the neutral pressure plane held a relatively stable pressure. The sewage and waste water of the bathroom, kitchen, and balcony were gathered and discharged into a dual-stack system in this building. There were no U-shaped traps in the drainage pipes in the building nor floor drains with water seal in the bathroom, kitchen, or balcony. The washing machine drain pipe plugs into the floor drain on the balcony. With the exhaust fans turned off, even in scenario 1 where the simulants were only poured into the toilet of room 707, after toilet flushing, the fluorescent microspheres could be observed on all the filter membrane samples from the bathroom. That confirmed the existence of a vertical aerosol transmission path from the toilet flush-soil stack-floor drain without water seal and provided experimental evidence for the outbreak in clusters across floors within high-rise buildings.

It is very common that toilets are used and flushed at the same time on different floors in high-rise buildings. When COVID-19 patients use toilets, they excrete virus. The simultaneous use of toilets on multiple floors exacerbated the spread of viral aerosols through the path of toilet flush-soil stack-floor drain without water seal. Although the neutral pressure plane was located on the 15th floor, when the toilet was flushed, the wind speed of the floor drain changed slightly. The pressure balance in it broke with the increase in the number of toilets being flushed simultaneously. The simulants were also observed on the filter membrane sample and smear swab sample from the bathroom of room 1507 in scenario 2, therefore the spread path also existed in the neutral pressure plane. The viral aerosol generated by toilet flushing in the soil stack would therefore spread into rooms from the floor drain without water seal.

This study was subject to some limitations. The field simulation experiment was a qualitative study. The experimentally confirmed aerosol transmission of the simulant does not represent the risk of infection posed by the virus.

The field simulation experiment showed the existing path of the toilet flush-soil stack-floor drain without water seal and its risks in high-rise buildings without U-shaped traps and water seal. Therefore, property management companies should check traps and water seal. Where it is possible odor-proof floor drains should be added into older buildings. Meanwhile, health education should be strengthened to teach building residents how to fill their floor drains regularly to ensure the water seal is deep enough (≥50 mm) in order to cut off the aerosol transmission. In addition, if bathrooms have windows facing the outside, the windows should be opened frequently for ventilation. If not, an exhaust fan needs to be installed and turned on frequently for ventilation in the case of ensuring that the floor drain water seal is deep enough. If the condition of water seal is uncertain, the bathroom door should first be opened, and then the exhaust fan should be turned on for ventilation. During the pandemic, if there are positive cases in the same house layout within a building, the chlorine-containing disinfectants can be poured into the floor drain regularly to effectively kill the virus.

Conflicts of Interest: No conflicts of interest.

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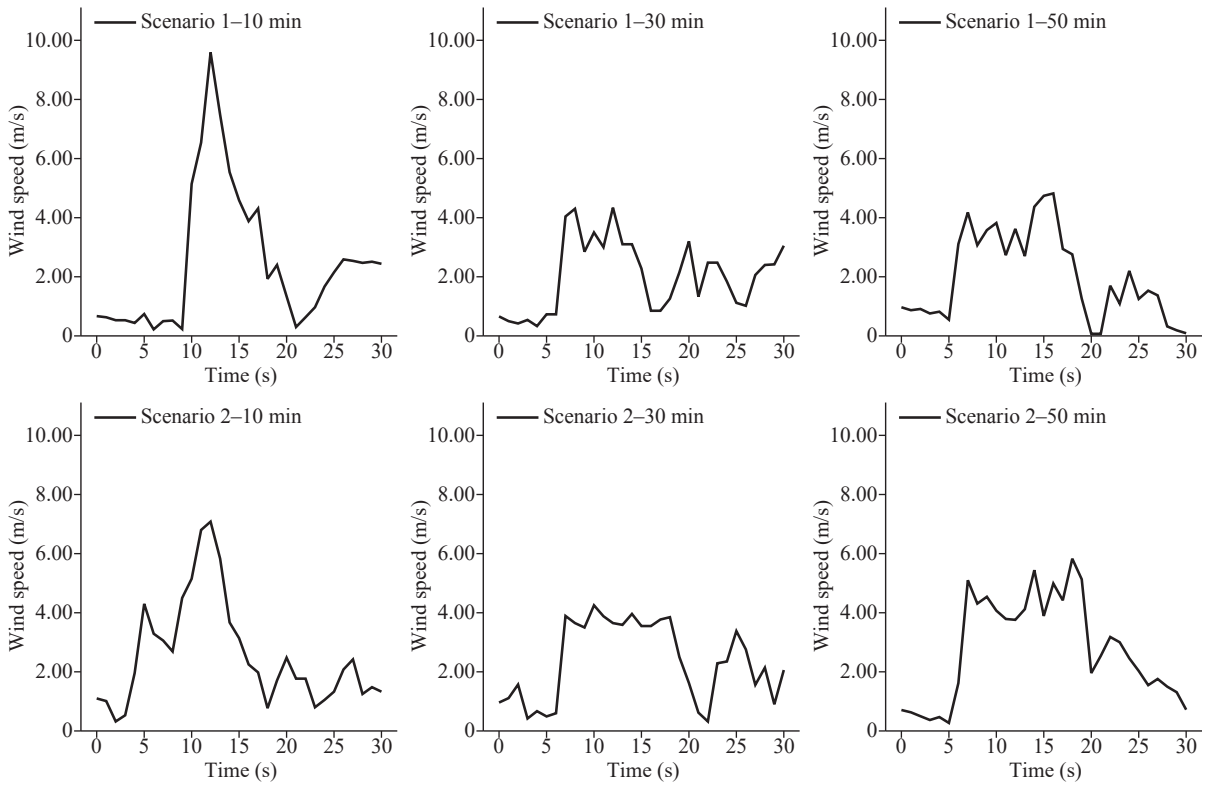
SUPPLEMENTARY MATERIALS

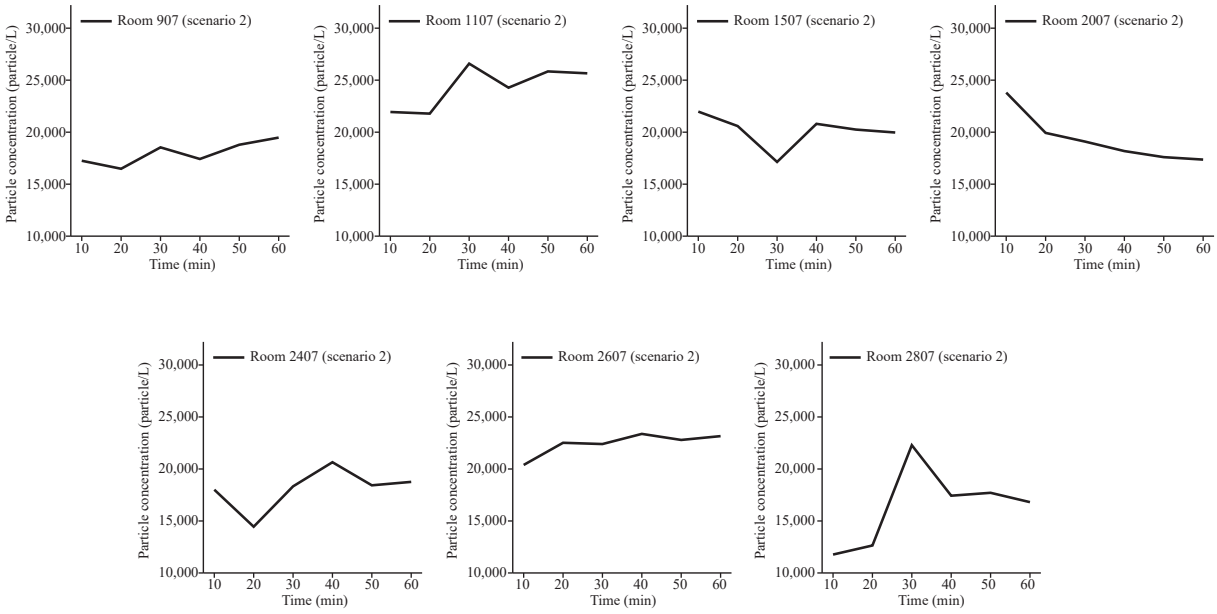
SUPPLEMENTARY TABLE S1. The array and combination mode of defection simulation and toilet flushing in 2 scenarios.

Scenario	Time (min)	Room numbers							
		707	907	1107	1507	2007	2407	2607	2807
1	10	D/F	F						F
	20	D/F		F			F		
	30	D/F		F				F	F
	40	D/F	F		F		F		
	50	F		F		F		F	F
	60	F	F		F	F	F		
2	10	D/F	F	D/F				D/F	F
	20	D/F		D/F	F		F	D/F	
	30	D/F	F	D/F	F			D/F	F
	40	D/F	F	D/F		F	F	D/F	
	50	F	F	F	F		F	F	F
	60	F	F	F		F	F	F	F

Note: The simulants were poured into the toilet for the first 40 minutes of the simulation experiment, and the toilet was flushed every 10 minutes. The letter “D” means pouring simulants into the toilet, and letter “F” indicates toilet flushing.



SUPPLEMENTARY FIGURE S1. Representative variations of the wind speed in the bathroom floor drain of room 707 during 2 scenarios.



SUPPLEMENTARY FIGURE S2. The changes of particle concentration over time at 0.3 μm in scenario 2 in different rooms.