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Vertical bioaerosol transmission in toilet environment

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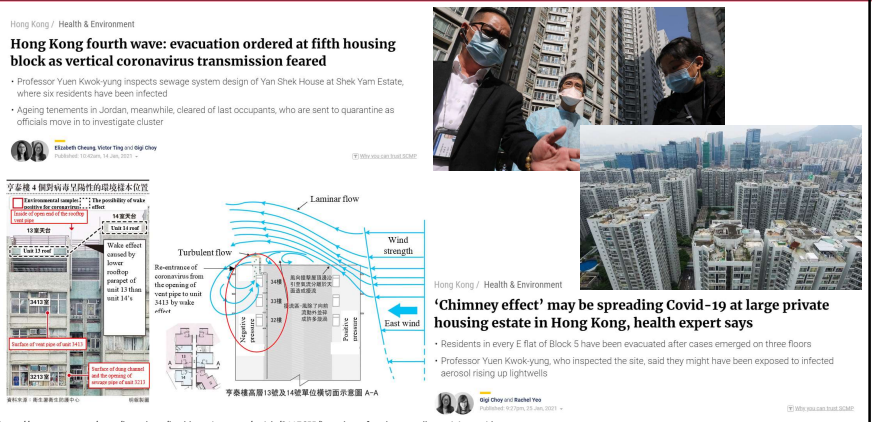
Vertical transmission of SARS-CoV-2



https://www.scmp.com/news/hong-kong/health-environment/article/3117655/hong-kong-fourth-wave-all-remaining-residents
https://www.scmp.com/news/hong-kong/health-environment/article/3119189/chimney-effect-may-be-spreading-covid-19-large

Cases in high-rise residential buildings in Hong Kong

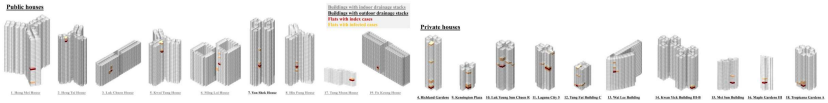
A total of 19 outbreaks with over 150 confirmed cases

The transmission primarily took place between flats through shared drainpipes

Indoor drainpipe system: both upstairs and downstairs neighbors of the index case flats were susceptible to infection

Outdoor drainage stacks: the majority of infected cases were located upstairs from the index case flats

- stack effect where air flow within the building contributes to virus spread
- lower infection risks



Zhao, P. (2023, May). Analysis of COVID-19 clusters involving vertical transmission in residential buildings in Hong Kong. In *Building Simulation* (Vol. 16, No. 5, pp. 701-711). Beijing: Tsinghua University Press.

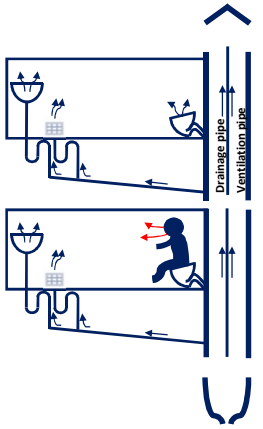
Bathroom bioaerosols

Within the drainage system:

- Viable viruses can be detected in human feces, leading to the possibility of **fecal aerosols**
- Wastewater contaminated with virus-laden respiratory fluids can generate aerosols during discharge, known as **washbasin aerosols**

Within the bathroom environment:

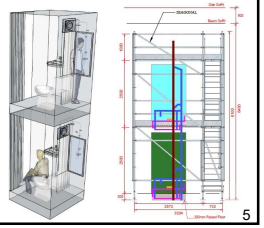
- Turbulence created by flushing toilets can generate **flushing-generated aerosols**
- **Respiratory aerosols** can be released through activities such as coughing, breathing, or singing during a bath, with the virus encapsulated by the water vapor in the humid environment



Research facility

The Research Platform of Sanitation Hygiene and Environment (RPSHE)

- Full-scale 3-floor mock-up toilet experimental research facility
- Built according to the design and the building of the bathroom of the single-person public housing flats in Hong Kong
- Functional toilet facilities
  - water closets with drainage pipes
  - floor drains connected to the U-trap with water seal and the drainage pipes
  - 6-inch exhaust fans with an air volume of 210m^3/hr
  - openable windows of size 600 mm × 900 mm
  - sliding doors with a low-level louver of size about 150 mm × 300 mm



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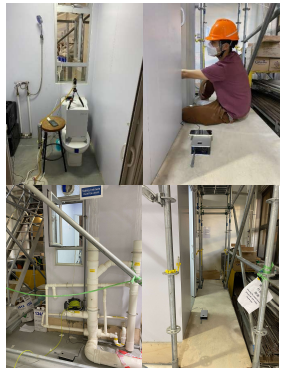
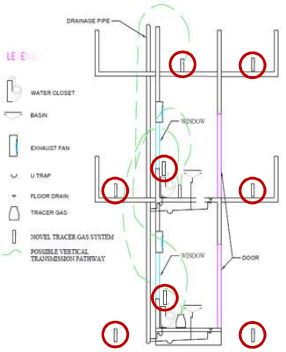
Tracer gas experiment

Tracer gas was released at the G/F toilet

- on top of the water closet at the height of 1.2 m above the ground (height of the mouth of a sitting person)
- at a flow rate of 6 L/min for 8 min (the average breathing rate for humans)



Schematic diagram of the experimental set-up



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Ventilation scenarios

Case	G/F Exhaust fan	G/F Window	1/F Exhaust fan	1/F Window
1	Off	Open	Off	Closed
2	Off	Closed	Off	Open
3	Off	Open	Off	Open
4	On	Open	Off	Closed
5	Off	Closed	Off	Closed
6	On	Open	On	Open
7	Off	Open	On	Closed
8	On	Open	Off	Open
9	On	Closed	On	Open
10	Off	Closed	On	Open
11	On	Closed	Off	Open
12	On	Closed	On	Closed
13	On	Open	On	Closed
14	On	Closed	Off	Closed
15	Off	Closed	On	Closed
16	Off	Open	On	Open

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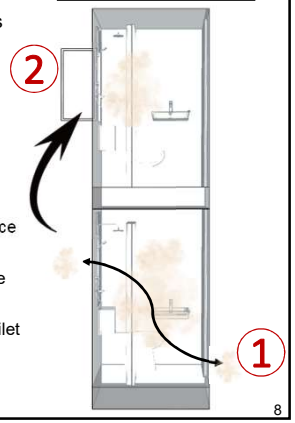
Potential infection risks

1. Among residents on the G/F after the infected person uses the washroom
2. Among the residents of the 1/F

Evaluation of infection risks based on:

- The ability to remove aerosols from the G/F toilet
  - ✓ Toilet ventilation should be adequate to remove the virus-laden aerosols as soon as they are released from the source patient
- The extent to which it minimizes the re-entrance of aerosols into the 1/F toilet
  - ✓ Consider the amount of aerosols that may enter the 1/F toilet when selecting an appropriate ventilation strategy to minimize infection risk

Potential transmission pathways



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Poor G/F ventilation

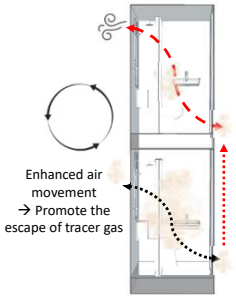
Cases with no mechanical ventilation at the G/F toilet

- Took 7 hours for tracer gas to decay when both windows were closed and both exhaust fans were off
- For cases with the G/F window closed
  - any form of ventilation at the 1/F toilet reduced the tracer gas decay time at the G/F toilet to around 3 hours
  - lower peaks at the G/F toilet when the 1/F exhaust fan was operating
- For cases with the G/F window open
  - switching on the exhaust fan at 1/F reduced the decay time by two-thirds

The operation of the 1/F mechanical exhaust fan enhanced the ambient air movement in the area outside the toilet and created negative pressure in the 1/F toilet

- Drew fresh air from the outside and promoted the removal of tracer gas from the G/F toilet
- Lower peaks of tracer gas concentration in the G/F toilet

Ventilation strategies in the 1/F toilet that facilitate the escape of tracer gas (aerosols) from the G/F area



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Re-entry of tracer gas into the G/F toilet

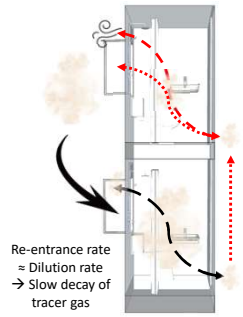
Switching on the 1/F exhaust fan and opening the window

- Prevented the initial build-up of tracer gas
- The tracer gas concentration increased after 10 min and decayed slowly over an hour

The open window and the exhaust fan create a pressure difference between the G/F and the 1/F toilet

- Allowing fresh air to enter the toilets and thus diluting the concentration of tracer gas in the G/F toilet
- However, the opening of the G/F window also created airflows that might cause the re-entrance of tracer gas from the ambient environment into the G/F toilet
- The dilution effect of the open windows was not strong enough to counteract the re-entrance of tracer gas

The re-entry of tracer gas due to an open window on the G/F



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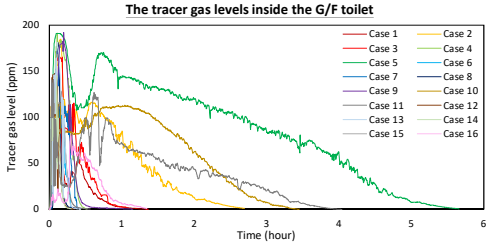
Good ventilation performance at the G/F toilet

Tracer gas at the G/F toilet was removed within 20 min when the exhaust fan was on

The best cases were when only the G/F exhaust fan was on while both windows were closed

- Operating an exhaust fan at the G/F toilet resulted in a negative pressure, which drew in fresh air from the outside and promotes the removal of tracer gas
- Closing the G/F window ensured there was no short-circuit of the airflow and prevented the re-entrance of tracer gas from the outdoor environment

The tracer gas levels inside the G/F toilet



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Minimizing infection risks of the G/F residents

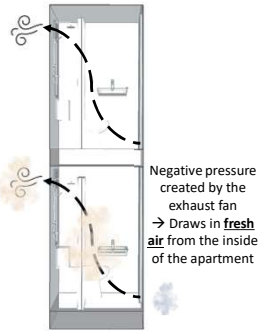
Elevated levels of tracer gas were detected outside the door of the G/F toilet within the first few minutes

- Decreased rapidly within 20 minutes
- Presented a potential risk to residents in the G/F household
- Worst case took up to 43 min for tracer gas to decay when no ventilation was adopted in the G/F toilet

When both the G/F and 1/F exhaust fans were operating without opening any of the windows, there was no increase in tracer gas levels near the door of the G/F toilet

- Gas was quickly removed from the G/F toilet to the outside of the window before it could reach the door

The use of exhaust fans in both toilets to prevent cross-infection among G/F residents



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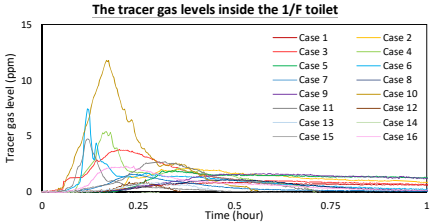
Minimizing the re-entrance of aerosols into the 1/F toilet

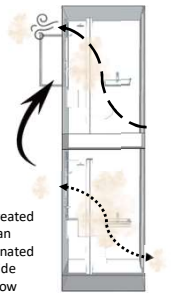
Elevated levels of tracer gas were detected in the 1/F toilet in some cases

- Likely entered the 1/F toilet through the window gap instead of the door louver
- When only the window and exhaust fans at the 1/F toilet were operating, highest level was detected which took 24 minutes to drop back to background levels
- Less tracer gas entered the 1/F toilet through the closed window, however, elevated level was still detected

The tracer gas levels inside the 1/F toilet



The re-entry of tracer gas due to an open window and the operation of an exhaust fan on the 1/F



Negative pressure created by the exhaust fan
→ Draws in contaminated air from the outside through the window

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Optimal ventilation for minimizing the infection risks

Optimal ventilation strategy for minimizing the overall infection risk

- Utilized only the exhaust fan on both floors without opening the windows
  - ✓ Achieve the good tracer gas removal performance in the G/F toilet
  - ✓ Prevent the aerosols from entering the G/F household
  - ✓ Prevent the aerosols from entering the 1/F toilet

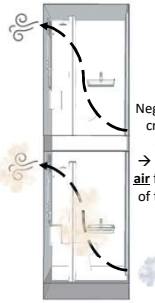
Special considerations

- Using a door gap or a door louver can ensure that fresh and clean air enters from the inside of the apartment rather than from the ambient air through window gaps

Other hygiene practices

- Frequent cleaning
- Regular inspection of the drainage pipe
- Ensure U-trap is filled with water

Optimal ventilation strategy for minimizing the overall infection risks



Negative pressure created by the exhaust fan
→ Draws in **fresh air** from the inside of the apartment

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Thank you!

Acknowledgement

This work was jointly supported by a grant from the Collaborative Research Fund (CRF) COVID-19 and Novel Infectious Disease (NID) Research Exercise and the General Research Fund, the Research Grants Council of the Hong Kong Special Administrative Region, China (Project no. PolyU P0033675/C5108-20G & PolyU P0037773/Q86B); the Research Institute for Smart Energy (RISE) Matching Fund (Project no. P0038532) and PolyU Internal funding (Project no. P0043713/WZ2N & P0043831/CE12).