A Full-scale 3-floor Mock-up Toilet Experimental Research Facility:

The Research Platform of Sanitation Hygiene and Environment (RPSHE)

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Background

- Airborne diseases spreading through sewage system was first discovered in Hong Kong in 2003 during the outbreak of SARS
  - Super-spreading of the SARS virus through dried U-traps and leakage from the sewage vent pipe at 4/F of Block E of Amoy Garden was identified
- Vertical airborne transmissions of the SARS-CoV-2 induced by toilet ventilation and poorly maintained drainage system have been suspected to be responsible for many in-building outbreaks in Hong Kong

Source from? WC flushing & via exhaust fan? Floor drain? … Any others?

In 2001 CIBW062 Symposium

Measurement of positive air pressure in a ventilation section of a 150-mm diameter stack during a branch pipe discharge

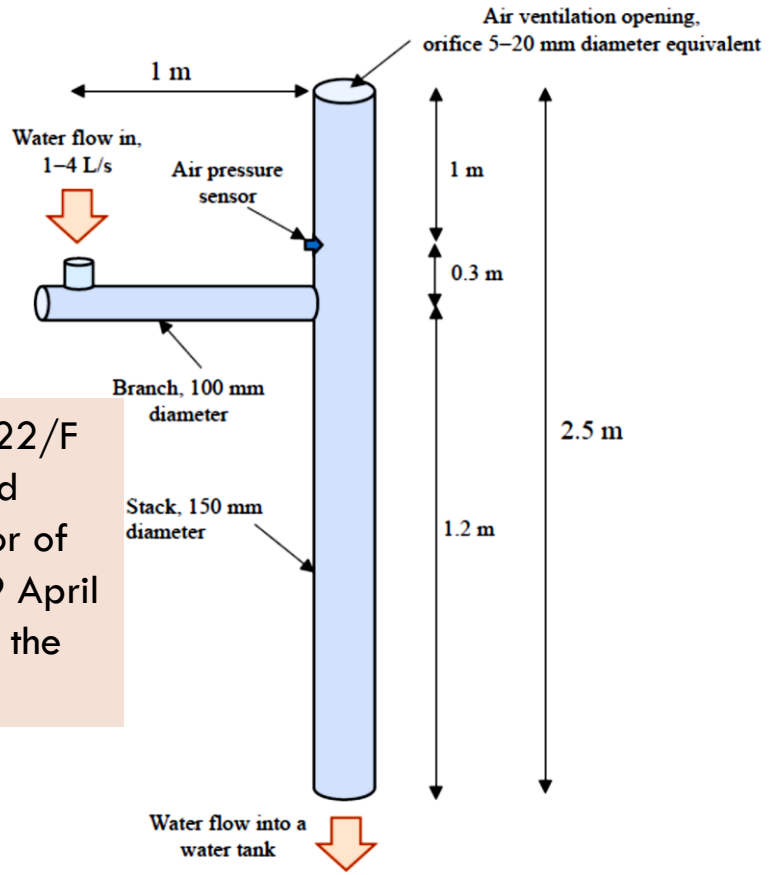
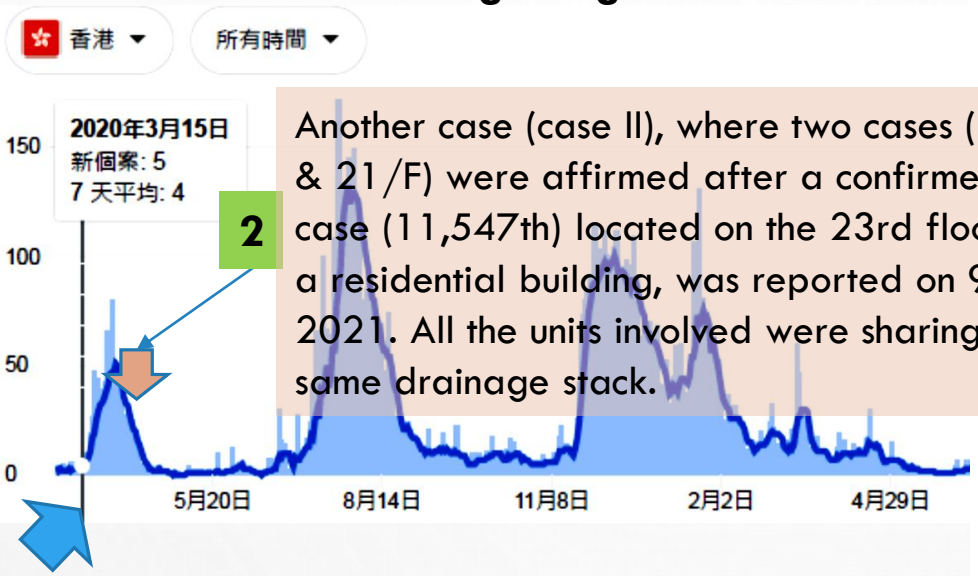


Figure 1- Experimental set-up

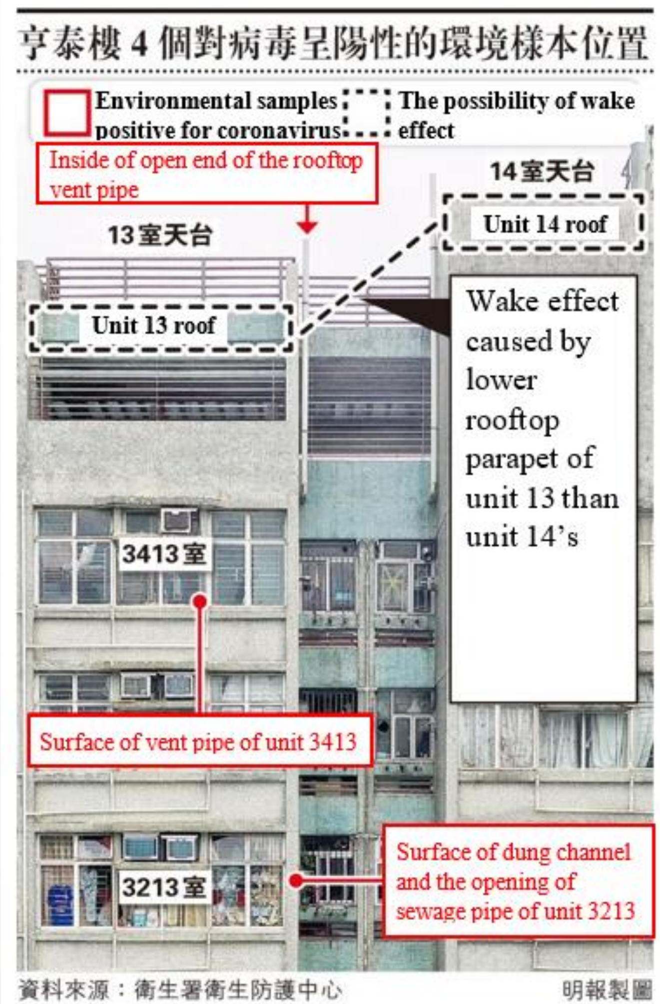
COVID-19 Cases in Hong Kong



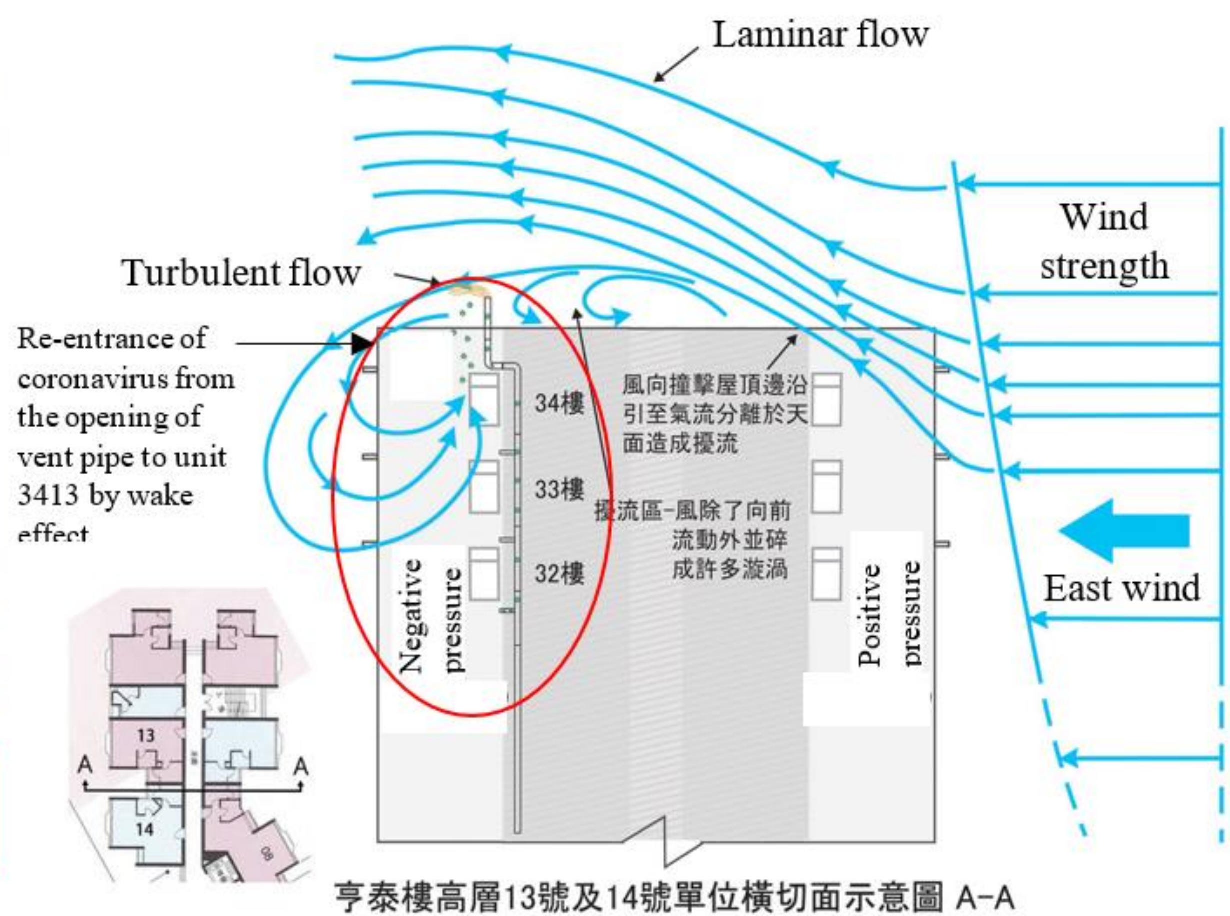
Another case (case II), where two cases (22/F & 21/F) were affirmed after a confirmed case (11,547th) located on the 23rd floor of a residential building, was reported on 9 April 2021. All the units involved were sharing the same drainage stack.

15 March 2020 case: the 140th COVID-19 case located on the 34th floor of a residential building was confirmed 3 days after another 2 confirmed cases (119th & 124th) found on the 32nd floor of the same building. The two units involved were sharing the same drainage stack. Among subsequent tests of 12 environmental samples collected at those two units and the rooftop, 4 of them were tested positive.

Transmission pathway illustrations



亨泰樓 4 個對病毒呈陽性的環境樣本位置
Environmental samples positive for coronavirus
The possibility of wake effect
Inside of open end of the rooftop vent pipe
14室天台
Unit 14 roof
13室天台
Unit 13 roof
Wake effect caused by lower rooftop parapet of unit 13 than unit 14's
3413室
Surface of vent pipe of unit 3413
3213室
Surface of dung channel and the opening of sewage pipe of unit 3213
資料來源：衛生署衛生防護中心
明報製圖



Laminar flow
Turbulent flow
Wind strength
Re-entrance of coronavirus from the opening of vent pipe to unit 3413 by wake effect
34樓
33樓
32樓
風向撞擊屋頂邊沿引至氣流分離於天面造成擾流
擾流區－風除了向前流動外並碎成許多漩渦
Negative pressure
Positive pressure
East wind
13
14
A
A
亨泰樓高層13號及14號單位橫切面示意圖 A-A

Reference: The height difference between unit 13's and unit 14's parapet 2020. (From Ming Pao: https://news.mingpao.com/pns/%E8%A6%81%E8%81%9E/article/20200311/s00001/1583864702600)

Wake effect in the re-entrant of top floors in the building 2020. (From Topick.hket.com: https://topick.hket.com/article/2591933?r=cpsdlc)

The potential airborne virus from the drainage pipe

Within the drainage system

- Viable viruses can be discovered in human faeces – **Faecal aerosols**
- Generated during the discharge of wastewater contaminated by virus-laden respiratory fluids – **Washbasin aerosols**

Within the bathroom environment

- Turbulence created by flushing toilets – **Flushing-generated aerosols**
- Released by coughing, breathing or singing during a bath; the virus encapsulated by the water vapour in the humid environment – **Respiratory aerosols**

Long-distance airborne transmissions through **ventilation and drainage system**

is a risk factor that cannot be ignored

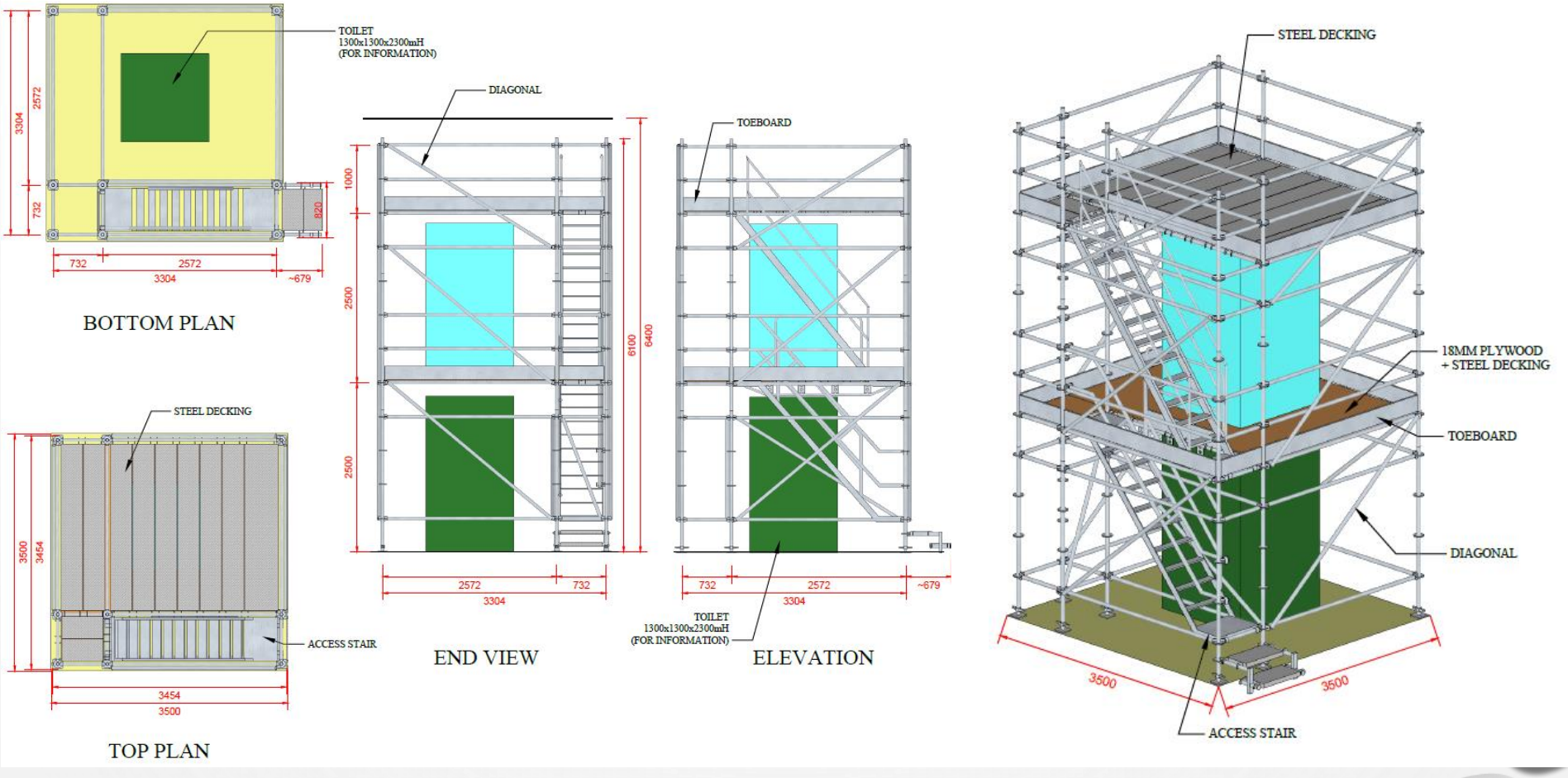
Research approaches

- ✓ Computational simulations
- ✓ Field surveys
- ✓ Epidemiological studies
- × Controlled experiment – LACK OF TESTING FACILITY

The Research Platform of Sanitation Hygiene and Environment (RPSHE)

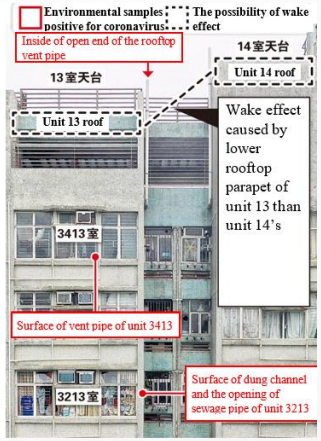
Design of the scaffolding

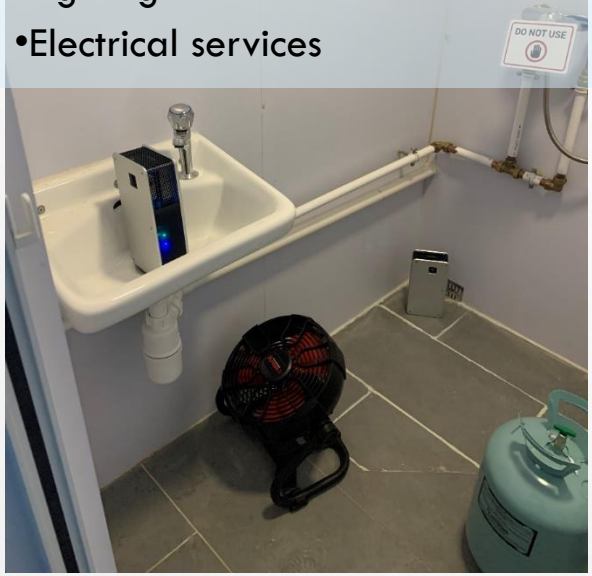
The timely issue, nature of problems & the decisions:
A temporary structure, built indoors, site rent, collaboration

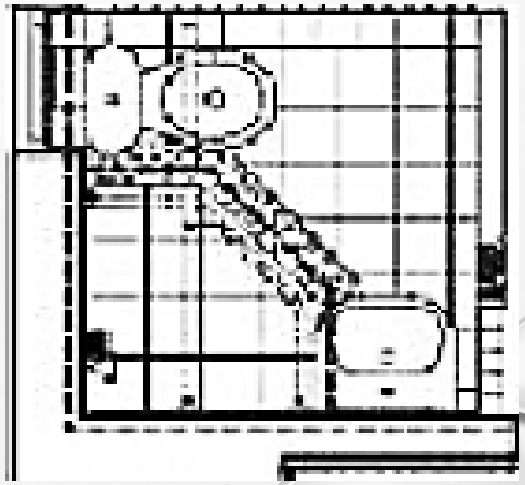


A single-person toilet of public housing

- Water closet fitted with drainage pipe
- Wash basin fitted with U-trap & drainage pipe; drainage-ventilating pipe extended 1m above the top floor
- 6-inch exhaust fan with an air volume of 210m^3/hr at a high level of one-panel wall
- Floor drain fitted with a drainage pipe & water seal
- A sliding door fitted with a low-level louvre of size about 150mm × 300mm
- An openable window (600mm × 900mm) in the middle level of the panel wall same side as the exhaust fan
- Lighting
- Electrical services



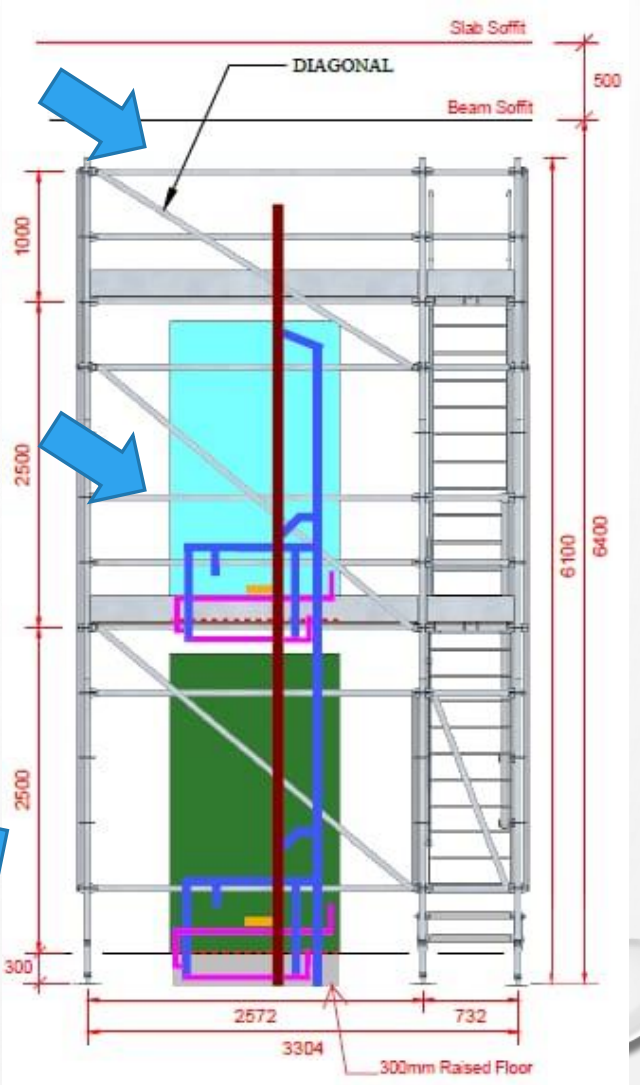




Building design and the service systems follow the Building Regulation Chapter 123I (Standards of Sanitary Fitments, Plumbing, Drainage Works and Latrines) in Hong Kong

The RPSHE facility

DRAINAGE SECTION 1-1



Preliminary works: Tracer gas experiments

- Tracer gas experiments were conducted under different ventilation schemes to evaluate the ventilation performance of the toilet to identify the potential vertical airborne transmission routes through ventilation
- Tracer gas: **released inside the G/F toilet (Cases),** well-mixed (by a fan)
- On the 1/F: toilet door (CLOSE), exhaust fan (ON), window (OPEN)
- Locations of tracer gas samplers
  - Inside the toilets on G/F and 1/F
  - Outside the toilets near the window side
  - At the roof
- Air change rate: the concentration-decay method: $C(t) = C_0 \times e^{-\lambda \times t}$

Case	Door	Exhaust fan	Window	Air change rate (h^{-1})
1	Closed	Closed	Closed	1.2
2	Opened	Closed	Closed	14.1
3	Closed	Opened	Closed	3.5
4	Closed	Closed	Opened	3.5
5	Closed	Opened	Opened	24.3
6	Opened	Closed	Opened	31.4
7	Opened	Opened	Closed	26.7
8	Opened	Opened	Opened	33.6

Set-up & Shows

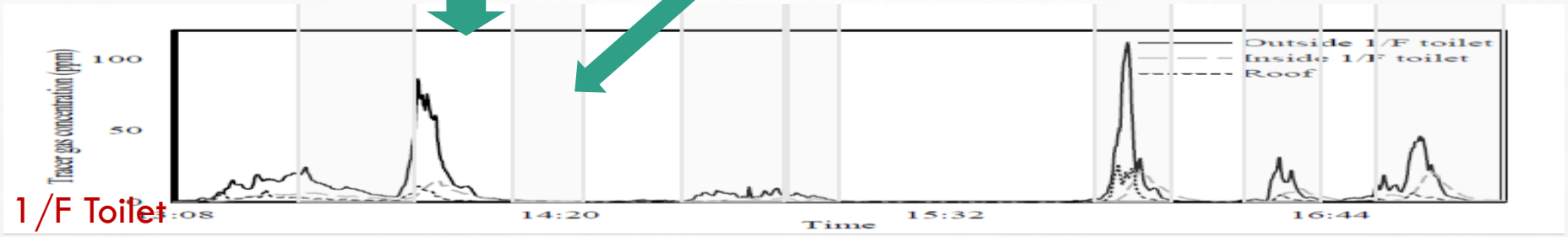

INNOVA 1412 Photoacoustic Field Gas-Monitor
1412 PHOTOACOUSTIC SINGLE-GAS MONITOR
INITIALIZING. PLEASE WAIT
配備精準測量儀器
is equipped with accurate measuring instruments

Sample Results

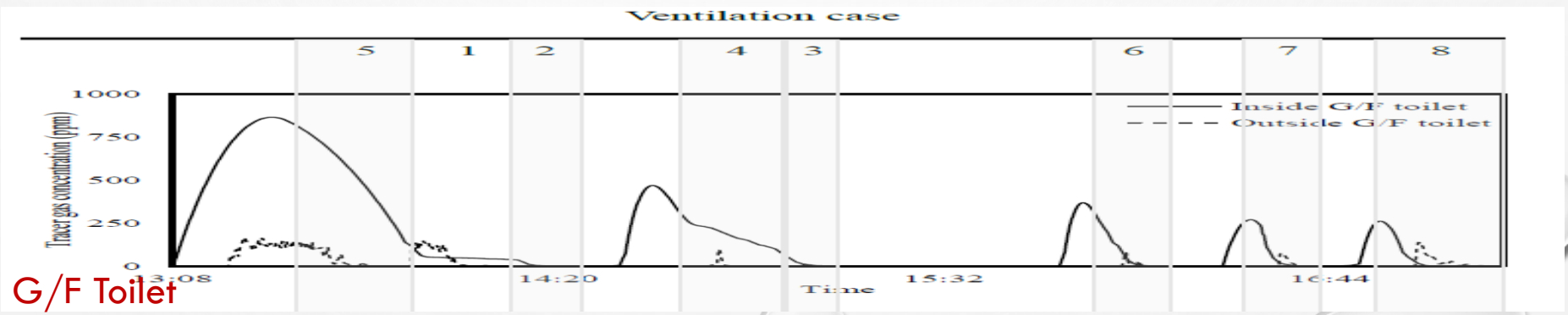
- Case 5 (door closed; exhaust fan and window on/opened)
- Tracer gas was detected at all locations
- Vertical dispersion from G/F to the roof

- Case 1 (all closed)
- Closing the door caused a sudden increase in tracer gas concentrations outside the G/F and 1/F toilets, and a small increase inside the 1/F toilet and on the roof
- The surge was quickly restored and no tracer gas was detected

- Case 2 (door opened; exhaust fan and window closed)
- Opening the door provided an air passage for the remaining tracer gas inside the G/F toilet to escape through the door opening
- The sampler located outside the G/F toilet near the window could not detect any change in the tracer gas level



1/F Toilet



G/F Toilet

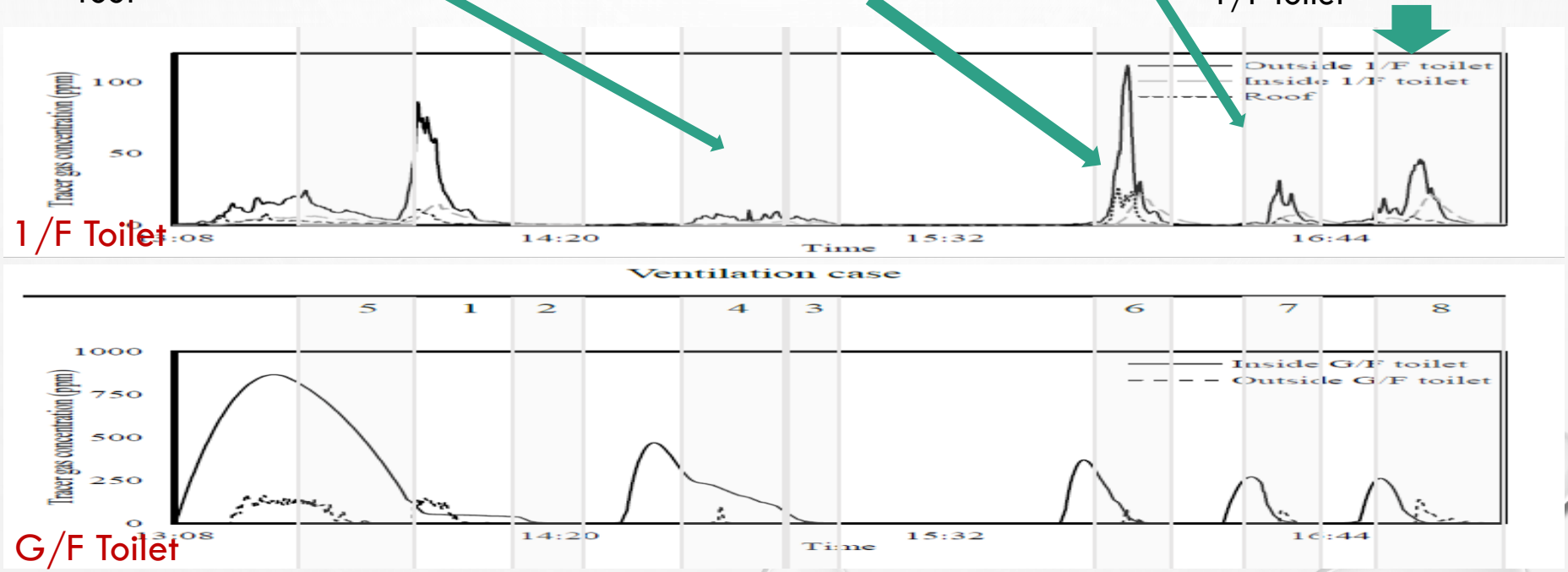
Sample Results

- Cases 3 and 4 (door closed; either the exhaust fan or the window opened)
- Tracer gas was detected both inside and outside the 1/F toilet but not at the roof

- Case 7 (door and exhaust fan on/opened; window closed)
- Relatively less tracer gas reached 1/F and the roof
- Tracer gas dispersed away in other directions driven by the turbulences created by the exhaust fan

- Case 6 (door and window opened; exhaust fan off)
- High levels of tracer gas were detected outside and inside the 1/F toilet and at the roof

- Case 8 (all opened)
- High levels of tracer gas were detected inside and outside the 1/F toilet



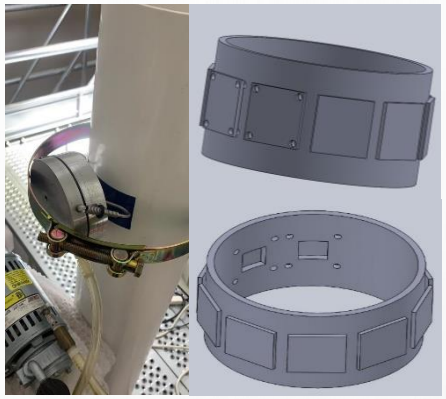
Dispersion pathways through toilet ventilation

- When the tracer gas escaped from the G/F toilet to other locations, it was often that the level increased in the order of
  1. Outside the 1/F toilet
  2. The roof
  3. Inside the 1/F toilet
- Contaminated air tends to move upward and disperse along the wind direction
- However, since the upward pathway was blocked by the ceiling and the air was stagnant, outside contaminated air would be drawn into the 1/F toilet through the window due to the negative pressure created by the exhaust fan

The Way Forward

Infection risk and disinfection

- Identification of the potential infection risk associated with toilet flushing
- Emission and disinfection of bioaerosol at the drainage-ventilation pipe using novel UV disinfection devices



Airborne transmission & dispersion

- Identification of transmission pathways within the bathroom environment and the drainage system
- Measurement of the air pressure & flow in/associated with the drainage pipes

Bathroom environment quality and energy demand

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Thank you

Collaboration Welcome