Media release Wed July 15, 2020

SARS-CoV-2 airborne transmission is opportunistic and ventilation works

新冠肺炎病毒空氣傳播的機會性和通風的重要性

Yuguo Li 李玉國
Department of Mechanical Engineering機械工程系
The University of Hong Kong 香港大學

***Acknowledgement* 致謝**

I thank my hard-working (former) students/post-docs (since 2003) and collaborators in studying Covid-19 transmission

HKU Mech Eng: Shenglan Xiao, Miao Te, Zhang Nan, Jack Chan, Chen Wenzhao, Zhao Pengcheng

HKU Public Health: Hui-Ling Yen, Ben Cowling, Malik Peiris; CUHK: David Hui

Co-Is of outbreak analyses: Qian Hua (South East U), Hang Jian (Sun Yat-Sen U), Liu Li (Tsinghua), Wei Jianjian and Lei Hao (Zhejiang U)

CDCs: Guangdong, Jiangsu and Hunan: Kang Min (Guangdong CDC), Ding Zhen (Jiangsu CDC), Hu Shixiong (Hunan CDC) and many colleagues

To RGC, HMRF, NSFC and HKU for supporting us in studying environment control of infection since 2003.

Airborne transmission of Covid-19 has been controversial Covid-19的空气传播一直存在爭議

- 9 Feb: First postulated (when certain conditions were met) by the Chinese National Health Council (NHC) (Li and Gao, 2020)
- Very early: WHO recognized airborne transmission with aerosol-generating medical procedures.
- 28 Mar: WHO Fact: COVID19- is not airborne
- 6 July: Morawska and Milton "It is time to address airborne transmission of COVID-19", CID
- 7 July: WHO "We have been talking about the possibility of airborne transmission and aerosol transmission as one of the modes of transmission of COVID-19".

Li X, Gao F. Public Prevention Guidelines of Infection due to the Novel Coronavirus Pneumonia (In Chinese, 新型冠状病毒感染的肺炎公众防护指南). Beijing, China: People's Medical Publishing House, 2020: page 9.

For intervention, the significant issue lies at not just if a disease is or can be airborne, but under what conditions it occurs and how to control it.

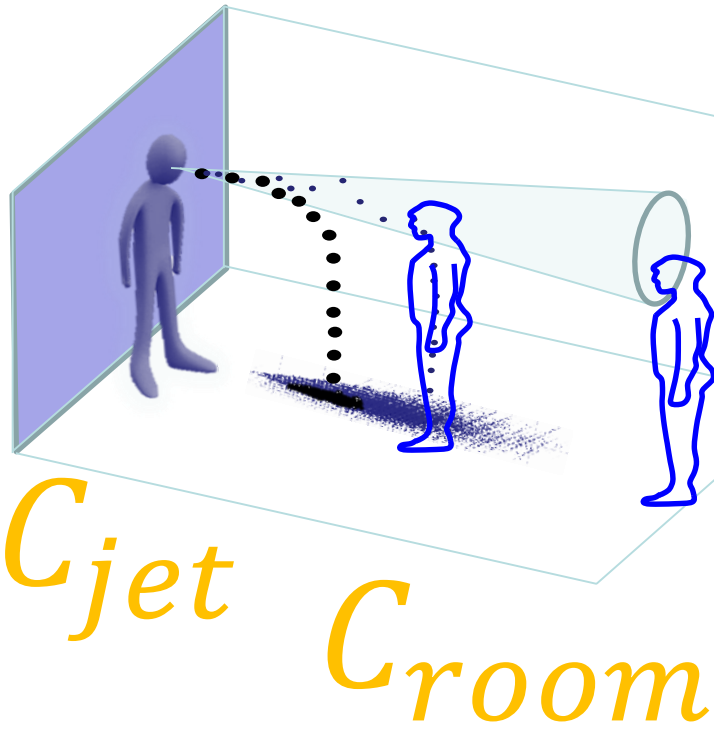
對於干預而言，重要問題不僅在於疾病是否是空氣傳播的或可以空氣傳播的，還在於在什麼情況下發生以及如何控制。

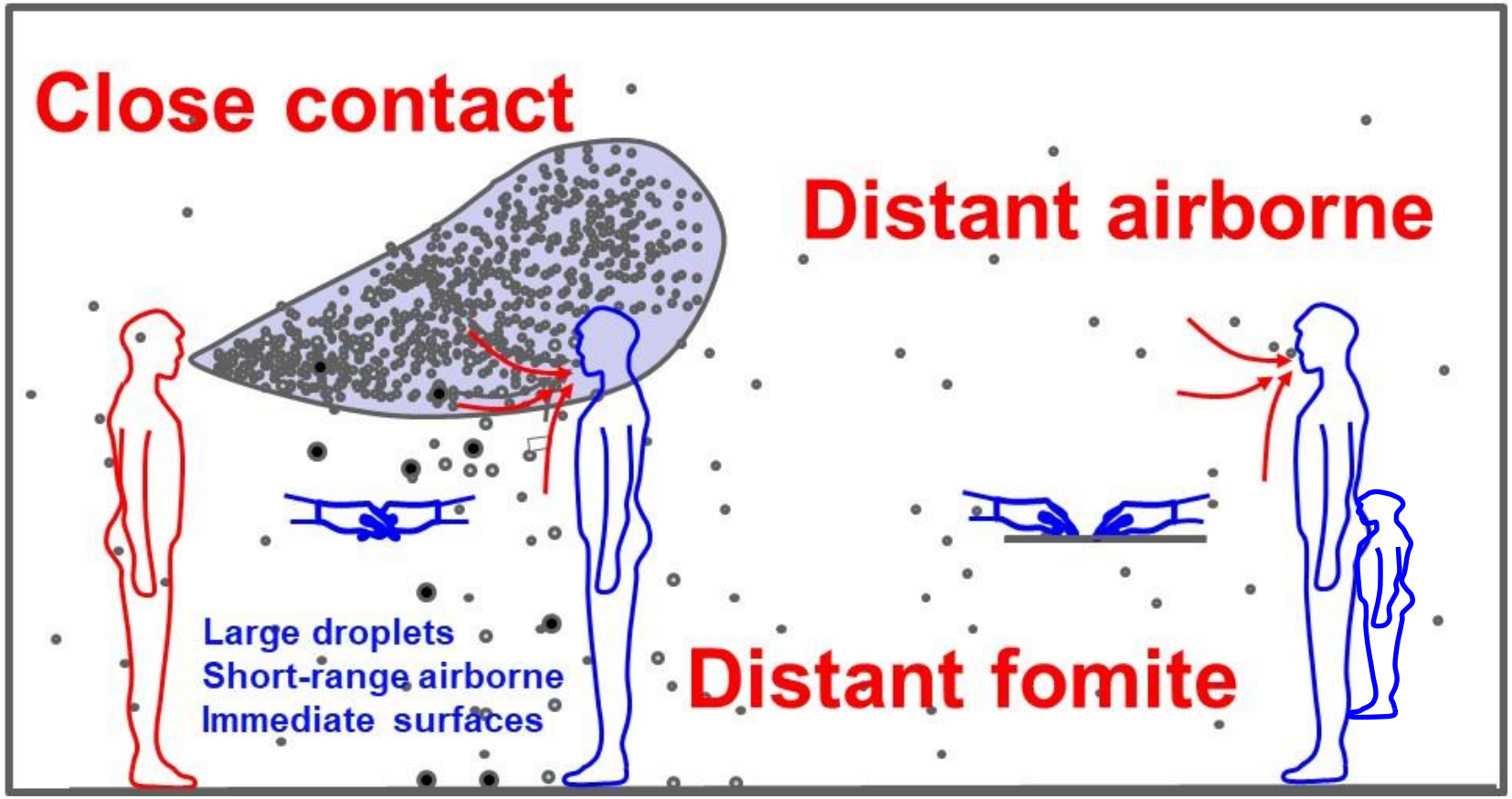
Major transmission routes of respiratory infection

呼吸道感染的主要傳播途徑

Short-range <1.5 m 近距

Long-range 遠距

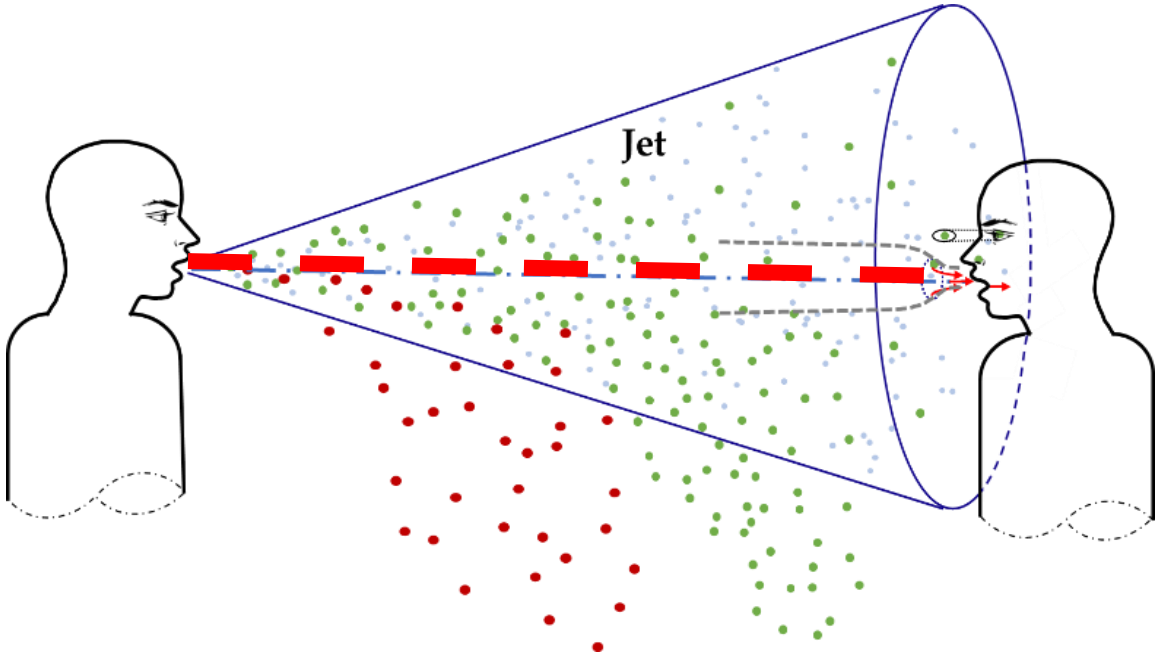


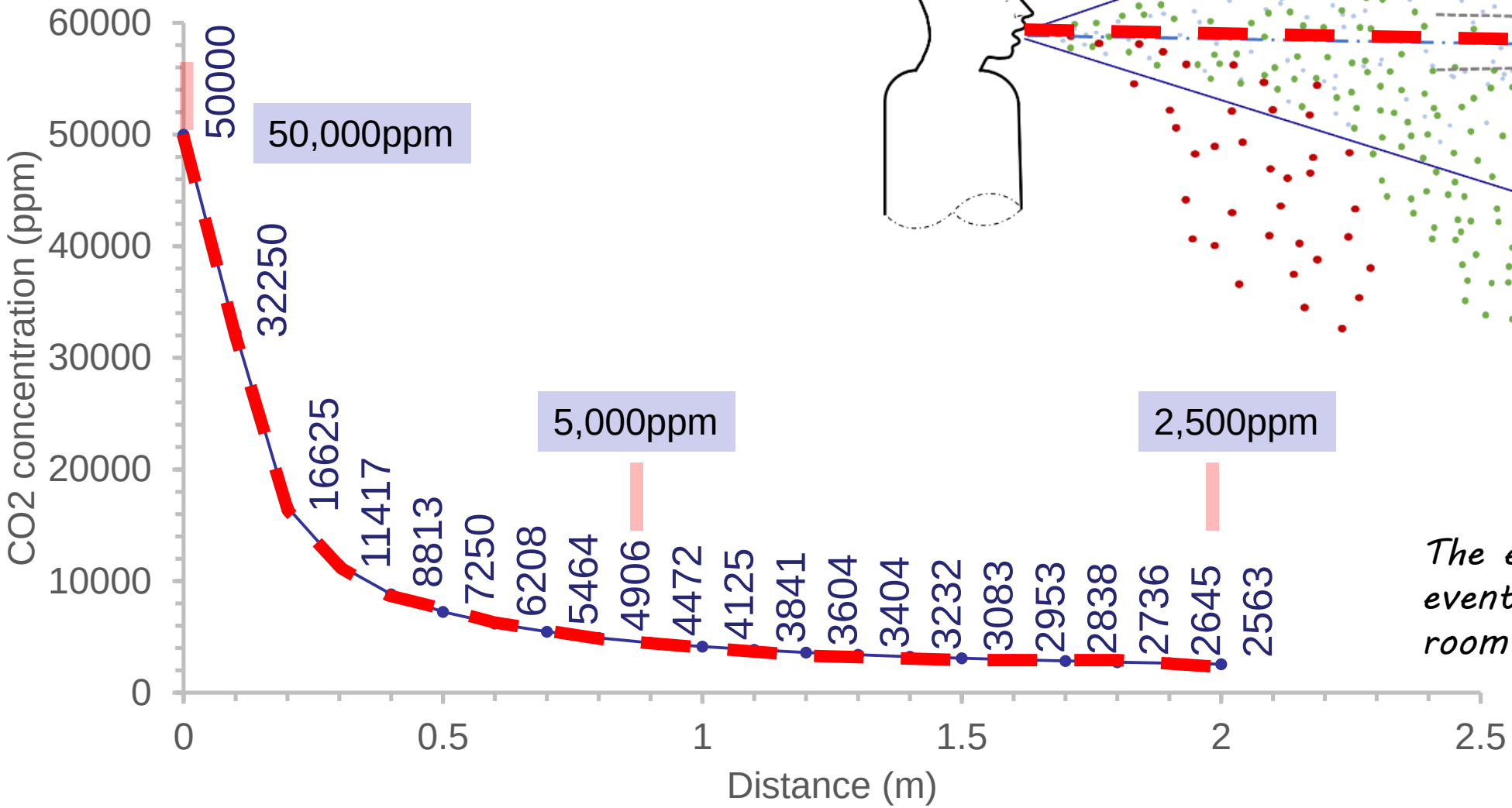


Wei J and Li Y (2016). *American Journal of Infection Control, 2016 Sep 2;44(9 Suppl):S102-8.*

This is how an expired jet works 呼出射流

Using expired CO_2 as surrogate (note: ideal conditions, illustration only)
Concentration at 1m is 1/10 at mouth; at 2m is 1/20

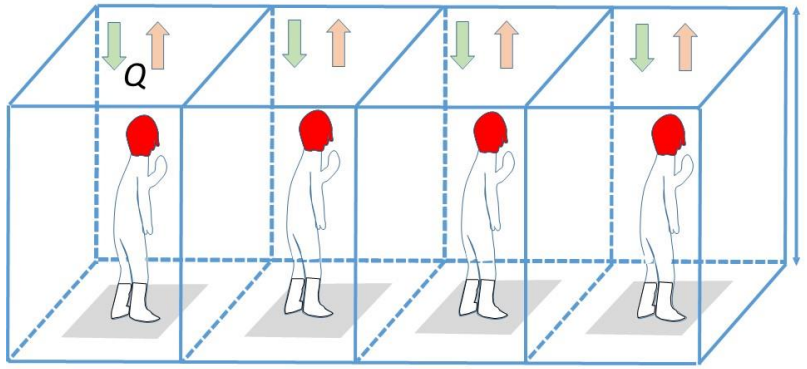




The exhaled jet eventually diluted by room flows (0·2 m/s)

Lee JHW & Chu V(2012). Turbulent jets and plumes: a Lagrangian approach. Springer Science & Business Media.

Consider a room with n people (all infected), each is an infector



At steady state, $C = \frac{nQ}{q}$

where nQ are the total quanta generation by n infectors

p is the pulmonary ventilation rate of each person

Assume quanta concentration at mouth of release is C_{mouth}; then $Q = pC_{mouth}$

If room ventilation rate q per person is the same as the pulmonary ventilation rate p per person (typically at 30 L/min or 0.5 L/s at normal work)

$$C = \frac{nQ}{q} = \frac{pC_{mouth}}{q/n} = C_{mouth}$$

The pulmonary ventilation rate p may be considered as a reference for considering ventilation rate 肺通氣量可作為考慮建筑通风量的参考

Let us consider four ventilation (rate) situations

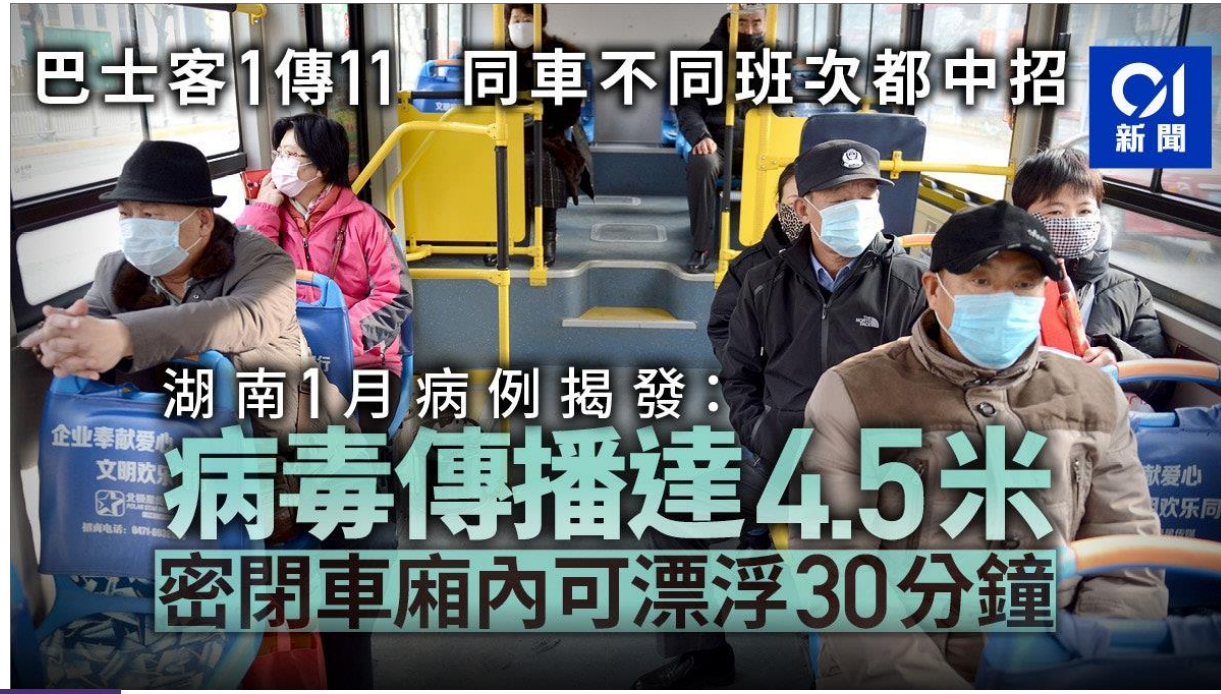
5 star: Outdoor air like 室外空氣般 (>> the required, e.g. in those with large open windows) (pleasant)

2 star: Good (sufficient足够) (≈ ASHRAE62.1 (e.g. 10 L/s per person) , i.e. about $20p$) (free from exhaled odour)

2 cross: Poor (insufficient不足) (just above 0.5 L/s per person (as bad as other's breath)

5 cross: Very bad (awful可怕) (below 0.5 L/s per person) (worse than other's breath)

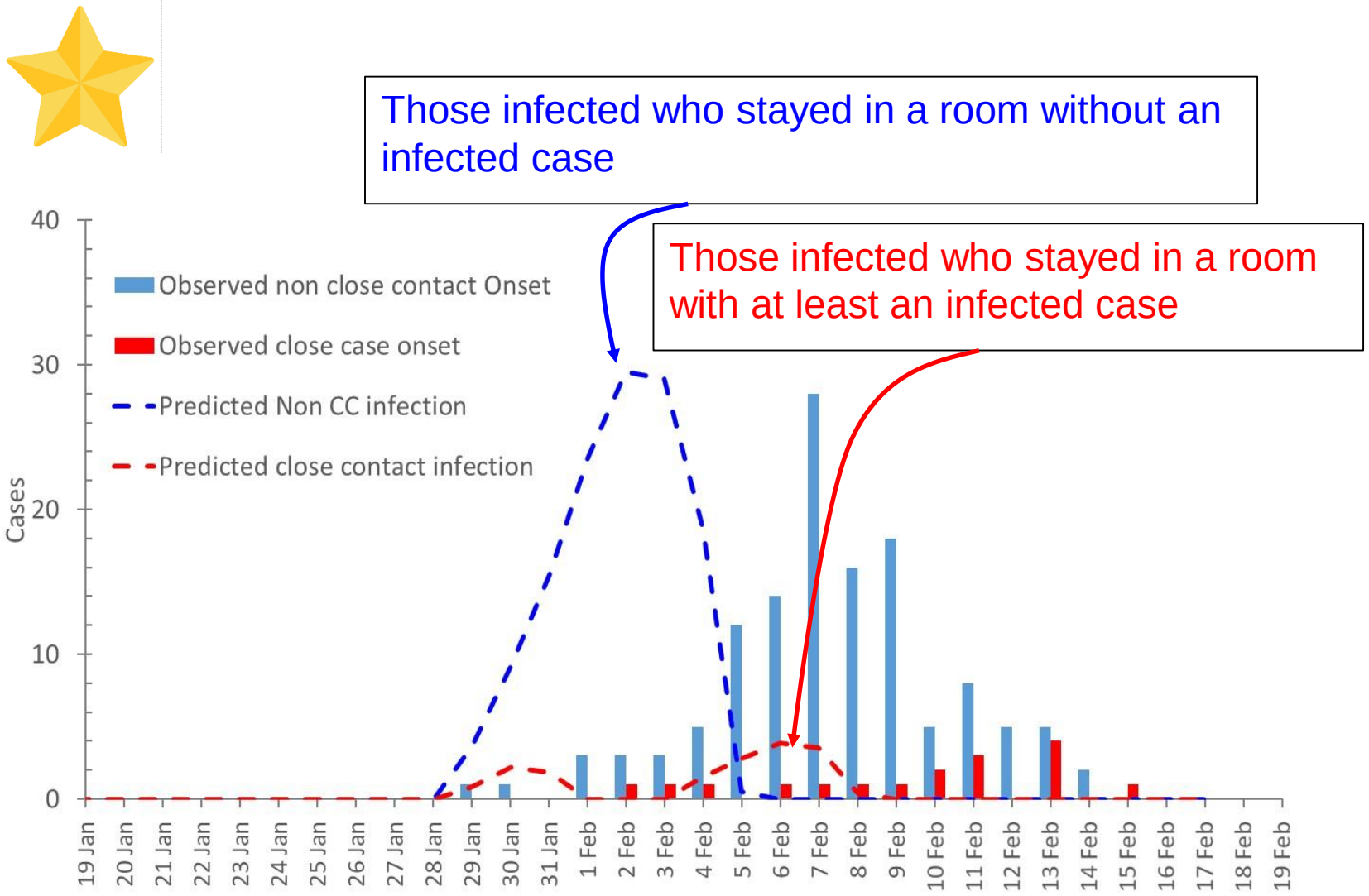
Internet images



Online images

We shall look at these three widely publicized outbreaks.

2 star ventilation: *Diamond Princess*· "sufficient ventilation" probably worked: preliminary study



Xu P et al. Transmission routes of Covid-19 virus in the Diamond Princess Cruise ship. https://www.medrxiv.org/content/10.1101/2020.04.09.20059113v1

Those infected who stayed in a room without an infected case were all infected before quarantine 5 Feb 2020. 在沒有感染病例房間的被感染者都是在2020年2月5日隔離之前被感染的。

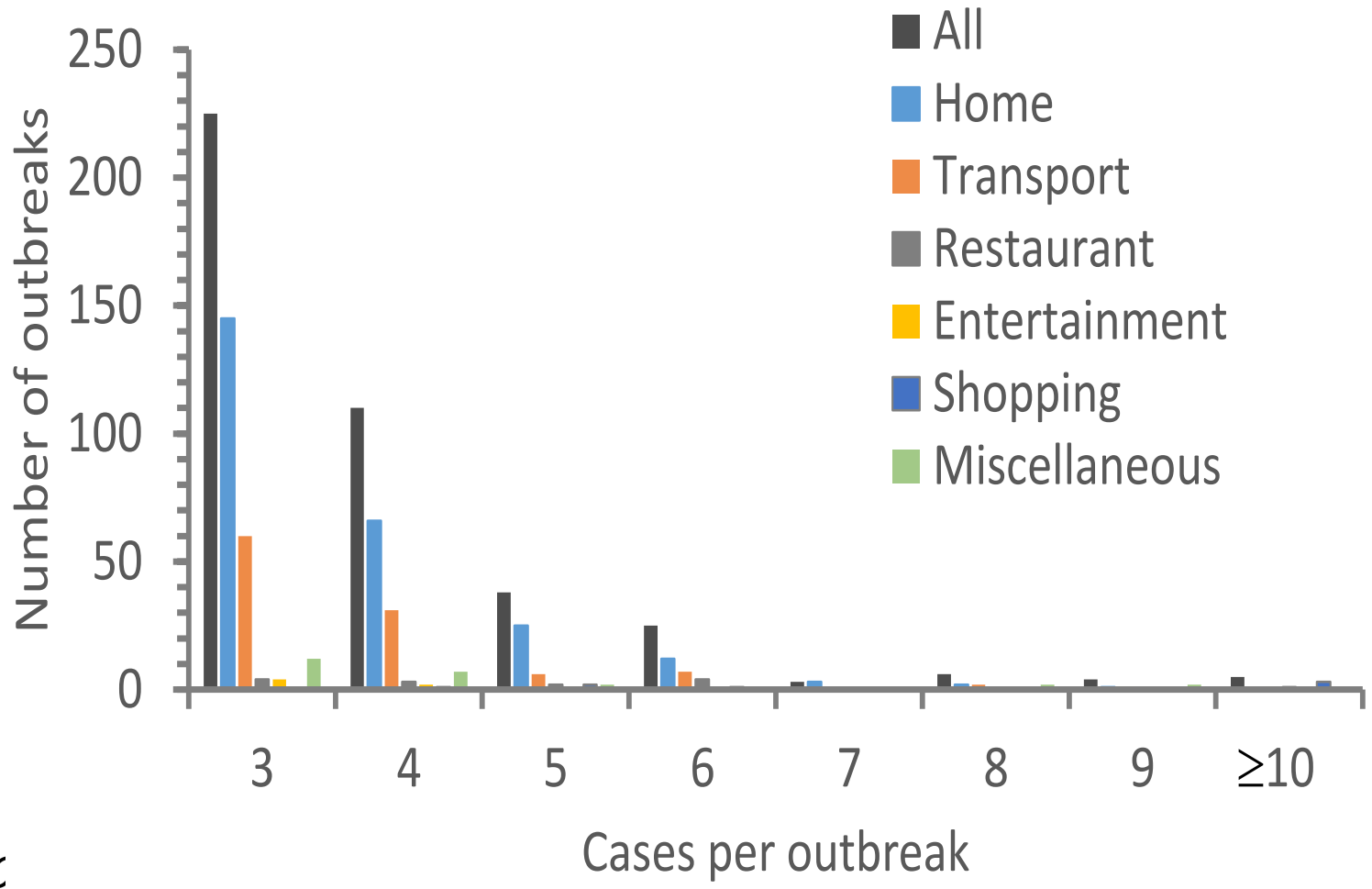
There was no spread between staterooms after 5 Feb 2020. 2020年2月5日之後，各客艙之間沒有傳播。

Room central air-conditioning probably did not spead. 房間中央空調可能沒有传播。

But no field measurement and lack of more detailed data so far 但是到目前為止，還沒有現場測量，也沒有更詳細的數據

5 star ventilation: There is a very low risk of long-range airborne infection outdoors.

Nearly all outbreaks in non-Hubei cities occurred indoors



Searched 7324 cases (66·7% of 10,98C
318 outbreaks with ≥ 3 cases

Qian, H. et al. Indoor transmission of SARS-CoV-2. https://www.medrxiv.org/content/10.1101/2020.04.04.20053058v1

A incomplete list of involved indoor environments in Covid-19

Mainland China: Apartment, villa, conventional train, high-speed rail cabins, private car, passenger plane, shuttle Bus, noodle house, restaurants, hotel lobby, restaurant dining room, hot pot restaurant, gym, chess room, tea house, mahjong parlour, barbershop, low-end shopping mall, low-end supermarket, hospital, community, thermal power factory, taxi, hotel room/conference rooms, long-distance bus, cruise ships, and prisons

Hong Kong: Hot pot, public estate, Buddhist temple, bars (Lan Kwai Fong, Wan Chai, and Tsim Sha Tsui), wedding banquet, karaoke, restaurant,...

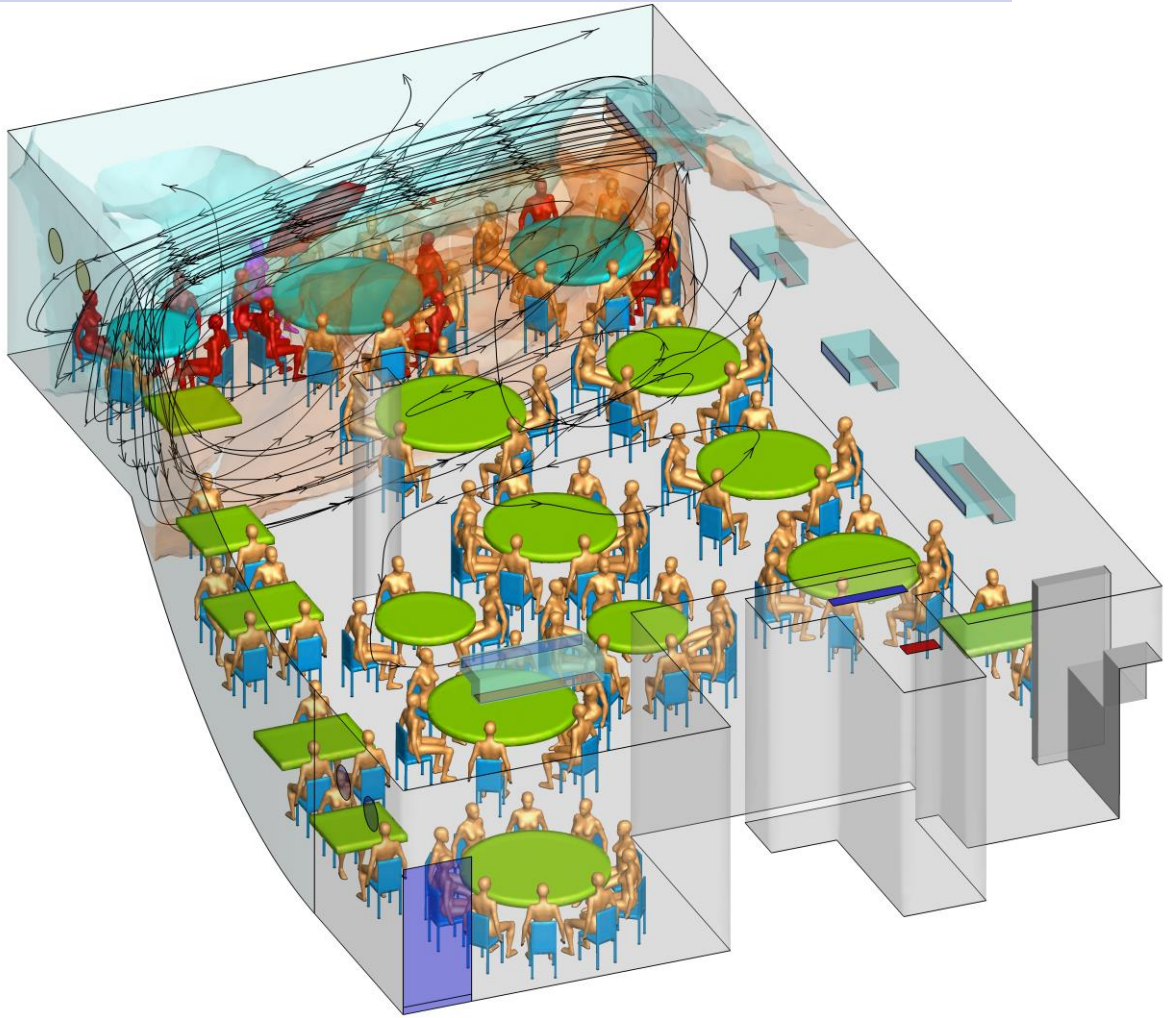
South Korea: church, hospital, call centre and gym

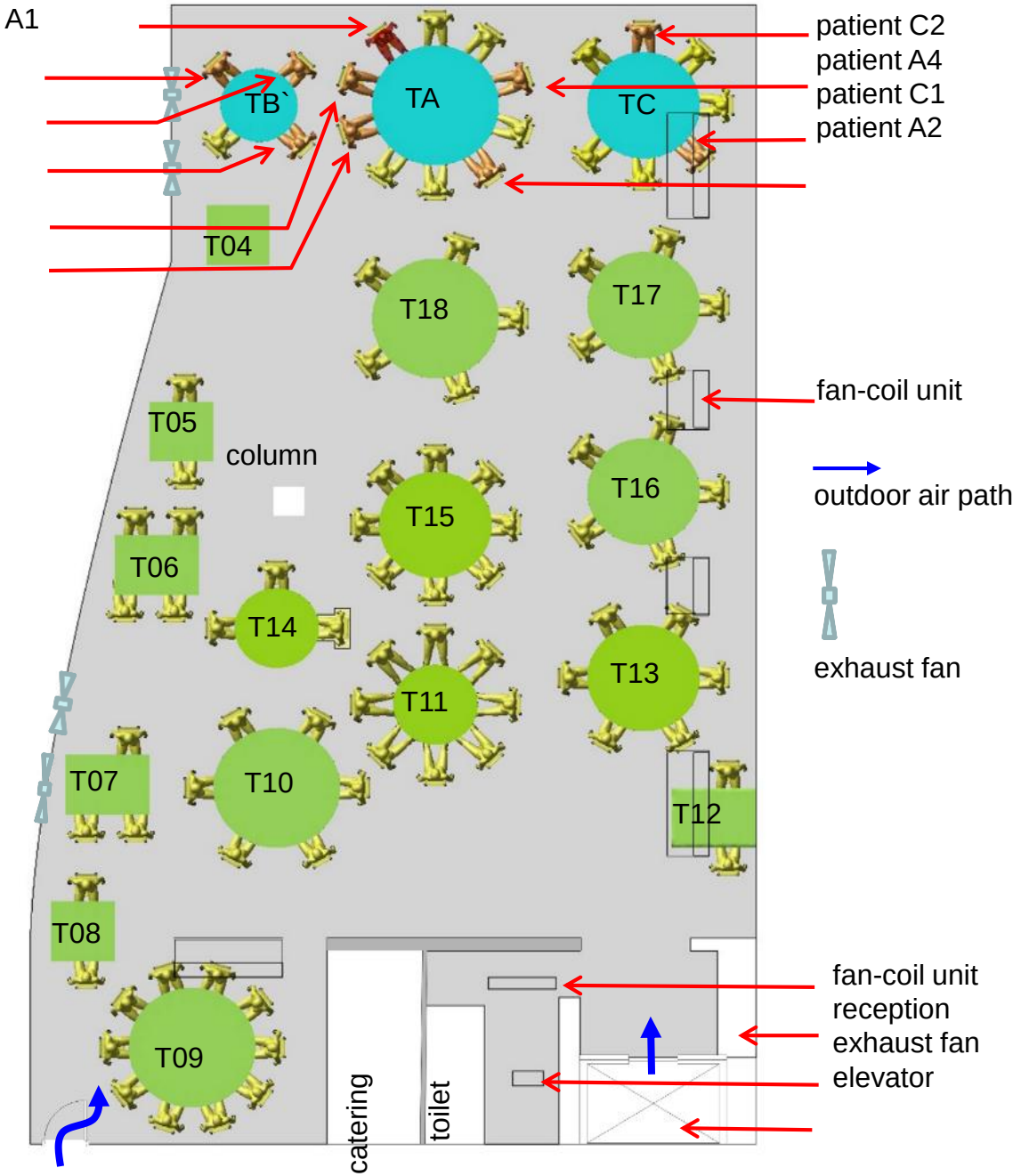
Singapore: migrant dormitories

What do they have in common?
Suspicious for low ventilation rate?

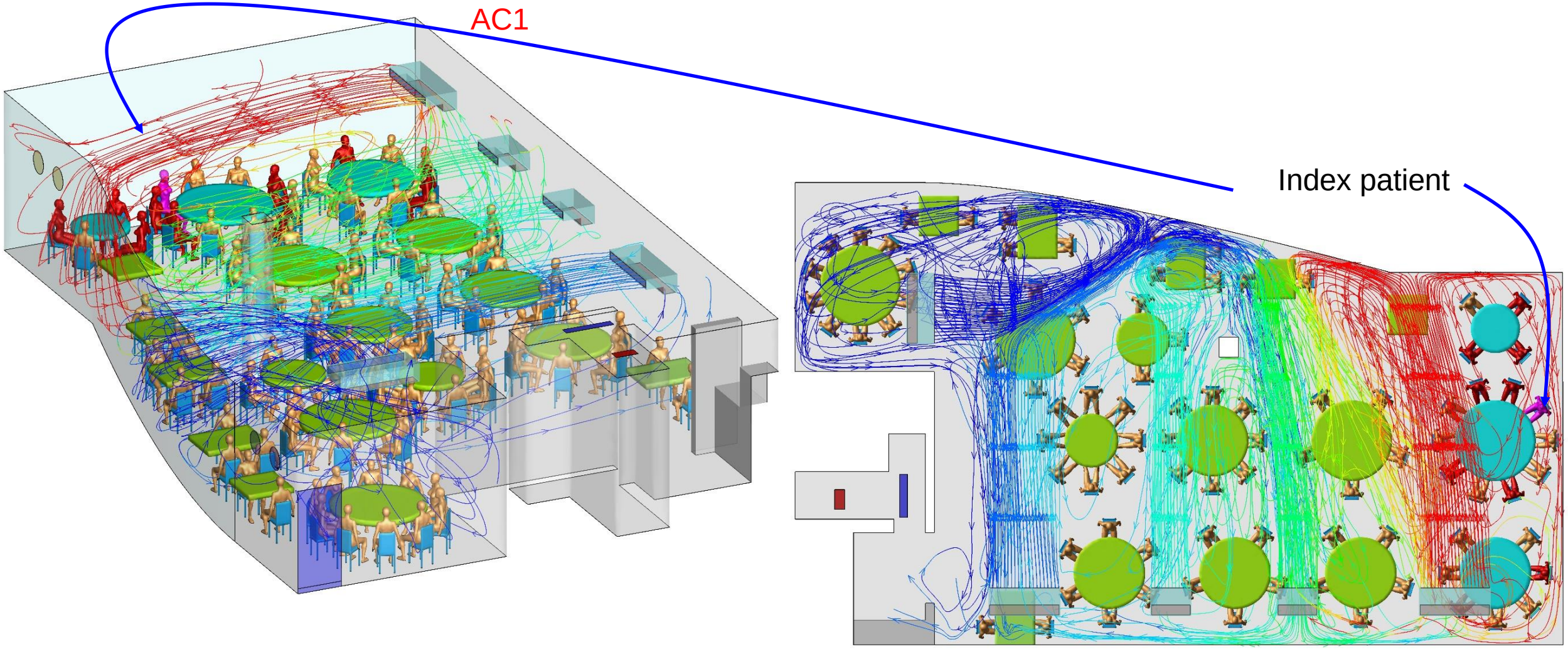
2 cases ventilation: The Guangzhou Restaurant Outbreak

- Family A of 10 visited from Wuhan
- Lunch on Jan 24 CNY eve
- 0·75-1·02 L/s per person ventilation





The streamlines showed how the ABC recirculation bubble was possibly established.

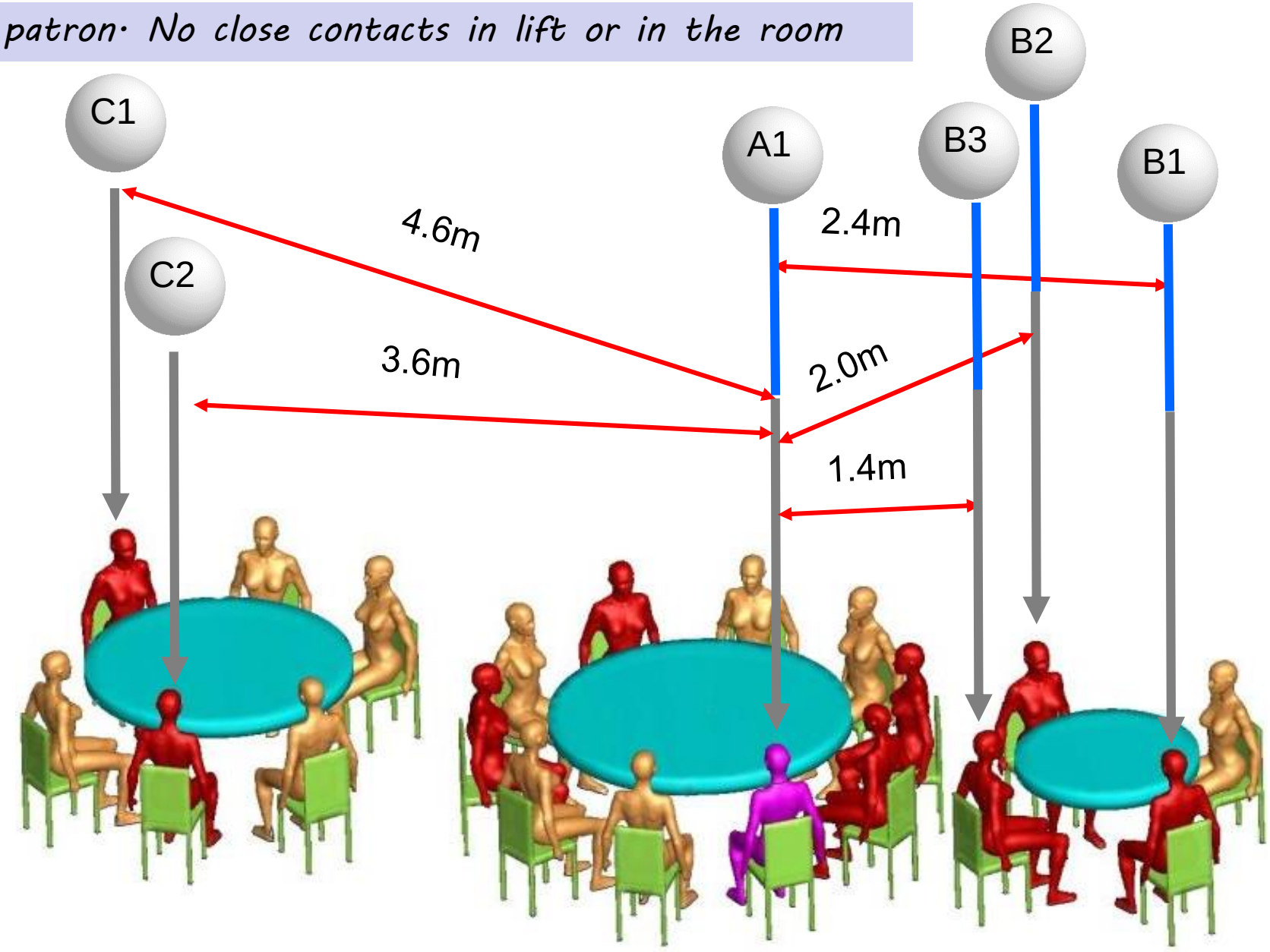


View from top of the restaurant 3F

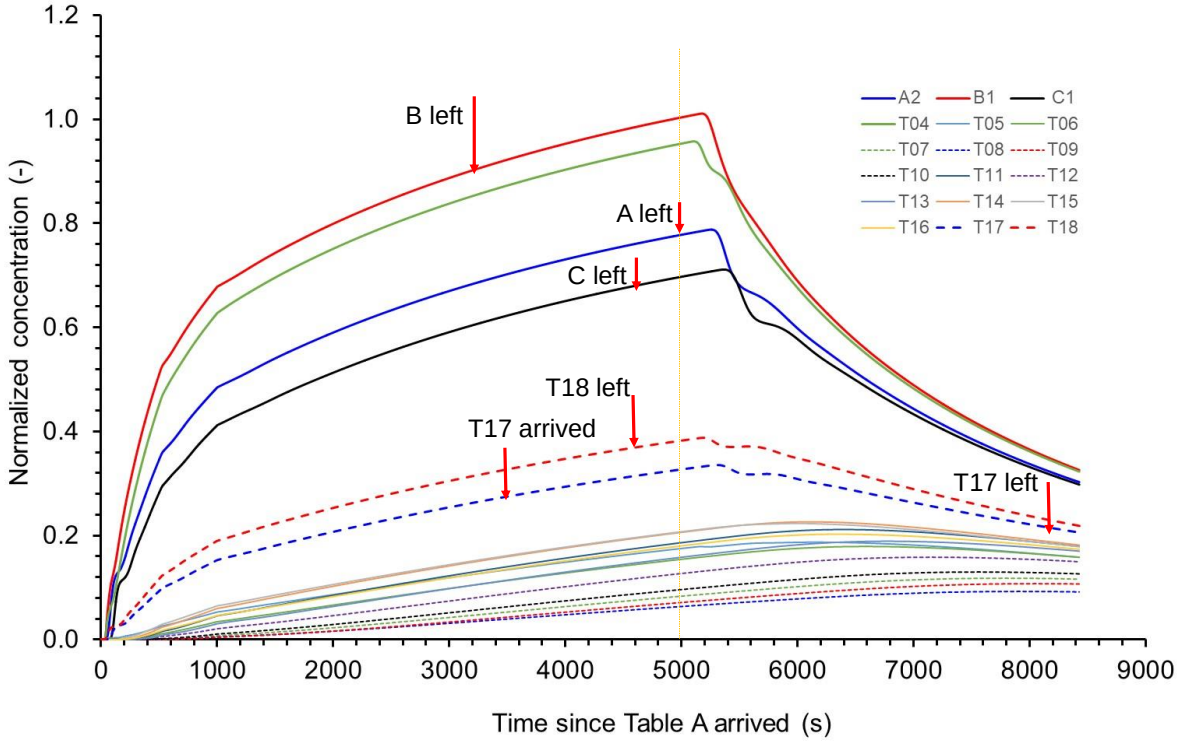
AC1

Poor ventilation at only 1 L/s per patron· No close contacts in lift or in the room

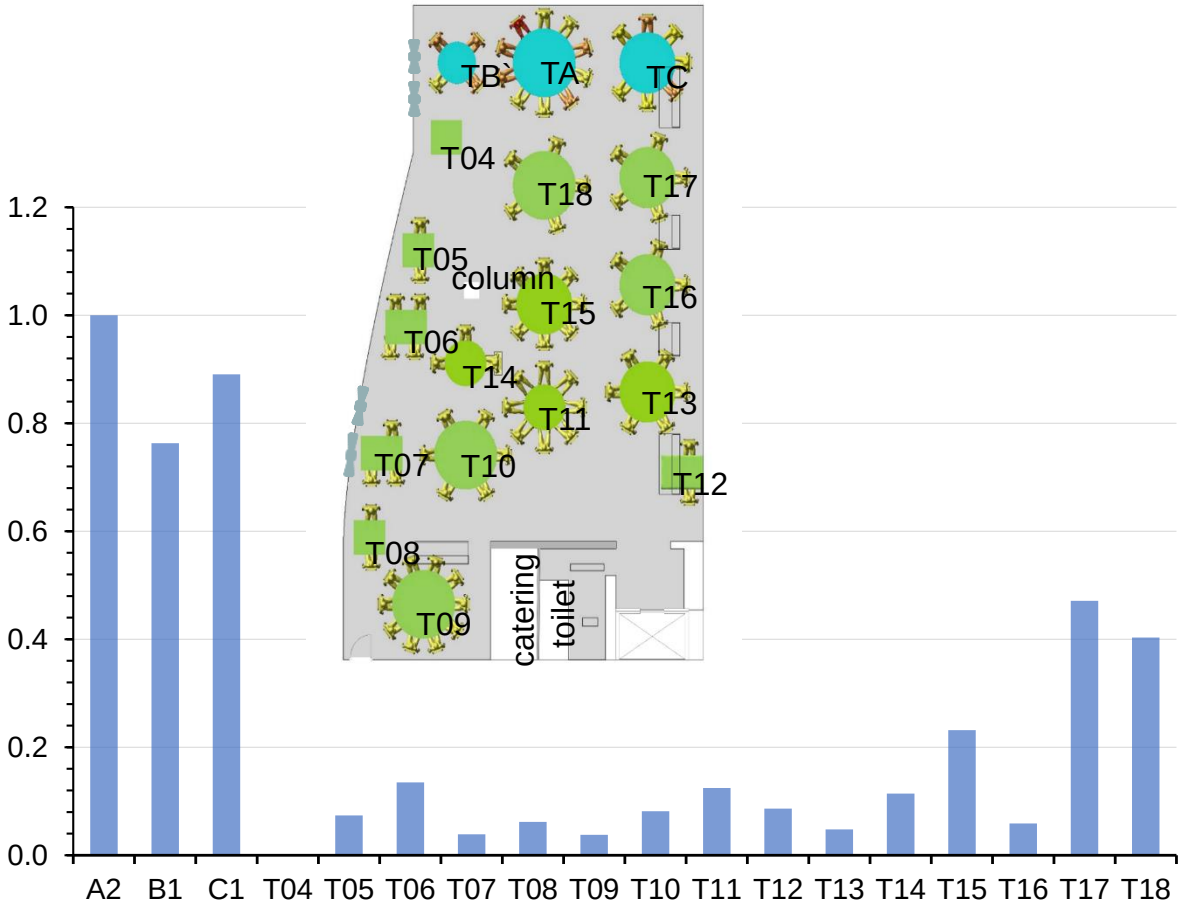
Field measurement: March 19–20



Li Y., et al. Evidence for probable aerosol transmission of SARS-CoV-2 in a poorly ventilated restaurant. https://www.medrxiv.org/content/10.1101/2020.04.16.20067728v1



Predicted normalized concentration for some patrons on Tables A, B and C, and other tables after Table A patrons arrived at time zero (12:01 pm).



The predicted normalized exposure of the infectious-virus-containing droplet nuclei during the period at all tables

Parameters	Big bus B1 from Changsha to city D (12:10 pm to 3:30 pm)	Minibus B2 (15:43 pm – 16:43 pm)
Number of persons (other passengers + driver (conductor))	46	17
Number of infected except index patient	7	2
Attack rate (%)	7/46, 15.2%	2/17, 11.8%
Ventilation rates (L/s per person)	1.72	3.22
Exposure time (min)	200	60

Learning from the three outbreaks: Diamond Pricness cruise ship, Guangzhou restaurant, and Hunan two buses:

Ventilation less than 3 L/s per person leads to long-range aerosol infection, but greater than 8-10 L/s per person (speculative) probably do not lead to long-range aerosol infection. No data exists for between 3 -8 L/s per person. 低於每人每秒3 升通風量會導致遠程氣溶膠感染，但通風量大於每人每秒8-10 升8-10 （推測）可能不會導致遠距離氣溶膠感染。每人每秒3 -8升之間沒有數據。

However, this does not rule out the short-range transmission and other routes.

This means that SARS-CoV-2 is normally non-long-range-airborne when there is reasonably sufficient ventilation, but becomes airborne when there is insufficient ventilation. 這意味著，在有足夠通風的情況下，SARS-CoV-2通常是遠距空氣傳播的，而在通風不足的情況下會變為遠距空氣傳播。

This is the opportunistic airborne transmission (Roy and Milton, 2004). Insufficient ventilation becomes a "favourable environment". 這是機會性的空氣傳播（Roy and Milton, 2004）。通風不足會成為一個所謂的"有利環境"。

Roy, C. J., & Milton, D. K. (2004). Airborne transmission of communicable infection--the elusive pathway. *NEJM*, *350*(17), 1710.

Useful to see what do airborne route and large droplet route mean in fluid mechanics

- Airborne transmission refers to the transport by air flow of the virus or virus-containing droplet or droplet nuclei from the source, which can be inhaled and subsequently lead to disease/infection by the susceptible. 空氣流動將細小液滴核擴散。近距離和遠距離的人都有可能吸入這些細小液滴核，並導致感染或者引發疾病。
- The transport “medium” is airflow, not air. It is airflow transmission. 空氣傳播的運輸“介質”是氣流，而不是空氣。準確的名字事是氣流傳傳播

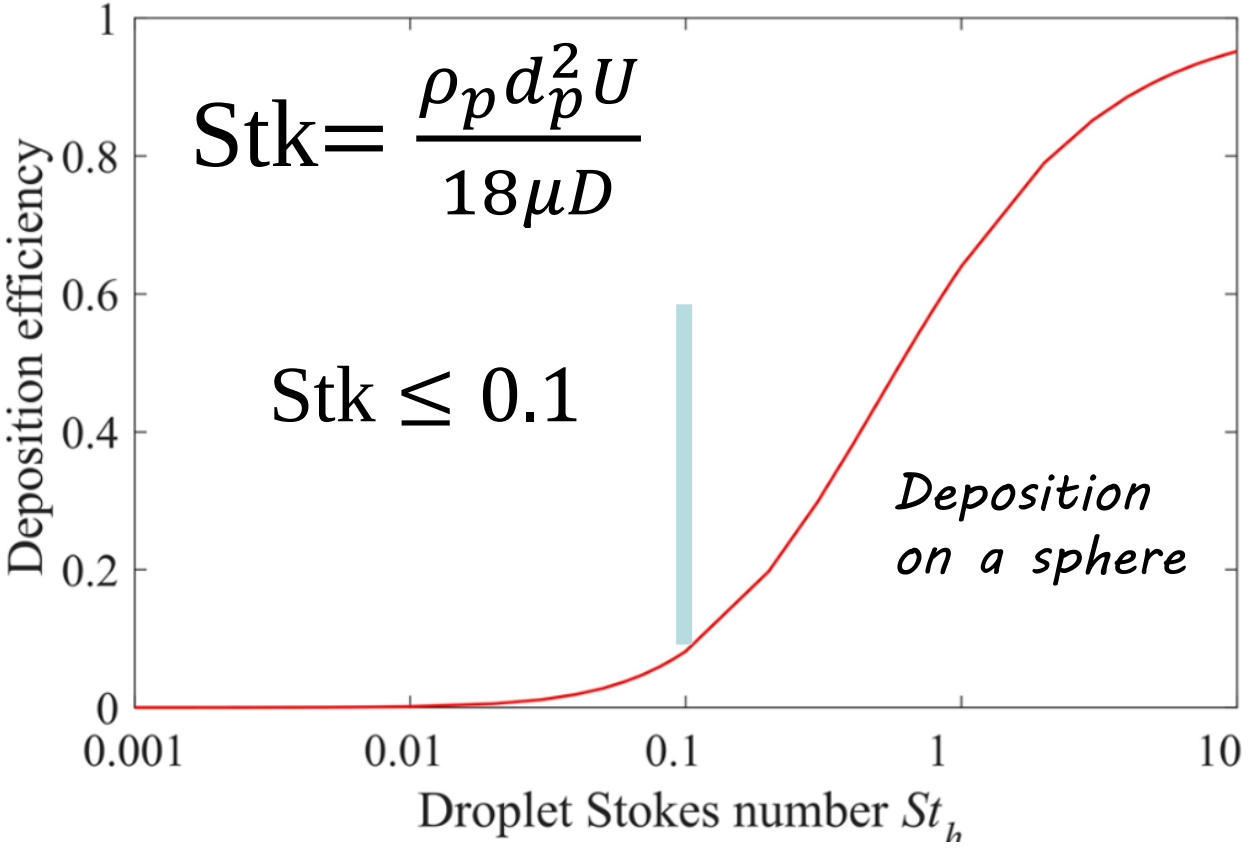
- Droplet transmission refers to the deposition of exhaled large droplets on the (mouth, nose and eye) mucus membrane of the susceptible, and subsequently leads to disease/infection. 飞沫（大液滴）传播：呼出的大液滴（大于50微米）沉积在1至2米之内的人嘴唇/眼睛/鼻孔粘膜上，随后导致感染或者引发疾病。
- The transport medium is momentum. The droplet movement is ballistic. 飞沫传播的運輸“介質”是动量。液滴运动呈现一定弹道轨迹。

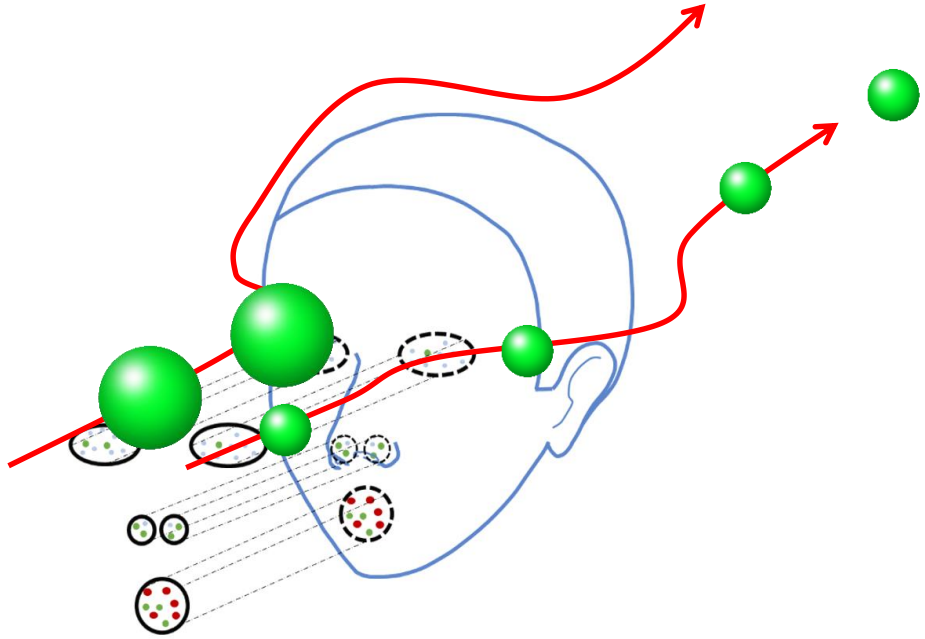
Ballistic - Wiki

Unfortunately, existing threshold droplet size in large droplet transmission is wrong! Causing a lot of confusions. 不幸的是，大液滴傳輸中現有的閾值液滴尺寸是錯誤的！造成混亂.

The threshold droplet size is 50-100 microns, not 5 or 10 microns! Only >50-100 microns can deposit on face (1m), and much less on noses, mouth and eyes. Small ones follow airflow.

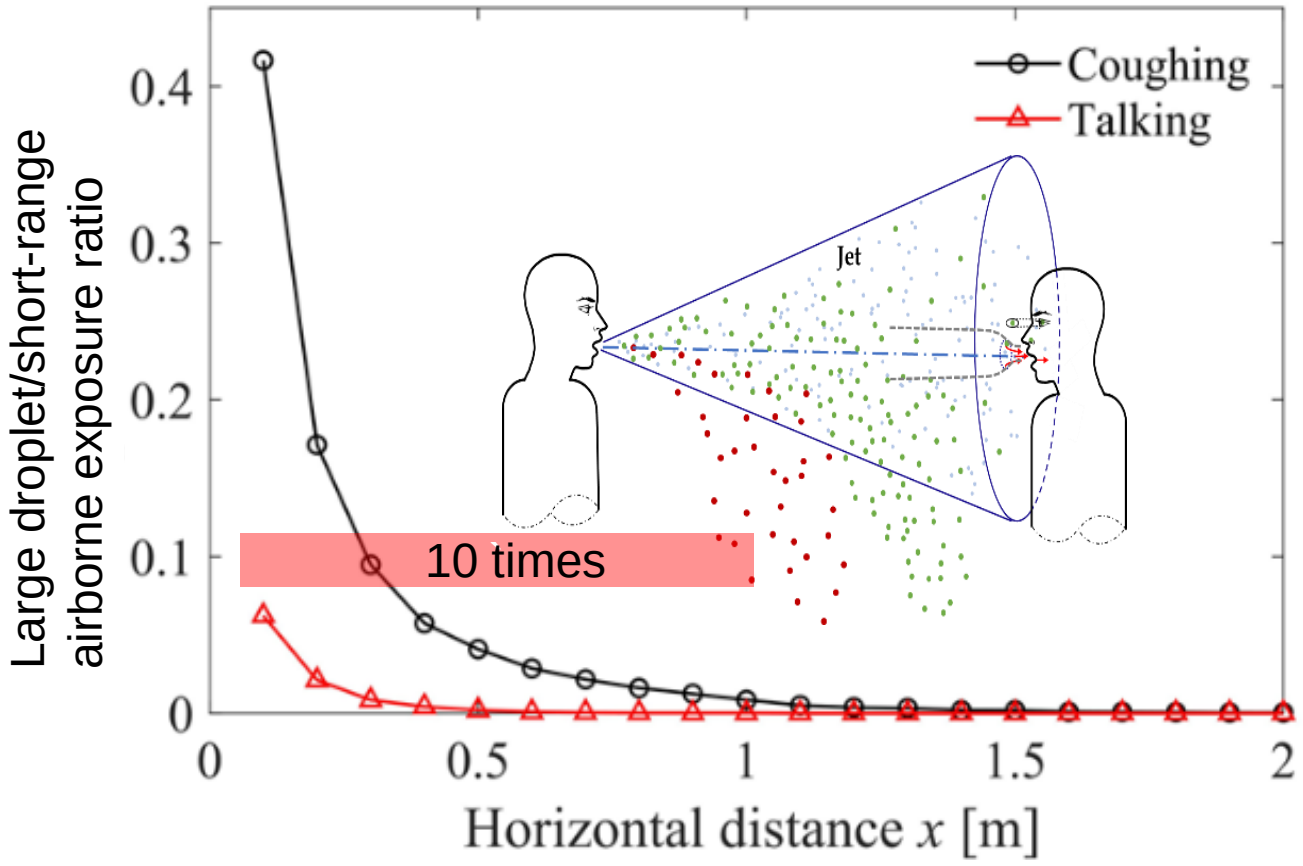
液滴的閾值大小為50-100微米，而不是5或10微米！面部（1m）上只有> 50-100微米能沉積，而鼻子，嘴和眼睛上的沉積則少得多。小液滴跟隨氣流。

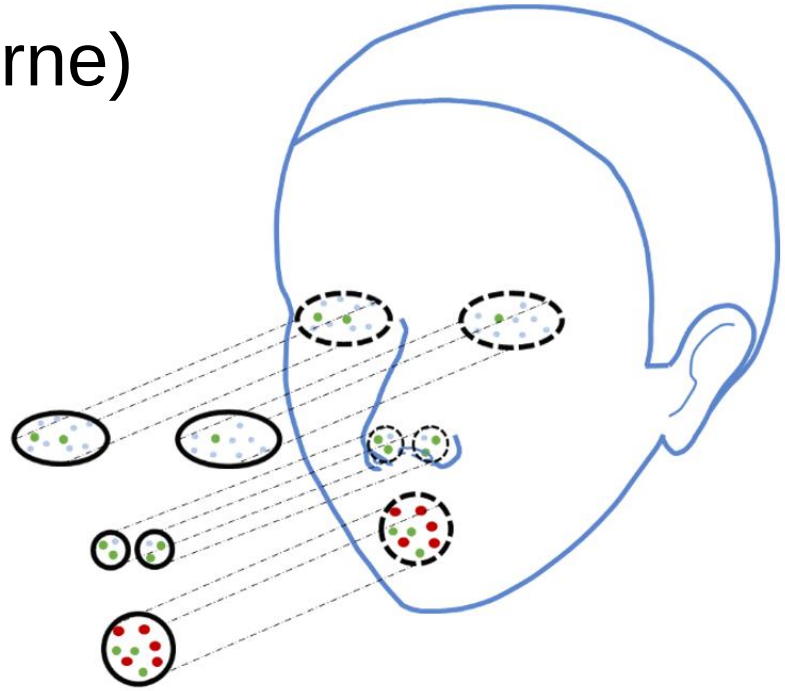


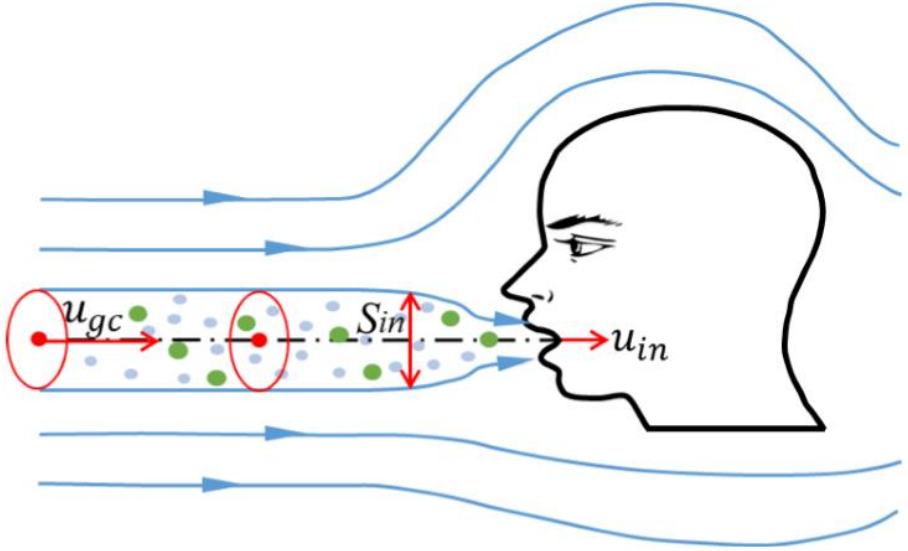


Chen et al. 2020. Short-range airborne route dominates exposure of respiratory infection during close contact. Building and Environment, 176

Exposure ratio (large droplets/short-range airborne)



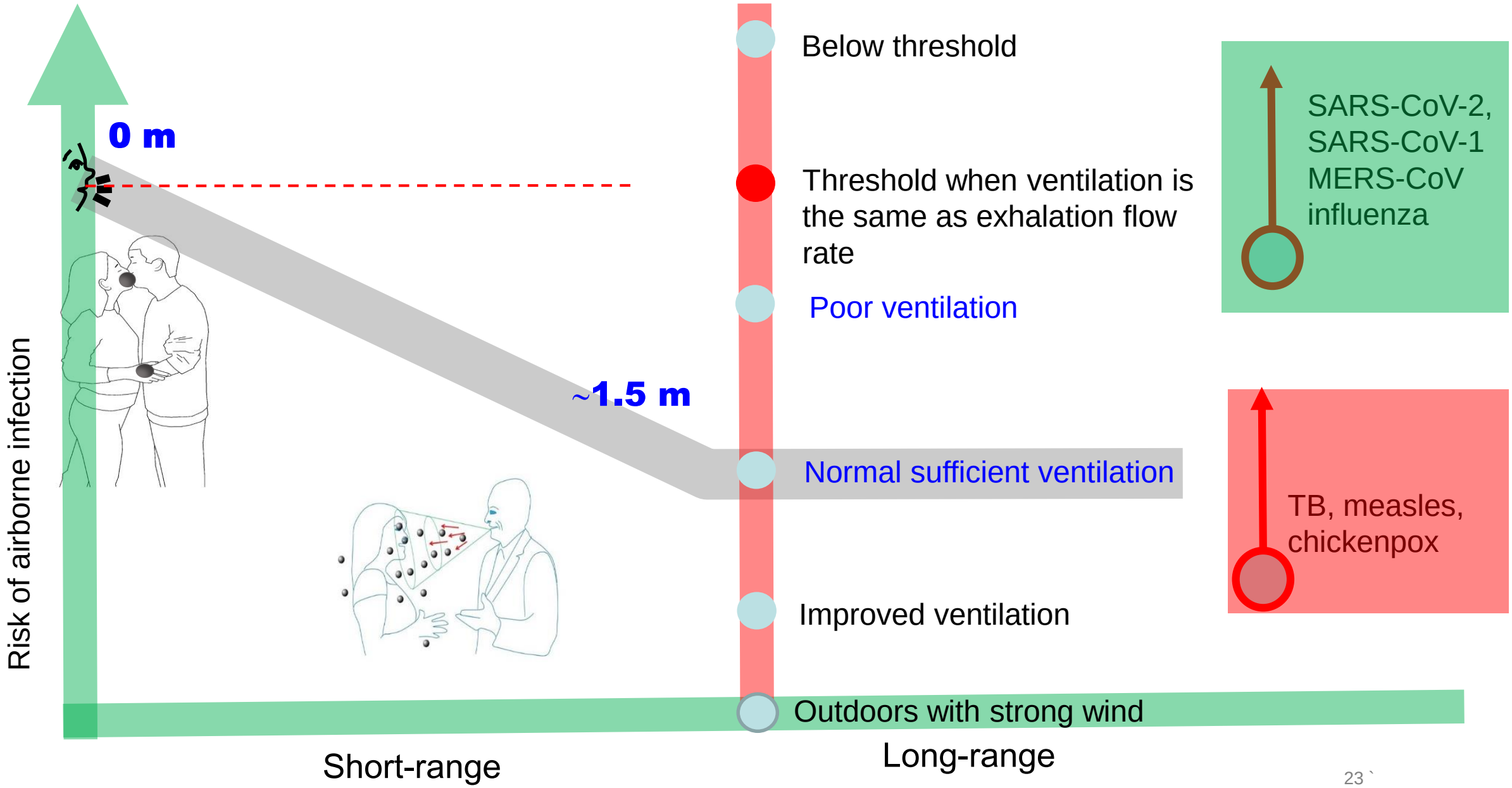




Mechanistically, short-range airborne can be 10 times more important than droplet transmission

Chen et al. 2020. Short-range airborne route dominates exposure of respiratory infection during close contact. Building and Environment, 176

A normally non-long-range-airborne infection turns to long-range airborne in poorly ventilated spaces



Useful to recognize two different types of airborne infection. 因此，認識兩種不同類型的空氣傳播感染有用。

Those not easy to control : Can occur at normal indoor conditions - might be indeed fearful, e.g. TB; measles and chickenpox (Obligate or preferential airborne)那些不容易控：可能會在正常的室內條件下發生-可能令人恐懼，例如結核;麻疹和水痘（基本或優先性空氣傳播）

Those easy to control : Only occur in crowded and poorly ventilated areas - better ventilation and staying away from such locations (Opportunistical airborne) 易於控制：僅發生在通風不足的场所（機會性空氣傳播）

Ventilation is important to airborne (or airflow) transmission of Covid-19 in two aspects

- *An insufficient ventilation leads to a probably non-airborne transmission of SARS-CoV-2 to long-range airborne transmission. Poor ventilation leads to opportunistic airborne.*

- *Recirculation bubbles (in minimizing inflow of clean air) or stratified air layers (in minimizing dilution) may also enhance the airborne transmission with unfavourable release of infectious aerosols.*

HVAC engineers play a role here.

Where do our 7 million people stay in Hong Kong?

Categories of people	Description	Number
Home stay	Mostly staying at home (housewives, retired people, youth children, domestic helpers etc.)	2,286,125
Office workers	Working in offices or factories during the daytime	1,503,830
Classroom attendances	Students and teachers (kindergarten to university)	1,267,850
Food service workers	Restaurant workers	196,940
Sellers	Working in all kinds of shops	352,000
Drivers	Driving or serving public transport vehicles	10,375
Public workers	Working in public places	64,980
Others	Individuals in labor force without classification	1,175,000
Overall	Total population	6,857,100
		Data in 2006

Gao, X., Wei, J., Lei, H., Xu, P., Cowling, B. J., & Li, Y. (2016). Building ventilation as an effective disease intervention strategy in a dense indoor contact network in an ideal city. *PloS one*, *11*(9), e0162481.

There are probably 2·5 million indoor environments in Hong Kong·

Name	Description	No of indoor environments
Home	Homes all the individuals stayed at night including university dormitories	2,201,000
Office	Offices	30,000
Classroom	Classrooms of kindergartens, primary schools, high schools, universities and training centers.	38,807
Restaurant	Restaurants	18,000
Shop	All kinds of shops including shopping malls, supermarkets, retail shops etc.	87,300
Transportation	Buses, MTR and KCR trains	70,134
Public location	Museums, cinemas, gyms, karaokes etc	4,940

We actually do not know much about the ventilation in these indoor environments.

Ventilation of buildings – standard and practice

Existing ventilation standards such as ASHRAE 62.1 do not consider infection control in recommending ventilation rates;

- The required minimum ventilation rate varies for different spaces (office 8.5 L/s per person, reception areas 3.5 L/s per person, courtrooms 2.9 L/s per person, barber shop 5.0 L/s per person).
- In the real world, the delivered ventilation rate depends on design, construction, operation and maintenance, and also usage (e.g. occupant density may be higher than designed).

The possible minimum required ventilation rates

- 10 L/s per person
- or a breath dilution ratio of 100 times (breath dilution ratio is defined as the reciprocal of the rebreathed fraction)
- or a rebreathed fraction of 0.01 (rebreathed fraction is the fraction of indoor air that is exhaled breath)

So it is about how much we dilute our exhaled air in our room. This allows us to compare room dilution to that close to our breath, i.e. comparing long-range airborne and short-range airborne.

CO2 sensor might be used for indicating ventilation for respiratory infection intervention?

Activities	Respiratory flow (L/s)	CO_2 release rate L/s
Sleep	0.08	0.004
Rest/low activity work	0.14	0.006
Normal work	0.6-0.8	0.02-0.6
Hard work	1.9-2.2	0.09-0.11

Online images, no conflict interest. Search Google “CO2 sensors with display”

We consider a respiratory flow of 0.1 L/s. CO_2 generation rate is $c_e q_e$ = 50000 ppm × 0.1 L/s = 0.05×0.1 = 0.005 L/s.

If q= 8 L/s, then $c_G = \frac{\dot{V}_{pol}}{q} = \frac{0.00510^{-3}}{1010^{-3}} = 0.0005$, which means that c_G = 500 ppm, dilution of 100 times.

If outdoor CO_2 at 400 ppm, then 400+500 = 900 ppm in the room

Recommendations:

- *Preliminary: Ventilation rate of < 3 L/s per person resulted in SARS-CoV-2 infection as shown in two outbreaks.* 低於每人每秒3公升的通風量升會導致*SARS-CoV-2*的遠距離空氣傳播。

- *Speculative: Possible sufficient ventilation of > 8-10 L/s per person would not result in Covid-19 transmission.* 推測每人每秒*8-10*公升的通風量可能足以將远距离空氣傳播的感染風險降至較低。

- *Keep sufficient ventilation for mitigating long-range airborne transmission, and CO2 sensors can be used. If >1000 ppm, be careful.* 在房間內可以安裝二氧化碳（*CO2*）傳感器，顯示二氧化碳濃度。濃度超過*1000 ppm*可能表明房間通風不足。

Thank you