Frontline Worker Safety in the Age of COVID-19

Health Watch USA[sm]

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Webinar Sept. 14th, 2022 - Registration Now Open

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Aerosolization and impact on do Frontier Workers

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QUT

World Health Organization Collaborating Centre for Air Pollution and Health

This presention

1. Generation of particles during respiratory activities
2. Detection of the particles
3. Particles characteristics and fate in the air
4. Mitigation of airborne infection transmission

Definitions:
is *IT* aerosol or droplet?

In aerosol science:

Aerosol: an assembly of liquid or solid particles suspended in a gaseous medium long enough to enable observation or measurement

Droplet: a liquid particle

In medical sciences:

Aerosol: smaller particles

Droplet: larger particles

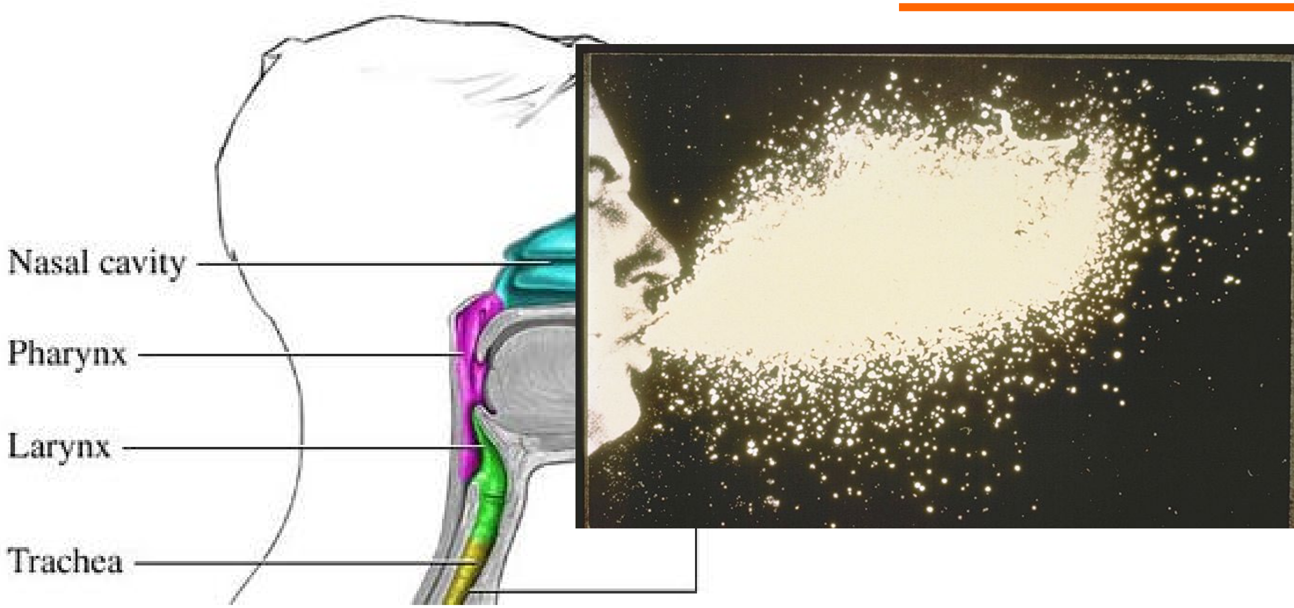
Let's don't worry about these differences!

I will call them particles

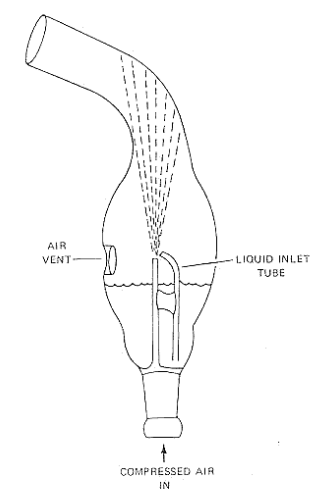
Randall, K.; Ewing, E.T.; Marr, L.; Jimenez, J.; Bourouiba, L. How Did We Get Here: What Are Droplets and Aerosols and How Far Do They Go? A Historical Perspective on the Transmission of Respiratory Infectious Diseases. (April 15, 2021) 2021.

GENERATION OF PARTICLES

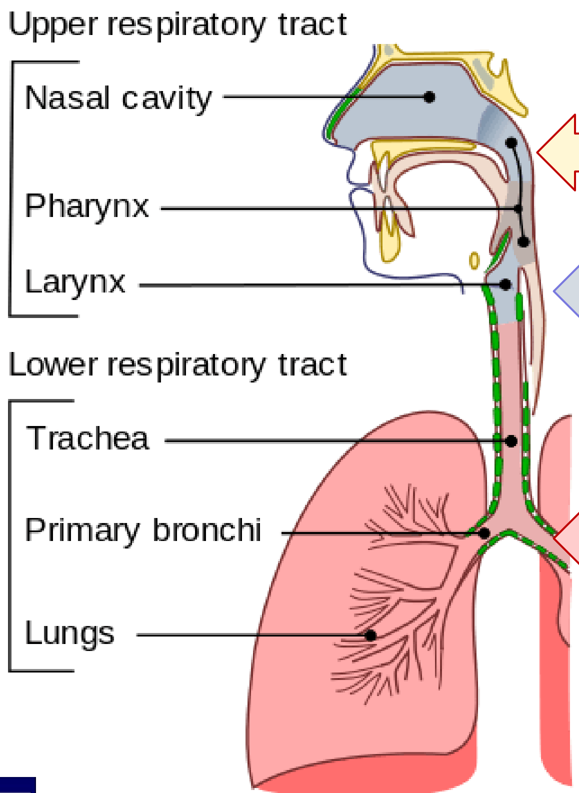
Particle aerosolization in respiratory activities



….results from the passage of an air-stream at a sufficiently high speed over the surface of a liquid



Generation of respiratory particles



Saliva in the **mouth** is aerosolised during interaction of the tongue, teeth palate and lips during speech articulation

Fluid bathing the larynx is aerosolised during voicing due to vocal fold vibrations

Fluid blockages form in respiratory **bronchioles** during exhalation

They burst during subsequent inhalation produce the particles

Viruses and bacteria are aerosolised as well!

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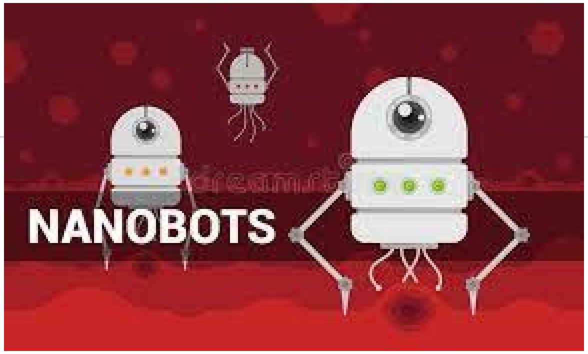
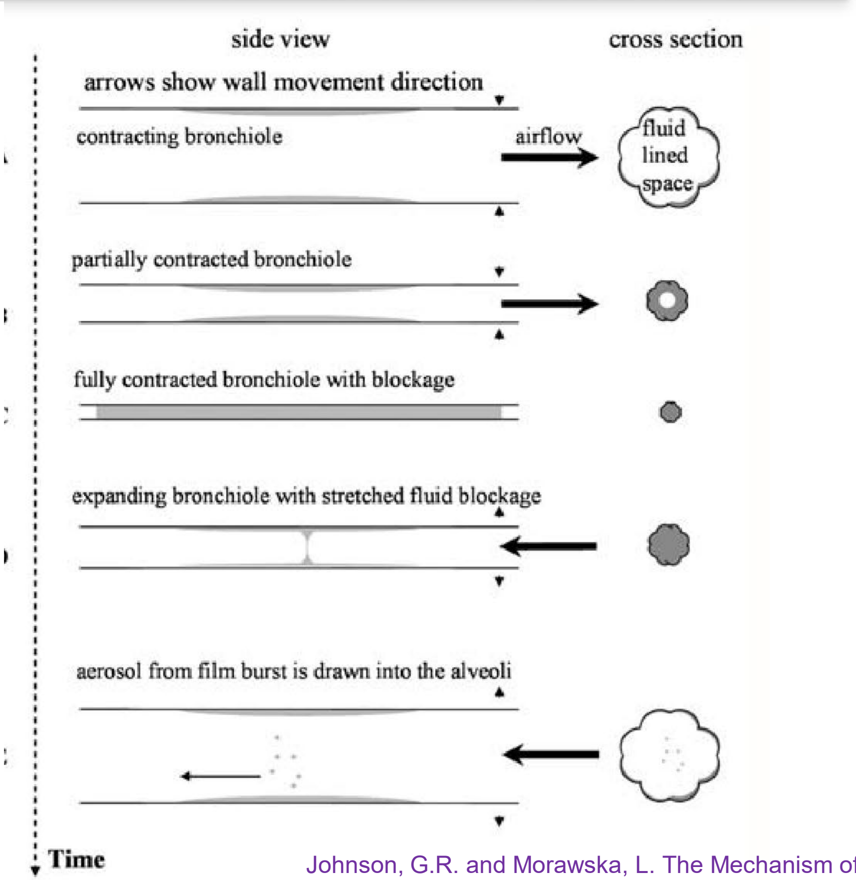
Bronchiole fluid film burst (BFFB)

?



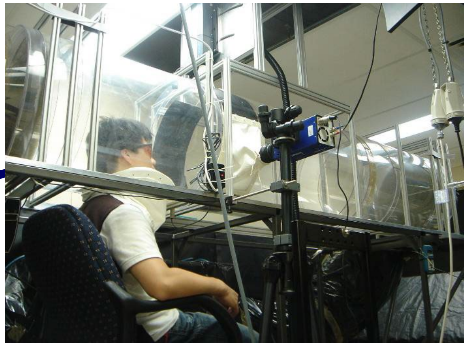
We cannot measure these processes directly, but model and simulate



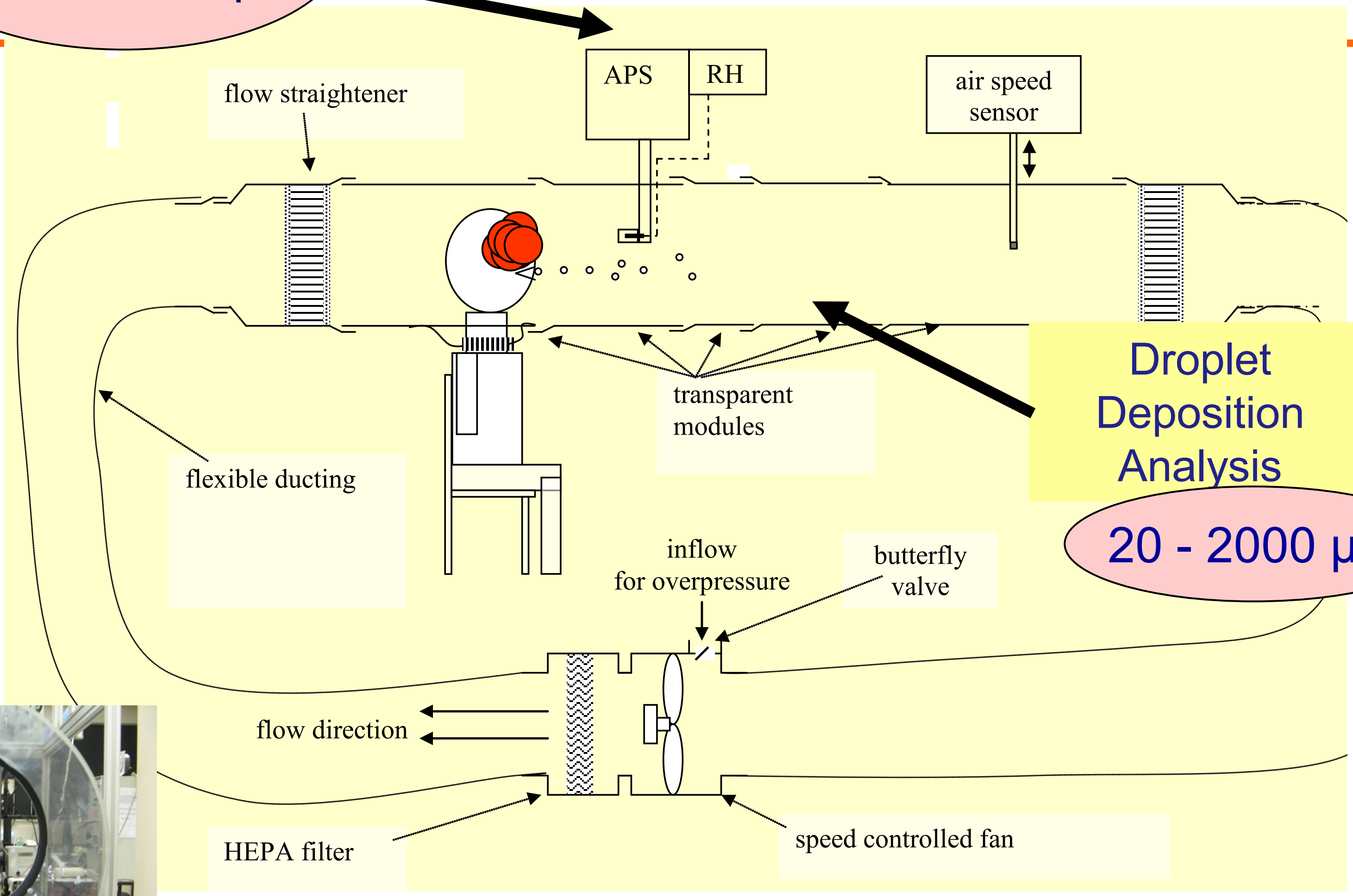
Johnson, G.R. and Morawska, L. The Mechanism of Breath Aerosol Formation. Journal of Aerosol Medicine and Pulmonary Drug Delivery, 22: 229-237, 2009.

DETECTION OF RESPIRATORY PARTICLES

Instrumental techniqu



Particle size
$0.5 \leq d \leq 20$ μm



Droplet Deposition Analysis

20 - 2000 μm

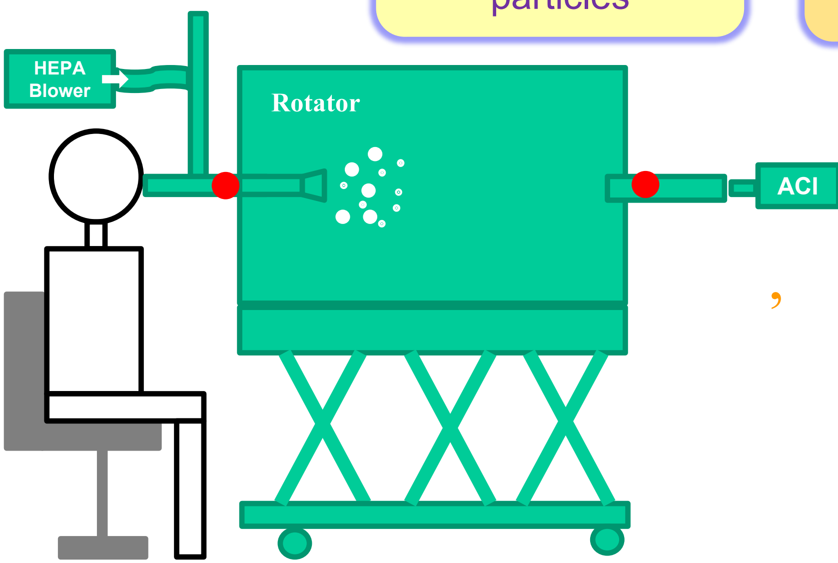
Morawska et al. 2009; Johnson et al. 2011

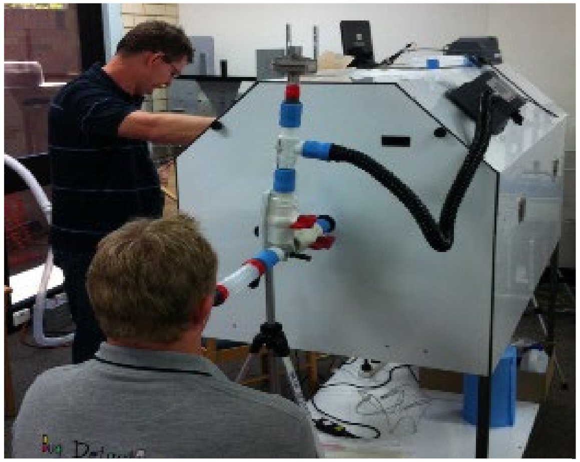
Instrumental techniques

Not suitable for fast changing processes

To achieve higher concentrations of particles

To test how long pathogens stay viable/infectious

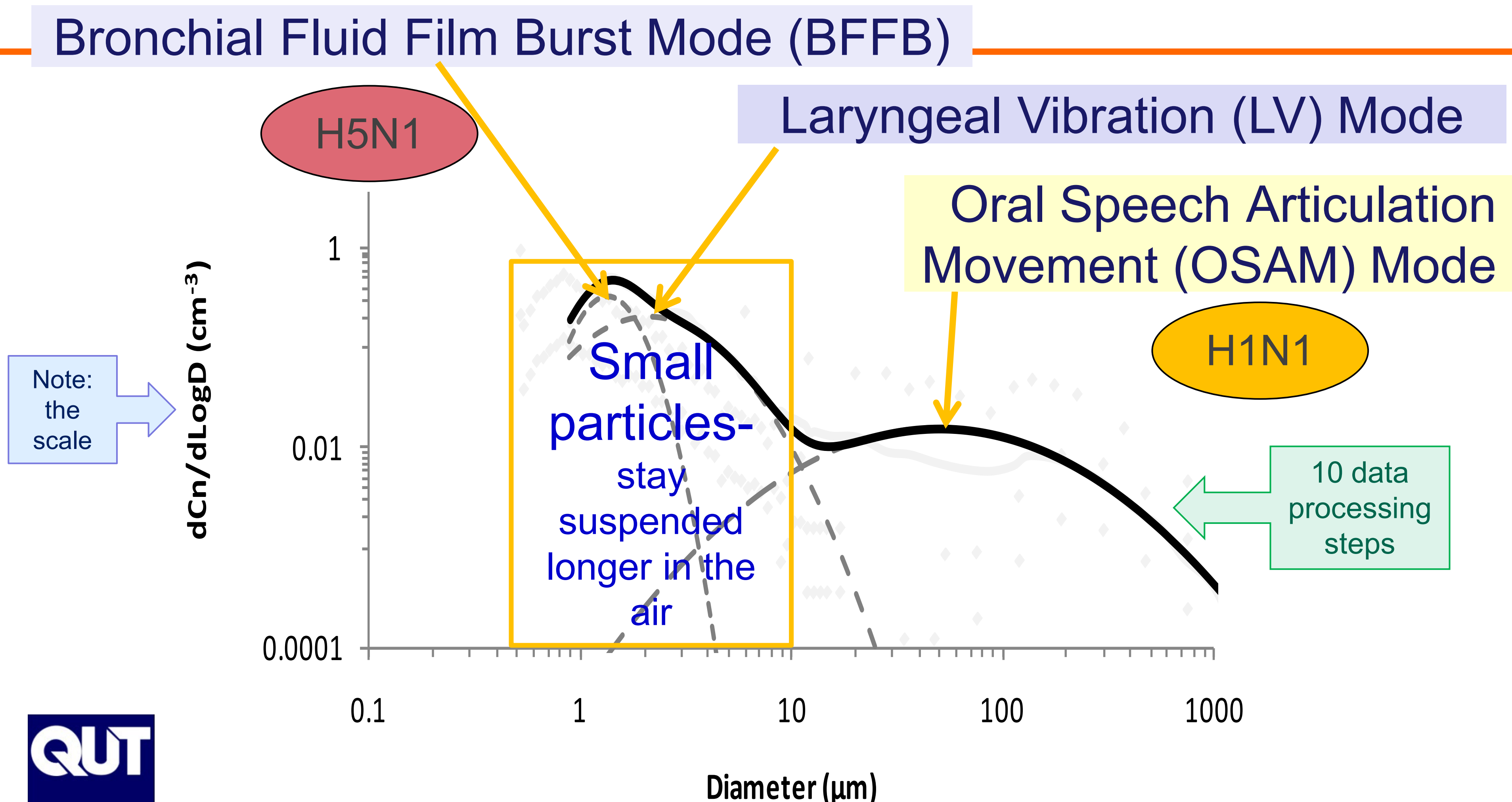




Johnson et al. 2016. A novel method and its application to measuring pathogen decay in bioaerosols from patients with respiratory disease; *PloS One*

PARTICLE CHARACTERISTICS AND FATE IN THE AIR

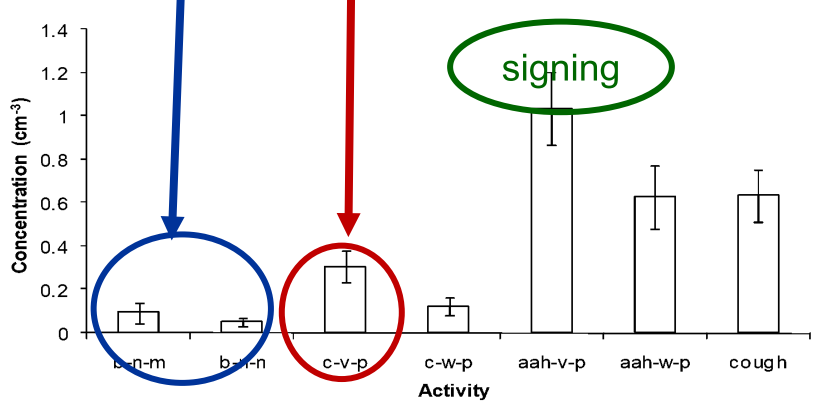
Number size distribution: speech + breathing

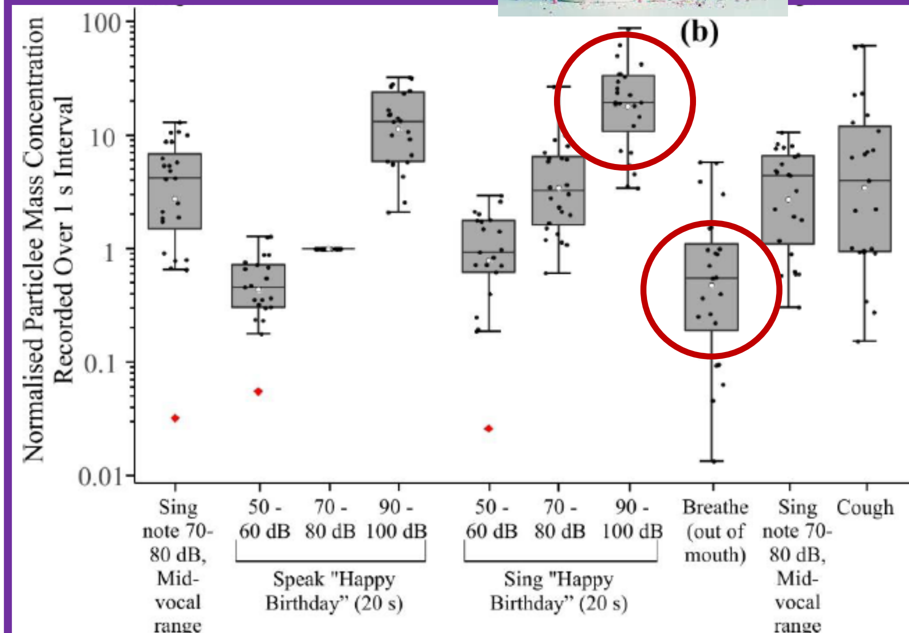


Morawska et al., 2009. Size distribution and sites of origin of droplets expelled during expiratory activities. *Journal of Aerosol Science*, 40: 256-269, 2009

Concentration/emission rates of particles – respiratory activities

b – breathing
n – nose
m – mouth
c – counting
v – voice
w – whisper





Morawska et al., 2009. Size distribution and sites of origin of droplets expelled during expiratory activities. *Journal of Aerosol Science*, 40: 256-269.

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Gregson, F.K.A., et al., Comparing the Respirable Aerosol Concentrations and 1 Particle Size Distributions Generated by Singing, 2 Speaking and Breathing, *ChemrXiv*

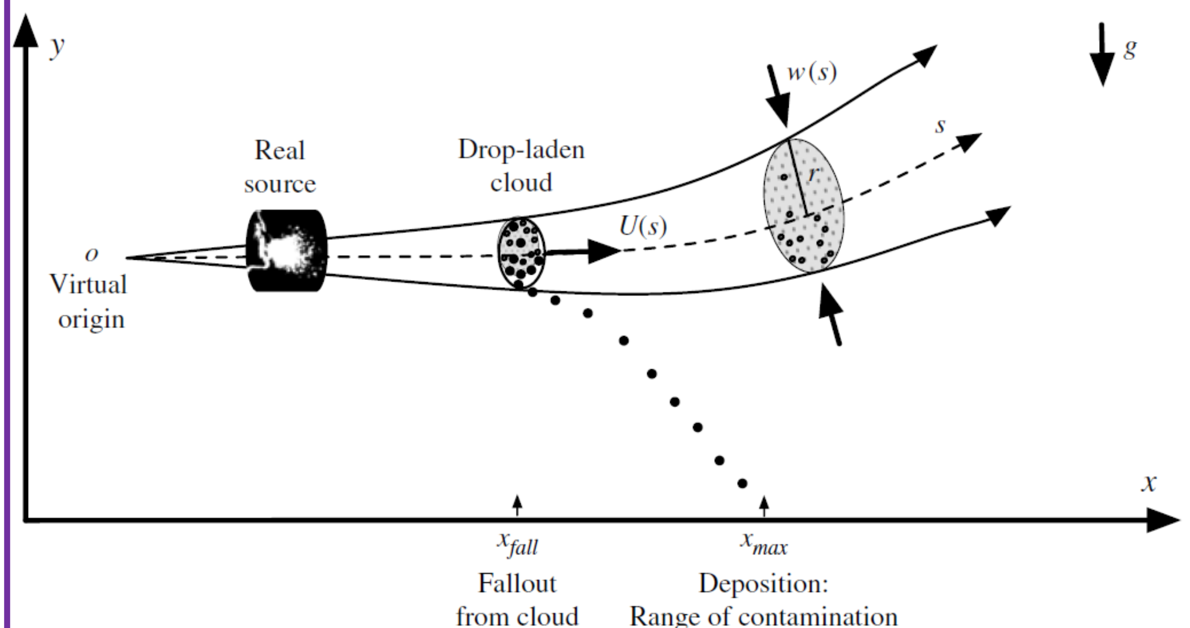
Particle fate in the air

Particle diameter [μm]	“Falling” time height 1 m [s]
1000	0.3
100	3
10	300
1	30,000

Wells 1934

How do particles from respiratory activities travel in the air?

Flow dynamics



Bourouiba, L., et al. Violent expiratory events: on coughing and sneezing. *Journal of Fluid Mechanics*, *745:* 537-563, 2014

State of the knowledge: particles

Particle size and emissions:

- The majority of particles are < 1 µm (and the vast majority are < 10 µm)
- Such small particles are light ⇨ **can stay suspended** in the air for a long time and travel long distances
- **All respiratory activities** (including breathing) generate particles, but vocalization ⇨ higher emission than other activities

Minutes?

Hours?

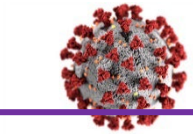
Meters (m)?

Tens of m?

Virus-laden particles from respiratory activities

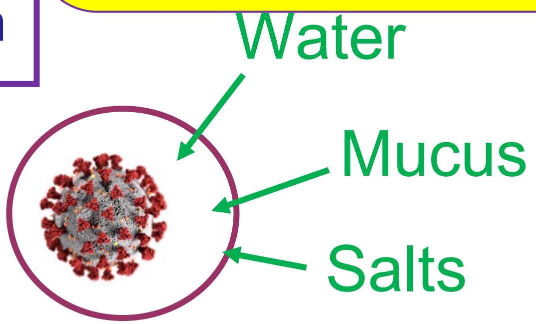
Such particles are light and can stay suspended in the air for a long time.

Virus in the particles



Size of a SARS-CoV-2 “naked virus”: ~ 0.12 µm

Size of the virus-laden particles: > 0.12 µm



Particles < 1 µm ⇨ contain higher loads of SARS-CoV-2

Santarpia et al., 2021. The Infectious Nature of Patient-Generated SARS-CoV-2 Aerosol. *Journal of exposure science & environmental epidemiology,* p.1-6.

Ma et al., 2020. ***COVID-19 patients in earlier stages exhaled millions of SARS-CoV-2 per hour***. *CID, ciaa1283*

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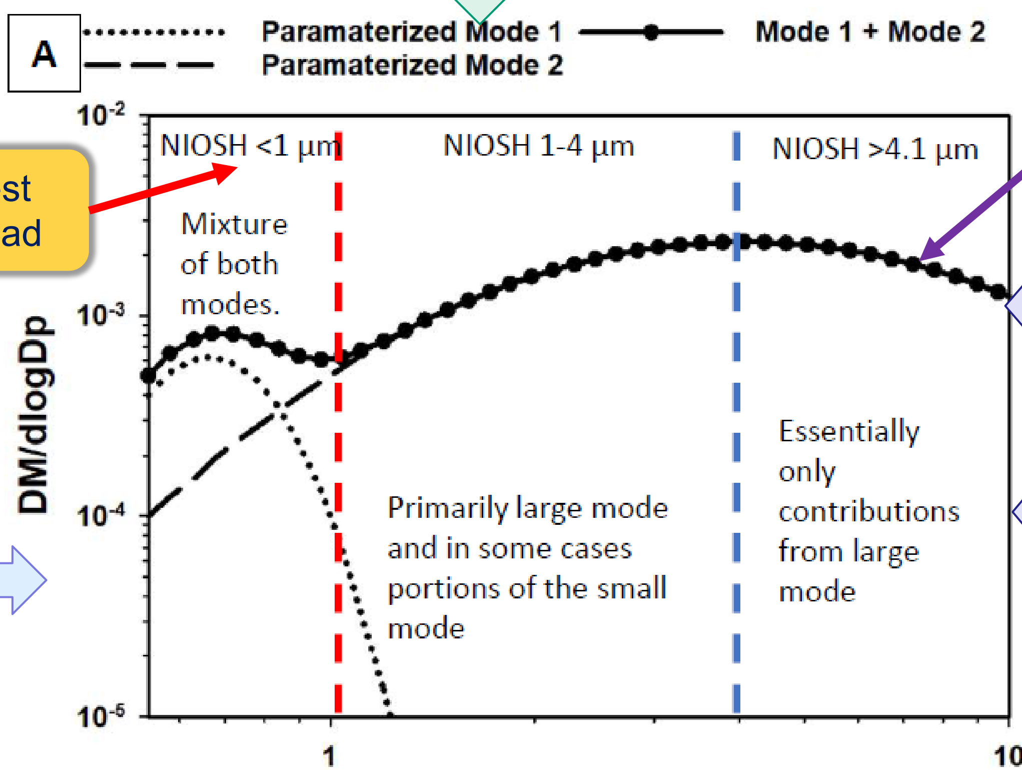
Mass size distributions - mixed acuity COVID-19 rooms

Several data processing steps



All respiratory activities + background

Highest viral load

Note: the scale

Particle size distribution: Aerodynamic Particle Sizer (TSI APS 3321) 0.542- 20 µm, **52 size bins**

Sample collection for virology: NIOSH BC251 sampler **3 stages**, cut-off sizes - the red and blue lines

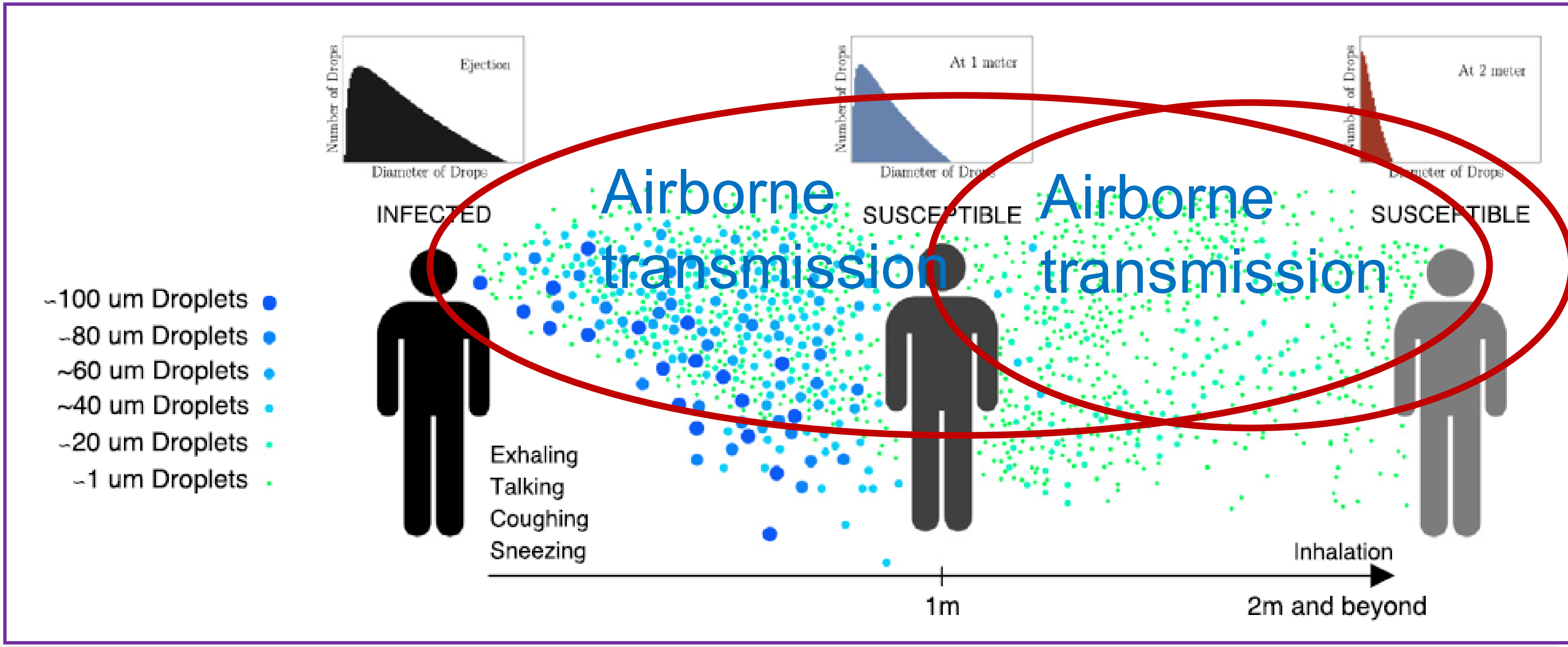
Santarpia et al., 2021. The Infectious Nature of Patient-Generated SARS-CoV-2 Aerosol. *Journal of exposure science & environmental epidemiology*, p.1-6.

State of the knowledge: virus-laden particles

Virus in the particles

- Overall, smaller particles ⇨ contain higher loads of SARS-CoV-2
- Smaller particles ⇨ from deeper parts of the respiratory tract ⇨ location of the virus
- To the contrary, larger particles ⇨ less virus, as they originate from the mouth
- Therefore, breathing/speaking ⇨ the main source of small, virus-laden particles

Airborne transmission: inhalation of virus-laden particles

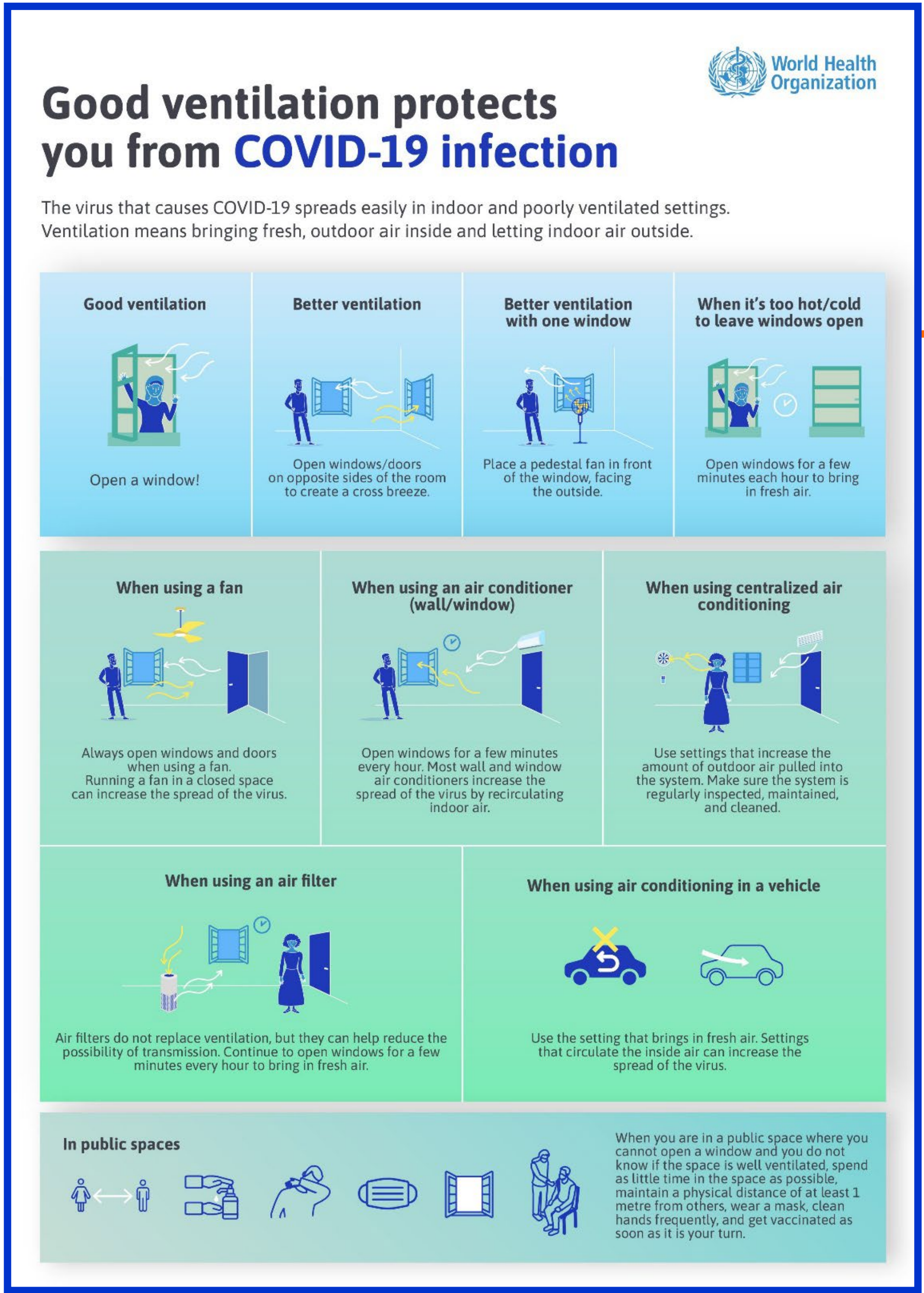


Balachandar et al. Host-to-host airborne transmission as a multiphase flow problem for science-based social distance guidelines, *International Journal of Multiphase Flow,* 132: 103439, 2020.

Morawska and Cao. "*Airborne transmission of SARS-CoV-2: the world should face the reality.*" *Environment International*, 139: 105730, 2020

Cortellessa, L., et al. Close proximity risk assessment for SARS-CoV-2 infection. *Science of the Total Environment,* 794: 148749, 2021

MITIGATION OF AIRBORNE INFECTION



23 Dec 2021

https://www.who.int/emergencies/diseases/novel-coronavirus-2019/question-and-answers-hub/q-a-detail/coronavirus-disease-covid-19-ventilation-and-air-conditioning

Natural ventilation (airing)
= no ventilation

Homes
Schools
Restaurants
Shops etc.

When it is NOT:
- too cold
- too hot
- too noisy

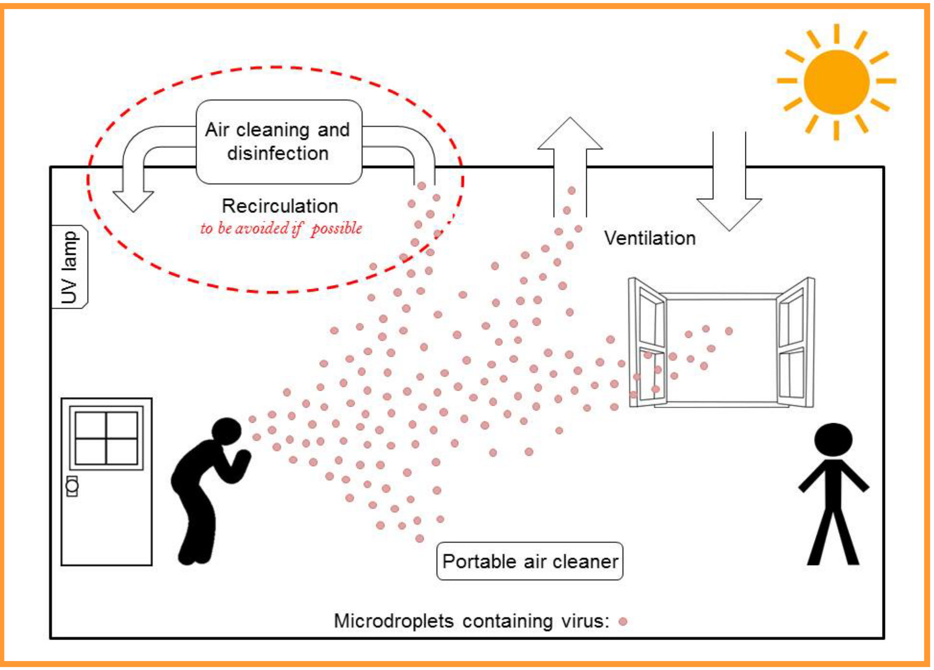
In reality, in most climates,
most of the time it is:
- too cold
- too hot
- too noisy.

NO VENTILATION

Disclaimer:
By “no ventilation” I mean “minimal ventilation”
- The building envelope always leaks
- Some countries/jurisdictions are more or less sophisticated regarding rules on natural ventilation

Building engineering controls

- Sufficient and effective ventilation
- Avoiding air recirculation
- Particle filtration and air disinfection
- Avoiding overcrowding



Morawska, et al. How can airborne transmission of COVID-19 indoors be minimised?, *Environment International*, 142: 105832, 2020

What is sufficient ventilation in relation to infection transmission?

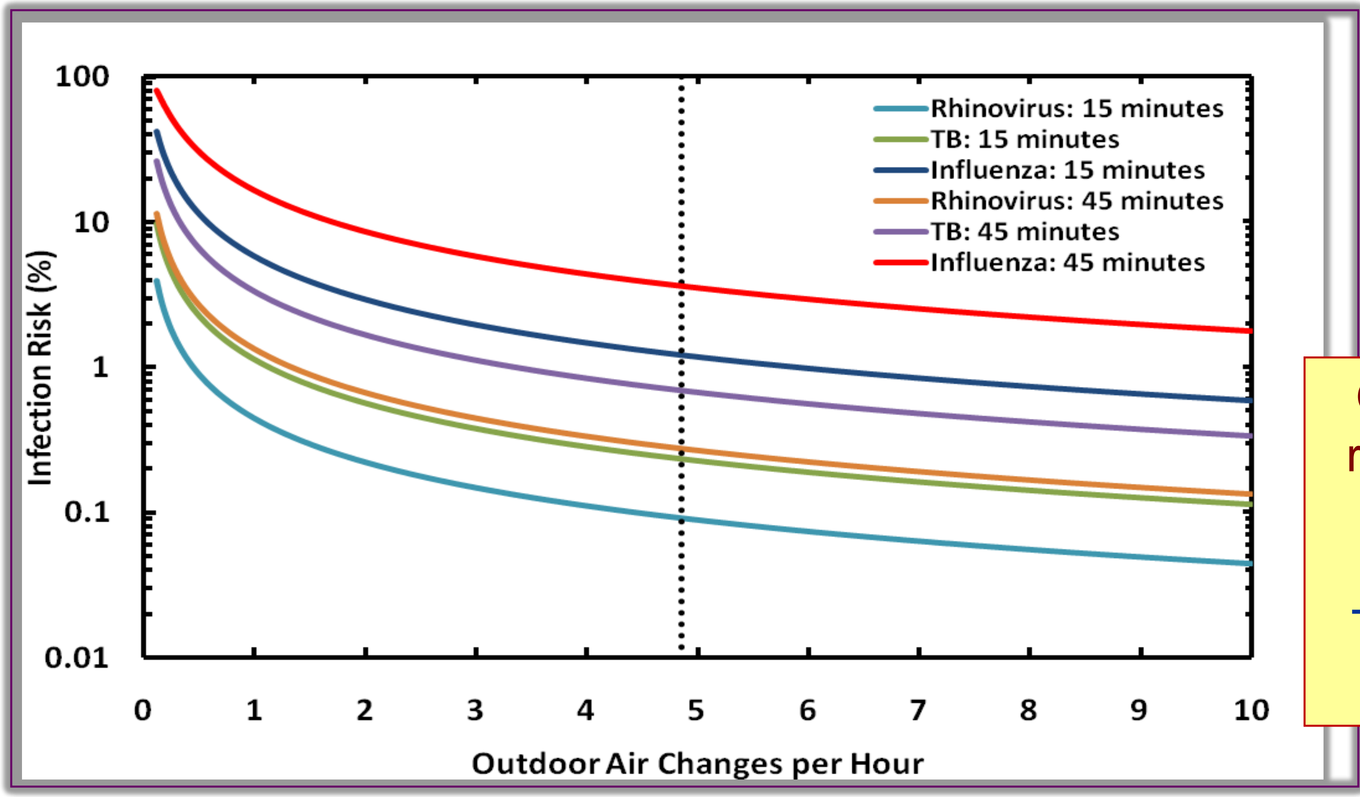
Can we use the **existing** ventilation guidelines for controlling infection transmission?

To find out we need to use risk assessment models and tools!

- Models based on Wells-Riley equation using *infectious quanta*
- But extended during the pandemic and more sophisticated

A quantum is the dose of infectious airborne particles required to cause infection in 63% of susceptible persons

Ventilation and infection risk



Using Wells-Riley model

Quanta generation rates from literature (quanta/hour):
Influenza - 67
Tuberculosis - 12.7
Rhinovirus – 5

The Prince Charles Hospital, Brisbane, Lung Function Laboratory: infection risk for 15 and 45 min occupancy

Laboratory for Air Quality and Health
WHO Collaborating Centre

Knibbs et al. *American Journal of Infection Control*, 39: 866-872, 2011

Limits of ventilation in airborne transmission risk mitigation

Airborne Infection

Theoretical Limits of Protection Achievable by Building Ventilation[1,2]

EDWARD A. NARDELL, JOANN KEEGAN, SALLY A. CHENEY, and SUE C. ETKIND

SUMMARY Of 67 office workers 27 (40%) had documented tuberculin skin test conversions after an estimated 4-wk exposure to a coworker with cavitary tuberculosis. Worker complaints for more than 2 yr before the tuberculosis exposure prompted investigations of air quality in the building before and after the tuberculosis exposure. Carbon dioxide concentrations in many parts of the building were found to be above recommended levels, indicating suboptimal ventilation with outdoor air. We applied a mathematical model of airborne transmission to the data to assess the role of building ventilation and other transmission factors. We estimated that ventilation with outside air averaged about 15 feet^3/min (cfm) per occupant, the low end of acceptable ventilation, corresponding to CO_2 levels of about 1,000 ppm. The model predicted that at 25 cfm per person 18 workers would have been infected (a 33% reduction) and at 35 cfm, a level considered optimal for comfort, that 13 workers would have been infected (an additional 19% reduction). Further increases in outdoor air ventilation would be impractical and would have resulted in progressively smaller increments in protection. According to the model, the index case added approximately 13 infectious doses (quanta) per hour (qph) to the office air during the exposure period, 10 times the average infectiousness reported in a large series of tuberculosis cases. Further modeling predicted that as infectiousness rises, ventilation would offer progressively less protection. We conclude that outdoor air ventilation that is inadequate for comfort may contribute to airborne infection but that the protection afforded to building occupants by ventilation above comfort levels may be inherently limited, especially when the level of exposure to infection is high.

AM REV RESPIR DIS 1991; 144:302–306

Introduction

Measles transmitted by infectious air in a pediatrician's waiting room; influenza spread on an airplane; tuberculosis transmitted within a shelter for the homeless, a nursing home, a prison, a hospital, or a clinic administering aerosolized pentamidine—are all current examples of airborne infection (1–7). If inadequate outdoor air ventilation is considered a contributing factor, it is often assumed that improved ventilation should prevent transmission. However, there is little in the medical literature to support or refute this assumption. We were stimulated to analyze the role of building ventilation and other transmission factors by the contact investigation of a case of tuberculosis occurring in an office building that was the source of air quality complaints.

The exposure was unusual because air quality measurements were available from which the outdoor air ventilation of the building could be estimated, because the duration of exposure was well defined,

less variables over a 4-wk period defy the precise description of exposure conditions for each worker. Such detail is not necessary for our purposes. Had the actual duration of exposure for some workers, for example, been

culosis treatment in another country years before they had met. He was asymptomatic at the time of the current contact investigation, and his chest X-ray showed only scarring. The patient's 3½-yr-old daughter had a positive

For:

- Adenovirus
- TB (untreated)
- SARS-CoV-2
- Measles

even a high ventilation rate of 14 L s^{-1} p^{-1} may be insufficient to maintain event reproduction numbers below one in a fully susceptible population, depending on indoor occupant activities.

Nardell, E.A., Keegan, J., Cheney, S.A. and Etkind, S.C., 1991. Airborne infection. *Am. Rev. Respir. Dis*, *144*, pp.302-306.

Mikszewski et al. The Airborne Contagiousness of Respiratory Viruses: A Comparative Analysis and Implications for Mitigation. Journal of Infectious Diseases, Accepted 8 August 2021, In Press. Published Online: 101285: 2021. https://doi.org/10.1016/j.gsf.2021.101285

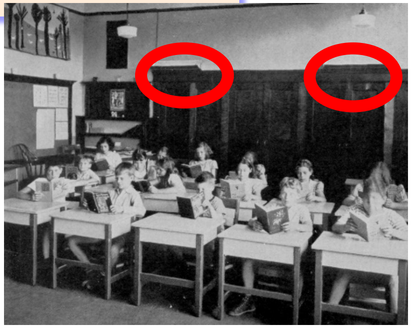
What can we do to control the risk of infection by such pathogens?

Disinfect the air in a way that no additional pollution is generated indoors

Germicidal ultraviolet (GUV) air disinfection:
- low energy requirements
- does not generate new pollutants in the air
- silent
- robust (low maintenance), low cost

In particular, far UV (222 nm) is safe, with very low penetration into human tissue.

It could be doing to the air what we already do to water: every drop of water we drink from the tap is disinfected.



Wells, W.F., Wells, M.W. and Wilder, T.S., 1942. *The environmental control of epidemic contagion.* I. An epidemiologic study of radiant disinfection of air in day schools. *Am J Hyg*, *35*, pp.97-121

Air flow distribution and direction

(A) Reported attack rate distribution

(B) Predicted average infection risk distribution

Price of Wales Hospital in Hong Kong

The conclusion:
up to 60% of transmissions was by the airborne route.
Linked in another study to flow direction.

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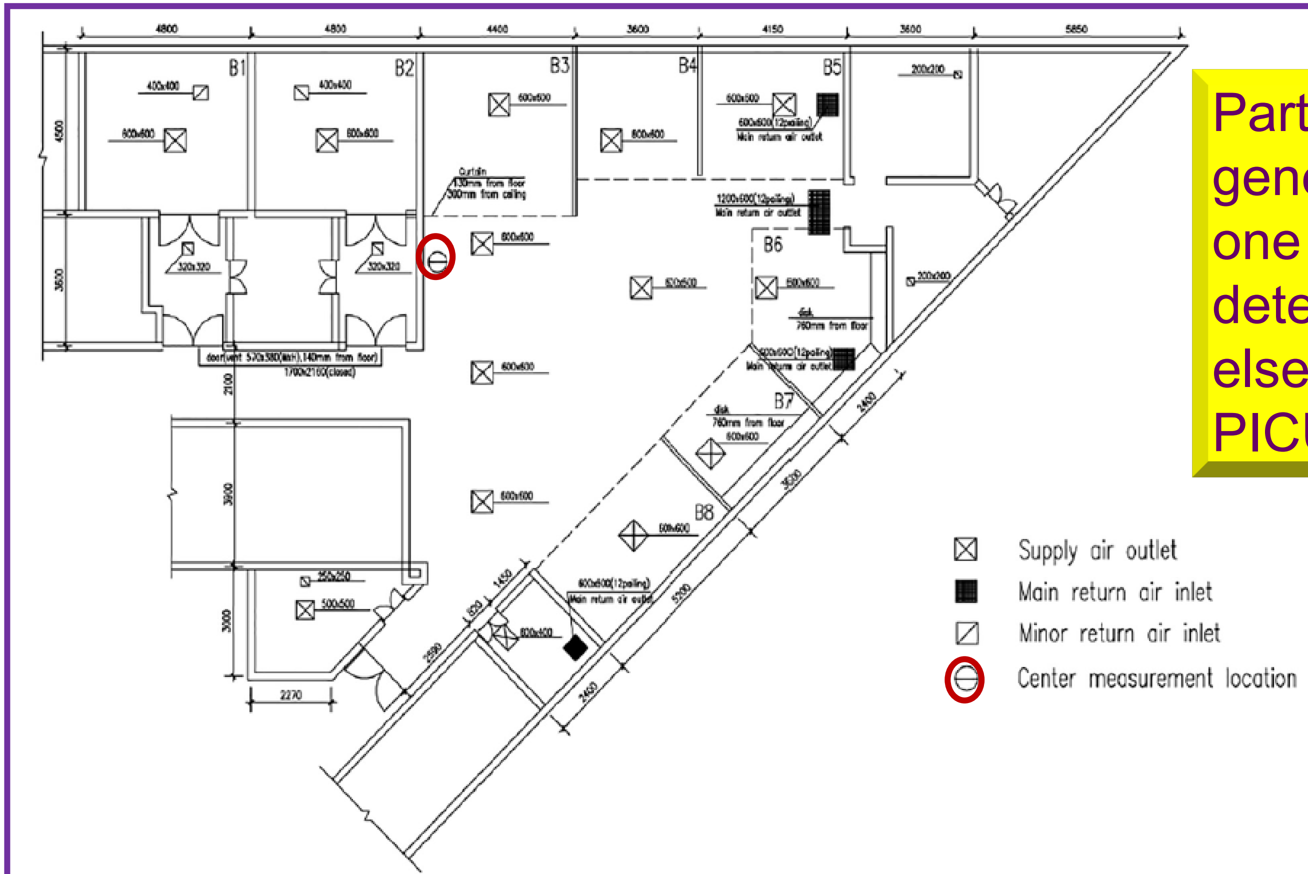
Xian et al. 2017, Role of fomites in SARS transmission during the largest hospital outbreak in Hong Kong, *PloS One,* 12(7)

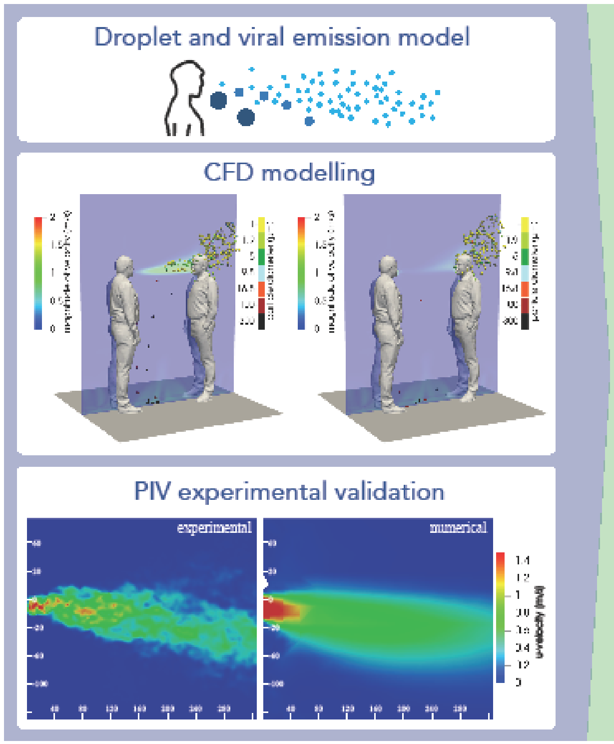
Paediatric Intensive Care Unit: case study

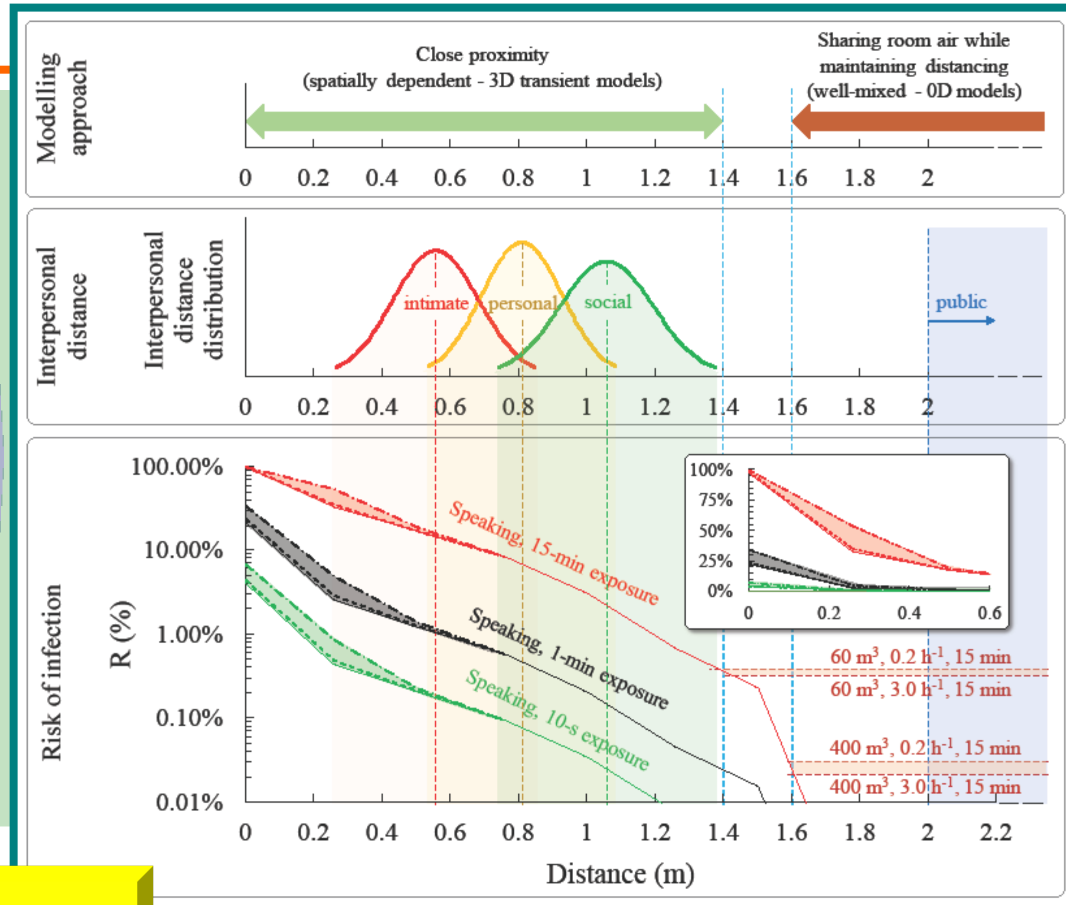


Particles generated in one place were detected elsewhere in PICU

He et al,, Particle and Bioaerosol Characteristics in a Paediatric Intensive Care Unit. *Environmental International,* 107: 89-99, 2017. https://doi.org/10.1016/j.envint.2017.06.020

Infection risk at close proximity





Protection:

- Minimum time
- Respirators

Cortellessa, L., et al. 2021. Close proximity risk assessment for SARS-CoV-2 infection. *Science of the Total Environment*, 794: 148749. https://doi.org/10.1016/j.scitotenv.2021.148749

AEROSOLIZATION AND ITS IMPACTS

BRIEF COMMUNICATION

National Science Review
7: 1865–1867, 2020
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Advance access publication 28 September 2020

EARTH SCIENCES

Distribution of airborne SARS-CoV-2 and possible aerosol transmission in Wuhan hospitals, China

Jia Hu[1,†], Chengfeng
Fei Deng[1], Yu Huang[2

The novel severe acute re
drome coronavirus 2 (SAR
caused an outbreak of CO
coronavirus infectious dis
led to a global public hea
spread of SARS-CoV-2 ca
there is still considerabl
about its main route of
[1,2]; that is, whether tr
by contact or through
Recently the WHO (W
Organization) released a
recognized the possibili
transmission of SARS-Co
environments and enclos
The purpose of the prese
to evaluate the airborne t
SARS-CoV-2 through a f
tion of its occurrence in th
samples collected from hea
Wuhan, China.

International Journal of Infectious Diseases 100 (2020) 476–482

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INTERNATIONAL SOCIETY FOR INFECTIOUS DISEASES

Viable SARS-CoV-2 in the air of a hospital room with COVID-19 patients

Check for updates

John A. Lednicky[a,b,*], I
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Karim Mohamed[e], Ara
Md. Mahbubul Alam[a,
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Healthcare Infection Society

Healthcare-acquired clusters of COVID-19 across multiple wards in a Scottish health board

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[c] *Institute of Occupational Medicine, Edinburgh, UK*
[d] *Infection Prevention & Control, NHS Lanarkshire, UK*

Summary

There is quantitative evidence on:

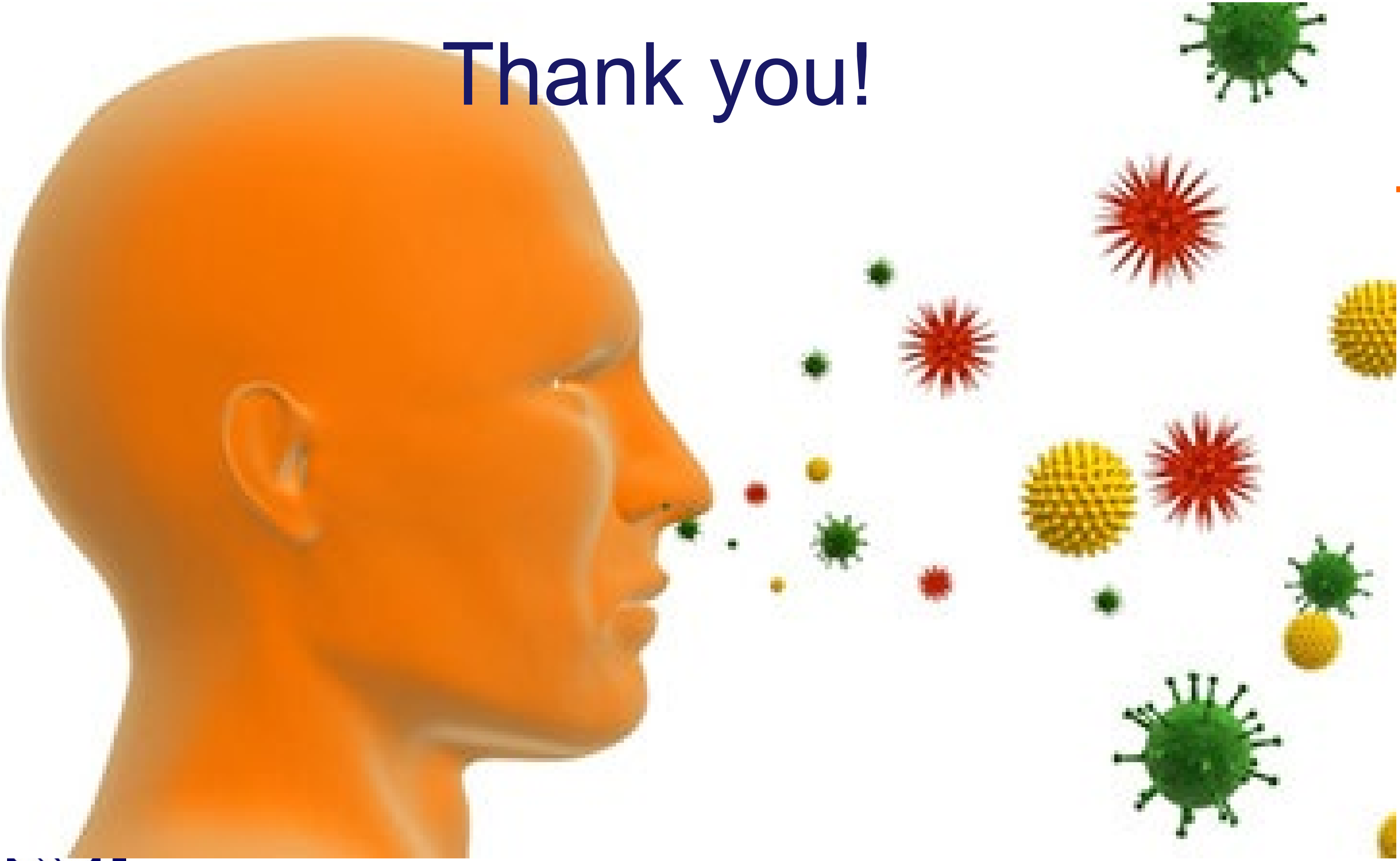
- Characteristics of particles/virus-laden particles from human respiratory activities
- What happens to the particles in the air – transport and removal dynamics
- Deposition of the particles in the respiratory tract upon inhalation

Is such evidence available for each outbreak?

No, because this is a complex process and retrospectively we never have all the required parameters for real life scenarios

But there is a great deal of evidence available form outbreaks supporting airborne transmission as the main cause of infection - *health care settings present a particular risk*

Thank you!



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