Managing Indoor Air Quality in Commercial and Public Buildings During the COVID-19 Pandemic

The Thursday Seminar, 19 November 2020

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Presentation overview

- Introduction (REHVA, COVID-19 Guidance, COVID-19 Course)
- COVID-19 transmission modes
- WHO acknowledgment of airborne COVID-19 transmission
- The role of ventilation – 15 recommendations
- Airborne transmission risk assessment
- Masks?
- Future challenges?

- **KTH**

  - Professor in Building Services Engineering (BSE), Div of Sustainable Buildings Department of Civil and Architectural Engineering, ABE

  - Academic & professional background in mechanical engineering and BSE

  - 35 yrs experience in HVAC, indoor environmental quality management, energy systems in the built environment, building performance management, and smart buildings (digitalisation)

- **Federation of European Heating, Ventilation and Air-Conditioning Associations (REHVA)**

  - Vice President

  - Core Member in Technology and Research Committee

  - Co-Chair of Education Committee

  - Chair of Task Force on Smart Buildings

- **Nordic Ventilation Group (est. 2020)**

  - Member

REHVA

- REHVA is The Federation of European Heating, Ventilation and Air Conditioning Associations, founded in 1963 (www.rehva.eu).
- Largest international professional HVAC organization representing over 120,000 HVAC designers, building services engineers, technicians and experts across 27 European Countries.
- Leading platform for European/international professional networking and knowledge exchange in HVAC, pursuing the vision of improving health, comfort, safety and energy efficiency in all buildings and communities.
- Direct impact on national and international strategic planning, policy and standardization processes, research, as well as on associated educational and training initiatives and programmes.
- This is achieved through the exchange of technical information, practical experience and research results by REHVA's task forces, seminars/webinars, and publications including the REHVA journal.

REHVA COVID GUIDANCE

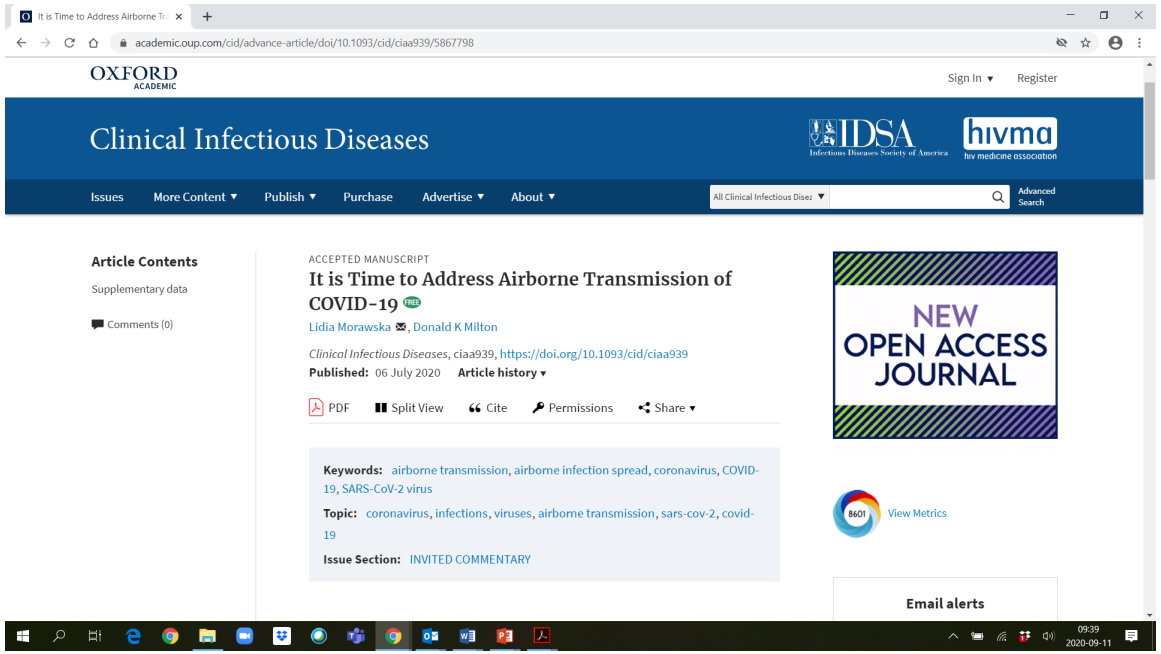
REHVA COVID-19 guidance for HVAC systems operation and reduction of the spread of viral diseases in workplaces

- https://www.rehva.eu/activities/COVID-19-guidance
- An addition to the general guidance for employers and building owners that is presented in the WHO document 'Getting workplaces ready for COVID-19'.
- First version March 17, 2020, latest update August 3 (4th version expected Nov 2020)
- Targetting HVAC professionals and facility managers but expected to be useful for occupational and public health specialists deciding on how to use buildings
- The scope is limited to commercial and public buildings
- The **guidance document mainly focuses on reduction measures of airborne transmission** while personal protective equipment such as wearing masks is out of the scope of the document. **The REHVA COVID-19 course also addresses the use of masks.**
- Practical guidance on temporary, easy-to-organize measures that can be implemented in existing buildings

REHVA COVID-19 COURSE

Safe operation of buildings and HVAC systems during the COVID-19 pandemic

Following petition by 239 scientists & publication - WHO acknowledges airborne transmission of COVID-19



Coronavirus: WHO rethinking how Covid-19 spreads in air

8 July 2020

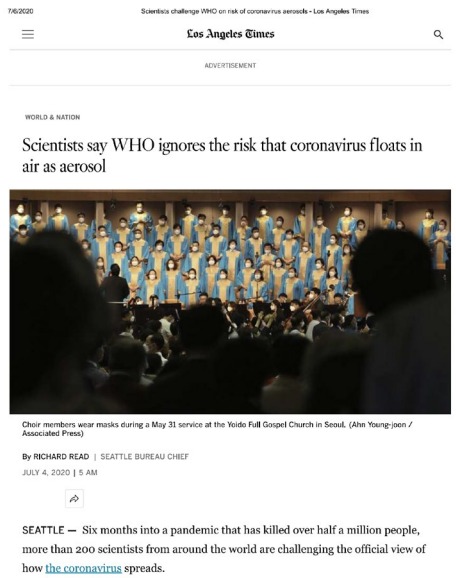
Coronavirus pandemic

The World Health Organization has acknowledged there is emerging evidence that the coronavirus can be spread by tiny particles suspended in the air.

The airborne transmission could not be ruled out in crowded, closed or poorly ventilated settings, an official said.

https://www.bbc.com/news/world-53329946

Transmission of SARS-CoV-2: implications for infection prevention precautions
https://www.who.int/news-room/commentaries/detail/transmission-of-sars-cov-2-implications-for-infection-prevention-precautions
2020-07-09



Key issues addressed in petition to WHO (Morawska et al. 2020) :

1. Ventilation plays a key role for indoor transmission control and infection management - ventilation rates should be increased;
2. Air should not be recirculated (re-used, even after filtration);
3. Individuals should avoid staying directly in the flow of air from another person;
4. The number of people sharing the same indoor environment should be minimized (kept as low as feasible);

No 1, 2 and 3, addressing air distribution – not easy to change in existing buildings

Substantial need for future research on ventilation rates, air cleaners, air distribution, component hygiene, system maintenance etc.…

Does aerosol (airborne) transmission of COVID-19 occur?

- **Aerosol transmission occurs when certain medical procedures are performed**
  - Health workers performing these procedures must wear personal protective equipment, including specifically designed masks (e.g. N95, FFP2).

- In **crowded poorly ventilated indoor spaces**, where people are **talking**, **shouting** or **singing**, aerosol transmission may also be occurring.
  - Aerosol transmission may play a role in COVID-19 outbreaks reported in closed settings such as nightclubs, restaurants, some places of work and places of worship.
  - Fabric masks can reduce transmission where physical distancing cannot be achieved.
  - To date, there is insufficient data to determine the contribution of aerosol transmission in community settings.

World Health Organization | EPI•WIN | infodemic MANAGEMENT

Source: World Health Organization (WHO), 23 July 2020:
https://www.who.int/docs/default-source/coronaviruse/risk-comms-updates/update-33-trasmission.pdf?sfvrsn=9b1b10aa_2

Long-distance airborne dispersal of SARS-CoV-2 in COVID-19 wards

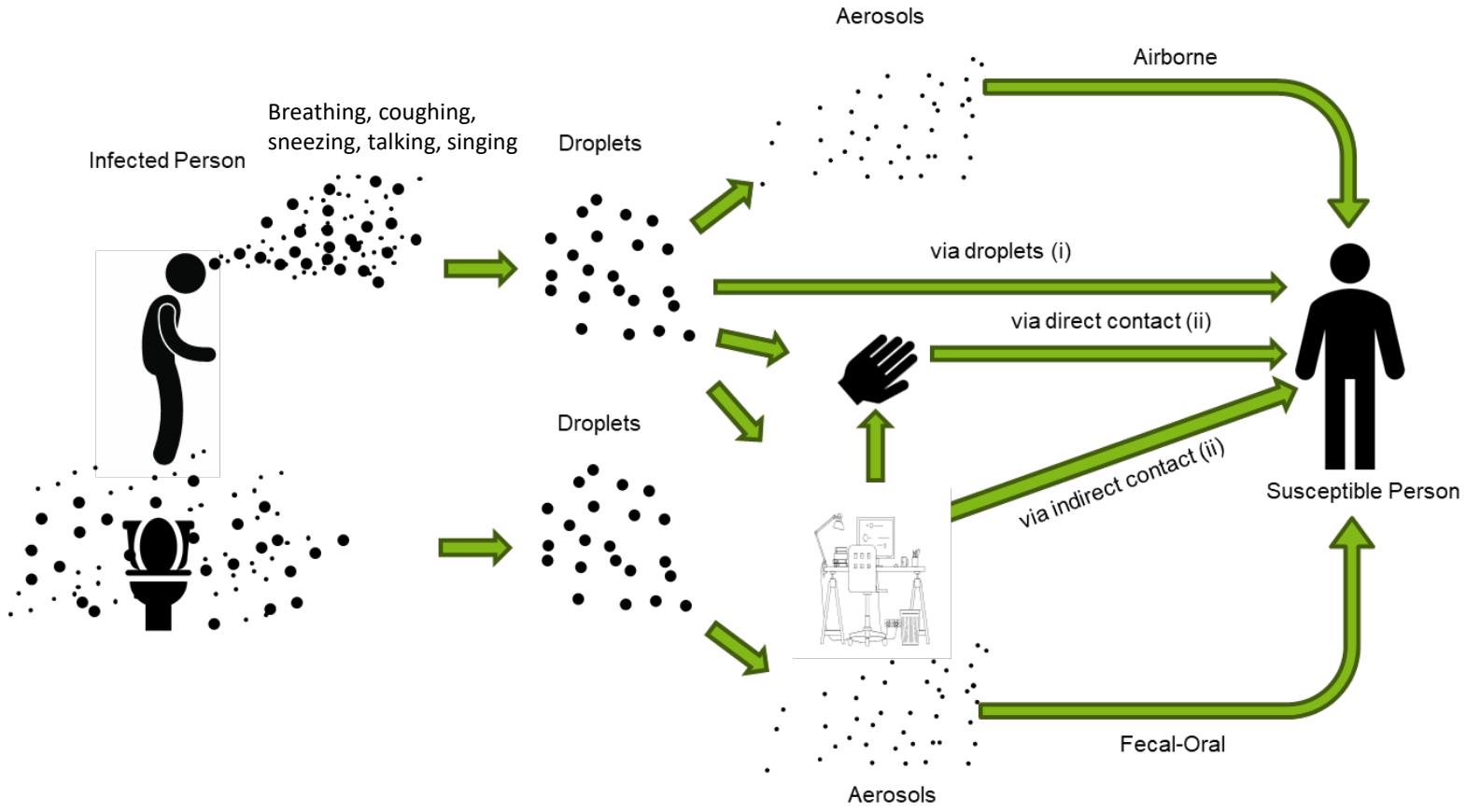
Karolina Nissen, Janina Krambrich, Dario Akaberi, Tove Hoffman, Jiaxin Ling, Åke Lundkvist, Lennart Svensson & Erik Salaneck

https://www.nature.com/articles/s41598-020-76442-2

Detection of SARS-CoV-2 in central ventilation systems, distant from patient areas, indicates that virus can be transported long distances and that droplet transmission alone cannot reasonably explain this, especially considering the relatively low air change rates in these wards. Airborne transmission of SARS-CoV-2 must be taken into consideration for preventive measures.

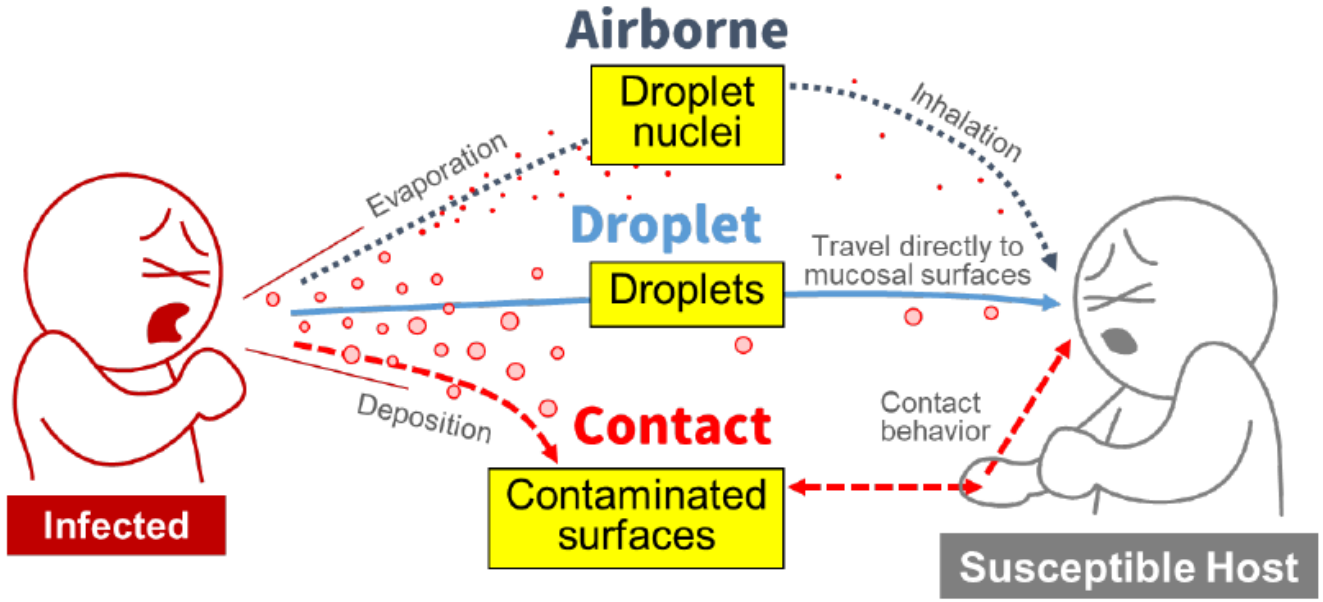
HVAC for COVID-19 Management – The Role of Ventilation

COVID-19 transmission modes



REHVA course - COVID-19 conform building operation - Fecal-oral transmission
rehva.eu

Transmission/Contamination Modes

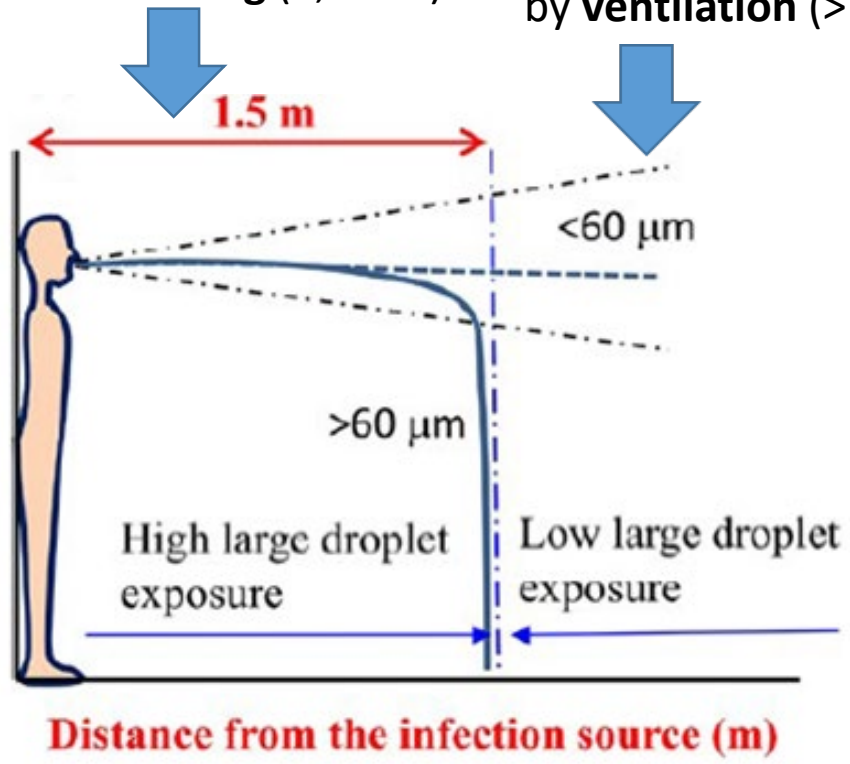


Role of ventilation in the control of the COVID-19 infection: Emergency presidential discourse SHASE, March 23, 2020.

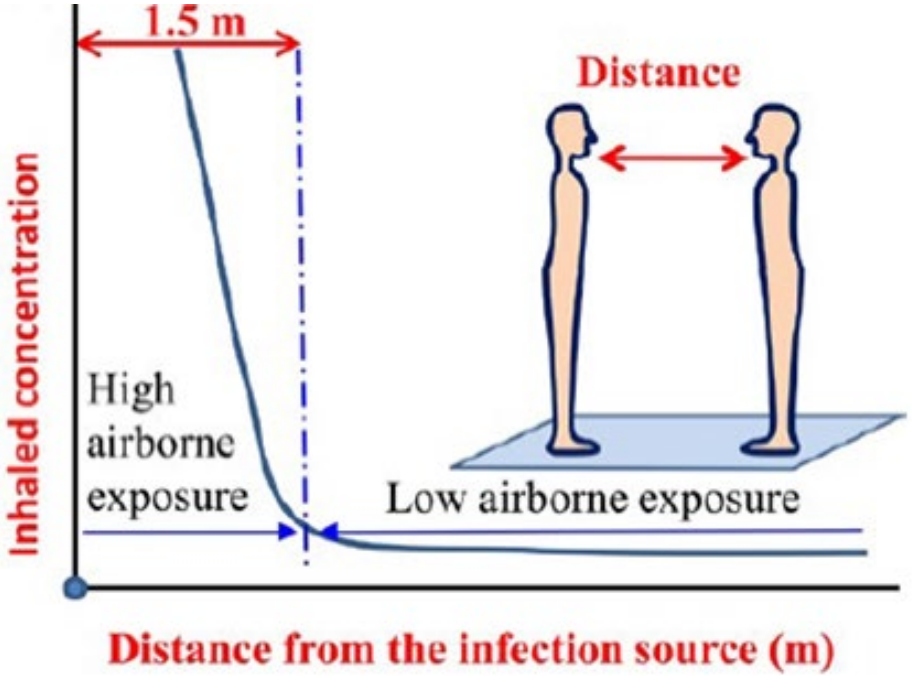
Mode	PM Size (µm)	Protective Measures
Airborne	< 10	Respirators, Masks, Face Shields, Ventilation
Droplets	10<D<50	Masks, Confinement, Social Distancing
Contact	> 50	Masks, Hygiene, Disinfection, Behaviour

Transport of exhaled/expectorated droplets and aerosolized particles

Key exposure management by **personal distancing** (1,5-2m)



Key exposure management by **ventilation** (>1,5-2m)



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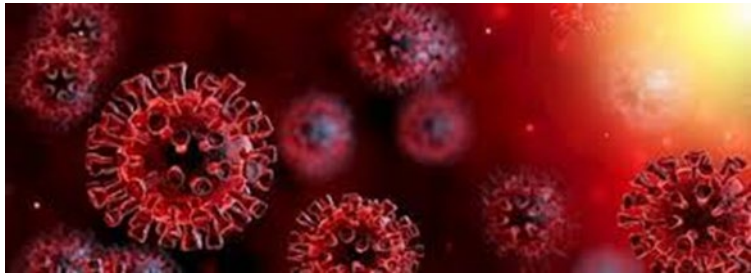
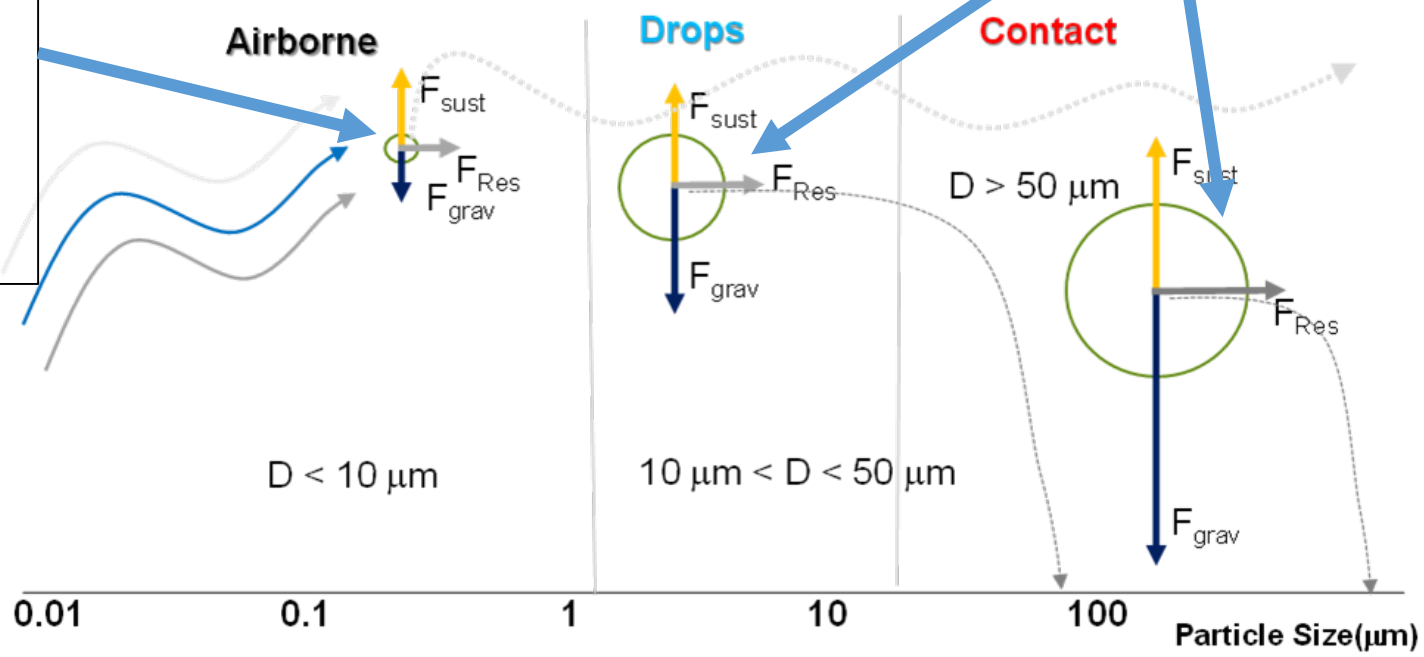


Particles larger than 10µm have a larger mass, movement dominated by gravitational forces, **REMOVAL BY SEDIMENTATION** on exposed surfaces, floor

HVAC for COVID-19 Management – The Role of Ventilation

Aerosolized particles have a small mass, movement dominated by drag forces, particles follow air movements and may remain suspended for several hours **REMOVAL BY VENTILATION**



Typical trajectories of particles in the air, depending on their size

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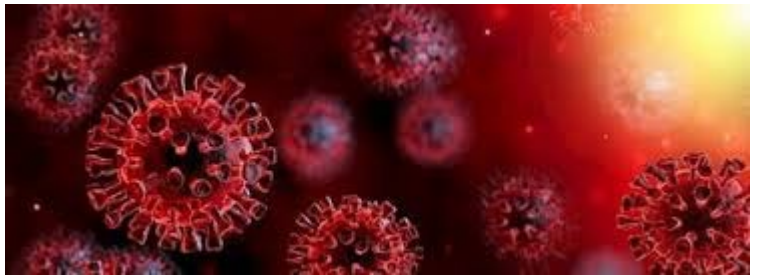
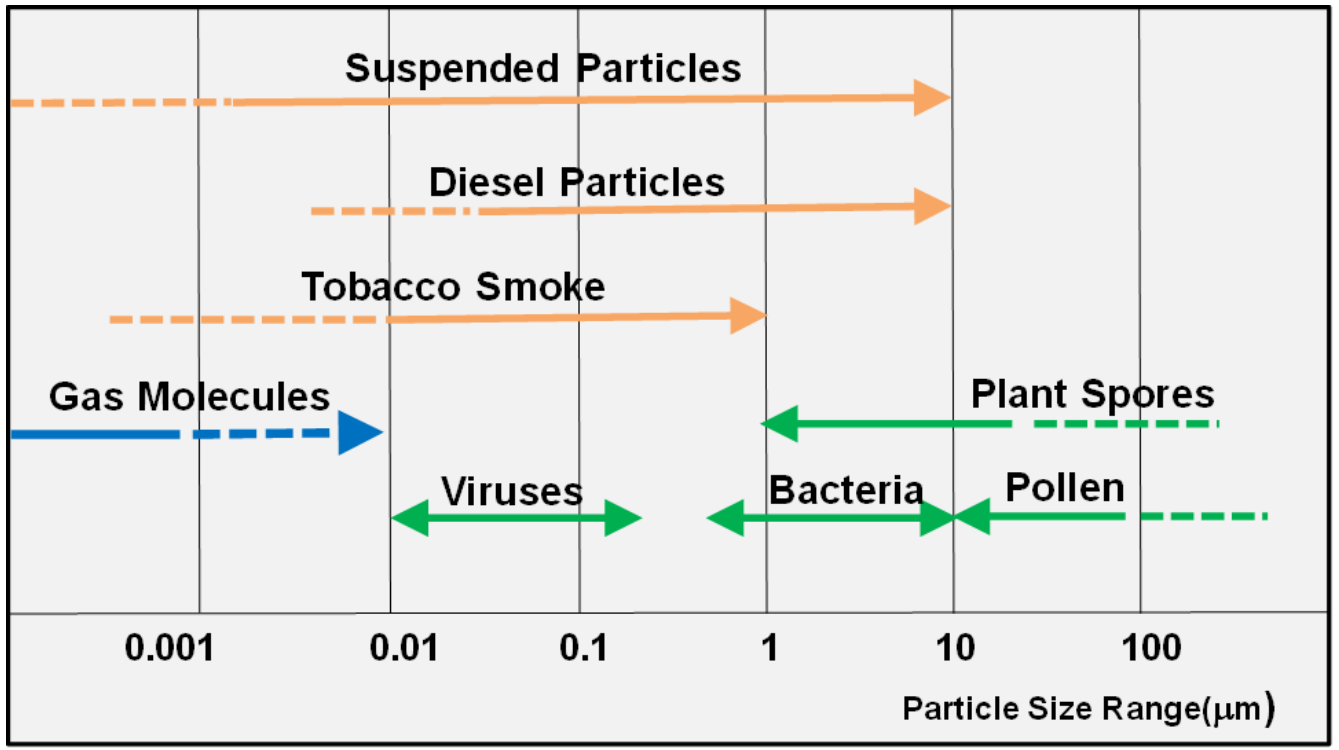


HVAC for COVID-19 Management – The Role of Ventilation

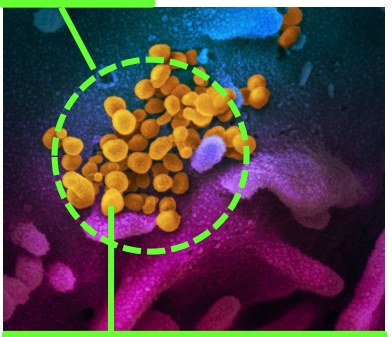
COVID-19
(SARS CoV-2)
Virus size
80-140nm
(0,08-0,14 microns)



Size ranges of the main types of particulate matter in indoor air

Dimension of Sars-CoV-2 vs Airborne Particles

1 µm X 1000 = 1 mm



80-140 nm ≈ 0.1 µm

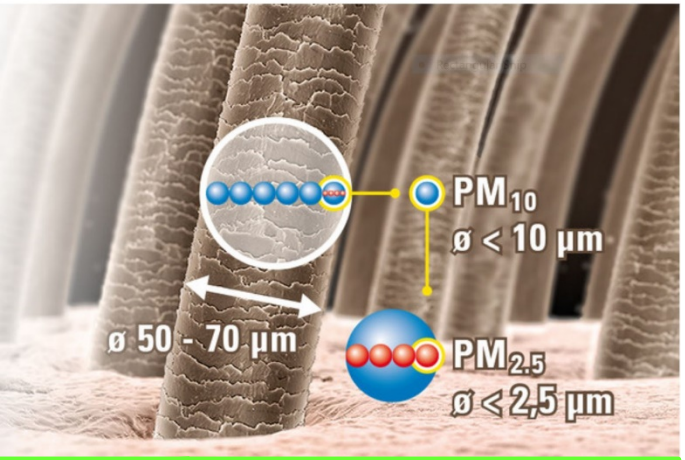
HEALTH

This Is What The COVID-19 Virus Looks Like Under The Microscope

JACINTA BOWLER

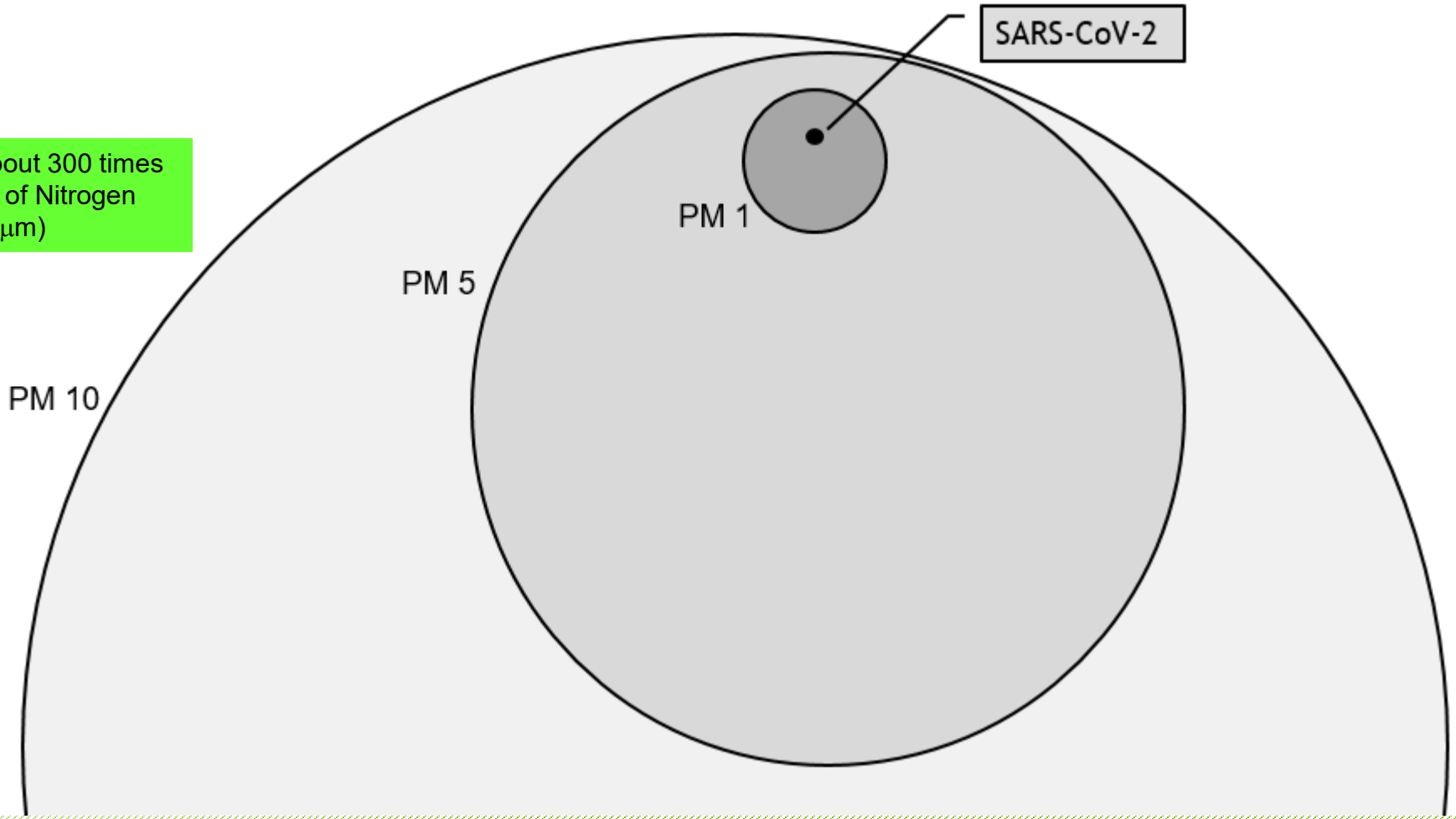
14 FEBRUARY 2020

The COVID-19 virus is about 300 times larger than the molecules of Nitrogen and Oxygen (≈ 0.000300 µm)



Virus is 600 times thinner than a hair

●●●●●●●●●●●● … X 10 000 = 1 mm



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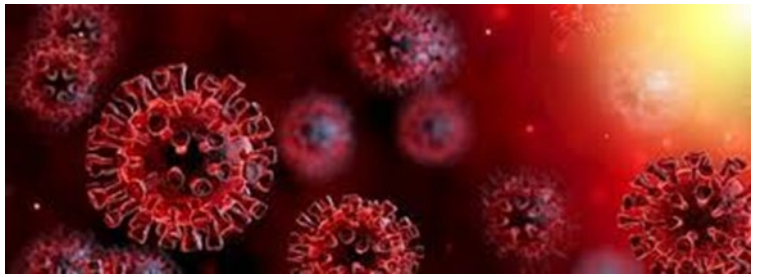
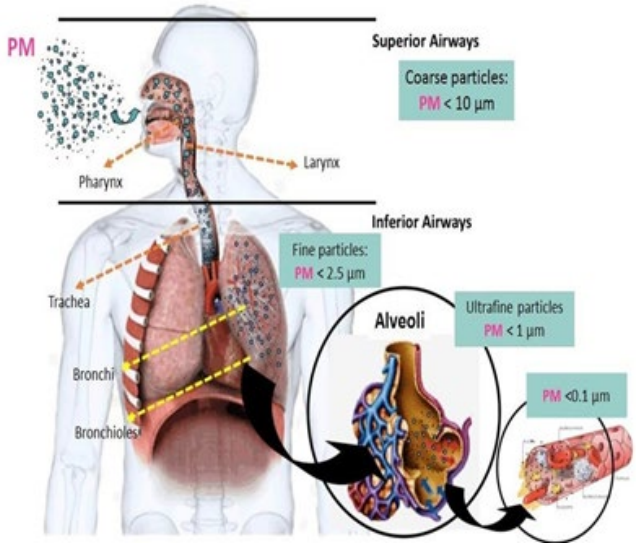


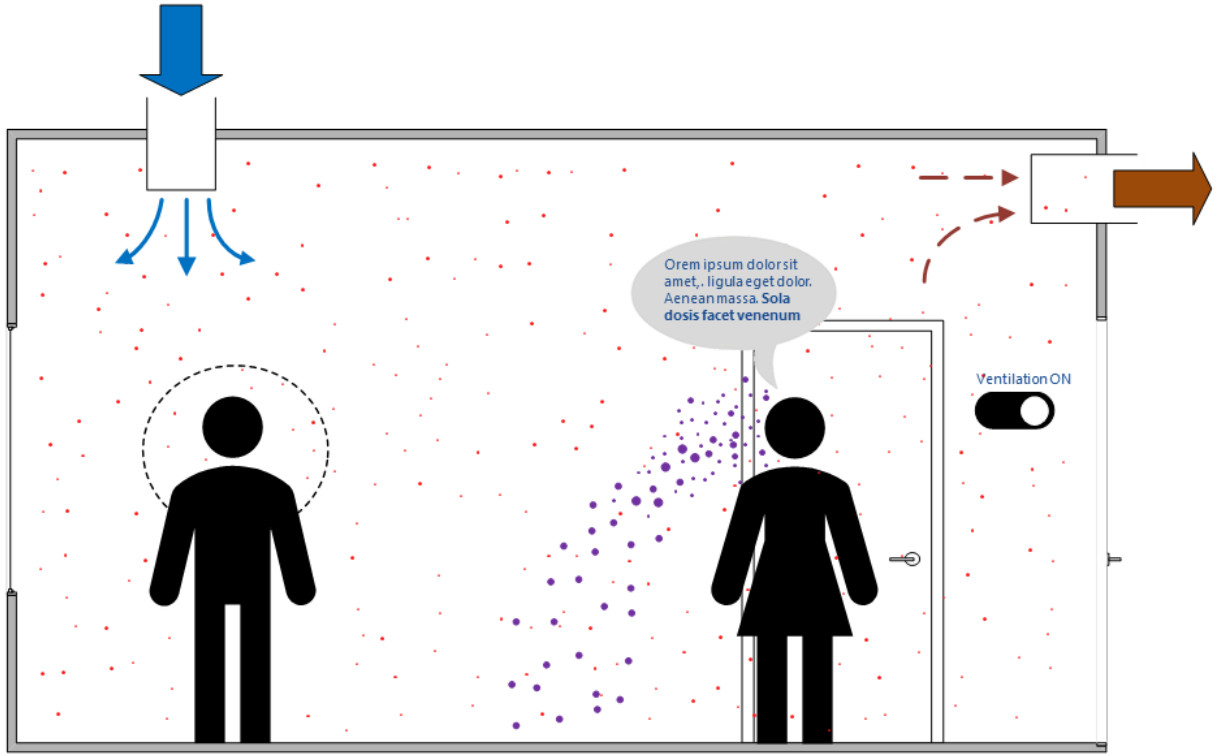
HVAC for COVID-19 Management – The Role of Ventilation

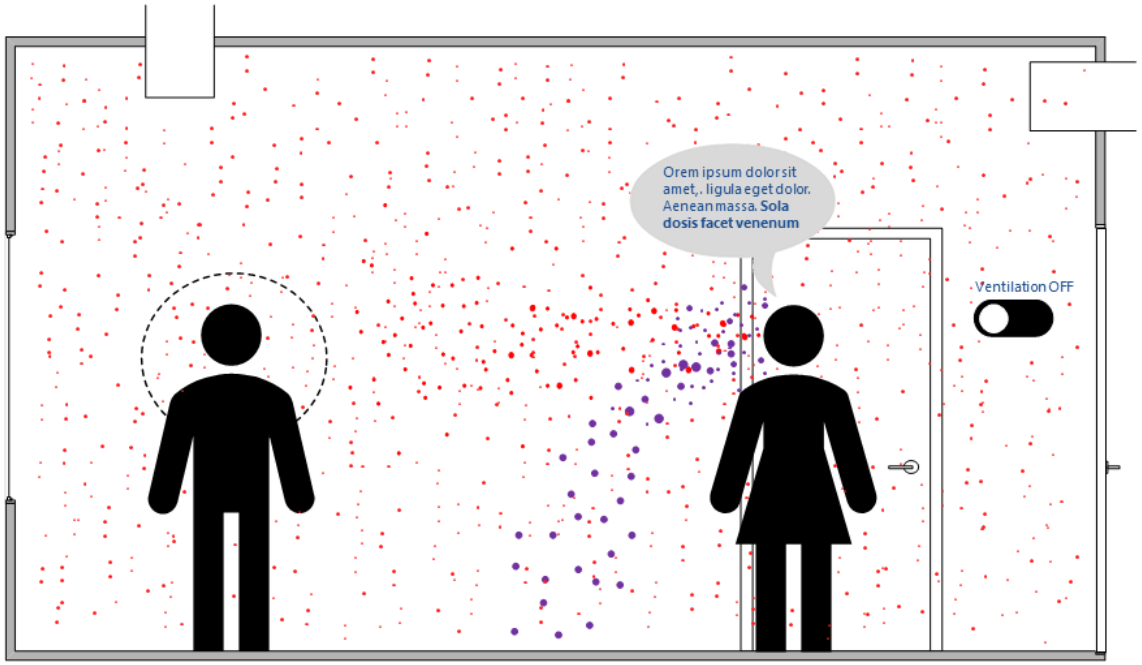


Diameter (µm)	Penetration Level	Classification
> 7	Oral and Nasal Cavities	Inhalable
4.7 – 7	Larynx	
3.3 – 4.7	Trachea and Bronchi	Thoragics
2.1 – 3.3	Secondary Bronchioles	
1.1 – 2.1	Bronchioles	Breathable
0.65 – 1.1	Alveoli	

Classification of particles according to the level of penetration into the respiratory system

Long range airborne transmission & ventilation

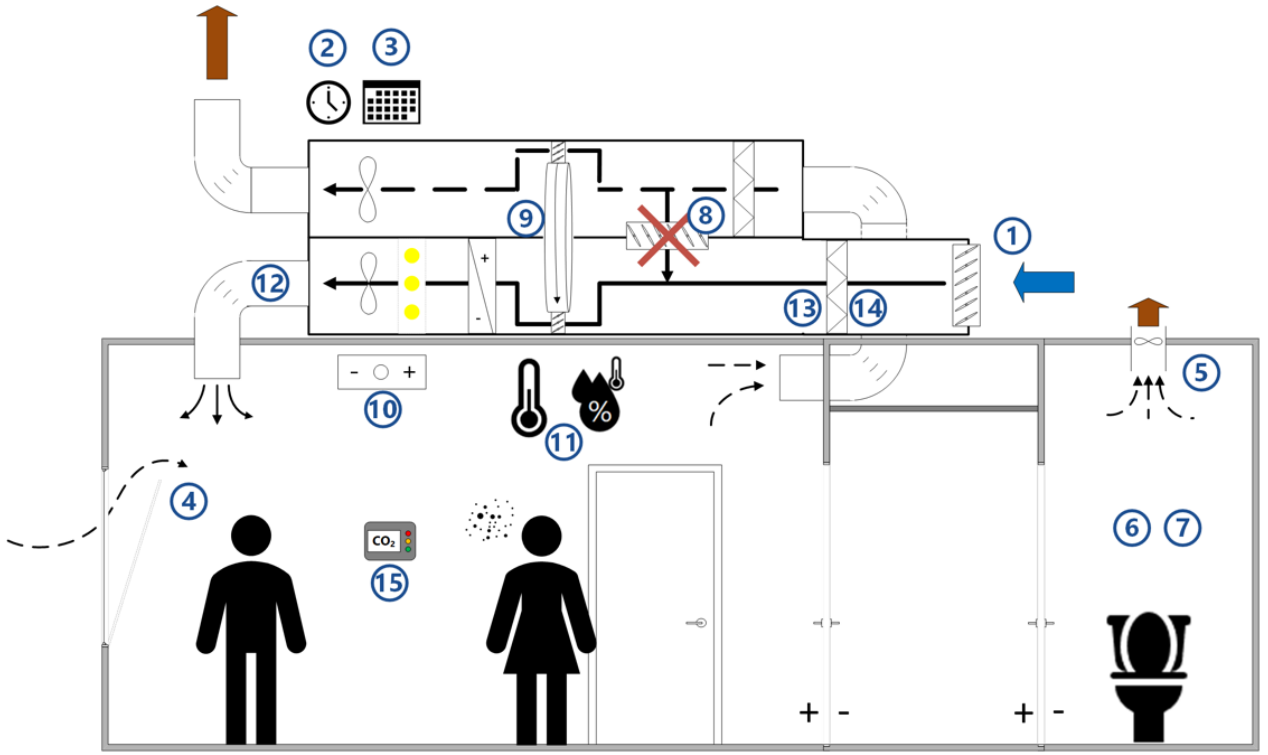




- The means to deal with close contact and long range airborne transmission routes are physical distance to avoid close contact, **ventilation to manage/mitigate (long-range) airborne transmission**
- In addition to ventilation with fresh outdoor air, virus-laden particles can be removed with filtration or incapacitated with germicidal ultra-violet technologies (GVU)

15 Recommendations for existing buildings

1. Ventilation rates
2. Ventilation operation times
3. Continuous operation of ventilation
4. Window opening
5. Toilet ventilation
6. Windows in toilets
7. Flushing toilets
8. Recirculation
9. Heat recovery equipment
10. Fan coils and induction units
11. Heating, cooling and possible humidification setpoints
12. Duct cleaning
13. Outdoor air and extract air filters
14. Maintenance works
15. IAQ monitoring

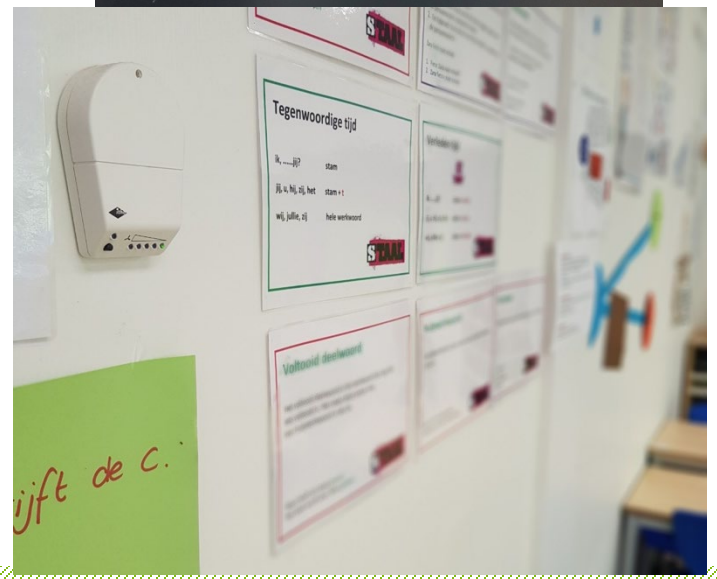


Longer and continuous ventilation operation

- Extended operation times are recommended: Change the clock times of system timers to start ventilation at nominal speed at least 2 hours before the building usage time and switch to lower speed 2 hours after the building usage time
- Do not switch off ventilation at nights and weekends, but operate at lowered speed
- Extended ventilation will remove virus particles from air and also released virus particles from surfaces out the building
- The general advice is to supply as much outside air as reasonably possible. **The key aspect is the amount of fresh air supplied per person**
- Enlarge the spacing among employees (min physical distance 2-3 m between persons) in order to foster the ventilation cleaning effect
- Exhaust ventilation systems of toilets should always be kept on 24/7, and make sure that under-pressure is created, especially to avoid the faecal-oral transmission

What to do if there is no mechanical ventilation?

- In buildings without mechanical ventilation systems, it is recommended to actively use openable windows
- Windows should be opened for 15 min or so when entering the room (especially when the room was occupied by others beforehand)
- In buildings with mechanical ventilation, window opening can be used to further boost ventilation
- Install CO_2-sensors in the occupied zone that can warn against underventilation, especially in spaces that are often used for one hour or more by groups of people, such as classrooms, meeting rooms, restaurants
- Set the warning level to 800 ppm and the alarm level to 1000 ppm in order trigger prompt action to achieve sufficient ventilation even in situations with reduced occupancy



Humidification and air-conditioning have no practical effect

- SARS-CoV-2 stability (viability) has been tested at typical indoor temperature of 21-23 ℃ and **RH of 65% with very high virus stability** at this RH. Previous evidence from MERS-CoV studies suggests that humidification up to 65% has very limited or no effect on the stability of SARS-CoV-2 virus.
- There is no evidence to support that maintaining moderate humidity (RH 40-60%) would be beneficial in reducing the viability of SARS-CoV-2. Active humidification is thus NOT a recommended as a method to reduce the viability of SARS-CoV-2.
- SARS-CoV-2 has been found highly stable for 14 days at 4 ℃; for one day at 37 ℃ and for 30 min at 56 ℃ (Chin et al, 2020)
- AC has no effect in this context (recirculation excluded)

Source: van Doremalen et al. 2020 Aerosol and surface stability of HCoV-19 (SARS-CoV-6 2) compared to SARS-CoV-1 (RH 65%)

Outdoor air filtration

- Outdoor air is not a source of viruses, thus no need to replace filters (outside regular maintenance)
- Outdoor air filters (filter class F7 or F8 or ISO ePM1) are not designed to capture viruses – the size of the smallest viral droplets in respiratory aerosols of about 0.2 mm (PM0.2) is smaller than the capture range of ePM1 / F8 filters (capture efficiency 65-90% for PM1)
- **No need to clean ventilation ductworks as well (outside scheduled maintenance) ?**
- Maintenance personnel needs to apply common protective measures when replacing filters including respirators, because filters may have active microbiological material on them

Room air cleaners

- Room air cleaners remove particles from the air, which provides an effect (particle/aerosol removal) similar to ventilation with fresh outdoor air (dilution);
- To be effective, air cleaners need to have HEPA filter efficiency or utilize electrostatic filtration principles (not the same as room ionizers!);
- In large spaces, air cleaners need to be placed close to people and should not be placed in a remote area of the room;
- Special GUV (germicidal ultra-violet) disinfection equipment may be installed in return air ducts in systems with recirculation, or installed in a room, to destroy/incapacitate viruses and bacteria (health care facilities);
- Air cleaners are an easy-to-apply short-term mitigation measure, but in the longer run, ventilation system improvements are needed to provide sufficient amounts of clean outdoor air.

Summary of practical measures for HVAC operation

1. Provide adequate fresh-air based ventilation of indoor environments
2. Extend (where needed) ventilation operation times: 2 hours before and after scheduled building use
3. Do not switch off ventilation during nights and weekends, but reduce the air volume/speed
4. Open windows regularly (even in mechanically ventilated buildings)
5. Keep toilet ventilation in operation 24/7
6. Avoid open windows in toilets to maintain the right direction of ventilation
7. Instruct building occupants to flush toilets with closed lid
8. Switch air handling units with recirculation to 100% outdoor air
9. Inspect heat recovery equipment to be sure that leakages are under control
10. Adjust fan coil settings to operate so that fans are continuously on
11. Do not change heating, cooling and possible humidification setpoints
12. Carry out scheduled duct cleaning as normal (additional cleaning is not required)?
13. Normal maintenance schedule for the replacement of central outdoor air and extract air filters
14. Maintenance personnel should apply protective measures including respiratory protection
15. Introduce an IAQ sensor network that allows occupants and facility managers to monitor that ventilation is operating adequately

The risky business of predicting infection risk: Standard airborne disease transmission Wells-Riley Model

- The probability of infection (p) is related to the number of quanta inhaled (n):

$p = 1 - e^{-n}$, where "quantum" is the minimum dose of an infectious agent to cause infection in a host

- n (quanta) depends on the time-average quanta concentration (C_{avg}, quanta/m^3), the volumetric breathing rate of an occupant (Q_b, m^3/h) and the duration of the occupancy (D, h)

$$\boldsymbol{n} = C_{avg} Q_b \mathrm{D}$$

- A fully mixed material balance model for the room:

$$\frac{dC}{dt} = \frac{\boldsymbol{E}}{V} - \lambda C$$

where

E	quanta emission rate (quanta/h);
V	volume of the room (m^3);
λ	first-order loss rate coefficient for quanta/h due to the summed effects of ventilation (λ_v, 1/h), deposition onto surfaces (λ_{dep}, 1/h) and virus decay (k, 1/h);
C	time-dependent airborne concentration of infectious quanta (quanta/m^3).

- (Concentration in larger rooms is not uniform (incomplete air mixing depending on air distribution mode)

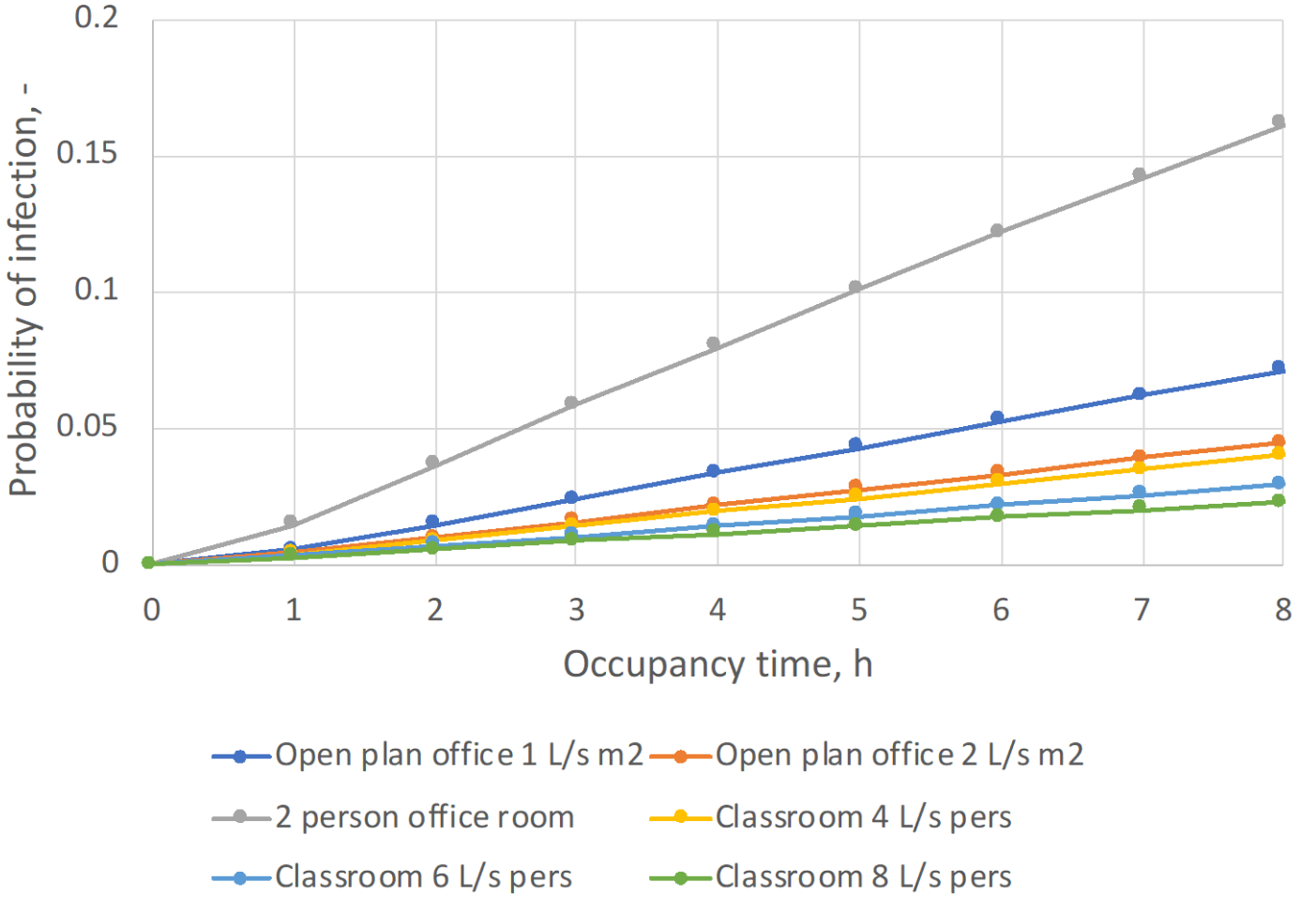
Quanta emission rates from literature

- Common cold/rhinovirus (Yuexia Sun et al. 2011) 1-10 quanta/h
- Influenza (Mesquita, Noakes and Milton 2020) 0.1-0.2 q/h in average, but 630 q/h max daily rate
- SARS-CoV-2 (Buonanno G, Morawska L, Stabile L, 2020):

Activity	Quanta emission rate, quanta/h
Resting – Oral breathing	2.0
Resting – Speaking	9.4
Resting – Loudly speaking	60.5
Standing – Oral breathing	2.3
Standing – Speaking	11.4
Standing – Loudly speaking	65.1
Light exercise – Oral breathing	5.6
Light exercise – Speaking	26.3
Light exercise – Loudly speaking	170
Heavy exercise – Oral breathing	13.5
Heavy exercise – Speaking	63.1
Heavy exercise – Loudly speaking	408

Calculation examples (1/2)

- Assumption of 1 infected person in all rooms
- 5 quanta/h for office work and classroom occupancy
- 1.5 L/s per m^2 ventilation rate in 2 person office room of 16 m^2
- 50 m^2 open plan office
- 56 m^2 classroom



Infection control pyramid

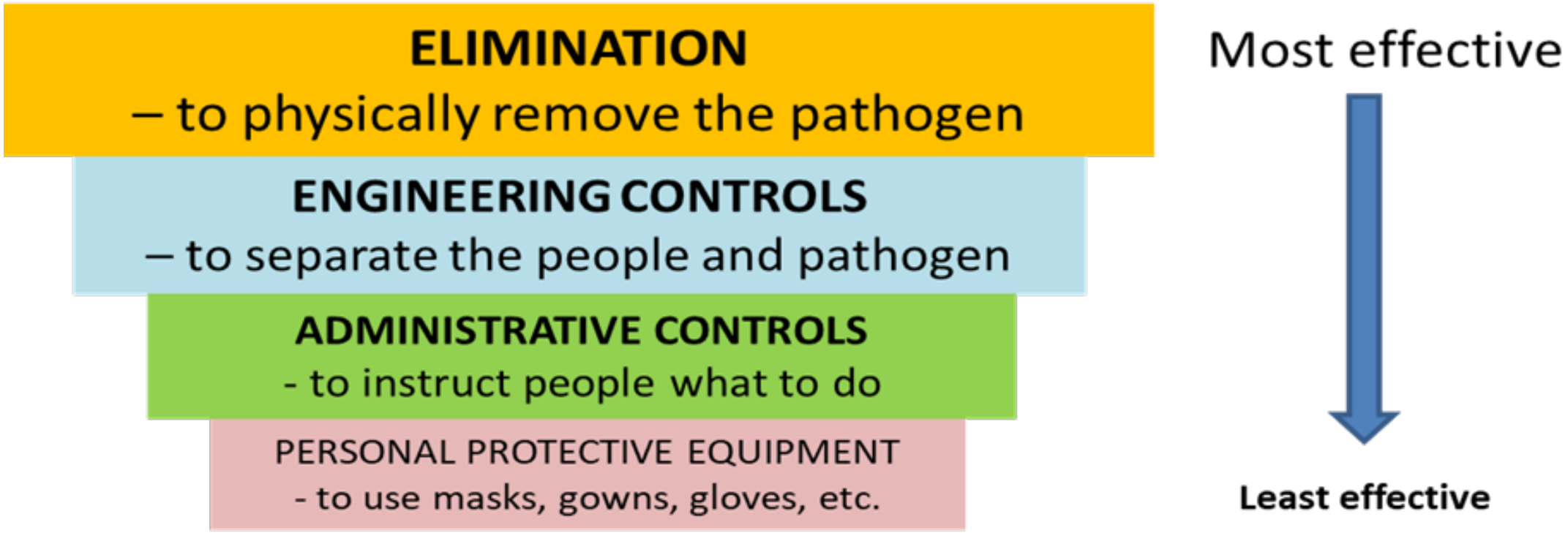
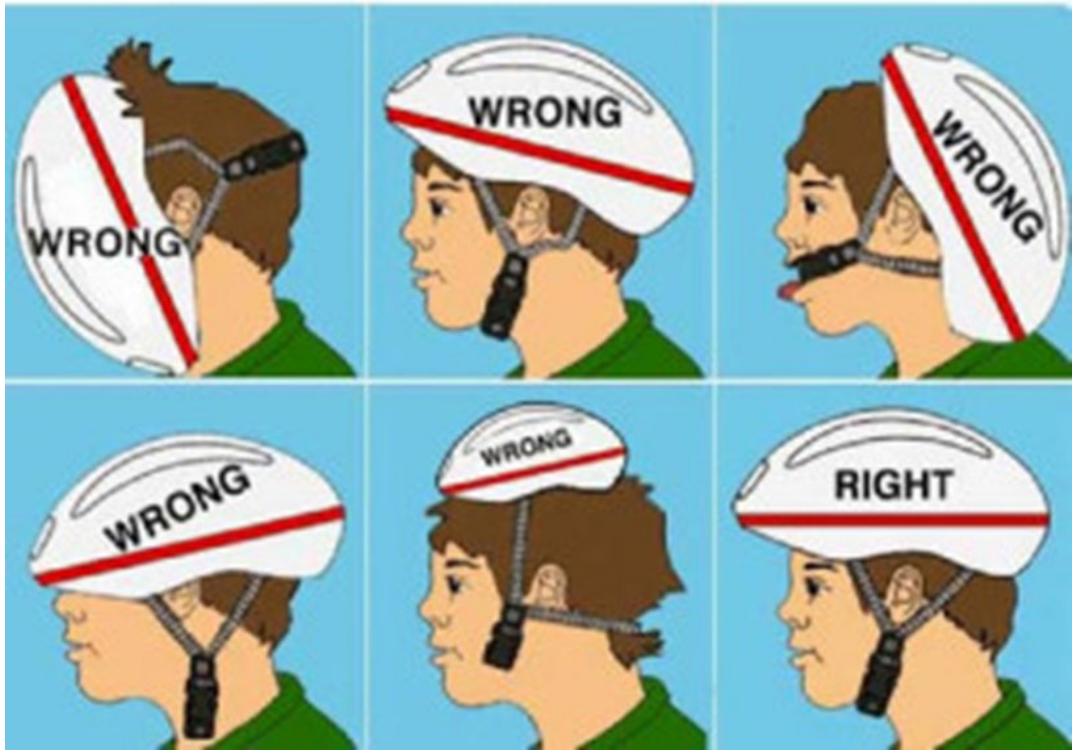


Figure 4. Traditional infection control pyramid adapted from the US Center for Disease Control

Personal protection equipment - masks

- The scientific evidence is convincing on the benefits of mask use in specific conditions, mainly when close contact (1,5-2 m) between people cannot be avoided or ventilation is inadequate (no rocket science).
- When used properly, masks can be a useful complement to transmission control in crowded indoor and outdoor environments, where social distancing cannot be maintained, as well as in crowded, poorly ventilated indoor settings (e.g. public transport means and infrastructure, restaurants/bars/cafés, shops, gyms, some types of elevators, etc.).

How to not wear a bike helmet



How to not wear a face mask

Sources: https://moffitt.org/endeavor/archive/5-mistakes-you-may-be-making-when-wearing-face-masks/, as accessed 201118, https://www.bikeauckland.org.nz/lawyer-bike-compulsory-helmet-elbow/wrong-way-to-wear-a-helmet-cartoon_zpsd2e81a89/, as accessed 201118

Mask wearing common sense…

- Do not touch your mask, wash you hands if you accidentally do
- Cover nose and mouth and adjust it to sit as tightly as possible without causing pain or discomfort
- Change (wash) your mask frequently (cost?)
- Handle the mask carefully while removing it and do not touch your eyes, face, etc.
- Only re-use your mask if you can maintain full control of potential contamination pathways (i.e. do not tuck it into your pocket…)
- Be prepared, know when a mask may be needed (err on the side of caution) and have a supply of masks handy
- …..
- Additional information:

https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/how-to-wear-cloth-face-coverings.html

Some answers and more questions…

- How much is "enough" fresh air?
- How far can airborne particles (aerosols) penetrate ventilation systems and how long can infectious agents remain alive? Can ventilation contribute to infection transmission?
- What does this mean for the cold&flu season?
- How should offices be designed and used in the future?
- To what extent will we use offices to the same extent as today?
- Innovative transmission control technologies?
- …

Additional information

World Health Organization (WHO):

https://www.who.int/docs/default-source/coronaviruse/risk-comms-updates/update-33-trasmission.pdf?sfvrsn=9b1b10aa_2

European Center for Disease Prevention and Control (ECDC)

https://www.ecdc.europa.eu/sites/default/files/documents/Heating-ventilation-air-conditioning-systems-in-the-context-of-COVID-19-first-update.pdf


STAY SAFE AND STAY HEALTHY!
THANK YOU!