HVAC research & technology trends emerging after the COVID-19 pandemic

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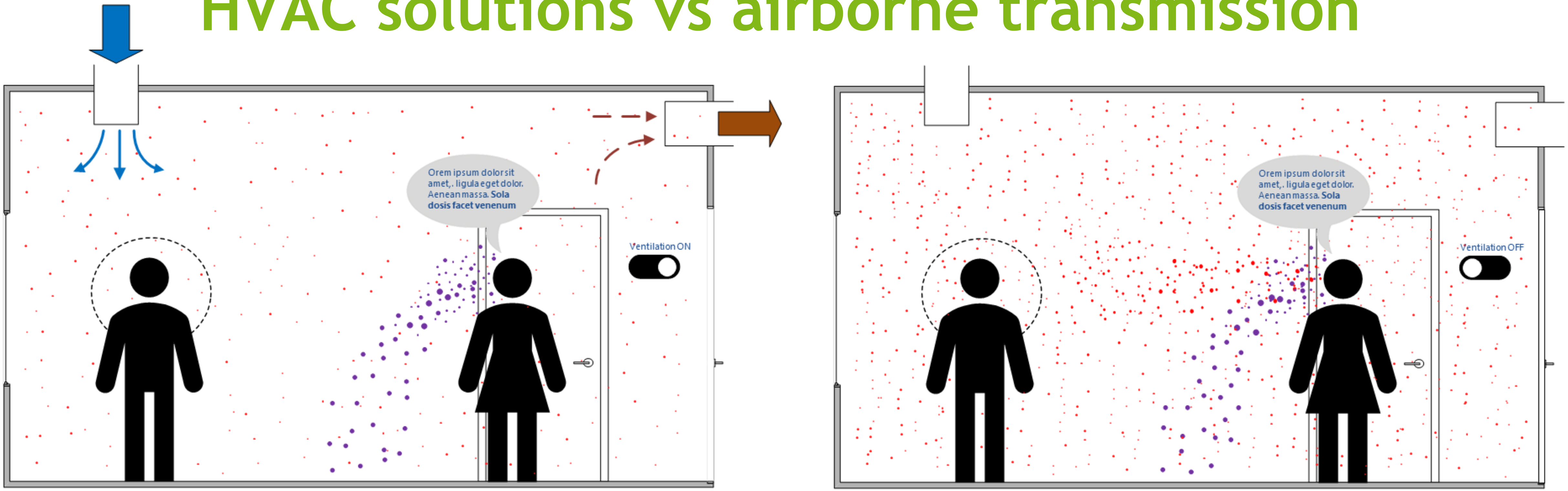
HVAC solutions vs airborne transmission



- Exposure = dose is a product of the breathing rate, **concentration** and time
- Concentration control of virus containing particles: remove with **outdoor air ventilation** and **filtration** or deactivate with **UVG**
- **General ventilation** solutions for >1.5 m may be complemented with **personal ventilation** solutions (may also be applied for <1.5 m concentration control)

Main issues

- Reliable infection probability calculation for various ventilation and room configurations
- How much ventilation – high capacity demand controlled dedicated ventilation systems
- Air distribution questions:
  - General ventilation – how to achieve good mixing in large rooms and local exhaust for the source with unknow location?
  - Personal and targeted ventilation solutions – not only to deliver clean air but also for local exhaust
  - Performance of air cleaners in real rooms: how to be located etc.
- Hygiene of ventilation components: heat recovery, circulation of room air
- Recirculation: generally to be avoided but also more evidence needed how to deal in existing buildings

Airborne transmission risk assessment

- COVID-19 disease has been associated with **close proximity** (for which general ventilation isn't the solution) and with spaces that are simply **inadequately ventilated**
- In superspreading events the outdoor air ventilation has been as low as 1–2 L/s per person (Guangzhou restaurant, Skagit Valley)
- Would 10 L/s per person recommended in existing standards be enough – no evidence available
- Some evidence of no cross infections from hospitals (about 40 L/s per patient, 6-12 ACH)

- Typical sizing according to ISO 17772-1:2017 and EN 16798-1:2019 results in default Indoor Climate Category II to 1.5 – 2 L/s per floor m^2 (10–15 L/s per person) outdoor airflow rates in offices and to about 4 L/s per floor m^2 (8–10 L/s per person) in meeting rooms and classrooms
- 4 L/s per floor m^2 in meeting rooms and classrooms corresponds to 5 ACH
- WHO 6 ACH https://www.youtube.com/watch?v=XJC1f7F4qtc&feature=youtu.be

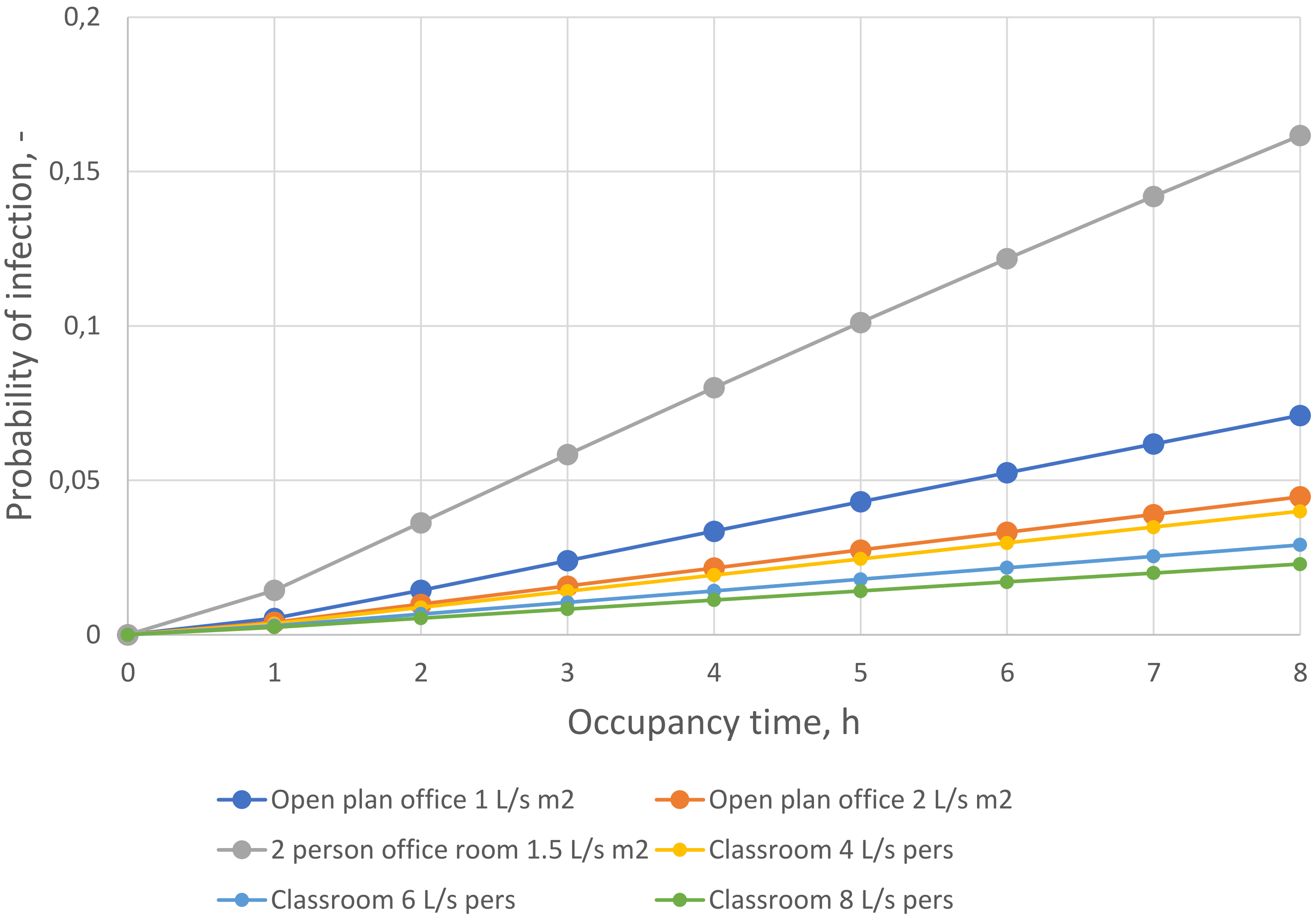
Standard airborne disease transmission Wells-Riley model application

- 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	3.1
Heavy activity, oral breathing	21
Light activity, speaking	42
Light activity, singing (or loudly speaking)	270

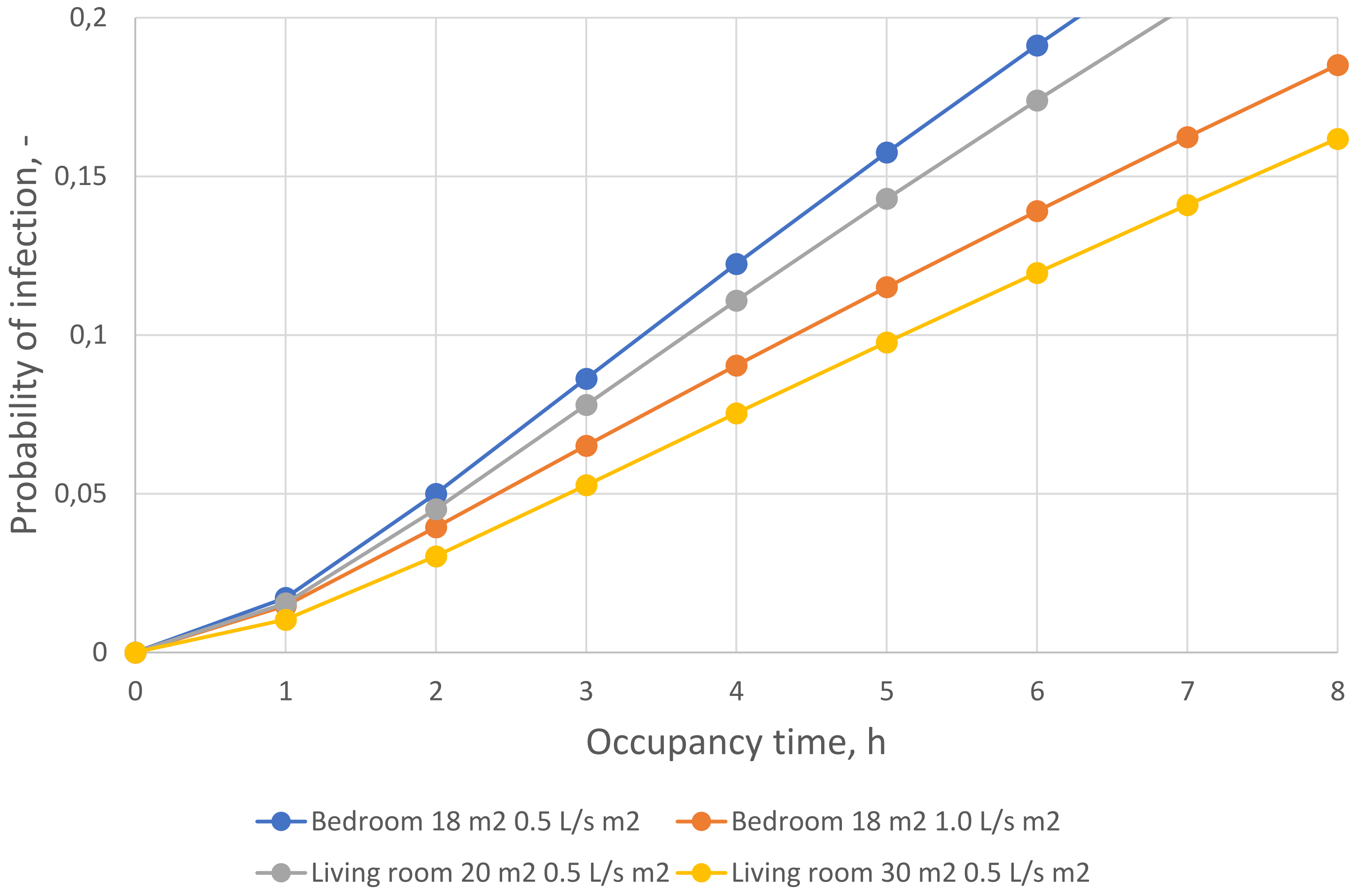
Individual risk calculation in public buildings

- Assumption of 1 infected person in all rooms
- 5 quanta/h for office work and classroom occupancy (applies for SARS-CoV-2 and common cold)
- Full mixing assumed
- 1.5 L/s per m^2 ventilation rate in 2 person office room of 16 m^2
- 50 m^2 open plan office and 56 m^2 classroom
- Both the ventilation rate and room size matter, resulting in the total airflow rate per infected person

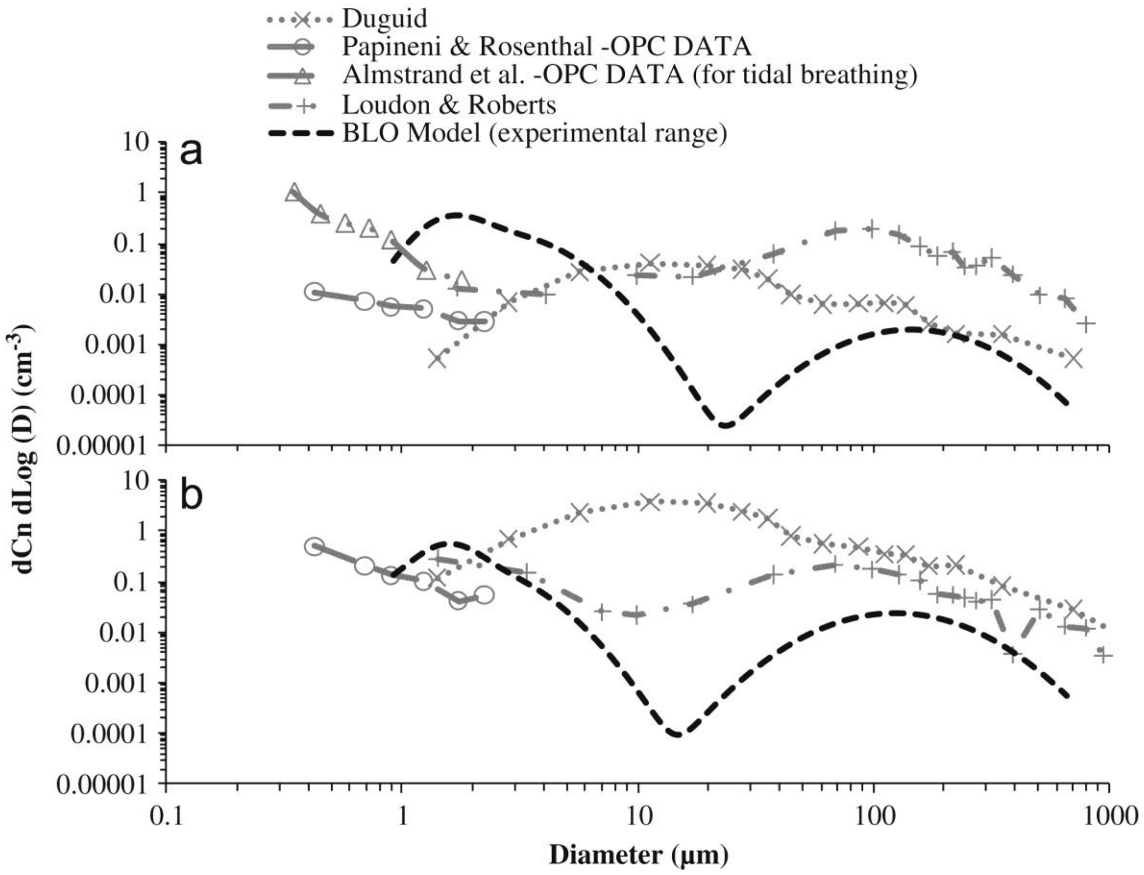


For comparison: home ventilation

- Very high risk even in well ventilated apartments (close contact not taken into account)
- CDC report showed that 53% of people who were living with a COVID-19 positive person wound up sick within a week https://www.cdc.gov/mmwr/volumes/69/wr/mm6944e1.htm?s_cid=mm6944e1_w
- (focus to staircases and other common rooms)



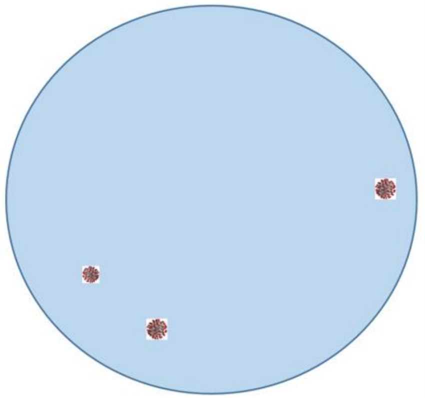
Filtration with ePM1 80% (former F8) filters



Expelled aerosol size distribution (a) speaking and (b) coughing

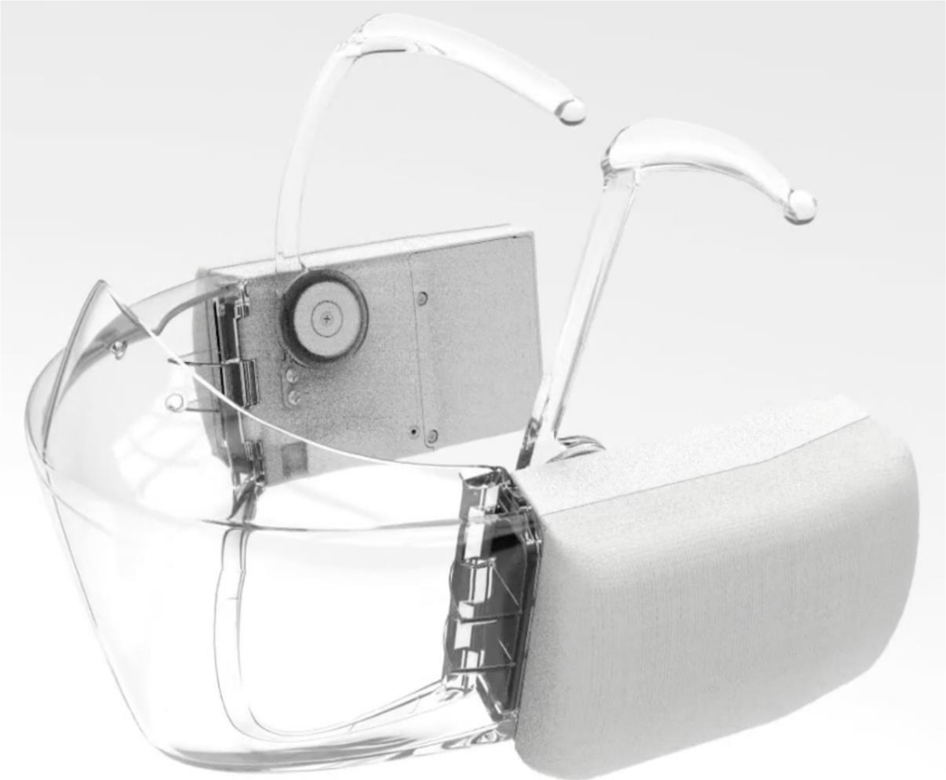
G.R.Johnson, L.Morawska et al. 2011 https://doi.org/10.1016/j.jaerosci.2011.07.009

- An airborne virus is not naked (0.1 µm) but is contained inside expelled respiratory fluid droplets (= droplet nuclei = virus containing aerosol)
- Most of expelled droplets > 1 µm
- ePM1 (F8) filters provide capture efficiency of 65-90% for PM1
- Therefore, already good fine outdoor air filters provide reasonable filtration efficiency for room or return air



> 1 μm particle filtration is relatively easy

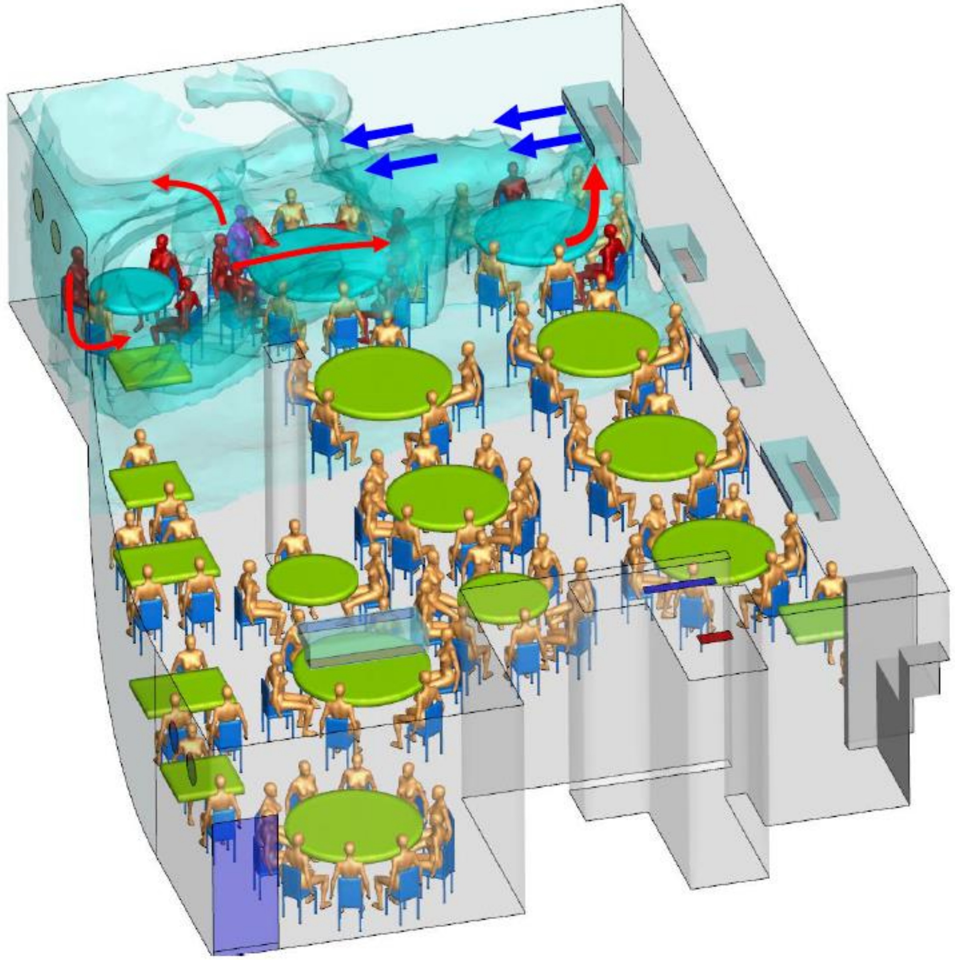
- Good opportunity for high-capacity air cleaners (2…5 ach), even less than HEPA filters enough for remarkable particle concentration reduction
- Performance of air cleaners in real rooms to be studied, how to be located and sized etc.



- More advanced personal protection (fan + filter) devices https://www.ao-air.com

Propagation and spread by air currents directed to a person

- New meaning for air movement/distribution
- ECDC addresses in their HVAC paper "Air flow generated by air-conditioning units may facilitate the spread of droplets excreted by infected people longer distances within indoor spaces."
- In reality, combined effect of directed air flow of the split unit and the poor ventilation (1 L/s per person) known in the Guangzhou restaurant
- Unfavorable airflow patterns may increase the concentration in the breathing zone for instance in some displacement and underfloor systems (Pantelic & Tham 2013, Bolashikov et al. 2012)
- → **Low velocity air distribution with good mixing probably the most robust solution**

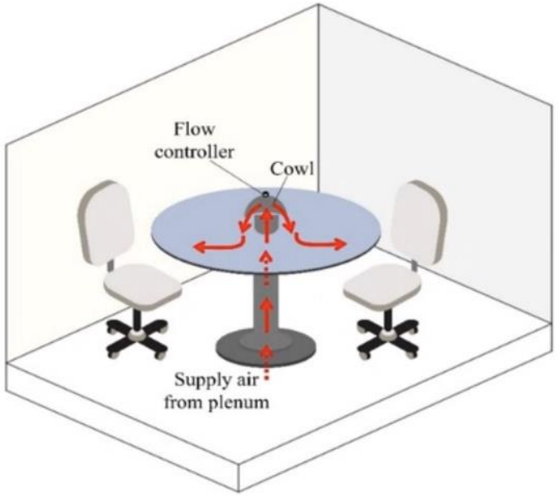


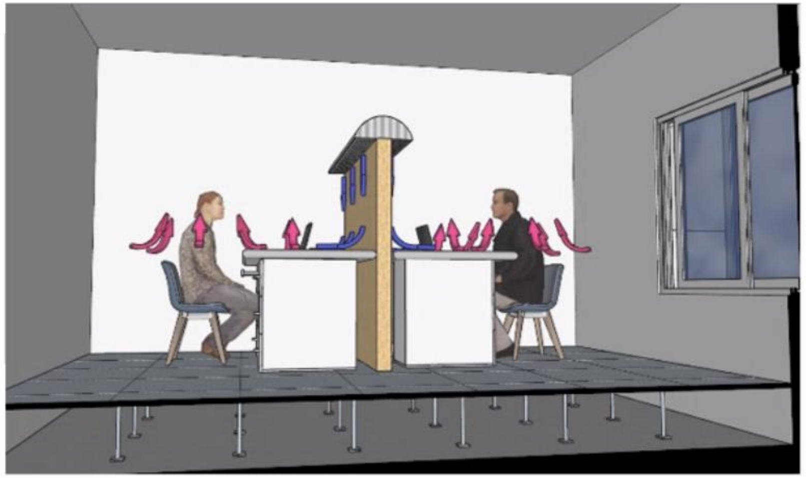
Research needs for improved general ventilation

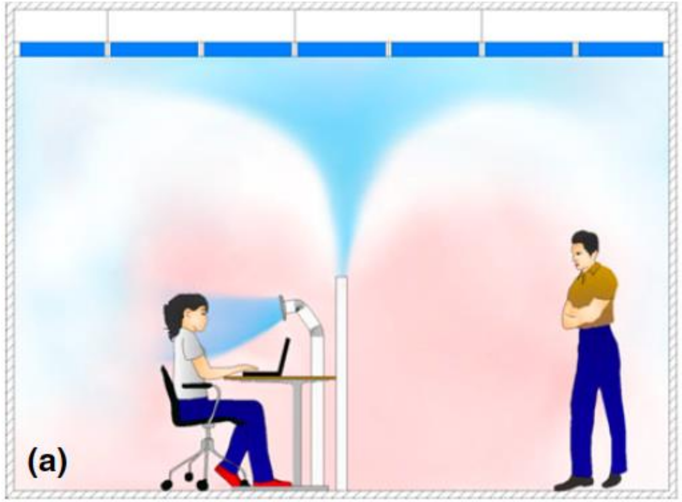
- Low velocity air distribution with good mixing for effective dilution (=concentration reduction) –air distribution/concentration measurements to be conducted in large rooms such as open plan offices, meeting rooms, classrooms etc.
- Would it be possible to achieve some local exhaust effect with proper positioning of extract terminals for possibly many source locations?
- Ventilation sizing/standardisation: at least Category I ventilation rates can be recommended as these provide significant risk reduction compared to common Category II airflow rates; infection risk could be introduced as one ventilation criterion in future standards
- High capacity demand controlled dedicated ventilation systems will provide new challenges:
  - Typical operation range of demand controlled systems 40…100%
  - If the capacity would be doubled, the operation range should be 20…100% to maintain energy efficiency in non-epidemic conditions – new design for AHUs and air distribution to work in wide range

General ventilation + targeted ventilation

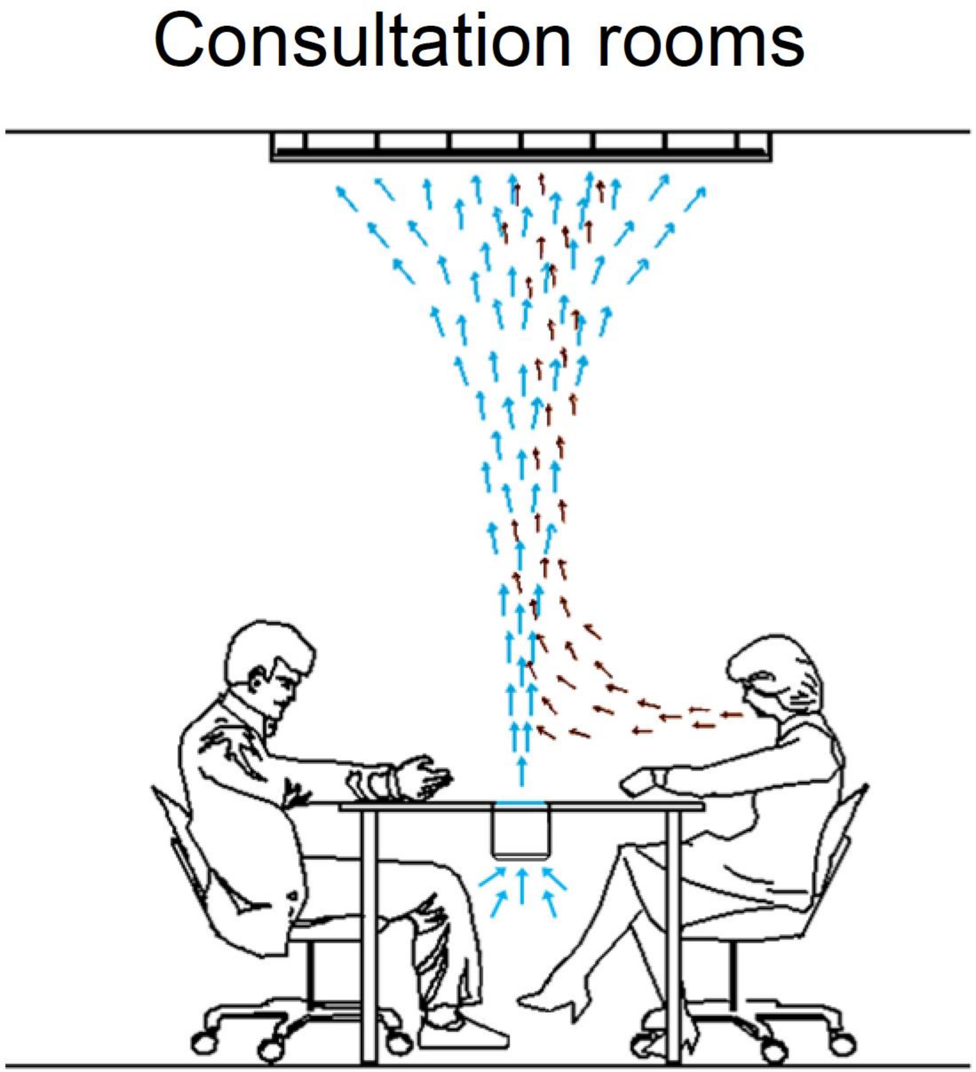
- REHVA occupant targeted ventilation Task Force (Arsen Melikov and Risto Kosonen)
- Many ideas how to deliver a small amount of clean air (in theory only 0.3 L/s for inhalation)
- Can be also applied to organise local exhausts

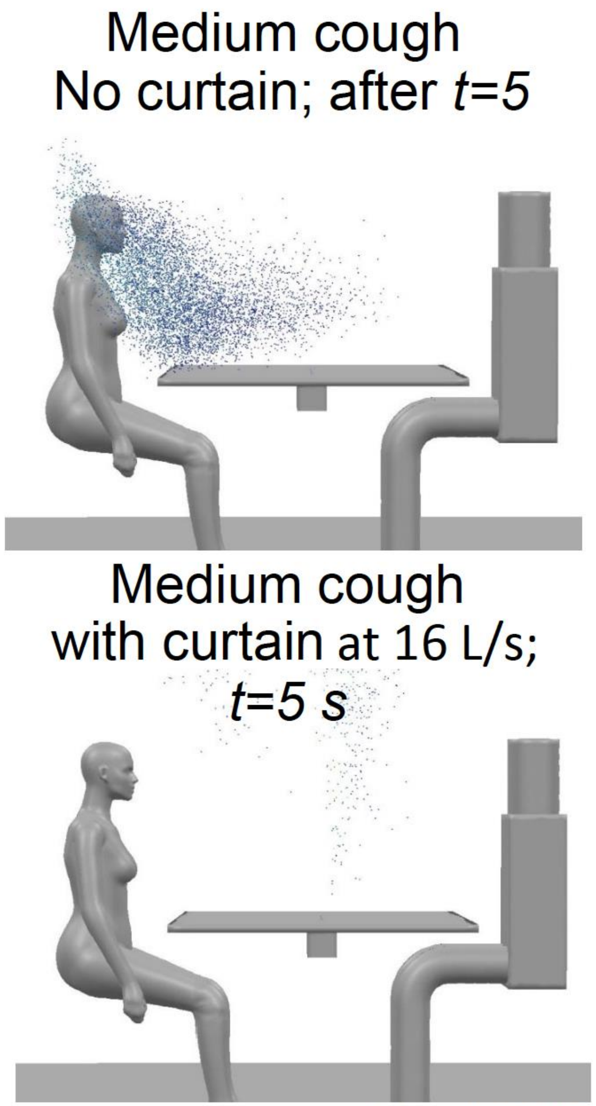






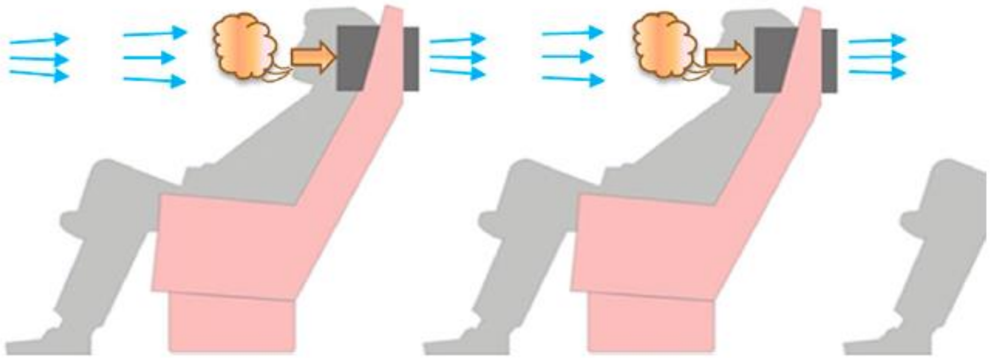
Targeted ventilation: source control

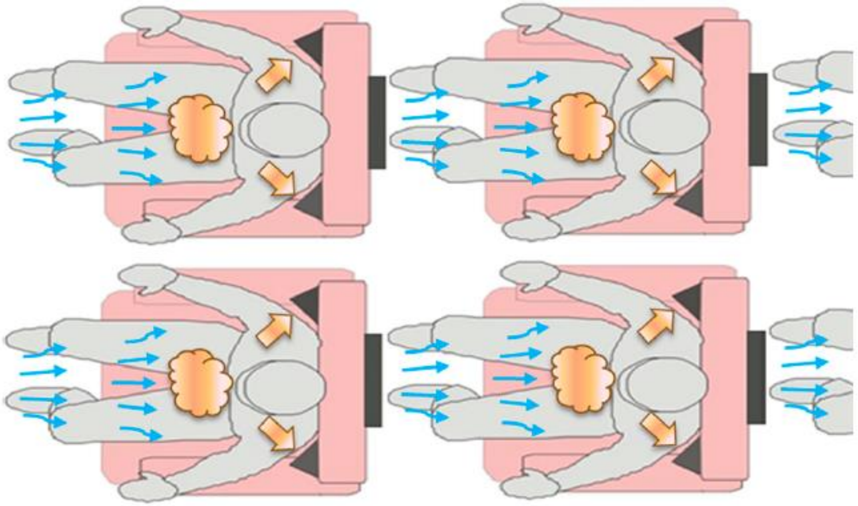




Mazei 2011

Personal ventilation in fixed seats



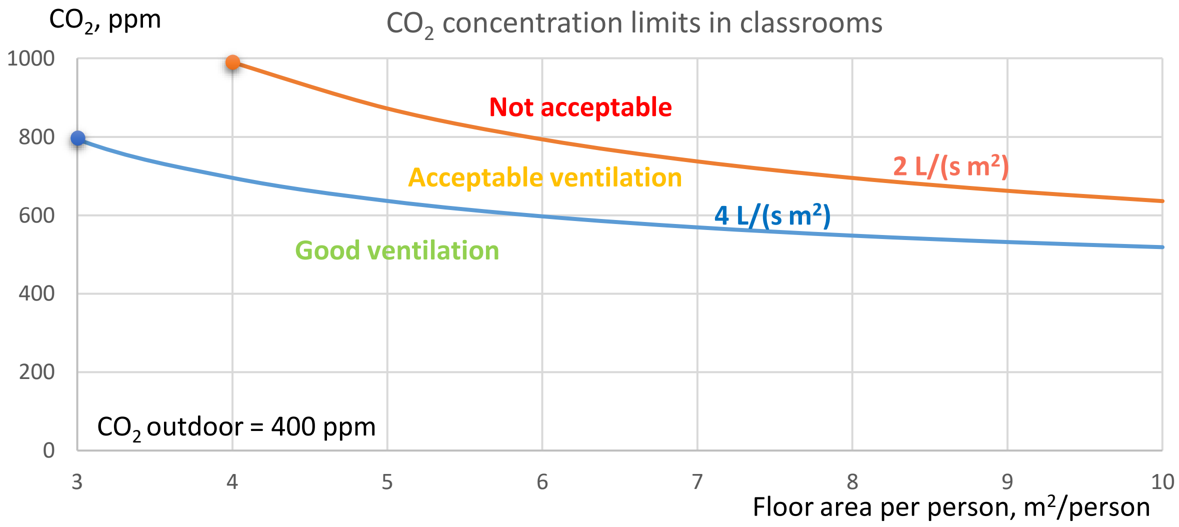


- Seat incorporated advanced air distribution for the removal of exhaled air at the source and delivery of clean air to the breathing zone (Melikov and Dzhartov, 2013)
- Why such solutions are not in use in airplanes and busses?

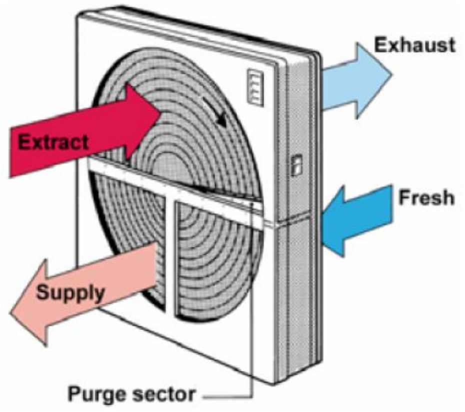
Visualization and monitoring of ventilation

- More dedicated IAQ monitoring systems than just CO_2 measurement

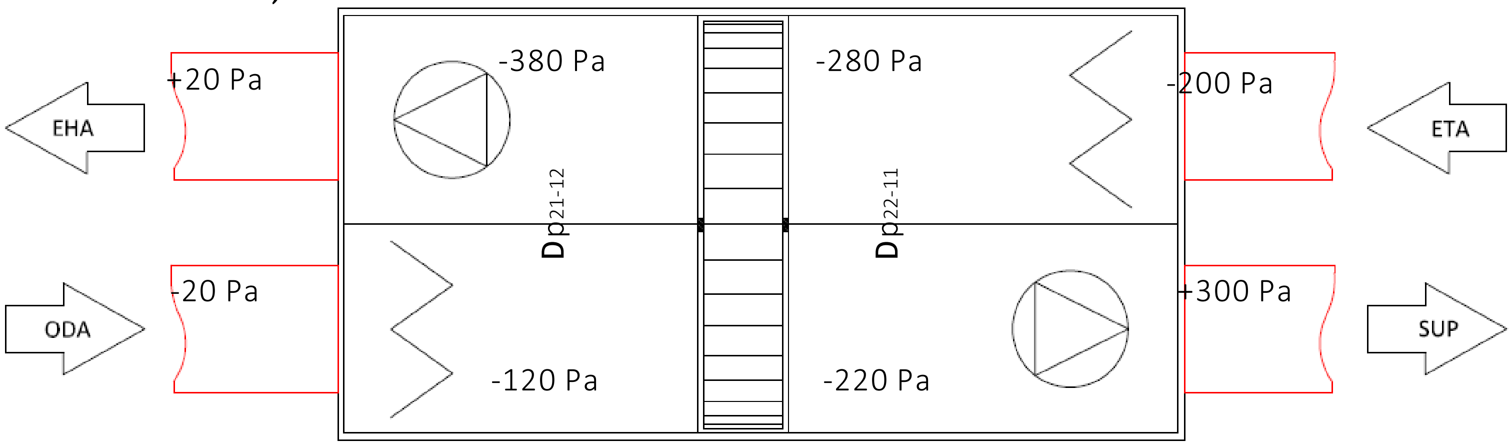
- Currently recommended to install CO_2 sensors and to use use openable windows especially in buildings without mechanical ventilation systems:
  - **Install CO_2 sensors** at the occupied zone that warn against underventilation especially in spaces that are often used for one hour or more by groups of people, such as classrooms, meeting rooms, restaurants
  - Set the yellow light to **800 ppm** and the red light up to **1000 ppm** in order trigger prompt action to achieve sufficient ventilation even with reduced occupancy



Hygiene of ventilation components



- Carry over of virus containing aerosols from the exhaust air side to the supply air side is not well known in many components/systems
- In the case of regenerative heat exchangers (rotors) the leakage through seals + carry over transfer is an issue
- Some Nordic studies from 1980-s suggest that rotors with adequate purge sector practically do not transfer particles, but the transfer is limited to gaseous pollutants (e.g. smells, tobacco smoke)
- Limited evidence on room conditioning units' room air circulation effects
- Very little studies/evidence about recirculation effects



Conclusions

- There are many possibilities to improve ventilation solutions to reduce the risk of transmission of COVID-19 type of infectious diseases in public buildings
- Category I ventilation rates can be recommended already now, but more significant improvements may be needed
- Future research should tackle outdoor air ventilation capacity, air distribution, cross-contamination, air cleaning and IAQ monitoring aspects as the first priority
- Quick and affordable retrofit solutions of improved ventilation efficiency resulting in reduction of risk of infection should be a specific focus for existing buildings (that can be developed as a part of energy efficient low carbon retrofit to meet 2030/2050 goals)
- Research funding agencies and industry should invest in developing practical technical solutions to protect against the aerosol transmission of infectious diseases in indoor environments and public transport
- Building codes, standards, and guidelines should be revised and updated to improve preparedness for future epidemics