Ventilation Design for Health and Airborne Transmission

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2024 ROOMVENT CONFERENCE

Airborne transmission of viruses

23 February 2020

The WHO does not r
spread across distar

28 March 2020

The agency explicitl
suggesting that it cc

9 July 2020

In a detailed 'Scientifi
droplets that fall onto
contact. But, for the fi
of medical settings m

"Outside of
related to indo
possibility of
droplet transmi
practice, in re
events, short-r
in specific indoor locations, such as crowded and inadequately ventilated spaces over a prolonged period of time with infected persons cannot be ruled out."

20 October 2020

The WHO states that aerosol transmission happens outside of medical settings.

30 April 2021

The WHO for the first time mentions that aerosols can stay suspended in the air or travel long distances.

23 December 2021

Nearly two years into the pandemic, the WHO uses the term 'airborne' for the first time.

"Current evidence suggests that the virus spreads mainly between people who are in close contact with each other, for example at a conversational distance …
The virus can also spread in poorly ventilated and/or crowded indoor settings, where people tend to spend longer periods of time. This is because aerosols can remain suspended in the air or travel farther than conversational distance (this is often called long-range aerosol or long-range airborne transmission)."

REHVA, March 17, 2020: COVID is airborne

FACT CHECK: COVID-19 is NOT airborne

This message spreading on social media is incorrect. Help stop misinformation. Verify facts before sharing.

The virus that causes COVID-19 is mainly transmitted through droplets generated when an infected person coughs, sneezes, or speaks. These droplets are too heavy to hang in the air. They quickly fall on floors or surfaces.

You can be infected by breathing in the virus if you are within 1 metre of a person who has COVID-19, or by touching a contaminated surface and then touching your eyes, nose or mouth before washing your hands.

To protect yourself, keep at least 1 metre distance from others and disinfect surfaces that are touched frequently. Regularly clean your hands thoroughly and avoid touching your eyes, mouth, and nose.

World Health Organization **#Coronavirus** **#COVID19**

WHO March 28, 2020

Why the WHO took two years to say COVID is airborne https://www.nature.com/articles/d41586-022-00925-7

GROUP 36, Sept 2020: How can airborne transmission of COVID-19 indoors be minimised? https://doi.org/10.1016/j.envint.2020.105832

Coronavirus Disease 2019 and Airborne Transmission: Science Rejected, Lives Lost. Can Society Do Better? https://doi.org/10.1093/cid/ciad068

Lessons learnt

- COVID changed basic understanding how viruses spread
- Should building ventilation be designed to use **shared indoor spaces** during epidemic periods?
- **Non-residential**, residential and health care setting
- Infection risk has not been addressed in IAQ and ventilation standards however the association between sick leave and ventilation known from 2000 (addressed in health care setting) Milton et al. 2001 https://doi.org/10.1034/j.1600-0668.2000.010004212.x

- Consensus statement 2024 Morawska et al. DOI: 10.1126/science.adl0677
  - IAQ standards to be made mandatory for public spaces and shall include airborne disease transmission
  - Ventilation, supported with filtration and disinfection, as well as productivity and learning performance issues – proposed parameter levels

Proposed parameter levels

Values may be adjusted to reflect local circumstances and priorities.

	LEVEL	AVERAGING TIME OR SETPOINT
$PM_{2.5}$, µg/m^3	15(i)	1-hour
CO_2, ppm	800 (absolute value)(ii)	threshold
	350(delta)(iii)	threshold
CO, mg/m^3	100(iv)	15 minutes(iv)
	35(iv)	1 hour(iv)
	10(iv)	8 hours(iv)
Ventilation, liters/s per person	14(v)	When the space is occupied

(i) 24-hour level from (3). (ii) When 100% of air delivered to the space is outdoor air, assuming outdoor CO_2 concentration is 450 ppm; based on classroom scenario (see SM). (iii) Delta is the difference between the actual CO_2 concentration and the CO_2 concentration in the supply air. (iv) 8-hour averaging time, from (*15*). (v) Clean air supply rate in the breathing zone; see (*12*). At 25°C and 1 atm for CO 1 ppb = 1.15 µg/m^3. Threshold is the concentration level of CO_2 that must not be exceeded.

VENTILATION DESIGN CRITERIA FOR HEALTH VS. COMFORT

Comfort – perceived air quality – odours/bioeffluents/material emissions:

- EN 16798-1:2019 ventilation rates are based on PAQ by the visitors (unadapted) in non-residential and occupants (adapted persons) in residential buildings
- Depend on the emissions from humans and building materials

Health and airborne transmission:

- Keep the likelihood of infecting others on the reasonable level to avoid the rapid spread of epidemic (one infector will cause no more than one new disease case)
- The infection risk should be considerably reduced but not eliminated (R_0 = 1)
- Relevant for shared indoor spaces (mostly non-residential), but not for health care with much more strict criteria

TAL TECH | TALLINNA TEHNIKAÜLIKOOL

BASIC QUESTIONS

- How much ventilation (including outdoor air, particle filtrated air, disinfected air) is needed?

- How the ventilation needs to be arranged – ventilation effectiveness/air distribution?

RoomVent 2024 Workshop 2: Understanding Requirements for Ventilation and IC

RoomVent 2024 Workshop 7: Ventilation Effectiveness in the Infection Risk Control

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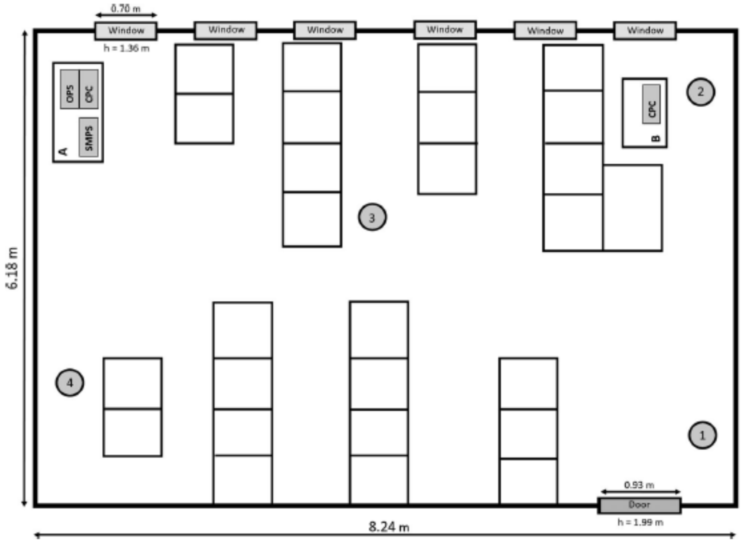
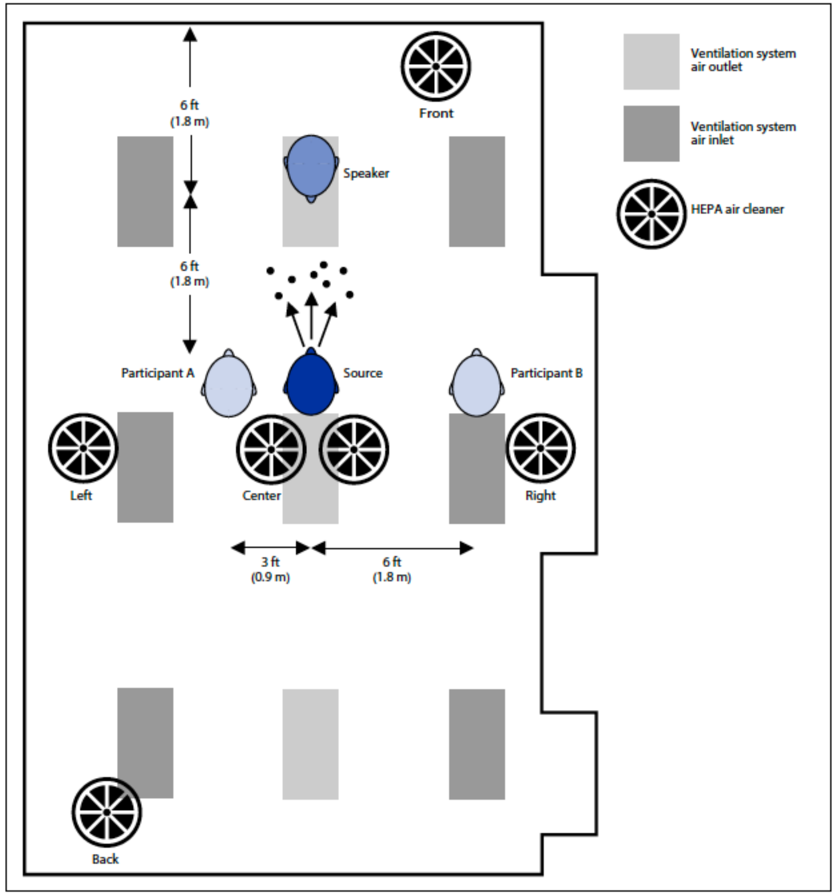
EXISTING EVIDENCE: VENTILATION AND FILTRATION

- Italian epidemiological study: ventilation rates of **10 L/s per person and higher reduced the likelihood of COVID-19 infection for students by 80%** compared with a classroom with natural ventilation Buonanno et al. 2022 https://doi.org/10.3389/fpubh.2022.1087087



https://doi.org/10.1080/02786826.2021.1877257



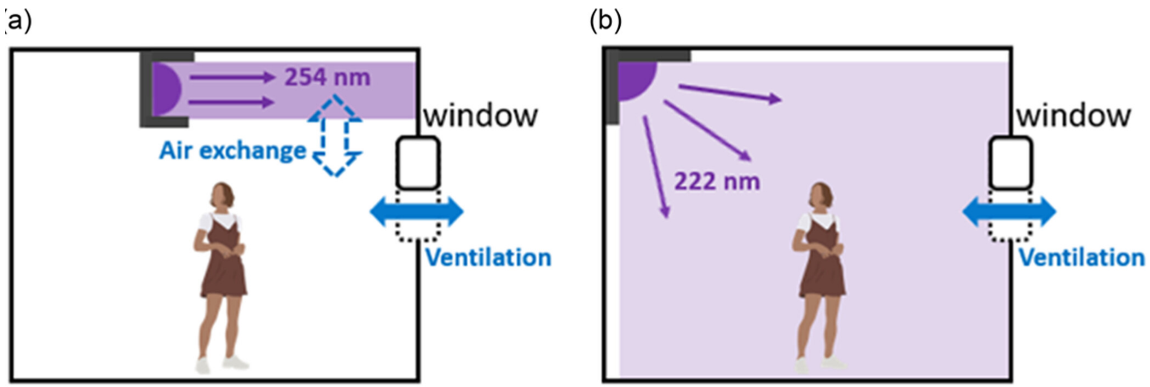
https://www.cdc.gov/mmwr/volumes/70/wr/mm7027e1.htm

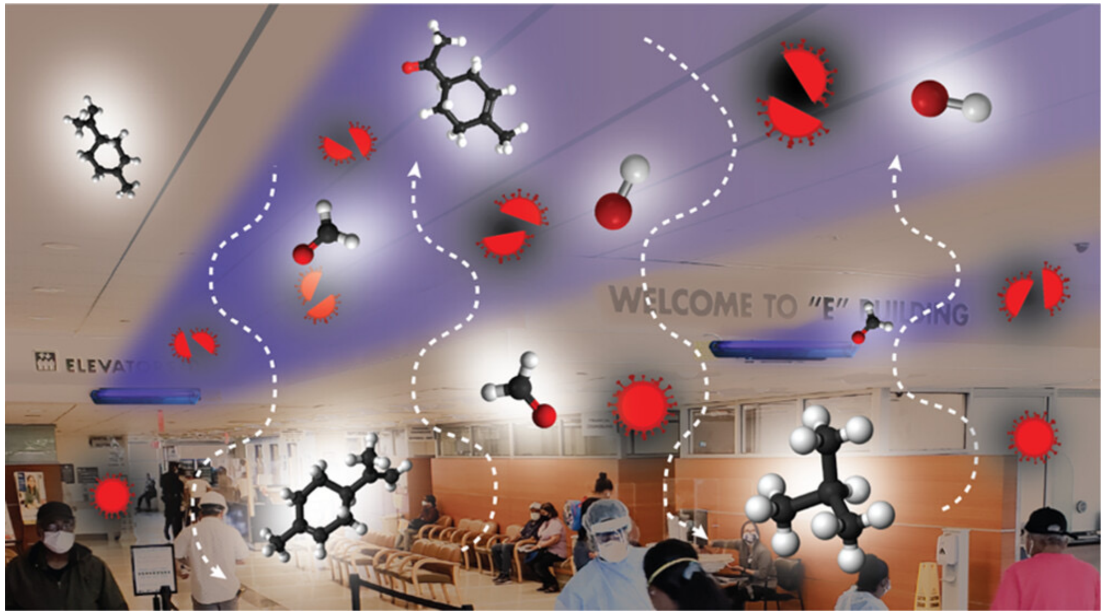
- Classroom studies suggest to use at least **2 air cleaners with air change rate of about 5 ach**
  - Equals to the air change rate of an adequate ventilation (i.e. in such a case will double the virus removal rate)
  - Will not replace, but supports outdoor air ventilation – CO_2 monitors recommended to follow IAQ
- Finnish laboratory and CFD studies show 50% of reduction with **air cleaners in offices** Kilpeläinen et al. RoomVent 2024

TAL TECH

EXISTING EVIDENCE: UV DISINFECTION

- Germicidal ultraviolet light (GUV) uses UVC lamps to inactivate microorganisms, but it also initiates photochemistry in air (indoor smog)
- Upper room or whole room UVC lamps
- GUV254 can significantly photolyze O_3, generating OH radicals that oxidize indoor (VOCs) into more oxidized VOCs and secondary organic aerosols (SOA) are formed
- GUV222 is recommended as it makes a smaller indoor-air-quality impact at **3 ach or higher ventilation**
- Especially effective with high ventilation rate Aganovic et al. 2024 https://doi.org/10.1016/j.scitotenv.2024.172278





Peng et al. 2022 https://doi.org/10.1021/acs.estlett.2c00599

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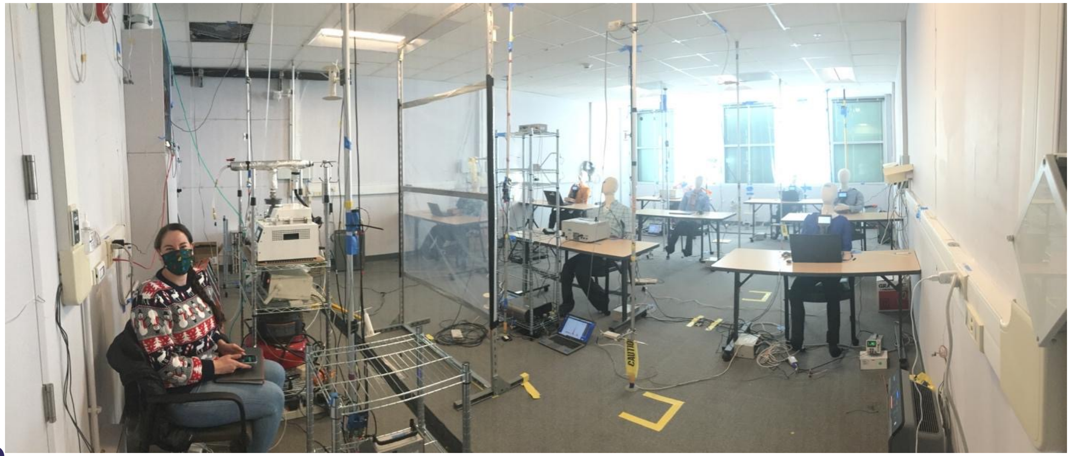
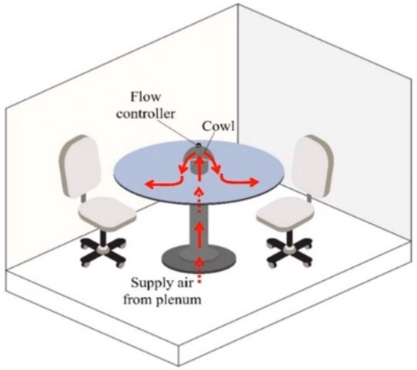
EXISTING EVIDENCE: VENTILATION EFFECTIVENESS

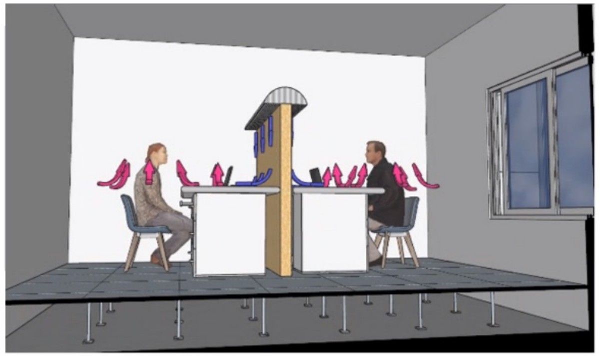
- Many studies on personal ventilation
- Personal or targeted ventilation may be combined with partitioning/ zoning – **ventilation effectiveness can be improved by a factor of 1.4 to 10** depending on the local partition configuration, exhaust location and flow rate Shen et al. 2021 (Dygert and Dang 2012 https://doi.org/10.1016/j.buildenv.2021.107926
- Practical applications still limited – more research with a point contaminant source needed

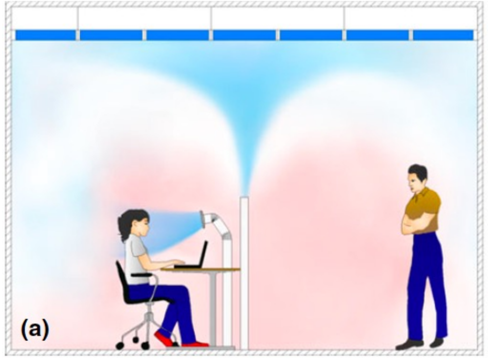


Classrooms & meeting rooms
https://onlinelibrary.wiley.com/doi/10.1111/ina.12917

https://newsletter.konzerthaus-dortmund.de/Pressemails/2020-21/Pressemitteilung/2021.01.11_Zusammenfassung_Aerosol-CO2-Messungen_Konzerthaus-Dortmund.pdf?utm_source=newsletter&utm_medium=email&utm_content







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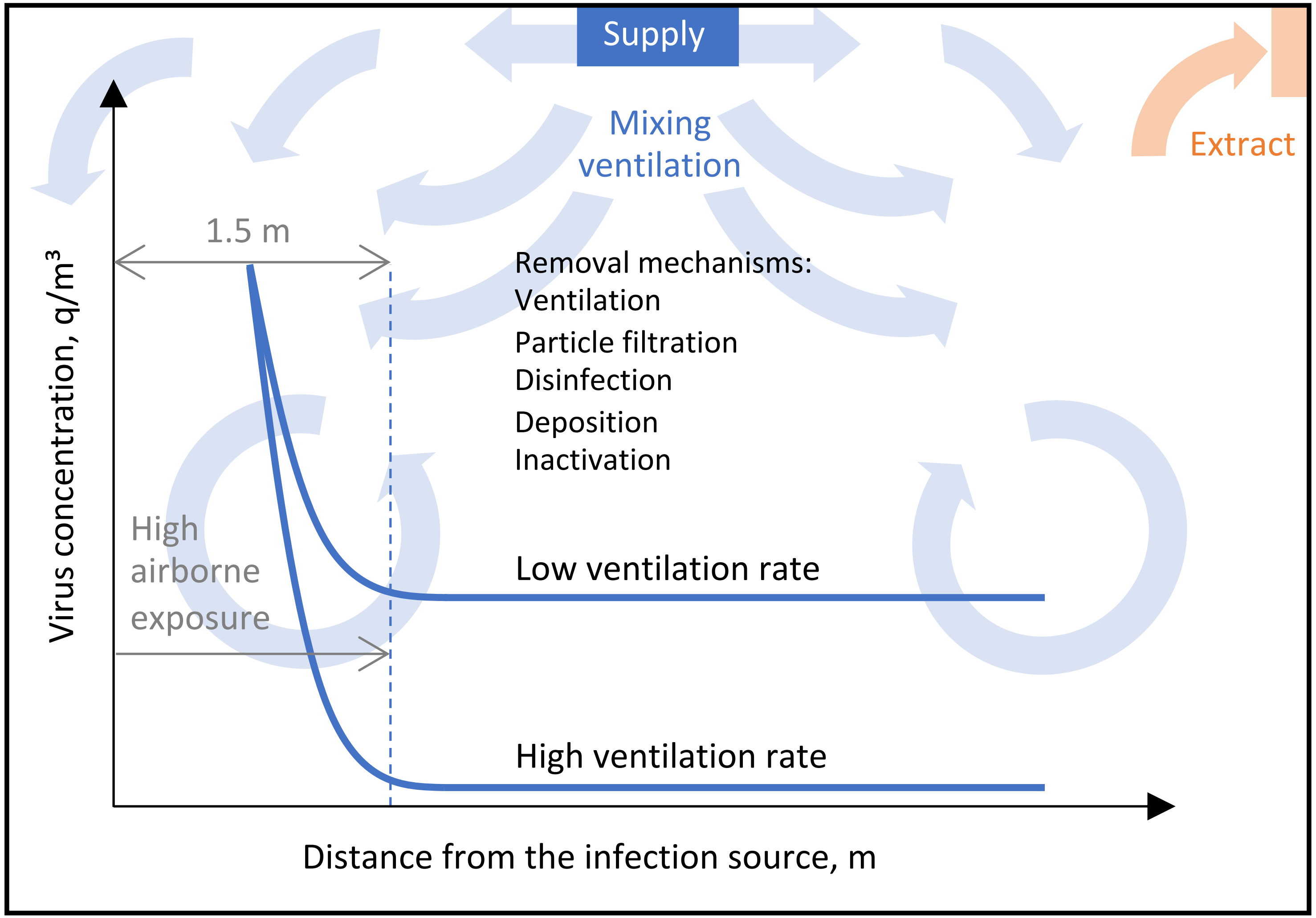
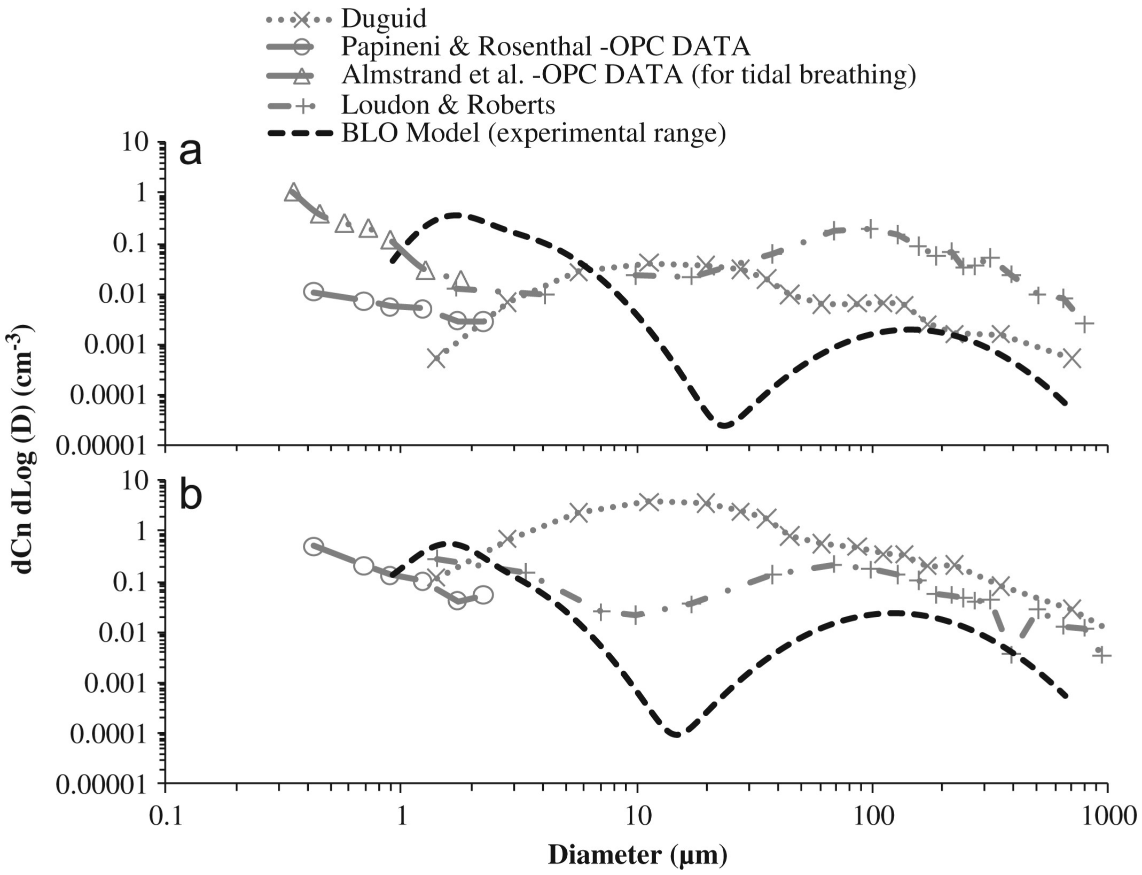
REHVA Task force on targeted ventilation
RoomVent 2024 Workshop 5 Occupant Targeted Ventilation

Fundamentals of airborne transmission control

- 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 **UV**
- **General ventilation** solutions for >1.5 m may be complemented with **personal ventilation** and room partitioning/zoning



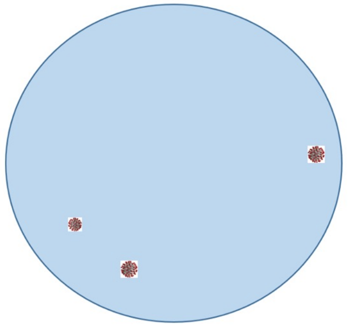
Airborne viruses



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) that are suspended in the air (which means **airborne)**
- Most of expelled droplets are aerosols close to 1 µm, main interest range 1–10 µm
- ePM1 (F8) filters provide capture efficiency of 65-90% for PM1 – already good fine outdoor air filters provide reasonable filtration efficiency for room or return air
- Easy to filtrate with high-capacity air cleaners (2…5 ach)

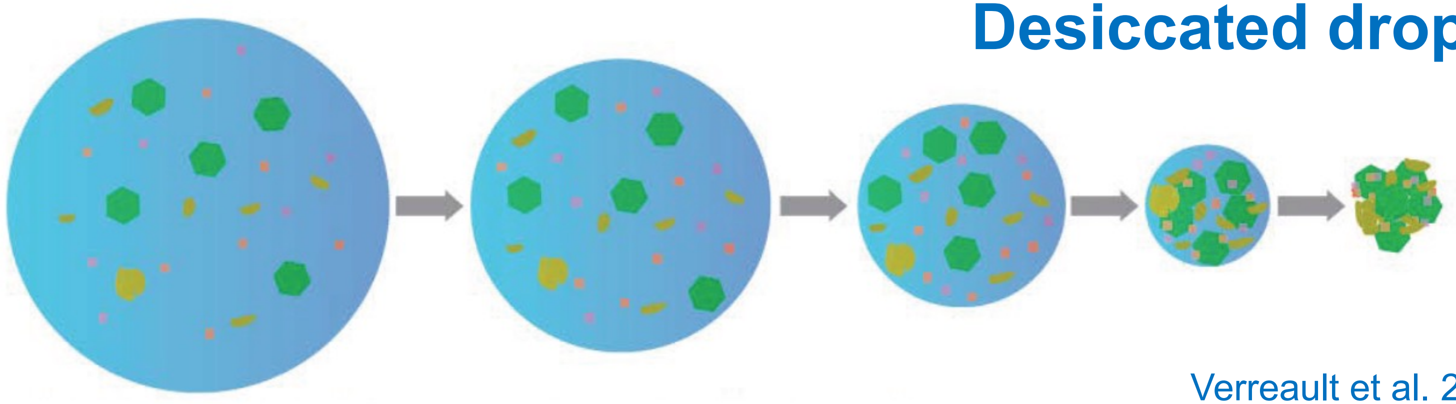


REHVA
Federation of European Heating, Ventilation and Air Conditioning Associations

Criteria for room air cleaners for particulate matter:
https://www.rehva.eu/activities/covid-19-guidance/rehva-covid-19-guidance

Evaporation and desiccation in the air

- Expelled droplets (=liquid particles) evaporate and desiccate in the air so that the final **droplet nuclei** shrink to roughly a half or one-third of the initial diameter



Desiccated droplet nuclei = solid particle

Verreault et al. 2008 https://doi.org/10.1128/mmbr.00002-08

- Droplet desiccation is a fast process; 50 μm droplets desiccate in about two seconds and 10 μm droplets in 0.1 s (desiccated droplets still contain some fluid)
- In indoor air SARS-CoV-2 can remain active up to 3 hours and up to 2-3 days on room surfaces at common indoor conditions – virus decay/inactivation – temperature and RH dependency

Modelling airborne infection risk

- Virus emission = respiratory fluid droplets = solid particles with size distribution
- Short range and **long range transmission**, airborne transmission dominates
- Standard airborne disease transmission Wells-Riley model:
  - the viral load emitted is expressed in terms of the quanta emission rate (quanta/h)
  - one quantum is defined as the dose of airborne droplet nuclei required to cause infection in 63% of susceptible persons
  - the probability of infection (p) is related to the number of quanta inhaled (n)
- Common expressions of Wells-Riley model:

$$p = \frac{N_c}{N_s} = 1 - e^{-n} = 1 - e^{-\frac{IqQ_bD}{Q}} = 1 - e^{-CQ_bD}$$

p probability of infection for a susceptible person (-)
N_c number of disease cases
N_s number of susceptible persons in the room
I number of infectious persons (-)
n number of quanta inhaled (quanta)
q quanta emission rate per infectious person (quanta/(h pers))
Q_b volumetric breathing rate of an occupant (m^3/h)
Q outdoor air ventilation rate for the breathing zone (m^3/h)
D duration of the occupancy (h)
C average quanta concentration in the room (quanta/m^3)

Quanta emission rates = virus emission

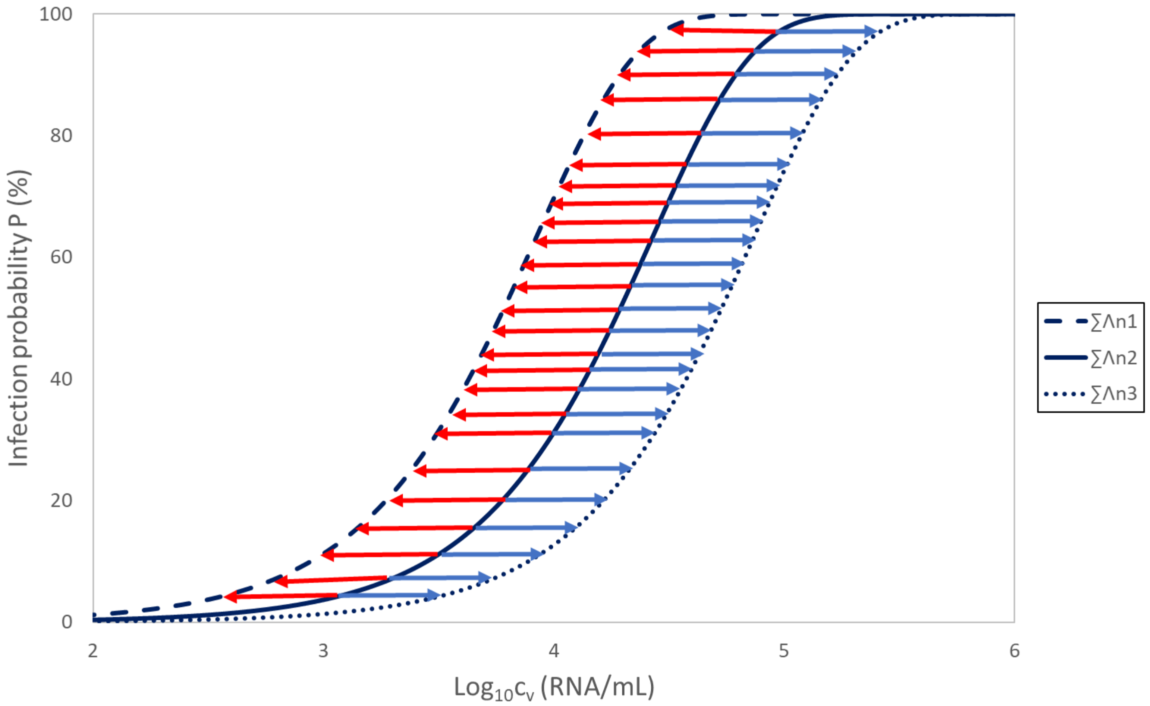
Derivation *quanta/h* from viral RNA:

- size ranges of droplets to calculate dry volume of aerosols per litre of exhaled breath
- viral RNA copies in fine dehydrated aerosols
- the viral load c_v in the sputum $10^7 \dots 10^9 \; \frac{RNA}{mL}$
- quanta-RNA relationship *1 quanta = X RNA copies* needed to calculate the quanta emission rate

$$q = c_v \cdot c_i \cdot V_{exh}$$

c_i – number of viral RNA copies required to infect at least 63.2% of susceptible persons, $\left[\frac{quanta}{RNA}\right]$

V_{exh} – total volume of respiratory fluid exhaled per unit time, [ml/h]



- *P(%) as a function of viral load c_v when changing the total removal mechanism $\sum \lambda_n$*
- *Increasing $\sum \lambda_n$ depicted by blue arrow lines, while decreasing $\sum \lambda_n$ shown by red arrow lines*

Aganovic et al. 2024 https://doi.org/10.1016/j.scitotenv.2024.172278

Wells-Riley or relative risk reduction approach

- High variation in the quanta emission rates complicates the use of WR:
  - Depends on respiratory & physical activities, the viral load and virus strain
  - Probability density function of the quanta emission rate or fixed values of the viral load to be used
- Relative risk reduction (quanta indepenent approach)
  - Define reference scenario with REI =1, REI > 2 indicates high risk
  - Relative Exposure Index (REI) Jones et al. 2021 https://doi.org/10.1016/j.buildenv.2021.107617
  - Relative infection risk parameter H_r, high risk H_r close to 1, low risk H_r < 0.1
    Peng et al. 2021 https://doi.org/10.1021/acs.est.1c06531
- Aganovic et al. 2024 has shown that the risk reduction in the steady state depends only on removal mechanisms before ($\sum \lambda_1$) and after ($\sum \lambda_2$) applying infection control measures:

$$\Delta p_{abs.max} = e^{-\frac{\sum \lambda_1 ln\frac{\sum \lambda_2}{\sum \lambda_1}}{\sum \lambda_2 - \sum \lambda_1}} - e^{-\frac{\sum \lambda_2 ln\frac{\sum \lambda_2}{\lambda_1}}{\sum \lambda_2 - \lambda_1}}$$

Aganovic et al. 2024 https://doi.org/10.1016/j.scitotenv.2024.172278

WELLS-RILEY APPLICATION FOR VENTILATION DESIGN

Pollutant/quanta mass balance:

$$Iq = C_e \lambda_v V + C \lambda_{rest} V$$

Insert ventilation effectiveness:

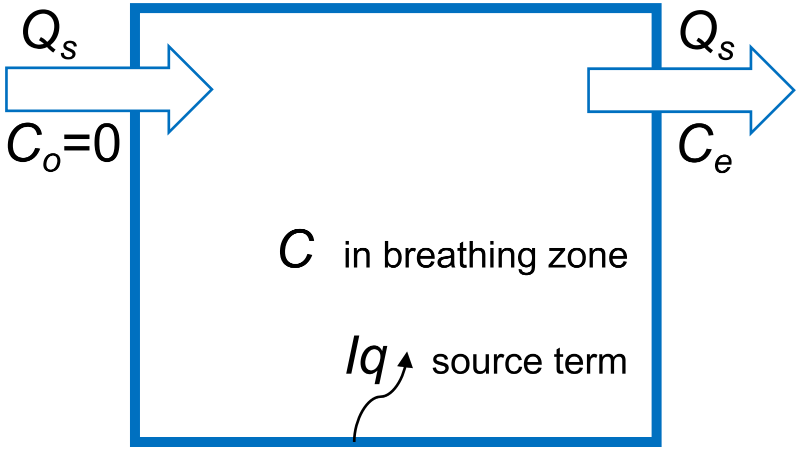
$$\varepsilon_b = \frac{C_e - C_0}{C - C_o}$$

and consider that ventilation rate supplied by the ventilation system $Q_s = \lambda_v V$ (m3/h):

$$C = \frac{Iq}{\varepsilon_b Q_s + \lambda_{rest} V}$$

Probability from Wells-Riley:

$$p = 1 - e^{-\frac{Iq Q_b D}{\varepsilon_b Q_s + \lambda_{rest} V}}$$



C_e quanta concentration in the extract air, quanta/m^3
C average quanta concentration in the breathing zone, quanta/m^3
C_0 quanta concentration in the supply air, quanta/m^3
V volume of the room, m^3
λ_v removal rate due to ventilation, 1/h
λ_{rest} other removal mechanisms than ventilation, 1/h
ε_b ventilation effectiveness (contaminant removal effectiveness), -

Shen et al. 2021 https:// doi.org/10.1016/j.buildenv.2021.107926
Aganovic et al. 2023 https://doi.org/10.1016/j.buildenv.2022.109924

WELLS-RILEY APPLICATION FOR VENTILATION DESIGN

- **Scenario of exposure** must be defined, and **risk assessment model** is to be applied
  - Individual probability ***p*** cannot be used alone, if the target is to limit the spread on population level
  - If the likelihood of infecting others (i.e. the number of infections per unit time) is constant over the pre-symptomatic infectious period, the event reproduction number ***R*** depending on the length of occupancy in a specific space can be calculated

$$R = \frac{pN_s}{I}$$

  - *R* – new disease cases per infectious person (*I* = 1 is the worst case to control *R*)
  - *R* based on pre-symptomatic period of 2.5 days: 9/22.5=0.4 in offices and 2/22.5=0.09 in meeting rooms Kurnitski et al. 2023 https://doi.org/10.1016/j.enbuild.2023.113386 for all possible out-of-home interactions

- For given *R* value, target ventilation rate for the breathing zone ***Q*** can be solved from equation of ***p***:

$$Q = \varepsilon_b Q_s$$

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GENERIC VENTILATION EQUATION

- Previous equations provide relations between *R* (event reproduction number) and *p* (individual probability), and *p* and *Q* (target ventilation rate)
- Assumptions applied: scenario of exposure, risk assessment model and viral load (fixed value, activity dependent)
- In the steady state, it is possible to derive infection-risk based target ventilation rate (fully mixing air distribution):

$$Q = q_q(N-1) - q_r V$$

Q	target ventilation rate (L/s) (sum of outdoor and clean recirculated airflow rate)
q_q	quanta emission specific ventilation rate for occupancy per person, L/(s person)
q_r	removal rate of virus decay, deposition and filtration, L/(s m^3)
N	**the number of persons in the room**
V	**volume of the room, m^3**

- q_q (viral load and risk level) and q_r (removal mechanisms) are virus specific parameters
- This equation may also be used to calculate allowed *N* at given ventilation rate

TAL TECH

Kurnitski et al. 2023 https://doi.org/10.1016/j.enbuild.2023.113386

Generic ventilation equation - proposed implementation in EN 16798-1 revision

- Tabulated values for virus specific ventilation parameters q_q and q_r

Space category	q_q, L/(s person)	q_r, L/(s m³)
Classroom	10	$0.24 + k_f/3.6$
Office	23	$0.24 + k_f/3.6$
Assembly hall	30	$0.24 + k_f/3.6$
Meeting room	40	$0.24 + k_f/3.6$
Restaurant	40	$0.24 + k_f/3.6$
Gym	70	$0.24 + k_f/3.6$

$$Q = q_q(N-1) - q_r V$$

- In the case of no air cleaner, filtration removal rate (1/h) $k_f = 0$

$$k_f = \frac{Q_f \eta_f}{V}$$

- There are no IEQ categories in this case
- Tabulated values are informative (Annex B) and may be changed in the national annex

Follows proposal by Nordic Ventilation Group and REHVA

Target outdoor air ventilation rates *Q* (L/s) are calculated using the number of persons in room *N* (-) and the room volume *V* (m³)

Space category	Ventilation rate, L/s
Classroom	Q = 10(N-1) – 0.24V
Office	Q = 23(N-1) – 0.24V
Assembly hall	Q = 30(N-1) – 0.24V
Meeting room	Q = 40(N-1) – 0.24V
Restaurant	Q = 40(N-1) – 0.24V
Gym	Q = 70(N-1) – 0.24V

Design ventilation rate supplied by the ventilation system:

$$Q_s = \frac{Q}{\varepsilon_b}$$

ε_b point source ventilation effectiveness for the breathing zone (-)

https://www.rehva.eu/activities/post-covid-ventilation

HOW MUCH VENTILATION IS NEEDED: NVG, REHVA, ASHRAE, WHO, LANCET COVID-19 COMMISSION, SCIENCE...

- Target ventilation (non-infectious) rate for infection risk control = outdoor air + particle filtered air + disinfected air

Organisation	Target ventilation rate
WHO	10 L/s per person
Lancet COVID-19 Commission	10, 14 and > 14 L/s per person, corresponding to 4, 6 and > 6 ach as good, better, and best ventilation levels
ASHRAE Standard 241–2023	20 and 15 L/s per person in classrooms and offices
Science Standards	14 L/s per person
NVG, REHVA, EN 16798-1 revision proposal	Depends on number of persons and room volume

Proposed parameter levels

Values may be adjusted to reflect local circumstances and priorities.

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CO_2, ppm	800 (absolute value)$^{(ii)}$	threshold
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Ventilation, liters/s per person	14$^{(v)}$	When the space is occupied

(i) 24-hour level from (*3*). (ii) When 100% of air delivered to the space is outdoor air, assuming outdoor CO_2 concentration is 450 ppm; based on classroom scenario (see SM). (iii) Delta is the difference between the actual CO_2 concentration and the CO_2 concentration in the supply air. (iv) 8-hour averaging time, from (*15*). (v) Clean air supply rate in the breathing zone; see (*12*). At 25°C and 1 atm for CO 1 ppb = 1.15 µg/m³. Threshold is the concentration level of CO_2 that must not be exceeded.

DOI: 10.1126/science.adl0677

HOW MUCH VENTILATION IS NEEDED: NVG, REHVA, ASHRAE, WHO, LANCET COVID-19 COMMISSION, SCIENCE…

- Model classroom with 26 persons, 50 m^2 and 150 m^3
- Model open office with 6 persons, 50 m^2 and 135 m^3

	Classroom L/s p / ach	Classroom q_q, L/s p	Office L/s p / ach	Office q_q, L/s p
WHO	10 / 6.2	12	10 / 1.6	18.5
ASHRAE Standard 241–2023	20 / 12.5	22	15 / 2.4	24.5
Science Standards	14 / 8.7	16	14 / 2.2	23
NVG, REHVA, EN 16798-1 revision	8.2 / 5.1	10	14 / 2.2	23

- q_q parameter is derived from: $Q = q_q(N-1) - q_r V$
- (while q_r = 0.24, q_q can be derived based on quanta or relative risk reduction)

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HEALTH VS. COMFORT – EXISTING EN 16798-1:2019

Airborne transmission

Target ventilation (non-infectious) rate for infection risk control = **outdoor air + particle filtered air + disinfected air:**

$$Q = q_q(N-1) - q_r V$$

Q = total ventilation rate for the breathing zone, L/s
N = design value for the number of the persons in the room
V = room volume, m^3
q_q = quanta specific ventilation rate, L/s person
q_r = removal rate of virus L/(s m^3)

Perceived air quality

Target ventilation rate = **outdoor air** (if no gas phase air cleaning):

$$q_{tot} = nq_p + A_R q_B$$

q_{tot} = total ventilation rate for the breathing zone, L/s
n = design value for the number of the persons in the room
A_R = room floor area, m^2

For low polluting materials:
q_p= 7 L/s person, q_B= 0.7 L/s per floor area in Category II
q_p= 10 L/s person, q_B= 1 L/s per floor area in Category I

	Classroom		Office	
	L/s pers.	ach	L/s pers.	ach
EN 16798-1, Cat II	**8.3**	**5.2**	**13**	**2.1**
EN 16798-1, Cat I	12	7.4	18	2.9
Science Standards	14	8.7	**14**	**2.2**
NVG, REHVA, EN 16798-1 revision	**8.2**	**5.1**	**14**	**2.2**

Higher ventilation rates in meeting rooms, restaurants and gyms – reduce occupancy

TAL TECH

FROM TARGET VENTILATION RATE (FULLY MIXED) TO DESIGN VENTILATION RATE SUPPLIED BY THE VENTILATION SYSTEM

- Design ventilation rate supplied by the **actual air distribution system** Q_s:

$$Q_s = \frac{Q}{\varepsilon_b}$$

- **Ventilation effectiveness ε_b for the breathing zone** as defined in EN 16798-3:2017, contaminant removal effectiveness in Rehva Guidebook No 2
- ε_b can be calculated as an average of two or more tracer gas measurements with different point source locations (or CFD simulations)

$$\varepsilon_b^j = \frac{C_{je} - C_{jo}}{C_{jb} - C_{jo}}$$

$$\varepsilon_b = \frac{\sum_j \varepsilon_b^j}{m}$$

where

ε_b^j point source ventilation effectiveness of measurement *j*

ε_b point source ventilation effectiveness for the breathing zone

C_{je} measurement *j* concentration in the extract air duct

C_{jb} measurement *j* concentration at the breathing level

C_{j0} concentration in the supply air

m total number of measurements with different point source locations

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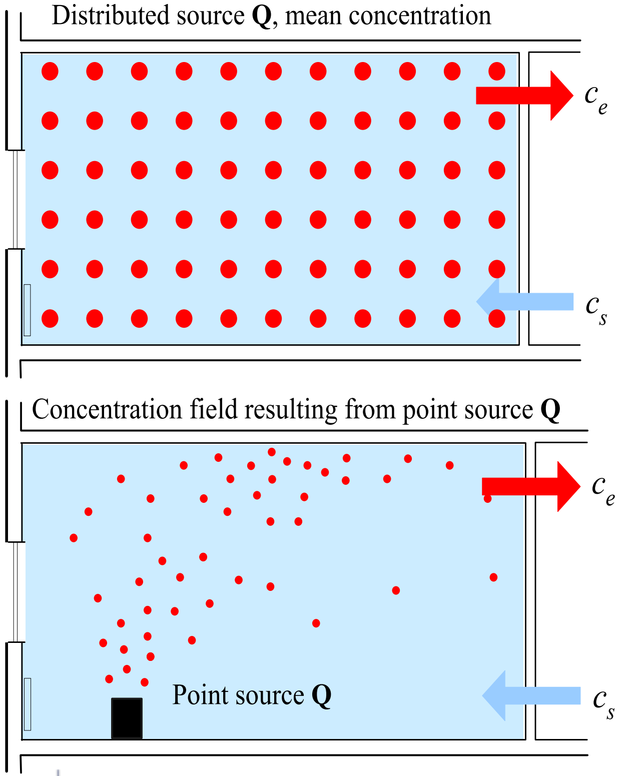
Calculation example: https://www.rehva.eu/activities/post-covid-ventilation

NOMENCLATURE OF VENTILATION EFFECTIVENESS

- Contaminant removal effectiveness
- Point source = infector



VENTILATION EFFECTIVENESS
includes

A
Indices representing the ability of a system to exchange the air in the room

- air change efficiency, ε^a
- local air change index, ε_P^a

B
Indices representing the ability of a system to remove air-borne contaminants

- contaminant removal effectiveness (CRE), ε^c
- local air quality index, ε_P^c

REHVA Guidebook No 2

(similar formulations of ε as dilution ratio, intake fraction, personal exposure with similar purpose)

VENTILATION EFFECTIVENESS

- Existing values in the literature do not mostly apply because measured with distributed source (=normal occupancy)
- To be measured with the point source (=infector)

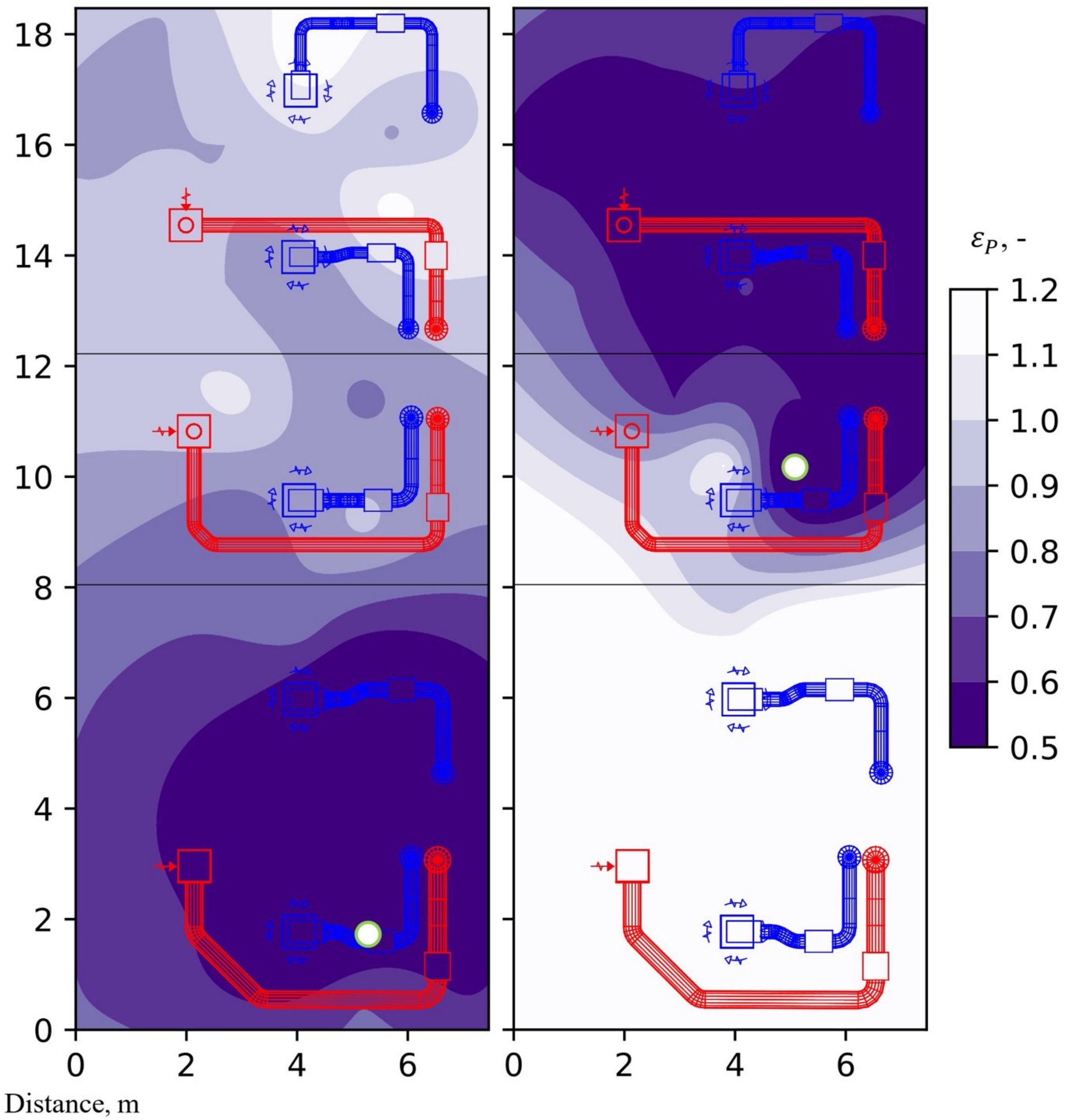
$$Q_s = \frac{Q}{\varepsilon_b}$$

- ε_b can be calculated from **local air quality index** ε_P values:

$$\varepsilon_{P,i} = \frac{C_e - C_o}{C_i - C_o}$$

$$\varepsilon_b^j = \frac{1}{\frac{\sum_{i=1}^{k}\left(\frac{1}{\varepsilon_{P,i}}\right)}{k}}$$

- In fully mixed conditions: C_e (in extract) = C (in all room points) ε_P = 1 and ε_b =1



Large teaching space of 130 m² with 4 L/(s m²) ventilation: ε_b^1=0.76 (left) and ε_b^2=0.77 (right), the average value of two measurements ε_b=0.76

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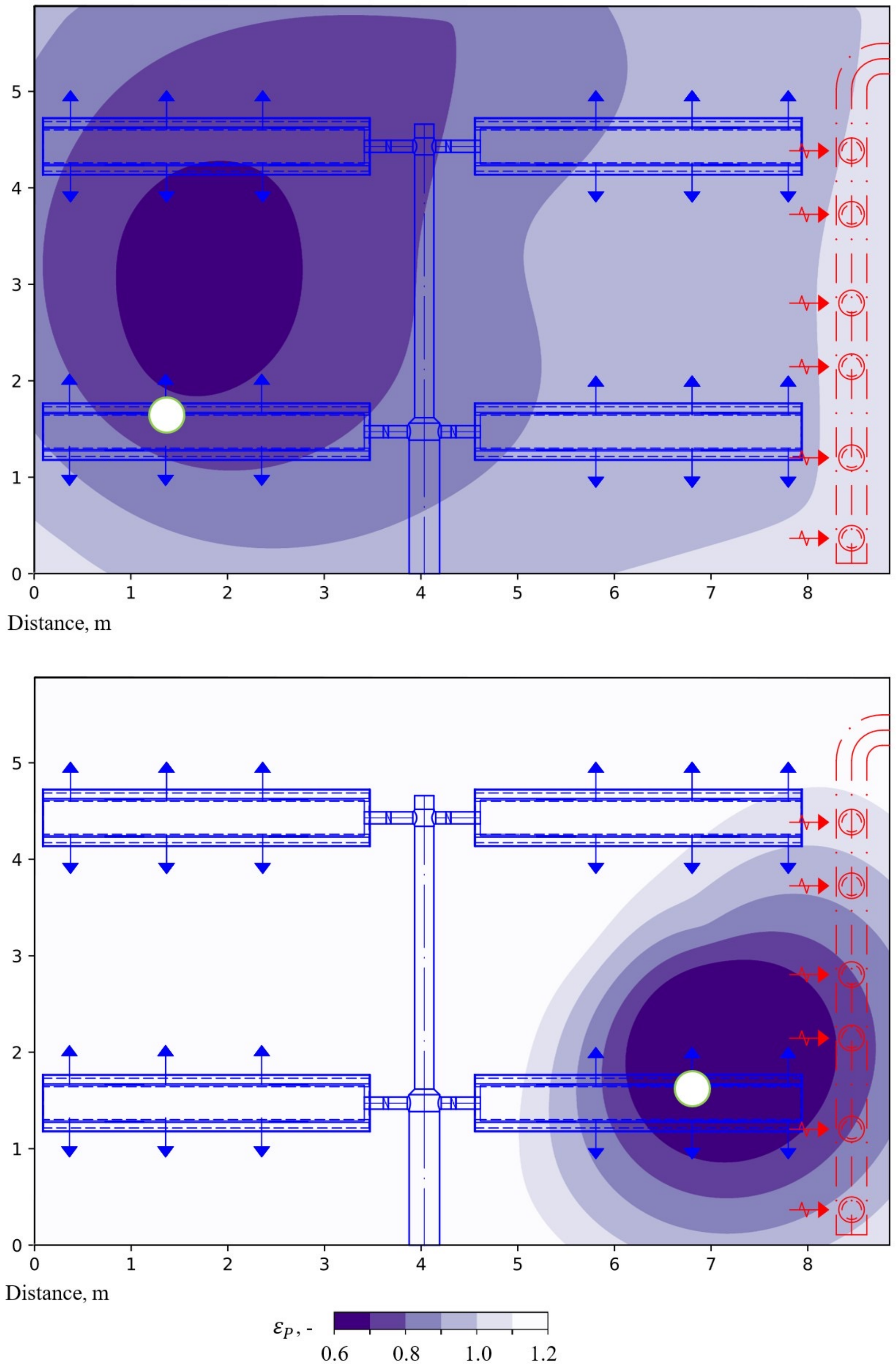
VENTILATION EFFECTIVENESS

- Example of tracer gas measurement in the meeting room of 52.5 m² with active chilled beams and 3.0 L/(s m²) ventilation
- Typical extract location in one side
- Concentrations/ventilation effectiveness depends on the source location, ε_b^j=0.77-1.37 and ε_b=1.00

➢ Mixing ventilation is not necessarily mixing ventilation with the point emission source



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LARGE SPACES

- Open plan office of 257 m^2, 2.3 L/s m^2
- Tracer gas forms local zones – not well mixed, low ε_b values
- Can still be treated/measured as one space:
  - Upper figure $\varepsilon_b^1 = 0.34$
  - Lower figure $\varepsilon_b^2 = 0.64$
  - Average $\varepsilon_b = 0.49$
- Air cleaners may be effective

Kilpeläinen et al. RoomVent 2024

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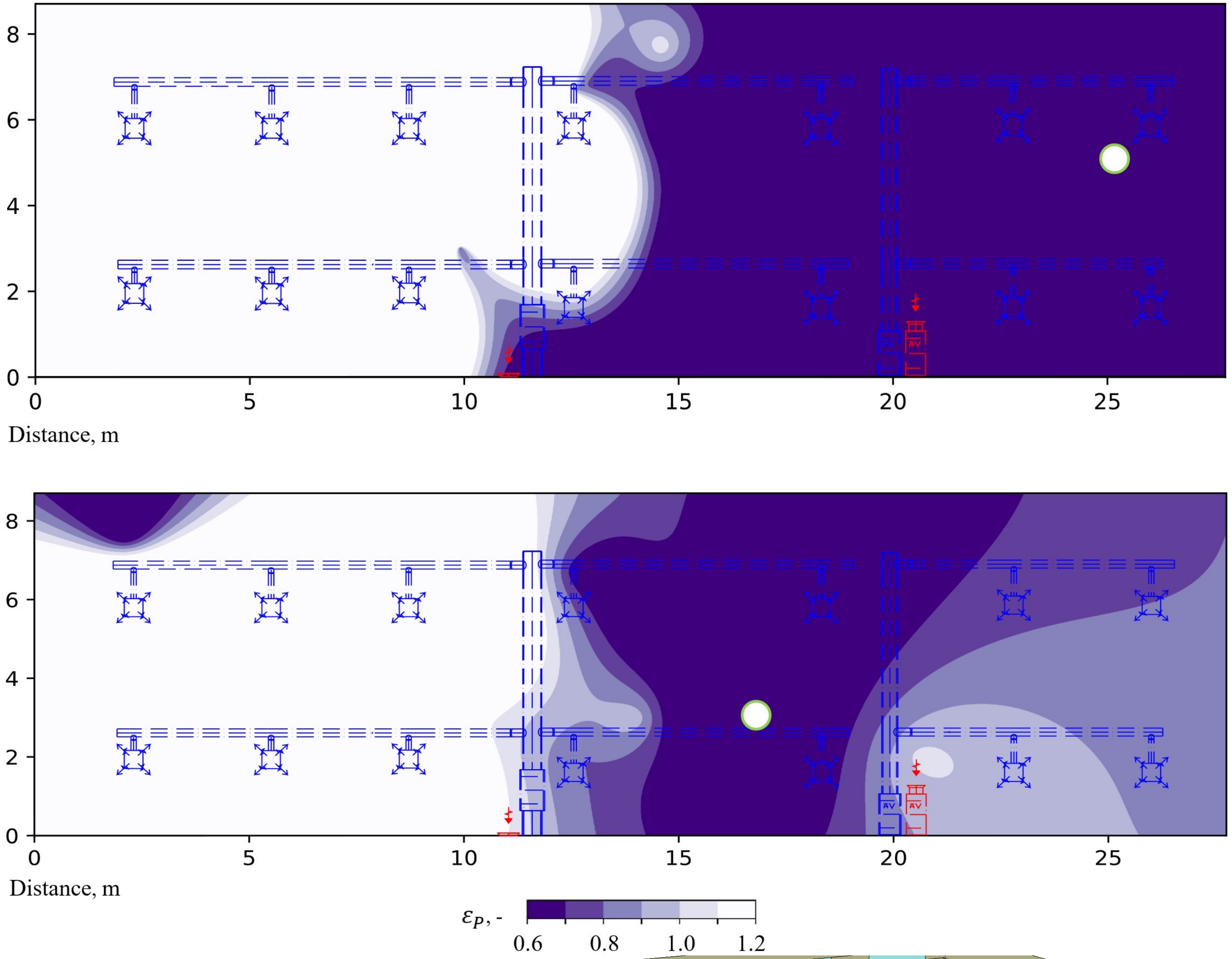
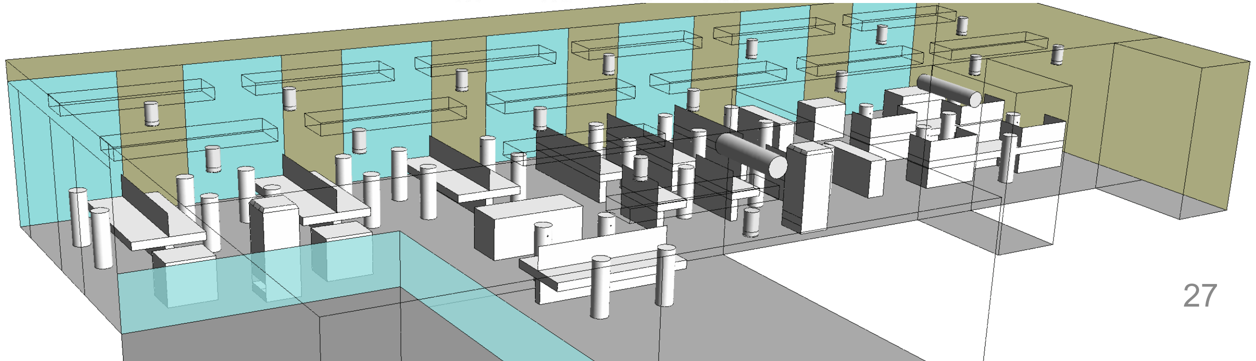
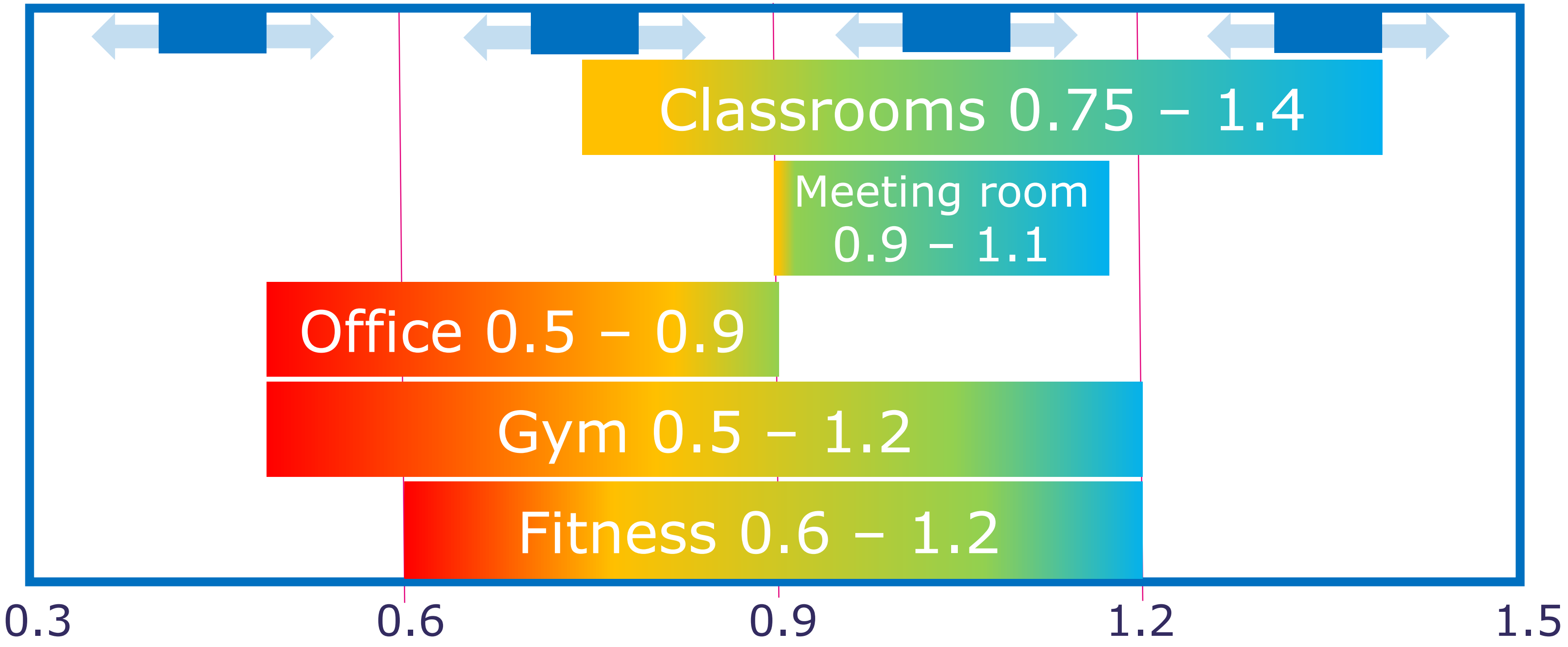




SOME MEASURED VALUES OF ε_b



- Rooms with mixing ventilation designed for distributed source (before COVID)
- Modern or renovated buildings with ceiling air distribution + some mock-up
- ➢ Large variation indicates good potential to improve air distribution

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RoomVent 2024 papers: Mikola et al., Ejaz et al., Kilpeläinen et al.
Kurnitski et al. 2023 https://doi.org/10.1016/j.enbuild.2023.113386

MORE RESEARCH ON ADVANCED AIR DISTRIBUTION NEEDED

$t_{room} - t_{supply} \approx 4^{\circ}C$; 240 l/s

Example of classroom ventilation renovation solution mock-up

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CONCLUSIONS

- COVID changed basic understanding about virus spread and building ventilation
- Infection risk-based ventilation design methods are developing – the aim is not to eliminate, but considerably reduce the infection risk in shared indoor spaces
- EN 16798-1 revision proposes normative but selected-by-the-client design method for airborne transmission – can be used for reverse engineering to calculate the max occupancy for epidemic periods at given ventilation rate
- Stresses the importance of ventilation effectiveness: to handle the point source / to improve the air distribution to reduce ventilation rates
- In classrooms and offices, infection risk-based ventilation rates mostly do not exceed Category I ventilation rates, ranging in classrooms 8-13 L/s per person
- In meeting rooms, restaurants and gyms, infection-risk based ventilation rates are remarkably high, indicating that feasible ventilation design would suggest to reduce occupancy and to use advanced air distribution

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