# CLAIRE

# Congres 2024

## On the efficacy of indoor air cleaners

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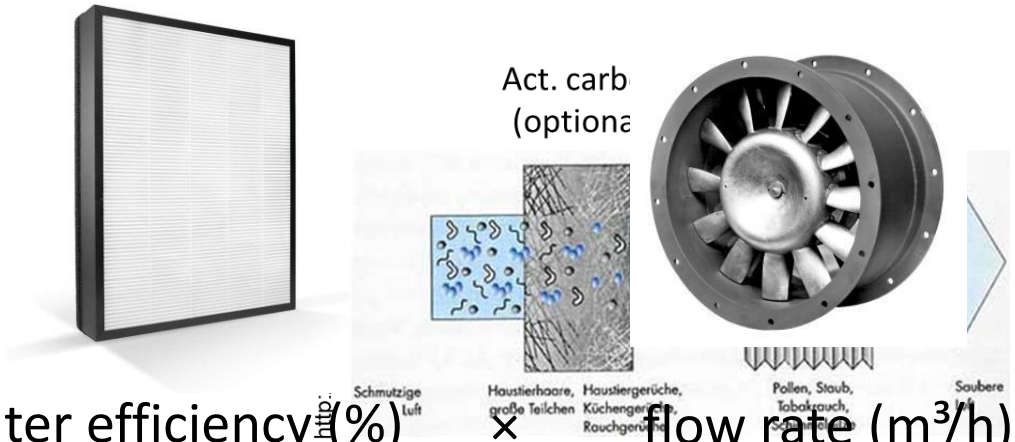
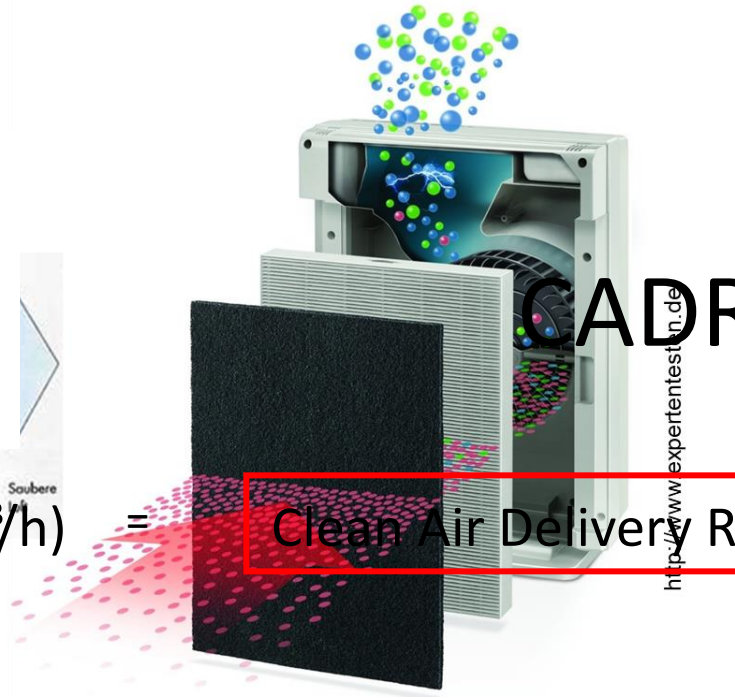
5 Juni

# Air cleaners

- Indoor air cleaners are widely used to improve indoor air quality
- Promoted during pandemic to reduce infection risks
- Clean Air Delivery Rate (CADR) used to rate the performance




CADR

filter efficiency (%) × flow rate (m³/h) = Clean Air Delivery Rate (CADR) (m³/h)

# CADR vs. efficiency

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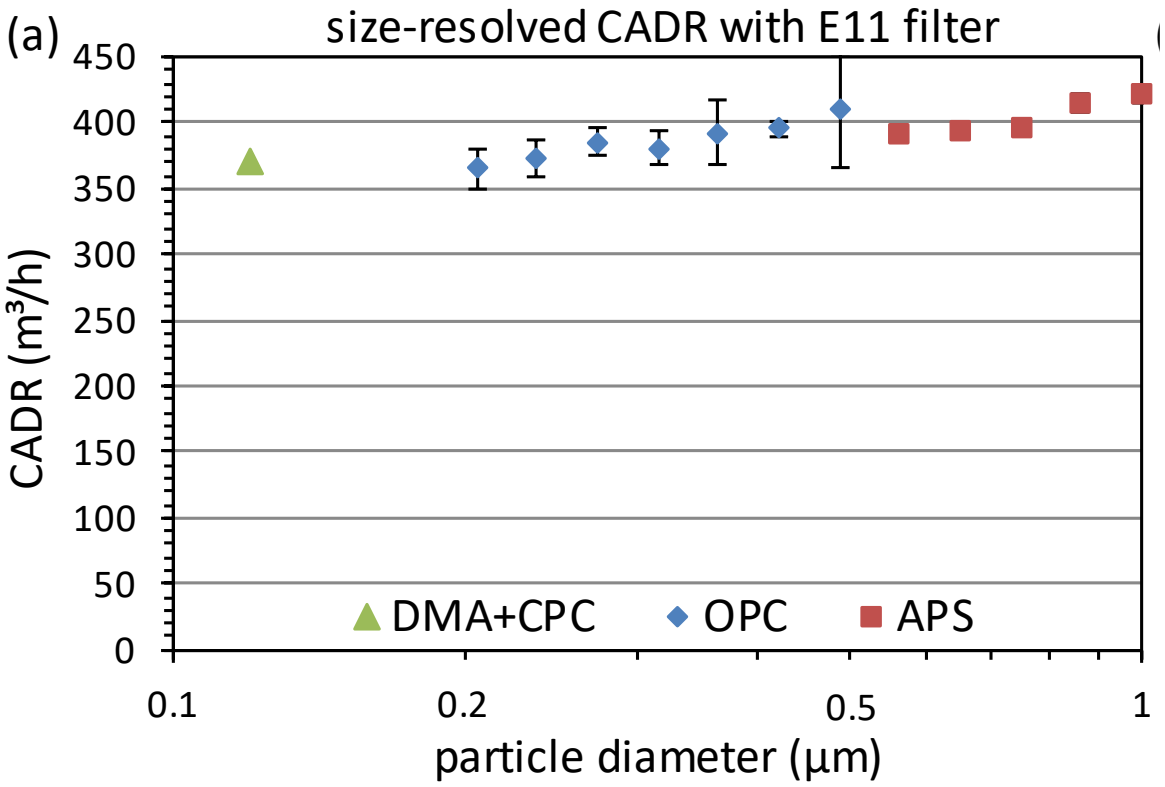


Schumacher et al., *Atmosphere* **13**: 1538, 2022

# Filter efficiency

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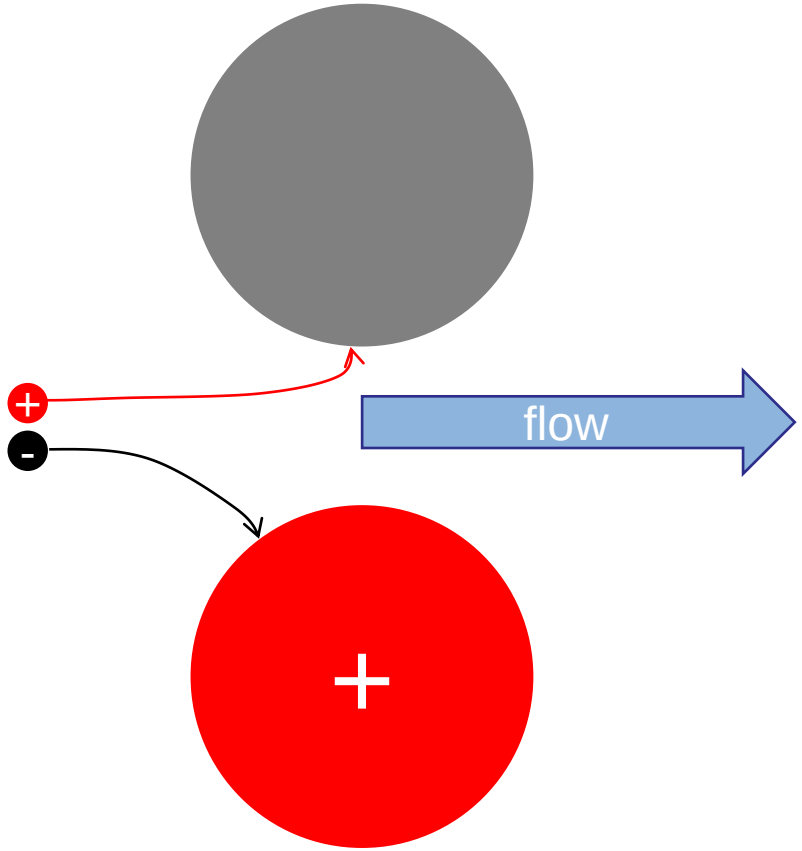
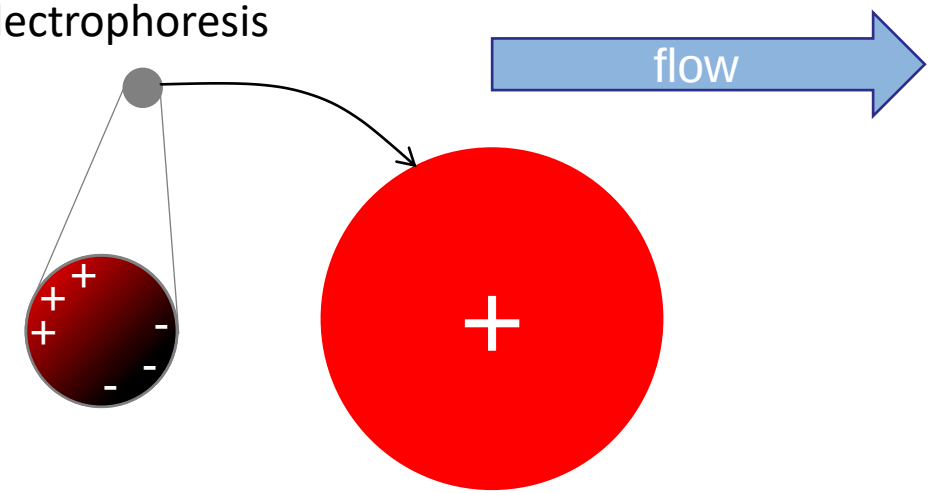
Most household air cleaners use electret filters

Electrophoresis

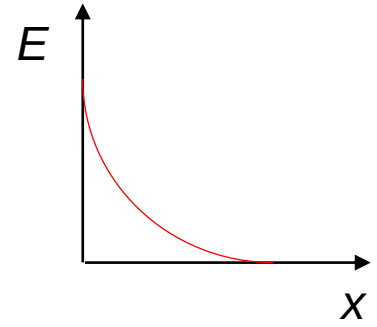



Most effective for small (charged) particles

Dielectrophoresis




Most effective for $d_p$ > 0.3 µm



# Filter efficiency

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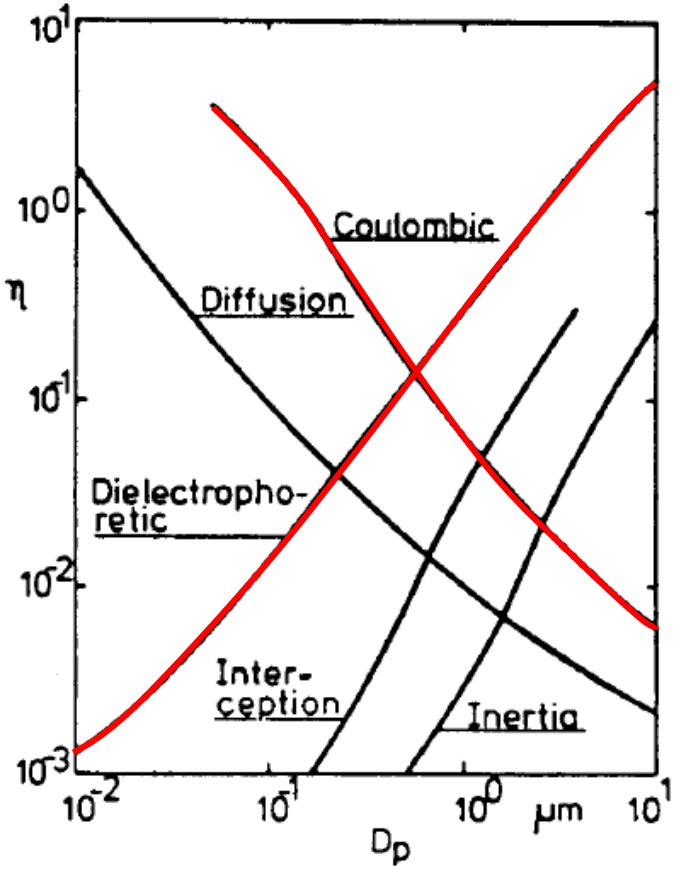
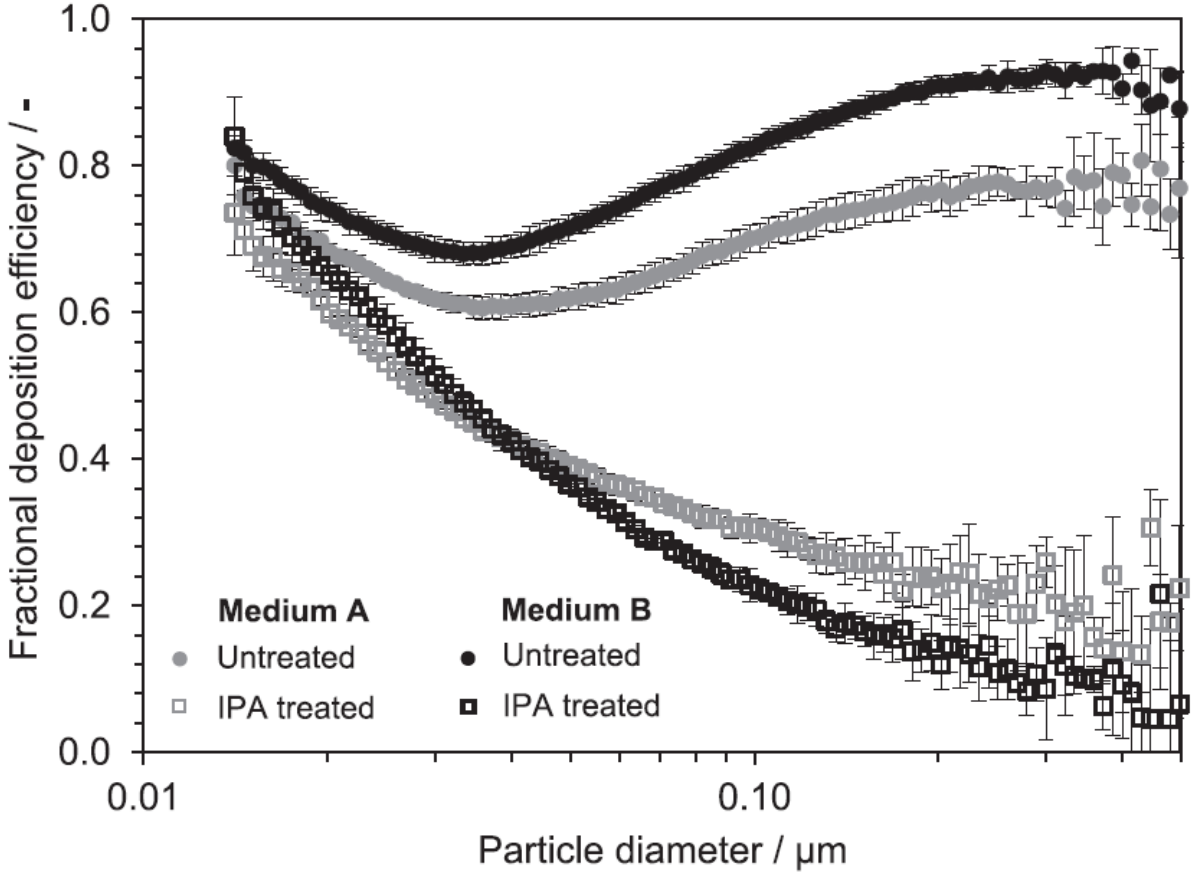



$Q = 0{,}6 \times 10^{-10}$ C/m
$q = 1{,}6 \times 10^{-19}$ C
$D_F = 5\,\mu m$
$\alpha = 0{,}03$
$v_a = 2$ cm/s

Lathrache and Fissan (1987): *Filtr. Separ.* **9/10 1987**: 418-422




Charged

Uncharged

Kerner et al., *Separ. Pur. Technol.* **239**: 116548, 2020

# Filter aging

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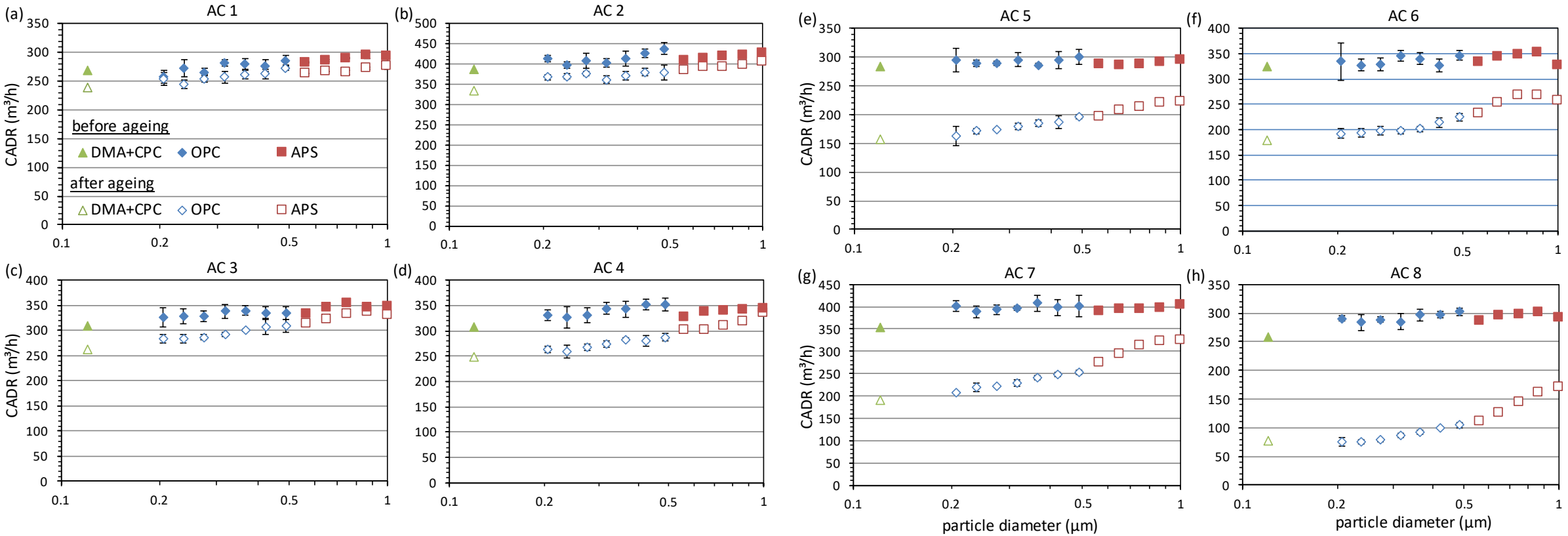
Aging with smoke from 100 cigarettes (corresponds to ~3 g) in 3 m³ chamber


Schumacher et al., *Atmosphere* **13**: 1538, 2022

# Scenarios

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Decay of particle concentration, after air cleaner switched on

$$C(t) = C_0 \cdot e^{-k \cdot t}$$

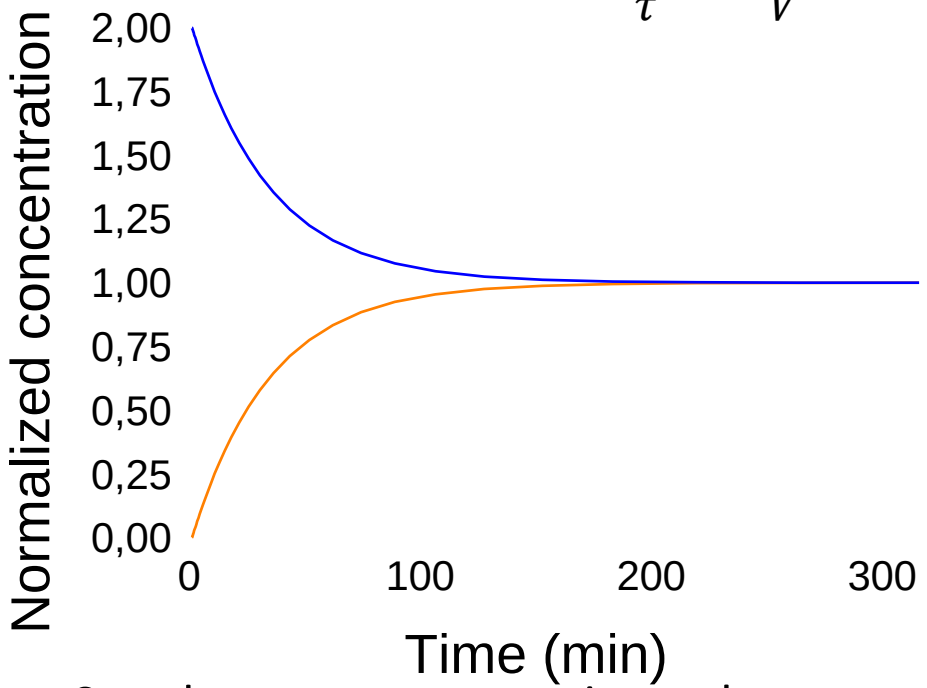
Increase of concentration in room with active source

$$C(t) = \frac{\dot{S}_0}{CADR}\left(1 - e^{-kt}\right)$$

High initial concentration, with active source

$$C(t) = \frac{\dot{S}_0}{CADR}\left(1 - e^{-kt}\right) + C_0 \cdot e^{-kt}$$

$$k = \frac{1}{\tau} = \frac{CADR}{V}$$




- Steady state concentration only dependent on source strength and CADR, not on room volume
- Room volume determines the time to reach steady state concentration

Schumacher et al., *Gefahrstoffe Reinh. Luft* **81**: 16-28, 2021

# Distribution in room

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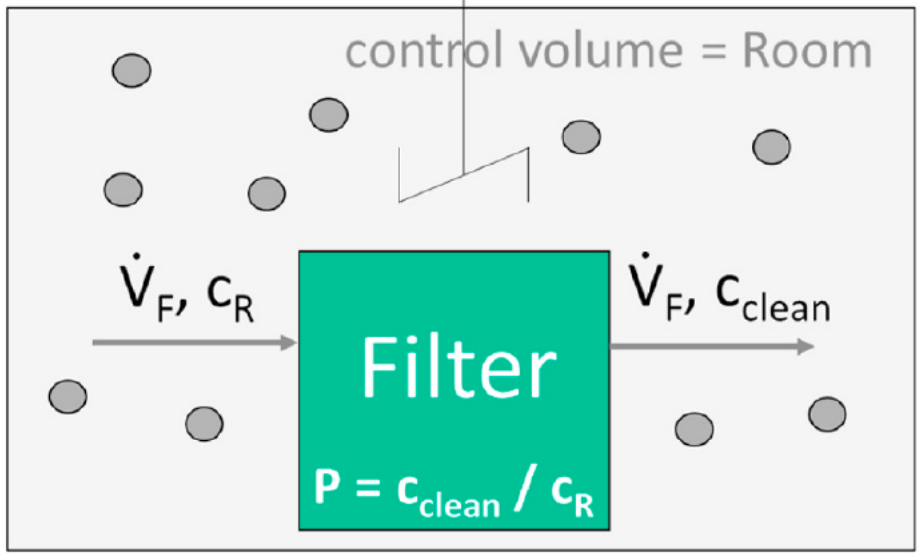
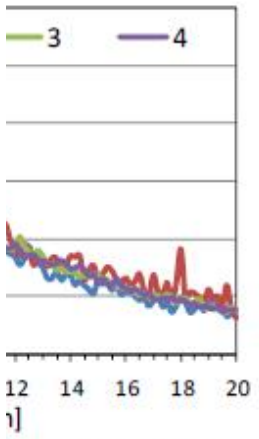
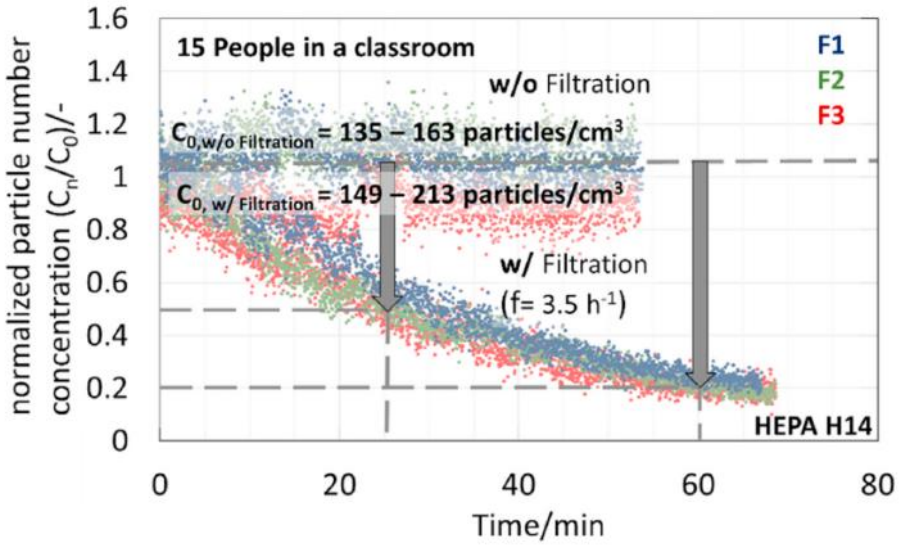
Cleaned air homogeneously mixed in entire room

➔ Like in stirred tank reactor




Szabadi et al., *J. Aerosol Sci.* **160**: 105906, 2022

Szabadi et al., *J. Aerosol Sci.* **160**: 105906, 2022

# Open plan office

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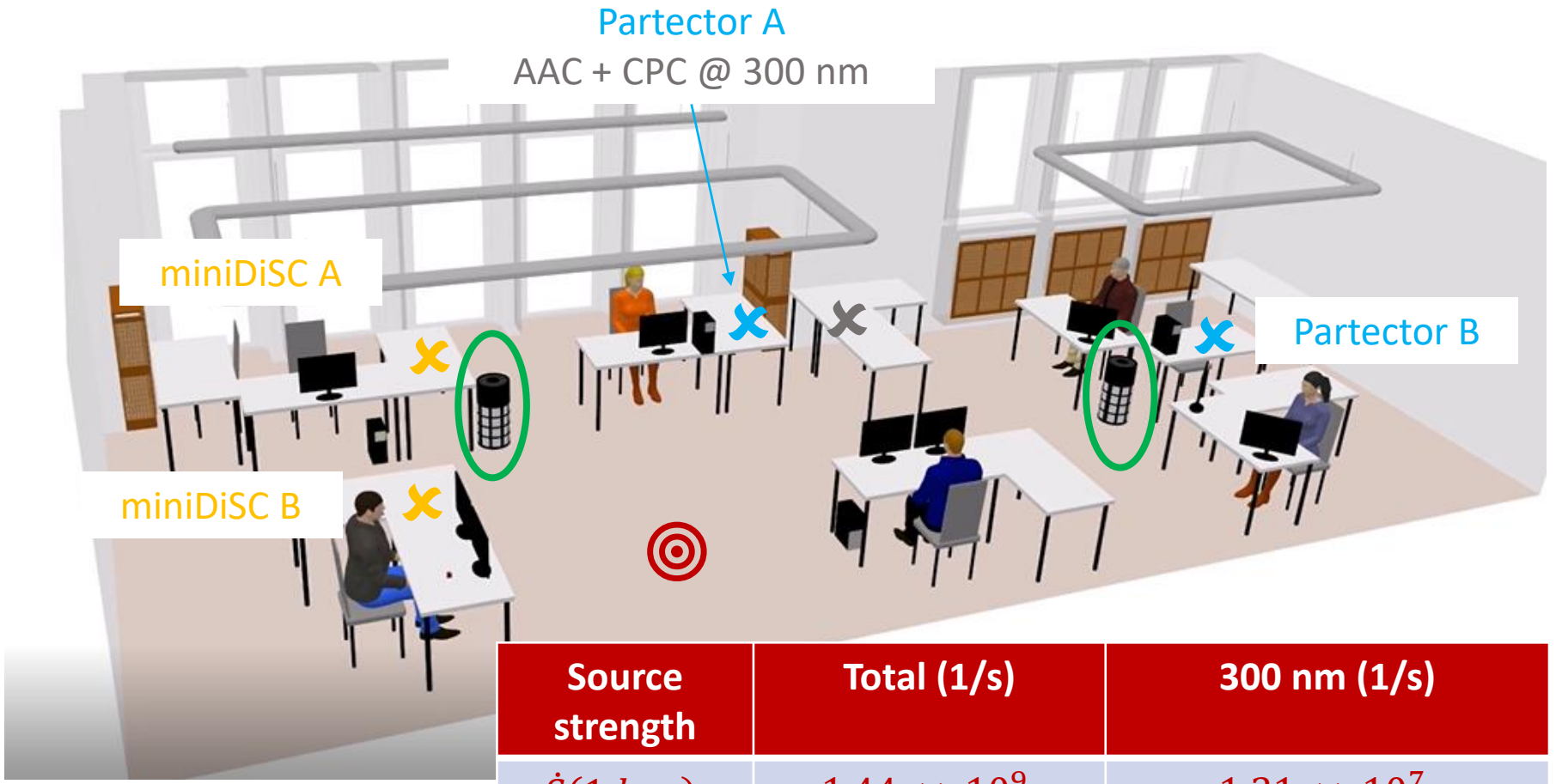
Area: 95.47 m²
Volume: 311.25 m³




| Source strength | Total (1/s) | 300 nm (1/s) |
|---|---|---|
| $\dot{S}(1\ bar)$ | $1.44 \times 10^9$ | $1.31 \times 10^7$ |
| $\dot{S}(3\ bar)$ | $8.66 \times 10^9$ | $9.27 \times 10^7$ |

- 6 desks
- 2 air cleaners (Duux tube, 550 m³/h each, max. ~ 3.5 ACH)
- Measurements with
  2x partector 2
  2x miniDiSC
  AAC+CPC @ 300 nm
- Aerosol generator AGK 20 1 or 3 ba

In collaboration with DASSAULT SYSTEMES

# Source and sink

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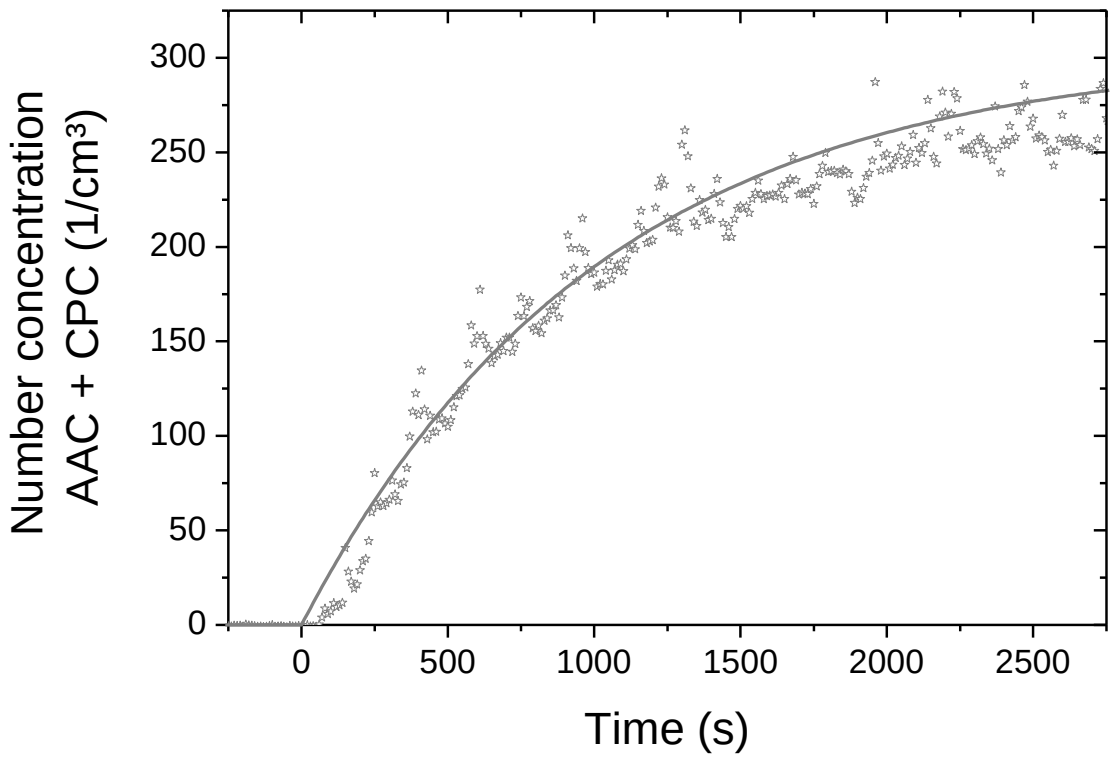
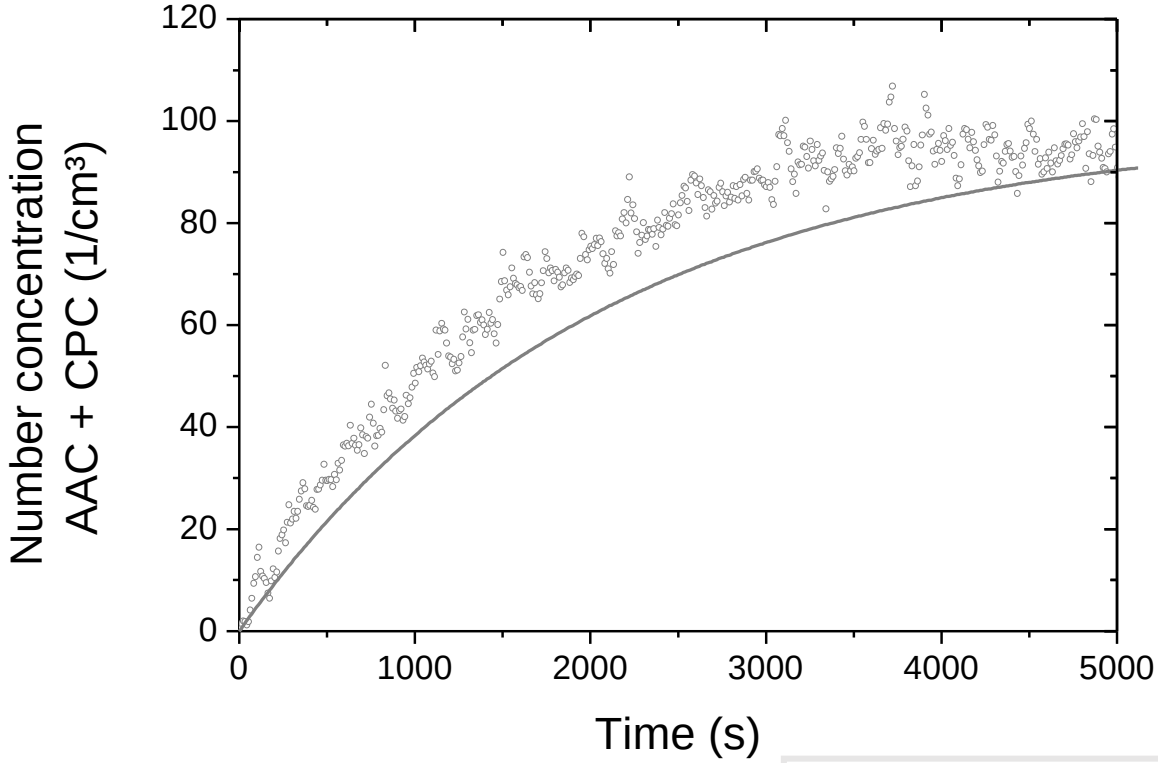
Room initially particle-free

2 air cleaners, generator @ 3 bar




1 air cleaner, generator @ 1 bar




Quintero et al., *Atmosphere* **13**: 2032, 2022

# Source and sink

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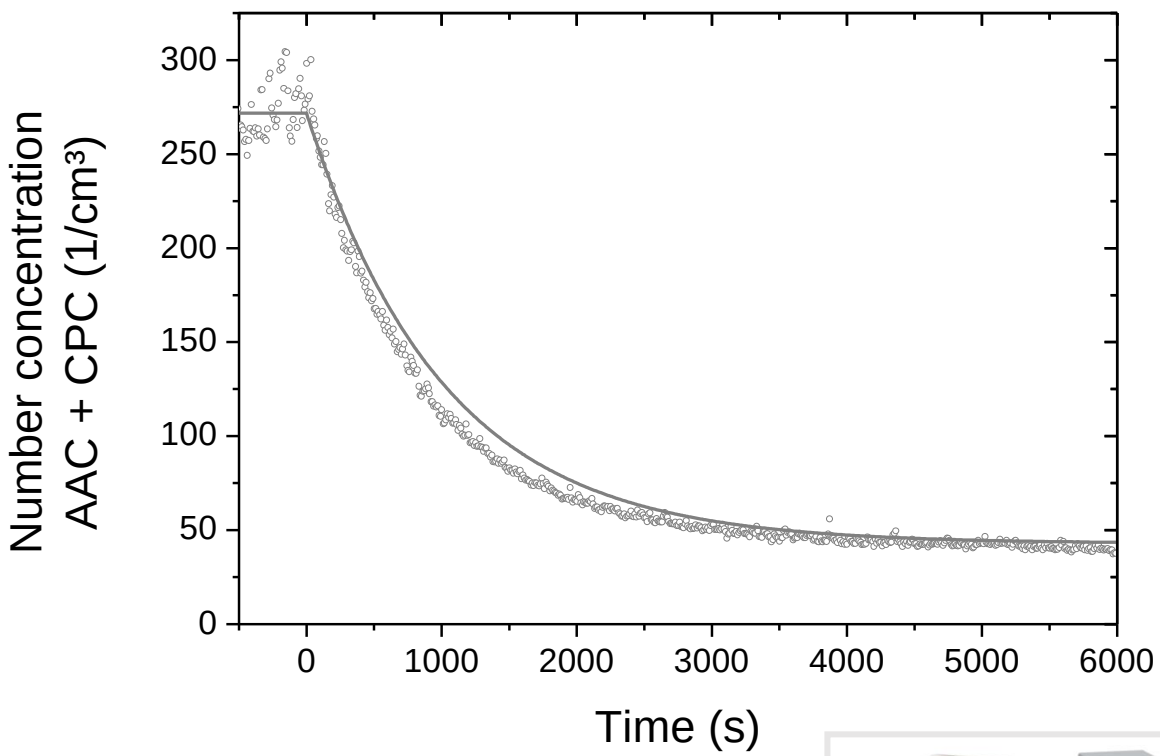
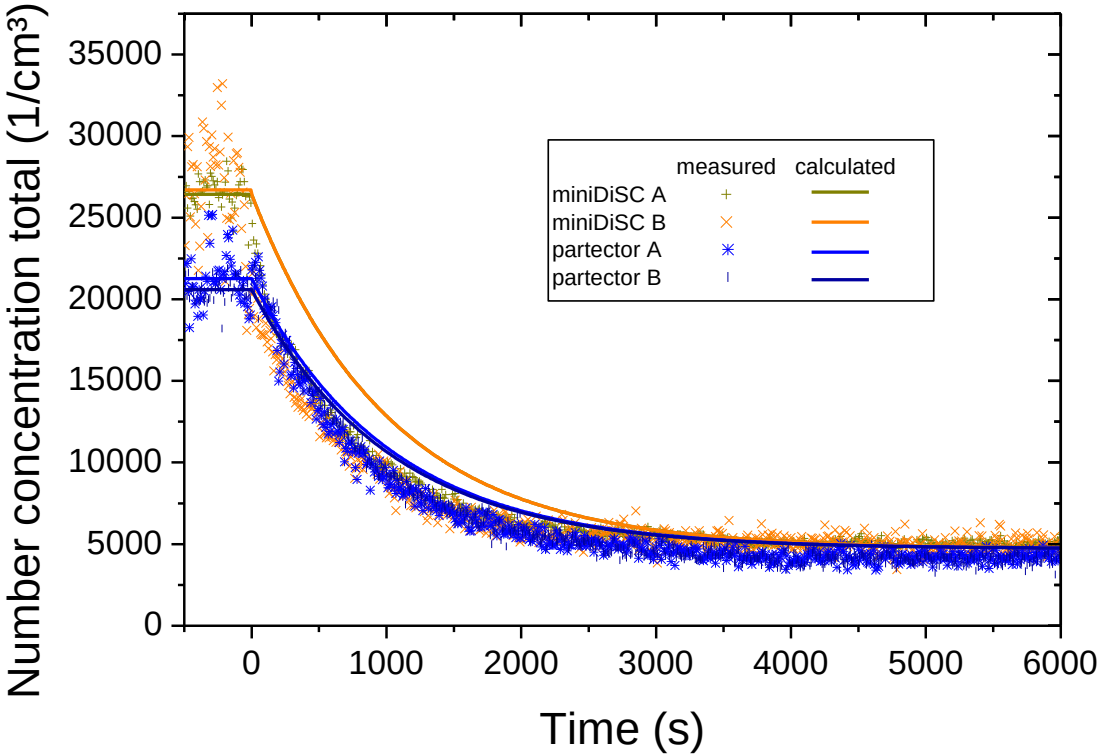
Room air initially contaminated

2 air cleaners, generator @ 1 bar




Quintero et al., *Atmosphere* **13**: 2032, 2022

# Meeting room

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Area: 22.8 m²
Volume: 62.7 m³

Duux tube

Nominal CADR: 550 m³/h

Measured CADR:

Level 1: 100 m³/h

Level 2: 280 m³/h

Level 3: 540 m³/h

# Meeting room

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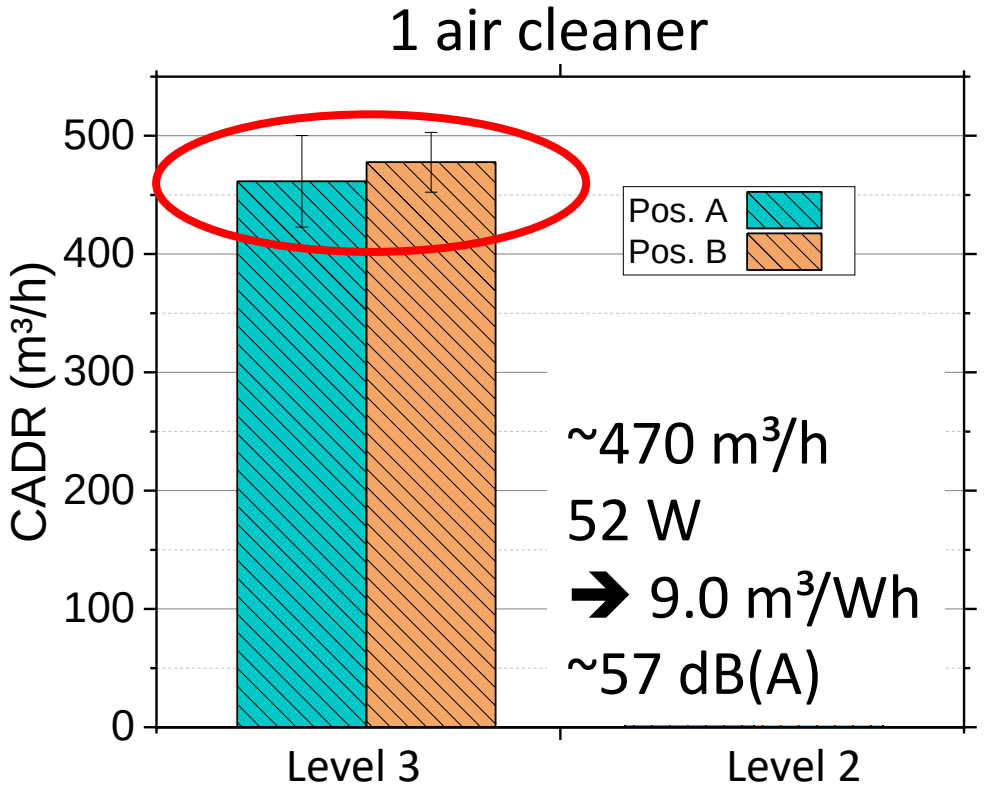


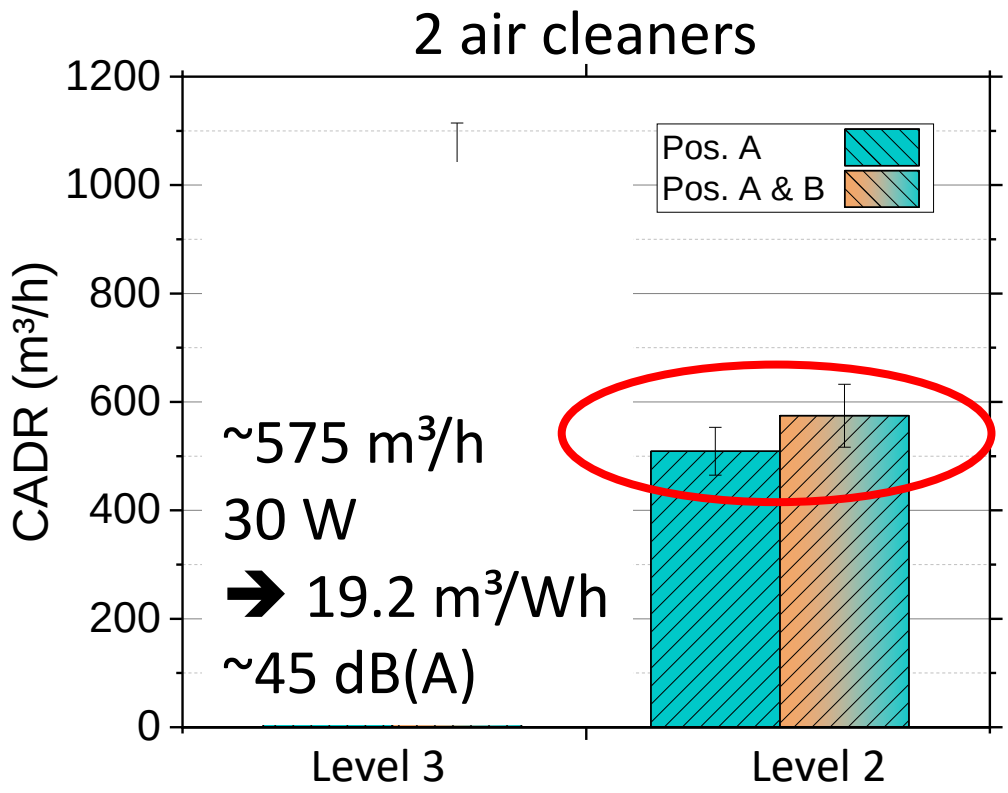



➔ It can be advantageous to use multiple air cleaners at lower level

# Airing vs. air cleaner

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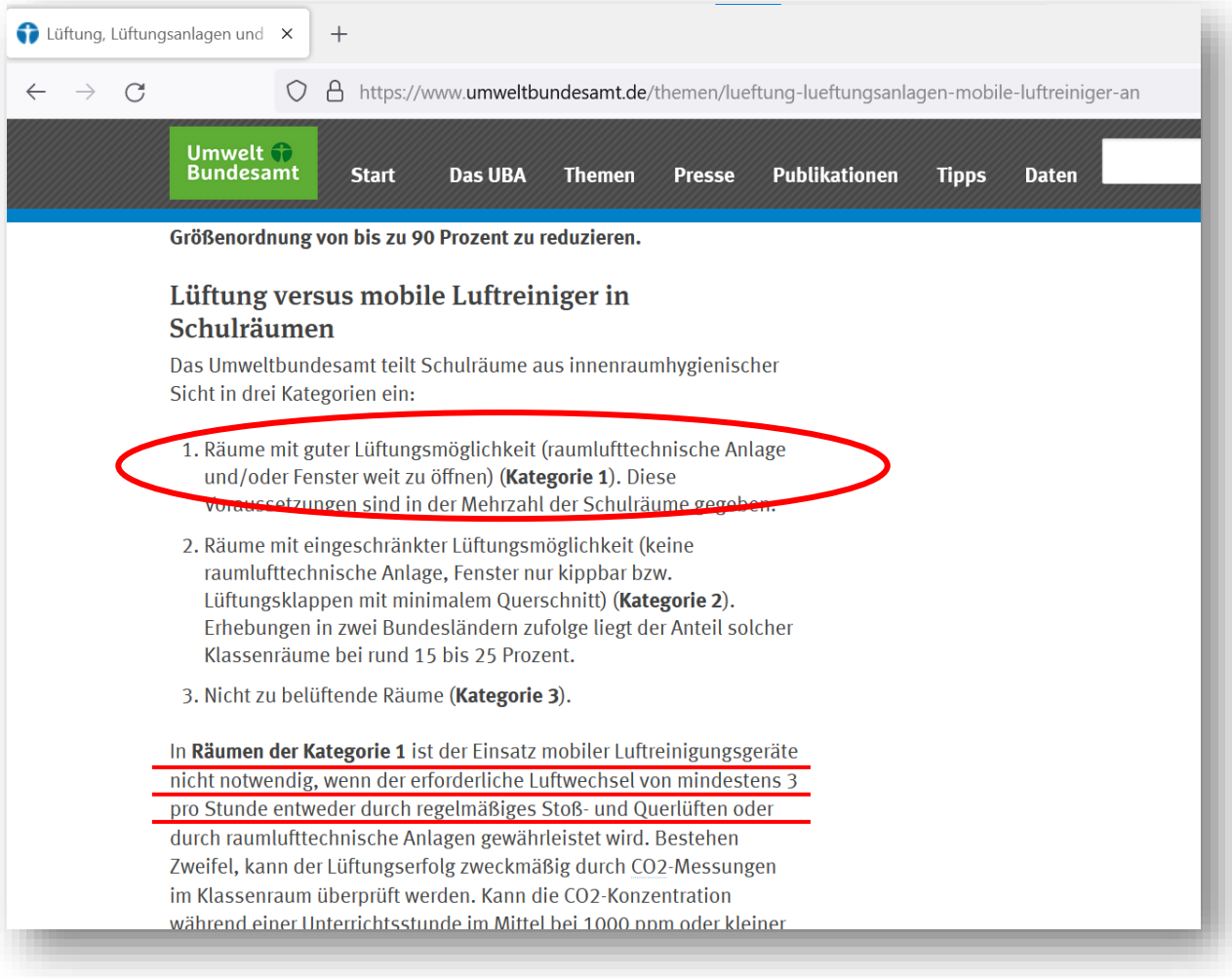

Lüftung, Lüftungsanlagen und

https://www.umweltbundesamt.de/themen/lueftung-lueftungsanlagen-mobile-luftreiniger-an

Umwelt Bundesamt | Start | Das UBA | Themen | Presse | Publikationen | Tipps | Daten

**Größenordnung von bis zu 90 Prozent zu reduzieren.**

## Lüftung versus mobile Luftreiniger in Schulräumen

Das Umweltbundesamt teilt Schulräume aus innenraumhygienischer Sicht in drei Kategorien ein:

1. Räume mit guter Lüftungsmöglichkeit (raumlufttechnische Anlage und/oder Fenster weit zu öffnen) (**Kategorie 1**). Diese Voraussetzungen sind in der Mehrzahl der Schulräume gegeben.
2. Räume mit eingeschränkter Lüftungsmöglichkeit (keine raumlufttechnische Anlage, Fenster nur kippbar bzw. Lüftungsklappen mit minimalem Querschnitt) (**Kategorie 2**). Erhebungen in zwei Bundesländern zufolge liegt der Anteil solcher Klassenräume bei rund 15 bis 25 Prozent.
3. Nicht zu belüftende Räume (**Kategorie 3**).

In **Räumen der Kategorie 1** ist der Einsatz mobiler Luftreinigungsgeräte nicht notwendig, wenn der erforderliche Luftwechsel von mindestens 3 pro Stunde entweder durch regelmäßiges Stoß- und Querlüften oder durch raumlufttechnische Anlagen gewährleistet wird. Bestehen Zweifel, kann der Lüftungserfolg zweckmäßig durch CO2-Messungen im Klassenraum überprüft werden. Kann die CO2-Konzentration während einer Unterrichtsstunde im Mittel bei 1000 ppm oder kleiner

https://www.umweltbundesamt.de/themen/lueftung-lueftungsanlagen-mobile-luftreiniger-an

Category 1: Rooms, in which the windows can be opened wide

In category 1 rooms, the use of mobile air cleaners is not necessary, if at least 3 air changes per hour can be achieved by window airing

# Inhaled viruses

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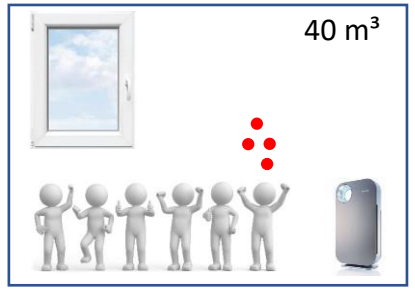


$$D(t) = \int_0^t Q_{breath} \cdot C(t')dt' = \frac{\dot{S}_{Vir}}{\dot{R}_{sink}} \cdot Q_{breath} \cdot \tau \cdot \left[\frac{t}{\tau} - \left(1 - e^{-\frac{t}{\tau}}\right)\right]$$

Sink:
- Air cleaner (CADR)
- Window opening (ACH)
- Decay of viral infectivity

# Airing vs. air cleaner

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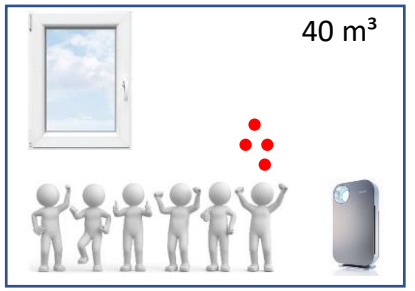
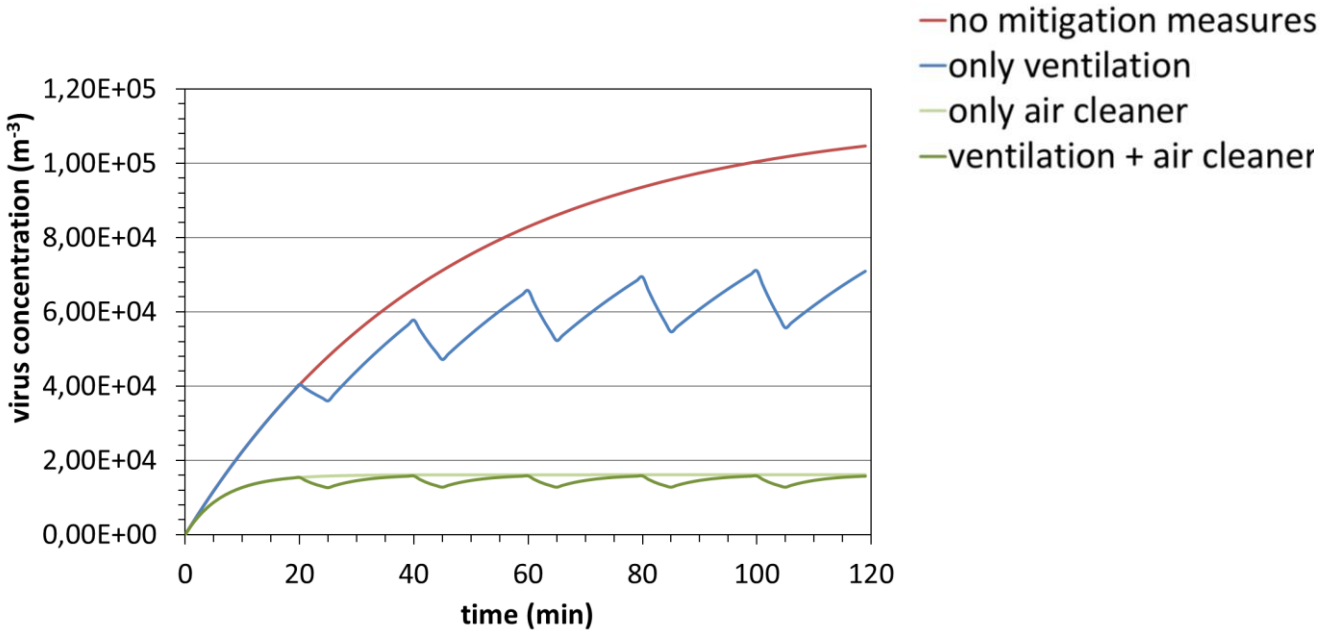
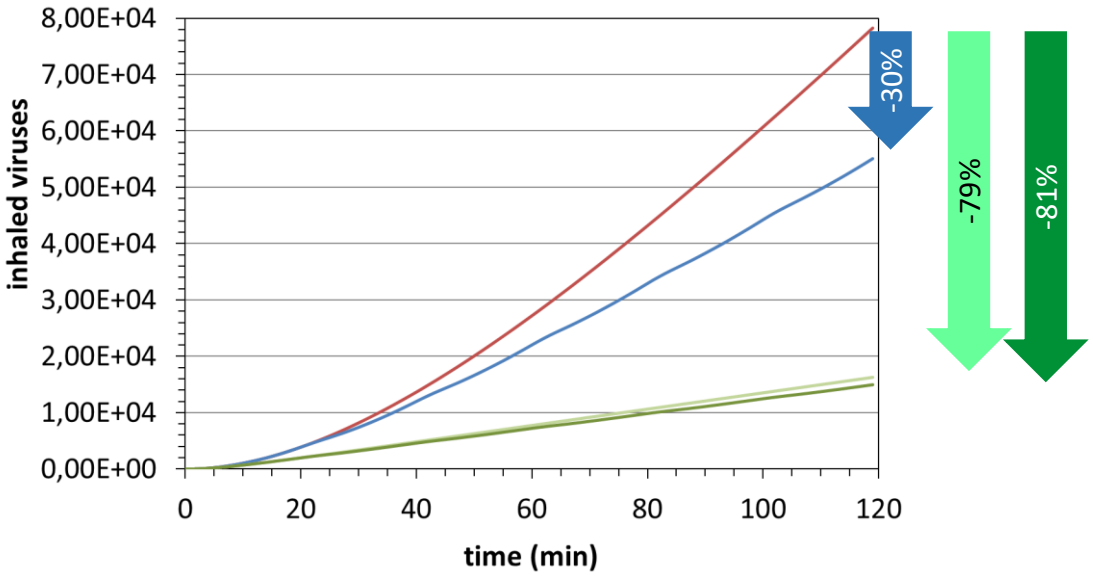
- Typical residential room (40 m³) considered, several people in room, one super-emitter
- Ventilation & air cleaning:
  - Air cleaner with 320 m³/h CADR
  - Every 20 min window ventilation for 5 min (4 ACH assumed)
  - Natural decay of infectious virus concentration due to deposition and inactivation of viruses (half life ~1.1 h)

van Doremalen et al., *N. Eng. J. Med.* **382**: 16, 2020




Breathing flow rate 9 l/min, 100,000 virus copies per min. (Ma et al., *Clin. Infect. Dis.* **72:** e652-e654)




model according to Schumacher *et al. Gefahrstoffe – Reinh. Luft* **81** 16, 2021

# Conclusions

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- Air cleaners can efficiently remove airborne pathogens and other pollutants from indoor air
- Clean air homogeneously distributed in room, like in stirred tank reactor
- Flow rate more important than filter efficiency for air cleaner efficacy
- Electret filters can significantly improve energy efficiency
- However, filter aging of low-quality electret filters can be an issue
- Use of multiple air cleaners at lower level beneficial compared to single air cleaner at high level