Prof. Dr.-Ing. Achim Dittler,
Leiter Institut für Mechanische Verfahrenstechnik (MVM)
Leiter der Arbeitsgruppe Gas-Partikel-Systeme
Karlsruher Institut für Technologie (KIT)

Dr.-Ing. Maximilian Weiß, CEO
M.Sc. Ann-Kathrin Goßmann, Projektingenieurin Entwicklung

Dr. Schnaudigel, Landrat
Ragnar Watteroth, Dezernat Finanzen und Beteiligungen

Assessment of ventilation concepts to avoid infection

Information about measurements taken at schools in the Karlsruhe district

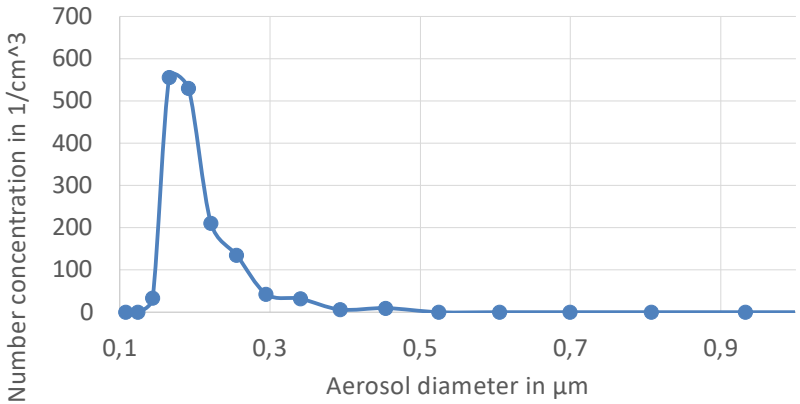
December 2020

Motivation

- Ventilation and indoor air quality during the pandemic: Many questions and few answers
- Evaluation of practical cases by measuring in schools in the Karlsruhe district
- Measuring the concentration of CO_2 and the concentration of particles in the size range of exhaled aerosol
- Evaluation of the effect of selected air purifiers

The problem

- Exhaled aerosol particles are very small and stay airborne for a long time
- Examination of the exhaled breath of persons suffering from Covid-19 has shown an increased aerosol concentration by a factor of 100 compared to healthy persons
- The AQ Guard, produced by Palas® GmbH in Karlsruhe, Germany is the only analyzer worldwide, designed specifically for assessment of infection risk, that features the required aerosol measurement capability in combination with a CO_2 sensor



Aerosol size distribution measured in exhaled breath of person suffering from Covid-19 (08-2020, Resp-Aer-Meter, made by Palas® GmbH)

AQ Guard - Analyzer for assessment of infection risk
By simultaneous measurement of CO_2 and aerosol number concentration

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Measurements at 3 schools in the Karlsruhe district

Balthasar-Neumann-School 1 (Bruchsal)

- Vocational school
- Rooms:
    1. Workshop (9-13 pupils)
    2. Classroom (25 pupils)
    3. Classroom (21 pupils)
- Ventilation as recommended
- Support by large air purifier

Astrid-Lindgren-School (Forst)

- Primary school
- Rooms :
    1. Dining hall (28 pupils)
    2. Classroom old wing (13 pupils)
    3. Classroom new wing (9 pupils)
- Ventilation as recommended

Thomas-Mann Gymnasium (Stutensee)

- Secondary school
- Rooms :
    1. Classroom old wing (23-31 pupils)
    2. Classroom new wing (23-28 pupils)
- Ventilation as recommended
- Support by small air purifier purchased at local store.


Workshop BNS1


Classroom BNS1


Classroom TMG

Data measured during one lesson – a typical course over time

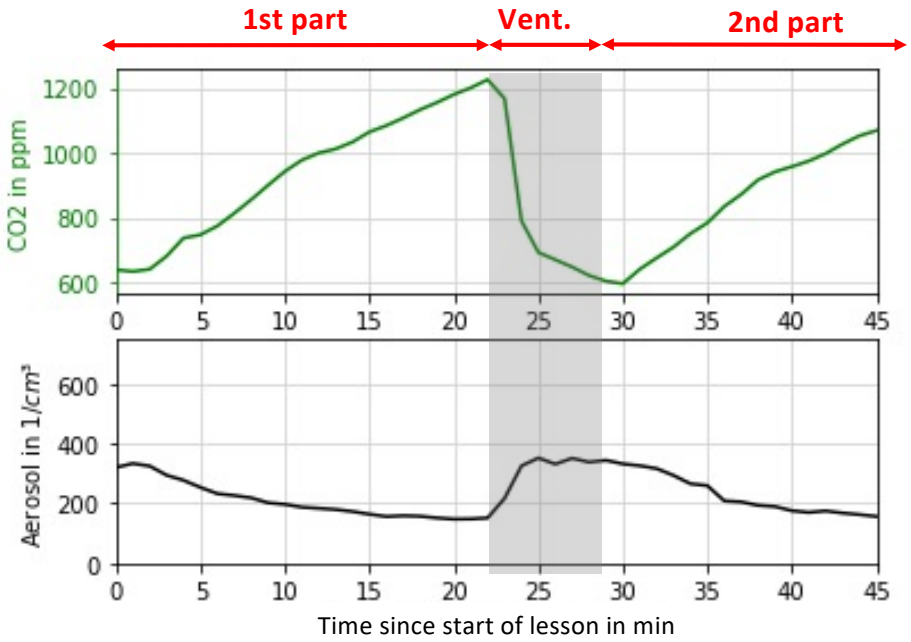
The levels of CO_2 and aerosols in the course of the lesson determine the result of the air quality. The concentration of CO_2 is a measure for the fraction of exhaled air – potentially contaminated by infectious aerosols – in the room. A decline of the aerosol concentration during the lesson shows at which rate potentially infectious aerosols are deposited. Exhaled aerosol can only be detected indirectly due to the high background aerosol level.

CO_2 concentration

- Rises continuously during first part of lesson to max level, immediately before ventilating the room
- Decreases rapidly in the first 2-3 minutes of ventilation, but then decrease slows down
- Rises again continuously during second part of lesson

Aerosol concentration

- Decreases during first part of lesson due to Aerosol deposition by:
  1. Natural deposition mechanisms (surface contact, deposition in the lung while breathing, …)
  2. Active filtration by air purifier
- Rises during ventilation since admitted air carries ambient aerosol (which is not infectious!)
- Decreases again continuously during second part of lesson



Course of CO_2 concentration and aerosol concentration during one lesson; every 20 minutes room is ventilated for 6 minutes; air purifier not running

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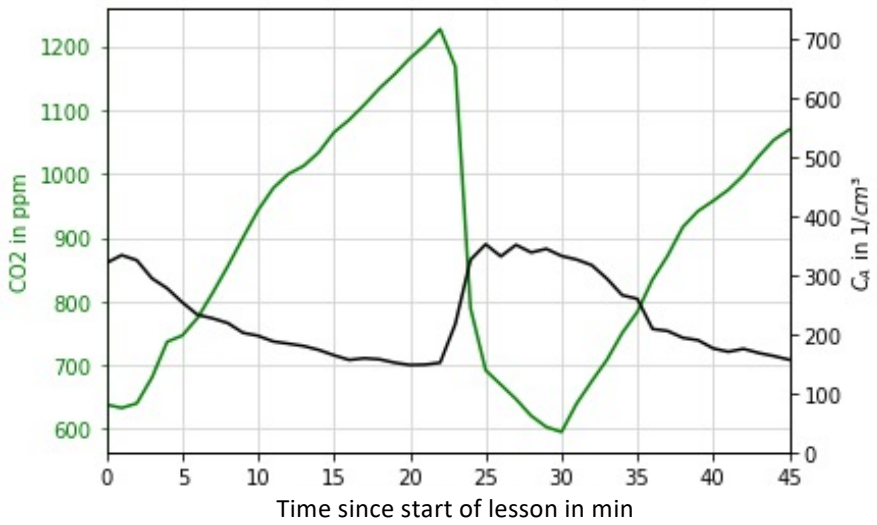
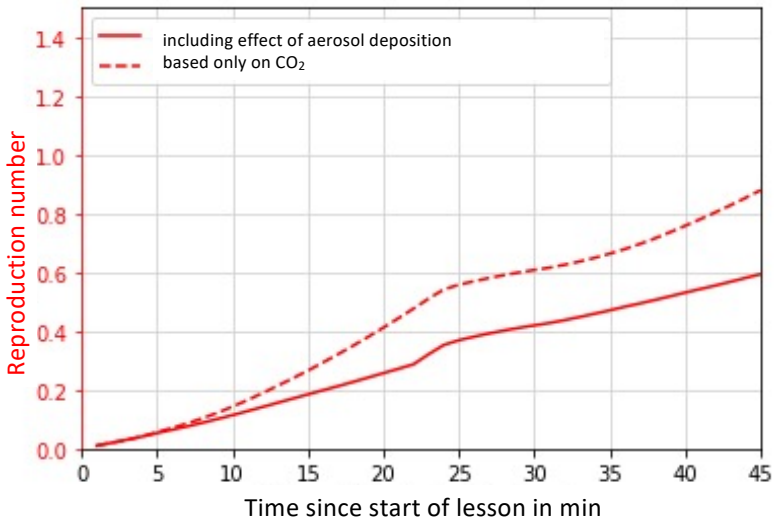
Assessment of infection risk

CO_2 concentration and aerosol concentration C_n during one lesson

1. Calculation of reproduction number (= number of persons a carrier of the disease present in the room might infect) based on CO_2 and a model used in epidemiology*
2. Introduction of the effect of aerosol deposition according to measured data





Reproduction number

- By definition the reproduction number is ever-increasing; as seen in the diagram ventilation only reduces the growth rate temporarily
- Introduction of the effect of aerosol deposition slows the increase of the reproduction number down, compared to an assessment based only on CO_2. Since the infection is in fact transmitted by aerosols this should be regarded as the actual reproduction number.

*„Risk of indoor airborne infection transmission estimated from carbon dioxide concentration" S. N. Rudnick et.al. Indoor Air 2003; 13; 237-245 assuming q = 100/h, C_a = 38000 ppm, $C_{CO2,0}$ = 410 ppm

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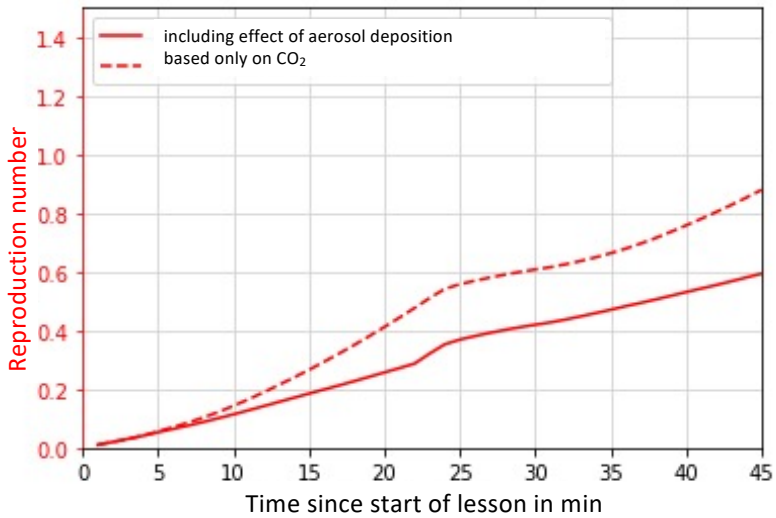
Reproduction number

- The reproduction number gives the probability that the Covid-19 infection is transmitted from an infected person in the room to others.



- A reproduction number of 1 after 45 minutes would indicate a probability of 100% that an infected person present in the room would transmit the disease to one other person, provided both attend for the full period of time.
- By definition the reproduction number is ever-increasing; accordingly the infection risk rises continuously over time
- The reproduction number does not take the effects of, for example, additional protection by masks or due to the age of the persons present into account

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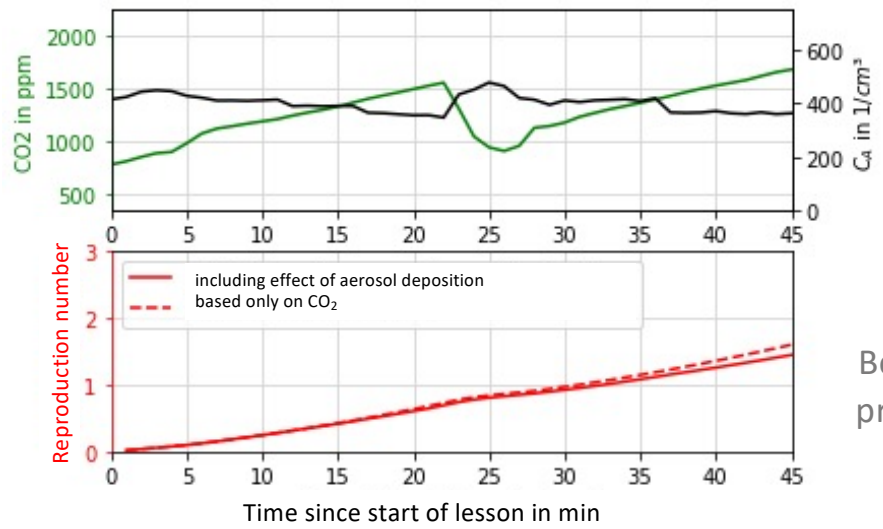
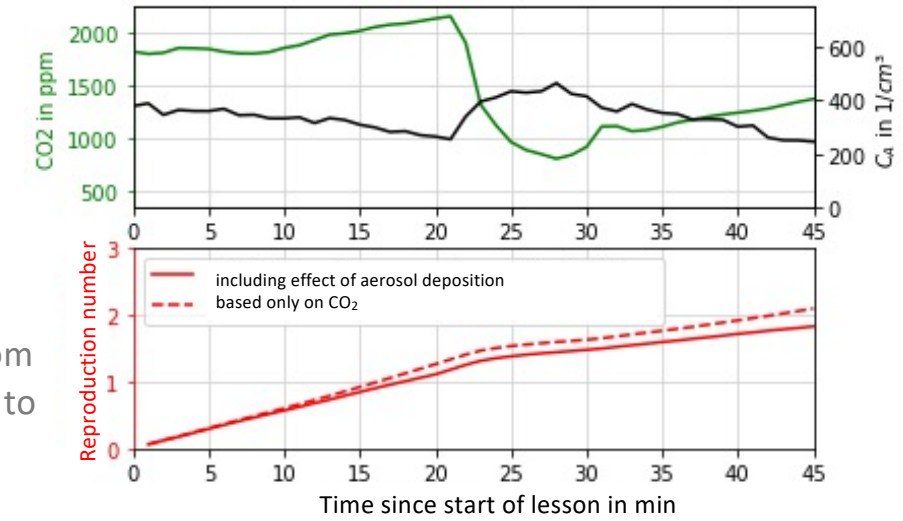
Infection risk in the course of the day

- A 5 minute ventilation phase every 20 minutes is usually insufficient for bringing the air quality back to „fresh air“ level every time -> more and more potentially infectious, spent air accumulates
- Unless the room is ventilated thoroughly during breaks or lesson-free periods the spent air, and potentially harmful aerosols, will be carried on into the next lesson since aerosol from exhaled breath remains airborne and infectious for hours



Following lesson

Begins with spent air from previous lesson, leading to higher infection risk



Calculations show that the risk of infection can be reduced by 40%-50% on average if every lesson starts at fresh air level

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Infection risk in the course of the day – typical data

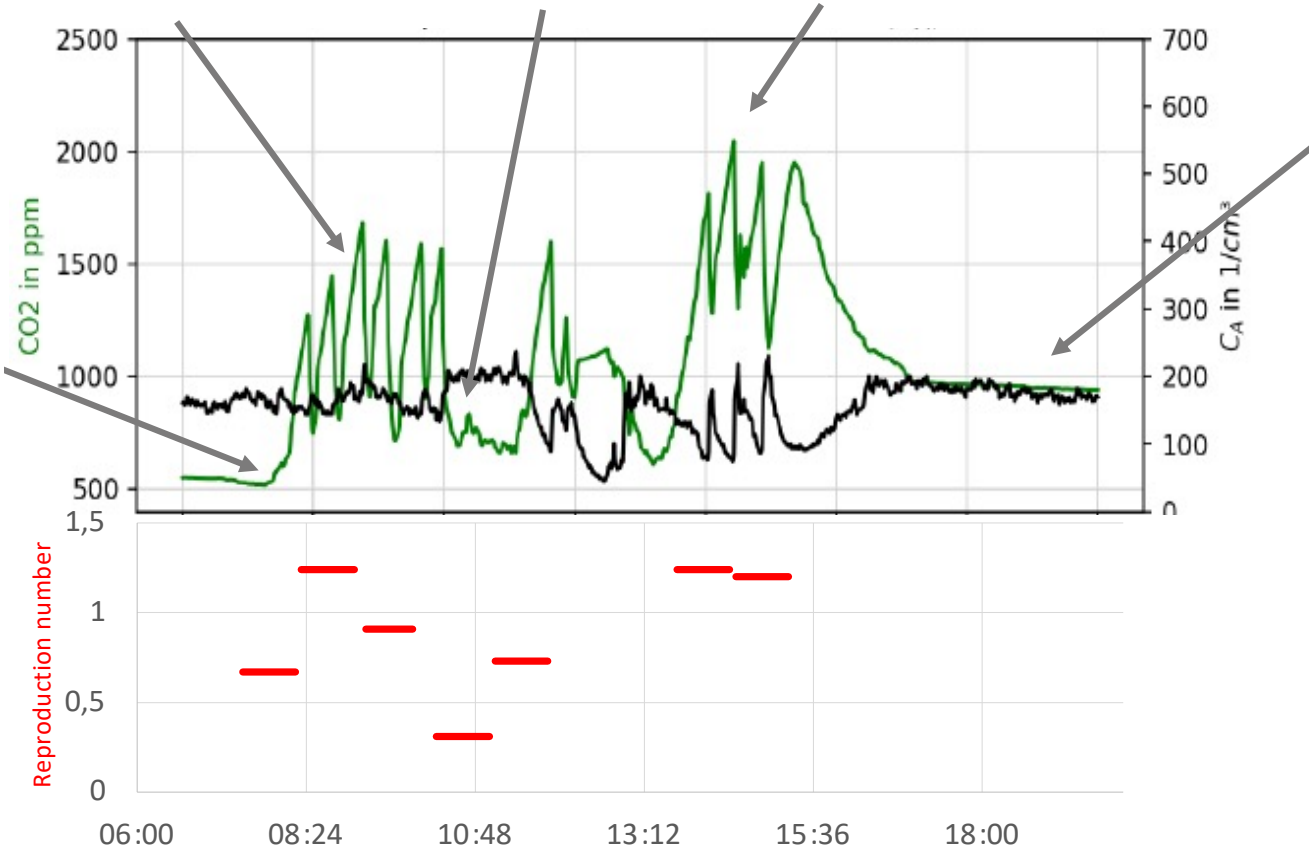
Short ventilation every 20 minutes is not enough to keep the concentration of CO_2 at a low level

Full ventilation across the room for one hour reduces the infection risk considerably

Short ventilation every 20 minutes again – the already high level of CO_2 cannot be reduced this way

Without ventilation after class aerosols stay airborne for many hours, even until the following day – the aerosol concentration hardly decreases.

School day begins here already at a CO_2 level of 520 ppm, about 100 ppm above ambient air level. Potentially infectious aerosol from the previous day may still be present.



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Infection risk in the course of the day

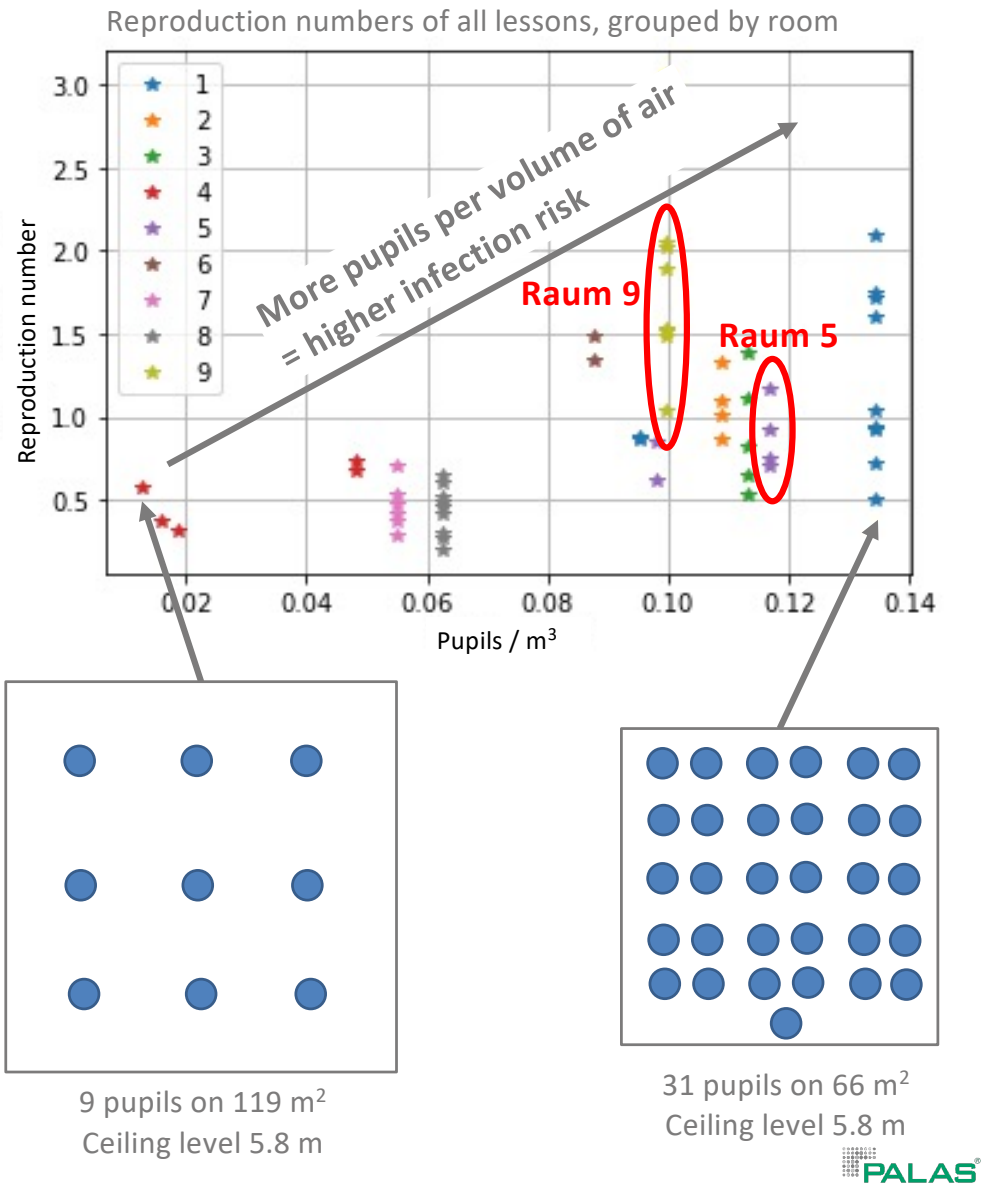
During almost all measurements the fraction of spent air (rated by the concentration of CO_2) increased in the course of the day. At the start of each lesson a residue of spent air from the previous lesson(s) is present, which build up from lesson to lesson. The infection risk per lesson thus increases continuously during each day.

Thorough ventilation during each lesson and during breaks and after class is necessary !

Effects of geometry and occupancy

- The infection risk also depends on dilution of exhaled breath by the available volume of air in the roo, i.e., on geometry and occupancy
- Rooms differ considerably regarding possibilities for ventilation (size & number of windows / opening angle). Room 9, for example, appears to ventilate much slower than room 5, as it exhibits much higher reproduction numbers even though the occupancy per volume is lower.

Individual circumstances (occupancy, geometry, size & number of windows) determine the effectiveness of ventilation, but basically the infection risk rises with occupancy density.

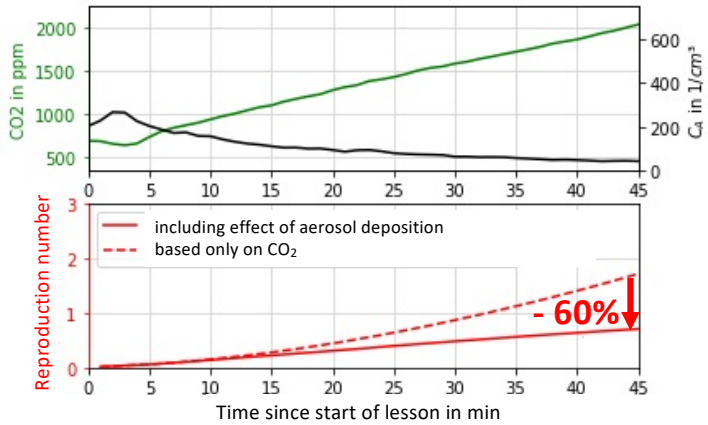


Effect of air purifiers

- During the measurements presented here air purifiers could reduce the infection risk by up to 65%
- Small units purchased at local stores already show good effect, but were considered unsuitable due to noise; substantial risk reduction requires that these devices run continuously at maximum performance level
- Large air purifiers showed very good effect at low noise levels

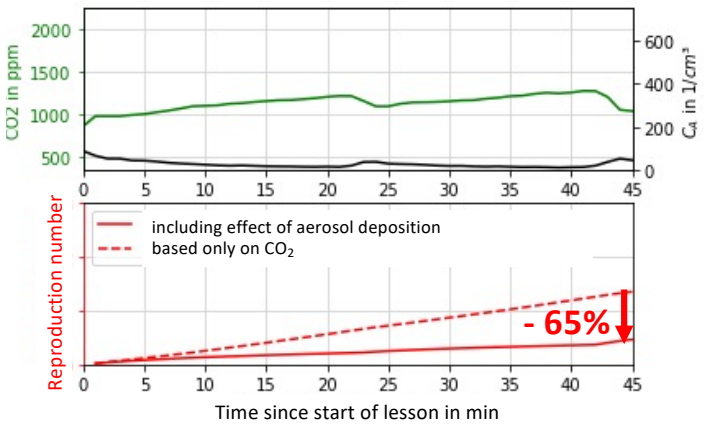
Active aerosol deposition with air purifiers

With air purifier



Small unit in „turbo“ mode (Philips AC3033)

With air purifier and ventilation



Large unit (Wolf AirPurifier)

Air purifiers reduce the risk by up to 65% at full power; noise produced by small devices was rated very distracting by pupils and teachers.

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Overview over results and recommended actions

- Ventilation is most effective during the first few minutes, after which further improvement of air quality progresses slowly

  -> Two short ventilation periods are more effective than one period twice as long

- Thorough ventilation between lessons is essential to avoid carrying potentially infectious air on into the following lesson
- Ventilation of unoccupied rooms and also after class reduced the risk in the whole building
- Effectiveness of ventilation depends very much on room geometry and occupancy

  -> Rooms without air purification may benefit from CO_2 gauges in order to ventilate on demand

- Air purifiers could lower the risk of infection by up to 65% but attention must be paid to operating noise

  -> Rooms which are difficult to ventilate will benefit from installation of low noise air purifiers

It is difficult to propose general rules for ventilation concepts due to the numerous factors taking influence. Clear results are only obtained from individual assessments of rooms and occupancy scenarios based on measurement of the CO_2 and aerosol levels.

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Go green to breathe clean.