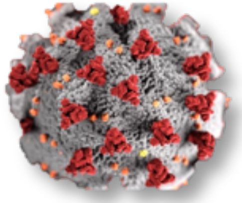
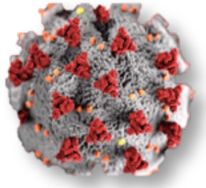
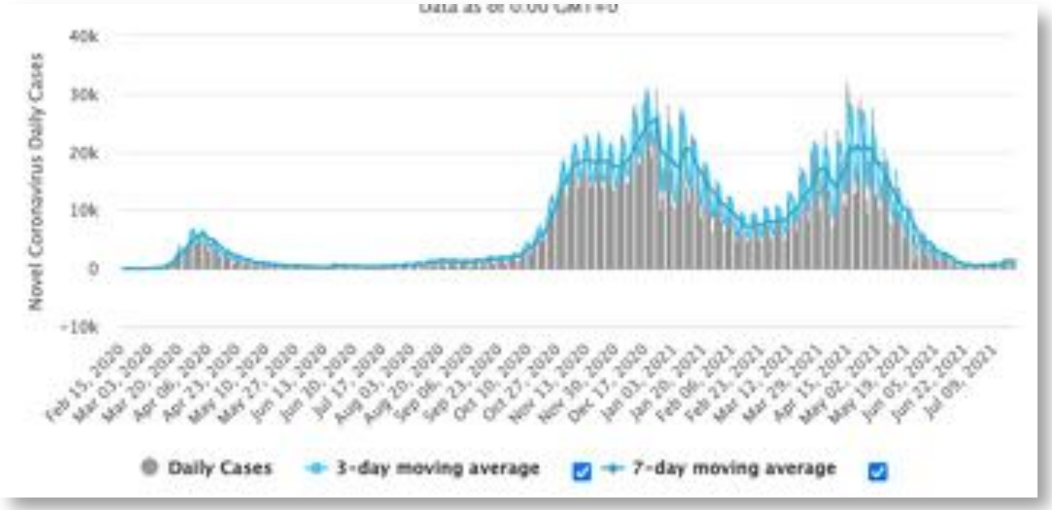
Air cleaning in  times

Horst Hahn

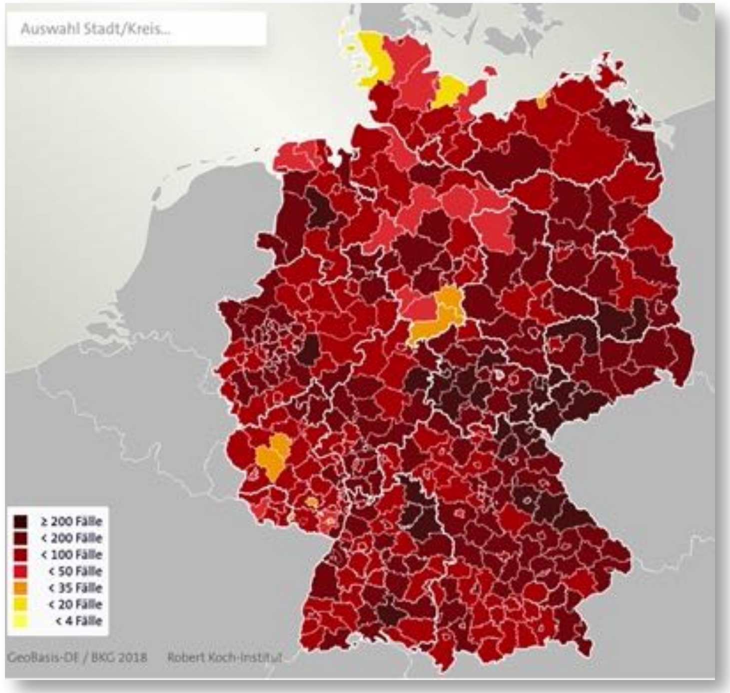
Institute of Nanotechnology

Facts on  : situation in Germany

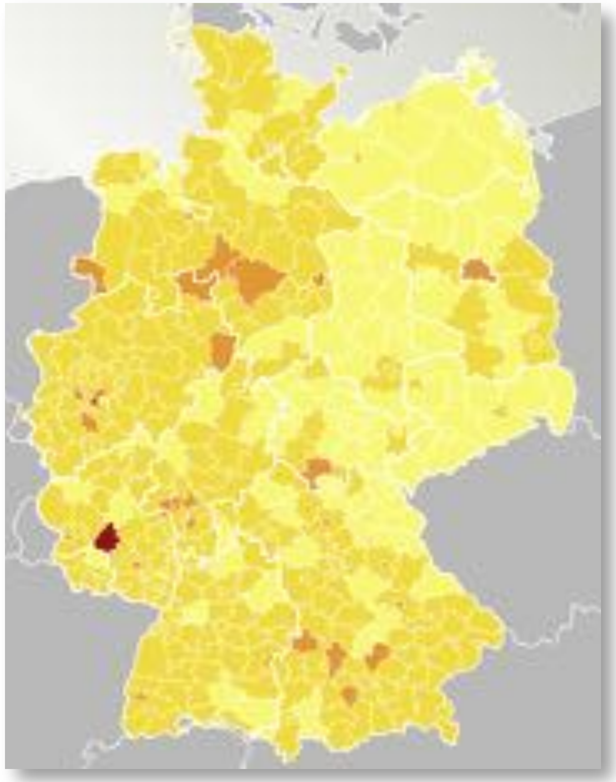
COVID-19 (Coronavirus SARS-CoV-2)



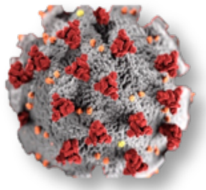
Source: https://www.worldometers.info/coronavirus/



ARD-Tagesschau from **25.03.201**



ARD-Tagesschau from **22.07.2021**

Facts on  : World, Germany, Italy

Karlsruhe Institute of Technology

COVID-19 (Coronavirus SARS-CoV-2)

(15.12.2020, 22:00)

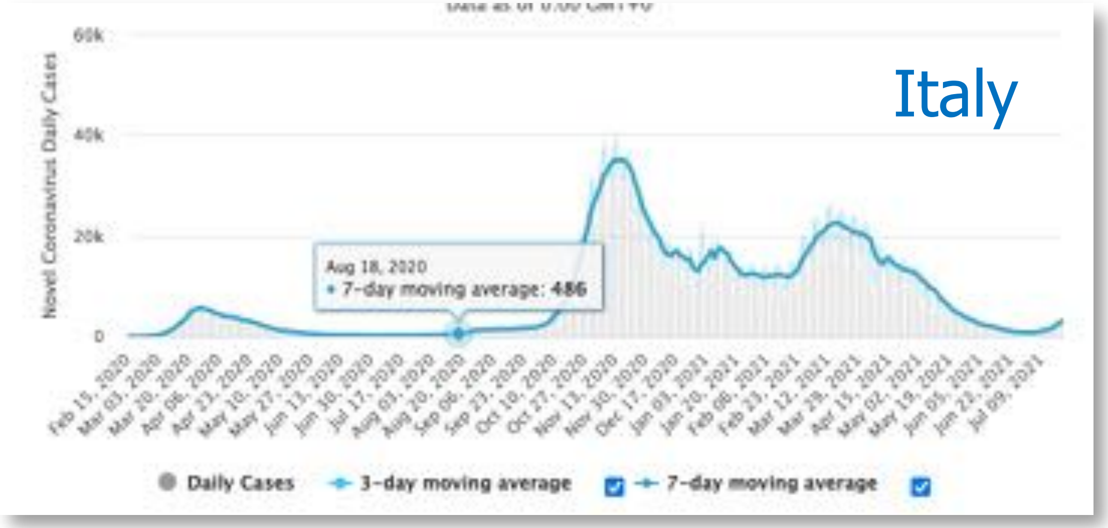
Germany
Coronavirus cases:
1,378,518
Deaths:
23,692
Recovered:
1,003,300

Worldwide
Coronavirus cases:
73,642,096
Deaths:
1,637,530
Recovered:
51,674,628

(21.07.2021, 08:00)

Germany
Coronavirus cases:
3,756,408
Deaths:
91,953
Recovered:
3,642,600

Worldwide
Coronavirus cases:
192,844,487
Deaths:
4,142,737
Recovered:
175,361,586



(21.07.2021, 08:00)

Italy
Coronavirus cases:
4,297,337
Deaths:
127,905
Recovered:
4,118,124

Source: https://www.worldometers.info/coronavirus/

What is needed?

need for a truely multidisciplinary effort of

- virologists
- epidemiologists
- physicians
- physicists
- chemists
- mathematicians
- statisticians
- aerosol experts
- fluid mechanic engineers
- ventilation experts
- simulation and experiments
- ...

Why did I get into virus de-activation and air cleaning, as a material scientist, with expertise in nanomaterials?

- size of virus in nanometer regime (20-200 nm)
- aerosol transmission
- in early 2020: transmission by droplets and smear infection, no word of aerosols (consequently: no recommendation for masks)

Clean water, clean air

biologically clean water is a standard in many countries

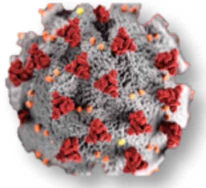
but not everywhere

idea of protective masks in early 1918 during Spanish flu

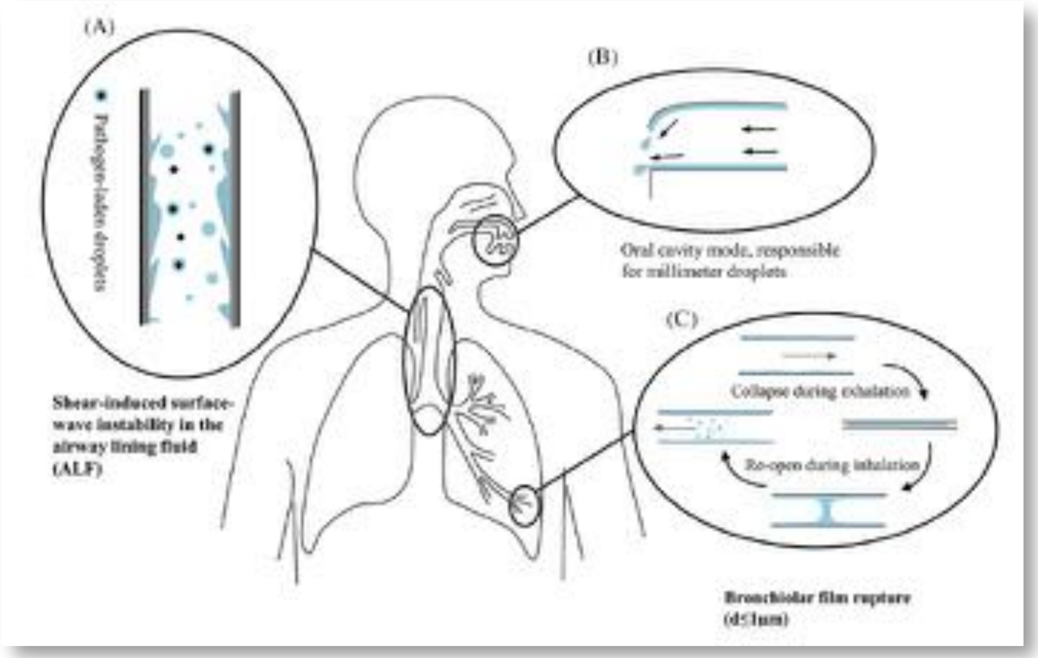
protective masks are common in Asia

but clean air indoors?

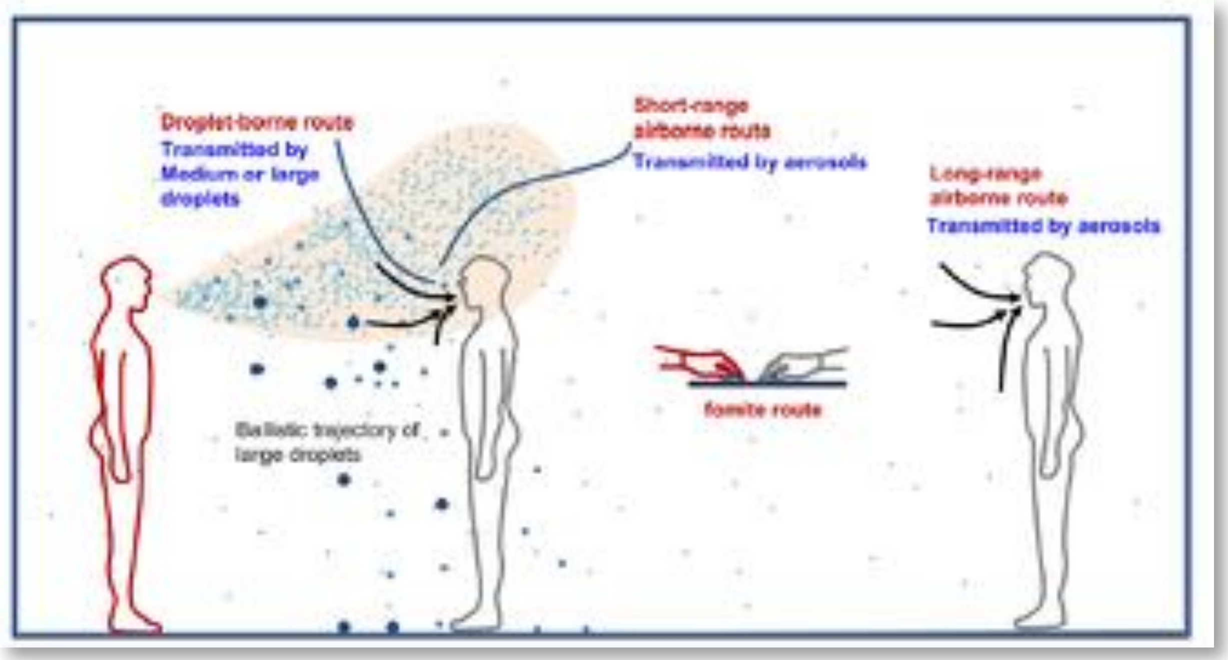
- the annual influenza
- pandemics, i.e. Spanish flu

Facts on  : source

Droplets and aerosols

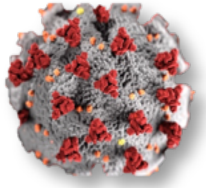


source of human aerosols and droplets



- large droplets (> 100 μm); fast deposition by gravity
- medium-sized droplets between 5 and 100 μm
- small droplets or aerosole (< 5 μm): responsible for airborne transmission

Jianjian Wie, Yuguo Li, American Journal of Infection Control 44 (2016) S102-S108
Airborne spread of infectious agents in the indoor environment

Facts on  : distribution / prevention

Droplets and aerosols


droplets and aerosols

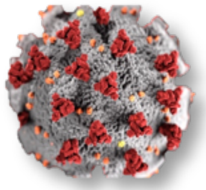

aerosole distribution during speaking, sneezing, coughing


aerosole distribution with mask

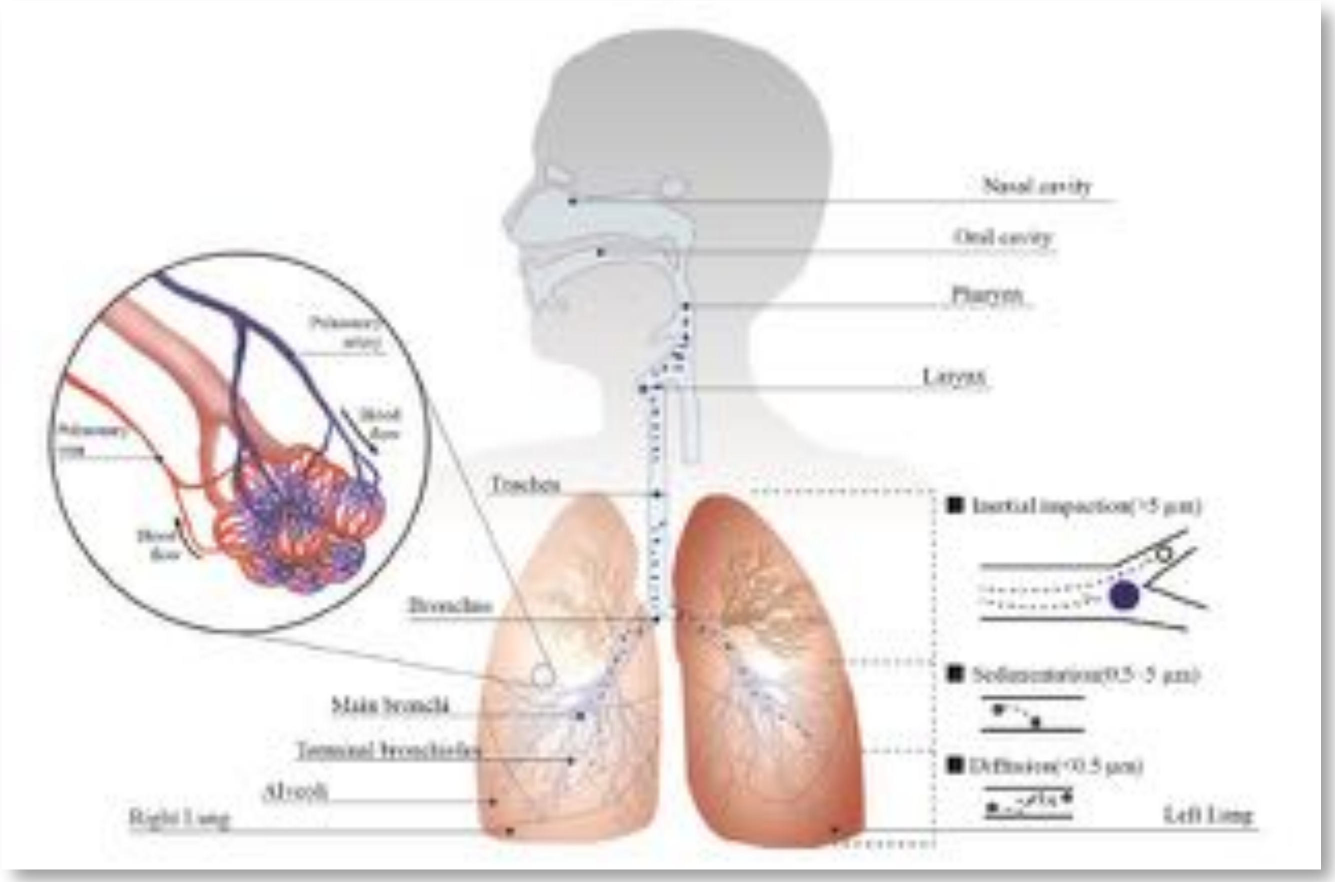
AHA-rules:
keep distance (**A**bstand halten)
follow **H**ygiene measures
wear mask (**A**lltagsmaske) (mouth-nose-coverage)
+ ...

Important during use of masks:

- high quality masks
- correct fitting of mask, in order to prevent air flow at the edges of the mask
- protects better towards the outside than to the inside

Facts on  : intake into body

Aerosols



Hong-Goo Lee, Dong-Wook Kim, Chung-Woong Park, Journal of Pharmaceutical Investigation 48 (2018) 603-616

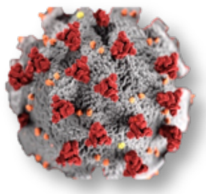
calculation of the average infection probability in a room:

HEADS — Human Emission of Aerosol and Droplet Statistics

data needed: room size, number of people, number of infected people, duration of stay

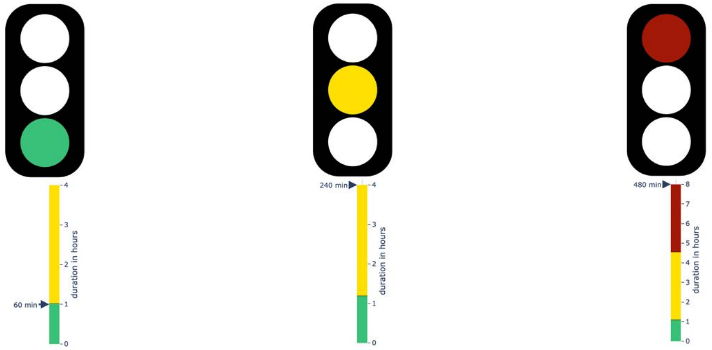
https://aerosol.ds.mpg.de/de/

Abteilung für Fluidphysik, Strukturbildung und Biokomplexität, Max-Planck-Institut für Dynamik und Selbstorganisation Göttingen

Facts on  : infection risks

Indoor rooms on Christmas

https://aerosol.ds.mpg.de/de/



Assumptions:
- Christmas with the family (indoors)
- **Room size**: 30 m^2, 2.8 m height, 84 m^3 volume
- different **activities** (dining, watching football game, partying)
- different **length of stay**
- **5 adults** (middle-age, 45 years) are considered, not children
- one infected person

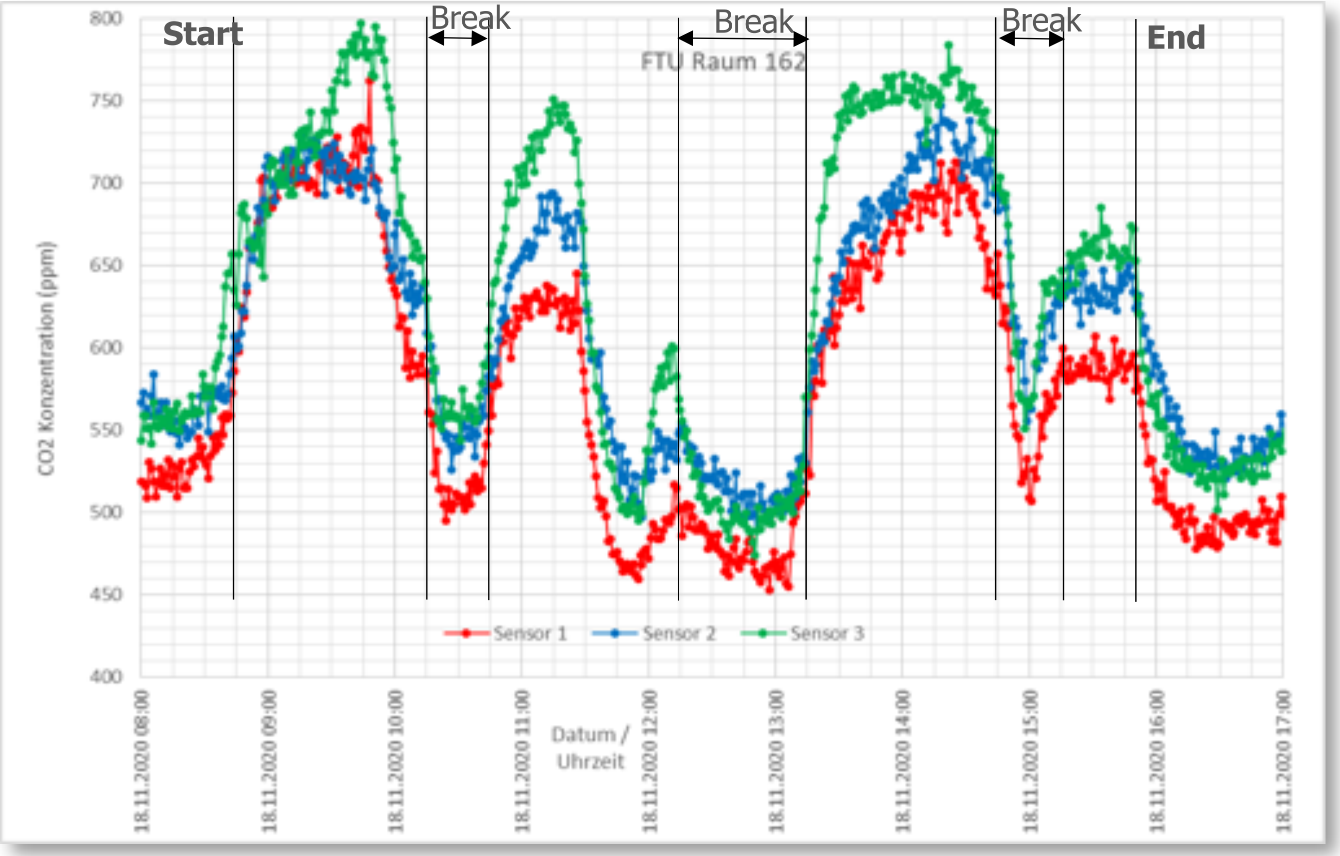
	4 h		8 h	
	I1 (%)	I2 (%)	I1 (%)	I2 (%)
Dinner	4	1	10	3
Watch football game	49	16	82	35
Party	61	21	90	44
Singing 1 hour	2	0,4		

I1: average infection risk with an estimated probability that at least one person gets infected

I2: risk for each individual non-infected person to get infected

Abteilung für Fluidphysik, Strukturbildung und Biokomplexität,
Max-Planck-Institut für Dynamik und Selbstorganisation Göttingen

How to get information on the room



CO_2-sensors for easy characterization of rooms, without detailed knowledge of existing ventilation

Example of a well-ventilated room

- Training class room, 248 m^3, 20 persons, Air Exchange Rate (AER) 10 /h, three CO_2 sensors
- Reduced number of persons during breaks and activities in other rooms
- Infection probability for class participants in case that one infected person should be present is **4,3 % per day**

Arrangement of air cleaning devices in rooms

office at Institute of Nanotechnology at different venting conditions

A: door open, windows closed

B: door open, one window completely open

C: door closed, one window completely open

D: door closed, both windows tilted

E: door closed, one window completely open

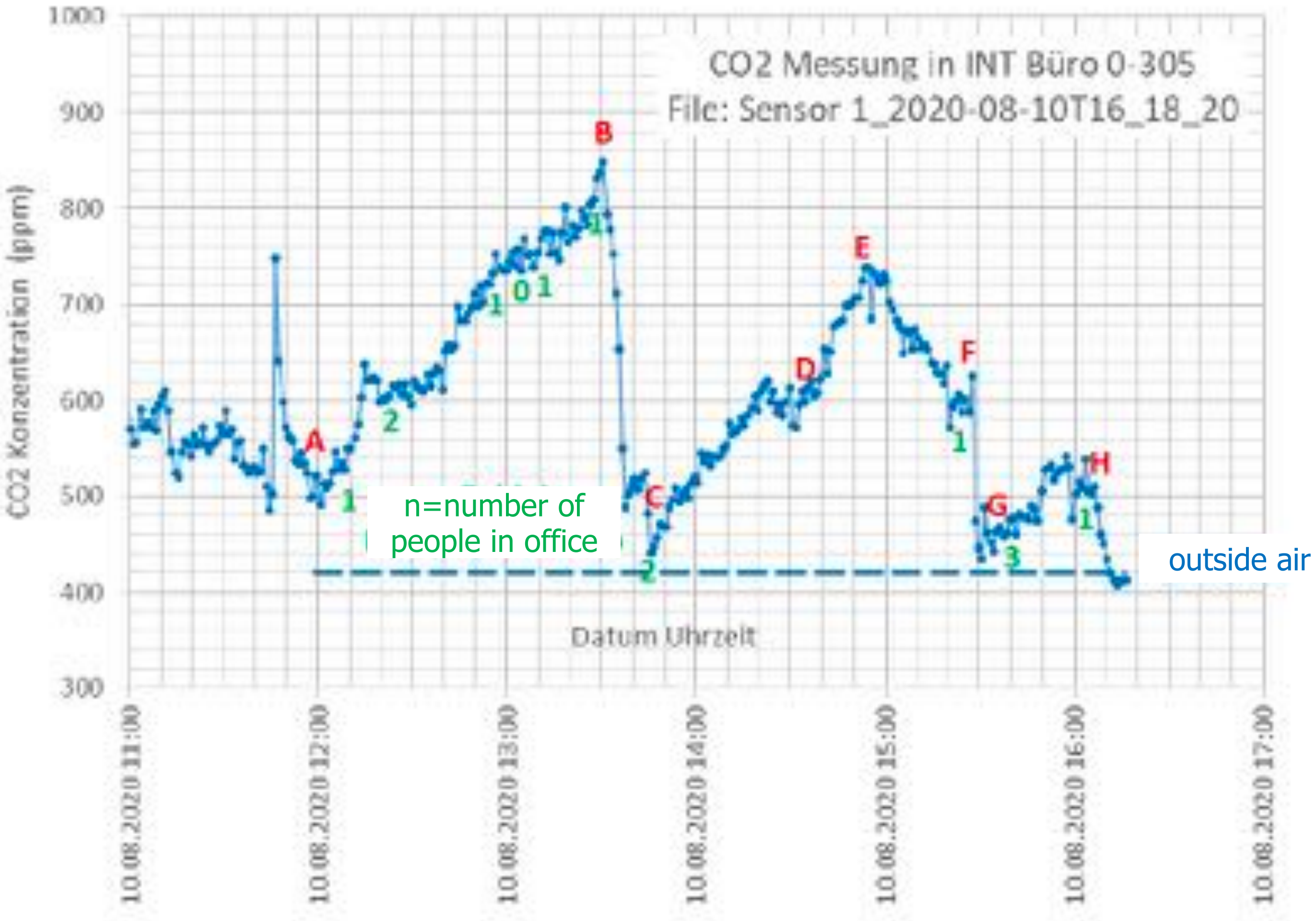
F: door open, both windows open (safest)

G: door closed, both windows open

H: door open, one window open

effective air exchange rate determined (LWR) is between 1 and 20 (1/h)

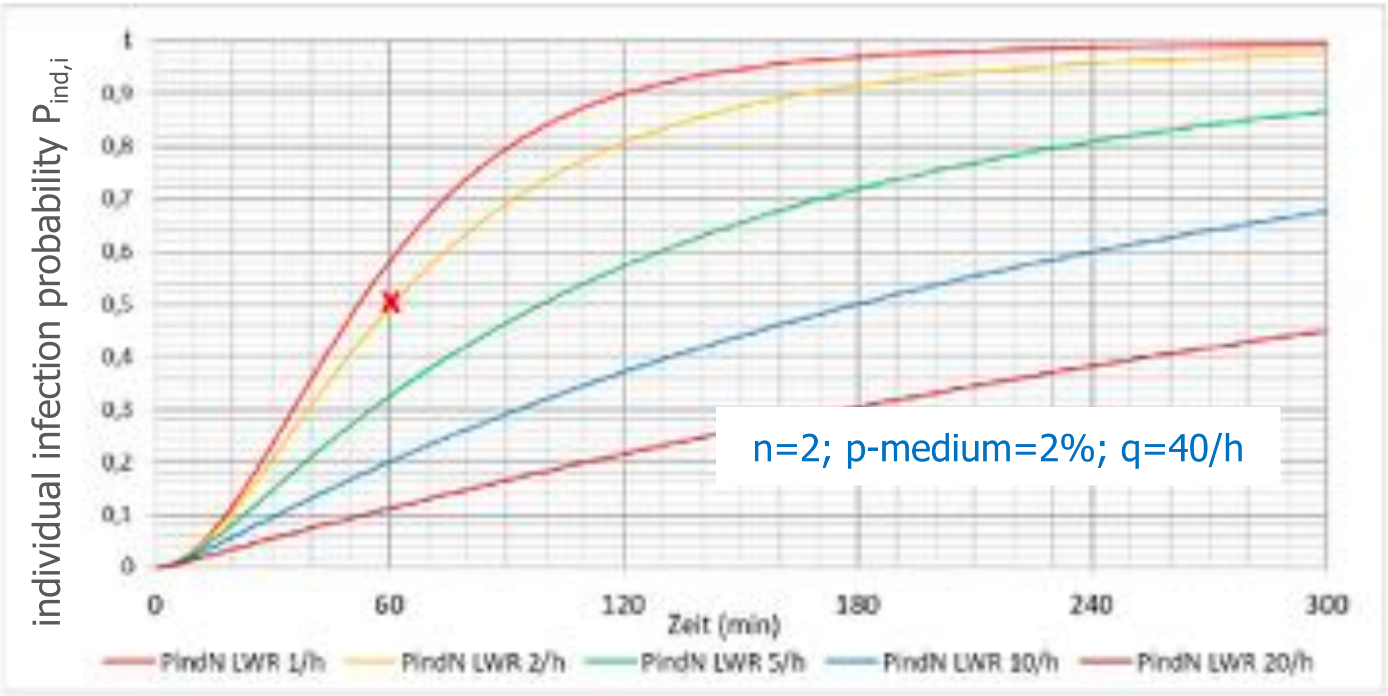
characteristic air exchange time τ=1/LWR (min) lies between 3 and 69 min



Calculation of infection probability

Q & A:

1. what is the probability of having an infected person, for example in an office room? that depends on the number of infected people in the areas from where the employees are coming to work.
2. what is the infection risk for others in case of an infected person being present?



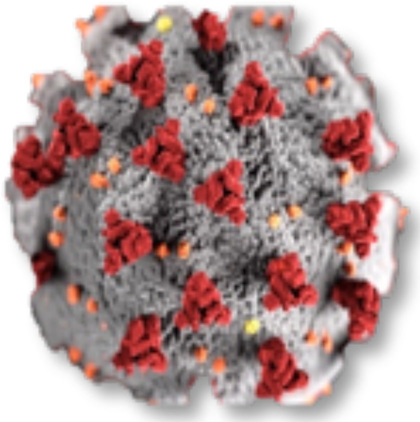
n: number of people in room

p: infectious degree in region

q: exhaled infectious doses per hour

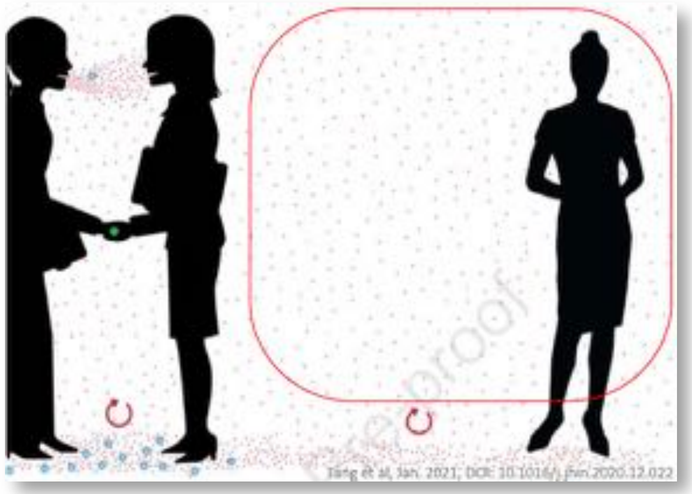
Air cleaning in Corona times

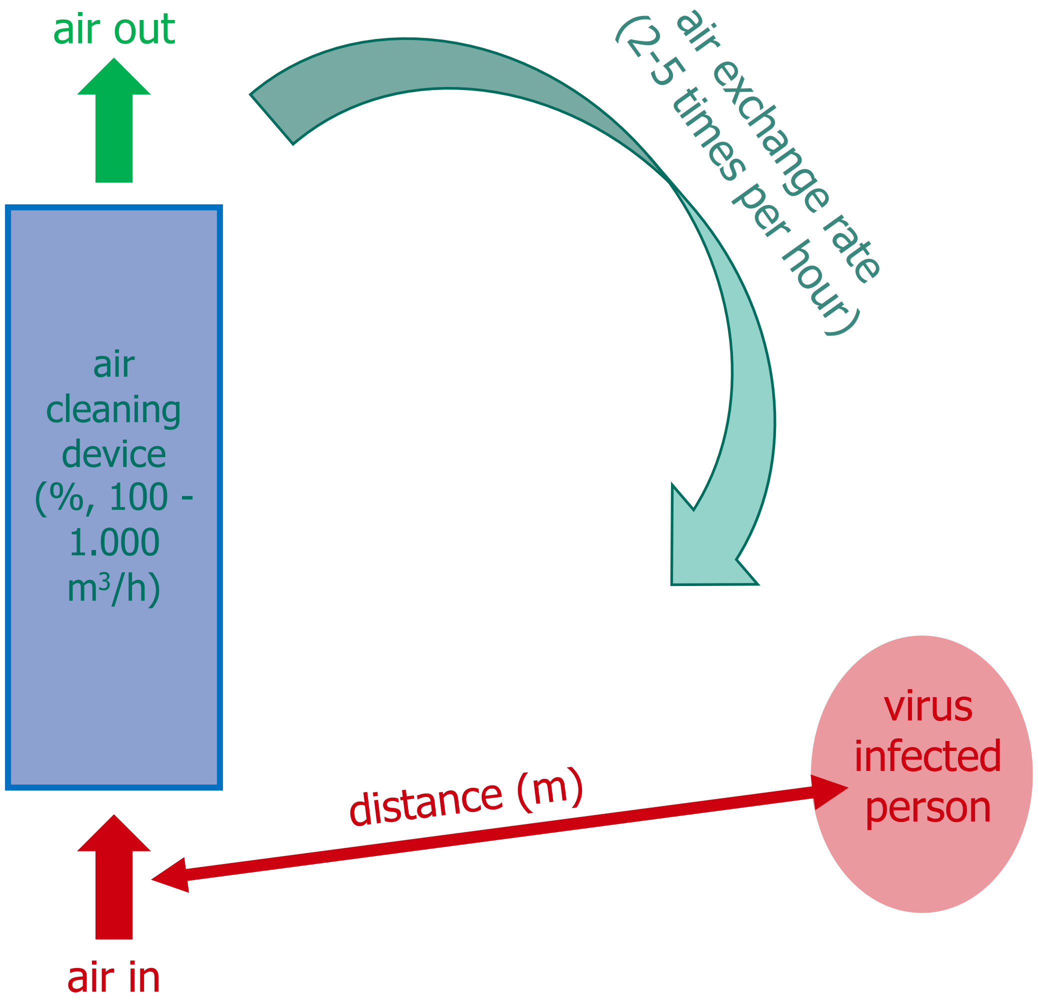
- aerosols are important transmissions routes indoors
  - class rooms, child care, offices, sales floors, production areas, retirement homes, public transportation, restaurants, etc.
- ways to avoid infections
  - ventilation
  - technical solutions
    - **collection in filters**
    - **de-activation during passage**
- vaccination



Considerations in design of air cleaning

- room size (m^2 and m^3), aspect ratio
- existing ventilation (windows, air conditioning, ...)
- number of people
- duration of stay
- air flow through the device (m^3/h)
- de-activation of virus in aerosols (%)
- humidity
- temperature
- cost of purchase and installation
- annual operation costs (electricity, replacement parts, maintenance)
- ...

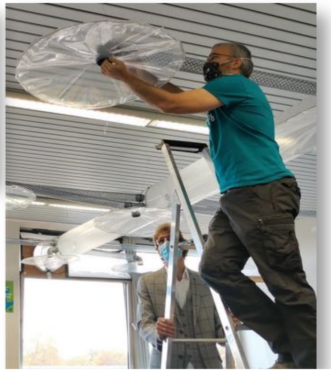


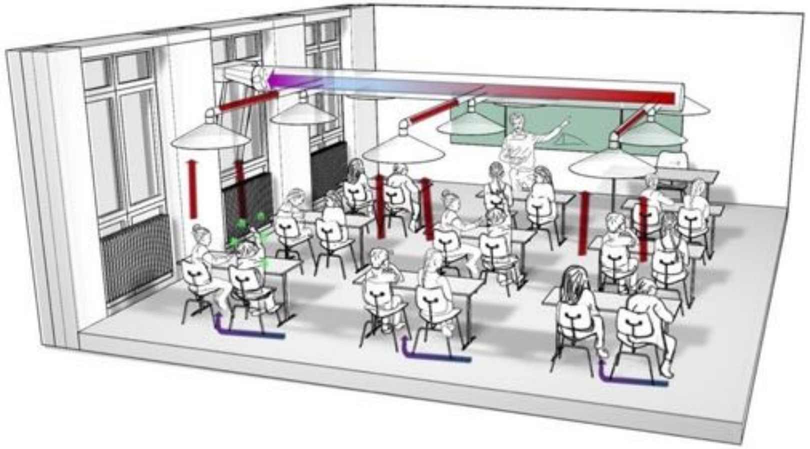


Technical (emergency-)solutions

open windows

parents as craftsman / woman





https://www.mpg.de/15962809/corona-lueftung-aerosole-luft

- inexpensive components (< € 200)

- assembly by parents (?) or company (additional costs)
- large volume exchange
- heating costs due to extensive supply of fresh air
- fire protection not solved
- cleaning
- not all-purpose

Technical solutions

air cleaning devices **with filter**: domestic appliance

Frankfurter Allgemeine Sonntagszeitung
November 22, 2020

a few hundred €

„The load of viruses in indoor air cannot be measured with reasonable effort, so we looked at how effectively they (the air cleaning devices) combat fine dust in closed rooms as an alternative - assuming that pathogens remain trapped in the filter to a similar extent. That's because even though a single coronavirus is smaller than the filters' pores, at 0.12 micrometers, the viruses are still retained because they don't float individually through the air. The aerosols or droplets to which the viruses attach themselves are large enough for a HEPA filter. *

→**assumptions or measurements**

* Original text: „Die Belastung der Raumluft mit Viren lässt sich nicht mit vertretbarem Aufwand messen, wir haben uns deshalb hilfsweise angesehen, wie effektiv sie den Feinstaub in geschlossenen Räumen bekämpfen – in der Annahme, dass Krankheitserreger in ähnlichem Umfang im Filter hängen bleiben. Denn auch wenn ein einzelnes Coronavirus mit 0,12 Mikrometern kleiner ist als die Poren der Filter, werden die Viren trotzdem zurückgehalten, denn sie schweben nicht einzeln durch die Luft. Die Aerosole oder Tröpfchen, an die sich die Viren hängen, sind groß genug für einen Hepa-Filter."

Technical solutions

air cleaning devices **with filter**: higher power devices

and many more

2.500 – 5.000 €

general principle of air cleaning devices with filter - **collection**:

- collection of particles, incl. viruses in Hepa-filters
- centralized „removal“ in one device per room
- replacement of filters

- plus distributed systems

No measurements of virus de-activation in advertisements

expensive „toys“

Ozonos (AU)

€ 1.099 – 1.199

Nanowave Air (USA)

US$ 3.450

with references to SARS-CoV-2-de-activation

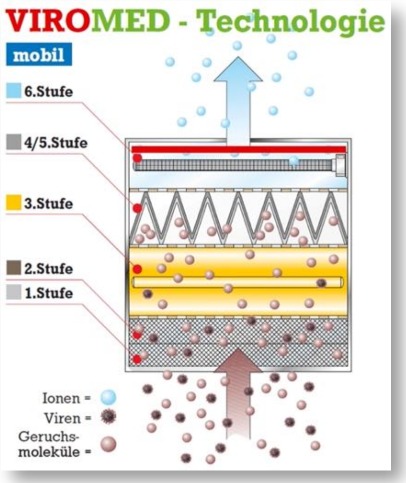
Technical solutions

air cleaning devices **without filter**

No measurements of virus de-activation in advertisements

general principle: **de-activation**

- temperature
- UV-C-radiation
- plasma
- ozone
- combinations



3.900 – 5.400 €

https://www.viromed.de/entkeimung/

- flow-through device
- UV-C de-activation
- high air flow rate
- **centralized** solution

> 2.000 €

https://youvee.de/

- removes Corona-virus and germs from the air
- scientifically approved UV-C-light-method
- removes even fungal spores from the air
- long-term use
- maintenance-free, because **no filter**

https://www.strub-lube.ch/produkte/broschueren

found in food store in Leopoldshafen

additional products

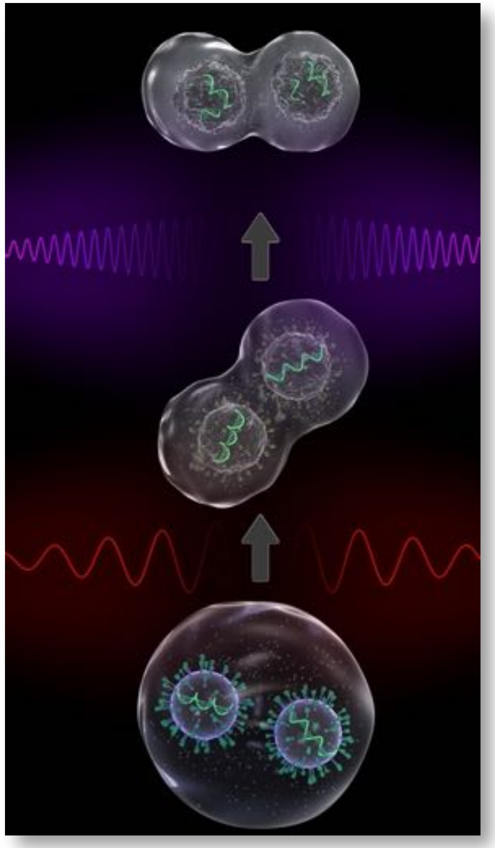
https://sayoli.eu/en/produkt/medicalc-uv-c-air-sterilizer-sayoli-200/

https://www.ltg.de

https://www.uvcare.de/

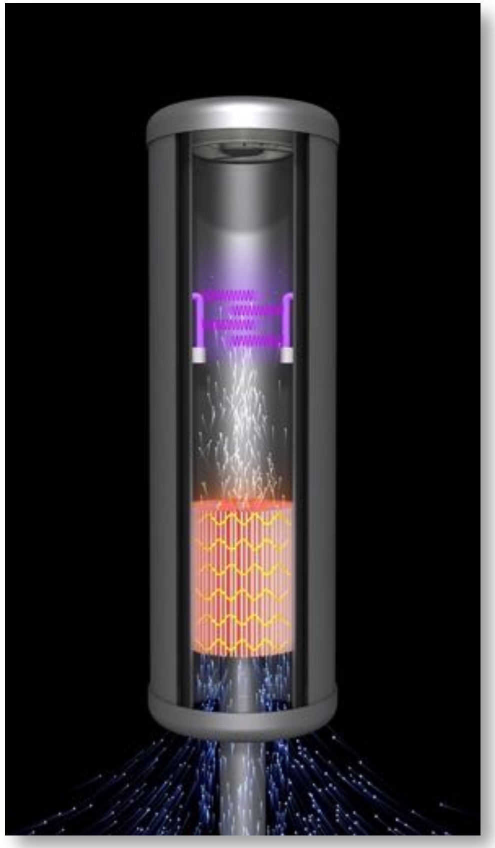
Technical solutions: Aerobuster

Schematic and mode of operation



- **no filter**
- lokal de-activation by
  - temperature (drying of aerosols and pre-damage of virus) – not necessary
  - UV-C-radiation
- distributed arrangement
- low costs
- maintenance-free

Aerosols contain water, proteins, salts, cell residues and viruses. In the first step, the aerosols are dried and the viruses are thus pre-damaged, then the genetic material is destroyed by UV-C



Images: Grupe / KIT

proof of virus de-activation (95-99 %)

Photo: Heid / KIT

Aerobuster: local - local

the approach and the implementation

Approach:

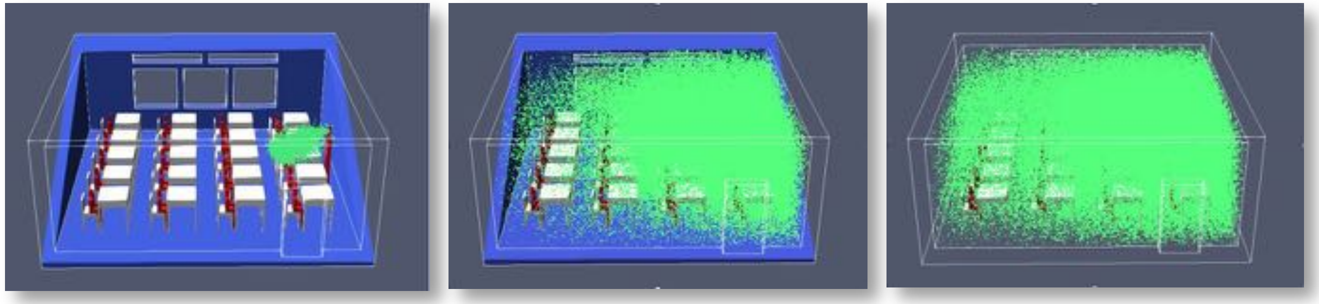
- no filter – no collection of harmful substances
- local de-activation of virus
- local coverage in room by use of several devices

how did we do it:

- assemble team of volunteers
- cooperation of many disciplines
- use of many infrastructures available at a national laboratory
- experienced patent office, innovation management and public relations
- no additional funding intially, use of base funding of institutes

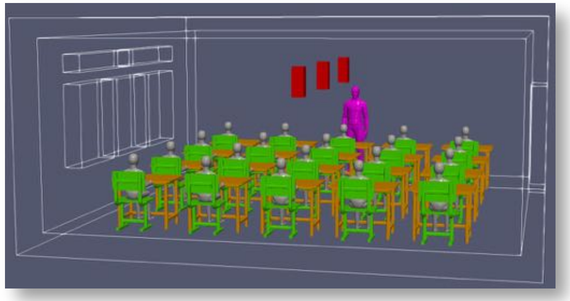
Distribution of (infected) aerosols

without ventilation and aerobuster



Start | after 7 minutes | after 15 minutes

room equipped with 3 aerobuster



situation in class room: 20 children, one teacher (infected) exhaling continuously, windows closed, aerosol distribution calculated based on the thermal motion of the air due to the temperature difference between body and room temperature

simulation using Gasflow MPI Aerosol Code

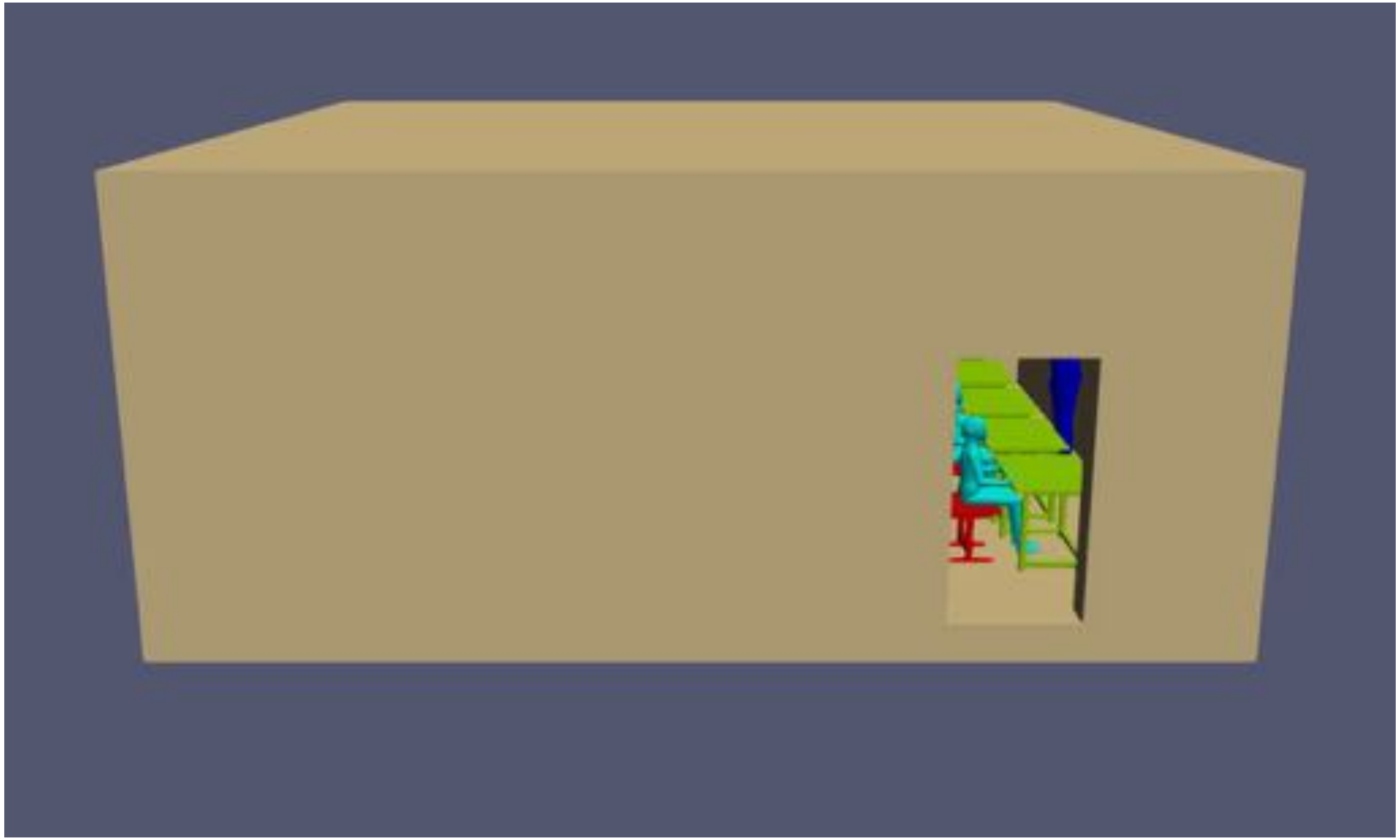
- optimized number and position of aerobuster
- free choice of room dimensions
- arbitrary number of people in room
- freedom of choice of air flow direction and volume flow
- individual calculation for each room

simulations show a drastic reduction of the aerosol spreading in entire room by the operation of the aerobusters

airflow simulations by Jianjun Xiao (ITES-KIT)

Distribution of (infected) aerosols

3-D particle visualization in the classroom



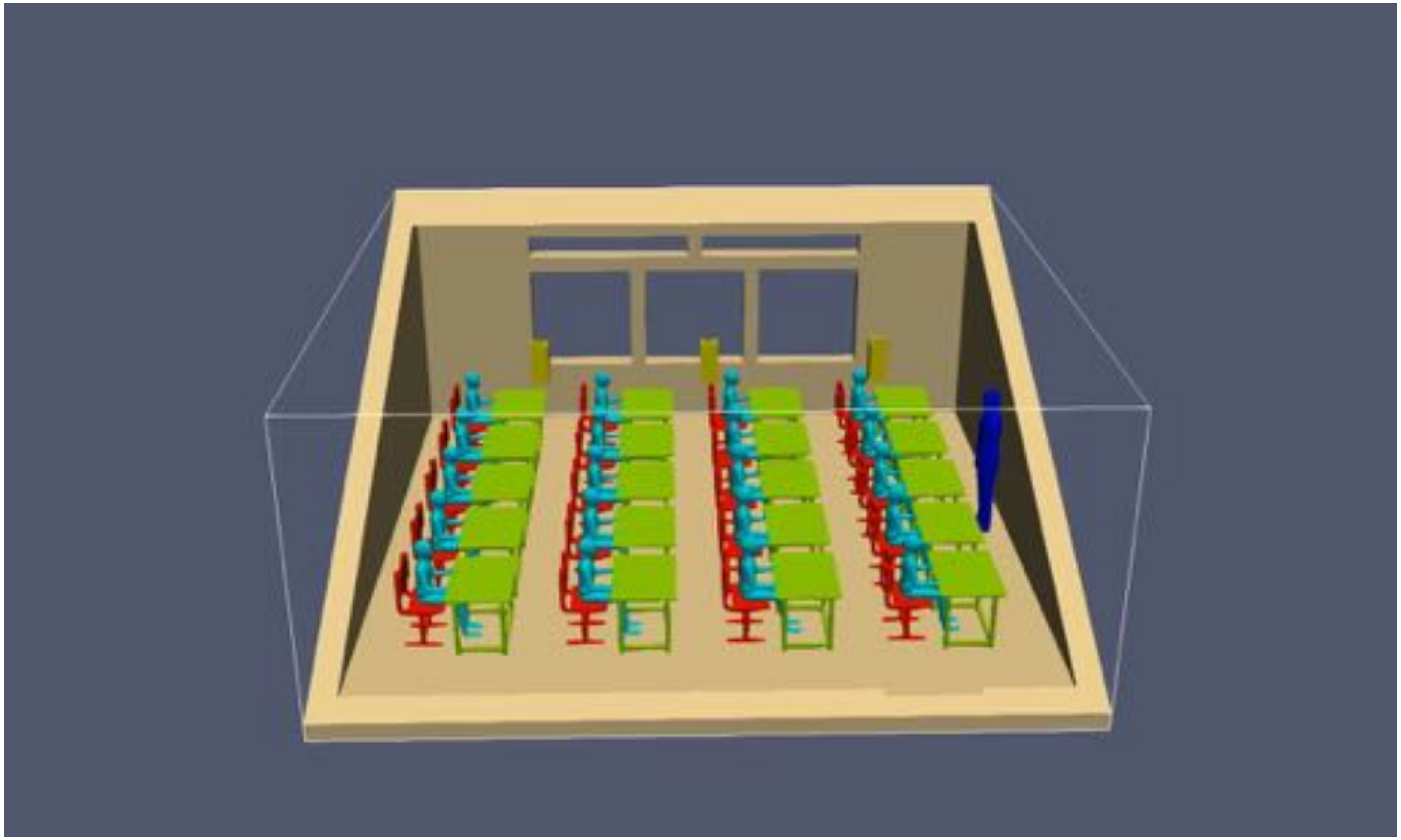
airflow simulations by Jianjun Xiao (ITES-KIT)

Distribution of (infected) aerosols

3-D particle visualization in the classroom

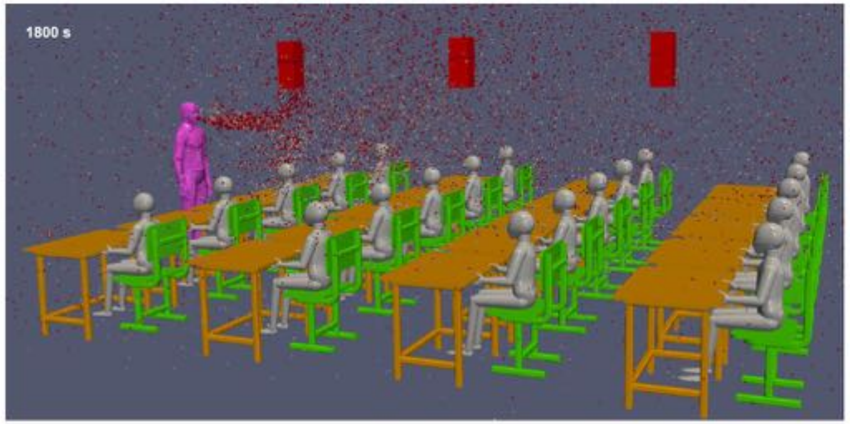
it can also go wrong! we did de-activate the virus using three aerobusters operated at high temperature

warm air keeps the aerosols at bottom of room

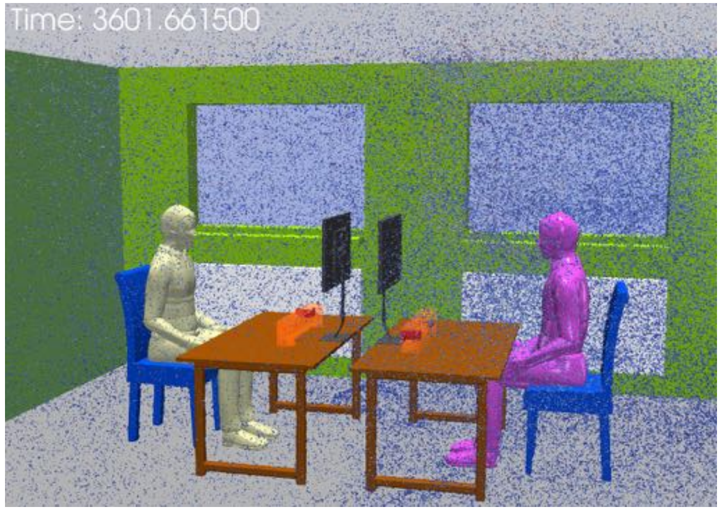


airflow simulations by Jianjun Xiao (ITES-KIT)

Further examples of 3-D AeroFLOW simulation

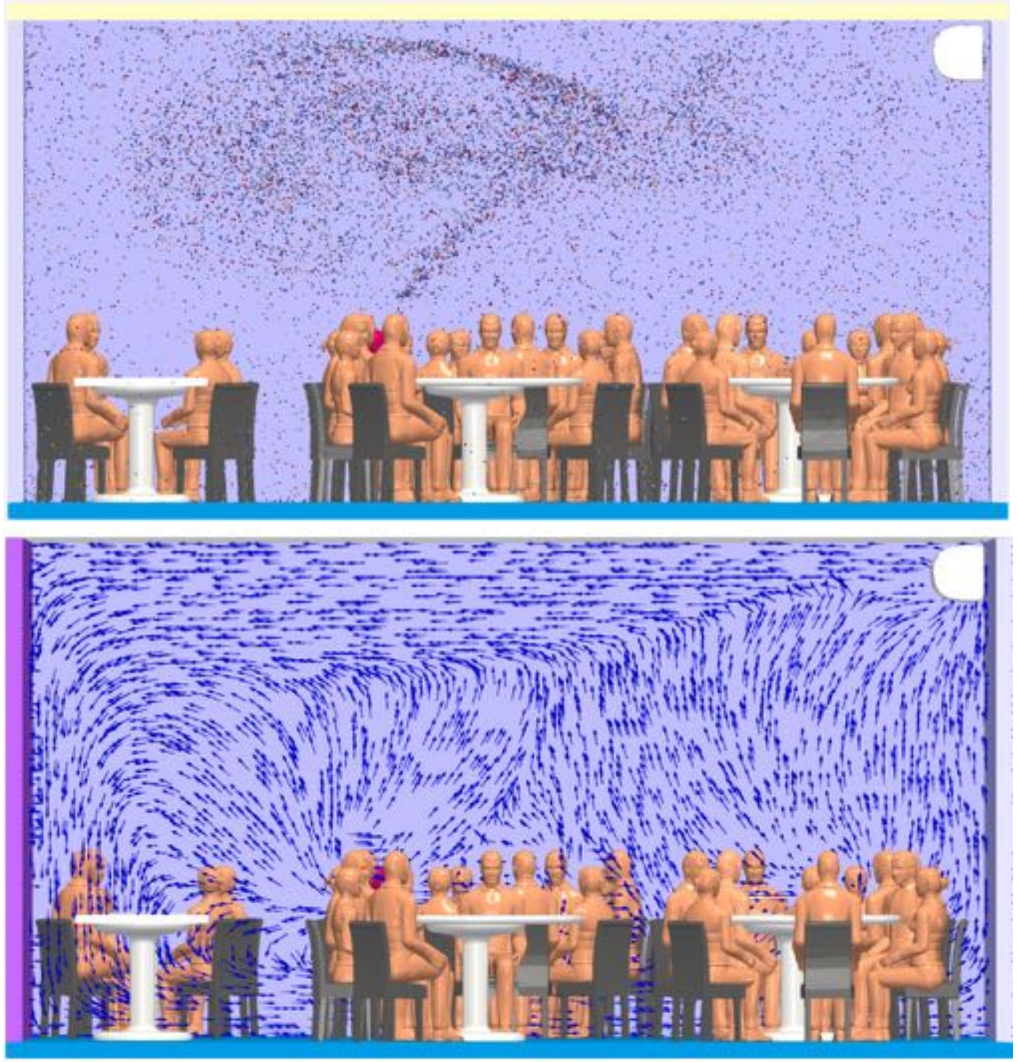


Classroom with Aerobusters



Office with small Aerobuster

Restaurant with air conditioner



airflow simulations by Jianjun Xiao (ITES-KIT)

Quantitative measurement of de-activation

simple principle – but...

„Aerobuster“ - air cleaning system developed at KIT

schematic of apparatus for phages

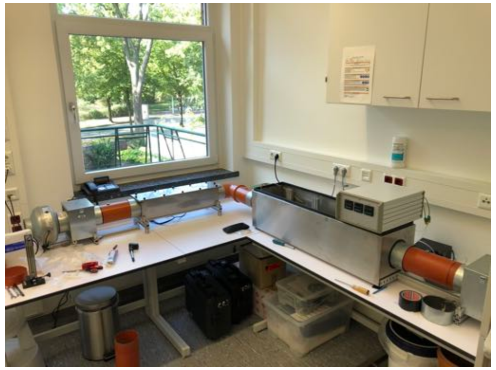
Testing system for de-activation of virus (bacteriophage MS2) loaded aerosols at Tierärztliche Hochschule (TiHo) Hannover

virus measurements by Jochen Schultz (TiHo Hannover)

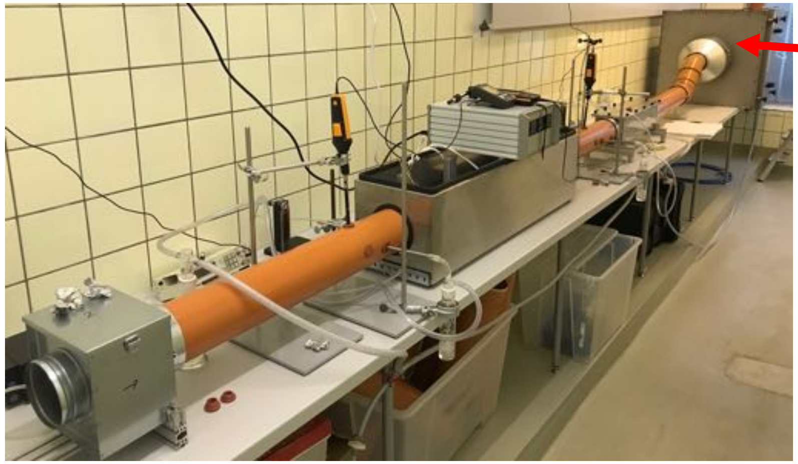
Quantitative measurement of de-activation

- Preparation of virus-loaded aerosols and transfer to measurement apparatus
- quantitative measurement of virus in aerosols
- flexible construction for adaptation of different devices

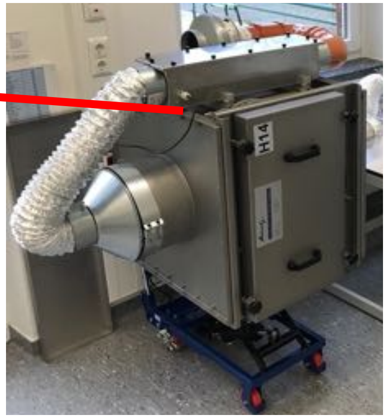
- initial measurements using model virus MS2 (Tierärztliche Hochschule Hannover (Veterinary University))



October 2020



May 2021

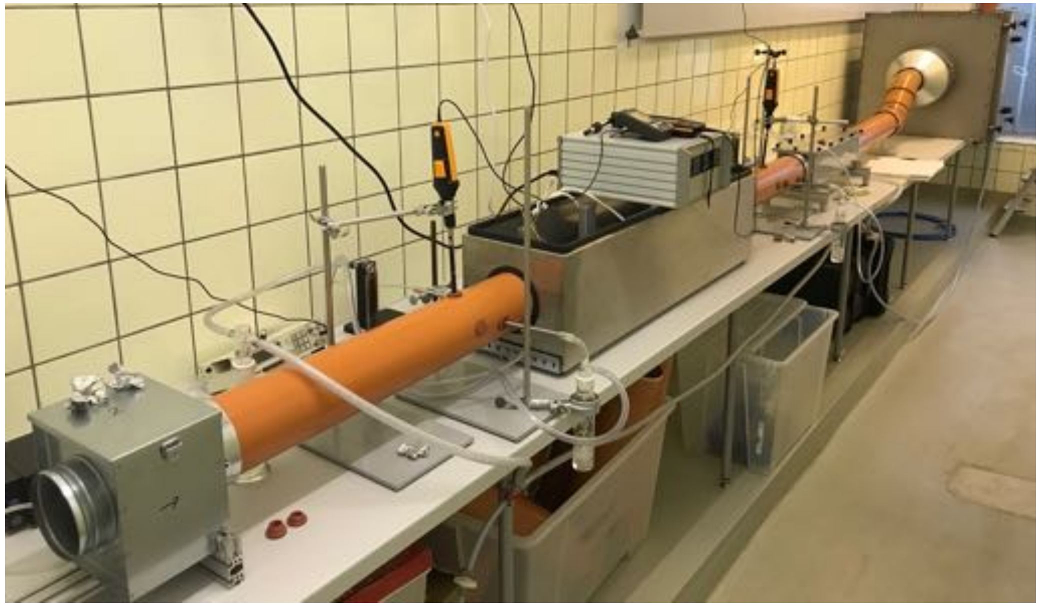


„gigantic“ Hepa-filter

- construction of an apparatus for measurements with SARS-CoV-2 virus (Munich)

Quantitative measurement of de-activation

	measurement point A (before device)						measurement point B (after device)						
virus conc. introduced	temp.	rel. humidity	velocity	particle class.	virus conc.	pressure	temp.	rel. humidity	velocity	particle class.	virus conc.	pressure	virus conc. in outgoing air flow
[pfu/L]*	[°C]	[%]	[m/s]	[μm]	[pfu/m3]	[Pa]	[°C]	[%]	[m/s]	[μm]	[pfu/m3]	[Pa]	[pfu/L]



plus measurement of UV-C-dose in the device to determine correlation between dose and de-activation

*pfu: plaque-forming unit

virus measurements by Jochen Schultz (TiHo Hannover)

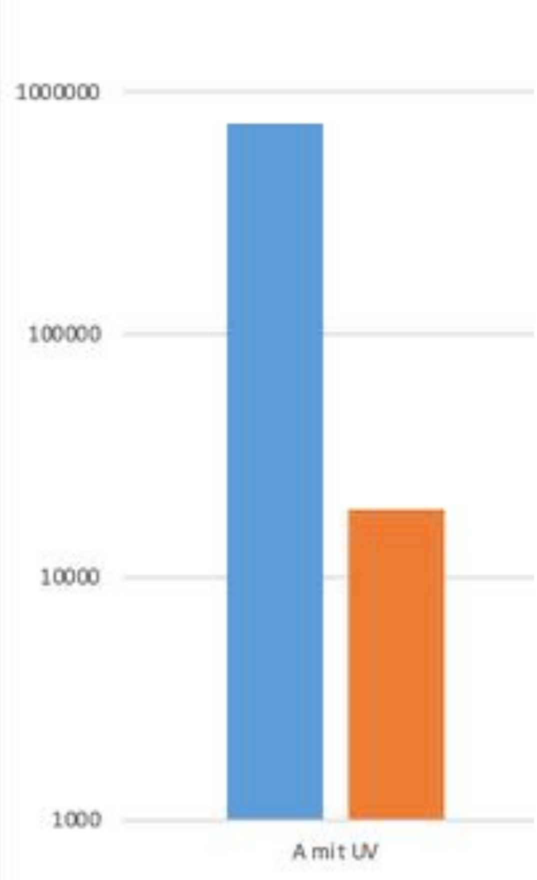
Quantitative measurement of de-activation

Karlsruhe Institute of Technology

measurements with phages MS2

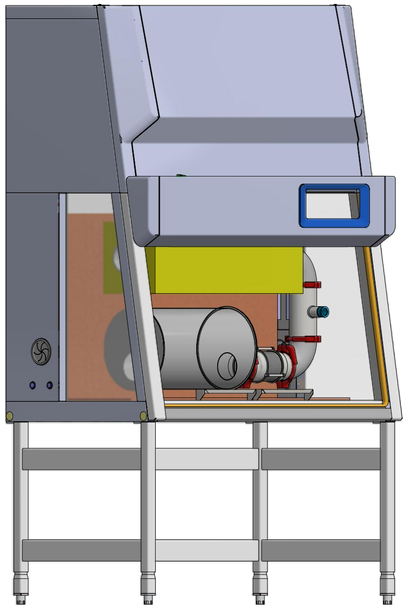
tests on **real air cleaning devices** with **aerosol-borne virus** under **realistic and controlled conditions** (UV-C-dose, volume flow, temperature, humidity, residence time, etc.)

- already achieved for MS2 virus (> 97,8%)
- available soon at TUM / HZM for SARS CoV-2 in collaboration with KIT and TiHo



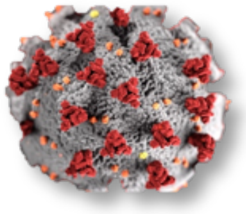
typical reduction of virus by aerobuster

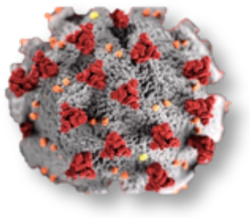
Set-up for SARS (being tested)



virus measurement by Jochen Schultz (TiHo Hannover)

Measurements with phages (TiHo)





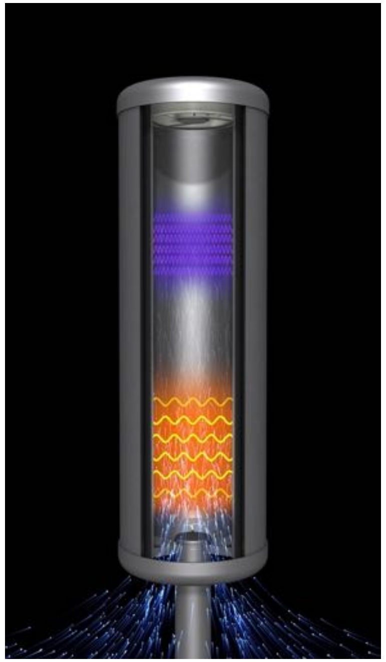
preliminary results of measurements:

- D_{90}-value is achieved für MS2 model virus
- considering that MS2 is more resistant than SARS CoV-2 de-activation of SARS CoV-2 is expected to be higher (> 98%) (background: data on almost complete UV-C de-activation of SARS CoV-2 yield a value of 1 mJ/cm² (1mWs/cm²)*)
- further optimization of measurement conditions necessary

*Of course, this assessment is subject to reservations. Since the irradiation experiments on SARS-CoV-2 were carried out in a medium and the viruses in the air are generally more sensitive to radiation, the assessment is well justifiable.

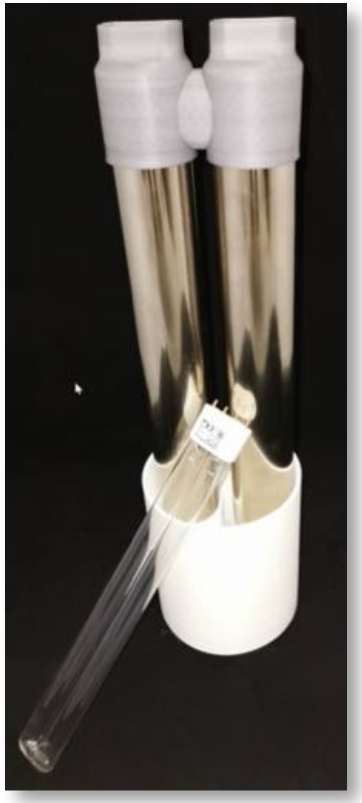
virus measurement by Jochen Schultz (TiHo Hannover)

Development of Aerobuster: variations



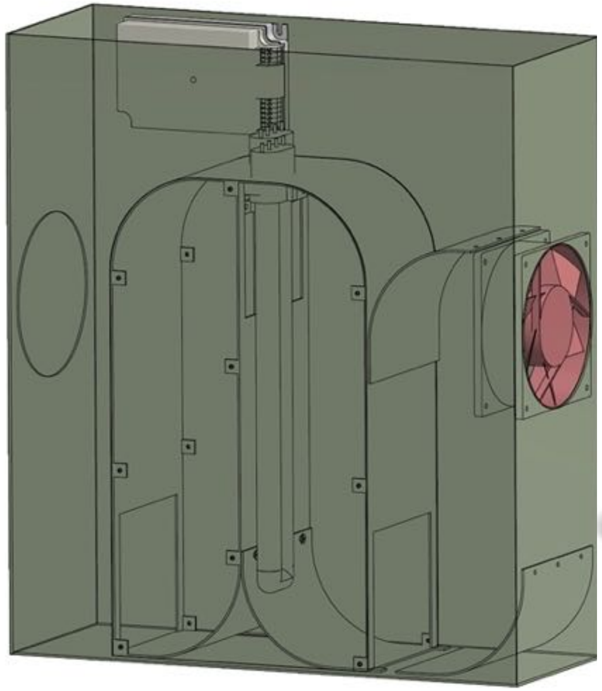
T + UV-C
or
UV-C

design by
Alessandro Boldrin



Increase of residence time

box design (sinus winding)



increased residence time, low-price production using sheet metal, flexible number of channels

cylinder design

design studies by
Alessandro Boldrin

technical development of Aerobuster

design parameter (planned):

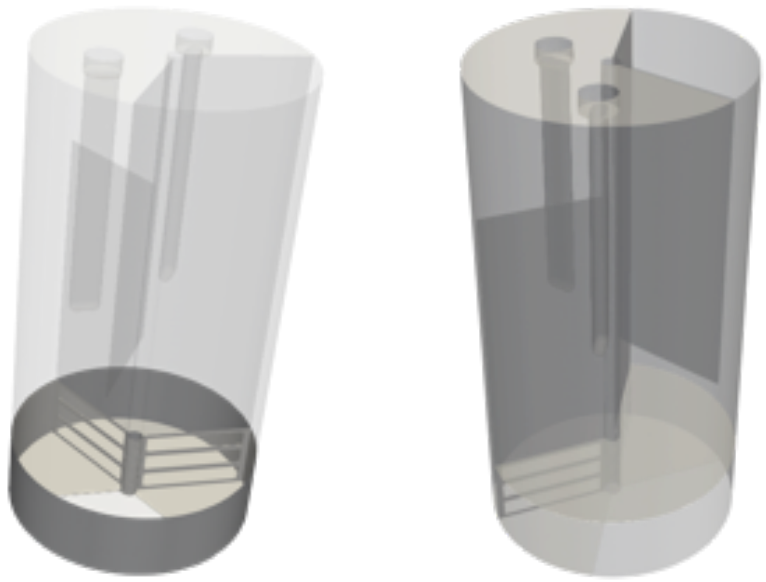
- 200 m^3/h volume flow in normal operation, using two UV-C lamps
- Booster to 300 m^3/h with third lamp
- different installation: Ständer, Wand- und Deckenmontage
- air flow
    - bottom up
    - top down
    - horizontal

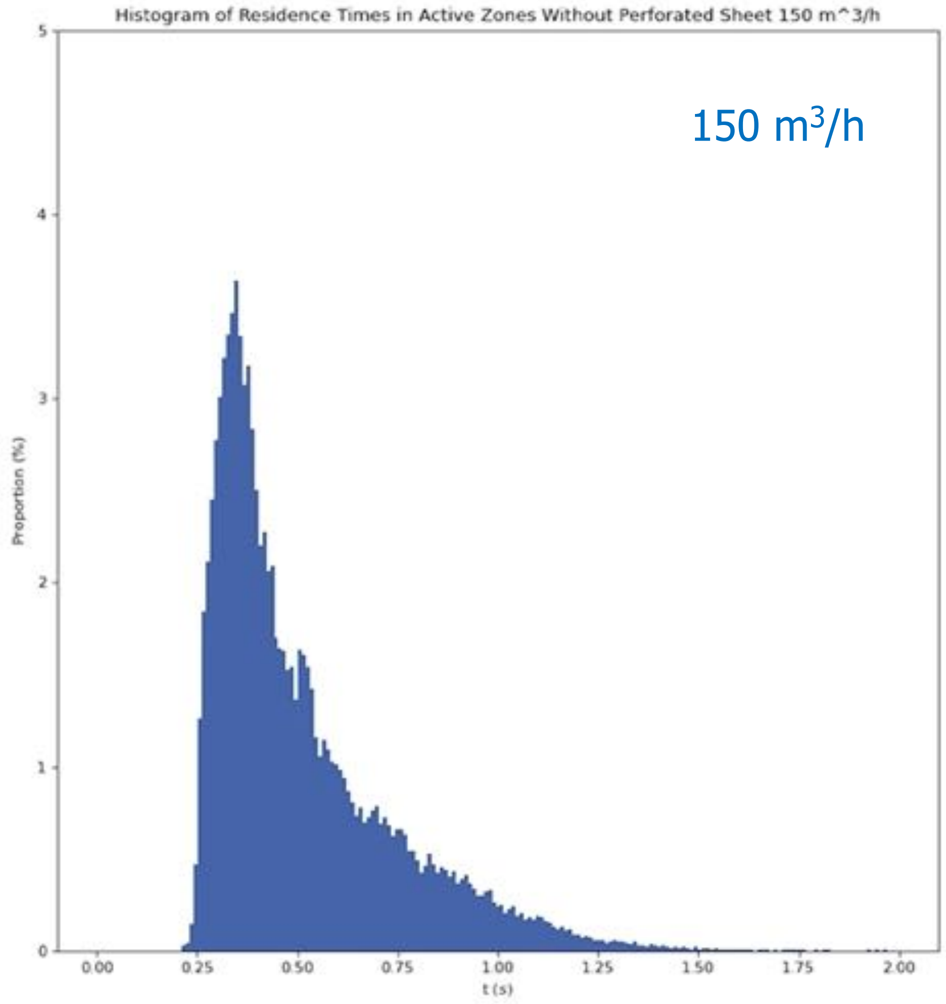
extras:

- "people counter" – intelligent operation
- …

Air flow simulations (inside Aerobuster)

Program: OpenFOAM (Open Source CFD Code)

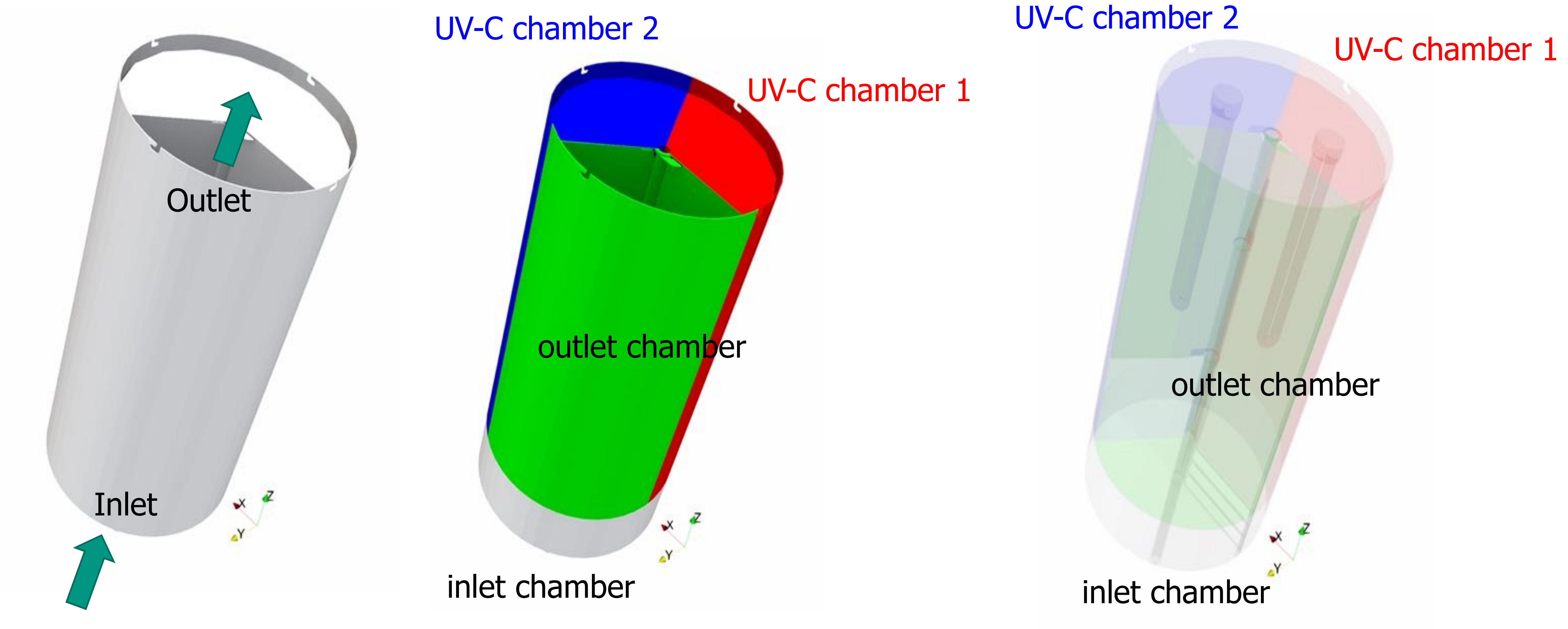




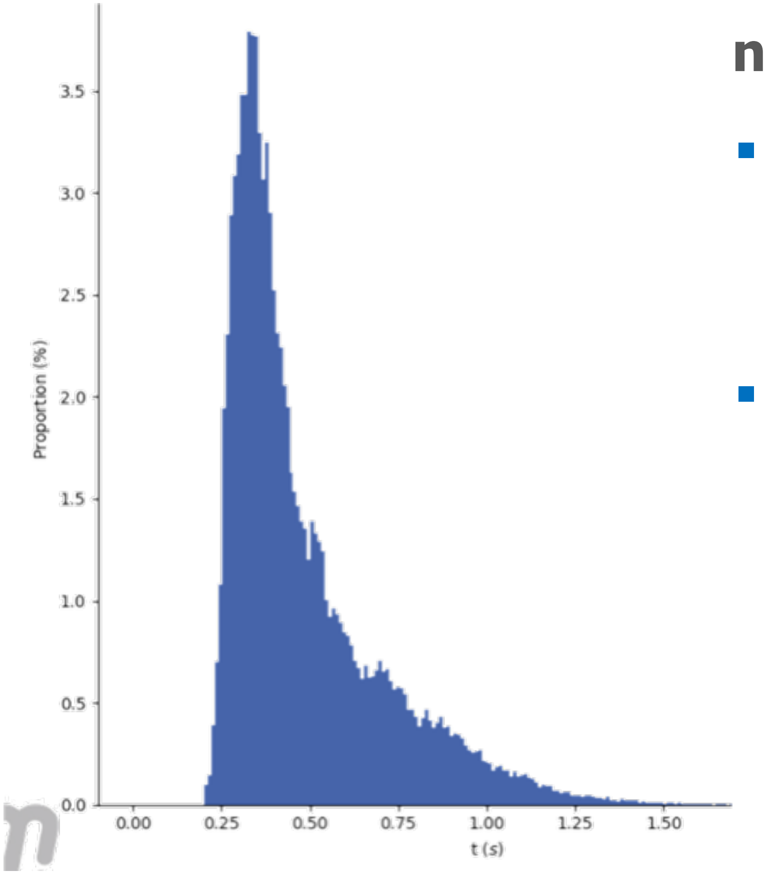
numerical solution: OpenFOAM (Open Source CFD Code) using pimpleFoam

simulations done using bwUniCluster2 with 80 Processors
total time: ~24h

Air flow simulations (inside Aerobuster)

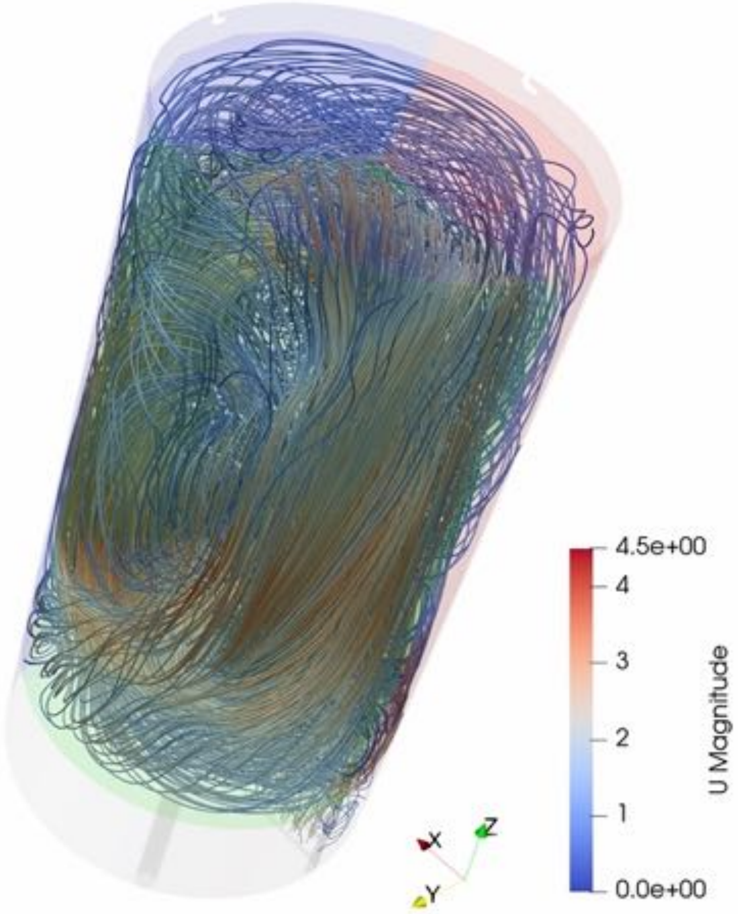


Air flow lines, residence time

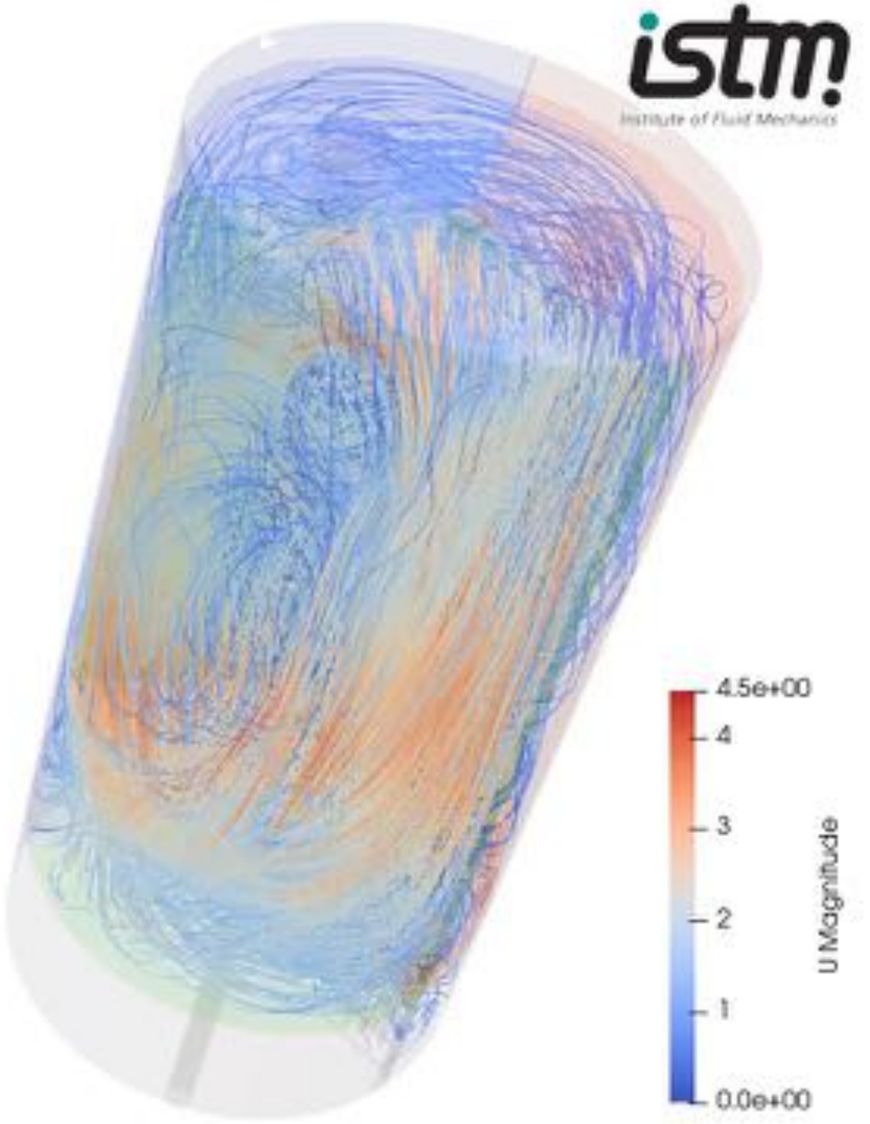


numerical efforts:

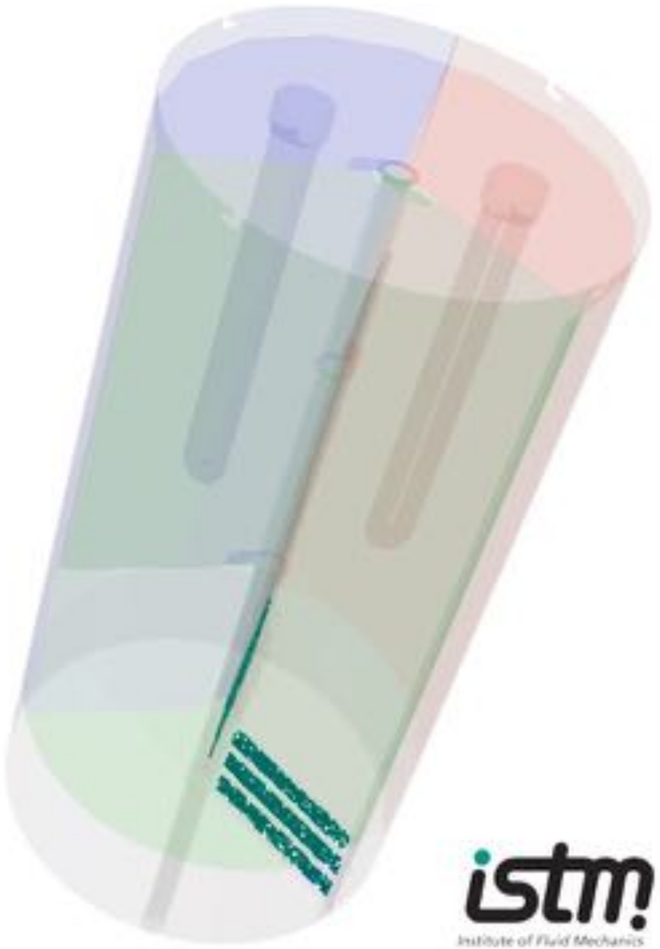
- internal flow topology analysis:
  - detailed flow field analysis provides relevant knowledge of internal flow mixing and heat-transfer rates
- particle residence time (PRT) quantification:
  - an accurate probability density function (PDF) of the PRT is of utmost importance for precise UV exposition rate determinations

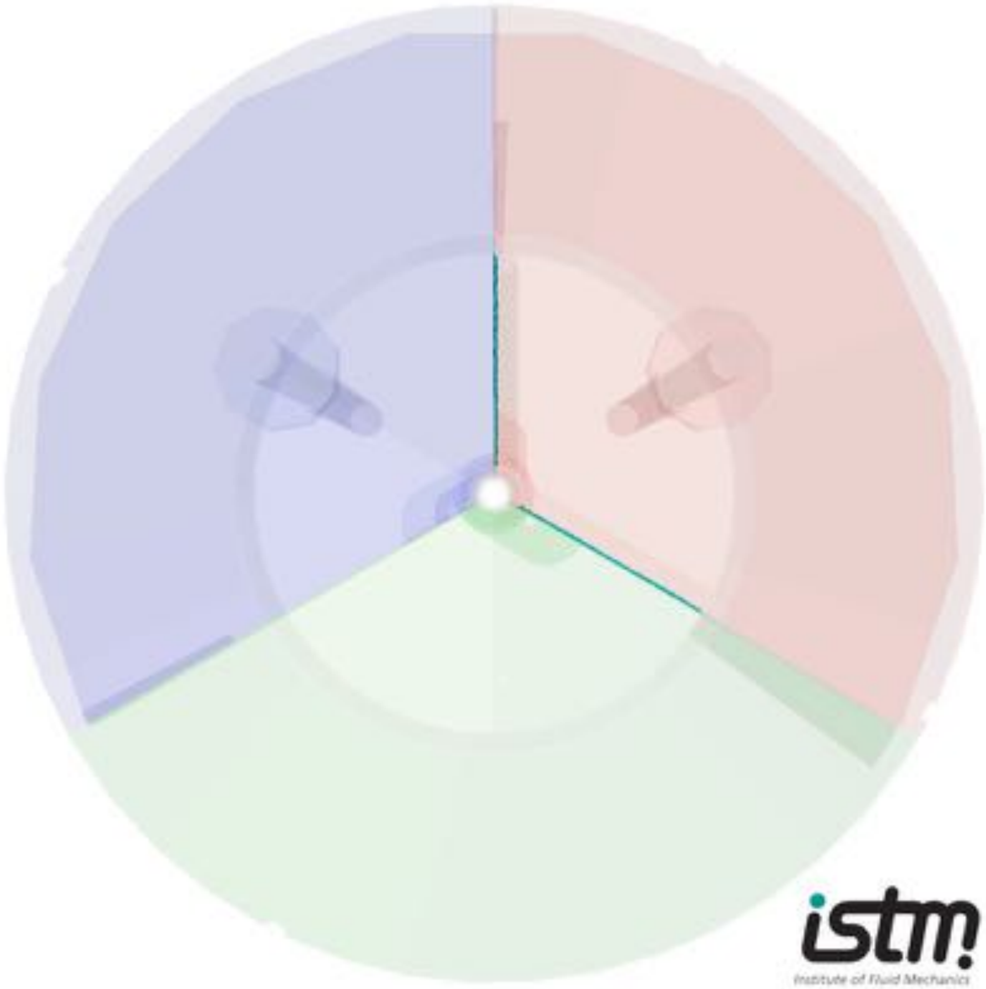


Air flow lines

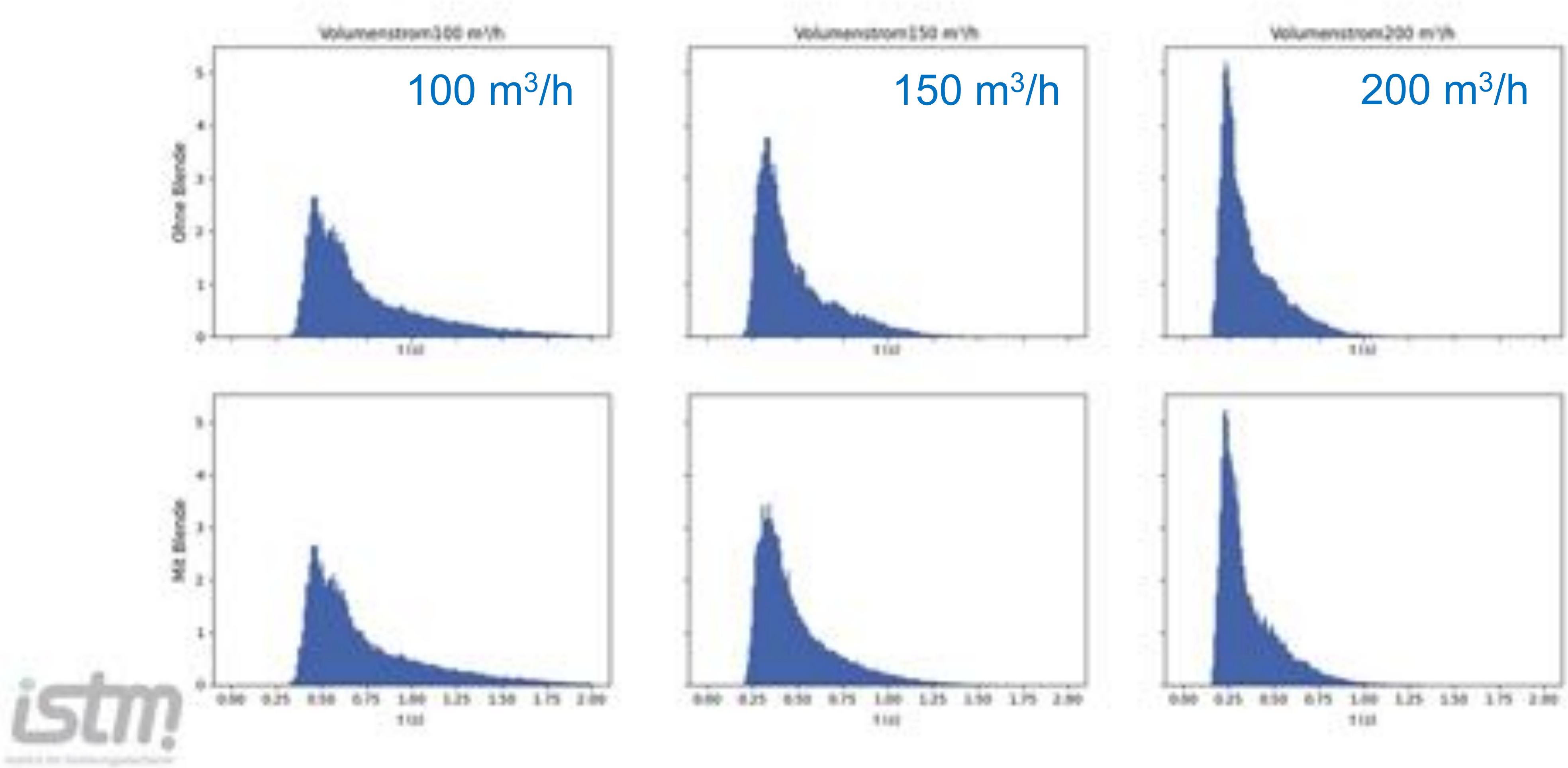


Scalar transport





Comparison of residence times



Development of Aerobuster

Karlsruhe Institute of Technology

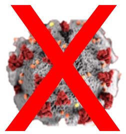
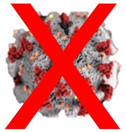
Basic ideas

- no collection of aerosols in filters
- local de-activation of virus during passage through device
- distributed arrangement of several devices instead of global solution
- proof of de-activation with virus-loaded aerosols
- simulation of aerosols spreading in rooms and effectiveness of device
- inexpensive components for mass use in schools, restaurants, offices, etc.

contributions of six institutes at KIT:
INT, IPE, ISTM, IMK, ITES, IFG
+ TiHo, TUM, HZM

05/20	tests of air flow in device and in the surrounding
06/20	consideration of various de-activation methods: temperature, UV-C, plasma, microwave, combinations of methods
08/20	patent application
09/20	measurements of de-activation of virus in aerosols using bacteriophages
09/20	simulations of aerosol distribution in rooms
11/20	press release
> 11/20	contacts to industrial partners for production and marketing of Aerobuster

design by A. Boldrin


Summary

- local de-activation of virus, no filter
- decentralized units for effective reduction of virus load in aerosols in the entire room
- modular design for flexible application in different environments
- assembly-free as a floor standing unit, or mounted at wall or ceiling
- cost-effective, by use of standard components
- maintenance-free

Our goals

- rapid implementation on a pilot scale
- rapid start of production in large quantities
- rapid start of sales
- large-scale use in public areas, such as schools, kindergartens, stores, offices, public transport, doctors' offices, hospitals, old people's and nursing homes, restaurants, etc.

Outlook

since July 2021, Helmholtz-funded project CORAERO

„ Airborne Transmission of SARS Coronavirus - From Fundamental Science to Efficient Air Cleaning Systems“

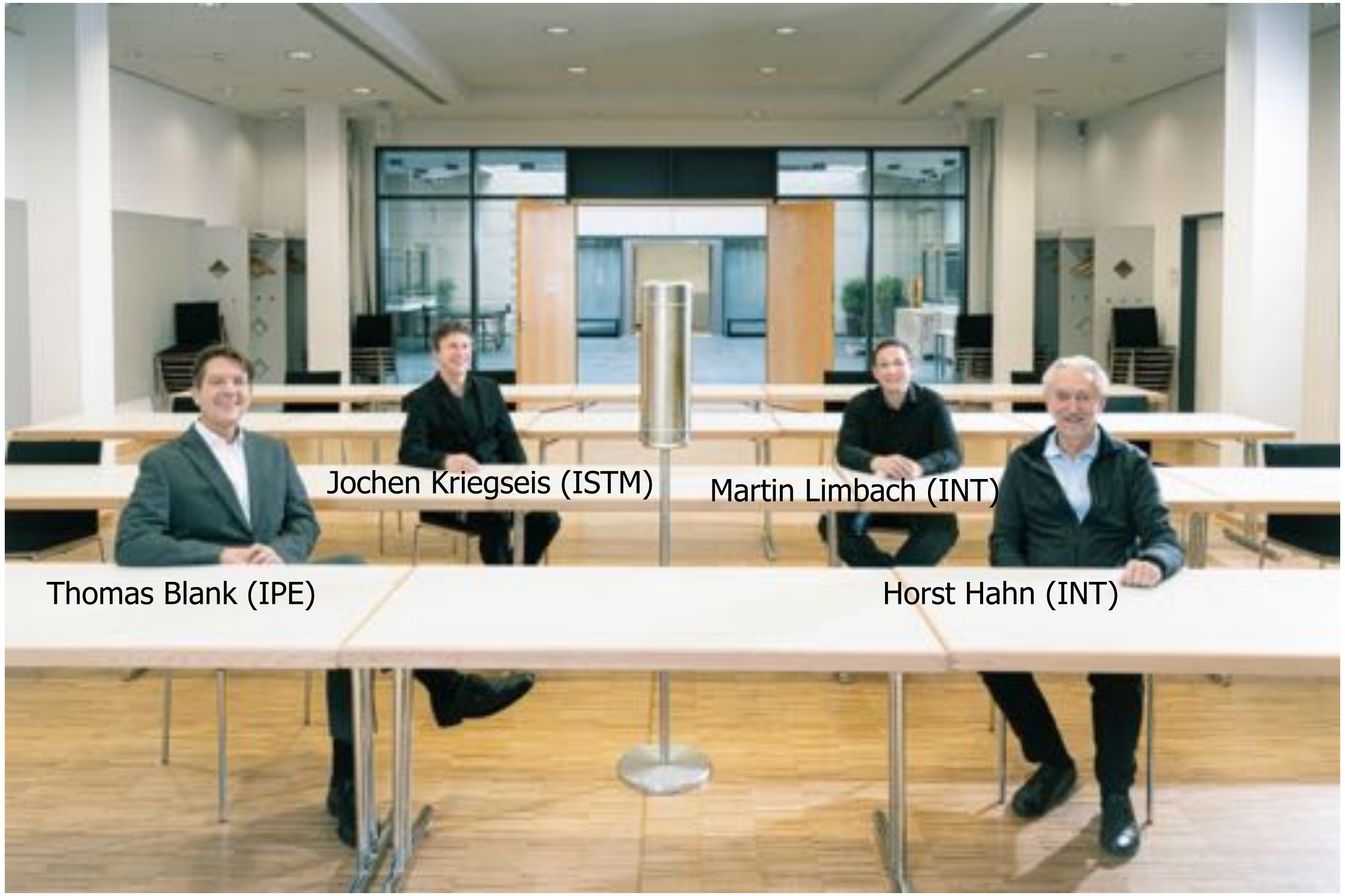
is funded for 5 years with an additional budget of approx. 6 Mill Euro (total) plus matching funds of the seven Helmholtz centers in same amount

goal: technical solutions for coming pandemics

interested?:

https://www.helmholtz.de/gesundheit/helmholtz-erforscht-ganzheitliche-loesungsansaetze-zur-pandemiebewaeltigung/

Thanks to all volunteers and the core team



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IPE:
Matthias Luh, Peter Schöck, Simon Bischof, Tibor Piller, Maximilian Feinauer, Thomas Blank

ITES:
Jianjun Xiao, Thomas Jordan, Gottfried Necker, Guang Hu, Wolfgang Breitung

IMK:
Nsikanabasi Umo, Ottmar Möhler, Thomas Leisner

IFG:
Thomas Schwarz, Norman Hembach

INT:
Martin Limbach

TiHo Hannover:
Jochen Schulz

Thank you

Idea of a 9-year old for solution of the problem (August 2020)