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IBP Report No. UHS-068/2020

Efficiency of the room air purifier from Heraeus (SoluvaAirW) on the reduction and inactivation of airborne viruses

Carried out on behalf of Heraeus
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The report includes:
25 pages of text
22 images
3 tables

Valley, December 14, 2020

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1 research object

The aim of the investigation was to test the reduction and inactivation of airborne surrogate viruses (enveloped Phi6 bacteriophage with a structure, particle size and environmental stability comparable to SARS-CoV-2 [1], [2], [3], [4], [5]) by the air purification device (device specifications see Table 1) in a specially equipped test room. This was equipped with dummies, tables and chairs for the investigation to simulate a classroom.

Table 1: Device specification

Device name	SoluvaAirW
Manufacturer	Heraeus Noblelight GmbH
Input of the device	November 09, 2020
Working principle	2x spotlights NNI 50 / 26XL, 70 W electrical power and 19 W UV-C flow each
installation	Wall mounting for experiments on specially made brackets, distance between lower edge of device and floor 1.78 meters
Flow velocity	0.5 m / s
Volume flow	410 m³ / h
Device dimension	W 998 mm x D 197 mm x H 685 mm 33 - 200
Room size	m³
IBP internal test number	E3423_1 and E3423_2
Measurement period	KW 46 and KW 49

The investigations related exclusively to aerosols in the air. The natural half-life of the virus (Phi6 bacteriophage) must be taken into account when calculating the efficiency of the device.

The structure was based on DIN ISO 16000-36 [6] for the examination of airborne bacteria, realistically adapted to the specific requirements of viruses. The viruses were collected from the room air analogously to DIN-ISO 16000-16 [7], the filters were processed in accordance with DIN ISO 16000-17 [8]. The number of active viruses (“virulence”) was determined in the laboratory using the plaque assay method ([9], [10]).

Note: Investigations of virus activity on surfaces require a different method, since the stability of viruses in liquids (“smear infection”) must be considered here.

2 method

The tests took place in a temperature and humidity controlled test stand (IBP Indoor Air Test Center, IATC: L: 8.2 m, W: 5.0 m, H: 3.1 m, A: 41 m², V:
127 m³). Typical room situations can be simulated in the IATC using surfaces that can be activated. In this series of tests, an outer wall was simulated on the east wall with a surface temperature of 19 ° C and window elements with 15 ° C (Fig. 1, top left). All other surfaces simulate internal walls and have a target value of 20 ° C. The heat emission by 16 students and the teacher is simulated with human-like heating dummies, which each emit approx. 75 W (Fig. 2, Fig. 3, Fig. 4). The occupancy density is 2.56 m² per student and is thus between the recommended 2 m² per student [11] and the median of 2.8 m² per student, which is determined in a survey by the IBP of schools in the district of Miesbach [12] has been.

The room was not additionally ventilated.

The measurement campaign is divided into three sub-campaigns:

0. Tracer gas measurements to determine the ideal emission and sampling location for surrogate viruses

1st measurement day 1 - November 12, 2020

2nd measurement day 2 - December 2, 2020

The following sensors are used for the measurements (Fig. 1 top right and bottom):

- Room air temperature: four-wire PT100 sensors with an accuracy of ± 0.1 K at 20 ° C according to DIN EN 60751 [13] class A. Relative humidity: Rotronic HygroClip
- HC2-C05 sensor with ± 1.5% RH accuracy

- Flow velocity: Ahlborn thermoanemometer omnidirectional up to 1m / s, type FVAD05TOK300
- CO_2: Vaisala GMW90 / 94, measuring range: 0-5,000 ppm, accuracy ± 2.7%

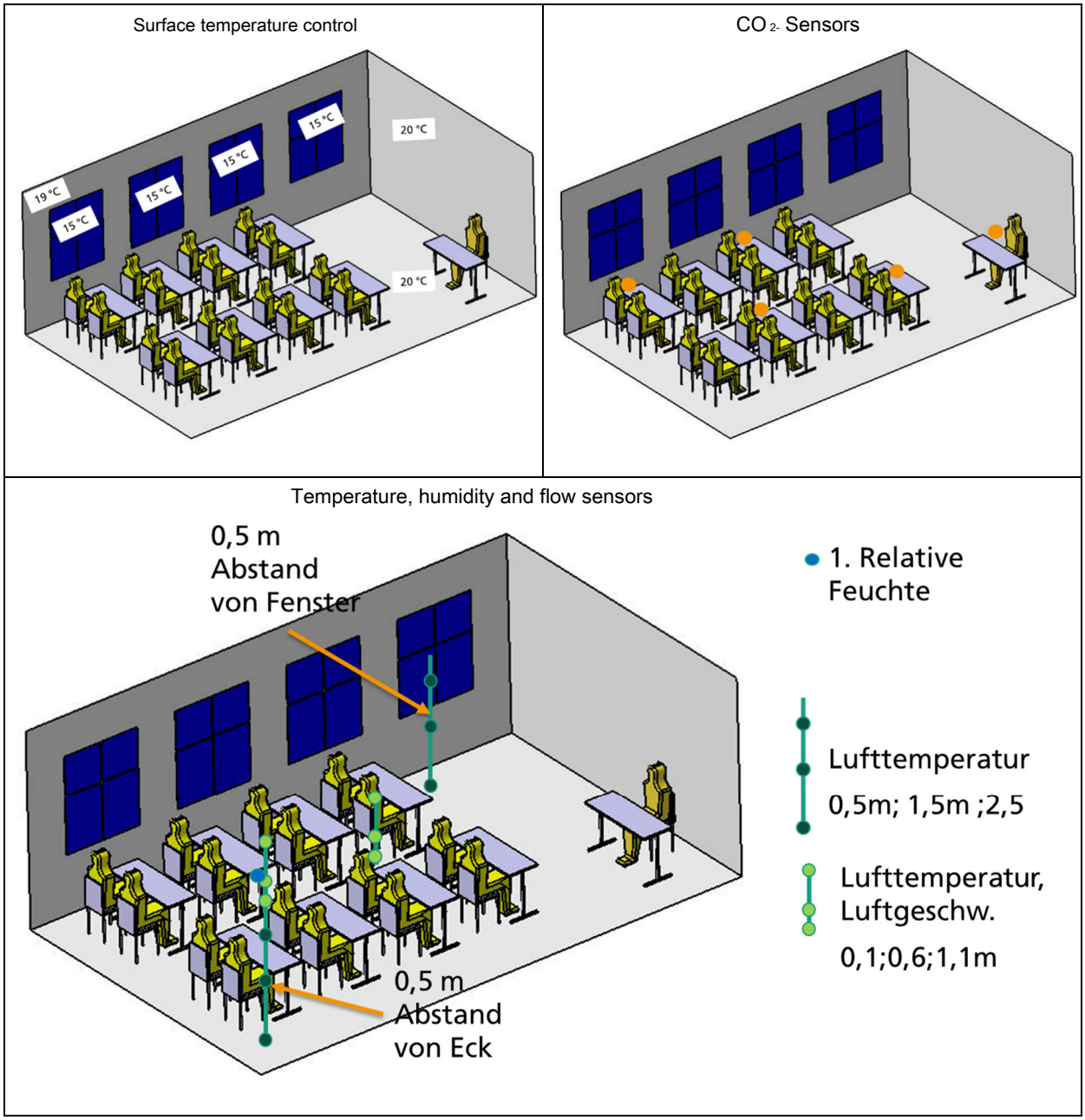
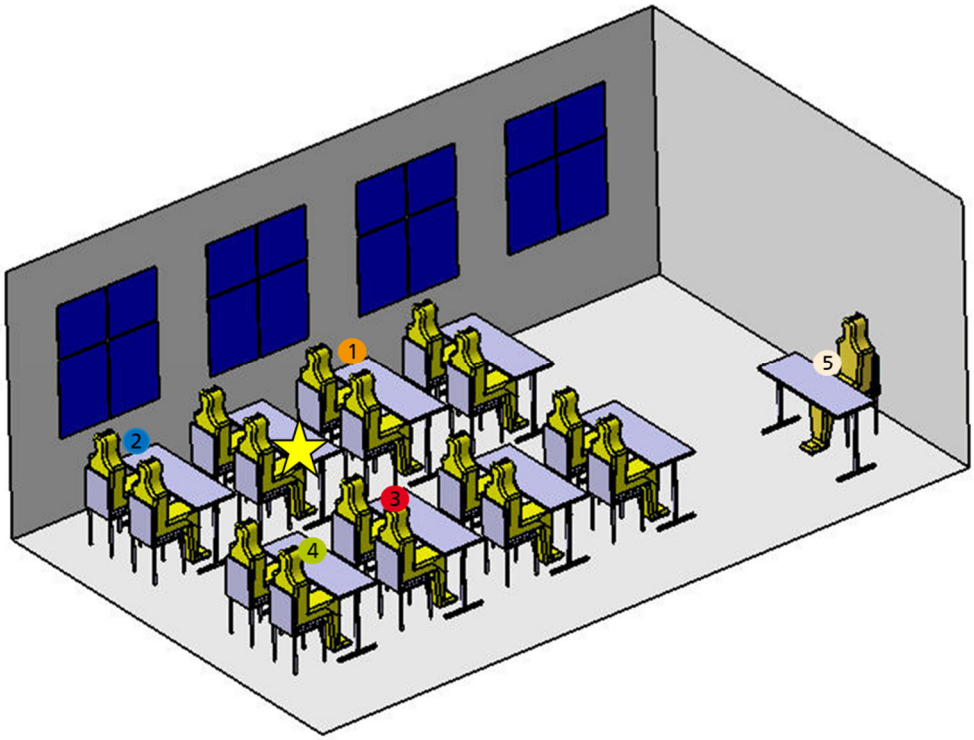


Fig. 1: Measurement setup

The final test set-up for examining the efficiency of the room air purifier is shown in Figure 2. The test setup was determined in consultation with the customer based on the results of the tracer gas measurements carried out (see Section 3 Results).

The two air cleaning devices were installed on the wall at a height of approx.
1.69 m lower edge of the device and approx. 2.5 m upper edge of the device (Fig. 3). The viruses were introduced into the room at a distance of 3.3 m (cleaner 1) to 4.1 m (cleaner 2) in front of the inlet of the two SoluvaAirW devices (0.5 m / s; 410 m³ / h). The dosage was initially carried out without switching on the device in order to achieve a high virus load in the room. After that, the dosing and the air purification devices were operated simultaneously before the dosing was deactivated,

to determine virus reduction. This three-part experimental set-up ran for a total of around 4 hours. The particle distribution in the room, the temperature and humidity as well as the ozone content were continuously measured over the entire running time. Figure 4 shows the temperature distribution of the dummies and window areas in the IATC during the test in the form of an IR image.



Legend

Aerosol generator (dosing device)

Sensor technology (ozone, particles, PID)

② and sampling point VOC as well

Aldehydes / ketones

③ Air sampler P1, P2, P3

④ Air sampler P4

Figure 2: Schematic structure of the SoluvaAirW air purification devices in the IATC with aerosol generator (dosing device), sensor technology and air samplers.

Figure 3: Structure of the SoluvaAirW air purification devices in the IATC with aerosol generator (dosing device), sensor technology and air samplers.

Image 4: Left: IR image of the dummies and window areas in the IATC. Right: Comparison of temperature distribution between dummy and human.

According to the requirements of the Federal Environment Agency, when using ozone-producing air cleaning processes (UV-C, plasma technology; ozone direct injection), the determination of by-products is required in the company [14]. These samples were taken on appropriate adsorption tubes for the detection of VVOC and VOC, analyzed using gas chromatography-mass spectrometry [15], as well as on DNPH cartridges for the determination of selected ketones and aldehydes, analyzed using high-performance liquid chromatography diode array methods [16].

At certain times, the viruses were drawn onto an air sampler (MBASS30 version 3 adapted for filter operation by Umweltanalytik Holbach GmbH, Wadern, Germany) and subjected to a plaque assay test for microbial analysis in the laboratory (see Figure 5). For this purpose, the

The sampled filter is processed immediately after sampling and within an hour in the laboratory.

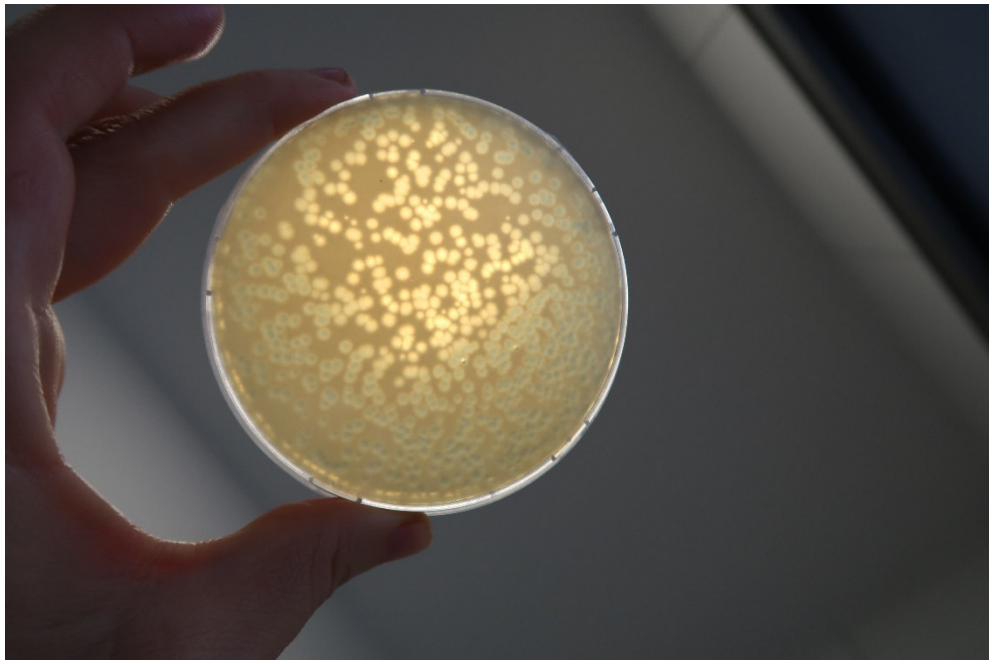


Figure 5: Microbial analysis. Agar plate with plaques caused by viruses (pfu, plaque-forming units)

3 Results

3.1 Tracer gas measurements

The aim of the tracer gas measurements is to gain a deeper understanding of the influence of the SoluvaAirW devices on the room air flow and to determine a suitable arrangement of virus emission and virus collection.

The tracer gas used was CO_2 used. The gas was injected into the room at points over a period of 5 or 20 min at a flow rate of 1.88 l / min.
brings and the time course of the measured CO_{2-} Concentration recorded at the measuring points. Before the measurement, it was ensured that a uniform
There is a moderate initial concentration in the room. This initial concentration was subtracted from the measured concentration in the measurement evaluation, so that the local increase in CO_{2-} Concentration is shown (and not absolute concentration). As a result, a higher number of individual experiments could be carried out within a given time window, since there is no need to ventilate the room and thus the need to recondition the room thermally.

The measurements took place on November 9, 2020 and November 10, 2020.

3.1.1 Emission in row 3, row of windows

For this position the course of the CO_{2-} Concentrations compared with both 5 and 20 minute dosing. In addition, the difference in distribution between switched off and switched on SoluvaAirW devices was
seeks. CO_2 was brought into the room through a hose at the level of the nose of the dummy marked with an asterisk (Fig. 6).

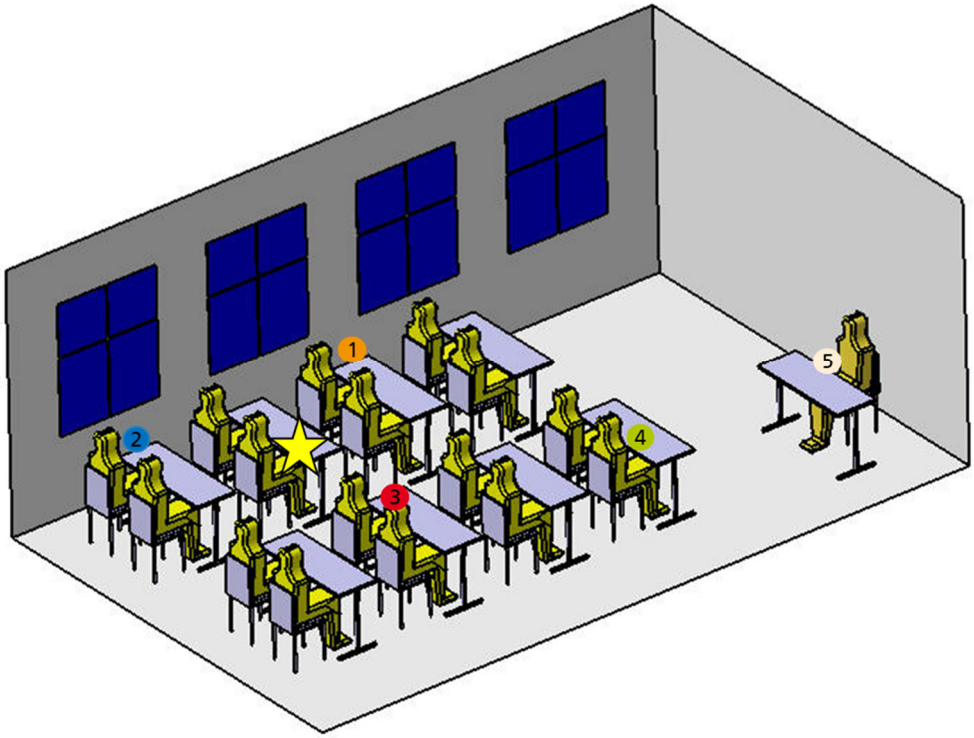


Fig. 6: Dosing and measuring locations for preliminary tests in row 3, row of windows.

Figure 7 shows the result of the course of the CO_{2-} Increase with and without the operation of the two SoluvaAirW devices. The dosing period is highlighted in blue.

Without the SoluvaAirW device, a concentration peak can be seen at measurement positions 1, 2 and 3. Positions 4 and 5 do not appear to be in the direct area of influence of the emission. About 10-15 minutes after the end of the dosing, a uniform concentration appears in the room, which is about 75 ppm higher than before the injection.

When operating the two SoluvaAirW devices, it can be seen that positions 2 and 3 show an increased CO2 concentration during the injection, while the course in positions 1, 4 and 5 is very similar. The spatial arrangement of the devices seems to divide the room into two air cylinders, with the emission being in the left part in Figure 6. As a result, position 1 is no longer in the direct area of influence of the metering point. About 3-4 minutes after the end

the dosing results in a uniform, approx. 75 ppm higher CO in the entire room 2- Concentration one.

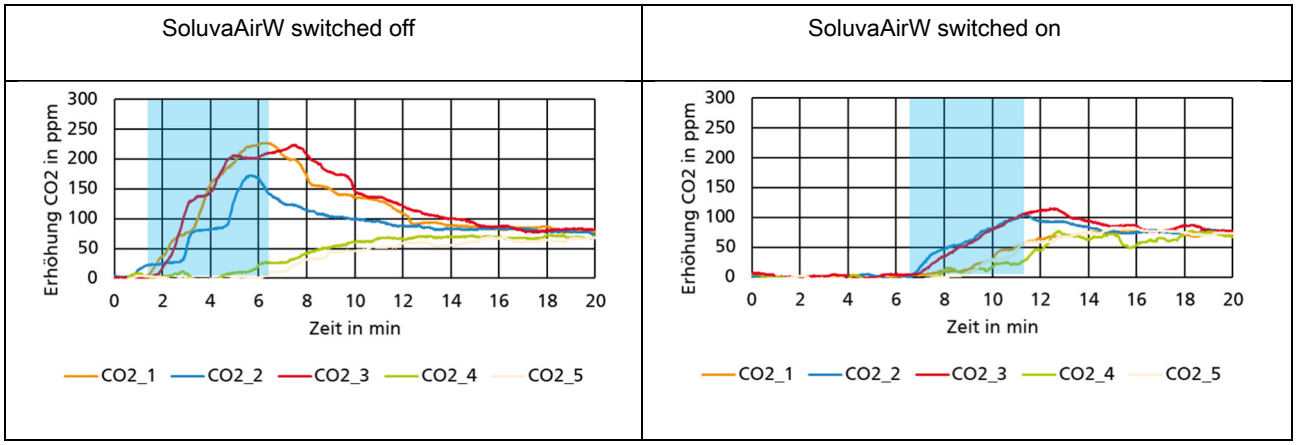


Figure 7: Result of the emission in row 3, row of windows (5 min).

Figure 8 shows the result of the same experiment with a dosage of 20 minutes. The result is very similar to that with a dosing of 5 minutes.About 15 minutes after the end of the dosing, the CO level is 300 ppm higher if the devices are not operated 2- Concentration evenly in the room. With device operation this is the case after 3-4 minutes. Here, too, it can be seen that position 1 was initially in the area of influence of the dosage, but is no longer after switching on the devices.

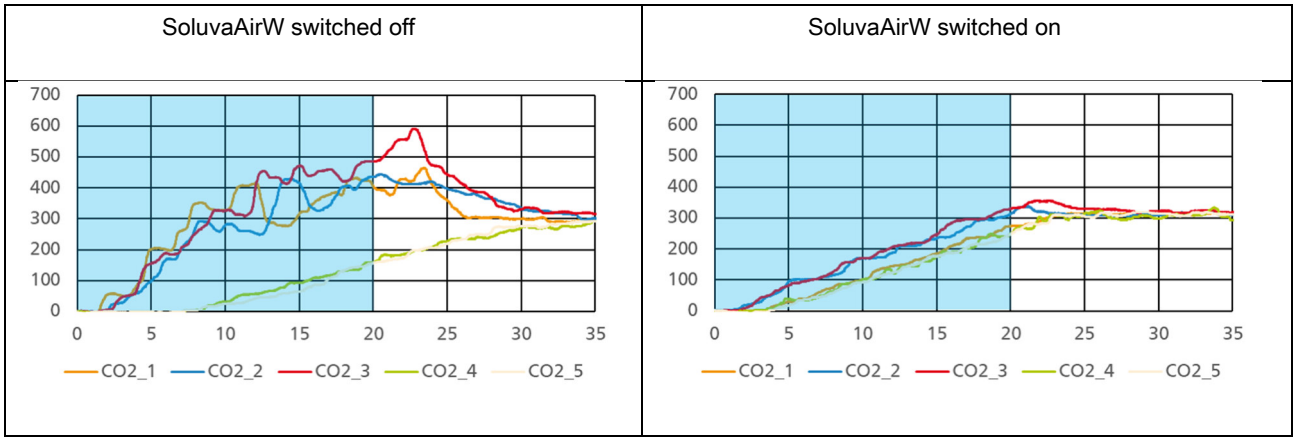


Figure 8: Result of the emission in row 3, row of windows (20 min).

A comparison of the four individual doses reveals a coherent picture, both
5 minute dosages lead to an equally high CO 2- Increase in concentration and the 20-minute dosage also lead to a factor of 4
higher final concentration. So it was decided that a 5-minute CO 2-
Dosage is sufficient for further experiments.

In order to finally secure the emission position for viruses, the experiment was repeated one more time, with the sensor 4 being moved from row 1 to row 4. The schematic measurement setup and the result are shown in Figure 9 and Figure 10. Without device operation, no direct influence on the new position 4 can be seen; When the devices are in operation, the concentrations are approximately the same as in positions 2 and 3.

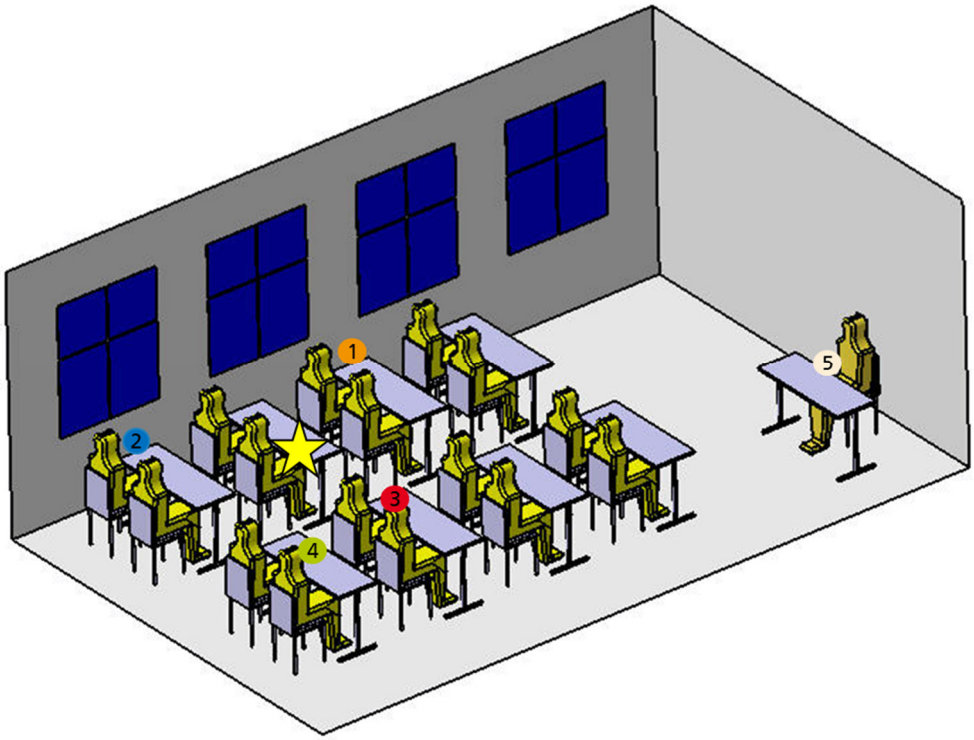


Figure 9: Adapted measurement setup to secure the emission position.

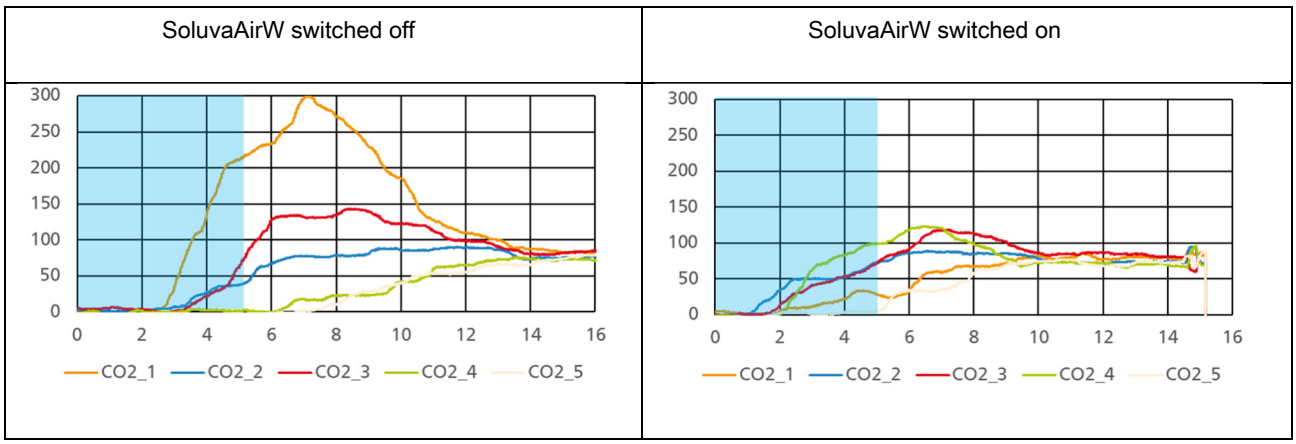


Figure 10: Result of the emission in row 3, row of windows (20 min).

The dispersion measurements make it clear that with an emission in the 3rd row, window row, a measurement of the viruses at positions 2 and 3 should take place. When operating the SoluvaAirW devices, measurements can also be made at position 4. Taking into account a necessary distance between

The measurement setup shown in Figure 2 was derived from the individual measuring devices for aerosol and virus sampling.

3.1.2 Further tracer gas experiments

Another dosage was carried out along the row of doors. The result of the measurements is shown in Figure 11. Overall, there is good mixing of the room, only in the direct vicinity of the metering point (3-b, 4-d) is a local peak. When dosing at point a, the air-side division of the room is shown again.

From these experiments it is deduced that emission and collection should not take place at the same table. An added value of one of these positions is not seen compared to the choice in chapter 3.1.1.

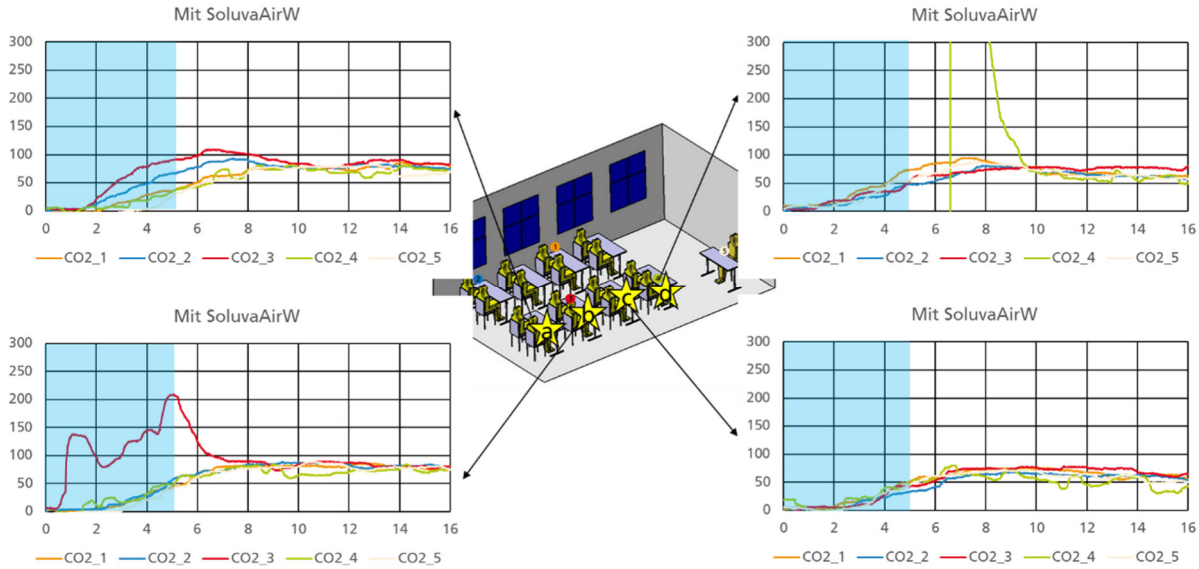


Fig. 11: Dosing attempts in the row of doors.

3.1.3 Assessment of the draft risk

The SoluvaAirW units are circulation units that suck in air from the room and blow it out in the occupied area. Against this background, the flow velocity was measured at ankle, hip and neck level (10, 60 and 110 cm). DIN EN 7730 [17], Table A.5, is used to assess the draft risk. The measurement was carried out during the preliminary test on November 9, 2020.

Figure 12 shows the averaged flow velocity on the measurement profile in the rear aisle for heights 110, 60 and 10 cm above the ground. It can be seen that the limit to category C is reached, especially at neck level.

In other words, if the flow velocity is only slightly higher, a comfortable room climate would no longer be guaranteed according to the standard. It should be taken into account that the

The experience of the Fraunhofer IBP even shows that the standard is not strict enough here, ie a loss of comfort due to drafts is to be expected.

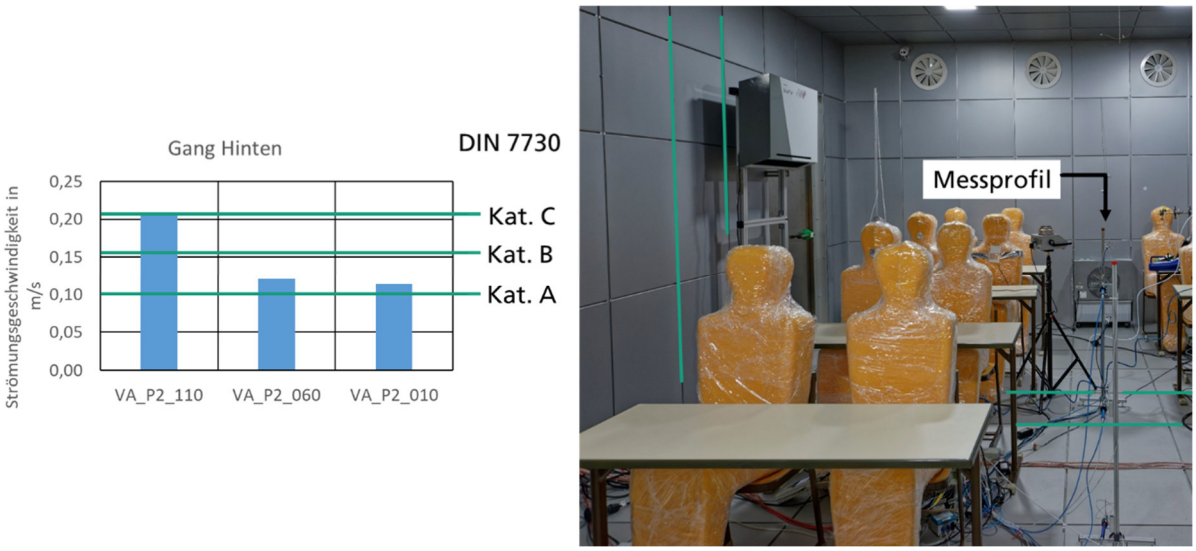


Figure 12: Flow velocity in the rear aisle (row 3).

Figure 13 shows the flow velocity at the rear table. The measurement profile was moved next to the student in row 3, door row. The flow velocity in the neck area is much too high for thermal comfort. As a result, this table could not be occupied in practice.

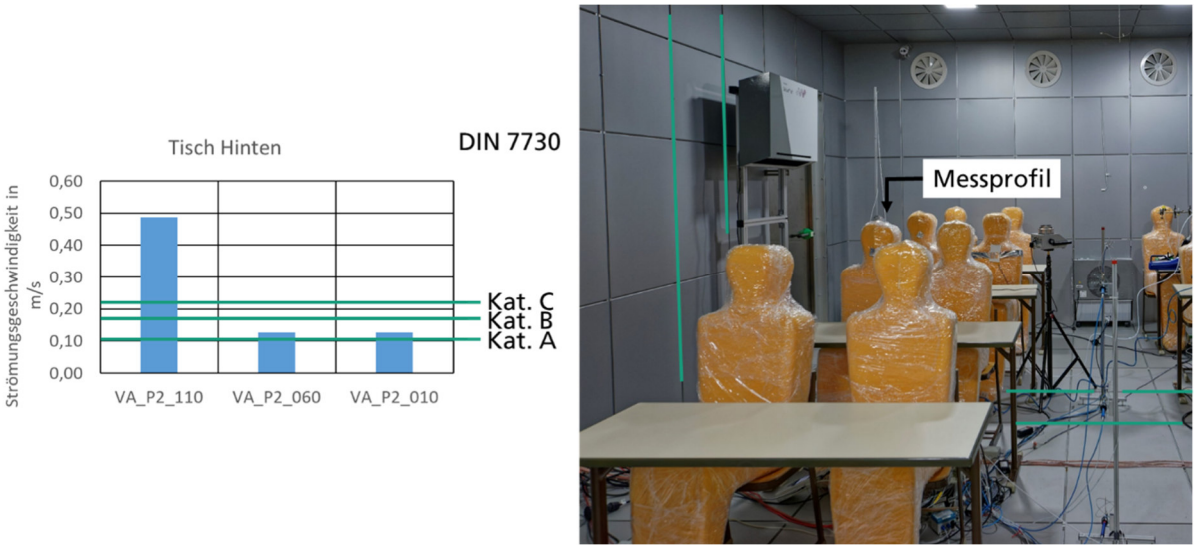


Figure 13: Flow velocity at the rear table (row 3).

Figure 14 shows the flow velocity in the front aisle. Compared to the rear aisle, the flow profile to the SoluvaAirW device is offset so that it is not in the direct throw area. The flow velocity at neck level is to be assigned to category C.

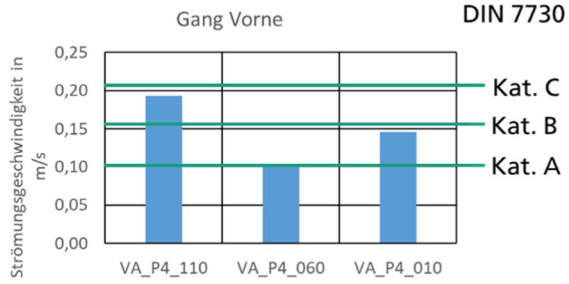


Figure 14: Flow velocity in the front aisle.

The consideration of the risk of drafts for the room users is regarded as a recommendation for the further development of the SoluvaAirW device. In the current setup or air flow, a loss of comfort due to drafts is to be expected. Solutions could be a redesign of the air ejection of the devices or a greater distance from the occupied zone.

3.2 Measurement day 1 - November 12, 2020

3.2.1 Sampling

The air purification devices pulled the virus-contaminated air through the filter channel. Viruses inside the device were inactivated by the action of UV-C. The virus was dosed in the time window from 9:51 a.m. to 12:30 p.m. and the SoluvaAirW air purifier was in operation from 11:14 a.m. to 1:45 p.m. The sampling points of the microbiology, which can also be seen in Figure 15, are listed below. In addition, at the sampling times P1 and P3, the room air was drawn onto Carboxen / Tenax sorbents and DNPH cartridges in order to be able to identify any emitters that could potentially result from UV-C radiation. This corresponds to the requirements of the Federal Environment Agency. The sampling times were standardized to the start of dosing.

- **BW:** Room blank value before the start of virus dosing.
- **P1:** Sampling in the period from 17 min to 77 min of phage dosing and SoluvaAirW inactive (corresponds to reference measurement).

- **P2:** Sampling over a period of 98 min to 158 min in simultaneous operation by virus dosing and SoluvaAirW (total duration of phage dosing 158 min; time window SoluvaAirW operation 83 min to 229 min).

- **P3:** Sampling in the period from 159 min to 219 min after the end of virus dosing and operation of the SoluvaAirW (time window SoluvaAirW operation 83 min to 229 min).

- **P4:** Sampling in a period of 169 min to 229 min after the virus dosing has ended and the SoluvaAirW has been switched on, the sampling point differs from P1, P2 and P3. Sampling programmed without interference with a 10 min offset to P3 (time window SoluvaAirW operation 83 min to 229 min).

3.2.2 Sensor technology

The maximum concentration of the ozone in the room itself remained low during the entire measurement period (max. 2 ppb; 4 µg / m³). Figure 15 shows the distribution of viruses in space over the measurement period and the times at which the samples were taken.

The two curves (Fig. 15) reflect the measuring ranges of the particle measuring devices (P-Trak / TSI and Fidas Frog / Pallas). The P-Trak covers the nanoscale range from 20 to 1000 nm, therefore mainly covers the range of individual viruses (virus size (approx. 100 nm) in the air. The Fidas Frog covers a larger-scale range from 0.2 to 20 µm and thus detects aerosol-bound viruses (approx. 1 to 3 µm).

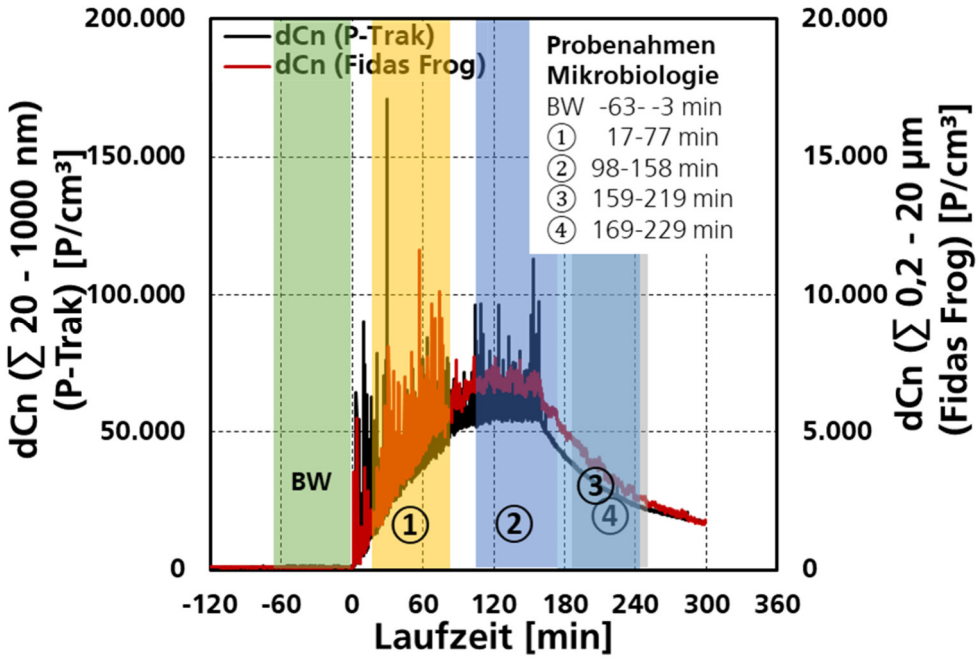


Fig. 15: Distribution of virus particles in the room and times of sampling.

The laboratory tests on substances produced by UV-C exposure (due to the formation of ozone) showed that few by-products could be detected. The created by-products are compared in the guideline value recommendations of the AIR [18]. The guideline value I (RW I) describes the concentration of a substance in indoor air at which, according to the current state of knowledge, no health impairment is to be expected when considering individual substances even if a person is exposed to this substance for life. This RW I is adhered to for all created by-products.

3.2.3 Microbiology

The number of viruses from the air decreased along the curve (time course) due to sedimentation ("deposition"). Since the air purifier is based on the principle of inactivating viruses, the recovery of the active viruses was determined at different times.

Table 2 shows the reduction in the recovery of active viruses analyzed in the laboratory in relation to measurement P1 (reference measurement) with virus dosing, without the influence of the device. In addition to the effect of the device, the decay curve due to sedimentation and the natural loss of activity of the viruses (natural half-life) in the aerosol also influence the reduction as a function of time. Sedimentation and natural half-life as a function of time are known from the Fraunhofer IBP's own measurements and are taken into account for P3 and P4 in the third column.

It should be noted here that the internal Fraunhofer IBP reference measurement was carried out without any influence from the device. The mixing of the SoluvaAirW without UV-C influence is not shown here and was therefore not included in the calculation of column 3.

Table 2: Measurement of virus activity (E3423_1)

Time of the pro-behavior	Recovery active units (Plaque forming units) with standard standard deviation [pfu / m³]	Measured reduction the recovery active viruses (pure measurement data in Relation to P1) [%]	Reduction rate R with consideration of Sedimentation and natural half-life time [%] *
BW	- * *	- * *	-
P1	1,800,000 (± 20%)	0	-
P2	832,917 (± 22%)	53.73	-
P3	36,000 (± 10%)	98.00	78.64
P4	5,825 (± 41%)	99.68	80.53 * * *

* Reduction rate based on DIN ISO 16000-36 [6]

R = 1-Ct / Ci (Ci without commissioning the air cleaner and Ct with the air cleaner running).

* * BW blank value before virus dosing, no findings in the room.

* * * Measurement time Ct: 10 min - 70 min after the end of virus dosing; Measurement time Ci: 10 min - 40 min after the end of the virus dosing, thus only partially comparable.

3.2.4 Room climatic boundary conditions Measurement day 1

Figure 16, Figure 17 and Figure 18 show the measured surface and air temperatures as well as the room air humidity during the test day.

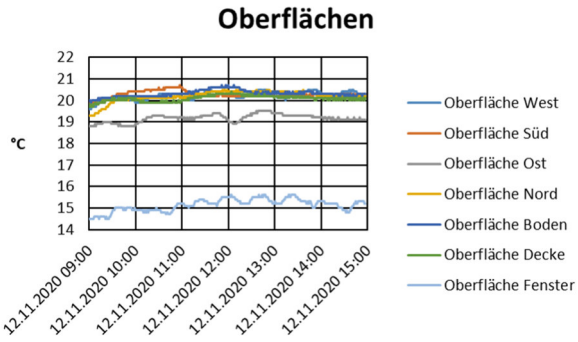


Figure 16: Surface temperatures measured in the IATC.

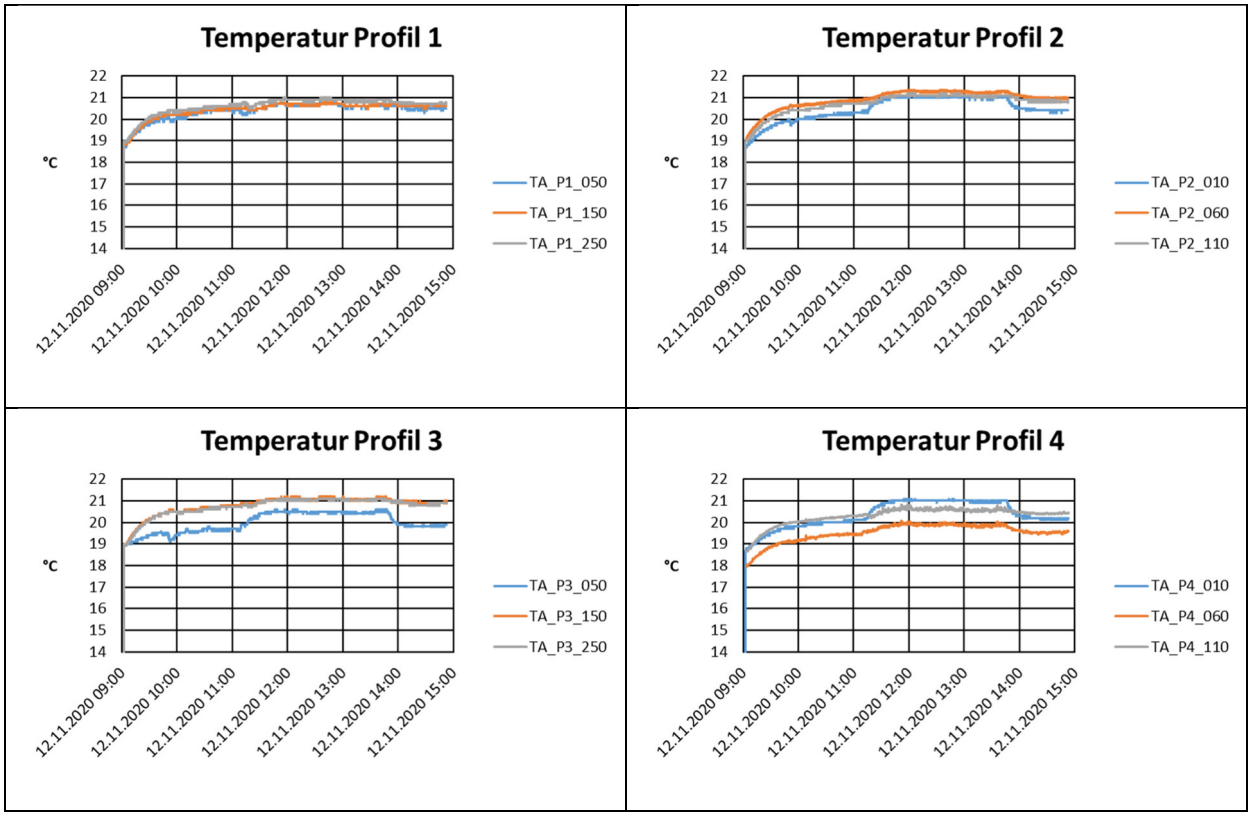


Figure 17: Measured air temperatures in the IATC.

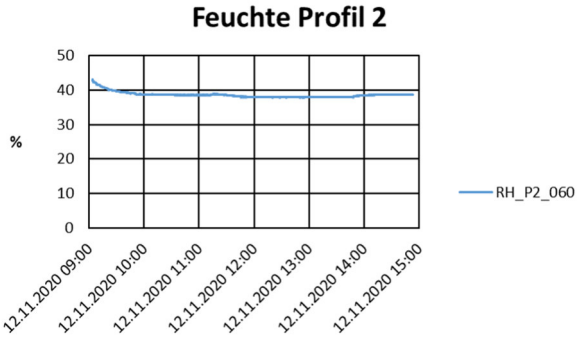


Figure 18: Measured indoor air humidity in the IATC.

3.3 Measurement day 2 - December 2, 2020

3.3.1 Sampling

The air purification devices pulled the virus-contaminated air through the filter channel. Viruses inside the device were inactivated by the action of UV-C. The virus was dosed in the time window from 10:55 h to 13:31 h and the SoluvaAirW air purifier was in operation from 12:13 h to 14:31 h. The sampling points of the microbiology, which can also be seen in Figure 19, are listed below. The sampling times were standardized to the start of dosing.

- **BW:** Room blank value before the start of virus dosing.
- **P1:** Sampling in the period from 47 min to 77 min of phage dosing and SoluvaAirW inactive (corresponds to reference measurement).
- **P2:** Sampling over a period of 125 min to 155 min in simultaneous operation by virus dosing and SoluvaAirW (total duration of phage dosing 155 min; time window SoluvaAirW operation 78 min to 197 min).
- **P3:** Sampling in the period from 157 min to 187 min after the end of the virus dosing and operation of the SoluvaAirW (time window SoluvaAirW operation 78 min to 197 min).
- **P4:** Sampling in the period from 167 min to 197 min after the end of the virus dosing and switching on the SoluvaAirW, the sampling point differs from P1, P2 and P3. Sampling programmed without interference with a 10 min offset to P3 (time window SoluvaAirW operation 78 min to 197 min).

3.3.2 Sensor technology

The maximum concentration of the ozone in the room itself remained low during the entire measurement period (max. 1 ppb; 2µg / m³). Figure 19 shows the distribution of viruses in space over the measurement period and the times at which the samples were taken:

The two curves (Fig. 19) reflect the measuring ranges of the particle measuring devices (P-Trak / TSI and Fidas Frog / Pallas). The P-Trak covers the nanoscale range from 20 to 1000 nm, therefore mainly covers the range of individual viruses (virus size (approx. 100 nm) in the air. The Fidas Frog covers a larger-scale range from 0.2 to 20 µm and thus detects aerosol-bound viruses (approx. 1 to 3 µm).

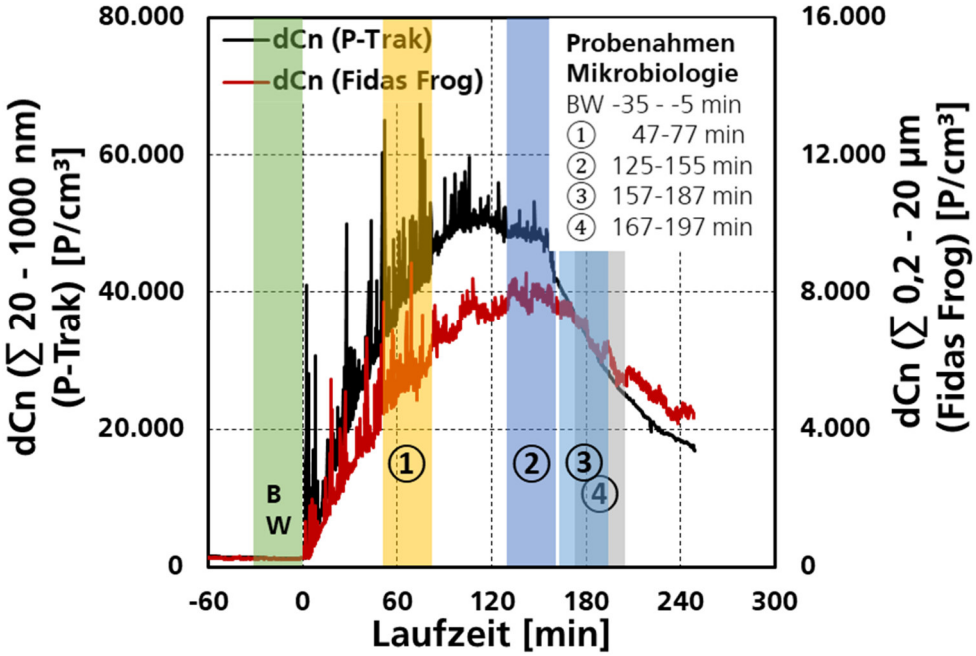


Fig. 19: Distribution of virus particles in the room and times of sampling.

No additional samples were taken for P1 and P3 from the room air on Carboxen / Tenax sorbents or on DNPH cartridges, as the device settings of the SoluvaAirW air purifier were identical to measurement day 1. The results can thus be taken from Section 3.2.2.

3.3.3 Microbiology

The number of viruses from the air decreased along the curve (time course) due to sedimentation ("deposition"). Since the air purifier is based on the principle of inactivating viruses, the recovery of the active viruses was determined at different times.

Table 2 shows the reduction in the recovery of active viruses analyzed in the laboratory in relation to measurement P1 (reference measurement) with virus dosing, without the influence of the device. In addition to the effect of the device, the decay curve due to sedimentation and the natural loss of activity of the viruses (natural half-life) in the aerosol also influence the reduction as a function of time. Sedimentation and natural half-life as a function of time are known from the Fraunhofer IBP's own measurements and are taken into account for P3 and P4 in the third column.

It should be noted here that the internal Fraunhofer IBP reference measurement was carried out without any influence from the device. The mixing of the SoluvaAirW without UV-C influence is not shown here and was therefore not included in the calculation of column 3.

Table 3: Measurement of virus activity (E3423_2)

Time of the pro-behavior	Recovery active units (Plaque-forming units) with standard standard deviation [pfu / m³]	Measured reduction tion of virus activity (pure measurement data in Relation to P1) [%]	Reduction rate R with consideration of Sedimentation and natural half-life time [%] *
BW	- * *	- * *	-
P1	43,244,444 (± 6%)	0	-
P2	300,000 (± 23%)	99.31	-
P3	44,667 (± 23%)	99.90	98.78
P4	34,333 (± 16%)	99.92	95.22

* Reduction rate based on DIN ISO 16000-36 [6]

R = 1-Ct / Ci (Ci without commissioning the air cleaner and Ct with the air cleaner running).

* * BW blank value before virus dosing, no findings in the room.

3.3.4 Room climatic boundary conditions Measurement day 2

Figure 20, Figure 21 and Figure 22 show the measured surface and air temperatures as well as the room air humidity during the test day.

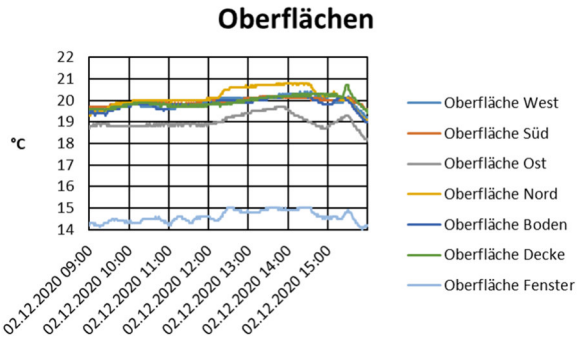


Figure 20: Measured surface temperatures in the IATC.

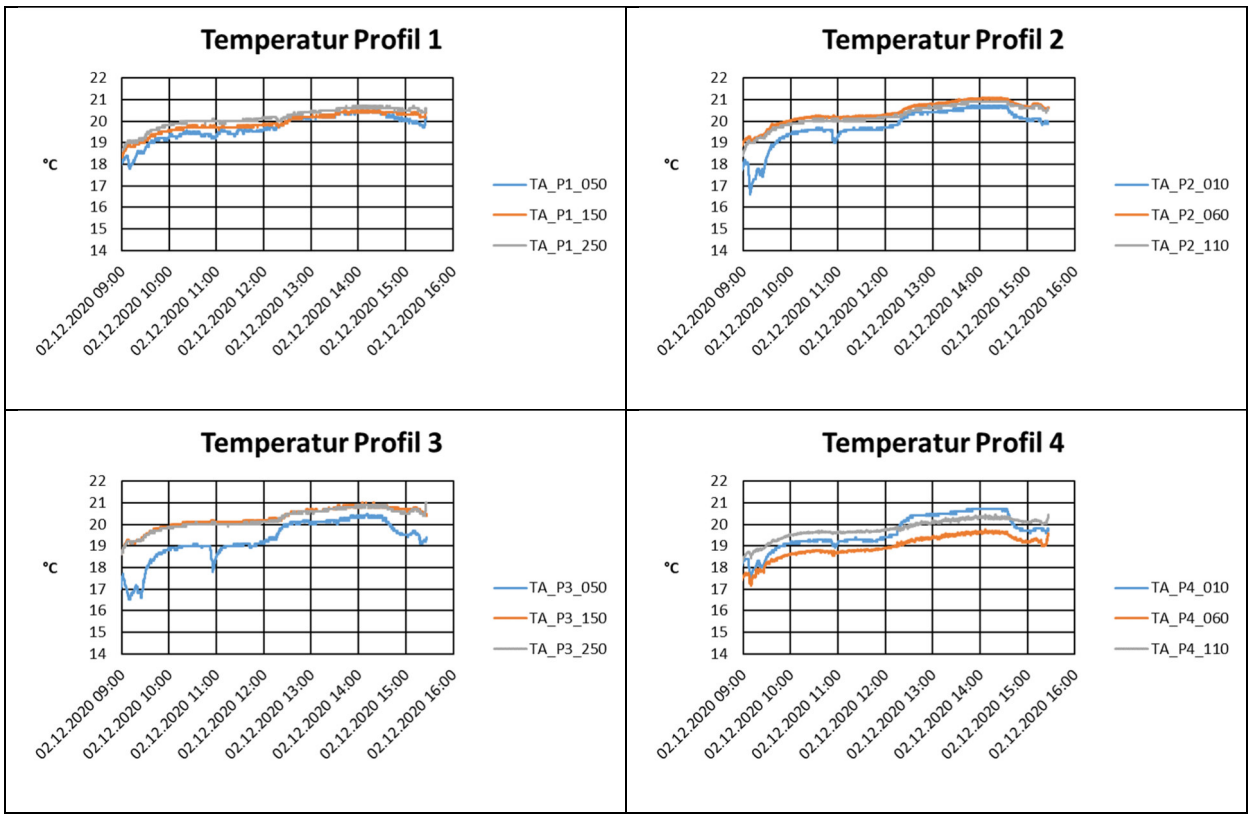


Figure 21: Measured air temperatures in the IATC.

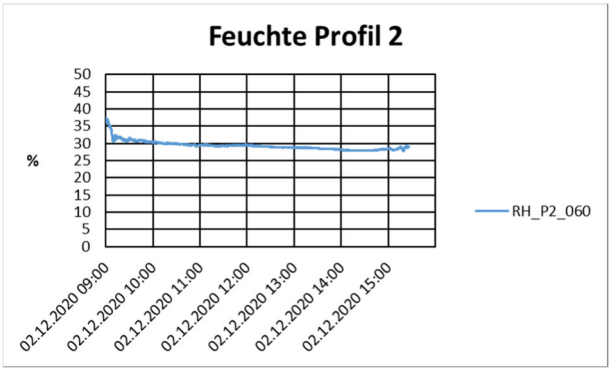


Figure 22: Measured indoor air humidity in the IATC.

4th Summary of the studies of the efficiency of the room air purifier from Heraeus (SoluvaAirW)

The IATC with a volume of 127 m³ was exposed to surrogate viruses (enveloped Phi6 bacteriophage with a structure, particle size and environmental stability comparable to SARS-CoV-2) for 2.5 hours. After 1.25 hours, the SoluvaAirW (Heraeus) air purification devices were switched on. The air purification devices ran to the aerosol generator simultaneously for 1.25 hours. After the virus aerosolization had ended, the air purification devices continued to operate for 70 minutes.

Samples lasting 1 hour were taken on measurement day 1 and a virus reduction of 53.73% (P2; pure measurement data without sedimentation and loss of virulence in the aerosol) was determined within the scope of these investigations after operating the device for 45 minutes. Sampling while the device was in operation for 105 minutes (P3) and 115 minutes (P4) resulted in a virus reduction in the room of 98.00% and

99.68% can be detected. Taking into account the internal Fraunhofer IBP reference measurements, a reduction was achieved for measurement day 1 **of over 78%** can be determined at both sampling positions (P3 and P4).

It could be proven that no by-products (VOC and aldehydes and ketones) that exceed RW I were formed by the air purification device.

On measurement day 2, samples were taken with a duration of 0.5 hours and within the scope of these investigations, a virus reduction of 99.31% (P2; pure measurement data without sedimentation and loss of virulence in the aerosol) could be determined after operating the device for 60 minutes. Sampling while the device was in operation for 95 minutes (P3) and 105 minutes (P4) resulted in a virus reduction in the area of 99.90% and

99.92% can be detected. Taking into account the internal Fraunhofer IBP reference measurements, a reduction was achieved for measurement day 1 **of over 95%** can be determined at both sampling positions (P3 and P4).

During the investigation, an ozone concentration in the air of a maximum of 4 µg / m³ was measured. That is less than a tenth of the statutory limit. The Federal Immission Control Act specifies up to 120 µg / m³ as a harmless upper limit (maximum target value). [19]

5 literature

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