MICROBIAL PERFORMANCE OF AMBIENT AIR FILTER UNITS

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AUTHORS

Dr. Christian Schurig
M.Sc. Meteorology
Management UWS
Expert
christian.schurig@gwp.eu

Dr. Julius A. Nickl
Dipl. Chemist
Managing Director
Senior Expert
julius.nickl@gwp.eu

Robert Göbel
Technical Director
Sunny Air Solutions GmbH
rgoebel@sunnyairsolutions.com

1 SUMMARY

Room air filtration devices can be an important infection control measure in the context of pandemic prevention. The comparison of different devices is difficult due to different fan performance, individually resulting flowin the room, and different disinfection technologies.

This document describes the development and standardisation of a method for determining the microbial cleaning efficiency in a standardised test room. In addition, a technology- and ventilation performance-independent standardisation procedure was developed for comparing different devices on the basis of the room size by means of universally valid key figures.

Thus, GWP work instruction 384 [12] provides a direct device comparison that is comprehensible, easy to implement, and adds up all the elusive device parameters: t50, t90, and efficiency.

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2 INTRODUCTION

The contamination of indoor air with microorganisms can lead to serious health problems. Even outside of particularly regulated areas, such as operating theatres or food production facilities, permissible germ loads in the air breathed are regulated as maximum workplace concentrations (MAK) by the employers' liability insurance associations. The germ load of indoor air has received wider public interest in the course of the SARS-CoV-2 pandemic. Since the coronavirus is essentially transmitted via the air we breathe, the public has increasingly focused on technical solutions for indoor air disinfection in addition to ventilation strategies and hygiene concepts. These measures serve, among other things, to maintain the operation of businesses, event venues, schools and kindergartens under pandemic conditions [1,2].

Technical solutions for room air disinfection include, on the one hand, devices to be installed in a room and, on the other hand, solutions to be integrated into a central ventilation system. In particular, devices to be installed in rooms can be easily retrofitted and thus enable safe operation with regard to infection. We are not aware of any widespread, standardised test procedures that are technically relevant.

Devices on the market are based on different technologies [3]. For example:

- Filter-based devices work according to the HEPA principle (High Efficient Particulate Air (filter)), similar to the air treatment system for clean rooms. Air contaminated with germs is sucked in by a fan and passed through a HEPA filter. Particles of a certain minimum size, including microorganisms (some µm to some dozens of µm in diameter), collect in this filter. With increasing occupancy of the filter, the pressure drop across the filter increases. Continued operation of the unit requires replacement of the filter. Loads of non-living aerosols are also removed from the indoor air; however, any germs that may be present are not killed.
- In contrast to filter technology, the use of UVC radiation – about 280 nm - directly reduces the germ load of the indoor air by killing any germs that may occur. The exhaust air of these devices can be considered less germ-laden, but a reduction of the aerosol load usually does not take place. The efficiency of this disinfection method depends less on the particle size than with the HEPA method, but rather on the required radiation dose of the microorganism to be disinfected. This is specific for various bacteria and viruses.
- Another method of disinfection is based on the nebulisation of oxidising agents such as a hydrogen peroxide solution (H2O2) or ozone (O3); this happens inside the treated room, outside

the unit. Microorganisms that come into contact with the aerosols of the H2O2 solution or the O3 gas are killed by oxidizing their cell components. The same happens to the cells of any persons present in the room. For this reason, H2O2- and O3-based disinfection devices may only be operated with limited concentration and/or in the absence of persons.

- Other methods such as thermal, ionization, plasma, high voltage dust deposition, and many more are also known.

Many manufacturers of such devices advertise disinfection efficiencies of 99.9 % and higher [4,5]. However, a direct comparison of different devices is difficult due to the different technologies used. In addition, direct measurement of the disinfection efficiency in germ-contaminated indoor spaces is usually not carried out. Instead, the manufacturers state the efficiency of the respective disinfection method with regard to model germs that are introduced directly into the device. Fluid mechanics considerations, such as the mixing of the air volume of the room to be disinfected, as well as the ratio of air flow rate to disinfection efficiency, are neglected. Or in other words: how the device works in a real room is not known.

A deeper understanding of the efficiency to compare different room air treatment devices to each other requires the determination of the microbial performance under standardized conditions in a realistic environment. To achieve this goal (1), a standardized test method for comparing different devices was first designed and validated, compare GWP Arbeitsvorschrift AV 384. This method allows direct comparison of the efficiency of different devices against different model germs (goal 2). The resulting data on decay times and efficiencies are used for device selection.

3 EXPERIMENTAL GWP AV 384

The determination of the disinfection efficiency of different devices requires a standardized procedure. To determine the air disinfection effectiveness, a test tent (GWP mbH, Munich) the size of a common room was set up on a laboratory scale. In this test tent, a defined bacterial concentration with the laboratory model organisms *E. coli* K12 or *B. subtilis* DSM 10 is induced by means of aerosol generators. Very well characterized, safe laboratory bacterial strains were used for the investigation [6,7] in order to exclude the risk of escaping microorganisms.

The strains were selected with regard to their UVC resistance as follows: The UVC radiation dose required to denature the Gram-negative bacterium *E. coli* K12 corresponds approximately to the radiation dose required to denature the SARS-CoV-2 virus (cf. Table 1). For the denaturation of the gram-positive bacterium *B. subtilis* DSM10, a radiation dose at least 5-fold higher is required. Consequently, the results of the tests with this bacterium mark an extreme value and can also be applied to other pathogens (cf. Table 1).

The bacteria concentration at the start of the test reaches a value of approx. 5.000 colony-forming units per m^3 of air and thus corresponds to highly polluted indoor air. With the completion of the nebulisation, the device to be examined is switched on. In the course of the experiment, the air of the test tent is regularly sampled using air samplers and agar plates. The agar plates are evaluated after incubation using the plate counting method. At the end of the test, any bacteria remaining in the air of the test tent are denatured by means of a hydrogen peroxide nebulizer, UVC tubes and forced ventilation, so that a clean atmosphere is available for each test.

Table 1: Required UVC radiation doses for denaturing the model germs and various known pathogens

Microorganism	**Radiation dose for denaturation** (mWs/cm^2)	**Source**
Escherichia coli K12	4 - 7	Walker et al. 2007, Heßling et al. 2020
Bacillus subtilis DSM10	24,5 - 26	Nicholson & Galeano 2003
SARS-CoV-2 virus (coronavirus)	2,5 – 4	Walker et al. 2007, Heßling et al. 2020
Influenza virus	3,4 - 13,2	Walker et al. 2007, Heßling et al 2020
Herpesvirus	6	Walker et al. 2007
λ-Bacteriophage	13,2	Walker et al. 2007
Legionella pneumophilia	1	Heßling et al. 2020
Staphylococcus aureus	2,2	Heßling et al. 2020
Salmonella enteridis	4	Heßling et al. 2020
Pseudomonas aeroginosa	5,5	Heßling et al. 2020

4 RESULTS AND DISCUSSION

4.1 Comparison of the natural decay curves

After developing the measurement methodology, it was first necessary to ensure that stable conditions prevailed within the test tent for the evaluation of the test specimens. For this purpose, natural decay curves, so-called zero measurements, were determined without test specimens. The approach is similar to a test with an air filter, except that no additional cleaning takes place. The natural decay curves were determined with both model microorganisms and can be found in Figure 1.

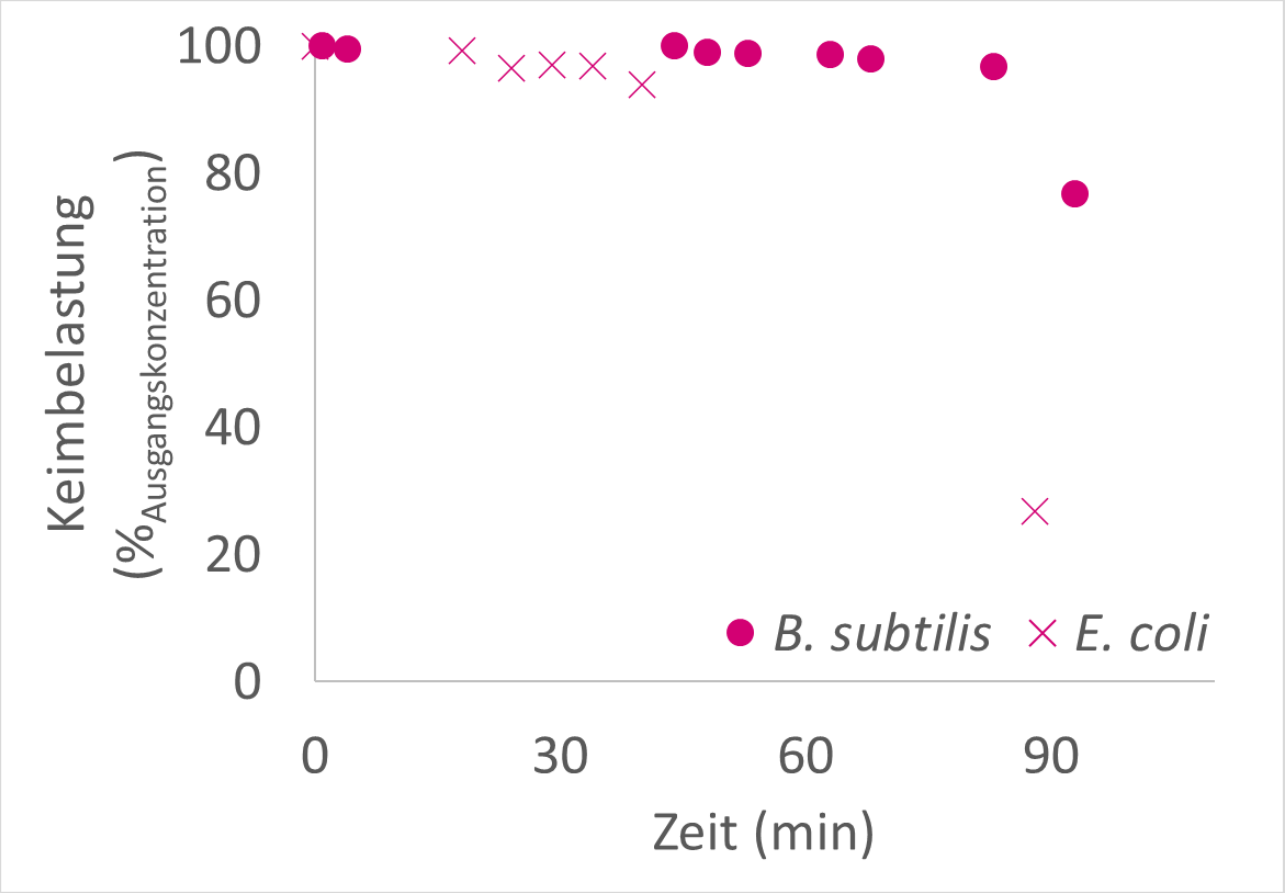

Figure 1: Natural decay curves of the model organisms *E. coli* & *B. subtilis*. Relatively constant concentrations are present in the "Prüfzelt" during a measurement period of up to 90 min.

Aerosols have a different atmospheric lifetime depending on their particle size. Particles with a size >10 µm tend to precipitate quickly on surfaces by gravity, due to their relatively higher mass compared to the particle size. Particles with a size < 5 - 10 µm, on the other hand, have a longer atmospheric lifetime depending on their size; they are also called *air born*. The model nuclei investigated have a size of approx. 1 µm and should therefore have a sufficient atmospheric lifetime for the experiments. As can be seen in Figure 1, *E. coli* nevertheless shows a faster decay than *B. subtilis*. Presumably, this result can be explained by the property of *B. subtilis to* form endospores. These permanent forms are formed under unfavourable growth conditions and are significantly smaller than the actual *B. subtilis cell*. Accordingly, endospores have a greater atmospheric lifetime and remain longer in the air of the test tent. Compared to the corona virus, which is significantly smaller, their atmospheric lifetime is nevertheless shorter.

4.2 Comparison of the cleaning decay curves

The determination of the cleaning decay curves was carried out in analogy to the procedure described under 3 Experimental separately for each microorganism. The following Figure 2 shows the cleaning decay curve of a UVC device with 700 m^3 h-1 air circulation rate in the test tent.

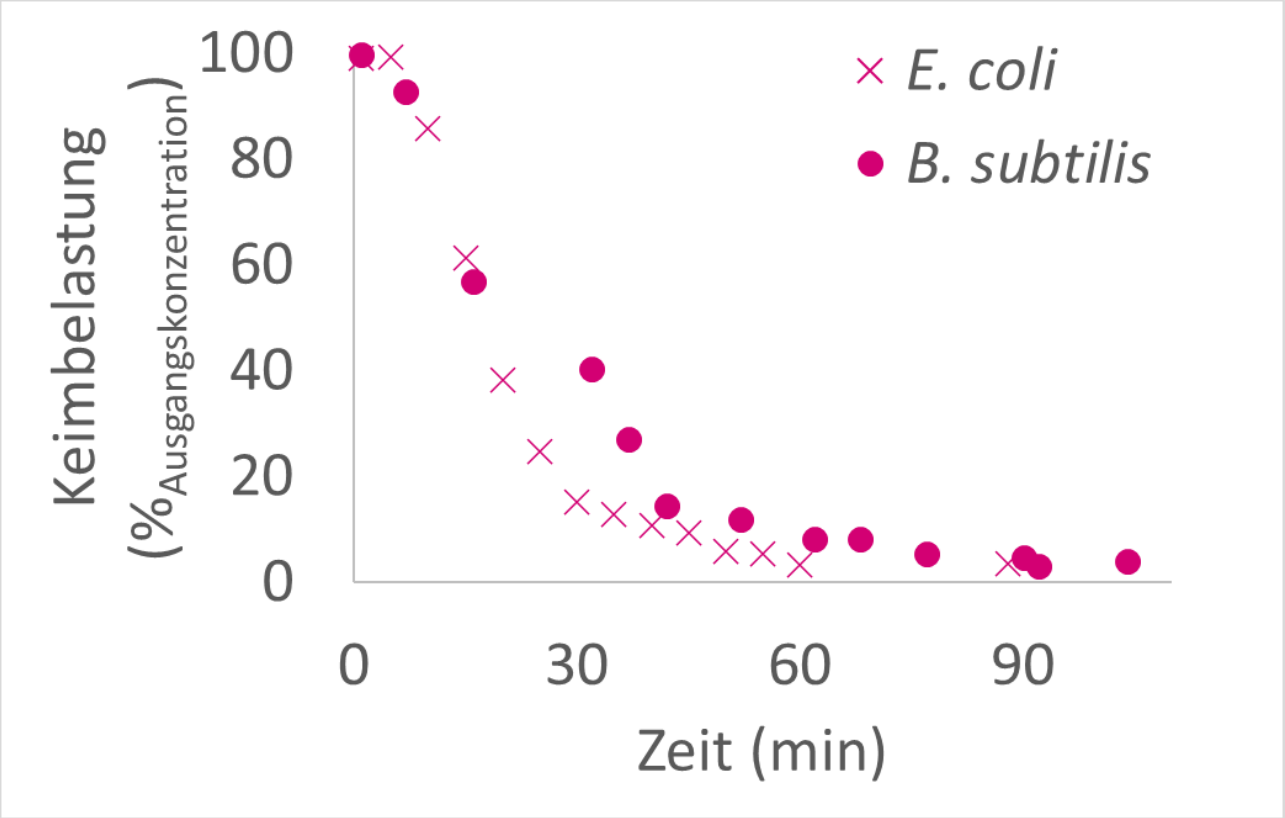

Figure 2: Purification decay curve of a UVC-based device with the model germs *E. coli* and *B. subtilis*

As can be seen from Figure 2, the investigated device shows a purification performance for both model germs, as the bacterial concentration decreases significantly faster compared to the natural decay curve (Figure 1). Furthermore, it can be observed that the concentration of the model organism *E. coli* decreases faster than that of the model organism *B. subtilis*. This observation can be explained by the higher UVC radiation resistance of *B. subtilis* (cf. Table 1). This causes fewer cells of *B. subtilis to be* denatured during a passage through the air sterilizer than in the case of *E. coli* and consequently the concentration remaining in the air of the test tent is higher in the case of *B. subtilis* at a given time.

For a device with a HEPA filter, one would expect the disinfection performance to be similar for both model germs, since both model germs have a comparable size. As can be seen in Figure 3, the decay curves for both model germs nevertheless differ.

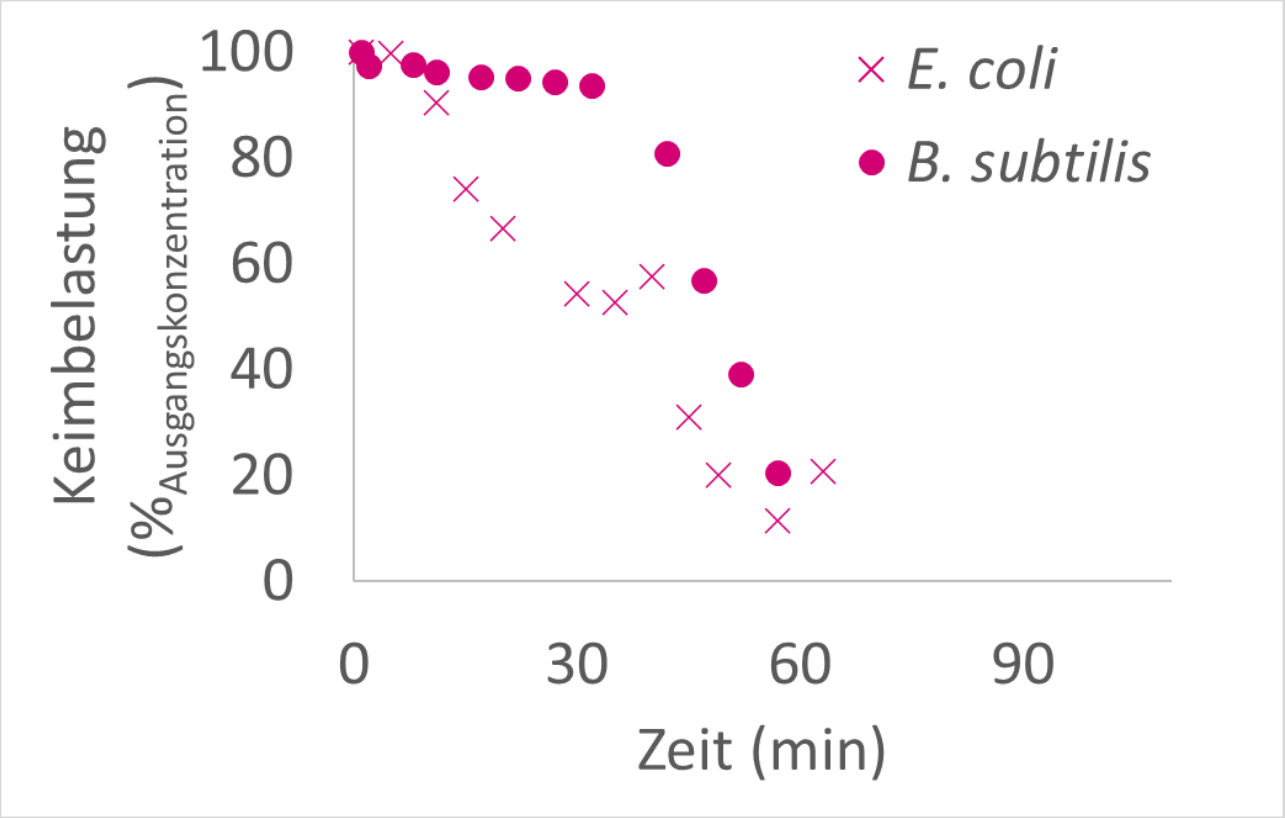

Figure 3: Cleaning decay curve of a HEPA-based device with 1000 m^3 h-1 ventilation capacity with the model germs *E. coli* & *B. subtilis*

This result can be explained on the one hand by the endospores of *B. subtilis*. Since these are smaller than *E. coli* cells, filtering them out will take longer. On the other hand, not only the cell size but also the cell shape plays a role in the filter efficiency. For example, a different surface structure implies a different aerodynamic diameter [11] of the cells, so they will behave differently in the airflow.

The comparison of the cleaning decay curves of the UVC device with those of the HEPA device shows that the UVC device tends to show an exponential decrease, while the HEPA device shows a linear decrease.

Figure 4 shows the cleaning decay curve of an H2O2 nebulizer. As with the UVC device, this also shows an exponential curve.

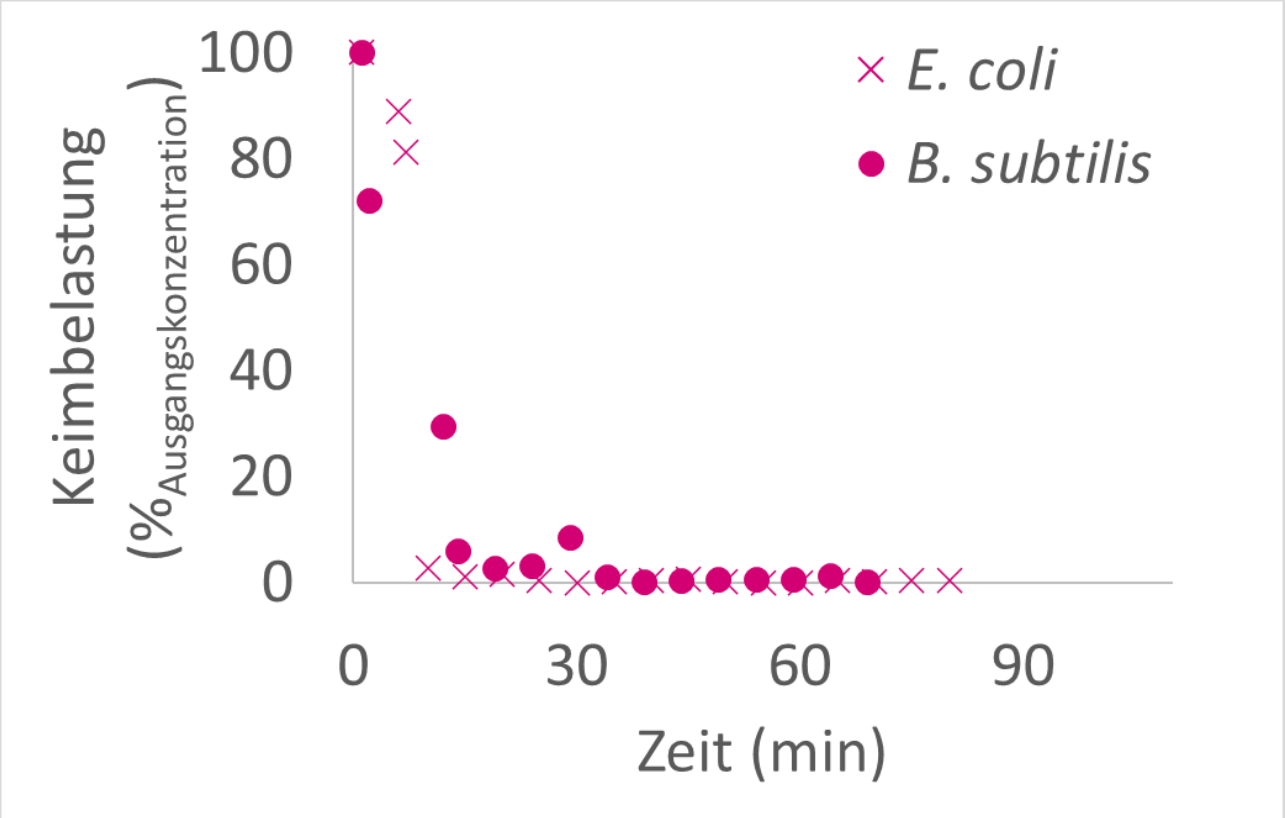

Figure 4: Cleaning decay curve of an H2O2-based device with 500 m^3 h-1 ventilation capacity with the model germs *E. coli* & *B. subtilis*

Fogging an oxidant for air disinfection is a very effective method with respect to both model germs. As can be seen in Figure 4, both model germs are effectively denatured. Also the more robust endospores of *B. subtilis* are apparently effectively denatured. Despite the very good disinfection performance, the use of this technology in rooms where people are present is prohibited, as described above.

All devices presented so far have been proven to be effective. As can be seen in Figure 5, there are also devices on the market for which no cleaning performance can be proven.

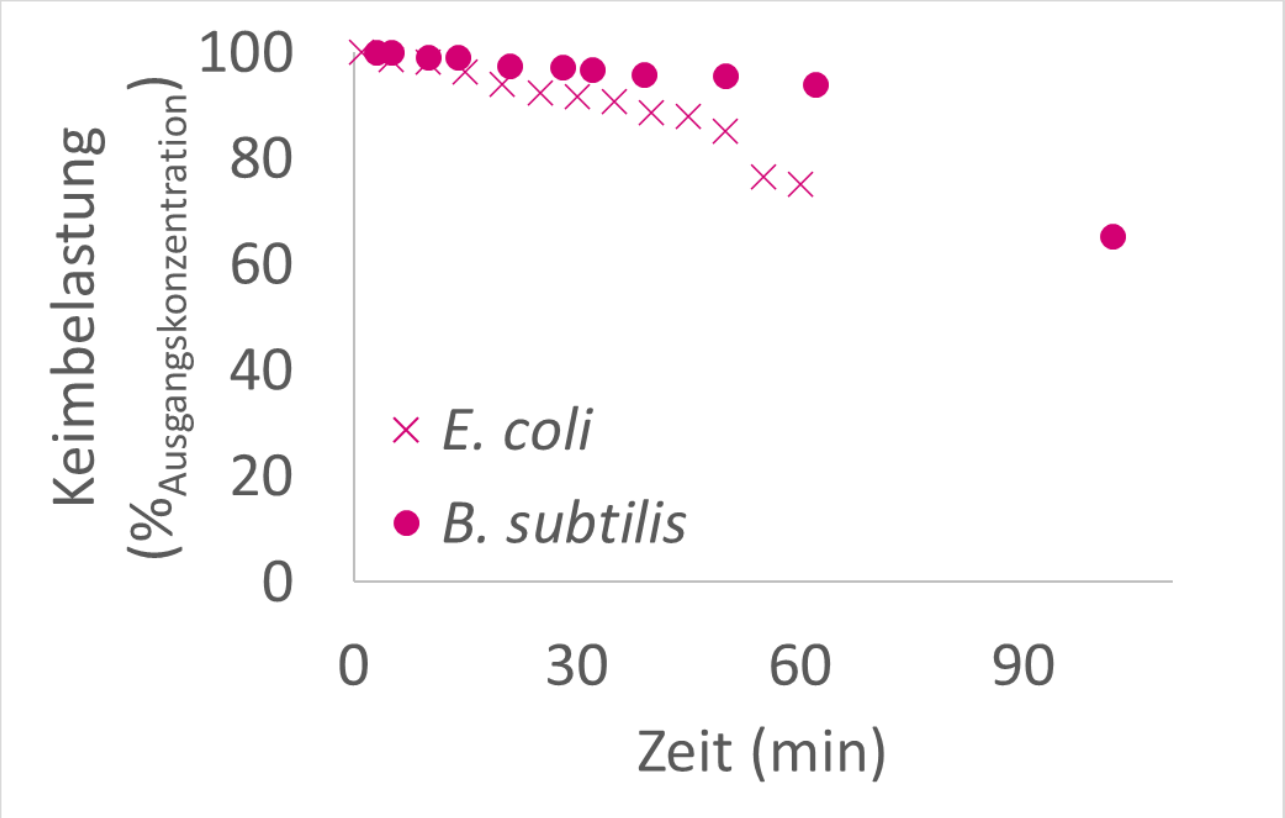

Figure 5: Cleaning decay curve of a HEPA-based device for home use with the model germs *E. coli* & *B. subtilis*

This device is intended for home use and is advertised as being 99% effective at an airflow of 1000 m^3 h-1. However, the measured data do not differ significantly from those of the natural decay curves shown in Figure 1.

For better comparison of each device, the time to reach 50 & 90 % cleaning efficiency (t50 and t90 time, respectively) was determined from the cleaning decay curves for both model nuclei. These data are presented in Table 2.

Table 2: Decay times of examined devices for the two model germs *E. coli* & *B. subtilis*

	E. coli		***B. subtilis***	
Measurement	**t50** min	**t90** min	**t50** min	**t90** min
nat. decay curve	90	120	160	600
UVC device	10	40	20	60
HEPA device	40	60	45	70
H2O2 device	5	15	6	16
HEPA home Device	90	120	155	520

Based on this data, different devices that are based on different processes and operate with different fan powers can each be standardised to 2 numerical values. This makes it easier for the user to compare different devices.

4.3 Comparison with theoretically possible performance

If one considers the dilution of the cleaned air in the measuring tent, there is an exponential drop in the germ concentration. It is assumed here that the air flowing through the fan unit is perfectly purified. Figure 6 shows theoretical best possible decay curves for the test tent for different ventilation capacities.

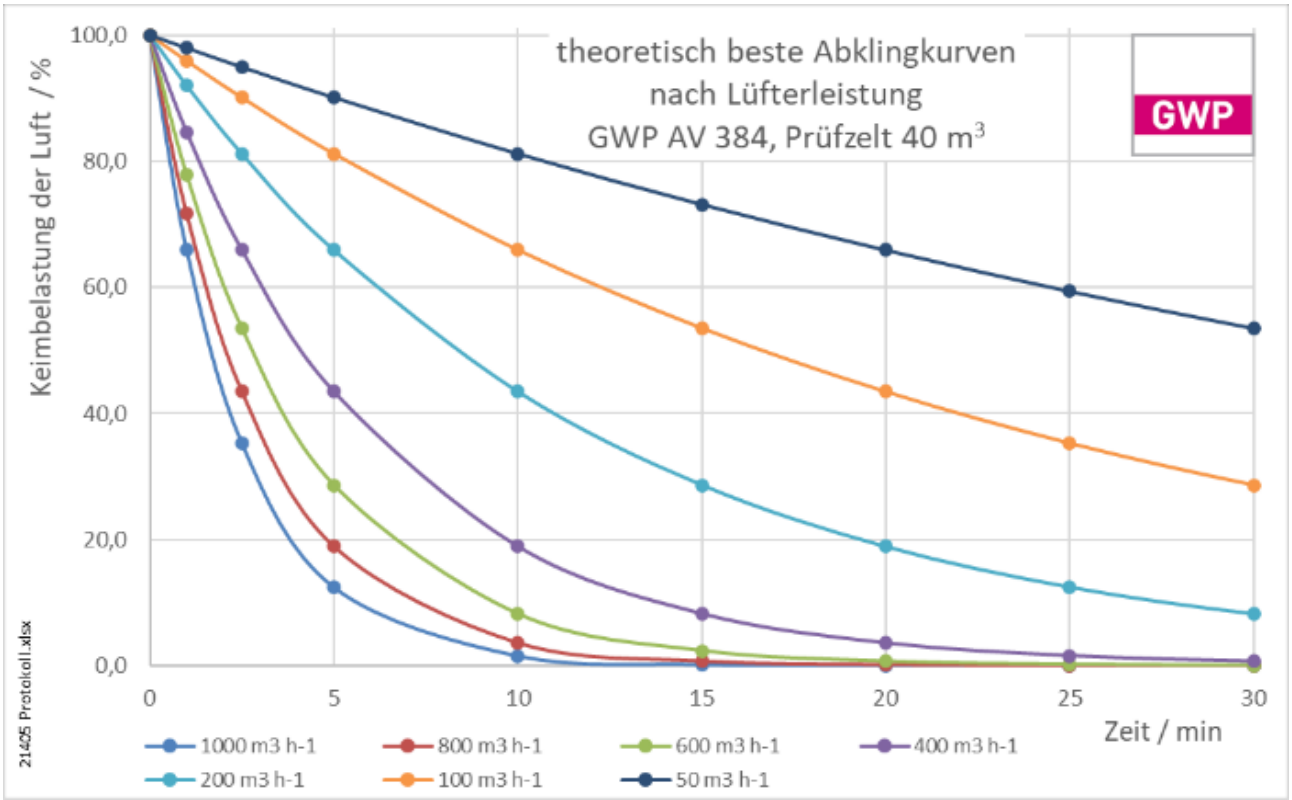

Figure 6: Theoretically achievable decay curves at 100 % effectiveness of cleaning in the fan stream

The data on which this is based are contained in the following Table 3 and relate to the test tent erected (see 3 Experimental)

Table 3: Overview of theoretically achievable t50 & t90 times

Fan power	**Decay time t50**	**Cooldownt90**	**Volume change**
$m^3 h^{-1}$	min	min	h^{-1}
50	37,2	> 90	outside measuring range; would be approx. 1
100	17	55	2,5
200	7,9	28,2	4
400	4,0	13,5	10
600	2,8	9,3	15
800	2,5	7,7	20
1.000	2,0	6,1	25

A comparison of this theoretical best performance with the measured data allows the calculation of a t90 efficiency of different devices. This parameter describes their efficiency independently of the t90 time of the devices, regardless of the ventilation power. For the presented devices calculated t90 efficiency values can be found in the following Table 4.

Table 4: t90 efficiencies (t90eff) of the examined devices allow comparison independent of the fan performance

DUT	*E. coli*		*B. subtilis*	
	t90	**t90eff**	**t90**	**t90eff**
	min	%	min	%
UVC device	40	20	60	13
HEPA device	60	10	70	9
H2O2 device	15	73	16	69
Home Device	120	5	520	1

As already seen from the decay curves of Figure 5, the H2O2 device shows the highest efficiency, while the home device shows only an efficiency between 5 to 1% although the fan power of the home device is twice as high. Similarly, the HEPA device shows good efficiency in Figure 3 but low efficiency as its ventilation power is very high. The UVC device studied shows an efficiency in the medium range.

Figure 7 below compares the theoretical best performance (blue curve) with measured data from a UVC-based device. The discrepancy between maximum efficiency and actual performance is very clearly visible here. Measurements according to GWP AV384 thus allow direct comparison of measured with theoretical data.

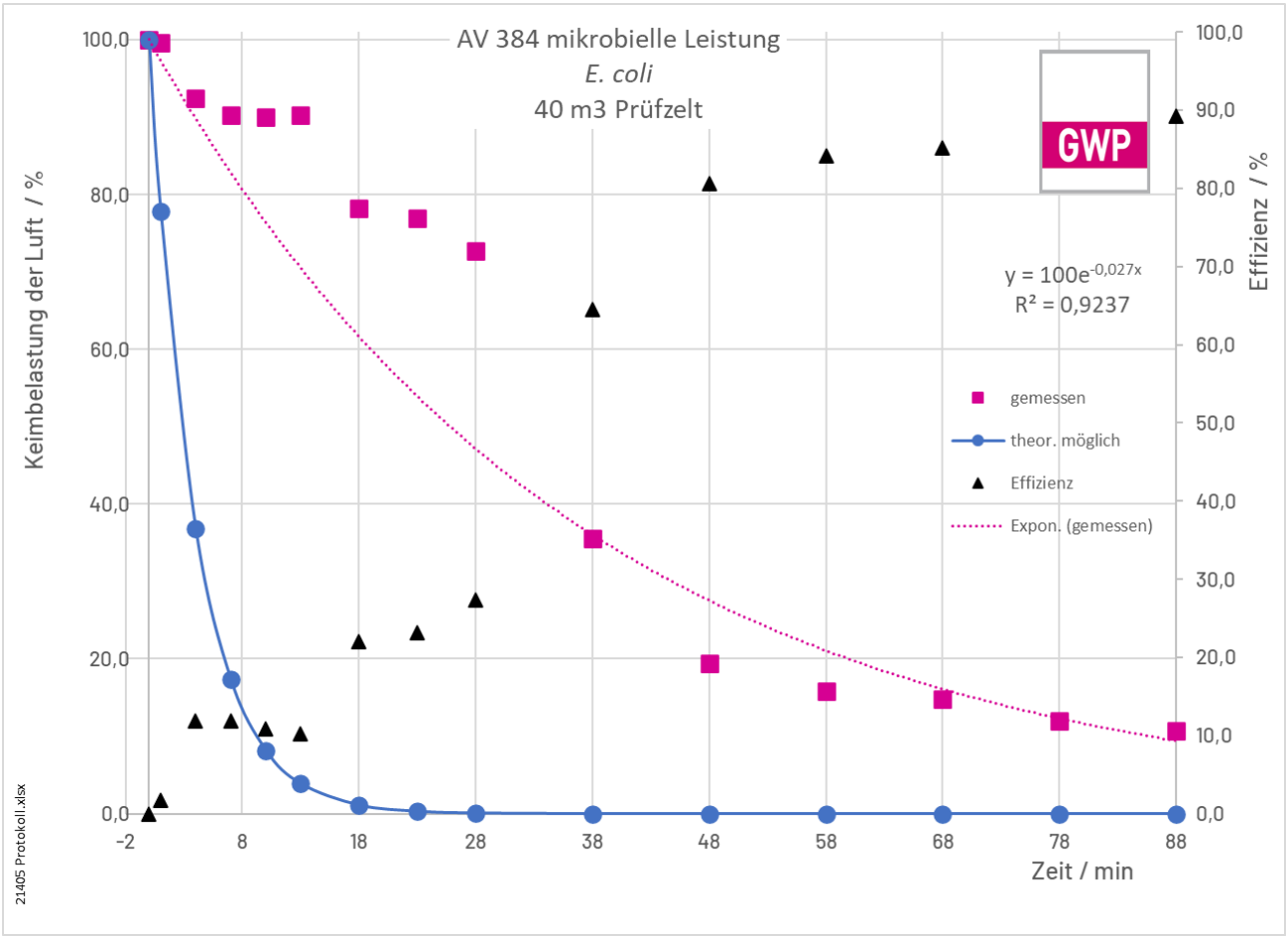

Figure 7: Comparison of the theoretically possible cleaning performance with an actual measurement to determine the device efficiency; UVC technology, approx. 600 m3 h-1.

5 SUMMARY

Clean indoor air can be a factor for the safe operation of public facilities not only in times of pandemics. The evaluation of different room air disinfection concepts and devices is of great importance, not least because of the need to make appropriate investment decisions.

Using the GWP AV384 method presented here, a wide variety of disinfection devices can be compared in terms of their microbial cleaning efficiency, irrespective of their performance. This makes it possible to distinguish between effective and ineffective devices. The determination of the efficiency allows the comparison of different devices and the selection of the most efficient device for a certain room size.

The continuous further development of the method will result in the creation of a database on the efficiency of a wide variety of device types, whereby their suitability remains transparent for the user thanks to comprehensible parameters such as t90 time and t90 efficiency.

6 APPENDIX

6.1 Bibliography

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7 VERSION CONTROL

Revision Date	REV	Author	Comment
2021-09-02	0, 1	SC	Creation
2021-09-06	2	JAN	Revision
2021-09-13	3	SC	new format, revision with exponential function Start 100