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Extract of Indoor air hygiene and use of air purification technologies in movie theaters during the Covid-19 pandemic (CineCov) - final report

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Project consortium:
- Fraunhofer Institute for Building Physics IBP
- Institute of Occupational Medicine, Safety Technology and Ergonomics e.V. (ASER)
- University of the Bundeswehr Munich, Institute of Fluid Mechanics and Aerodynamics
- Fraunhofer Singapore
- Fraunhofer Austria
- Central Organization of the Film Industry (SPIO)

1. Background

As businesses set to reopen and with **less covid restrictions**, people look forward to live with some semblance of normalcy. Cinema operators have **intensified their efforts to offer a safer environment for moviegoers**. Hygiene protocols, face masks, reduced occupancy, social distancing, and increased ventilation for cinema halls are in place but **more preventive measures are needed to reduce the risk of infections**. This led to the **CineCoV Study** which was **initiated by the organisation of the film industry `Spitzenorganisation der Filmwirtschaft`, e. V. (SPIO) and funded by the German government.**

The CineCoV study was conducted by Fraunhofer Institute, **Europe's largest application-oriented research organization**. Two air purification technologies were selected and tested using aerosolized model viruses in comparison to the established ventilation system.

2. Objective

The objective of the study was to test the efficiency of **ventilation system operating with and without different air purification technologies** in different cinema halls, and its **impact on the reduction and inactivation of airborne viruses**.

3. Methodology

The study took place in the Cincinnati cinema in Munich and the Trifthof cinema in Weilheim. In the Cincinatti cinema hall in Munich, the infectious viral load with and without the use of air purification devices with its existing ventilation system was tested using Cerafusion™ Technology. The cinema hall was equipped with the air purification devices that released active oxygen into the hall via eight nozzles distributed throughout the cinema ceiling. Active oxygen that produces low ozone concentration was adjusted to an average level of 120 µg/m³ ozone in the cinema hall that complies with the WHO recommendation. A comparison was made with the existing ventilation working with Medklinn PRO AS500D. The existing ventilation system operates with 10% fresh air. The test in the cinema hall was carried out with temperature-controlled dummies to simulate moviegoers. The cinema hall had 428 seats with a room size of 2252 m³.

The other study was conducted in Trifthof cinema hall in Weilheim where the infectious viral load with and without the use of upper air UV-C devices were used with its existing ventilation system. These devices emit UV-C light into the open airspace below the cinema ceiling. The installation was designed in such a way that the radiation exposure in the seating area was below the limit value for permanent residence at a maximum of 1.55 mW/m². The existing ventilation system was operating with 100% fresh air (according to the cinema operator) and was tested with and without two air purifiers Philips WL345C 500mW. The test in the cinema hall was carried out with temperature-controlled dummies to simulate moviegoers. The cinema hall had 55 seats with a room size of 233.7 m³.

Surrogate viruses (enveloped Phi6 bacteriophage) with a comparable structure, particle size and environmental stability to SARS-CoV-2 were used as test organisms.

The tests done were exclusively on aerosols in the air. The natural half-life of the virus (Phi6 bacteriophage) was taken into account when calculating the efficiency of the device.

The structure was based on DIN ISO 16000-36 for examining airborne bacteria, realistically adapted to the specific requirements of viruses. The viruses were collected from the room air on gelatine filters in accordance with DIN ISO 16000-16, and the filters were processed in accordance with DIN ISO 16000-17. The number of active viruses (“virulence”) was determined in the laboratory using a plaque assay.

Test schedule

Two days of test measurements were carried out for each different air purification technology to determine the influence of the air purifier. Measurement on day 1 (reference measurement day), the timing was identical to the second measurement day, apart from the connection of the air purifier, which was only in use on measurement day 2. The investigations of the two measurement days were carried out according to the following scheme (Table 1) and are graphically visualized in Figure 1.

The dosing was initially carried out without switching on the ventilation and the air purifier in order to achieve a high virus load in the room. After about 90 minutes, the ventilation was switched on with the fresh air proportion set in the respective ventilation system. The cinema hall was not adjusted to a fixed room climate (temperature and humidity). The dosing and the room air purification technology (only on measurement day 2) were

switched on simultaneously to determine the virus reduction. This test setup was operated for a total of about 3.5 hours with continuous dosing of the virus during this duration. At certain points in time, the viruses were drawn onto gelatine filters using an air sampler and subjected to a plaque assay test in the laboratory for microbial analysis. The loaded gelatin filters were processed within one hour and evaluated after 24 hours.

Table 1: Timing of the two measurement days

Schedule	Measurement Process	Measurement day 1 (reference measurement day) 9/6/21 & 1/12/21**		Measurement day 2 16/6/2021 & 2/12/21**	
		Ventilation	Air Purifier	Ventilation	Air Purifier
0 – 60 min	Virus Dosage	-	-	-	-
60 – 90 min	Virus dosage; Sampling 1 biology / chemistry	-	-	-	-
90 – 120 min *	Virus Dosage; Sampling 2*	Active	-	Active	Active
120 – 150 min	Virus dosage; Sampling 2 biology / chemistry	Active	-	Active	Active
150 – 180 min	Virus dosage; Sampling 3 biology	Active	-	Active	Active
180 – 210 min	Virus dosage; Sampling 4 biology	Active	-	Active	Active
210 mins	End of trial	-	-	-	-

*) Based on the results from the first cinema hall (Cincinnati cinema), this sampling was also carried out in the second investigation (Trifthof cinema).

**) Measurements taken from Cincinnati cinema – 9/6/21 and 16/6/21 and Trifthof cinema – 1/12/21 and 2/12/21

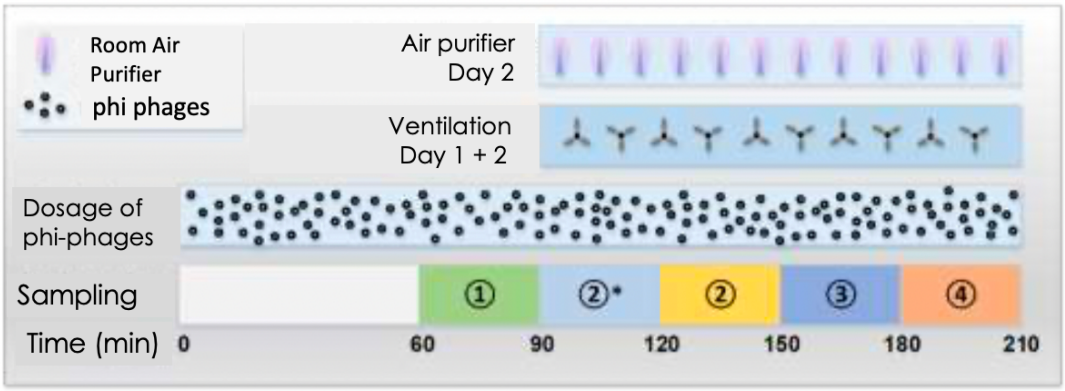

Figure 1: Time Visualization of both measurement days

4. Summary of Results:

4.1 Measurement of virus activity collected in Cincinnati Cinema in Munich for both measurement days with and without Cerafusion™ Technology.

Table 2: Measurement of virus activity in Cincinnati cinema (Day 1: 9th June 2021 and Day 2: 16th June 2021).

		Day 1			Day 2		
		Ventilation without Disinfection Device (Reference Measurement)			Ventilation with Cerafusion™ Sterilization Technology		
Sampling	Sampling Interval (min)	Determination of active units in [pfu/m3]	Air Purifier (ON/OFF)	Reduction of Virus, %	Determination of active units in [pfu/m3]	Air Purifier (ON/OFF)	Reduction of Virus, %
P1 1)	60 - 90	12,567	OFF	0 2)	80,111	OFF	0 2)
2*	90 - 120		OFF		*	ON	
P2	120 - 150	14,567	OFF	-15.92% 3)	22 4)	ON	99.97%
P3	150 - 180	7,467	OFF	40.58%	22 4)	ON	99.97%
P4	180 -210	1,800	OFF	85.67%	< 22 5)	ON	> 99.97%

Note:
2* Active oxygen is switched ON and conditioned to the desired ozone level. No sampling data was collected.
1) Value for daily reference measurement (concentration P1 is set as 100%) Recovery [%] = 100/P1*P2, or recovery [%] = 100/P1*P3;
2) Value is set as 0% reduction.
3) n.r.: no reduction
4) The result is below the limit of quantification of 667 pfu/m3.
5) The result is below the detection limit of 22 pfu/m3.

A comparison of the two measurement days shows an increase by 16% in the active virus concentration on the reference measurement day and a decrease by 99.97% in the active virus concentration on the second measurement day in relation to the respective daily reference measurement (sampling P1) at the sampling interval P2 with and without Cerafusion™ Technology. On both measurement days when the ventilation was switched ON after 60 minutes total running time, particles that had already settled could have been whirled up, which led to a short-term increase in concentration on the reference measurement day however this is not the case for the second day due to the effect of Cerafusion™ Technology. In the further sampling P3 and P4 for both measurement days, the active virus concentration continues to show decrease in trend

but it is more obvious with the effect of Cerafusion™ Technology even when the second measurement day sampling P1 is at a higher value.

During the two measurement days, the particle distribution of virus aerosols in the room was continuously recorded over the measurement periods. After starting up the ventilation system without and with the influence of the Cerafusion™ Technology, the particle number concentration fell in all over the entire test period. The reduction in the particle number concentration results from the dilution by the supplied outside air. While the Cerafusion™ Technology inactivates the viruses it does not influence the virus particle numbers in the room.

Different volatile organic substances (VOCs) and total volatile organic compounds (TVOC) were also measured to determine if the active oxygen which released low level of ozone creates potential critical by-products. The measurements indicated that the level of VOCs and TVOC are within the threshold levels provided by the Federal Environmental Agency, Germany.

4.2 Measurement of virus activity collected in Trifthof Cinema in Weilheim for both measurement days with and without using upper air UV-C Technology, Philips WL345C 500mW.

Table 3: Measurement of virus activity in Trifthof cinema (Day 1: 1st December 2021 and Day 2: 2nd December 2021).

		Day 1			Day 2		
		Ventilation without Disinfection Device (Reference Measurement)			Ventilation with UV-C Air Disinfection		
Sampling	Sampling Interval (min)	Determination of active units in [pfu/m3]	Air Purifier (ON/OFF)	Reduction of Virus, %	Determination of active units in [pfu/m3]	Air Purifier (ON/OFF)	Reduction of Virus, %
P1 1)	60 - 90	97,250	OFF	0 2)	124,167	OFF	0 2)
P2*	90 - 120	160,000 3)	OFF	-64.5%	19,514	ON	84.3%
P2	120 - 150	15,933	OFF	83.6%	2,517	ON	98.0%
P3	150 - 180	9,533	OFF	90.2%	3,817	ON	96.9%
P4	180 -210	4,367	OFF	95.5%	5,650	ON	95.4%

Note:
2* - UV-C Air Disinfection device is switched ON for Day 2. Sampling data was collected.
1) Value for daily reference measurement (concentration P1 is set as 100%) Recovery [%] = 100/P1*P2, or recovery [%] = 100/P1*P3;
2) Value is set as 0% reduction.
3) n.r.: no reduction

In table 3, a comparison of the two measurement days shows an increase by 65% in the active virus concentration on the reference measurement day and a decrease by 84.3% in the active virus concentration on the second measurement day in relation to the respective daily reference measurement (sampling P1) at the sampling interval P2* with and without upper UV-C devices. The increase in active virus concentration at the sampling interval P2* on the reference measurement day could be due to the initial air movement when the ventilation system was switched ON after 60 mins total run time similar to Cincinnati cinema.

In the further sampling intervals (P2 to P4), there were further reduction effects but it became smaller over time. The sampling interval at P4 of the second measurement day, no further reduction effect could be detected compared to the same sampling interval of the reference measurement day. On the longer run times, the reduction in viral load in the room was comparable on both measurement days. Do note that for the sampling interval P2* to P3, an additional positive effect of the air cleaner could be shown in comparison to ventilation and ventilation with upper UV-C devices. The results thus show that the upper UV-C devices reduce the virus load in the room with shorter runtimes.

Similar to Cincinnati cinema during the two measurement days, the particle distribution of virus aerosols in the room was continuously recorded over the measurement periods. The reduction in the particle number concentration was recorded as the ventilation system was switched ON without and with the upper UV-C devices. There was no discernible influence of the upper UV-C device similar to the results from the Cincinnati cinema.

The measurements of different volatile organic substances (VOCs) and total volatile organic compounds (TVOC) comparing ventilation without the upper UV-C devices, and ventilation with upper UV-C devices show not much different and are within the threshold levels provided by the Federal Environmental Agency, Germany.

The overall results from the study of ventilation with and without the air purification technologies show that the dilution effect of the ventilation without the air purifiers is given but it is less efficiency in comparison with the air purification technologies. If the ventilation is not in operation sufficiently in advance before the cinema auditorium is occupied, or if there is not enough fresh air, the air purifiers will be a good addition to consider. Both technologies used should have proper protocol and under constant monitoring with relevant sensors and documented according to the hygiene concept and during commissioning.