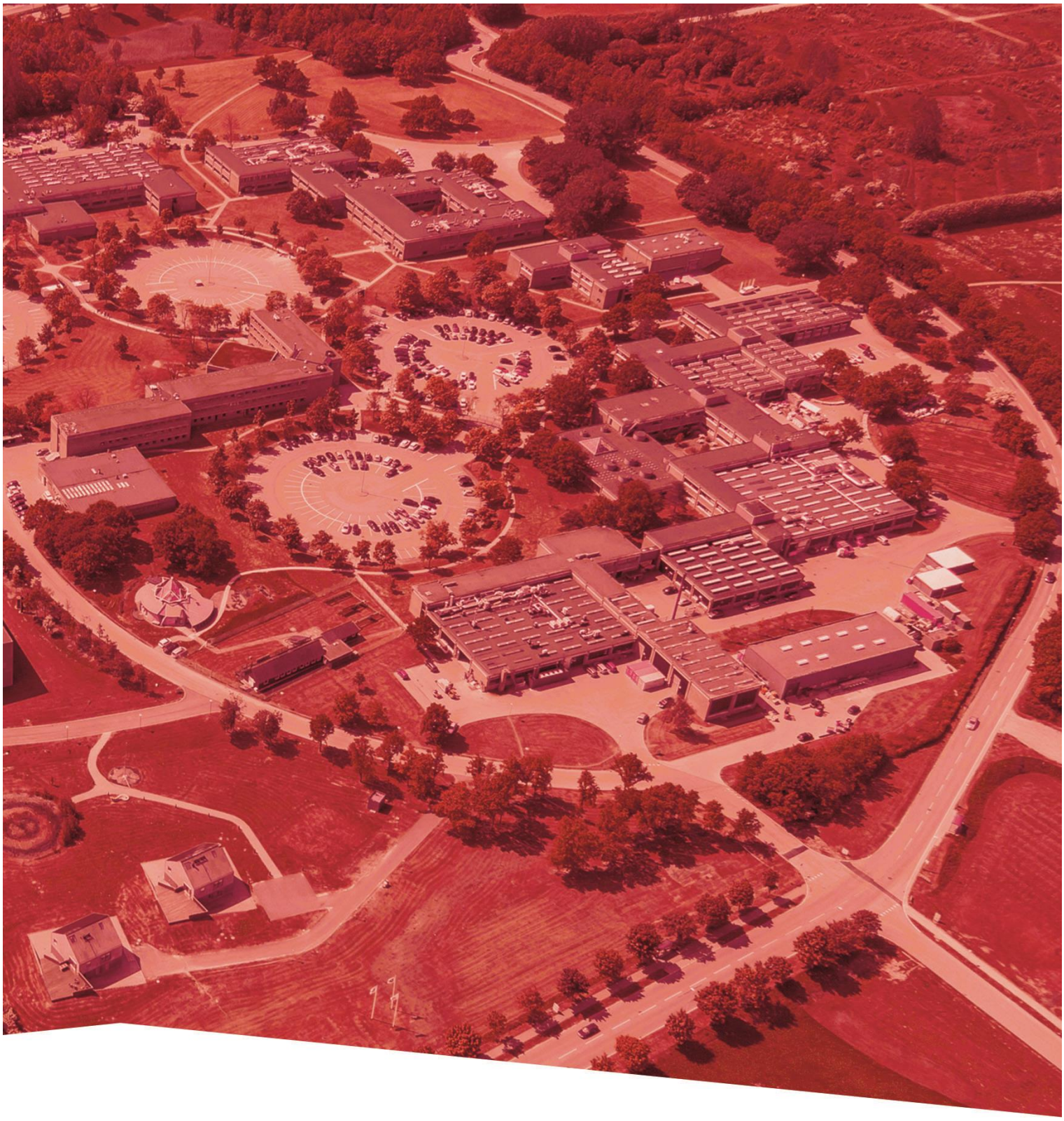

Measuring virus inactivation by the NORDICCO Northern Light system

UVC light integrated in the fan blades of a HVLS fan

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Measuring virus inactivation by the NORDICCO Northern Light system

UVC light integrated in the fan blades of a HVLS fan

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1. Summary

This report covers the physical testing of a Nordicco Northern Light HVLS fan and its ability to disinfect air using UVC light. The Northern Light HVLS fan (3 m diameter) has been tested in a large room (665 m³) filled with aerosolized MS2 virus. To our knowledge, this is the largest controlled experiment conducted to analyze the inactivation of airborne viruses utilizing UVC light. The reduction of virus in the room has been measured in two pairs of trials during one hour with UVC lights either off or on. After 15 min the MS2 virus concentration is 75 % with UVC light turned off and 5 % with UVC turned on relative to the start concentration. Comparing the UVC light sensitivity of MS2 virus to SARS-CoV-2 virus the Northern Light system would very likely have an even higher inactivation of SARS-CoV-2 virus according to the majority of published articles known to the authors of this report. To our knowledge this is the most efficient system for disinfection and distribution of large air volumes while occupants are present in the room.

2. Background

Light has been used for disinfection since 1904 when the Faroese-Danish doctor Niels Ryberg Finsen won the Nobel prize for treating skin tuberculosis with light. Since then, universities worldwide have investigated inactivation of bacteria and viruses with light and ultraviolet (UV) light. UV light is invisible to the naked eye and is classified according to their light spectrum. UV radiation is classified as UVA at a wavelength of 315 – 380 nm, UVB at 280 – 315 nm, and UVC at 200 – 280 nm. Figure 1 shows a lamp radiating light in the UVC spectrum.

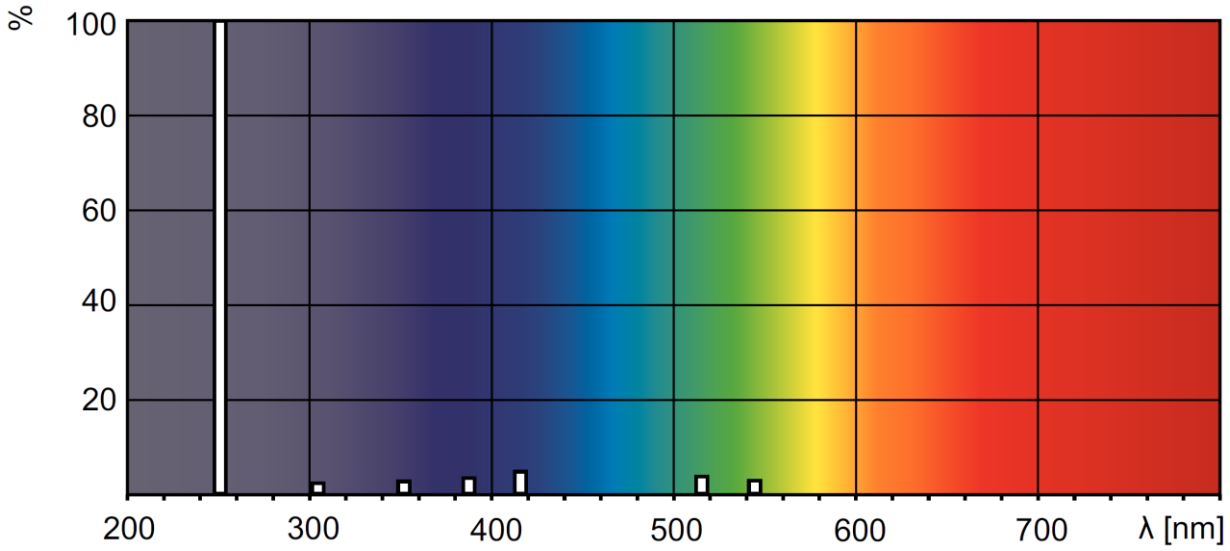


Figure 1. Light spectrum of a lamp with a peak at 254 nm.

Studies have found that UVC light efficiently inactivates airborne viruses, including human coronaviruses [1]. Multiple independent studies have also proven that UVC light at a certain dosage can inactivate 99.9% of Coronavirus [3]. From our review of published studies, One study reviewed 8 other articles concerning UV resistance, suggesting that the CoV family is likely more sensitive to UV inactivation than MS2 [5] in agreement with the other studies [2-4].

Figure 2 illustrates the sensitivity, dose-response, of MS2 and SARS-CoV-2 based on data from two collections of multiple studies [4, 5]. The data shows that SARS-CoV-2 is significantly more receptive to UVC than the MS2 virus. As an example, only 11 % of MS2 is inactivated at a dose of 1 mJ/cm² compared to 46 % for SARS-CoV-2.
The equations for calculating dose response are explained in Appendix B.

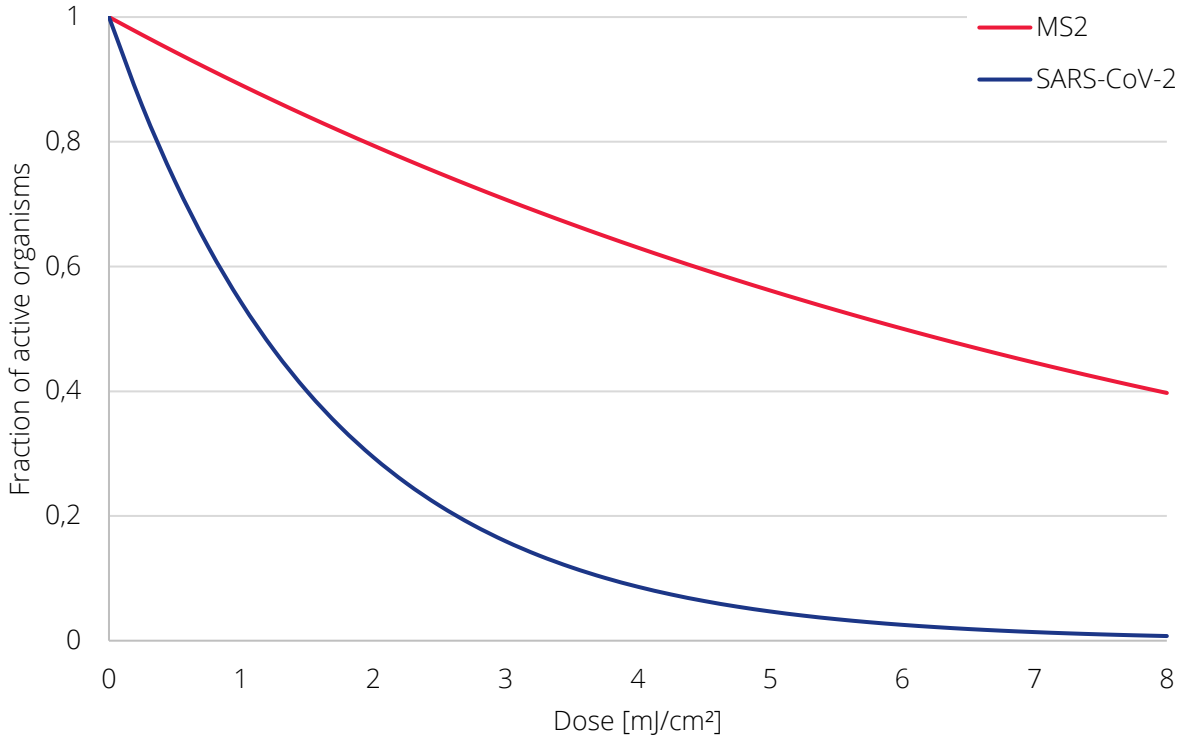


Figure 2. UVC sensitivity (254 nm) for different types of viruses.

High volume low speed (HVLS) ventilators are a type of mechanical fan which is greater than 2.1 m in diameter. HVLS fans are generally ceiling mounted and move slowly compared to a small fan while distributing large amounts of air.

3. Purpose

Full-scale test of airborne virus inactivation efficacy using a HVLS fan equipped with upwards facing UVC-lights.

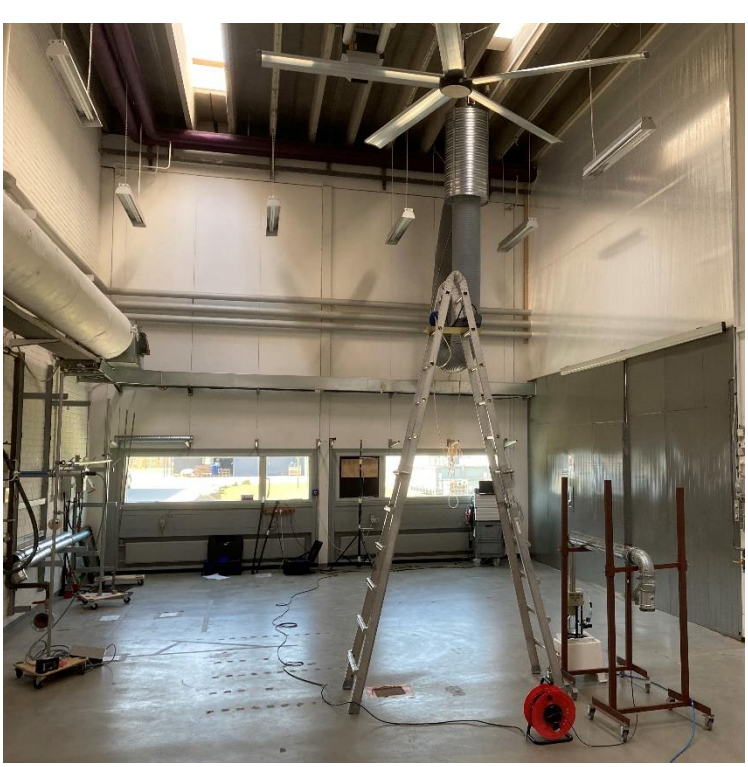
4. Method

The experiment was performed at full-scale with the HVLS fan installed in a room of length, width, height: 13.91 m, 6.78 m, and 7.05 m, respectively. The HVLS fan with integrated UVC lighting has a diameter of 3 m and is mounted from the ceiling at the height of 4.64 m above the floor. A picture and a plan drawing of the room can be seen on Figure 3. The experiment consists of four trials where the last two trials were performed the same day as seen on Table 1.

Table 1. Conducted trials.

Trial	Description	Particle measurements	Air samples (impingers)	Date
1	UVC lights turned off	10 s interval, continuous	Intervals 0-10, 2-12, 4-14, 10-20, 20-30, 30-40, 60-70 min	2021-04-20
2	UVC lights turned on	10 s interval, continuous	Intervals 0-10, 2-12, 4-14, 10-20, 20-30, 30-40, 60-70 min	2021-04-27
3	UVC lights turned on	10 s interval, continuous, start after 18 min	Intervals 0-10, 2-12, 5-15, 10-20, 20-30, 30-40, 60-70 min	2021-05-19
4	UVC lights turned off	10 s interval, continuous	Intervals 0-10, 2-12, 5-15, 10-20, 20-30, 30-40, 60-70 min	2021-05-19

Before each trial, the room was swept clean and completely vented with outdoor air. All windows and doors were closed 15 - 30 min before each trial to stabilize the air temperature, relative humidity, and air movements in the room. The HVLS fan had a constant rotational speed of 33.5 rpm ± 1.5 rpm during each trial. The rotational direction of the HVLS fan was set to blow air downwards.



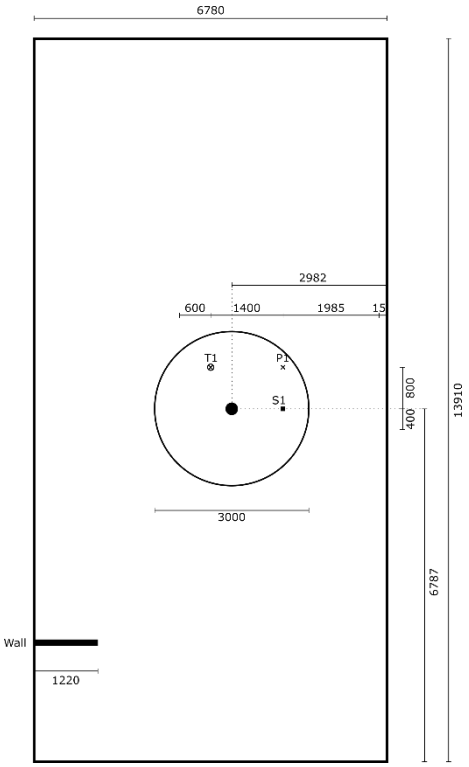


Figure 3. Left: Picture of the room. Right: plan drawing and sampling positions. The full-size plan drawing illustrated in appendix A.

Bacteriophage-MS2, commonly called MS2 virus was used for the experiment. MS2 virus contains a ssRNA (Single Stranded Ribonucleic Acid) genome similar to SARS-CoV-2 (coronavirus) [5]. The MS2 virus was transported in a cooler box in a SM buffer solution to make sure the virus is preserved during transport. A Palas AGK 2000 nebulizer was used to aerate the MS2 virus (see Figure 4) which was released at a height of 1.1 m located at S2 on the plan drawing. Before and after each trial the nebulizer was cleaned for at least 15 min with demineralized water. The nebulizer was supplied with 4 bar pressurized air from an oil-free air compressor which is reduced to 2 bar at the nebulizer. A suspension of virus particles was prepared and aerosolized in the room. The nebulizer was aerating liquid with MS2 virus suspension for exactly one hour releasing 20 mL of the MS2 virus suspension into the air to build up the virus concentration in the room. The virus particles travel up through a drying column in a spiral motion and emerge as a very fine mist which is barely visible. The mist is propelled forwards by a horizontal air stream with a velocity of 1.2 m/s.

Air temperature and relative humidity was measured using a NOVASINA HygroDat 100 (see Figure 4) at a measuring height of 1.1 m located at T1 on the plan drawing (see Figure 3).

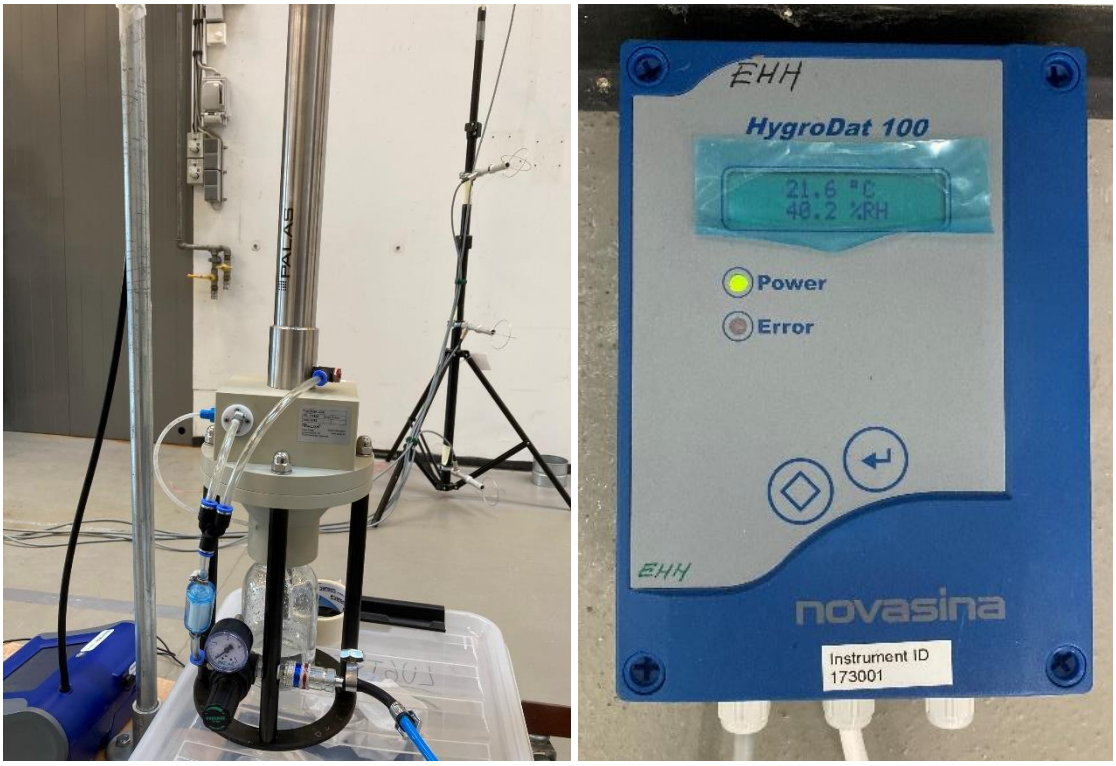


Figure 4. Left: Palas AGK 2000 nebulizer with demineralized water. Right: NOVASINA HygroDat 100.

Particle concentrations were measured in size segregated mass fractions for PM_1, $PM_{2.5}$, respirable, PM_{10} and total were measured with a DustTrak DRX 8533 at a measuring height of 1.1 m located at P1 on the plan drawing (see Figure 3). Ultrafine particles were measured with a P-Trak 8525 at a measuring height of 1.1 m also located at P1 on the plan drawing. The P-Trak 8525 and DustTrak DRX 8533 can be seen in the bottom right corner of Figure 5.

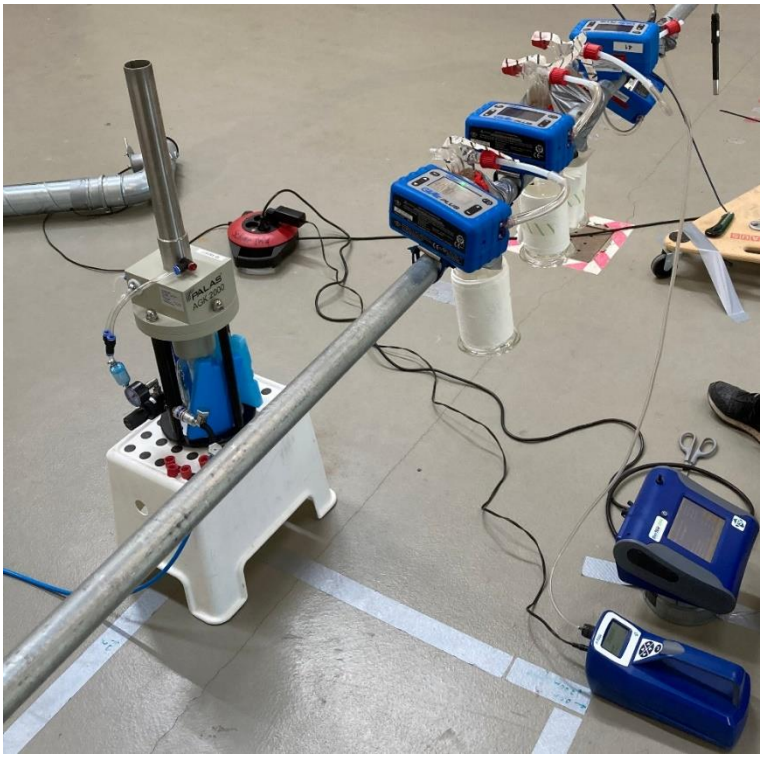


Figure 5. Picture of the experimental setup at sampling position P1. From left to right: Palas AGK 2000 nebulizer, hanging from a steel rod three impingers and four GilAir pumps, on the floor P-Trak 8525 and DustTrak DRX 8533.

Glass impingers were used to take air samples to determine the amount of active MS2 virus in the air. Air is sampled for 10 min at a flow rate of 4 L/min such that the sampled volume is 40 L ± 1 L. The impingers are sent back to the laboratory in the cooler box for analysis.

The laboratory analysis procedure for determining the concentration of MS2 virus is described next. Subsamples of the air inside the chamber were taken and the virus particles were collected by using impingers. The concentration of active virus particles was quantified by mixing dilution series of the samples with the host cells, incubating to allow growth of non-infected host cells, and enumerating plague forming units (pfu). The experimental conditions are listed in Table 2. Pictures from the laboratory and two agar plates can be seen on Figure 6.

Table 2. Experimental conditions for air cleaning.

Test organism:	MS2 bacteriophage, ATCC 15597-B1
Host organism for MS-2:	*Escherichia coli*, ATCC 15597
Growth conditions for enumeration of pfu:	Coliform agar at 37±2°C for 18-24 h

Growth conditions for host organism:	First on TSA plates and then in TSB at 250 rpm. at 37±2°C for 20-24 h.
Sampling and dilution solution:	SM buffer
Sample volume (SM-buffer):	60 mL per bottle
Test suspension for aerosolization:	SM buffer with 10^{10} - 10^{11} pfu/mL

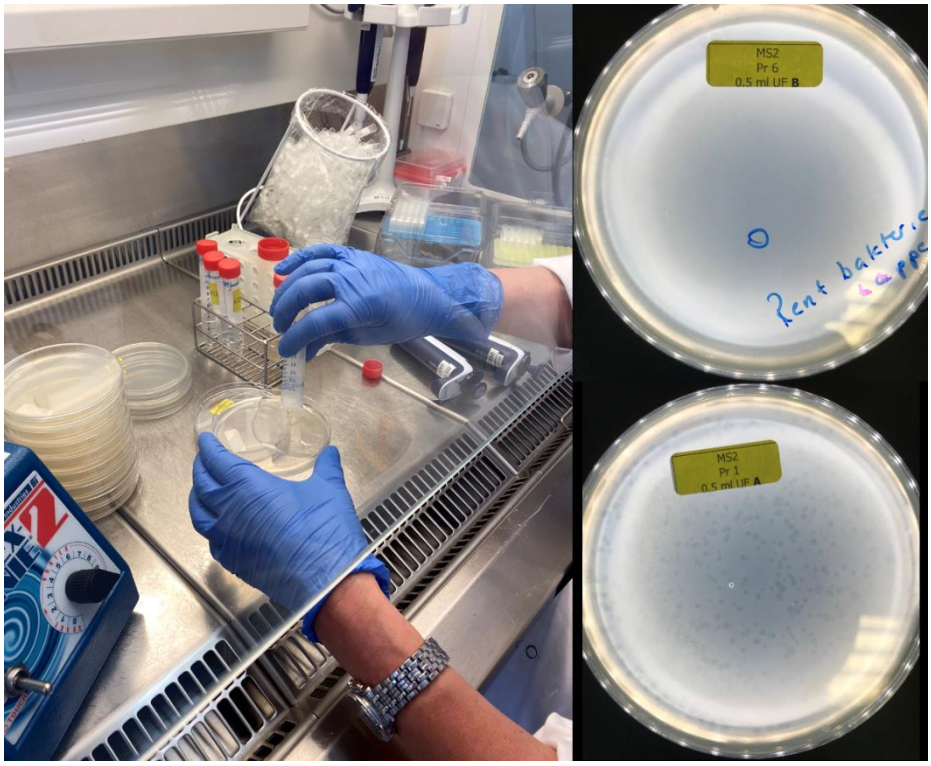


Figure 6. Left: Pouring top agar onto bottom agar. Top right: Petri dish with no infectious virus (plaque forming unit). Bottom left: Petri dish with multiple infections viruses (multiple plaque forming units).

5. Results and analysis

The air temperature in the room during all trials was 21 °C ± 1 °C. Relative humidity was 25 % ± 1 % during trials 1 and 2 and 40 % ± 1.5 % during trials 3 and 4.

Results from air particle samples can be seen on Figures 7 and 8. All red colored results are with the UVC light turned off while all blue colored results are with the UVC light turned on. The particle concentrations have been normalized to compare measurements from the four different trials. The linear correlation between any of the trials is very high ≥ 0.95.

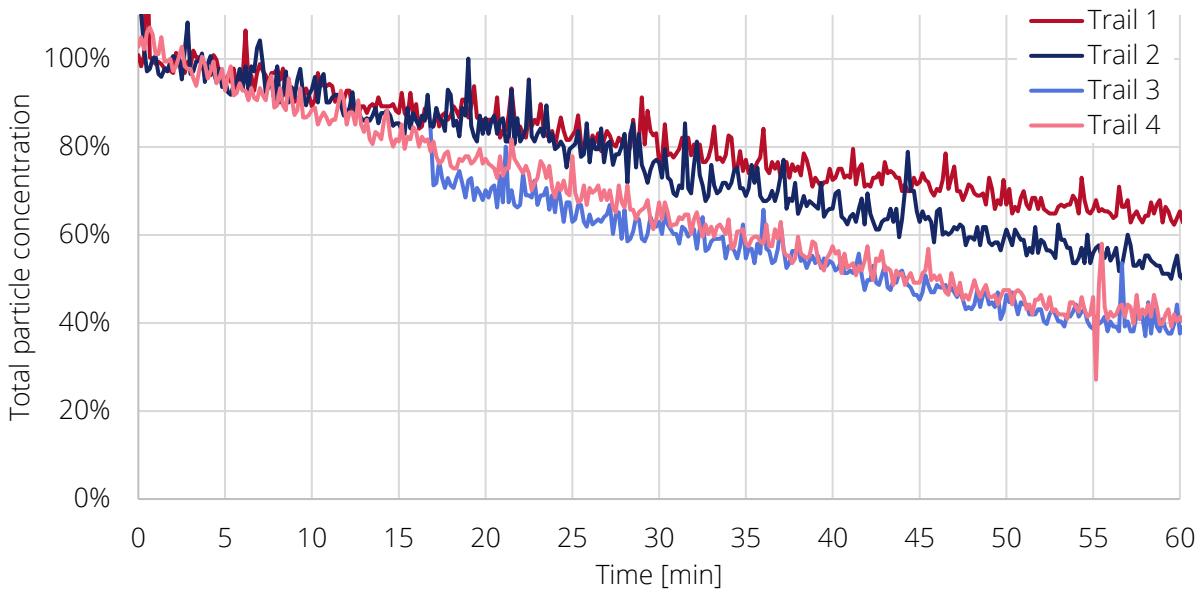


Figure 7. Normalized total particle concentration measured with DustTrak DRX 8533.

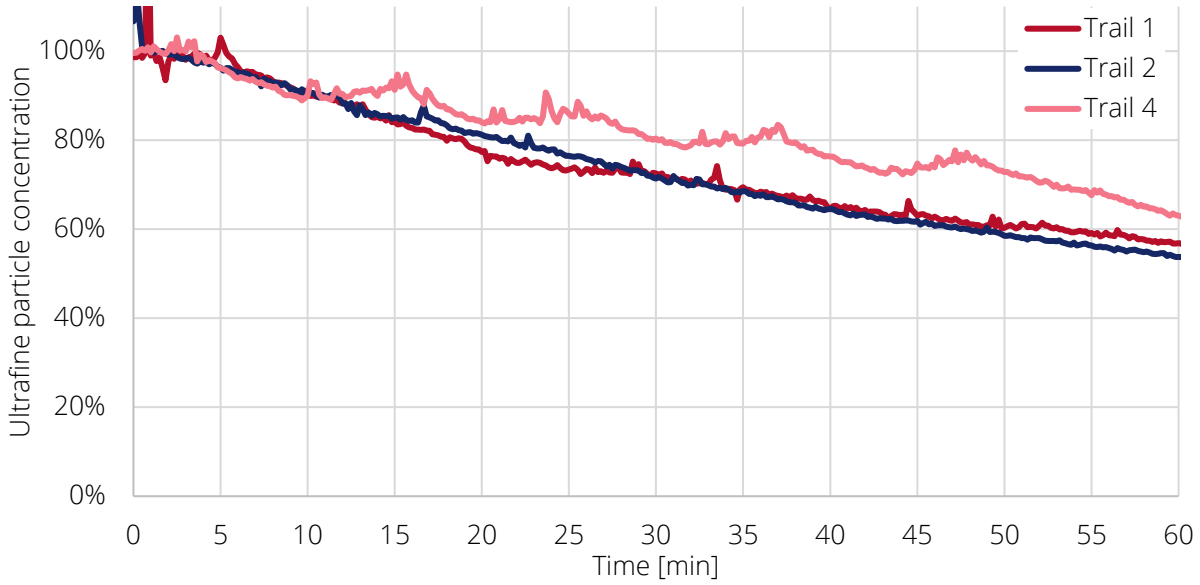


Figure 8. Normalized ultrafine particle concentration measured with P-Trak 8525.

Figure 9 show the concentration of active MS2 virus sampled from the impingers and analyzed from the laboratory. All samples are within normal biological variation. The measuring period for each sample was 10 min. Therefore, the results on Figure 9 are the average of a 10 min period. For example, for trials

1 and 4 the first sample illustrated at 5 min is reflecting the sampling period 0 – 10 min. For trials 2 and 3 the geometric mean is used due to the rapidly declining virus concentration.

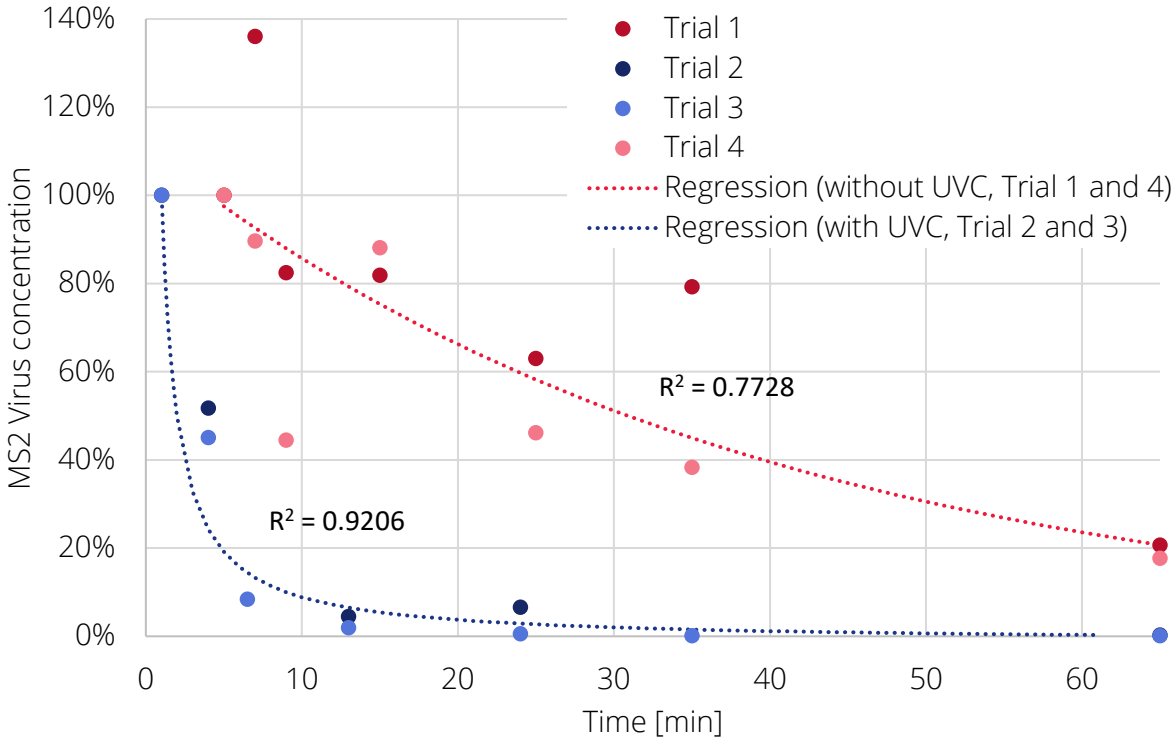


Figure 9. Regression of normalized active MS2 virus sampled from impingers. The red regression line is compiled of data for the two trials without UVC, trial 1 and 4 and the blue line is compiled of data for the two trials with UVC, trial 2 and 3.

From the regression functions, the MS2 virus concentration after 10 min is 86 % (relative to the start concentration) with UVC turned off and 9 % (relative to the start concentration) with UVC turned on. After 15 min the MS2 virus concentration is 75 % with UVC turned off and 5 % with UVC turned on.

6. Discussion

The results from the particle measurement shows a good correlation between the trials strongly indicates that all four trials have been performed identically. Room air temperature and moisture conditions were stable and pairwise close to identical (trials 1 & 2 and trials 3 & 4) which also suggests that the experimental conditions have been the same which justifies making comparisons. Measurements of the MS2 virus concentration were also within normal biological variation. An analysis of covariance between sampled data from impingers without UVC (trials 1 and 4) and with UVC (trials 2 and 3) showed that the

difference with and without UVC is virtually certain (>99 %). The concentration of virus in the room was for all samples above the detection limit to obtain reliable data.

To establish a realistic scenario for the experiment the distance between the virus source and sample point is 0.8 m corresponding to two persons sitting at a table. Similarly, the sample height of 1.1 m is the standardized theoretical average value for head height of a sitting sedentary person.

Possible sources of errors include: natural infiltration, ventilation due to door opening, natural light from skylights and windows, small errors with timing the start and stop of pumps, natural biological variation when counting the active virus concentration and particle pollution from subjects.

Comparing the UVC sensitivity of MS2 virus to SARS-CoV-2 virus (see Figure 2) the system would very likely have an even higher inactivation of SARS-CoV-2 virus according to the majority of read articles.

To our knowledge, it is the largest experiment to document airborne virus inactivation by UVC light.

7. Evaluation / conclusion

The experiments show that the MS2 virus concentration after 10 min is 86 % (relative to the start concentration) with UVC turned off and 9 % (relative to the start concentration) with UVC turned on. After 15 min the MS2 virus concentration is 75 % with UVC turned off and 5 % with UVC turned on.

8. References

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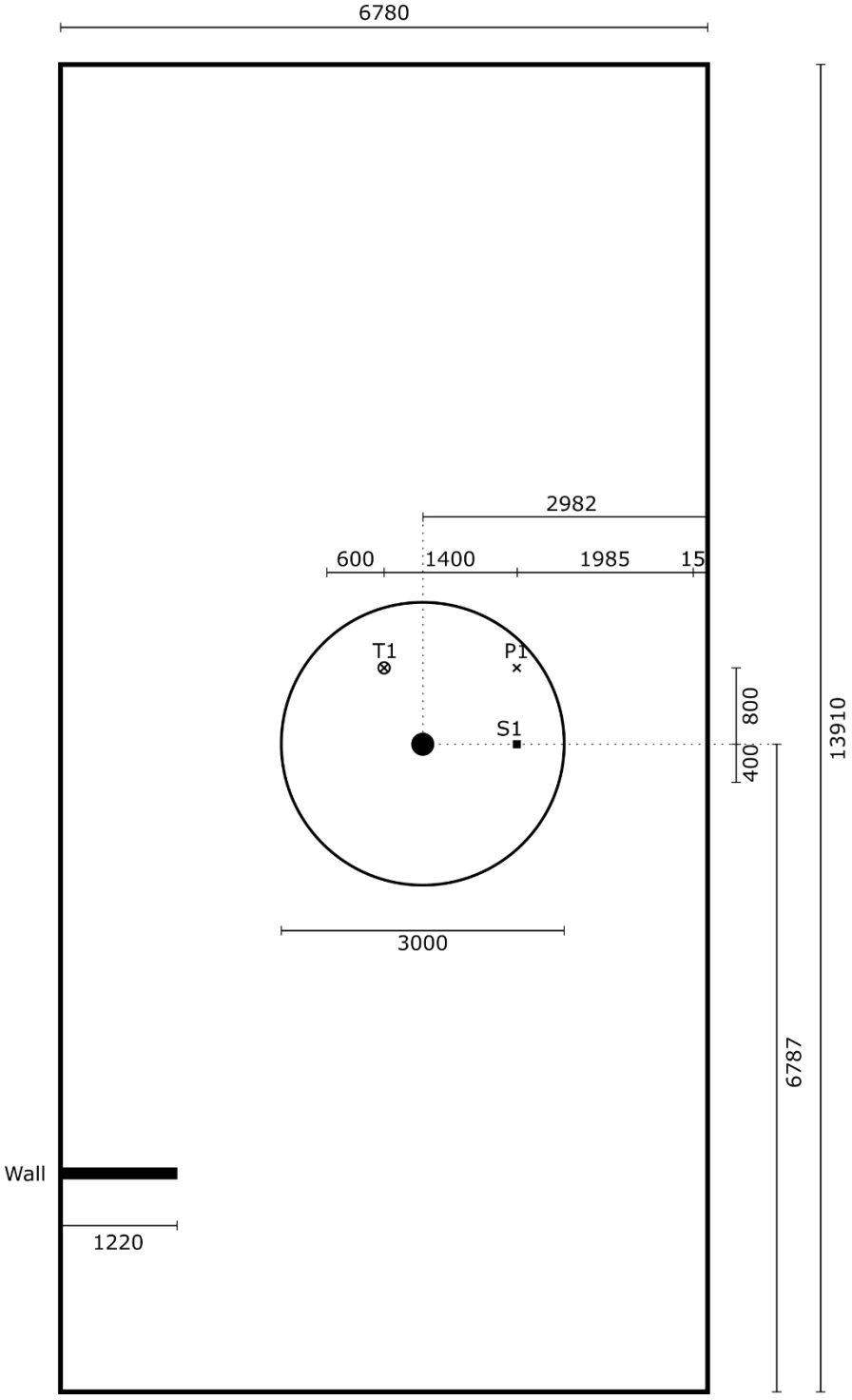
Appendix A – Plan drawing of the room



Measurement units in millimeter

Measurement sample height

Impingers
P1 1100 mm

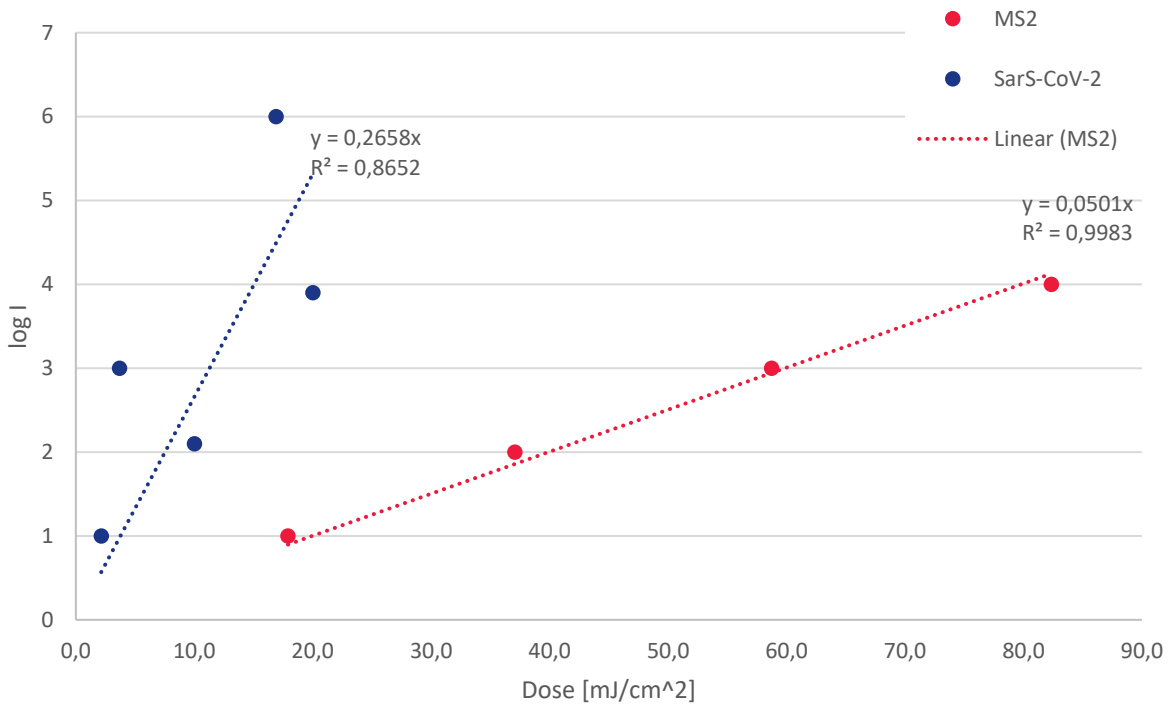
Virus source
S1 1100 mm

Temperature and relative humidity
T1 1100 mm

HVLS fan

Diameter 3000 mm
Height above floor 4640 mm

Appendix B – Determining k-values for dose-response graph



The dose response from the two studies [4, 5] is plotted in the figure above. Then the k-value can be found using the linear regression and isolating *k* in the equations below.

$$\log\left(\frac{n}{n_0}\right) = -kD\log(e) \Leftrightarrow$$
$$\log\left(\frac{n_0}{n}\right) = kD\log(e)$$

The dose response for UV exposure follows the following equation (plotted in Figure 2):

$$\frac{n}{n_0} = e^{-kD}$$

Where:

n	Number of active organisms [L^{-1}]
n_0	Initial number of organisms [L^{-1}]
k	UV sensitivity factor [cm^2/mJ]
D	UV dose [mJ/cm^2]

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