Heraeus

Noblelight

WHITE PAPER

UV-C Disinfection System for Public Transport Vehicles

CONTENT

ACKNOWLEDGEMENTS

SPECIAL THANKS SHOULD BE GIVEN TO:

- Ms. Amanda Mellek; HNG: Innovation Global
- Mr. Gerald Ritter; HH: Excellence
- Mr. Christian Rüth; HNG: Sales UV Germany
- Dr. Oliver Weiß; HNG: Innovation Product Development
- Ms. Claudia Winter; HNG Quality Manager SQA
- Mr. Volker Reith; HNG Global operation
- Ms. Flordelisa Amann; HH Dual training program
- Mr. Mimoun Ayada; HNG: Sales – EFMD
- Michael Lyhs; HNG: Global Operations
- the Staff of the HNG Measurement Laboratory

for their contribution during the project.

WE WISH TO THANK:

- Mr. Philippe Ehmes
- Mr. Manfred Senger

for their valuable technical support on this project and the whole staff of HSB (Hanauer Straßenbahn GmbH).

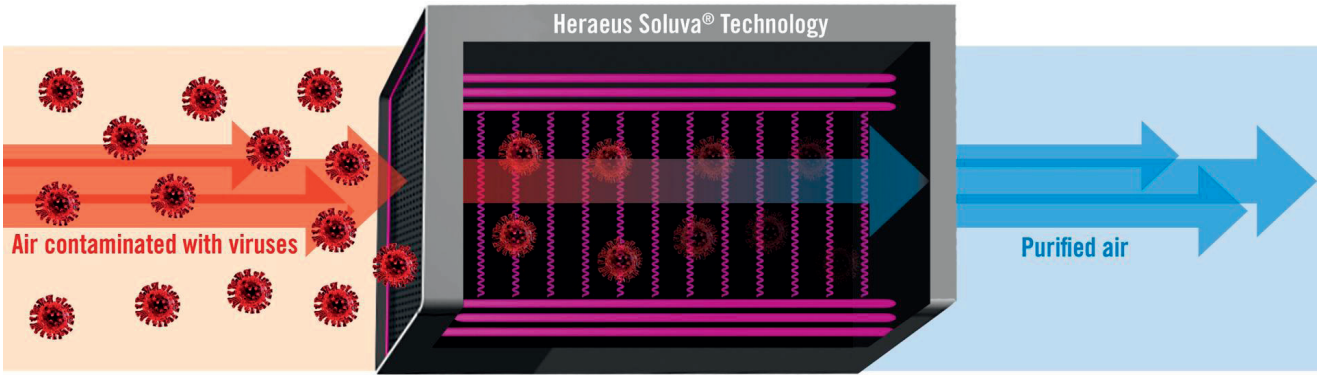
SUMMARY

This document provides a reference for design and implementation of an integrated UV-C air disinfection system in a transit vehicle in public transport.

There are certainly many approaches for so-called standalone products available which can be purchased on the market. In addition to the current products, SOLUVA® AIR V offers an "integrated" solution. That requires only tiny modifications of the existing parts in a vehicle.

Based on the SOLUVA® AIR V approach, the UV-C lamp units are mounted in the existing air duct/ channel of the vehicle.

Depending on the air channel geometry, air volume and velocity, the required optical power can be adjusted.



INTRODUCTION

Persons, particularly those who are at risk of severe illness from COVID-19, were advised repeatedly to avoid unnecessary travel. Moreover, government and private companies are struggling by providing some regulations and guidelines to reduce the chance of spreading COVID-19.

Shifting traffic peaks, using private vehicles, separating panes between the driver and the passengers on the bus, increasing transport capacity, wearing certified FFP2 masks, physical distancing, avoiding touching surfaces, using hand sanitizers containing at least 60 % alcohol and finally improving ventilation and getting more fresh air are some of the measures to improve passenger safety when travelling via public transport.

In the short term, those actions have a huge direct economic consequence to the transit agencies, vehicle manufacturers and their employees who are not able to work. Many transportation employees and crews in cruise lines, airlines, and public transportation sectors have lost their jobs due to the pandemic.

When will the COVID-19 pandemic end? It is still a tough question after one year. A return to normal life is still not foreseeable. It is not yet certain that the vaccines will be effective against coming mutations or how long immunity will last after vaccination. To enable a positive long-term perspective for the transportation sector, the passengers and vehicle transportation crews, actions to improve the air quality and inactivate the pathogen causing the COVID-19 pandemic actions are essential.

Heraeus Noblelight, one of the leading suppliers of industrial ultraviolet (UV) process solutions has introduced the SOLUVA® product family for disinfection of air and surfaces as the newest addition to its technology portfolio.

As the first enterprise world-wide, Heraeus Noblelight succeeded to develop an integrated UV-C upgrade for buses under the designation SOLUVA® AIR V. This solution passed the first on-road tests and is already being used in real operation in buses in Hanau, Germany and can be used in public transport worldwide with relatively low effort. And with success: The air in the vehicles can be disinfected within a few minutes.

In comparison to other air cleaning methods such as HEPA filters, ozone generators, ionizer purifier and air purification UVGI systems, SOLUVA® AIR V introduces a high-performance integrated UV-C solution which works under high volume air condition.

The combination of hygiene rules (e.g. wearing masks and maintaining minimum distances) and the air cleaned by our SOLUVA® AIR V solution significantly reduces the risk of each individual passenger and employee becoming infected.

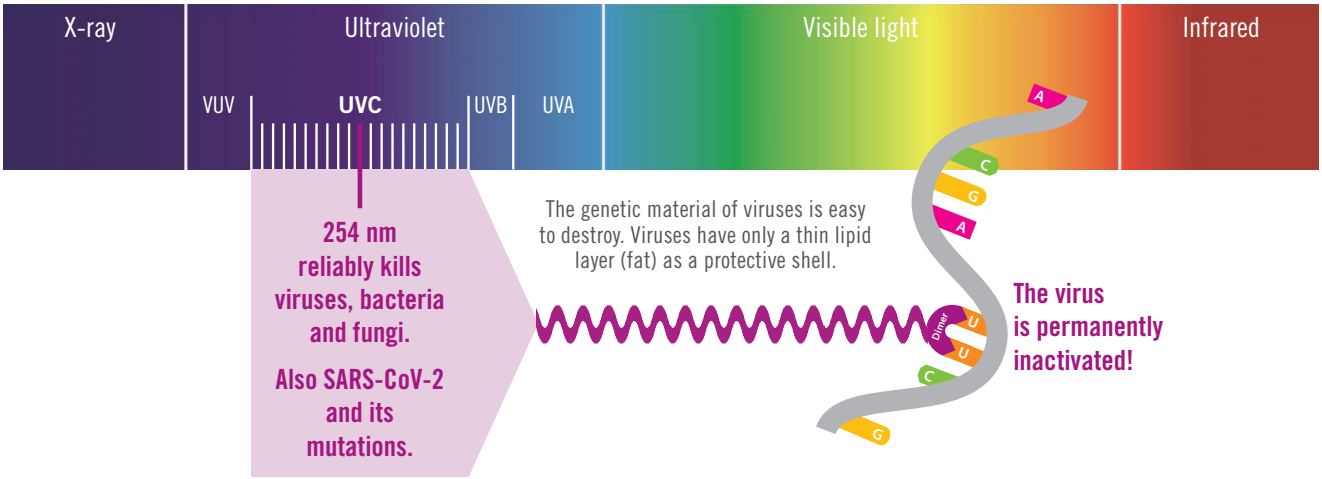
This describes an important building block to return to a normal life even with COVID-19.

This document is a story of success. The users of this documentation should consider necessary actions to adapt this advanced solution for their own project.

REVIEW OF THE LITERATURE

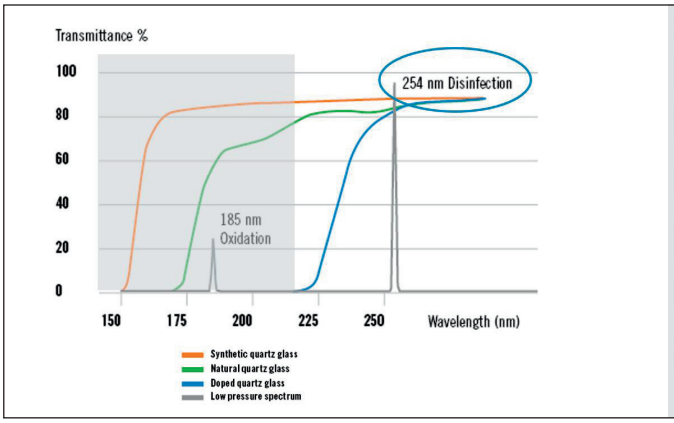
If UV rays hit the DNA of pathogens such as viruses, bacteria, molds or mites, their genetic material is destroyed. 99.99 % of the germs are inactivated.

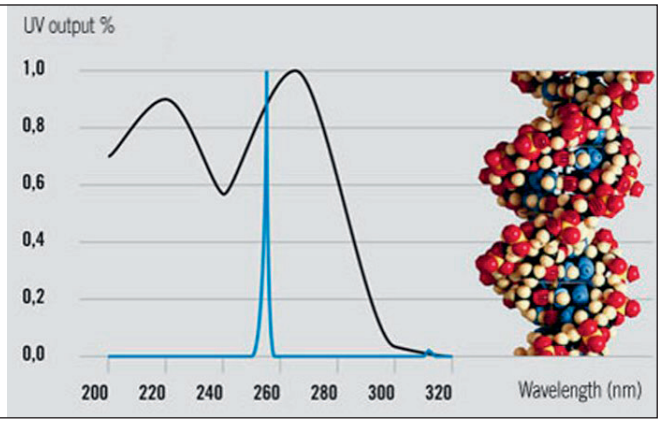
This also applies to multi-resistant germs - without creating resistance themselves. UV disinfection is effective at wavelengths from 200 nm to 300 nm.



A new study (Ruetalo, Businger, & Schindler, 2020) conducted by the University Hospital of Tübingen in cooperation with Heraeus Noblelight confirms that UV light is also able to render the SARS-CoV-2 virus, the pathogen causing the COVID pandemic, harmless. The surface disinfection was tested with two Heraeus products from the Soluva range. What is unique about the study is that it was not tested with similar viruses, but with the real pathogen. The result: 99.99 % inactivation of the SARS-CoV-2 virus.

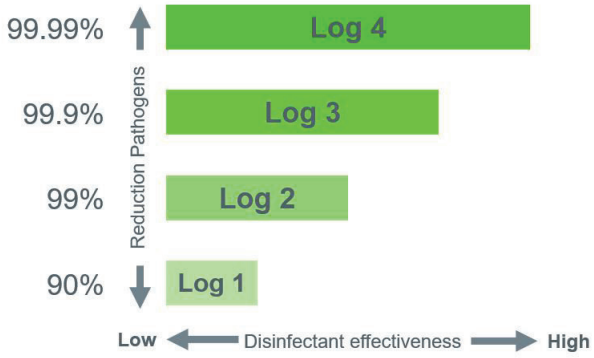
In another study (Heraeus Noblelight, 2021), Heraeus Noblelight together with Fraunhofer Institute for Building Physics (IBP), demonstrated for the first time under real conditions that UV-C (UVGI) disinfection significantly reduces the airborne virus load in a classroom. Special tempered dummies simulated students, one of whom constantly exhaled viruses (Phi6 bacteriophages as corona surrogate virus). In the room, the Heraeus Soluva® Air W equipment circulated the air and purified it with UV-C (UVGI) light. Measurements showed a virus count reduction of 99 %.

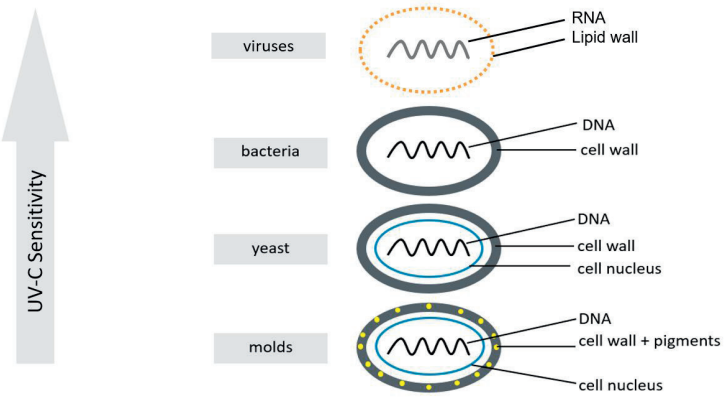




Results of the study (Heraeus Noblelight, 2021) on the inactivation analysis of airborne viruses with Soluva® Air M10 was carried out together with the Hygiene Institute Biotec GmbH shows a very high inactivation rate for the surrogate virus used. In this research project, the inactivation of the surrogate virus by the Soluva® Air M10 was investigated by introducing surrogate viruses into the aspirated air as an aerosol from a nebulization head at the air inlet. A reduction of ≥ 4.9 log levels could be demonstrated, which corresponds to an inactivation rate of ≥ 99.99875 %.

In terms of infection control, 'Log Reductions' convey how effective a product is at reducing pathogens. A summary of log reduction values using a starting point of 1,000,000 CFUs is outlined below:





UV-C SENSITIVITY OF DIFFERENT MICROORGANISMS

Dose (mJ/cm²)
= Irradiance (mW/cm2) x Exposure Time (s)

- Lethal Dose Ranges for 99,9 % (log 3) Inactivation
- Virus: 2 – 16 mJ/cm²
  Bacteria: 4 – 60 mJ/cm²
  Molds: 15 – 400 mJ/cm²

LETHAL DOSE FOR CORONA VIRUS SARS-COV-2 CAUSING COVID19

Various values were used as a reference for the UV-C dose. Previous experience and literature values indicate values of 2 – 16 mJ/cm² for a 99.9 % deactivation of viruses. All values are species-specific.

For the new SARS-CoV-2 virus, there were initially only estimates for typical corona virus strains: (Kowalski, Walsh, & Petraitis, 2020) gives an average of 6.7 mJ/cm² for a 90 % reduction (LOG1). This agrees with other data of 3.7–10.6 mJ/cm² (Heßling, Hönes, Vatter, & Lingenfelder, 2020).

Based on the measured values for a wide variety of microbes (Adel Haji Malayer), it can be estimated that a further UV-LOG1 dose is necessary for each further LOG disinfection stage. This suggests a dose of 20.1 mJ/cm² (= 6.7 x 3) for 99.9 % disinfection (LOG3).

Initial measurements on the actual SARS-CoV-2 virus typically assume only 3.7 mJ/cm² for LOG3 disinfection (99.9 % reduction); with very strong virus concentrations (and thus shadowing), UV-C doses of 16.9 mJ/cm² were sometimes necessary for 99.9 % disinfection (LOG3) (Andrea Bianco, 2020). Shadowing = the radiation source being covered by other viruses (colonies) on the culture media – are not to be expected in the Soluva Air V. Viruses that pass the unit via the air duct adhere to aerosols and are therefore almost unprotected exposed to UV-C radiation.

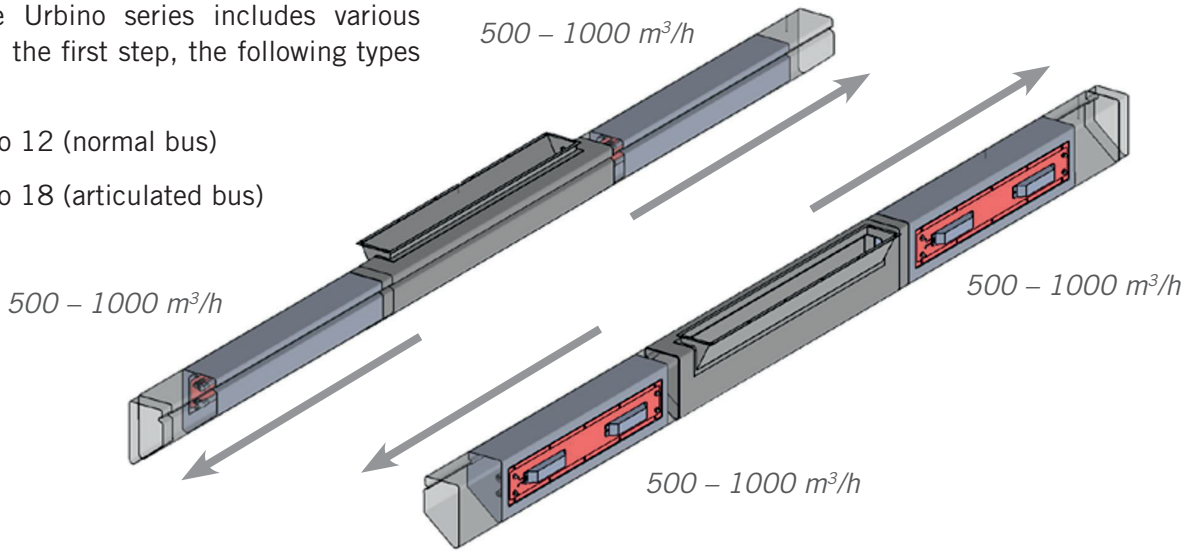
This coincides with further investigations of 5 mJ/cm² for LOG2 reduction and 22 mJ/cm² for LOG6 reduction of the SARS-CoV-2 virus by UV-C radiation (Griffiths, 2020). By converting these two values to a LOG3 reduction, the inactivation doses of 7.5 and 11 mJ/cm² can be concluded.

Note: in this document, inactivation doses for LOG3 is considered: 7.5 mJ/cm².

SCOPE OF WORK

This work initially, focuses on the Solaris Urbino series bus. The Urbino series includes various models which in the first step, the following types are ingesting:

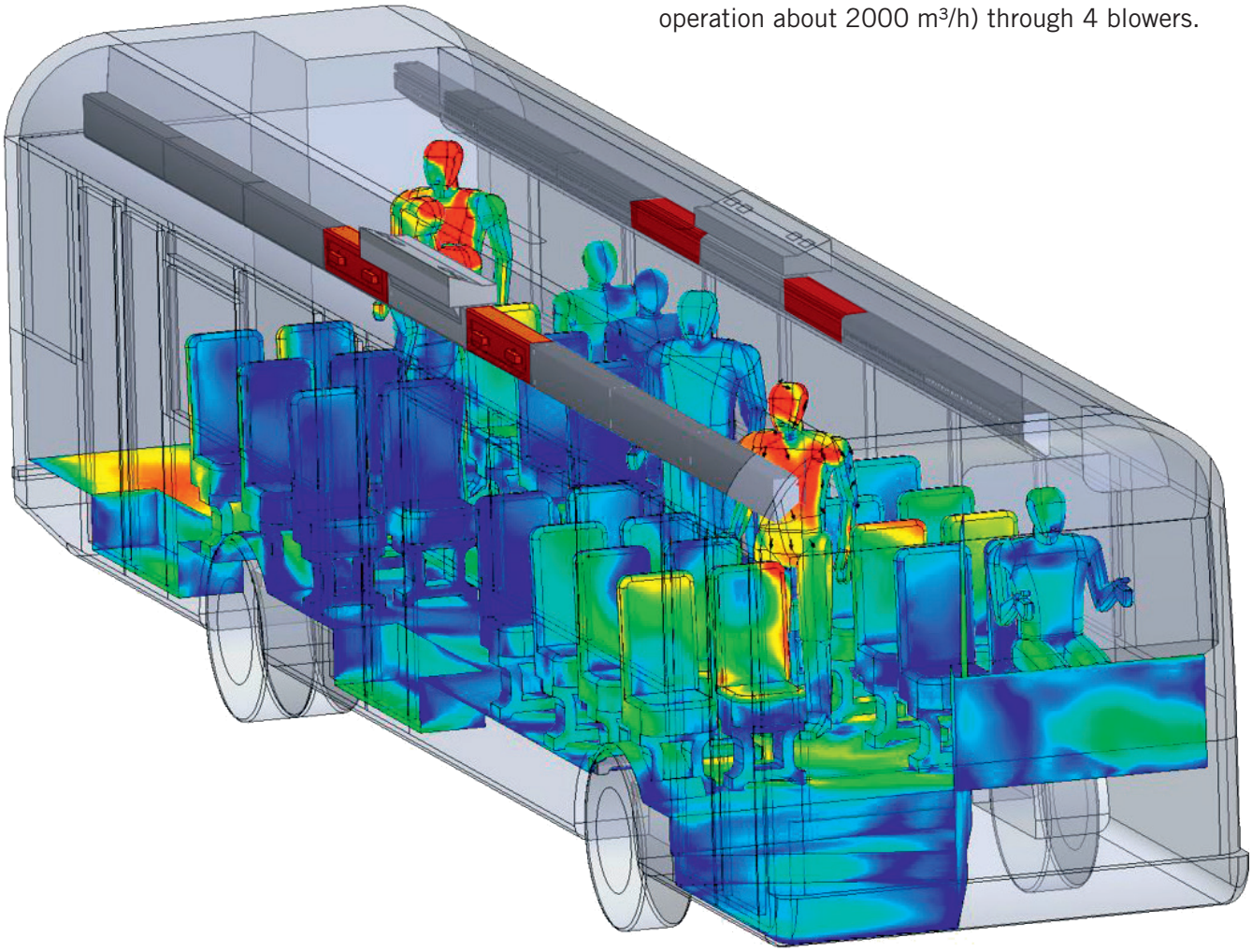
- Solaris Urbino 12 (normal bus)
- Solaris Urbino 18 (articulated bus)



Since SOLUVA® AIR V(Solaris) solution is a modular concept, it can be compatible with all these types by adding or deducting the number of units. Based on the number of units, the disinfection time could be decreased.

To narrow the project goal, the city of Hanau was selected for the pilot phase and 15 buses with 4 units per bus were equipped by SOLUVA® AIR V during December-January 2020/2021.

Existing Solaris Urbino 12 buses generate a maximum air volume of 4000 m³/h (in normal operation about 2000 m³/h) through 4 blowers.



METHODOLOGICAL APPROACH

Simulation models are being used to aid in decision-making. In modern process development, numerical simulation (Computer Aided Engineering – CAE) is a key technology. Production facilities are analyzed and optimized with the help of virtual product data models. Applied at a very early stage of the product development process, CAE provides methods tried and tested in practice to reduce development times and costs within the projects.

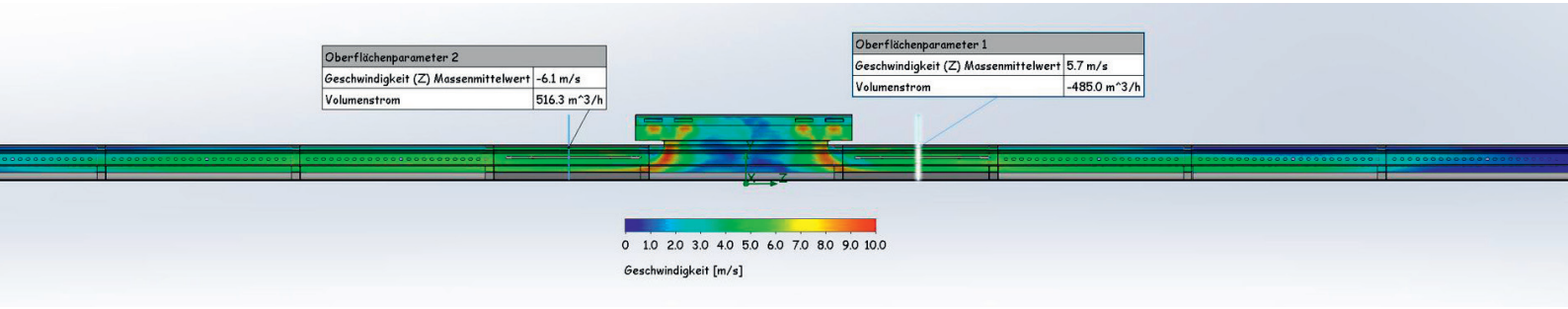
In SOLUVA® AIR V project, two simulation softwares are employed:

- SOLIDWORKS served to calculate air flow and possible pressure drops within various geometry.
- Ray tracing simulation: to enable the calculation of precise information about irradiance.

SOLIDWORKS: AIR FLOW SIMULATION

- Normal operation definition: 500 m³/h per unit or 2000 m³/h per bus
- Maximum operation definition: 1000 m³/h per unit or 4000 m³/h per bus

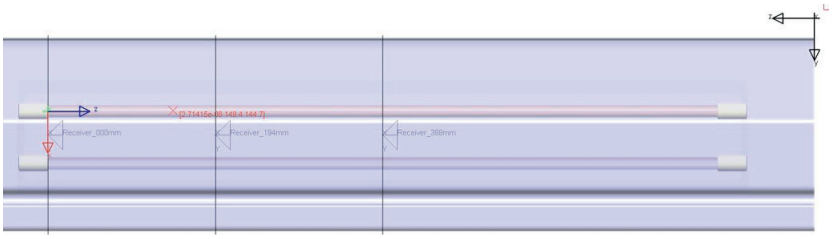
Based on the simulation result, the mean flow velocity in the channel is about 5.7 – 6.1 m/s. This results in an exposure time to the viruses per channel length (0.8 m) = 0.15 sec in normal operation and 0.075 sec in maximum operation.

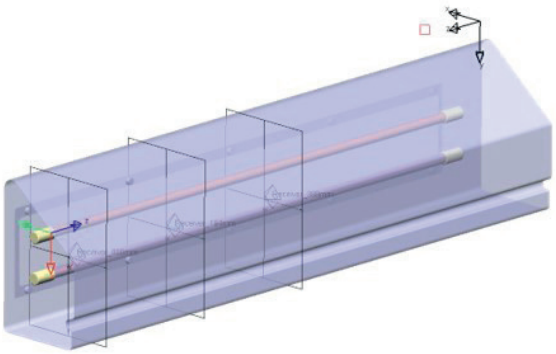


RAY TRACING SIMULATION: IRRADIANCE

Based on following parameters, raytracing simulation shows an homogeneous and sufficient UVC intensity for the existing design.

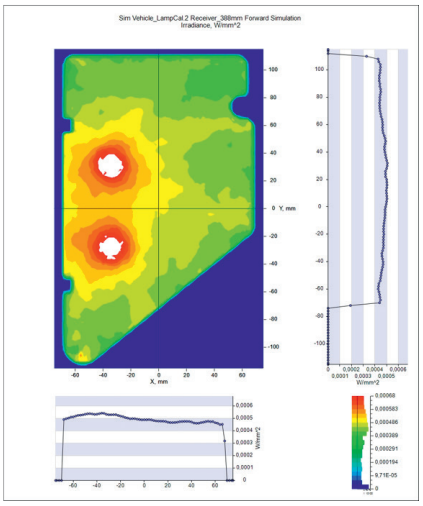
- **Geometry:**
  Air channel area: 0.0250 m²
  Lamp length: 0.8 m
  channel length was 1 m assumed for simulation.
- **Power:**
  Electrical power: 2 x 38 W (Per unit)
  Optical power 254 nm: 2 x 14.3 W (Per unit)
- **Materials:**
  Light gray aluminum, 90 % reflection
  Beige ceramic base, 50 % diffuse reflection
- **Detector:**
  150 x 230 mm
  Pixel size 2 x 2 mm

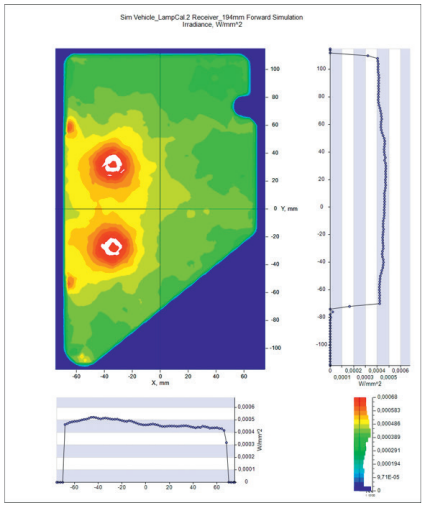


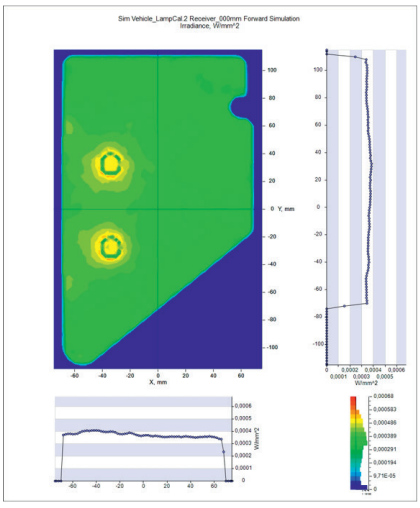


VERIFYING SIMULATION RESULTS WITH MEASUREMENTS

AIR VELOCITY MEASUREMENT



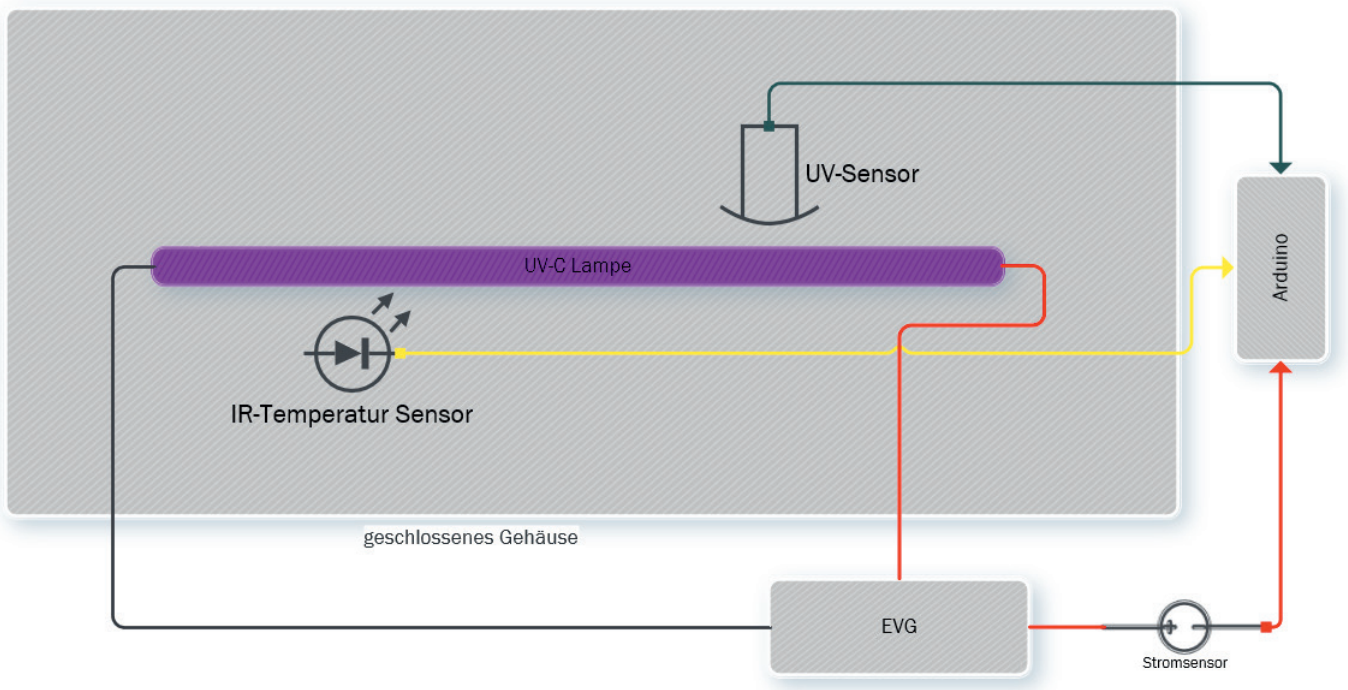




Percentage of air speed in AC	20 %	50 % (Normal)	75 %	100 % (Maximum)
Speed in m/s	3	6.18	8.88	9.96

SHRINKING TUBE TRANSPARENCY TEST

Shrinking tube is used to reduce the risk of damage of UV-C lamp in case of an accident. Hence, no glass parts spreaded in the air channel even in an accident. Due to the unique properties like UV resistance and long lifetime, special plastic has to be employed. It must be taken into consideration that even a good material has a transparency factor which reduces the general lamp UV-C output. Based on the selected material, experiment shows, 15 % reduction needs be considered as a correction factor in the dose calculation.

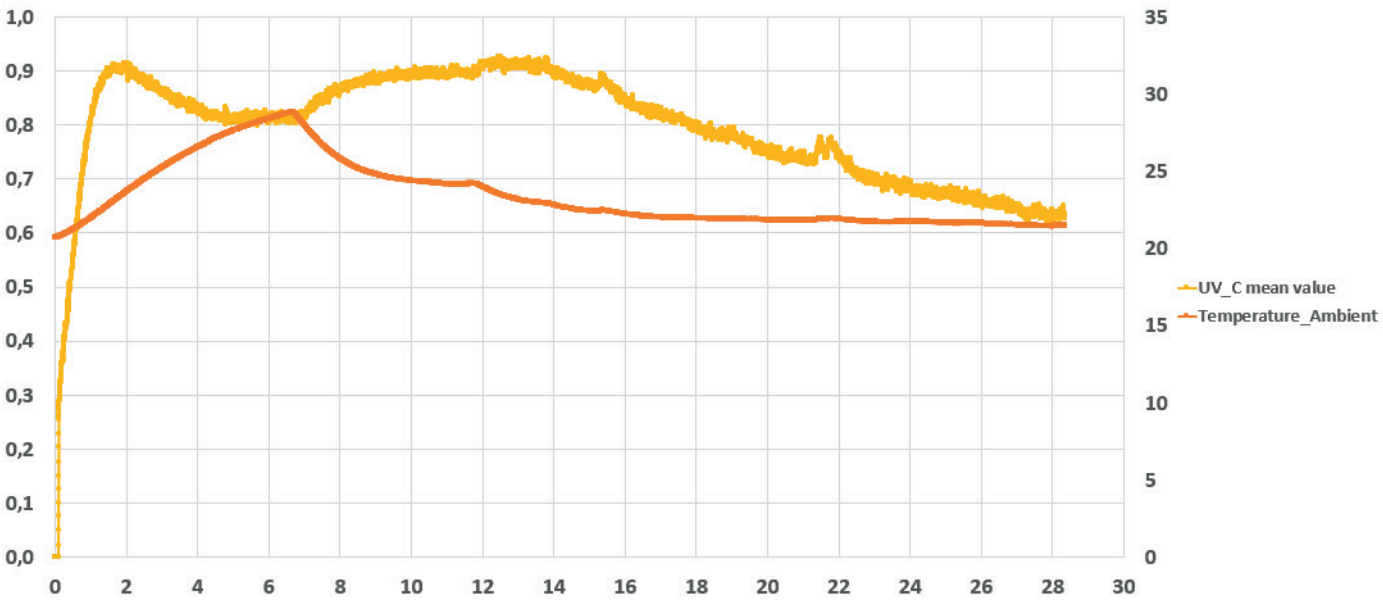


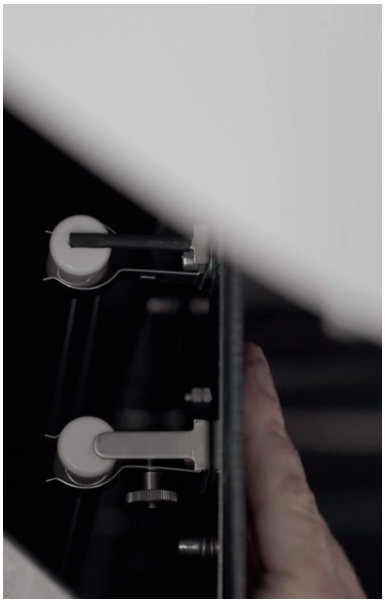
UV-C LAMP OUTPUT AND TEMPERATURE DEPENDENCIES

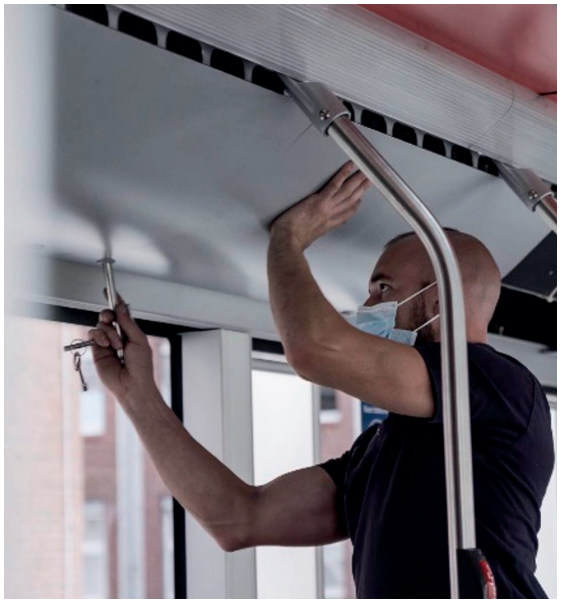
Air velocity and temperature have a significant effect on the lamp output. In fact, the lamp output is a function of lamp surface temperature. Any changes in air velocity and ambient temperature could influence the lamp output. Hence, it needs to be measured and considered as a correction factor in the dose calculation. In this experiment, the lamp was installed in the air channels which air volume is about 1500 m³/h with an air velocity at maximum 9 m/s. This is very close to the maximum operation mode in the bus.

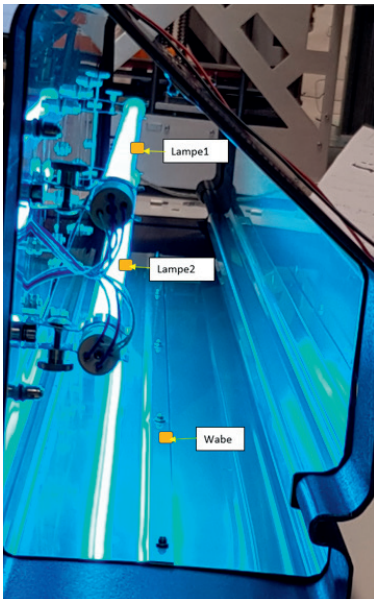
The experiment shows a correction factor in the dose calculation need to be considerd:

- Normal operation in SOLUVA® AIR V
  (Air speed 6 m/s) ➔ Correction factor: 20 %
- Maximum operation in SOLUVA® AIR V
  (Air speed 9 m/s) ➔ Correction factor: 35 %





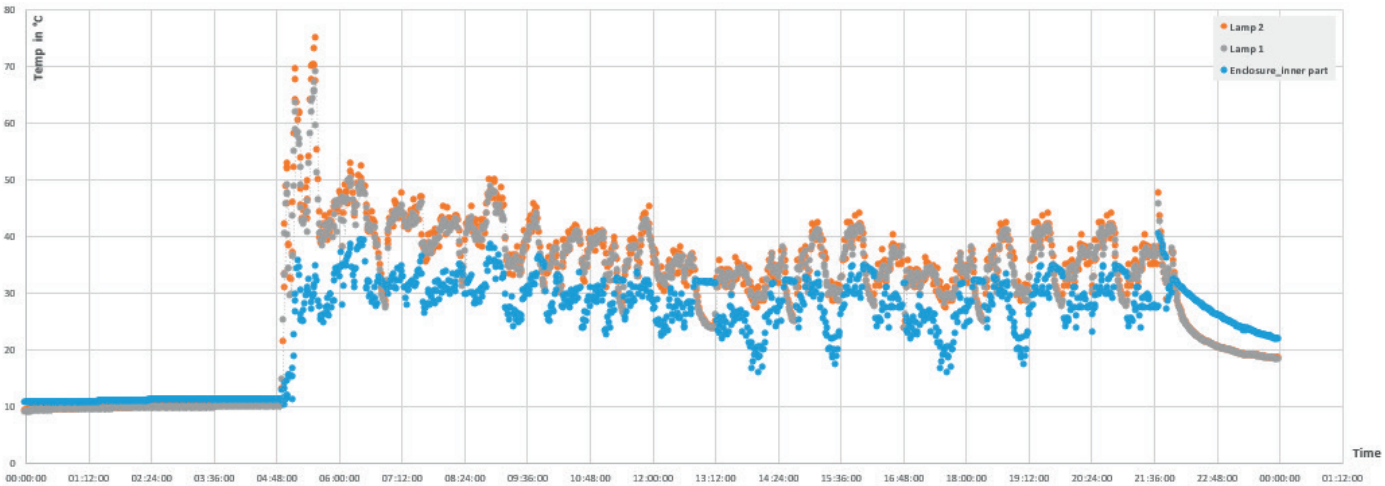




ON-BOARD TEMPERATURE TEST

To record and monitor the temperature, a temperature data logger was installed in the bus during 16–23 Feb 2021. The data logger was capable to collect 8 sensors data in 2 units in different positions. Based on the collected information, the bus was for about 16–17 hours per day on duty. An example of data history of 17 Feb is presented in the figure below. The average temperature on the shrinking tube was about 40 °C which is very close dose calculation assumptions. The lamp temperature reached to 70 °C once the bus air condition was switched off.

The hourly forecast of the outside air temperature also can be seen here. The following information could be used also as base for rough lifetime estimation. At the time of writing this paper, March 2021, no failure on the lamp filament, electronic ballast or any glass breakage were reported in whole 60 installed units.



DOSE CALCULATION

Air channel geometry, airflow velocity, amount of UV-C output of the lamp and its position in the air channel all influences on total UV dose. Furthermore, lamp enclosure surface reflectivity, shrinking tube transparency and lamp surface temperature also have a huge impact in the final dose calculation. Those factors can amplify or restrict the effects of UV lamp.

Heraeus, as a leading UV technology company, has extensive technical knowledge and expertise in simulation-driven approach to optimize, verify, and evaluate the product design. This significantly increases the safety of the UV-C dose required for disinfection.

By using a computer modeling and considering all mentioned parameters and correction factors, dose can be calculated as below.

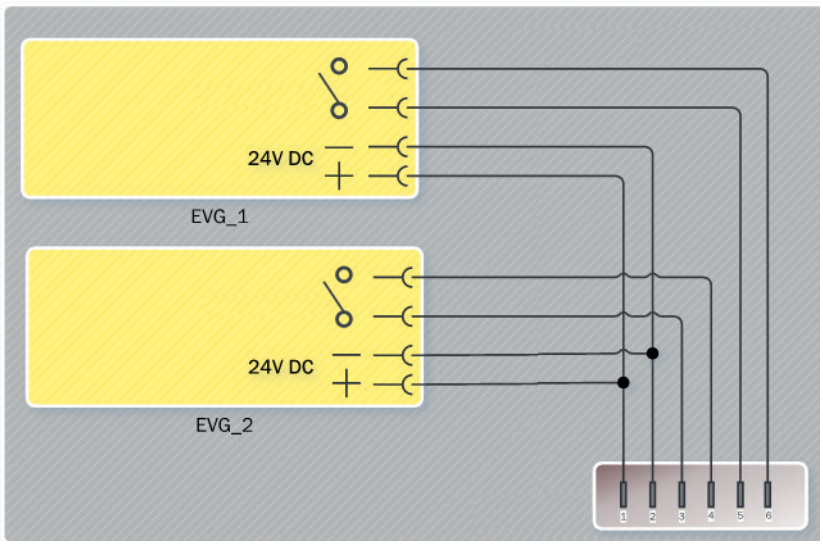
Calculation shows that Log 4 (99.99 %) can be reached in less than 10 minutes.

2 units		Bus volume m^3	AC/Fan Airflow m^3/h	1 cycle time min	Time to reach 90% (Log1) min	Time to reach 99% (Log2) min	Time to reach 99,9% (Log3) min	Time to reach 99,99% (Log4) min
Solaris Gold solution	Normal operation	75.00	2000.00	2.25	1.98	2.97	4.45	6.67
	Maximum operation	75.00	4000.00	1.13	5.17	7.76	5.82	8.73

ELECTRICAL CONCEPT AND STATUS SIGNALS

SOLUVA® AIR V typically consists of two UV-C lamps which are connected to 24 V DC with via the vehicle electrical system supplied with a suitable fuse. The 24 V electronic ballasts are robust enough to meet all requirements such as surge spike protection relevant to bus operation. The product also successfully passed the electromagnetic compatibility norms in accordance with UN/ECE regulation No. 10.

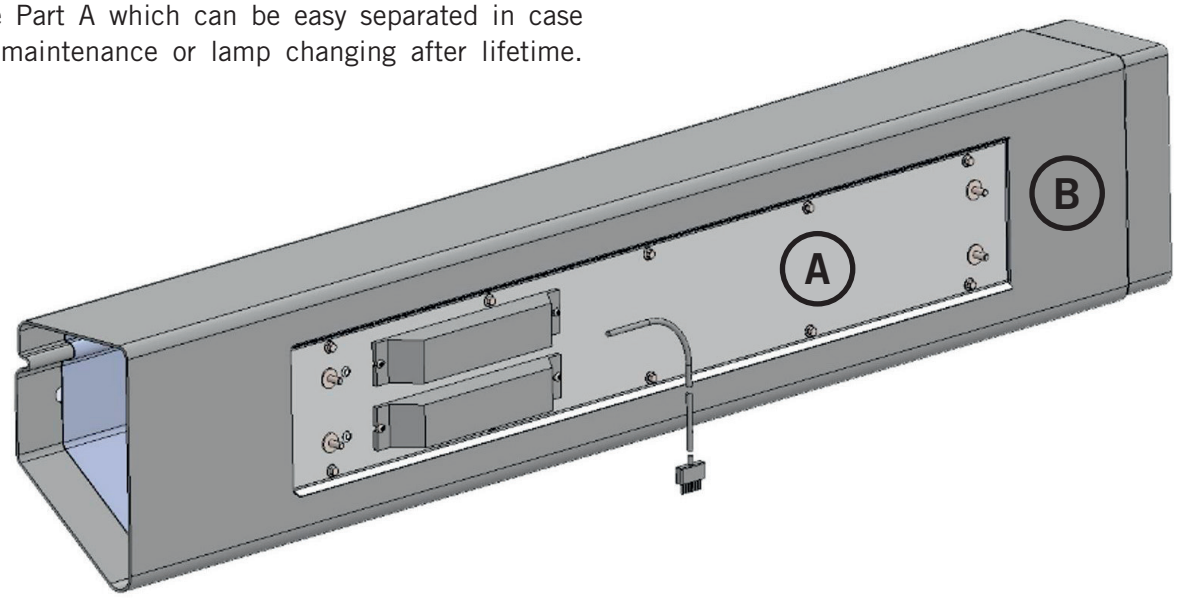
Based on the current design, as soon as the motor is running, the relays of the electronic ballasts are energized. Relays switch on the electronic ballasts after a defined delay time, and the UV lamps light up. The signaling contacts of the electronic ballasts will be closed and the customer has the possibilities to see the signaling contacts and errors with the LEDs indicator on the dashboard. All electronic ballasts from SOLUVA® AIR V must be connected in parallel to the 24 V DC on-board network with a suitable fuse by the customer.



MECHANICAL CONCEPT

SOLUVA® AIR V unit consists of two parts. Part A is the separable part and part B is the fixed part. EVGs (ballast) and lamps will be mounted on the Part A which can be easy separated in case of maintenance or lamp changing after lifetime.

Moreover, special lamp brackets were considered to reduce any vibration issues during transit.

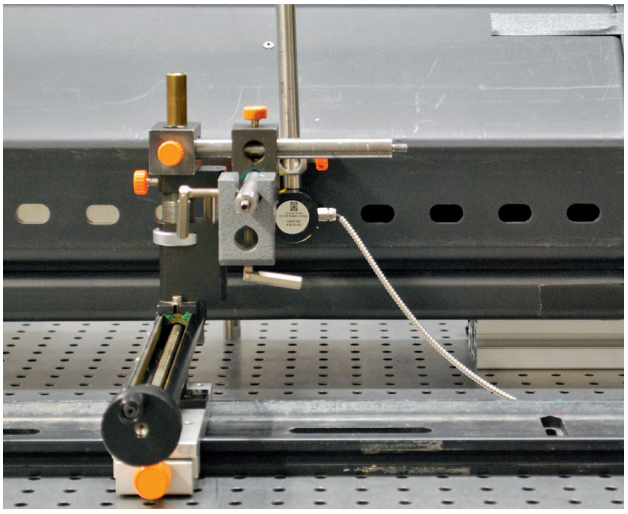


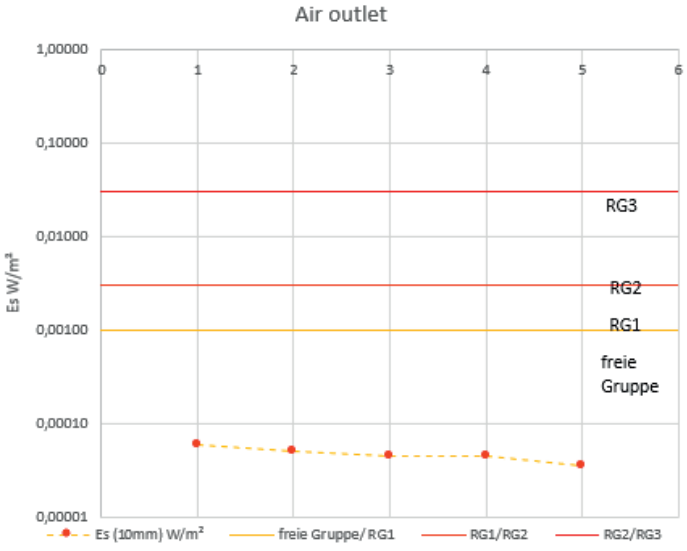
ASSESSMENT OF THE PHOTOBIOLOGICAL SAFETY OF LAMP SYSTEMS

Heraeus Noblelight operates an independent measurement laboratory which is accredited as a test laboratory in accordance with DIN EN ISO/IEC 17025:2005. In this laboratory, the Soluva Air V was tested for photobiological safety and personal exposure to UV light in the workplace.

To facilitate the safe use of product, various sources of information are available in the form of harmonized standards and technical rules together with European directives and national laws. They contain requirements and instructions for risk group classification, AOR risk assessment, technical design, technical controls, labeling and possible safety precautions for users.

The EU Directive 2006/25/EC on minimum requirements for the protection of health and safety from artificial optical radiation requires employers to assess whether and to what extent harmful optical radiation, including UV and IR radiation, is emitted by the product and what exposure risk this poses for the employees in the field of foreseeable exposure duration and foreseeable accessible





distances. This is a legal requirement addressed to the employer regarding health and safety at work and not a product-related legal requirement of the manufacturer.

Following EN 62471 (Photobiological safety of lamp systems) the product SOLUVA® AIR V belongs to risk group 0 at a distance of 10 mm, provided that the device has been properly installed in the air ducts according to the manufacturer's instructions.

NEW PRODUCT LAUNCHES

SOLUVA® AIR V team is pleased to announce two new products will be launched in May 2021! The first new product, Soluva Air V MAN will provide an additional integrated solution designed for MAN buses and the second, Soluva Air V Universal will be a standalone solution which can be mounted into many different buses.

CONCLUSION

This document provides a reference for design and implementation of an integrated UV-C air disinfection system on transit vehicles in public transport.

To narrow the project goal, the city Hanau was selected for the pilot phase and 15 buses with 4 units per bus were equipped by SOLUVA® AIR V during December-January 2020/2021.

By using a computer modeling and considering all mentioned parameters and correction factors, simulation result shows that Log 4 (99.99 %) can be reached in less than 10 minutes.

BIBLIOGRAPHY

Adel Haji Malayer, M. M. (no date of publication). Fluence (UV Dose) Required to Achieve Incremental Log Inactivation of Bacteria, Protozoa, Viruses and Algae. Source: IUVA.org

Andrea Bianco, M. B. (2020). UV-C irradiation is highly effective in inactivating and inhibiting SARS-CoV-2 replication. medrxiv.

Griffiths. (2020). NEIDL, Boston University.

Heraeus Noblelight. (5. March 2021). Heraeus Noblelight. Source: https://www.heraeus.com/en/landingspages/lp_hng/soluva/press_and_customer_stories/press_releases_soluva_2021/uv_light_reduces_viruses_in_classrooms_tested_under_real_conditions.html

Heraeus Noblelight. (2021). Heraeus Noblelight. Source: https://www.heraeus.com/media/media/hng/doc_hng/press_3/Biotec_Summary_UVC_Studie_de.pdf

Heßling, M., Hönes, K., Vatter, P., & Lingenfelder, C. (2020). Ultraviolet irradiation doses for coronavirus inactivation – review and analysis of coronavirus photoinactivation studies. GMS Hyg Infect Control.

Koilawi, A. Y. Akhlaq-us-Salihin. Karachi, Pakistan: Maktaba-tul-Madinah.

Kowalski, W. J., Walsh, T. J., & Petraitis, V. (2020). 2020 COVID-19 Coronavirus Ultraviolet Susceptibility. PurpleSun.

Ruetalo, N., Businger, R., & Schindler, M. (2020). Rapid and efficient inactivation of surface dried SARS-CoV-2 by UV-C irradiation. University Hospital of Tübingen.

ADDRESS INFORMATION

Heraeus Noblelight GmbH
Heraeusstraße 12–14
D-63450 Hanau

Phone: +49 6181 35 8492

AUTHOR

Meghdad Barimani

CO-AUTHORS

Dr. J. Winderlich, M. Mahabadipour,
S. Schadt, J. Grade, N. Barthel

DOCUMENT DATE

March 2021