How Automated, Chemical-free UV-C LED Systems Significantly Reduce Microbial Load in Real-world Conditions

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The topic of necessary disinfection has been omnipresent not only being underscored since the COVID-19 pandemic. When someone coughs or sneezes, countless tiny virus microdroplets are released into the air, which can cause infection by inhalation directly or settle on surfaces and then cause smear infection by touch. It has been known for some time that UV light can kill up to 99.9% of viruses and bacteria. The light destroys (by cracking) the molecular components, because subsequently UV-C successfully disables the DNA & RNA of the microorganism rendering it unable to replicate (schematic representation in Figure 1). Stopping their reproduction consequently prevents them from infecting anyone else. Therefore, ultraviolet light (which is also part of sunlight) is a longstanding tool in the battle against microbial pathogens.

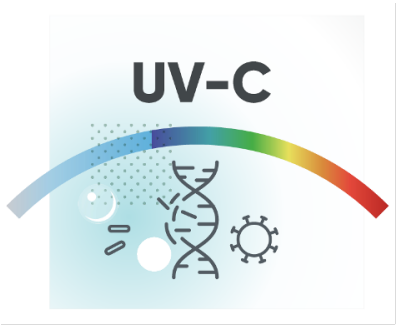

Figure 1: UV-C light: mode of action.

In a nutshell: with a proper dose (time and emitting power) UV-C light can kill all sorts of bacteria, fungi, and virus particles without (toxic) chemicals, such as chlorines, or other resilience causing materials.

From Mercury Tubes to LED Innovation

The UV light is currently mainly produced by mercury tubes, which have the following disadvantages: the dangerous mercury content per se and the limited tube lifespan, especially for high switching frequencies. However, thanks to the LED technology there is a disruptive innovation just starting (similar to the general lighting) in order to replace the tube technology with environmentally friendly LEDs. Moreover, LEDs make a free choice of form-factor possible, which means design is no longer restricted to previously mandatory tube-design.

Product Overview: The UV-C LED Disinfector

The following detailed field-study illuminates the results of disinfection with UV-C light powered / generated by LEDs for disinfection in the particularly demanding environment of a childcare facility. This is done by the so-called UV-C LED disinfector (**Figure 2**), developed by the Austrian company Lumitech. It is a small, ceiling-mounted device similar to a smoke detector (regarding its design), with an integrated UV-C LED module for surface disinfection.

Product Features

- Fully automated surface disinfection by UV-C LED irradiation

Figure 2: UV-C LED disinfector (Lumitech).

- Integrated sensor intelligence for highest safety in automatic mode: rooms/surfaces are irradiated by UV-C light only if no persons are present
- Visual indication for displaying the operating mode
- Timing control
- Possibility for integration into DALI networks
- Simple mounting and installation: standalone device on the surface, only to be connected to mains supply voltage
- UV-C LED disinfection of a 50 m^2 room in 8 hours
- General proof of concept available from OFI (Austrian research and testing institute), tested on bacteriophages (viruses that infect and replicate within bacteria) of the type Pseudomonas phage phi6.

Pilot Study Setup and Methodology

It is commonly known that institutions such as schools or especially childcare facilities tend to be affected by a higher germ load than other places, since infections can spread more easily among (little) children. Therefore, applying UV-C LED disinfection

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in childcare facilities seems to be a very sensible approach, which is e.g. already described in [1]. In childcare facilities, it is not uncommon for toddlers to put a lot of things in their mouths. For investigating the effectiveness of the UV-C LED disinfector in a real environment, 3 group rooms of a childcare facility in the village Sankt Martin an der Raab (located in the South-East of Austria) were made available as a testing field: 1 nursery room with children between the ages of 1 and 3 (denoted as GR1 in the following) and 2 childcare facility rooms with children between the ages of 3 and 6 (denoted as GR2 and GR3 in the following).

Each group room was equipped with 2 UV-C LED disinfectors in a simplified operation mode as requested by the childcare facility staff: the sensor-controlled automatic mode was deactivated, and the timing function was set to a fixed UV-C LED radiation between 22:00 and 06:00. The number of installed UV-C LED disinfectors was based on a simplified calculation of the provided UV-C LED radiation dose: Starting from a radiating power of ~276 mW (transmission of the used quartz glass cover included) and the radiation distribution of the disinfectors with peak wavelength of 275 nm, the number of UV-C LED disinfectors for each room as well as the test positions (distance between disinfector and test position 2m-2.2m on average) was chosen. That way, and setting a radiation durance of 8 hours, an average dose value of 30 mJ/cm^2 was calculated, which approximately covers the known dose values needed for eliminating SARS-CoV-2 and influenza viruses and E.coli bacteria up to 99.99% (log4), described e.g. in [2] for a typical UV-C wavelength of 254 nm (based on standard mercury low pressure lamps), but also in [3] for higher UV-C LED wavelengths.

The childcare facility pilot study was carried out over an overall period of three weeks, split into two weeks in September/October 2024 and one week in November of the same year to include weather-related influences (occupancies indoor/outdoor).

There were four fixed test dates defined for each test day:

- 06:30: opening time, before first contamination after UV-C LED disinfection over night
- 09:00: directly after first playtime in the childcare facility (children are indoors)
- 11:30: directly after second playtime in the childcare facility, before lunch
- 14:30: after last contamination caused by children's attendance and before standard manual cleaning process.

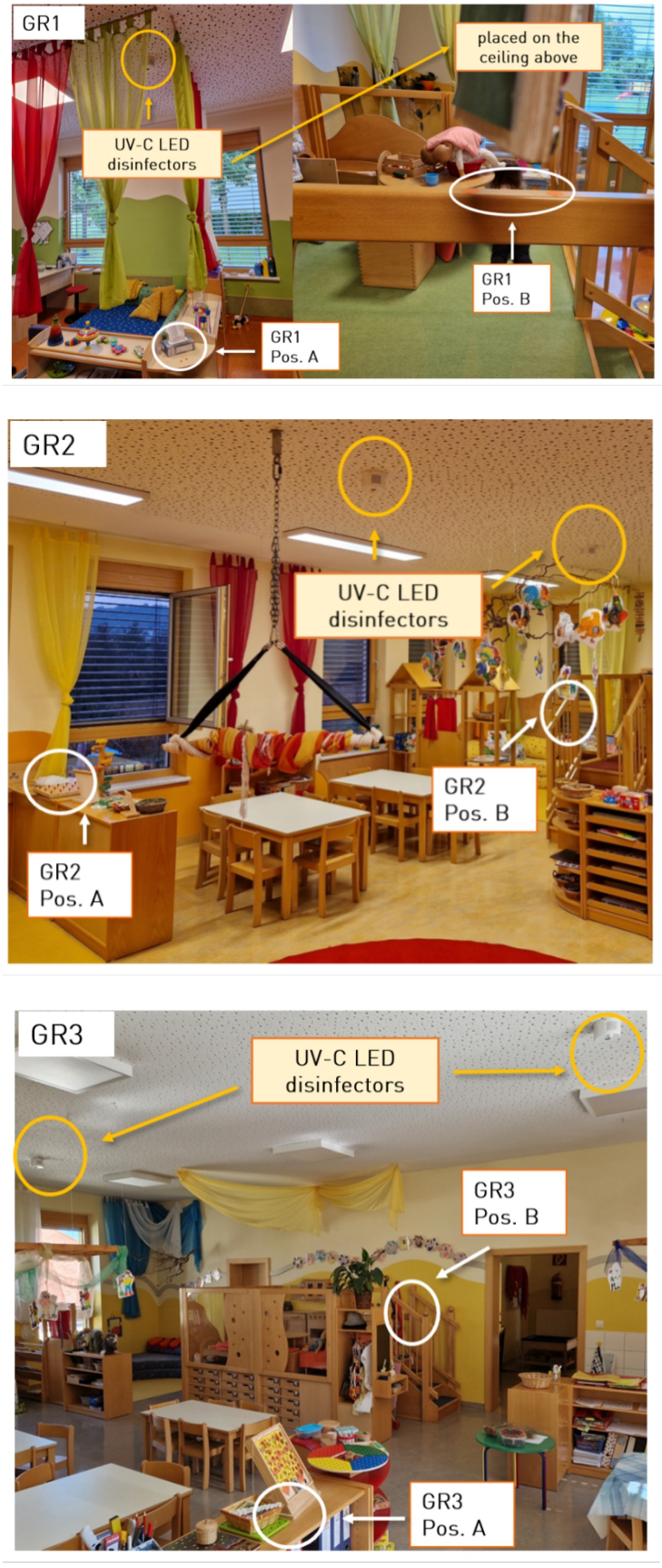

Figure 3: Group rooms, positions of UV-C LED disinfectors and sample points.

For all test runs, the germ contamination of the specified surfaces in the group rooms was determined by using dip slides of type Hygicult TPC [4] for the most common bacteria and fungi. After sampling, these dip slides were incubated and then evaluated, partially by an external lab (W.H.U. GmbH Bischofshofen - Labor, Prüf- und Inspektionsstelle). Analysis data were expressed in so-called CFU per cm^2, where CFU means colony forming unit (standard unit for microbiological investigations). It should be noted that there are no concrete regulatory CFU/cm^2 limit values for surfaces in e.g. childcare facilities, but only general hygienic recommendations [5]. **Figure 3** shows GR1, GR2, GR3 with the positions of the installed UV-C LED disinfectors and the positions of the sample points. These points were chosen after consultation with the childcare facility staff primarily as points with high "touching frequency" and less considering their optimum UV-C radiation position. **Table 1** summarizes the attendances and room occupancies of the whole test period as well as the chosen test setup:

- No UV-C LED disinfection carried out, standard cleaning process performed
- UV-C LED disinfection carried out between 22:00 and 06:00 (every night, also during the weekend), no standard cleaning at the sample points
- UV-C LED disinfection between 22:00 and 06:00 (every night, also during the weekend) and standard cleaning at the sample points performed.

Results: Germ Load Reduction in Practice

For the results, presented in the following, all obtained data underwent a validity check[3]. Valid data were averaged to generate curves for the germ load, depending on the chosen test setup, that are as generic as possible in the context of this concrete pilot study. It is noted that germ load data belonging to test time 11:30 have been excluded in the final evaluation of the results because there was no significant change to the germ load data belonging to test time 09:00 (changes only

[3]Clearly, the pilot study is subject to some slight uncertainties (100% reproduceable results are not possible e.g. due to daily routines, children's behavior etc. are not completely comparable from day to day).

Date DD.MM.YYYY	GR1	GR2	GR3
23.09.2024	9 children Occupancy until ~10:45 (afterwards outdoors) **Setup: UV-C LED + cleaning**	14 children Occupancy until ~10:15 (afterwards outdoors) **Setup: UV-C LED + cleaning**	18 children Occupancy until ~10:15 (afterwards outdoors) **Setup: UV-C LED + cleaning**
24.09.2024	9 children Occupancy until ~10:45 (afterwards outdoors) **Setup: UV-C LED + cleaning**	13 children Occupancy until ~10:15 (afterwards outdoors) **Setup: UV-C LED + cleaning**	19 children Occupancy until ~10:15 (afterwards outdoors) **Setup: UV-C LED + cleaning**
25.09.2024	9 children Occupancy until ~10:45 (afterwards outdoors) **Setup: UV-C LED + cleaning**	15 children Occupancy until ~10:15 (afterwards outdoors) **Setup: UV-C LED + cleaning**	19 children Occupancy until ~10:15 (afterwards outdoors) **Setup: UV-C LED + cleaning**
30.09.2024	8 children Occupancy until ~10:45 (afterwards outdoors) **Setup: cleaning only**	13 children Occupancy until ~10:15 (afterwards outdoors) **Setup: cleaning only**	18 children Occupancy until ~10:15 (afterwards outdoors) **Setup: cleaning only**
01.10.2024	10 children Occupancy until ~10:45 (afterwards outdoors) **Setup: cleaning only**	14 children Occupancy until ~10:15 (afterwards outdoors) **Setup: cleaning only**	17 children Occupancy until ~10:15 (afterwards outdoors) **Setup: cleaning only**
02.10.2024	10 children Residence only indoor **Setup: cleaning only**	16 children Residence only indoor **Setup: cleaning only**	16 children Residence only indoor **Setup: cleaning only**
25.11.2024	10 children Occupancy until ~12:30 **Setup: cleaning only**	14 children Occupancy until ~11:00 (afterwards outdoors) **Setup: UV-C LED, no cleaning**	15 children Occupancy until ~11:00 (afterwards outdoors) Between 12:30 and ~15:00 2 children present (afternoon care) **Setup: UV-C LED, no cleaning**
27.11.2024	10 children Occupancy until ~12:30 **Setup: cleaning only**	16 children Occupancy until ~11:00 (afterwards outdoors) **Setup: UV-C LED, no cleaning**	14 children Occupancy until ~11:00 (afterwards outdoors) Between 12:30 and ~15:00 4 children present (afternoon care) **Setup: UV-C LED, no cleaning**
28.11.2024	11 children Occupancy until ~12:30 **Setup: cleaning only**	16 children Occupancy until ~11:00 (afterwards outdoors) **Setup: UV-C LED, no cleaning**	15 children Occupancy until ~11:00 (afterwards outdoors) Between 12:30 and ~15:00 5 children present (afternoon care) **Setup: UV-C LED, no cleaning**

Table 1: Attendances, room occupancies and test setups of the pilot study.

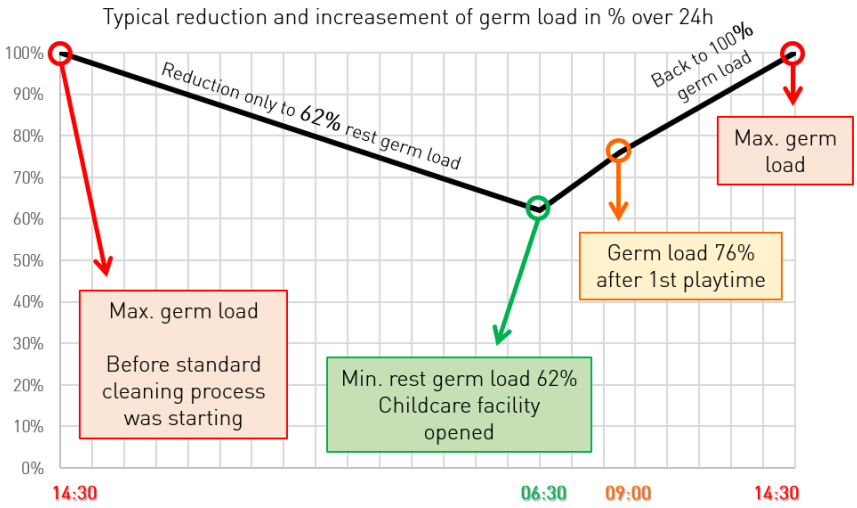

Figure 4: Resulting germ load curve for standard cleaning process only.

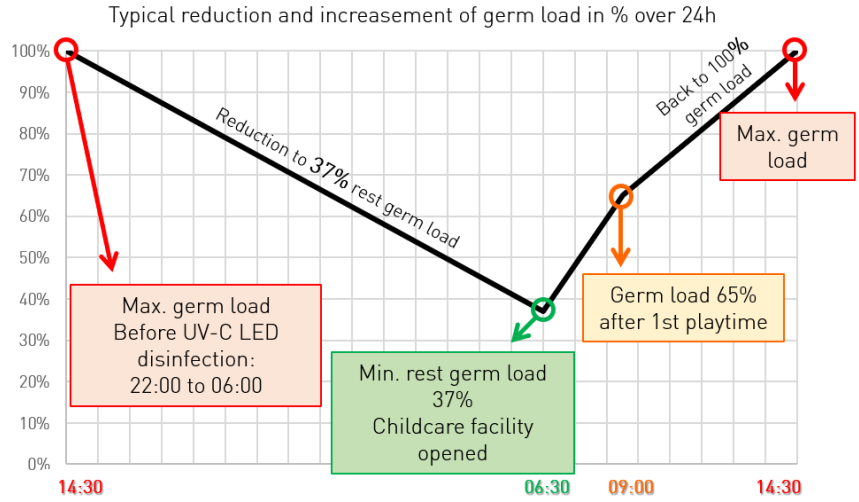

Figure 5: Resulting germ load curve for UV-C LED disinfection only.

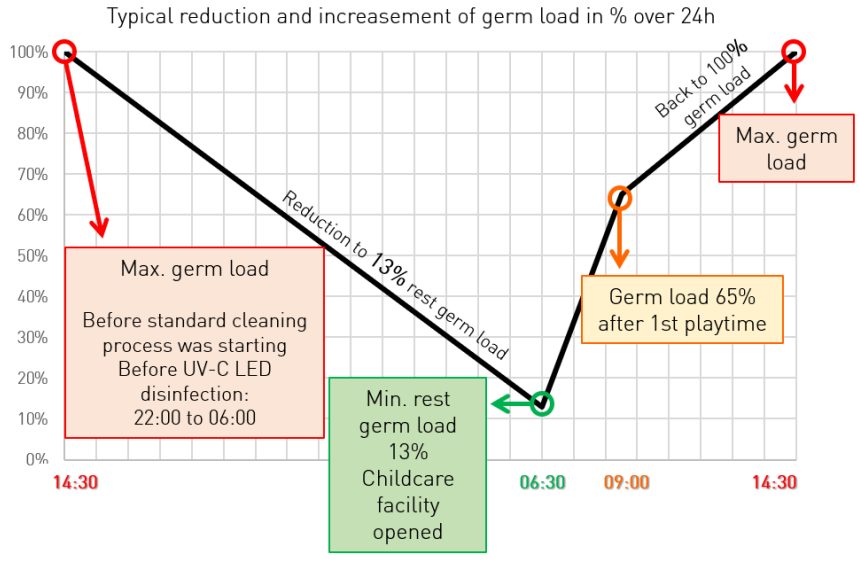

Figure 6: Resulting germ load curve for UV-C LED disinfection in combination with standard cleaning process.

within the calculated variation). Explanation: typically, not continuous occupancy of the rooms between 9:00 and 11:30 due to several activities. Furthermore, it is noted that transitions between different germ load values are illustrated as linear approximations in **Figure 4**, **Figure 5**, **Figure 6** and **Figure 8** for a clearer demonstration of the results.

In addition to **Figure 4**, **Figure 5**, **Figure 6** and **Figure 8**, it can be summarized that:

- **Figure 4**: Without UV-C LED disinfection, but carrying out the standard manual cleaning process, the maximum germ load of 100% detected at 14:30 on a test day was reduced to a minimum germ load of 62% detected at 06:30 in the morning on the following test day, where between these dates no children were present. **Obviously, 62% is quite a high rest germ load level and shows that standard cleaning might not be sufficient, especially for high absolute maximum values as e.g. 1,500 CFU/cm^2**, which was detected a few times during the pilot study for setups without UV-C LED disinfection and for which **the consulted external lab made the urgent recommendation for additional disinfecting measures**.
- **Figure 5**: With active UV-C LED disinfection between 22:00 and 06:00, but without the standard cleaning process performed for the selected sample points, the maximum germ load of 100% detected at 14:30 on a test day was reduced to a minimum rest germ load of 37% detected at 06:30 in the morning on the following test day, where between these times no children were present. **This shows that UV-C LED disinfection (in the setting chosen for this pilot study) has a clearly higher impact on germ load reduction than standard cleaning only**.
- **Figure 6**: With active UV-C LED disinfection between 22:00 and 06:00, and carrying out the standard cleaning process, the maximum germ load of 100% detected at 14:30 on a test day could be reduced to a minimum rest germ load of 13% detected at 06:30 in the morning on the following test day, where between these times no children were present.
- The smallest measured value for rest germ contamination in the morning was 5 CFU/cm^2 for the setup "UV-C LED disinfection in combination with standard cleaning process", **which can be interpreted as no existing germ load**.

- **Figure 7** shows a comparison of dip slides with bacterial growth after three days of incubation. The **top slides** refer to samples taken at a test position in the afternoon at 14:30, while the **bottom slides** show the samples taken at the same position the following morning, after cleaning and overnight UV-C LED disinfection.

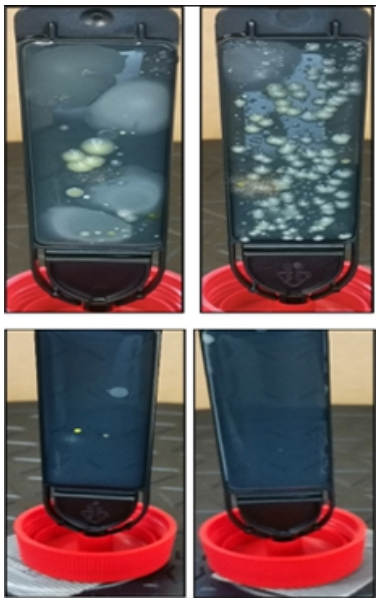

Figure 7: Dip slides after incubation, before and after cleaning and UV-C LED disinfection.

These impressive results show that applying UV-C LED disinfection with the chosen product, even if used in a simplified operation mode for the 8 hour period during the night, leads to a considerably higher reduction of microorganisms on the surfaces than applying only the standard cleaning process. An already higher reduction of the germ contamination as a starting point in the morning futhermore leads to a flattened increase of the germ contamination in the course of the day (**Figure 8**) and therefore to a general reduced risk for infections. In addition, it could be seen that UV-C LED disinfection only (without cleaning) might not be sufficient regarding germ load because there is of course also dust, dirt, etc. Therefore, the need for standard cleaning processes still remains.

It can be clearly stated that UV-C LED disinfection, based on the given radiance parameters, can make an important contribution to the reduction of bacterial load in institutions with a possible high presence of infectious germs, even if only used during the closing hours.

As an upside potential, the germ load curves for active UV-C LED disinfection (**Figure 8**) could be flattened from morning to afternoon by switching to the automatic mode of the UV-C LED disinfector (as stated earlier). Outdoor time slots would be recognized by the disinfector as no presence so that the device would activate itself for UV-C LED disinfection during the day as well.

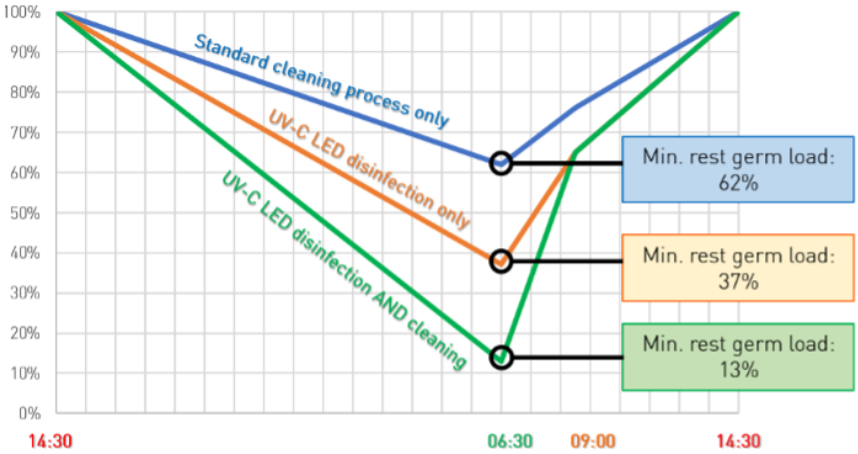

Figure 8: Comparison of resulting germ load curves for the different test setups.

Regarding concerns about potential material damage, tests have been conducted on various materials (especially plastics). They have shown that no yellowing, brittleness, etc., occurred. Based on the average solar irradiance (2.24 mW/cm^2 at 270–380 nm), the following comparison can be made: One year of continuous (24/7) irradiation by the UV-C room disinfector (mounted on the ceiling at a height of 3 m) corresponds to only one hour of direct sunlight exposure. A negative impact on the condition of irradiated materials and surfaces can therefore be ruled out.

Conclusion and Outlook

The field study impressively demonstrates the proven effectiveness of germicidal ultraviolet technology based on UV-C light generated by LEDs for disinfection in standalone safe operating mode.

LUMITECH as LED innovation-leader develops and manufactures state of the art UV-C LED-technology (COB as well as SMT) in Austria, with best in class UV-C efficiency combined with specific optics, well considered thermal management, and optimized layout- and connection-technology especially for UV like the UV-C room-disinfector, that was used in the field study described above and which can be used autonomously while guaranteeing intrinsically safe operation. All this as an upper-room germicidal system in a well-known design for surface mounting on the ceiling similar to commonly used smoke detectors. ■

References

[1] G. Messina, R. Bosco, D. Amodeo, N. Nante, I. De Palma, C. Petri, G. Cevenini. *Safer school with near-UV technology: novel applications for environmental hygiene. 26.01.2023*
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