NICHIA

A guide to UV-C LED-based disinfection

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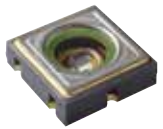
INTRODUCTION:

There is a clear and emerging opportunity for the latest UV-C LED-based solutions to provide effective disinfection in a range of facilities. However, reaching mass roll-out of this highly anticipated technological development demands buy-in and co-operation between all stakeholders, including research institutes, LED manufacturers such as NICHIA, LED optic manufacturers, LED module solutions providers and system integrators.

The technology is proven, but bringing it to the commercial arena in safe and adequate products requires expertise. Beyond the LED's output power, many other factors must be considered to help form the most efficient solution, including irradiation, time, geometry and targeted organisms.

This guide sets out the technologies and way forward for UV-C LED-based disinfection; its advantages and the opportunities for new applications.

UV-C LED	6.8x6.8mm PACKAGE	3.5x3.5mm PACKAGE
SUPER HIGH POWER	**UPCOMING** 4-IN-1 PACKAGE	
HIGH POWER	 NICHIA **NCSU334B 280nm 70mW Flux** 1.9W Input Power	**UPCOMING**
MIDDLE POWER		 NICHIA **NCSU434A 280nm 17.5mW Flux** 0.5W Input Power

UV-C disinfection - the basics

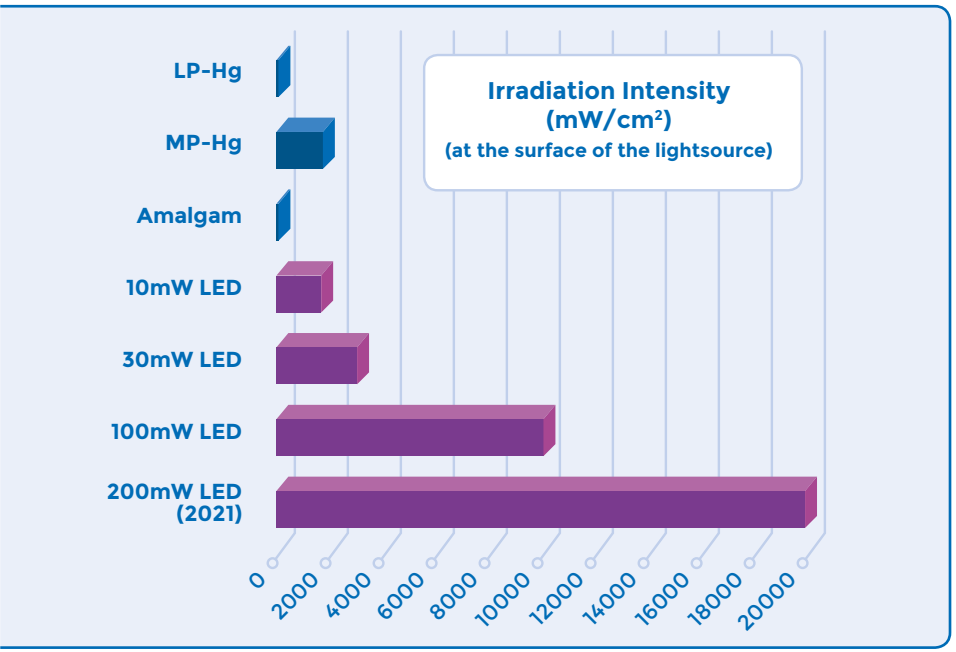
The disinfection effect of UV radiation arrives by splitting chemical bonds between nucleic acids in the DNA of the virus or bacteria. Thanks to the subsequent formation of thymine dimers, the DNA can no longer duplicate during the cell-division process.

This DNA damage is dependent upon the wavelength of the radiation source and the acting dose. Another factor to consider is that different pathogens have different sensitivity to UV-C. For instance, E. coli and staphylococcus are relatively easy to inactivate, while SARS-CoV-2 (which causes COVID-19) requires a dose some 5-17 times higher.

To exacerbate the challenge, it is worth indicating that UV light can also repair damaged DNA via a process known as photo-reactivation. Essentially, light in the range of 300-500nm activates the photolyase to repair DNA.

ADVANTAGES OF UV-C LEDS VERSUS MERCURY LAMPS

The best disinfection efficiency of UV-C LEDs for the inactivation of micro-organisms ranges between 260 and 270nm. Notably, LEDs can be produced in different wavelengths and distribute emission energy over a wide wavelength range. In contrast, low-pressure mercury lamps only offer a narrow, fixed-emission wavelength of 254nm. The disinfection effect of LEDs is, therefore, better than that of mercury lamps with the same dose.



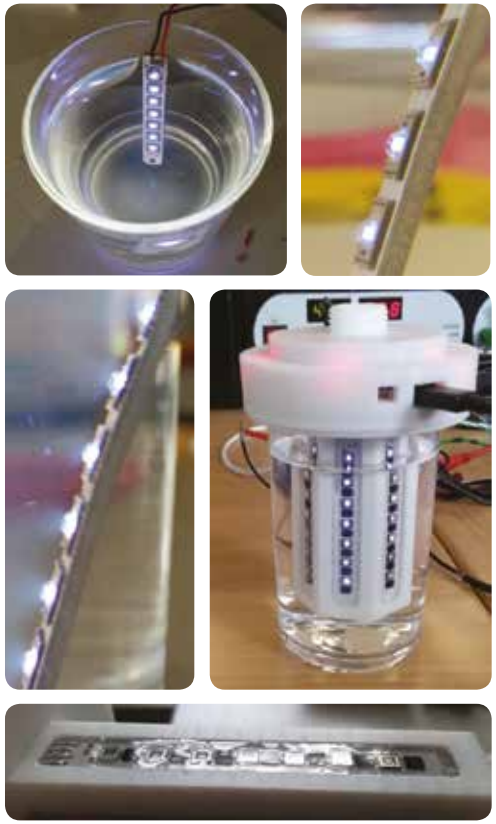
Another advantage is that UV-C LEDs are completely ozone-free because they have no wavelengths less than 240nm. Ozone is an undesirable irritant gas.

Notably, LEDs require no warm-up phase, with full power available immediately to make them ideal for timed on/off operation. Conversely, mercury lamps need around a few minutes to attain full output performance. LEDs can also be pulsed for higher output and, unlike mercury lamps, are suitable for dimming from 0-100%, ensuring their suitability in applications that demand variable intensity.

A further benefit of UV-C LEDs is their high irradiation intensity at close range. In turn, high density is achievable on the array (with appropriate cooling in place - there is no issue using water as a coolant for UV-C LEDs). It is also possible to use lenses or reflectors for beam shaping to focus radiation energy on the surface requiring disinfection.

Last but not least, whereas a risk of glass breakage renders mercury lamps fragile, LEDs (that do not contain any mercury) provide high mechanical stability, offering both shockproof and waterproof attributes. Solutions of this type are therefore ideal for mobile applications.

UV-C LED disinfection application is possible by potting directly in water and parylene coating.



> ***Unlike mercury lamps, which offer a restricted tubular geometry, it is possible to combine UV-C LEDs of different types and wavelengths into single arrays, thus providing 'positive irradiation geometry' (from outside to inside).***
>
> ***As a result, designers can create completely new, optimized radiation geometries - including 3D arrays - to meet the requirements of specific disinfection challenges.***

Thomas Westerhoff
Deputy Group Leader - Embedded Systems, at Fraunhofer IOSB-AST

USE OF WATER AS A COOLANT → **HIGHER OUTPUT POWER POSSIBLE**

Latest UV-C LED-based solutions to provide effective disinfection range of options.

TARGET UV-C APPLICATIONS

UV-C disinfection - the basics

The main market disinfection opportunities for UV-C LED technology essentially comprise four areas: surface, HVAC, water and biomedical.

Surface disinfection is the current focus of most UV-C LED developers, due to the specific benefits this technology offers, such as form factor and zero on/off time.

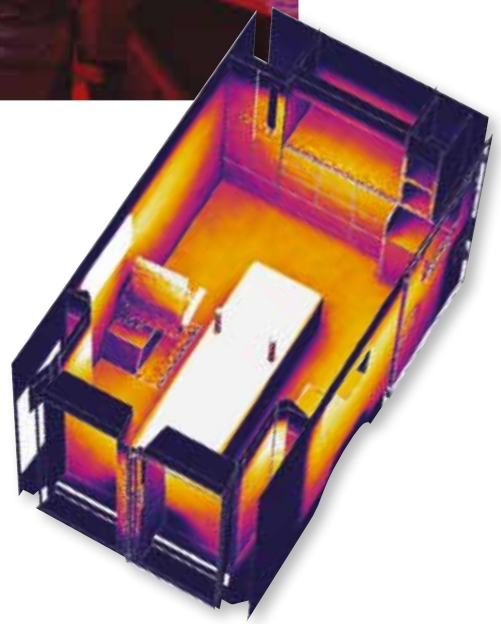
HVAC applications differ from surface disinfection tasks regarding the potential to apply UV-C LED solutions within the system's contained nature, meaning there is less concern about the exposure of humans to radiation.

The water segment offers arguably the most significant potential for UV-C LED-based solutions. A global necessity exists as many areas of the planet are still without access to clean drinking water. New developments and ideas are emerging to optimize UV-C LED solutions for water disinfection.

Biomedical applications in hospitals, clinics and research laboratories are in constant need of innovative solutions to disinfection.

Images include examples of a mobile disinfection robot and interior disinfection of an ambulance.

THE MARKET VOLUME IS LOWER, BUT UV-C LEDS CAN ADD SIGNIFICANT VALUE.



EXISTING AND UPCOMING UV-C LED SOLUTIONS

NICHIA currently offers many UV-C LED solutions, including a mid-power 17.5mW product in a 3.5 x 3.5mm package and a high-power 70mW product measuring 6.8 x 6.8mm. A high-power UV-C LED in a 3.5 x 3.5mm package is currently in development, alongside a super high-power 4-in-1 package, the details of which are due for release shortly.

NICHIA's current leading-efficiency UV-C LED offers a peak wavelength of 280nm and an output of 70mW at 350mA. However, thanks to its high quality and reliability, users can drive the current up to 500mA, achieving an impressive output of circa 100mW from a single LED chip.

PART NO.	NICHIA's NCSU334B	Competitor[1]
Peak Wavelength	280nm	265nm
Input Power (T_F)	1.9W (350mA)	1.9W (290mA)
Radiant Flux	70mW	35mW
V_F	5.5V	6.6V
Efficacy	3.6%	1.8%
Reliability	Major Advantage	-

Note[1]: The value in right is based on a competitor's specification and adjusted to the same conditions.

Hermetic sealing

The 280nm UV-C LED from NICHIA comes in a hermetically sealed package for superior lifetime and reliability at high temperatures and humidity. A hermetic shield is important when deploying UV-C LEDs in demanding environmental conditions. It protects the LED, and the LED die from the potentially damaging effects of moisture, condensation and corrosive gases.

NICHIA tests demonstrate the critical nature of hermetic sealing. Under challenging environmental conditions of 60°C ambient temperature and 90% relative humidity, a NICHIA UV-C LED with hermetic shielding still provided around 85% flux intensity after 8,000 hours. In contrast, a product's flux intensity with a non-hermetic shield fell to around 40% after just 6,000 hours.

The sterilization factor

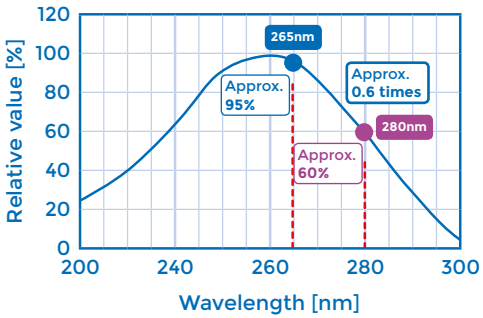
While traditional UV-C technologies, such as low-pressure mercury vapor lamps, were limited to a 254nm peak, the most efficient wavelength to disinfect bacteria and viruses is known to be 260nm due to the peak absorption spectrum of the DNA/RNA. However, NICHIA has demonstrated that 280nm delivers the highest virucidal power as it has a very strong irradiance, wall-plug efficiency and lifetime, all at practical operating conditions vs. many other unreasonable claims in the market. Indeed, data highlights that the virucidal power of the 280nm LED is approximately 1.3 times (127%) that of 265nm LEDs. The 280nm LED also delivers a lifetime ten times longer than a 265nm LED.

In tests pitching the NICHIA 280nm UV-C LED solution against a randomly selected competitor offering 265nm, the former's flux intensity (92% after 4,000 hours) compares favorably against the latter (67% after the same time and driving conditions). Furthermore, 280nm is still highly effective for sterilization (independent third-party test data for disinfection is available from NICHIA upon request). In the future, if it becomes possible to transpose NICHIA's current levels of quality and reliability to a lower wavelength, the company will do so. Still, for now the 280nm solution remains the optimum offer currently in production.

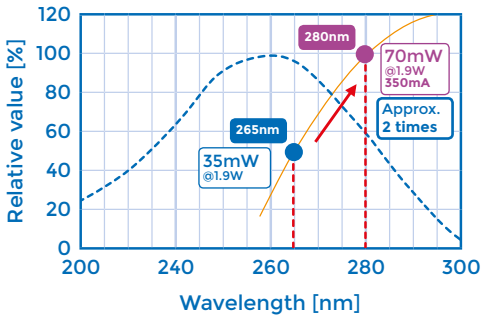
> *"The efficiency/efficacy of NICHIA's existing UV-C LED solutions is around 3.6%, which is world-leading.*
>
> *At this moment in time there is no other company on the planet that can deliver this level of UV-C efficiency. What's more, we are committing a lot of time, effort and capital investment into improving the efficacy of our solutions even further."*

Jonatan Klee
UV LED Account Manager, NICHIA

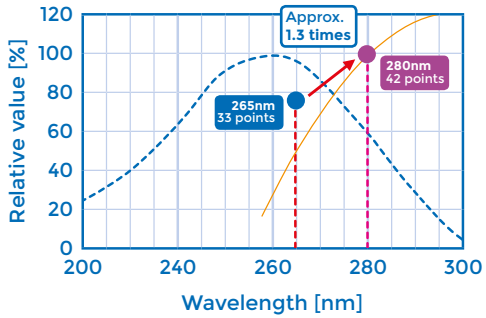
Difference in the virucidal effect according to wavelength (relative values)



Optical output power



Virucidal power



The sterilization effect of NICHIA's 280nm is better than the other commercially available 265nm LEDs. Additionally, the efficacy AND relibility are significantly better at 280nm vs. 265nm.

OPTICS FOR UV-C LEDS

The use of optics allows users to shape the energy emitted by a UV-C LED, providing concentration in areas where it is needed most. This effect also helps to conserve energy.

LEDiL has released the world's first standard optic family specifically for UV-C LED applications. Known as Violet, the optics features a superior type of silicone, rather than conventional quartz glass, for high UV transmittance rates (80%) and the creation of more cost-efficient solutions without shape restrictions. The lens is held in place using a stainless-steel frame, so all materials can withstand long-term UV-C use. Three beams are available at present, ranging from a 14° spot beam to a 60° wide beam.

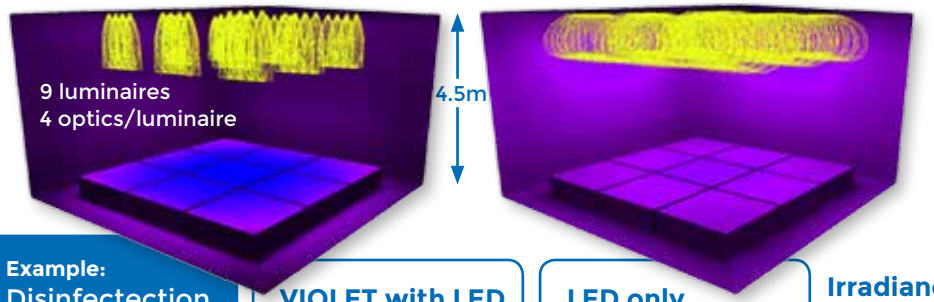
Optics and LED versus LED only

Test performed by LEDiL reveal the impact of optics. Take the case of nine ceiling-mounted luminaires suspended 4.5m above a 3 x 3m target area, where each luminaire consists of four modules. Using UV-C LEDs alone, the average irradiance achieved was 119mW/m². However, when using complementary optics, irradiance climbed to an average of 258mW/m².

As this figure is more than twice the intensity of bare LEDs, it is possible to half the surface disinfection time, or reduce the number of LEDs to save costs. In short, optics provide some of the key tools to optimize the luminaire in a unique way.

> *"Our silicone optic family of solutions can be retrofitted into existing office lighting luminaires, for example, thus representing a new and somewhat disruptive way of disinfecting commercial workplaces."*

Tero Mäkinen
Business Development Manager - Outdoor BU, LEDiL



Example:
Disinfectection with VIOLET vs. LEDs only

VIOLET with LED

RESULTS
On workplane at 0.6m

Average:	258mW/m2
Min:	243mW/m2
Max:	280mW/m2
u0:	0.942

LED only

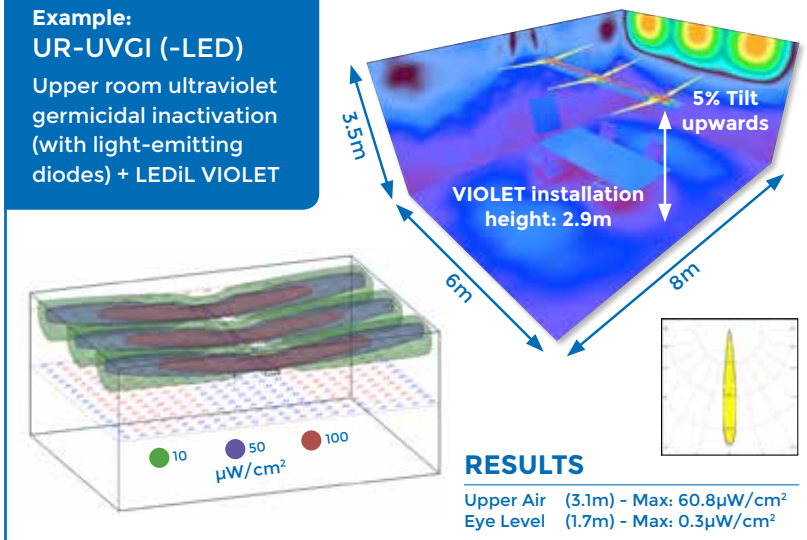
RESULTS
On workplane at 0.6m

Average:	119mW/m2
Min:	116mW/m2
Max:	121mW/m2
u0:	0.977

Irradiance

- 350mW/m²
- 175mW/m²
- 0W/m²

Example:
UR-UVGI (-LED)
Upper room ultraviolet germicidal inactivation (with light-emitting diodes) + LEDiL VIOLET



RESULTS

Upper Air	(3.1m) - Max: 60.8µW/cm²
Eye Level	(1.7m) - Max: 0.3µW/cm²

Surface reflectance: 10%
Optics: LEDiL VIOLET-12-RS (80% eff.)
LED: Nichia NCSU334A (280nm)
Total UV-C output/VIOLET-RS: 528mW
Total power/12 LEDs: 21.84W

Upper-air UVGI applications

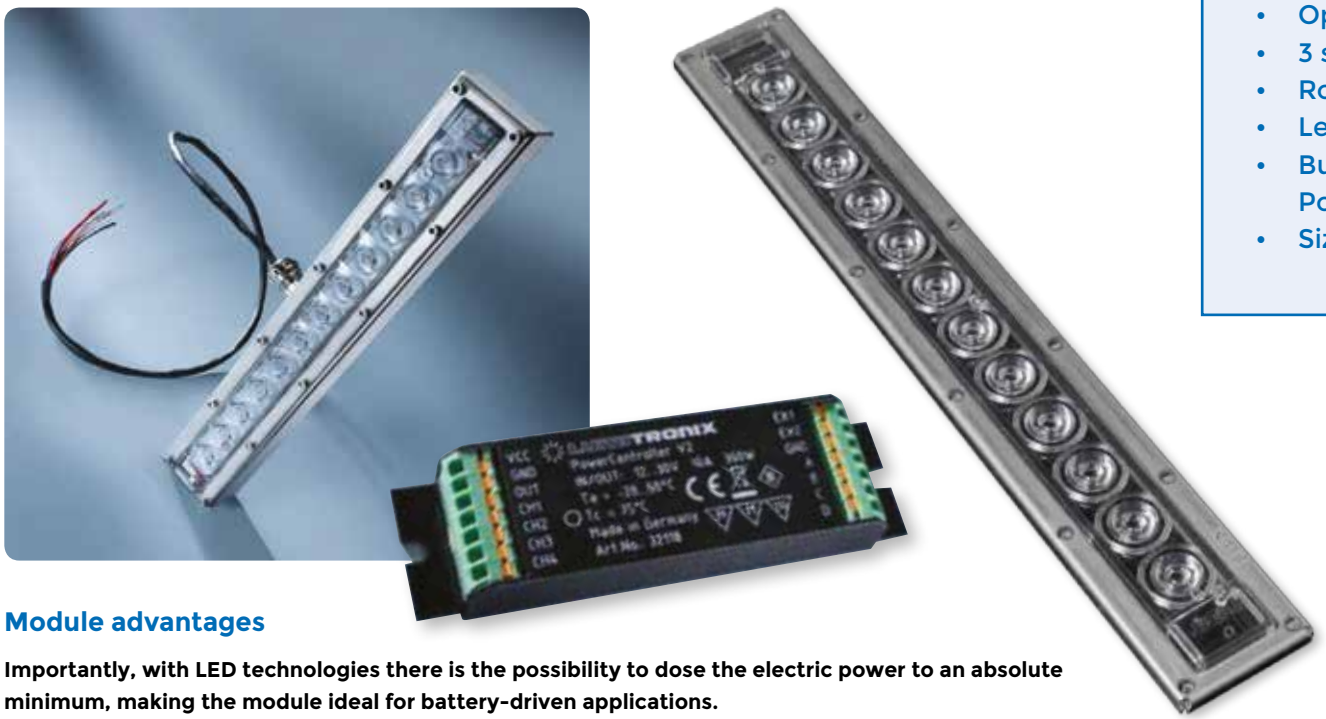
Optics also have an important role in upper-air UVGI (UV germicidal inactivation) applications, which relate to disinfection in the space above the heads of room occupants. Here, UV-C disinfection can occur simultaneously when occupants are present in the room, with large volumes of air disinfected at once. Warm contaminated air within the room rises upwards into the disinfection zone, with cool, clean air descending. Optics use UV irradiation to help ensure it stays in the upper ceiling portion of the room, safeguarding those occupants using the space.

There are, of course, limits on the amount of UV dose that can be applied in upper-air UVGI applications. For an 8-hour exposure time, the limit is currently 0.4µW/cm². LEDiL has tested its technology in UVGI applications using LEDiL Violet-12-RS optics featuring a 14° beam (80% efficiency) and NICHIA 280nm LEDs. In the trials, the beam remained successfully focused into the upper part of a room while producing a maximum irradiance of 0.3µW/cm².

REAL LIFE UV-C MODULES COMBINING LEDS AND OPTICS

Lumitronix, an LED specialist and distributor of NICHIA and LEDiL products, has successfully combined optics from LEDiL and UV-C LEDs from NICHIA into one of its ready-to-use modules.

The Lumitronix UV-C LED module includes the company's PowerController V2 (to aid security requirements) integrated in a robust aluminium housing measuring 297.3 x 44.6mm. Representing a professional UV-C LED solution for the decontamination of surfaces, there are 12 NICHIA UV-C 280nm LEDs on board complemented by LEDiL optics, providing a total optical power of 630mW.



Professional UV-C LED solution for the decontamination of surfaces

- Constant voltage 48V, 23W
- 12 UV-C LEDs on board (NCSU334B, 280nm)
- Optical power: 630mW
- 3 status LEDs (red, green, blue)
- Robust aluminium housing
- Ledil UV-C optics (FN17294_VIOLET-12X1-S)
- Built-in control (LUMITRONIX PowerController V2)
- Size: 297.3 x 44.6mm

Module advantages

Importantly, with LED technologies there is the possibility to dose the electric power to an absolute minimum, making the module ideal for battery-driven applications.

A software-based security system can also be adopted alongside the Lumitronix PowerController V2 to ensure no one is harmed by UV-C exposure. This three-layer safety concept comprises a motion sensor inside the room, a button connected to the door, and a pushbutton located outside the room to activate the UV-C fixtures manually. Activating the external pushbutton is only permissible if no motion is detected inside the room and the door is confirmed as closed. If one of these conditions changes, the UV-C LED turns off instantly.

UV-C LED technology enables a controlled disinfection of defined areas. But it is critical to place the UV-C LED lights directly over the important surfaces to avoid shading.

TESTS AND RESULTS

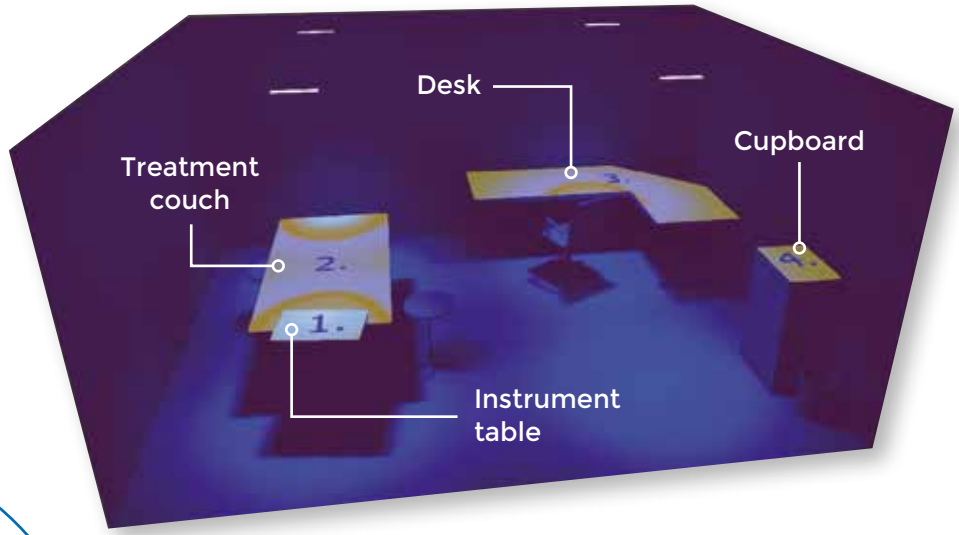
The Lumitronix case study took the example of a doctor's office, with a floor space of 4 x 5m and a height of 2.5m. The office contained an instrument table, treatment couch, desk and cupboard. Two questions were posed: how much optical power would reach the surfaces, and how long would it take to inactivate viruses and germs? In an optical simulation according to the installation situation of the UV-C LED sources, the radiation flow can be visualized. Lumitronix purposely chose a non-optimal arrangement of furniture to show the different range of disinfection results on the surfaces. With the help of LEDIL, a simulation of the optical power of four Lumitronix modules installed on the ceiling, was calculated.

The most critical surfaces, the treatment couch and instrument table (which come into patient contact), showed promising results, with irradiation times for SARS-CoV-2 of around 20 and 12 minutes respectively. However, room for improvement remained in terms of the placement of light sources and furniture in optimum locations. Desk and cupboard were not optimally reached by UV-C radiation, shadow effect prevents a safe disinfection. Indeed, the tests highlighted the importance of having the UV-C LED system directly above the most essential surfaces.

Of course, disinfection/inactivation can be only performed overnight or during the day when the space is empty. However, the doctor's office is just one application example and there are countless others to consider. The fact that the Lumitronix UV-C LED module is customisable for different power outputs, layouts and beams shows the big advantage of LED-technology in terms of design flexibility.

EXAMPLE: Simulation - Disinfection in the room

- **Case Study "Doctor's office":** Length = 4m, Width = 5m and Height = 2.5m
- UV-C irradiation with 4 x linear module "Violet" emitting at 280nm (Non-optimal arrangement)



The initial findings of the case study must be scientifically proven for customer projects with research partners. Tests under real-life conditions are carried out by Lumitronix with scientific partners such as Fraunhofer Institute.

With the power and efficiency of Nichia's UV-C LEDs, measurable disinfection can be achieved at longer intervals. A minimum duration for UV-C radiation for between treatment appointments or overnight allows an effective disinfection of the surfaces.

Irradiation with UV-C LED systems is an effective approach to keep heavily frequented rooms germ-free in addition to classical sterilization methods, like chemical disinfectant liquids or sprays.

Peter Sonnenschein
Head of Sales, Lumitronix

1. STEP:
OPTICAL SIMULATION
(TECH. SUPPORT BY LEDIL)

2. STEP:
TEST IN REAL CONDITIONS

ROLE OF THE APPLICATION BUILDER

The role of application builders such as Efsen, which has in-depth knowledge of both UV curing and disinfection, should not be underestimated. It involves choosing the most beneficial UV-C source to meet the needs of end-users.

The dose is the most crucial factor for disinfection, although time is often the most critical for end-users. The dose is calculated by multiplying the irradiance (mW/cm^2) by time (seconds). Irradiance depends on the source and the size of the area it has to reach, and the distance involved. Any reputable application builder will also evaluate the cost of the dose.

Surface disinfection solutions are likely to take many different forms, including UV-C wands, bars, benches and towers, with selection dependent on how much time is commercially permissible to achieve satisfactory results.

At present, Efsen reports that UV-C LED solutions are ideal for small and narrow applications, and can be competitive for larger areas and surfaces if time is not a constraint. In the near future, Efsen anticipates an increase in LED output and a fall in price, making more and more applications accessible to UV-C LEDs.

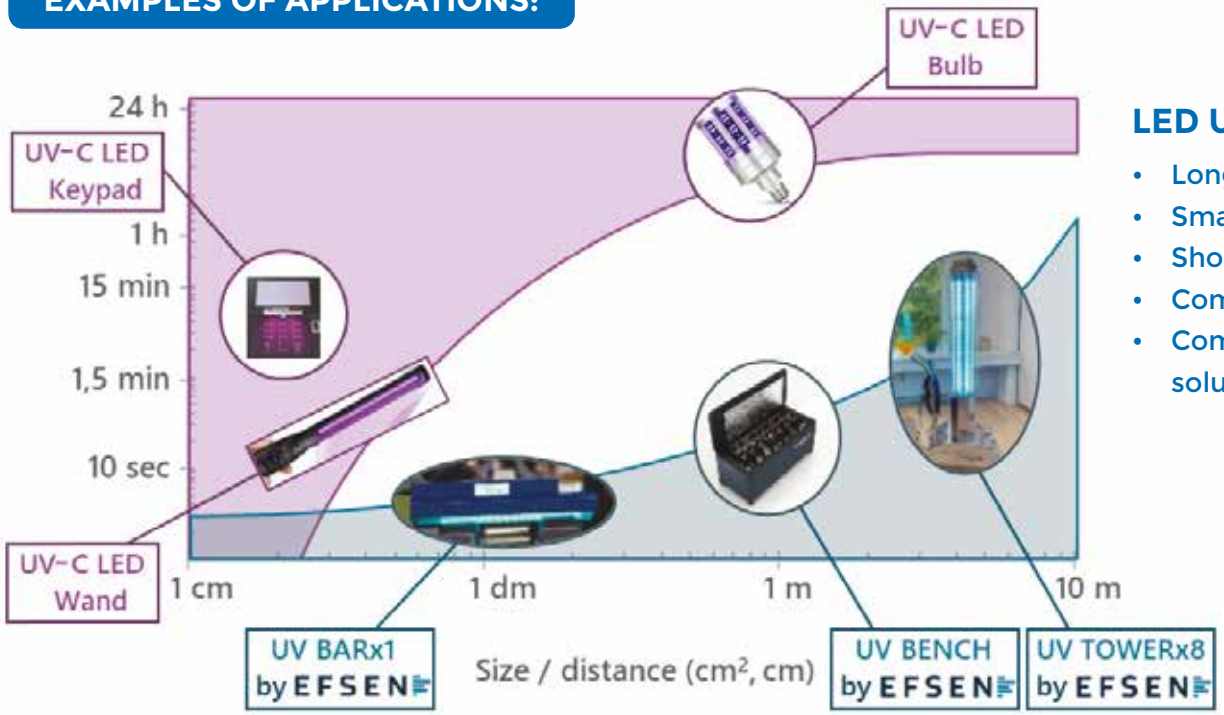
Timeline for real UV-C LED applications

Right now, payment terminals and compact surface areas can already benefit from UV-C LED solutions.

According to Efsen, the market will see many wands/bars become available within 1-3 years, depending on the price-performance ratio. A UV bench comprising a high number of LEDs could emerge in 2-4 years, again depending on costs, while tower configurations that can blast entire rooms with a high UV dose are a little further out, maybe 5+ years.

In all cases, the advent of regulations will be essential to avoid the market becoming proliferated with fundamentally unsafe solutions simply unfit for purpose.

EXAMPLES OF APPLICATIONS:



LED UV-C suitable for:

- Longer exposure time
- Small area to cover
- Short distances
- Complex geometry
- Compact, shielded solutions

> *We have tested the latest NICHIA UV-C LED solutions and seen a big leap in performance - irradiance versus distance - over previous-generation products available just six months ago.*
>
> *As the performance continues to increase, we believe LEDs will take more and more of the disinfection market.*

Thomas Efsen
Managing Director, Efsen

NICHIA

The future of UV-C LED technology as an efficient, safe and cost-effective way to achieve disinfection is assured. Output levels are already high, with super-high solutions imminent. With the mass production of these products will arrive greater cost efficiencies, bringing an increasing number of applications within reach.

The time to plan for an LED-based UV-C future is now.

To learn more, email NICHIA today: **info_de@nichia.eu**

View our webinar:

www.nichia.com