brightgreen®

Germicidal UV-C Lighting

Benefits of automated UV - C Lighting in sterilising indoor environments

Version 1.1

Ultraviolet Germicidal Irradiation

Ultraviolet germicidal irradiation (UVGI) is a disinfection method that uses short-wavelength ultraviolet (UV-C) light to kill or inactivate microorganisms by destroying nucleic acids and disrupting their DNA, leaving them unable to perform vital cellular functions. [1] UVGI is used in a variety of applications, such as food, air, and water purification, and it has been used extensively in medical environments. UV-C light does not make it through to the Earth's surface as the ozone layer of the atmosphere absorbs and reflects it. UVGI devices in the past have been used in closed systems of circulating air or water to make them inhospitable environments to microorganisms such as bacteria, viruses, moulds and other pathogens.[2] [3] The application of UVGI to disinfect has been an accepted practice since the mid-20th century. It has been used primarily in medical sanitation and sterile work facilities. Increasingly, it has been employed to sterilise drinking and wastewater, and in recent years UVGI has found renewed application in air purifiers.[4]

Effectiveness of UV-C Lighting in eliminating viruses

All bacteria and viruses tested to date (many hundreds over the years, including other coronaviruses) respond to UV disinfection. Some organisms are more susceptible to UV-C disinfection than others, but all tested so far do respond at the appropriate doses. UV light, specifically between 200-280nm (UV-C or the germicidal range), inactivates (aka, 'kills') at least two other coronaviruses that are near-relatives of the COVID-19 virus: 1) SARS-CoV-1 and 2) MERS-CoV. UV-C disinfection is often used with other technologies in a multi-barrier approach to ensure that whatever pathogen is not "killed" by one method (say filtering or cleaning) is inactivated by another (UV-C).[5]

The novel application of Ultraviolet Germicidal Irradiation is the use of UV light to disinfect environmental surfaces in vacant rooms. Studies have evaluated the effectiveness of using UV Technologies for disinfecting patient rooms in hospitals using a variety of portable and fixed devices. These studies cited have reported that UV light can significantly decrease the bio-burden of common multidrug-resistant and spore-forming pathogens, including MRSA, Acinetobacter spp., VRE, Mycobacteria, Ebola virus, and Clostridium Difficile on contaminated environmental surfaces in the healthcare settings by up to 4 log.

[1] ULTRAVIOLET GERMICIDAL IRRADIATION
https://web.archive.org/web/20160806185506/https://www.liverpool.ac.uk/media/livacuk/radiation/pdf/UV_germicidal.pdf

[2] ULTRAVIOLET DISINFECTION GUIDANCE MANUAL FOR THE FINAL LONG TERM 2 ENHANCED SURFACE WATER TREATMENT RULE, 2006
https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=600006T3.txt

[3] ULTRAVIOLET LIGHT DISINFECTION TECHNOLOGY IN DRINKING WATER APPLICATION - AN OVERVIEW
https://bit.ly/3dEDLuv

[4] ULTRAVIOLET LIGHT DISINFECTION IN THE USE OF INDIVIDUAL WATER PURIFICATION DEVICES https://bit.ly/2QVx25T

[5] IUVA RELEASES FACT SHEET ON UV DISINFECTION FOR COVID-19 https://bit.ly/2wKMFG8

This research also found that continuous low doses of UV-C light will kill airborne flu viruses.[6] IUVA (The International Ultraviolet Association) establishes that UV-C lighting can help play an important role in a multiple barrier approach to reducing the transmission of the virus causing COVID-19, SARS-CoV2 based on current disinfection data and empirical evidence. [7]

Many tests on coronaviruses, including the SARS coronavirus, have concluded that the viruses are highly susceptible to ultraviolet inactivation[8]. It is estimated that the SARS-CoV-2 virus can survive on surfaces from 6 hours and up to 9 days, based on its similarity to SARS and MERS. Standard disinfectants are effective against SARS-CoV-2 but as an extra level of protection, and to shield against errors in the manual disinfection process, ultraviolet light can be used to disinfect surfaces and equipment after the manual chemical disinfection process is completed. ASHRAE recommends ultraviolet germicidal irradiation as one strategy to address COVID-19 transmission. (ASHRAE 2020)

Table 1 summarizes the results of studies that have been performed on coronaviruses under ultraviolet light exposure. The specific species is indicated in each case. The D90 value indicates the ultraviolet dose for 90% inactivation. Although there is a wide range of variation in the D90 values, this is typical of laboratory studies on ultraviolet susceptibility. The range of D90 values for coronaviruses is 7-241 J/m2. The mean of which is 67 J/m2. This should adequately represent the ultraviolet susceptibility of the SARS-CoV- 2 (COVID-19) virus.

Table 1: Summary of Ultraviolet Studies on Coronaviruses

Microbe	D_{90} Dose J/m^2	UV k m^2/J	Base Pairs kb	Source
Coronavirus	7	0.35120	30741	Walker 2007[a]
Berne virus (Coronaviridae)	7	0.32100	28480	Weiss 1986
Murine Coronavirus (MHV)	15	0.15351	31335	Hirano 1978
Canine Coronavirus (CCV)	29	0.08079	29278	Saknimit 1988[b]
Murine Coronavirus (MHV)	29	0.08079	31335	Saknimit 1988[b]
SARS Coronavirus CoV-P9	40	0.05750	29829	Duan 2003[c]
Murine Coronavirus (MHV)	103	0.02240	31335	Liu 2003
SARS Coronavirus (Hanoi)	134	0.01720	29751	Kariwa 2004[d]
SARS Coronavirus (Urbani)	241	0.00955	29751	Darnell 2004
Average	**67**	**0.03433**		

[a] *(Jingwen 2020)* [b] *(estimated)* [c] *(mean estimate)* [d] *(at 3 logs)*

UV-C Lighting is shown to provide comparable results to cleaning with Hydrogen Peroxide. Based on a study comparing the two,[9] it was found that both the UV and the hydrogen peroxide technologies can be

[6] UV LIGHT THAT IS SAFE FOR HUMANS BUT BAD FOR BACTERIA AND VIRUSES https://www.genengnews.com/topics/translational-medicine/uv-light-that-is-safe-for-humans-but-bad-for-bacteria-and-viruses/

[7] IUVA RELEASES FACT SHEET ON UV DISINFECTION FOR COVID-19 https://bit.ly/2wKMFG8

[8] 2020 COVID-19 CORONAVIRUS ULTRAVIOLET SUSCEPTIBILITY https://bit.ly/2VRADEB

[9] REVIEW OF THE EFFICACY OF UVC FOR SURFACE DECONTAMINATION INTRODUCTION https://bit.ly/2xFJP5I

used for disinfecting room surfaces and equipment because of their broad-spectrum antimicrobial activity against pathogens. However, using Hydrogen Peroxide for Surface Disinfection is not viable in most environments. This is due to the cost of installation, ongoing use costs, and the cleaning processes required to be introduced. The installation of a hydrogen peroxide system for Schools and Offices requires closing the HVAC system and sealing the doors to prevent its escape. It is also time-consuming. The process requires 2.5 to 5 hours, manual cleaning, and the fumes to be ventilated out of the room before use. In addition, the constant use of chemicals in classrooms, daycare facilities, and aged care facilities will further complicate health issues. Germicidal Lighting, on the other hand, is comparably easy to install, requires no HVAC alteration, and has no chemical safety implications.

A study made by Dr Edward A. Nardell et al. on the safety of Upper-Room UVGI in the Tuberculosis Ultraviolet Shelter Study (TUSS)[10] with the use of louvred wall-mounted and ceiling-mounted UVGI fixtures in retro-fitted buildings such as factories, schools etc. concludes that Upper-Room UVGI has the capability to provide substantial protection at a low cost and can be adapted to older buildings. This research complied with the guidelines set forth by The American Conference of Government Industrial Hygienist (ACGIH) committee on physical agents in establishing a TLV for UV-C exposure, which is supported by the International Commission on Non-Ionizing Radiation Protection and is used in setting lamp safety standards by the Illuminating Engineering Safety Standards of North America. Safety precautions were also taken, such as utilizing equipment containing switches that deactivate fixtures when opened. UV systems were installed on dedicated electrical circuits that can be turned off only with special keys possessed by maintenance personnel. Training was given to all shelter personnel, and bilingual notices about safety practices were placed to inform occupants that UV was in use. Although it was primarily focused on air purification, TUSS constitutes the largest study of UV safety to date.

Numerous studies are now being conducted to defeat COVID-19. In particular, is the study done by Robert J. Fischer et al. on different decontamination methods, including the first test seen using UV radiation (260-285nm) for decontamination purposes[11]. Four different decontamination methods - UV radiation (260 – 285 nm), 70 degC Heat, 70% Ethanol, and Vaporized Hydrogen Peroxide (VHP) were used. For each of the decontamination methods, they compared the inactivation rate of SARS-CoV-2 on N95 filter fabric to that on stainless steel. It was found that UV inactivated SARS-CoV-2 rapidly from steel but more slowly on N95 fabric, likely due to its porous nature.

[10] SAFETY OF UPPER-ROOM ULTRAVIOLET GERMICIDAL AIR DISINFECTION FOR THE ROOM OCCUPANTS: RESULTS FROM THE TUBERCULOSIS ULTRAVIOLET SHELTER STUDY https://bit.ly/3dMjQtV

[11] ASSESSMENT OF N95 RESPIRATOR DECONTAMINATION AND RE-USE FOR SARS-COV-2 https://bit.ly/2Yuvbtb

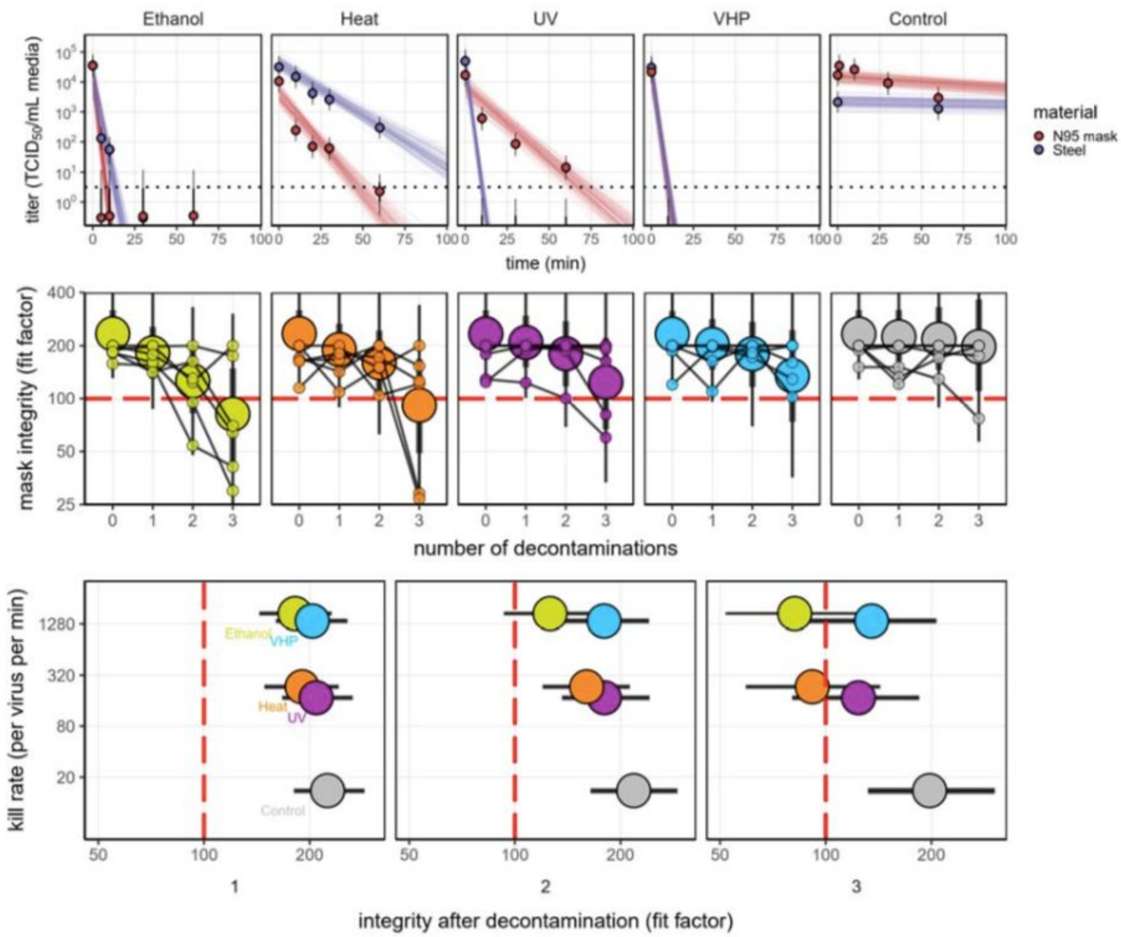

Figure 1. Decontamination of SARS-CoV-2 by four different methods. A) SARS-CoV-2 on N95 fabric and stainless steel surface was exposed to UV, 70 degC Dry Heat, 70% Ethanol and Vaporized Hydrogen Peroxide (VHP). 50 µl of 105 TCID50/mL of SARS-CoV was applied on N95 and stainless steel (SS). Samples were collected at indicated time points post exposure to the decontamination method for UV, Heat and Ethanol and after 10 minutes for VHP. Viable virus titer is shown in TCID50/mL media on a logarithmic scale. All samples were quantified by end-point titration on Vero E6 cells. Plots show estimated mean across three replicates (dots and bars show the posterior median estimate of this mean and the posterior inter-quartile range, or IQR). Lines show predicted decay of virus titer over time (lines; 50 random draws per replicate from the joint posterior distribution of the exponential decay rate, i.e. negative of the slope, and intercept, i.e. initial virus titer). Black dashed line shows maximum likelihood estimate titer at the Limit of Detection (LOD) of the assay: 100.5 TCID50/mL media. B) Mask integrity. Quantitative fit testing results for all the decontamination methods after decontamination and 2 hours of wear, for three consecutive runs. Data from six individual replicates (small dots) for each treatment are shown in addition to the predicted median and IQR (large dots and bars respectively) fit factor. Fit factors are a

measure of filtration performance: the ratio of the concentration of particles outside the mask to the concentration inside. The measurement machine reports value up to 200. A minimal fit factor of 100 (red dashed line) is required for a mask to pass a fit test. C) SARS-CoV-2 decontamination performance. Kill rate (y-axis), versus mask integrity after decontamination (x-axis; bar length represents IQR). The three panels report mask integrity after one, two or three decontamination cycles.

IUVA encourages consumers to exercise caution when selecting UV-C equipment given the wide array of UV-C devices marketed for disinfection of air, water, and solid surfaces. This is due to the lack of uniform performance standards and the highly variable degree of research, development, and validation testing that is performed on different devices.[12]

The intense wavelength of UV light is known to degrade colour and chemical composition of plastics. This is most commonly due to the wider spectrum UVA and UVB light. In the photodeterioration of paints, varnishes, and textiles, the quantum yield is several orders of magnitude less than unity.[13] For the bleaching of certain dyes, the quantum yield has been reported to be about 0.002, meaning a thousand photons must be absorbed before two molecules are bleached. Quantum yields as low as 0.0001 (10,000 photons per molecule) have been reported for most plastics. High-quality pure plastics are relatively resistant to UV, but impurities and residual solvents in low-grade plastics are mainly responsible for their quick photodegradation. The proposed commercial areas that could benefit from UVGI lighting contain materials that are of commercial standards and will not commonly fade. The nature of UVGI being composed of a narrower wavelength than UVA and UVB light means they are absorbed by other smaller molecules before reaching the pigment of the dye. Most materials have a protective coating which is resistant to this narrow wavelength UVGI spectrum and does not allow the pigment underneath to be affected. Based on several decades of use, experience has shown that, with few exceptions, any UV induced damages tend to remain superficial and do not generally affect the structural or mechanical integrity of plastic components. Plastics such as motor belts and conduits used in the HVAC industry have proven to withstand UVGI very well over the last 20 years of accumulated field experience.

(Kowalski, 2010) UVGI has a definite future in the control of contagious diseases and, if applied on a widespread basis, it may be the key to controlling epidemics and pandemics. No other current technology has the capability, the adaptability, and the favourable economics to make it viable for an extremely wide variety of disease control applications. From healthcare applications to schools and residential environments, UVGI has the ability to eradicate many contagious diseases in an efficient and automated manner. The advent of multidrug-resistant microbes like MRSA and XTB and emerging pathogens like SARS and Avian Influenza is likely to stimulate the increased use of UVGI systems in an ever wider number of applications.[14]

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[12] IUVA RELEASES FACT SHEET ON UV DISINFECTION FOR COVID-19 https://bit.ly/2UvhKXw

[13] ACCELERATED AGING, PHOTOCHEMICAL AND THERMAL ASPECTS https://bit.ly/2WTohgk

[14] ULTRAVIOLET GERMICIDAL IRRADIATION HANDBOOK: UVGI FOR AIR AND SURFACE DISINFECTION https://bit.ly/3awLUiP

The Brightgreen Solution - Germicidal UV-C Lighting

UV-C (254nm), as multiple studies have shown, kills viruses, bacteria, and other organisms. It is able to sterilise surfaces, as well as kill viruses in the air. Brightgreen has designed a combination of UVGI and white visible light with advanced human presence sensors and automated software that ensures the probability of unsafe human exposure is minimised to manageable levels. This is achieved with a lighting system containing advanced presence detection and tracking using stereoscopic sensors and a connected array of traditional PIR sensors. Software has been developed for smart scheduling and networked sensing to allow for multiple levels of redundancy to prevent exposure and minimise compliance for procedure and human operation.

At the core of the system, is Brightgreen's Wellness software. This is based on smart algorithms which are updated in real-time from the sensor network installed in the building. This enables the system to recognise the occupancy and activity of rooms. The system also involves digital interface devices allowing the configuration, programming, and notification of the lighting system. This ensures that multiple parameters are met before enabling the germicidal lighting function to sterilise the room. The lights have their own second layer of safety with the UV and Tru-Colour white lighting being configured on separate circuits inside the single fitting. Each fitting contains a localised occupancy sensor which deactivates the UV-C light when movement is detected.

Through the set-up and correct use of this system, UV-C germicidal lighting is suitable to be installed in many commercial settings without any dangerous exposure to humans. The system complies with the following Guidelines and Standards:

AS/NZS STANDARDS

- AS/NZS 60335.2.27:2010
    - *3.101* Ultraviolet emitter (200nm to 400nm)
    - *3.103* Effective irradiance
    - *6.101* Appliances for commercial use only
    - *7.* Marking and instructions
    - 22.110 UV appliances shall incorporate a control that terminates the emission of the radiation. *Annex BB.1.4* UV appliance wavelength shorter than 320nm (UV type 4 appliance).
- AS 1807.23-2000

Ultraviolet Germicidal Irradiation Handbook Guidelines: UVGI for Air and Surface Disinfection
UV Exposure Limits as shown in the Table below:

The exposure limits in Table 12.1 apply to both skin and eyes and for general or occupational exposure to UV incident upon the skin or eye within an 8 h period. These EL values may be used to evaluate potentially hazardous exposure from UV from any incoherent sources, which excludes lasers. Most incoherent UV

Table 12.1 UV Exposure Limits and Spectral Weighting Functions

Band	Wavelength nm	Relative spectral effectiveness	Exposure limit, J/m^2	Band	Wavelength	Relative spectral effectiveness	Exposure limit, J/m^2
	180	0.012	2500		320	0.001	29000
	190	0.019	1600		322	0.00067	45000
	200	0.03	1000		323	0.00054	56000
	205	0.051	590		325	0.0005	60000
	210	0.075	400		328	0.00044	68000
	215	0.095	320		330	0.00041	73000
	220	0.12	250		333	0.00037	81000
	225	0.15	200		335	0.00034	88000
	230	0.19	160		340	0.00028	110000
UVC	235	0.24	130		345	0.00024	130000
	240	0.3	100	UVA	350	0.0002	150000
	245	0.36	83		355	0.00016	190000
	250	0.43	70		360	0.00013	230000
	254	0.5	60		365	0.00011	270000
	255	0.52	58		370	0.000093	320000
	260	0.65	46		375	0.000077	390000
	265	0.81	37		380	0.000064	470000
	270	1	30		385	0.000053	570000
	275	0.96	31		390	0.000044	680000
	280	0.88	34		395	0.000036	830000
	285	0.77	39		400	0.00003	1000000
	290	0.64	47				
	295	0.54	56				
	297	0.46	65				
	300	0.3	100				
	303	0.19	250				
	305	0.06	500				
UVB	308	0.026	1200				
	310	0.015	2000				
	313	0.006	5000				
	315	0.003	10000				
	316	0.0024	13000				
	317	0.002	15000				
	318	0.0016	19000				
	319	0.0012	25000				
	320	0.001	29000				

Note: This Table adopts the current convention in which UVB is defined as 280–320 nm and UVA is defined as 320–400 nm. Many sources still define UVB as 280–315 nm and UVA as 315–400 nm. The following subdivisions of UVA have also recently been defined: UVA2: 320–340 nm UVA1: 340–400 nm

The extensive use of the Brightgreen Wellness system will ensure the guidelines for UV-C exposure to humans will at all times be adhered to. With 0 J/m^2 being the norm. Conventional glass acts as an appropriate filter absorbing all UV-C rays, that allows for existing spaces to be adequately sealed off to protect users on the outside. Protocols such as locking the room or area in which germicidal function is in use should be followed and will be prompted to be checked by the Wellness system as another level of redundancy.

When installed, the system will be able to clean all visible surfaces and the air of viruses and other microbes to 4 log levels (99.99%) whilst operating in a completely safe environment. It is to be noted that, for maximum effectiveness, it should be used after classical manual cleaning to ensure that a layer of dirt does not stop the sterilisation of viruses on surfaces.

Brightgreen Troffer lights will be the first luminaries to be produced due to the ease of installation as recessed, surface, and suspended luminaires. It has an effective irradiance of 1.5W/m2 and these fittings have been designed with dual light spectrums that can be controlled independently for both visible and virus killing light spectrums. These are controlled by the Brightgreen Wellness system to automatically switch between normal visible light during the day and a safe virus killing light during the night when no one is occupying the space.

To determine the required time to disinfect, we follow a log scale reduction computation (90% to 99.99% reduction). The calc $D = -\ln[1 - 0.95]/k$ as illustrated in the example below:

40W Germicidal Lamp with coverage of 24m2, UV Power measured on surface at 5µW/cm2 = .05W/m2
The log reduction of the virus for 99.99% would need a dose of 268W/m2 = 178.5 seconds = ~ 3minutes
Longest would be around 240W/m2 = ~ 10.6 minutes

10.6 minutes also coincides with the study done by Robert J. Fischer et al.[15] which concluded that UV sterilization of steel happened at approximately 10 minutes while the fabric of an N95 mask takes 10x longer at 100 minutes due to its porous nature.

Use Cases : Deep Clean 100min (4 Log 99.99% Kill Rate)
Speed clean During Day 10min (hard surfaces (steel) 4 Log 99.99% Kill Rate)

Products: Lighting Products , refer to table below:

LIGHTING TYPE	SIZE	WATTAGE	THEORETICALLY STERILISED AREA
TROFFER	600 x 600 mm	20W	14 m2 (1.5 W/m2)
TROFFER	1200 x 300 mm	40W	28 m2 (1.5 W/m2)
TROFFER	1200 x 600 mm	40W	28 m2 (1.5 W/m2)
PANEL	TBC	TBC	TBC
LINEAR	TBC	TBC	TBC

Wellness Hardware: Tablets, Hub, Controllers, Stereoscopic Sensors, Motion Sensors, Relays
Wellness Software: App

Brightgreen is ready to produce this system in a range of different applications; from Schools, Offices, and Mining camps to Aged care, pharmacies, GP clinics, and Hospitals. Contact us at Brightgreen, and we will advise on the ideal solution for your project application (1300 672 499). To get started, please make available a floor plan, a description of the use of space and timing, and the current lighting and control

[15] ASSESSMENT OF N95 RESPIRATOR DECONTAMINATION AND RE-USE FOR SARS-COV-2 https://bit.ly/2Yuvbtb

systems used. There is no clear indication of how long this pandemic will last. In the meantime, sustainable, innovative solutions to work around it may be the answer.

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