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A Study on Eco-friendly Quarantine System Using Antiviral Surface Lighting

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Abstract: Due to the aftermath of COVID-19, we are using a continuous sterilization response system, such as sterilizing the interior of the building or using sterilized air in the air conditioning system. Chemical spraying is cumbersome and requires a lot of labor, and air conditioning systems have good air cleaning functions, but sterilization functions are difficult because they require sufficient residence time. Therefore, we developed an eco-friendly sterilization system that can disinfect the entire building with a single switch by adding a sterilization function to the existing lighting. It is a concept that sterilizes the space sufficiently by combining UVC-LED with high sterilization power with the existing LED surface lighting, using lighting during the day and sterilizing light inside the building without people at night. A PIR sensor was attached to each entrance or light to stop disinfection with a human body sensor in case people enter even at night. For the sterilization performance test, it was confirmed that 99.99% of 5 types of bacteria were sterilized as a result of testing the sterilization performance of attached bacteria at the maximum height of 1.5m or less of the certification body. The radiation intensity was simulated with a value similar to the dose irradiated in the experiment to have sterilizing power at the lighting height of 2.6m in an actual general office. As a result of calculating the sterilization time of the indoor space by coding the UVC-Led specification and the office space with MATLAB as input conditions, sterilization is possible if it is more than 4 hours. Through this study, an eco-friendly smart disinfection system was developed that disinfects the entire building with one switch when UVC is combined with general lighting and controlled from the central control room.

Keywords: Pandemic, Antibiotic Building, UVC-LEDs, Sterilization, Radiation, Simulation

1. Introduction

Due to the corona pandemic, constant disinfection of buildings where an unspecified number of people live has become important. The need for disinfection inside buildings has been raised as a research result that indicate microbial damage such as bacteria and fungi in indoor buildings [1]. In windless offices without air conditioning, most airborne bacteria fall or adhere over time. When an air conditioner is operated, airborne bacteria in the air must be sterilized or removed with a large amount of outdoor air, but in the case of introducing all outdoor air, energy costs rise rapidly, making it difficult to adopt [2].

In the case of the disinfectant of the Ministry of Environment based on the Infection Prevention Act, it is in the form of wiping or spraying with an object surface agent, and the effective contact time is rather long, 1 to 10 minutes. In the case of non-medical environmental disinfection related equipment, there is no certification standard, and in the case of UVC irradiation, the WHO restricts it to an enclosed type out of concern for harm to the human body. Even spray-type disinfectants do not reduce the risk of droplet transmission to patients, and rather, it is not recommended to use them directly on the human body in consideration of the effect on the respiratory system.

In addition to spray-type chemical products, there is a disinfection method by ultraviolet rays and visible rays as a physical disinfection method without direct stimulation. Ultraviolet sterilization is known to inactivate RNA, inhibit proliferation, and has excellent sterilization effects against viruses and bacteria, but it is also harmful to the human body, limiting exposure to the skin and eyes to 30 J/m^2 [3].

In addition, the electric sterilizer product standard of the electrical appliance safety standard is limited to a structure in which ultraviolet rays do not leak directly, so it can be used only when the disinfection target is placed in an enclosed space [4]. Therefore, UVGI (Ultraviolet Germicidal Irradiation) sterilization is possible in a limited space where there is no contact with the human body, such as inside an air conditioner, and significant results were obtained as a research result that applied to temporary shelters [5].

405 nm LED [6], which has sterilizing power in the visible light range, is harmless to the human body and can be exposed for a long time, but its radiant energy is only 1/700 to 1/1,000 compared to 275 nm. So, it has less sterilizing power, so a lot of energy must be input for a long time. As a result of a field application study, it showed a sterilizing effect on mold at a short distance (5 cm), but it is difficult to show a sterilizing effect from the lighting attached to the ceiling to the entire indoor space and the floor [7].

On the other hand, regarding the problem of effectively arranging LEDs, Kim et al. [8] argued that installing LEDs in places where the flow velocity is concentrated would have high sterilization power. In addition, Lee et al. [9] argued that sterilizing power can be secured by low-speed flow in the sterilization section and the sterilized air can be discharged at high speed in any direction by narrowing the flow path at the end of the sterilization section. In addition, Jo et al. [10] studied the actual interaction of ozone and UVC and optimal integration conditions suitable for virus inactivation using a system that applied ozone and UVC.

On the other hand, when the ultraviolet sterilization function was added to the lighting, it was confirmed that the indoor space was kept clean. A simulation study in which UVC lamps were applied to kitchen lighting and a sterilization power equation by UVC was introduced to sterilize the kitchen environment showed that the calculated value was about 30% higher than the actual value. It was analyzed that the reflectance material based on the literature was not reflected well because it was different from the real one [11]. In addition, it was suggested that data applying the ratio of falling and attached bacteria as a result of simulation of airborne bacteria in individual office spaces using a simulation program and CFD applied to ventilation analysis should be accumulated [12].

Therefore, this study combines UVC with office lighting for building disinfection and tests the sterilizing power of adherent bacteria on the floor to design indoor space radiation disinfection with UVC.

2. Method

2.1. Design of Space Sterilization Lighting

2.1.1. Light-Combined Sterilization Lamp Design

The subject of the study designed a lamp with lighting and sterilization functions as a fusion lighting that inserts a UVC module into a general rectangular led surface lighting used in offices. To exclude human hazards such as UVC sterilization, three or more safety devices were set. Install a real time clock (RTC) to turn on the lighting LED during the daytime and turn on the UVC only at midnight when people leave the room. Control the switch so that the lighting and sterilization light do not turn on at the same time. The sensor is interlocked with the program switch so that the UVC sterilization lamp is automatically turned off when it is turned off. The block diagram of the sterilization surface lighting combined with UVC is shown in Figure 1 below.

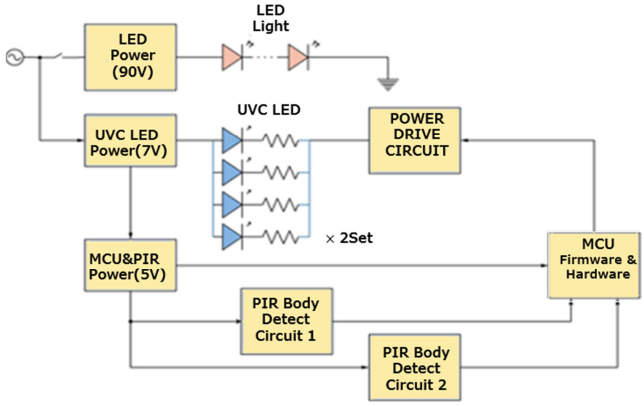

Figure 1. *Block Diagram of antivirus face light.*

2.1.2. Design of Ultraviolet Sterilization Light Module

4 UVC LEDs were placed on both sides of the 130×32 cm^2 surface lighting, and one blue LED was connected to visualize UVC lighting. A PCB module was fabricated by inserting a PIR (Passive Infrared) sensor to detect the human body and turn off the sterilization lamp. The UVC PKG used was a domestic product [13] with a size of 3.5×3.5×1.8 cm^3, wavelength of 275 nm, light output of 10 mW, current and voltage values of I_f 100 mA, V_f 6 V and beam angle of 125°.

The measured voltage value of the UVC LED connected to the small power supply (SMPS) separate from the lighting is 5.2 V, the current value per unit is 48 mA, and the total radiant energy is 4.8 mW/unit x 4 units. Therefore, 19.2 mW light output is output on each side of the surface light. Multiplying UVC light output and time becomes a factor that can adjust the sterilization power with the total sterilization energy (dose).

2.1.3. Surface Lighting Fixture Design for Sterilization

Surface lighting was analyzed, and BS and HT products were analyzed among edge-type surface lighting. As a result of analyzing the mechanical part structure and SMPS, HT surface lighting SMPS has excellent performance, and in the case of compact BS products, there is a heating problem in designing UVC driving part and MCU power supply part.

UVC-Led products were first selected for the design of UVC LED modules that can be combined with surface lighting. Among S-light's various product groups, we completed calculation of power intensity of UVC circuit, heat test, UVC PCB board design and module.

A mechanical part structure that can be combined with surface lighting was designed and UVC was installed. It was equipped with a left and right frame for surface lighting, a light irradiation unit, a sensor, and a quartz glass plate.

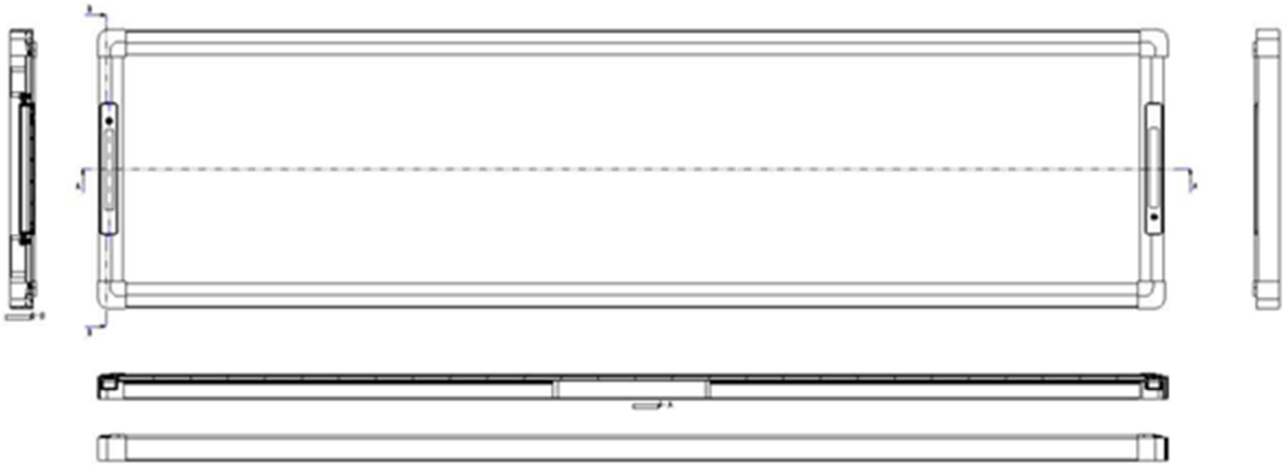

Figure 2. *Design of mechanical part combining surface lighting with sterilization light.*

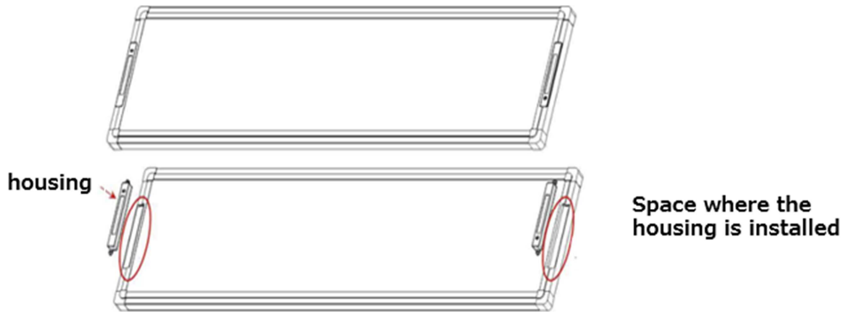

Figure 3. *Surface lighting housing with sterilization device.*

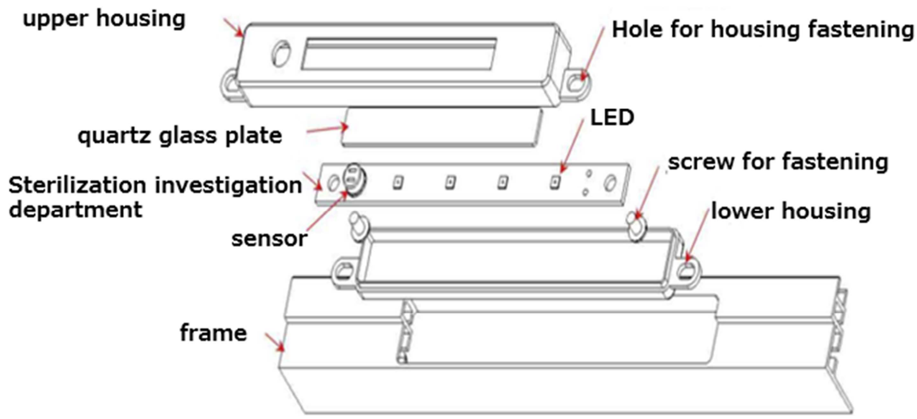

Figure 4. *Surface lighting frame combined with sterilization device.*

2.1.4. PIR Sensor and AMP

The movement of the human body is detected by the PIR sensor, and UVC on/off is controlled, and it is amplified with high sensitivity so that even weak movements can be detected.

The pre-amplifier has a gain of 2 times. And the output voltage after amplification has half the effect of the supply voltage.

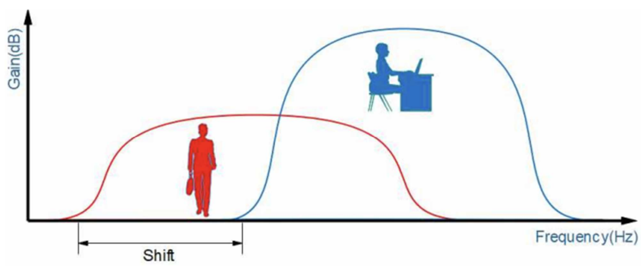

Figure 5. *PIR sensor frequency shift.*

2.2. Space Sterilization Experiment

To disinfect the office space with a lighting fusion type ultraviolet sterilization lamp, a sterilization experiment was conducted in the area where UVC is illuminated from the ceiling.

As shown in Figure 6, UVC LED modules were inserted on both sides of the surface lighting and sterilization experiments were conducted at various locations perpendicular to the floor. The maximum height that can be tested by an authorized test institute (KCL [14]) is 1.5 m.

The sterilization rate for 5 types of bacteria attached to the floor was tested. First, if the building workers work overtime and get off work late, the experiment was conducted by setting the maximum time that can be investigated until going to work as 8 hours, and then the investigation time was reduced.

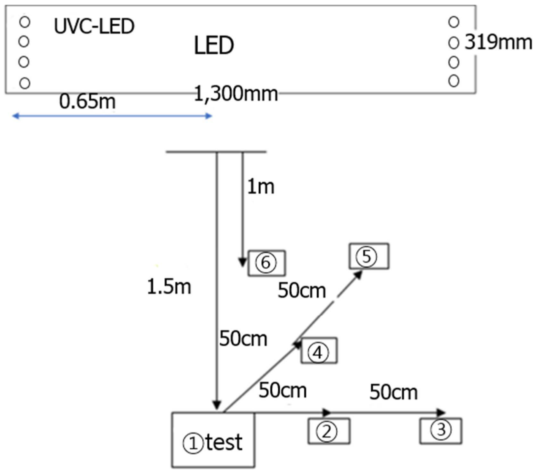

Figure 6. Position of sterilization experiment.

2.3. Space Sterilization Modeling

2.3.1. Sterilization Lamp Irradiation Design

To quarantine the entire office space inside the building, space sterilization modeling was designed in consideration of the lighting arrangement interval.

The UVC radiant energy used in the modeling is the dose (mJ/cm) multiplied by the time and the light energy that obtained a 99.9% sterilization rate in the bacterial experiment. Since the area radiated in the form of a cone in the space in degrees must be considered, the formula of the method for measuring harmful ultraviolet radiation (KS A 5006 [15]) was used.

This standard is a regulation on how to physically measure harmful irradiance in general artificial light and natural light and is measured in terms of density per unit area of incident surface, W/m^2. If a point radiation source is perfectly diffusive, the irradiance H of a point at a distance D (m) is given by the following equation (1). The irradiance calculation for space sterilization modeling was coded in MATLAB.

$$H = NA/D^2 (W/m^2) \quad (1)$$

N: radiant luminance of the radiation source [W/($sr \cdot m^2$)]

A: Area of radiation source (m^2).

2.3.2. Modeling Input Condition

The modeling input data is the same as the spatial arrangement of the sterilization light, the light distribution data according to the output of the light source and the UVC-Led angle of view (Figures 7-8).

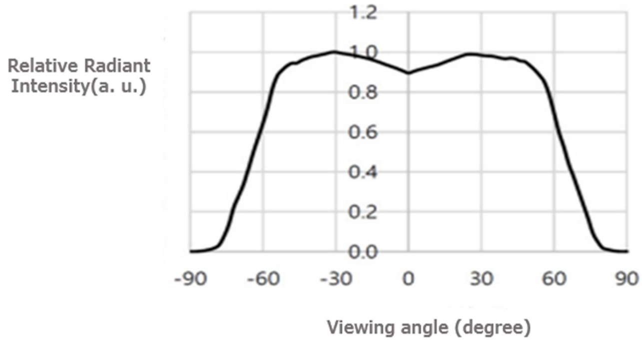

Figure 7. Light Distribution curve of case 1.

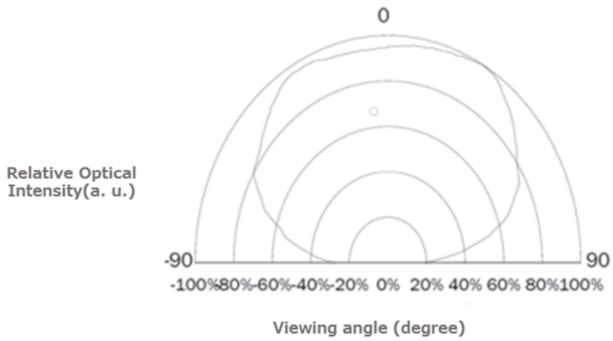

Figure 8. Light Distribution curve of case 2.

As for the simulation conditions, as shown in Table 3, the sterilization lamp conditions used in the bacterial experiment (case 1) and the floor sterilization conditions under the actual office ceiling height (case 2) were compared. The dose amount was maintained to maintain similar sterilization performance on the floor, and in case 2, a product with higher UVC light output was used because the distance from the ceiling to the floor was longer.

The dose used for space sterilization was about 4mJ/cm^2, which was smaller than the 99.99% sterilization dose of Cov 19, 16mJ/cm^2, suggested in the literature [16]. The reason for this is that the sterilization performance by ultraviolet rays has a greater effect of irradiation time than light output intensity even at the same dose, and it is judged that the effect of reflection from the surrounding walls is included.

Table 1. The condition for sterilization light design.

condition	Case 1	Case 2
UV-C	10mW (100mA)	20mW (100mA)
angle view	125°	160°
radiation power (mW)	4.8 (48mA)	12 (60mA)
array	2parallel, 4series	2parallel, 6series
total (mW)	38.4	144
height (m)	1.5	2.6
irradiation (hr.)	6	4
Dose (mJ/cm^2)	4.53	4.12

3. Results

3.1. Sterilization Test

The results of Table 1 show the sterilization rate for 5 types of bacteria after 8 hours under 1.5 m as the first antibacterial test. All 5 strains showed a sterilization rate of 99.9%, indicating a sufficient disinfection effect.

Table 2. *The 1'st antibacterial test in an office.*

Strain type	Antibacterial Performance	Experimental Condition
Coli Staphylococcus aureus Pseudomonas aeruginosa Pneumonia MRSA	99.9%	1.5 m below 8 hr. radiation

As shown in Table 2, the results of the second experiment by reducing the time and number of bacteria showed a sterilization rate of more than 90% in 2 hours of irradiation, and 99.9% of both bacteria in 6 hours. Escherichia coli showed a sterilization rate of 99.9% after 4 hours of irradiation, showing weaker viability than other bacteria, like previous studies.

Table 3. *The 2nd antibacterial test in an office.*

strain type	2hr	4hr	6hr	Experimental Condition
Coli	93.7%	99.9%	99.9%	1.5 m below
Staphylococcus aureus	91.5%	98.6%	99.9%	

Therefore, when disinfecting a building with UVC light, it is judged that space sterilization is possible if irradiated for more than 6 hours in the middle of the night.

Therefore, it is possible to sterilize the entire interior of the building with a single central control switch in the middle of the night when the workers leave work, compared to the effort of the manager going around the building and sterilizing chemicals.

3.2. Space Sterilization Modeling

Sterilization performance simulation was performed for four surface lights arranged at legal intervals in the office space. The front and back distance of the surface lighting is 2,700 mm, and the side distance is 2,400 mm (Figure 9).

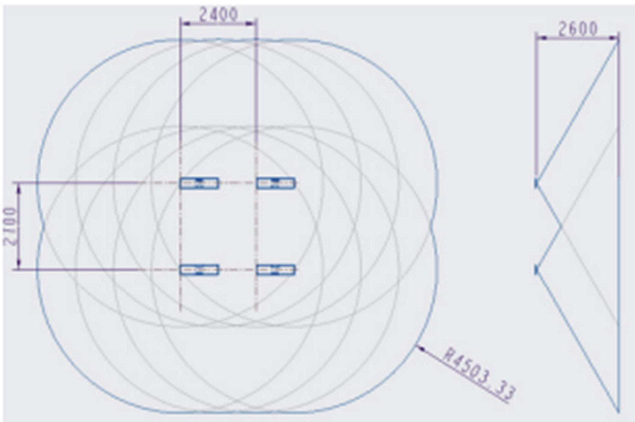

Figure 9. *4face light array in an office.*

The UVC sterilization light appeared to overlap all four lights in the radiation area by the 160° light distribution curve. Therefore, it is judged that the space sterilization effect is much greater than the sterilization performance by the experiment. Figure 10 shows the irradiance distribution by the light distribution curve of a UVC LED with a directivity angle of 160°. As the distance from the center increases, the intensity value decreases.

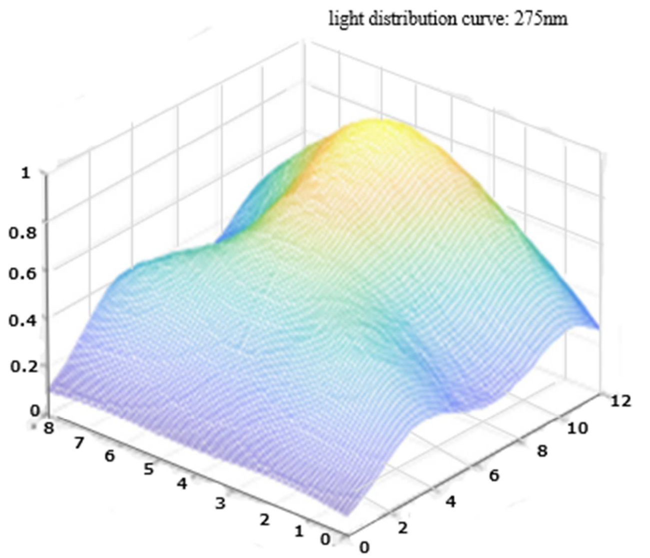

Figure 10. *Simulation of UVC radiation flux by a face light in office room.*

Figure 11 shows the UV radiation distribution combined with the whole surface lighting in the office. It is judged that the actual sterilization effect is greater because the irradiance is all overlapped in the upper, lower, left, and right directions of lighting.

Figure 11. *Simulation of UVC radiation area by total face light in office room.*

4. Conclusion

As a building disinfection system, the possibility of indoor space sterilization by UVC ultraviolet rays combined with surface lighting was studied. As a result of testing the bacterial sterilization performance attached to the maximum height of 1.5m or less by the testing and certification agency, the UVC module was combined with a general surface lighting and showed a 99.9% sterilization rate within 6 hours.

A simulation was performed to predict the sterilization rate at the lighting and floor height inside the actual building. The illuminance measurement formula was coded and simulated in MATLAB to design germicidal lighting for a general office at a distance of 2.6m from the ceiling with a value similar to the radiation dose in the experiment.

It is judged that the sterilization effect will be further strengthened by adding overlapping effects and reflection effects as many as the number of lights within the lighting arrangement interval by the UVC light distribution curve.

UVC ultraviolet rays are harmful to the human body, so disinfection is performed only at night when no one is present, but when a person's intrusion or movement is detected, the PIR sensor controls UVC blocking.

Through this study, space disinfection is possible by combining UVC with general lighting, and when managed together with lighting in the central control room, it is possible to implement a smart quarantine building that disinfects the entire building with a single switch.

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