Application of UV-C LED Technology in Air sterilizer: Sterilization and Odor Removal

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ABSTRACT

Air sterilizers have gained widespread market adoption, but their functionality remains limited to singular purposes such as disinfection or odor removal.The MassPhoton's Q6060-D UV-C air sterilizer utilizes solid-state semiconductor technology with UV-C LEDs emitting 260-280nm single-wavelength ultraviolet light, which can inactivate a broad spectrum of microorganisms by blocking DNA and RNA replication. Installed on the ceiling of meeting rooms, garbage rooms, and corridors in a normally operating shopping mall in Hong Kong, the MassPhoton's Q6060-D UV-C air sterilizer achieved a sterilization rate of 70.8% in the garbage room and 61.62% in the meeting room. Although during the odor removal test, wall painting activities in a rented shop significantly increased TVOC levels, the use of the MASSPHOTON air sterilizer reduced the initial TVOC level from 10.00 mg/m³ to 3.53 mg/m³ within 2 hours. In a simulated test conducted in a 112 m³ room, after four cigarettes were completely burned, the MassPhoton's Q6060-D UV-C air sterilizer was immediately activated. After 4 hours, the PM2.5 concentration was effectively reduced by 61.1%, and the TVOC concentration was reduced by 98.2%. Using 10% ammonia solution as a volatile ammonia gas test, the ammonia removal rate reached 99.9% within 90 minutes. Based on all experimental results, it can be concluded that the MassPhoton's Q6060-D UV-C air sterilizer can effectively reduce the number of natural bacteria in the air while adsorbing particulate matter in the environment, decomposing odor molecules, maintaining air cleanliness and freshness, preventing the spread of respiratory diseases, and protecting vulnerable populations.

Keywords: UV-C LED, Natural bacteria, Photocatalyst, Ozone-free, infection control and prevention

1. INTRODUCTION

Air pollution severely impacts various aspects of our lives, including our living, learning, and working environments. Pollutants such as volatile organic compounds, particulate matter, and pathogens affect the health of the respiratory and nervous systems, while odors from food waste fermentation, toilet smells, and cigarette smoke negatively impact mood. Research by Sierra-Varga et al. found that particles with a diameter of less than 2.5 micrometers (PM2.5) deposit in the alveolar region of the lungs [1]. Pathogens, on the other hand, are suspended in the air in two forms: droplets (diameter >5 μm) and aerosols (diameter ≤5 μm), which can spread diseases through the respiratory system. Aerosol particles, in particular, can survive in enclosed spaces for hours to days and enter the human body through the respiratory system, causing infections [2]. This transmission characteristic has been fully demonstrated during recent epidemics, making air sterilizers a key technological solution for breaking the chain of transmission. Air sterilizers have shown great potential in preventing and reducing airborne diseases [3]. Common air sterilizers on the market primarily use ultraviolet (UV) technology for sterilizer. The use of UV light for sterilizer has a history of several decades [4]. UVC light, with a wavelength of 100-280 nm, inactivates a broad spectrum of microorganisms, including viruses, bacteria, protozoa, fungi, yeast, and algae, by forming pyrimidine dimers—photoproducts of genetic material—that block DNA and RNA replication [5, 6]. However, traditional UV irradiation technology uses a wavelength of 254 nm, which has drawbacks such as the use of toxic mercury, large device size, and ozone production [7]. In contrast, UV-C LEDs emitting at 275 nm are smaller in size, offer higher optical output, eliminate the risk of mercury pollution [8], and have a longer lifespan, up to 25,000 hours, which is 2 to 25 times longer than that of 254 nm mercury vapor lamps [9, 10]. This study focuses on the sterilizer efficacy of air sterilizers using UV-C LED technology for indoor air purification, while also monitoring the removal of specific odors that affect human health, well-being, and comfort. The research fully demonstrates the significant potential of UV-C LED technology in controlling and preventing airborne infections, while addressing the gap in air freshness improvement for such devices.

2. MATERIALS AND METHODS

2.1 MATERIALS

The equipment used in this study is MassPhoton's Q6060-D UV-C air sterilizer, independently developed and produced by MASSPHOTON. Natural air enters the device through the small hole in the center of the front cover under the power of the fan. As the air passes through the HEPA filter, particles in the air are adsorbed onto it, which constitutes the first step of purification. The filtered air then enters the UV-C LED module, where it is exposed to ultraviolet light for sterilizer, representing the second step of sterilization. The sterilized air then reaches the photocatalyst module, where the photocatalyst is activated by visible light, generating a photocatalytic reaction that removes odor molecules from the air, which is the third step of odor elimination. After undergoing these three processes—purification, sterilization, and odor elimination—the fresh air is released into the room through the pores around the front cover of the device along the air duct. Figure 1 shows the exploded view of the product.

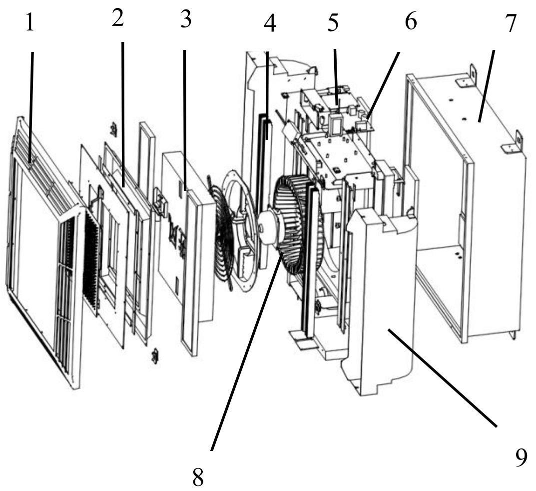


Figure 1 MassPhoton's Q6060-D UV-C air sterilizer unit used in this study: 1 -front cover , 2 – lighting panel - high UV reflective air duct,3 –HEPA fan mount, 4 -UV-C LED, 5 –Control module, 6 – photocatalyst, 7 - back cover, 8 –Fan module， 9 - Ventilation duct.

2.2 METHODS

The sampling method and calculation formula refer to Appendix D of GB28235 - "Hygienic requirements for ultraviolet appliance of disinfection" for sampling. This method is issued by the State Administration for Market Regulation and the Standardization Administration of the People's Republic of China, serving as the national standard of the People's Republic of China, and is more professional and scientific.

3. RESULTS AND DISCUSSIONS

3.1 Sterilization rate

A MassPhoton's Q6060-D UV-C air sterilizer was installed on the ceiling of a basement level 1 meeting room in a Hong Kong shopping mall to test its natural bacteria elimination rate. The meeting room is used from Monday to Friday, 8:30 am to 11:30 am, by mall office employees.To establish a control group, the airborne bacterial colony count was measured after three days of non-operation. The experimental group data was collected after three consecutive days of operation. Sampling was conducted both before and after meetings to compare the sterilizer effectiveness of the device during continuous room usage.The results showed an average elimination rate of 59.5% before the morning meeting (8:30 am) and 63.7% after continuous use throughout the morning (11:30 am). This indicates an average elimination rate of 61.6% during meeting hours with the device in continuous operation (as shown in Table 1).

Table 1 MassPhoton’s Q6060-D UV-C air sterilizer in conference room.

Time	8:30 AM	11:30 AM
sterilizer rate	59.5%	63.7%
Average sterilizer rate	61.6%	

As shown in figure 2, depicting the culture medium, clearly shows a significant reduction in natural airborne bacteria after MassPhoton’s Q6060-D UV-C air sterilizer turn on. This demonstrates the device's effectiveness in reducing the risk of disease transmission in crowded environments.

a. (-) UV

b. (+) UV

Figure 2 Example of petri-dish results comparing when air sterilizer is OFF and after MassPhoton's Q6060-D UV-C air sterilizerr is ON.

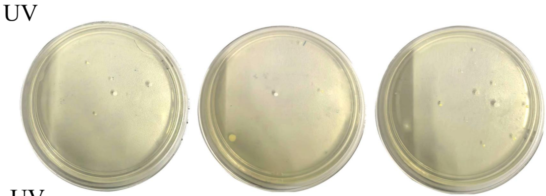
An evaluation was conducted on the disinfection efficacy of the MassPhoton 06060-D UV-C air sanitizer against ambient airborne bacteria in a refuse room located on the second floor of a Hong Kong shopping mall. Considering the non-fixed occupancy pattern of the space , the baseline airborne bacterial colony count was collected before r MassPhoton’s Q6060-D UV-C air sterilizerr is turn on as the control group. After 3 hours of operation, the airborne bacterial colony count was measured again as the experimental group. Airborne bacteria levels were sampled before and after device operation for 5 consecutive days, with the results indicating an average bacterial reduction rate of 70.8% (Table 2).

Table 2 sterilizer rate Garbage room.

Time	Day 1	Day 2	Day 3	Day 4	Day 5	Average sterilization rate
sterilizer rate	81.8%	71.2%	71.8%	60.0%	69.2%	70.8%

As shown in figure 3, showing the bacterial colonies in the culture dish, also indicates a significant reduction in the number of natural bacteria after the device was operated, effectively controlling the growth of natural bacteria in the garbage room and reducing the risk of disease infection for personnel when discarding garbage.

a. (-) UV



b. (+) UV

Figure 3. Example of petri-dish results comparing when air sterilizer is OFF and after MassPhoton’s Q6060-D UV-C air sterilizer is ON.

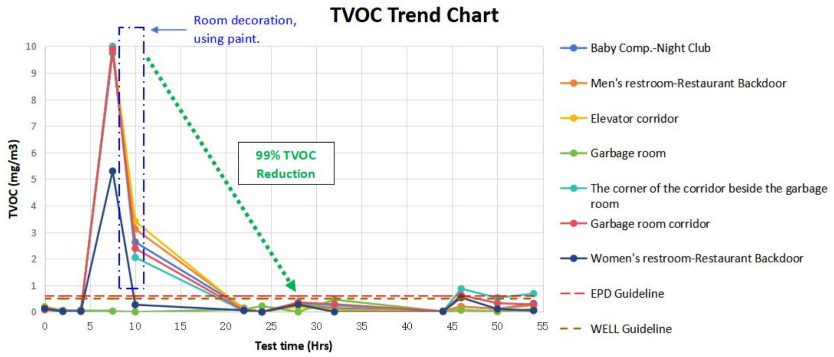
3.2 Odor Removal Experiment

Choose a corridor and the ceiling above the garbage room on the third floor of a shopping mall in Hong Kong to install 8 MASSPHOTON air sterilizers to test the effectiveness of odor removal. The corridor is connected to multiple scenarios, including a bar, kitchen back door, restroom, and maternity store. After turning on the devices, continuous measurements were taken for three days to observe and analyze the changes in the test data. The air sterilizers were turned on at 8:00 AM, which was recorded as 0h, and the time was accumulated thereafter.

As shown in Figure 3a, a rented shop began renovation 7 hours after the air sterilizers were activated. Before the renovation, the measured TVOC levels were normal and showed a decreasing trend. However, after the renovation started, the TVOC levels rose from 0.01 mg/m³ to 10.0 mg/m³, and a strong paint smell was detected in the air. After 10 hours of operation, the TVOC concentration was measured again and found to have decreased to 3.53 mg/m³, with the paint smell significantly reduced.

Three points were selected to test the PM2.5 concentration: the entrance of the bar and maternity store, the men's restroom and kitchen back door, and the corridor. It was found that before work hours, the PM2.5 concentration could be maintained below 15 µg/m³. However, as the number of people increased, the PM2.5 concentration showed a slight upward trend, but the operation of the air sterilizers helped maintain and initially reduce the PM2.5 levels. Additionally, it was observed that the use of paint during the renovation had almost no impact on PM2.5 levels (as shown in Figure 3b).

a



b

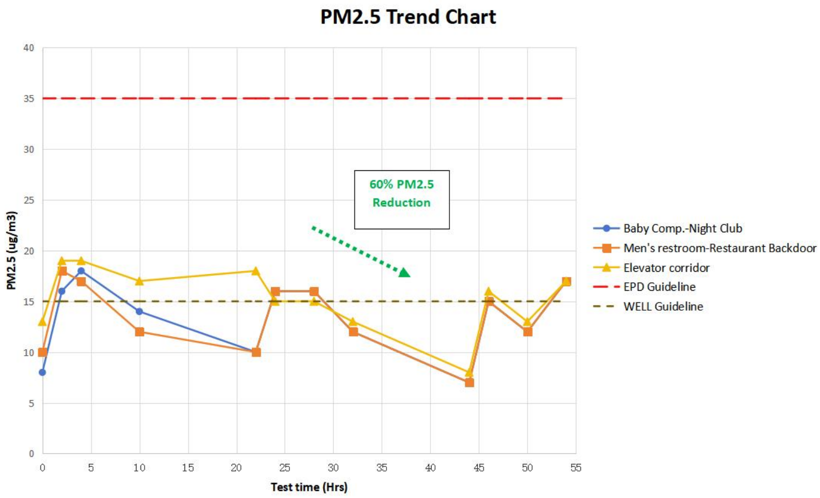


Figure 4. Removal of TVOC and PM2.5 by MASSPHOTON Air sterilizer Machine.

From the test results, it can be seen that the overall TVOC concentration and PM2.5 particulate matter concentration in the environment are within the guidelines set by the HK EPD and WELL standards. However, the use of the MASSPHOTON air sterilizer machine can effectively remove harmful gases and particulate matter from the air, maintaining indoor air quality and providing a more suitable working and shopping environment for office workers and shoppers.

3.3 Testing for Ammonia in Cigarette

In a closed room with a volume of 112 m³ within the factory premises, a MASSPHOTON air sterilizer machine was installed on the ceiling to test its effectiveness in removing PM2.5, formaldehyde, and TVOC after burning 4 cigarettes, as well as its ability to remove ammonia after evaporating 20 ml of 10% ammonia solution for 30 minutes.

Four cigarettes were simultaneously lit inside the room. After they completely burned out, the initial concentrations of PM2.5, formaldehyde, and TVOC were measured using a handheld formaldehyde concentration detector, with values of 3.6 μg/m³, 0.12 ppm, and 0.15 mg/m³, respectively. The air sterilizer machine was then turned on and operated continuously for 4 hours. After this period, the concentrations were measured again, showing that PM2.5 had decreased to 14 μg/m³, formaldehyde to 0.01 ppm, and TVOC to 0.01 mg/m³. The removal rates were 61.10% for PM2.5, 87.50% for formaldehyde, and 98.20% for TVOC, effectively reducing the levels of harmful gases and particulate matter in the enclosed space (as shown in Table 3).

Table 3 Removal of Cigarette Odor by MassPhoton's Q6060-D UV-C air sterilizer Machine.

	Time(h)	Measurement value	Removal rate
PM2.5 (ug/m³)	0h	36	61.10%
	4h	14	
HCHO (ppm)	0h	0.12	87.50%
	4h	0.01	
TVOC (mg/m³)	0h	0.15	98.20%
	4h	0.01	

Using ammonia gas to simulate the odor in a restroom, 20 ml of 10% ammonia solution was placed into two Φ90 × 18 mm petri dishes. The dishes were left uncovered to allow natural evaporation for 30 minutes, and the initial concentration of NH_3 was measured using a portable NH_3 gas detector as the control group. The air sterilizer machine was then turned on, and the indoor ammonia concentration was tested every 10 minutes. After running the air sterilizer machine for 90 minutes, the ammonia concentration decreased from 4.5 ppm to 0.2 ppm, resulting in an ammonia removal rate of 95.5% (as shown in Table 4).

Table 4 Ammonia Removal by MassPhoton's Q6060-D UV-C air sterilizerr

	Time(min)	Measurement value	Removal rate
NH_3(ppm)	0	4.5	99.9%
	30	0.7	
	60	0.2	
	90	0.0	

In addition to the visually observable data mentioned above, we also tested the MassPhoton's Q6060-D UV-C air sterilizer for its ability to remove strong odors such as fishy smells and leftover food odors. These intense odors were completely eliminated within 2 hours in a closed room of 112 cubic meters. The internal test results fully demonstrate that the MASSPHOTON air purifier can effectively remove indoor living odors, making it suitable for use in restaurants, homes, public restrooms, and other similar environments.

4. CONCLUSIONS

The MassPhoton's Q6060-D UV-C air sterilizer utilizes solid-state semiconductor technology [11] to emit UV-C LED light with a single wavelength of 260-280 nm. Preliminary experiments have shown that this wavelength range does not produce ozone, nor does it result in ultraviolet light leakage [12]. This technology is more environmentally friendly, has a longer lifespan, and consumes less energy [7, 13]. Building on the foundation of maintaining a high sterilizer rate for natural bacteria, the 2.0 version adds a photocatalytic module and a High-Efficiency Particulate Air (HEPA) filter. When exposed to visible light or ultraviolet light [13], the photocatalytic module activates a photocatalytic reaction on the surface of TiO_2, generating reactive oxygen species (ROS) such as hydroxyl radicals (OH-) and superoxide radicals (O^{2-}) [13]. These ROS possess strong oxidizing capabilities and can decompose organic compounds, thereby effectively removing and breaking down odorous substances [12]. The HEPA filter is composed of extremely fine interwoven fibers with very small gaps between them, enabling it to effectively capture tiny particulate pollutants in the air. This helps remove fine particulate matter, improve indoor air quality [14], and prevent the spread of diseases.

The MassPhoton's Q6060-D UV-C air sterilizer features mercury-free, ozone-free, and ultraviolet leakage-free operation, along with compact and intelligent design. It allows for human-machine coexistence, efficiently eliminates odors, and includes an IoT module that enables real-time monitoring of indoor air quality via a mobile app. It is an excellent assistant for improving quality of life in environments such as homes, shopping malls, and offices. In the future, further validation of the MassPhoton's Q6060-D UV-C air sterilizer's efficacy in specialized environments such as hospitals can be explored.

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