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Disinfection Equipment and Technology for Clean Bathrooms

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This research presents the design and construction of disinfection equipment for toilets because there is a risk of easily becoming infected with various diseases when using toilets since it is a humid area, germs can accumulate and grow very well especially public restrooms where there are a lot of people using and some of them may be sick with infectious diseases that can spread. This can clearly be seen during the recent COVID-19 epidemic, where most toilets cleaning solutions cannot be done in a short period of time and cannot eliminate germs. It all causes inconvenience and lacks user confidence. Therefore, this research has chosen to use fluorescent lamps that create UV rays at a length of 254 nanometers and are effective in killing germs to be installed in the toilets in the appropriate position in order to kill germs after using the toilets. In addition, a system has been designed and installed to protect against harmful UV rays while disinfecting to ensure the safety of users.The experiment was set up in a toilet measuring 0.95 x 1.5 x 2.0 meters. E.coli bacteria (E.coli OD 0.05, wavelength 600 nm) were used as the pathogen for testing by placing E. coli bacteria in the culture tray in 4 places that are most frequently touched while in use: the area where the toilet is flushed, the bidet hose, and the toilet seat and the door latch. The duration of the sterilization experiment was 3, 5, 10, 20, and 40 minutes. Results of testing of disinfection efficiency according to the proposed principles was able to kill all E.coli bacteria in every location from 10 minutes or more. From the results of the experiment, it can be seen that the toilet disinfection equipment can effectively kill germs. This will reduce the chance of contracting germs from using the toilets.

Keywords: Disinfection equipment, Technology for clean bathroom, UVC.

1. Introduction

In human daily routines, it is inevitable to use the bathroom due to the body's waste disposal process. However, using the bathroom, especially a public bathroom, can cause various infections if there is contact with surfaces or sanitary ware that are latently contaminated with germs, such as the toilet flusher, bidet hose, toilet seat, and bathroom door latch. In 2012, Best et al. published an article about flushing the toilet without closing the cover, which found that it increases the risk of spreading Clostridium difficile bacteria and causes microorganisms to spread in the air around the bathroom (Public Health Science Research Institute, 2019). In addition, the bathroom is an area with high humidity and is also an area used for excreting waste and cleaning the body. This causes the accumulation and growth of germs more easily. In the same year, Watutantrige et al. found that bacteria on the hands of medical students increased after using the bathroom, especially the dominant hand (Kitja Jitphirom et al., 2014). These germs in the bathroom can cause various diseases, such as Faecal Coliform bacteria, which can cause diarrhea, loose stools, urinary tract and respiratory tract infections (Nithiya Rattanapanon and Phimphen Phonchalempong, 2015). Clostridium difficile bacteria can cause diarrhea and enteritis (Nantarat Sonprasan, 2021). Staphylococcus aureus can cause skin diseases or food poisoning (Faculty of Pharmacy. Department of Microbiology, 2015). Since these germs can live in the environment for a long time, if the bathroom is not cleaned regularly, these germs can spread widely and be dangerous to bathroom users. Therefore, this research presents the design and creation of disinfection equipment in the bathroom. It uses fluorescent lamps to create UV-C rays at a length of 254 nanometers, along with a UV-C radiation protection system while sterilizing for the safety of users. This device will reduce the chance of infection from using the bathroom.

In recent years, maintaining high hygiene standards in public and private restrooms has gained significant attention due to rising concerns about infectious diseases. Bathrooms are often breeding grounds for bacteria, viruses, and other pathogens that thrive in moist and enclosed environments. Effective disinfection methods are essential to mitigate the risks of spreading infections through bathroom surfaces. Traditional cleaning methods often rely on chemical disinfectants, which may leave residues and pose health hazards with prolonged exposure. Moreover, many pathogens have shown resilience against standard cleaning practices. This has driven interest in alternative, chemical-free disinfection solutions, such as ultraviolet (UV-C) light, which can destroy microorganisms by disrupting their DNA and RNA. UV-C disinfection at a wavelength of 254 nanometers has proven to be effective in deactivating bacteria and viruses, making it a promising solution for bathroom sanitation.

This study aims to design and develop a UV-C disinfection device for bathrooms. By incorporating fluorescent lamps that emit UV-C light at an optimal wavelength, the device is expected to effectively reduce the microbial load on surfaces within a short time. Additionally, implementing a UV protection system will ensure that the device operates safely, preventing accidental exposure to UV-C radiation. By focusing on these objectives, this study addresses the need for a safe, efficient, and easy-to-use disinfection method that minimizes the risk of infection following bathroom use.

Bathrooms are commonly used spaces that harbor a wide range of pathogens, including bacteria, viruses, and fungi, which can be easily transmitted through contact with contaminated surfaces. Traditional disinfection methods rely heavily on chemical cleaning agents, which can leave behind harmful residues and require frequent application. These methods may not be fully effective in eliminating all microorganisms, especially those that develop resistance over time. Additionally, manual cleaning poses practical challenges, as it may be inconsistent and time-consuming, leading to gaps in sanitation coverage. This inadequacy of current methods raises the need for a reliable, non-chemical disinfection solution that can offer consistent and effective microbial control in bathroom settings.

The study aims to address the problem by developing a UV-C disinfection device specifically designed for bathroom environments. UV-C radiation at a wavelength of 254 nanometers has been shown to deactivate a wide range of pathogens effectively; however, it must be applied correctly and safely due to its potential health hazards. Therefore, this research seeks to design a UV-C device that is both effective in reducing microbial contamination and equipped with protective features to prevent accidental exposure.

Despite the proven effectiveness of UV-C disinfection technology, limited studies have focused on its application in bathroom settings, where the need for frequent and effective disinfection is critical. Existing studies primarily explore UV-C technology in medical, laboratory, and food processing environments, with less emphasis on small-scale, user-friendly solutions suitable for household or public bathroom use. Moreover, while there is ample research on UV-C disinfection, there is a lack of studies addressing safe operational mechanisms that protect users from accidental exposure, particularly in devices designed for regular bathroom environments.

To fill this gap, this study focuses on developing a UV-C disinfection device specifically for bathrooms, incorporating a safety mechanism to protect users from direct UV exposure. By addressing these aspects, this research aims to contribute a novel solution that not only enhances bathroom hygiene but also ensures user safety through a tailored UV protection system. The study's findings could lay the groundwork for further research on accessible, effective disinfection devices for various public and private spaces.

2. Objectives

1. To design and construct a bathroom disinfection device using fluorescent lamps that generate UV-C radiation at a wavelength of 254 nanometers.

2. To design a UV protection system that is suitable for disinfecting the bathroom.

3. To reduce the risk of infection after using the bathroom.

3. Literature Review

Designing and constructing a bathroom disinfection device using ultraviolet (UV) technology, particularly UV-C lamps at a wavelength of 254 nanometers, is a compelling approach to enhancing public health. UV-C radiation is known for its germicidal effects, which have been widely documented in sterilization and infection control research. This literature review examines the efficacy of UV-C disinfection in various environments, discusses design considerations for UV-C devices in bathrooms, and explores the safety measures necessary to prevent accidental UV-C exposure, highlighting the relevance of UV protection systems in such devices.

UV-C Disinfection Mechanism and Efficacy

Ultraviolet light, particularly the UV-C spectrum (200-280 nm), is highly effective in deactivating microorganisms by disrupting their DNA and RNA, rendering them incapable of reproduction and thus non-infectious. The peak germicidal effectiveness is found around 254 nm, which has been established as a standard for disinfection purposes in various industries, including healthcare, food processing, and public sanitation (Kowalski, 2009). Studies by Malayeri et al. (2016) have shown that UV-C at 254 nm can eliminate up to 99.99% of common pathogens such as E. coli, Staphylococcus aureus, and even certain viruses in controlled settings.

In bathrooms, where surfaces frequently harbor pathogens due to humidity and regular human use, UV-C can effectively reduce microbial loads when applied at an adequate dosage (Akgün et al., 2020). UV-C disinfection systems have been used in hospital settings to reduce hospital-acquired infections (HAIs), which indicates the potential efficacy of similar systems in public or shared bathroom spaces (Rutala & Weber, 2019). The high-contact surfaces in bathrooms, such as door handles, sinks, and toilet seats, are particularly well-suited to UV-C disinfection due to their consistent exposure to potentially harmful bacteria and viruses.

Considerations for UV-C Lamp Design in Bathroom Disinfection

The design of a UV-C disinfection device for bathrooms requires careful consideration of several factors, including dosage, lamp placement, exposure time, and surface material compatibility. Dosage, measured in mJ/cm^2, is crucial in determining the effectiveness of UV-C in achieving significant microbial reduction. According to Kowalski (2009), the required dose for achieving a 3-log (99.9%) reduction varies depending on the microorganism but generally ranges from 10 to 100 mJ/cm^2 for most pathogens. Therefore, UV-C lamps need to be selected and positioned to ensure sufficient irradiance across all critical surfaces.

Lamp placement is another key design factor, as it affects the reach and intensity of UV-C radiation. Ideally, UV-C lamps should be positioned to cover high-touch and horizontal surfaces without leaving significant shadowed areas, as shadows prevent UV-C light from effectively reaching and disinfecting these zones. Automated rotational or oscillating UV-C systems may enhance disinfection by ensuring comprehensive coverage. Studies by Nerandzic et al. (2015) emphasize the importance of optimizing lamp placement, as improper positioning can lead to areas with suboptimal disinfection levels, thus leaving some pathogens active.

The exposure time of UV-C radiation is equally significant, with typical disinfection processes requiring anywhere from a few seconds to several minutes, depending on dosage and lamp power. However, prolonged exposure could lead to material degradation, especially for plastics and certain polymers commonly found in bathrooms. Research by Murdoch et al. (2012) highlights that frequent UV-C exposure can cause yellowing, brittleness, and reduced structural integrity in some materials. Thus, understanding material compatibility is essential for the design of durable and effective UV-C bathroom disinfection devices.

Safety and UV Protection Systems

While UV-C is effective in inactivating pathogens, it poses health risks if humans are directly exposed to it. UV-C radiation can cause skin burns and eye damage, with symptoms of UV-induced erythema and photokeratitis (CIE, 2010). Therefore, implementing robust safety measures is crucial to prevent accidental exposure, particularly in a bathroom setting where users may inadvertently come into contact with active UV-C radiation. Various approaches to UV-C protection can be integrated into bathroom disinfection systems. One effective method is to install motion sensors or door sensors that deactivate the UV-C lamps when motion is detected within a specific radius, ensuring that the device only operates when the bathroom is vacant. Studies by Setlow and Carrier (2021) suggest that sensor-based control systems are highly effective in public and shared spaces, as they allow for automated disinfection cycles without risking human exposure. Additionally, lock-in systems that prevent access during disinfection cycles can be incorporated to enhance safety.

Reflective shields or barriers are another design feature that can minimize unintended exposure. Reflective materials can be strategically placed to focus UV-C light on targeted surfaces while preventing leakage into unintended areas. Research by Bintsis et al. (2000) indicates that aluminum or other metallic reflectors can be used to direct UV-C radiation, improving the device’s efficiency and reducing unnecessary exposure. Alternatively, enclosures with interlocking systems could serve as a physical barrier between the user and the UV-C source. UV-transparent materials, such as quartz, may also be used for protective shielding, as they allow UV-C light to penetrate for disinfection purposes while reducing the risk of scattered radiation. These measures align with guidelines from safety organizations, such as the American Conference of Governmental Industrial Hygienists (ACGIH), which recommend limiting direct UV-C exposure to reduce health risks.

Infection Control Benefits and Limitations

Deploying UV-C disinfection in bathrooms can significantly reduce microbial contamination, thereby lowering the risk of infection transmission among users. A meta-analysis by Simmons et al. (2017) found that UV-C systems effectively reduce bacterial and viral loads in various public spaces, which supports the applicability of this technology for bathrooms. By addressing high-contact areas with UV-C, the device can serve as a non-chemical, environmentally friendly solution to maintaining hygiene, especially in high-traffic locations. However, UV-C disinfection has limitations that warrant consideration. For instance, UV-C does not have a residual effect, meaning that once the lamp is turned off, surfaces can quickly become re-contaminated through subsequent use (McDevitt et al., 2012). Therefore, while UV-C is effective as a supplementary measure, it may not entirely replace traditional cleaning methods that offer some level of residue-based antimicrobial protection. Additionally, certain types of pathogens, such as spores from Clostridium difficile, require higher doses of UV-C for inactivation, which may be challenging to achieve within short exposure cycles.

The integration of UV-C disinfection devices in bathrooms offers a promising approach to infection control, providing a rapid, chemical-free method for reducing microbial contamination. A well-designed device would optimize UV-C lamp placement, dosage, and exposure time to maximize coverage across high-contact surfaces. Furthermore, implementing UV protection systems, such as motion sensors, reflective barriers, and interlocking mechanisms, is essential for ensuring user safety. While UV-C disinfection can significantly reduce the risk of infection after bathroom use, it should be considered a complementary measure alongside regular cleaning protocols for optimal effectiveness.

This literature review suggests that continued research into the durability of materials under UV-C exposure, as well as advancements in UV-C safety mechanisms, can further enhance the viability of these devices for widespread use in public sanitation. By leveraging UV-C technology in bathroom disinfection, facilities can achieve higher standards of hygiene, ultimately contributing to public health and safety.

4. Materials and Methods

1. Design and construction of bathroom sterilization equipment

Bathroom sterilization equipment has various components and installation locations as shown in Figure 1. The details of the components are as follows:

Figure 1: Components of bathroom disinfection equipment and installation location.

1.1 UV-C tube box is a box designed for installing 4 fluorescent tubes that produce UV-C rays at a wavelength of 254 nanometers, with a power of 20 watts. The front of the box has a cover that can be opened/closed for user safety. When using the bathroom or the bathroom door is open, the front cover will be closed so that the tubes are not visible. The cover will only open when the tubes are working while disinfecting.

1.2 The status light box in front of the bathroom is a box used to show the status of the bathroom, including vacant, ready for use, vacant, or in the process of cleaning.

1.3 The Infrared Proximity Sensor box checks whether there are users in the bathroom.

1.4 The door latch box locks the bathroom door while disinfecting to prevent danger and provides an audible alert. In addition, the door latch box also checks the opening/closing of the bathroom door.

1.5 The door latch socket box works together with the door latch box to lock the door and check the opening/closing of the bathroom door.

2. Working principle and circuit design used in the bathroom disinfection device

The operation of the bathroom disinfection device is divided into 3 states, and the operation diagram is shown in Figure 2.

2.1 The bathroom is ready to use state

In this state, the door will not be locked, the buzzer will not sound a warning sound, the indicator light in front of the bathroom will be green to show the user that the bathroom is ready to use. For the display on the mobile application, the message "Bathroom is ready to use" will be displayed.

2.2 The bathroom is in use state

In this state, the bathroom door is opened. The Infrared Proximity Sensor device will check if there is a user in the bathroom. If there is no user in the bathroom, the system will not notify. The door is open but there is no user may be because the bathroom door is pushed or blown by the wind. However, if there is a user, the system will sound a warning sound for the bathroom user to lock the door via the buzzer. The indicator light in front of the bathroom will remain green. The mobile application will display the message "Please lock the door". However, if the bathroom user has already locked the door, the indicator light in front of the bathroom will be off to show from the outside that there is currently a user in the bathroom. The mobile application will display the message “The bathroom is currently in use.” When the user finishes their business and unlocks the door, the Infrared Proximity Sensor will check whether the bathroom user has left the bathroom. If not, the buzzer will sound to alert the user to leave the bathroom. When the user leaves the bathroom, the door will be automatically locked.

2.3 Sterilization status

After the door is automatically locked, the indicator light in front of the bathroom will remain red. The mobile application will display the message “Sterilization in progress.” Then, the UV-C tube box will open the front cover and all 4 UV-C tubes will be on for the specified time. When the time is up, all 4 UV-C tubes will turn off. The front cover will be closed. The bathroom door will be automatically unlocked. The indicator light in front of the bathroom will be green to indicate to the user that the bathroom is ready for use. The display on the mobile application will display the message “Bathroom ready for use” or enter the ready-to-use bathroom status again.

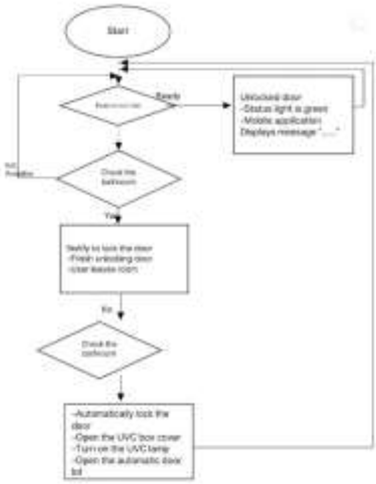

Figure 2: shows a schematic diagram of the bathroom disinfection equipment.

3. Design and create an application to test and install a bathroom disinfectant device.

The design and creation of an application to test and install a bathroom disinfectant device uses MIT App Inventor to design the display screen on the application. The components are shown in Figure 3 and Table 1.

Figure 3: Components of the display screen on the application

Table 1: Components of the application display screen

No.	Component
1	Bluetooth connection button
2	Bathroom sterilizer operation status bar
3	Bathroom sterilizer operation control button bar

4. Experimental design to test the disinfection efficiency of the bathroom disinfectant

The equipment used to test the disinfection efficiency of the bathroom disinfectant consisted of 75 Petri dishes, culture media, E. coli with OD value of 0.05 at 600 nm, the bathroom disinfectant designed according to the proposed principle, and the incubator.

The locations used to test the disinfection efficiency of the bathroom disinfectant were selected from the locations with the most contact during use, as shown in Figure 4 and Table2

Figure 4: Location used to test the efficiency of disinfection of bathroom disinfectant equipment.

Table 2: Location used to test the disinfection efficiency of bathroom disinfectant devices.

No.	Testing Position
1	Toilet flusher and bidet
2	Toilet seat
3	Toilet floor
4	Bathroom door latch

The disinfection efficiency test of bathroom disinfection equipment has the following steps:

1. Prepare the culture medium and put it in 25 Petri dishes.

2. Place 4 Petri dishes with the culture medium in 4 test positions, 1 in each position, for 30 minutes, and then put it in an incubator at 37 degrees Celsius for 24 hours to test whether the bathroom is contaminated with germs when the disinfection equipment is not in use.

3. Put E. coli with an OD value of 0.05 at 600 nm in a Petri dish with 1 culture medium and put it in the incubator. At a temperature of 37 degrees Celsius for 24 hours to be used as a comparison between the Petri dishes that were not exposed to UV-C light and the Petri dishes that were exposed to UV-C light.

4. Put E. coli with an OD value of 0.05 at 600 nanometers in 4 Petri dishes with culture media and place them in the 4 test positions, 1 tray per position. Then turn on the disinfection device in the bathroom to disinfect for 10 minutes. Then place the Petri dishes in an incubator at a temperature of 37 degrees Celsius for 24 hours.

5. Repeat the experiment in step 4, but turn on the disinfection device in the bathroom to disinfect for 5 minutes, 10 minutes, 20 minutes, and 40 minutes, respectively.

6. Repeat the experiment in steps 1-5 2 times and observe and record the results. If after disinfection and placing the Petri dishes in the incubator at a temperature of 37 degrees Celsius for 24 hours, E. coli in the Petri dishes is less than or equal to 10 percent of the total area of the Petri dishes, Therefore, it is considered that the bathroom disinfectant can kill germs.

Results of the disinfection efficiency test of bathroom disinfectant devices

In testing the efficiency of killing E. coli, the OD value of 0.05 at 600 nanometers of the bathroom disinfectant device was tested in a bathroom measuring 0.95x1.0x2.0 meters in 4 locations, by disinfecting for 3, 5, 10, 20 and 40 minutes, and then placing the Petri dish in an incubator at 37 degrees Celsius for 24 hours, as shown in Figures 5 to 10. The results of the E. coli disinfection efficiency test are shown in Table 3

Figure 5: shows a Petri dish containing E. coli with an OD of 0.05 at 600 nm.

Figure 6: shows a Petri dish sterilized with four bathroom sterilizers at 3 min.

Figure 7: shows a Petri dish sterilized with four bathroom disinfectant stations at 5 min.

Figure 8: shows a Petri dish sterilized with four bathroom disinfectant stations at 10 min.

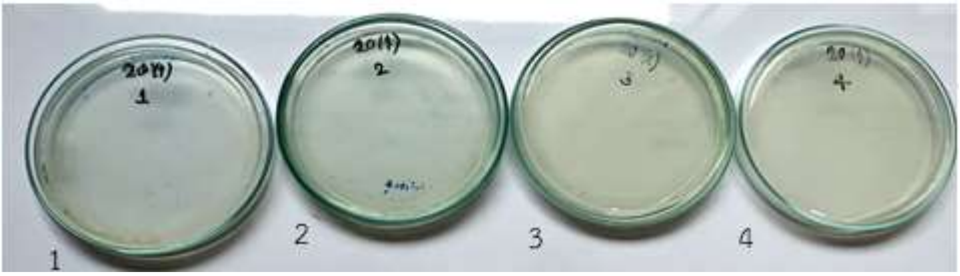

Figure 9: shows a Petri dish sterilized with four bathroom sterilizers at 20 min.

Figure 10: shows a Petri dish sterilized with four bathroom sterilizers at 40 min.

Table 3. Results of the E. coli sterilization efficiency test with OD value of 0.05 at 600 nm of the bathroom disinfectant device.

Position	Disinfected Period														
	3 Min			5 Min			10 Min			20 Min			40 Min		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
2	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
3	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
4	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Remark: N means that the bathroom disinfectant cannot kill E. coli.

Y means that the bathroom disinfectant can kill E. coli.

5. Discussion

From Figure 6, it was found that the results of the sterilization of E. coli (OD) value of 0.05 at 600 nanometers of the disinfectant in the bathroom for 3 minutes, 3 times, it was found that the disinfectant in the bathroom was able to kill E. coli (E. coli) all 3 times at position 1, but could not kill E. coli (E. coli) all 3 times at position 2, position 3, and position 4, indicating that the disinfectant in the bathroom could not kill E. coli (E. coli) with OD value of 0.05 at 600 nanometers in all tested positions at 3 minutes.

From Figure 7, it was found that the results of the sterilization of E. coli (OD) value of 0.05 at 600 nanometers of the disinfectant In the bathroom for 5 minutes, 3 times, it was found that the disinfectant in the bathroom was able to kill E. coli at position 1, 1st time and 3rd time, but could not kill E. coli at position 1, 2nd time, could kill E. coli at all 3 times at position 2, and could not kill E. coli at all 3 times at position 3 and 4, indicating that the disinfectant in the bathroom could not kill E. coli at OD value of 0.05 at 600 nm at all positions tested at 5 minutes.

From Figure 8, it was found that the results of killing E. coli at OD value of 0.05 at 600 nm of the disinfectant in the bathroom for 10 minutes, 3 times, it was found that the disinfectant in the bathroom was able to kill E. coli at all 3 times at position 1, position 2, position 3 and position 4. This shows that the bathroom disinfectant can kill E. coli with an OD value of 0.05 at 600 nanometers in all tested locations at 10 minutes.

From Figure 9, it is found that the results of killing E. coli with an OD value of 0.05 at 600 nanometers of the bathroom disinfectant for 20 minutes, 3 times, it is found that the bathroom disinfectant can kill E. coli all 3 times at location 1, location 2, location 3, and location 4, it is shown that the bathroom disinfectant can kill E. coli with an OD value of 0.05 at 600 nanometers in all tested locations at 20 minutes.

From Figure 10, it is found that the results of killing E. coli with an OD value of 0.05 at 600 nanometers of the bathroom disinfectant for 40 minutes, 3 times, it is found that the bathroom disinfectant can kill E. coli all 3 times at location 1. Position 2, Position 3 and Position 4 indicate that the bathroom disinfectant can kill E. coli with OD value of 0.05 at 600 nm at all tested positions at 40 minutes.

From the test results of the E. coli killing efficiency with OD value of 0.05 at 600 nm of the bathroom disinfectant, it was found that the bathroom disinfectant can kill E. coli with OD value of 0.05 at 600 nm at all tested positions at 10, 20 and 40 minutes.

6. Recommendations for applying research results

1. Use a sterilizing device with a closed bathroom to prevent UV-C light from passing through to the outside of the bathroom, or design a device to prevent UV-C light from passing through to the outside of the bathroom.

2. Increase the intensity of UV-C light used in the sterilizing device and/or increase the number of UV-C bulbs used to reduce the time required for sterilization.

3. Choose a strong material to make the sterilizing device to achieve the desired opening angle for the UV-C bulb box.

4. Use a method to open and close the UV-C bulb box that makes the sterilizing device smaller.

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