UV-C TECHNOLOGY TO SUPPORT AIR QUALITY FOR SAFETY WORK AND SECURITY FROM BIOLOGICAL AGENT THREATS

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Abstract: The UV-C-based air disinfection device is the equipment used for air disinfection whose working principle uses UV-C radiation to inactivate microorganisms. This study aimed to determine the effectiveness of UV-C devices for disinfection in the indoor air at the workspace and the safety of humans in the room from being exposed to UV-C radiation when the disinfectant is operating. The research used quantitative methods through laboratory experiments. The working principle of the UV-C device is to circulate air in the room through a chamber equipped with a UV-C radiation source from an electric lamp with a wavelength of 254 nm. Laboratory tests were carried out with the Total Plate Count (TPC) parameter to determine its effectiveness by measuring the number of conditions before and after treatment. The average effectiveness value at 30 minutes was 64.14% and at 60 minutes it was 86.26%, so the effect increased with time. In terms of the dangers of UV-C radiation, UV-C devices are safe to use with designs and engineering that can prevent or minimize UV-C radiation outside the device. The radiation in human skin is not beyond the specified allowed. The result of measuring UV-C radiation in the workspace was 0.000 μW/cm^2. UV-C technology can be used as a defense tool against biological agents effectively and safely.

Keywords: Air Disinfection; UV-C; Total Plate Count

Abstrak: Perangkat disinfeksi udara berbasis UV-C merupakan alat yang digunakan untuk disinfeksi udara yang prinsip kerjanya menggunakan radiasi sinar UV-C untuk menonaktifkan mikro organisme. Tujuan penelitian ini adalah menentukan efektifitas perangkat UV-C pada disinfeksi mikroorganisme di udara dalam ruang kerja dan menentukan keamanan terhadap manusia yang berada di dalam ruangan dari paparan radiasi sinar UV-C pada saat disinfektor beroperasi. Prinsip kerja perangkat UV-C adalah mensirkulasikan udara pada ruangan untuk melalui chamber yang telah dilengkapi dengan sumber radiasi UV-C yang berasal dari lampu elektrik dengan panjang gelombang 254 nm. Dilakukan uji laboratorium dengan parameter *Total Plate Count* (TPC) untuk mengetahui efektifitasnya dengan mengukur jumlah kondisi sebelum dan sesudah sehingga diperoleh nilai rata-rata efektifitas pada 30 menit adalah 64,14% dan 60 menit adalah 86,26% sehingga efektifitas naik dengan ditambahnya waktu. Perangkat UV-C dari segi bahaya radiasi UV-C aman digunakan dengan desain yang dapat mencegah/meminimalisir radiasi UV-C sehingga tidak sampai pada kulit manusia melebihi nilai ambang batas yang ditentukan. Hasil ukur radiasi UV-C di ruang kerja adalah 0,000 μW/cm^2. Teknologi UV-C dapat digunakan sebagai alat pertahanan terhadap agensia biologi dengan efektif dan aman.

Kata kunci: Disinfeksi udara; UV-C; *Total Plate Count*

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Introduction

The development of technology in the field of science and technology has a positive and negative influence on human life. The positive effect is in the form of welfare if technology is used correctly. The negative influence threatens human survival-for example, the development of biological weapons as weapons of mass destruction. Technology development will produce various products that provide solutions to meet various needs with always inseparable risk. Increasingly sophisticated technology will reduce risk to close to 0% and increase success up to 100% by creating products that provide benefits in an effective, efficient, and safe manner.

Job security is the supporting element that supports the creation of a safe working atmosphere, both material and non-material (Affifudin, 2019). Material supporting elements of security, namely: clothes, helmets, goggles, and gloves. Non-material security supporting elements, namely: manuals on the use of tools, signs and danger signals, appeals, and security officers. Occupational safety and health (K3) are one of the efforts to create a safe, healthy workplace, free from environmental pollution so that it can reduce or be free from work accidents and occupational diseases which can ultimately increase work efficiency and productivity. (Hasibuan et al., 2020).

Many pollutants are excreted with animal waste, including nutrients, pathogens, natural and synthetic hormones, veterinary antimicrobials, and heavy metals, which enter the soil, and surface water in local farmland during the storage and disposal of animal waste and groundwater. and pose direct and indirect risks to human health. The widespread use of antimicrobials in concentrated animal feed factories (CAFOs) has also contributed to the global public health problem associated with antimicrobial resistance (AMR). Efforts should be made to dispose of the large volumes of manure produced by CAFO (e.g. through biogas digesters and integrated farming systems) to minimize their impact on the environment and human health. (Hu, Y., 2017)

The workplace environment has many hazards. Hazards originating from the environment are classified into vibration, chemicals, radiation, lighting, and noise. By utilizing occupational safety and health control technology, Workers are expected that workers have high physical endurance, work power, and health (Hasibuan et al., 2020).

Air quality in a room is a significant factor that affects the degree of health of workers (Arjani, 2011). Indoor air buildings are always more polluted by human-sourced contaminants than outdoor air. The primary sources of indoor air pollutants are microbes, allergens, volatile organic compounds, pesticides, combustion products, tobacco smoke, radon, and particulates (Morey et al., 2001).

Air is an essential factor that must be protected from contamination. In a room that several humans use with various health conditions, it is very susceptible to spreading airborne pathogens. Respiratory droplets can carry microorganisms such as bacteria and viruses. The relationship between droplet size, evaporation, and fall rate was revealed in the classical study of air displacement. Droplet size and route of movement in the air, tiny droplets start to evaporate after being expelled and thereby change their size so that the droplets which are small enough remain suspended in the air for a long time and are still infectious (Wahyuni, 2018).

The COVID-19 pandemic has highlighted key knowledge gaps in our understanding and the need to update traditional views on the transmission routes of respiratory viruses. Long-standing definitions of droplets and airborne transmission have not explained the mechanism by which virus-laden respiratory droplets and aerosols spread through the air and cause infection. (Wang, 2021)

There is no consensus on the role of aerosol transmission on SARS-CoV-2. To this end, we wanted to review the evidence for aerosol transmission of SARS-CoV-2. Multiple studies support the aerosol transmission of SARS-CoV-2 as plausible, with a plausibility rating (weight of combined evidence) of 8 out of 9. Preventive control strategies should consider aerosol transmission to effectively contain SARS-CoV-2.(Tang, S. et al., 2020)

The possible virucidal effect of UV-C irradiation on SARS-CoV-2 was experimentally evaluated for different light doses and virus concentrations (1000, 5, 0.05 MOI). At virus densities comparable to SARS-CoV-2 infection, UV-C doses as low as 3.7 mJ/cm^2 were sufficient to achieve greater than 3 log inactivation without evidence of viral replication. Furthermore, complete inactivation was observed at all virus concentrations of 16.9 mJ/cm^2. (Biasin, M. et al., 2021)

Some methods are introduced, such as B. Improve ventilation, especially in hospitals and crowded places, keep the interpersonal distance more than 2m, so that indoor air quality experts think it is to improve the indoor air environment. Finally, airborne routes of transmission should be considered in addition to recommendations from centres and official authorities, such as handwashing and social distancing, to further protect health workers, patients in hospitals and the public in other public buildings. (Noorimotlagh, Z.,2021)

Airborne SARS-CoV-2 RNA levels were undetectable in most public areas except for two areas prone to aggregation; this increase may be due to SARS-CoV-2-infected individuals in the population. The study found that some areas of healthcare workers initially had high concentrations of viral RNA, with aerosol particle size distributions that peaked in the sub-micron and/or sub-micron range; however, these levels have decreased following the implementation of stringent disinfection procedures. to undetectable levels. Although we have not yet determined the infectivity of the viruses detected in these hospital areas, we suspect that SARS-CoV-2 may be transmitted by aerosols. The results show that the concentration of SARS-CoV-2 RNA in aerosols can be effectively limited by indoor ventilation, open space, disinfection of protective clothing, and proper use and disinfection of toilet areas. (Y. Liu, 2020)

Technical control support is needed to reduce the potential for the spread of pathogens indoors. Air circulation in the closed room is limited for effective temperature. This circulation restriction will of course circulate the air in the room so that if pathogens have entered the room, it will cause a more significant potential to infect humans in the room. Proper engineering control of buildings includes adequate and effective ventilation in particulate filtering and air disinfection, avoiding air recirculation, and avoiding overcrowding (Morawska et al., 2020).

Respiratory viruses can be spread by four main routes of transmission: direct (physical) contact, indirect contact (bacteria carriers), (large) droplets and (fine) aerosols. The relative contribution of each mode to the spread of a given virus in different settings, and how its variation affects transmissibility and transmission dynamics. Continue the discussion of particle size thresholds between droplets and aerosols and the importance of aerosol transmission for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and influenza viruses. Understanding the relative contributions of different modes of transmission is critical for obtaining information on the effectiveness of non-pharmaceutical interventions in populations. Intervention on multiple transmission paths should be more effective than intervention on a single transmission path. (Leung, N. H., 2021)

Occupational safety and health are some of the factors to protect workers by implementing technology to control all factors that have the potential to harm workers (Rejeki, 2016). Air disinfection in office spaces is one way to anticipate the spread of pathogens in the workspace to minimize various diseases that can attack humans in the work environment. A safe disinfection system for humans is needed so that optimal performance results are obtained with minimal side effects.

Countermeasures against the threat of biological agents need to be prepared quickly and precisely so that the impact of losses can be prevented or minimized. The key to success is to select the proper air disinfection method for handling biological agents. Disinfection using UV-C technology has been suitable means of disinfecting a surface, air, and water pathogens for decades (Kowalski, 2009). UVGI in air conditioning systems can help kill or inactivating mold (Menzies et al., 1999).

The use of UV-C aims to reduce biological agents in the air through physical processes with UV-C radiation. However, if not Appropriately designed, UV-C devices can pose a new hazard to health due to UV-C radiation. UV-C light at a wavelength of about 254 nm has properties that are harmful to health because it can cause skin cancer and eye diseases (Zaffina Salvatore et al., 2012).

The Indonesian government has issued a Regulation of the Minister of Manpower and Transmigration of the Republic of Indonesia Number Per.13/MEN/X/2011 regarding Threshold Values for Physical Factors and Chemical Factors in the Workplace to minimize hazards that Workers can accept. ISO 15858 (ISO-15858, 2016) establishes minimum human safety requirements for using UVC lighting devices applicable to indoor UVC systems, overhead UVC systems, portable indoor disinfection UVC devices, and other UVC devices that may cause UVC exposure to humans.

Ultraviolet radiation was discovered by Isaac Newton in 1672 by experimenting with the splitting of sunlight using a glass prism. In 1877, Downes and Blunt discovered that ultraviolet light can kill bacteria and discovered that blue Ultra Violet was more effective at killing germs. (Kowalski, 2009). UV has been recognized as an effective method for inactivating microorganisms (Duizer et al., 2004).

The UVGI mechanism in microorganisms is uniquely susceptible to light at wavelengths at or near 253.7 nm because the maximum absorption wavelength of DNA molecules is 260 nm (Anderson et al., 2000). After UVGI irradiation, UVGI Energy damages DNA, interfering with replication thereby rendering microorganisms inactive (Brickner et al., 2003). The effectiveness of UVGI for inactivating microorganisms is related to the strength/intensity of the irradiation. The longer the irradiation, the greater the effectiveness (Rinaldi & Anggraini, 2021). The relationship between dose, intensity, and time of administration of UV-C radiation is shown in the following equation:

$$\text{Dose UVGI (mJ/cm}^2\text{)} = \text{radiation (mW/cm}^2\text{)} \times \text{time (seconds)} \qquad (1)$$

Methods

The research was conducted using quantitative methods with data collection through laboratory experiments. The subjects in this study were colonies of *Escherichia coli, Staphylococcus aureus, and Salmonella Sp*. TPC examination was carried out quantitatively with the method of counting bacteria on a plate containing agar media. The medium used for this calculation is Plate Count Agar (PCA) and the calculation is done with a colony counter. The results of observations are presented in the form of tables and graphs using descriptive analysis. The object of this research is a disinfectant with UV-C. technology. The effectiveness of UVGI control was determined as a ratio, N_S/N_0, where N_S and N_0 are the colony concentrations collected by the Andersen, single-stage sampler at UVGI D and zero doses, respectively. (Lin & Li, 2002). The effectiveness of UV-C (E) device performance can be determined based on the number of initial conditions of bacteria and the number of final conditions using the equation (Yang et al., 2019):

$$\text{Percent reduction} = \frac{(\text{B-A})}{\text{B}} \text{ x } 100 \text{ ……………………………….. (1)}$$

Where:

B = Number of viable microorganisms.

A = Number of viable microorganisms after UV-C irradiation.

To limit the scope of the research, restrictions were held so that the research was more focused. The restrictions imposed are as follows: UVC device used in this study is AirdisinfeX with HNS 30 W UVC Lamp from OSRAM where One unit of AirdisinfeX is equal to 25 m^2 of the room area. And then, AirdisinfeX does not use any chemicals in the disinfection process.

Based on the findings that have been obtained and the existing limitations, the devices have potentially supported indoor air quality by inactivating microorganisms through the air. The characterization of microbes is still needed to look further future research. Moreover, it is also necessary to design a device combined with an air conditioner so that the air circulation process is faster, does not need to be installed separately, and is more practical.

Research Stages

The stages of the research can describe below: 1) Literature Review: compiling the literature data relevant to the research, then a data collection design is carried out; 2) Collection: input, processing, and analysis of data. Types of data consist of primary data and secondary data. Primary data collection was carried out by laboratory tests using the TPC method. Secondary data obtained from literature studies, journals, and related documents; 3) Discussion and conclusions of research results.

Location dan Time of Research

The research was conducted by laboratory tests and data collection of room air samples. Sampling was carried out on 24, 30 September, and 7 October 2021 at PT Mutuagung Lestari Depok and the Departement of Industrial Engineering of the Faculty of Engineering Universitas Indonesia (FTUI).

Data Types and Sources

The data collection carried out in this study is in the form of primary data and secondary data. Primary data were obtained from laboratory tests by conducting UV-C disinfection effectiveness tests and indoor and safety tests on UV-C devices. Secondary data is supporting data available from previous research, the internet, or sources related to research as a literature study. The data collection method is described as follows:

Test the effectiveness of disinfection in UV-C devices

The test was carried out on several types of bacteria using the TPC method with variations in radiation time: 0 seconds, 1 second, 2 seconds, 10 seconds, 1 minute, 5 minutes, and 10 minutes. This test was conducted at PT Mutuagung Lestari Depok. The placement of the test sample in the disinfectant is shown in Figure 1.

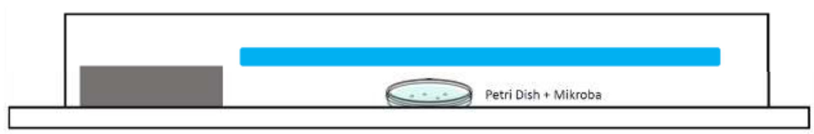

Figure 1. Test Sample Placement inside AirdisinfeX. *Source:* Author, 2021.

Determination of the number of microbes using the Microbial Test (UJI-MIK 314, Settle Plate). The way it works is as follows: a) A certain number of test bacteria in a petri dish is placed in a UV-C unit that has been made to determine the effect of radiation on the inactivation of bacteria with varying time; b) Incubation of Petri Dish was carried out for 2 x 24 hours and the total number of microbes (Total Plate Count) was counted on the 3rd day; c) The initial number of bacteria before being given radiation was measured as the initial condition (N_0) and the final number of bacteria after receiving radiation with a time variation (t) was measured as the final condition (N_t); d) The effectiveness of the UV-C device in the device (Ep) is shown by entering the values of N_0 and N_t into equation 2.

Test the effectiveness of room disinfection with a UV-C device

Tests were carried out on several office spaces at FTUI using the TPC method based on ISO: 14698-1 (ISO 14698-1, 2003). Data retrieval was carried out by varying the operating time of the UV-C device for 30 minutes and 60 minutes at different times with the radiation intensity in the device being constant At around 5.48 - 7.31 mW/cm2. The way it works is as follows: a) Determination of the number of bacteria before treatment (N_0) in the room being tested by circulating 1000 liters of air on a sterile Petri Dish using a sample device: b) Determination of the number of bacteria after treatment (N_s) in the room being tested by circulating 1000 liters of air on a sterile Petri Dish using a sample device after being treated in the room using a UV-C device; c) Incubation of Petri Dish was carried out for 2 x 24 hours and the total number of microbes (Total Plate Count) was counted on the third day; d) The initial number of bacteria before being given radiation was measured as the initial condition (N_0) and the final number of bacteria after receiving radiation with time variation (s) was measured as the final condition (N_s); e) The effectiveness of the UV-C device in the device (Ep) is shown by entering the values of N_0 and N_s into equation 2.

Safety test from UV-C radiation in workspaces that are installed with UV-C devices

This test is carried out using radiation measuring instruments and procedures following SNI 16-7060-2004 (SNI 16-7060-2004, 2004). Implementation is based on the following guidelines: a) The instrument is Calibrated correctly; b) The measurement point is at least 3 points consisting of: (1) Vision zone with a maximum distance of 30 cm from the eye; (2) Elbow height (according to the working position sitting or standing) with a maximum distance of 30 cm from the outermost part of the body; (3) Calf height with a maximum distance of 30 cm from the calf: c) The procedure for using measuring instruments is as follows: (1) Close the sensor and turn on the appliance; (2) Set the adjustment knob so that the monitor shows zero (zero adjustments); (3) Bring the instrument to the measuring point; (4) Place the sensor at each measurement point facing the ultraviolet light source; (5) Take measurements at each measurement point; (6) Read and record measurement results.

Data Processing Method

The data processing and analysis method in this study used a graph of the effectiveness of disinfection vs. radiation time using equation 2. The graph represents the data to determine the device's effectiveness.

Result And Discussion

Test the effectiveness of disinfection in UV-C devices

The microbial test results (indoor air) on September 24, 2021, at the Laboratory at PT Mutuagung Lestari Depok with disinfection times of 0, 1, 2, 10, 60, 300, and 600 seconds are shown in Table 1.

Table 1. Microbial Test Results on Disinfectors

Time (seconds)	Bacteria Count (CFU/m^3)		
	E. Coli	S. Aureus	Salmonela. sp.
0	104,5	194,0	58,0
1	26,5	175,5	58,0
2	37,5	141,5	28,0
10	15,0	105,5	6,5
60	9,5	4,0	1,5
300	3,0	1,5	2,0
600	1,0	6,0	0,01

Based on the data on the number of bacteria before and after radiation, it can be further included in equation 2 so that the effectiveness value is obtained in Table 2.

Table 2. Disinfection Effectiveness on Disinfector

Time (seconds)	Effectiveness (%)		
	E. Coli	S. Aureus	Salmonela. sp.
0	0,0	0,0	0,0
1	74,6	9,5	0,0
2	64,1	27,1	51,7
10	85,7	45,6	88,8
60	90,9	97,9	97,4
300	97,1	99,2	96,5
600	99,0	96,9	99,98

Based on the effectiveness data in table 2, a graph is then made in Figure 2. Based on the graph of the results of the study in Figure 2, it can be seen that in general there is an increase in the effectiveness of the disinfection of UV-C devices along with radiation time. This follows the theory that the effectiveness is proportional to the amount of radiation dose received by the sample.

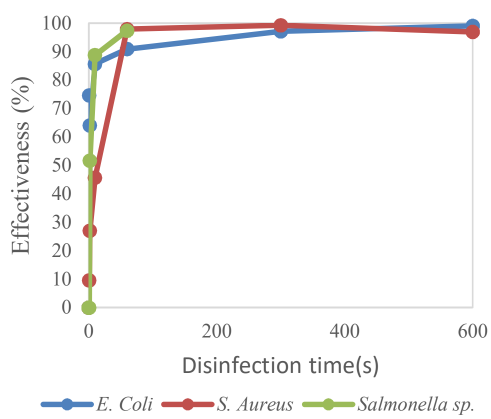

Figure 2. Effectiveness of Disinfection in Disinfectors.

However, of 18 data consisting of 6 radiation time data with three different types, two are not in line with the theory. Inconsistent data on samples of E.Coli on radiation for 2 seconds and samples on Salmonella sp. at 5 minutes of radiation. Many possibilities cause the data to deviate from the theory. However, from 21 data there were two abnormalities, which means 90.48% of the data follows the theory.

Effectiveness test of UV-C Device

The results of the microbial test in indoor air on September 30, 2021, at the FTUI office with a disinfection time of 60 minutes are shown in Table 3.

Table 3. Microbial Test Results in Room (t=60 minutes).

Room Name	Condition		E (%)	Average
	Before	After		
Purwoto Meeting	20,00	5,00	75,00	
Departemen Head	4,00	0,00	99,99	86,26
Departemen Sekertaris	16,00	2,00	87,50	
Floors 4 Comp. Lab	63,00	11,00	82,54	

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The results of the microbial test in room air on October 7, 2021, at the FTUI office with a disinfection time of 30 minutes are shown in Table 4.

Table 4. Microbial Test Results in Room (t=30 minutes).

Room Name	Condition		E (%)	Average
	Before	After		
Purwoto Meeting	21	0	99,99	
Departemen Head	75	9	88,00	64,14
Departemen Sekertaris	7	5	25,57	
Floors 4 Comp. Lab	85	51	40,00	

Based on the effectiveness data from Table 3 and Table 4, a graph can be made in Figure 3.

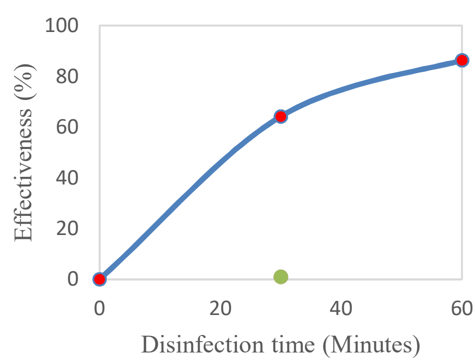

Figure 3. Graph of the Effectiveness of Disinfection in the Room.

Based on the study's results, it can be seen that the room that has been disinfected with a UV-C device has a significant decrease in the number of

bacteria when compared to before disinfection. The percentage decrease in the amount of effectiveness increases with the increase in the amount of radiation time, which means increasing the dose. These results are following the theory that the effectiveness is proportional to the amount of radiation dose received by the sample. The initial conditions of the room at different time treatments showed the results of the initial amount before treatment (N_0) which is not the same due to the time difference in sampling so the environmental conditions are also different.
The variation in the effectiveness of UV-C devices can be influenced by the volume of different rooms at the sampling location so that the air circulation that has been disinfected is not entirely homogeneous.

Based on the two activities, it provides a relationship between the air disinfection process that occurs in UV-C devices which will continue to be continuous with the operational time of UV-C devices. The UV-C device has a working principle of circulating the incoming air through the input of the disinfectant and out of the output of the disinfectant as shown in Figure 4.

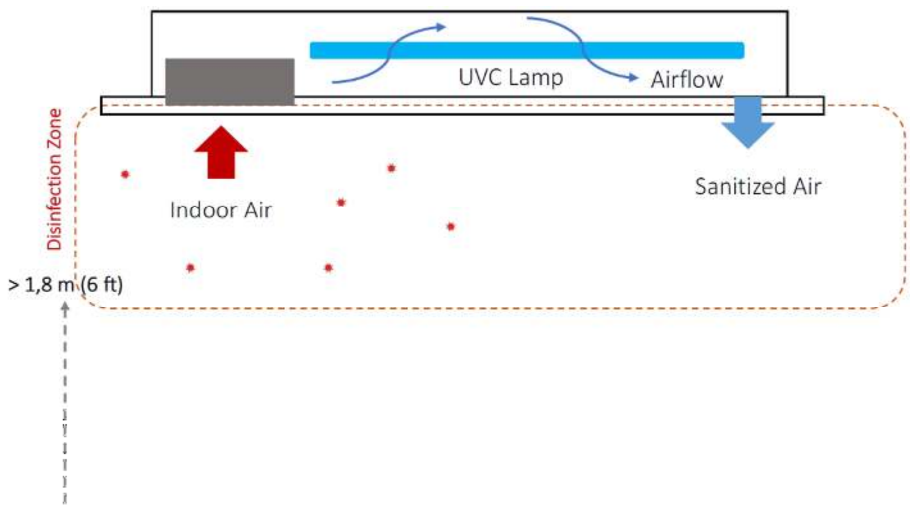

Figure 4. The working principle of the air disinfection device. Source: Author, 2021.

During the process of air input and air output in the device, the air disinfection process occurs so that the number of bacteria in the air will gradually decrease. Given constant UV-C radiation intensity and increasing time, it will increase the dose received by bacteria in the air, causing inactivity which in turn will increase the effectiveness of using UV-C devices up to 100%.

Safety Test from UV-C Radiation.

Measurement of UV-C radiation in the workplace using the SNI 16-7060-2004 procedure and the data are presented in Table 5.

Table 5. UV-C Radiation Intensity Test Results.

Sampling Area/Place	Measurement results ($\mu W/cm^2$)
Eyes	0,000
Elbow	0,000
Knee	0,000
Table Surface	0,000

Based on the measurement results, it can be seen that the UV-C radiation received by the three parts of the human body that carry out activities in the room is 0,000 $\mu W/cm^2$. Regulation of the Minister of Manpower and Transmigration of the Republic of Indonesia Number Per.13/MEN/X/2011 concerning Threshold Values for Physical Factors and Chemical Factors in the Workplace Article 9 paragraph (1) states that the Threshold Value for ultraviolet radiation is set at 0,0001 mW/cm^2 or 0,1 $\mu W/cm^2$, while based on ISO 15858 of 2016 stated that the maximum permissible limit of UV-C radiation intensity of 254 nm wavelength is 0,2 $\mu W/cm^2$ with an exposure time of 8 hours. Based on the two regulations above, it can be concluded that the radiation intensity in the room that has been installed with a disinfectant on the room’s ceiling does not reach the skin surface of human organs so it is safe to operate in the workspace following the provisions.

UV-C radiation in the workspace at the target area is read with a value of 0,000 $\mu W/cm^2$, Which means there is no radiation leakage and can be isolated only inside the UV-C device. UV-C radiation has properties such as visible light which will be trapped and reflected due to the presence of barrier material. Selection of the correct type of barrier material and dimensional shape in making UV-C devices is critical.

Conclusions

The UV-C device can be used for air disinfection with the average colony form of bacteria reduction in 30 and 60 minutes being 64.14% and 86.26% respectively. Within the period of use, the user can ensure radiation safety.

The effectiveness of UV-C devices in disinfecting bacteria in the air increase by the time of the air disinfection process. UV-C devices are used for indoor air. The longer the operating time will be more effective

Exposure to radiation outside the UV-C device is safe by showing measurement results of 0,000 $\mu W/cm^2$. This means that UV-C devices are still following the existing regulations

Further research is needed to gather more test results to draw a broad conclusion about the effectiveness of disinfection.

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