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Ultraviolet – C Dose Spread Simulation based on the Fixed-Lamp System in Universitas Multimedia Nusantara

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***Abstract*—Since Corona Virus Disease (COVID) – 19 is considered a pandemic by the World Health Organization (WHO), governments, and communities, worldwide trying to prevent transmission and reduce the number of deaths caused by the virus. One method of preventing transmission is spraying disinfectants using certain chemical compounds. However, chemicals can also hurt the environment and humans themselves if the doses used are not by existing standards. An alternative disinfectant method that does not use chemicals and is environmentally friendly, namely by using the UV (Ultraviolet)-decontamination method, UV-C rays. This research aims to find out the results of UV irradiation from UV-C lamps in theory and measurement. Then, the optimal placement of a fixed - UV lamp system to obtain an effective disinfectant dose and the length of time it takes to reach the target dose prevent the spread of the COVID-19 virus. The methods include theoretical calculations and data measurements to see the results of UV radiation irradiation on UV-C lamps and look for correlations between the two to find the conversion value. Moreover, with the help of DIALux Evo 9.2 software to find out the radiation value from the conversion equation, see the optimum UV dose spread, and reach the desired dose target time. The result is that there are differences in the results of UV irradiation on UV-C lamps with the efficiency of lamps and ballasts as well as on the measurement method that affects UV-C radiation, but according to field conditions and does not affect the actual application. The number of lamp placements and the dimensions of the room affects the dose spread. Moreover, the minimum time to achieve the target dose in the case study is 29 minutes using six placements of UV-C lamps with two lamps each at the six placement points.**

***Index Terms*—COVID-19; disinfectant; UV(Ultraviolet)-decontamination; DiaLux Evo 9.2; UV-C lamp**

I. Introduction

Since Corona Virus Disease (COVID) – 19 is considered a pandemic by the World Health Organization (WHO), governments and communities from all parts of the world are working to prevent transmission and reduce the number of deaths caused by the virus [1]. COVID-19 is a new type of virus, which is spreading very quickly. The virus has the potential to infect a person if the person makes direct contact with an already infected person. Even a person who touches the surface of an object in a public place, can be exposed to the virus because the surface has been contacted with the infected. One method of preventing its transmission is spraying disinfectants using certain chemical compounds. Spraying is carried out on common areas before use or traversed by many people. However, the use of chemicals can also adversely affect the environment as well as humans themselves if the dosage is not appropriate and the side effects of the chemical are not noticed [2]. There is an alternative disinfectant method that does not use chemicals and is environmentally friendly, namely by using the UV (Ultraviolet)-decontamination method, in this case UV-C light (Type C) [3,4].

David Welch and his research team tested the use of UV-C light with the need to prevent the transmission of influenza A/H1N1 virus through the air. The method used is the observation of viruses with UV-C rays with a wavelength of 222 nm with a target dose reached of 2 mJ/cm^2. With results above 95% that the virus is no longer able to develop and the number decreases over time [5]. The research is one of many studies that support the development of UV-C light technology in previous years [6]. Currently, the application of technology has been widely applied in addressing the spread/transmission of COVID-19, namely for the stelirization of hospital rooms [7,8] and medical equipment such as masks [9,10]. The research that has been mentioned using the method of measuring and installing UV-C technology to meet the required dose, there are already conducting simulations to find out the spread of UV-C rays in the room or area. The simulation was conducted to find out which areas were not illuminated by UV-C lights. In research dr. Hui Leng Choo from Malaysia, also used measurement and simulation methods to estimate the dose achieved in a certain area or equalization, without having to install UV lamps first [11]. Another simulation of uv-C light dissemination was conducted with a case study of aircraft cabins, of which there are three ways of spreading the dose, one of which is with a fixed-lamp system [12]. Previous research did not include a complete theory (formula or equation) about UV light itself and its limited application to medical or hospital activities. Researchers want to apply UV-C light technology to be used outside of these activities, one of which is used in educational or campus activities.

This reserch will simulate UV-C light with fixed-lamp system to obtain the spread of UV-C light in one of the classrooms at Multimedia Nusantara University (UMN). The room is a classroom that will be used by students in conducting lectures if face-to-face meetings can take place in the future. The simulation was conducted with DIALux Evo 9.2 software device and supported by theoretical calculations of UV-C lamps to be simulated, as well as the target dose as well as the time or duration to achieve the dose.

II. Fundamental Theory

A. *UV-C light (Ultraviolet – C)*

UV-C rays are classified as UV rays, which are electromagnetic radiation with wavelengths shorter than visible light and longer than X-rays. UV rays are divided into 2, namely Vacuum UV rays (200 - 10 nm) and Almost UV Rays (380 - 200 nm). When viewed from the wavelength, Figure 1 describes UV rays divided into 3 types, namely UV-A (380 - 315 nm), UV-B (315 - 280 nm), and UV-C (280 - 10 nm) [13].

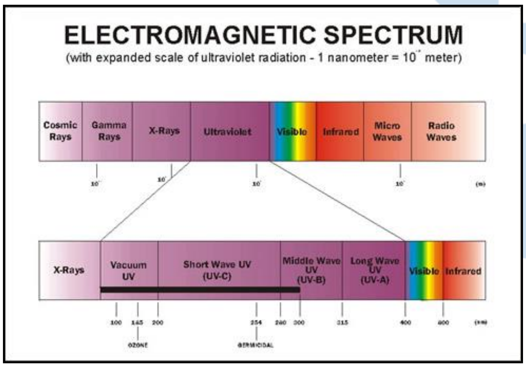

Figure 1. Spectrum Division of Ultraviolet (UV) Light[19]

UV-C light is an artificial light if it wants to be used in certain purposes (not free in nature). Because when UV light from the sun enters the Earth, UV light is absorbed by Earth's ozone, only a portion of UV light can reach the surface of the Earth, depicted in Figure 2 (such as: Full UV-A rays and 5-10% UV-B rays). UV-C rays are classified as UV rays that are quite dangerous because the effect can damage the surface of human skin if exposed directly [14].

In various studies, UV-C rays can be used to kill microbes and viruses, which can absorb up to the size of cells, which damage the R/DNA of microbial cells and viruses so that they can not develop again [4]. For this reason, the development of UV-C light is applied in light products used to illuminate certain areas that have the potential for microbes or viruses attached to an object/object surface.

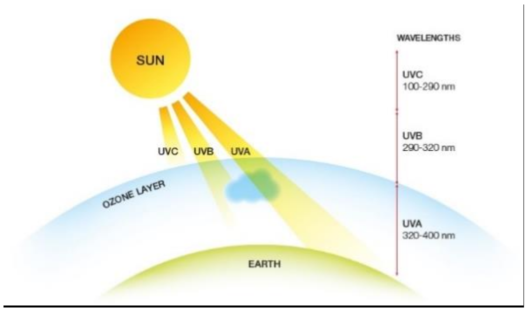

Figure 2. Ultraviolet (UV) Light Passing Through Earth's Atmosphere[20]

B. *Definition of Illumination or Irradiance*

Illumination is a term for the process of dispersing a wave of light from a light source that reaches an area or area with a certain distance. Physically, by radiometry method, radiation/illumination is the radiation flux (optical power) received by a surface per unit area, which has watts per square meter (W/m^2) [15].

C. *Mathematical Equations in Lighting Engineering*

In finding a light illumination value, a mathematical solution is needed to determine that value. In theory about lighting techniques, this can be achieved using existing formulas/theorems. However, the theorem in lighting techniques only applies if the electromagnetic wave is a visible wave of light, which in this study, the electromagnetic wave is UV light, which has different wavelengths and energy. So there needs to be another theorem/method to know the irradiation value of UV rays.

The Keitz equation found that with a line-shaped light source of a certain length, it can be known the illumination value of the lamp, in this case the UV lamp [16]. Keitz's equation is based on two laws of photometry lighting physics, namely Inverse-Square Law and Lambert's Cosine Law. Which is then adapted to line-shaped light sources and radiometry lighting. At first, Keitz equation to find the power value of the UV lamp, which can be searched with the following equation:

$$P = \frac{(2ELD\pi^2)}{(2\alpha+\sin(2\alpha))} \qquad (1)$$

where P is the total UV power of lamp (Watt); α is Arctan value(L/2D) (radians); L is Lamp length (m); E is Illumination/Irradiance (W/m^2); and D is Distance of the lamp to the illumination point (m).

With the formula, if you want to know the irradiance value of the UV lamp, then the Equation (1) is changed to:

$$E = \frac{P}{2\pi^2 LD}(2\alpha + \sin(2\alpha)) \quad (2)$$

D. *Mathematical Equations of Time Reaching Target Dosage*

In achieving the desired dosage target, it must be identified the type of virus that will be illuminated by UV cyanr. Because for each type of virus, different dosage targets will be achieved. The target dose taken is SARS coronavirus (Urbani) type of 241 J/m^2, because it is the latest dosage information [17]. It should be understood in advance that the target dose is the result of irradiance and exposure time. So when we have set a target dose at a wavelength and have targeted the surface or object that will be subjected to UV light at a certain distance, we can get the irradiance value using the Keitz equation. Therefore, to obtain exposure time on a surface or object can be calculated as the following equation [18]:

$$Time\ (s) = \frac{target\ dose\ (\frac{J}{m^2})}{Irradiance\ (\frac{W}{m^2})} \quad (3)$$

III. METHOD

A. *Tools and Materials*

There is several hardware needed in this research, such as: Philips TUV 36W SLV/6 Lamp, Lutron YK-37UVSD, Lutron LX-105, and Laser Distance Meter (LDM). As well as for software, use DIALux Evo 9.2 to simulate case studies.

B. *Research Methods*

1) *Theoretical Calculation Methods*

The calculation uses the Kertz Equation to determine the radiation value of the UV-C lamp. Data to find out which variables are in the formula have been searched before. As the radiation value from the source is seen in the product catalog and the distance of the lamp to the area to be illuminated. Distance data is taken by measuring the average height of the area in the classroom as the location of the case study. In this case, the point or distance measured is just below the lamp and the center point of the lamp. The goal is to facilitate calculation and know the maximum value of radiation produced.

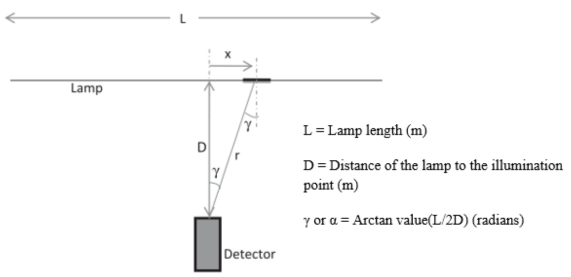

Figure 3. Geometry Used for the Keitz Equation[16]

In theoretical calculations, several variables have been determined based on the specifications of the lamp and have been measured the desired distance. Based on the Equation (2), for the values P and L is 15 watts and 1.2 meters according to the specifications. D values vary between 0.5 metres, 1.0 metres, 1.5 metres and 2.0 metres, while the α values depend on the D value and point you want to calculate. The calculated value is the irradiance value of UV-C radiation at a certain point. If the point is exactly in the middle and under the lamp (Fig. 3), then the Equation (2) can be used directly. However, if the calculated point is not exactly in the middle and bottom of the lamp, then the Equation (2) must be adjusted. Equation (2) is a simple form of the following equation:

$$E = \frac{P}{\pi^2 LD}\frac{1}{4}(2\alpha_1 + \sin(2\alpha_1) + 2\alpha_2 + \sin(2\alpha_2)) \quad (4)$$

The values α_1 and α_2 are angles formed from a point calculated by the position of the lamp against that point perpendicular (Figure 4). Because the value $\alpha_1 = \alpha_2$, the value at the midpoint of the lamp follows the Equation (2). Beyond that, the values α1 and α2 can be calculated by the formula:

$$\alpha_1 = \tan^{-1}\frac{L}{2D} \quad (5)$$

$$\alpha_2 = \left(\tan^{-1}\frac{L}{D}\right) - \alpha_1 \quad (6)$$

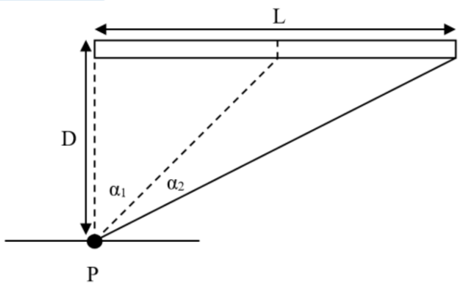

Figure 4. Geometry Illustration for Keitz Equations with $\alpha 1 \neq \alpha 2$ values

2) *Data Measurement Methods with Experimental Experiments*

Measurements are performed by means of lighting techniques in measuring the intensity of light on a lamp. When the UV-C lamp will be turned on, Lutron YK-37UVSD as a UV radiation measuring device will measure the radiation received on the table and chairs in the area. Philips TUV 36W SLV/6 lamps are installed at a certain distance and at the measuring point that is used as a reference as a comparison with the calculation results. The position of the lamp will be horizontal with the measuring instrument (Fig. 5). Then the measurement results are used to compare theoretical calculations and correlated with simulations.

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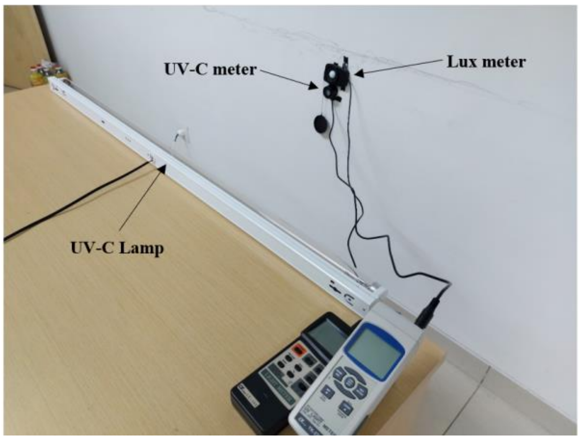


Figure 5. Position of Lamps and Measuring Instruments in Measurement Methods

In data measurement, there are two measured data, namely: UV-C light data in µW/cm^2 and UV-C lamp lighting data in Lux units. UV-C light data is obtained with Lutron YK-37UVSD measuring instrument, while UV-C lamp lighting with Lux meter measuring instrument. The two tools are mounted close together on the wall and parallel to the center point of the lamp with a certain distance. The second purpose of the data was measured to look for the correlation of both data and find conversion equations to convert the value of UV-C light into UV-C lamp lighting [11].

The position of the lamp in Figure 5 is on the edge of the table, the purpose of which is so that the lamp's radiation light has no effect on the reflection of the table material. This measurement aims to see the radiation light of the lamp without being affected by the reflection of nearby object material, such as a lamp mounted on the ceiling of the room and the measuring instrument is just below it. Therefore, the position of the lamp is not hung but placed horizontally with a measuring instrument. Furthermore, there are two things that are varied for measurement, namely the measuring point on the lamp and the distance of the lamp to the measuring instrument (Figure 6). Measuring points 1 and 3 are at the end of the lamp, while measuring point 2 is in the middle of the lamp. The distance variation depends on the value of variable D that was previously mentioned in theoretical calculations.

Measurements are performed in a room where the lights are turned off and during the day. Measurements are performed at measuring points 2, 1, and 3 with the position of the lamp changing (the lamp is shifted with the measuring point right in front of the measuring instrument), and repeated for 5 times at a distance of D. When retrieving measurement data, the UV-C lamp is turned on for 2 minutes, in order to keep the measurement result value stable/unchanged – change. The results of UV-C radiation measurement can be directly seen on the device. While Lux measurement is done before and after the lamp is turned on, the goal is to be able to know the lighting value of UV-C lamps. After obtaining both measurement data, the data was processed by looking for a correlation between radiation illumination and the lighting value of the UV-C Lamp. The correlation results will be used to compare theoretical calculation values in order to be analyzed, while in simulations to find out the lumen flux that will be simulated in the classroom.

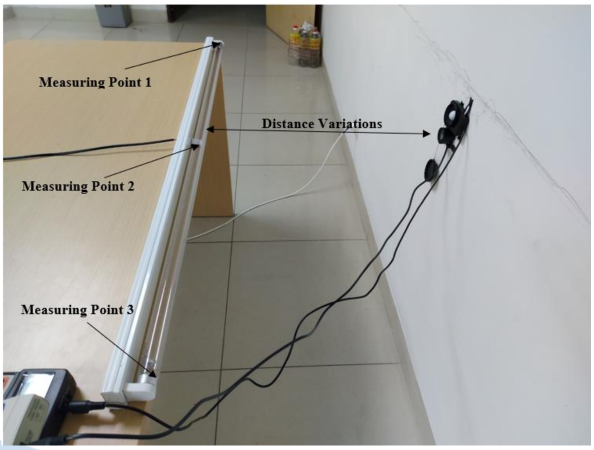


Figure 6. Position of Measuring Points and Distance Variations on Lamps and Measuring Instruments

3) *Simulation Method or Case Study Modeling*

DiaLux Evo 9.2 software will be modeled from the classroom as well as UV-C lights, which will be put together for simulation. The focus of the simulation was to see the dissemination of the received lighting value (illuminace) in the room instead of the uv radiation illumination value. The equations used in the simulation are unknown due to the lack of information about the use of mathematical equations on both official websites and other scientific research that also uses DIALux, for that there needs to be other methods. To get the value, the search for the equation of conversion of lighting value into the value of UV radiation illumination obtained when conducting analysis on the results of the exposure. This is true because the position of the lamp with the distance in the simulation is adjusted to the layout of the lamp and the measuring instrument in the measurement method. After obtaining the conversion equation, the equation is used to calculate the dose and calculate the minimum time of achieving the target (Eq. (3)) based on simulation.

Data to model of the classroom was obtained from Building Management (BM) Multimedia Nusantara University. In simulation, modeling from a case study of this project requires a room plan and an overview of the room. The room plan given is the floor plan of the New Media Tower Building 7th Floor overall, so that when creating a model of the room focuses only on the room. An overview of the room is obtained when reviewing the room (Fig. 7). The purpose of reviewing to make the modeling of the room as similar as possible to the original room.

Figure 7. Class Room Photo C703

Modeling is made in DIALux Evo 9.2 software, the initial design of the room only contains the dimensions / size of the room along with the funiture model in the software. One of the advantages of this software, can include the type of material or type of color that can be added to the simulation model. Due to the materials and colors included in the simulation, it affects the final result of the spread of UV-C lamp lighting. The interior design in the simulation follows Figure 7, including the layout of furniture, doors and windows.

Figure 8. Screenshots modeling on DIALux Evo 9.2

After modeling the room in DIALux (Fig. 8), the next stage is the layout and model of the lamp used for simulation. The UV-C lamp layout does not follow the layout of the room lamp for artificial lighting, the reason is the function of UV-C lamps for UV-decontamination or sterilization of the room. So, if in the future UV-C lamps are installed do not interfere or wrongly turn on the lights because the light switches are not separated. For the lamp model in the simulation, the length dimension of the model in the simulation is only half the size of the actual UV-C lamp size, so the model is combined in length to fit.

In the simulation lamp photometry data settings, the data set is the luminous flux value that will be obtained when connecting the luminous flux value of the software with the Lux value of the measurement results. Next is the number of lights in the simulation, to know the exact amount required, the conduct of trial and error in the simulation. By using 1 to 8 lights interchangeably, to see which lighting spreads evenly in the room area (Fig. 9).

For lighting data taken in the simulation is the lighting data of each table in the room (lecturer's desk and student table) which amounts to 22 tables to see the spread. After knowing the number of lights needed, a simulation is then carried out on the number of lights. Then taken all lighting data on the table, senderan chair, and seat base with the minimum lighting value, so that when looking for time to reach the target dose with the Equation (7) and (3) can get a minimum time how long the sterilization process of the room.

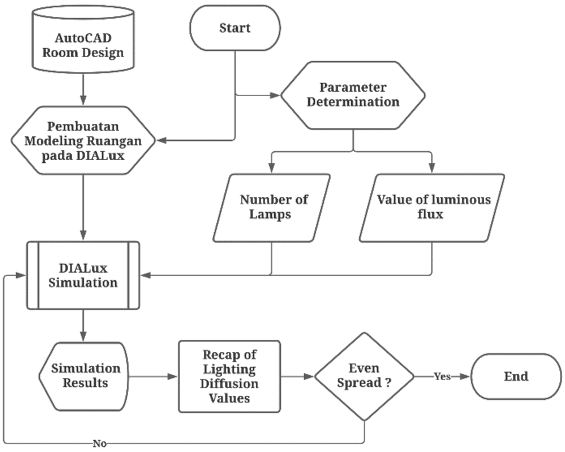


Figure 9. Scheme or Flow of Simulation Method or Case Study Modeling.

IV. Results

A. *Theoretical Calculation and Measurement Analysis*

After taking measurements in the UV-C lamp experiment, the data of the measurement results are processed with the standard deviation statistical formula or Standard Deviation (S.D.), in Excel is already available in the STDEV function. Standard Deviation has a function to see the spread of data and see if the data deviates from the average value of the data obtained. In measurement data, S.D. serves to calculate how much the upper and lower limits of each data obtained, to see if the measurement results are trustworthy and precise with the results obtained. The S.D. value specified in the final task is 10% of the average value of the measurement data per measuring point. The value is obtained with the consideration that the measurement data results have a minimum confidence level of 90%, which means that the data is trustworthy and has a relatively small error rate [19].

TABLE I. UV-C RADIATION MEASUREMENT DATA ON UV-C LAMPS

Distance (m)	Measuring Point	Measurement Results						
		UV-C ($\mu W/cm^2$)						S.D.
		1	2	3	4	5	Average	
0,5	1	86	84	84	84	84	84,4	0,894
	2	195	192	193	191	192	192,6	1,517
	3	83	93	84	81	81	84,4	4,980
1	1	42	42	42	42	42	42,0	0,000
	2	76	76	78	77	78	77,0	1,000
	3	41	41	41	42	42	41,4	0,548
1,5	1	27	25	27	27	27	26,6	0,894
	2	40	39	39	39	40	39,4	0,548
	3	26	26	26	26	27	26,2	0,447
2	1	18	19	18	18	17	18,0	0,707
	2	24	24	24	24	24	24,0	0,000
	3	17	18	18	17	18	17,6	0,548

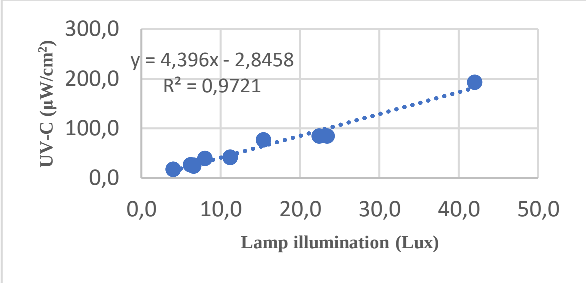
TABLE II. EXPOSURE MEASUREMENT DATA ON UV-C LAMPS

Distance (m)	Measuring Point	Measurement Results						
		Lux						S.D.
		1	2	3	4	5	Average	
0,5	1	25	22	23	23	24	23,4	1,140
	2	44	42	42	41	41	42,0	1,225
	3	22	25	22	22	21	22,4	1,517
1	1	12	11	10	11	12	11,2	0,837
	2	16	17	15	14	15	15,4	1,140
	3	11	11	12	11	11	11,2	0,447
1,5	1	7	6	6	6	6	6,2	0,447
	2	7	8	9	8	8	8,0	0,707
	3	7	6	6	7	7	6,6	0,548
2	1	4	4	4	4	4	4,0	0,000
	2	6	7	7	7	6	6,6	0,548
	3	4	4	4	4	4	4,0	0,000

Processed in Excel, measurement data of both UV-C radiation values (Table I) and UV-C lighting (Table II) have measurement errors below 10%, so both measurement result data can be trusted and proven to be the true value of the UV-C lamp used in this final task. The error in question is the dissemination of measurement result data, which if measured the value does not differ much from other measurement values, so that the measurement results are not anomalous / distorted. The error value obtained is a random error that is not estimated by the researcher because of unexpected factors, while in the measuring instrument used already has a calibration certificate so that systematic errors on the tool do not occur. Then both data are re-processed to find relationships / correlations between data using simple linear regression. Linear regression is one statistical method to test whether there is a closeness between variables to be tested. The data collected is the average data of UV-C radiation values and UV-C lamp lighting, which aims to find multiplier factors when compensating lux values to µW/cm² and see correlation values between those variables. The result of the regression that has been done (Graph 1), it was obtained that the R^2 value in linear regression is 0.9721 which indicates a strong correlation between the two variables. The multiplier factor value obtained is 4,396 µW/lux-cm² from the following equation:

$$Irradiance\left(\frac{\mu W}{cm^2}\right) = 4{,}396 \times Illumination\ (\text{Lux}) - 2{,}8458 \qquad (7)$$

Equation (7) will help to find the uv-C illumination value in the simulation result whose value is in the form of lighting (Lux), and can find the time to reach the dose with the equation (3).



Graph 1. Graph comparing radiation illumination with UV-C Lamp Lighting in Tables 2 and 3

To compare with the calculation results, Table 4 captures the results of calculations performed with equations (2) and (4), as well as the average measurement values taken from Table 2. The result is different from what is expected from the theoretical calculations that have been done, with an average ratio of 50%. The Keitz equation used has been diderivated by the latest method in previous scientific journals, so that the equation has been updated [16]. The assumption used in his update was that Keitz's equation did not describe that the UV radiation was uneven throughout the lamp, so previous research has again reduced the formula to look for the value of the "normalization factor" of the actual spread of UV radiation. `

To analyze the power of UV-C lamps at the time of experiment (compared to the ideal specifications of the tool), it was attributed to the average value of UV-C radiation Measuring Point 2 at each distance in Table 2, and then included in the equation (1). With the aim of recalculating the total power of UV radiation beams emitted on uv-C lamps on each data taken. After recalculating, the total power of UV radiation rays is averaged by:

$$P_1 = \frac{(2 \times 1{,}926\ \mu W/m^2 \times 1{,}2\ m \times 0{,}5\ m \times \pi^2)}{(2 \times 0{,}876 + \sin(2 \times 0{,}876))}$$

$$P_1 = 8{,}338\ Watt, at\ a\ distance\ of\ 0{,}5\ meters$$

$$P_2 = \frac{(2 \times 0{,}77\ \mu W/m^2 \times 1{,}2\ m \times 1\ m \times \pi^2)}{(2 \times 0{,}54 + \sin(2 \times 0{,}54))}$$

$$P_2 = 9{,}29\ Watt\ at\ a\ distance\ of\ 1\ meters$$

$$P_3 = \frac{(2 \times 0{,}394\ \mu W/m^2 \times 1{,}2\ m \times 1{,}5\ m \times \pi^2)}{(2 \times 0{,}381 + \sin(2 \times 0{,}381))}$$

$$P_3 = 9{,}65\ Watt, at\ a\ distance\ of\ 1{,}5\ meters$$

$$P_4 = \frac{(2 \times 0{,}24\mu W/m^2 \times 1{,}2\ m \times 2\ m \times \pi^2)}{(2 \times 0{,}291 + \sin(2 \times 0{,}291))}$$

$$P_4 = 10{,}032\ Watt, at\ a\ distance\ of\ 2\ meters$$

$$Average\ \bar{P} = \frac{(P_1 + P_2 + P_3 + P_4)}{4}$$

$Average\ \bar{P} = 9{,}328$ Watt , different from the specifications of UV-C lamps listed at 15 Watts.

There are two factors that can influence the measurement results, including the efficiency of the lamp and ballast (lamp holder) and the material at the measurement site. Lamp output power is generally compared to the electrical power (channel) consumed to calculate the efficiency of the lamp/ballast system, or compared to the electrical power transmitted to the lamp to calculate the efficiency of the lamp [20]. Electrical power needs to be measured accurately, so that efficiency can be determined accurately. This electrical power measurement should be done using calibrated instruments for power measurement, using equipment such as power analyzers with adequate frequency response. In particular, it is not enough to measure the voltage and reciprocating current to obtain lamp power with a theoretical formula. While the measurement location is in class, the material on the table and wall can affect the measurement result, namely uv reflection on the material. It is recommended that measurements be made with a room on the wall and the floor covered in black cloth [20], black color itself being a color/material that does not reflect UV light. It can be done if you want to actually get the same measurement results as theoretical. However, when applied in the field must be adjusted to the real conditions of the room. If black fabric is attached to the room, it can make the use of UV-C light technology inefficient. Therefore, for comparison with the simulation used is the result of measurement, not theoretical value.

TABLE III. THEORETICAL CALCULATION DATA COMPARISON WITH UV-C LAMP MEASUREMENT DATA

Distance (m)	Measuring Point	Theoretical Calculation of UV-C (µW/cm²)	Average UV-C Measurement Results (µW/cm²)	Percenta Differen
0,5	1	247	84,4	34%
	2	346	192,6	56%
	3	247	84,4	34%
1	1	103	42,0	41%
	2	124	77,0	62%
	3	103	41,4	40%
1,5	1	55	26,6	49%
	2	61	39,4	64%
	3	55	26,2	48%
2	1	33	18,0	54%
	2	36	24,0	67%
	3	33	17,6	53%

B. *Measurement Analysis and Simulation*

1) *Correlation of Lumen Flux with Illuminance*

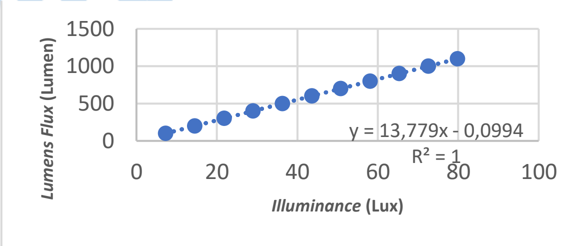
After obtaining the results of uv-C lamp lighting measurement, UV-C lamp lighting data was obtained to be compared with simulation. For lumen flux values (light source output of lights, in Lumen or Candela.Steradian units) in simulations obtained by looking for linear regressions that connect with lighting values in DIALux simulations. This is done to find alternative methods in finding the value of lumen flux, due to the lack of information about the equation/solution used in the software (some previous studies do not explain the details to get the value of lumen flux on DIALux). In the simulation, the range of flux lumen values varied by 1100 to 10 lumens, with the position of the lights in the simulation being above and parallel to the table 2 meters away. After the regression (Graph 2), the multiplier factor value from illuminance to lumens flux was obtained in the simulation of 13,779 lumens/lux with a correlation of R^2 value of 1, which is a strong correlation between the two variables, in accordance with the following equation:

$$Lumens\ Flux\ (lumen) = 13{,}779 \times Illuminace\ (lux) - 0{,}0994 \quad (8)$$

The point of exposure value taken in the simulation as in point 2, which is at the center point of the lamp, where the lighting value with a distance of 2 meters and the measuring point 2 in the measurement results table 2 averaged 6.6 Lux. So, when the value of 6.6 Lux is entered into the equation (8), then the value of lumen flux that must be entered in the simulation is:

$$Lumens\ Flux\ (lumen) = 13{,}779 \times 6{,}6\ lux - 0{,}0994$$

$$Lumens\ Flux = 91\ Lumen$$



Graph 2. Graph comparing lamp lighting with Lumen Flux Lamp In DIALux Simulation

2) *Determination of The Number of Lamp Placements*

After knowing the lumens flux entered, the number of lamp placements required is taken into consideration with the reason that the spread of UV-C lamp lighting in the simulation is evenly distributed and the amount is optimum. One method of finding it with trial and error experiments, by recording the lighting value of each table in the simulation, as the number of lamp placements increases. The rate of spread can be calculated by S.D. , the smaller the percentage value of S.D. hence the spread is evenly distributed. Figure 10 is the result of a simulation using 1 lamp placement, it appears that the lighting spread is uneven on all tables. To support this, Table IV is the result of a recap of lighting value data on all areas of the table in the simulation. With the percentage of S.D. obtained by 77%, so it is necessary to increase the number of lights back in the simulation to find the smallest percentage value of S.D. The result is shown in Graph 3, the number of lights needed to achieve the most even spread as much as 6 placements.

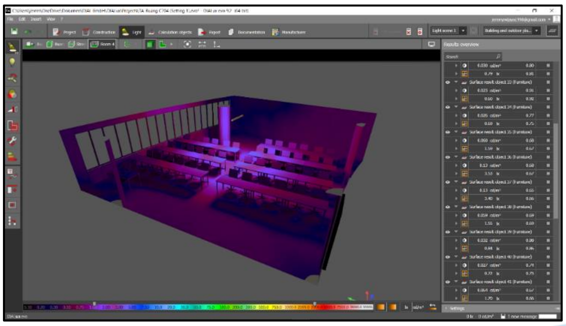
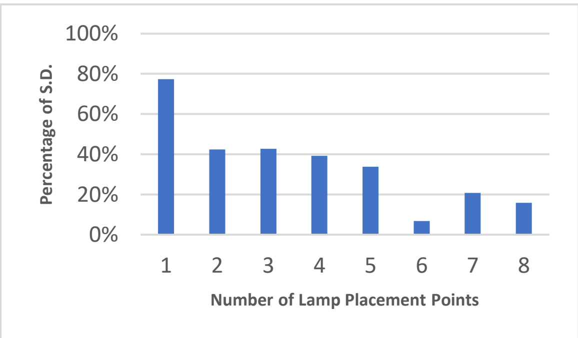


Figure 10. Screenshot of Lighting Simulation Results with 1 Lamp

TABLE IV. SPREADING LIGHTING VALUES IN THE TABLE AREA USING 1 LAMP

Desk Area	Lux Value
1	0,76
2	0,47
3	0,29
4	1,14
5	1,17
6	0,85
7	0,62
8	0,68
9	1,54
10	3,68
11	3,79
12	1,66
13	0,87
14	0,67
15	1,6
16	3,69
17	3,78
18	1,68
19	0,85
20	1,39
21	0,94
22	0,61
S.D.	1,152
Mean	1,488
% S.D	77%



Graph 3. Graph comparing number of lamp placements with percentage S.D. Table Area Rupture Data in DIALux Simulation

3) Lighting simulation and Time to Reach Dosage Target

After finding the value of lumens flux and the number of lights in the simulation, the data was entered into the simulation to find the lighting value on the table, seat back and seat base (Figure 11).

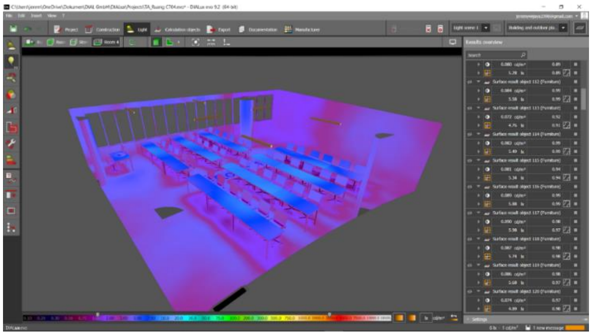


Figure 11. Screenshot of Lighting Simulation Results with 6 Lights

All of these values are recorded and searched for the smallest/least exposure values. It was obtained that the minimum exposure value in the simulation was 2.1 Lux (complete data attached to the Appendix). If included in the equation (7) and (3), the minimum time to reach the target dose is:

$$Irradiance \left(\frac{\mu W}{cm^2}\right) = 4{,}396 \times 2{,}1 \text{ Lux} - 2{,}8458$$

$$Irradiance = 6{,}39 \frac{\mu W}{cm^2}$$

$$Time\ (s) = \frac{241 \frac{J}{m^2}}{0{,}0639 \frac{W}{m^2}}$$

$$Time = 3774\ seconds\ or\ 63\ minutes$$

The time is very long considering if this UV-C light system will apply to the room or other classrooms. If the condition of the campus environment returns to normal with the classroom used as scheduled, the transition of class change is between 15 to 30 minutes depending on the number of semester credit unit courses. Thus, in the simulation the number of each lamp location is doubled to 2. After re-simulating with double lights, the result is a minimum exposure value of 3.81 Lux (complete data attached to Appendix), re-inserted in the equation (7) and (3), obtained the minimum time to reach the target dose to be:

$$Irradiance \left(\frac{\mu W}{cm^2}\right) = 4{,}396 \times 3{,}81 \text{ Lux} - 2{,}8458$$

$$Irradiance = 13{,}90 \frac{\mu W}{cm^2}$$

$$Time\ (s) = \frac{241 \frac{J}{m^2}}{0{,}139 \frac{W}{m^2}}$$

$$Time = 1733\ seconds\ or\ 29\ minutes$$

That time is already in the time span of the class change mentioned earlier. Table 6 is a recap of the minimum value of lighting and the time to reach the dose on the table, seat back and seat base by comparing the number of lamps installed at 1 point of placement of the lamp.

TABLE V. SPREADING LIGHTING VALUES IN THE TABLE AREA USING 1 LAMP

Number of Lights	Area (m^2)			Minimal Illuminance Value (Lux)			Minimum Time To Reach Target Dose (Minutes)		
	Table	Seat Back	Seat Cushions	Table	Seat Back	Seat Cushions	Table	Seat Back	Seat Cushions
1	0,9	0,15	0,18	7,25	3,44	2,1	14	33	63
2				12,3	6,59	3,81	8	15	29

After knowing the fastest minimum time by using 6 placement points with each point 2 lights, please be aware of the effect produced if the funiture material / object is too long exposed to UV-C radiation. UV radiation absorbs in all kinds of materials both organic and non-organic [21]. In living things / organisms, the effect that is often associated even if it does not cause directly, is skin cancer in humans. However, UV rays can have a good or bad impact, depending on radiation exposure and the dose to be achieved in order to be on target [22]. In inanimate objects/objects/non-organisms, few types of material can be affected by UV rays, especially with UV-A and UV-B rays, one of which is color fading in fabric products[23] and structural and physical changes of polymer products [24]. To date, there has been no scientific research that shows changes that occur in object/non-organism material due to UV-C radiation overdose. But some types of material objects / non-organisms exist that can reflect or deflect UV-C rays, depending on certain interests.

In the real use case, if the distance between the object and the UVC lamp is longer, then there needs to be a re-measurement to measure the radiation received by the object in the room installed by the UVC lamp. Because distance will affect the exposure of UV radiation from UVC lights in an area of objects that want to be sterilized.

V. CONCLUSIONS AND SUGGESTIONS

Based on the research, it can be concluded that:

1. There are differences in the value of UV illumination from UV-C lamps in theory as well as direct measurements. Direct measurements show an average illumination value of 50% of the theoretical calculations. The efficiency factors of lights and ballast as well as the conditions and methods of measurement influence the difference. However, because for the purposes of field applications need to adjust to real conditions, then what is then used for the simulation process is the irradiation value of direct measurement.

2. The number of fixed placements - UV lamp system that is optimal for obtaining effective disinfectant doses depends on the seating position in a room. In the classroom space case study, the placement of lamps at 6 points resulted in an even spread of UV-C radiation with a deviation of 7%

3. The minimum time or duration of UV-C dose for COVID-19 virus disinfection is 29 minutes using each of the 2 lights at the six placement points.

Based on the conclusion of the analysis, there are several suggestions that should be considered for the future works, including:

1. This article can be an introduction to a future research article to discuss the effect of the distance between objects and UVC lamps on UV radiation presented.

2. There needs to be a measurement method to determine the efficiency of lights and ballastes that can affect the performance of UV-C lamps.

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