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Microbial Air Pollutant Control using Commercial UV-C Lamp for Preparing Re-opening Class Activities at Universitas Indonesia

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***Abstract*—Airborne microorganisms must be controlled, especially during the COVID-19 pandemic, to prevent infectious diseases. This research was conducted to prepare a clean room and eliminate infectious pathogens. This study studied a 36-watt UV C commercial lamp to examine its effectiveness in controlling airborne microorganisms in rooms at Universitas Indonesia. The germicide effect of lamp (100 mJ/cm^2) predicted by the UV-C test card could be achieved at a distance of 2 to 3 meter after exposure for 60 minutes. UV-C's effectiveness as a germicide was also tested on bacteria, yeast, and mold. No germicides were observed in *A. parasiticus* and *C. lunata* after being exposed to the UV-C light at 1 to 2 meters distance for 60 minutes. The germicides UV-C lamps were also applied in examined rooms. Active and passive sampling methods measured airborne microorganisms before and after the treatment of UV-C lamp. The lowest germicide effect of UV-C lamp was 37.66% in the collaboration laboratory, and the highest was 86.12% obtained in seminar room at Department of Biology. Many factors, such as the type of group of microorganisms, air circulation, and equipment in the room, influence the germicide effect of UV-C lamp. Based on existing microorganism populations, the examined indoor air has good quality under 1,000 CFU/m^3.**

***Keywords*— Air pollutant microorganism; commercial UV-C lamp; effectiveness of UV-C.**

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I. INTRODUCTION

The outbreak of the Coronavirus Disease 2019 (COVID-19) pandemic that began in Wuhan, China, has caused panic and anxiety in the community. COVID-19 is suspected to be spread by aerosol through contaminated air [1]. Therefore, air decontamination from pathogenic microorganisms must be done to prevent the spread of COVID-19. The studies conducted were related to the gradual re-opening of face-to-face lectures, which is particularly important to do as a precautionary measure to prevent the spread of COVID-19.

Control of microorganisms in a room and an object's surface can be done by chemical or physical disinfection [2]. Common disinfection in today's society uses chemical compounds, such as alcohol, hydrogen peroxide, and chlorine [3]. However, chemical compounds are considered less effective in controlling microorganisms because excessive chemical compound disinfectants can harm humans and the environment due to the residues produced. In addition, using chemical compounds in liquid form is relatively more difficult to apply to the surface of certain objects due to the reactions that can be caused [2]–[4].

UV-C light is one decontaminating pathogenic microorganism technique in the air [5]. Guridi et al. (2019) [6] stated that disinfection could be done physically using Ultraviolet-C (UV-C). The wavelength of UV-C light ranges from 200 to 280 nm, with the highest effectiveness at 254 nm [7], [8]. Disinfection with UV-C light can be effectively used because it can spread evenly to various objects' surfaces, including air-containing microorganisms. The UV-C light can quickly sterilize the material without producing chemical residue, is easy to use with low cost [9], [10] and does not degrade the material [11]. Ploydaeng et al. [12] stated that bioaerosol could absorb the shortwave of UV-C light, damaging the microbial genetic material. The UV-C light radiation caused the formation of dimer bonds in the genetic material of both RNA and DNA [6], [13] that cause transcription disorders, as well as replication, and can have an

impact on death [4], [14]. Buonanno et al. [15] stated that exposure to UV-C for 25 minutes in the air can kill 99.9% of coronavirus 229E and OC43 that causes flu. The use of UV-C light as one of the disinfectant agents is recommended to be widely applied [8], especially in the re-opening of classrooms or public spaces [16].

Studies on population control of pathogenic microorganisms in the air have been widely conducted. It is proven effective in lowering the transmission of infectious diseases caused by airborne pathogens [5]. However, an independent study is needed to prove that UV-C lamps sold commercially and widely available in the Indonesian market are effective and in alignment with written claims.

This study aims to evaluate the effectiveness of commercial UV-C lamps against a population of microorganisms in the air. The microorganisms were studied as bacteria, yeast, and mold but excluded viruses due to the difficulty in detecting them in the air. However, according to the CDC, viruses are generally more sensitive than bacteria to sterilization and disinfection processes [6]. In other words, a decrease in bacterial population due to the disinfection process can indicate or be analogous to a decrease in the virus population.

II. Materials and Methods

The schematic method of study is shown in Fig 1. The first step in this study was to determine the effective dose (mJ/cm2) of a commercial UV-C lamp to kill the microbial cells using a UV-C test card (Germs away). The effective dose will be decided based on the UV-C test card's color change after exposure to the UV-C lamp. The dose will correlate the UV-C lamp's distance with the exposure duration time. The second step was to determine the UV-C lamp's distance and exposure duration time. The microorganisms tested on agar plates were exposed to commercial UV-C lamps at certain distances and duration of exposure time. The third step was to prove the effectiveness of a commercial UV-C lamp as a germicide under the company's claim. The company stated that the UV-C lamp could kill 99.9% population of bacteria in a room with a 40 m^2 area. Finally, the last step was to measure the effectiveness of commercial UV-C lamps as a germicide. As obtained in the previous step, the number of UV-C lamps used was determined by calculating the ratio of room area to be disinfected and the optimal distances at a certain exposure time.

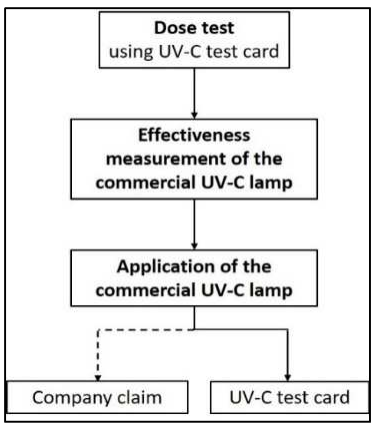

Fig. 1 The schematic method to evaluate the effectiveness of a commercial UV-C lamp.

A. UV-C Test Card

The UV-C doses test card is a visual aid of commercial colorimetric indicators for estimating the dose of commercial UV-C light exposure. The UV-C test card uses the principle of changing the molecular structure when exposed to UV-C light. Changes in the substance's molecular structure ultimately impact the discoloration of the substance-exposed [17]. The indicator color in a central square of the test card will change if UV-C test card (Germs away) is exposed to commercial UV-C light. That change then can be compared to the control color in outer square. The outer square color indicates that UV-C dose range is 50 mJ/cm^2 to >1000 mJ/cm^2. In this experiment, a 36-watt UV-C lamp is exposed to the test card with distance variations (2, 3, and 4 meters) and different exposure duration (30 and 60 minutes). The result obtained will be used as a basis of dose effectiveness and to predict the number of UV-C lamps used to disinfect a room according to the square area.

B. The Effectiveness of Commercial UV-C Lamp

The effectiveness of commercial UV-C lamps was tested against bacteria, yeast, and mold. The bacteria used for the test were *Escherichia coli*, *Pseudomonas* sp., *Staphylococcus aureus*, and *Bacillus siamensis*, the yeasts tested were *Saccharomyces cerevisiae*, *Candida parapsilopsis*, and *Rhodotorula* sp., while the molds tested were *Aspergillus parasiticus* and *Curvularia lunata*. The media in each plate were divided into two regions, and each region was inoculated with the same species of microorganism tested. The half plate was then covered with aluminum foil, and the other half plate was left open [18]. The Petri were exposed to commercial UV-C light with exposure distances of 1 and 2 meters for 60 minutes. The effect of UV-C light is observed after the plates were incubated for 1 and 2 days. The effectiveness of UV-C can be observed as an inhibition growth of microorganisms tested.

C. Application of the Commercial UV-C Lamp

The commercial UV-C lamp is applied in seminar and lecture rooms and a laboratory to determine the effectiveness of UV-C lamps that indicated the reduction of airborne population. A sampling of microorganisms was conducted before and after exposure to the 36-watt UV-C lamp in the room being tested. Sampling is done by two methods: active method using air sampler MASS 100-NT (Merck) and passive method using settle plate. The medium used was Trypticase Soy Agar (TSA) supplemented with 1% (w/w) glucose.

The flow rate of air sucked by MAS 100-NT was 100 L/min and was operated up to 5 min to get a total volume of 500 L from each room tested. The colonies that grew in each plate were calculated, and the population data were then converted using the table Feller [19]. The population of microorganisms in the air was expressed in CFU/m^3. For the settle plate method, the population of colonies microorganisms will be calculated using the formula by Li et al. [20] as follows:

$$C = \frac{(50000 \times N)}{A \times t} \quad (1)$$

where C is number of air colonies (CFU/m^3), N is counted colonies, A is culture plate area (cm^2), and t is a time exposure (minute).

1) The Effectiveness of UV-C Lamp based on the Company Claim: The company claims that their commercial UV-C lamp can kill 99.99% of the microorganism population in an airy room with 40 m^2 square area after 60 minutes of exposure. To prove the claim, the effectiveness of commercial UV-C germicides was tested in 3 seminar rooms with approximately 54 m^2 area (seminar room A and C) and 18 m^2 (seminar room B). About 1 to 4 UV-C lamps were used in the experiment to disinfect that area. The airborne microorganism population was sampled by active sampling using MAS 100-NT.

2) The Effectiveness of UV-C Lamp based on the Result of UV-C Test Card: Other experiments were conducted in 2 lecture rooms, 1 seminar room, and 1 laboratory with a different square area. The provided UV-C lamps in each examined room were calculated based on the result of UV-C test card. Population of airborne microorganisms was sampled by active sampling using MAS 100-NT and also passive sampling by settle plate method. The number of sampling site adjusted with the number of UV-C lamps used in the room (Table I).

TABLE I
THE EXAMINED ROOM AND NUMBERS UV-C LAMP

Room	Area	Numbers of UV-C Lamp	Numbers of Air Sampling Site
Seminar room 3rd floor (C)	54 m^2	5	5
Collaboration Lab. (D)	100 m^2	8	8
B302 (E)	42 m^2	4	4
B306 (F)	30 m^2	4	4

All Petri dishes from both of air sampler and settle plate were incubated for 2-5 days. The growing colonies were calculated and expressed as CFU/plate, and the population of microorganisms was converted into CFU/m^3 units. The effectiveness of UV-C was calculated based on a decrease in population after indoor air was exposed to UV-C. The percentage of UV-C effectiveness was calculated based on the formula.

$$UV-C.Effectiveness(\%) = \frac{(P1-P2)}{P1} \times 100\% \quad (2)$$

where P_1 is the number of colonies before UV C exposure and P_2 is the number of colonies after UV C exposure. The obtained data will be analyzed using a parametric Paired T-test.

III. Results and Discussion

A. UV-C Test Card

The effectiveness of UV-C light as a disinfection agent will depend on the dose of the light received by the object to be disinfected [9]. The light dose depends on the intensity, distance, and duration of UV-C light exposure [8], [21]. Results of UV-C test card are presented in Fig. 2. Based on the UV-C test card. It reveals that the color in the center square was changed after exposure to UV-C light with different distances and exposure duration. It was due to photoactive ink in disposable indicator that will react with UV-C light received [21]. In this experiment, the yellow color of the center square will change to green color. The dark green color will appear when the distance of UV-C light is 2 meters as well as 3 meters with 60 minutes exposure duration (Fig. 2e and 2f).

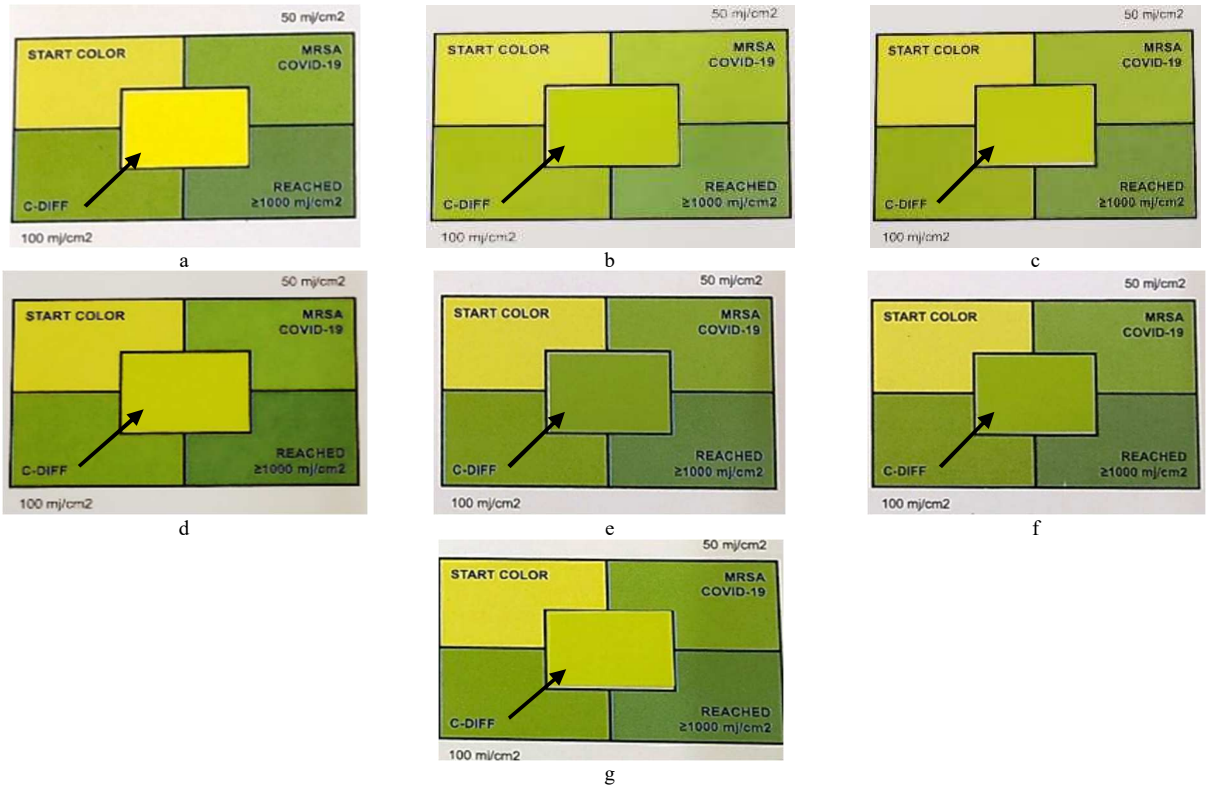

Fig. 2 The result of UV-C test card: control (a); expose for 30 min at 2 m (b), 3 m (c), and 4 m (d); expose for 60 min at 2 m (e), 3 m (f), and 4 m (g), arrow: observed part.

In such a condition, the dark green indicated that the exposed object would receive a dose equivalent to 100 mJ/cm^2. It means that the dose is effective enough to kill *Clostridioides difficile* (C-DIFF), MRSA, and also COVID-19 virus as written on the product label of the company (Germs away). Jureka et al. [22] reported COVID-19 virus, SARS-CoV-2, can be inactivated with a dose of UV-C up to 52.5 mJ/cm^2 on the stainless steel surface. Based on the result, the UV-C lamp will be most effective at a distance of 2 to 3 meters with 60 minutes of exposure. That condition will be set as a standard for a further experiment to assess the effectiveness of UV C lamps when disinfecting microorganisms in the air.

B. The Effectiveness of Commercial UV-C Lamp

The effectiveness of UV-C lamps as germicide will also be affected by the condition or characteristics of the microorganisms. Zhang et al. [23] stated that the sensitivity of microbial cells depends on their characteristics, such as cell size and molecular weight of genetic material. In addition, the UV-C lamp exposure to microorganisms can be affected by several factors, such as the characteristics of strain, media, phase culture, and density of cells [24]. The radiation of UV-C lamp will be absorbed directly by the nucleic acid and could induce the pyrimidine dimer [21], [25]. The pyrimidine dimer will interfere with the DNA replication process, which can lead to cell death [13], [26]. Results of UV-C lamp exposure showed that the UV-C lamp was able to kill the bacterial growth and yeast growth at the distance of 1 and 2 meter for 60 minutes of exposure, but not the mold (Fig. 3).

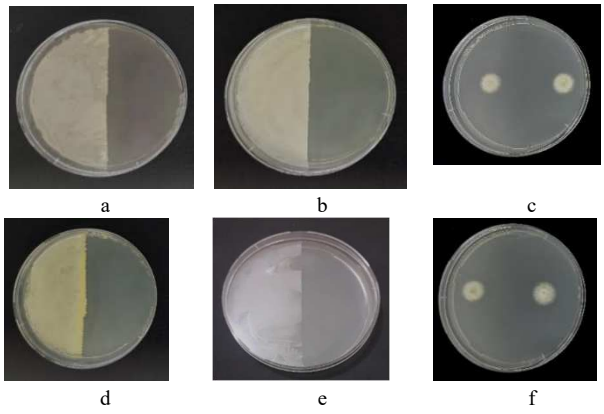

Fig. 3 The effectiveness of commercial UV-C lamp at a distance 1 m (above) and 2 m (below) towards *Staphylococcus aureus* (a,d); *Candida parapsilopsis* (b,e); and *Aspergillus parasiticus* (c,f).

The UV-C light (254 nm) can inactivate the vegetative cell; nevertheless the generative cell is resistant [27], [28]. Research conducted by Hameed et al. [29] using conidia of several species of *Aspergillus* showed that after 6 hours UV-C exposure, only about 77.0% to 88.5% of conidia were killed. Fungi produce conidia spores which are more compact structures than hyphae and also have characteristics as dormant cells. It means the conidia are more resistant to UV-C exposure [13]. The conidia cells still could germinate and grow slowly. Wong et al. [30] stated that micro-fungi have survived in many stressful environments, including UV radiation. Many fungi produce several pigments that are known as a primary defense mechanism to prevent cell damage caused by UV radiation.

C. Application of UV-C Light Commercial

1) The Effectiveness of UV-C Lamp based on the Company Claim: One of the research purposes is to prove the state of the commercial UV-C lamp company. One UV-C lamp can kill 99.99% of microorganisms in the air in a 40 cm^2 room after exposure with a UV-C lamp. However, our experiment showed weak support for the claim, as the resulting effectiveness was far below the claimed one, as seen in Table II.

TABLE II
THE RESULT OF UV-C LAMP EFFECTIVENESS BASED ON ITS NUMBERS

Room	Number of UV-C Lamp	Population (CFU/m^3)		Effectiveness (%)
		Pre-UV	Post UV	
Seminar room A 2nd floor (9 x 6 m)	3	748	350	53.20
	4	790	210	73.41
Seminar room B 3rd floor (3 x 6 m)	1	604	116	80.79
	2	406	14	96.55
Seminar room C 3rd floor (9 x 6 m)	3	362	150	58.56
	4	364	130	64.28

The effectiveness of UV-C lamps is below 99.99% (Table II). The highest effectiveness obtained was 96.55%, resulting from using 2 lamps in room B with an area of 18m^2. This implies that 1 lamp only cover 9 m^2 area. In other 2 bigger rooms (A and C), with an area of 54 m^2 each, the 3 UV-C lamps only decrease the microorganisms' population by 53.20% to 58.56% after 60 minutes of exposure. Adding 1 lamp into the rooms increased the effectiveness by 20.21% to reach 73.41% for room A; implying that 1 lamp covered about 13.5 m^2 area. Whereas for room C, the addition of 1 lamp only increases the effectiveness by 5.72%, far lower than that of room A. The difference in the increase in effectiveness in the three rooms might be due to many factors, such as distance [21], [31], and duration exposure[32]. According to Lindblad et al. (2020) [21], the effectiveness of UV-C lamp as germicidal is also influenced by the organic material, which will absorb and block the penetration of UV-C.

2) The Effectiveness of UV-C Lamp based on the Result of UV-C Test Card: Based on previous results of UV-C test card, it was determined that the radius of 2-3 meters would give the most effective of UV-C lamp as a germicide. By comparing the square area of the rooms and the effective distance of UV-C light to the object, amount of lamps needed for the experiment can be calculated. The results of the measurement of the airborne microorganism population from the examined room can be seen in Table III.

The results of UV-C effectiveness in the examined rooms, where the microbial population was sampled using an air sampler MAS 100-NT and settle plate, were presented in Table III. The effectiveness varies from the lowest of 37.66% (passive sampling) in collaboration laboratory (D) to the

highest of 86.12% (active sampling) in seminar room C in 3rd floor. In general, the effectiveness calculated from the active sampling is higher than that from the passive sampling in all rooms. The largest difference is obtained in the collaboration laboratory, where the active sampling results in an effectiveness of 68.75%, almost double the respective one from passive sampling. Acceptable effectiveness of greater than 75% only results from 2 of the 4 examined rooms.

Microbial population decreased in seminar room C when the UV-C lamps adjusted to 5. The microbial population after UV-C exposure decreased, therefore, the effectiveness of UV-C were increased up to 86.12% in active sampling. By adding lamps, so the total was 5 lamps, the cover area for each lamp will be 10.8 m^2, an improvement of effectiveness about 21.84% compared to the coverage area of 13.5 m^2 in the same room (seminar room C) with 4 lamps (Table II). This evidence showed that the distance of UV-C light or the coverage area would determine the UV-C effectiveness as a germicide, as Katara et al. [32] and Lindblad et al. [21] mentioned.

The collaboration laboratory room (D) is in the same building as the seminar room (C), although it has different functions and characteristics. As a collaboration laboratory, this room is full of laboratory equipment, such as racks or shelves with reagent bottles and chemical cabinets. The use of 8 lamps in 100 m^2 of room collaboration laboratory meant that the coverage area of each lamp is 12.5 m^2. Despite the larger coverage area, the effectiveness of UV-C light in collaboration laboratory room (D) is lower than that of seminar room (C), which is decreased by 17.37% (active sampling) and by 45.14% (passive sampling) (Table III). This condition could be explained by Katara et al. [32]. In addition to the distance or cover area factors**,** goods and pieces of equipment in a room will affect the effectiveness of UV-C lamps. Generally, a germicide lamp will not be effective in killing bacteria if it is not directly exposed to UV-C light [33], [34] or if it is hindered by other materials [21].

TABLE III
THE RESULT OF EFFECTIVENESS OF COMMERCIAL UV-C LAMP EXPOSURE IN EXAMINED ROOM

Rooms	Repetition	Active sampling		Passive sampling	
		Pre-UV	Post UV	Pre-UV	Post UV
		(CFU/m^3)			
	1	491.20	42.80	335.22	68.09
	2	307.60	71.60	424.26	31.43
Seminar Room 3rd floor (C)	3	711.60	95.20	214.75	68.09
	Average	**503.47**	**69.87**	**324.74**	**55.87**
	Effectiveness (%)		**86.12%**		**82.80%**
	1	307.00	131.50	389.56	212.79
	2	358.75	130.50	274.98	196.42
Collabo-ration Lab. (D)	3	751.25	180.75	477.90	303.04
	Average	**472.33**	**147.58**	**380.81**	**237.42**
	Effectiveness (%)		**68.75%**		**37.66%**
	1	550.50	162.50	700.56	268.44
	2	249.50	127.50	412.48	202.96
Lecture Room B302 (E)	3	457.00	100.50	314.27	124.40
	Average	**419.00**	**130.17**	**475.77**	**198.60**
	Effectiveness (%)		**68.93%**		**58.26%**
	1	2128.50	408.00	798.80	65.50
	2	634.50	251.50	805.31	314.27
Lecture Room B306 (F)	3	1333.00	328.00	471.40	130.94
	Average	**1365.33**	**329.17**	**691.84**	**170.24**
	Effectiveness (%)		**75.89%**		**75.39%**

The location and condition of the rooms to be disinfected should also be considered. It seems that large rooms will need more lamps [35]. The air movement or air circulation also needs to be considered. The lecture rooms, B302 (E) and B306 (F), are in the same building and floor. The cover area for each lamp in lecture room B302 is 10.5 m^2, and in B306 is 7.5 m^2, whereas the cover area of each lamp in seminar room C is 10.8 m^2 (Table III). Although the cover area of UV-C lamp in room B302 and B306 are lower than in seminar room C, but the effectiveness of UV lamp is not as good as in room C. This might be due to the different rooms' locations and conditions. The building location of room B302 and B306 as lecture buildings is in the open area. There are 4 open access to the lecture building, the car park area, and the main road. For those reasons, it is reasonable that there are variations in the percentage decrease of the germicide population in each room. Memarzadeh [31] stated that the condition of the rooms, such as temperature and humidity, can affect the efficacy of UV-C light.

In general, the UV-C lamp can be used to decrease the airborne microorganisms in the rooms chosen in this experiment (Fig. 4). It is a significant difference in the effectiveness results of collaboration laboratory room (D) using active sampling method (68.75%) and passive sampling method (37.66%). The significant difference is affected by the condition of the collaboration laboratory located above the ecological laboratory, which is connected by an open staircase. It is assumed that there was unintended airflow from the ecological laboratory during the passive sampling. The movement of people will greatly affect the airborne contaminant counts [19]. Although the results data of percentage effectiveness to reducing population are varied, the statistical analysis using parametric Paired T-test showed no difference between the sampling methods used in the

experiment. The result of the microbial population in all rooms examined showed that the examined indoor air has good quality based on India's and Hong Kong's air quality standards of under 1,000 CFU/m^3 [36].

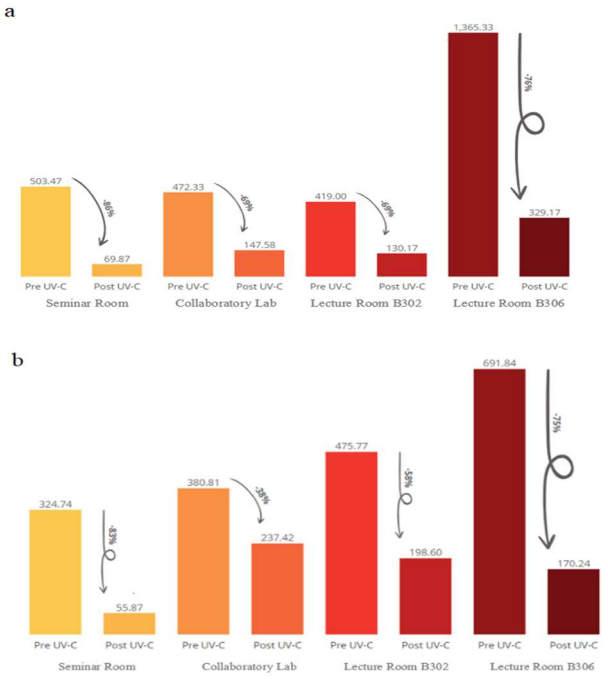

Fig. 4 The effectiveness of commercial UV-C germicidal lamp in examined rooms: active sampling (a), passive sampling (b).

IV. Conclusion

The commercial UV-C lamp can be applied as the disinfecting agent of airborne microorganisms, although company claim is not fully true. The UV-C lamp will be more effective if applied in an air of a closed room. Hence, the effectiveness of UV-C lamps was also can be affected by various factors, such as an existing group of microorganisms, air ventilation system, humidity, activity level, and the number of objects in a room, and it will affect the population of microorganisms in a room. Furthermore, the distance should also be considered to provide some lamps related to a square area that has to be disinfected.

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