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Daylight Performance of Fiber Optic Daylighting in Deep Plan Office Room

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Abstract

Most buildings have spaces far from the windows that require artificial lighting for illumination throughout the day. In fact, artificial lighting contributes to the second highest electrical energy consumption, especially in educational institutions that require more lighting. One of the appropriate solutions to illuminate areas far from windows is using a fiber optic daylighting system. FOD is used to distribute sunlight into the spaces away from the window. This research tested the lighting levels produced by alternative collector and diffuser models of FOD systems to meet the lighting level standards (lux) in discussion room P. 06. 05. Petra Christian University. This research uses experimental methods under actual weather exposure and simulation with DIALux software. Simulation results show that the room requires 6 collectors and 2 diffusers, arranged centrally and symmetrically. It produces 365 lux and a uniformity ratio of 0.59, which meets the standard. The lighting level data used was at 10:30 AM during partially cloudy conditions.

INTRODUCTION

Along with the development of society and the advancement of technology, the need for electrical energy is also increasing (Siregar, 2019). The electrical growth increased to 4.1% annually. According to the World Green Building Council (2019), buildings consume a large amount of energy, around 39% of the world's energy. In Indonesia, buildings consume approximately 50% energy and electricity consumption increases by 70% (Wicaksono & Soebiyakto, 2020). That is the reason why Indonesia is called an electricity-wasting country. From 70%, around 25% of the electrical energy is used for lighting, making lighting the second largest electrical consumption (Luzerina & Alvi Utari, 2018). According to existing research, educational institution buildings are in second place in consuming electrical for artificial lighting, which is 25% as described in Figure 1 (Luzerina & Alvi Utari, 2018).

The wasteful use of electricity in Indonesia has also caused global warming in Indonesia (Mulyani, 2021). That issue can happen because of burning coal for electrical energy (Mulyani, 2021). Coals are fossil fuel and non-renewable energy that will run out if we use them excessively (Wiratmaja & Elisa, 2020). In addition, the increase in fossil fuel use has an impact on increasing the intensity of greenhouse gas emissions and worsening the quality and sustainability of the environment (Allifah et al., 2022).

The 7th aspect of the United Nations Sustainable Development Goals has several goals for 2030 including developing renewable energy to support economic and human development (Kroll et al., 2019). Renewable energy comes from natural sources such as sunlight, wind, rain, geothermal, and biomass (Rahman et al., 2022). This research examines the sun's benefits as a renewable source of natural lighting. It is because the research location is in Surabaya, Indonesia and it has a lot of solar lighting potential. With the help of technology, sunlight can be used for solar collector systems, photovoltaic systems, and solar thermal power (Rahman et al., 2022). The sun's potential in Indonesia can reach 4.80 kWh/m2/day which is enough to support these uses (Jumina & Wijaya, 2012).

The lighting system is a crucial factor for activities in a room (Furqoni & Prianto, 2021). User activities will be optimal in a room that has appropriate lighting quality (Furqoni & Prianto, 2021). The most significant way to reduce electricity consumption due to artificial lighting is to maximize natural lighting from sunlight (Idrus et al., 2020). Utilizing natural lighting combined with technological assistance can save 50% of the building's total energy needs for lighting (Wiyanto, 2021). Not only has an impact on saving energy, but natural lighting is also beneficial for mental and physical health, increases productivity, and livens up the atmosphere of space (Santoso & Antaryama, 2005; Sreelakshmi & Ramamurthy, 2022).

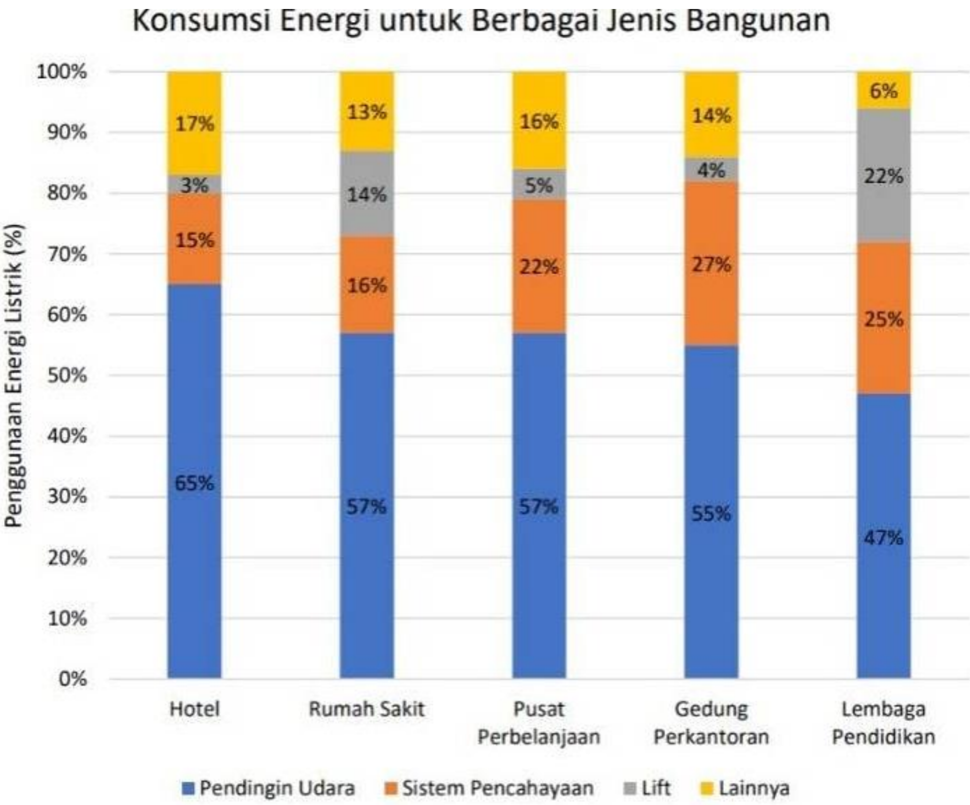


Fig. 1. Buildings's Energy Consumption Chart (Source: Luzerina & Alvi Utari, 2018)

One way to include natural lighting inside the building is to provide openings such as windows (Natalia & Suharjanto, 2022). However, not all parts of buildings can be given windows easily, especially in thick or deep-plan types of buildings (Abdel-Azis et al., 2019). A deep-plan building is a building that has a plan depth dimension of more than 8 to 10 meters as described in Figure 2 (Hansen, 2006; Abdel-Azis et al., 2019). This deep-plan design causes areas that do not get natural light (Hansen, 2006; Abdel-Azis et al., 2019).

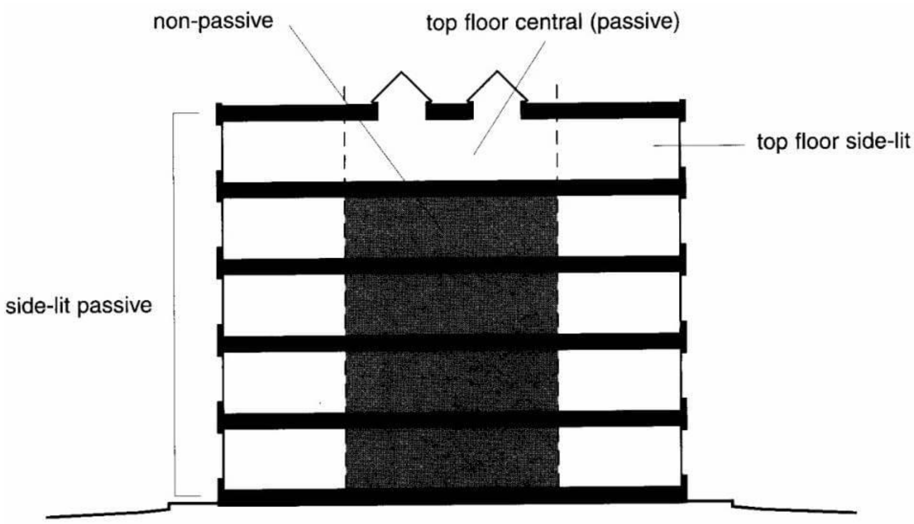


Fig. 2. Passive and Non-Passive Lighting Inside the Building (Source: Hansen, 2006)

One of the best-implemented systems is to use fiber optic daylighting (Liu et al., 2023) (Figure 3). It is a natural light distribution system for tall buildings. This distribution system absorbs and channels sunlight through optical fibers into the building (Ruck & Aschehoug, 2000; Liu et al., 2023). Fiber optic daylighting has many advantages in its application in multi-storey deep-plan buildings (Sreelakshmi & Ramamurthy, 2022; Ndujiuba et al., 2014). Fiber optic daylighting system is more flexible, does not interfere with spatial planning, and can be placed as far away from the light source as far as 15 m (Ndujiuba et al., 2014; Tembhare et al., 2020).

Channeled light also does not cause glare to users in the room, increases productivity, and also stimulates the user's circadian system (Sreelakshmi & Ramamurthy, 2022). Besides improving thermal comfort, an application of a fiber optic daylighting system also creates a sustainable building and environment (Sreelakshmi & Ramamurthy, 2022). However, in its design, it is necessary to consider the sun's conditions and the materials used so that the transmitted light can still meet the standards (Sreelakshmi & Ramamurthy, 2022).

Fig. 3. Fiber Optic Daylighting System (Source: Wilson, 2010)

Previous studies have shown that fiber optic daylighting systems efficiently continue natural light into buildings. However, several studies have found problems with the reflected light influx from the collector into the fiber and exposure to different weather and climates that affect the effectiveness of fiber optic daylighting. The things proposed in this study are collector design modifications, alternative diffusers, and diffuser layout to meet the room's standard lighting level (lux).

FIBER OPTIC DAYLIGHTING

Fiber optic or optical fiber is a transmission channel or cable made of glass or plastic that is small in size and can be used to transfer light from one place to another (Andre & Schade, 2002). This technology has high popularity because of its function to enter sunlight deep into the inside of a building (Ndujiuba et al., 2014; Song et al., 2021). A fiber optic daylighting system consists of light sources and collectors, fiber optic cables, and outputs or luminaires (Andre & Schade, 2002). Because it takes advantage of direct sunlight, weather factors play roles in its use (Mayhoub, 2014). It is necessary to use this system when the weather is sunny to support its optimal performance (Mayhoub, 2014). Weather with a tropical climate is perfect for the application of this system (Munaaim et al., 2014).

The collector in the fiber optic daylighting system is the most significant part (Sreelakshmi & Ramamurthy, 2022). It is because of its function as a receiver and director of the amount of sunlight (Sreelakshmi & Ramamurthy, 2022). Collectors divide by diverting or concentrating sunlight (Sreelakshmi & Ramamurthy, 2022). However, to avoid solar radiation and efficiently collect sunlight, using a collector that concentrates the light is more suitable (Sreelakshmi & Ramamurthy, 2022).

The type of collector used in this study is a biconvex lens collector with a size of 50 mm. It is based on previous research by Andre & Schade (2002) and Bharathwaj & Srinivasan (2009) as their explanation about the advantages of this lens-type collector (Table 1). Biconvex lenses can help block UV radiation and have a better ability than single convex lenses in concentrating light (Andre & Schade, 2002) as described in Figure 4. The collector's size in this study takes a reference from Kumar et al. (2013) research. He found that with a lens diameter of 50 cm and a focal length of 35 cm, the resulting temperature was 130 degrees Celsius, lower than other types and sizes of collectors as described in Sreelakshmi & Ramamurthy, (2022).

The type of fiber used for this research is PMMA as described in Table 1. Based on a literature review from Sreelakshmi & Ramamurthy, (2022), PMMA has a good light transmission efficiency value of 93-96%. The number of fibers used could be measured from the size of the focal length. A focal length of 3.5 cm can be filled with 7 pieces of fibers (this research uses a scale of 1:10). Another study that uses 7 pieces of fibers is Alhajri et al. (2020) and Savaş (2022). Other research by Al-Obaidi et al. (2017) uses 7 mm fiber. Fiber length is a scale of 1:10 according to reality, namely 1.2 m.

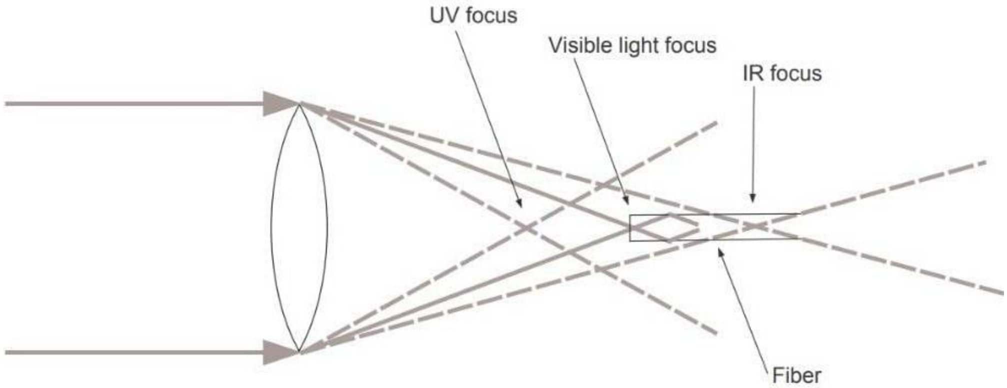


Fig. 4. Biconvex Lens Scheme (Source: Andre & Schade, 2002)

Tabel 1. Previous Research

Previous Research of Fiber Optic Daylighting System		
Elements	**Authors**	**Explamation**
Collector	Biconvex Glass Lens (Andre & Schade, 2002; Bharathwaj & Srinivasan, 2009; Kumar et al., 2013)	Useful for focusing sunlight, able to filter the beat, IR and UV filters.
Fiber	7 PMMA Fiber 1 mm (Alhajri et al., 2020; Savas, 2022), 7 mm PMMA (Al-Obaidi et al., 2017)	PMMA efficiency is in the range of 93-96%
Diffuser	Parabolic Diffusers (Sims, 2022)	Parabolic shape is suitable for work area.

The shape of the diffuser tested in this study is the parabolic type as described in Table 1. Parabolic diffuser was chosen because it has light distribution in all directions making it more even and suitable for the work area (Sims, 2022). The several alternative parabolic shapes will be tested to find out which parabolic shape can produce better lighting (Figure 5 and Figure 6).

(a) (b)

Fig. 5. (a) Short Parabolic Type A (b) Short Parabolic Type B

(a) (b) (c)

Fig. 6. (a) Long Parabolic Type A (b) Long Parabolic Type B (c) Long Parabolic Type C Doff Surface

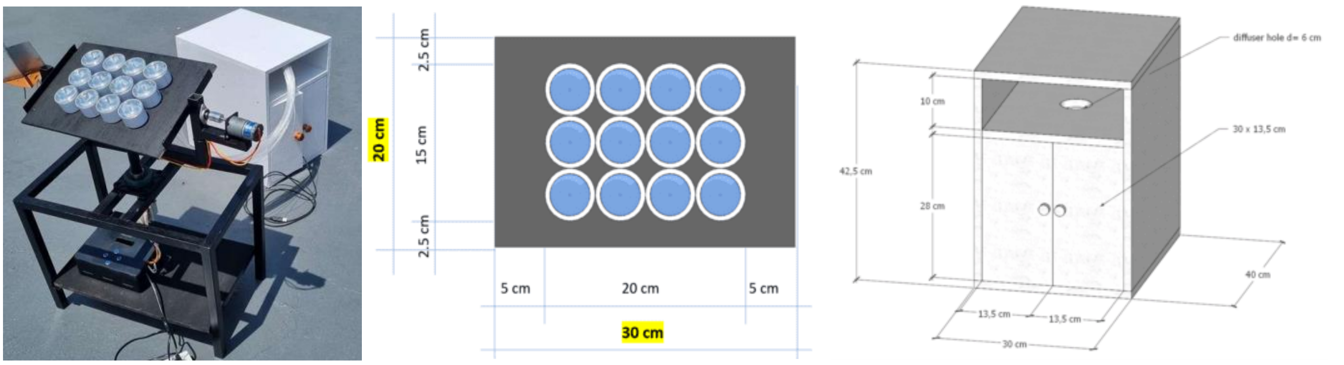
METHODOLOGY

The methods used in this study are experiments and simulations assisted with SketchUp and DIALux software. The simulation used a discussion room P. 06. 05. at Petra Christian University, Surabaya (Figure 7). The experiments used a mockup model consisting of collectors, diffusers, fibers, and the experiment box with a 1:10 scale (Figure 8).

(a) (b)

Fig. 7. (a) Position of Discussion Room P. 06. 05. (b) Long Parabolic Type B

Overall, this research consists of 4 phases. The first phase was the collection of data for discussion room P. 06. 05. including the size of the room and the level of lighting. The second phase was the creation of a 1:10 mockup for experimentation. The third phase was the experimental phase. The first experiment was a pretest, namely an experiment with diffuser shapes to choose the best alternative diffusers to produce the best lighting level (parabolic diffusers 2B and 2C). After the pretest, the following experiment is according to working hours, namely 08.00 AM - 4.00 PM, with a selected diffuser in the previous stage to choose the best one (parabolic diffuser 2B).



(a) (b) (c)

Fig. 8. (a) Mockup Scale 1:10 For Experiments (b) Collector's Size Scale 1:10 (c) Room Mockup Scale 1:10

After knowing the best diffuser, the following experiment was accomplished by reducing the number of collectors from 12-9-6-3 with the selected diffuser (parabolic diffuser 2B). This reduced amount of collectors was because, in the previous experiment with 12 collectors, the results of the lighting level were still too bright. The fourth phase is the simulation and design proposal. A simulation was accomplished with the help of SketchUp software to create a 3D room. From SketchUp, the 3D models moved into DIALux to simulate the lighting levels with each number of collectors.

RESULT AND DISCUSSION

We experimented with the model several times. For the first experiment, we measured the collector and tested the diffuser alternative on 9 February 2023 at 09.30 on the 7th-floor deck. At 09.30, the sun was at an altitude of 56.53' and the azimuth of 105.78' as described in Figure 9. The measurements of the alternative diffuser were carried out under the same conditions and alternately. At the time of the experiment, the weather was cloudy.

Fig. 9. Sun's Position on The First Experiment Day (Source: suncalc.org)

The experiment results showed that parabolic diffuser 2B with a reflective surface produced the best lighting level compared to other alternatives (Figure 10 and Figure 11). The minimum lighting level produced by parabolic 2B is 227.8 lux then the maximum can reach 238.4 lux. The average level of illumination produced by parabolic 2B is 233.1 lux with 2797.2 lm. The diffuser with the second highest lighting level is the parabolic 2C with a doff surface (Figure 10. and Figure 11). The diffuser parabolic 2C has a minimum lighting level of 183.4 lux and a maximum of 198.4 lux. The average luminance level of the parabolic 2C is 190.9 lux with 2290.8 lm.

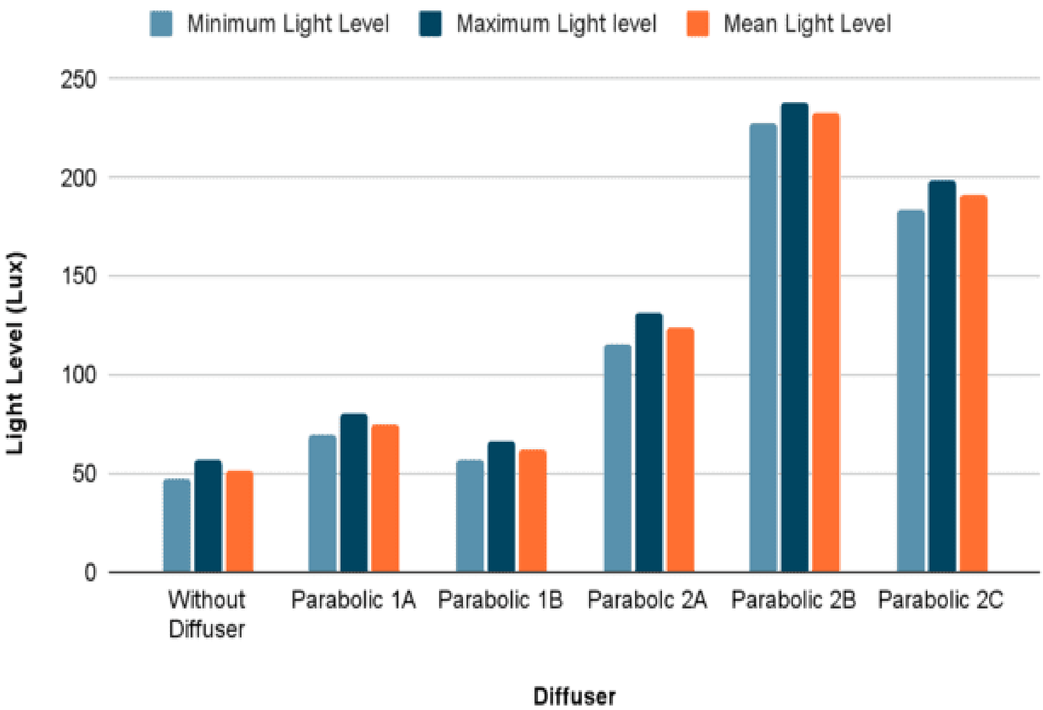


Fig. 10. Parabolic Diffuser Experiment

(a) (b)

Fig. 11. (a) Parabolic 2B Reflective Surface (b) Parabolic 2C Doff Surface

In terms of shape, both are longer parabolic than the other parabolic shapes. In the next stage, the two diffusers, parabolic 2B and 2C will be experimented more accurately by adjusting the height of the table and the diffuser attached to the ceiling. Tests were carried out according to working hours at 08.00 AM - 04.00 PM according to SNI 03-2396-2001 to estimate more detail about the lighting level.

The lighting level (lux) measurements of the parabolic diffuser 2B were experimented on 15 March 2023. Initially, the experiment used to be planned from 08.00 AM - 04.00 PM. However, the process finally stopped at 02.40 PM because the weather was dark and cloudy as it started to drizzle. Because there was no sunlight, the lighting level dropped far below standard. The experimental results (Figure 12.) show that at 08.00 - 08.50 AM, the weather conditions were cloudy so that the lighting level of the parabolic diffuser 2B could reach 248.3 lux at 08.00 AM and the maximum could reach 965.8 lux at 08.50 AM. The lighting level can meet the minimum target for the discussion room lighting level, namely 300 lux based on SNI 03-6575-2001.

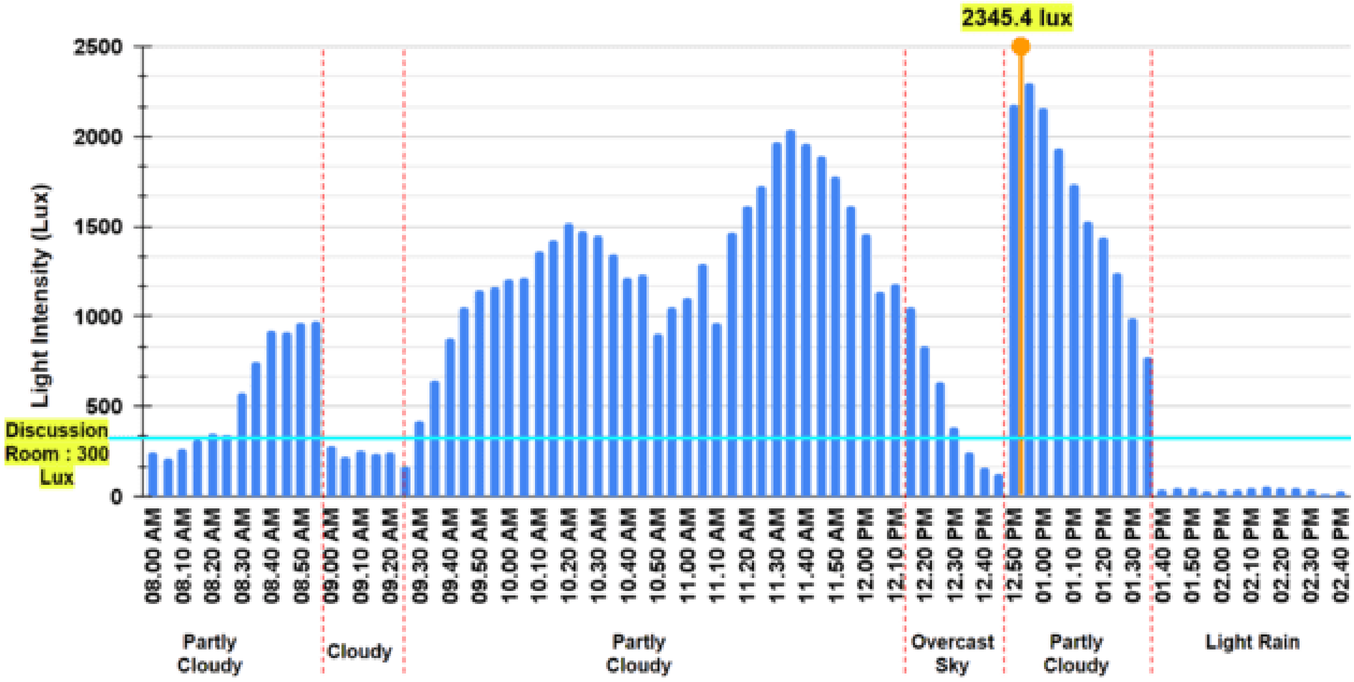


Fig. 12. The Result of Diffuser Parabolic 2B

However, starting at 09.00 - 09.25 AM, the weather conditions became cloudy and blocked the sunlight. The experimental results (Figure 12) also show that at 09.00 AM the lighting level dropped to 279.9 lux then the lowest was 169.5 lux at 09.25 AM. At 09.30, the weather conditions returned to cloudy and blocked the sunlight. In this condition, the lowest lighting level is at 09.30 AM namely 421.8 lux. Meanwhile, the highest lighting level in these conditions can reach 2038 lux at 12.52 PM.

From 12.15 to 12.45 PM, the weather changed from sunny to cloudy to moderately cloudy. These conditions caused the lighting level to decrease again (Figure 12). At 12.15 PM, the lighting level dropped to 1052.5 lux and hit the lowest 122.2 lux at 12.45 PM. 5 minutes later, the weather gradually cleared to partly cloudy. These caused the light level to increase to 2172 lux at 12.50 PM. The lighting level reaches its maximum value of 2345.4 lux at 12.52 PM. These conditions decreased to overcast gradually and caused the lighting level to drop to 776.6 lux at 01.35 PM.

Within 10 minutes, the weather conditions became dark and the lighting level decreased to 35.5 lux at 01.40 PM. The highest lux from the experiment during dark overcast sky was only 43.4 lux at 02.25 PM. While the lowest lux obtained during this dark overcast is 11.8 lux at 02.35 PM. Until 02.40 PM, the weather was still dark, and cloudy also started to drizzle. Because there was no change in conditions, we stopped the experiment.

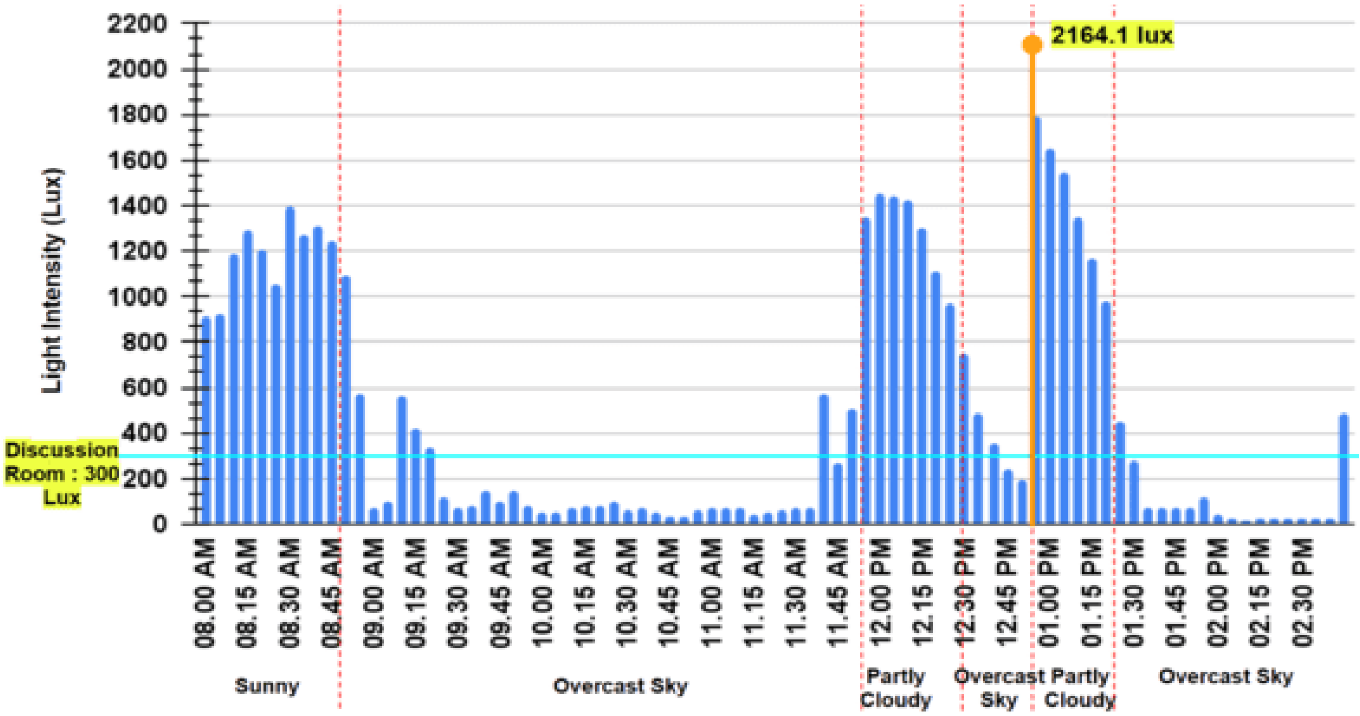


Fig. 13. The Result of Diffuser Parabolic 2C

Measurement of the lighting level (lux) of the diffuser parabolic 2C experimented on Monday, March 20, 2023. The experiment of parabolic 2C is planned for 08.00 AM - 04.00 PM. However, due to cloudy weather conditions which did not change until sunset, the experiment was stopped at 02.40 PM. The experimental results (Figure 13) show that when the sky conditions are clear at 08.00 - 08.50 AM the lighting level of the parabolic diffuser 2C is able to reach 910.6 lux at 08.00 AM so that it meets the target lighting level for the discussion room of 300 lux. The maximum lighting level generated by the 2C parabolic diffuser in bright conditions is capable of reaching 1399.4 lux at 08.30 AM. This sunny condition then gradually decreased until 08.50 when the lighting level also decreased to 1091.9 lux.

At 08.55 - 11.50 AM, the weather conditions became dark and gradually became partly cloudy at 12.00 PM. At 08.55 AM, the lighting level was 571.6 lux and decreased to 67 lux at 09.15 AM. The lighting level increased to 563.7 lux at 09.10 AM. At 12.00 PM, the lighting level can reach 1454.6 lux. However, this condition did not last long because the weather decreased to cloudy until 12.50 PM when the lighting level decreased to 193.2 lux. Conditions brightened in a short period, until 12.52 PM when the parabolic 2C's lighting level reached its maximum 2164.1 lux (see Figure 13).

From 12.52 PM to 01.20 PM, the weather was partly cloudy and gradually became cloudy. At 01.20 PM, the lighting level decreased to 981.5 lux. From 01.25 PM to 02.40 PM, weather conditions continued to become dark and overcast. At 01.25 PM, the lighting level decreased to 445.4 lux then at 02.40 the lighting level produced by parabolic diffuser 2C only reached 67 lux, far from the target lighting level required for the discussion room of 300 lux. The weather conditions were dark and cloudy and did not change so the experiment was stopped at 02.40 PM.

From the parabolic diffuser 2B and 2C experiments, we found that both of them could meet the minimum lighting standards for the discussion room. Diffuser parabolic 2B has the brightest lighting level than diffuser 2C. Even so, the results of the two were still too flashy. Therefore, we tried the next experiment by reducing the number of biconvex lens collectors. The following experiment on May 3, 2023, was accomplished by reducing the number of collectors to 9 collectors with the selected diffuser, namely model 2B (Figure 14). So based on experiments with room mockups measuring 30 x 40 cm, the result is that the lighting level is still very dazzling in several conditions depending on the sky conditions.

At 08.00 - 11.40 AM, the sky is relatively bright with thin clouds and fog. In this condition, the lighting level can reach a maximum of 965.8 lux at 10.35 AM and a minimum of 272 lux at 09.20 AM. From 11.50 AM to 04.00 PM, the weather became cloudy and caused the lighting level to decrease. In this condition, the maximum lighting level produced is 540 lux at 01.00 PM, and the minimum is 35.5 lux at 04.00 PM. At 03.30 PM, the buildings covered the sunlight. In that condition, the lighting level drops drastically.

The following experiment on May 5, 2023, was accomplished by reducing it to 6 collectors (Figure 15). From 08.00 - 11.00 AM, the weather was sunny with thin clouds. The minimum lighting level is 82.8 lux at 08.00 AM, and the maximum can reach 839.6 lux at 10.11 AM. This figure is the highest level of lighting produced from 6 collectors. From 11.10 AM to 01.00 PM, the weather conditions decreased to become cloudy until conditions became quite cloudy. Therefore, the maximum light level is only 208.9 lux at 12.10 - 12.20 P M and a minimum of 27.6 lux at 01.10 PM.

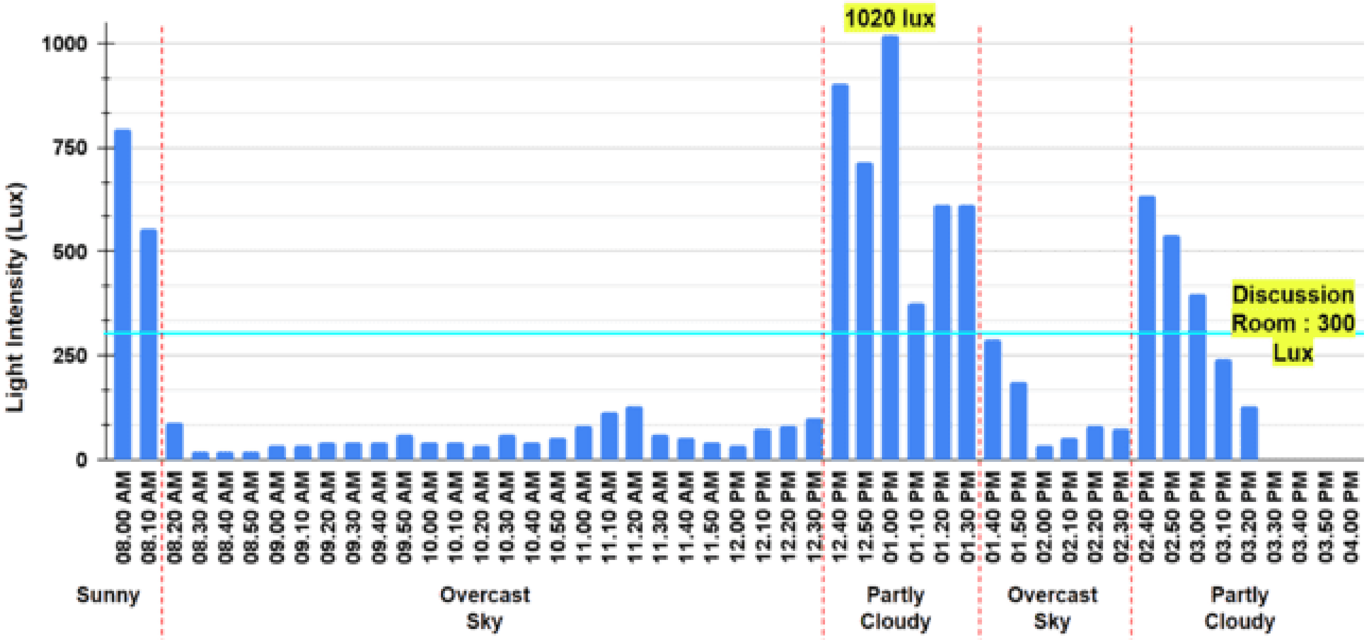


Fig. 14. The Result of Diffuser Parabolic 2B with 9 Collectors

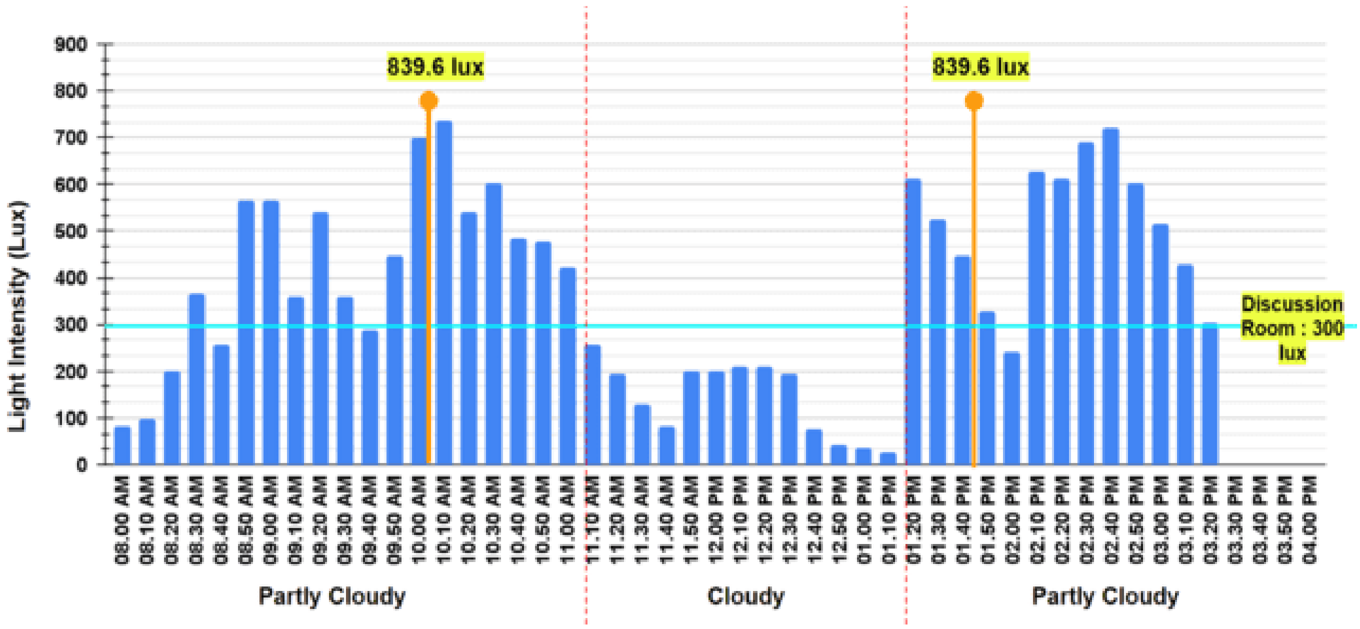


Fig. 15. The Result of Diffuser Parabolic 2B with 6 Collectors

After that, the weather conditions became cloudy starting at 01.20 PM. This condition lasted until 04.00 PM. In this condition, the maximum light level is at 01.45 PM, which is 839.6 lux. This lighting level is the highest at 10.11 AM. In addition, the lowest lighting level is at 04.00 PM, which is 11.8 lux. The lighting level decreased because the buildings blocked the sunlight.

For the last experiment on May 8, 2023, the lens collectors reduced to 3 and experimented from 08.00 AM - 4.00 PM. In this experiment, the sky conditions are very dynamic (Figure 16). From 08.00 - 09.00 AM, the weather condition was partly cloudy, and the maximum lighting level produced can reach 342.9 lux at 08.50 AM. At 08.10 AM, the lighting level decreased to its lowest, namely 114.3 lux. From 09.10 - 09.30 AM, the weather became cloudy. In this condition, the maximum light level only reached 82.8 lux at 09.30 AM, and the lowest was 43.4 lux at 09.20 AM.

At 09.40 - 11.30 AM, the weather was partly cloudy. The highest light level obtained was 382.4 lux at 10.20 AM, and the lowest was 208.9 lux at 11.30 AM. The highest point during measurements with these 3 collectors was 382.4 lux. At 11.40 - 11.50 AM, the weather conditions became cloudy again, and the lighting level dropped drastically to 106.4 lux and then decreased to 67 lux. At noon, the lighting level could reach 295.6 lux in partly cloudy conditions. The weather gradually became overcast, and the lighting level dropped to 43.4 lux. At 02.30 PM, the maximum lighting level increased to 295.6 lux and decreased to 59.1 lux. The lowest lighting level is only 11.8 lux at 04.00 PM.

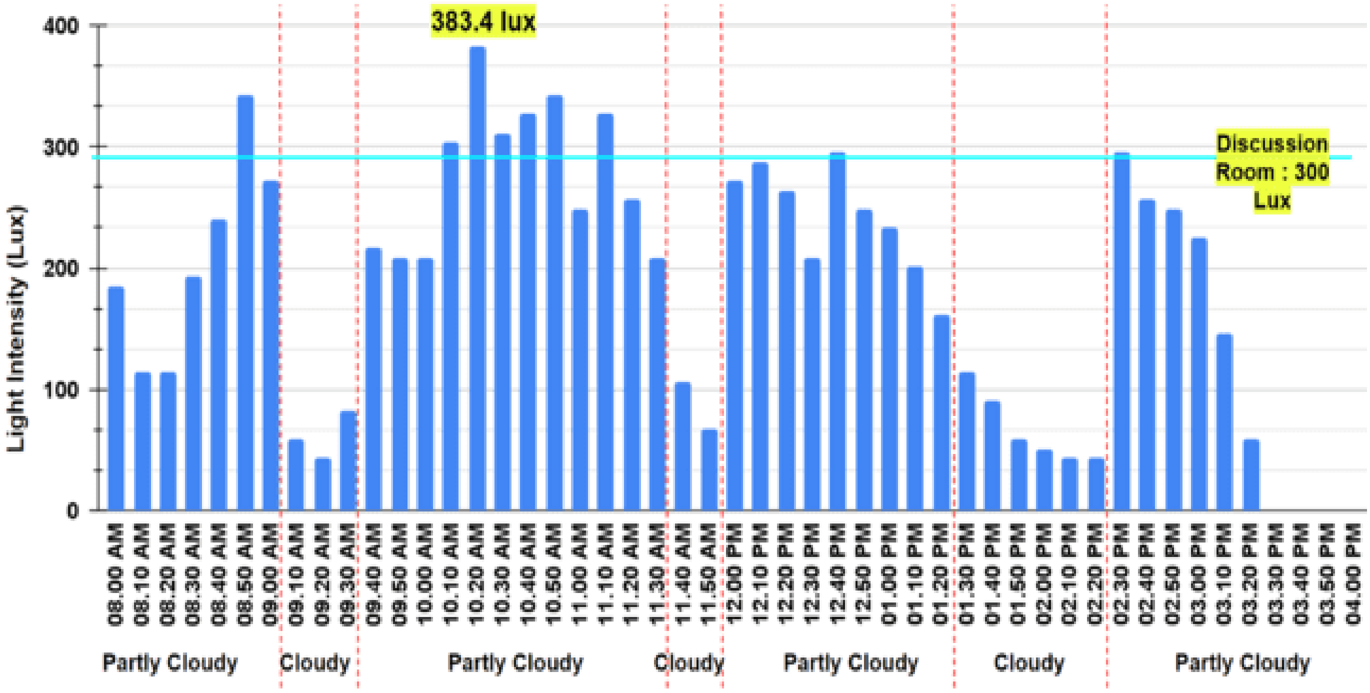


Fig. 16. The Result of Diffuser Parabolic 2B with 3 Collectors

After that, a simulation was accomplished for each collector with selected diffuser 2B to see the lighting level inside the existing discussion room P. 06. 05 (Table 2 and Table 3). The simulation used the lighting level experiment's result at 10.30 AM when the weather was partly cloudy. The lighting level from the experiment's result was used to find the lumen first. This lumen was used to search the lamp catalog on LUMsearch in the DIALux software, whose results are close to the experimental results to represent a diffuser. The simulation was accomplished using existing table and chair furniture to find the existing lighting conditions.

The discussion room has a floor-to-ceiling height of 2.75 m. The ceiling material is gypsum white painted with 91% LRV. The paint catalog used is Nippon Paint Vinilex Ceiling 001 Brilliant White. The plastered walls used the same paint as the ceiling. The floor material is ceramic with LRV 79% taken from the Grestec Ceramic Anti Slip YCA5391 catalog. The windows use clear glass with 10% LRV and aluminum frames with 70% LRV. The door used a mahogany wood catalog from Gustafs with 16.5% LRV, and the chair used the blue color from the Chieftain Fabrics Legend Bluebell catalog with 3.25% LRV adjusted to the color in reality.

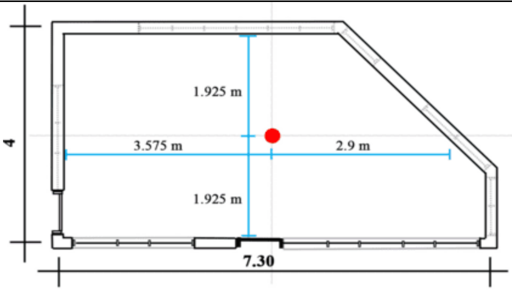
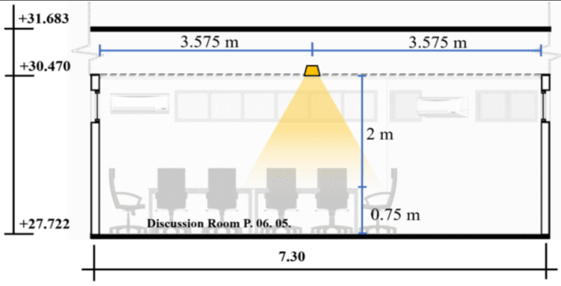
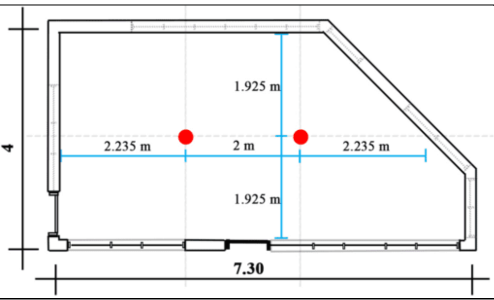
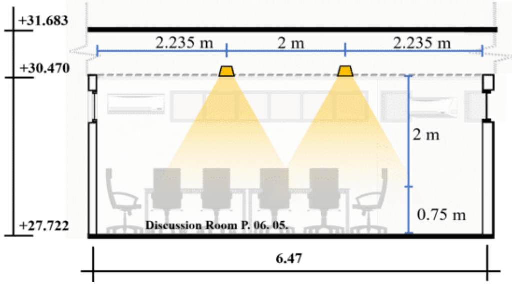
The placement of lights in the simulation used the PUPR standard (2020). The height of the work area with the light source in the discussion room is 2m. From this height, according to PUPR, the distance between lights should be 1 - 1.5 times the height, so for the discussion room, the distance between lights should be 2-3m. The distance between the lights and the wall in the discussion room is at least half the distance between the lights. The placement of lights on PUPR (2020) is preferably in a symmetrical gap in both directions (Table 2 and Table 3).

The simulation results (Table 3.), show that the number of collectors and diffusers and the arrangement affect the lighting level and the uniformity ratio. Based on the simulation, 6 collectors with 2 diffuser points with a 3 m distance between the points produced the best average lighting level and uniformity ratio for 10.30 AM. The diffuser's position is central, 1,725 m on both the right and left and 1,925 m on both the top and bottom sides. The position of the diffuser has a height of 2m from the working plane. The work area is 0.75 m from the floor. This arrangement conforms to the PUPR diffuser placement guide (2020).

The average lighting level produced by 6 collectors and 2 diffuser points 3 m apart is 365 lux, which already meets the minimum standard of SNI 03-6575-2001 for a discussion room, namely 300 lux. The highest lighting level was 530 lux, and the lowest was 214 lux. The uniformity ratio is 0.59, in the standard range of 0.5 - 0.7, as stated in the study by Mathalamuthu et al. (2018) and Liu et al. (2020). The atmosphere condition of the room using 6 collectors with a distance of 3 m becomes evenly brighter.

The collector will be located outside the building, away from the eaves, and get maximum sunlight (Figure 16. a). The collector position should be aligned horizontally with the diffusers in the discussion room to keep the distance below 15 m (maximum limit). Parallel placement also minimizes indentations in the fiber to continue the sunlight efficiently. In addition, the collector's place required additional planes and structures.

Tabel 2. Diffuser's Placement Inside the Discussion Room

First Plan (1 Diffuser)	
Plan	Section
	
Second Plan (2 Diffusers 2m Distance)	
Plan	Section
	
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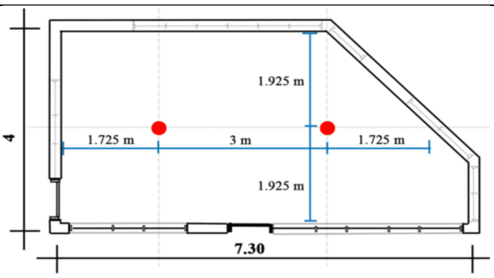
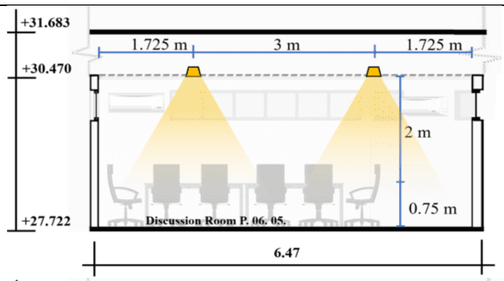
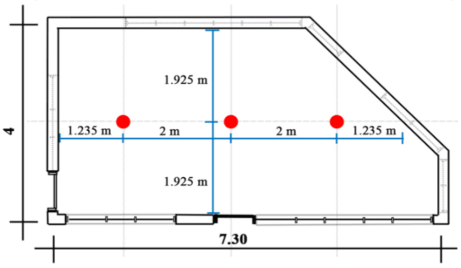
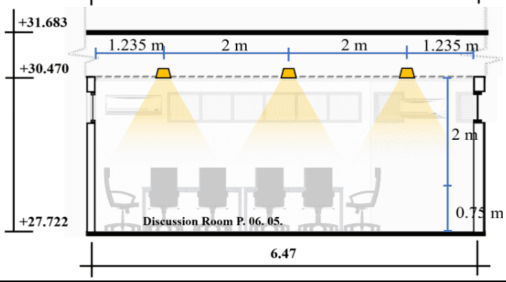
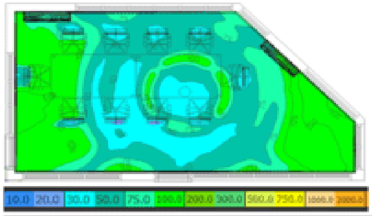
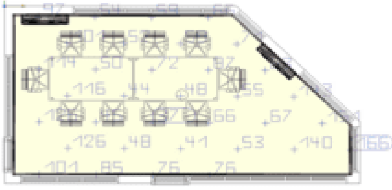
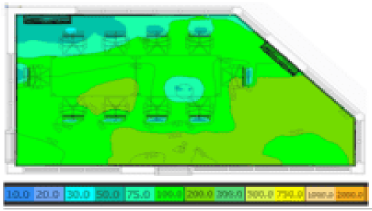
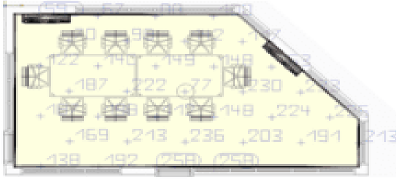
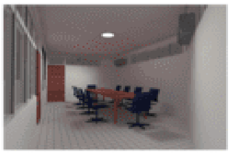
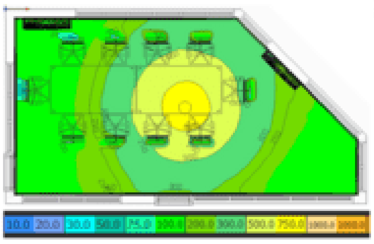
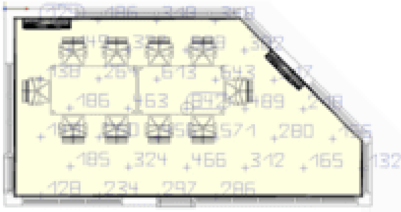
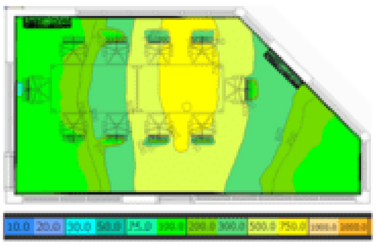
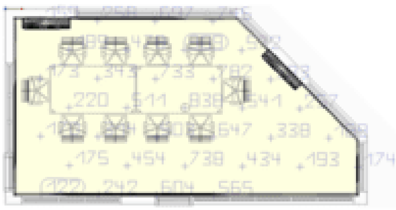
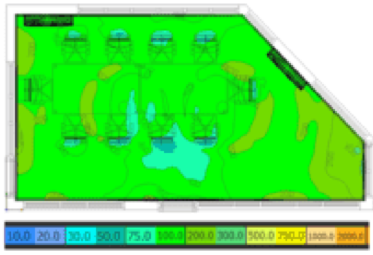
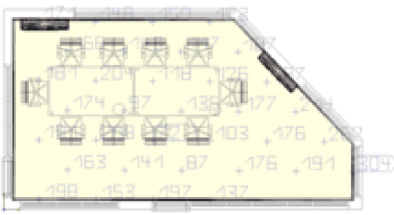
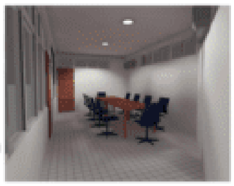
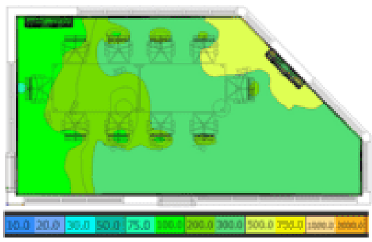
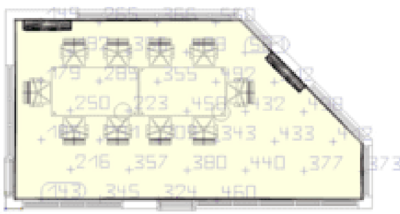
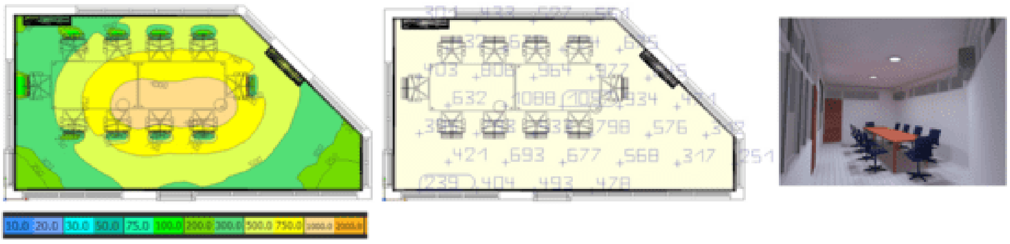
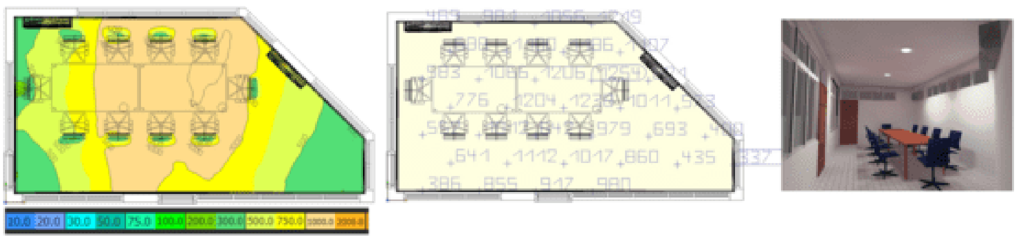
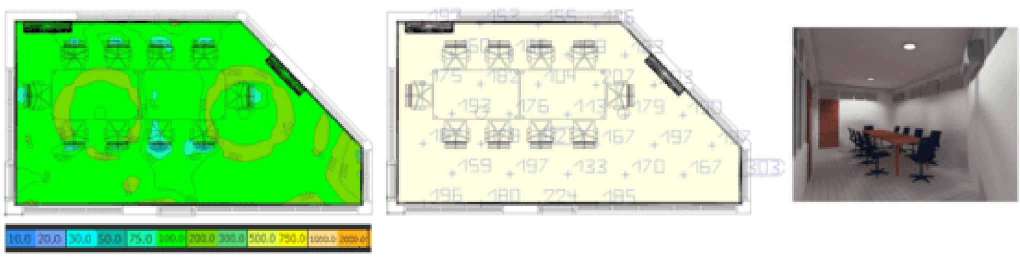
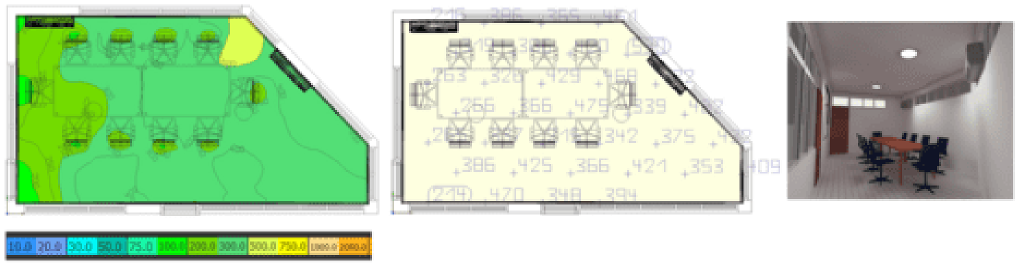
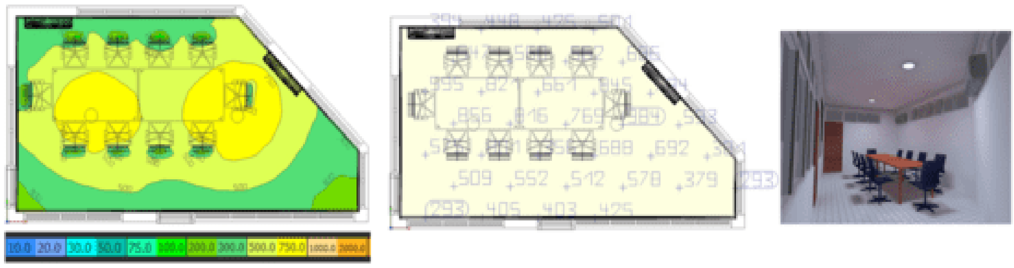
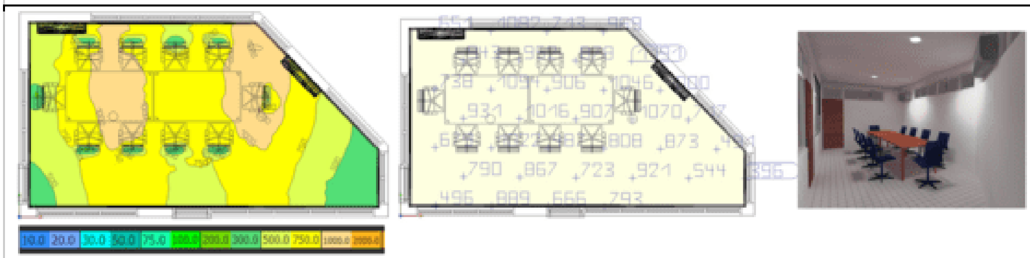
Plan	Section
	
	

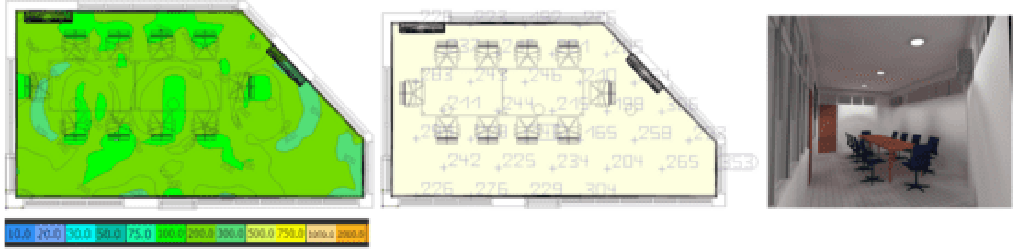
Tabel 3. Simulation Results

First Plan (1 Diffuser)			
3 Collectors - May, 8 2023 10.30 AM			
			Ē = 83.9 lux E min = 37 lux U = 0.44
6 Collectors - May, 5 2023 10.30 AM			
			Ē = 162 lux E min = 59 lux U = 0.37
9 Collectors - May, 3 2023 10.30 AM			
			Ē = 318 lux E min =124 lux U = 0.39
12 Collectors - May, 15 2023 10.30 AM			
			Ē = 414 lux E min = 122 lux U = 0.3
Second Plan (2 Diffusers 2m Distance)			
3 Collectors - May, 8 2023 10.30 AM			
			Ē = 164 lux E min = 72 lux U = 0.44
6 Collectors - May, 5 2023 10.30 AM			
			Ē = 342 lux E min = 143 lux U = 0.42

9 Collectors - May, 3 2023 10.30 AM	
	Ē = 600 lux E min= 239 lux U = 0.4
12 Collectors - May, 15 2023 10.30 AM	
	Ē = 845 lux E min = 337 lux U = 0.4
Third Plan (2 Diffusers 3m Distance)	
3 Collectors - May, 8 2023 10.30 AM	
	Ē = 171 lux E min = 62 lux U = 0.36
6 Collectors - May, 5 2023 10.30 AM	
	Ē = 365 lux E min = 214 lux U = 0.59
9 Collectors - May, 3 2023 10.30 AM	
	Ē = 600 lux E min= 239 lux U = 0.4
12 Collectors - May, 15 2023 10.30 AM	
	Ē = 817 lux E min = 396 lux U = 0.48

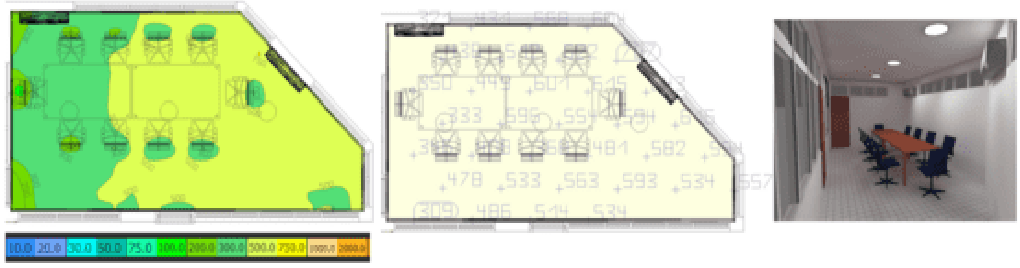
Fourth Plan (3 Diffusers)

3 Collectors - May, 8 2023 10.30 AM



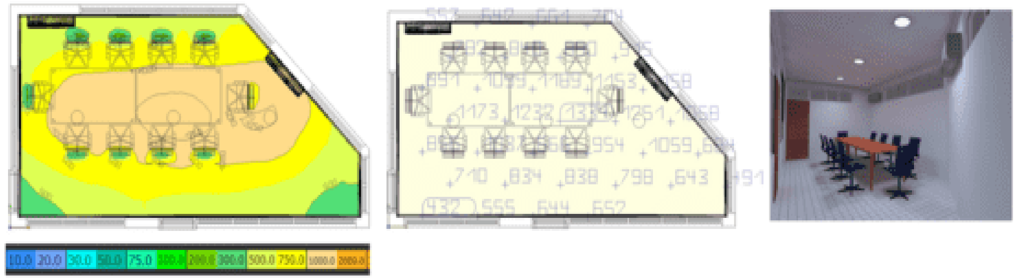
Ē = 235 lux
E min = 72 lux
U = 0.62

6 Collectors - May, 5 2023 10.30 AM



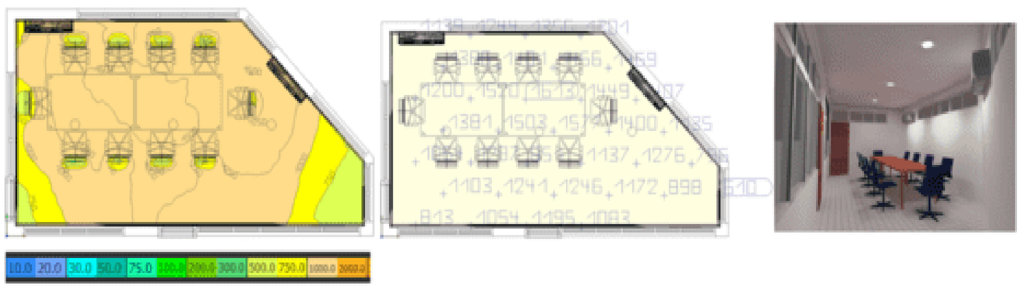
Ē = 504 lux
E min= 309 lux
U = 0.61

9 Collectors - May, 3 2023 10.30 AM



Ē = 875 lux
E min = 432 lux
U = 0.49

12 Collectors - May, 15 2023 10.30 AM



Ē = 1216 lux
E min = 610 lux
U = 0.5

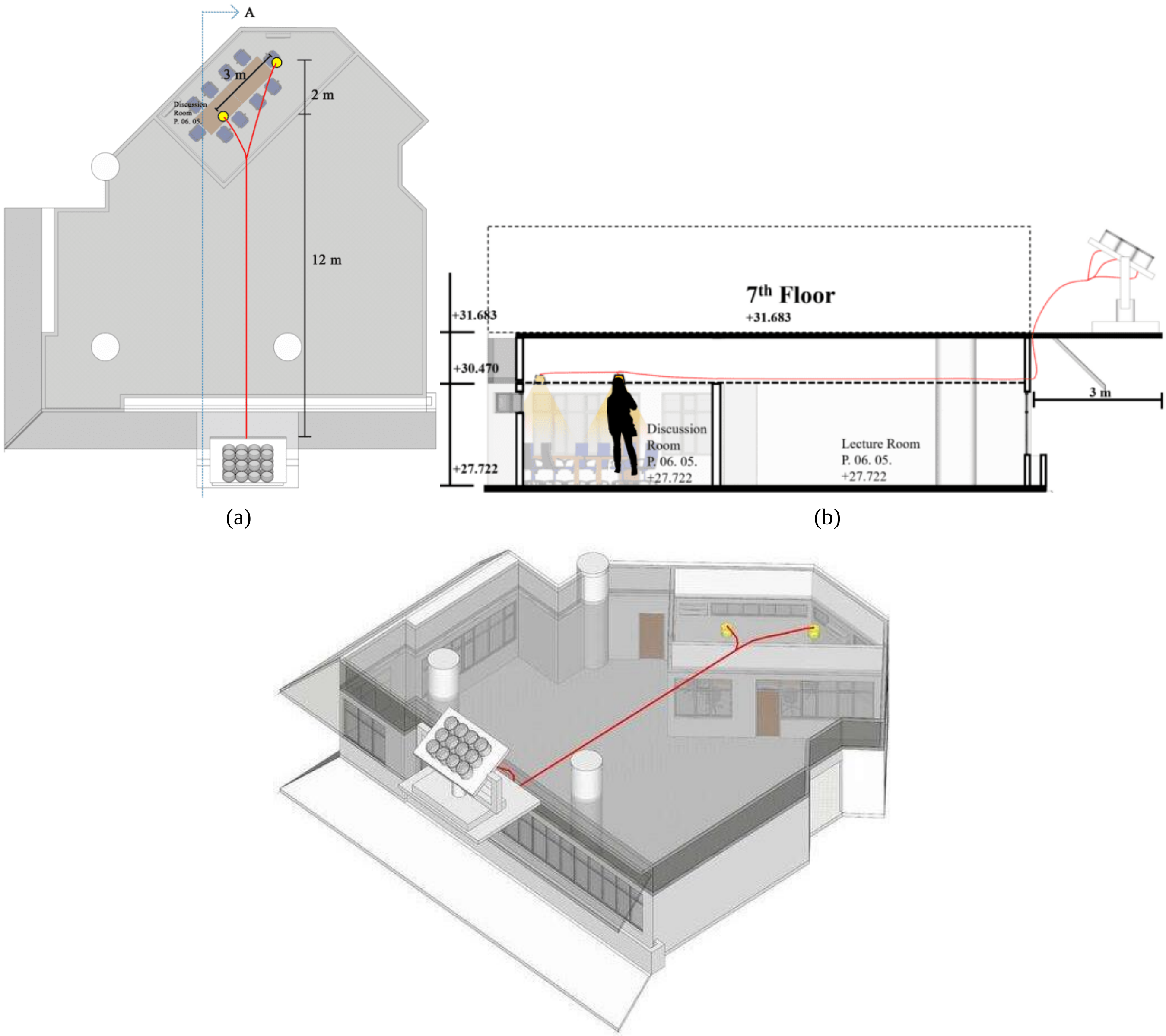


Fig. 17. (a) Plan of Collector, Fiber, and Diffuser Position (b) Section of Collector, Fiber, and Diffuser Position (c) Perspective of Collector, Fiber, and Diffuser Position

One diffuser point originates from 6 biconvex lens collectors (Figure 17). The total number of collectors needed is 12 pieces. Each lens has a diameter of 50 cm with a focal length of 35 cm in reality. The cross-section is 3 x 2 m, adjusted according to the number of lenses. This collector section will be placed on the roof of the 6th floor or parallel to the 7th floor horizontally (Figures 17. b). This placement aims to facilitate fiber span installation because they can be placed above the ceiling and make the space tidier. Because fiber is elastic and does not require a large area, it can get through a small hole in the wall and will not disarrange the building's structure.

CONCLUSION

The fiber optic daylighting system is a sustainable building and environmental solution. This system can continue natural lighting in areas far from windows up to 15 m without much damage to the existing building layout. The results showed that with 6 collectors and 2 diffusers spaced 3 m between points, the fiber optic daylighting system met the lighting needs in discussion room P. 06. 05. of 365 lux with 0.59 uniformity ratio at 10.30 AM. The best diffuser shape to use is a parabolic shape that resembles a hyperbolic at the ends and has a shiny surface. These results indicate that the fiber optic daylighting system can replace artificial lighting during the daytime to save electricity.

However, this passive daylighting fiber optic system depends on sunny or partly cloudy weather conditions to meet the lighting level requirements. Because the weather is dynamic, it will need further research with a combination of hybrid lighting technology. In addition, there is still a potential for overheating in this system. Therefore, advanced knowledge about materials or additional radiation filters inside the collector is needed to overcome overheating problems.

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