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EVALUATION AND OPTIMIZATION OF NATURAL LIGHTING ON THE SECOND FLOOR OF THE LAMPUNG HAPKIDO MARTIAL ARTS ROOM AT BTC (BAGOES TRAINING CENTER) GYM SEPUTIH RAMAN

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ABSTRACT

The light source that comes from sunlight entering directly into the room, especially in the morning and afternoon, is called natural lighting. SNI 03-2396-2001 states that ideal natural lighting during the day, from 08:00 to 16:00 WIB, should provide evenly distributed light throughout the room without causing glare. The standard illumination for martial arts training rooms ranges from 300 lux (minimum), 350 lux (medium), and 500 lux (maximum). The aim of the research is to evaluate and optimize natural lighting in sports spaces, particularly the Hapkido room on the second floor of the BTC (Bagoes Training Center) Gym in Seputih Raman, Lampung. The quality, orientation of window openings, and the distribution of light entering the building through windows are important factors in utilizing natural lighting. With larger window sizes, there is a need to control the amount of light entering the room. A quantitative method is used in this research. Data is collected through observation, literature review, light intensity measurements in the field, and simulations of current conditions using DIALux Evo. Data analysis uses mathematical formulas. The results show that lighting at BTC (Bagoes Training Center) Gym lacks light intensity and does not meet the standard. As a result, athletes feel less comfortable during training. At BTC Gym, lighting intensity has been adjusted to meet the lighting standards through several changes, such as lowering glass reflectance, altering window sizes, changing the type of window glass, and reducing sun shading. The lighting level has been improved, and the room now meets the SNI 03-2396-2001 standard. The Daylight Factor should be between 2% and 5%, with TUU between 0.5 and 0.8, and TUS between 0.3 and 0.5. A Daylight Factor above 10% can cause glare, uneven light distribution, and excessive heating, which requires design modifications to ensure optimal natural lighting.

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INTRODUCTIONS

The phenomenon of natural lighting in sports buildings is one of the important aspects in improving visual comfort and energy efficiency of buildings (Olotuah & Adeniji, 2020). Many sports facilities in Indonesia, including martial arts training rooms, still face problems related to uneven distribution of natural light and lighting levels that do not meet national standards (Rachmawati & Siahaan, 2021). These conditions can affect the comfort of space users and the effectiveness of exercise activities (Liu et al., 2023).

Since SNI 03-2396-2001 sets the standard of sports hall lighting in the range of 300-500 lux with an even and glare-free light distribution, lighting improvements are required. Visual problems such as eye fatigue can be prevented with proper natural lighting. It can also help athletes stay competitive during training (Matusiak & Houser, 2023). It is possible that the hapkido room on the second floor of BTC Gym Seputih Raman has not met those standards and needs to be further evaluated.

DIALux software has been used in several previous studies to assess natural lighting in sports and educational buildings (Amping et al., 2021; Ikhsanty, 2023). While martial arts training rooms like Hapkido BTC Gym are still understudied, most studies focus on large-scale sports buildings. In addition, architectural factors such as window position, glass type, and building orientation have not been widely studied in the context of martial arts training rooms.

Therefore, this study aims to evaluate and optimize the natural lighting in the Hapkido BTC Gym Seputih Raman training room using DIALux simulation. This study was conducted to assess the suitability of the intensity and distribution of natural lighting with SNI 03-2396-2001. The results of the study are expected to provide recommendations for the best lighting design that can improve visual comfort, energy efficiency, and athletic performance.

METHOD

Tools and Materials

The tools and materials used in the study were UNI-T mini light meter UT383, meter, OPPO A5 mobile phone camera, *portable laser distance meter* (Fluke 414D), laptop, notebook, and stationery.

Design Method

The flow chart in this study illustrates the stages of the methodology used, starting from the beginning to the end of the research. Each step in this flowchart shows the overall research process. A research flow diagram can be seen in Figure II.1, which describes the workflow as follows:

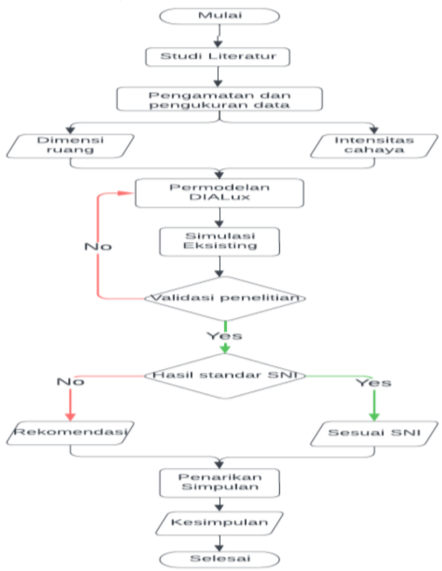

Figure II.1 Research Flow Diagram

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a. Literature Studies
The literature used includes books, journals, and previous theses that discuss lighting in sports buildings, especially martial arts rooms. Building observations are also carried out to obtain data on dimensions, space openings, and types of materials that affect lighting intensity. The information will be adjusted to secondary data obtained from the building's DIALux model.

b. Data Observation and Measurement
Lighting level measurements are carried out at several key points in the room to get a complete picture of the light distribution. The measurement point is selected in the center of the room, the work area, the natural light source, and the corner of the room. The area of the room is divided into two parts, with the size of room 1 being 12 x 3.76 meters and room 2 being 6 x 6 meters. The measurement point of natural light intensity is shown in the following Figure II.2:

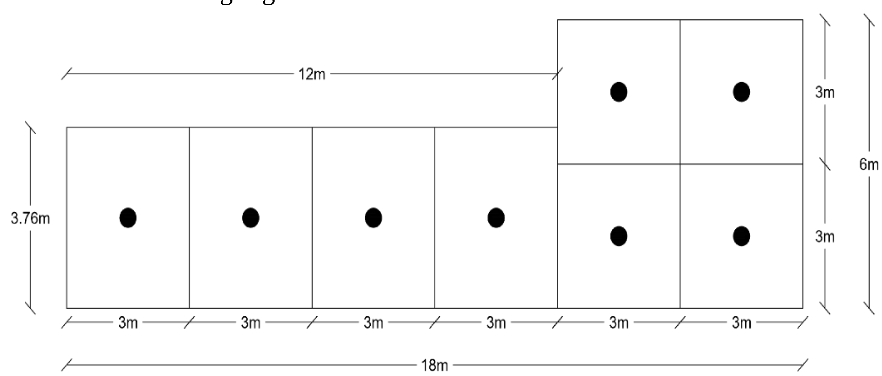

Figure II.2 Measuring points of natural light intensity

Based on SNI 03-2396-2001, there are provisions in the requirements for determining daylight factor measuring points according to the direction of the window and others. Figure II.3 below is a plan of *daylight factor measurement points:*

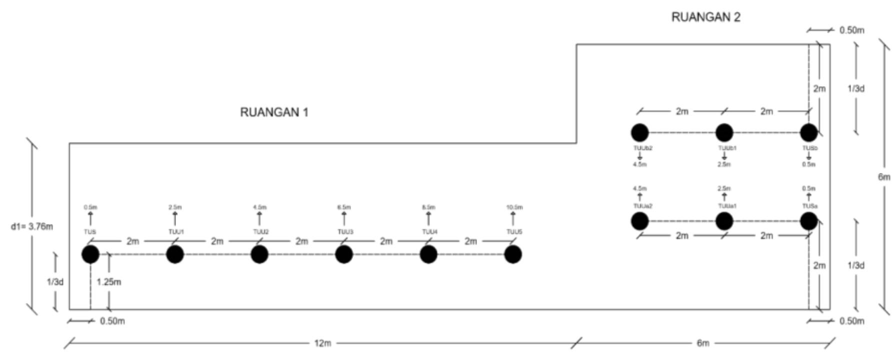

Figure II.3 Lighting level measurement point plan

c. Data Collection
Data were collected through a quantitative approach using a luxmeter tool. Measurements were carried out three times, namely at 08.00 WIB, 12.00 WIB, and 15.00 WIB, to collect light intensity data. Simulations of existing buildings are carried out using DIALux, Autocad and SketchUp, the building models are adjusted based on field observations. A model of a hapkido martial arts building is shown in Figure II.4. The following:

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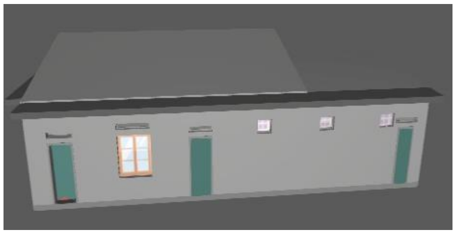

Figure II.4 Existing building model of hapkido lampung

d. DIALux Modeling
DIALux software is used to design and inspect natural lighting systems. Modeling is carried out by creating a digital model of the building that includes the dimensions of the room, the location of the windows, and other factors that affect the distribution of natural light. The results of the DIALux simulation are validated with the results of field measurements to ensure the accuracy of the model.

e. Research Validation
Validation was carried out by comparing the results of field measurements and the results of the DIALux simulation. The validation process uses the Mean Absolute Percentage Error (MAPE) method to measure the accuracy of the prediction from the DIALux simulation.

f. SNI Standard Results
The measurement and simulation results were compared with SNI 03-2396-2001 lighting standard. Natural lighting in martial arts buildings is assessed based on light intensity of at least 300 lux, medium intensity of 350 lux, and maximum of 500 lux. Recommendations are made if there are areas that do not meet the standards.

g. Conclusion
Conclusions were drawn based on the analysis of measurement results and simulations. The study evaluated the effectiveness of DIALux in modeling natural lighting and provided recommendations for improvements such as window sizing adjustment or installing sun shading to improve the quality of lighting indoors.

Research Variables

The study on the evaluation of natural lighting intensity on the second floor of the Hapkido Lampung martial arts room at BTC GYM Seputih Raman provides recommendations for the ideal natural lighting design in accordance with SNI 03-2396-2001. This study used control variables (location and orientation of buildings, dimensions, and spatial functions), bound variables (natural lighting intensity, daylight factor, and glare), and independent variables (glass type, window size, and sun shading location). The limitations of the study only focus on these independent variables to provide optimal recommendations in meeting lighting standards.

Research Observations

Observation of the architecture of the Hapkido martial arts hall building at BTC GYM Seputih Raman shows that the dimensions, types of glass openings, and the materials of building elements have a significant effect on the intensity of natural lighting. Natural lighting is used throughout the day through openings on the east and west sides, with open corridors and shadows on the east side, but no shadows on the west side.

The dimensions of the opening, which include height, width, and depth, affect the distribution of natural light entering the space. In this space, there is a combination of awning and fixed windows, with several glass blocks. Windows use frosted glass to reduce exposure to excess sunlight, especially due to the orientation of the building that faces directly east and west. The window-to-wall (WWR) ratio on the east side of wall 2 meets natural lighting standards with a WWR value of 25%, while the west side and the other wall have a WWR well below standard, indicating the need for adjustments to optimize lighting.

The materials used in building elements also affect lighting. Brick walls with a white finish have 50% reflectance, concrete ceilings have 70% reflectance, and clear glass has up to 90% reflectance. The use of white concrete sun shading on the east side also helps reduce the intensity of direct light and increase the energy efficiency of the building. *Sun shading* is one of the important strategies in reducing exposure to direct sunlight, improving

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thermal comfort, and optimizing natural lighting. The size of sun shading in this building is 18 meters long and 1 meter wide.

RESULT AND DISCUSSIONS

Standard Deviation Values in Existing Spaces with TUU and TUS

Based on SNI 03-2396-2001, there are provisions in the requirements for determining daylight factor measuring points according to the direction of the window and others.

Standard Values of Natural Lighting Deviation in the Morning

The following results of the standard values of lighting deviation in existing rooms in the morning can be shown in Table III.1, Table III.2A and Table III.2B.

Table III.1 Results of Standard Deviation Values in Room 1 in the Morning

Measuring Point	**Measurement (Lux)**				**Average (Lux)**	**Standard Deviation**	**Margin of Error (%)**
	1	**2**	**3**	**4**			
TUS	185	184	188	182	184.75	2.5	1.80
TUU_1	248	249	250	254	250.25	2.62	1.89
TUU_2	989	998	1002	997	996.50	5.44	3.92
TUU_3	390	338	334	339	350.25	26.58	19.14
TUU_4	250	252	249	250	250.25	1.25	0.90
TUU_5	360	362	349	350	355.25	6.70	4.82
Total Average					397.87	7.52	5.41

Table III.2A Results of Standard Deviation Values in Room 2 in the Morning

Measuring Point	**Measurement (Lux)**				**Average (Lux)**	**Standard Deviation**	**Margin of Error (%)**
	1	**2**	**3**	**4**			
TUS_A	444	447	453	451	448.75	4.03	2.90
TUU_{A1}	481	476	472	480	477.25	4.11	2.96
TUU_{A2}	542	548	588	576	563.50	22.05	15.87
Total Average					496.50	10.06	7.247

Table III.2B Results of Standard Deviation Values in Room 2 in the Morning

Measuring Point	**Measurement (Lux)**				**Average (Lux)**	**Standard Deviation**	**Margin of Error (%)**
	1	**2**	**3**	**4**			
TUS_B	337	329	335	336	334.25	3.59	2.58
TUU_{B1}	442	439	452	448	445.25	5.85	4.21

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Volume 14 No. 4. Desember 2025 https://ejournal.unibabwi.ac.id/index.php/sosioedukasi/index

TUU_{B2}	452	458	462	461	458.25	4.50	3.24
Total Average					412.58	4.64	3.34

Standard Values of Natural Lighting Deviation during the Day

The following results of the standard values of lighting deviation in existing rooms during the day can be shown in Table III.3, Table III.4A and Table III.4B.

Table III.3 Results of Standard Deviation Values in Room 1 during the Day

Measuring Point	**Measurement (Lux)**				**Average (Lux)**	**Standard Deviation**	**Margin of Error (%)**
	1	**2**	**3**	**4**			
TUS	158	148	150	149	151.25	4.57	3.29
TUU_1	145	146	156	162	152.25	8.18	5.88
TUU_2	1126	1168	1680	1726	1425	322.01	231.84
TUU_3	219	208	214	213	213.50	4.50	3.24
TUU_4	90	98	97	93	94.50	3.69	2.66
TUU_5	217	198	204	189	202	11.74	8.45
Total Average					373.08	59.11	42.56

Table III.4A Results of Standard Deviation Values in Room 2 during the Day

Measuring Point	**Measurement (Lux)**				**Average (Lux)**	**Standard Deviation**	**Margin of Error (%)**
	1	**2**	**3**	**4**			
TUS_A	528	529	530	532	529.75	1.70	1.22
TUU_{A1}	317	323	321	328	322.25	4.57	3.29
TUU_{A2}	227	228	218	224	224.25	4.5	3.24
Total Average					358.75	3.59	2.58

Table III.4B Results of Standard Deviation Values in Room 2 during the Day

Measuring Point	**Measurement (Lux)**				**Average (Lux)**	**Standard Deviation**	**Margin of Error (%)**
	1	**2**	**3**	**4**			
TUS_B	213	211	220	221	216.25	4.99	3.59
TUU_{B1}	232	231	230	231	231	0.81	0.58
TUU_{B2}	164	163	162	163	163	0.81	0.58
Total Average					203.41	2.20	1.58

Standard Values of Natural Lighting Deviation in the Afternoon

The following results of the standard values of lighting deviation in existing rooms in the afternoon can be shown in Table III.5, Table III.6A and Table III.6B.

SJP Sosioedukasi
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Volume 14 No. 4. Desember 2025 https://ejournal.unibabwi.ac.id/index.php/sosioedukasi/index

Table III.5 Results of Standard Deviation Values in Room 1 in the Afternoon

Measuring Point	Measurement (Lux)				Average (Lux)	Standard Deviation	Margin of Error (%)
	1	2	3	4			
TUS	67	68	68	69	68	0.81	0.58
TUU_1	116	109	103	108	109	5.35	3.85
TUU_2	480	505	510	493	497	13.39	9.64
TUU_3	68	69	67	69	68.25	0.95	0.68
TUU_4	40	39	38	36	38.25	1.70	1.22
TUU_5	125	124	122	126	124.25	1.70	1.22
Total Average					150.79	3.98	2.87

Table III.6A Results of Standard Deviation Values in Room 2 in the Afternoon

Measuring Point	Measurement (Lux)				Average (Lux)	Standard Deviation	Margin of Error (%)
	1	2	3	4			
TUS_A	276	294	292	291	288.25	8.26	5.94
TUU_{A1}	258	257	256	258	257.25	0.95	0.68
TUU_{A2}	164	162	160	173	164.75	5.73	4.13
Total Average					236.75	4.98	3.58

Table III.6B Results of Standard Deviation Values in Room 2 in the Afternoon

Measuring Point	Measurement (Lux)				Average (Lux)	Standard Deviation	Margin of Error
	1	2	3	4			
TUS_B	154	151	153	155	153.25	1.70	1.22
TUU_{B1}	184	182	188	190	186	3.65	2.62
TUU_{B2}	122	121	123	125	122.75	1.70	1.22
Total Average					154	2.35	1.69

In the morning, some of the measurement points have met the lighting standards. During the day, some points exceed the standard, but others are still lacking. In the afternoon, most spots show low and substandard lighting.

Daylight *Factor Value* in Existing Rooms

SNI 03-2396-2001 states that for sports buildings, the minimum sky factor is 0.25d TUU and 0.20d TUS. Since data collection is done in the afternoon, afternoon, and evening, the sides of the aperture that are considered important are east and west. If described by d, which means that d room 1 is 3.76 meters and d room 2 is 6 meters, it will be produced:

a) The east side of room 1 is 0.25 x 3.76 meters = 0.94 %. Fl_{min}
b) TUU east side of room 2 is 0.25 x 6 meters = 1.5%.Fl_{min}
c) The TUU on the west side of room 1 is 0.20 x 3.76 meters = 0.752%.Fl_{min}
d) TUS on the west side of room 2, which is 0.20 x 6 meters = 1.2%.Fl_{min}

SJP Sosioedukasi
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Volume 14 No. 4. Desember 2025 https://ejournal.unibabwi.ac.id/index.php/sosioedukasi/index

Daylight *Factor* *Value* in the Morning

Table III.7, Table III.7A, and Table III.7B show the results of the measurement of the sky factor in the current building for the east and west side measurement points taken in the morning.

Table III.7 *Daylight Factor* in Room 1 in the Morning

Measurement Point	**Indoor Light Intensity (Lux)**	**Outdoor Light Intensity (Lux)**	**Daylight Factor (%)**	Fl_{min} **(%)**	**PUT** Fl_{min} **(%)**	**TUS**
TUS	184.75	3716.25	4.97	1.24	0.99	
TUU_1	250.25	3628	6.89	1.72	1.37	
TUU_2	996.5	3728	26.73	6.68	5.34	
TUU_3	350.25	3220	10.87	2.71	2.17	
TUU_4	250.25	3449.25	7.25	1.81	1.45	
TUU_5	355.25	2706.75	13.12	3.28	2.62	

Table III.7A *Daylight Factor* in Room 2 in the Morning

Measurement Point	**Indoor Light Intensity (Lux)**	**Outdoor Light Intensity (Lux)**	**Daylight Factor (%)**	Fl_{min} **(%)**	**PUT** Fl_{min} **(%)**	**TUS**
TUS_A	448.75	3140.25	14.29	3.57	2.85	
TUU_{A1}	477.25	3157.25	15.11	3.77	3.02	
TUU_{A2}	563.5	3495.75	16.11	4.02	3.22	

Table III.7B *Daylight Factor* in Room 2 in the Morning

Measurement Point	**Indoor Light Intensity (Lux)**	**Outdoor Light Intensity (Lux)**	**Daylight Factor (%)**	Fl_{min} **(%)**	**PUT** Fl_{min} **(%)**	**TUS**
TUS_B	334.25	2482.75	13.46	3.36	2.69	
TUU_{B1}	445.25	3284.25	13.55	3.38	2.71	
TUU_{B2}	458.25	2593.25	17.67	4.41	3.53	

Daylight *Factor* *Values* During the Day

The following Table III.8, Table III.8A, and Table III.8B show the results of the measurements of the sky factor in the current building for the east and west side measurement points taken during daytime.

Table III.8 *Daylight Factor* in Room 1 during the Day

Measurement Point	**Indoor Light Intensity (Lux)**	**Outdoor Light Intensity (Lux)**	**Daylight Factor (%)**	Fl_{min} **(%)**	**PUT** Fl_{min} **TUS (%)**
TUS	151.25	7078.25	2.136	0.534	0.42
TUU_1	152.25	7574.75	2.00	0.50	0.40
TUU_2	1425	8085.75	17.62	4.40	3.52
TUU_3	213.5	8763.75	2.43	0.60	0.48

SJP Sosioedukasi
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ISSN: 2086-6135 E-ISSN: 2541-612x
Volume 14 No. 4. Desember 2025 https://ejournal.unibabwi.ac.id/index.php/sosioedukasi/index

TUU_4	94.5	8018.75	1.178	0.29	0.23
TUU_5	202	8295.50	2.43	0.60	0.48

Table III.8A *Daylight Factor* in Room 2 during the Day

Measurement Point	Indoor Light Intensity (Lux)	Outdoor Light Intensity (Lux)	Daylight Factor (%)	Fl_{min} PUT (%)	Fl_{min} (%) TUS
TUS_A	529.25	9489.75	5.57	1.39	1.11
TUU_{A1}	322.25	8551.50	3.76	0.94	0.75
TUU_{A2}	224.25	9019.75	2.48	0.62	0.49

Table III.8B *Daylight Factor* in Room 2 during the day

Measurement Point	Indoor Light Intensity (Lux)	Outdoor Light Intensity (Lux)	Daylight Factor (%)	Fl_{min} PUT (%)	Fl_{min} (%) TUS
TUS_B	216.25	9559.75	2.26	0.56	0.45
TUU_{B1}	231	8678.25	2.66	0.66	0.53
TUU_{B2}	163	8083.75	2.01	0.50	0.40

Daylight *Factor Value* in the Afternoon

The following Table IV.9, Table IV.9A, and Table IV.9B show the results of the measurements of the sky factor in the current building for the east and west side measurement points taken during daytime.

Table III.9 *Daylight Factor* in Room 1 in the Afternoon

Measurement Point	Indoor Light Intensity (Lux)	Outdoor Light Intensity (Lux)	Daylight Factor (%)	Fl_{min} PUT (%)	Fl_{min} TUS (%)
TUS	68	8320	0.81	0.2	0.16
TUU_1	109	8998.25	1.21	0.30	0.24
TUU_2	497	8271.75	6.00	1.50	1.20
TUU_3	68.25	9258	0.73	0.18	0.14
TUU_4	38.25	8652.25	0.44	0.11	0.08
TUU_5	124.25	8077.25	1.53	0.38	0.30

Table III.9A *Daylight Factor* in Room 2 in the Afternoon

Measurement Point	Indoor Light Intensity (Lux)	Outdoor Light Intensity (Lux)	Daylight Factor (%)	Fl_{min} PUT (%)	Fl_{min} TUS (%)
TUS_A	288.25	9860	2.92	0.73	0.58
TUU_{A1}	257.25	9874.75	2.60	0.65	0.52
TUU_{A2}	164.75	7920.75	2.07	0.51	0.41

Sosioedukasi
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Table III.9B *Daylight Factor* in Room 2 in the Afternoon

Measurement Point	**Indoor Light Intensity (Lux)**	**Outdoor Light Intensity (Lux)**	**Daylight Factor (%)**	Fl_{min} **PUT (%)**	Fl_{min} **TUS (%)**
TUS_B	153.25	9817.75	1.56	0.39	0.31
TUU_{B1}	186	9848.75	1.88	0.47	0.37
TUU_{B2}	122.75	7505.75	1.63	0.40	0.32

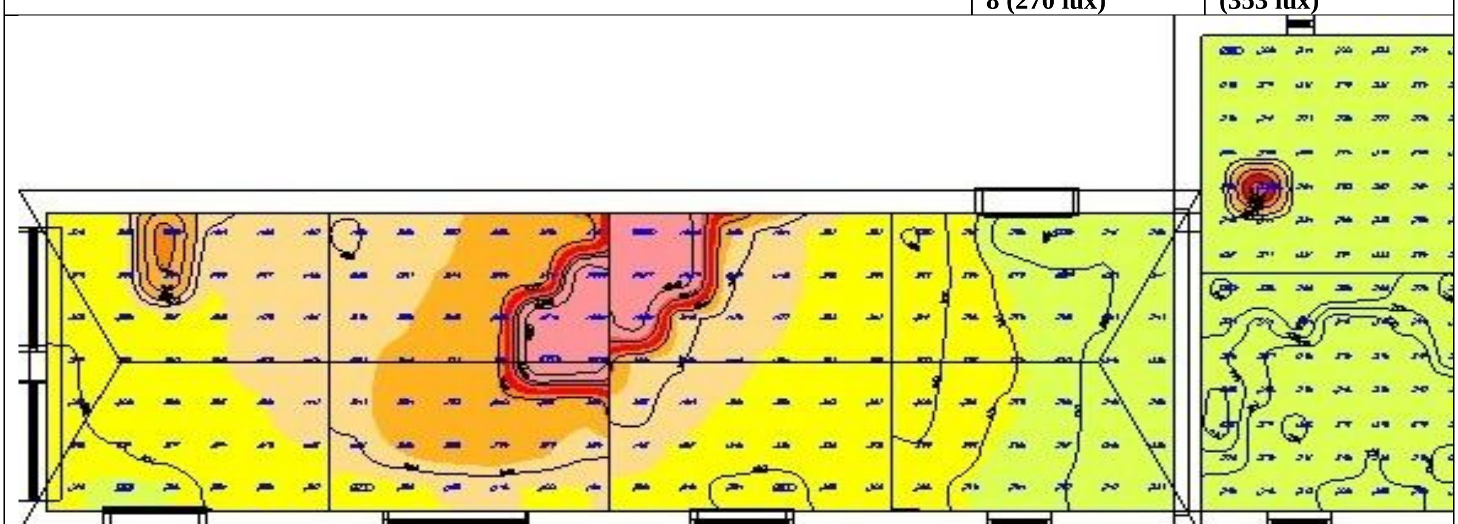
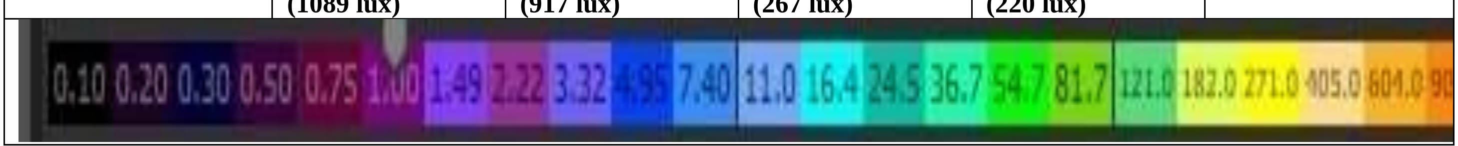
The sky factor in the morning and afternoon has exceeded SNI standards, ensuring sufficient natural lighting in both rooms. The afternoon shows a decrease in lighting, with some points below standard, especially on the west side of the room. Simulation Results of Natural Lighting Intensity Level in the Field

Simulation with Dialux software is needed to find out the level of natural lighting in the Lampung hapkido martial arts room. The simulation begins with simple condition modeling. The goal is to ensure that the data collected is correct if the measurement results match or are comparable to the field results. The measurements were taken on the same date and time as measured in the field on July 14, 2024 at 08.00 am, 12.00 pm, and 15.00 pm.

Simulated Results of Natural Lighting Levels in the Morning

Table III.10 Describes the results of simulating the level of natural lighting in the morning.

Table III.10 Results of simulation of natural lighting levels in the morning

<table>
<tr><td colspan="4"></td><td>Measuring Point 8 (270 lux)</td><td>Measuring Point 7 (353 lux)</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td>Measuring Point 1 (390 lux)</td><td>Measuring Point 2 (1089 lux)</td><td>Measuring Point 3 (917 lux)</td><td>Measuring Point 4 (267 lux)</td><td>Measuring Point 5 (220 lux)</td><td>Measuring Point 6 (233 lux)</td></tr>
<tr><td colspan="6">
</td></tr>
</table>

Simulation Results of Natural Lighting Levels during the Day

Sosioedukasi
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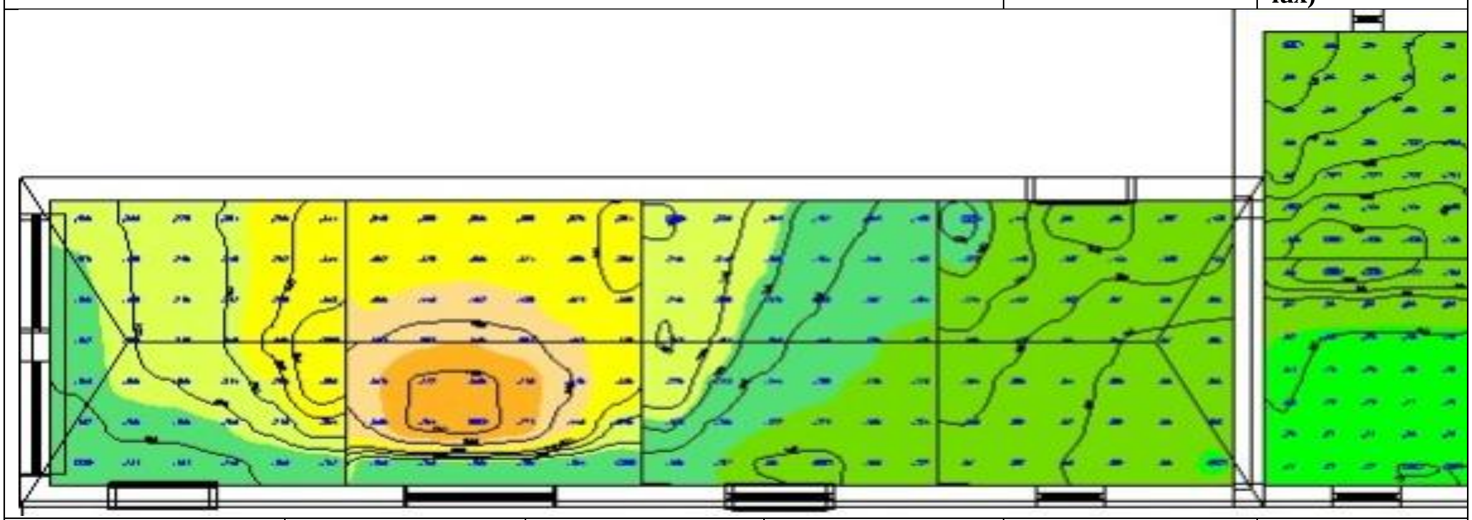
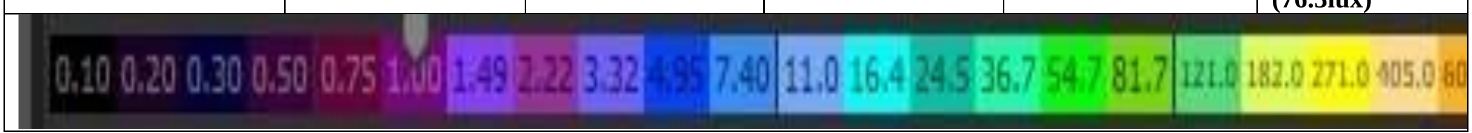
The results of the simulation of natural lighting levels during the day are described in the following Table III.11, which includes the measurement point number, the existing image, and the description of the image

Table III.11 Results of simulation of natural lighting levels during the day

				Measuring Point 8 (99.6lux)	**Measuring Point 7 (98.4 lux)**
					
Measuring Point 1 (220 lux)	**Measuring Point 2 (424 lux)**	**Measuring Point 3 (156 lux)**	**Measuring Point 4 (97.6 lux)**	**Measuring Point 5 (82 lux)**	**Measuring Point 6 (76.3lux)**
					

Simulation Results of Natural Lighting Levels in the Afternoon

The results of the simulation of natural lighting levels during the day are described in the following Table III.12, which includes the number of measuring points, existing images, and descriptions of the images.

Table III.12 Results of simulation of natural lighting levels in the afternoon

	Measuring Point 8 (99.1 lux)	**Measuring Point 7 (92.3 lux)**

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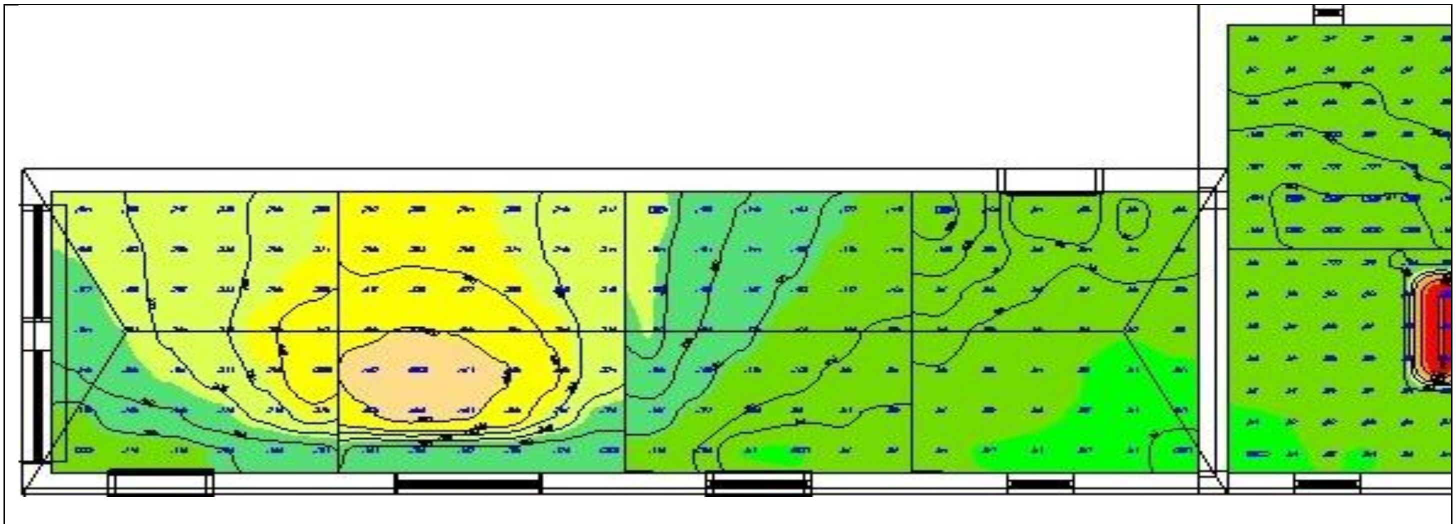
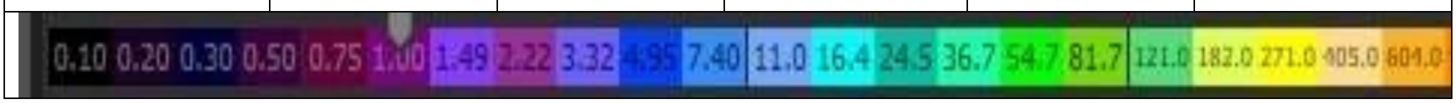
Volume 14 No. 4. Desember 2025 https://ejournal.unibabwi.ac.id/index.php/sosioedukasi/index



Measuring Point 1 (205 lux)	Measuring Tip 2 (290 lux)	Measuring Point 3 (124 lux)	Measuring Point 4 (87.8 lux)	Measuring Point 5 (205 lux)	Measuring Point 6 (79.7 lux)



The results of natural lighting simulations in the morning, afternoon, and evening showed that some measurement points had light intensity over or below the standard of 300-500 lux, so optimization was needed through changes in the design of windows, glass, and sunshades to achieve an even and standard light distribution.

Comparison Between Measurement Results and Natural Lighting Level Simulation

Comparison Between Measurement Results and Simulation of Natural Lighting Levels in the Morning

The following comparison between the measurement results and simulations of natural lighting existing in the field in the morning can be shown in Table III.13 below

Table III.13 Comparison between measurements and simulations of existing natural lighting in the field in the morning

Measurement Point	Average Value (Lux)	Simulation Value (Lux)	Error Values	Absolute Value
1	388.4	390	-1.6	0.0041
2	1088	1089	-1	0.0009
3	915.6	917	-1.4	0.0015
4	264	267	-3	0.0113
5	214	220	-6	0.0280
6	232.8	233	-0.2	0.0008
7	354.6	353	1.6	0.0045
8	269.4	270	-0.6	0.0022
Total Absolute Value				0.053

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N=8 and MAPE=0.669

Comparison Between Measurement Results and Simulation of Natural Lighting Levels During the Day

The following comparison between the measurement results and simulations of natural lighting existing in the field during the day, shown in Table III.14 below, is as follows:

Table III.14 Comparison between measurement results and simulated natural events in the field during the day

Measurement Point	Average Value (Lux)	Simulation Value (Lux)	Error Values	Absolute Value
1	221.6	220	1.6	0.0072
2	424.8	424	0.8	0.0018
3	151.4	156	-4.6	0.0303
4	97	97.6	-0.6	0.0061
5	81	82	-1	0.0123
6	75.4	76.3	-0.9	0.0119
7	93.6	98.4	-4.8	0.0512
8	95.6	99.6	-4	0.0418
Total Absolute Value				0.1630

N=8 and MAPE=2.038

Comparison Between Measurement Results and Simulation of Natural Lighting Levels in the Afternoon

The results of the measurement of the level of natural lighting present in the field in the afternoon, which are shown in Table III.15 below as follows:

Table III.15 Comparison between measurements and simulations of natural lighting in the field in the afternoon

Measurement Point	Average Value (Lux)	Simulation Value (Lux)	Error Values	Absolute Value
1	200.2	205	-4.8	0.0239
2	293.2	290	3.2	0.0109
3	119.6	124	-4.4	0.0367
4	87	87.8	-0.8	0.0091
5	201.8	205	-3.2	0.0158
6	78.2	79.7	-1.5	0.0191
7	92.2	92.3	-0.1	0.0010
8	98.6	99.1	-0.5	0.0050
Total Absolute Value				0.12205

N=8 and MAPE=1.525

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The results of the comparison between the measurements and the simulation of natural exposure levels showed that the simulation was quite accurate, with low MAPE values at all times, but some points still needed exposure optimization to reach the ideal standard of 300-500 lux.

3.5 Glare

After validation of the lighting model, the glare index value (UGR) of the hapkido room was below 10 at all times, well below the maximum limit of 22, indicating adequate lighting without excessive glare, creating a comfortable environment for exercising.

CONCLUSION

The natural lighting on the second floor of the hapkido martial arts room has mostly met the minimum standard of 300 lux, although some areas are still below 350 lux. Field simulations and measurements ensure an ideal natural light distribution can be achieved through design adjustments, such as window opening size, glass type, and sun shading. With this optimization, natural lighting can be improved, reducing reliance on artificial light and improving visual comfort for athletes.

It is recommended that:

a. Optimize window placement and size based on simulation results and field measurements, by adding or expanding windows in areas that receive more natural light.
b. It is recommended to use glass material according to SNI with a high light transmission rate to increase natural lighting without the need to significantly increase the number of windows.
c. Sun shading settings, such as the addition of a canopy or louver, need to be considered to reduce glare without compromising natural lighting.
d. It is recommended to use reflective surfaces on walls or ceilings to maximize natural light distribution and create even lighting.

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