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Efficiency on artificial lighting energy: dome, pyramid and flat shaped - ceiling mosque

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Efficiency on artificial lighting energy: dome, pyramid and flat shaped - ceiling mosque

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Abstract. Indonesia is the largest Muslim country in the world, around 87.2% of its population are Muslim. Mosque, as the center of Muslim activities, has important roles for Muslim's physical and social aspects. Therefore, it causes a massive addition of mosque buildings in Indonesia. Mosques are mostly built in spacious areas that increase the possibility of extravagance in lighting. This study explores the different types and configuration patterns of artificial lighting to be applied in the different shapes of mosque ceiling and how they relate to energy efficiency. Using the software simulation DIALux, this study aimed to find the best artificial lighting types and configuration patterns that possible for most efficient energy in terms of its illuminance distribution quality. Al Musyawarah Mosque, al Falah Mosque and Sunda Kelapa Mosque in Jakarta are the sample chosen for this study. Those mosques were chosen because their ceiling shapes represent the shape of Indonesian mosque ceiling in general: dome, pyramid and flat-shaped ceiling. As the result, a basic guideline for efficient lighting configuration in different shaped ceiling mosques is proposed.

1 Introduction

Indonesia is the fourth-largest country in the world in terms of its population. 87,2 % of Indonesia's population are Muslims, which makes Indonesia became the biggest Muslim country in the world [1]. Mosque as Muslim's worship facility is a crucial element, physically and socially. For Muslims, mosque is a communication system [2], not only between them and their god but also between fellow Muslims.

The number of mosque buildings in Indonesia is exceedingly large and continues to increase every year. In 2013, the number of mosques in Indonesia counted as many as 731.096 buildings. However, the number was growing by 20% and reach about 1.169.753 in 2016, where 90% of them were built independently by society [3]. The construction of the mosque that is carried out independently by the community often carried out without involving experts such as architects and lighting designers. Without a lighting expert, lights are often placed excessively and without proper calculations. Mosques, which generally built on a gigantic scale tend to increase the possibility of excessive use of lights.

Aside from its large number, mosques in Indonesia also have varied ceiling shapes [4], which generally classified in three shapes: dome, pyramid and flat. The difference in ceiling shapes causes the difference of the room shapes and characteristics of the room, therefore a specific lighting analysis and treatment for each different ceiling shape of mosques is needed.

Lighting is substantial in architecture. It gives certain functions, emotions, shape perception and atmosphere to the building, more importantly, it makes people able to see, communicate and do things in the buildings [5]. The importance of lighting in architecture especially in mosque comes with problems of energy. 28% of electricity used in worship facilities are used for lighting [6]. Electricity in Indonesia is sourced from 87,5% of non-renewable energy source, including 58% of coal [7]. Indonesia is the largest coal exporter in the world, but the country has much smaller reserves and production rates of coal [8].

The discussion above explains background problems of this study, they are: the large number of mosques, the varied shaped of its ceiling, the importance of lighting in mosque, highly potential of inefficient lighting use in mosque and the amount energy used for lighting in mosques.

This research aims to find the most efficient artificial lighting types and configuration pattern that is possible for mosques with different ceiling shapes: flat, pyramid and dome-shaped ceiling. The term efficient referred to the illuminance distribution quality. The results will be a basic guideline for efficient lighting types and configuration patterns for different shaped ceiling mosques which is expected to fulfill the necessary information for architect, lighting designer and society.

2 The Lighting of The Mosques

Lighting in architecture has three effects on human, they are visual function, emotional perception and biological effects [5]. For mosques, the visual function is to make mosque's user visually able to do worshipping activities well. The emotional perception is how lighting can enhance the mosque's architectural scenes and elements. The biological effect is how lighting can be stimulating and relaxing.

Table 1 shows specification of illuminance (E), minimum glare value (UGR), minimum illuminance uniformity (U) and Color Rendering Index (CRI) determined by Commission Internationale d'Eclairage (CIE), the Society of Light and Lighting (SLL) [9] and Standar Nasional Indonesia (SNI). SNI is the only nationally valid standard in Indonesia, determined by the National Standardization Agency (BSN) of Indonesia.

Table 1. Standards of illuminance, glare, color rendering index and illuminance uniformity

	CIE			**SLL**				**SNI**		
	E (lx)	UGR	CRI	E (lx)	UGR	CRI	U	E (lx)	UGR	CRI
Body of Mosque	100	25	80	150	22	80	0.4	200	22	70
Mihrab	300	22	80	300	22	90	0.6	200	22	70
Mimbar	300	22	80	300	22	80	0.6	200	22	70

The table shows that SNI has the same maintained illuminance value for all of mosques areas. SNI suggested the highest level of maintained illuminance for the body of mosque, 200 lx which is suitable for reading activity. Minimum illuminance uniformity is only determined by SLL. Therefore, lighting simulation in this study will refers to maintained illuminance, CRI and UGR by SNI and illuminance uniformity by SLL.

Former research shows that the shape of different surfaces when it comes to light, will give different directions of the light reflection [10]. Another former research stated that the acoustic performance in buildings with dome roofs is better than buildings with pyramid roofs [11]. From these two researches, it can be concluded that light and sound are both waves that can be reflected on a surface and will also have different direction when reflected to different surfaces.

3 Materials and Methods

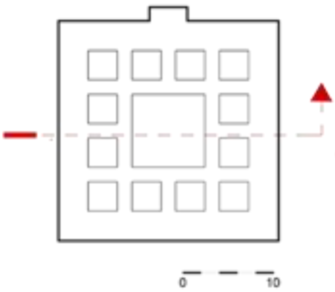
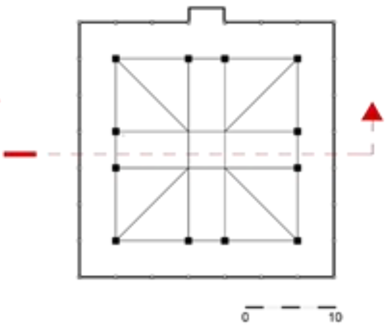
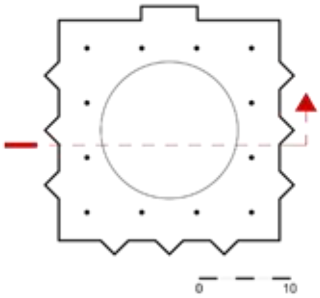
In order for the research objectives to be met, an experimental strategy with a quantitative approach is used. The intention of an experiment strategy is to test the impact of an intervention on an outcome [12]. For this study, the intervention are varied lighting types and configuration pattern and the outcomes are the three mosques with different ceiling shape.

The experimental strategy was done by computer simulation using lighting software DiaLux. The outputs of the software simulation that was used for lighting efficiency analysis are lighting distribution false-color diagram, average illuminance and illuminance uniformity for each different lighting types and configuration patterns in three different mosques. Those outputs are then being analyzed to determine which lighting configuration is the most efficient for each different mosque.

3.1 Mosque Samples

This study chose three different samples of mosques, each of them represents the different shapes of ceilings that are generally used in the country, flat-shaped ceiling, pyramid-shaped ceiling and dome-shaped ceiling [4]. Those mosques are Sunda Kelapa Mosque (flat shaped ceiling), al-Musyawarah Mosque (pyramid ceiling) and al-Falah Mosque (dome ceiling). The three mosques are chosen because they have similar: main hall area size, main hall plan proportion (all has square plan), number of floor and location (all located in Jakarta, Indonesia). Table 2 shows the interior view, floor plan and section of three mosque's main hall.

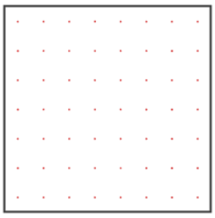
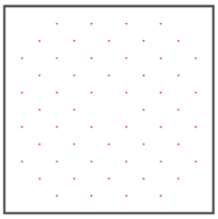
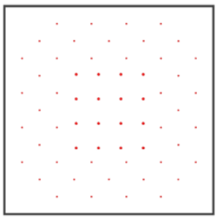
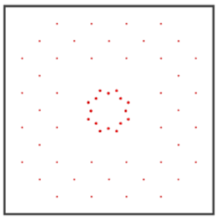
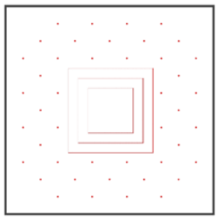
Table 2. Mosque Samples

	Sunda Kelapa Mosque	**Al-Musyawarah Mosque**	**Al-Falah Mosque**
Interior view			
Section			
Floor Plan			
Total Areas	576 m^2	784 m^2	605.25 m^2
Total Lumen Needed	174120 lm	209480 lm	188925 lm

3.2 Lighting Design

Each mosque sample will be applied to five different lighting designs. One lighting design has different lamp fixture types and configuration patterns from the other lighting designs. The variation of five lighting design was chosen because those types of lighting designs were used frequently and generally in buildings [13], especially mosque buildings. Those five lighting designs are: (1) evenly arranged downlights; (2) another evenly arranged downlight with different position; (3) evenly arranged pendant lighting combined with downlight; (4) centrally arranged pendant lighting combined with downlights; and (5) strip lights combined with downlights. The specification of five lighting types and configuration patterns for Mosque Sunda Kelapa, al-Musyawarah and al-Falah are given in table 3.

Table 3. Five Lighting Types and Configuration Pattern

	Design 1	Design 2	Design 3	Design 4	Design 5
1	**Lighting Types:**				
	Downlights	Downlights	Downlights & Pendant lights	Downlights & Pendant lights	Downlights & Strip lights
2	**Lighting Configuration Pattern:**				
	Evenly arranged	Evenly arranged	Evenly arranged	Centrally arranged	
3	**Lighting Plan**				
					

The five designs have exactly the same total lumens for each mosque. Therefore, the only variable that would be compared for lighting efficiency is the lighting types and configuration pattern. The lumen requirements for interior areas is principally calculated by using the following equation:

$$E = \frac{I}{h^2 + cos^3 x} \qquad (1)$$

Where, E (lx) is the targeted illuminance, I (lm) is the required lumen, h is the lamp height from the work area and x is the width of the lamp angle. The total lumen requirement for this study were determined by DiaLux software. The total lumen for Sunda Kelapa Mosque is 174120 lm, for al-Musyawarah Mosque is 209480 lm and for al-Falah Mosque is 188925 lm.

3.3 Software Application

3.3.1. Revit

Before lighting simulations were performed on DiaLux, Revit software was used to make geometric models of mosque samples. Revit is software for BIM (building information modelling) with tools to create intelligent 3D models of buildings [14]. It allows the user to be able to put the information about the building such as material types and specifications.

Three mosque samples that were geometrically modelled by Revit software were made exactly the same as the existing mosques. both the original building and the computer modelling have the same size, material, color and finishing materials.

3.3.2. DiaLux

Following the making of mosque's geometry model, the model than converted from Revit to DiaLux. DiaLux is a program of natural and artificial lighting that includes the information of the latest lighting technology, has the ability to make automatic technical reports and has visual rendering capabilities that are continuously improved [15]. On Dialux, the five different lighting types and configuration patterns were applied to the three different mosque samples. All of the lamps on DiaLux model were set to have the same switch, 100% LOR (Light Output Ratio) and the maintenance factor (MF) has been taken as 1.

Table 4 and 5 gives a results summary of total thirteen DiaLux simulations. Table 4 shows the average illuminances and illuminances uniformity at three surface areas: working areas (set at a height of 50 cm throughout the floor of the mosque hall), wall areas and ceiling areas. Table 5 shows false color diagrams of illuminance distribution on the working areas.

Table 4. Average Illuminances and Illuminances Uniformity

Design Area	Lighting Design 1	Lighting Design 2	Lighting Design 3	Lighting Design 4	Lighting Design 5
			Sunda Kelapa Mosque		
Working area (lx)	223	233	221	221	230
Working area	0,65	0,43	0,48	0,48	0,45
Wall surface (lx)	57,28	40,40	49,36	50,40	44,91
Wall surface	0,32	0,40	0,45	0,45	0,37
Ceiling (lx)	29,35	28,41	38,01	37,11	28,46
Ceiling	0,87	0,70	0,69	0,70	0,78
			Al-Musyawarah Mosque		
Working area (lx)	-	211	162	165	190
Working area	-	0,40	0,58	0,55	0,63
Wall surface (lx)	-	46,08	86,36	85,00	66,09
Wall surface	-	0,36	0,40	0,44	0,40
Ceiling (lx)	-	22,74	53,04	55,76	55,75
Ceiling	-	0,74	0,72	0,73	0,58
			Al-Falah Mosque		
Working area (lx)	235	-	193	194	204
Working area	0,67	-	0,34	0,27	0,48
Wall surface (lx)	51,99	-	72,94	68,78	54,06
Wall surface	0,19	-	0,25	0,21	0,17
Ceiling (lx)	5,66	-	52,64	54,22	54,91
Ceiling	0,54	-	0,18	0,14	0,47
Reading area (lx)	297	-	293	292	287
Reading area	0,55	-	0,54	0,54	0,53

Lighting design 1 is not applied in al-Musyawarah mosque because column arrangements and shape of the exposed ceiling that is not suitable for the placement of the lights. Lighting design 2 is also not applied in al-Falah mosque because column arrangements and shape of the exposed ceiling that is not suitable for the placement of the lights.

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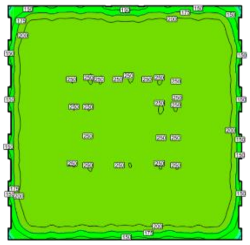
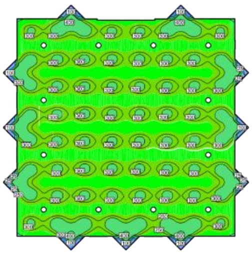
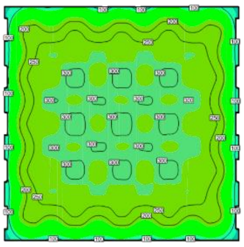
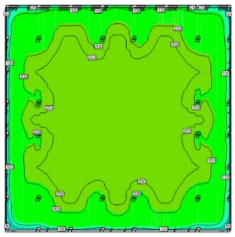
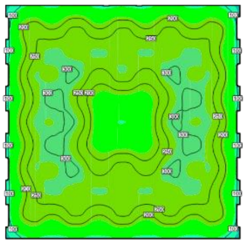
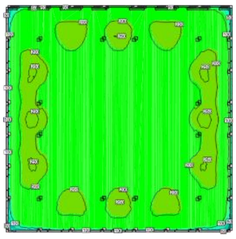
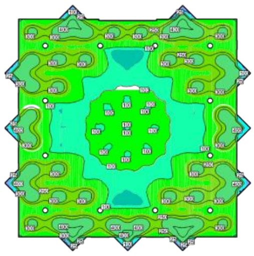
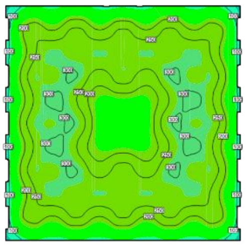
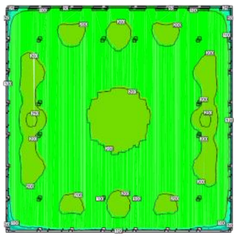
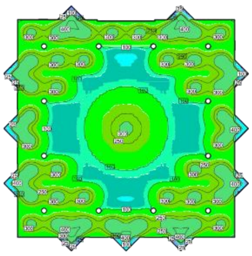
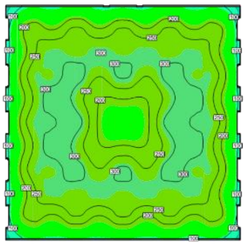
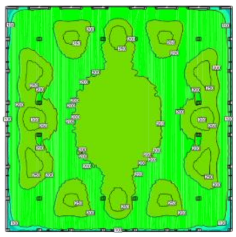
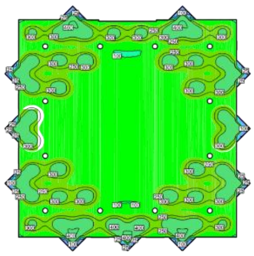
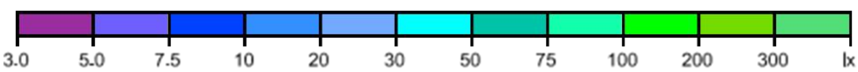
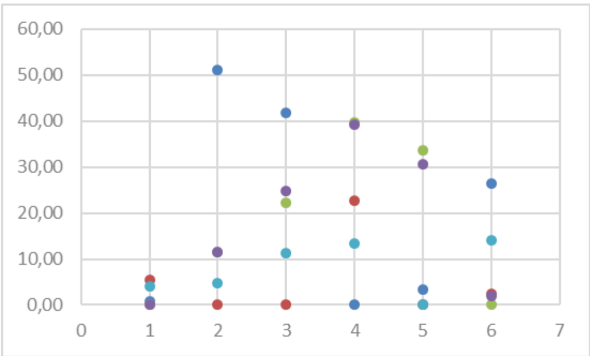
Table 5. False color diagrams of illuminance distribution on the working areas

	Sunda Kelapa Mosque	Al-Musyawarah Mosque	Al-Falah Mosque
Lighting Design 1			
Lighting Design 2			
Lighting Design 3			
Lighting Design 4			
Lighting Design 5			
Total Lumen	174120 lm	209480 lm	188925 lm

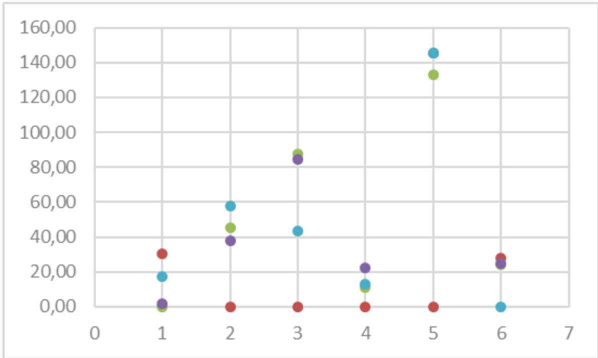
Note:



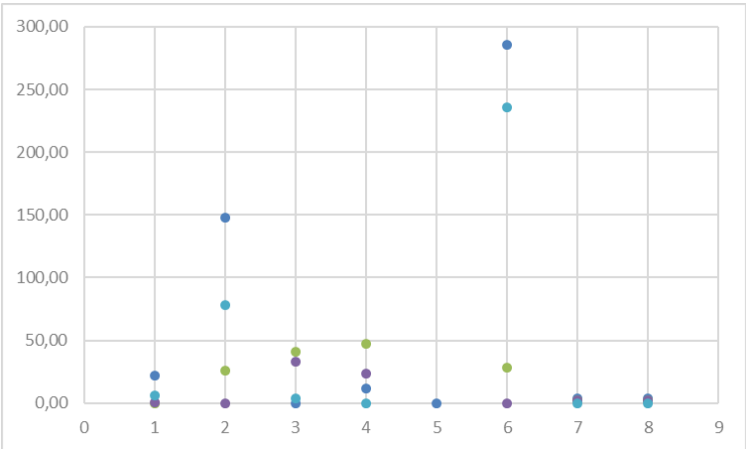
3.4 Analytical Methods
DiaLux simulation showed lots of numbers, therefore a further data processing is needed. The value of average illuminance and illuminance uniformity were transformed to percentage so that the difference level of average illuminance and illuminance uniformity in each area between one design and another can be seen. Figure 1 gives the difference in average illuminance and illuminance uniformity in percent which shows how big the difference between one design and another.



(a) Sunda Kelapa Mosque



(b) al-Musyawarah Mosque



(c) al-Falah Mosque

Notes
1: Working area (lx)
2: Working area
3: Wall surface (lx)
4: Wall surface
5: Ceiling (lx)
6: Ceiling
7: Reading area (lx)
8: Reading area

● Design lighting 1
● Design lighting 2
● Design lighting 3
● Design lighting 4
● Design lighting 5

Figure 1. Differences in average illuminance and illuminance uniformity in percent

To determine which design is the most efficient, the weighting is carried out in each area. this is because the illuminance quality of a particular area is more essential than some other areas. For all three mosques, the working area is the most essential area because it is where the user does their activity. For Sunda Kelapa and al-Musyawarah Mosques, the wall area is more essential than the ceiling area because it functions as an architectural element and the roof area as a background area. While for al-Falah Mosque, the dome-shaped ceiling functions as an architectural element and the wall as a background area. Table 6 gives the weights given in each area for three mosques.

Table 6. Weighting Proportion for Lighting Efficiency Calculation

Criteria		Weighting Percentage		
		Sunda Kelapa	**Al-Musyawarah**	**Al-Falah**
Working Area	Average lluminance	30%	30%	30%
	Illuminance uniformity	30%	30%	30%
Bookshelf area	Average illuminance	-	-	5%
	Illuminance uniformity	-	-	5%
Ceiling	Average illuminance	5%	5%	10%
	Illuminance uniformity	5%	5%	10%
Walls	Average illuminance	15%	15%	5%
	Illuminance uniformity	15%	15%	5%
	Total	100%	100%	100%

4 Results and Discussions

Tables 7 gives a summary of average illuminance and illuminance uniformity for three mosques after being weighted. The summary result efficiency ratings for five lighting designs in each mosque.

Table 7. Final Lighting Efficiency Points

	Design 1	Design 2	Design 3	Design 4	Design 5
Sunda Kelapa	233,8	51,8	144 ,7	147,0	70,0
al-Musyawarah	-	104,71	361,55	364,15	382,56
al-Falah	805,0	-	982,4	889,5	1358,3

4.1 Sunda Kelapa Mosque (flat-shaped ceiling mosque)

The simulation results for Sunda Kelapa Mosque shows that the difference between the highest and the least average illuminance on the working area between the five design are small, which is only 3.08%. While The lux uniformity coefficient in the working areas shows a much bigger number, 51.11%. **Design 1** (evenly arranged downlights) shows the highest lighting efficiency point compared to other designs. Although it's illuminance average on the working area is only ranked in the third place, design 1 produces the highest illuminance average with a much higher percentage compared to another designs.

4.2 al-Musyawarah Mosque (pyramid-shaped ceiling mosque)

The simulation results for al-Musyawarah Mosque shows big difference between the highest (design 2) and the least (design 3) average illuminance on the working area between the five design, 30.25%. While The illuminance uniformity coefficient in the working areas shows a bigger number, 45.06%. **Design 5** (strip lights and downlights) shows the highest lighting efficiency point compared to other designs. Although it's illuminance average on the working area only ranked in the second place, design 5 produces a much higher illuminance average on the working compared to other designs. On the ceiling and wall areas, design 5 did not produce the highest number of illuminance average and average uniformity, but tends to be balance.

4.3 al-Falah Mosque (dome-shaped ceiling mosque)

Compared to another design, **design 5** (strip lights and downlights) shows the highest lighting efficiency points on the simulation results for al-Falah Mosque. Design 5 produces the highest illuminance average and illuminance uniformity in the working area and ceiling with a large difference of number. In the wall areas, design 5 produces a value that tends to be low compared to other lighting designs, but with a small difference of number. Therefore design 5 is the most efficient lighting types and configuration patterns for al-Falah Mosque. The simulation results for al-Falah Mosque shows that the difference between the highest and the least average illuminance on the working area between the five design are 21.76%. While the lux uniformity coefficient in the working areas shows a significant bigger number, 148.15%.

Those finding show that the different shapes of mosque ceiling give different lighting performances. It is also consistent with previous studies which stated that the surface of a different object will produce a different direction of light reflection when reflected with light [10].

5 Conclusions

Arising from the massive growth, varied ceiling shape and the excessive lighting use of mosque, this study shows a correlation between the shape of the roof and the lighting types and configuration patterns for lighting efficiency in the mosque building. A flat-shaped ceiling Mosques have the highest lighting efficiency when evenly arranged downlights are applied in the building. A pyramid-shaped ceiling Mosques have the highest lighting efficiency when strip lights combined with downlights are applied in the building. A dome-shaped ceiling Mosques have the highest lighting efficiency when strip lights combined with downlights are applied in the building.

The main purpose of this study is to determine the most efficient lighting types and configuration patterns for each different shaped ceiling mosque. However, the main concern of this study is the quality of light especially the average illuminance and illuminance uniformity. Further improvements can be provided by prospective studies.

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