Designing process of efficient lighting for field of play at Aquatic stadium – GBK for Asian Games XVIII

Agust Danang Ismoyo¹, Joice Sandra Sari², Nurul Wulandari³

¹Universitas Mercu Buana, Jl. Meruya Selatan no.1, Jakarta Barat 11650, Indonesia
²Himpunan Teknik Iluminasi Indonesia, Jl.Gatot Subroto Kav 53, Jakarta 10260, Indonesia
³Pavilion 95, Jl. Ciputat Raya 27E, Jakarta 12310, Indonesia

E-mail: rizky.dinata@mercubuana.ac.id

Abstract. Lighting on the field of play in Aquatic Stadium includes only general lighting on above the floor of the stadium. This paper assesses types of lighting for GBK aquatic stadium, which were done in order to find the suitable lighting needs. It involves the process of designing to provide minimum requirement illuminance of FINA standard. The paper compares two lighting design proposals by illumination measurements, the values expected during the design phase, that used to fulfill a good level of lighting in Aquatic Stadium.

Keywords: Aquatic stadium; asian Games, lighting design, lighting simulation; sport lighting

1. Introduction
On August 2018, Indonesia hosts the Asian Games that is held in Jakarta and Palembang. It rewrites the last Asian Games held in Indonesia back in 1962. Knowing the previous history and the prestigious of this event, the government renovates whole area of sport center called Gelora Bung Karno (GBK) Arena. The renovation process was finished in July 2018.

Lighting is a branch of building physic that is concerned with achieving human comfort by providing adequate and acceptable luminance and illuminance. The importance of lighting is also underlined by the many lighting application standards such as sports lighting (Bedocs, 2009). It involves the process of calculating to provide minimum requirement illuminance of FINA standard.

Lighting design is a critical element that if implemented carefully, energy efficient system at affordable cost can be developed. Designing lighting system is a complicated task since there are various parameters which need to be taken care. There parameters include the selection of proper luminaire and its specifications because, if not selected properly, then the required illumination and luminance can not be achieved and the result can be certified.

The author was called upon to join the design team of Aquatic Stadium, during the construction, to propose lighting design system for international competition such as Asian Games. At that time together with architect and other stakeholders the position of luminaires and the design of its placement were considered, taking into account the architectural and economical restrictions.

The rapid-evolving light sources, LEDs (Light Emitting Diodes) have increasing luminous efficacy, long lifetime, and low power requirements make them suitable to be used for sport lighting. Cost-benefit analysis of LED based lighting systems driven with renewable energy sources have shown to be cost effective in comparison with the other conventional light sources (Halonen, 2009). LED lamps offer a
long service life and high efficacy (lumen/Watt). The energy conserving lighting design methodology based on LED will help to secure a green future by enlightening the past perfectly.

Luminaires with LED technology are available in aesthetic and functional designs. Whether realized as recessed luminaires or pendant luminaires with direct-indirect components, they are always shining examples of energy efficiency and longevity.

Aquatic Stadium

One of the advanced venues for this international championship is the semi indoor swimming hall or the aquatic stadium built in 1962. The stadium is one of the six heritage buildings in GBK sport complex. Since October 2017 this stadium has proofed certification from Fédération Internationale de Natation (FINA – International Swimming Federation).

The new Aquatic Stadium was redesigned as an international standard aquatic stadium. The renovation process must be able to meet the rules of preservation of heritage buildings. It reopened in November 2017 with total capacity of 8630 seats. This aquatic hall consists of 4 (four) international standard pools. Those are one Olympic sized pool with ten lines, water polo pool with depth of three meters, beautiful diving pool and warming up pool.

Architect Andra Matin as the principal architect, who designed this building makes an iconic roof shape by taking the form of wave of water. The movement of water representing the hope of Indonesia swimming sports will enthusiastically lead onward. The Aquatic Stadium is designed in accordance with the building preservation regulations. The GBK Swimming Stadium concept is semi indoor building with some parts are left open to prevent rust from evaporating chlorine from the pool as well as beautiful designs, plus to control the water temperature.

Apart of its function as international swimming pool competition, its indoor building requires sufficient lighting for different purposes. This paper assesses types of lighting for aquatic stadium, which were done in order to find the suitable lighting needs.

2. Method

For the purpose of this work, the paper outlines the lighting design techniques and calculations that were employed to achieve good lighting conditions in the room. Then, the paper compares among illumination measurements, the values expected during the design phase, to be applied on field. Figure 2 illustrates the methodology applied in this paper.
Architectural approach

- Architectural description for the room
- Brief discussion for the different limitations (location, maintenance and economic)

Description for phases of the lighting design for the Aquatic Stadium under consideration

- Phase one; determining the requirement of illumination level and uniformity by FINA
- Phase two; selecting the optimum luminaire
- Phase three; luminaire positioning
- Phase four; lighting calculation using computer simulation on FoP

Comparison

- Illumination level above the Field of Play
- Uniformity the whole area

Discussion and conclusions

- Results interpretation and justification

**Figure 2. Methodology**

2.1. Lighting Basic Variables

There are several basic variables of lighting such as illuminance, luminance distribution (brightness distribution), glare limitation (direct and reflected glare), direction of light and modelling, light color and color rendering properties of lamps. They are the quality features that define good lighting quality (Licht Wissen 08, 2000).

Achieving good lighting design is combining the performance, efficiency and comfort that determine the effectiveness of lighting, its impact on people using it, and its impact on the natural environment (Bedocs, 2009). The results offer the ability to provide optimum lighting solutions for people and places while conserving raw materials, energy and costs.

Designing sport lighting must take care of illuminance and uniformity ratio. Illuminance takes a particularly important role in determining how swiftly, reliably and easily a visual task is identified and performed. To establish the illuminance for a playing area, for example, the surface is overlaid with a grid of assessment points. At each point, a measurement area is defined in a particular alignment at a specified height. The results of measurements at all assessment points enable the average illuminance to be calculated for the entire playing area. Uniformity ratio is defined by evenly distribution of brightness. Light is uniformly distributed where illuminance values at assessment points are similar.

2.2. The Formulas for Lighting Design

Based on SNI 03-2396-2001, the level of illumination can be calculated using the following equation:

\[ E_p = \frac{I_{\alpha} \times \cos^3 \alpha}{h^2} \text{...}(\text{lux}) \]  

where:
- \( E_p \) : the illumination level at a point on the measurement area (lux)
- \( I_{\alpha} \) : the light intensity at the angle \( \alpha \) (lumen)
- \( h \) : the armature height above the work plane (meter)
There are around 400 luminaires that will be placed on the ceiling of 18 meters. Therefore, total illumination level in one point must be calculated 424 times. Computer simulation by RELux will help the calculation of the total illumination level around 1000 points, including the minimum illumination, maximum illumination and the average illumination level.

\[ E_{\text{total}} = E_{p1} + E_{p2} + E_{p3} + \ldots + E_{p424} \text{ (lux)} \]  

Uniformity is measured on a plane and expressed as the ratio of minimum \((E_{\text{min}})\) to average \((E_{\text{av}})\) or minimum \((E_{\text{min}})\) to maximum \((E_{\text{max}})\) illuminance.

\[ g_1 = \frac{E_{\text{min}}}{E_{\text{av}}} \]  
\[ g_2 = \frac{E_{\text{min}}}{E_{\text{max}}} \]

### 3. Designing illumination for field of play

#### 3.1. Architectural limitation

The most appropriate approach to the lighting design of Aquatic Stadium is to reach an optimized solution between the architectural form on one hand, and the FINA’s lighting requirements for international competition conditions on the other. The tough limited designing time mandated LEDs luminaires as light source for achieving the green building requirement for the 18th Asian Games.
The architect has designed the roof, which is constructed separate from the existing structure claimed as heritage building. The structure has 86-meter-wide gap in order not to harm the old podium. The roof, which has dimension of 175 by 100 meter with height of 6 meter, covers two side of observer podium on the long side of the pool. Ceiling height is 18 meter from the ground floor (figure 4 and 5).

3.2. FINA’s Requirements
Artificial lighting shall be provided at all swimming pools which are to be used at night, or which do not have adequate natural lighting, so that all portions of the pool, including the bottom, may be readily seen without glare. Lights shall be installed so as to provide uniform distribution of illumination not less than 0.6. Lighting needs to meet higher requirements for television broadcasts than for athletes and spectators – both in qualitative and in quantitative terms. The right lighting conditions can support good television pictures taken by TV cameras (Licht Wissen 08, 2000). In other side, FINA has illumination requirements due to international competition such as Olympic Games or World Championships. The light intensity at the level of 1 meter above the water surface shall not be less than 1500 lux.

Table 1. The lighting objectives on field of play, the related objective indicators considered in this work and FINA’s minimum requirement values

| Objective                                                      | Indicator        | Minimum Value |
|----------------------------------------------------------------|------------------|---------------|
| To fulfill good lighting design with minimum requirement of FINA | $E_{min}$ (Illuminance) | 1500 lux      |
|                                                              | Uniformity $g_1$ | 0.6           |
|                                                              | Uniformity $g_2$ | 0.6           |

3.3. Luminaires selection
Luminaires selection need to meet the requirements of the relevant lighting task in terms of quality of light such as colour temperature and colour rendering index. Luminaires should have at least a good colour rendering rating (Ra index) above 80. Colour temperature is important particularly for broadcasts that commence in daylight but continue through dusk into the night. Colour temperature of 5,000 to 6,000 Kelvin are suitable for mixing with daylight.

Table 2. The Luminaire Specification at Aquatic Stadium

| No. | Specifications      | NNY 24735 | NNY24740 | NNY24741 |
|-----|---------------------|-----------|----------|----------|
| 1.  | Lumen Output (lm)   | 21.000    | 42.400   | 43.400   |
| 2.  | Power (W)           | 154       | 320      | 320      |
| 3.  | Luminous Efficacy (lm/W) | 136.3    | 132.5    | 135.6    |
| 4.  | Degree              | 60        | 60       | 120      |
| 5.  | Weight (kg)         | 9         | 12.5     | 12.5     |
| 6.  | Color Temperatures (K) | 5000    | 5000     | 5000     |
| 7.  | Ra                  | 80        | 80       | 80       |
| 8.  | Photometric Picture | ![Image](image1.png) | ![Image](image2.png) | ![Image](image3.png) |
| 9.  | Picture             | ![Image](image4.png) | ![Image](image5.png) | ![Image](image6.png) |
| 10. | Quantity            | 340       | 48       | 36       |
LEDs as rapid-evolving light source have many rating of luminous efficacy. Luminous efficacy is the measure of a lamp’s energy efficiency. Luminous flux has relation to its power rating and is expressed in lumens per Watt (lm/W). The higher the lm/W ratio, the more efficiently a lamp turns the energy it consumes into light. Three luminaires will be used on the Aquatic Stadium based on their performance and specifications (table 2). The luminaires are produced by Japanese lighting manufacture such as NNY-24735, NYY-24740 and NYY-24741. Only one manufacture was chosen because of ease of maintenance in the future.

3.4. Luminaires positioning
There are two luminaires position design proposals to complete the task. Both designs placed the luminaires on the height of 17.5 meter above the ground. The placement of luminaires need catwalk as advantage and disadvantage that are attempted to align with the principle’s architectural design.

In the first design Alt.1, shown on figure 6 and 7, luminaires were placed at the dale of wavy shape roof in order to ease the maintenance and grouping of luminaires. Each group of luminaire contains 17 pieces of vary luminaires. Figure 8 and 9 shown the second design, Alt.2. The position of luminaires placed above the side edge of pools. This position will cut off the wavy shape roof.

**Figure 6. Section of Placement Alt.1**

**Figure 7. Plan of Placement Alt.1**
3.5. Computer Lighting Simulation

The measurements have been conducted with computer lighting simulation program named RELux. Using CAD software, a 3-D model has been constructed, which contains all of the architectural details. Having validated the computer modelling option, an investigation was made into the possibility of providing international competition, that must reach 1500 lux according to FINA’s requirements.

| Table 3. Measurement result of Alt. 1 |
|--------------------------------------|
| Polo pool | Main pool | Diving pool |
| Illuminance | | | |
| Average illuminance | 1,570 | 1,610 | 1,670 |
| Minimum illuminance | 1,280 | 1,350 | 1,360 |
| Maximum illuminance | 1,770 | 1,840 | 1,870 |
| Uniformity g1 | 0.81 | 0.84 | 0.82 |
| Uniformity g2 | 0.72 | 0.74 | 0.73 |

The measurement areas cover 1500 points, which were put 1 meter above the surface ground including on Polo pool, Main pool and Diving pool. 424 pieces of luminaires are calculated to achieve the requirements. Average indirect fraction was used as calculation algorithm with maintenance factor of 0.80. The result of computer calculation of Alt.1 has been shown on figure 10 and table 3. The result
of Alt.2 has been shown in figure 11 and table 4. The total amount of luminous flux is around 10Mlumen, which is produced by energy of 79KWatts. Comparison of both calculation indicates Alt.2 is much better than Alt.1. The result of Average illumination level above all pools of Alt.2 are much better, including the uniformities on each pools.

Figure 10. Pseudo Color of Illumination Level

Figure 11. Pseudo Color of Illumination Level
### Table 4. Measurement result of Alt. 2

| Illuminance                        | Polo pool | Main pool | Diving pool |
|------------------------------------|-----------|-----------|-------------|
| Average illuminance                | 1,660     | 1,670     | 1,660       |
| Minimum illuminance                | 1,510     | 1,510     | 1,510       |
| Maximum illuminance                | 1,850     | 1,810     | 1,800       |
| Uniformity g1                      | 0.91      | 0.90      | 0.91        |
| Uniformity g2                      | 0.82      | 0.83      | 0.84        |

4. **Conclusion**
This paper presents the phases of the lighting design of the Aquatic Stadium of GBK, which will be used for 18th Asian Games. Two computer simulations were studied to match the all requirements on the field. From this paper, implementing the design approach in practice may reasonably be studied by computer simulation. The effects of several physical variables deserve more study, such as the color of the interior and giant LED monitor used in the Aquatic stadium. They may affect light calculation.

5. **Acknowledgement**
The authors would like to express their deep thanks and gratitude first and foremost to the reviewers of the paper. Thanks also to Andra Mattin as the architect of Aquatic Stadium, pak Anggoro Putro as Project Manager from Ministry of Public Works, pak Hans and pak Rafi from PT. Mandala Putra Prima (MPP) as lighting system supplier and applicator and Dr. rer. nat Ova Candra Dewi for providing valuable knowledge and discussion to complete this article.

6. **References**
[1] Bedocs, Lou, 2009. Sustainable Quality Lighting with PEC. *Light & Engineering*, Vol. 17, No.1, pp. 24-31
[2] Holonen, L., Tetri, E., Amogpai, A., 2009. Needs and Challenges for Energy Efficient Lighting in Developed and Developing Countries. *Light & Engineering*, Vol. 17, No.1, pp. 5-10
[3] Licht Wissen 08 – Sport and Leisure, 2000. Available online at: http://en.licht.de/fileadmin/Publications/licht-wissen/1001_lw08_E_Sport_Leisure_web.pdf, Accessed on 14.08.2015
[4] SNI 03-2396-1991. Tata Cara Perancangan Sistem Pencahayaan Alami Siang Hari untuk Rumah dan Gedung. ICS 91.160.01, Badan Standardisasi Nasional.
[5] SNI 03-6197-2000. Konservasi Energi pada Sistem Pencahayaan. ICS 91.160.01, Badan Standardisasi Nasional.
[6] SNI 03-2396-2001. Tata Cara Perancangan Sistem Pencahayaan Alami pada Bangunan Gedung. ICS 91.160.01, Badan Standardisasi Nasional. Wardani, L. K., & Sitinjak, R. H. I. (2014). Batik and Its Implementation in Art and Design. The International Journal of Social Sciences, 24(30 Jun).